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IDENTIFICATION AND EVALUATION OF DEEPWATER PORT HOSE INSPECTION--ETC(U)
JAN 79 W T HATHAWAY, L FRENKEL, G R PLANK
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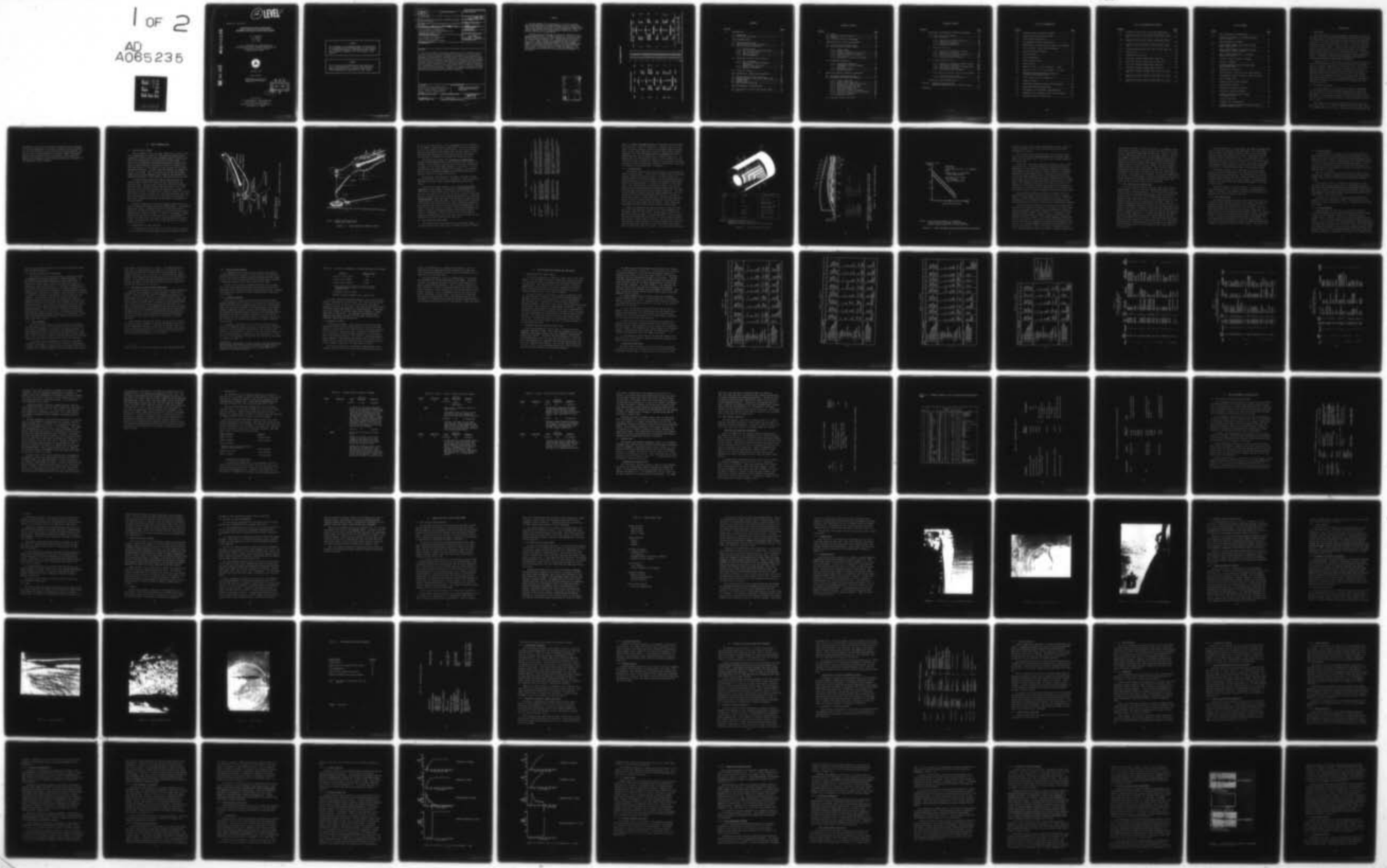

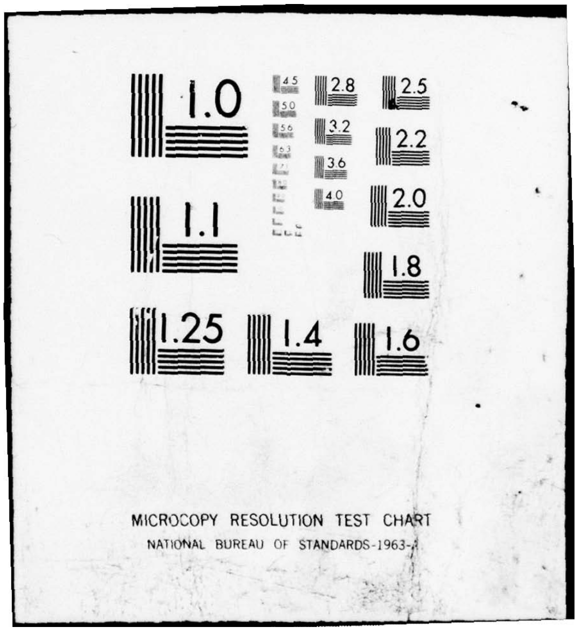

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REPORT NO. CG-D-02-79

IDENTIFICATION AND EVALUATION OF DEEPWATER PORT HOSE INSPECTION METHODS

W.T. Hathaway
L. Frenkel
G.R. Plank
S.N. Bobo

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 02142

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16. Abstract

The work contained in this report consists of a review of deepwater port hose failures to date, and the causes leading to these failures, as well as an evaluation of current hose inspection techniques and procedures, and an examination of available non-destructive test procedures which are not currently used on deepwater port hoses but show potential in this application. Inspection methods which appear to show potential for immediate application are x-ray inspection for hose component placement, durometer testing for liner hardness, and pressure-volume testing for overall structural characteristics. Those methods judged to require more experimental investigation, both in the laboratory and the field, are ultrasonic inspection and acoustic emission inspection. Included in the report are the results of laboratory tests with acoustic emission, ultrasonic, and durometer techniques and recommendations for further work utilizing these techniques.

17. Key Words

Deepwater Ports, Oil Transfer Hoses, Hose Inspection Methods, X-Rays, Ultrasonics, Acoustic Emission, Pressure-Volume, Durometer, Non-Destructive Testing

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PREFACE

With the enactment of the Deepwater Port Act of 1974 the Department of Transportation and, through delegation, the United States Coast Guard became responsible for regulation of most aspects of deepwater ports, from licensing through construction, testing, and operations. The Transportation Systems Center is providing technical support to the Coast Guard in this area of its responsibility.

The authors wish to acknowledge the support and contributions from the following individuals: Mr. Edward Briggs and Mr. George Wolfe of the Southwest Research Institute for their contributions to section 5 which were drawn from their previous report, "Failure Analysis of DWP Hoses," Dec 17, 1976; James R. Mitchell of Dunegan/Endevco for his helpful suggestions on acoustic emission measurements; and Donald Laaksonen, CDR Stephen J.T. Masse and LCDR Richard G. Jones of the United States Coast Guard for their guidance and valuable discussion and comments on the entire project. The authors also wish to thank representatives of the rubber industry and the OCIMF for their assistance and cooperation in this effort.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

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1. INTRODUCTION

1.1 BACKGROUND

Data on presently operating deepwater port (DWP) single point moorings (SPMs) indicate that the failure of hoses used to transfer oil from the ship to the mooring, and from there to the submarine pipelines, is a major source of oil spills. To date the most comprehensive study of hose failures was carried out by the Southwest Research Institute (SWRI)[1]. However, that study was directed toward hose performance, with the eventual objective of proposing design changes which would result in longer hose life. (Hoses are expensive and longer hose life would therefore reduce replacement costs. In addition, frequent hose replacement and inspection necessitate shutdowns of the transfer operation.)

Guidelines call for inspection of hoses at periodic intervals. The current guidelines involve dockside inspection of operating hoses at intervals comparable to actual hose life. This practice has two drawbacks. First, failure is likely to occur before a dockside inspection discloses incipient problems and second, the handling during removal from service may itself create damage. Thus, from an environmental as well as economic point of view, continuous monitoring and onsite inspection methods could make an important contribution to the detection and prevention of hose-related oil spills.

1.2 OBJECTIVES AND SCOPE

It is the objective of this study to provide a methodology for the inspection of cargo transfer system hoses at DWP sites. The intention is to employ existing technology to forestall the deployment of a hose having a high risk of failure, and to provide for hose removal from service before a failure resulting in an oil spill occurs.

This report reviews the available hose data and associated hose failure modes. It considers nondestructive test (NDT) inspection methods applicable to hoses, along with their capabilities and limitations, as well as the results of laboratory tests conducted to verify the application of the most suitable inspection methods. Not all hose failures will be detected with existing methods, and several of the existing methods will require further development before they can be used for hose inspection. This report also addresses the problem of developing new methods and techniques for the inspection of hose failures.

2. CARGO TRANSFER HOSES

2.1 CALM AND SALM SYSTEMS

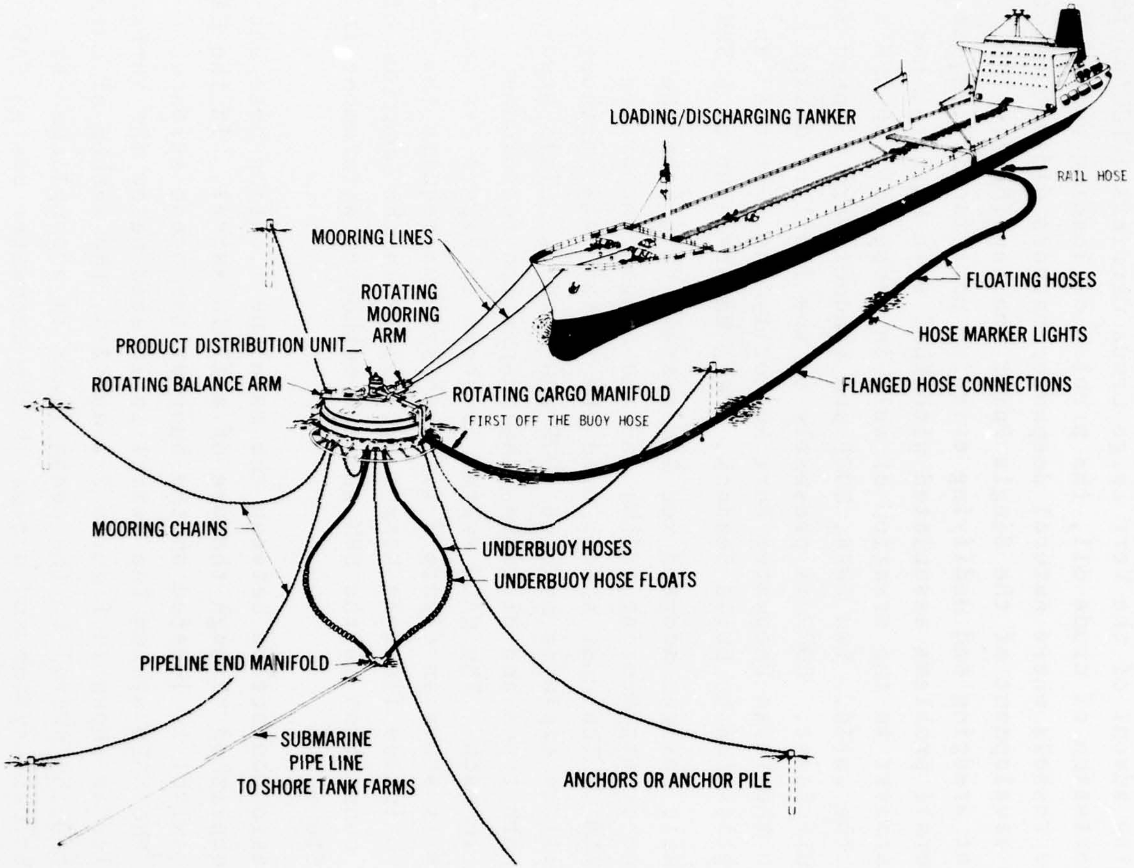
With the advent of the Very Large Crude Carriers (VLCC's) for the transportation of crude oil, the problem of loading and unloading the vessels where natural deepwater harbors did not exist led to the development of the Single Point Mooring (SPM). The high cost of dredging and modifying existing port facilities, as well as overall problems associated with VLCC's in harbors, has been the catalyst to the creation of well in excess of 150 SPM's throughout the world. Two DWPs, LOOP and Seadock, are planned for the U.S. Gulf Coast. LOOP is presently in the facility design stage while the Texas Deepwater Port Authority has submitted an amended application to build Seadock. Each may have up to 6 SPM'S.

Two basic designs adopted for SPM systems have been the Catenary Anchor Leg Mooring (CALM) and the Single Anchor Leg Mooring (SALM). The most widely used SPM is the CALM, although the SALM will be employed by both LOOP and Seadock. This study considers both types and discusses the inspection techniques applicable to each. The CALM system is shown in Figure 2-1 and the SALM system is shown in Figure 2-2. Both systems require the "rail hose" and "mainline floating hose", but differ in the location of the swivel connection to the SPM and the method of attachment to the ocean floor.

The basic connection between the mainline floating hose and SPM is accomplished through the use of a fluid swivel. In the CALM system the swivel is located on the buoy at the ocean surface, whereas in the SALM system the swivel is located below the surface. Additionally, as shown in Figures 2-1 and 2-2, the method of cargo transfer from the swivel to the ocean floor is accomplished by hoses in the CALM system and a pipe in the deepwater design SALM system. In the shallow water SALM design, the swivel is located on the ocean floor.

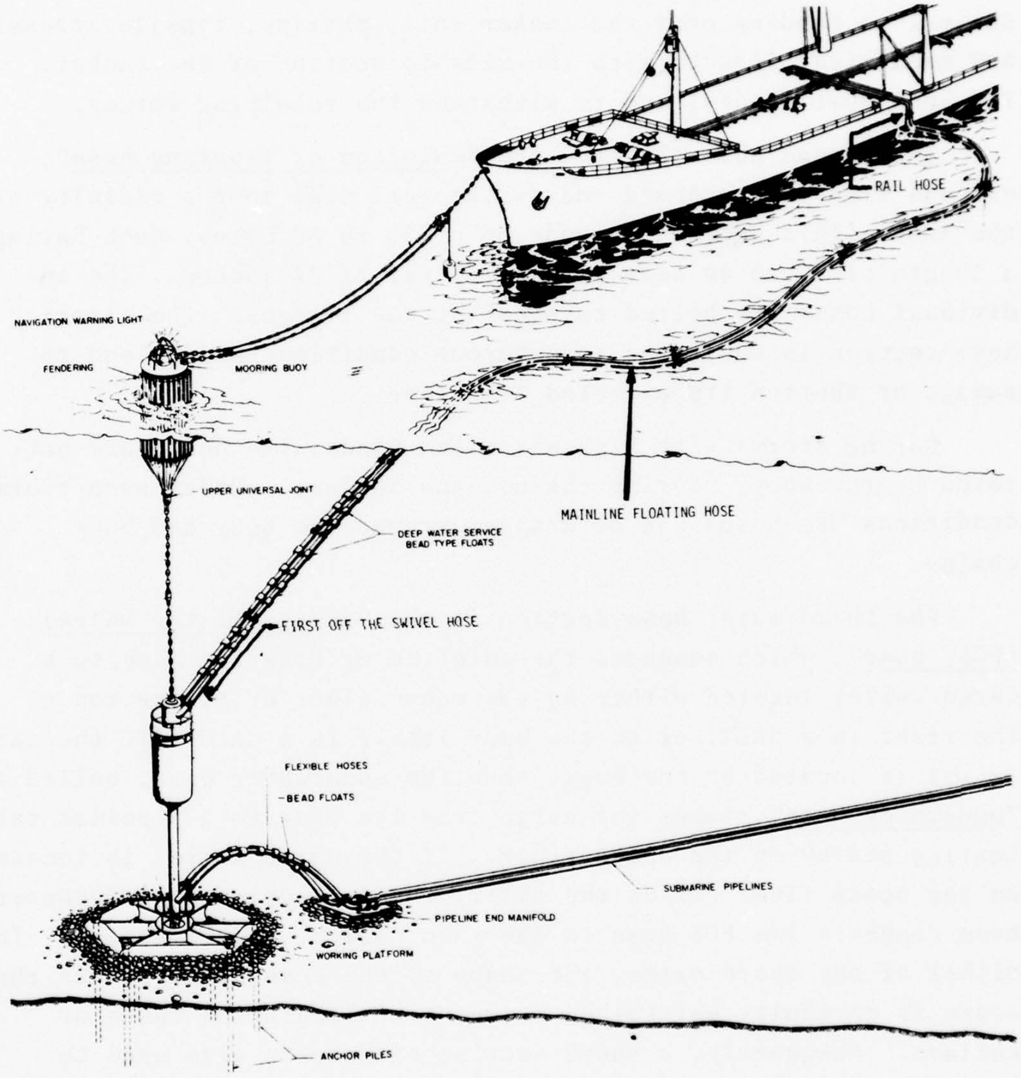
2.2 IDENTIFICATION OF HOSE SECTIONS

For the purposes of this analysis, the hose string is considered to consist of three functional sections as shown in Table 2-1.



Source: IMODCO International Inc.
Bulletin No. IMO-72-100

FIGURE 2-1. CATENARY ANCHOR LEG MOORING (CALM)



Source: IMODCO International Inc.
Bulletin No. IMO-72-100

FIGURE 2-2. SINGLE ANCHOR LEG MOORING (SALM)

The first of these sections is the "rail hose" which is connected to the tanker's manifold and is comprised of up to two sections of 16 to 20 inch diameter hose bolted together. This hose section is subject to bending over the tanker rail, chafing, tensile stress, and mechanical impacts with the midship section of the tanker. The hose must be designed to withstand the resulting forces.

The second hose section, the "mainline or floating hose", extends from the outboard end of the rail hose to the vicinity of the buoy. This section is made up of 30 to 50 hoses, each having a length of 20 to 40 feet and a diameter of 24 inches. The individual hoses are bolted together at the flanges. The floating hose section is subjected to numerous conditions which lead to damage or shorten its expected life time.

During storms with high waves and winds, the hoses are battered by the buoy, mooring chains, and hawsers. Under such storm conditions the hoses can be wrapped around the buoy and buoy chains.

The third major hose section is the "first off the swivel (FOS) hose", which connects the mainline or floating hose to a cargo swivel located either on the ocean floor or at the top of the riser in a SALM, or on the buoy itself in a CALM. If the cargo swivel is located on the buoy, then the underwater hose, called an "underbuoy hose", takes the cargo from the buoy to a pipeline terminating nearby on the ocean floor. If the cargo swivel is located on the ocean floor (or on the riser) then a section of underwater hose connects the FOS hose to the main body of floating hose. In either of the above cases, the shape of the hose string under the ocean is carefully maintained by means of floatation tanks or collars. Frequently, a short section of hose is also used to connect the bottom end of the cargo swivel in SALM systems to the pipeline end manifold (PLEM) on the ocean floor.

2.3 HOSE DESIGN AND MANUFACTURE

All flexible hose is currently made of reinforced rubber. An oil-resistant (nitril) rubber liner is bonded to several "breaker

TABLE 2-1 - HOSE FUNCTIONS AND REQUIREMENTS

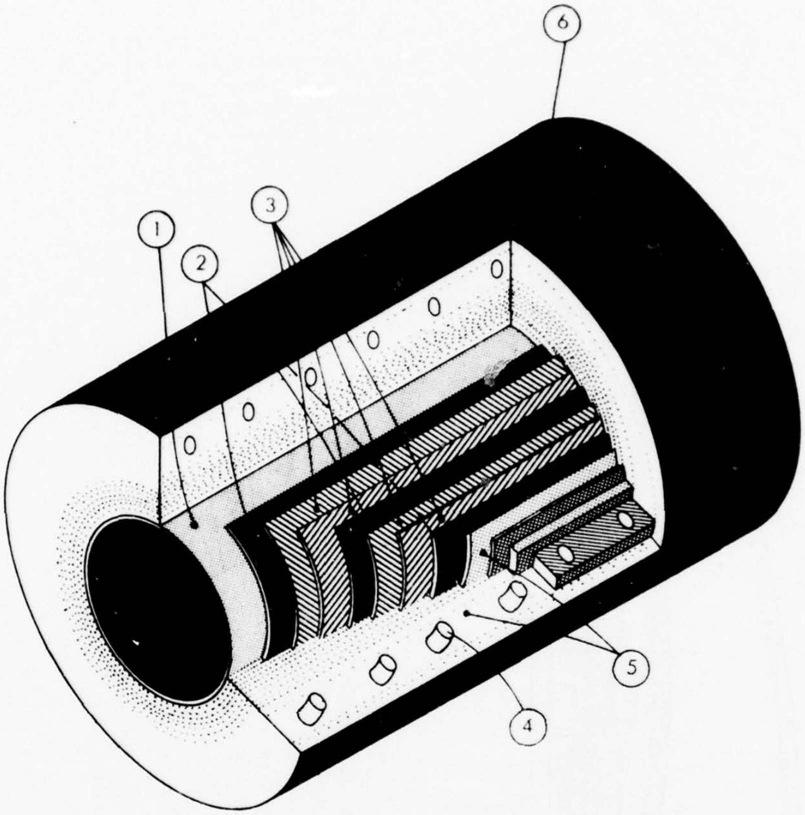
Sections	Function	Requirements
Tanker Rail Hose,	Connects tanker Manifold to Floating Hose Section	Flexibility and abrasion resistance over the rail, tensile strength and nipple adhesion along entire length. Must float when not in use.
Floating Section or Main Line	Connects rail section to the First off the Buoy Section in CALM System or to Subsea Segment in SALM System	Medium flexibility and abrasion resistance - Reserve Buoyancy -Shielding against contact with tanker bow and from contact with other hoses in the string.
First off the Buoy or *First off the Swivel* Hose Section	Connects the Swivel of SALM system to the subsea section-In CALM systems, connects buoy swivel to Floating Hose section	High stiffness required to rotate swivel. Must withstand large bending moments. In CALM system additional resistance to torsional stress is required because of buoy **rocking motion.** Section usually is end-reinforced and Half Floated.
Subsea Hose	Connects floating Section to First off swivel hose in SALM Systems	Stiffness required to prevent kinking at **floatation tanks.** Floatation to maintain configuration is provided by tanks.
Under Buoy Section	Connects CALM buoy to ocean floor pipeline end manifold	Flexibility is required to accomodate tidal motion of buoy. Resistance to kinking is required to accommodate lateral buoy displacement.

plies" of rubber-impregnated fibers or wire mesh, which are bound over the liner as shown in Figure 2-3. A helical metal wire provides stiffness, pressure resistance and support against collapse under vacuum. Where appropriate, plastic foam provides integral buoyancy. The liner and breaker plies are generally tied to a shaped nipple by metal binding wires as shown in Figure 2.4. One manufacturer has eliminated the nipple, but this product has not been fully tested in operation. Details of the designs for various sections of hose are given below, and more information is available in Reference 1 and manufacturers' literature.

2.3.1 Floating Hose

The longest length of hose is the floating section between the tanker and the mooring. In the case of a CALM system, the floating section terminates at the buoy swivel. In SALM systems, the floating section transitions smoothly into the underwater section, which terminates at a swivel located at the anchoring platform of the buoy in shallow waters, or on top of a tubular riser in deep water. The floating hose is of medium stiffness. The requirements here are that the hose must withstand bending action in the vertical plane arising from the wave motion of the sea. The study by the Southwest Research Institute (SWRI) demonstrates that low stiffness is basically advantageous for this type of motion in short, choppy waves. On the other hand, idle hose must withstand wind and current action without kinking; also the foam and the outer shell are less pliant than the rubber. These conflicting requirements probably afford little freedom to the designer.

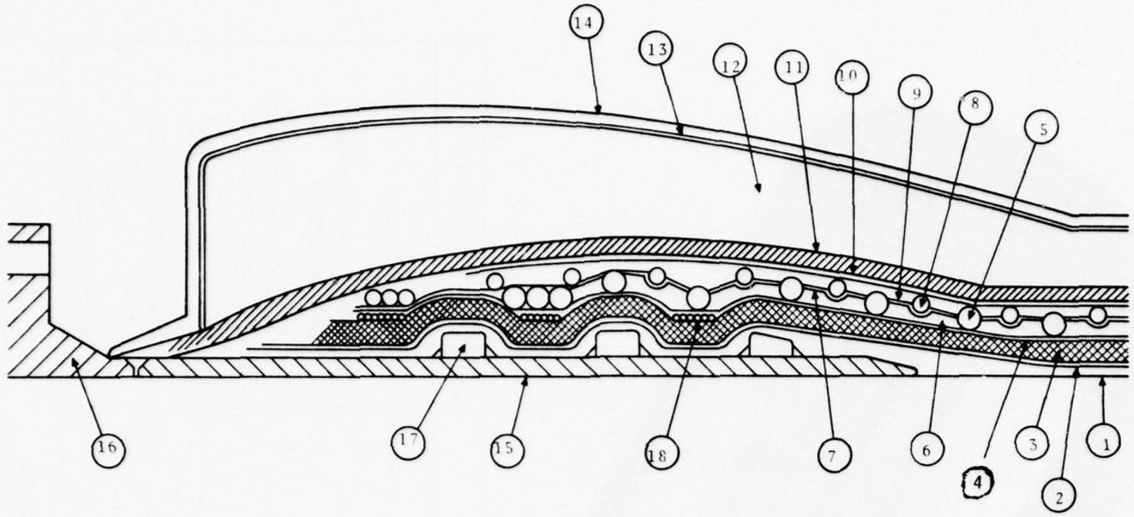
Hoses must withstand high surge pressures arising from emergency shut down operations (Figure 2-5) or from irregular flow resistance caused by wave motion. Normal working pressures are generally below 150 pounds per square inch (psi). Test pressures are generally between 200 and 300 PSI and burst pressure requirements may be as high as 800 to 1000 PSI. The hoses must also withstand partial vacuum conditions. The requirements for high burst pressure and vacuum resistance are met by incorporating a metal helix or metal rings into the carcass. It may be noted that vacuum



ITEM	NAME	MATERIAL OR NOTE
1	Liner	Nitrile, C. P. Rubber
2	Breaker	Nylon, Rayon, Cotton, Steel, Rubber Impregnated
3	Reinforcing Plies	Textile or Steel, Rubber Impregnated, Counter Wound
4	Helical Wire	Steel-3/8" Dia. to 5/8" Dia.
5	Filler Material	Nitrile, S. B. Rubber, Natural Rubber
6	Outer Cover	Neoprene, Polyurethane

Source: Southwest Research Institute
Project No. 03-4178-001, "Study of
Large Bore Offshore Loading and Discharge Hoses"

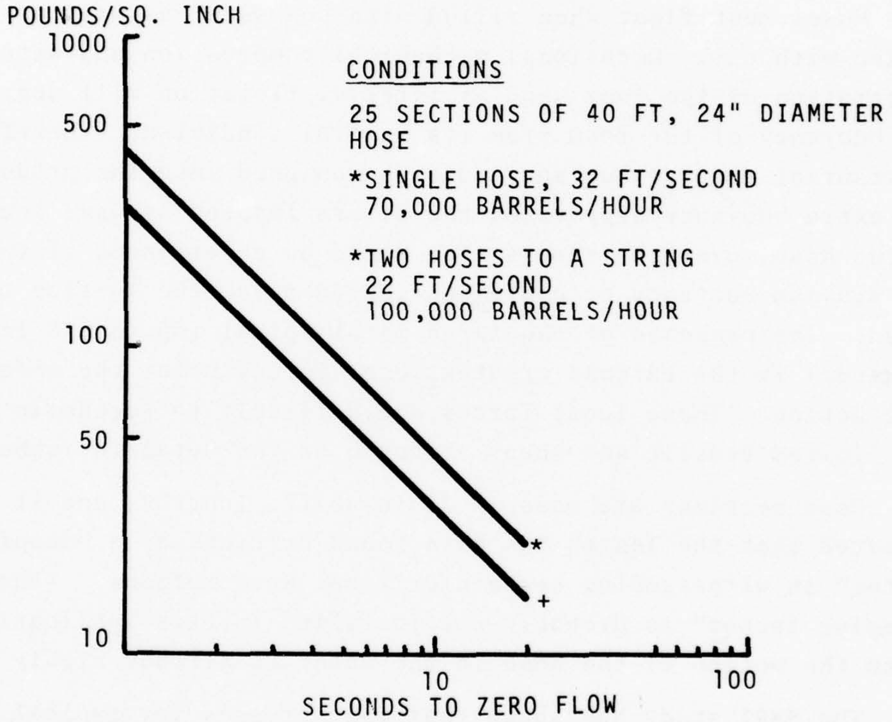
FIGURE 2-3. HOSE CONSTRUCTION DETAILS



(1)	Rubber Lining	(10)	Breaker iles
(2)	Breaker	(11)	Rubber Cover
(3)	Wire Cords (4-8 Piles)	(12)	Flotation (Close Cellar Foam)
(4)	Breaker	(13)	Breaker
(5)	Wire Helic, High Tensile Steel	(14)	Outer Cover
(6)	Filler Rubber	(15)	Nipple
(7)	Fabric Layer	(16)	Flange
(8)	Wire Helic, High Tensile Steel	(17)	Rings (Usually 3)
(9)	Filler Rubber	(18)	Binding Wire

Source: Southwest Research Institute Project No. 03-4178-001 "Study of Large Bore Offshore Loading and Discharge Hoses", September 15, 1975.

FIGURE 2-4. HOSE NIPPLE INTERFACE CONSTRUCTION



Source: "Risk Analysis Methods for Deepwater Port Oil Transfer Systems", Transportation Systems Center, Report CG-D-69-76, June 1976

FIGURE 2-5. SURGE-PRESSURE RESULTING FROM SUDDEN FLOW STOPPAGE conditions would tend to produce delamination of inner liners if the outer surface is not tight, hence adhesion must be good throughout the carcass.

The area where the inner liner goes over the nipple constitutes an area of maximum bending moments and of extreme vulnerability for the inner liner. This calls for a careful design of the nipple edge.

Hoses must float when filled with sea water as well as when filled with oil. Occasional mechanical compression and water penetration of the foam used as integral flotation will degrade the buoyancy of the foam from its initial condition. Therefore, substantial reserve buoyancy must be designed into the product. The extra buoyancy aggravates the stress imposed by wave action on the hose, over the stress that would be experienced if the hose had minimum buoyancy or could be floated below the surface of the ocean. The presence of the large metal spiral (up to 5/8 inch diameter) in the carcass creates local forces under the effect of wave action. These local forces are difficult to reconcile with the limited tensile and shear strength of the metal-to-rubber bond.

Hose sections are made in 20 to 40 ft. lengths, and it is reported that the length has been found critical as a "damping factor" in withstanding certain critical wave motions. (The term "damping factor" is probably not justified in this application, since the motion of the hose in the water is already highly damped.)

The SWRI study has shown that the stresses for typical waves increase as a function of stiffness. In an effort to improve hose life, port operators and rubber companies alike have in the past tended to increase nominal "test pressure." Increasing the test pressure generally means a stronger or closer-wound helix, and therefore a stiffer product. This tendency toward a stiffer hose seems to run counter to the results of the study mentioned above. In this area, too, the opinions of experienced port operators seem to vary. For example, ARAMCO increased the test pressure of its hoses from 225 psi to 275 psi in an effort to improve hose life. It is reported that they found an increase in flexural fatigue and that they have recently returned to 225 psi. At Canaport, on the other hand, an increase in test pressure from 225 psi to 275 psi led to a substantial improvement in hose life. There are several factors which might account for such divergent results. First of all, Canaport represents one of the most demanding environments whereas the Arabian Gulf is an area of relatively moderate seas. Another factor is the ambient temperature which is much lower at Canaport than in the Arabian Gulf. Rubber, like any elastomer, becomes stiffer at lower temperatures. Thus, at first sight, it would appear that hoses in the Arabian Gulf would require more stiffness in their spiral to make up for the loss of stiffness in the rubber. This seems to be a paradox. One possible explanation may be that it is advantageous to match the stiffness of the spiral to the stiffness of the rubber since this perhaps reduces the strain on the interface between the two materials.

2.3.2 The "First-off-the-Swivel Hose"

For a long time the CALM was the only single point mooring system design. In this system the floating hose connects to a swivel on top of the mooring buoy. The section of hose connecting to the swivel was therefore appropriately called, "the-first-off-the-buoy hose". In the case of the SALM system, the swivel is located at some point under water, and the designation used in the heading of this section is therefore more fitting. There are several advantages to the SALM system as far as hose life in concerned. The general motions of the buoy are not transmitted to the swivel if the latter is located on the ocean floor, and even if the swivel is located on a riser, the effects of lateral buoy displacement are largely damped out. A further advantage is that there is no need for the under-buoy hose system which connects the CALM buoy to the PLEM on the ocean floor. Under-buoy hoses must accommodate the tidal excursions of the buoy as well as the lateral and rocking motions of the CALM buoy, and they must be so arranged as not to come into contact with the anchor chains, ocean floor, or with each other.

In the proposed Gulf of Mexico SPM's, the depth is moderate and no risers will be required in the SALM design. The subsea hoses used to connect the floating section to the first-off-the-swivel hose are largely shielded from the effect of wave motion and are expected to have a good service life. The replacement of the underwater hoses will have to be done by divers. One special function of this section of hose is to rotate the swivel as the tanker "weathervanes" around the buoy. This section of hose therefore experiences its maximum bending moments in a horizontal plane.

In addition, in the case of CALM buoy, the FOB hose must absorb the torsion resulting from the remainder of the floating hose and the buoy rocking motion. Since the rotation will cause winding and unwinding of the spiral inside the hose carcass, the internal bonds are subjected to severe stress. The only design parameter available to meet the bending requirements of this hose is the stiffness.

Increased stiffness is accomplished by a closer spacing of the supporting spiral (or rings). Sometimes, a second spiral is added. At Canaport, the second hose section off the buoy is also reinforced at the end closest to the buoy.

2.3.3 Over-the-Rail Hose

The special problems associated with the section of hose connecting the main floating hose body to the tanker's manifold are chafing, bending, and being hoisted, full of seawater or oil, aboard the tanker some 40 or 50 feet above sea level. This hose must therefore be very flexible and resistant to abrasion. It must also be able to withstand extreme tensile stress. The chafing problem calls for an extra tough outer shell or appropriate fendering. The tensile and bending requirements at the tanker rail are sometimes met by fiberglass or wire mesh reinforcements. To some extent, hose life could be improved by appropriate connecting methods, as described further on in this report. (Section: 2.4.1)

2.3.4 Quality Control

Hose manufacture is considered an art and mass production manufacturing concepts have apparently not been adopted. Accordingly, skill and experience prevail over measuring apparatus and feedback controls. Hoses are manufactured on a large lathe capable of turning a steel mandrel of the internal hose diameter. The lathe turns at several revolutions a minute and three shifts of three men per shift can complete a 35 foot long section of 24 inch diameter hose in 24 hours.

The hose customers have certain "inspection rights" during manufacture. However, in general these involve the inspection of records rather than the supervision of the production process itself.

The testing of hoses is conducted in the factory on the finished product in accordance with the recommendations of the Hose Guide of the OCIMF and according to the special provisions in each sales contract. Such testing involves bending, vacuum-testing and elongation measurements, both during pressurization and after. Leak-testing is done with kerosene.

In addition to these tests, welds between the flange and nipple are, in some instances, X-rayed. Prototype hose is subjected to a variety of destructive tests as specified in the OCIMF Hose Guides.

2.3.5 New Developments

Quite possibly one could devise a practical flexible or articulated transfer system that would eliminate the hose system. If this has not been done to date, it is probably because of economic factors. However, one new hose type has appeared on the market. It is constructed without conventional nipples and utilizes rings of metal in place of the continuous spiral. This hose has not yet gained wide acceptance, but since the construction of the flange-hose interface evidently did require novel production methods, the designer could not use conventional methods for forming large-bore shaped terminations. Furthermore, the rings are not subject to the winding and unwinding problems of the spiral and therefore should help in CALM applications.

2.4 OPERATING PRACTICES AND PROCEDURES

Hose failures can often be the result of operating practices or procedures as has been evidenced in several instances. The more serious cases involve the abuse of hoses either while preparing to deploy them or while moving them into position for attachment to the tanker manifold. As reported in Reference 2, it was estimated that at some terminals, more than 50 percent of all failures can be attributed to handling. Permanent damage can result from shipping, picking up, or stacking a hose improperly, or storing it where it is exposed to long periods of heat and poor air circulation. Other failures which can be directly attributed to operating practices are the result of overpressure, creation of a vacuum, or when valves are closed rapidly against the flow of products in the hoses. An incident has been reported where a butterfly valve was not properly secured and slammed shut during discharge operations. This resulted in a blowout of the hose from the nipple and caused a large spill. Liner damage has resulted from a vacuum created when hot, crude oil in an underwater section cooled and thermally contracted while valves at both ends of the hose section were closed.

2.4.1 Hose Attachment

There are several reasons for the short life of rail hose. The most important point to be discussed in this section concerns the method of attachment of the hose to the tanker manifold. In many instances the hose is attached to the manifold four or five feet inboard of the rail, and less than one foot above the tanker deck. Thus, the hose is subject to severe bending and to localized mechanical forces which fully explain its low life expectancy.

By contrast, at some Japanese ports the hose is attached outboard of the tanker, to the vertical section of right-angular extension pipes supported inboard between the manifold and the rail. A number of oil industry engineers were asked whether such attachment methods could be used at U.S. ports. The general opinion is that lack of standardization would make it very difficult for a common carrier facility to provide the necessary adapters for all tankers that might call at their ports. In addition, the tanker might not have adequate boom lifting capacity to lift the extension aboard. It would seem that these problems might be solved by requiring the tankers to provide the necessary fixtures rather than placing that obligation on the ports.

2.4.2 Initiation of Cargo Transfer Operations

Hose failures during the start-up of cargo transfer operations, although not well documented, do exist and pose a serious spill threat. These failures may result from damage sustained by the hose during a period of idleness or improper system start-up. The possibility of any release of oil into the ocean when starting the cargo transfer operation would be reduced by static pressurization test of the hose system before cargo transfer operation, as is done at Canaport and as is recommended in the Hose Guide by OCIMF[3]. The entire line to the pumping platform complex (PPC) would have to be pressurized if no valve were available between the tanker and the PPC.* However, since the pipeline between the mooring base and the PPC is not likely to leak, this old method is entirely practical.

Hose failures from improper system start up may be a result of incorrect valve alignment or improper sequencing of the initiation of pumping and valving. In one case of improper valve set up, oil was directed to an SPM not in use at the time and with the over-the-rail hose blanked off. The surge caused the rupture of one of the hoses and resulted in an oil spill.

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*Such a valve is required by current U.S. Coast Guard regulations.

2.4.3 Normal System Shutdown

At completion of the cargo transfer operation the normal shutdown procedure may result in a hose failure. Such hose failures may be caused by improper sequencing of pump and valve operations as well as by leaving warm oil in the hose thereby creating a vacuum and possible liner failure when the oil cools.

At some ports, hoses are flushed and filled with sea water after each cargo transfer operation, and a pressure of 50 psi is maintained on the sea water in the sealed-off hose-string. Pressure loss during the idle period provides a warning that a leak exists in the system.

2.4.4 Emergency Shutdown

When a leak is spotted on the water during cargo transfer, pumping operations must be halted. In the case of a serious leak, when the shutdown must be rapid, relief valves must be operated to effect the most rapid slowdown of the flowing mass of oil without causing a dangerous surge, or vacuum, such as would result from the closing of a butterfly valve. The oil in the hose must then be replaced by sea water to prevent large losses of oil into the environment when the failed hose section is replaced. This raises the question as to the provisions necessary to pump and receive the oily water.

At Canaport, where the oil is routinely replaced by water after every completed tanker discharge, a ballast tank is provided off-shore for the storage and separation of the liquids in the system. In the proposed U.S. Gulf of Mexico ports, the contents of the system would have to be pumped back into the tanker.* To get an idea of the magnitude of the problem, the capacity of the system is tabulated in Table 2-2.

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*Although the contaminated oil-water mixture could theoretically be pumped ashore, there would be mixing problems with the crude oil in the main trunk lines from the PPC to shore, and separation and storage of the oil-water mixture may be a problem when it is received at the onshore terminal.

TABLE 2-2. CAPACITY, IN BARRELS, OF VARIOUS SECTIONS OF THE SYSTEM

Section	Capacity (bbl)
1,000 ft. of 24" hose*	562
1 mile of 36" pipe**	7,081
2 miles of 54" pipe***	31,863

*Corresponding to Canaport or Gulf of Mexico deepwater port.

**Canaport, buoy to shore

***Gulf of Mexico deepwater port, buoy to PPC.

The most frequent predictable emergency in the Gulf of Mexico region is the arrival of a hurricane. The fastest and safest way to secure the hoses in case of a hurricane is to sink them to within 20 or 30 ft. of the bottom. This subject has been discussed with SOCAL, EXXON, and Canaport, but opinions differ. Some would insist on filling the hose with water before sinking it; others would sink it full of oil. An important consideration here is component life under the effects of sea water, and pipe line corrosion between the SPM and the PPC.

2.5 ECONOMICS OF HOSES

In the current market, large bore hose sections cost about $30,000 each and each hose string consists of 30 to 50 sections. There are on the order of 150 installations in the world using one or more strings of large bore hoses. Assuming an average hose life of two years, the total market potential is in the order of $100 to $150 million annually. This market is distributed among seven companies. Their approximate share of $20 million each is a small fraction of their tire business, which is the main activity of most companies involved in the manufacture of hoses.

The major applications for large bore floating hoses are in loading systems in areas where high volume producing wells exist, and at off-loading ports of industrialized nations. The first application has a diminishing market potential since many new areas coming into produciton, such as those in the North Sea, have relatively low yields per well.

The growth potential of the off-loading ports is also minor since perhaps only the United States now lacks DWPs. Currently, two ports are planned, and these will have a total capacity of about 3 billion barrels annually. Thus, in order to provide the major importer of crude oil, the United States, with DWPs it will only be necessary to add a maximum of 60 to 70 hose strings to the world's inventory. This is assuming a limit of five ports altogether, with about six buoys each. This increase in the market can probably be absorbed by current manufacturing capacity, particularly if it should turn out that no new high volume flow wells are developed during the period of construction of these five ports.

3. HOSE FAILURE DATA SOURCES AND EVALUATION

3.1 IDENTIFICATION OF DATA SOURCES

The failure mechanisms of SPM hose systems are not well understood. It is, however, necessary to learn what types of failures are occurring in order to determine what inspection methods will be applicable. The identification of failure modes is severely hampered by a lack of data on in-service experience with these hoses, resulting from the fact that hose failures are not well reported (often not even to the parent company).

To understand this lack of data, it must be understood that the large majority of SPM sites are located in underdeveloped or sparsely settled areas of the world, i.e., Africa, the Mideast, and Southeast Asia. Pollution is a minor concern compared to reduced throughput. When a hose fails it is removed from service when and replaced; the failed hose is then dumped or destroyed. Sources of data which are presently available do not form a comprehensive data base from which one can predict with a high level of confidence the exact precentages of failure types in the entire SPM hose population. This ideal data base does not now, and probably never will, exist. Without these data, it is necessary to review and codify the existing data sources for hoses to obtain estimates of in-service failure types.

3.2 SOUTHWEST RESEARCH INSTITUTE (SWRI) DATA

The most comprehensive study to date, on SPM hose failure types, was conducted by SWRI. This study was prepared for the Hose Committee, Buoy Mooring Forum of the Oil Companies International Marine Forum (OCIMF). The study consisted primarily of visits to hose manufacturers, SPM sites, and buoy manufacturers. SWRI sent out 78 questionnaires to companies representing approximately 100 sites; 31 complete questionnaires were returned representing about 40 sites. SWRI visited six manufacturing sites, and 15 terminals, and discussed hose problems with terminal operators.

The data on hose life assembled during the SWRI study (Reference 1) are reproduced in Table 3-1. Also reproduced is a detailed listing of failures for first-off-the-swivel hoses (Table 3-2), mainline hoses (Table 3-3) and rail hoses (Table 3-4). These data represent the best information available to the authors. Information from representatives of the OCIMF indicates that improved in-plant inspection has led to better design practices and that hose life has been increased. The data, however, still represent the types of failure that occur while the frequency of occurrence may have been altered somewhat since publication of the data. The basic conclusions on hose failure drawn by SWRI, based on the data gathered, are as follows:

a. Large diameter hoses (20 and 24 inch) show a tendency toward premature failure (four to eighteen months) in areas where nominal sea conditions exist. A nominal sea is defined as one where the significant wave, over one-third of the time, is two to three meters (six to ten feet).

b. First-off-the-buoy hoses and the over-the-rail hoses appear to have service lives averaging one to twelve months under nominal sea conditions. Rail hose failure data indicates that failure rate is relatively insensitive to environmental conditions but very sensitive to handling procedures.

c. Most first-off-the-buoy hose failures occur within two diameters of the nipple. Observed failures were similar in different locations, indicating that the same forces were responsible for the failures. The mechanism for failure appears to be flexural fatigue. Apparently the gross leaks and large splitting of the carcass were preceded by nipple or nipple area leaks.

d. The other most often reported and observed failures were liner blisters, liner collapse, kinking, outer cover abrasion and buoyancy material failure.

Evaluation of SWRI Data

The data clearly indicate that the first-off-the-buoy hoses in CALM systems have the shortest lives of all hoses and that the predominant failure mode is a deterioration of the liner in the

TABLE 3-1.

QUESTIONNAIRE DATA SUMMARY

ITEM \ OPERATOR	1	2	3	4	5	6	7	8
I. Site Information								
A. Buoy Type	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM
B. Water Depth (ft)	250	50-100	50-100	50-100	162	50-100	50-100	100-150/>150(4)
C. Current (k) - Avg/Max	.5/.5	2-3/4	1-2/1.5	1-2/3	.5/.5	1-2/na	73/3.4	.5-1/1.5-2
D. Wind Speed (k) - Avg/Max	16-20/80	720/75	11-15/63	16-20-50	5-10/40	16-20/60	11-15/75-80	11-15/45
E. Wave Height (ft) - Avg/Max	<8/50	78/22	2-4/16	4-8/12	2-4/6	4-8/12-15	4-8/18-20	>8/25
F. Air Temp (°F) - Winter/Summer	58/na(1)*	52/82	60/110	32-50/77-86	46/64	55/90	37/67	74/100
G. Water Temp (°F) - Winter/Summer	42/na	61/75	70/85	45/70	45/54	58/81	32/64	70/90
II. Hose Information								
A. Floating Hose								
1. Manufacturer	3	2, 3, 6	6	2, 3, 6	2, 6	2, 3	2	2, 3, 4, 5
2. No. of Hoses								
a) FOB	3	2	2	2	2	2	1	4
b) Mainline	6	60	42	47	50	52	22	90
c) Tail	0	2	14	6	2	2	2	4
3. Avg Replacement (mo)								
a) FOB	na	5	2	3(2)	48	8	11	9
b) Mainline	na	6-1/2	27	12(2)	48	48	>24	24
c) Tail	na	2	24	6(2)	48	12	24(3)	4-6
4. Flotation	Integ.	Integ.	Integ. / Bead	Integ.	Integ.	Integ.	Integ.	Integ.
B. Underbuoy Hose								
1. Manufacturer	3	3	6	3, 6	6	2, 3	2	2, 3
2. Hose Configuration	Lazy-S	Lazy-S	Chinese Lantern	Chinese Lantern	Lazy-S	Lazy-S	Lazy-S	Lazy-S
3. Avg Replacement (mo)	na	12-24	<24	6-12	>24	12-24	12-24	>24
4. Flotation	Buoyancy Tanks	Buoyancy Tanks	Bead	Bead	Buoyancy Tanks	Buoyancy Tanks	Buoyancy Tanks	Buoyancy Tanks
III. General Failure Data								
A. Hose Failure Records Kept	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
B. OCIMF Test Procedures Required	Yes	Yes	Yes	Yes	Yes	No	Yes	No
C. SPM Standards when Specified	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
D. Hose Standards Adequate	na	Yes	Yes	Yes	No	Yes	Yes	No
E. Gaps in Hose Technology	na	•Design •Nipple Transitions •Reinforcement	•Nipple Transitions •Hose & Buoy Match-Up	•Design •Materials	•Flotation Material	•Handling Procedures	•Nipple Transitions •Outer Covers	•Construction Techniques •Reinforcement

*See last page for numbered notes.

TABLE 3-1. (CONT'D)

OPERATOR ITEM	9	10	11	12	13	14	15	16
I. Site Information								
A. Buoy Type	CALM	CALM	CALM/SMB	CALM	CALM	CALM	na	na
B. Water Depth (ft)	100-150	100-150	50-100	Over 150	100-150	100-150	50-100	50-100
C. Current (k) - Avg/Max	.5-1/1.2	1-2/2	2-3/>3	2-3/3-4	2-3/3.5	.5-1/1.5	2-3/6	1-2/2.5
D. Wind Speed (k) - Avg/Max	11-15/45	11-15/55	5-10/>20	11-15/55-60	>20/70	11-15/65	2.5-10/80	16-20/55
E. Wave Height (ft) - Avg/Max	>8/12	>8/14	4-8/12	>8/10-12	>8/35-40	4-8/15	2-4/10	2-4/16
F. Air Temp (°F) - Winter/Summer	60/106	60/106	85/85	70/110	10/65	na	79/86	70/90
G. Water Temp (°F) - Winter/Summer	68/95	66/91	80/80	68/98	52/56	na/85	57.61	70/90
II. Hose Information								
A. Floating Hose	(5)							
1. Manufacturer		2, 3, 5	2, 3	5, 6	2	3, 5, 6	2, 6	2
2. No. of Hoses								
a) FOB	9	5	na	1	1	1	na	2
b) Mainline	234	81	na	24	22	24	19	13
c) Tail	33	15(6)	na	1	2 Strings of 4	2	na	na
3. Avg Replacement (mo)								
a) FOB	5	7.4	12-14	(7)	6	6	na	na
b) Mainline	6	12+	24-36	(7)	18	na	6	na
c) Tail	4	8.7	6	(7)	12	na	na	na
4. Flotation	Integ.	Integ.	Integ.	Integ.	Integ.	Integ.	Integ.	Integ.
B. Underbuoy Hose								
1. Manufacturer	2	2	3	5	2	5, 6	6	2
2. Hose Configuration	Lazy-S	Lazy-S	Chinese Lantern	Lazy-S	Lazy-S	Lazy-S	na	Lazy-S
3. Avg Replacement (mo)	6-12	12-24	12-24	(7)	12(8)	48	6-12	na
4. Flotation	Bead	Combination	Bead	Buoyancy Tanks	Buoyancy Tanks	Buoyancy Tanks	Buoyancy Tanks	Buoyancy Tanks
III. General Failure Data								
A. Hose Failure Records Kept	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
B. OCIMF Test Procedures Required	Yes	Yes	Yes	Yes	Yes	No	No	No
C. SPM Standards when Specified	Yes	Yes	Yes	No	Yes	Yes	Yes	No
D. Hose Standards Adequate	No	Yes	Yes	na	Yes	Yes	Yes	na
E. Gaps in Hose Technology	•Design •Construction	•Design	•Construction Techniques	•Design •Materials •Handling	•Design	•Materials •Nipple Transitions	•Materials •Nipple Transitions	•Nipple Transitions

TABLE 3-1. (CONT'D)

ITEM / OPERATOR	17	18	19	20	21	22	23	24	25
I. Site Information									
A. Buoy Type	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM
B. WaterDepth (ft)	50-100	50-100	50-100	50-100	50-100	50-100	<50	50-100	50-100
C. Current (k) - Avg/Max	.5-1/3	<.5/.5	.5-1/1	.5-1/1.5	.5-1/1.5	.5-1/1	1-2/1	1-2/2	1-2/2
D. Wind Speed (k) - Avg/Max	11-15/60	11-15/60	11-15/60.	11-15/70	5-10/73	5-10/54	5-10/30	16-20/56	16-20/54
E. Wave Height (ft) - Avg/Max	2-4/10	2-4/11	>8/10	>8/10	2-4/9	>8/6	4-8/3	4-8/6	2-4/10
F. Air Temp (°F) - Winter/Summer	41/83	27/65	40/79	43/77	48/81	59-73	41/93	46/77	41/84
G. Water Temp (°F) - Winter/Summer	47/83	46/64	48/73	46/73	50/77	52/63	36/77	47/74	46/79
II. Hose Information									
A. Floating Hose									
1. Manufacturer	7	1	1	1	1	1	7	1	1
2. No. of Hoses									
a) FOB	3	3	7	2	6 6	5	2	14	7
b) Mainline	18	13	16	44	36 40	21	2	34	16
c) Tail	2	6	5	8	6 6	5	2	10	5
3. Avg Replacement (mo)									
a) FOB	18	24	36	12	48	12	12	24	24
b) Mainline	12	60	60	48	48	60	12	24	48
c) Tail	11	48	24	24	48	12	12	24	48
4. Flotation	Sink/ Float	Sink/ Float	Sink/ Float	Sink/ Float	Sink/ Float	Sink/ Float	Sink/ Float	Sink/ Float	Sink/ Float
B. Underbuoy Hose									
1. Manufacturer	7	1	1	1	1	1	7	1	1
2. Hose Configuration	Chinese Lantern	Chinese Lantern	Lazy-S	Lazy-S	Lazy-S	Chinese Lantern	Chinese Lantern	Lazy-S	Lazy-S
3. Avg Replacement (mo)	12-24	>24	>24	>24	>24	>24	12-24	12-24	>24
4. Flotation	Bead	Bead	Bead	Bead	Bead	Bead	na	Combination	Combination
III. General Failure Data									
A. Hose Failure Records Kept	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
B. OCIMF Test Procedures Required	No	No	No	Yes	No	No	No	Yes	No
C. SPM Standards when Specified	No	No	No	Yes	No	na	No	Yes	Yes
D. Hose Standards Adequate	No	Yes	No	Yes	Yes	na	No	Yes	Yes
E. Gaps in Hose Technology	•Design •Materials		•Handling Procedures	•Nipple Transitions					•Construction •Nipple Reinforcement-Construction Techniques

TABLE 3-1. (CONT'D)

ITEM / OPERATOR	27	28	29	30	31
I. Site Information					
A. Buoy Type	CALM	CALM	CALM	SALM	CALM
B. Water Depth (ft)	50-100	50-100	50-100	na	50-100
C. Current (k) - Avg/Max	.5-1/1	1-2/3	.5-1/1	na	.5-1/2
D. Wind Speed (k) - Avg/Max	11-15/40	5-10/76	11-15/60	na	5-10/30
E. Wave Height (ft) -Avg/Max	78/10	78/42	>8/10	na	4-8/8
F. Air Temp (°F) - Winter/Summer	41/86	37/75	40/79	na	90/95
G. Water Temp (°F) - Winter/Summer	50/83	43/64	48/73	na	80/80
II. Hose Information					
A. Floating Hose					
1. Manufacturer	7	2, 8	1	6	3, 2
2. No. of Hoses					
a) FOB	1	1	7	na	2
b) Mainline	24	18	16	24	38
c) Tail	1	1	5	6	4
3. Avg Replacement (mo)					
a) FOB	36	6	36	-	12
b) Mainline	36	48	60	18	36
c) Tail	36	48	24	-	6
4. Flotation	Sink/ Float	Bead	Sink/ Float	Buoyancy Tanks	Integ.
B. Underbuoy Hose					
1. Manufacturer	7	1, 8	1		2, 3
2. Hose Configuration	Chinese Lantern	Lazy-S	Lazy-S	30(9)	Lazy-S
3. Avg Replacement (mo)	>24	>24	>24		>24
4. Flotation	Combination	Bead	Combination		Buoyancy Tanks
III. General Failure Data					
A. Hose Failure Records Kept	Yes	Yes	Yes	Yes	Yes
B. OCIMF Test Procedures Required	No	Yes	No	Yes	Yes
C. SPM Standards when Specified	No	Yes	No	Yes	Yes
D. Hose Standards Adequate	Yes	Yes	No	Yes	No
E. Gaps in Hose Technology	•Materials •Construction Techniques	•Determination of Useful Service Life			•Design of Tail Hoses •Handling Procedures

NOTES

(1) na - not answered
(2) Scheduled removal, not failure
(3) Rail hose 6-12 mo
(4) Two buoys
(5) Total of 3 SPM
(6) Six at OTT, Nine at FSV
(7) None changed after nine months of operation
(8) Scheduled replacement
(9) Underwater buoy

TABLE 3-2.

HOSE FAILURE SUMMARY DATA
FIRST OFF BUOY HOSES
(POSITION #1)

Operator	Hose Diameter (Inches)	Manufacturer	Hose Type	Service Life (Months)	Failure Location (Hose Length)	Failure Type	Failure Cause (Operator Opinion)	Total Failures (This Type)
2	24	3	Self Float	13	Nipple	Hole, Crack, Delamination	Poor Hose Design	1
	24	3	Half Float	7	Nipple	Hole, Crack, Delamination	Poor Hose Design	1
	24	3	Vari Flex	4	Nipple	Hole, Crack, Delamination	Poor Hose Design	1
	24	3	Vari Flex	1.5	Nipple	Hole, Crack, Delamination	Poor Hose Design	1
	24	3	Self Float	1.5	Nipple	Hole, Crack, Delamination	Poor Hose Design	1
3	20	6	Half Float	2	Mid Bay	Kink	Buoy Fault	8
	16	6	Half Float	2	Mid Bay	Kink	Buoy Fault	5
4	20	6	na	12	Mid Bay	Crack	Handling Kink	1
6	20	2	Half Float	10	Nipple/Hose Interface	Hole, Nipple Leak	Poor Hose Design	4
	20	3	Half Float	1	Mid Bay	Hole, Abrasion	Poor Hose Design	1
	20	2	Half Float	9	Nipple	Nipple Leak	na	1
	20	2	Half Float	33	Nipple/Hose Interface	Nipple Leak	Handling Problem	1
	16	2	Half Float	7	Nipple/Hose Interface	Handling Kink	Handling Problem	1
7	24	2	Half Float	6	Mid Bay	Abrasion	Handling	
	24	2	Half Float	8	Nipple/Hose Interface	Crack	Normal Wear	
	24	2	Half Float	3	Nipple/Hose Interface	Hole	Normal Wear	
	24	2	Half Float	6.5	Nipple/Hose Interface	Hole	Normal Wear	
8	24	2	Half Float	9-12	Nipple/Hose Interface	Crack	Normal Wear	5
	16	2	Half Float	12	Nipple/Hose Interface	Crack	Normal Wear	4
9	24	2	Half Float	4	Nipple	Nipple Leak	Manuf. Defect, Poor Design	
	24	2	Half Float	5.5	Nipple	Nipple Pullout	Manuf. Defect, Poor Design	
10	24	2	Half Float	7	Nipple	Handling Kink	Manuf. Defect	3
11	24	2	Half Float	4	Nipple	Rupture	na	1
	24	2	Half Float	1	Mid Bay	Cut	Boat Damage	1
	24	2	Half Float	8	Nipple	Leak	Fatigue	1
	24	3	Half Float	4	Nipple	Split	Fatigue	1
	24	2	Half Float	14	Nipple	Split	Fatigue	1
13	24	2	Half Float	4	Nipple/Hose Interface	Crack	Normal Wear	6
	24	2	3/4 Float	3	Nipple	Nipple Leak	Poor Design	1
20	20	1	na	2	Nipple/Hose Interface	Nipple Leak	Manuf. Defect	4
25	20	1	Self Float	24	Mid Bay	Abrasion	Normal Wear	1
27	20	2	Float	8	Nipple/Hose Interface	Handling Kink	Rough Weather	4

TABLE 3-3.

HOSE FAILURE SUMMARY DATA
MAINLINE HOSES (FLOATING) (20" AND 24" ONLY)

Operator	Hose Diameter (Inches)	Manufacturer	Hose Type	Time in Service (Months)	Failure Type	Failure Location (Hose Length)	Failure Cause (Operator Opinion)	No. of Occurances
4	24	6	Self Float	9.4	Crack or Fissure	At Nipple	Poor Design	3
	24	3	Sel. Float	11	Crack or Fissure	At Nipple	Poor Design	5
	24	2	Self Float	3.5	Crack or Fissure	At Nipple	Poor Design	5
5	20	6	Self Float	12	Flotation Material	na	Manuf. Defect	1
6	20	2	Self Float	27	Nipple Leak	At Nipple	Handling	1
	20	2	Self Float	34	Flotation Material	na	Handling Wear	1
	20	2	Self Float	7	Handling Kink	Mid Bay	Handling	1
	20	2	Self Float	35	Nipple Leak	At Nipple	Handling	1
	20	2	Self Float	35	Flotation Material	na	Normal Wear	1
	20	2	Self Float	39	Hole	Mid Bay	Normal Wear	1
	20	2	Self Float	43	Hole	At Nipple	Normal Wear	1
	20	2	Self Float	52	Flotation Material	na	Normal Wear	1
	20	2	Self Float	18	Throughput & Flotation Material	na	Normal Weak	1
	20	2	Self Float	35	Hole and Crack	Mid Bay	Handling	1
	20	2	Self Float	40	Ship Broke Out	na	na	1
	20	2	Self Float	48	Throughput & Flotation	na	Normal Wear	3
	20	2	Self Float	48	Throughput & Flotation	na	Normal Wear	4
7	24	4	Self Float	21	Flotation Material	Mid Bay	Normal Wear	5
8	24	2	Self Float	21	Crack or Fissure	Nipple/Hose Interface	Poor Design	40
9	24	2	Self Float	5.5	Nipple Leak	At Nipple	Materials & Poor Design	3
	24	2	Self Float	6.0	Kink	At Nipple	Materials & Poor Design	1
	24	2	Self Float	7.5	Liner Failure	Nipple/Hose	Materials & Poor Design	2
10	24	2	Full Float	6.5	Crack or Fissure	Mid Bay	Normal Wear	1
	24	2	Full Float	6	Liner Failure	Mid Bay	Normal Wear	3
	24	2	Full Float	12	Liner Failure	Mid Bay	Normal Wear	5
	24	2	Full Float	12	Liner Failure	At Nipple	Normal Wear	4
	24	2	Full Float	10	Nipple Pull Out	At Nipple	na	1
	24	2	Half Float	5.5	Liner Failure	Mid Bay	Handling	3
	24	2	Half Float	1	Nipple Leak	At Nipple	Handling	1
	24	2	Half Float	4	Kink	At Nipple	na	2
11	24	2	Full Float	7	Cut	Mid Bay	Boat Prop.	1
	24	2	Full Float	18	Crack or Fissure	Nipple/Hose Interface	Fatigue	1
	24	2	Full Float	na	Excess Tension	All	Entangle Boat Prop	24
12	24	5	Full Float	6	Abrasion	6 Ft from Nipple	Turntable Problem	3
13	24	3	Full Float	10	Crack	Hose/Nipple Interface	Normal Wear	1
	24	2	Full Float	11	Crack	Hose/Nipple Interface	Normal Wear	1
19	20	1	Full Float	44	Flotation Material	Air Jacket	Handling	1
20	20	1	Sink/Float	17	Hole	Mid Bay	Normal Wear	11
	20	1	Sink/Float	14	Nipple Leak	Nipple/Hose Interface	Manuf. Defect	2
	20	1	Sink/Float	15	Delamination	Nipple/Hose Interface	Manuf. Defect	11
21	20	1	Sink Float	72	Various	Various	Normal Wear	9

TABLE 3-4.

HOSE FAILURE SUMMARY DATA
TAIL/RAIL HOSES (12" AND 16")

Operator	Hose Diameter (Inches)	Manufacturer	Hose Type	Service Life (Months)	Failure Type	Failure Location	Probable Cause	No. of Failure Reported
4	16	6	Rail	1	Cut		Ships Prop	1
		6	Rail	5	Kink and Crack	Nipple	Poor Design	1
		2	Rail	6	Crack	Mid Bay	Poor Design	1
6	16	2	Rail	8	Crack, Abrasion	Mid Bay	Normal Wear	2
		2	Rail	7	Crack and Abrasion	All Over	Normal Wear	1
		2	Rail	6	na	na	Normal Wear	2
		2	Rail	16	Crack and Abrasion	na	Handling	1
		2	Rail	17	Liner Failure	Nipple/Hose Interface	Normal Wear	1
7	16	2	Rail	11.5	Abrasion	Mid Bay	Normal Wear	1
		4	Rail	8	Kink	Mid Bay	Handling	1
8	16	2	Rail	5	Crack	Nipple/Hose Interface	Normal Wear	4
		4	Rail	3	Throughput	Nipple/Hose Interface & Mid Bay	Poor Design	1
9	16	2	Rail	4	Liner	Mid Bay	Mfg. Defect and Handling	4
		2	Rail	6.5	Liner	Mid Bay	Mfg. Defect and Handling	1
		2	Rail	7	Flotation Material	Mid Bay	Handling and Normal Wear	1
		2	Tail	6	Liner	Mid Bay	Mfg. Defect and Handling	3
		2	Tail	6.5	Abrasion	Mid Bay	Normal Wear	1
		2	Tail	7	Liner	Nipple/Hose Interface	Mfg. Defect and Poor Design	2
11	12	3	Rail	4	Rupture	Mid Bay	Tension While Heaving	3
19	16	1	Rail	5	Kink	Mid Bay	Handling	8
		1	Rail	10	Kink	Mid Bay	Handling	1
20	16	1	Tail	24	Kink	Mid Bay	Handling	3
		1	Tail	12	Crack	Mid Bay	Normal Wear	1
		1	Tail	12	Nipple Leak	Nipple/Hose Interface	Mfg. Defect	2
		1	Tail	3	Nipple Leak	Nipple/Hose Interface	Mfg. Defect	-
		1	Tail	24	Delamination	Nipple/Hose Interface	Mfg. Defect	2
25	16	1	Tail	24	Liner Failure	Mid Bay	Normal Wear	2
		1	Tail	24	Time Up	-	Normal Wear	3
28	16	6	Rail	10	Kink	Mid Bay	Handling	4
		6	Rail	9	Abrasion	Near Nipple	Handling	1
		3	Rail	25	Kink	Mid Bay	Handling	2

vicinity of the nipple, leading to leakage at the nipple - flange interface. This was confirmed independently by personnel at Canaport where this phenomenon is described as "weeping." Weeping will also occur when oil can force its way between the liner and the nipple because of insufficient bonding. This failure can occur anywhere in the string.

Liner delamination is another frequent problem. When the liner breaks in a small area, the carcass behind the liner deteriorates under the influence of oil. This leads to large blisters and eventually to a flaking of the liner. Most other failures are caused by accidents or poor handling, and cannot easily be classified.

The life expectancy of first-off-the-swivel hose is stated by SWRI to be ten months if Japanese ports are excluded. When including Japanese ports, one finds a life expectancy of about 18 months, (for Japanese ports alone, 24 tc 48 months). This longer life expectancy may be due to a less severe environment, hose design, operational procedures, or a combination of these factors. The main line (floating sections) lasts 20 months, if Japanese hoses are excluded, and about 25 months if all the data are used. It can be seen that at some ports an average of 60 months of life can be achieved. Rail hose lasts only 7.5 months, if Japanese ports are excluded, and 16 months if all the data are used. It should be noted that the majority of Japanese ports are located in sheltered waters. And, as mentioned earlier, the Japanese use a special method of attachment, which may explain the longer service life of their rail hoses.

The main result of the study (confirmed also independently at Canaport) is that hoses deteriorate primarily as a result of flexural fatigue, and impending failure is usually preceded by the symptom of weeping near the nipple. It may be noted that this kind of failure is highly localized and may be very difficult to detect. The SWRI study did not list events which led to large oil spills or investigate their causes or history; therefore, it sheds no light on inspection methods that might have been useful in the prevention of such events. The study did establish that environmental effects are predominant determinants of hose life. The conclusion is that hoses are not properly designed to function in seas where the "normal" wave is of short length and has an amplitude exceeding about 5 feet. Also, the study seems to have established that catastrophic failures are rare, but that leaks are frequent. Suppose now that it were possible to design a hose which would have a long average life in a rough environment, but which might be more prone to catastrophic failure without prior leakage. Such a design, for example, might feature lower test pressures and higher flexibility. If such a design could lead to an average life of 60 months, it would be an economic success, but not necessarily an environmental blessing. Because of these factors, matters of design are of considerable environmental interest since the effective inspection methods required to minimize oil spills will become clear only as the predominant failure mode of each design emerges during testing.

3.3 "DURBAN DATA"

The "Durban Data" were evidence submitted to the House of Lords (U.K.) on accidents at Shell's Durban (Union of South Africa) SPM facility, during the inquiry by the select committee on the Anglesey Marine Terminal Bill. These data included details on 23 spills at Durban in a one year period from 1970 to 1971.

The data confirm that the floating hoses are a principal source of spills. In the case of Durban, 11 out of the 23 spills were hose-related. Table 3-5 lists the hose-related spills. Another set of data, shown in Table 3-7 (given in the same reference for SPMs) showed 33 out of 51 spills to be hose-related.

Before discussing these events (shown in Table 3.5), some further statistics are of interest. The total oil spilled in the 23 spills amounted to 13,322 gallons (317 barrels) over a one-year period. The events A to F, of Table 3-5 accounted for 2,587 gallons (61 barrels) or about 25% of the total spillage. The other major causes of spills are as shown below:

Names of Event	Quantity
Tanker overrun	(2,500 gallons)
Tanker breakout	(2,500 gallons)
Ship's pipeline	
Blowout (valve closed accidentally against ship's manifold)	(3,500 gallons)
Tanker valve leak	(1,225 gallons)
Tanker overflow	(500 gallons)

Evaluation of "Durban Data"

In reviewing the Durban Data, it is noteworthy that not a single first-off-the-buoy hose leaked, and that the major spills occurred from the 16-inch hose section near the tanker end. Problems were also experienced at a reducer at the end of the rail hose string. Presumably, the problems of nipple adhesion and rail

TABLE 3-5. LISTING OF HOSE FAILURES AT DURBAN

Event	Spill No.	Date	Time to Detection	Quantity
A	3	9/30/70	5 min.	70 gallons
		A section of the south underwater hose string developed a slight leak. Prior to the departure of the tanker on berth at the time of the leak, both floating and underwater hose strings were flushed with 175 tons of sea water in an attempt to locate the leak. A dye was injected into the system through the dome of the SPM swivel and the system was then pressure tested by air to 100 lbs. P.S.I. but the location of the leak could not be determined.		
B	4	10/4/70	nil	5 gallons
Note		This event is related to event A above. During the removal of the blind flange at the tanker end, when connecting the hose to the ship's manifold, on oily water mixture passed the butterfly valve. During the discharge of the tanker, the leak in the underwater hose string noted in spill No. 3 above was traced to the seaward nipple of the No. 3 hose section, south string. As an interim measure, a clamp was placed on the hose to stop the leak.		

TABLE 3-5. (Cont.) LISTING OF HOSE FAILURE AT DURBAN

Event	Spill No.	Date	Time to Detection	Quantity
C	5	10/10/70	nil (diver's inspection)	1 pint

Note

This event is related to events A and B, above.

The Clamp fitted to the No. 3 hose section of the south underwater hose string was not sealing properly.

Event	Spill No.	Date	Time to Detection	Quantity
D	7	11/18/70	nil	1,225 gallons

A 16-in. rail hose, on the outer floating hose string, ruptured four feet from the flange where the hose support chain was attached. This was due, in the opinion of the operator, to a manufacturing defect.

Event	Spill No.	Date	Time to Detection	Quantity
E	9	12/22/70	nil	35 gallons

A leak develop in the seaward nipple of the No. 5 hose section of the south underwater hose string. This was evidently a leak detected by a diver. Presumably the 35 gallons represent an estimate of the quantity leaked between inspections. The leak was due, in the opinion of the operator, to a manufacturing defect.

TABLE 3-5. (Cont.) LISTING OF HOSE FAILURE AT DURBAN

Event	Spill No.	Date	Time to Detection	Quantify
F	16	3/27/71	nil	17 gallons
		During hose connection operations at the tanker manifold, a small quantity of oil spilled onto the tanker's deck and, due to heavy rainfall at time, overflowed over the side.		
G	17	3/31/71	nil	735 gallons
		During a cargo discharge operation, the nipple of a 16-in. hose section, in the outer floating hose string, detached from the hose body at a 16"-20" reducer connection.		

Event	*Spill No.*	*Date*	Time to Detection	*Quantity*
H	23	10/24/71	nil	500 gallons
		A 16-in. rail hose, on the outer floating hose string, ruptured six feet from the flange where the hose support chain was attached. This was due, in the opinion of the operator, to a manufacturing defect.		

hose tensile strength have been addressed since the 1970-71 period. The tanker overrun and breakout also caused hose leaks, but of course, these leaks cannot be ascribed to hose failure. In fact, most of the major spills other than those due to hose failure must be considered as, in one way or another, preventable by proper procedures. Perhaps the overrun and breakouts could have been avoided by proper approach and mooring inspection procedures. The tanker overflow (at an offloading port!) was perhaps a result of improper valve settings or inattention during the filling of a ballast tank.

Assuming then that preventable major leaks will not occur with such frequency, (two spills per month, on the average) at U.S. ports where, it is hoped, extreme caution will be used, the unavoidable failures are likely to constitute the major remaining hazard. Hose problems encountered in the tanker rail area can be expected to be reduced by proper hose design, handling, and inspection methods. The design would be such that only "normal" wear occurs, which visual inspection or continuous monitoring of elongation and bending characteristics can detect.

3.4 CANAPORT DATA

The National Environmental Emergency Center of the Canadian Government has a partial spill record which shows only three major spills at Canaport. These spills are listed in Table 3-6. Discussions with the New Brunswick District Office of the Canadian Ministry of Transport revealed that several smaller spills have occurred at the Canaport facility. Three additional spills which occurred in 1970 are listed in Table 3-7. No additional data are available on these earlier spills.

Evaluation of Canaport Data

The three spills reported involve a total of 63,426 gallons. Two spills (42,420 gallons) resulted from hose-associated incidents. The 420 gallons spilled during repair was a result of improper procedures (i.e., not assuring that the oil in the hose was duly replaced by sea water prior to disassembly). The large spill of 42,000 gallons, (representing about one minute of full flow after the break), could have been reduced substantially by proper precautions and operating procedures. Perhaps the hose in question could have been identified as faulty by a test prior to the unloading operation. There were 21,000 gallons spilled when a mooring line broke and two 16-inch discharge hoses ruptured while a ship was discharging oil at the refinery. This hose rupture was unavoidable once the mooring line failed. The mooring line failure was reported to have been the result of an accidental shift on the ship to full ahead power.

3.5 BUOY MOORING FORUM DATA

The Buoy Mooring Forum data is shown in Table 3-7. These data were initially provided for an MIT report[4] on the impact of offshore petroleum developments. As shown in Table 3-7, the spill sizes and causes are listed but no failure modes are detailed.

Buoy Mooring Forum Data Evaluation

Table 3-8 summarizes the relevant statistics which can be extracted from Table 3-7. The proportion of oil spilled from the hoses versus all causes (72%) is similar to that spilled at Durban, and the proportion spilled as a direct result of hose failures (32%) is also similar. About half of the hose failure related oil spills are not separated from the rail hose or mainline hose failures so that no conclusions can be made here. Table 3-9 compares major spills of the one fixed installation listed in Table 3-7 with spills at all of the 18 SPMs and with all major hose spills. Underbuoy hose spills represent only 14% of all the major events listed.

It should also be noted that the three last spills on Table 3-7 occurred at Canaport from 1970 to 1972 (i.e., during the early years of operation). These spills were due to an arrangement of underbuoy hoses which has since been changed. In the original arrangement, three hoses were used to connect the buoy to the undersea pipeline. Because of the high tidal range it was impossible to prevent chafing of these underbuoy hoses against each other or against anchor chains. At present, a single 20-inch hose arranged in a "Lazy-S" system is used.

TABLE 3-6. SPILLS AT CANAPORT

Date:	Cause	Quantity: Gallons
14 June 74	Hose rupture during transfer	42,000
6 Nov. 74	Oil left in hose accidentally during disassembly	420
29 June 71	Mooring line break, resulting in rupture of both 16" rail hose strings	21,000

Source: National Environmental Emergency Center, Canadian Government.

TABLE 3-7. OFFSHORE TERMINAL SPILLS OBTAINED FROM BUOY MOORING FORUM

YEAR INSTALLED	PORT	TYPE	MAXIMUM TANKER SIZE	SPILL SIZE, GALLONS	REPORT PERIOD	CAUSE
62	Brega	Fixed	100	33,600	62-72	Unloading arm
62	Brega	Fixed	100	21,000	62-72	Unloading arm
62	Brega	Fixed	100	8,400	62-72	Unloading arm
62	Brega	Fixed	100	16,800	62-72	Unloading arm
62	Brega	Fixed	100	4,200	62-72	
69	Brega	SALM	300	2,100	69-72	Hoses
70	Singapore	CALM	250		70-71	
71	Nakagusaku	SALM	250		71-72	
72	Botany Bay	SBM	80	1,260	72-72	Expansion piece
67	Huelva Bay	SBM	100	25,200	71-72	Mooring line and hose
67	Huelva Bay	SBM	100	420	71-72	Hoses
67	Huelva Bay	SBM	100	840	71-72	Hoses
67	Koshiba	SBM	100	21,000	67-72	Fishing vessel tore hoses
67	Koshiba	SBM	100	840	67-72	Hoses
67	Koshiba	SBM	100	420	67-72	Hoses
71	Tetney	SBM	210	25,200	71-72	Tanker hit buoy
71	Tetney	SBM	210	200	71-72	Hoses
71	Tetney	SBM	210	400	71-72	Hoses
70	Durban	SBM	220	8,400	71-72	Underbuoy hose
70	Durban	SBM	220	1,680	71-72	Hoses
70	Durban	SBM	220	420	71-72	Hoses
68	Wulsan	SBM	200	420	71-72	Hoses
68	Wulsan	SBM	200	630	71-72	Hoses
65	Gamba	SBM	90	420	67-72	Hoses
65	Gamba	SBM	90	6,300	67-72	Underbuoy hose
65	Gamba	SBM	90	200	67-72	Hoses
72	Porto Baleo	SBM	100		72-72	
72	Porto Baleo	SBM	250		72-72	
66	Wulsan	SBM	75	840	70-72	Hoses
66	Wulsan	SBM	75	600	70-72	Hoses
65	Chiba	SBM	120	2,520	70-72	Buoy chain
65	Chiba	SBM	120	400	70-72	Hoses
65	Chiba	SBM	120	600	70-72	Hoses
68	Kawasaki	SBM	260	2,100	70-72	Buoy hit by vessel
68	Kawasaki	SBM	260	840	70-72	Hoses
68	Kawasaki	SBM	260	200	70-72	Hoses
71	Java	SBM	80	1,050	71-72	Swivel seals
71	Java	SBM	80	400	71-72	Swivel seals
72	Java	SBM	140		72-72	
63	Port Dickson	SBM	100	7,140	70-72	Hoses
63	Port Dickson	SBM	100	400	70-72	Hoses
63	Port Dickson	SBM	100	200	70-72	Hoses
63	Port Dickson	SBM	100	800	70-72	Hoses
64	Miri	SBM	65	400	70-72	SBM hose connection
64	Miri	SBM	65	600	70-72	Hoses
71	Seria	SBM	250		71-72	
67	Subic Bay	SBM	108	400	70-72	Valves
67	Subic Bay	SBM	108	1,000	70-72	Hoses
70	Saint John	SBM	350	200	70-72	Chafed underbuoy hose
70	Saint John	SBM	350	400	70-72	Chafed underbuoy hose
70	Saint John	SBM	350	200	70-72	Chafed underbuoy hose

TABLE 3-8. DEEPWATER PORT ANALYSIS

Assignment	Quantity Gallons		Percentages
Total spilled at SPM's	117,240		100%
Not involving hose	30,410		26%
Total involving hoses	86,830		74%
Mooring line breaks and overruns causing hose failure	46,200	or or	40% of total, 66% of total hose failures
Total direct hose failures	40,630		35% of total 45% of total hose failures
Underbuoy hose spill incidents	15,900		14% of total 43% of direct hose spill
Mainline and rail hose	20,570		50% of direct hose spill

TABLE 3-9. MAJOR EVENTS AT SPM'S AND FIXED INSTALLATIONS

Installation	Failure	Spill Size Gallons	Notes
Fixed:	Unloading Arm	33,600	at a single installation
	" "	21,000	during a 10 year period
	" "	16,000	
	" "	8,000	
		78,600	
SPM	Mooring line	25,200	19 installations over an
	Vessel overrun	21,000	average of a 2 year
	" "	25,000	period
		71,200	
	Hose failure	8,400	this represents 8% of all
	" "	6,300	the major spills listed

4. HOSE ENVIRONMENTAL CONSIDERATIONS

4.1 SITE-SPECIFIC FACTORS AND FAILURE MODES

The environment to which the hose is exposed can significantly influence both the hose life and failure modes as shown in Table 4-1. From Reference 1, it can be shown that hose life in sheltered waters is greater than hose life in locations where high waves and winds predominate. Hence we see that hose life and failure modes can be related to the particular site of the SPM.

At the Canaport facility located in St. John, New Brunswick on the Bay of Fundy, where the tides run to 35 ft., early failures of subsea hoses were, until recently, quite frequent. These failures resulted from chafing of the hoses against each other and against the catenary chains used to anchor the buoy. After the problem was alleviated by redesigning the undersea hose layout, failures of the FOB and rail hoses began to predominate.

At Durban, the predominant failures seemed to have occurred at the rail section. The high swells characteristic of the Durban area may have contributed to the flexural fatigue and tensile wear at the nipples of rail segments at that site.

Current inspection practices at various sites may very well have evolved in response to experience at those sites and may have served to minimize spills from the most exposed section of the hose at each site. It is therefore not expected that spill statistics, even if available, would provide a complete picture as far as new installations are concerned.

In the following sections, the action of the environment on the individual segments of hose is discussed so that the segments most likely to fail in a given environment can be identified. In Section 4.6, information on the Gulf environment will be presented and characterized in terms of its most likely impact on hose life.

TABLE 4-1. ENVIRONMENTAL CAUSE AND EFFECT CHART FOR HOSES

ENVIRONMENTAL FACTOR	SIGNIFICANT PARAMETER	HOSE SEGMENT MOST AFFECTED	EFFECTS ANTICIPATED
WAVES AND SWELLS	HEIGHT, PERIOD AND DIRECTION	FLOATING SECTIONS RAIL SECTION FIRST-OFF-BUOY (CALM)	FLEXURAL STRAIN (VERTICAL PLANE) FLEXURAL AND TENSILE STRAIN TORSIONAL STRAIN
SUBSEA CURRENTS (TIDAL, COMPONENT)	SPEED	SUBSEA SECTIONS (SALM) UNDER BUOY SECTION	ALIGNMENT OF BUOYANCY TANKS CHAFING AGAINST FIXED COMPONENTS CHAFING AGAINST ANCHOR CHAINS
SURFACE SURRENTS (TITLE, DENSITY AND WIND COMPONENTS)	SPEED PERSISTENCE	FLOATING SECTION FIRST-OFF BUOY SECTION (CALM)	CHAFING AGAINST TANKER-BOW BENDING STRAIN AT SWIVEL DUE TO FREQUENT CHANGES IN TANKER DIRECTION
WIND, LOCAL WEATHER (PREDOMINANT HIGHS AND LOWS)	SPEED AND DIRECTION	FLOATING SECTIONS	AS ABOVE (CURRENTS AND WINDS) IF NONALIGNED WILL CAUSE HOSE TO CHAFE
	PERSISTENCE	FIRST OF BUOY SECTION (CALM) IDLE HOSE	AS ABOVE KINKING IN IRREGULAR SEAS
CLIMATE	TEMPERATURE SALINITY HUMIDITY ELECTRICITY (ATMOSPHERIC)	ALL SECTIONS	DETERIORATION DURING STORAGE
TIDE	EXCURSION CURRENTS	SUBSEA SECTIONS SUBSEA SECTIONS	KINKING, FLEXURAL STRAIN SEE SUBSEA CURRENTS ABOVE

4.2 WAVES

The effect of waves on flexible hoses has been briefly discussed in earlier sections. The effects include the flexing of hoses in the vertical plane and a rocking motion of the buoy which results in a torsional strain at the FOB hose in CALM systems.

Reference 1 contains a brief and preliminary theoretical investigation which indicates that eight-foot waves of approximately 300 ft. wave length result in significant bending stresses at the floating hose. These bending stresses are shown to be related to the stiffness of the hose and will generally increase with increasing stiffness.

The length of individual hose sections is between 30 and 40 feet and it is therefore likely that shorter waves of the same amplitude will impose larger stresses. Future analysis in this area is desirable.

It is not possible to quantify the hazard without knowing the complete and detailed effect on the hose of occasional waves at the extreme end of the annual distribution curve of height and period. Generally, it is to be expected that the bending action of the waves will lead to flexural fatigue and cause breaks of the liner near the nipple.

As already pointed out, the rocking motion of the buoy may lead to damage to the hose carcass due to the winding and unwinding of the supporting spirals. In this area, experimental work is needed to determine the type of damage and the most suitable methods of detection.

It should be noted that no torsional strains of this type are involved in SALM systems.

4.3 TIDES

The tidal motion takes place both in the vertical and horizontal planes. The vertical movement of the CALM buoy or SALM floating hoses changes the shape of the underwater section of the hose system and, in particular, the angles which various sections of the underwater hoses subtend at fixed terminations and at buoyancy tanks. Surface currents associated with large tidal excursions are treated in the next section. The motion below the surface in the horizontal plane is important where the lateral displacement of subsea hoses may cause these to come into contact with, and be chafed by, nearby obstructions such as anchor chains (in the case of (CALM) systems). Hoses in the SALM system are less subject to damaging responses due to tidal currents below the surface since the anchoring devices present few obstructions to the movement of the subsea hoses.

4.4 WINDS AND SURFACE CURRENTS

The direct action of wind and surface currents in the present context is to move the tanker or idle hose around the mooring buoy. Frequent changes in wind direction are therefore likely to lead to increased flexural fatigue of the hose. It is not possible within the scope of this investigation to determine the frequency of rotational movement of the swivel as a result of these environmental factors. Even if data on the rotation of the swivel could be obtained, it would be difficult to estimate in any detail the effect on the FOB or FOS hose since the resistance of the swivel to rotation would probably vary from installation to installation, and would probably be a function of time, temperature, and buoy motion.

When the hose is not connected to a tanker, the idle hose will snake due to surface currents and surface winds. The snaking motion in combination with irregular wave motion may cause kinking in the idle hose, which may account for some of the damage to the outer layers of the carcass of floating sections. Where two parallel strings are used, damage is frequently observed to arise from chaffing as a result of physical contact between the two strings.

4.5 CLIMATE

Climate has an impact, primarily on the deterioration of stored hose. The provisions suggested in the OCIMF Hose Guide for the storage of hose are intended to preserve hoses in good condition during storage. Such factors as temperature, humidity, atmospheric ozone content and salinity may be important.

4.6 THE GULF OF MEXICO ENVIRONMENT

In reviewing the environment for the DWPs on the Gulf Coast, two sources of information were examined, these were:

a) "Environmental Guide for the U.S. Gulf Coast" prepared in 1972 by the National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center, Asheville, NC.

b) "Meteorological-Oceanographic Conditions Affecting Tanker Terminal" prepared by A.H. Glenn and Associates, 1972, on behalf of LOOP Inc. and submitted as part of the Environmental Analysis by the applicant.

The first of these documents presents detailed environmental profiles for seven potential Gulf Coast Deepwater Port sites. The information presented for the Galveston-Freeport areas consists of data for the climatic normals, means and extremes, general environmental summaries, monthly summaries of wind directions and speeds, and an annual summary of marine weather data.

The other document presents data for the Grand Isle Block 46; 100-ft. mean low water depth; offshore Louisiana. Relevant data presented consist of annual wind summaries by speed and direction, annual wave summaries by height and direction, height vs. period and length, tides, and 100-year storm information. For the presentation of the actual data the reader is directed to the two documents.

When a comparison is made of the data in the two documents, with the environmental relationships presented in Table 4-1 on hose failure statistics at specific installations, a clear picture emerges. The Gulf environment is generally one of low tidal variation and moderate winds. Because of the gradual increase in depth, the ports would be located in open waters where the wave heights are moderate to heavy. A significant proportion of the waves between 8 and 15 feet are of short lengths and are likely to impose stress on the floating section. Currents are moderate.

The main hazard to the hose system is the frequent occurrence of tropical storms, and careful provisions for safeguarding hose during hurricanes must be made. Sinking hoses (designed for this purpose) below the surface could provide such safeguards.

The Gulf environment must play an important role in the design requirements for the hoses of deepwater ports. Because of the frequency of short waves of medium and high amplitude, the predominant failure modes are expected to be liner breaks at the nipples in the floating section. The rising and sinking of the tail end of the floating section will be transmitted to the rail hose and cause fairly heavy wear of the rail section unless specific provisions are made to attach the hoses outboard of the tanker's side.

Hose life cannot at present be predicted with any degree of accuracy, but proper and diligent inspection methods should help prevent oil spills.

5. IDENTIFICATION OF HOSE FAILURE MODES

5.1 HOSE FAILURE CLASSIFICATIONS

As discussed in Section 3, the data base from which a comprehensive analysis of hose failures could be made does not exist. The existing data are presented in Section 3 along with information gained from discussions with terminal operators and hose manufacturers. These data serve as the basis for classifying hose failures. Additional information obtained in Reference 2 was employed to supplement the information provided in Reference 1.

It should be noted that by employing historical data, only those failure modes which appear in the data base will be identified. Additional possible failure modes, not shown in any data base, must also be identified and considered as they may cause future problems. Examples of such potential failures involve nipple to flange welds, gaskets and bolts/studs connecting the various sections of hose, etc.

The problem of identifying the classifying hose failure modes is further complicated by the lack of a full understanding of the relationship between hose failure modes and the causal mechanisms. This is particularly true of instances where in-service hoses fail as a result of improper design or flaws introduced into the hose during manufacture. Only when hoses fail as a result of improper system operation, collision with another object, or damage while being handled or stored can the hose failure type and cause be identified. To date there has been very little effort expended on correlating hose failures with a specific cause, be it improper design, a manufacturing flaw, etc. The importance of such correlations cannot be underestimated, as this type of information would enhance both hose design and inspection.

Hose failures may be classified into four broad categories: 1) failure due to the hose itself, i.e., design, manufacture, etc., 2) failure due to handling, 3) a combination of both 1 and 2, and 4) failure resulting from the environment. One hose manufacturer has estimated that more than 90% of hose troubles are caused by design. Hose failures may be further classified into the categories shown in Table 5-1. These failure types are the ones for which inspection procedures will be developed.

The primary emphasis of this study is on nondestructive inspection and test methods for hoses. Flaw to failure mode correlations are beyond the scope of this study. The following sections examine those hose flaws which, in service, result in a leak and those manufacturing defects which may, and probably have, resulted in hose failures.

5.2 IN-SERVICE HOSE FAILURE MODES

Failures occurring while the hose is in service and are detected at that time or at an inspection interval, are mainly caused by the hose design, damage inflicted during service or deployment into service, and improper system operation. Hose failures resulting from hose design occur because the hose operating environment (wind, waves, currents, etc.) is not compatible with the design. Two design hose manufacturers have stated that in a hose string of, for example, fourteen hoses, there will be a failure pattern where the first, sixth, and tenth hoses fail more often than the remaining hoses in the string.

Although most hoses fail in service from natural loadings, some failures are induced by poor mooring or loading techniques. The basic system arrangement, such as the hose attachment to the buoy along with the height of the attachment above the waterline, is also a critical factor. The number and size of hoses, their relative positions, and current and wind condition will sometimes cause the hoses to scrape against each other causing abrasion. Careless operational procedures, such as closing valves too rapidly, carrying a vacuum of more than 10 psi, and break-outs may also result in hose failure. These causes still leave the majority of failures not related to handling and operational procedures. The remainder of the failures result in low service life and are attributed to poor hose design or congenital flaws.

TABLE 5-1. HOSE FAILURE TYPES

- Nipple Integrity
  - Bond to Body
  - Bond to Liner
  - Bond to Flange

- Flange Integrity
  - Bolting
  - Cracks
  - Welding

- Hose Body Integrity
  - Component Adhesion
  - Oil Intrusion
  - Stiffness/Flexure Uniformity (kinking)
  - Rupture or helix fracture

- Liner Integrity
  - Liner Adhesion
  - Surface Smoothness and tightness

- Flotation Integrity
  - Adhesion to Hose
  - Floatation/Bulk Modulus
  - Surface Condition

- Hose String Integrity
  - Electrical Conductivity

Floating hoses fail more often than submerged hoses. One of the reasons for the higher failure rate of floating hoses is the failure of the floatation material, which is reason enough to remove the hose from service, even though the hose structure may be intact. Floating hoses are also more visible and vulnerable to environmental effects and other surface-related damage than submarine hoses. Under-buoy hoses are protected from surface-related damage, but at present must be inspected by divers. A common failure mode of the underbuoy hose is nipple leaks, which are more easily detected on under-buoy hoses than on the floating hoses. The floatation tanks used to support the underbuoy hoses (in many Lazy-S configurations) may also cause high bending stresses in the hoses and, therefore, eventual failure.

Because of the differences in hose functions, it is not possible to adequately compare the various failure types. However, two hose types do fail more often than the others: First-of-the-buoy (FOB) or swivel (FOS) hoses, and over-the-rail hoses. The FOB hoses fail because of the connection to the buoy where the large change in stiffness induces bending loads. There is a poor understanding of the effect on failures that the entrance angle to the buoy has on hoses as they enter the air-sea interface. Most FOB failures are probably caused by bending fatigue. Half-float hoses are now in wide use to reduce the FOB failure rate. The half-float hose has the flotation on only one-half the length of the hose resulting in a lower buoyant force acting on the hose and decreasing the hose "entrance angle" into the sea. The use of the SALM system eliminates many of the problems associated with the CALM FOB hose failures.

The "over-the-rail" or "tail" hoses fail due to the chafing and bending associated with the shipboard interface as the hose is bent over the rail or the ship and connected to the ship manifold. The present lack of uniform manifolding on various ships is a problem. The OCIMF has recommended a standard manifold on all ships; however, many ships have not adopted the suggested standard. Shipboard hose handling systems are also not standard. Many ships that go to a particular terminal do not have sufficient hoist capacity to handle the hoses and therefore, "man handle" the hoses severely. Hose connections are not a standard height or distance from the rail. The Japanese do not use an "over-the-rail" hose; instead they use a steel elbow and nipple as shown in Figure 5-1.

Hose failures occurring in service are described in the following sections.

5.2.1 Nipple Leaks

This failure is characterized by the leakage of oil from between the nipple and the liner. This type of failure can be partially attributed to poor preparation of the nipple, and/or poor interply bonding during manufacture. Nipple leaks will also occur when the liner has been torn at the nipple, this is shown in Figure 5-2.

5.2.2 Carcass Failure

This failure usually appears as a fracture or break completely through the carcass circumference as shown in Figure 5-3. This fault almost always occurs within one hose diameter of the inside end of the nipple. In Figure 5-3, it appears as if the helical wire has caused the failure since it protrudes through the failed area. Carcass failures frequently start as nipple-leaks. The overall reason for the failure is believed to be bending fatigue with the failure brought about by a congenital flaw such as lack of component bonding either to the nipple or interply. If the liner allows oil to saturate the various layers, lack of interlayer bonding might occur in the helical wire area. Since the wire is 3/8 to 5/8 inch in diameter and wound under some tension, if it is not secured to surrounding material it will move relative to the ply during hose bending modes. This movement will cause serious damage and eventual failure. The scenarios described are from Reference 2 and are based on observed failures. These do not reflect laboratory tests.

FIGURE 5-1. "OVER-THE-RAIL" STEEL ELBOW AND NIPPLE

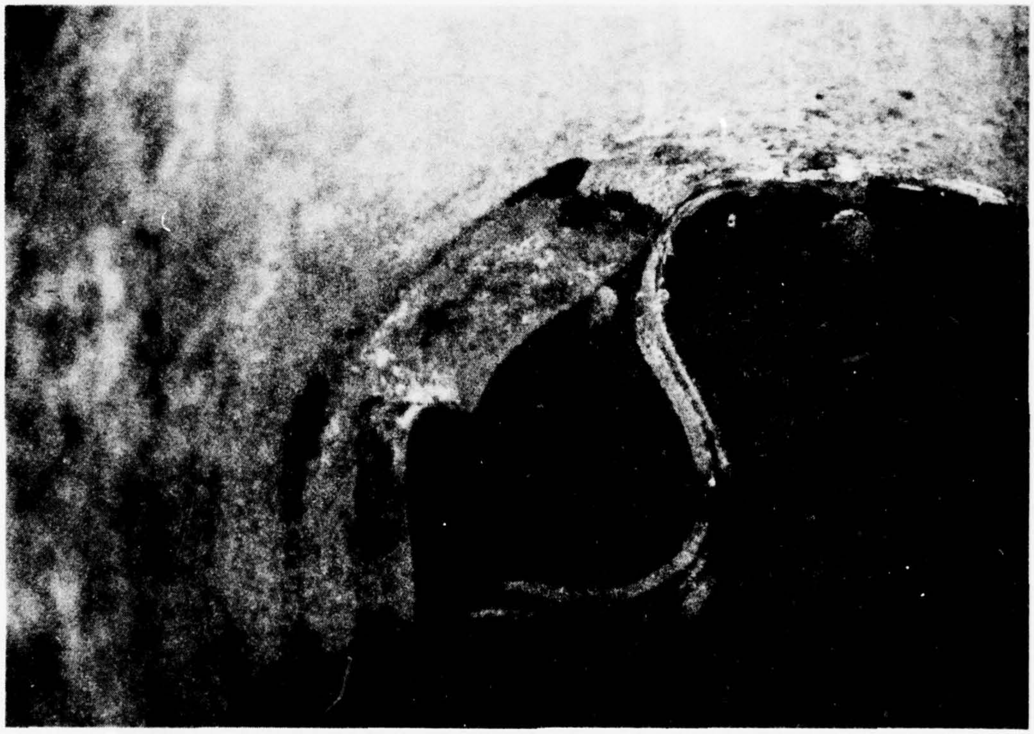


FIGURE 5-2. HOSE LINER TEAR AT NIPPLE

FIGURE 5-3. CARCASS FAILURE (NOTE HELIX WIRE PROTRUDING)

5.2.3 Kinking, Abrasion and Break-Out

If the minimum bend radius of a hose is exceeded, the hose will kink. A kink can be caused by handling, shipping or installation. It can also be caused by service operations such as pulling or pushing the hoses in place. A kink will eventually cause a through-carcass failure similar to that described in 5.2.2 except the kink can occur anywhere along the length of the hose.

Abrasion is the result of continued rubbing of the hose against an overlapping or adjacent hose or some object as shown in Figure 5-4. Under buoy hoses may rub against each other or the ocean floor if the configuration is not properly designed. In the case of floating hoses, loss of buoyant material caused by abrasion may cause automatic submergence and subsequent removal from service.

Break-out results in the nipple being pulled out of the hose. This failure is almost always the result of excessive axial force; often caused by poor mooring techniques or unexpected, sudden heavy weather. Nipple pull out may also result from the binding wires being improperly tensioned or secured during the manufacture of the hose.

5.2.4 Floatation Material Failure

This type of failure is characterized by the sinking of floating hoses. Often when older hoses are filled with water, they will sink. It is to the operator's advantage to have floating hoses float with a minimum of excess buoyancy since the bending stresses will be significantly reduced. However, the floatation materials used (PVC and foamed material rubber) will absorb water with time, as the material deteriorates, or as damage to the outer covering removes pieces of buoyant material. This absorbed water can cause the hose to sink. If the hose starts to sink, the compression of the floating material decreases buoyancy so that the hose sinks at an increasing rate, (i.e., the bulk modulus of the floating material is significantly less than the bulk modulus of water). Once a hose has sunk, the foam may take a permanent set or loss of buoyancy, and the hose itself may collapse, causing permanent damage necessitating the removal of the hose from service. Marine growth, as shown in Figure 5-5, will also decrease the effective buoyancy of the hose.

5.2.5 Liner Failure

Liner failures are characterized by both separation of the liner from the carcass, and tearing or flaking of the liner. Separation of the liner from the carcass can be the result of allowing a vacuum to remain in the hose for long periods of time (12 hours or more) after loading warm oil. There have been instances where, after loading the oil, complete liners have been pumped into the receiving tanks. Liner deterioration such as flaking can occur from the transfer of products for which the hose was not designed, thereby allowing the product to attack the liner material. Also, liner failures occur when the liner is not smooth and therefore creates perturbations in the product flow. Figure 5-6 shows a liner failure.

5.2.6 Estimates of Failure Percentages

Actual estimates of the percentage of failure types are quite crude and incomplete. Reference 2 estimated, as shown in Table 5-2, that 70% of all failures are service-connected, while 30% of all failures are a result of handling, shipping, and storage. Only 10% of all failures are liner-related, while 35% are nipple leaks leading to carcass failures. These estimates have been disputed by a manufacturer who stated that when hoses are returned they are examined, and that 85% of the failures classified as nipple leaks are in fact liner failures. With this in mind, it then becomes difficult to place actual percentages on any of the failures, and hence one must consider only failure itself and the appropriate inspection method.

5.3 MANUFACTURING DEFECTS

In many instances, hose failures that occur in service are the result of manufacturing defects. Table 5-3 shows some typical defects with the failures associated with them. Section 6 reviews inspection methods which may detect most of these defects, and Section 7 discusses methods for uncovering these defects in service.

FIGURE 5-4. HOSE OVERLAPPING

FIGURE 5-5. MARINE GROWTH ON HOSE

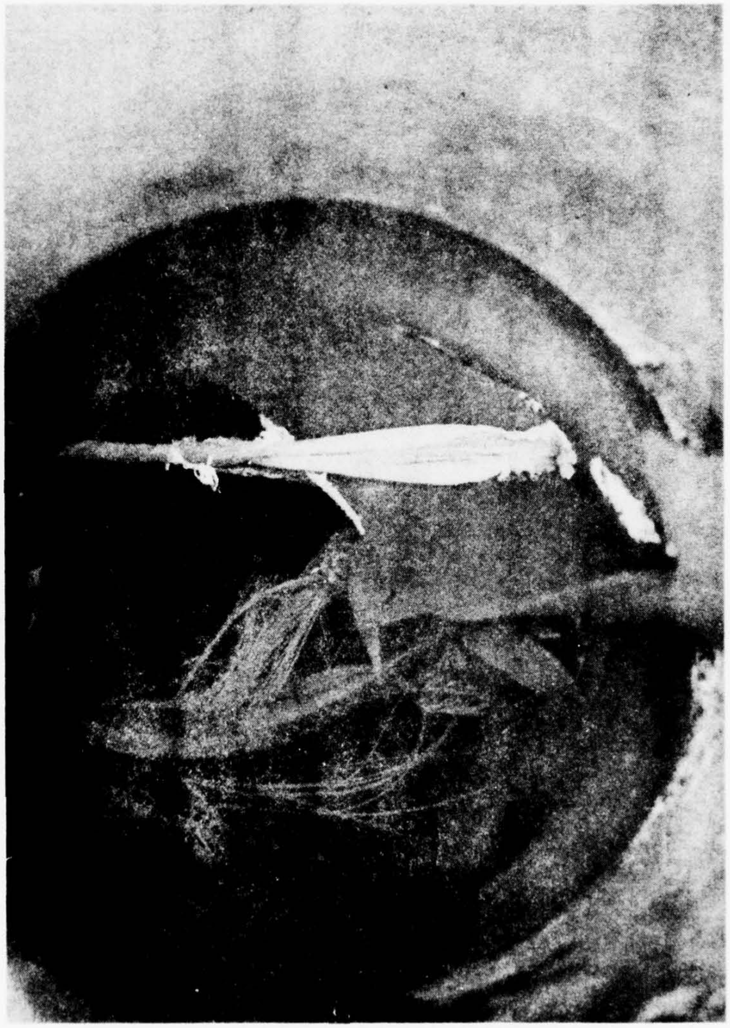


FIGURE 5-6. LINER FAILURE

TABLE 5-2. ESTIMATED HOSE FAILURE FREQUENCY

Failure Type	Percent
Liner Failure	10
Nipple Leak to Through Carcass Failure	35
Auto-Submergence	10
Other Service Connected Failures	15
Handling Shipping and Storage Damage*	30

NOTE: Only some of these hoses get into service.

SOURCE: Reference 2

TABLE 5-3. MANUFACTURING DEFECTS

DEFECT TYPE	EXPECTED FAILURE
INTERLAMINAR ADHESION	
RUBBER TO RUBBER	
RUBBER TO HELIX	
RUBBER TO NIPPLE	
LINER ADHESION	LEAKS
TENSIONING OF COMPONENTS	
HELIX	FATIGUE FRACTURE
BINDER WIRES	NIPPLE LEAKS
FABRICATION DEFECTS	
MISPLACED COMPONENTS	FATIGUE FAILURE
MISSING COMPONENTS	FATIGUE FAILURE
IMPROPER SPACING OF HELIX	KINK
IMPROPER BREAKER SPLICE	LEAK
WELDING DEFECTS	
MARTINSITIC CONDITION	NIPPLE OR FLANGE FRACTURE
BURNED RUBBER	LEAKS
STRESS CRACKS	NIPPLE OR FLANGE FRACTURE
POROSITY	NIPPLE OR FLANGE FRACTURE

A description of some of the manufacturing defects follows.

5.3.1 Interlaminar Adhesion

One of the more prevalent failure modes in hoses is caused by the progressive degradation of the bond between the hose liner and the hose carcass. Causes for loss in adhesion can usually be found in the plant under the heading of workmanship or poor building practice. For example, when one ply has been completed, the surface of the hose is primed with butyl acetate prior to assembly of the next layer. In some plants this is done by using a rag dipped in the butyl acetate solution. In other plants, a brush or spray may be used. This attacks the rubber on the mandrel and permits a high "tack" on the next layer of material. Too much solvent will cause migration between components, too little may prevent adhesion. This accepted practice would only cause a problem in areas where the hose was subjected to excessive fatigue in regions where too little primer caused poor adhesion. Dirty or dusty surfaces can also prevent good adhesion, and can be caused by the component contacting dirty or contaminated surfaces.

Adhesion of rubber to metal is generally a more difficult process that requires good preparation of the metallic surfaces. Some shops sandblast the nipple prior to building it into the hose; others merely clean or solvent wash the surface. These different procedures result in differences in adhesion levels.

5.3.2 Placement of Metallic Support Structure

The helix is tensioned and assembled into the hose using a manual or semi-automated control of both tension and spacing. Tensioning is not generally as critical as spacing, unless the tension becomes sufficiently great to crush other components in the lay-up, or alter the characteristics of the helix by causing it to go into the plastic range.

Helix spacing on the other hand can have a great effect on the flexure and flotation properities of the hose. It has been observed that helix spacing during manufacture can vary as much as 50% from the desired range.

5.3.3 Fabrication Defects

Misplaced or missing components can frequently contribute to hose failure. One common flaw of this type is too great, or too little overlap in the helical lay-up of breaker or ply material. Other problems can be related to the order of termination of component layers at the nipple. If, for example, a breaker ply is wound to a point where it either touches the nipple or does not lie under all the binding wires, then this becomes an unplanned weak spot.

5.3.4 Welding Defects

Welding problems for hoses are the same as for other weldments; brittleness, slag inclusions, too mucn spatter, and stress cracks are examples. One condition not occurring in most weldments, but possible with hoses, is the burning of the non-metallic components in the hose. If care is not taken to avoid this and the other manufacturing defects cited, then uneven quality during manufacture may be the result.

6. REVIEW OF EXISTING INSPECTION TECHNOLOGY

The purpose of this section is to review all available inspection methods applicable to hoses, and identify the most promising methods for laboratory testing. This review and subsequent selection of candidate methods is limited to nondestructive inspection methods. Results of the laboratory tests of the feasibility of selected methods are reported in Section 7.

Inspection methods presently in use at several DWP's are based on guidelines and standards developed by the Buoy Mooring Forum of the OCIMF[3]. These guidelines and standards have been incorporated in the American Bureau of Shipping "Rules for Building and Classing Single Point Moorings." Also, the USCG has incorporated these guidelines into the published Rules and Regulations for Deepwater Ports (Title 33 Part 150.400).

In utilizing available inspection methods for DWP hose systems, consideration must be given to the time frame in which inspection will take place. In principle it would be desirable to provide a means for the continuous automatic monitoring of hose performance in order to detect gradual deterioration. While some hose characteristics can probably be monitored continuously, there is also a need for inspection of those characteristics that cannot be monitored continuously. Inspection of hoses during manufacture, prior to deployment, before and during offloading operations, or when removed from service for inspection, are phases which are candidates for the application of nondestructive inspection methods.

6.1 AVAILABLE INSPECTION METHODS

A review of the available nondestructive inspection methods, together with comments on their potential application, is presented in Table 6-1. The utility of any of these methods will depend on several factors, such as the cost or feasibility associated with their implementation. As an example, it would be useful to monitor the acoustic emissions from hoses during product transfer since some defect types will no doubt cause noises having identifiable signatures. Similarily, strain gages may be useful in detecting excessive bending near the cargo swivel and at some points close to the tanker rail. The time integral of strain beyond certain "safe" levels may serve as an indicator of possible failure due to fatigue. Also, technical means can certainly be devised to detect the presence of oil outside of the liner near the nipple. This would be useful because nipple leaks constitute the predominant failure events. In all of these examples, the overriding consideration is that these inspection methods be practical, cost effective, and provide a high degree of technical reliability.

The success of any particular inspection method must be judged by its performance in the real world environment. Therefore, in the selection of the most promising inspection methods, one must consider not only where the inspection method will be used, but also what personnel will be required to operate the necessary equipment.

Application of Inspection Methods to Hoses

As discussed in Section 5, hose failures may result from manufacturing defects, damage during handling or operation, and the natural in-service environment. To adequately detect damaged hoses requires that inspection methods be employed not only during manufacture, but also prior to deployment into service, periodically after offloading operations, and when hoses are removed from service for inspection. Considering the variety of conditions noted above under which inspection methods may be employed, and the variations in the design of DWP hose systems, it is apparent that no single inspection method will be applicable to all conditions. Table 6-1 delineates the types of failures or flaws to which each inspection method is potentially applicable.

6.2 DISCUSSION OF INSPECTION METHODS

The purpose of this section is to discuss all available inspection methods shown in Table 6-1, as well as the advantages and disadvantages of each method, and the feasibility of its use for hose inspection.

TABLE 6-1. PROSPECTIVE INSPECTION METHODS

INSPECTION METHOD	PRINCIPLE OF OPERATION	CONDITION INSPECTED FOR	APPLICABLE TO HOSE INSPECTION	USED IN WHAT WAY
VISUAL	(a) OBSERVATION OF DEFECTS AND DAMAGE	SURFACE CRACKS, KINKS, LEAKS	YES	AT MANUFACTURE, PRIOR TO DEPLOYMENT INTO SERVICE
	(b) OBSERVATION OF OIL SPILLS	ABRASION DAMAGE, MARINE GROWTH		PERIODIC ON-SITE INSPECTION
	(c) DIMENSIONAL MEASUREMENTS	GENERAL CONDITION, FLOTATION INTEGRITY		PERIODIC DOCKYARD INSPECTION
AIDED VISUAL	(a) VIDEO MONITORS	OIL SPILLS, DAMAGE BY ABRASION, KINKS	MARGINAL	INSPECTION DURING TRANSFER
	(b) HOLOGRAPHY	LINER SEPARATIONS	PROBABLY NOT	INSPECTION DURING VACUUM TESTING
	(c) FLUORESCENCE SPECTRA	OIL SPILLS	YES	INSPECTION DURING TRANSFER
	(d) OPTICAL STRESS ENHANCEMENT (1) BRITTLE COATING (2) PHOTOELASTIC COATING	OVERSTRESSED HOSE	MARGINAL	INSPECTION FOR CONDITIONS OF EXCESSIVE STRESS EXPERIENCE DURING HANDLING AND POSSIBLY IN SERVICE
PHYSICAL AND CHEMICAL TESTS	(a) RUBBER DUROMETER	DEGRADATION OF RUBBER	YES	AT MANUFACTURE AND DURING PERIODIC PREVENTIVE MAINTENANCE AND INSPECTION
	(b) ELASTICITY	RUBBER QUALITY CONTROL	YES	DURING HOSE MANUFACTURE
	(c) MODULUS OF COMPRESSION	INTEGRITY OF FLOATATION MATERIAL	YES	PERIODIC PREVENTIVE MAINTENANCE
	(d) HEAT TRANSFER OR INFRA-RED	LOSS OF INTERNAL ADHESION	NO	IF USED, WOULD BE DURING TRANSFER OPERATIONS
	(e) SAMPLING MANUFACTURING EFFLUENT	VARIATIONS IN PROCESSING CURE	NO	WOULD, IF FEASIBLE, BE USED DURING MANUFACTURE
MECHANICAL TESTS	(a) VACUUM TESTS	LINER FAILURE	YES	AT MANUFACTURE AND PERIODIC DOCKYARD INSPECTION
	(b) PRESSURE TESTS	LEAKS	YES	PRIOR TO TRANSFER, PERIODIC ON-SITE, PERIODIC DOCKYARD
	(c) PRESSURE VOLUME TESTS	LEAKS, PLY FAILURE, INHERENT WEAKNESS	YES	PRIOR TO TRANSFER, PERIODIC ON-SITE, PERIODIC DOCKYARD
	(d) FLEXURE TESTS	PROPENSITY TO KINK	YES	NEW HOSE
	(e) NATURAL FREQUENCY VIBRATION	MAJOR FLAWS IN HOSE	QUESTIONABLE	ON-SITE PERIODIC INSPECTION IF IT WERE FEASIBLE
	(f) LENGTH	NIPPLE SLIPPAGE, PLY FAILURE ETC.	YES	AT MANUFACTURE AND PERIODIC DOCKYARD INSPECTION
	(g) PRESSURE DROP	LEAKS	YES	ANY TIME
FLAW ENHANCEMENT TESTS	(a) LIQUID PENETRANT	CRACKS ON SURFACE	YES	AT MANUFACTURE AND DURING INSPECTIONS
	(b) FILTERED PARTICLE	CRACKS ON SURFACE OF NIPPLE	NO	
	(c) MAGNETIC PARTICLE	" " " " "	NO	
	(d) ELECTRIFIED PARTICLE	" " " " "	NO	
PENETRATING RADIATION	(a) X RAY (RADIOGRAPHY)	PLACEMENT OF COMPONENTS,	YES	INSPECTION AT MANUFACTURE BEFORE SHIPPING
	(b) X RAY DIFFRACTION	BUILDERS DEFECTS, WELD INCLUSIONS,	NO	
	(c) FLUOROSCOPY	HELIX SPACING	NO	
	(d) XERORADIOGRAPHY			
	(e) ISOTOPE SOURCES			
	(f) PROTON RADIOGRAPHY			
ULTRASONICS	(a) ACTIVE	FLAWS WITHIN HOSE, LINER SEPARATIONS, ETC.	YES	AT MANUFACTURE AND POSSIBLE IN-SERVICE INSPECTION
	(b) PASSIVE	SEE ACOUSTIC SENSING	YES	DURING TRANSFER OR PRESSURIZATION
ACOUSTIC SENSING	(a) ACOUSTIC EMISSION	ABNORMAL NOISES WHICH ARE A SIGN OF PARTIAL OR INCIPIENT FAILURE AND LEAK DETECTION	YES	AT MANUFACTURE, DURING TRANSFER AND AT INSPECTION INTERVALS
	(b) SONIC SENSING			
ELECTRICAL CONTINUITY	(a) ELECTRIC CURRENT	ELECTRICAL CONTINUITY	YES	PERIODIC ON-SITE INSPECTION TO INSURE ELECTRICAL CONTINUITY
	(b) EDDY CURRENT	INTEGRITY OF METALLIC STRUCTURE	MARGINAL	
EXPERIENCE SENSORS	(a) PEAK PRESSURE MONITOR	MAXIMUM PRESSURE EXPERIENCED	YES	IN SERVICE
	(b) KINK MONITOR	WHETHER HOSE HAS BEEN SUBJECTED TO EXCESSIVE BENDING	YES	IN SERVICE

6.2.1 Visual Inspection

Visual inspection of DWP hoses, as presently mandated in Reference 5, requires an inspection of the hose string be conducted prior to connecting the hose string to the vessel manifold. Additional visual inspections are also required at various times during the operation of a SPM-OTS. Consideration should be given to inspection of not only the hose string but the entire OTS, through the use of overflights at regular intervals.

During manufacture of hoses, visual inspection will play an important role in minimizing the possibility of a congenital flaw in the hose. Items of concern are the helix spacing, attachment of the liner to the nipple, binding wires, condition of the liner, etc.

Prior to deployment into service, the hoses should again be visually inspected to assure that no damage has occurred during shipping and handling. This visual inspection should be directed at both the external and internal surfaces of the hose. There should be no cuts, gouges, kinks, soft spots, slacks or loose covering. Attention should also be given to the hose length, and to any variations in diameter that might indicate stretching, necking, or nipple pullout.

In-service visual inspections should require all of the above information where possible and should include a close examination of the nipple area for any leakage resulting from failure of the nipple hose interface, failed gaskets, or loose bolts, etc. Also, the geometric relationship of the hoses to any fixed object, or to each other, should be examined. The angle of attachment of the hoses to the SPM swivel and the depth of buoyancy tanks on underwater hose sections must be inspected.

6.2.2 Aided Visual Inspection

Several concepts that can expand the utility of pure visual inspection are discussed below.

6.2.2.1 Video Monitors

The cost of videomonitors and low light level TV is presently at a level where they can be considered useful in providing full inspection coverage for an entire hose string from a single station, like the ship or SPM. This technique possesses distinct advantages. First, it increases the area of coverage of hose inspection for watch standers and places them in an environment condusive to operational efficiency. Secondly, the equipment functions under light levels considered insufficient for visual leak detection, Disadvantages associated with video monitors include the placing of a camera on the tanker, possible transmission difficulty and power availability requirements.

6.2.2.2 Holography

Laser holography uses the properties of laser light and interferometry to detect minute changes in the surface character of materials as a result of a small exciting stimulus.

Generally the surface to be inspected is irradiated with laser light, and a high resolution film is exposed by the laser light reflected from that surface. When this film is developed, a three dimensional hologram appears. If the surface then undergoes a small topographical change, for example, as the result of strain relaxation within the material, and a second exposure is made on the same film, then any minute changes of topography are recorded as an interference fringe pattern when the film is scanned by laser.

Such a system has been proposed as a means for finding flaws within the hose. The approach would be to make a holographic image of the internal surface of a hose; then to subject the hose to an internal vacuum. Any change in topography as a result of liner separation would be easily identifiable.

Theoretically, this method is attractive since changes can be detected. However, the cost and complexity of such a system as well as the hose preparative requirements may make its use infeasible.

6.2.2.3 Fluorescence Spectra

Detection of oil leaking from the OTS can be accomplished by spectroscopic means, since oil reflects energy in discrete wavelengths characteristic of its composition. This technique uses the fluorescing properties of the hydrocarbons in the oil when irradiated by a light source, such as ultraviolet, to detect the presence of oil leaking from a component. Under conditions of reduced visibility, this fluorescence phenomena permits the detection of oil seepage that would otherwise go undetected.

6.2.2.4 Optical Enhancement of Stress Conditions

Techniques such as brittle or photoelastic coatings could be used with hoses as stress indicators. The advantage to this type coating is that it cracks, peels, changes color or otherwise becomes noticeable if the hose exceeds a maximum strain limit. This technique has long been used in industry to detect excessive strain at stress points in structural members and piping. There are problems in developing a coating of this type as it must be resistant to the damaging effects of the environment (e.g., sunlight, humidity, chaffing, sea growth, possible exposure to oil, etc.). Such coatings are however applicable in assessing whether a hose has been damaged in handling or transport. Development of a suitable coating to detect incidents of excessive strain would probably be quite costly.

6.2.3 Physical and Chemical Properties

Several physical and chemical properties may be utilized to detect prospective failures. In most instances, it is necessary to first test these properties at the time of manufacture and then at periodic inspection intervals when the hose is removed from service. Also, many of the properties can only be tested on a sampling basis, in which case the procedure is usually to obtain a sample of the material in question during fabrication of the hoses. This is the case with helix material and other materials comprising the internal structure of the hose.

6.2.3.1 Rubber Hardness

The conventional test for rubber cure is the durometer test for hardness. One measurement referenced in the literature is the Shore test, in which hardness numbers for normal rubber run from 50 to 80 with the 60s being the range in which natural rubber, BR, PBD, and Butyl rubbers of the type used in hoses are found. The Shore tests can be used on hoses on-site. However, temperature should be recorded since this will cause the rubber hardness to vary substantially.

The OCIMF Guide for the Handling, Storage, Inspection and Testing of Hoses in the Field, recommends that upon removal of the hose from service for inspection, the hose or liner should be examined for soft spots. This examination, when conducted on large bore hoses, requires that a man physically examine by hand the full interior length of the hose for soft spots. If any evidence of soft spots is found, the hose should be retired. This approach leaves the detection of soft spots to the judgment of a skilled individual.

Utilization of the durometer test for hardness, both during manufacture of the hose and its removal from service for inspection, would complement the tactile inspection and provide objective evaluation of the hose condition. Furthermore, with this test it would be possible to track any changes which may occur in liner properties during the lifetime of the hose.

The cost of testing devices like the Shore tester are in the neighborhood of a few hundred dollars. The test can be performed quickly.

6.2.3.2 Rubber Elasticity

Tests for the elasticity of the rubber being used in hose manufacture would assure that the quality of rubber conforms to specifications. The test for elasticity is a conventional tensile test conducted on specimens cut from the stock being used in the hose, cured at the same time and conditions as the hose. A description of the elasticity test may be found in ASTM Test Specification

28-D2630. Although this test is only useful at the time of manufacture, it does provide a means of quality assurance in hose manufacture.

6.2.3.3 Modulus of Compression

Two types of floatation are in common use for hoses. The Dunlop material, or variations thereof, consists of natural rubber laid spirally on the hose in strips. Other hose manufacturers use sections of PVC foam, which is more rigid. These sections are adhered to the hoses by bonding or wrapping with a protective cover material.

In order to insure the integrity of the hose, the buoyancy material should permit floatation of the hose with excess positive buoyance when filled with water. Under all other conditions, the hose should float higher. Generally, manufacturers provide between 15 and 30% reserve buoyancy when the hose is filled. However, hoses tend to lose their buoyancy due to damage of the cellular integrity of the foam by abrasion, bruising, cuts, etc.; accretion of marine growth, and compression or saturation of the foam by water. Furthermore, once the hose is submerged, the closed cell foam tends to compress; the hysteresis properties of the base material are such that it tends to remain compressed to some extent, thereby losing buoyancy.

Tests and inspection of foam are standard. At manufacture, samples of the material are evaluated in terms of their density and the percentage of closed cells. These are usually included as part of the manufacturers compliance package.

After the hose has been used, its buoyancy is determined by measuring it when floating separately from the string. A hose is retired if it is found to have less than 15% reserve buoyancy.

One additional test could be conducted as part of the user's acceptance, and as part of the buoyancy test. When the foam density is measured, its bulk modulus could also be obtained. This may be accomplished by submerging a sample of foam in water in a closed container and measuring the displaced volume. Pressurization of the container using a supply of water will provide changes in displacement as a function of pressure which are functions of the bulk modulus. Pressure is relieved and water is then allowed to leave the container. The difference between the amount of water used to pressurize the sample and the amount removed during sample expansion, is related to the hysteresis properties and bulk modulus of the sample. This test is not at present considered feasible for use with entire hose sections, as it is possible that the hose could be damaged, and the container size necessary for testing the entire hose would be extremely large.

6.2.3.4 Heat Transfer or Infrared

Infrared has been suggested as a possible technique for inspecting hoses. The application of infrared is based on the assumption that changes in the condition of the hose might cause oil to seep into the hose structure. If the oil is a different temperature from the hose, then this seepage would be manifested as a change in hose surface temperature, which is detectable by an infrared system. Unfortunately, other problems weigh heavily against the probable success of such a procedure. The time for oil to leak into the hose structure must be short, the difference in temperature must be large, and the hose's thermal conductivity must be high. Moreover, the surface of the hose must be uniform, and preferably exposed to air.

None of the above criteria are fulfilled completely. Moreover, well over half of any hose string is completely submerged, precluding measurements by infrared.

6.2.3.5 Chemical Property Testing

Certain classical tests can be made on the rubber constituents of hoses. These tests are generally concerned with determining the relative proportions of the various rubber constituents. For example, tests can be made to determine the amount of carbon black or other filler. Other tests can monitor the amount of extender and natural rubber, as opposed to synthetics. One of the chemical techniques becoming increasingly used, and of future use with hoses, is sampling of manufacturing effluents. Quite often in the manufacture of plastics, a sample is taken of the gaseous effluent from a product during cure. From such samples it is possible to infer the stage of completion of the chemical process. This is generally used as a quality assurance tool and has become popular because of the widespread availability of portable, easily operated, gas chromatography equipment. Although the technique is relevant to hose manufacture, the potential yield of information from such a procedure probably would not warrant the development effort required to put it into practice.

The procedure if used would involve sampling the gasses given off by the hose at several locations in the curing ovens. These gasses would then be passed through a vapor phase chromatograph for identification of their constituents. The results would provide data on the amount of solvents driven off, and on the byproducts of polymerization in their approximate mix. Whether variations from some norm would have an effect on the service life of the hose is open to question.

6.2.4 Mechanical Inspection Test

Several mechanical inspection tests are available for detecting in-service leaks and prospective hose failures. Of these inspection tests, several are presently employed for testing DWP hose systems.

6.2.4.1 Vacuum Tests

Vacuum testing is presently mandated by the USCG which requires that Section 6 Part A of the "Buoy Mooring Forum Hose Standards" be employed. The test consists of sealing off a hose using plexiglass blanks, evacuating it, and visually inspecting for separations and bubbles in the liner. However, if the liner is vented to the hose interior, nothing will be observed. After the vacuum test, further examination is accompanied by a visual and tactile inspection of the inside surface of the hose. This is accomplished by having a man go into the hose to examine it for "soft" spots.

Vacuum tests are valuable to tentatively establish the integrity of the hose, but like many of these tests it depends very heavily on the skill and reliability of the individual making the test.

6.2.4.2 Pressure Testing

Pressure testing, as with vacuum testing, is presently required by the USCG for all new hoses. It must also be performed at periodic inspection intervals. This pressure test requires that the hose be hydrostatically stressed to 1.5 times its maximum working pressure, and held in that state for a period of time. The overall hose length is then measured, and the hose is visually inspected. This test is in fairly widespread use. It provides the basis for qualification of new hoses, and for certification of those in service.

6.2.4.3 Pressure-Volume Test

Pressure versus volume testing is a minor modification to the existing pressure test and should provide insight into the possibility of hose failure while in service. This test method is predicated on establishing curves of pressure versus time, and pressure versus volume for hoses without flaws, and comparing these with curves for hoses which contain inherent weaknesses. This method has been employed in testing tires which have characteristics similar to hoses. For example, Figure 6-1 shows pressure versus volume curves for a leaky tire. Note that once this tire has a certain pressure, the volume will continue to increase with no corresponding increase in pressure. If the pressure is then differentiated with respect to time, so as to plot pressure rate versus time, a large change is seen at the flexure point. A similar characteristic would be observed for a hose if the nipple had slipped with respect to the carcass and liner. In essence, Figure 6-1 is the signature of a defective or failed component. Figure 6-2 shows the same curves for a normal tire, which continues to expand in volume with corresponding increases in pressure until the tire bursts. This is the signature of a tire with no defects. The slope of pressure versus volume curves, together with any change in pressure after a holding time, may be good indicators of hose condition, which would permit the identification of prospective

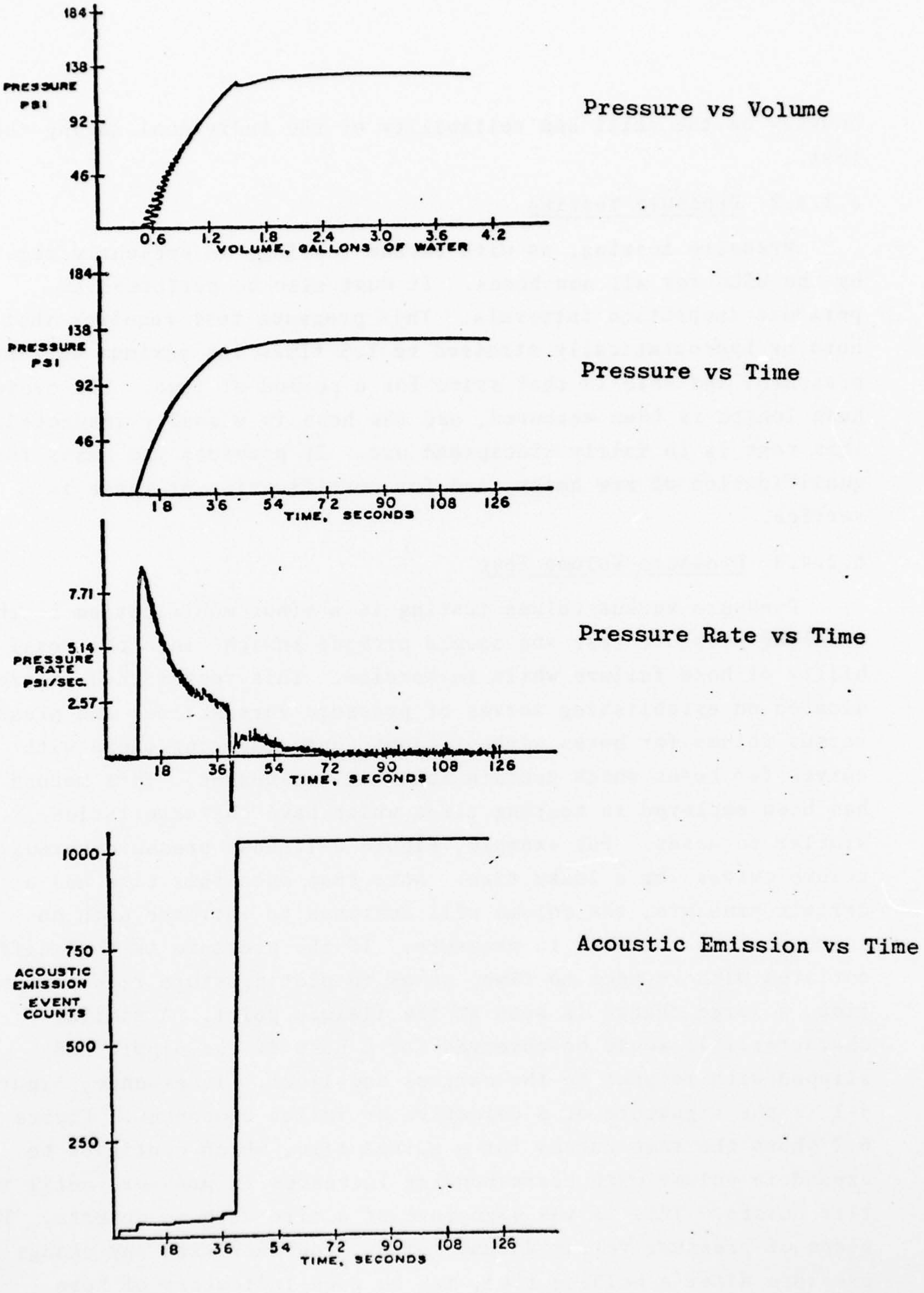
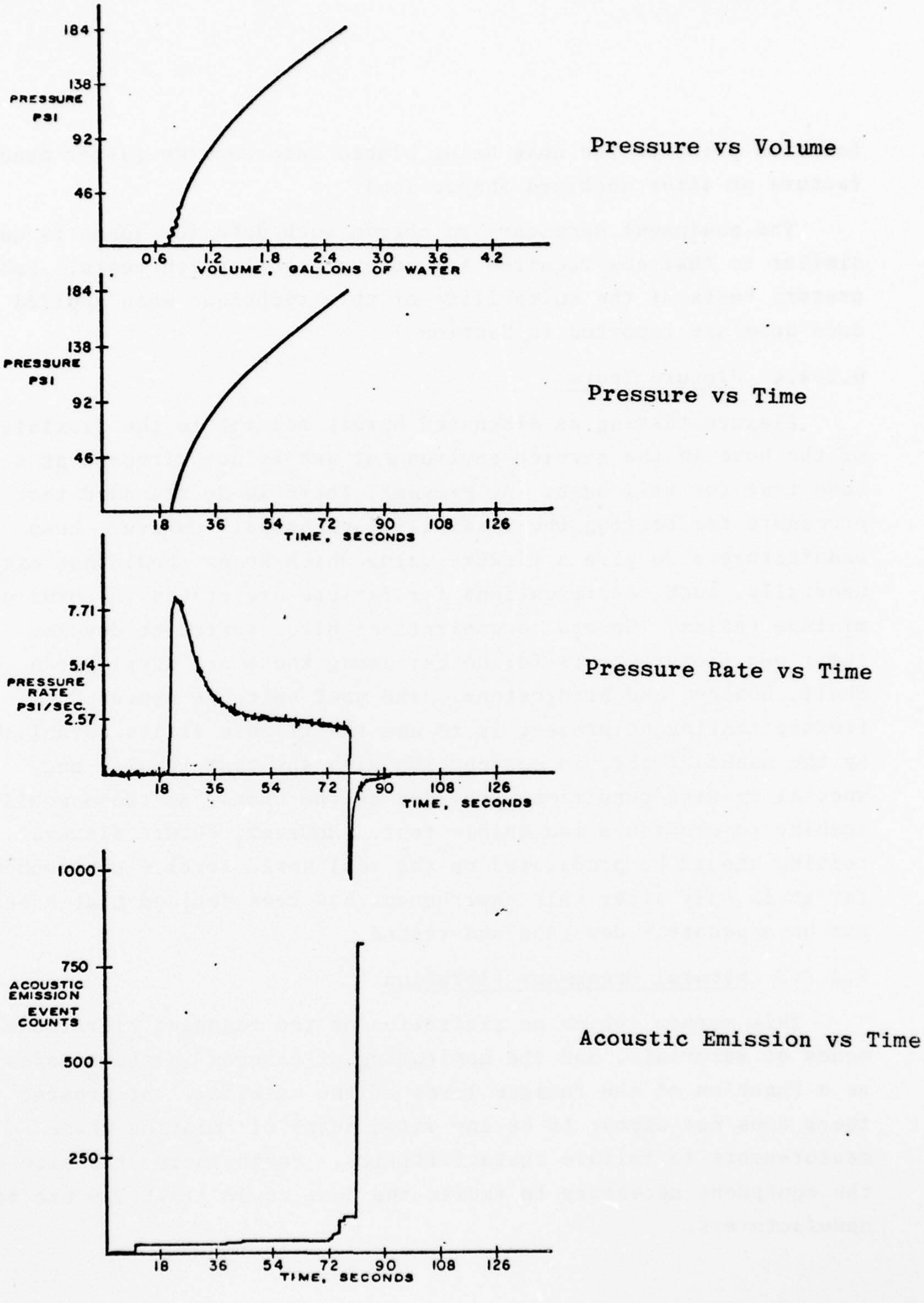


Figure 6-1. Data for 6.45 x 14 2 Ply Polyester - Leak



Pressure vs Volume

Pressure vs Time

Pressure Rate vs Time

Acoustic Emission vs Time

Figure 6-2. Data for 6.45 x 14 2 Ply Polyester - no Leak failures prior to the hose being placed into service (after manufacture or after dockyard inspection).

The equipment necessary to obtain such data for hoses is quite similar to that now required for hose pressurization tests. Laboratory tests of the suitability of this technique when applied to dock hose are reported in Section 7.

6.2.4.4 Flexure Tests

Flexure testing as discussed herein relates to the flexibility of the hose in the service environment and is not directed at a bend test for rail hose. At present, there is no standard test procedure for testing the flexibility of hoses. However, hose manufacturers do give a flexure value which hoses should not exceed. Generally, such specifications for flexure are stated in terms of minimum radius. Several organizations have started to develop their own flexure tests for hoses; among these are Royal Dutch Shell, Dunlop, and Bridgestone. The most suitable approach to flexure testing at present is to use the flexure limits established by the manufacturers in conjunction with any test results and special on-site conditions provided by the users, as these would combine to provide a reasonable test. However, future flexure testing should be predicated on the real world service environment, for it is only after this environment has been defined that hoses can be adequately designed and tested.

6.2.4.5 Natural Frequency Vibration

This method relies on excitation of the resonant vibrational modes of materials, and the monitoring of changes in these modes as a function of the fatigue level of the material. At present there does not appear to be any valid means of relating these measurements to failure characteristics. Furthermore, the size of the equipment necessary to excite the hose could limit its use to manufacturers.

6.2.4.6 Length Versus Pressure Drop

Hose length measurements are presently recommended, by the OCIMF, during the pressure test. This is a useful characteristic, but is not as sensitive as the use of change in hose volume, in defining any change in the hose. Length measurements are therefore recommended only as an adjunct to the pressure volume tests of Section 6.2.4.3.

Pressure drop, or change in differential pressure along the length of the hose string, is a potential method for inferring linear damage, or leak conditions during transfer. Pressure losses are dependent on the velocity and viscosity of the material being handled, as well as the hose length, bore diameter, and surface characteristics of the liner. The pressure differential for a given fluid velocity in larger diameter hoses is much smaller than in small hoses, and hence sensitive transducers would have to be employed for large hoses. Also, absolute pressure will change during transfer. Therefore, it is essential that pressure be compared at inlet and outlet on a real time and continuous basis.

This method has several problems (e.g., changes in temperature of cargo will change viscosity). Considerable effort would have to be expended in laboratory and field tests to ascertain its usefulness.

6.2.5 Flaws Enhancement Methods

Several available flaw-enhancement methods are applicable primarily to the detection of surface flaws, such as cracks. These methods include the use of liquid or dye penetrants, megnetic, electrified, and filtered particles, all of which are used in crack detection.

Penetrating dyes have long been applied to crack detection, and are often used to analyze castings and weldments. The method is particularly useful in components where stresses have developed cracks on the base of the metal. As such, this method is straight-forward in application and should be employed in checking hose flanges and nipples, both at manufacture, and during inspection periods. This type of test can be performed in about fifteen minutes at minimal cost.

Methods using magnetic, electrified, or filtered particles, although having some advantages, are not considered to be as suitable for use with hoses. The magnetic and electrified particle methods are usually associated with rigid surfaces having well defined electrical characteristics. Filtered particle detection depends upon the propensity of a liquid to flow into a crack site, thereby stranding larger particles near the site. This is usually used where a crack is present in a porous or rough surface. These three methods are not considered to be applicable for use with hoses.

6.2.6 Penetrating Radiation

Several forms of penetrating radiation have been employed in nondestructive testing, radiography being the best known. In addition to radiography, other uses of penetrating radiation have been applied with reasonably good results. A major advantage to using radiography for inspecting hoses is that both a well-structured inspection methodology and the necessary equipment are available (as similar methods are employed in pipe inspection). For other penetrating radiation (e.g., proton radiography, x-ray diffraction, isotope sources, xeroradiography and fluoroscopy) the equipment necessary for hose inspection does not exist. Therefore, it is not believed that these methods would easily fit into the applications context necessary for hose inspection.

X-Ray (Radiography) Inspection

X-Ray inspection is now used in several hose facilities for verification of the weld between the nipple and the flange and liner to nipple adhesion, but the full capabilities of this method have not been exploited. With the advent of techniques developed for the pipeline industry, it is reasonable to consider the use of X-rays in some routine applications to hoses, e.g., product assurance. X-rays are ideal for establishing the proper dimensions and placement of binder and helix wire as well as the location of components, splices, etc.

Success of the procedure depends on the penetration of the X-rays through the hose in such a way that good resolution (or sharpness of image) is obtained. When a beam of X-rays strikes an object, some of the radiation is absorbed by the object. The amount transmitted through is a function of the nature of the material, composition, and thickness.

X-ray units for the hose application would probably be similar to those used in pipelines (i.e., self-contained emitters using a mechanical follower to centralize themselves within the hose). This centralized source of X-rays, emitting in a 360° circle, is then dragged through the hose while an x-ray film covers the outside of the hose. This film may be purchased in strips ideally suited for wrapping around the hose and thereby giving area coverage of the hose.

This technique is common practice in field work, requiring only a source emitter and film. Other techniques such as fluoroscopy and xeroradiography require screens and complex image-making equipment not suitable for field work. For this reason, they have been removed from consideration in this application.

Isotopes are highly effective sources of penetrating radiation used for inspection. Of several hundred sources known to exist, several have become widely used for radiography. The most popular are Cobalt, Iridium, Thulium and Cesium. Considerations in their use as sources for radiation are the shielding necessary for protection of personnel and the ability of the source to penetrate the hose. It is reasonable to consider that isotope sources in their properly designed containers would be suitable substitutes for electrically generated x-rays.

6.2.7 Ultrasonic Inspection Methods

Inspection and testing systems can be grouped into two broad categories. The first are those systems that scan an entire object, on a more or less random basis, for conditions which occur at discrete locations. These may be called large area sensors. Visual infrared imaging and x-ray are examples of these. The second are testing systems which, through inspection at discrete locations, either by prior knowledge or at random, are able to infer information about the overall condition of certain elements of the object. An example is a hardness tester.

Ultrasonics uses a transducer to generate acoustic energy as penetrating radiation and is effective over a very small area. Frequently, however, the transducer is moved either manually or automatically over a line and in some cases even programmed to cover very large areas. For hose inspection, this is probably not cost effective. However, ultrasound has properties which make it a very powerful inspection technique, particularly when used to detect the internal laminar integrity of hoses. Several organizations (References 6 and 7) have reported good results in monitoring damage and fatigue degradation within cord rubber laminates. It is therefore reasonable to assume that, used as a point detector, a properly designed reflection ultrasonic probe could yield useful information about the properties of a hose.

A particular interest in hoses is the problem of internal damage as a result of abrasion, overbending, etc. Other conditions possibly detectable by ultrasonics are, for example, the failure of the interlaminar adhesion of hose constituents and failures at the nipple to hose interface.

An ultrasonic probe for point inspection of questionable areas on hoses would be dependent for its success on the degree of sound penetration through the laminar constituents of the hose. The interfaces within the hose are often highly reflecting to most ultrasonic energy. Moreover, attenuation through hose material is apt to be very great. Sound propagation depends upon the character of the medium to be penetrated as well as on the frequency and intensity of the sound. Figure 6-4 shows a typical reflection pattern from a cord rubber laminar structure of an automobile tire. The signal is exactly matched to the structure. From this it can be seen that higher frequency materials are attenuated to a much greater degree by the rubber than the lower frequency signals. Ultrasonic inspection is considered to be a good technique for application to hoses and several laboratory tests of the method are reported in Section 7.

6.2.8 Acoustic Sensing Inspection Methods

Acoustic emission of sounds from materials undergoing stress can be analyzed to detect failures. Some materials when stressed undergo a deformation and emit acoustic energy during this deformation. When the stress is removed, the materials will return to a state other than their original (i.e., will have a permanent deformation or residual stress). If these materials are then subject to stress again, they will emit little acoustic energy up to their previous state of stress or deformation. They will recommence acoustic emission upon reaching that point at approximately the same level as during the original stress condition. This is known as the Kaiser effect. In metallics, acoustic emission is characterized by spikes of sound, pings, or pops, within frequency ranges which are a function of the material.

Two applications can be foreseen for passive acoustic sensing. The first is to monitor acoustic emissions during test pressurization. The principal failure modes which may be expected to result in noise emission during pressure testing are tears and rents in the liner, and breaks in supporting reenforcing material. The noise generated at these faults would presumably propagate through the liquid contained in the hosestring, so that a microphone could be used to pick up fault-generated noises, regardless of the location of the fault, during test pressurization.

The second application of acoustic sensing is the monitoring of the noise generated by the flow of product through the hose. The specific failure mode which can best be detected in this way is liner detachment over small areas of the hose. According to Exxon

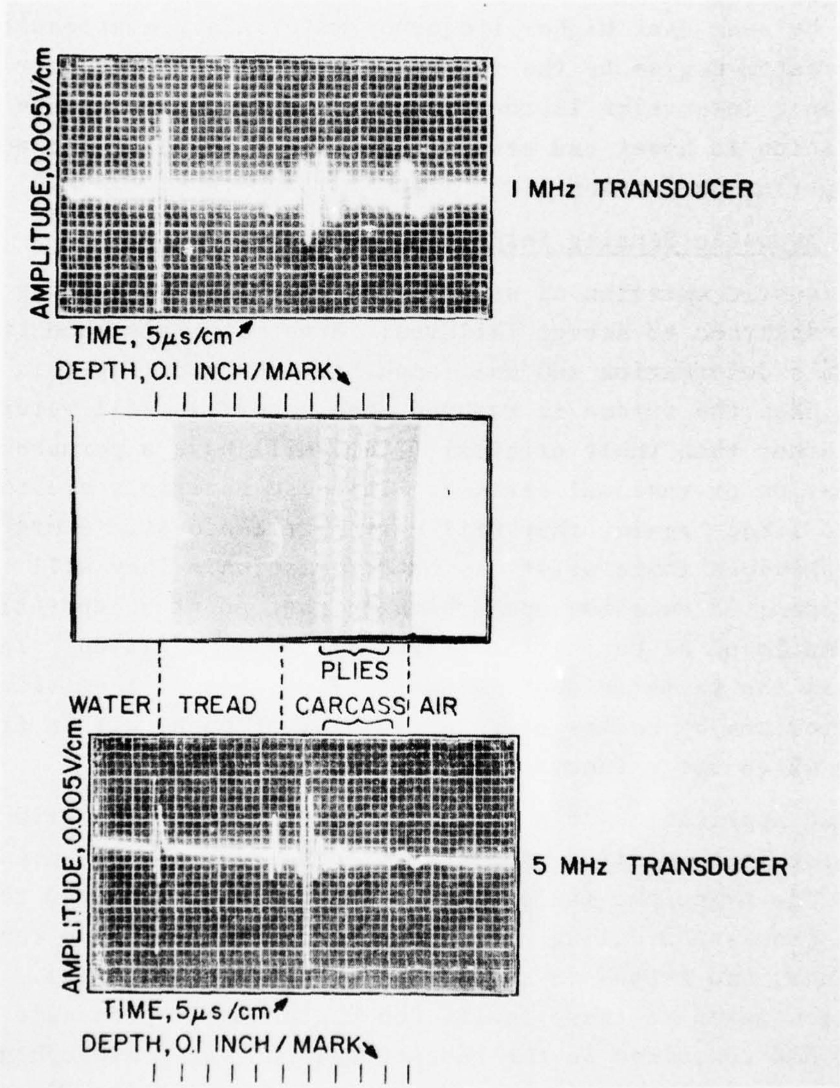


FIGURE 6-3. REFLECTION SIGNAL MATCHED TO STRUCTURE OF BELTED TIRE SECTION (TS4)

research personnel, blisters are formed when the liner becomes detached, or develops a pinhole. The detached material is then believed to "flutter" in the liquid flow. This strain is believed to lead to the eventual disintegration, and complete detachment of the liner. The noise generated by the flutter of liner material is an obvious candidate for acoustical sensing. Other faults may also give rise to acoustic emission signatures which differ from the normal rush of product in more subtle ways.

Several experimenters have reported work on acoustic emission in rubber composites (See References 8 and 9). This technique appears quite attractive from the standpoint of the ability to find incipient flaws in hose sections. However, very little work has been done in this area. In order to apply this technology to hoses, it will be necessary to obtain several pieces of information for each of the applications profiles, i.e., New Hose Inspection; Periodic-On-Site Inspection; and Transfer Monitoring. Essentially, the information lacking is the amplitude and frequency spectrum of the anticipated background noise, and characteristic flaws. Current data indicate that cord rubber composites emit primarily between 20 and 60 KHz, and the background from 4 to 30 KHz. A series of laboratory tests using acoustic emission for hose inspection are reported in Section 7.

6.2.9 Electrical Continuity

Methods such as eddy current, induction heating, electric current, and flux generation, may give information about the existence and character of metallics within the hose. However, it is not conceivable that these methods would be sufficient to reliably detect potential flaws within the hose. Electrical current may be used to check hoses designed for electrical continuity.

6.2.10 Experience Sensors

Experience sensors are a means of recording any extreme condition or parameter to which a component may have been subjected. There are several sensors available which may be employed on hoses to detect these extremes. These may be used to record peak

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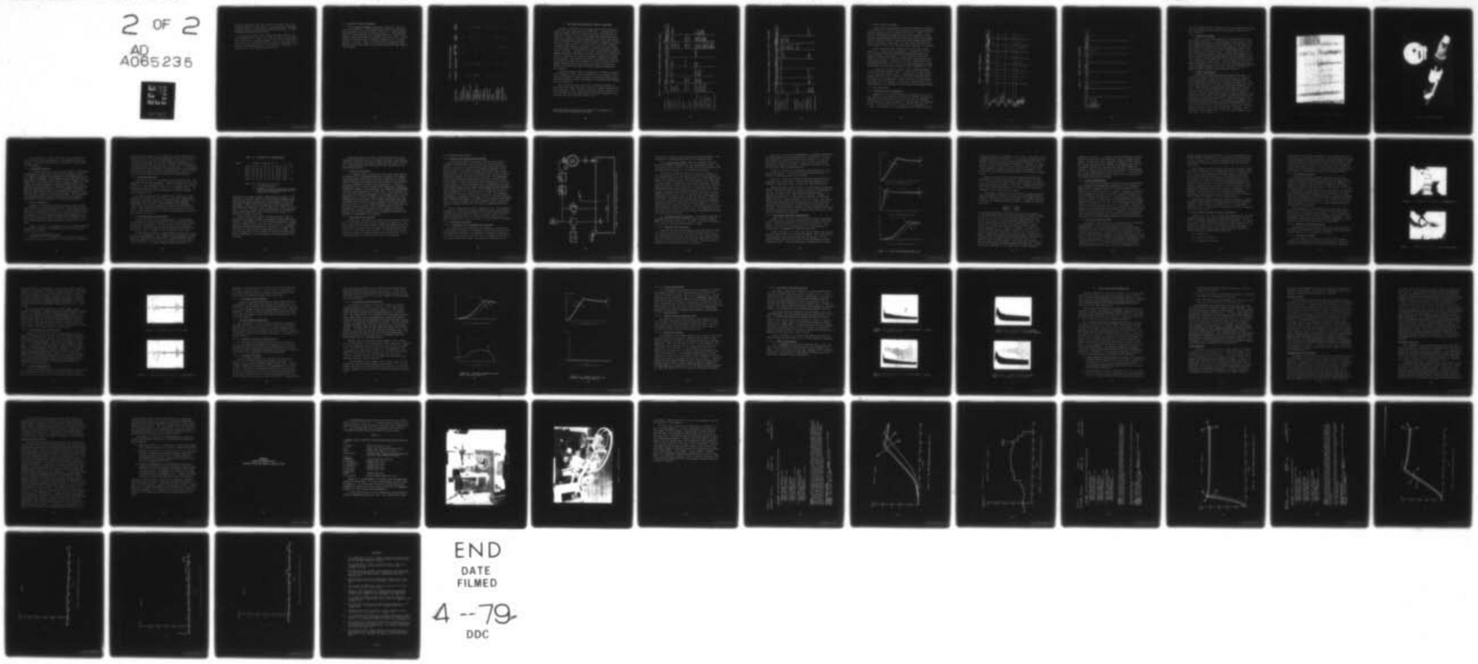

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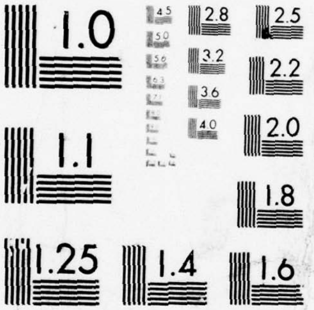

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pressures, kinking of the hose, peak flow velocity, etc. By utilizing sensors of this type, it may be possible to highlight potential problems resulting from operating practices, or other conditions experienced in the hose.

Peak pressure sensors are probably the most relevant, and least expensive type. There are a number of these on the market, using a variety of sensing techniques. One of the simpler pressure sensors uses the Kaiser effect to measure the pressure experienced by a diaphragm exposed to oil pressure. The sensor is reported to be very accurate and low in cost.

6.3 CANDIDATE INSPECTION METHODS

Of the inspection methods presented in Table 6-1, and discussed in Section 6-2, those methods which offer the most promise for application to hoses are shown in Table 6-2. Each applicable method is shown along with the situation where it is most useful. Several inspection methods are generally applicable, (i.e., visual methods), and others only for specific purposes, (i.e., at manufacture). Section 7 reports on the results of laboratory tests, and discusses in more detail the various methods and their application to hoses.

TABLE 6-2. CANDIDATE INSPECTION METHODS

INSPECTION METHOD	AT MANUFACTURE	BEFORE DEPLOYMENT	PRODUCT TRANSFER		ON-SITE INSPECTION	DOCK INSPECTION
			BEFORE	DURING		
Visual	X	X	X	X	X	X
AIDED VISUAL						
a) Video Monitor			X	X	X	
b) Fluorescence Spectra			X	X		
Physical & Chemical						
a) Durometer	X	X				X
b) Elasticity	X					
c) Modulus of Compression	X				X	X
Mechanical						
a) Vacuum Tests	X	X				X
b) Pressure Tests	X	X	X		X	X
c) Pressure-Volume Tests	X	X				X
d) Flexure Tests	X					X
e) Length	X	X				X
f) Pressure Drop				X		
Flaw Enhancement						
a) Liquid Pentrant	X	X				X
Pentrating Radiation						
a) X-Ray	X					X
b) Isotope Sources	X					X
Ultrasonics						
a) Active	X	X			X	X
Acoustic Sensing						
a) Acoustic Emission	X	X			X	X
b) Sonic Sensing			X	X		
Electrical Continuity						
a) Electric Current	X	X			X	X
Experience		X	X	X	X	

7. APPLICABLE NON-DESTRUCTIVE INSPECTION METHODS

Section 6 reviewed existing nondestructive (NDT) inspection methods for their applicability to DWP hoses. Candidate NDT inspection methods for use in inspecting hoses were delineated in Table 6-2. Table 7-1 lists each of these NDT inspection methods (with the exception of visual inspection), and states the specific flaw or prospective failure that each method is intended to detect* The left column in Table 7-1 specifies all of the hose component conditions that should be inspected. Along the top of the table are those points in time during the life of the hose where inspection is desirable. The body of the table contains those inspection methods which were identified in Section 6 as feasible, and may be used for inspection of a specific component condition at a particular interval. The lower case letters in parentheses, following the inspection methods in the body of the table, indicate the component conditions that these methods are capable of detecting. Blanks in the table occur where existing inspection methods are not adequate.

Inspection methods which are immediately available for application to DWP hoses are: visual inspection, x-ray inspection, mechanical and physical property testing, and pressure-volume testing. Those which require further development are ultrasonic and acoustic emission inspection.

This section discusses each type of inspection method, its application and, where available, laboratory results obtained from tests conducted at TSC. Inspection methods presently required, or in use at DWP's, are not discussed here with the exception of visual inspection and a modified pressure test.

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*These NDT inspection methods are intended to supplement the existing OCIMF recommended inspections.

TABLE 7-1. POTENTIAL HOSE INSPECTION METHODS (EXCLUDING VISUAL)

COMPONENT CONDITION	AT MANUFACTURE	BEFORE DEPLOYMENT	ON SITE			DOCKYARD		
			BEFORE TRANSFER	DURING TRANSFER	AFTER TRANSFER	PERIODIC	AFTER STRESS BLOCKAGE	AFTER STORM COLLISION
NIPPLE INTEGRITY (a) Bond to Body (b) Bond to Liner (c) Bond to Flange (d) Corrosion (e) Base Metal Integrity	Ultrasonics* (a,b,c) Pressure-Volume(a,b) x-ray(a,b,c, d,e)	Pressure-Volume (a,b)	Pressure-Volume (a,b)	Fluorescence (a,b,c,e)		Pressure-Volume(a,b) Ultrasonics* (a,b,c) x-ray(a,b,c, d,e)	Pressure-Volume(a,b)	Pressure-Volume(a,b)
FLANGE INTEGRITY (a) Bolts (b) Cracks (c) Gasket Mating (d) Weldment	Die Penetrant* (b,d) x-ray(a,b,c,d)	Pressure-Volume(c) Fluorescence (c)		Fluorescence(c)		Die Penetrant*(b,d) x-ray(a,b, c,d)	Die Penetrant*(b,d) x-ray(a,b, c,d)	
HOSE BODY INTEGRITY (a) Impervious to Oil Intrusion (b) Surface Good (c) Stiffness/Flexure Uniformity (d) Tensile Resistance (e) Compression Resistance (f) Component Placement (g) Component Adhesion	Pressure-Volume (a,c,d,e,g) x-ray(f) Durometer(b,c) Elasticity(d) Flexure(c) Eddy Current(f) Ultrasonics(g,a)	Pressure-Volume(a,c, d,e,g) Acoustic* Emission (a,d,e)	Pressure-Volume (a,c,d,e,g) Acoustic* Emission(a,d,e) Pressure Drop	Acoustic* Emission (a,d,e)	Pressure-Volume (a,c,d,e,g)	x-ray(f) Durometer (b,c) Elasticity (d) Flexure(c) Acoustic Emission* (a,d,e) Eddy Current* (f) Pressure-Volume(a,c,d, e,g) Ultrasonics* (a,g)	Pressure-Volume(a, c,d,e,g) Ultrasonics* (a,g) Flexure(c) Acoustic Emission* (a,d,e)	Peak Pressure Monitor (c,d,g) Pressure-Volume(a, c,d,e,g)

*Requires further development

TABLE 7-1. POTENTIAL HOSE INSPECTION METHODS (EXCLUDING VISUAL) (CONTINUED)

COMPONENT CONDITION	AT MANUFACTURE	BEFORE DEPLOYMENT	ON SITE			DOCKYARD		
			BEFORE TRANSFER	DURING TRANSFER	AFTER TRANSFER	PERIODIC	AFTER STRESS BLOCKAGE	AFTER STORM/COLLISION
LINER INTEGRITY								
(a) Surface Smoothness	Elasticity(d)	vacuum(c)	Fluorescence(b)	Fluorescence(b)	Fluorescence(b)	Acoustic Emission (b,c)	Ultra-sonics* (b,c,d)	
(b) Barrier Intact	Vacuum (c)				Pressure Drop (a,c)			
(c) Liner Adhesion Good						Vacuum(c)	Vacuum(c)	
(d) Softness (Rubber Condition)						Ultra-sonics* (b,c,d) Durometer (d)	Durometer (c,d)	
FLOATATION INTEGRITY								
(a) Surface Condition	Bulk Modulus* (b)					Bulk Modulus*(b)		
(b) Bulk Modulus								
(c) Floatation								
(d) Adhesion to Hose								
HOSE STRING INTEGRITY								
(a) Electrical Continuity	Electric Current(a)	Electric Current(a)	Pressure-Volume (b)		Pressure-Volume(b)			Pressure-Volume (b)
(b) Mechanical Continuity	Pressure-Volume(b)							

*Requires further development

7.1 VISUAL INSPECTION METHODS

Visual inspection requirements presently mandated in Reference 5 are directed at visually inspecting hoses on site and at periodic intervals when the hose is removed from service. Table 7-2 presents a comprehensive schedule for the visual inspection of hose elements and conditions which may lead to hose failure and leakage. The left column of Table 7-2 defines the hose elements and conditions which should be inspected. The top line of the table lists the intervals in the life of the hose where inspection is desirable.

Visual inspection, when coupled with three of man's other senses (i.e., touch, smell and hearing), is inexpensive and the most convenient method of inspection (assuming the senses are trained to detect the problem). Visual inspection may also be aided by other devices such as dye penetrant, video monitors, and fluorescence spectra. Verification of visual inspections can be accomplished through the use of certification papers and an inspection checklist which would accompany the hose throughout its life.

It should be noted that with all of the inspection methods, visual inspection included, there is a potential for hose damage in the inspection process itself. Furthermore, any time a hose is removed from service for inspection, there exists an opportunity for damage due to mishandling. Visual inspection, when performed during service, will require a small boat to approach the hose at close quarters, risking impact with the hose and subsequent damage.

7.2 X-RAY INSPECTION

7.2.1 Objective of X-ray Inspection

Inspection by x-rays was discussed in Section 6.2.6.1, and in this context will be employed principally to identify placement of components within the hose; and in assuring that the components are present in the specified quantity. An experiment was conducted at TSC, in which a section of a 24 inch DWP Floating hose was x-rayed. The purpose of the experiment was to establish the level

TABLE 7-2. VISUAL INSPECTION

COMPONENT CONDITION	AT MANUFACTURE	BEFORE DEPLOYMENT	ON SITE			DOCKYARD		AFTER STORM/COLLISION
			BEFORE TRANSFER	DURING TRANSFER	AFTER TRANSFER	PERIODIC	AFTER STRESS BLOCKAGE	
NIPPLES								
Seepage		x		x			x	x
Leaks		x		x				
Distortion	x	x	x	x	x	x		x
FLANGES								
Loose Bolts		x	x		x			x
Surface Defects	x		x			x		x
Cracks & Corrosion		x	x			x		x
LINER								
Softness		x				x		
Separation	x					x		
Bubbles	x					x		
COUPLING		x	x				x	x
HOSE SURFACE								
Leaks		x		x		x	x	x
Uniformity		x	x	x	x	x	x	x
Fairness	x	x	x	x	x	x	x	x
Marking	x	x				x		
Marine Growth			x			x		
Abrasion		x	x		x	x		x

TABLE 7-2. VISUAL INSPECTION (CONTINUED)

COMPONENT CONDITION	AT MANUFACTURE	BEFORE DEPLOYMENT	ON SITE			DOCKYARD		AFTER STORM/COLLISION
			BEFORE TRANSFER	DURING TRANSFER	AFTER TRANSFER	PERIODIC	AFTER STRESS BLOCKAGE	
<u>HOSE BODY</u>								
Cuts, Gouges, Tears		x	x		x	x		x
Kinking		x	x	x	x	x		x
Elongation	x					x		x
Changes in Diameter	x					x	x	x
Surface Cracks		x	x			x		
Crazing		x	x			x		
<u>Floatation</u>		x	x			x		

of x-ray energy necessary to penetrate a typical deepwater port hose and to determine what information can be gained from the use of this technique.

7.2.2 Laboratory Findings

Figure 7-1 is an x-ray composite of a section of the 24 inch hose used in this work. It was found that a power level of 70 KV was adequate to penetrate the hose material. In this particular hose, there were two helical wire reinforcements - an inner and outer helix - the inner helix having a bend radius about 1 inch less than that of the outer helix. It can be seen in the figure that the two helices appear to have different wire diameters. The two wires were in fact the same diameter, and the apparent difference is due to the fact that the x-ray source was, in this application, essentially a point source. This resulted in a cross-sectional projection of the wires on the film with dimensions dependent upon the distances among wire, source, and film. The wire of apparent smaller diameter is that nearest the film.

7.2.3 Further Investigation

One method which has considerable potential for rapid x-ray inspection of hoses in the field would be the use of a crawler built for pipeline inspection. The crawler containing the x-ray source would move inside the entire length of the hose, which would be covered completely, or in part, with specially prepared x-ray film. These crawlers typically make 100% inspection of welded joints in pipes, and are designed for pipes from 10" to 40" in diameter. The more sophisticated units are battery operated, self-propelled systems, which receive commands transmitted from outside the pipe to a receiver in the crawler. They can be made to move backwards and forwards and emit x-ray radiation on command. Using a telltale isotope which can be detected from outside the pipe, they can be positioned very accurately with respect to a film pack which is affixed to the outside of the pipe. Generally, these crawlers travel on rubber tires which will prevent damage to the hose liner. (See Figure 7-2).

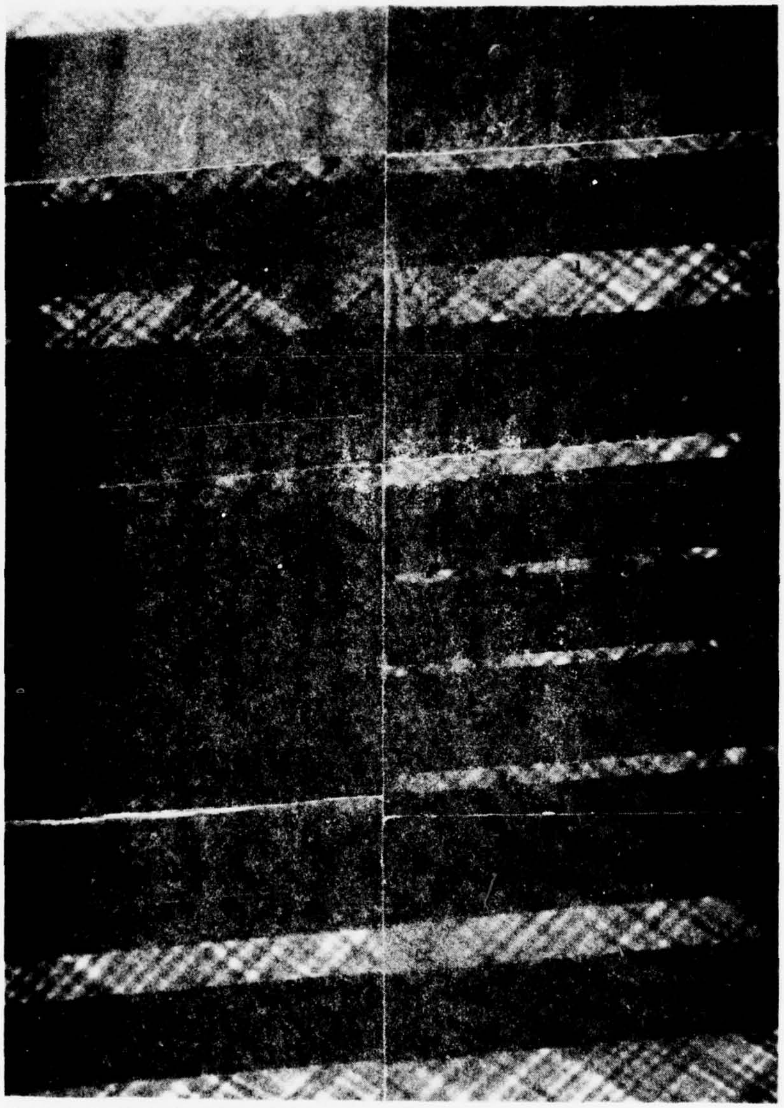

FIGURE 7-1. X-RAY OF HOSE SECTION (COMPOSITE)

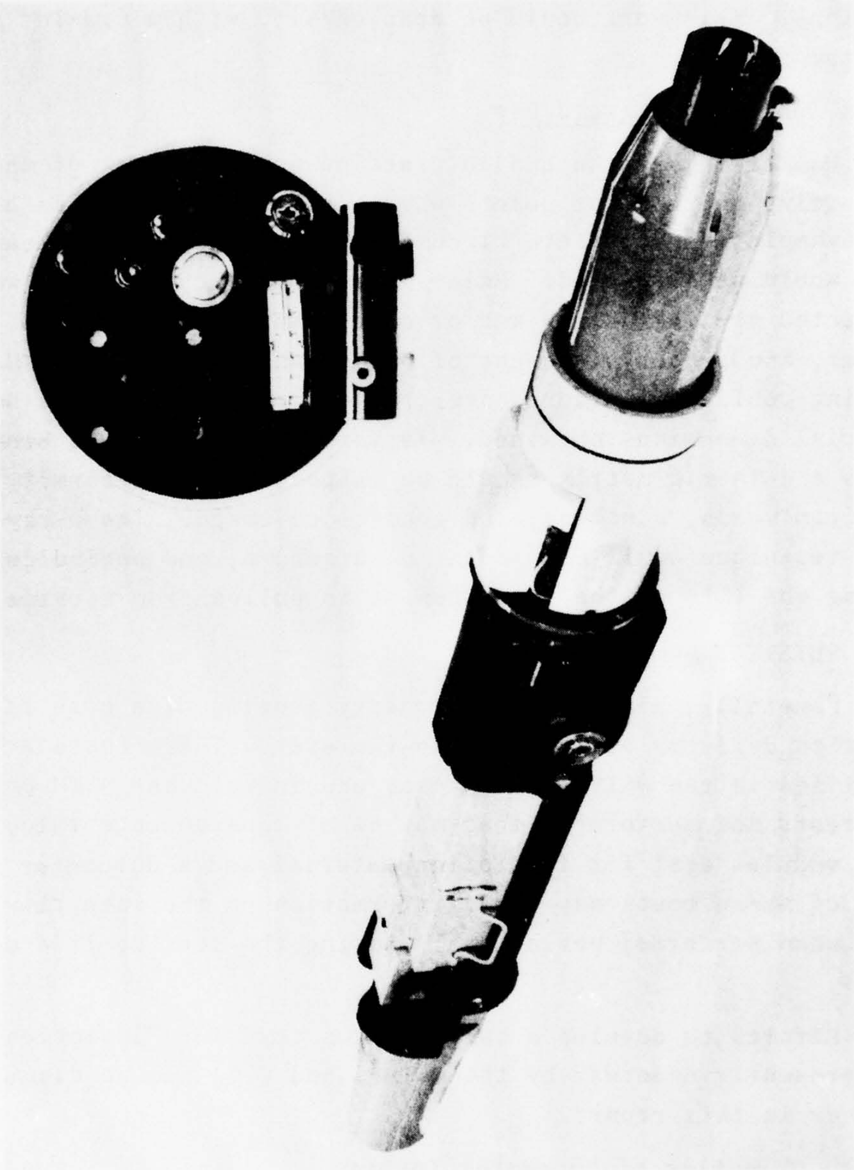

FIGURE 7-2. COMPACT CRAWLER

The feasibility of using a crawler for x-ray inspection of hoses must be tested experimentally, using deepwater port hose sections. This work could be done on-site with a crawler rented for the purpose.

7.2.4 Envisioned Field Use

Use of this technique in practice would consist of thoroughly inspecting the hose at points where failure potential is high. For example, the complete circumference of the nipple area of the hose would be inspected. Major items for which the hose would be inspected are inclusions and/or cracks in welds, evidence of burned rubber, and proper placement of binder and helix wires. Helix spacing could be monitored over the entire length of the hose and material dimensions obtained. As far as possible, the breaker plies and fabric matrix should be inspected for uniformity, freedom from voids, bunching, and general coverage. The x-ray inspection technique would be used at manufacture, and periodically during the life of the hose when it is pulled from service.

7.3 PHYSICAL PROPERTIES

Generally, all physical property testing of a hose is done prior to delivery of the hose to the user. These tests are well specified in the OCIMF hose manual and in relevant ASTM procedures. Two tests not performed, that may be of considerable value, are a bulk modulus test for floatation material and a durometer test. Both of these tests may yield information on the integrity of the hose when performed periodically during the service life of the hose.

Efforts to develop a bulk modulus test for floatation material are presently underway by the OCIMF, and will not be discussed further in this report.

7.3.1 Objective of Durometer Testing

The objective of the durometer tests performed at TSC was to investigate the ease with which this technique could be applied to measuring liner hardness in the laboratory, and its potential for use in the field. At least one manufacturer bases its estimate of residual liner service life on its retention of elasticity. As elasticity and hardness are related, a measure of hardness may be an indirect means of predicting liner service life. To investigate the potential of this technique in this application, several measurements were made on the liners of three dock hoses. The tests were performed in accordance with the appropriate ASTM procedures.

7.3.2 Laboratory Procedure

The hoses used in this experiment were 8 inch dock hoses. One hose (hose #1) was new and unused. Another hose (hose #2) exhibited a number of liner separations over 1/3 of its length, after it had been used to transfer Number 2 fuel oil at a loading facility. And a third hose (hose #3) had been subjected to excessive tensile stress during service.

The ends of each hose were labeled end A, and end B. Liner hardness was measured at six locations around the circumference of each end of the hoses immediately behind the steel coupling. The measurement device used was a Shore quadrant style durometer (Type 20-80), and the measurements were made at room temperature (72°F). Each reading was taken within one second after firm contact was made with the liner. Extensive liner separations were present at end B of hose #2.

7.3.3 Test Results and Interpretation

The data in Table 7-3 were gathered and "t- tests" applied to determine significant differences in the liner hardness between opposite ends of each hose. For the purpose of this experiment, the data were assumed to be normally distributed with homogeneity of variance, and a two sample t-test was applied to each hose.

A significant difference in liner hardness between the two ends of hose #2 was expected as end A appeared to be structurally intact while end B had extensive separations. The mean hardness value at end A was found to be 64.83 ±0.41, while that at end B was found to be 62.33 +3.33. The large standard deviation at end B is

TABLE 7-3. DUROMETER TEST MEASUREMENTS

Hose #		Durometer Readings (D)						$\bar{D}$	S	P
1	End A	65	65	67	65	63	67	65.33	1.51	<.02
	End B	69	66	67	70	69	67	68.00	1.55	
2	End A	64	65	65	65	65	65	64.83	0.41	<.10
	End B	64	58	63	67	63	59	62.33	3.33	
3	End A	66	65	64	64	64	65	64.67	0.82	
	End B	61	65	60	63	64	63	62.67	1.86	<.05

where: $\bar{D}$ = mean durometer reading
S = standard deviation
P = probability that the difference in mean durometer readings between each end of a hose was due to chance.

believed to be caused by debris lodged behind the liner, as the liner was in very poor condition and had pulled completely away from the hose body at many points. Nevertheless, a t-test was performed. Results show the probability of the difference in the mean hardness between ends A and B being due to chance, was less than 10% ($p<.10$). Because of the uncertainties in this measure, further measurements were taken on the new hose (hose #1) to establish a control base line.

As can be seen in the table, the data on hose #1 shows a significant difference in mean liner hardness between each end of the hose. The probability of this difference being due to chance and not systematic effects was less than 2% ($p<.02$). It appears then that the manufacturing process can result in a significant difference in liner hardness between each end of the hose. This fact will make the effort to measure the presence of liner degradation, separations, or other anomalies, with a durometer more difficult.

Measurements were also taken on the ends of hose #3, and a significant difference in liner hardness was found. The probability of this difference being due to chance was less than 5% ($p<.05$). It is suspected that this difference was also the result of the manufacturing process.

7.3.4 Further Investigation

It is apparent that if detection of hose liner flaws such as separations is to be accomplished using a durometer, the comparative measurements taken must be done at the same end of the hose. Further tests must be performed to firmly establish the possibility of using a durometer to detect these separations. A series of measurements must be taken on known liner separations, preferably separations created in the laboratory, and compared to measurements on intact, nearby portions of the same liner. The durometer, however, may have immediate application in the detection of hose liner degradation as a result of changes in liner hardness due to environmental effects and aging. The hardness measurements must then be related to elasticity in order to predict the residual service life of the hose. As the available durometer used in the tests at TSC had a flat base plate, it was not particularly suited for application to a hose liner with an inside radius of curvature. Further tests should be conducted with a modified version of this durometer to accommodate this curvature.

7.3.5 Envisioned Field Procedure

To apply this technique in the field will require the establishment of relationships between liner hardness and elasticity. With this established, the field inspector would take sample readings of liner hardness in areas that are subject to the most severe conditions (i.e., the nipple liner junction). With sufficient data it should be possible to predict residual liner service life, as well as detecting hose liner singularities such as separations.

7.4 PRESSURE-VOLUME TESTING

7.4.1 Objective of Pressure-Volume Testing

The current procedure for pressure testing hoses, both at purchase and periodically during the service life of the hose, consists of a series of pressurization cycles during which representative measures of temporary and permanent elongation of the hose are taken. During this procedure, the hose is also visually inspected for leaks. These are essentially static tests and do not examine the dynamic characteristics of the hose. The measurement of the dynamic pressure-volume characterisitics of a hose offers an opportunity to gain substantially more information on its structural integrity. These measurements may be accomplished with very little modification of the current test procedure and be accompanied by the usual inspection for leaks. Each pressure-volume test of a hose throughout its life will provide a P-V signature (curve) of that specific hose at a particular point in time. This signature may change as a function of hose age, severity of the field environment, manufacturing defects, or damage. With sufficient experimental data, it may be possible to correlate dynamic pressure-volume data with the residual service life of a hose, or impending hose failure.

Several laboratory tests were conducted at TSC. The laboratory procedure for measuring the dynamic pressure-volume characteristics consisted of pressurizing the hose at a constant volume flow rate, while recording pressure as a function of time. The result is a curve of pressure vs. time (or volume, as the flow rate is constant).

7.4.2 Laboratory Procedures

7.4.2.1 Laboratory Test Arrangement and Equipment

To measure the pressure-volume characteristics, specialized pressurization equipment was developed. Three 8 inch ID dock hoses were obtained for testing. The equipment, designed to pressurize the hoses at a constant volume flow rate, was capable of delivering up to four gallons per minute. The pressure in the hose was re-

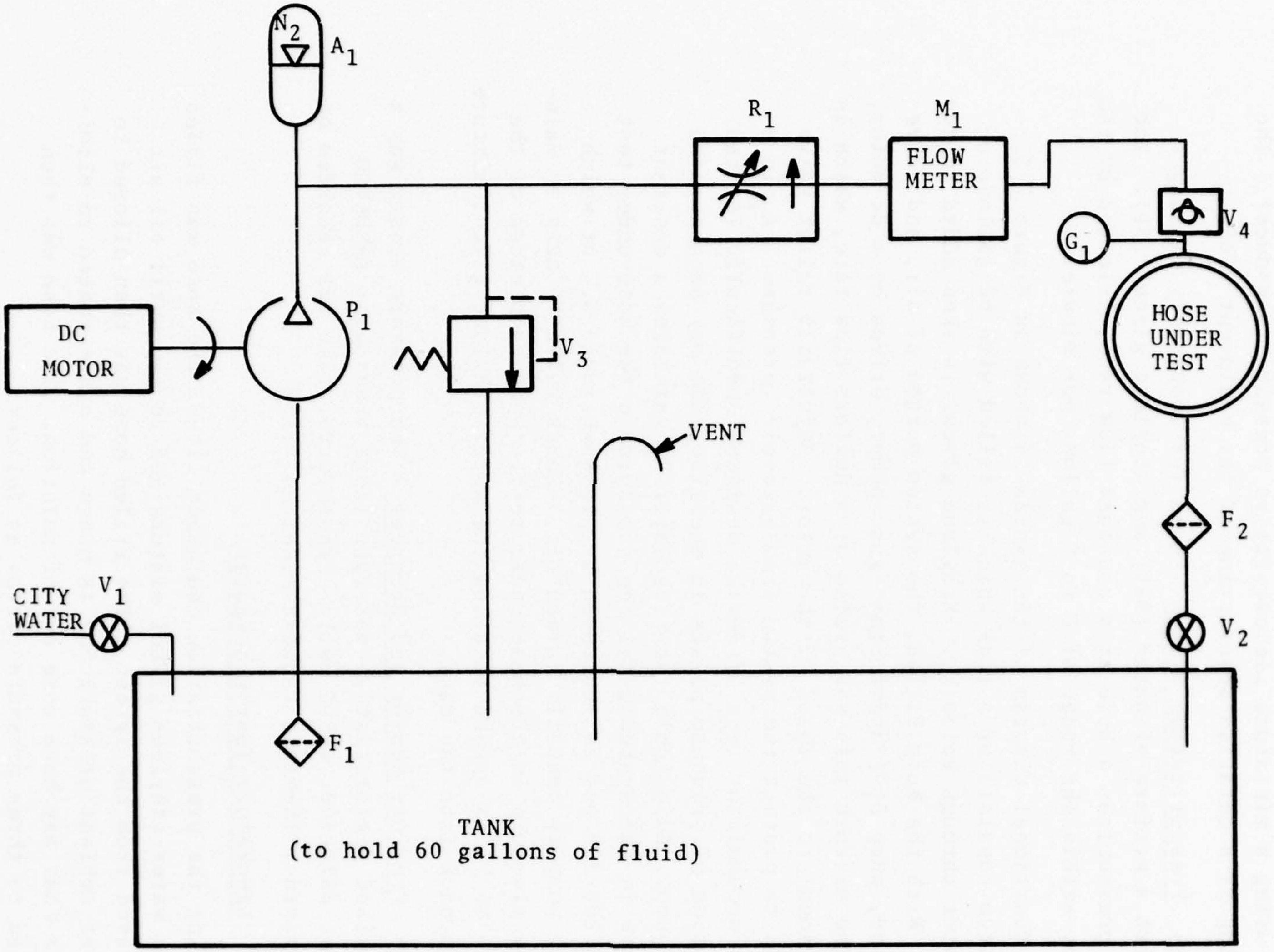

FIGURE 7-3. FUNCTIONAL DIAGRAM OF PRESSURIZATION SYSTEM

corded using a miniature piezoresistive pressure transducer. The following is a detailed description of the equipment used:

(1) Pressurization System - Used for completely filling a hose with a mixture of water (95%) and ethylene glycol (5%). The system pressurizes a hose at a constant flow rate, selected by the operator within the range of 0 to 5 gallons per minute.

A functional diagram of the system is shown in Figure 7-3. The system consists of a tank which is filled with 60 gallons of city water through valve V_1. Ethylene glycol is then added to the water. With the hose filled, the system purged of air, and valve V_2 closed, pump P_1 ("Hydra Star"-gear pump), driven by a dc motor, pumps the mixture into the system at a uniform flow rate, which is proportional to the speed of the motor. Adjustable relief valve V_3, acts to protect the system from excessive pressure. A_1 is a bladder accumulator type of device designed specifically for the suppression of pressure pulses in the line that may be generated by the pump. Adjustable flow regulator R_1 maintains a constant flow rate in the system until the pressure in the hose under test reaches 200-250 psi as indicated by pressure gauge G_1, at which time the pump is manually turned off. Check valve V_4 acts to maintain the pressure in the hose under test. Upon completion of the test, valve V_2 is opened to allow the water-ethylene glycol mixture to drain back into the tank.

(2) Pressure Sensor and Recorder - The pressure sensor was a miniaturized piezoresistive moderate range transducer (ENDEVCO Model No. 8510-500, 0-500 psi). Pressure vs. time was recorded on a X-Y recorder (Hewlett Packard Model No. 135M).

7.4.2.2 Laboratory Test Procedures

Using the pressurization equipment cited, the hose was filled with the water-ethylene glycol mixture and vented until all air was removed from the system. The filled hose was then allowed to remain at ambient pressure for 48 hours and again vented to eliminate air that may have come out of solution. The hose was then subjected to three pressure cycles as follows:

Cycle (1): The hose was pressurized at a constant flow rate of two gallons/minute to a maximum pressure of 200-250 psi. Pressure was recorded as a function of time on the recorder. As the flow rate remains constant (2 gal./min.) this is also a recording of pressure as a function of volume. Pressure in the hose was held for 10 minutes before depressurization.

Cycle (2): The hose was immediately repressurized at 2 gal./min. to 200-250 psi. It was then depressurized and allowed to "relax" at ambient pressure for 30 minutes.

Cycle (3): After the 30 minute relaxation time the hose was repressurized at 2 gal./min. to 200-250 psi and pressure was recorded as a function of time. The hose was then depressurized.

During the three pressure cycles, the hose length was measured before each pressurization, at pressure, and after each depressurization. The three 8 inch dock hoses discussed in Section 7.3 were used in these tests. They differed slightly in length. At ambient pressure prior to testing, hose #1 was 16' 11 7/8" long, hose #2 was 15' 2" long, and hose #3 was 16' 7" long. The pressure-volume data presented in the following section are absolute data and have not been corrected for differences in hose length (normalized). The differences in length are small, however, and as will be seen from the data, the pressure-volume characteristics of these hoses are dramatically different.

7.4.3 Test Results and Data Interpretation

Figures 7-4a, 7-4b, and 7-4c are pressure-volume relationships of the three hoses which were pressurized in the manner described above. Figure 7-4a (hose #1) is data from the new hose. From Cycle (1) to Cycle (2) a hysteresis effect is present while recovery (after "relaxation") is noted in Cycle (3).

Figure 7-4b (hose #2) is data from the hose whose liner failed and had a small leak of a few drops per minute. The curves exhibit a much shorter pressurization time than the new hose. It was suspected that significant structural design differences existed between the hoses. This was confirmed by examination of the hose

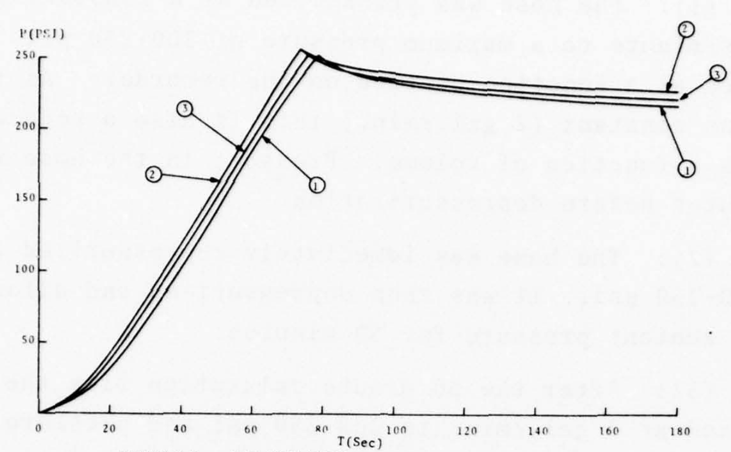

FIGURE 7-4a. DOCK HOSE PRESSURE-VOLUME DATA (HOSE NO. 1)

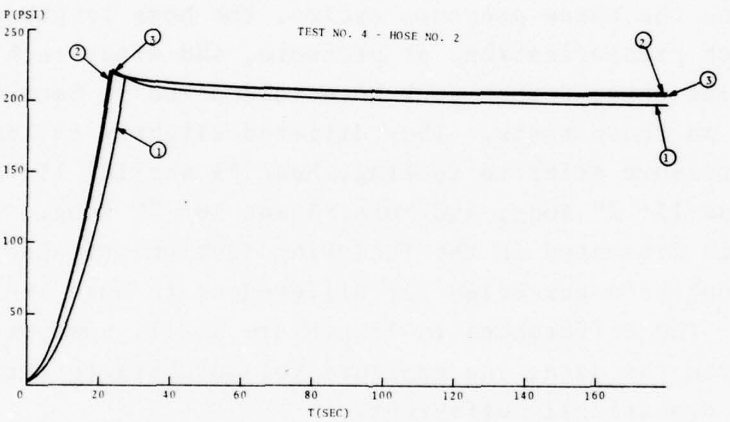

FIGURE 7-4b. DOCK HOSE PRESSURE-VOLUME DATA (HOSE NO. 2)

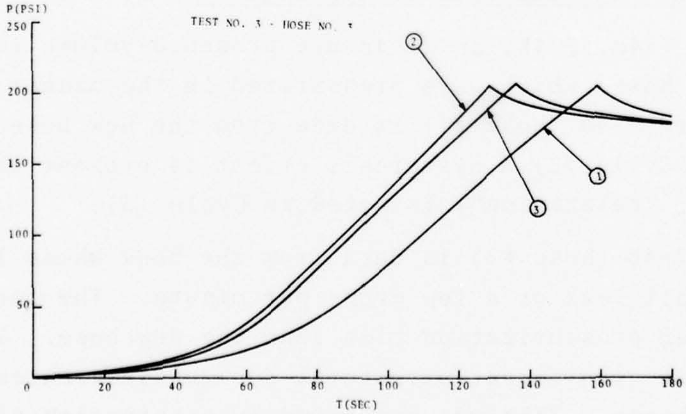

FIGURE 7-4c. DOCK HOSE PRESSURE-VOLUME DATA (HOSE NO. 3)

FIGURE 7-4. DOCK HOSE PRESSURE-VOLUME DATA structures using x-ray techniques. Hose #1 had a steel helix reinforcement while hose #2 did not. It is also quite likely that the laminar structures of the two hoses, which could not be seen in the x-ray, were quite different in character. Hysteresis is again present in hose #2 from cycle (1) to cycle (2) but in this case, little recovery is noted in cycle (3) after "relaxation". The slow leak in this hose was not detectable from the pressure-volume curves.

Figure 7-4c (hose #3) is data from the hose that had been subjected to excessive tensile stress. From cycle (1) to cycle (2) it can be seen that substantial hysteresis effects are present while some recovery is noted in cycle (3). Although this hose also had a steel helix-reinforcement, it was found to be excessively compliant as can be seen from the curves.

The dramatic differences in characteristics among these three hoses can further be shown by looking at the percentage change in volume of each hose at a specific pressure. From ambient pressure to 200 psi the following percentage change in volume was noted for each hose:

hose #1 - 4.81%
hose #2 - 2.19%
hose #3 - 12.24%

From length measurements taken during the tests (see Appendix A), it was further noted that of the 4.81% percentage change in volume for hose #1, 2.98% was due to increased length under pressure, while 1.83% was due to increased diameter under pressure. Hose #2, the hose without the steel helix reinforcement, actually became 1/4" shorter under pressure indicating that its entire volume change was due to a change in diameter. For hose #3, of the 12.24% total percent change in volume, 5.39% was due to increased length under pressure and 6.85% was due to increased diameter. A number of factors may dictate the shape of the curves as illustrated in the figures and the differences noted in the manner in which the hose expands. The first, most certainly, is the structural design and manufacturing techniques used. Another factor, most important in this application, is the structural integrity of the hose. It is quite likely that certain structural failures of hoses will cause these data curves to change significantly. At the very least, a change in compliance due to structural failure should be easily detected by comparing data taken on a new hose with data for the same hose taken after damage has occurred. Another factor that may have an effect on the measured data is the recent pressure history of the hose. It is felt that, for reliable measurements, the hose should be in a relaxed state for several days prior to testing.

7.4.4 Further Investigation

It is likely that structural failure of a hose can cause dramatic changes in its compliance characteristics. It remains to quantify these changes in detail by testing a number of hoses, both new and with known structural defects. Variables of interest to be investigated in order to recognize significant patterns of failure included such measures as: 1) percentage hysteresis and recovery in three cycle testing, 2) pressure change vs. percentage volume increase (p vs $^{\Delta V}/_{V}$), and, 3) differential pressure-volume changes vs. volume ($^{dP}/_{dV}$ vs. V). It is recommended that measurements of these variables be carried out on new hoses, retained, and compared to like measurements periodically taken on the same hoses after having been placed in service. Routine use of dynamic pressure volume testing should yield substantially more information than the static pressure-length measurement currently being used.

7.4.5 Envisioned Field Procedure

The purpose of the initial field testing will be to begin the establishment of a data base of information on DWP hose characteristics, and their relationships to flaws and failures. The pressure-volume signatures obtained will be analyzed to determine the relationships, if present, of these signatures to component conditions such as nipple to hose body bond integrity, hose body oil intrusion, hose stiffness and flexure characteristics, and component displacement (i.e. helix displacement or deformation, delamination, etc.). The tests should be carried out before deployment when the hose is new, as well as periodically (as is current practice with the hydrostatic test) in a preventative maintenance program, and whenever the hose integrity becomes suspect, as after a severe storm. Current technology will not permit pressure-volume inspection without the removal of the hose sections from service.

After removal of a hose section from service, pressure-volume inspection is conducted by suspending the hose in a sling to allow for its free volume expansion, and pressurizing it in the three cycle fashion discussed previously in the laboratory procedure. To pressurize the hoses from ambient to working pressure in one or two minutes, a flow rate of .05X nominal hose volume/minute appears to be sufficient. This may be accomplished easily (even with the largest hoses in use today) with a pressurization system composed of standard "off the shelf" hydraulic components. The pressure-volume characteristics are measured and permanently recorded for comparison with previous and future tests in order to detect significant changes in these characteristics.

The pressure-volume inspection technique represents a simple, straight-forward method for obtaining more data on the structural integrity of hoses than is currently the case. The necessary equipment is easy to operate and can be made to be easily transportable from site to site.

7.5 HOSE INSPECTION METHODS REQUIRING DEVELOPMENT

Sections 7.2, 7.3, and 7.4, addressed nondestructive test (NDT) inspection methods, utilizing existing technology which are suitable for immediate application to DWP hose inspection. The following sections discuss those NDT methods which have potential for use in DWP hose inspection, but which require further development. There are at present three methods which have been identified as having potential for application to DWP hoses:

(1) Ultrasonics

(2) Acoustic Emissions

(3) Fluorescence Detection.

Laboratory tests have been conducted at TSC to demonstrate the use of ultrasonics and acoustic emissions in DWP hose inspection; these tests are reported in subsequent sections of this Section. Fluorescence detection as a means of spill detection has been explored by the Coast Guard in several previous projects (10, 11, and 12) and will not be discussed here. This Section will document the present status of the ultrasonics and acoustic emission methods.

7.5.1 Ultrasonic Inspection

Ultrasonic inspection has been identified as one of the methods that offers considerable potential for detecting various classes of component failure within the lamina of a DWP hose. Of principal interest is the detection of separations in the hose lamina, particularly liner separations. The integrity of the liner is important when transferring crude oil, because loss of integrity is a precursor to further damage of other materials in the hose which are susceptible to hydrocarbon attack. The hose is operated with product pressures and velocities very near those which would tear the liner from the hose wall. If this occurs, it is apt to cause a blockage at a strainer, or a valve precipitating a surge and subsequent overpressure.

Existing methods of hose inspection, as specified by the OCIMF, call for evacuation of the hose and visual observation of the liner using transparent blank flanges. This is not entirely satisfactory from either a cost or reliability standpoint. On the otherhand, ultrasonic probes, which have been developed for other purposes, may be directly applicable to this problem.

7.5.1.1 Objective of Ultrasonics Tests

The objective of the ultrasonic tests performed at TSC was to investigate the application of this technique to the detection of a liner separation in a large DWP hose section.

7.5.1.2 Laboratory Procedure

The test sample was a section of Dunlop 24 inch diameter floating fuel transfer hose obtained from Canaport. Figure 7-5 is a photo of the commerical "flaw detector" electronic instrument

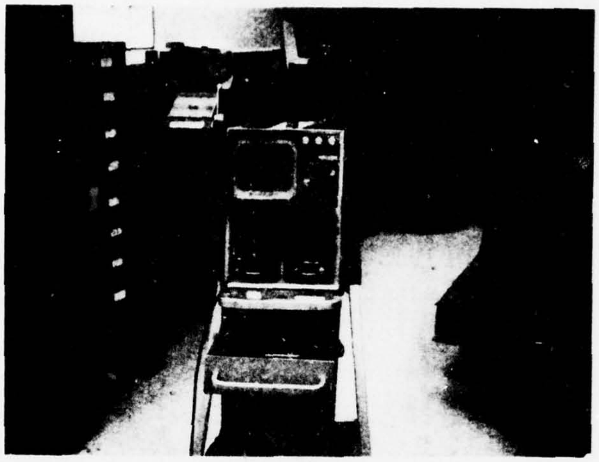

FIGURE 7-5. ULTRASONIC FLAW DETECTION INSTRUMENTATION

FIGURE 7-6. APPLICATION OF ULTRASONIC PROBE TO HOSE LINER

used, specifically, a Krautkramer-Branson "Sonoray 600", which has available a wide range of parameter adjustment and display options, making it suitable for use in testing rubber products. Figure 7-6 is a photo showing the method of applying the probe to the liner. The couplant used was a commercial water-based product (EXOSIN-2) with the consistency of a semi-fluid gel, but other fluid or semi-fluid materials such as glycerine, grease, motor oil, etc., could be used.

The ultrasonic test probe was a 2.25 Mhz, highly damped, Panametric VIP model. A higher sensitivity probe (AeroTech "Gamma" Series) was tried and discarded as inappropriate, because of the need for short pulses to provide adequate thickness resolution. Reverberations from the transducer necessitated moving the probe some distance away from the liner surface in order to obtain a clear signal. Acoustic coupling was therefore accomplished by use of a 2 inch thick Plexiglas block as a delay medium.

7.5.1.3 Test Results and Interpretation

Figures 7-7, and 7-8, show the resulting traces, at well-bonded and separated spots respectively, seen when the transducer and Plexiglas delay buffer assembly is pressed against the liner. A delayed sweep has been used to eliminate the round-trip travel time in the Plexiglas buffer, so that the first interface reflection, i.e., (the first echo from the back face of the Plexiglas) appears at the left edge of the screen. Figure 7-7 is an image of the display when scanning a section of hose having its liner tightly bonded to the hose body. Figure 7-8 is a trace showing a reflection from a separation between the liner and the hose body. It is apparent that ultrasonic detection of liner separation in deepwater port hose is clearly feasible using techniques well within the state-of-the-art.

7.5.1.4 Further Investigation

Further investigation should be directed towards a field evaluation of a device for detection of the lamina structure of hoses. This device may be similar to that used in the inspection of steel

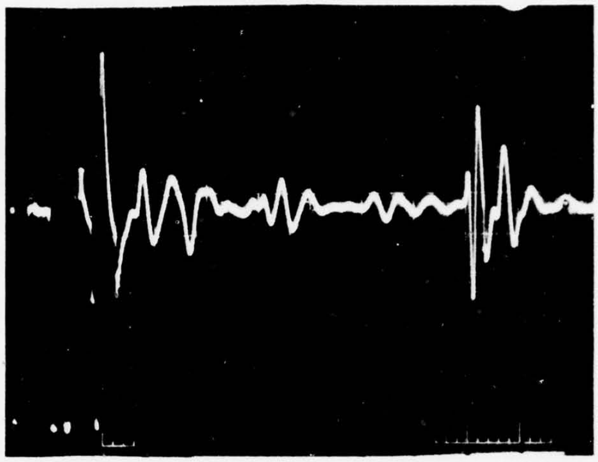

FIGURE 7-7. ULTRASONIC SCAN OF INTACT HOSE

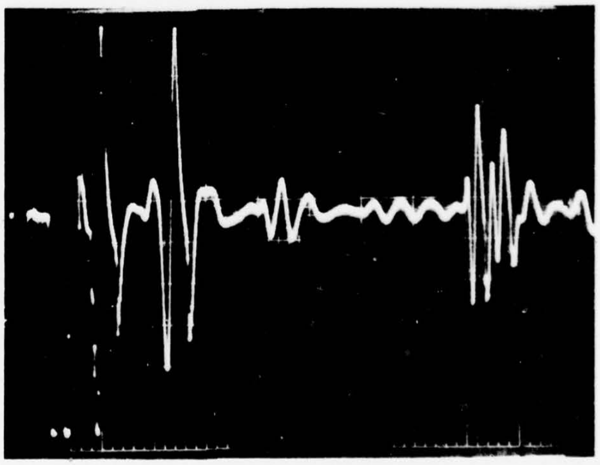

FIGURE 7-8. ULTRASONIC SCAN OF HOSE WITH LINER SEPARATION

pipelines. The relative success of this device will dictate the direction of further efforts. If these tests are successful, it may be desirable to develop an automatic inspection device that will inspect the lamina structure of the entire hose.

7.5.1.5 Envisioned Field Procedure

A portable, hand-held probe would be used to spot-check the circumference of the nipple liner junction for separations. In large hoses, the operator would enter the hose and check sections of liner that appear to have any discontinuities or other abnormal appearance. The tests could be performed very quickly and serve as an important adjunct to the visual and tactile inspection that is current practice.

7.5.2 Acoustic Emission Inspection

The techniques of acoustic emission detection as applied to deepwater port hoses can be considered to have two applications: the detection of emissions related to structural damage in the hose, during initial testing and periodic retest; and the detection of emissions related to hose damage, degradation, or escaping oil, during transfer.

7.5.2.1 Objective of Acoustic Emission Tests

The objectives of the acoustic emission tests conducted at TSC were to examine the feasibility of using water as the transmission medium for acoustic emissions occurring during hose pressurization, and to investigate the presence or absence of emissions with regard to the condition of the hose being tested.

7.5.2.2 Laboratory Procedure

During the pressurization of three hoses (as discussed in Section 7.4), acoustic emission measurements were taken. An acoustic emission sensor (TRODYNE, model #7538A, 50 kHz - nominal resonant frequency) was placed on the blank flange at one end of the hose. The initial measurements were done by setting the gain of the instrumentation at a level that would mask the emissions generated by the pump system. No emissions exceeding this level were observed during the pressurization of hose #2. Further measurements were made by looking at the difference in emission rate between the background noise (pump), and the hose. In this mode, emissions were observed during the pressurization of hose #3 (the hose that had been subjected to excessive tensile stress and found to be very compliant).

7.5.2.3 Test Results and Interpretation

The results of the tests on hose #3, plotted as acoustic emission counts per second as a function of time, and pressure-volume characteristics, are shown in Figure 7-9. This figure shows the emission count rate produced during cycle #3 of this test. The count rate at t=0 is indicative of the background noise level (pump noise), and is approximately 20 counts per second. It can be seen that as the pressure in the hose increased to about 130 psi, the count rate increased to a maximum. The rate declined slightly thereafter until the motor was shut off at the maximum pressure. The rate then fell off sharply and went to zero at 160 seconds. It should be noted that the hose continued to emit even after the motor was shut off and the pressure was maintained. As this was the third cycle of the test, it is apparent that the Kaiser effect was not a prominent factor.

Further tests in this mode on hoses numbers 1 and 2 failed to show the presence of any significant acoustic emissions. Results of a test conducted on the new hose (hose #1) are shown in Figure 7-10. Note that the emission remained at the background level throughout the pressure cycle (cycle #1), The results for cycles numers 2 and 3 of this test, and the tests on hose #2 were similar. For more detailed test documentation including instrumentation settings, see the Appendix.

These preliminary tests suggest that certain classes of hose damage emit acoustic energy during pressurization. It is not yet certain that the degree of emissions from a good hose, or one only slightly damaged, will be useful in inferring the condition of that hose.

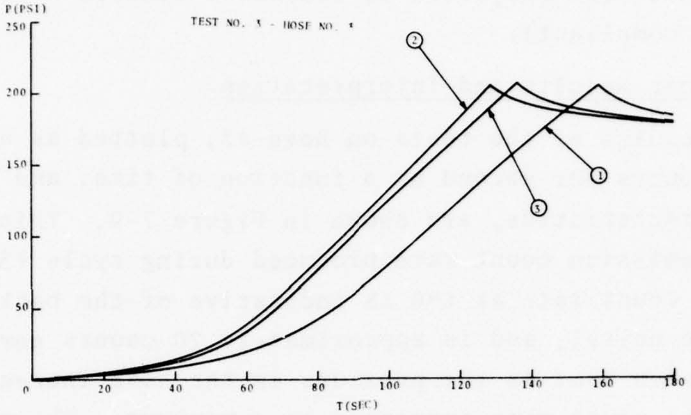

FIGURE 7-9a. DOCK HOSE PRESSURE-VOLUME DATA (HOSE NO. 3)

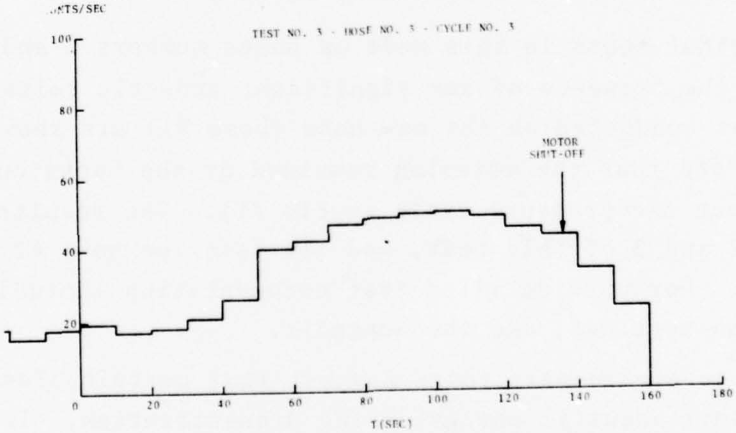

FIGURE 7-9b. ACOUSTIC EMISSION TEST DATA (HOSE NO. 3)

FIGURE 7-9. ACOUSTIC EMISSION AND PRESSURE VOLUME DATA (HOSE #3)

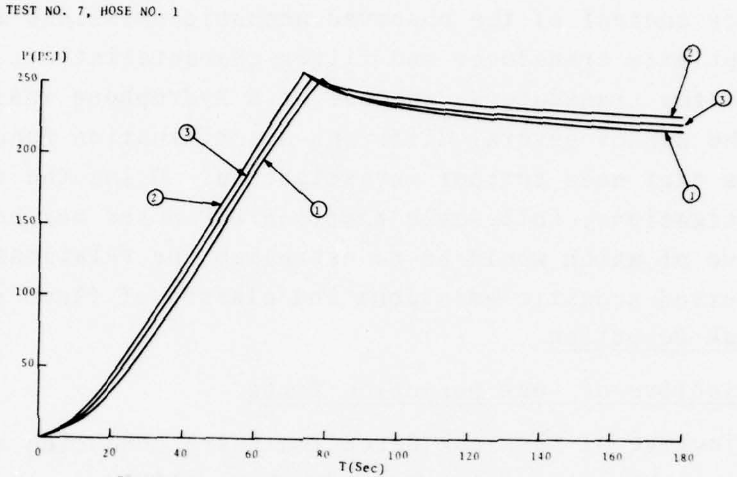

FIGURE 7-10a. DOCK HOSE PRESSURE-VOLUME DATA (HOSE NO. 1)

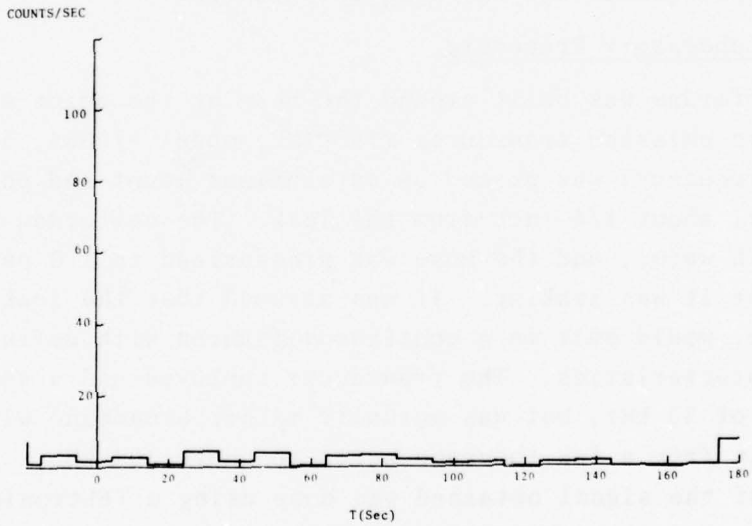

FIGURE 7-10b. ACOUSTIC EMISSION TEST DATA (HOSE NO. 1)

FIGURE 7-10. ACOUSTIC EMISSION AND PRESSURE VOLUME DATA (HOSE #1)

7.5.2.4 Further Investigation

It is recommended that further tests be conducted to establish the frequency content of the observed acoustic emissions in an effort to optimize transducer and filter characteristics. Optimal placement of the transducers, the use of a hydrophone inside the hose, and the use of several different discrimination functions are other points that need further investigation. Using the results of these investigations, full-scale tests on DWP hoses may be initiated, the objective of which would be to establish the relationships between observed acoustic emissions and classes of flaws present.

7.5.2.5 Leak Detection

7.5.2.6 Objective of Leak Detection Tests

The objective of the leak detection tests conducted at TSC was to examine the potential for detecting small leaks in a hose using acoustic emission transducers outside the hose. Hose #2 (previously used in pressure-volume tests) had a small leak of a few drops per minute and was used in this test.

7.5.2.7 Laboratory Procedure

A cofferdam was built around the hose at the point of the leak. An acoustic emission transducer (TRODYNE, model #7538A, 50 kHz - nominal frequency) was placed on an aluminum mount and positioned underwater, about 1/4 inch from the leak. The cofferdam was then filled with water, and the hose was pressurized to 170 psi to assure that it was leaking. It was assumed that the leak, if detectable, would emit in a continuous fashion with definite frequency characteristics. The transducer employed had a nominal resonance of 50 kHz, but was actually rather broadband with considerable gain from a few thousand hertz to above 100 kHz. A spectral analysis of the signal obtained was done using a Tektronics oscilloscope (Type 547) with a plug-in spectrum analyzer (Type 1L5). The measurements were taken first with the hose at ambient pressure (no leak) and then at 170 psi (a leak of a few drops per minute).

7.5.2.8 Test Results and Interpretation

The signal frequency spectrum from 0-100 kHz obtained with the hose at ambient pressure is shown in Figure 7-11a. It is nothing more than a relative measure of system noise. The spike at the far left is a spurious dc signal with no physical meaning. The hose was then pressurized to 170 psi to assure a leak, and the spectrum from 0-100 kHz was again recorded. This is shown in Figure 7-11b; and as can be seen, there is no significant difference between this recording and the one obtained at ambient pressure.

To examine the lower frequencies in more detail, tests were performed again, this time recording spectral information from 0-10 kHz. The result with the hose at ambient pressure is shown in Figure 7-12a, and the result with the hose at 170 psi is shown in Figure 7-12b. Again, there is no discernible difference between these spectral measurements. The whole spectrum was also examined in 1000 Hz increments from 0-100 kHz; and again, no differences could be detected between the spectral content when the hose was at ambient pressure and when it was at 170 psi.

It was concluded that a leak of that magnitude could not be detected using spectral analysis and a 50 kHz (nominal) transducer.

7.5.2.9 Further Investigation

It is recommended that the same experiment (which takes less than a day to perform) be carried out with a low frequency hydrophone. Leaks of various sizes and types (induced in the laboratory) should also be investigated to determine the limitations of the measurement equipment in this application.

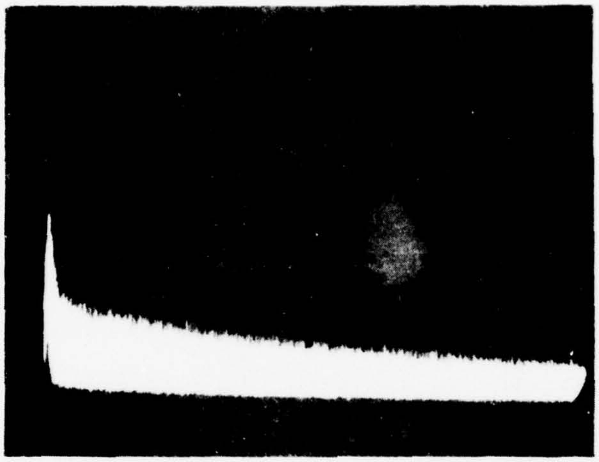

FIGURE 7-11a. ACOUSTIC EMISSION SPECTRUM FROM 0 - 100 kHz
HOSE #2 - AT AMBIENT PRESSURE

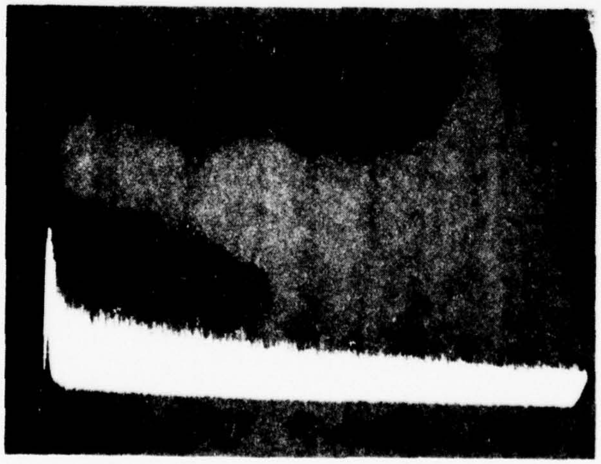

FIGURE 7-11b. ACOUSTIC EMISSION SPECTRUM FROM 0 - 100 kHz
HOSE #2 - AT 170 psi

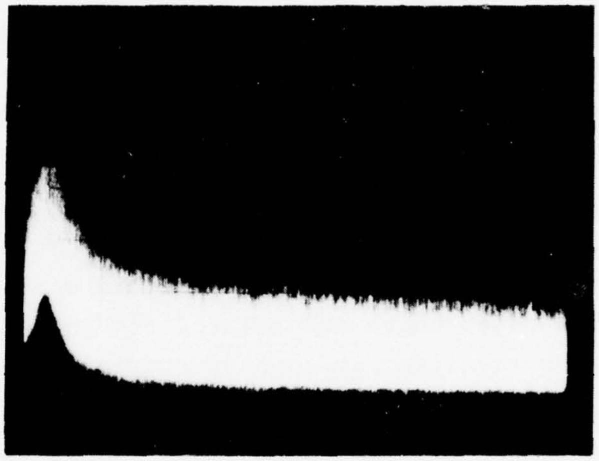

FIGURE 7-12a. ACOUSTIC EMISSION SPECTRUM
FROM 0 - 10 kHz HOSE #2 - AT AMBIENT PRESSURE

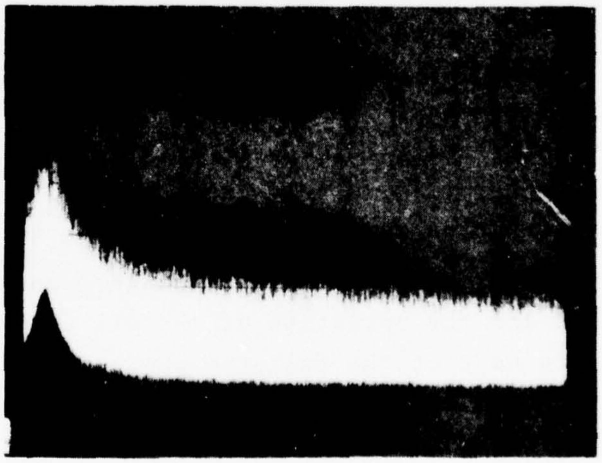

FIGURE 7-12b. ACOUSTIC EMISSION SPECTRUM
FROM 0 - 10 kHz HOSE #2 - AT 170 psi

8. CONCLUSIONS AND RECOMMENDATIONS

The work contained in this report consists of a review of DWP hose failures to date, and the causes leading to these failures. Also included is an evaluation of current hose inspection techniques and procedures, and an examination of available non-destructive test procedures which are not currently used on DWP hoses but show potential in this application.

Hose failure data sources were identified, and the data were examined in detail. Environmental conditions responsible for hose degradation were discussed, and hose failure modes were identified including those modes which are related to "in-service" conditions as well as those resulting from manufacturing defects.

The available data indicate mishandling to be one of the primary causes of hose failure in the field. More formal training in handling procedures may relieve this problem somewhat. The remainder of the data indicates that the "first-off-the-buoy" and "rail" hoses have the highest failure rates in service. This is to be expected as, being the interface between the main hose string and the buoy or tanker, they experience a harsher environment. In general, a more diligent application of current inspection techniques should serve to reduce the failure rate at these critical points. For the remainder of the hose string, failure occurs in a less predictable fashion. The reliable detection of impending failure will require additional development of test and inspection techniques. In general it is felt that an immediate improvement in the current situation may be effected by the following:

- Proper procedures and training of personnel in the handling of hoses and the operation of the oil transfer system will eliminate many of the failures currently experienced. This includes handling during inspection as well as during installation and operation.
- Visual inspection of hoses should take place at all stages of hose life, and should be accompanied by a thorough check-off list. Proper procedures for this inspection should be

followed to avoid damage done to the hose by a boat or inspection personnel.

- All facilities should be required to provide, as a minimum, the OCIMF test and inspection procedures.
- Hose requirements and failure modes vary with the site and hoses must be designed for each specific site.

The performance of a large portion of the inspection procedures currently used requires a highly trained individual. Overall hose integrity is judged on a visual basis. Liner separations are detected visually, and tactilely. The use of nondestructive testing (NDT) techniques was investigated, and all NDT inspection methods that appeared to have any potential for use in the inspection of DWP hoses were reviewed and where possible, laboratory tests were conducted to verify their potential. The methods which appeared to show potential for immediate application were x-ray inspection for hose component placement, durometer testing for liner hardness, and pressure-volume testing for overall structural characteristics. Those methods which will require more experimental investigation, both in the laboratory and the field, are ultrasonic inspection and acoustic emission inspection. The following is a brief discussion of each of these methods, summarizing findings and recommendations for further work.

X-Ray Inspection

X-Ray inspection of DWP hoses has been discussed as showing great potential, substantiated by its established success as a technique for inspecting pipe lines. Two major problems, which x-ray techniques may aid in detecting, are loss of nipple-liner adhesion and structural flaws leading to kinking. At least one manufacturer has used x-ray techniques to detect nipple-liner separation. The use of x-rays to examine dock hoses at TSC indicated that this technique is suitable for inspecting structural configurations such as helix spacing. An effort is needed to investigate the potential of hardware (x-ray pigs) currently available from the pipeline industry as a means for nondestructive inspection of DWP hoses. Those specific instruments which may be suitable to DWP hose inspection must be identified.

Durometer Testing

At least one hose manufacturer bases part of their estimate of nominal service life of a hose on its retention of cord strength and liner elasticity. Rubber hardness and elasticity are theoretically related, and in the case of a specific material used for a hose liner it should be possible to relate its hardness and elasticity precisely. If this is the case, then residual liner service life may be predicted using a durometer to measure liner hardness. The durometer tests conducted at TSC were inconclusive for two reasons. The available durometer was constructed with a flat base plate which was not particularly suited for application to a hose liner with an inside radius of curvature. Also, there were no data available on the liner hardness of the two used hoses when they were new. To apply this technique in the field will require that a record be made of liner hardness at manufacture and measurements then taken during the service life of the hose would be compared to this value and an assessment of changes in elasticity could be made. Accurate measurements will require a modification of the base plate of currently available durometers to accommodate the curvature of the liner. This method is very easy to apply and has potential as a means of predicting residual liner service life at extremely low cost.

Pressure-Volume (P-V) Testing

Laboratory tests on three dock hoses at TSC demonstrated significant differences in the pressure-volume characteristics among the hoses. The differences were attributed primarily to structural design and secondarily to the condition of the hoses. Currently, there is insufficient data to establish any meaningful relationships between the pressure-volume signature of a hose and its structural integrity. Because of the wide variations in hose structural design resulting in unique pressure-volume characteristics, future work should be directed toward establishing a data base of information on P-V characteristics of actual deepwater port hoses, both when new and at periodic intervals during their service life. When sufficient information has been gathered on new, used, and damaged hoses, the relationships among observed changes in pressure volume characteristics, flaws present, and the remaining service life of the hoses before failure may be established. As mentioned previously, at least one manufacturer currently bases part of their estimate of nominal service life of a hose on its retention of cord strength and liner elasticity. Significant changes in these variables may cause detectable changes in the pressure-volume characteristics of a hose, thereby providing a means for detecting changes in these variables in a non-destructive manner. It is recommended that further work be initiated to develop additional data on the pressure-volume technique as a non-destructive means of inspecting large DWP hoses. This effort will require the application of statistical analyses to establish the relationships between P-V characteristics and hose deterioration or flaws. Sources of available hoses must be identified and additional hardware obtained to pressurize the large DWP hoses and record the characterisitcs. Based upon the information gathered, predictors of residual hose life may be developed.

Ultrasonic Inspection

TSC's experience with water-coupled ultrasonic inspection of tires has shown this technique to be a powerful tool for the non-destructive testing of cord rubber laminates. It is reasonable to assume that a properly designed, hand-held ultrasonic probe could be of great value as a field inspection technique for DWP hoses. A device of this type has been used to detect a liner separation in a section of DWP hose in the laboratory at TSC.

A portable field probe would be used to spot check areas of the hose where laminar separations frequently occur (i.e., liner separations at the liner-nipple junction). If successful, this technique would complement and enhance the credibility of the current tests for liner separations which are visual inspection through transparent flanges during a vacuum test and tactile inspection, both of which require skilled and experienced inspectors.

Initial work should be conducted with a device similar to that used in the quality assessment of steel, after appropriate modifications have been made for detection of laminar structures within rubber. Equipment and procedures may be validated on smaller hoses (i.e., 8 inch dock hose) first , and later on large DWP hoses. If these initial tests prove successful, it may be desirable to investigate the feasibility of developing an ultrasonic apparatus to automatically inspect the laminar structure of an entire hose.

Acoustic Emission Testing

Acoustic emission testing of dock hoses in the laboratory at TSC has shown that acoustic emission signatures may or may not be present during pressurization, depending upon hose condition and/or structural design. The precise mechanisms which act as the sources of the emissions are currently unknown. The hose from which emissions were recorded had been excessively stretched in service and on x-ray examination exhibited helix-hose body separations. It is felt that, with sufficiently sophisticated equipment, acoustic emission may represent a very effective means for non-destructive testing of DWP hoses. Equipment is available commercially that is capable of measuring acoustic emissions in pressure vessels, and determining the location of each source of emission through the use of two-dimensional arrays of transducers. In the case of hoses, all that would be necessary would be a one dimensional linear array to determine the location of an emission source along the length of the hose. The major problem facing the application of acoustic emission techniques to the inspection of DWP hoses, is the fact that the hose material (composite-rubber) is a poor transmission medium for acoustic energy. The proposed approach is to utilize the water used to pressurize the hose as the transmission medium. It is recommended that in order to optimize data acquisition techniques, an experiment be conducted using an appropriate hydrophone within the water in a hose to maximize signal reception and determine the frequency content of the observed acoustic emissions. Using the results of these tests, full scale tests on DWP hoses may be initiated. If successful, the potential for using a passive acoustic array along the entire length of a hose string to detect leaks and other flaws should be investigated. The objective of these tests would be to establish relationships between observed acoustic emission signatures and classes of flaws leading to hose failure. These tests would best be accomplished on a contractual basis with a manufacturer of acoustic emission monitoring equipment, and could be performed during the tests on pressure-volume characteristics discussed earlier.

In summary, with regard to the implementation of these nondestructive inspection techniques, the following considerations must be applied.

- Wherever possible, it is desirable to replace human judgement with more objective, scientific inspection techniques.
- Further investigation of the techniques of x-ray inspection, durometer inspection, and pressure-volume inspection represent the least risk as there is already commerical instrumentation available to perform these tests and the initial investment would be low.
- Further investigation of the techniques of ultrasonic inspection and acoustic emission inspection carry a higher risk factor as the techniques, with respect to DWP hoses, are more difficult to implement and will require a larger investment due to developmental costs. However, the potential payoffs from these techniques could be substantial.

With all of the NDT methods reviewed, the fundamental problem of data interpretation exists. Sufficient data must be gathered to allow for a thorough test signature-flaw-failure analysis. Properly done this will allow the operator of a deepwater port to make an effective judgement on the residual life of each hose section and maintain a cost-effective operation while preventing major oil spills.

APPENDIX

LABORATORY DOCUMENTATION

PRESSURE-VOLUME AND ACOUSTIC EMISSION TESTS

The documentation presented here contains data on the three hoses discussed in the text. It includes detailed results of the combined pressure-volume and acoustic emission tests conducted at TSC. The following table lists the equipment that was used in the combined pressure-volume and acoustic emission tests.

TABLE A-1

Equipment used for Combined Pressure-Volume and Acoustic Emission Tests

D-C Motor	General Electric, 1.5 HP
Fluid	Water (95%) and ethylene glycol (5%)
Pump	"Hydra Star" Model No. 2-N1-3G
Pump Control	Ratiotrol Motor Speed Control, Boston Gear Division, North American Rockwell
Pressure Transducer	Endevco Model No. 8510-500
AE Transducer	TRODYNE Type 7538A
AE Preamplifier	TRODYNE Type 7529A
AE Amplifier	TRODYNE Type 7504
AE Processor	TRODYNE Type 7503A
Linear Rate Module	TRODYNE Type 7506
X-Y Recorders	Hewlett Packard Model No. 135M

Figure A-1 is a photograph of the pump system developed specifically for these tests. The entire experimental set-up is shown in Figure A-2. As can be seen, the hose is suspended from an aluminum "I" beam by four nylon slings to allow for the unimpeded expansion of the hose during pressurization.

The data that follows are test documentation sheets that were completed immediately after each test. They contain hose length

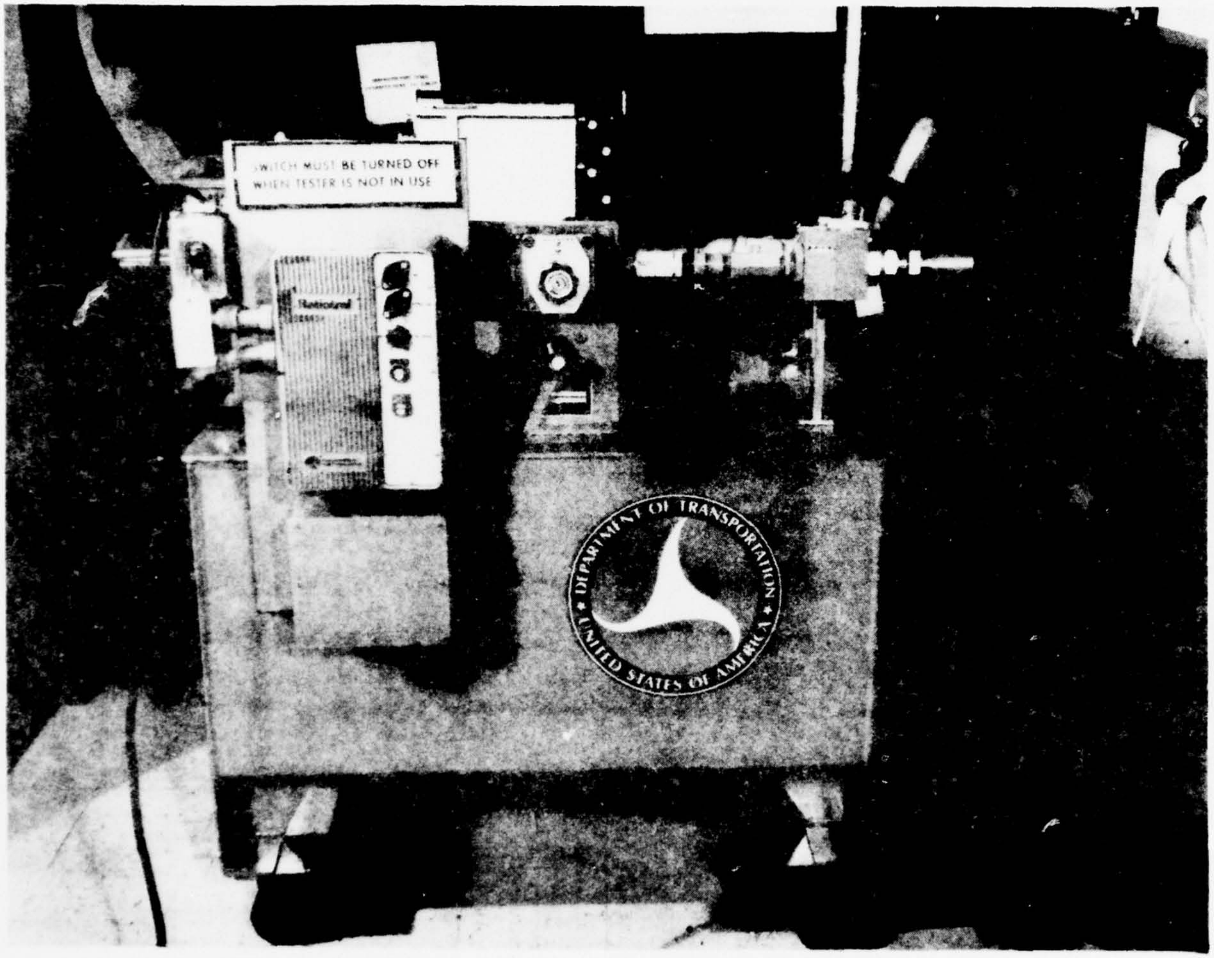

FIGURE A-1. PUMP SYSTEM

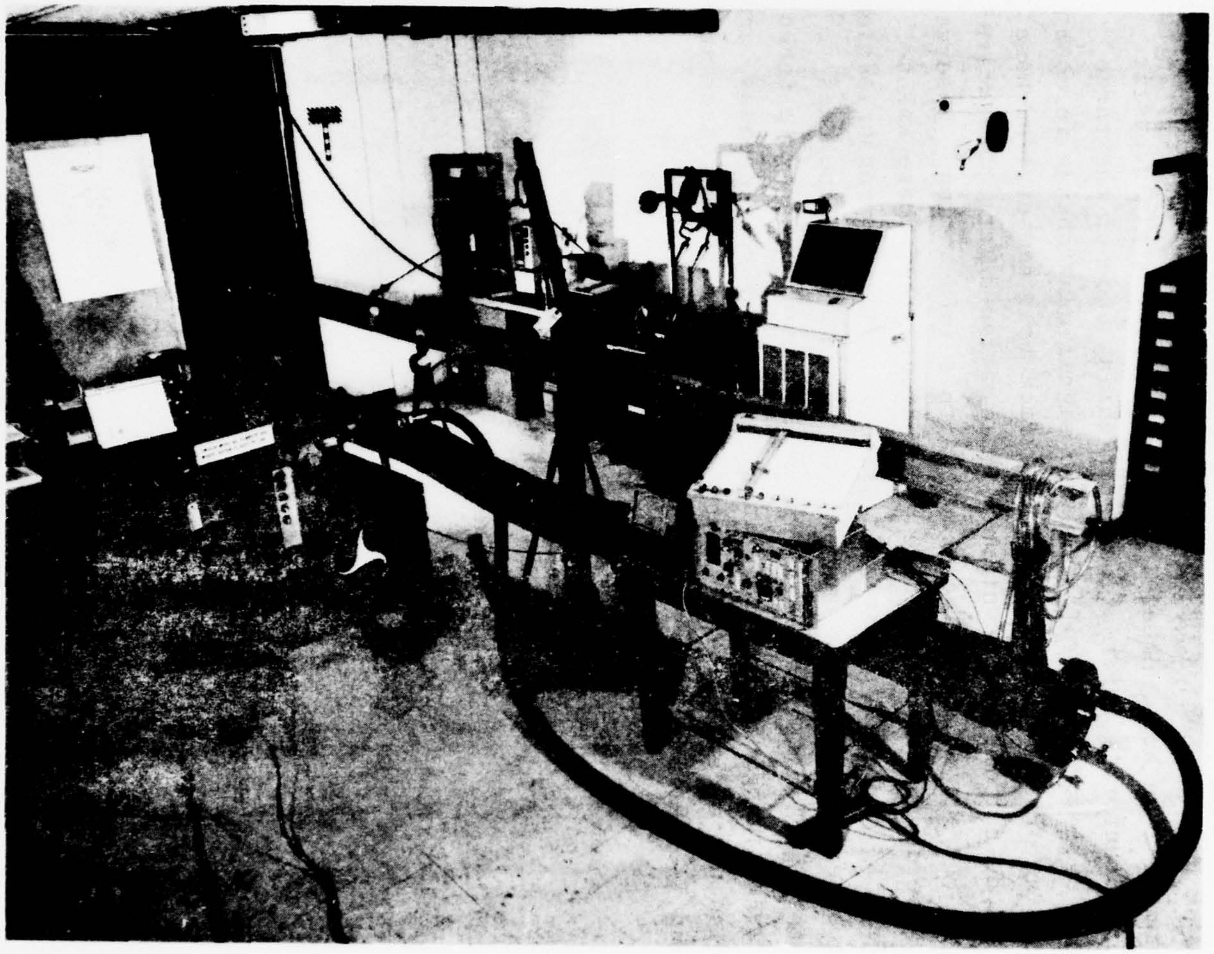

FIGURE A-2. LABORATORY TEST SET-UP

measurements taken during each test as well as equipment settings and comments on the procedure.

The three tests shown here are laboratory test numbers 3, 4, and 7, on hose numbers 3, 2, and 1, respectively. The data for test number 7 on hose number 1 (the new hose) contain acoustic emission count rate information taken during each of the three pressure cycles. The results show no significant change in count rate during pressurization. The data from test number 4 on hose number 2 do not include count rate information during pressurization, as there exists no clean copy of this information. Observations made during the test, however, indicate that there was no significant change in acoustic emission rate during pressurization in all three cycles. Test number 3 of hose number 3 includes count rate information taken during pressurization in cycle three. There is a significant increase in rate as pressure increases, and a continuance of emissions after the pressure increase ceases and the pump is shut off.

TEST NO.: 3 HOSE NO.: 3 DATE: 10/7/77

TEST PRESSURE: 200-250 psi FLOW RATE: 2 gpm FLOW RATE SETTING: 4.0

<u>TEST FORMAT</u>: Hose had been pressurized to 200 psi 24 hours earlier.

1) - length before pressurization -- 16'7"
   - length at pressure -- 17'5 3/4"
   - pressure held for 10 minutes
   - length after depressurization - 16'9"

2) - pressurized again immediately
   - length at pressure 17'6 1/4"
   - depressurized immediately
   - length after depressurization - 16'8 1/2"

3) - hose allowed to "relax" for 30 minutes
   - length before pressurization 16'7 1/2"
   - length at pressure - 17'6 1/4"
   - depressurized immediately
   - length after depressurization -- 16'8 1/2"

<u>COMMENTS</u>: During pressure cycles 1) and 2), an attempt was made to measure acoustic emissions by setting the gain of the amplifier to mask the emissions from the pump system and pass those from the hose. In both cases, not a single count was registered. In cycle 3, no attempt was made to mask the emissions from the pump system using gain settings. Instead, the system was set up to read rate of counts instead of cumulative counts, and the results were encouraging. About 30 seconds of background readings (pump) were taken before the valve was closed. The rate increased significantly as the pressure rose (See attached graph). The acoustic emission transducer was attached to the blank at end B of the hose which was also the inlet end of the hose.

<u>TRODYNE equipment settings</u>
<u>Processor</u> - 10 us rise time, ΔT 5000 usec. <u>Amplifier</u> - Gain 65 db, filter B (100-400kHz)
<u>Lin Rate</u> - Event, 10^{0}, Rate Base 10. <u>Preamp</u> - Model 7529A, S/N 188
<u>Transducer</u> - Model 7538A - 50K S/N 2953

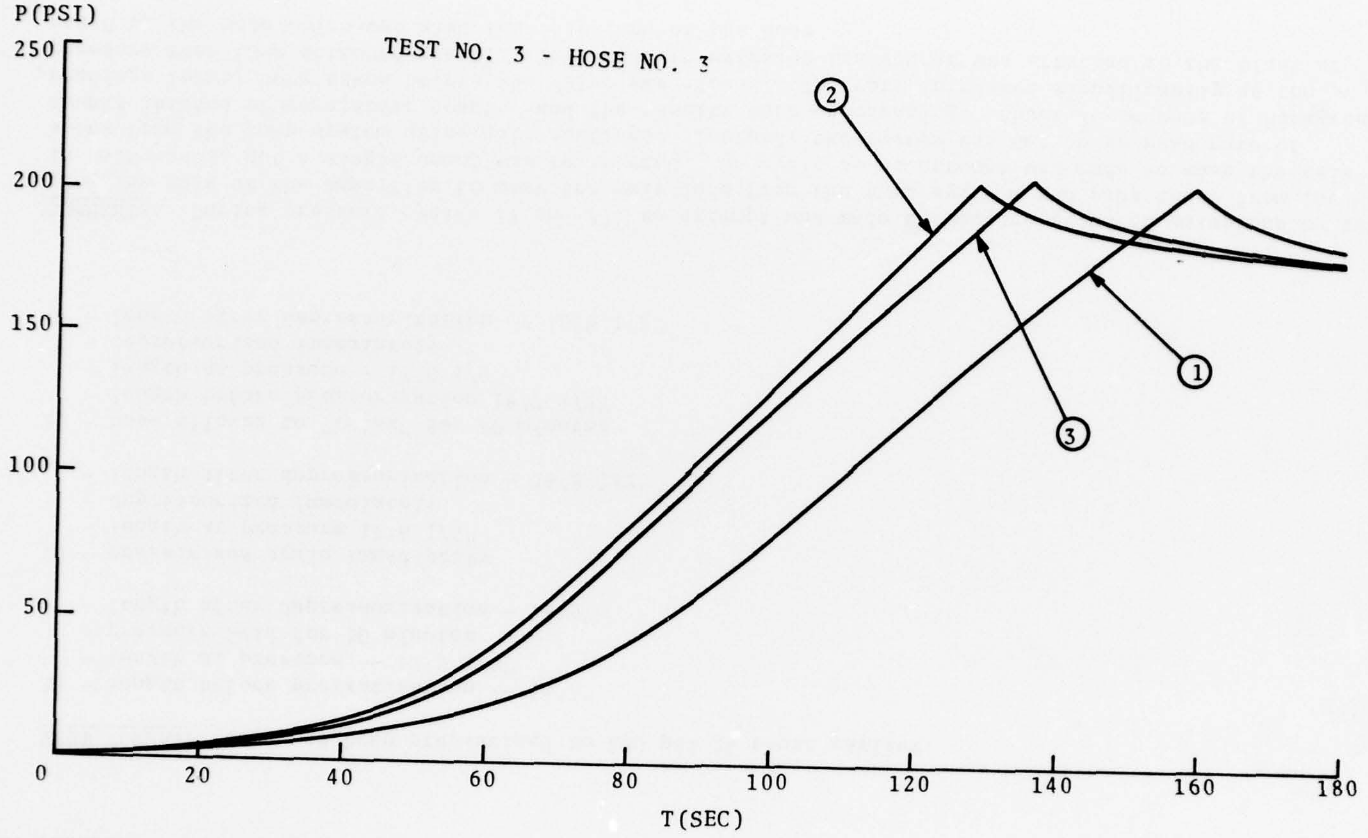

FIGURE A-3. DOCK HOSE PRESSURE-VOLUME DATA (HOSE NO. 3)

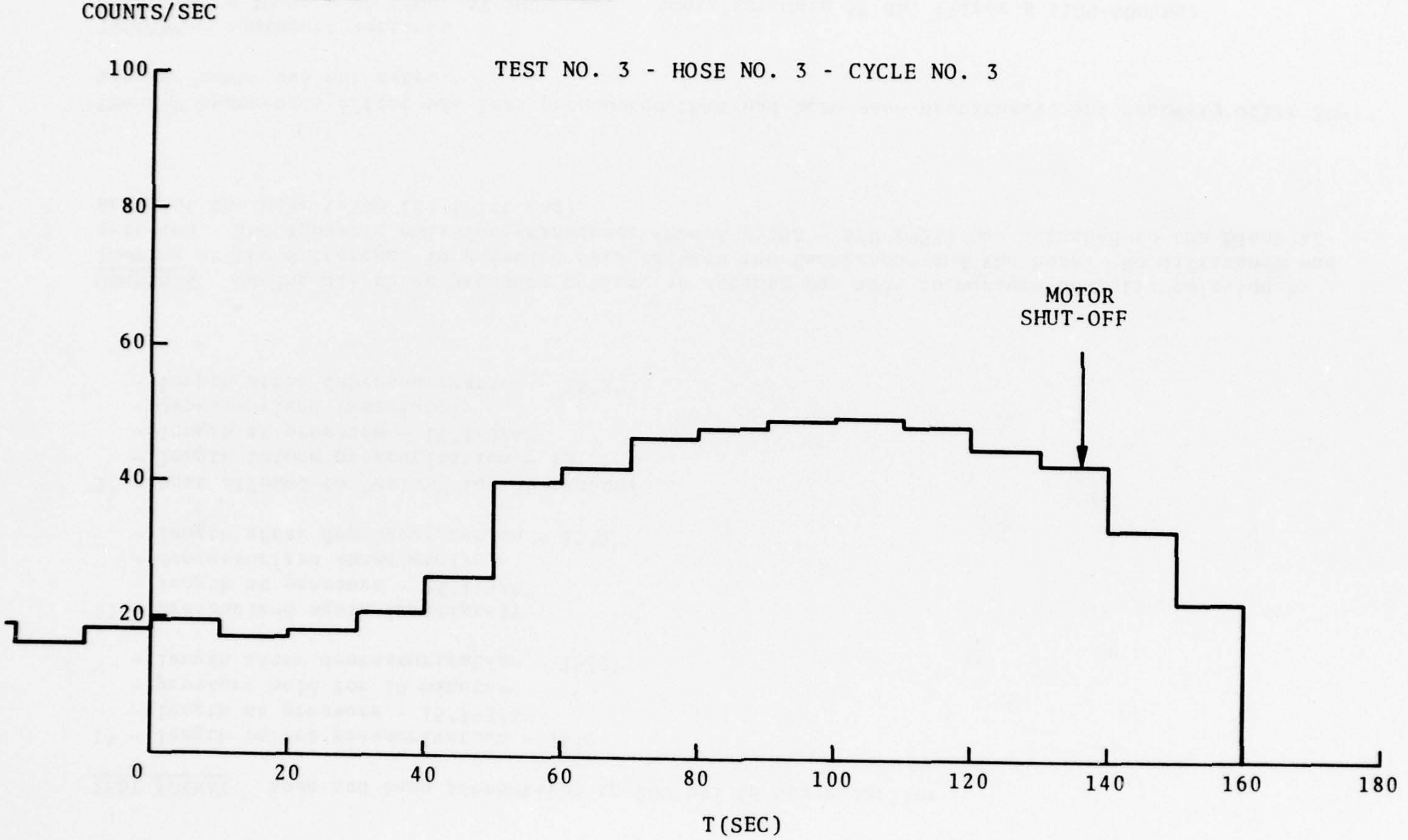

FIGURE A-4. DOCK HOSE ACOUSTIC EMISSION DATA (HOSE NO. 3)

TEST NO.: 4 HOSE NO.: 2 DATE: 10/7/77

TEST PRESSURE: 200-250 psi FLOW RATE: 2gpm FLOW RATE SETTING: 4.0

TEST FORMAT: hose had been pressurized to 200 psi 48 hours earlier

1) - length before pressurization - 15'2
   - length at pressure - 15'1-3/4"
   - pressure held for 10 minutes
   - length after depressurization - 15'2"

2) - pressurized again immediately
   - length at pressure - 15'1-3/4"
   - depressurized immediately
   - length after depressurization - 15'2"

3) - hose allowed to "relax" for 30 minutes
   - length before pressurization - 15'2"
   - length at pressure - 15'1-3/4"
   - depressurized immediately
   - length after depressurization - 15'2"

COMMENTS: During all three pressure cycles, an attempt was made to measure acoustic emission by looking at the difference in emission rate between the background and the hose. No difference was detected. The acoustic emission transducer (Model 7538A - S/N 2953) was attached to the blank at end A of the hose (also the inlet end).

The P-V hysteresis effect was less pronounced than had been seen previously, and recovery after 30-minute "rest" was not noted.

TRODYNE - equipment settings
Processor - 10 us rise time, ΔT 5000 usec. Amplifier Gain 57 db, filter B (100-400kHz)
Lin Rate - Event, 10^{0} Rate Base 1. Preamp - Model 7529A, S/N 188
Transducer - Model 7538A - 50K S/N2953

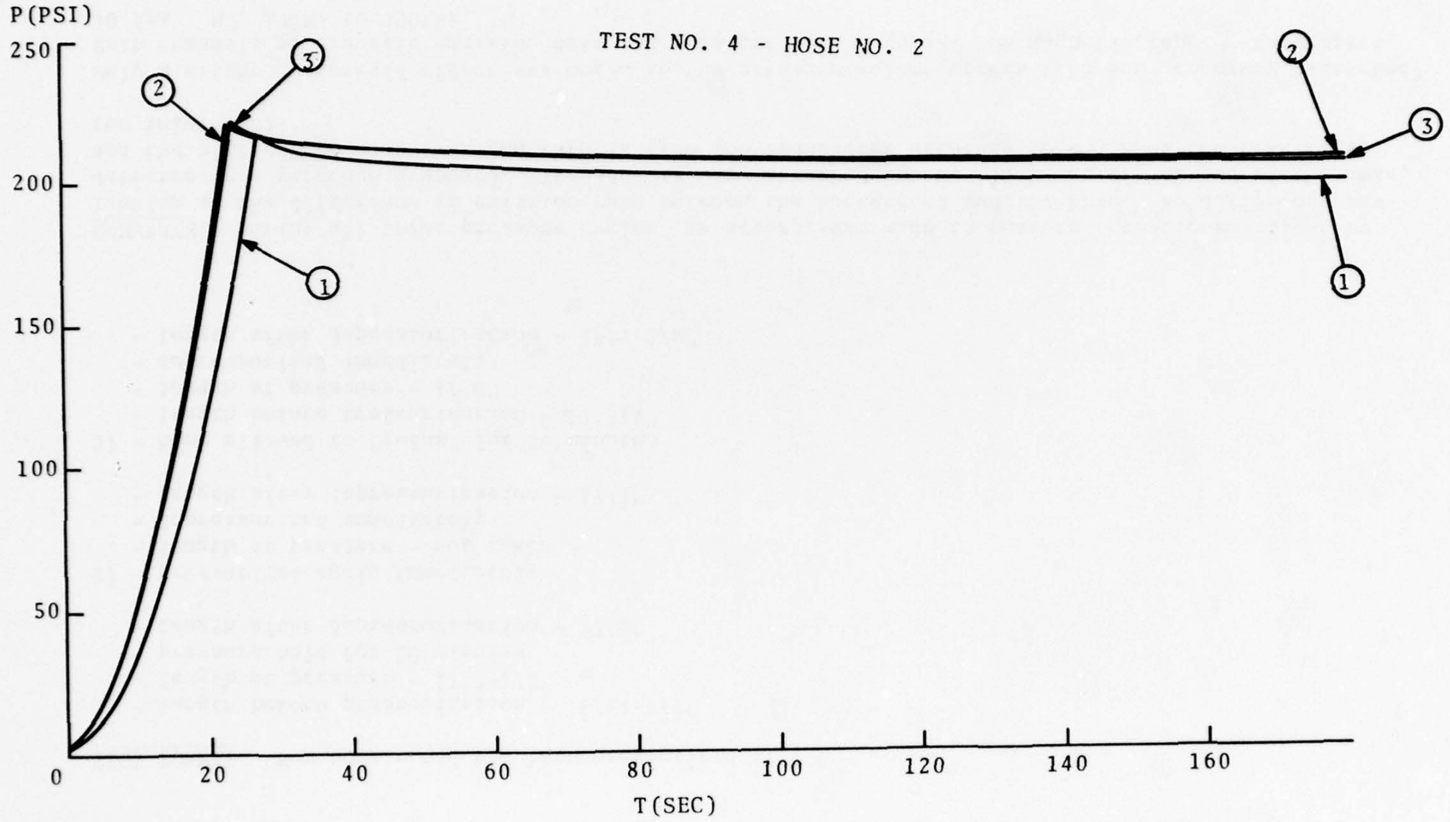

FIGURE A-5 . DOCK HOSE PRESSURE-VOLUME DATA (HOSE NO. 2)

TEST NO: 7
TEST PRESSURE: 200-250 psi
HOSE NO.: 1
FLOW RATE: 2 gpm
DATE: 11/10/77
FLOW RATE SETTING: 4.0

TEST FORMAT: New hose - had not been pressurized at TSC

1) - length before pressurization - 16'11-7/8"
   - length at pressure - 17'7-1/2"
   - pressure held for 10 minutes
   - length after depressurization - 17'2"

2) - pressurized again immediately
   - length at pressure - not taken
   - depressurized immediately
   - length after depressurization - 17'1"

3) - hose allowed to "relax" for 30 minutes
   - length before pressurization - 17'3/4"
   - length at pressure - 17'8"
   - depressurized immediately
   - length after depressurization - 17'1-3/4"

COMMENTS: During all three pressure cycles, an attempt was made to measure acoustic emission by looking at the difference in emission rate between the background and the hose. No difference was detected (see attached graphs*). Transducers were attached to the blanks at either end of the hose, and the plotted acoustic emission rate is from the transducer attached to end A of the hose (also the inlet end).

Only a slight hysteresis effect was noted in the pressure volume traces with some recovery (attached). Both channels of acoustic emission data and pressure were recorded on magnetic tape -- tape speed, 30 ips BW, 100Hz to 150kHz.

TRODYNE equipment settings
Processor - 10 us rise time, ΔT 5000 usec. Amplifier - Gain 65 db, filter B (100-400kHz) Lin Rate - Event, 10°, Rate Base 10. Preamp - Model 7529A, S/N 188
Transducer - Model 7538A-50K S/N 2953

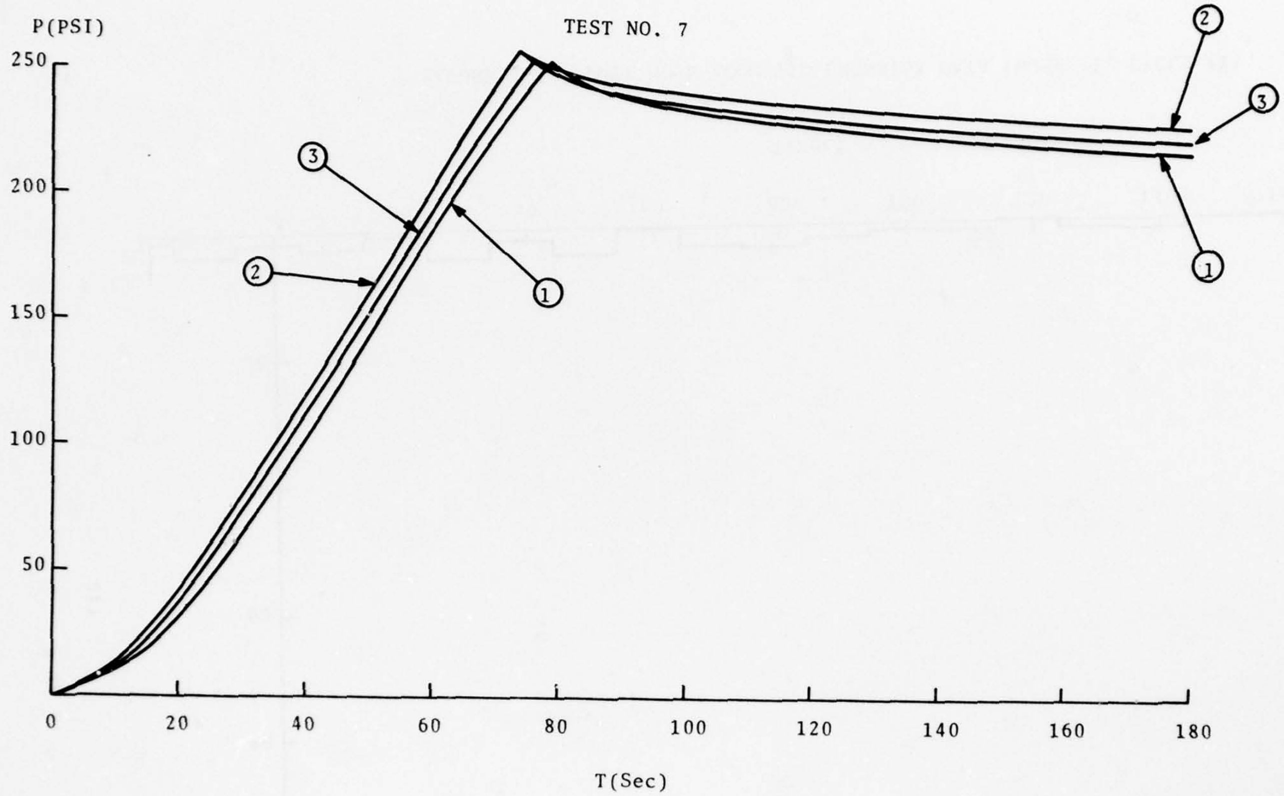

FIGURE A-6. DOCK HOSE PRESSURE-VOLUME DATA (HOSE #1)

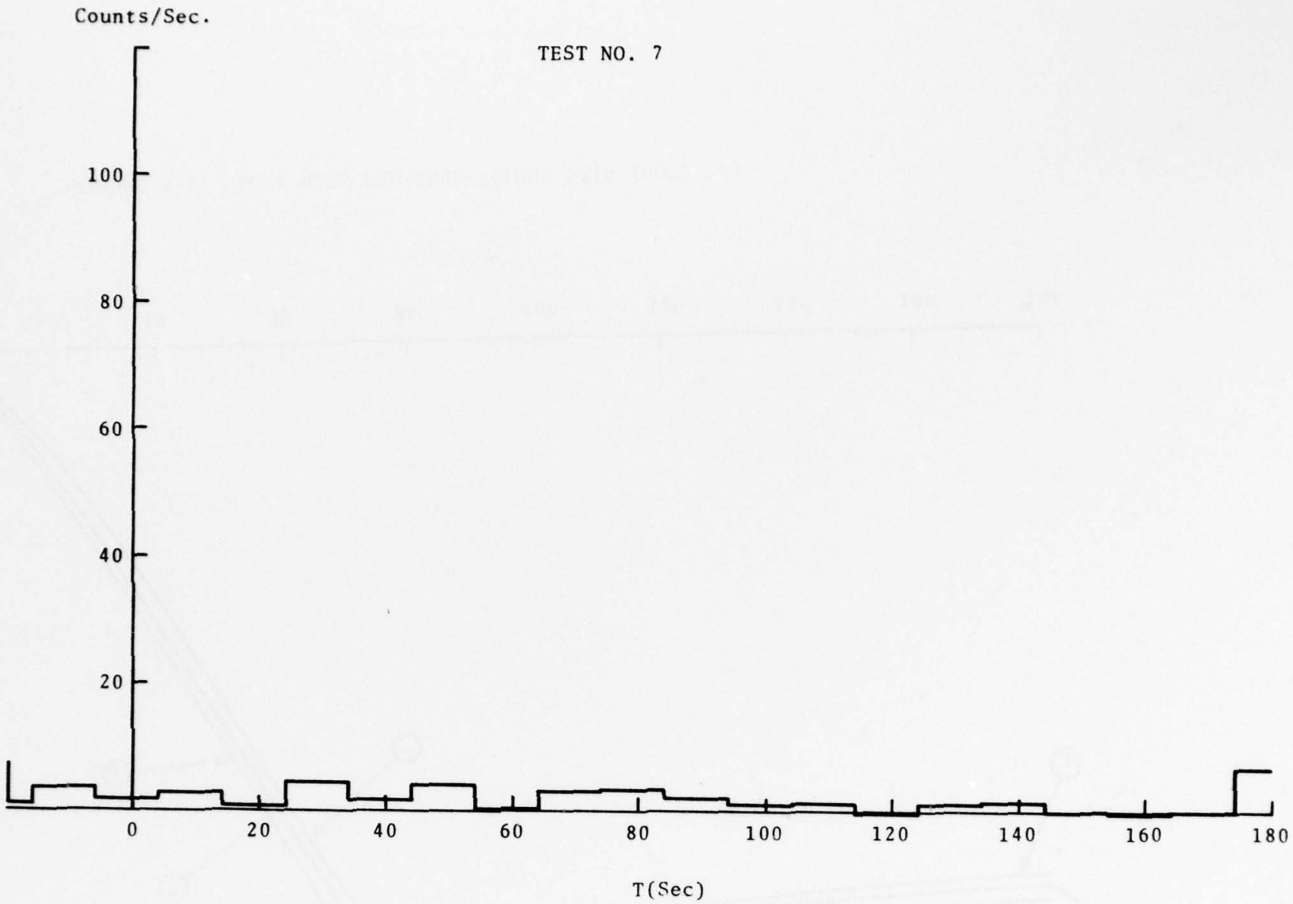

FIGURE A-7. DOCK HOSE ACOUSTIC EMISSION DATA (HOSE #1, CYCLE #1)

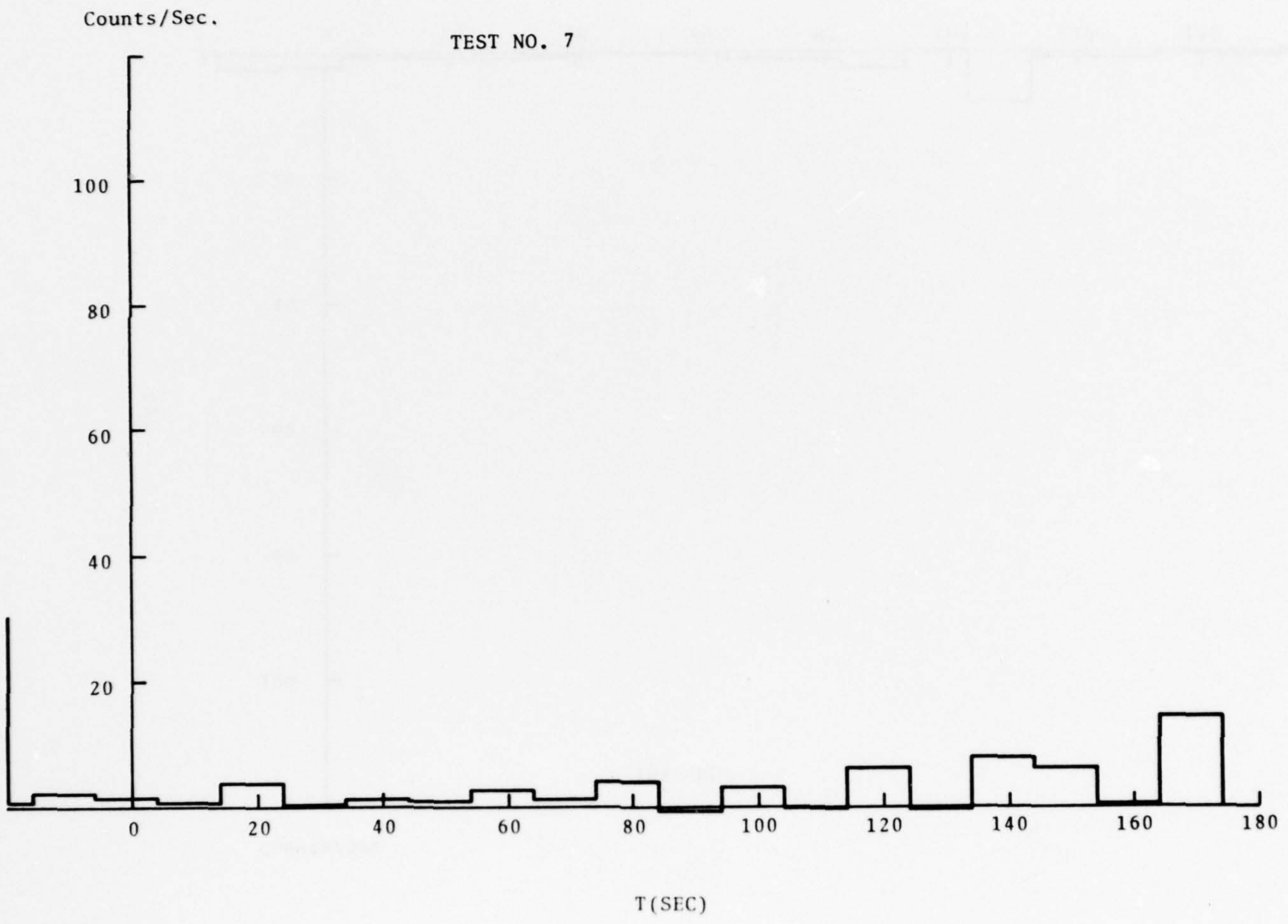

FIGURE A-8. DOCK HOSE ACOUSTIC EMISSION DATA (HOSE #1, CYCLE #2)

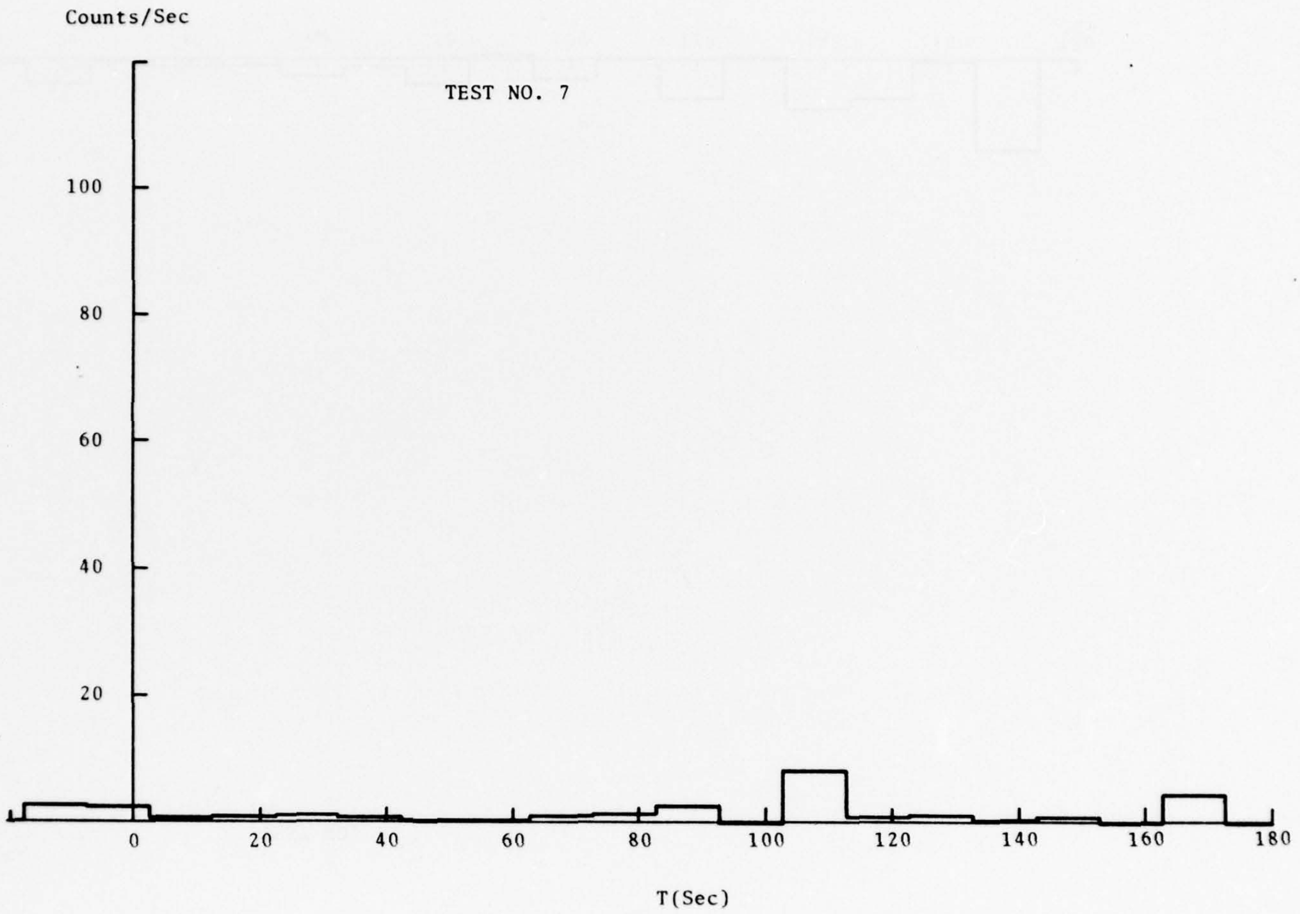

FIGURE A-9. DOCK HOSE ACOUSTIC EMISSION DATA (HOSE #1, CYCLE #3)

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