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IDENTIFICATION AND EVALUATION OF DEEPWATER PORT HOSE INSPECTION METHODS

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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.

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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.

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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

2. CARGO TRANSFER HOSES

2.1 CALM AND SALM SYSTEMS

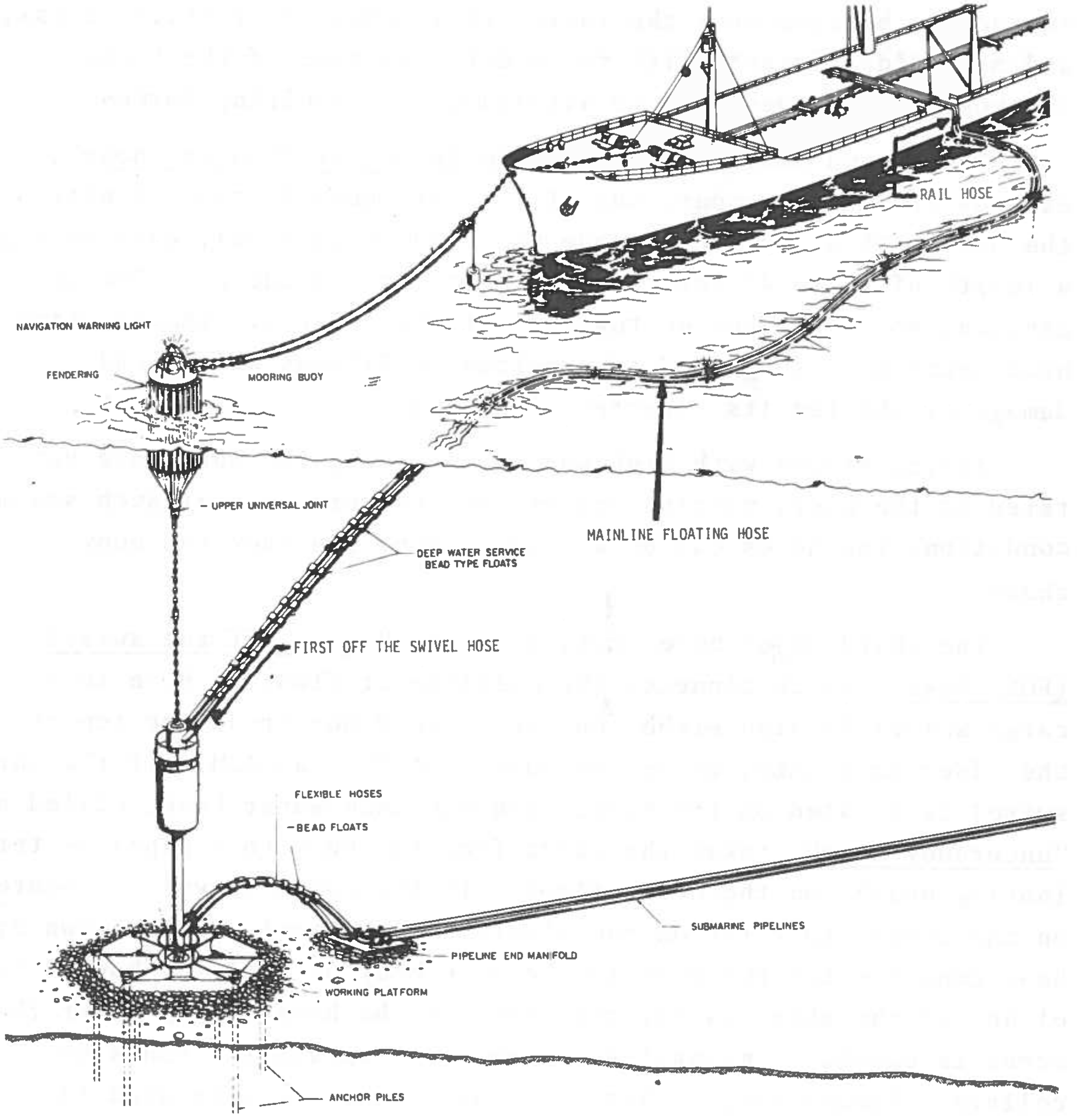
With the advent of the Very Large Crude Carriers (VLCC's) for the transportation of crude oil, the problem of loading and unloading the vessels where natural deepwater harbors did not exist led to the development of the Single Point Mooring (SPM). The high cost of dredging and modifying existing port 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.

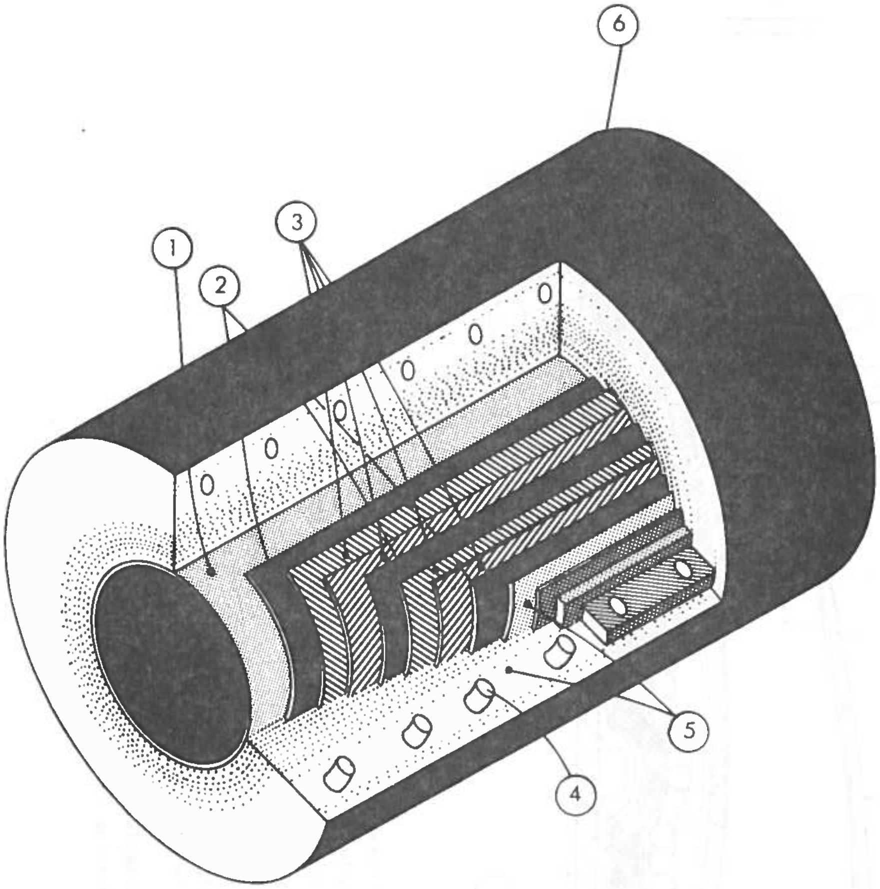


Source: IMODCO International Inc.
Bulletin No. IMO-72-100

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

TABLE 2-1 - HOSE FUNCTIONS AND REQUIREMENTS

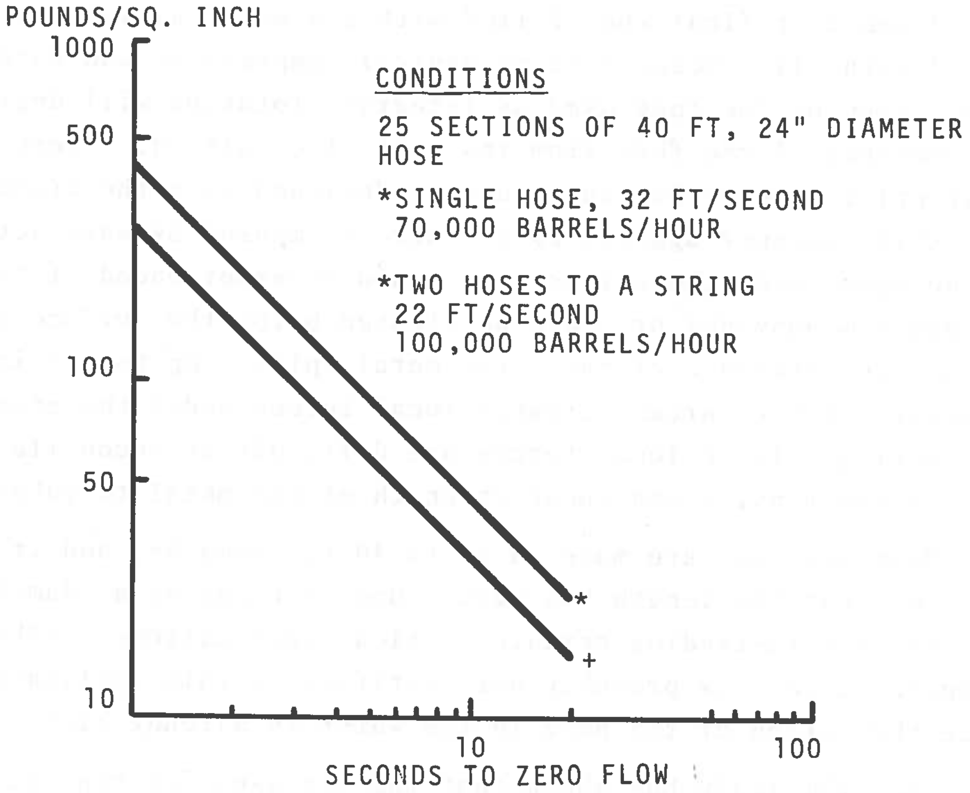
Sections	Function	Requirements
Tanker Rail Hose,	Connects tanker Manifold to Floating Hose Section	Flexibility and abrasion resistance over the rail, tensile strength and nipple adhesion along entire length. Must float when not in use.
Floating Section or Main Line	Connects rail section to the First 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.



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



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 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.

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 ment 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.

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

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*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,

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.

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. Gains 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)

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 3-2.

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 3-4.

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
		5	Rail	9	Abrasion	Near Nipple	Handling	1
		3	Rail	25	Kink	Mid Bay	Handling	2

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.

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	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.		

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 3-7. 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 3-9. 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

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

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, 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.

turer 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.

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

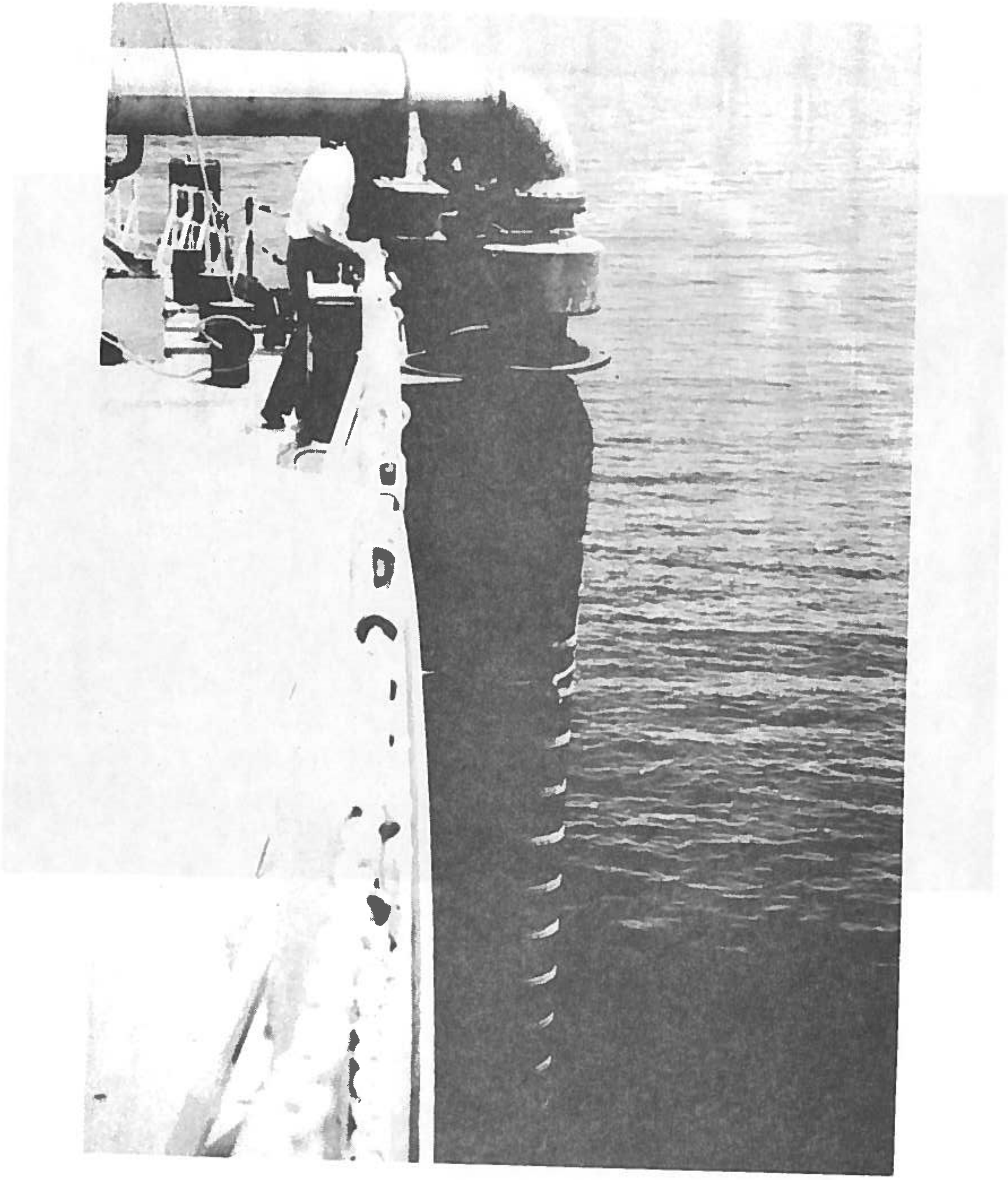

FIGURE 5-1. "OVER-THE-RAIL" STEEL ELBOW AND NIPPLE

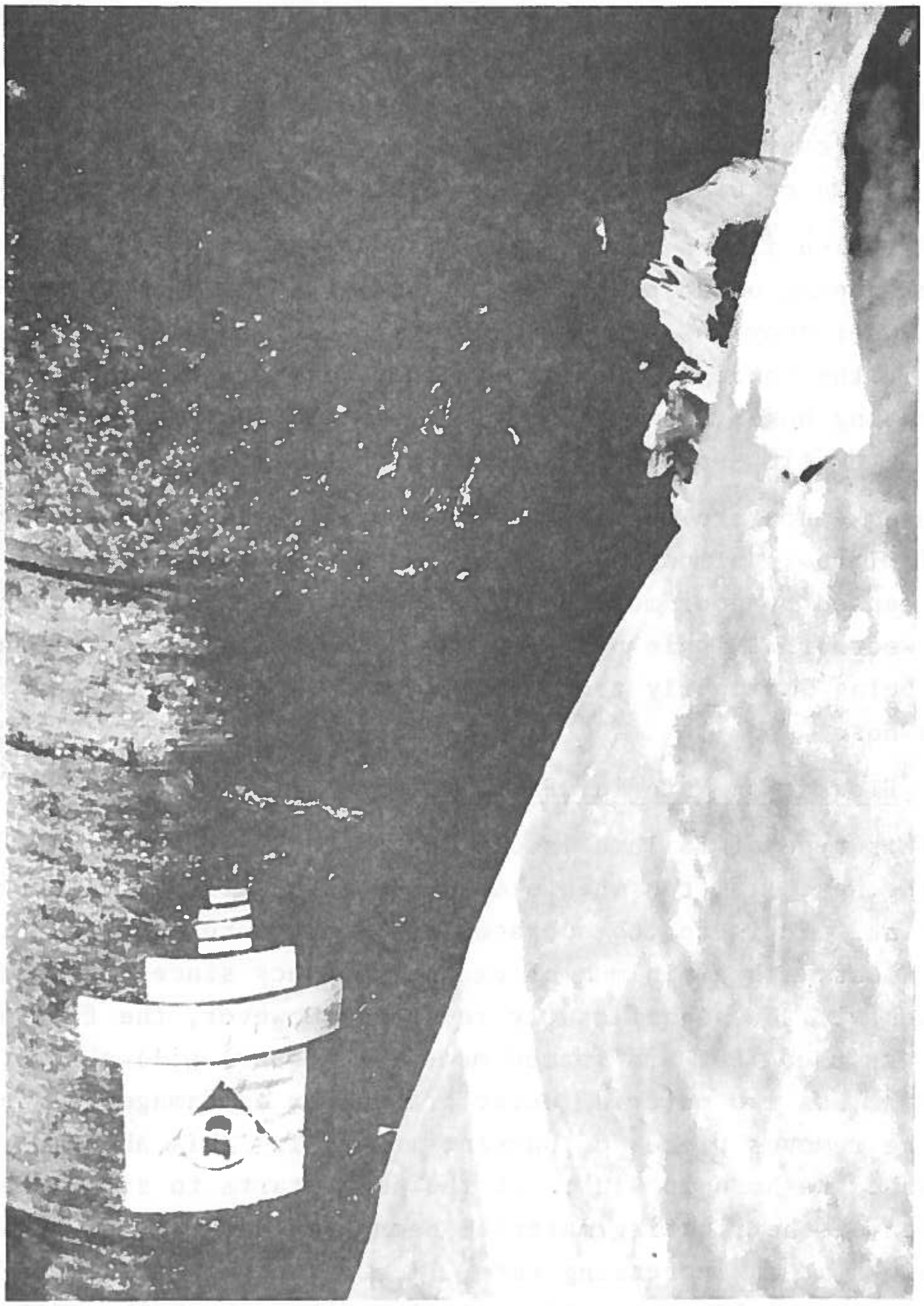

FIGURE 5-3. CARCASS FAILURE (NOTE HELIX WIRE PROTRUDING)

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 5-5. MARINE GROWTH ON HOSE

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

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.

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

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

6.2.2.1 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.

6.2.3.1 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 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 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

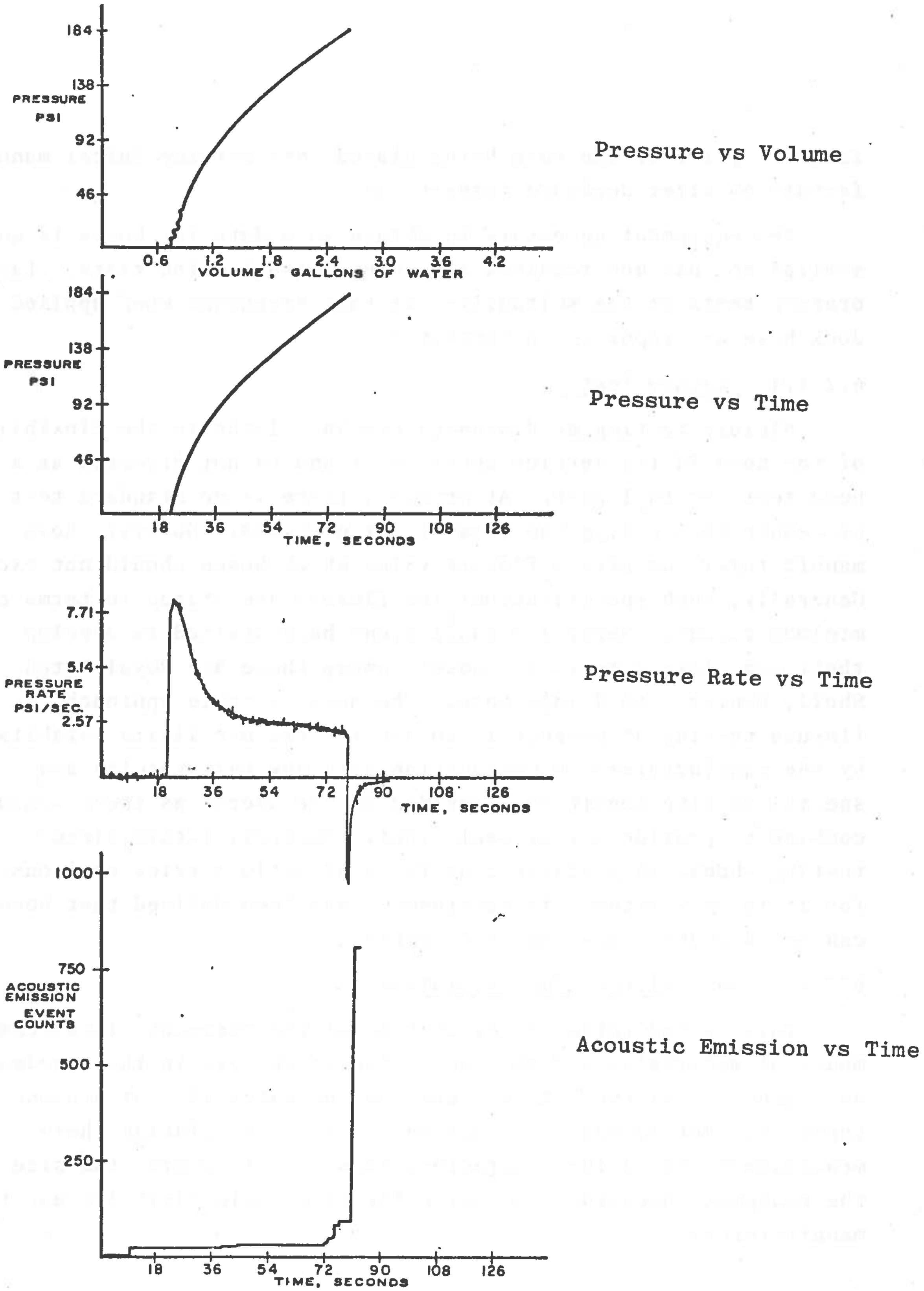

Figure 6-2. Data for 6.45 x 14 2 Ply Polyester - no Leak

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 straightance. 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.

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 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

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.

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) (CONTINUED)

COMPONENT CONDITION	AT MANUFACTURE	BEFORE DEPLOYMENT	ON SITE			DOCKYARD		AFTER STORM/COLLISION
			BEFORE TRANSFER	DURING TRANSFER	AFTER TRANSFER	PERIODIC	AFTER STRESS BLOCKAGE	
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)							

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*Requires further development

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

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).

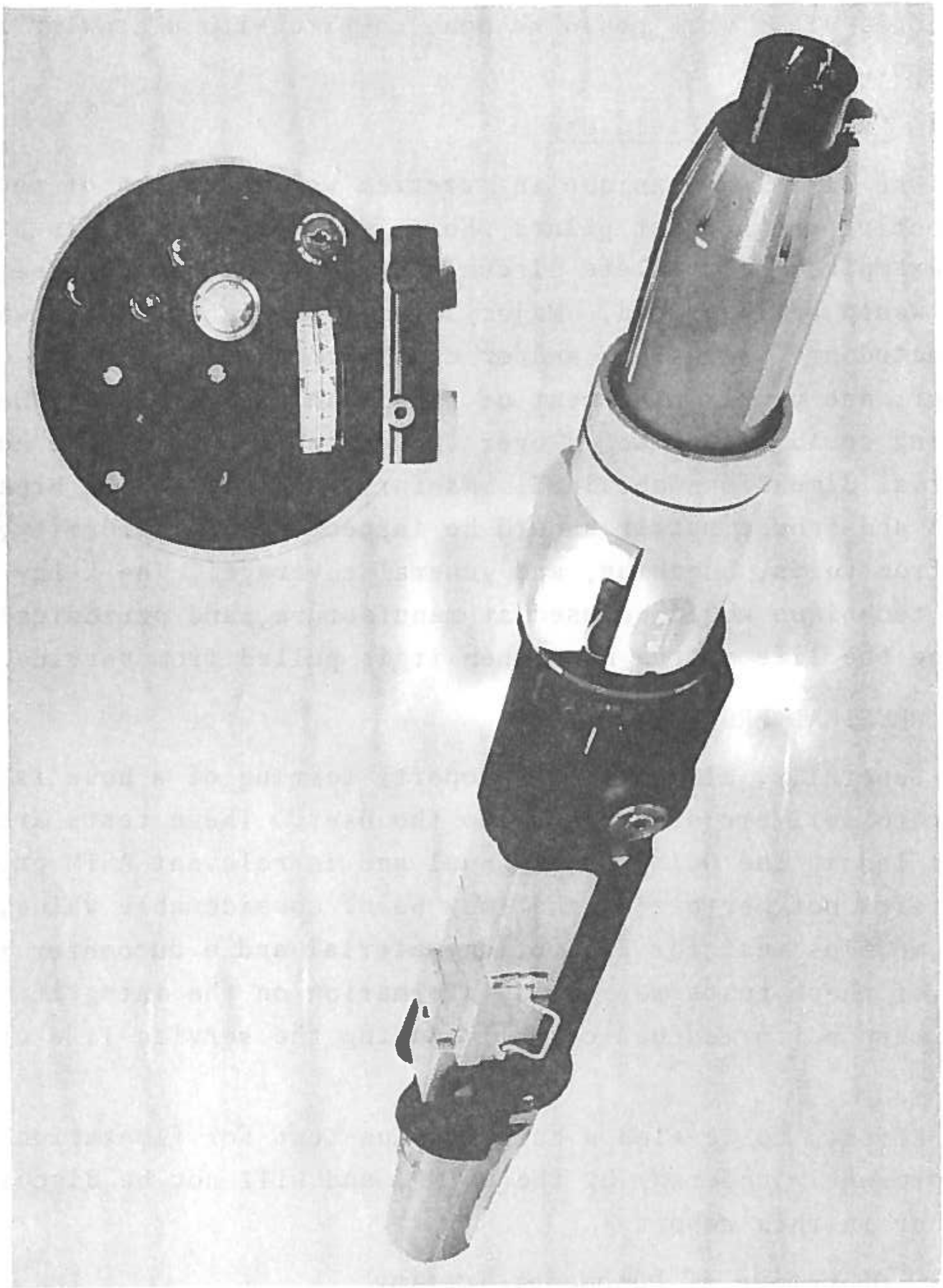

FIGURE 7-2. COMPACT CRAWLER

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

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.

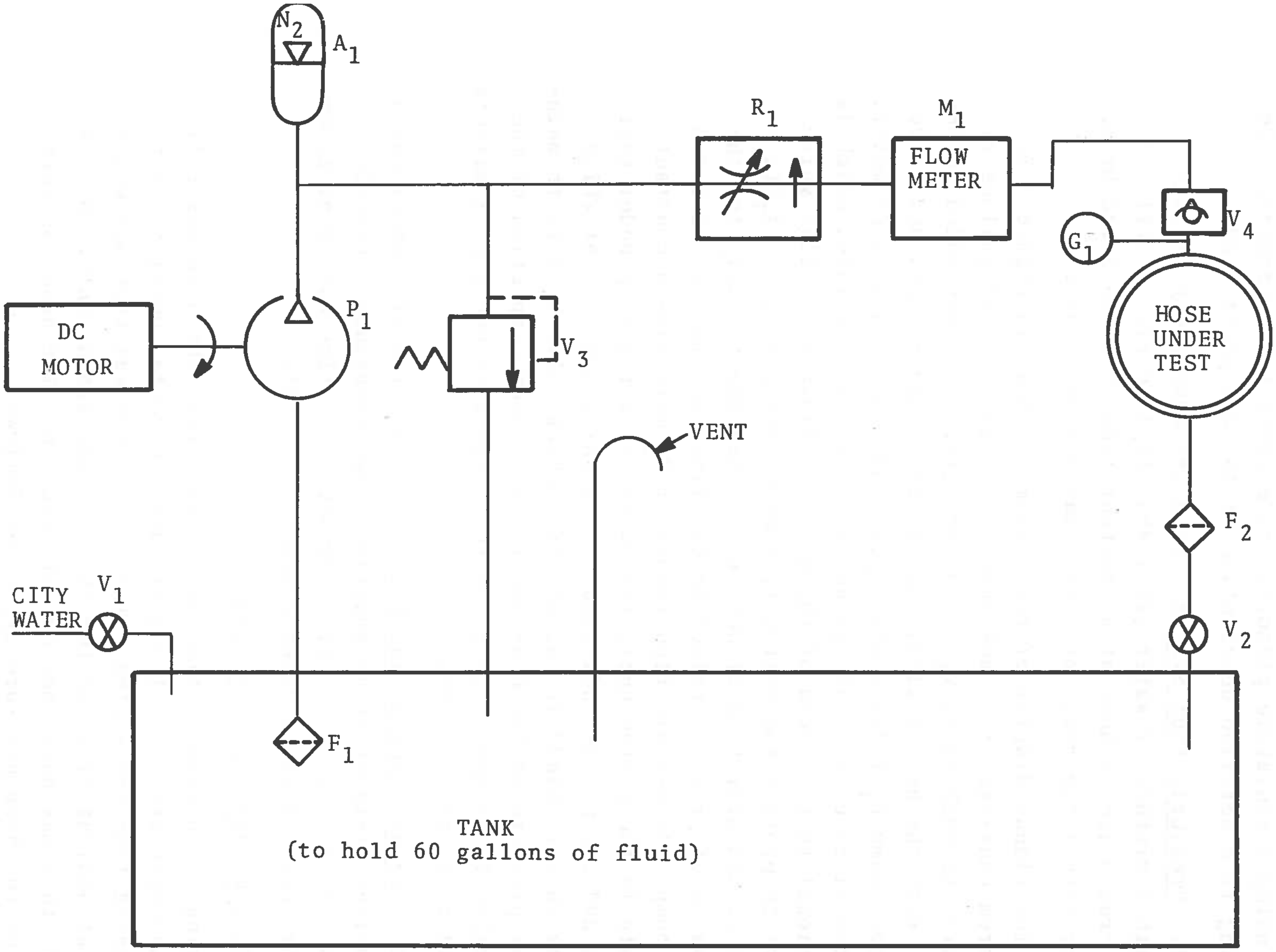

FIGURE 7-3. FUNCTIONAL DIAGRAM OF PRESSURIZATION SYSTEM

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 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 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.

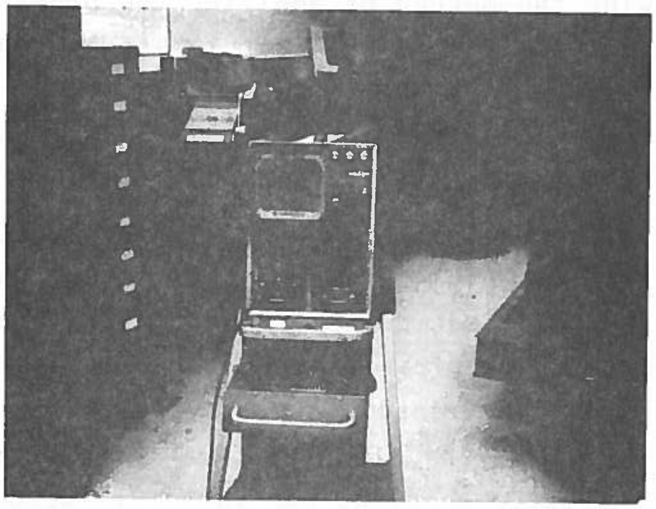

FIGURE 7-5. ULTRASONIC FLAW DETECTION INSTRUMENTATION

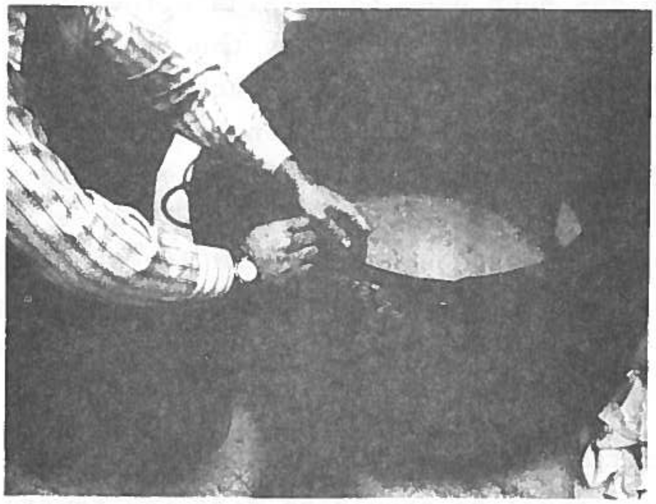

FIGURE 7-6. APPLICATION OF ULTRASONIC PROBE TO HOSE LINER

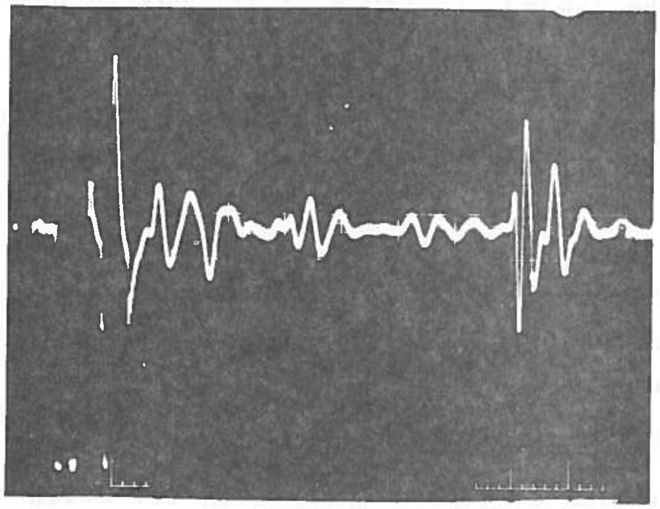

FIGURE 7-7. ULTRASONIC SCAN OF INTACT HOSE

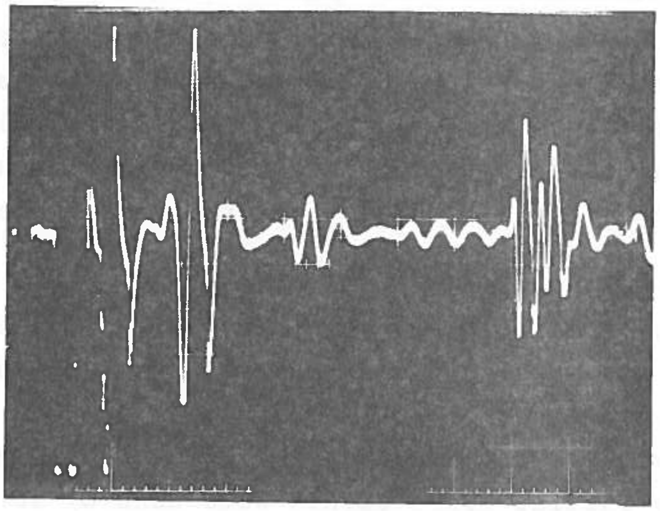

FIGURE 7-8. ULTRASONIC SCAN OF HOSE WITH LINER SEPARATION

ments 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.

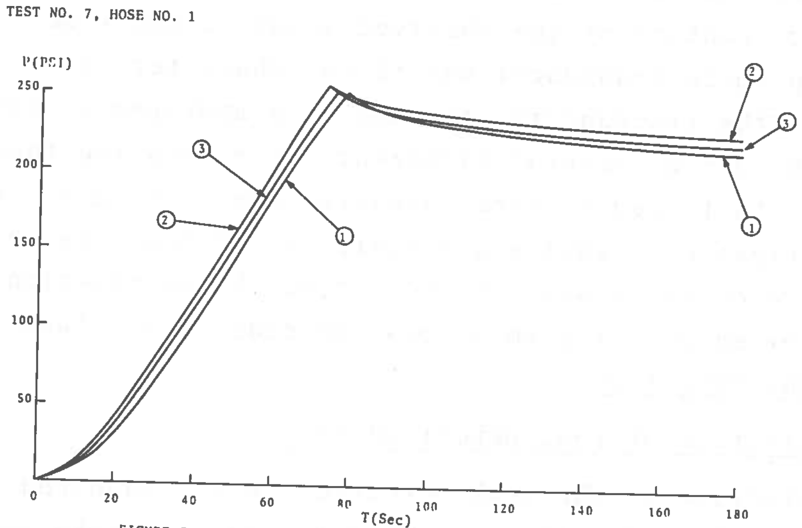

FIGURE 7-10a. DOCK HOSE PRESSURE-VOLUME DATA (HOSE NO. 1)

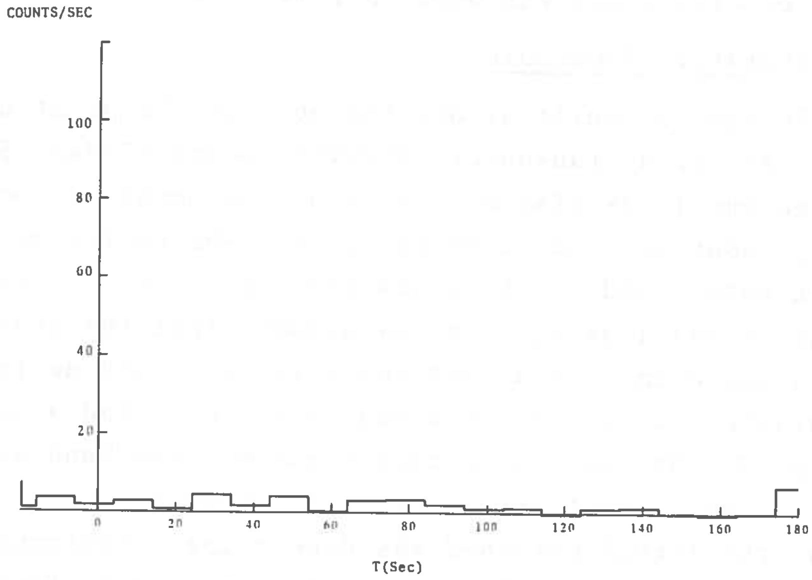

FIGURE 7-10b. ACOUSTIC EMISSION TEST DATA (HOSE NO. 1)

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

7.5.2.8 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.

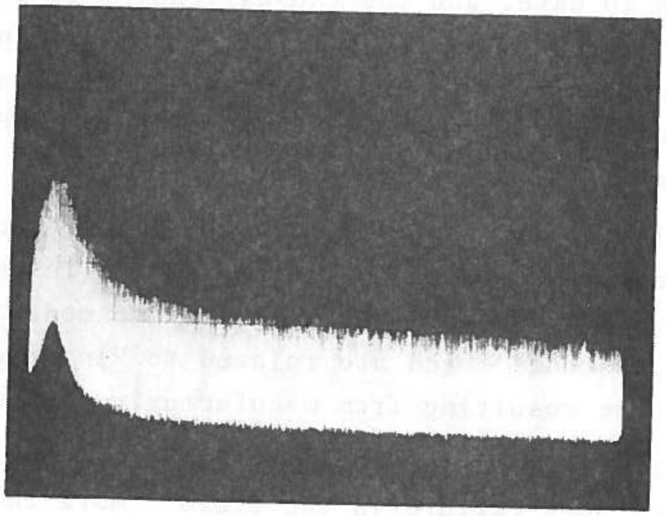

FIGURE 7-12a. ACOUSTIC EMISSION SPECTRUM FROM 0 - 10 kHz HOSE #2 - AT AMBIENT PRESSURE

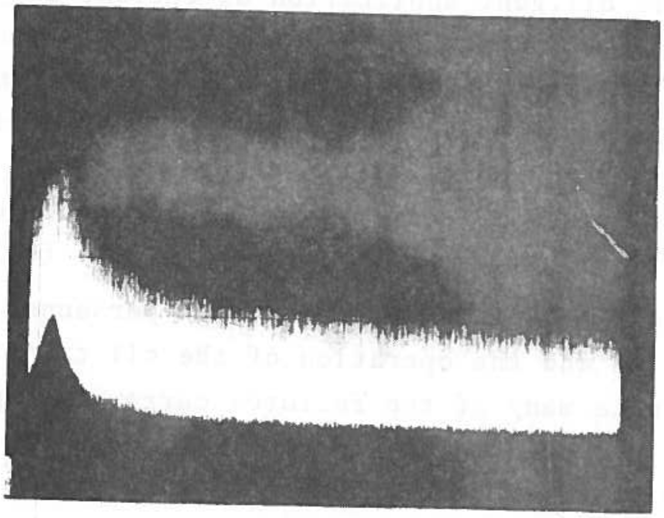

FIGURE 7-12b. ACOUSTIC EMISSION SPECTRUM FROM 0 - 10 kHz HOSE #2 - AT 170 psi

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 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 tc 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.

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.

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

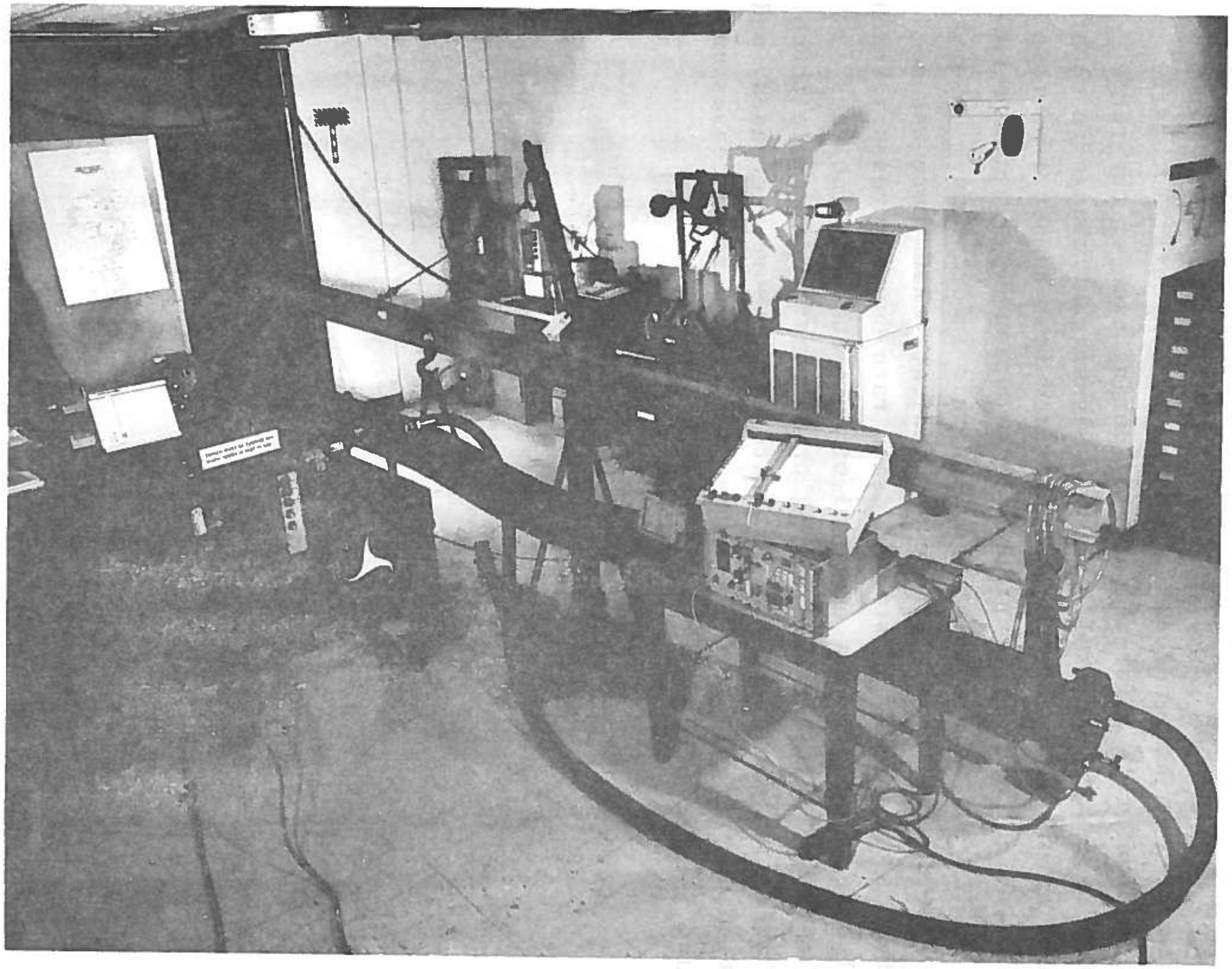

FIGURE A-2. LABORATORY TEST SET-UP

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^{o}, Rate Base 10. <u>Preamp</u> - Model 7529A, S/N 188
<u>Transducer</u> - Model 7538A - 50K S/N 2953

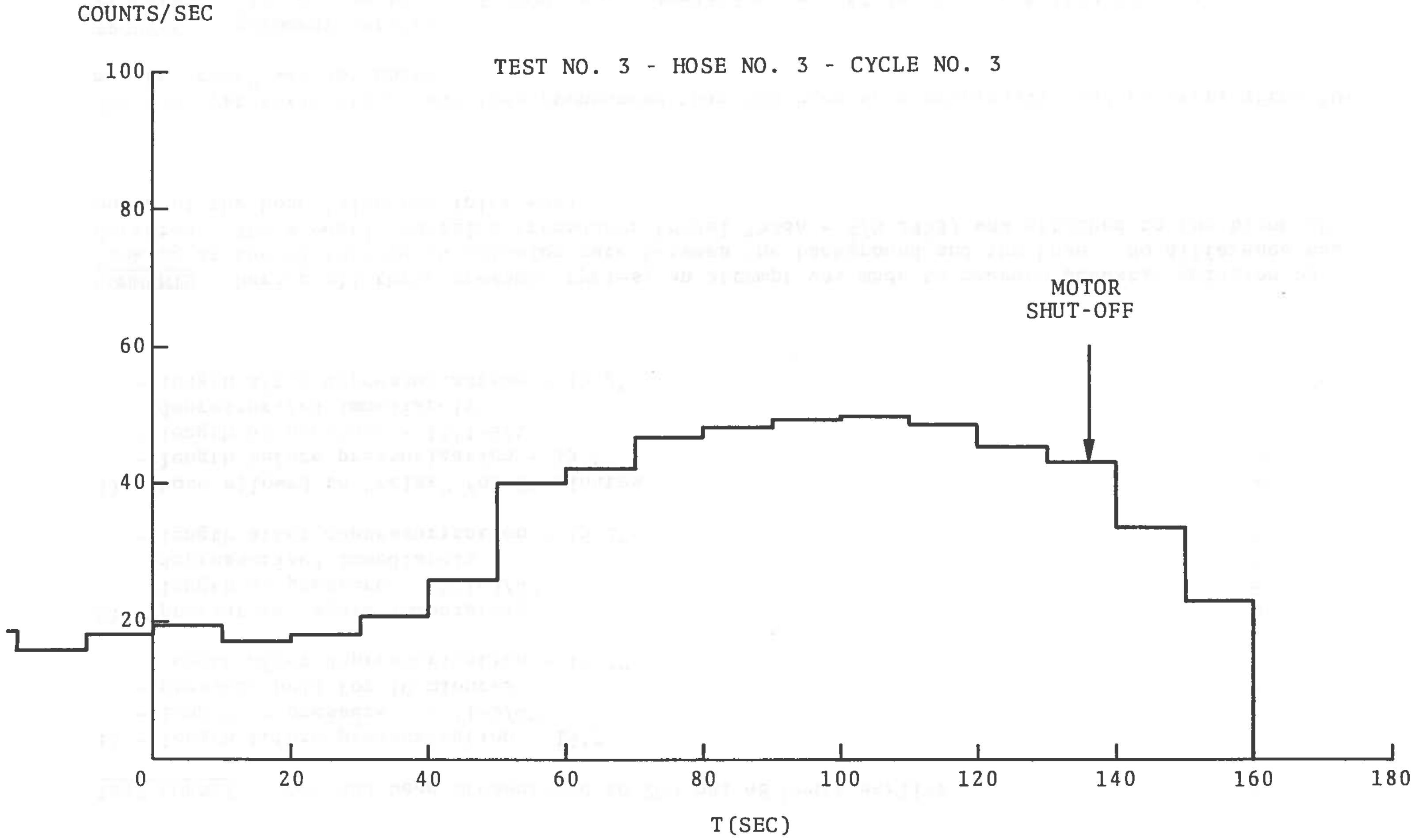

FIGURE A-4. DOCK HOSE ACOUSTIC EMISSION DATA (HOSE NO. 3)

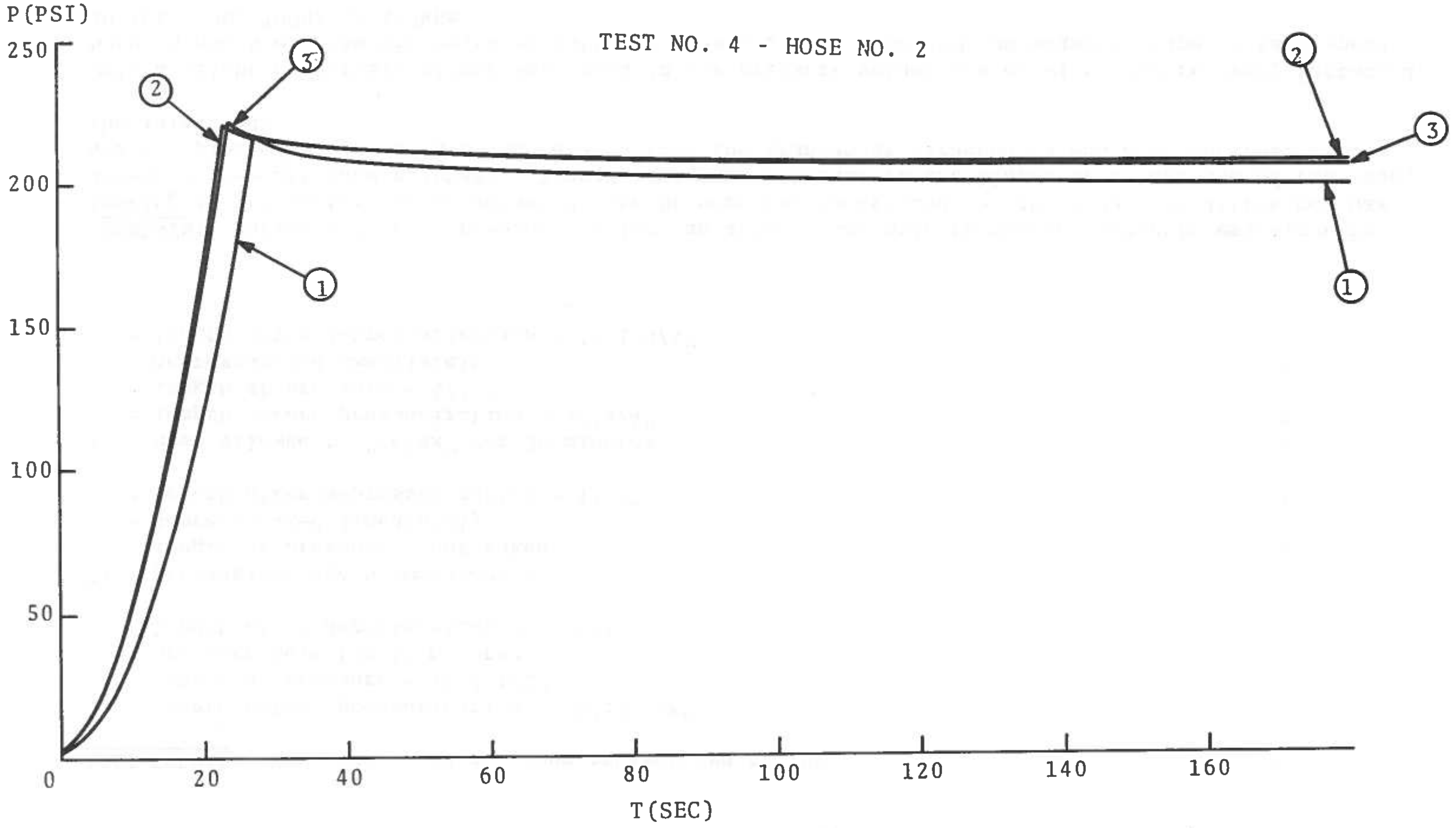

FIGURE A-5 . DOCK HOSE PRESSURE-VOLUME DATA (HOSE NO. 2)

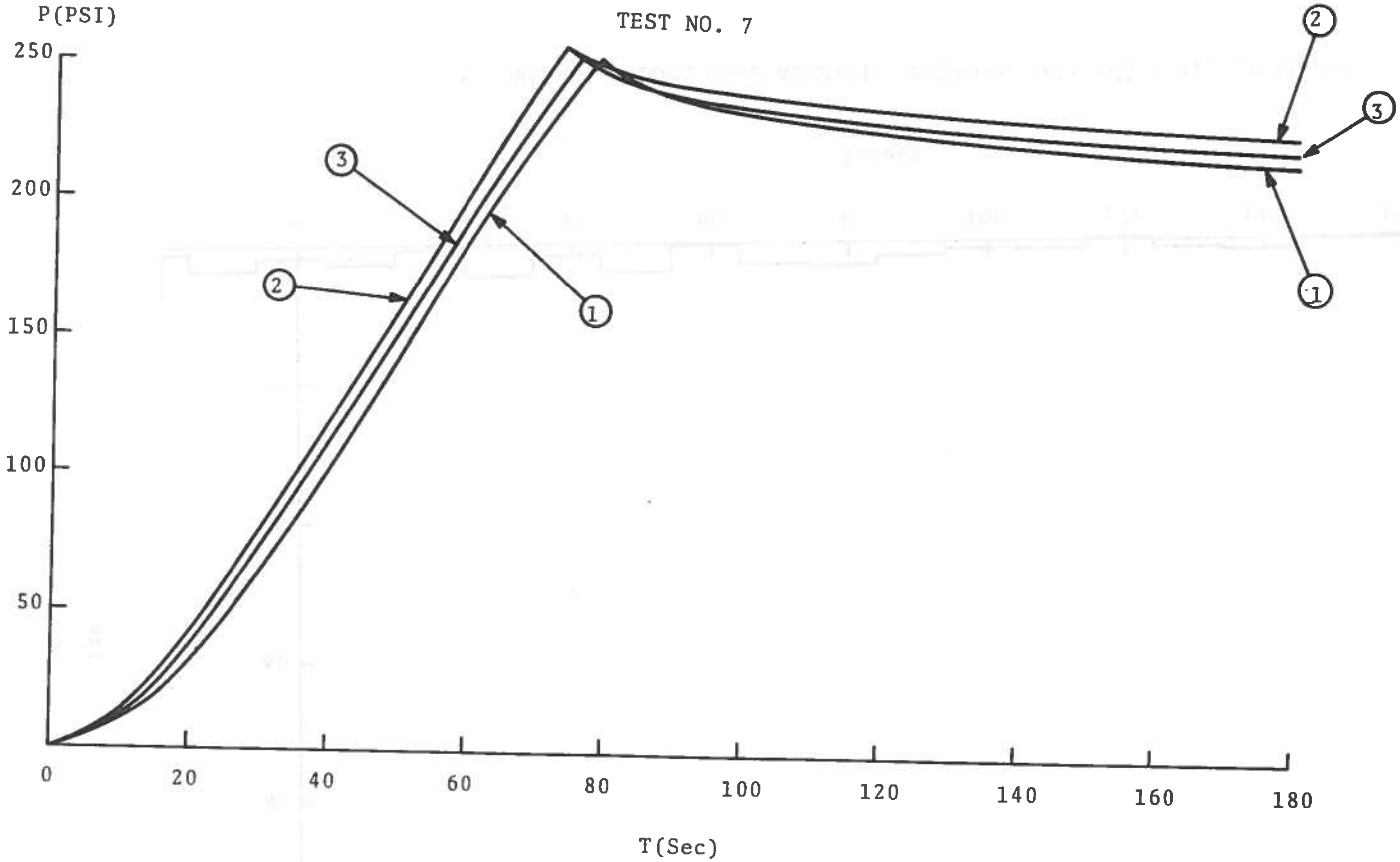

FIGURE A-6. DOCK HOSE PRESSURE-VOLUME DATA (HOSE #1)

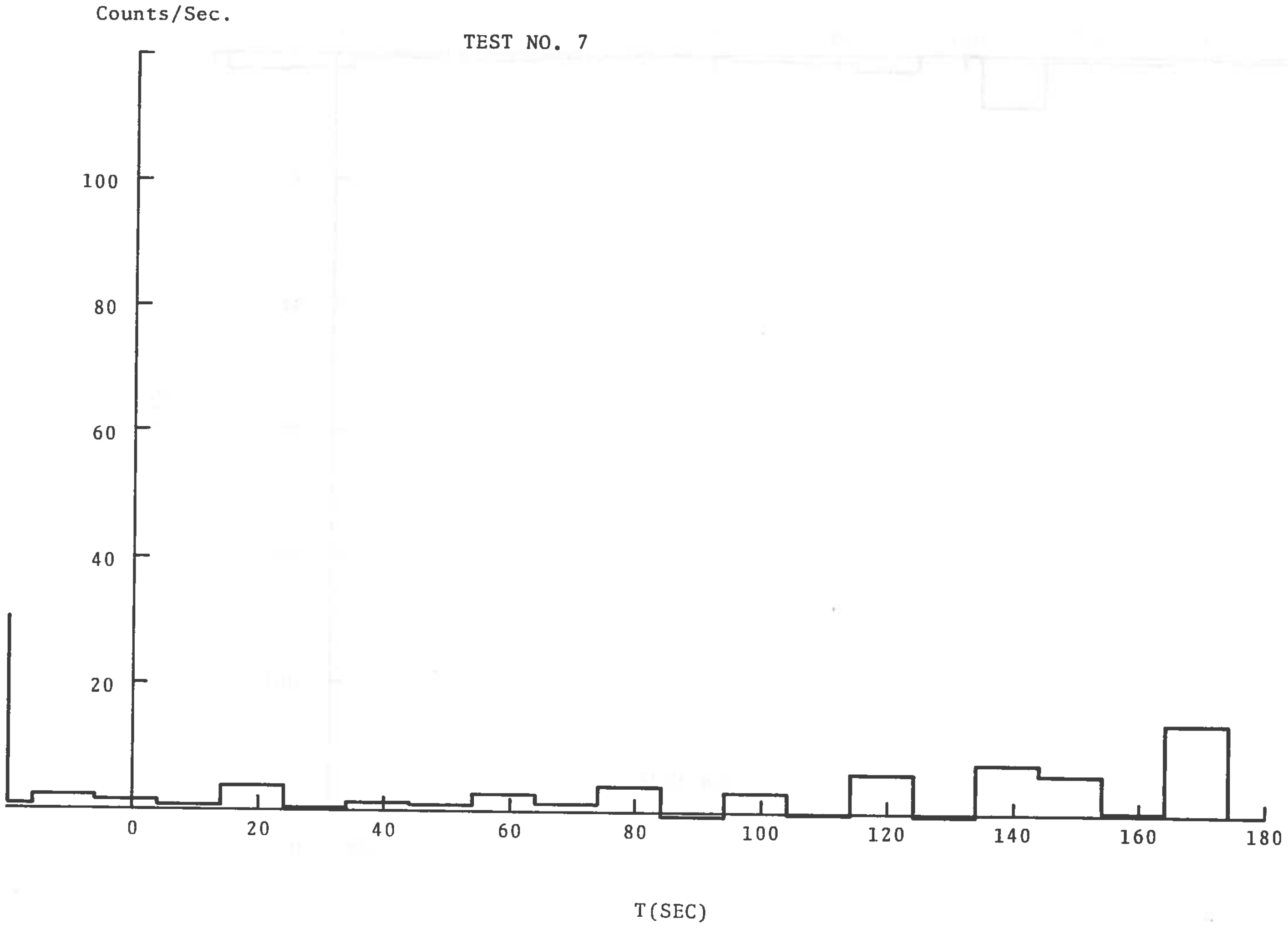

FIGURE A-8. DOCK HOSE ACOUSTIC EMISSION DATA (HOSE #1, CYCLE #2)

REFERENCES

1. E.M. Briggs and G.K. Wolfe, "Study of Large Bore Offshore Loading and Discharge Hoses", Southwest Research Institute Project No. 03-4178-001, September 15, 1975.

2. E.M. Briggs and G.K. Wolfe, "Failure Analysis of DWP Hoses", Southwest Research Institute Project No. 03-4752-001, December 17, 1976.

3. Buoy Mooring Forum of OCIMF, "Hose Standards, Hose Guide, SPM Hose System Design and Ancillary Equipment Guide", Hitherby & Co. Ltd., 32-36 Aylesbury Street, London ECIR. OET. UK., December 1974.

4. Massachusetts Institute of Technology, "Primary Physical Impacts of Offshore Petroleum Development", MITSG 74-20, April 1974.

5. Code of Federal Regulations, Rules and Regulations for Deepwater Ports, Title 33 Part 150.400.

6. Robert P. Ryan, "Feasibility of High-Resolution Pulse-Echo Techniques For Automobile Tire Inspection", Transportation Systems Center, Report No. DOT-TSC-NHTSA-72-11, June 1973.

7. I.R. Kraska "Ultrasonic Inspection for Tire Retreadability, "Great American Transportation Corp., Niles, IL.; GARD No. 1580 November 1974.

8. A.A. Pollock, "Use of Acoustic Emission for Inspection of Oil Transfer Hoses at Deepwater Ports", Dunegan/Endevco Co., January 1977.

9. Personal Commication from Allen T. Green, Acoustic Emission Technology Corp., Sacramento, CA November 1976.

10. H.G. Eldering, A.W. Hornig and W.A. Webb, "Detection and Identification of Oil Spills by Remote Fluorometric Systems", Baird Atomic, Inc., Bedford, MA, Report No. CG-D-73-75, September 1974.

11. W.A. Webb and H.G. Eldering, "Optimization and Evaluation of a Fluorescence Oil Spill Detector, Vol. 1 -Laboratory Measurements and Field Evaluation", Baird Atomic, Inc., Bedford, MA, Report No. CG-D-108-75, May 1975.

12. H.G. Eldering and W.A. Webb, "Optimization and Evaluation of a Fluorescence Oil Spill Detector, Vol. 2 - Prototype Design", Baird Atomic, Inc., Bedford, MA, Report No. CG-D-109-75, May 1975.