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TEST PROTOCOL FOR THE EVALUATION OF OIL-SPILL CONTAINMENT BOOMS FINAL

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- Department of the Interior, Minerals Management Service (MMS)
- U.S. Environmental Protection Agency (EPA)
- U.S. Coast Guard (USCG)
- Environment Canada (EC)

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PREFACE

In September 1988, the Proposed Test Protocol for Offshore Oil Spill Booms was delivered to the member agencies of the OITC. The content of the protocol was based on fourteen years of tests and evaluations (T&E) conducted at Ohmsett and five years of offshore work strongly supported by the Minerals Management Service (MMS). Because Ohmsett was scheduled for abandonment, a goal in developing a protocol was to reduce or eliminate the need to do T&E at test basins. Ohmsett's uniqueness was recognized by the OITC, however, funds were not available to maintain the facility.

As a result of a reawakening of public awareness to oil spills, Ohmsett will shortly be available for needed spill equipment testing. In spite of the many previous years of testing only 20% of the spill devices available have been performance tested under controlled conditions.[1] The need to increase the number of evaluated products is amplified by recent failures/difficulties in mechanically recovering spilled products from water surfaces. The spill equipment that will be tested includes skimmers and booms for inland, harbor and offshore applications.

As part of its mission, MMS has oversight of offshore drilling, and is committed to proper evaluation of offshore spill equipment. Proper evaluation includes controlled measurements in a test basin such as Ohmsett and open ocean testing like the protocol development supported by MMS between 1982 and 1987.

The following test protocol is an amended version of the 1988 proposed protocol and includes support documentation and ancillary test methods.

INTRODUCTION

PAST BOOM PERFORMANCE STUDIES: ENGINEERING/DESIGN, AND HYDRODYNAMIC

Boom performance studies have followed two basic approaches: the hydrodynamic approach and the engineering/design approach. The engineering/design approach investigates material strengths, design features and mechanical behavior to pursue the development of mathematical descriptions for boom strength and motion on water surfaces. Mathematical models developed from such studies can be used to either optimize boom performance or describe the limits of the booms performance on various surface conditions. Lehr and Scherer[2] wrote:

> The oil retention capability of a barrier device is influenced by several factors. Wind and current will build a pool of oil against the upstream side of the barrier. However, the built-up pool that can be retained will be significantly less than might be expected based on potential flow or simple hydrostatic analysis. The reasons for this are unclear. The physical phenomena associated with run-under need to be defined. Furthermore, the influence of barrier draft and cross-section geometry in enhancing the thickness of the built-up pool before run-under occurs must be determined. The loss of oil over the top of a boom may be more readily understood. In general they do not respond to passing waves quickly enough and are incapable of conforming to the ocean surface. Thus as a wave train passes, parts of the boom will intermittently submerge allowing oil to escape. Some optimum combination of freeboard, longitudinal flexibility, and underwater shape must therefore be determined if carryover is to be eliminated.

Boom performance can therefore be improved if boom loads, shapes, and motions can be optimized. Others have considered design and mathematically predictable behavior characteristics. Milgram and O'Dea[3] in 1974, and Main Port Authority[4] in 1970 used boom behavior and design characteristics to evaluate performance.

The hydrodynamic approach pursues the discovery of the mathematical descriptions of oil flow under a barrier. Hydrodynamic investigators have regarded boom designs and boom handling as sources of premature oil loss. Griffiths[5] concluded, "Except for failing to maintain stability, the primary containment failure mode will be droplet shedding from the oil slick at roughly 0.5 [meters per second relative current speed]. . . . This is an oil slick failure and not a boom failure." In 1981 Fannelop[6] considered it, ". . . desirable to separate [boom] losses due to poor handling, design deficiencies, etc., from the unavoidable losses associated with fundamental hydrodynamic phenomena." Among the hydrodynamic studies cited by Fannelop, Wicks[7] reported both a mathematical model and laboratory studies of fundamental hydrodynamic loss.

Droplet failure (the escape of oil droplets beneath mechanical barrier) was shown to occur abruptly when water velocity exceeded a predictable value. The predictable droplet failure was shown to be dependent on specific gravity of the oil and interfacial tension between the oil and water surface. Experimental data was presented graphically as "Failure Diagrams."

TANK TESTING AT OHMSETT

Between 1975 and 1987 many booms were tested at Ohmsett.[8] These tests consisted of both water surface conformance tests where no oil was used in testing and hydrodynamic tests of oil loss. Schwartz[9] reported eight performance characteristics:

- Critical Tow Speed - Stability
- Mode of stability loss (Splashover, Submarining)
- Critical Tow Speed - First Oil Loss (Equivalent to Wick's Droplet Failure)
- Mode of First Oil Loss
- Freeboard Tilt (Angle change from static flotation)
- Immersion (Depth of boom below water during tow)
- Freeboard (Height of boom above water during tow)
- Tow Tension (Tension in the tow lines)

These eight characteristics were measured or observed at tow speeds up to 1.17 meters per second (m/sec.) (2.3-knot) and 0.45 m wave height. McCracken[10 11], McCracken and Schwartz[12], Widawsky[13], Lichte[14], Breslin and Royer[15], Breslin[16], and Smith[17] reported tests run on several booms. Each of the test programs involved similar approaches. Although tilt measurements were not continued, each test series had some unique feature that was being tried-out. Tilt measurement was the first reported instance of tests at Ohmsett that used an electronic sensor to detect boom motion.

BOOM TESTING OFFSHORE PERFORMANCE EVALUATIONS WITHOUT OIL

Beginning in 1980, Ohmsett testing protocols were applied to at-sea tests. Lichte[18] reported test preparations, and operations in addition to performance of Shell's Spilled Oil Containment Kit (SOCK.) Although SOCK is a skimmer, the experiences gained from that test program were used to start testing booms in the open ocean. In 1985, Borst and Lichte[19] reported a standard boom test procedure that involved tank testing and offshore testing. During tank testing, investigators see and photograph oil loss and boom motion in precisely produced and measured waves. Water current passing the boom is controlled and measured to within 0.05 m/sec. In open water such observations are often subjective and measurements are limited. In order to provide investigators with reliable equipment and methods for measuring and reporting offshore boom performance, experimental tank testing procedures using electronic instrumentation were conducted. Intentional oil spills in open water, as was allowed in the SOCK offshore tests, was not considered possible. Therefore, in addition to providing investigators with data producing instruments, tests had to be performed so that a correlation between the parameters measured offshore without oil could be used to predict boom performance in capturing and containing oil. Is there a predictable functional relationship between boom motion on water surfaces and the ability of a boom to capture or contain oil on water surfaces? This unanswered question brought together two approaches to measuring boom performance. The first step taken toward answering this question was to select a mathematical tool used in ship design known as Response Amplitude Operator (RAO).

PREDICTION OF BOOM PERFORMANCE USING RESPONSE AMPLITUDE OPERATORS

The idea of RAO comes from studies of ship pitching and heaving motions in irregular seas. RAO is an application of the principal of superposition. Lewis[20] describes the principal of superposition for ships as, "The response of a ship to an irregular sea can be represented by a linear summation of its responses to the components of the sea.". Therefore, a ship's response to monochromatic regular waves, determined by model tests or by calculation, can be used to predict that same ship's response to an irregular sea. Each response to a specific wave frequency is an RAO. If graphically presented over a range of frequencies, RAO's for the frequency range form a response amplitude curve. The response of the ship would be dependent on amplitude and distribution of the sea spectrum.

After determining that RAO had application in boom evaluating, a decision had to be made. Which boom response was going to be measured? How could it be measured in the tank and at sea? What instruments and sensors could be used to make the measurements? The selected response was Wave Conformance. Earlier extensive work by Milgram[2] for the US Coast Guard had a strong influence on selecting heave, pitch and roll as specific components of boom wave conformance. Heave, pitch and roll could be sensed by accelerometers mounted on a boom at the waterline. Voltage outputs from accelerometers could also be recorded and later analyzed by computer. A second response was also selected - skirt depth as measured by pressure transmitters fastened at the lowest point on the boom. The pressure transmitter would provide the investigators with an electronic record of the skirt position with respect to the water surface. A 30.5 m section of fence-type boom was rigged in a catenary configuration in the Ohmsett tank. A pressure sensor was attached at skirt depth at the apex. Above the pressure sensor a pair of accelerometers were attached at the waterline. Data cables attached along the boom at the waterline were used to transmit the electrical signals to meters and recorders on the towing bridge. Responses from the electronic sensors were recorded on a stripchart recorder for immediate data review and on magnetic tape for subsequent computer analysis. Test conditions ranged from calm water to 0.3 m wave heights, wave periods between 1.6 and 8.0 sec., and relative current speeds (Tow Speeds) up to 0.76 m/sec (1.5 kt).

After the data was analyzed, it was determined that signals from the accelerometers could not be segregated into heave, pitch, and roll components. In the case of the fence barrier test, the accelerometers picked up boom vibrations. (Perhaps water drag strumming the submerged boom section.) The task of translating second order differentials into first order spatial distances became too difficult. There were too many degrees of freedom to use accelerometer data. Pressure transmitter signals, on the other hand, were depth measurements, unaffected by directional changes and the resulting values easy to understand. RAO's were therefore determined for Pressure-Defined Boom Depth.[21]

TEST PROTOCOL FOR THE EVALUATION OF OIL-SPILL CONTAINMENT BOOMS

1. SCOPE

1.1 This protocol specifies tests to determine the efficiency of oil spill containment booms in the presence of currents, a variety of wave conditions and when they are subjected to towing. Tests are outlined which include tank studies to determine currents or tow speeds in which boom distortion permits escape of the surface oil. Harbor and open ocean tests are described which measure the dynamic response of the booms to both currents and sea (wind waves) and swell, which may cause them to become unstable and distorted, allowing oil to pass over or under them. The tests are described to provide standardized procedures for any boom system and hence, should provide the following results:

A. An evaluation of a particular boom's attribute in different environmental conditions.

B. The ability to compare test results of a particular boom type with others having undergone these standard tests.

2. SUMMARY OF THE METHOD

2.1 The tests described provide a measure of the following parameters or characteristics in tank tests and open water tests.

A. Towing ability at high speeds in calm water and waves.

B. Towing and relative current speeds at which the boom first loses oil (both in calm water and in various wave conditions).

C. The rate of oil loss once the currents and wave action have exceeded the critical values.

D. The oil loss rate as a function of increasing current and wave conditions.

E. The character of the boom conformance to the surface wave conditions for various wave heights, wavelengths and frequencies. This is done in tank tests during oil loss tests and in open water tests when no oil is used.

F. Boom sea-worthiness relative to its hardware, fastenings and general durability.

Tank tests will examine the dynamics and loading of the booms as a function of tow (and relative current) speeds. Harbor and open ocean tests will examine the effects of currents and wave forces on the stability of the boom and its ability to contain surface oil.

3. SIGNIFICANCE

3.1 The maximum wave and tow speeds (boundary conditions) that any boom can effectively gather and contain oil are determined by fluid mechanisms between the water and floating oil. Booms that cannot maintain draft, flotation and design profile at the boundary condition are ineffective. The boundary conditions depend on the characteristics of oil viscosity, oil/water interfacial tension and oil/water density gradient.

3.2 The purpose of this protocol is to test booms in conditions both within and beyond the boundary conditions. The more severe tests evaluate a boom's mechanical strength and design characteristics. Booms are expected to work within the boundary. Tests are run to confirm this. In order to extend the test boundary, test oils are specified that could be defined as "best case". Testing with worst case oils, or oil that (1) easily sheds (has low interfacial tension); (2) has a long rise time (low density gradient) or (3) sheds from internal viscous pull (high viscosity) would be testing hydrodynamic phenomena between oil and water.

4. APPLICABLE DOCUMENTS

4.1 ASTM Standards:

ASTM F 625 Standard Practice for Describing Environmental Conditions Relevant to Spill Control Systems for Use on Water.

ASTM F 818 Standard Definitions of Terms Relating to Spill Response Barriers.

5. TANK TESTS

5.1 Tests run under controlled and restricted conditions result in data that are used to predict behavior in open water. A test tank where oil can be distributed on water is required to determine the relationship between boom motion and oil capture/containment. The test tank must meet dimensional criteria and specific oil handling apparatus is required.

5.2 Apparatus:

- Wave tank.
- Oil boom, 27 to 35 meters (m) in length.
- Boom towing equipment or water recirculating pumps.
- Tow speed or current meter.
- Wave meter, electronic output.
- Pressure Sensors.
- Multi-channel analog or digital datalogger.
- Video cameras, underwater and surface.
- Test oil.
- Oil Distribution system.
- Oil collection, skimming system.
- Oil recovery tanks.
- Stratified fluid samplers.
- Sample bottles, 250 millimeters (ml).
- Laboratory centrifuge, 980 x G.
- Centrifuge tubes, 100 ml pear shaped.
- Toluene.
- Radio or intercom communication system.
- Anemometer, 10 m above tank.
- Thermometers, for air and water.
- Hydrometers for oil and tank water.

5.2.1 The tank must have the following characteristics:

Length: For test tanks where the barrier is moved through stationary water, the test tank must be long enough to provide a steady state tow condition for the barrier lasting at least three (3) minutes (min.) when towed at 10.2 centimeters/second (cm/sec), [0.2 knots (kt)] greater than the first-gross-loss tow speed. Present state-of-the-art would require a tank 170 m in length. The minimum length requirement for test tanks which circulate the water relative to a fixed barrier to produce an effective tow speed is 125% of the apex to boom-end mooring. For the rest of this test protocol, towing the boom will be equivalent to circulating the water at the prescribed relative velocities.

Width: In order to minimize wall effects, the test tank will be wide enough to provide clearance between the barrier ends and tank walls that equals two and a half times barrier draft when towed in the prescribed catenary (See 5.4).

Depth: In order to minimize bottom effects, the water depth in the tank must be at least four times the barrier draft.

Tow Speed Requirements (Water Circulation Requirements): The test facility shall have the ability to vary the relative velocity between the barrier and the water. The relative velocity shall be variable in at least 5.1 cm/sec (0.1 kt) or less increments. The relative velocity of the barrier will be measurable to a precision of ±2.55 cm/sec (0.05 kt) or better.

Wave Generation: The ability to generate both sinusoidal and harbor chop (random sea) is required. The wave conditions are specified in Section 5.3.

Underwater Observation: There must be provision to observe oil loss occurrences from beneath the boom.

Oil Distribution: In order to distribute oil at the required rate in 5.6.2, the test facility shall have the ability to distribute oil into the barrier at a minimum of 40 m^3/hr. All distributed oil must be floating and encountered by the boom.

5.2.2 Instrumentation: The tow speed or current meter is for the use of the tank operator and need not have electronic output for recording. However, communication between the tank operator and boom observers must be constant. The wave meter must have an electronic output for recording either on a stripchart or digitally for subsequent data manipulation. The wave meter must detect changes as little as 0.5 centimeters (cm) on waves up to 60 cm in height.

5.3 Wave Conditions for tank testing are:

5.3.1 Calm Water: Surface conditions with wind-produced wave heights less than 10% of the barrier freeboard is considered calm water. There will be no mechanically-generated waves.

5.3.2 Breaking Regular Wave (Wave #1): There must be evidence of white caps on the wave crests at some portion of the test tank length. Spectral analysis must show that the wave record is nearly monochromatic. The wave record will be considered monochromatic if there is a concentration of wave energy (90% of the total) over a narrow frequency band between 0.7 and 1.0 Hz.

Apparent Length - The wave will have an apparent wave length of less than 300 cm.

One-third Significant Wave Height - The wave will have a one-third significant wave height of (H 1/3)19 ±8 cm. Various statistical values of visible wave properties are used to describe a wave spectrum. Three values are: (1) the average apparent wave height crest to trough (or average amplitude); (2) the average of the 1/3 highest waves or significant height, and (3) the average of the 1/10 highest waves. The average of the 1/3 highest waves is referred to as the "one third significant wave height" (H1/3).

Apparent Wave Period - This wave will have an apparent wave period of at least 1.0 second and at most 1.5 seconds.

5.3.3 Harbor Chop (Wave #2): The time required to develop a harbor chop in a wave tank is characteristic of the individual tank, as are the relationships between the magnitude and periodicity of the wavemaker and the resultant harbor chop. The waves generated prior to establishing equilibrium are considered part of pretest conditions not to be used for testing.

One-third Significant Wave Height - The one-third significant wave height (H l/3) of the harbor chop will be 45 ±8 cm.

Apparent Wave Period - The wave will have an apparent period of 2.2 ±.2 seconds.

5.3.4 Conduct tests in additional regular waves to model boom behavior in random seas as needed or appropriate.

TABLE 1 - WAVE CONDITIONS FOR BOOM CONFORMANCE MODEL CONSTRUCTION

PERIOD (SEC.)	HEIGHT (CM)
7	15
3.5	32
3.5	50
2.5	15
2.5	30
2.5	45
1.7	20

5.4 Pretest Setup: Barrier Requirements: The barrier under test shall be at least 27 and not more than 35 m long. It will be a full-scale representative section of the barrier. These specified lengths will form catenaries that are close to the shapes of longer booms towed in open water. If a manufacturer cannot make sections as short, that boom would be considered for open water testing only. The barrier will be tested using the manufacturer's towing assembly when possible.

Set-Up: Rig the boom in a catenary configuration, with the gap equal to 67% of the length. The boom will be attached to the towing assembly with tethers on both ends of the barrier. The tether will be at least 150 cm and at most 500 cm long. The oil distribution system will be placed so that all the oil will enter the gap. The pressure transmitters and load cell should also be installed if performance in the offshore is going to be modeled. See Figures 1 and 2.

5.5 Test: Record the ambient conditions before and during testing. These include air and water temperature (as measured with a thermometer, thermistor, or thermocouple), wind speed and direction relative to the test tank and direction of tow (as measured with a wind vane and anemometer). Since wind acts on the boom freeboard, it is recommended that tests not be run if wind speed is greater than 10 m/sec (20 kt), 10 m above the tank surface. The wind speed limitation is included here to maintain consistent environmental conditions for all tests. Wind is not a controllable factor like waves and tow speed are at Ohmsett.

5.5.1 Calm-water Critical Tow Speed: Tow the barrier in calm water at 25.5 cm/sec (0.5 kt) without oil present. After the barrier has formed a catenary, increase the tow speed in 10.2 cm/sec (0.2 kt) increments until the barrier either loses all freeboard (submarines), loses all draft (planes), mechanically fails, or the maximum safe tow speed of the test tank has been reached. Record this speed as the critical tow speed along with the method of failure. Report the critical tow speed as "greater than" in the event of the barrier not reaching the critical tow speed prior to reaching the maximum safe tow speed of the test tank. Maximum safe tow speed for the tank is based on safety and mechanical strength. Tow cables and the structures they are connected to have specified working load strengths. The speed at which the towing resistance of the device equals the working load strength is the maximum safe tow speed. In general, tow force is proportional to tow speed squared if the device maintains a constant profile in the water.

Although this test may cause damage, it is short in duration compared to a spill response. In contrast to the rough handling, rapid towing and significantly greater waves likely to occur offshore, any tests in the tank are mild. It is better to know the boom is mechanically deficient prior to wasting resources and producing waste oil by running tests.

5.5.2 Oil Loss Speed Tests: Tow the barrier at 12.75 cm/sec (0.25 kt) while preloading it with 0.38m^3 of test oil. After the oil preload has been distributed and has stabilized at the apex of the barrier, increase the tow speed in 5.1 cm/sec (0.1 kt) increments. Record as first loss tow speed the speed at which droplets of oil first begin to escape under the barrier. See Figure 3.

Continue to increase the tow speed in 5.1 cm/sec. (0.1 kt) increments until the oil escapes under the barrier in streams. Record as the first-gross-loss tow speed the speed that the streaming loss is first witnessed. Repeat these two oil loss speed tests for Wave #1 (breaking regular wave, 5.3.2) and Wave #2 (harbor chop, 5.3.3) surface conditions.

5.5.3 Wave Conformance Tests: Wave conformance tests will provide data to correlate boom motion and oil loss. Using the principal of superposition through the mathematical approach in Appendix A, boom motion in open water can be modeled. Subsequent verification of the model in open water testing will allow predictions of oil handling capability.

With the instruments setup as in Figures 1 and 2, measure and record the pressure-defined depth of the boom skirt for the maximum time permitted by the tank length and first loss tow speed. In order to maximize the time, the conformance test should follow the first loss tow speed test using the full length of the tank at the first loss speed. See Figure 2.

5.5.4 If a boom performance model is required, select other wave conditions from Table 1 to determine first loss tow speeds.

5.6 Oil-Loss-Rate Test: This test is conducted to quantify the loss rate in calm water.

5.6.1 Test Oil: Use heavy oil as defined in Table 2. The oil will be sampled each time there is an addition to the oil supply. The oil sample will be taken from the bottom of the container holding the oil supply. As a minimum, the oil will be sampled daily and analyzed for surface tension, specific gravity

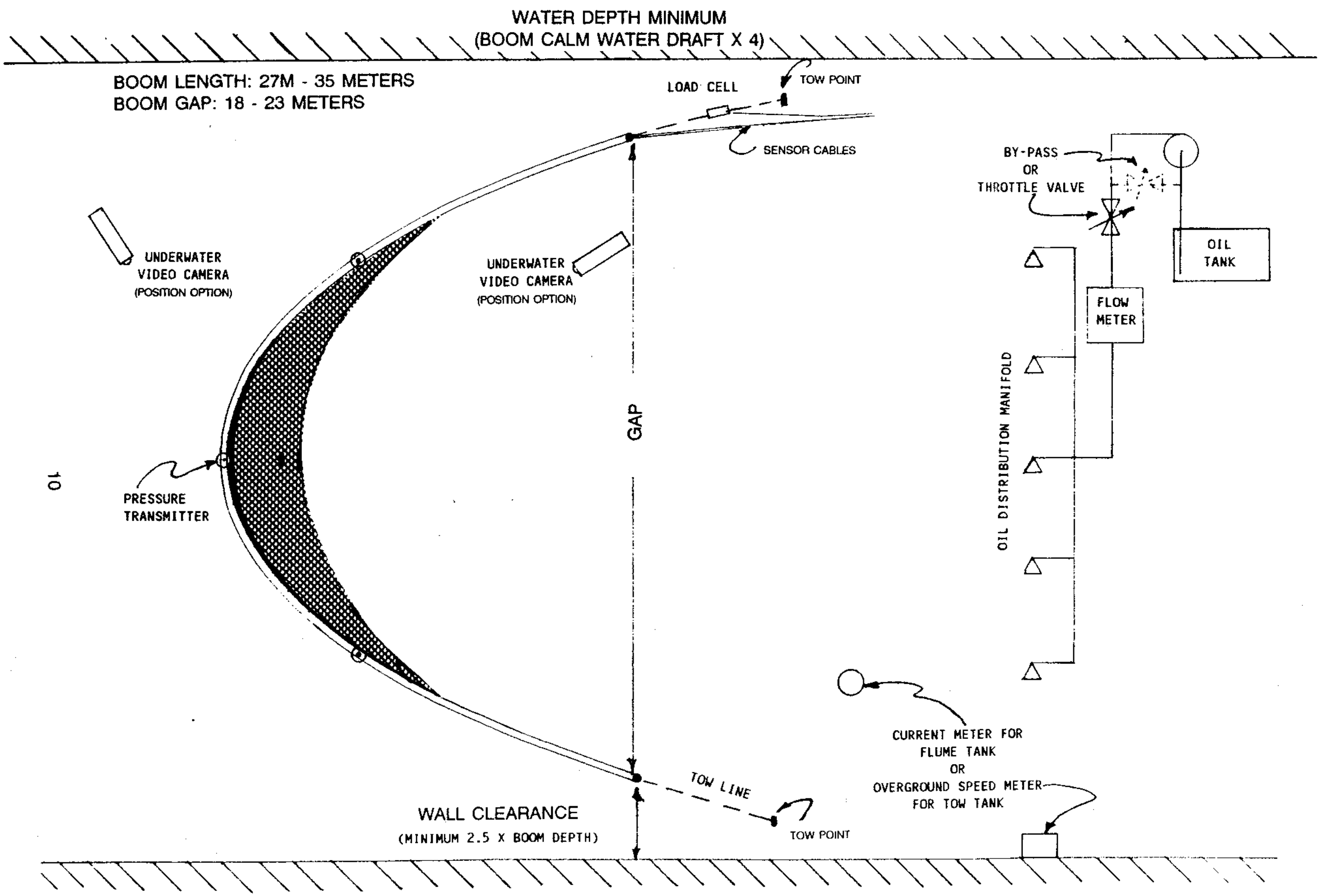

FIGURE 1 - Tank Test setup for a boom evaluation.

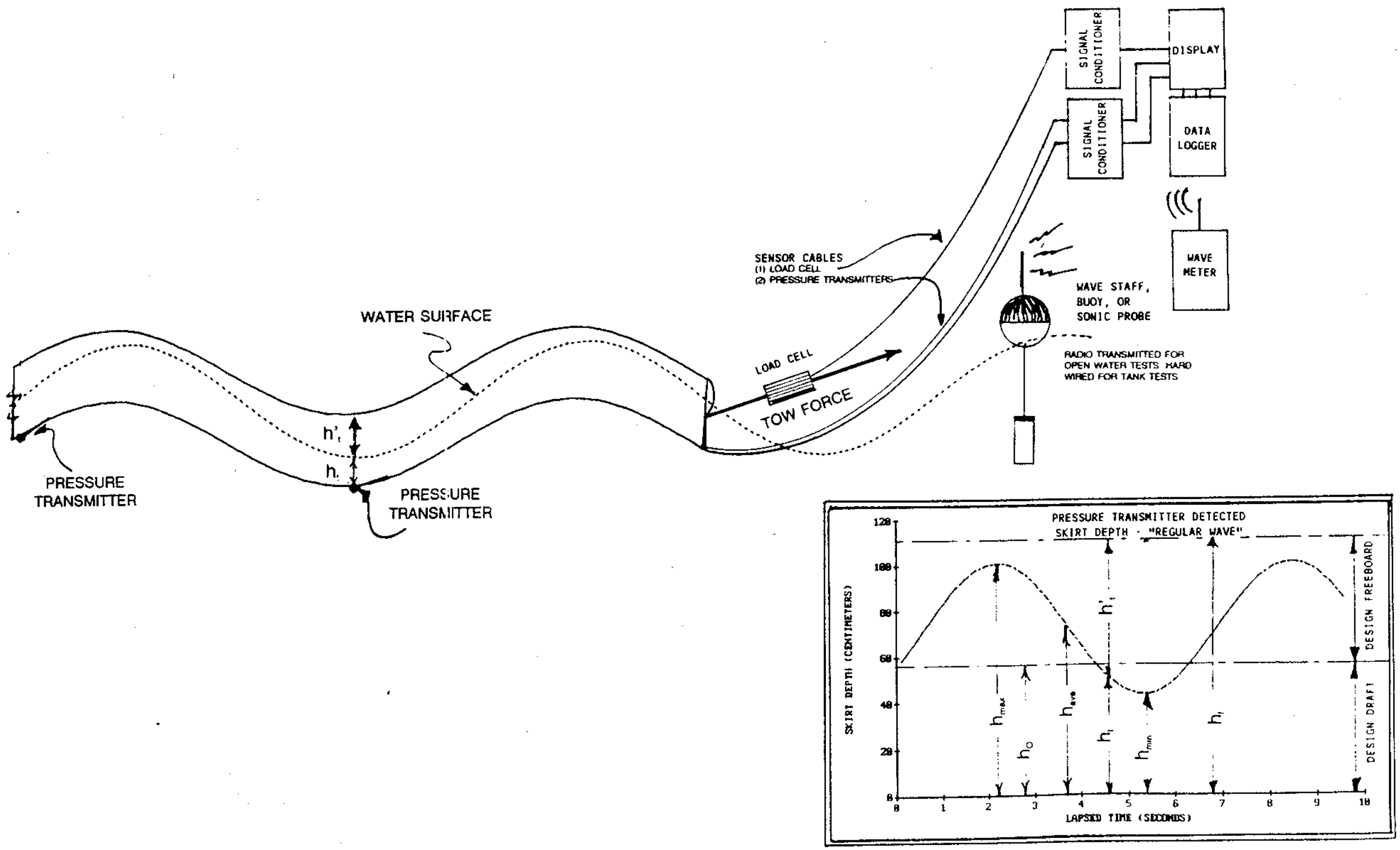

FIGURE 2 - Instrument locations for Tank Tests and Towed Open Water Tests.

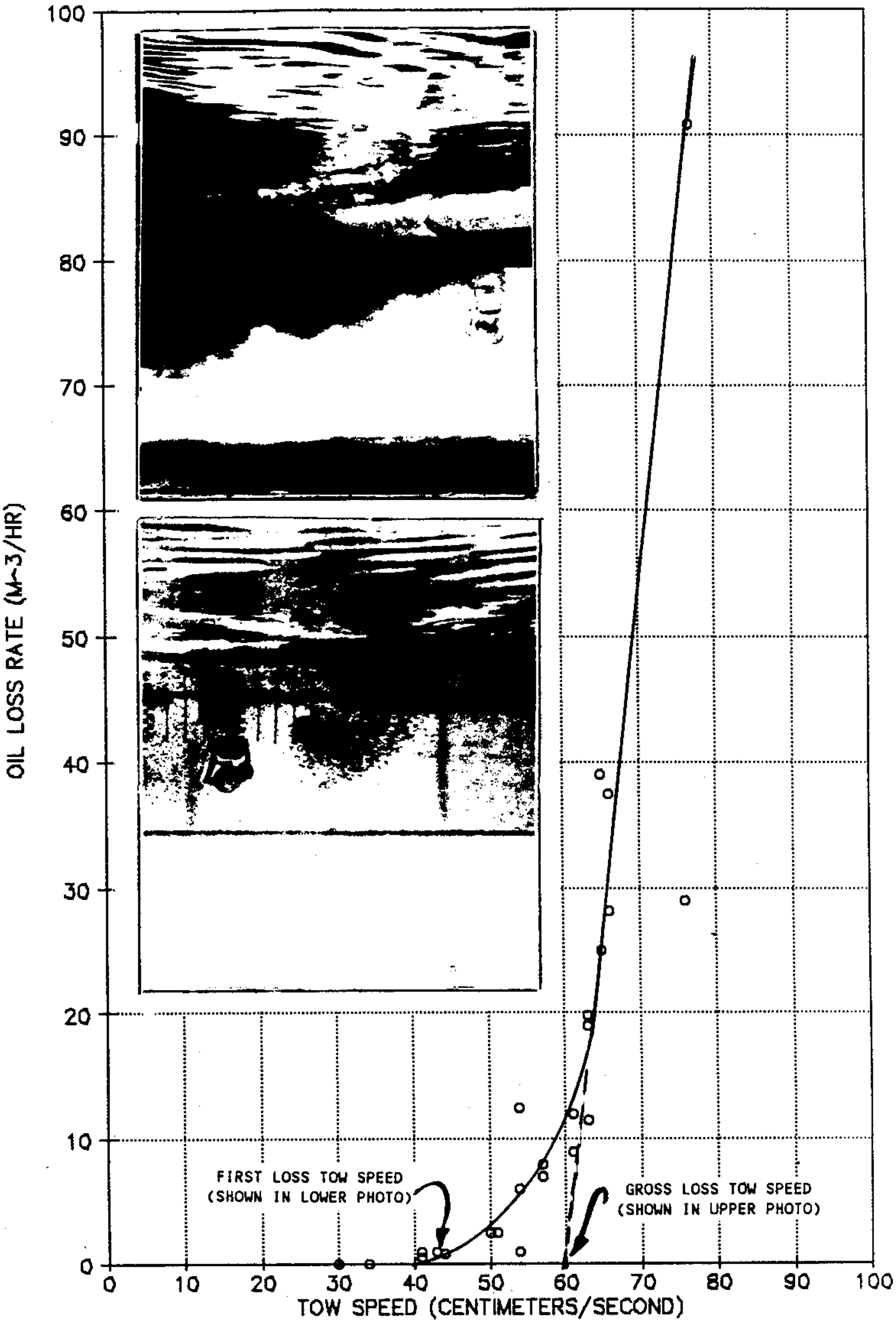

FIGURE 3 - Boom Oil Loss during Tank Tests showing First Loss and Gross Loss.

TABLE 2 - TEST FLUID'S SPECIFICATIONS

	FLUID		
SPECIFICATION	TANK WATER	LIGHT OIL	HEAVY OIL
SALINITY (PARTS PER THOUSAND)	5-35		
SPECIFIC GRAVITY	1.003-1.28	0.88-0.93	0.90-0.95
SURFACE TENSION (DYNES/CM)@20°		>20	>20
O/W INTERFACIAL TENSION (DYNES/CM)		>18	>18
VISCOSITY - cSt @ WATER TEST TEMP.		10-50	700-1000
BOTTOM SOLIDS & WATER (%BY COL)		<1%	<1%

and water bottom solids in water. See Methods section. The results of each analysis as presented in Table 2 will be reported. Repeating measurements of the oil viscosity at the tank water temperature is tedious and expensive. Determination of the oil viscosity at an elevated and depressed temperature relative to the expected range of tank water temperatures can save time and unnecessary expense. A composite sample of the water in the test tank will be taken at the start of the testing and at the completion of the testing for analysis of these properties. Average results will be reported.

The composite sample is made up of three discrete samples taken at one-foot depths along the centerline of the test tank. The three locations along the centerline are at 20%, 50% and 80% of the tank length.

5.6.2 Test Procedures: The goal of this test is to measure a steady-state oil-loss-rate. The steady state requires maintaining the quantity of oil in the preload even as the oil is being lost. Anticipated loss rates based on historical data with 30 m lengths of test boom are presented in Table 3. This information should be used as a guide; adjustments can be made during testing.

Oil Preloading: Tow the barrier at 10.2 cm/sec (0.2 kt) less than the first-loss tow speed as determined in 5.5.2 while distributing a preload of 0.19 ±0.02m^3 of oil.

After preloading the barrier, distribute oil at the rate determined from Table 3. Increase the tow speed from the preloading speed to the designated tow speed when the newly distributed slick first reached the preload. Continue the test for 3 min. of steady state operation then stop distributing oil. Tow at the preloading speed until the last of the newly distributed oil reaches the preload. Carefully use fire hose streams to push the oil lost behind the boom away to be recovered. At the same time, keep the captured oil in the boom area.

5.6.3 Optional Oil-Loss-Rate Determination: Collect all the oil contained by the boom. This requires capturing, containing, and skimming the lost oil. Free water from the skimming activity should be separated from the oil and water emulsion by gravity in a calibrated recovery tank, after draining the free water, and measuring the depth of the remaining fluid, the remaining oil/water mixture is then sampled using a stratified sample thief. See Methods: Oil Sampling From Recovery Tank. Using Method: Water and Sediment in Petroleum - Centrifuge (Bottom Solids in Water), determine the quantity of water (%OIL) from the total stratified sample, then calculate the quantity of oil lost.

$$Q = Q_T - Q_R(\%OIL)$$

where:

Q is the volume of oil lost by the booms,
Q_T is the total oil distributed and
Q_R is the volume of fluid in the recovery tank.
The quantity of oil lost by the barrier is divided by the steady state time period to determine the oil loss rate at the tow speed.

Test Unacceptable: An individual test is unacceptable if it shows a difference between oil-loss-rate determined, and oil distribution rate of more than the greater of 0.5 m^3/hr or 5% of the oil distribution rate.

Tow Speeds: Determine oil loss rates at four tow speeds that span 20.4 cm/sec (0.4 kt) above the first loss tow speed. Figure 3 is a graphical presentation of an oil-loss-rate test.

There is evidence that a relationship between oil loss ratios and boom design does not exist beyond first loss tow speed.

5.7 Indicative Wave Stress (Endurance) Test: Tow the barrier into a harbor chop that has a one-third significant wave height (1/3 = 45 cm) and a 2.5 to 4 sec. period at 25.5 cm/sec (0.5 kt) until the end of the test tank is encountered. Hold the barrier for 10 min., then tow it to the opposite end of the tank, hold stationary for 10 more minutes. Repeat this process for 40 min. of exposure.

During the test, record the booms

TABLE 3 - TEST OIL DISTRIBUTION RATE EQUALS APPROXIMATE LOSS RATE

SPEED	APPROXIMATE LOSS RATE
First loss speed	1.1 m^3/hr
First loss + 5.1 cm/sec. (0.1 kt)	6 m^3/hr
First loss + 10.2 cm/sec. (0.2 kt)	12 m^3/hr
First loss + 15.3 cm/sec. (0.3 kt)	24 m^3/hr
First loss + 20.4 cm/sec. (0.4 kt)	40 m^3/hr

motion on videotape identifying points of stress. Points to look for include twisting, abrupt tugging or pounding between two elements of the boom, submerging under crests, bridging over troughs, internal floatation members pushing against the outer fabric and other nonfunctional, fatigue- producing behavior. Thoroughly examine the boom after it is removed from the test tank and take photos for documentation.

6. OPEN WATER TEST OF BOOMS

6.1 Scope: This test measures the variation in immersion of an oil spill boom skirt in waves. Measurements are made at three or more points along the boom. These tests are intended for booms that would be used in open water (harbor and offshore booms), and provide data that can be used to predict boom failure without spilling oil.

6.2 Summary of the Method: By either mooring or towing a boom in a catenary configuration on a natural sea surface, the depth of the boom skirt will remain constant as long as the boom is conforming to the waves. When the boom is not conforming to the waves, the depth of the skirt will vary in time at any given location along the boom. This is a functional definition of wave conformance. The definition does not fully describe the relationship between the skirt motion and the motion of the boom as a whole. The definition is as adequate as the instrumentation is in confirming or disproving wave conformance. The forces on the skirt are both horizontal and vertical and forces from either direction can affect the depth. In waves and a relative current speed the boom will decrease in wave conformance as either or both the relative current speed and wave encounter frequency increases. In open ocean tow tests conducted recently on two booms of different size but identical (proportionately) design profiles, the smaller boom showed little difference in behavior being towed into the waves (thereby increasing encounter frequency) or with the waves (thereby decreasing encounter frequency.) The larger boom with deeper draft exhibited better wave conformance being towed with the waves. Fourier analysis of the measurements included responses of one of the towing vessels. It was found that measured skirt depth changes were occurring at frequencies characteristic of the tow vessel response. Data from a moored test arrangement would be expected not to contain component responses at low frequencies.

Mounting electronic pressure sensors at selected locations permits analog or digital recording of a time-based, pressure-defined, skirt depth. The data analysis determines the minimum, average and maximum immersion.

During an open water test, the wave conditions are measured using conventional time-based methods. The time-based wave height measurements are then transformed to a frequency-height relationship by Fast Fourier Transform (FFT) as shown in Figure 4.

6.3 Significance: Data from this open water test can be used to calculate three derived quantities, explained below, called the immersion ratios. These ratios will decrease from 1.0 in calm water to 0.0 in some sea conditions. At 0.0 a boom will not hold oil. At present, there is insufficient data to establish functional relationship between the motion of a boom in waves and oil holding ability. A functional relationship between wave conformance as measured by the depth of a boom skirt and oil holding capability is not presently defined mathematically and cannot be universally applied. Differences in wave conformance have been measured and confirmed by visual observation, however, only one boom has had simultaneous oil loss tests and wave conformance test to generate comparison data. During the development of this protocol, an Albany Oil Fence (now, GLOBE Oil Fence) was used in trials that involved both types of measurements.

What has been shown is that ratios between 1.0 and 0.9 produce little loss in oil holding ability due to waves. Loss of oil holding ability due to waves is significant when corresponding ratios are less than 0.1.

6.4 Site Selection: The wind driven waves desired in the sea surface spectra during open water testing covers the range from 10

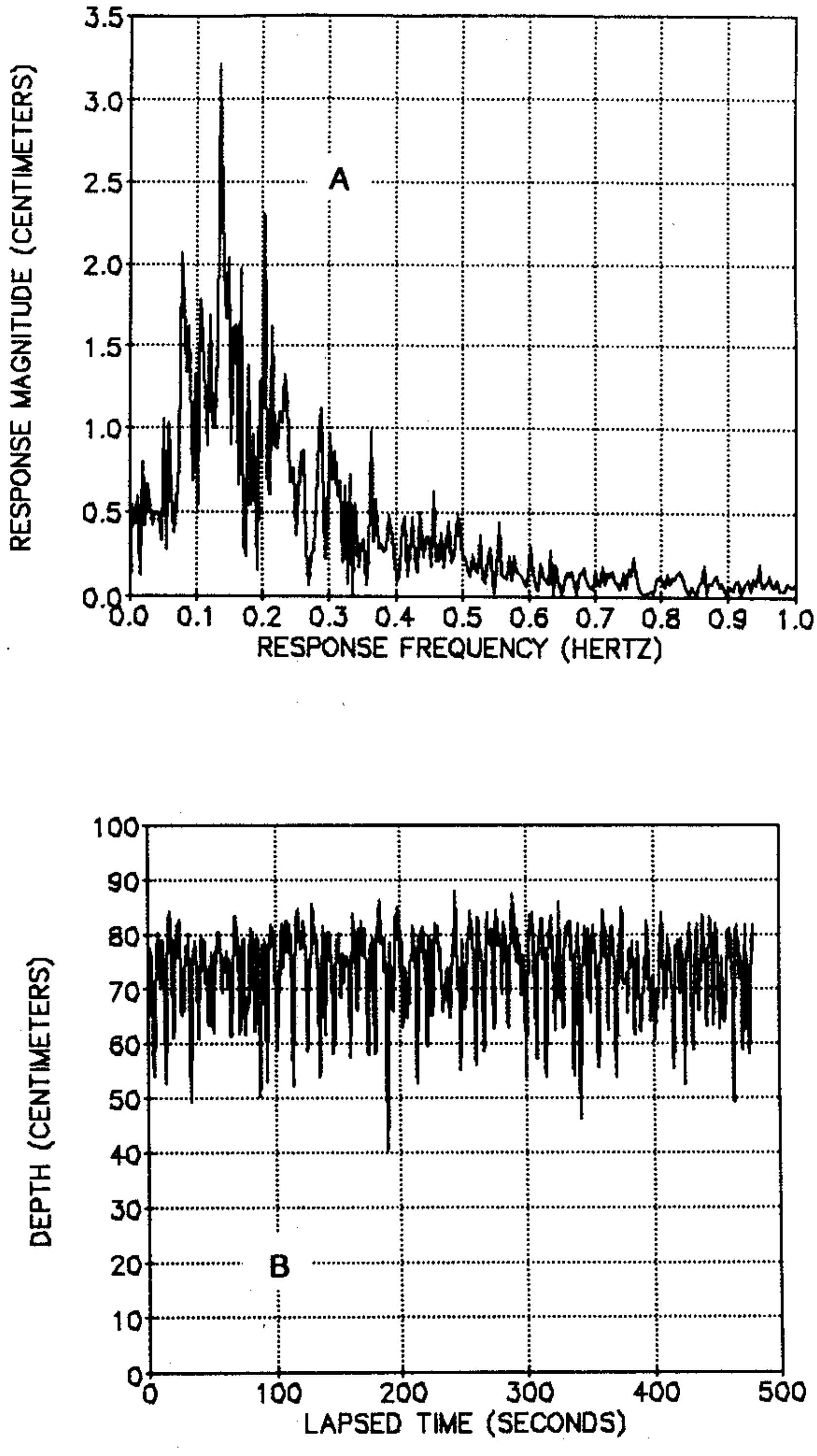

FIGURE 4 - A booms relative motion to water surface: (A) Frequency Based, (B) Time Based.

second waves at 300 cm to 3.5 second waves at 180 cm. A primary consideration in the open-water testing is the selection of a region of open water that has a good probability of providing the designated sea spectrum. The site must be clear of heavily-traveled channels, be approved by the Captain of the Port, and not be part of a military test or exclusion zone. In terms of wind conditions to achieve this sea surface, the site must provide a 315 kilometer fetch for a 1.275 m/sec. (25 kt) wind blowing for 16 hours. The length of the fetch that the wind blows is part of the requirement to be considered a fully-developed sea. A 315-kilometer fetch is considered the required length beyond which a 25-knot wind will not produce any increase in wave energy. This requirement in practice is not going to be necessarily fulfilled. Using a boom response model to calculate performance may have to suffice if weather or geographical conditions are not conducive.

6.5 Test Apparatus, Open Water Testing: The test instrumentation consists of the following:

- At least 122 m of boom.
- At least two (2) submersible ±5 psig (±34 kPa) pressure sensors.
- A submersible 2,270 - 4,500 kg load cell.
- Data cable and/or telemetry system to a recording system.
- Anemometer and wind direction indicator.
- Multi-channel analog or digital recorder/datalogger to record signals from 2 and 3 above.
- Wave staff or Wave Rider(R) with required auxiliary equipment to measure the sea surface between .1 meter, 0.5 second waves to 4.5 meter 10 second waves. The wave data must be sufficient to calculate a wave amplitude-frequency spectrum.
- Two 3,900 kg sinkers or two tow vessels that can pull the boom and maintain way.
- Stationary tests will need (2) 450 kg net buoyancy mooring buoys; 7/16 in 7 x 16 IWRC steel cable for a 4.5:1 scope; (2) 55 kg net buoyancy floats.
- Video and still cameras.
- Two (2) rigid hull inflatable boats to help in the rigging.
- A large deployment vessel such as an oil field work boat, 26 to 38 meters.

6.6 Preparation of the Apparatus/ Calibration: Before mounting any of the instruments of the boom, perform a calibration of the entire measurement system. The pressure sensors and load cell(s) should have response and output signals that equal the characteristics listed in Table 4.

Calibrate the load cell. Use either the manufacturer or a reliable test and evaluation laboratory.

The pressure sensors can be calibrated in a static column of water. Measure the density of the water to 0.005 grams/cm^3. Using the data recording system, record pressure readings at zero immersion, half boom draft, boom draft, and full boom immersion depths. Record these depths with the corresponding pressure reading. Determine the calibration factor. During the testing, the calibration factor (K_T) for pressure reading to boom immersion is calculated using the density of the water at the test temperature.

$$K_T = \frac{\text{Kc x density of Calibration Water}}{\text{density of test water}}$$

Once calibrated, mount the pressure sensors and connecting data cables. The sensor should be less than 2.5 cm from the bottom of the solid section. Take pressure measurements at, as a minimum, two positions on the boom. One of the positions must be at or near the apex of the boom. Mark the boom at each data station so that the position of the station along the boom length will be obvious in the visual record. The data cables should be mounted so as not to restrict normal boom motion. Once the pressure sensors and cables are attached to the boom, carefully pack the boom for shipment to the test location for deployment.

For stationary testing, moor the barrier from its end connectors so that the barrier gap equals 67% of the barrier length when the barrier is at the ideal orientation (waves directly

TABLE 4 - BOOM INSTRUMENT CHARACTERISTICS

	MEASUREMENT RANGE	OUTPUT	98% RESPONSE AT
Pressure Sensor	0-Full Boom Depth	4-20 ma*	4 Hz
Load Cell	0-10,000 lbs.	0-10 VDC	2 Hz
DATA RECORDING			
Computer	20-90% of 0-2046 BCD's**		
Stripchart (Multi Range)	20-90% of a 4" Chart		4 Hz

* A low impedance loop is highly recommended for the long cable lengths associated with the pressure sensors. Conversion to a voltage signal using precision resistors at the recording unit. A 62.5 OHM resistor would result in a 0.25-1.25 VDC output.

** BCD's are "binary code decimals" and represent the resolution of the measuring system, i.e. 2046 BCD's means resolution is 1/2046 of the range of the sensor.

into the mouth of the catenary). See Figure 5.

The mooring system consists of 3,900 kg conçrete sinkers and 450 kg net buoyancy mooring buoys joined with 7/16 in. diameter 7 x 16 IWRC steel cable at 4.5:1 scope. The barrier is joined to the mooring buoy with 9 m of the same cable supported at the midpoint with 55 kg net buoyancy floats. The sinkers are positioned using triangulation from three geodetically fixed points on shore. The sinkers are oriented so that a line joining the sinker is perpendicular to the direction of the anticipated predominant wind direction. Setting up a mooring configuration to test booms has some drawbacks compared to towing the booms. The sinkers must be placed to anticipate wave directions (both sea and swell), water current directions (tidal, longshore or wind driven) and dominant wind direction. Of course, wind direction and sea will be the same. If water currents are significantly counter to anticipated wind, the test site may need to be reconsidered. The principal advantage that mooring has over towing is cost. Booms can be moored over extended periods of time thereby limiting labor and vessel costs to deployment and retrieval. Adding to the cost, however, is the requirement for a more durable data collection system that can be remotely operated.

The water depth is a minimum of 12 m. See Figure 5.

Information on the water depth at specific locations can be found on NOAA nautical charts. Tide tables are published with sunrise/sunset data by the Department of Commerce. Near-Shore current tables are available, published by NOAA. Climatological studies are available from Sea Grant institutions in the area. Local fishermen can provide general information as to weather conditions in various months. Many government agencies routinely record weather conditions on a periodic basis (airports, harbor masters, U.S. Coast Guard, U.S. Navy, are a few). When choosing a site, it is wise to remember that wave size is dependent on fetch (the distance over water to nearest land mass) and to a lesser degree water depth. A stationary configuration allows a reasonably long test duration at low expense. However, there is no control over the catenary alignment with respect to the wind direction.

An alternative is to conduct a tow test. The expense for the tow vessels generally prohibits long duration tests and, therefore, the desired sea spectrum is less likely to occur. If tow tests are desired, the boom configuration would be the same as for stationary tests. Boats would replace the mooring apparatus, and the electronic data acquisition should be done on board one of the boats. See Figures 6 and 7.

6.7 Wave Conformance Test: This test determines an immersion to draft ratio for a boom in the sea spectra existing during the test. The ratio of how the boom maintains its calm water draft in waves is the measure of wave conformance. This behavior is affected by the sea state, wind blowing on the freeboard, surface currents, boom orientation and boom tension. Data outputs from instruments on the boom are: Pressure (that defines the booms immersion), and boom tension. Boom orientation can be measured with an electronic compass. The sea surface (wave spectra) is measured by either a Wave Rider Buoy (R) or wave staff capable of measuring 10 cm waves at 0.4 to 1.0 second periods up to 450 cm waves at 10 second periods. Wind speed and direction are measured at the test site during the test. Water surface current speed and direction are measured using a cross T float and stop watch. A cross T float is two 2 X 4's, each 61 cm long, mortised at their centers and joined to form a 61 cm x 61 cm tee. In the case of a tow test, a current meter attached to the towing assembly is recommended.

6.7.1 Data Recording: There are two data recording methods. The most useful method is to use electronic sensors to measure all the parameters and digitally log all the information for subsequent computer manipulation. Make digital records four times per second for waves and boom immersion. Wave measurements must be recorded this way to permit a spectral analysis of the

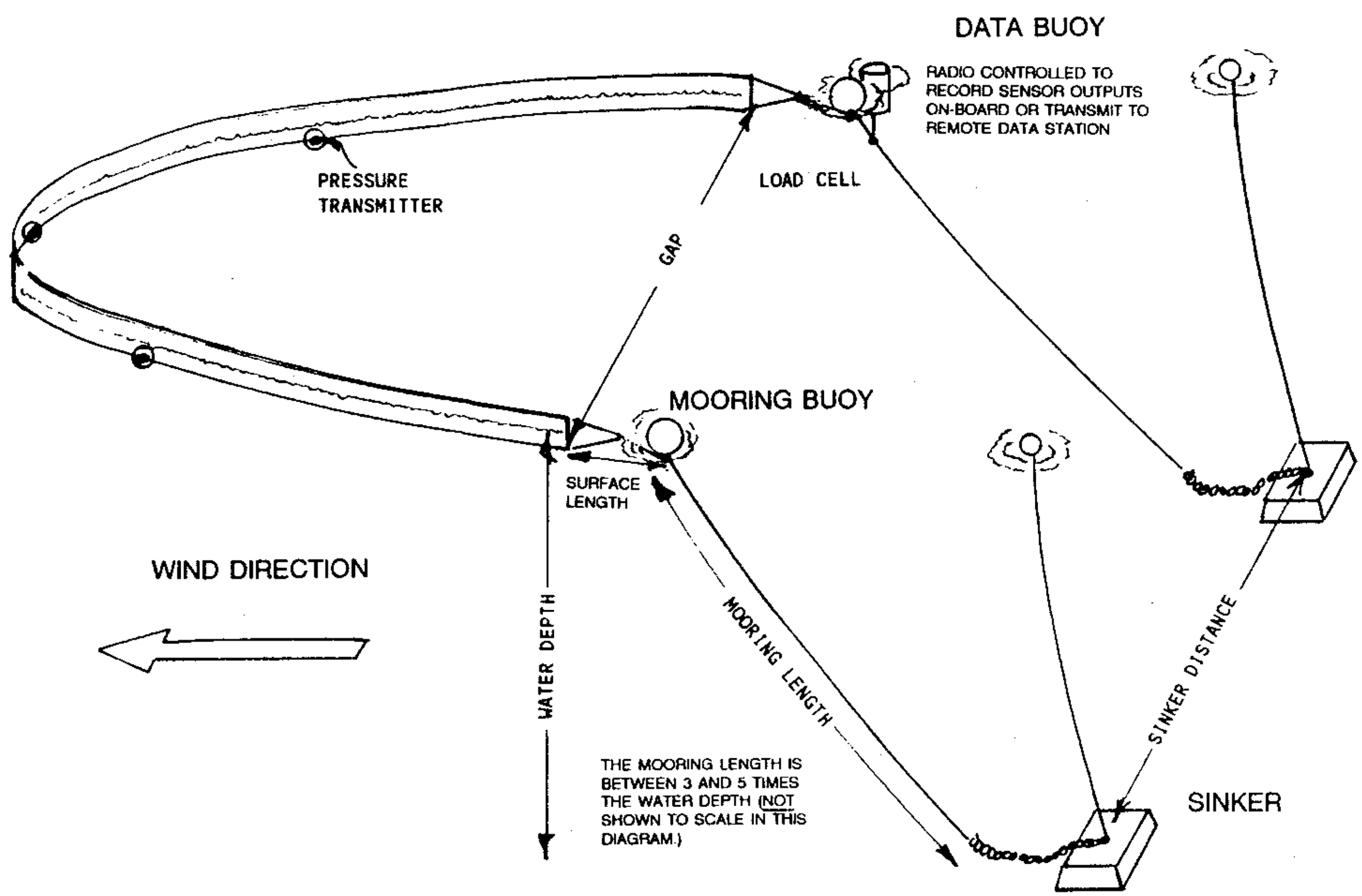

FIGURE 5 - Open water stationary test, boom mooring and instrument location.

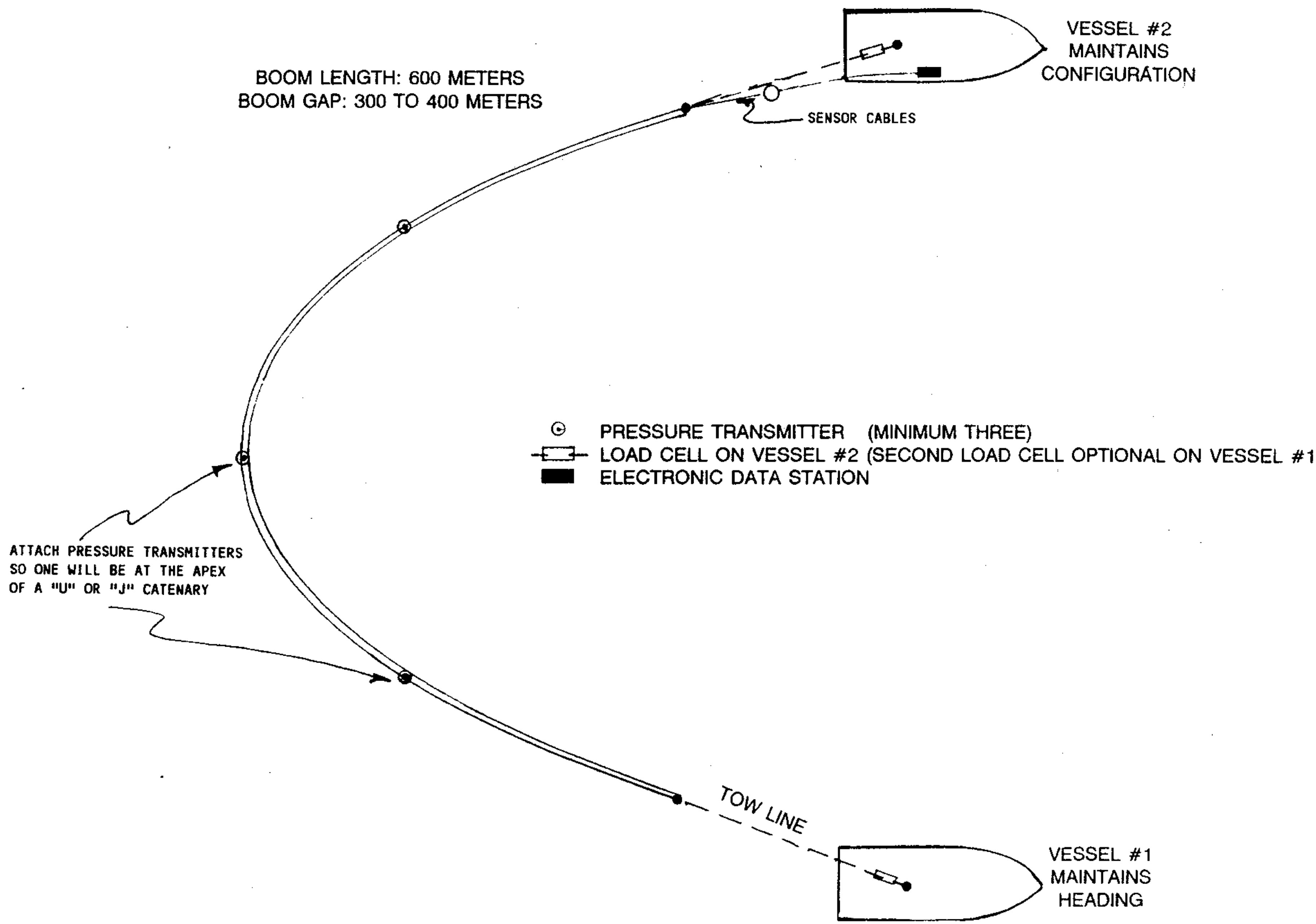

FIGURE 6 - Open water towed test, U-catenary configuration and instrument location.

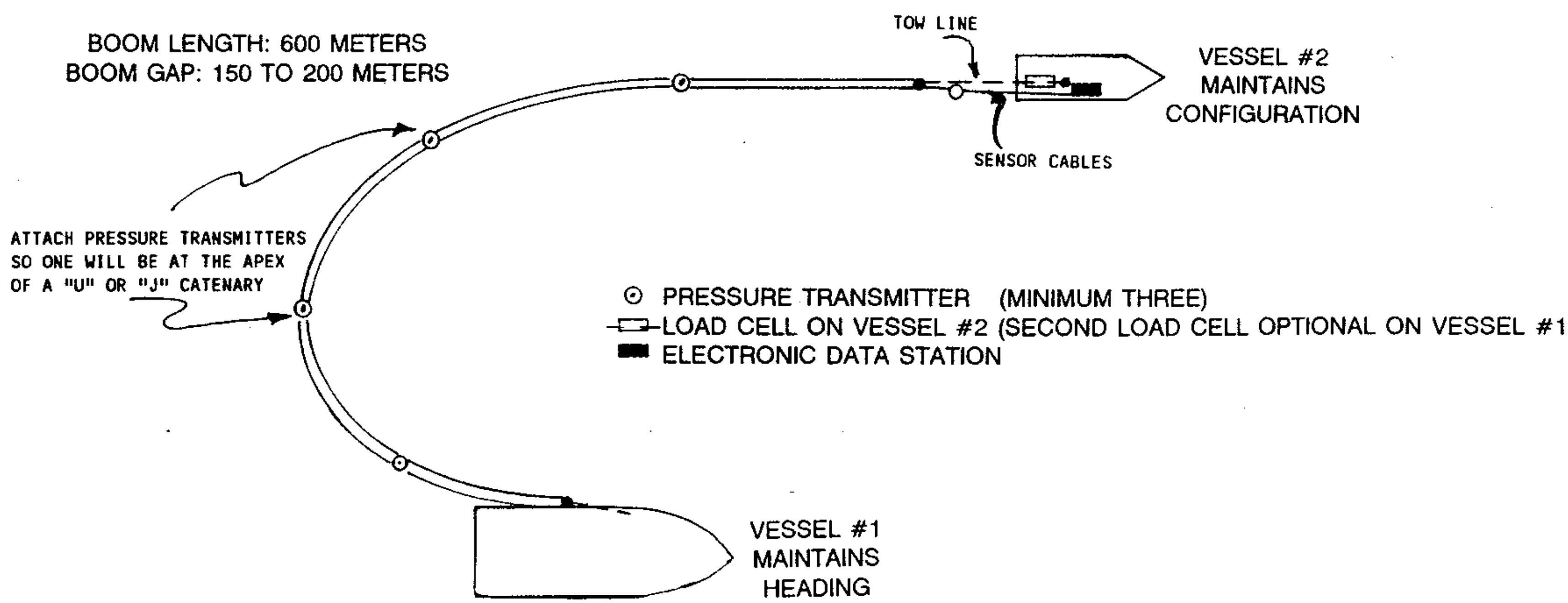

FIGURE 7 - Open water towed test, J-catenary configuration and instrument location.

polychromatic sea surface. Optionally, the dynamic boom measurements (pressure and tension) can be recorded on a stripchart. Spectral analysis becomes more difficult with data recorded this way but the booms immersion or lack of immersion in the sea state is immediately obvious. See Methods: Determining a Response Amplitude Operator and Creating a Sea Spectra Boom Response Model from Tank Test Measurements. Record wind speed and direction (3 m above the water surface) and boom orientation at the beginning, middle and end of each test period. Two tests (duplicate runs) are run sequentially with no more than two minutes between runs.

Digitally logged data requires 2,048 data points for each parameter. This represents an 8.5 minute test. Duplicate tests will be run within a 19-minute time period. Videotape the barrier during data logging. The BASIC program PROTOCOL.BAS (See Appendix A, page A-28) requires 1024 data points for each transform. In order to calculate a duplicate transform, 2048 data points are required.

6.8 Durability Test: The boom's durability is an empirical assessment of the boom's condition before, during and after two weeks or more of open water tests. Take photographs before, during and after the test. Also record evaluations made by on-scene observers paying particular attention to twisting, abrupt tugging or pounding between two elements of the boom, submerging under crests, bridging over troughs, internal floatation members pushing against the outer fabric and obvious wear. The durability data includes wave records, current or towing speeds and impact from debris or vessels.

7. Calculations

7.1 Oil Loss Rate: The oil loss rate (Q) is calculated from the percent oil value (%O) of the stratified samples, the total volume of fluid recovered (Q_T) the total oil spilled (Q_S) and the elapsed time during the steady state oil loss (T). T is in minutes and Q is in gallons or other consistent units.

$$Q = \frac{(Q_s - Q_T \times \%0)}{T}$$

7.2 Calculate the response amplitude operator over the frequency range of waves in tank testing and open testing. See Methods: Determining a Response Amplitude Operator and Creating a Sea Spectrum Boom Response Model from Tank Test Measurements.

7.3 Determining the Boom Wave Conformance. See Methods: Determining a Response Amplitude Operator and Creating a Sea Spectra Boom Response Model from Tank Test Measurements.

7.4 Maximum freeboard immersion to freeboard ration (f/F)

$$\frac{P_f - P_{max}}{P_f - P_o} = \frac{h_f - h_{max}}{h_f - h_o}$$

Where:

P_f = the pressure measured when the boom is submerged to the depth h_f,

P_{max} = the maximum pressure measured during the test run,

P_o = the pressure measured when the boom is at rest in calm water,

h_f = the full height of the boom (draft plus freeboard) and is equivalent to P_f divided by the water density,

h_{max} = the maximum immersion depth that occurs during the test. It is equivalent to P_{max} divided the water density, and

h_o = depth of boom at rest in calm water and is equivalent to P_o divided by water density.

Refer to Figure 4. The frequency of maximum freeboard immersion is counted for P or h within 5% of P_{max} or h_{max}. The depth profile from the Protocol Basic summary output lists h_{max}.

7.5 Average Draft Difference Ratio:

The difference between the boom's calm

water rest draft (P_o or h_o) and the average posture of the boom during the open water test (P_{ave} or H_{ave}) is calculated as a ratio

$$\frac{P_o - P_{ave}}{P_o} = \frac{h_o - h_{ave}}{h_o}$$

Where:
P_{ave} = the average pressure measured during the test run, and
h_{ave} = the average immersion depth that occurs during the test.

The depth profile from the Protocol Basic summary output lists h_{ave}.

8. Report

8.1 Tank Tests: Wave tank test description.

Test date(s)
Test fluid data as in Table 2 for each required sample

Salinity
Specific gravity
Surface tension
Viscosity
Bottom solids and water

Boom Description

Manufacturer
Model #
Length
Draft
Freeboard
Fence or curtain type boom
Net buoyancy

Critical tow speeds
First loss tow speeds
Gross loss tow speeds
Oil loss rate (graph, speed vs rate)
Frequency-based wave data graphs
Time-based wave data graphs, one-third (1/3) significant wave height and wave period printed on the graph
Test on the wave stress test.

Boom Description

Manufacturer
Length
Draft
Freeboard
Fence or curtain type
Net buoyancy

Test Location

Mooring or towing configuration
Test date(s)
Wave data plots

Time-based wave height graph
Frequency-based wave height graph
Energy spectra graph

Environmental Conditions

Wind speed, direction and duration
Current velocity or tow speed
Water and air temperature
Water density

Immersion Ratios

Minimum immersion to draft ratio and frequency of occurrence
Maximum freeboard, immersion to freeboard ratio and frequency of occurrence
Wave conformance ratio

Test with photos to document the durability of the boom.

Figures 8, 9 and 10 show data that was collected during offshore boom evaluations. Figure 8 shows depth measurements over a 500 second test period. The tracing on the left was obtained from a pressure transmitter mounted on the arm of a boom in a U catenary configuration. The tracing on the right was obtained from a pressure transmitter mounted at the boom's apex. The effect of tow speed on the towing force and the resulting effect on boom depth measurements are shown in Figure 9. An increase in tow force brought about by an increase in tow speed can be clearly seen at 200 seconds into the test; the tracing of the depth measurements show how the skirt at the

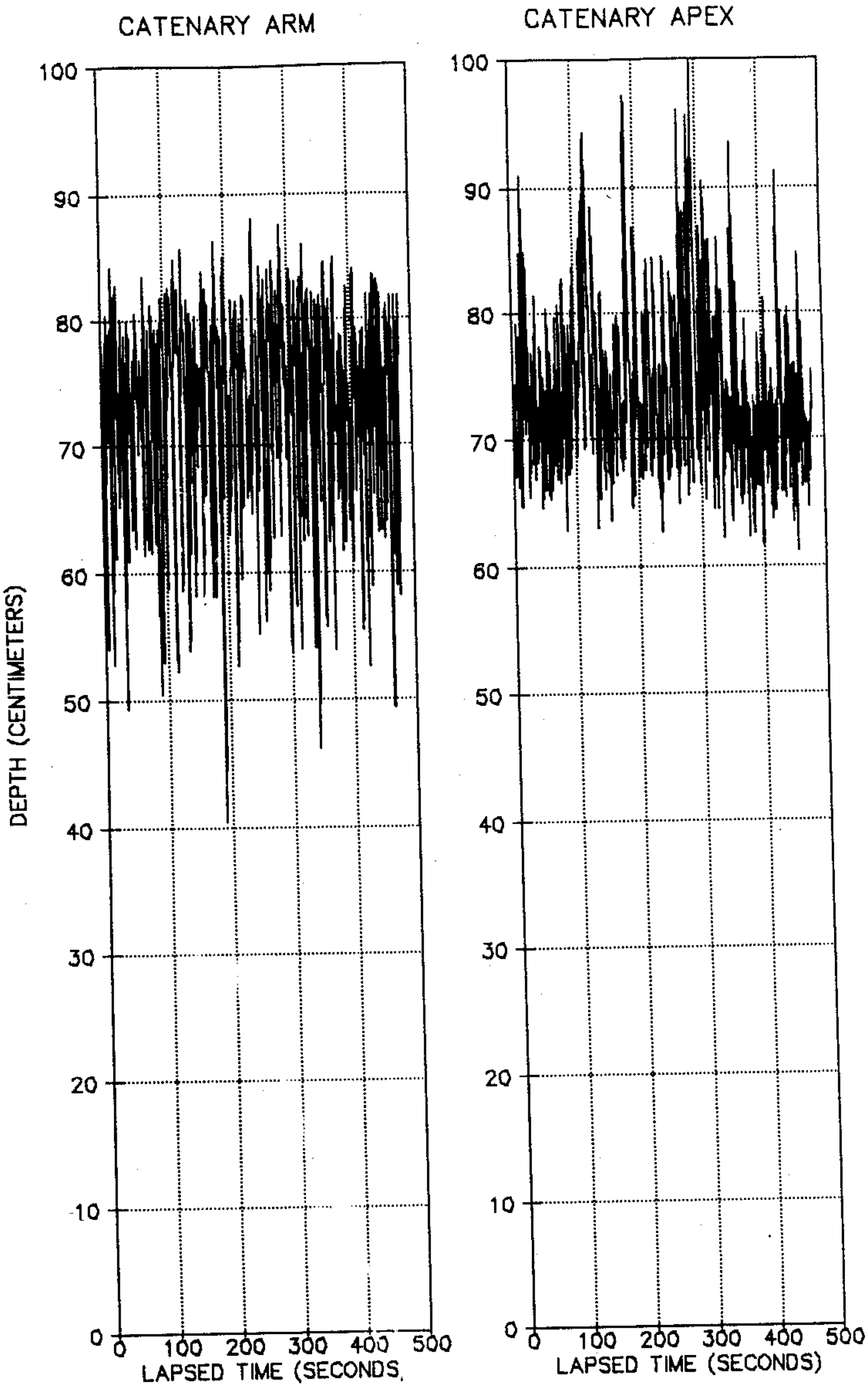

FIGURE 8 - Boom depth measurements at the "arm" and apex of a U-catenary.

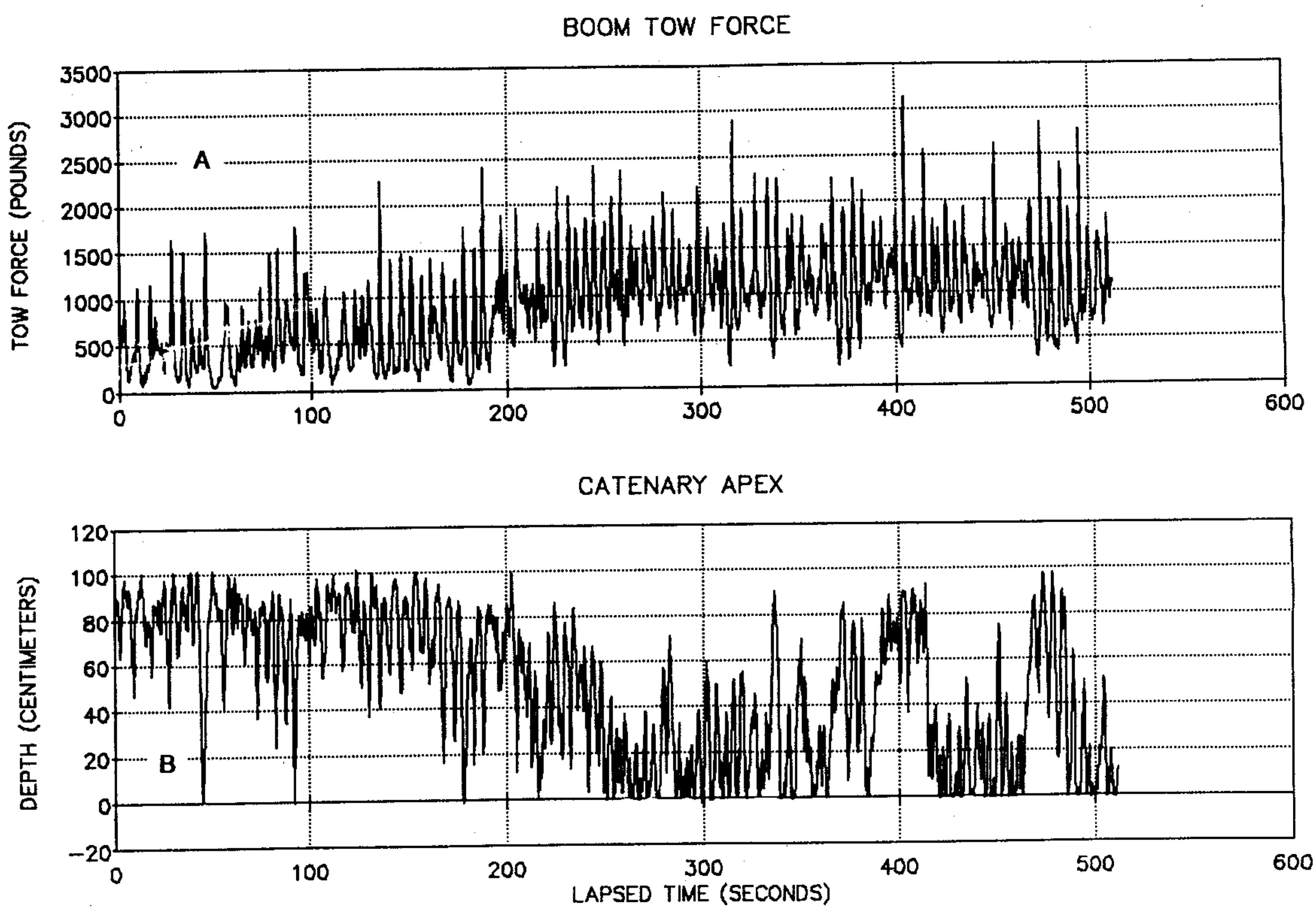

FIGURE 9 - Tow force measurements (A) reflect increased tow speed at the same time the pressure transmitter measurements (B) detect boom failure.

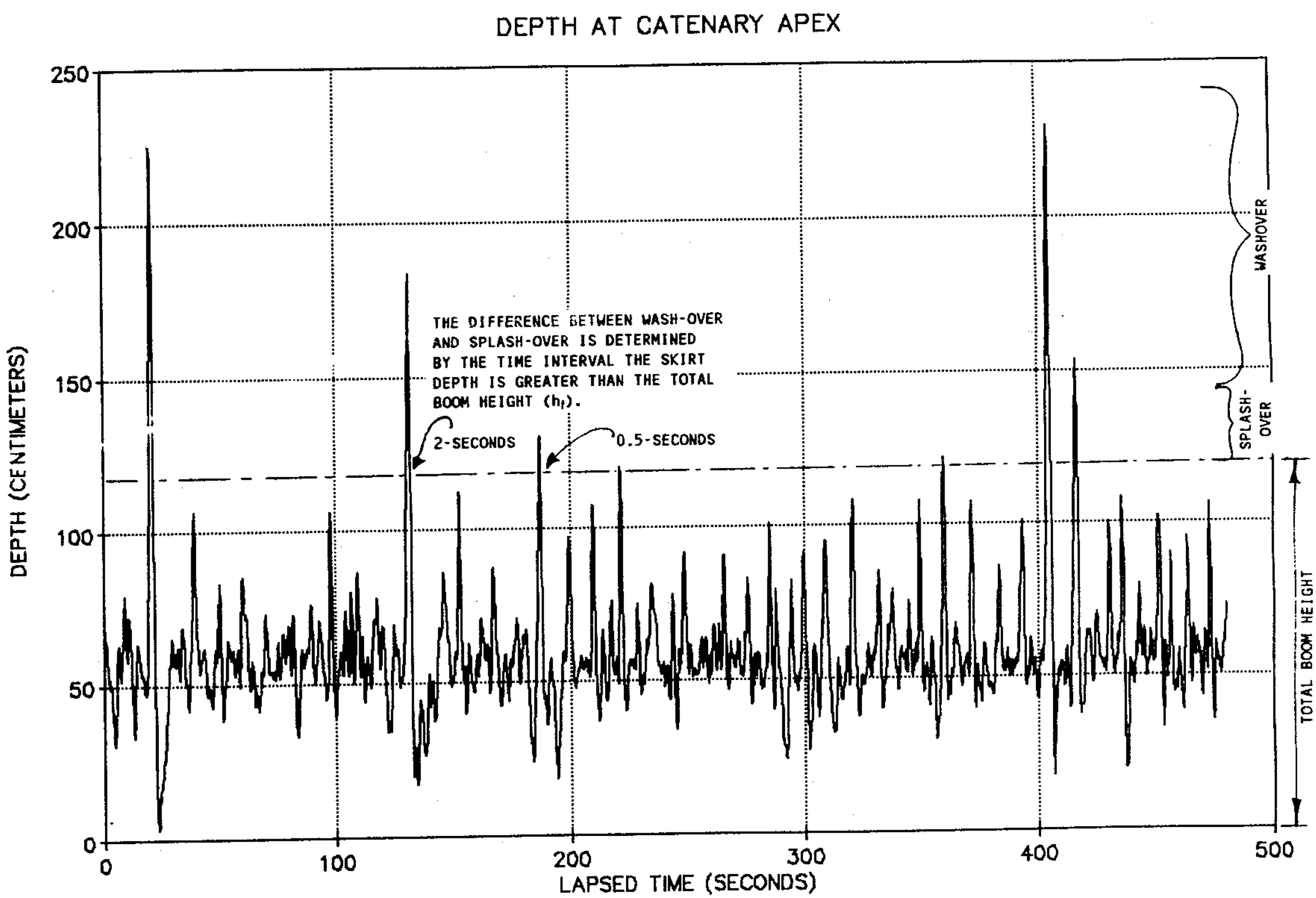

FIGURE 10 - Splash-over and wash-over as detected by a pressure transmitter.

apex of the boom came out of the water due to the increase in towing speed. The splashover and washover occurrences are detected by pressure transmitters as can be seen in Figure 10. Any depth measurement that exceeds the dashed line in the figure represents a wave passing over the boom.

The report should contain graphical data representations as in Figures 8, 9 and 10 and completed Oil Spill Boom Evaluation Data Forms, Figures 11 and 12.

9. Precision and Accuracy

Table 5 is a listing of the accuracy and precision data objectives for the Boom Test Protocol. These values are based on tank testing experience of over four years. The investigator must consider the effect of random events during open water testing. Test periods of twenty minutes may not result in data with the desired precision when comparing one test to another.

OIL SPILL BOOM EVALUATION DATA

Boom Name: EPITOME Model: 46 A 60

Draft: 60 CM Freeboard: 46 cm Length: 26 M

TANK TESTS

CRITICAL TOW SPEED:

	HT	PER	Tow Speed	Fail Mode	Test	Date
Calm Water			1.17	SUBMARINE	201-1	2/14/92
Waves						
1.	40	7	.65	SUBMARINE	201-10	2/14
2.	30	4	.41	SUBMARINE	201-11	2/14
3.	30	HC	.13	SPLASHOVER	201-12	2/14
4.	60	HC	.00	SPLASHOVER	201-13	2/14

OIL LOSS

	HT	PER	1st Loss	Gross Loss	Depth Profile Ave.	Max.	Min.	Test	Date
Calm Water			0.56	—	55	79	51	201-14	2/14
Waves									
1.	40	7	.46	—	63	82	49	201-19	2/14
2.	20	1.7	.32	—	58	68	18	201-20	2/14
3.	30	6	.48	—	61	80	49	201-21	2/14
4.	30	6	—	.54	66	87	53	201-22	2/14

INDICATIVE WAVE STRESS:

OPEN WATER TESTS

Significant Wave: Height	Period	Wave Spectra 17	15	13	11	9	7	5	Depth Profile Ave.	Max.	Min
66	7	10	12	15	24	45	66	58	58	85	49
50	9	11	14	15	35	50	43	37	61	72	53
92	5	12	21	21	43	51	71	92	43	106	20

FIGURE 11 - Oil Spill Boom Evaluation Data

OIL SPILL BOOM EVALUATION DATA
OIL LOSS: RATE DETERMINATION

Boom Name: EPITOME Model: 46 A 60

TEST OIL: Type: Medium New: X Refurbished:

Weathered:

Surface Tension Dyne/cm @°C	Interfacial Tension Dyne/cm @°C	Dynamic Viscosity Dyne sec/cm² @°F	Density Gram/cm³ @°F	Date	For Boom Test Numbers
34.0 @ 18	23.5	29	.875	2/14/92	201
33.5 @ 15	24.2	35	.886	2/14/92	1 to 22
33.6 @ 14	25.0	38	.891	2/14/92	

RECOVERED FLUID: Analysis By Centrifuge: X 2/15/92 Distillation: Other:

Depth in Tank	Tank Constant	Fluid Recovered (F_{REC})	Test Number	Sample Number	Analyzed Volume (or Mass)	Water Volume (or Mass)	% Oil (%O)
60	2.07	124	15	201-15	98.6 ml	6.9 ml	93.1
80	2.15	172	16	201-16	100.2	7.3	92.7
75	2.02	152	17	201-17	100.1	6.8	93.2
90	2.12	191	18	201-18	99.6	5.3	94.7

OIL LOSS RATE:

Pre-load (P)	Rate (R)	Time (t)	TOTAL (Q_S=P+Rt)	Recovered Oil (F_{REC} X %O)	Loss Rate (Q_S - O_{REC})/t	Test	Date
50	125	2.5	362	115	99 gpm	201-15	2/15/92
50	145	1.5	268	159	109	201-16	2/15/92
50	135	1.0	185	142	43	201-17	2/15/92
50	175	1.0	225	181	44	201-18	2/15/92

FIGURE 12 - Oil Spill Boom Evaluation Data, Oil Loss: Rate Determination

TABLE 5 - MEASUREMENT PRECISION AND ACCURACY

MEASUREMENT	PRECISION	ACCURACY
Bottom Solids and Water	0.001 g	0.0005 g
Oil Distribution	0.05 m^3/HR	0.3 m^3/HR
Pressure	1.4 mm	6 mm
Salinity	0.1 ^{o}/oo	0.1 ^{o}/oo
Specific Gravity, Density	0.0001	0.0002
Surface Tension	0.05 Dyne/cm	0.1 Dyne/cm
Temperature	0.1°C	0.1°C
Time	0.01 sec.	0.25 sec.
Tow, Current Speeds		
Tank	2.55 cm/sec. (0.05 kt)	.51 cm/sec. (0.1 kt)
Open Water	10.2 cm/sec. (0.2 kt)	25.5 cm/sec. (0.5 kt)
Tow Force	10#	20#
Viscosity	5 cSt	10 cSt
Wave Meter		
Tank	1.4 mm	6 mm
Open Water	10 mm	10 mm
Wind Direction	10°	10°
Wind Speed	25.5 cm/sec. (0.5 kt)	153 cm/sec. (3 kt)

TABLE 5 - MEASUREMENT PRECISION AND ACCURACY

MEASUREMENT	PRECISION	ACCURACY
Bottom Solids and Water	0.001 g	0.0005 g
Oil Distribution	0.05 m^3/HR	0.3 m^3/HR
Pressure	1.4 mm	6 mm
Salinity	0.1 ^{o}/oo	0.1 ^{o}/oo
Specific Gravity, Density	0.0001	0.0002
Surface Tension	0.05 Dyne/cm	0.1 Dyne/cm
Temperature	0.1°C	0.1°C
Time	0.01 sec.	0.25 sec.
Tow, Current Speeds		
Tank	2.55 cm/sec. (0.05 kt)	.51 cm/sec. (0.1 kt)
Open Water	10.2 cm/sec. (0.2 kt)	25.5 cm/sec. (0.5 kt)
Tow Force	10#	20#
Viscosity	5 cSt	10 cSt
Wave Meter		
Tank	1.4 mm	6 mm
Open Water	10 mm	10 mm
Wind Direction	10°	10°
Wind Speed	25.5 cm/sec. (0.5 kt)	153 cm/sec. (3 kt)

GLOSSARY

BARRIER/BOOM	any floating mechanical device intended to prevent the spread of floating oil, increase the thickness of floating oil, or divert the flow of floating oil.
BARRIER APEX	the portion of the barrier which is farthest from the barrier tow points when towed in symmetric catenary.
BARRIER DEPTH	the perpendicular distance from an imaginary line between barrier tow points to the apex.
BARRIER DRAFT	the maximum distance below the calm-water surface of any boom segment not part of the towing assembly or connector. (D)
BARRIER FREEBOARD	the vertical height of the barrier above the water line in calm water. (F)
BOOM SKIRT	the structural component of an oil spill boom that hangs beneath the floatation member. There is often a ballast chain or other weight at the bottom of the skirt to hold it vertically in the water column.
CATENARY CONFIGURATION	the "U" (U catenary) or "J" (J catenary) shape of a boom when towed by two vessels or held in place at two fixed mooring points.
HARBOR CHOP	an irregular condition of the water surface produced by an interference pattern of waves. This is also known as random sea.
OHMSETT	National Oil Spill Test Facility. NWS Earle, Waterfront Area, Leonardo, NJ.
PRELOAD	during testing, the quantity of oil distributed in front of and contained by the barrier prior to the onset of oil loss.
SIGNIFICANT HEIGHT	when measuring waves, an average of the highest one half, one third or one tenth are used to characterize the sea surface. The "one third significant wave height" is commonly use.
TEST TANK	a wave tank which can create a relative velocity between a boom and the water surface.
TOW SPEED	the relative speed difference between a barrier and the water in which the barrier is floating. In this protocol "current speed" is equivalent.

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APPENDIX A

STANDARD TEST METHODS

APPENDIX A

STANDARD TEST METHODS

The following methods are based on ASTM, EPA and "Standard Methods", American Waste Water Association standards and are used to measure the physical characteristics required for this protocol.

OIL AND GREASE, TOTAL RECOVERABLE (Infrared)

A. SCOPE AND APPLICATION

1. This method include the measurement of Freon extractable matter from surface and saline waters, industrial and domestic wastes. It is applicable to the determination of hydrocarbons, vegetable oils, animal fats, waxes, soaps, greases and related matter.

2. The method is applicable to measurement of most light petroleum fuels, although loss of about half of any gasoline present during the extraction manipulations can be expected.

3. The method covers the range for 0.2 to 1000 mg/l of extractable material.

B. SUMMARY OF METHOD

The sample is acidified to a low pH (less than 2) and extracted with Freon. The oil and grease is determined by comparison of the infrared absorbance of the sample extract with standards.

C. INTERFERENCES

The definition of oil is based on this infrared procedure. The source of the oil and the presence of extraneous matter may influence the material measured and the interpretation of results.

D. COMMENTS

1. The minimum concentration of 5 mg/l for quantifying oils with unknown identity is derived from an EPA method for Oil and Grease.

2. Carbon Tetrachloride is more efficient than Freon 113 for extracting high concentrations (greater than 200 mg/l) of viscous oils (100 centistokes at 100°F) from water dispersions.

3. Freon 113 is less hazardous to exposed laboratory personnel than carbon tetrachloride (1000 ppm TLV vs. 10 ppm TLV) and is therefore preferred in situations where adequate ventilation may be lacking.

4. Carbon tetrachloride is always the solvent of choice when: a) oil appears as a separate layer, or b) the sample exhibits discoloration.

5. Difficult to handle emulsions may form when oil in water concentrations exceed the method's concentration limit (1000 mg/l).

E. DEFINITIONS

1. The definition of grease and oil is based on the procedure used. The source of the oil and/or grease and the presence of extractable non-oily matter will influence the material measure and interpretation of results.

2. An "Unknown Oil" is defined as one for which a representative sample of the oil or grease is not available for preparation of a standard. Examples of unknown oils are the oil and grease in a mixed sewerage or an unidentified oil slick on a surface water.

3. A "Known Oil" is defined as a sample of oil and/or grease that represents the only material of that type used or manufactured in the processes represented by a wastewater.

F. APPARATUS

1. Separatory funnel, 2000 ml, with Teflon stopcock.

2. Infrared spectrophotometer, double beam, recording.

3. Cells, quartz, 10 mm and 100 mm path length.

4. Syringes, 10, 25, 50, 100 microliter capacity.

5. Filter paper, Whatman No. 40, 11 cm.

G. REAGENTS

1. Sulfuric acid, 1:1. Mix equal volumes of concentrated H_2SO_4 and distilled water. (Concentrated hydrochloric acid may be substituted directly for concentrated sulfuric acid for this reagent).

2. Freon 113, b.p. 48°C, 1, 1, 2-trichloro-1, 2, 2-trifluoroethane. Freon 113 is available from E.I. DuPont de Nemours, Inc. and its distributors, in 5-gallon cans. It is best handled by filtering one gallon quantities through paper into glass containers. and maintaining a regular program of solvent blank monitoring.

3. Sodium sulfate, anhydrous crystal.

4. Known oil reference standard. Accurately weigh about 0.05 g of known oil directly into a 100 ml volumetric flask. Add 80 ml Freon and dissolve the oil. If, as in the case of a heavy fuel oil, all the oil does not go into solution, let stand overnight. The next day, filter through paper into another 100 ml volumetric flask and dilute to mark. Treat calculations as if all oil had gone into solution.

5. Unknown oil reference standard (10 ml = 7.69 mg oil). Pipette 15.0 ml n-hexadecane, 15.0 ml isooctane, and 10.0 ml toluene into a 50 ml glass stoppered bottled. Assume the specific gravity of this mixture to be 0.769 and maintain the integrity of the mixture by keeping stoppered except when withdrawing aliquots.

H. PROCEDURE

1. Mark the sample bottle at the water meniscus for later determination of sample volume. If the sample was not acidified at time of collection, add 2 ml sulfuric or hydrochloric acid (G.1) to the sample bottle. After mixing the sample, check the pH by touching pH sensitive paper to the cap to ensure that the pH is 2 or lower. Add more acid if necessary.

2. Pour the sample into a separatory funnel.

3. Add 30 ml Freon (G.2) to the sample bottle and rotate the bottle to rinse the sides. Transfer the solvent into the separatory funnel. Extract by shaking vigorously for 2 minutes. Allow the layers to separate.

4. Filter the solvent layer into a 100 ml volumetric flask through a funnel containing solvent-moistened filter paper.

   Note: An emulsion that fails to dissipate can be broken by pouring 1 g sodium sulfate (G.3) into the filter paper cone and draining the emulsion through the salt. Additional 1 g portions can be added to the cone as required.

5. Repeat steps H.3 and H.4 twice more with 30 ml portions of fresh solvent, combining all solvent in the volumetric flask.

6. Rinse the tip of the separatory funnel, filter paper and the funnel with a total of 10-20 ml Freon and collect the rinsings in the flask. Dilute the extract to 100 ml and stopper the flask.

7. Select appropriate calibration standards and cell pathlength according to the following table of approximate working ranges:

PATHLENGTH	RANGE
1 cm	4-40 mg/liter
5 cm	0.5-8 mg/liter
10 cm	0.1-4 mg/liter

   Prepare calibration standards by pipetting appropriate amounts of the known oil reference standard (G.4) into 100 ml volumetric flasks and diluting to mark with Freon. Alternately, transfer appropriate amounts of the unknown oil reference standard (G.5) using microliter syringes to 100 ml volumetric flasks and diluting to mark with Freon.

   Note: Ten microliters of the unknown oil is equivalent to 7.69 mg per 100 ml Freon and 7.69 mg per sample volume.

8. Scan standards and samples from 3200 cm^{-1} to 2700 cm^{-1} with Freon in the reference beam and record the results on absorbance paper. The absorbances of samples and standards are measured by constructing a straight baseline over the range of the scan and measuring the absorbance of the peak maximum at 2930 cm^{-1} and subtracting the baseline absorbance at that point. If the absorbance exceeds 0.8 for a sample, select a short pathlength or dilute as required.

   Note: Caution must be exercised in the selection of the 2930 cm^{-1} peak as it may not always be the largest peak in the range of the scan. For an example of a typical oil spectrum and baseline construction, see Gruenfeld (3).

9. Use a calibration plot of absorbance vs. mg oil prepared from the standards to determine the mg oil in the sample solution.

I CALCULATION

mg/l total oil and grease = RXD/V

where:

R = oil in solution, determined from calibration plot in milligrams.

D = extract dilution factor, if used.

V = volume of sample, determined by refilling sample bottle to calibration line and correcting for acid addition, if necessary in liters.

J. PRECISION AND ACCURACY

By this method, a single laboratory determined the oil and grease level in sewerage to be 17.5 mg/l. When 1 liter portions of the sewerage were dosed with 14.0 mg of a mixture of #2 fuel and Wesson oil, the recovery was 99% with a standard deviation of 1.4 mg. See Quality Assurance section.

K. REFERENCES

1, Standard Methods for the Examination of Water and Wastewater, 13th Edition, p. 254, Method 137, (1971).

2. American Petroleum Institute, "Manual on Disposal of Refinery Wastes", Vol. IV, Method 733-58 (1958).

3. Gruenfeld, M., "Extraction of Dispersed Oils from Water for Quantitative Analysis by Infrared Spectroscopy", Environ. Sc. Technology 7,636 (1973).

4. Methods for Chemical Analysis of Water and Wastes, U.S. EPA, 1973, pp. 232-235.

SPECIFIC GRAVITY

A. SCOPE AND APPLICATION

1. This method covers the laboratory determination, using a glass hydrometer, of the density, specific gravity, or API gravity of crude petroleum and non-petroleum products normally handled as liquids, and having a Reid vapor pressure (ASTM Method D323, Test for Vapor Pressure of Petroleum Products (Reid Method) of 26 lbs. or less. Values are measured on a hydrometer at convenient temperatures, readings of density being reduced to 15°C, and readings of specific gravity and API gravity to 60°F, by means of these same tables, values determined in any one of the three systems of measurements are convertible to equivalent values in either of the other two so that measurements may be made in the units of local convenience.

2. The hydrometer method is most suitable for determining the density, specific gravity or API gravity of mobile, transparent liquids. It can also be used for viscous oils by allowing sufficient time for the hydrometer to reach equilibrium, or for opaque oils by employing a suitable meniscus correction.

3. When used in connection with bulk oil measurements, volume correction errors are minimized by observing the hydrometer reading at a temperature close to that of the bulk oil temperature.

B. SUMMARY OF METHOD

The sample is brought to the prescribed temperature and transferred to a cylinder at approximately the same temperature. The appropriate hydrometer is lowered into the sample and allowed to settle. After temperature equilibrium has been reached, the hydrometer scale is read and the temperature of the sample is noted. If necessary, the cylinder and its contents are placed in a constant-temperature bath to avoid excessive temperature variation during the test.

C. COMMENTS

1. The density, specific gravity or API gravity by the hydrometer method is most accurate at or near the reference temperature of 15°C or 60°F.

2. When the hydrometer value is to be used to select multipliers for correcting volumes to standard temperatures, the hydrometer reading should be made preferable at a temperature within +/-3°C (+/-5°F) of the temperature at which the bulk volume of the oil was measured.

D. DEFINITIONS

1. Density - for the purpose of this method, the mass (weight in volume) of liquid per unit volume at 15°C. When reporting results, explicitly state the density in units of mass (kilograms) and volume (liters) together with the standard reference temperature, e.g. kilograms per liter at 15°C.

2. Specific Gravity - for the purpose of this method, the ratio of the mass of a given volume of liquid at 60°F to the mass of an equal volume of pure water at the same temperature. When stating results explicitly report the standard reference temperature, e.g. specific gravity 60/60°F.

3. API gravity - a special function of specific gravity 60/60°F represented by:

API gravity, deg. = (14.5/sp gr 60/60°F) - 131.5

No statement of reference temperature is required, since 60°F is included in the definition.

4. Observed values - since all hydrometers are calibrated to read corrected at a specified reference temperature, values observed at other temperatures are only hydrometer readings and not density, specific gravity or API gravity at that other temperature.

E. APPARATUS

1. Hydrometers, glass, graduated in units of density, specific gravity or API gravity as required, conforming to ASTM specifications or specifications of the British Standards Institution.

2. Thermometers having a range from -2 to 40° centrigrade and conforming to specifications of the ASTM or the Institute of Petroleum.

3. Hydrometer Cylinder, clear glass, plastic or metal. For convenience in pouring, the cylinder may have a lip on the rim. The inside diameter of the cylinder shall be at least 25 mm greater than the outside diameter of the hydrometer used in it. The height of the cylinder shall be such that the hydrometer floats in the sample with at least 25 mm clearance between the bottom of the hydrometer and the bottom of the cylinder.

Note: Hydrometer cylinders constructed of plastic materials shall be resistant to discoloration or attach by oil samples and must not become opaque under prolonged exposure to sunlight and oil samples.

4 Constant Temperature Bath, for use when the nature of the sample requires a test temperature much above or below room temperature.

Note: The user should ascertain that the instruments used for this test conform to the requirements set out above with respect to materials, dimensions and scale errors. In cases where the instrument is provided with a calibration certificate issued by a recognized standardizing body, the instrument is classed as "certified" and the appropriate corrections listed shall be applied to the observed readings. Instruments which satisfy the requirements of this test method, but are not provided with a recognized calibration certificate are classified as "uncertified".

F. PROCEDURE

1. Adjust the temperature of the sample according to the indications given above. Bring the hydrometer cylinder and thermometer to approximately the same temperature as the sample to be tested.

Note: When testing completely opaque samples, metal hydrometer cylinders may be used. When such cylinders are used, accurate reading of the hydrometer can only be assured if the level of the sample is within 5 mm of the top of the cylinder.

2. Transfer the sample to a clean hydrometer cylinder without splashing to avoid the formation of air bubbles and to reduce to a minimum the evaporation of the lower boiling constituents of the more volatile samples to the cylinder by water displacement or by siphoning. Remove any air bubbles formed, after they have collected on the surface of the sample by touching them with a piece of clean filter paper before inserting the hydrometer.

   Note: Highly volatile samples containing alcohols or other water-soluble material should always be transferred by siphoning.

3. Place the cylinder containing the sample in a vertical position in a location free from air currents. Ensure that the temperature of the sample does not change appreciably during the time necessary to complete the test; during this period, the temperature of the surrounding medium should not change more than 2°C (50°F). When testing at temperatures much above or below room temperature, a constant-temperature bath may be necessary to avoid excessive temperature changes.

4. Lower the hydrometer gently into the sample. Take care to avoid wetting the stem above the level to which it will be immersed in the liquid. Continuously stir the sample with the thermometers, taking care the mercury thread is kept fully immersed and that the stem of the hydrometer is not wetted above the immersion level. As soon as a steady reading is obtained, record the temperature of the sampie to the nearest 0.25°C (0.5°F) and then remove the thermometer.

5. Depress the hydrometer about two scale divisions into the liquid and then release it. The remainder of the stem of the hydrometer which is above the level of the liquid must be kept dry since unnecessary liquid on the stem affects the reading obtained. With samples of low viscosity, impart a slight spin to the hydrometer on releasing to assist in bringing it to rest, floating freely away from the walls of the cylinder. Allow sufficient time for the hydrometer to come to rest and for all air bubbles to come to the surface. This is particularly necessary in the case of more viscous samples.

6. When the hydrometer has come to rest, floating freely away from the walls of the cylinder, estimate the hydrometer scale reading to the nearest 0.001 sp gr or density or 0.05 deg API. The correct hydrometer is that point on the hydrometer scale at which the principal surface of the liquid cuts the scale. Determine this point by placing the eye slightly below the level of the liquid and slowly raising it until the surface, first seen as s distorted ellipse, appears to become a straight line cutting the hydrometer scale.

7. With an opaque liquid, take a reading by observing with the eye slightly above the plane of the surface of the liquid, the point on the hydrometer scale to which the sample rises. This reading, at the top of the meniscus, requires correction since hydrometers are calibrated to be read at the principal surface of the liquid. The correction for the particular hydrometer in use may be determined by observing the maximum height above the principal surface of the liquid to which oil rises on the hydrometer scale when the hydrometer in question is immersed in a transparent oil having a surface tension similar to that of the sample under test.

8. Immediately after observing the hydrometer scale value, again cautiously stir the sample with the thermometer keeping the mercury thread fully immersed. Record the temperature of the sample to the nearest 0.2°C (0.5°). Should this temperature differ from the previous reading by more than 0.2°C (0.5°), repeat the hydrometer and then thermometer observations until the temperature becomes stable within 0.5°C (1°F).

Note: After use at a temperature higher than 38°C (100°F), allow all hydrometers of the lead shot in wax type to drain and cool in a vertical position.

G. CALCULATIONS AND REPORT

1. Apply any relevant corrections to the observed thermometer reading (for scale or bulb) and to the hydrometer reading (scale). For opaque samples, make the appropriate correction to the observed hydrometer reading as given in F.7. Record to the nearest 0.0001 density or specific gravity of 0.1 deg API the final corrected hydrometer scale reading. After application of any relevant corrections, record to the nearest 0.5°C or 1°F, the mean of the temperature values observed immediately before and after the final hydrometer reading.

Note: Hydrometer readings at temperatures other than calibration temperatures (15°C or 60°F) should not be considered as more than scale readings.

2. To convert corrected values from G.1 to standard temperature, use the following referenced tables from the The American Petroleum Institute's Petroleum Measurement Tables.

3. When a density-scaled hydrometer has been employed, use Table 53 to obtain density at 15°C.

4. When a specific gravity hydrometer has been employed, use Table 23 to obtain Specific Gravity 60/60°F.

5. When an API gravity-scaled hydrometer has been employed, use Table 5 to obtain the gravity in API degrees.

6. When a value is obtained with a hydrometer scaled in one of the units described herein and a result is required in one of the other units, make the conversion by one of the appropriate tables given in the Petroleum Measurement Tables. For conversion from density at 15°C, use Table 51; from specific gravity 60/60°F, use Table 21; from API gravity, use Table 3.

7. Report the final value as density in kilograms per liter at 15°C, or as specific gravity at 60/60°F, or as gravity in degrees API, as applicable.

H. PRECISION AND ACCURACY

1. The following criteria should be used for judging the acceptability of results.

2. Repeatability: Duplicate results by the same operator should be considered suspect if the results differ by more than the following amounts:

Product	Temperature Range	Units	Repeatability
Transparent	-2 to 24.5°C	Density	0.0005
Nonviscous	29 to 76°F	Specific gravity	0.0005
	42 to 78°	API gravity	0.1
Opaque	-2 to 24.5°	Density	0.0006
	29 to 76°F	Specific gravity	0.0006
	42 to 78 °F	API gravity	0.2

3. Reproducibility: The results submitted by each of two laboratories should not be considered suspect unless the results differ by more than the following amounts:

Product	Temperature Range	Units	Repeatability
Transparent	-2 to 24.5°C	Density	0.0012
Nonviscous	29 to 76°F	Specific gravity	0.0012
	42 to 78°F	API gravity	0.3
Opaque	-2 to 24.5°C	Density	0.0015
	29 to 76°F	Specific gravity	0.0015
	42 to 78°F	API gravity	0.5

4. For very viscous products, or when the conditions given in H.2 and H.3 are not complied with, no specific variations can be given.

I. REFERENCES

1. ASTM D287-67

2. ASTM D1298-67

SURFACE AND INTERFACIAL TENSION

A. SCOPE AND APPLICATION

This method covers the measurement under nonequilibrium conditions of the interfacial tension of mineral oils against water, which has been shown by practice to give a reliable indication of the presence of hydrophilic compounds.

B. SUMMARY OF METHOD

Interfacial tension is determined by measuring the force necessary to detach a planar ring of platinum wire from the surface of the liquid of higher surface tension, that is upward from the water-oil interface. To calculate the interfacial tension, the force so measured is corrected by an empirically-determined factor which depends upon the force applied, the densities of both oil and water, and the dimensions of the ring. Measurements are made under rigidly standardized nonequilibrium conditions in which the measurement is completed 1 minute after formation of the interface.

C. APPARATUS

1. Tensiometer with a torsion sire to apply the force to lift the ring; the torsion wire is attached to a scale graduated in dynes/cm.

2. Ring of fine platinum wire in a nearly true circle of 4 or 6 cm circumference welded to a suitable stirrup made of the same wire. It is necessary to know, to three significant figures, the circumference of each ring, and the ratio of the diameter of the ring to the diameter of the wire of which it is made.

3. Sample container: glass beaker or cylindrical vessel having a minimum diameter of 45 mm.

D. SAMPLING AND STORAGE

Filter aqueous samples through a 150 mm diameter, unwashed filter paper of medium porosity.

E. PROCEDURE

1. Clean all glassware by removing any residual oil with Toluene, soap and water, followed by several washes with Freon 113. Rinse thoroughly with tap water and then with distilled water. Unless it is to be used immediately, drain the sample container in an inverted position over a clean cloth.

2. Clean the platinum ring by rinsing it in Toluene and Freon 113. Then heat the ring in the oxidizing portion of a gas flame until orange vapors are no longer visible.

3. Calibrate the tensiometer against known weights and adjust its zero point according to the procedure of it manufacturer. Make certain that all portions of the ring are in the same horizontal plane.

4. Introduce 50 to 75 ml of tank water at a temperature of 25 +/- 1°C to a freshly-cleaned sample container and place it on the adjustable platform of the tensiometer.

5. Slowly lower the platform, increasing the torque of the ring system by maintaining the torsion arm in the zero position. As the film of water adhering to the ring approaches the breaking point, proceed slowly with adjustment to assure that the moving system will be in the zero position when rupture occurs. Using the scale reading at which this occurs, calculate the tension of the water sample as described below using the value of 0.997 for difference of density of water and air (D-d); a value of 71 to 72 dynes/cm should be obtained. When low values are found, possibly due to improper adjustment of the tensiometer or improperly-cleaned apparatus, make readjustments; clean the sample container with hot chromic acid cleaning solution, rinse and repeat the measurement. If a low value is still obtained, further purify the distilled water (for instance, by redistilling from an alkaline solution of potassium permanganate).

6. Return the tensiometer scale to zero and raise the adjustable platform until the ring is immersed to a depth of about 5 mm in the distilled water. Pour the filtered oil, previously brought to a temperature of 25 +/-1°C on the water to a depth of about 10 mm. Take care that the ring doe not touch the oil-water interface. If a ring with a short stirrup is used, keep the oil level below the top of the stirrup to prevent bridging. If this is not possible, break the bridge with a suitable clean, sharp instrument as soon as possible after withdrawing the stirrup from the oil.

7. Allow the oil-water interface to age for 30 +/-1 s, then slowly lower the platform, increasing the torque of the ring system by maintaining the torsion arm in the zero position. As the water adhering to the ring approaches the breaking point, proceed slowly with adjustment to assure that the moving parts will be in zero position when rupture occurs. Time these operations so that, as nearly as possible 30 s are required to draw the ring through the interface. Proceed very slowly as the breaking point is approached, since the break is usually sluggish and too rapid movement may result in a high reading. Complete the entire operation, from the time of pouring the oil into the sample container until the firm ruptures, in about 1 min. Record the scale reading at which the ring breaks free from the interface.

F. CALCULATION

1. Calculate the interfacial tension of the sample by means of the following equations:

Interfacial tension, dynes/cm = PcF

where:

P = scale reading when film ruptures, dynes/cm and

F = factor converting scale reading in dynes/cm to interfacial tension obtained as described in 6.2.

2. Using the value of diameter ratio, R/r, specified by the manufacturer for the rings used, prepare a graph of correction factors, F, by means of the following equation; the graph should cover even increment of P/D-d from 0 to 800 and should give correction factors to three digits:

$$F = 0.7250 - (0.01452O/C^2(D\text{-}d)) + 0.4534 - (1.679/Rr)$$

where P =	scale reading, dynes/cm
C =	circumference of ring, cm
D =	density of water at 25°C, g/ml
d =	density of sample at 25°C, g/ml
R =	radius of ring, cm and
r =	radius of wire of ring, cm.

G. PRECISION AND ACCURACY

See Quality Assurance Section

H. REFERENCES

ASTM D971-50.

FISHER SURFACE TENSIOMAT

A. CALIBRATION

The calibration of the torsion wire, and hence of the Surface Tensiomat, has been carefully tested at the factory but should be checked before use and adjusted if necessary. The calibration is carried out so that the dial will read directly in dynes per centimeter.

Weigh a piece of paper (approximately 600 mg) on the analytical balance and record the weight below.

Place the known mass for calibration on the paper platform (600 milligrams is quite suitable and simplifies calculations). Release the torsion arm. Turn the knob on the right side of the case in a counter clockwise direction until the index and its image are exactly in line with the reference line of the mirror. Record the dial reading to the nearest 1/10 scale division (by use of the vernier).

It is now necessary to determine the accuracy of the calibration from the reading obtained. The apparent surface tension, S, is given as follows:

$$S = Mg/2L$$

where:

M = the weight expressed in grams = ____

g = acceleration of gravity expressed in cm/sec^2 =98.7 cm/sec^2

L = mean circumference of the ring in centimeters = ____

S = dial reading = apparent surface tension in dynes/cm = ____

For example, suppose that a 600 milligram weight was used. The circumference of the ring is 6.00 cm and the value for g is 980 cm/sec^2. Then we find that:

$$S = Mg/2L \quad (0.6 \times 980)/(2 \times 6) = 49.00 \text{ dynes/cm}$$

If the dial reading differs form the calculated value, then the effective length of the torsion arm must be adjusted until these two values do agree. This adjustment is accomplished by turning the knurled knob at the left end of the lever so as to move the hanger hook. If the recorded dial reading is greater than the calculated value, move the hook to shorten the effective length of the arm. Conversely, if the dial reading is less than the calculated value, move the hook to lengthen the effective length of the arm. Repeat the calibration procedure until the dial reading and calculated value agree. The dial will read directly in dynes/cm.

VISCOSITY-BROOKFIELD

A. SCOPE AND APPLICATION

This method covers procedures for the empirical measurement of Kinematic Viscosity by use of a Brookfield Viscosimeter.

B. SUMMARY OF METHOD

Viscosity is measure by amount of torque exerted by the fluid against a rotating spindle immersed in the fluid. A torsion wire is connected to a dial calibrated in centipoise (cps).

C. COMMENTS

Correct spindle size is important as each spindle is applicable only in a limited viscosity range.

D. APPARATUS

1. Spindles - various sizes and shapes for various viscosity fluids.

2. Brookfield Model LV viscosimeter.

E. REAGENTS

Calibration fluids (Silicone oils).

F. PREPARATION AND CALIBRATION

1. Periodic calibration is needed for maintaining instrument performance. Calibration fluids are available in several viscosities.

2. These instruments are calibrated to Bureau of Standards values on the basis of immersion in an infinite body with the spindle guard attached. They are accurate to within 1% of full scale when centered in any container over 2 3/4" in diameter. Using the viscosimeters in small containers will reduce the effective range of measurement provided by the #1 and #2 spindles. The Calibration of the #3 and #4 spindles will remain the same regardless of the size of the container used, as long as the guard is attached.

3. The #4 LV spindle has a reduced section in its shaft rather than the groove found on the other spindles. The spindle should be immersed in the fluid to the approximate midpoint of this section.

4. Readings obtained in small containers and/or without the guard can be used only for comparative purposes unless definite correction factors are used with each spindle and with each container. The booklet, "Solutions to Sticky Problems" outlines the procedure to be followed in the establishment of these factors.

5. At 60 rpm, air resistance to rotation has a certain effect on the LV pointer. The values obtained at this speed, with any spindle, should be reduced by 0.4 on the 100 scale (or 2.0 on the 500 scale) before using the Factor Finder provided with the instrument.

6. A condition of turbulent flow is created by the #1 spindle when rotating at 60 rpm in materials having viscosities less than 15 cps. If measurements of absolute accuracy are needed in this region, it is suggested that the U.L. Adapter accessory be used.

G. PROCEDURE

1. Attach spindle to lower shaft. It is best to lift the shaft slightly while it is held firmly with one hand while screwing the spindle on with the other. Care should be taken to avoid putting side thrust on the shaft to protect its alignment.

2. Insert spindle in the test material until the fluid's level is at the immersion groove cut in the spindle's shaft. With a disc-type spindle it is sometimes necessary to tilt the instrument slightly while immersing to avoid trapping air bubbles on its surface. (You may find it more convenient to immerse the spindle in this fashion before attaching it to the Viscometer.) Care should be taken to not hit the spindle against the sides of the fluid container while it is attached to the viscometer, since this too can damage the shaft alignment.

3. Level the viscometer; the bubble level on all models will be of help in this respect.

4. Depress the clutch and turn on the viscometer's motor. following the procedure of having the clutch depressed at this point will prevent unnecessary wear. Release the clutch and allow the dial to rotate until the pointer stabilizes at a fixed position on the dial. The time required for stabilization will depend on the speed at which the spindle rotates; at speeds above 4 rpm, this will generally be about 20-30 seconds, while at lower speeds, it may take the time required for one revolution of the dial. It is possible to observe the pointer's position and stability at low speeds while the dial rotates, but at higher speeds it will be necessary to depress the clutch and snap the motor switch to stop the instrument with the pointer in view. Very little practice is needed to stop the dial at the right point.

5. If check readings are required, start the Viscometer with the clutch still depressed, holding the original reading and then release. This will speed up readings by reducing oscillation of the pointer. If pointer does not stabilize, the material may either thixotropic or its temperature may not be constant. Having the spindle at the temperature of the test material will eliminate the latter possibility.

H. CALCULATIONS

1. Readings obtained from observation of the viscometer dial need to be multiplied by a calibration factor. Each spindle and rotation speed have a different factor. Factors are found using the chart accompanying the viscometer.

2. Results are reported as centipoise or may be converted to other viscosity units.

I. PRECISION AND ACCURACY

See Quality Assurance section

J. REFERENCES

1. Operating manuals of Brookfield Instrument Company.

2. ASTM 341-77

3. ASTM D2161-74

WATER AND SEDIMENT IN PETROLEUM - CENTRIFUGE (BOTTOM SOLIDS AND WATER)

A. SCOPE AND APPLICATION

This method is applicable to oils, fuels and crude oil. The method involves selection of a number of factors such as type and amount of demulsifier, temperature of the sample during testing and the duration of centrifuging. Crudes containing asphaltenes require an aromatic solvent such as toluene. Waxy crudes require that test samples be heated to higher temperatures, emulsions present in some oils may call for the use of demulsifiers and high viscosities and finely divided suspensions often necessitate longer than normal centrifuging times.

B. SUMMARY OF METHOD

A sample is mixed with an appropriate solvent and a demulsifier if needed and is rotated in a centrifuge for a time. The amount of water and sediment is then measured and the percentages calculated from the amount of sample used.

C. APPARATUS

1. Centrifuge - capable of whirling two or more filled centrifuge tubes at a speed that can be controlled to give a relative centrifugal force (rcf) of between 500 and 800 at the tip of the tubes. The revolving head, trunion rings and trunion cups, including the cushions shall be constructed to withstand the maximum centrifugal force capable of being delivered by the power source. The trunion cups and cushions shall firmly support the tubes when the centrifuge is in motion. The centrifuge shall be enclosed by a metal shield or case strong enough to eliminate danger if any breakage occurs. Calculate the speed of the rotating head as follows:

   $$rpm = 265 \times rcf \times d$$

   where:

   rcf = relative centrifugal force, and

   d = diameter of swing in inches measured between tips of opposite tubes when in rotation position.

2. Centrifuge tubes - 100 ml, pear-shaped, bottom solids and water annealed glass tubes (such as VWR Scientific brand).

D. REAGENTS

1. The following solvents and demulsifiers have been reported as satisfactory for field testing.

Solvents	Demulsifiers
Stoddard solvent or other naphtha solvents with low aromatic content	Commercial crude oil demulsifiers
Toluene	Phenol
Xylene	Nitrogen gases
Kerosene	Naphthenic acids
White Gasoline	

2. Water-saturated toluene is the preferred solvent. Other solvents may be used when the clients involved are satisfied that they will provide equivalent results. The majority of solvents will dissolve varying amounts of water. Water saturation at either centrifuging temperature or at test temperature is imperative, but the solvent shall be free of suspended water. This may be accomplished by the addition of 2 ml of water to a centrifuge tube filled with solvent which is then placed in a bath maintained at centrifuge grindout temperature. Shaking will aid in saturation, but adequate settling time or centrifuging is necessary to ensure that the solvent is free of suspended water before use. Kerosene and Stoddard Solvent dissolve a negligible amount of water and do not require water saturation. Gasoline containing tetraethyl lead or de-icer compounds should never be used. Unleaded motor fuels generally contain aromatic compounds and require water saturation before use.

3. The use of a demulsifier is generally beneficial and may be used where comparative tests demonstrate a need. The type and concentration is not limited provided that the demulsifier itself does not contribute to the water and sediment.

E. SAMPLING AND STORAGE

The sample must be thoroughly representative of the material in question and the portion used shall be thoroughly representative of the sample. This requires the addition of a suitable amount (2-3 drops) of surfactant (Igepal 540) and the vigorous agitation of a sample before transfer to a centrifuge tube. Prior to the transfer of any sample to centrifuge tube, vigorous shaking must be repeated.

F. PROCEDURE

1. Fill the centrifuge (one or two tubes may be used) to the 50 ml mark with the oil to be tested and then to the 100 ml mark with solvent. The sample of oil is to be well mixed and poured into the centrifuge tube directly from a sample container previously shaken or from a circulating stream used for mixing, using precautions outlined in E.1. Stopper the tube and shake until the contents are thoroughly mixed. While filling the centrifuge tube first with the oil sample and then with the solvent gives a more accurate measurement of the oil sample volume, some crudes may cause deposits in the tip of the tube which are not easily removed. When tests indicate such a problem with a particular crude, the order of adding the crude oil and solvent to the centrifuge tube may be reversed. Immersed the tube in a bath or dry heating device and heat the contents of the tube to 49 +/-1°C (120 +/-1.8°F). Make every effort to ensure a

consistent sample temperature after whirling, shall not drop below 38°C (100°F) unless mutually acceptable comparative test has established that the results are unaffected by the lower temperatures.

2. If wax contributes to the volume of water and sediment observed, preheat the oil solvent mixture to 60°C (140°F) before first swirling; the final temperature of the mixture shall not drop below 52°C (125°F) with a water-saturated solvent of 46°C (115°F) otherwise. A heated centrifuge may be required to maintain this final temperature (see Appendix X1 for discussion on the effect of higher than recommended temperatures on the solubility of water in solvents).

3. Invert tube to ensure that the oil and the solvent are uniformly mixed. If shaking is necessary, proceed cautiously because the vapor pressure at 60°C (140°F) is approximately double than at 38°C (100°F). Place tubes in trunion cups on opposite sides of the centrifuge to establish a balanced condition, and whirl for 3 to 10 minutes depending upon the character of the sample, at a rate calculated from the equation given in C.1, sufficient to produce a relative centrifugal force (rcf) of between 500 and 800 at the tip of the whirling tubes.

4. Read and record the combined volume of water and sediment at the bottom of the tube to the nearest 0.05 ml from 0.1 to 1 ml graduation and to the nearest 0.1 above 1 ml graduation. Below 0.1 ml, estimate to the nearest 0.025 ml. If experience with the oil is limited, it is advisable to reheat the sample and return the tube to the centrifuge without agitation and repeat the operation until two consecutive readings are in agreement. Once an acceptable whirling time is established, this may be used without repeating by mutual consent.

5. With certain types of oil it is difficult to obtain a clean break between the oil layer and the separated water. In such cases one or more of the following remedies may be effective: 1) raise the temperature to 60°C (140°F); 2) shake the mixture between whirling in centrifuge just sufficiently to disperse the emulsion; 3) use a demulsifier or determine if a different type or an increased amount of demulsifier is needed; however, it should not contribute to the water and sediment; 4) use a different or increased amount of solvent and adjust reading and reporting procedure accordingly. After a satisfactory procedure for a particular type of oil has been worked out, it will ordinarily be found suitable for all samples of the same type.

G. CALCULATION

1. If a single tube is used, multiply the reading obtained according to procedure described in 6.3 by two and record the results as the percentage of water and sediment. For example, if a reading is 0.025 ml, record the percentage of water and sediment at 0.05. If a reading is 0.15 ml, record the percentage of water and sediment as 0.30. The percentages to be recorded can be read directly from a 200-part tube provided the tube contains 50 ml or 100 parts of oil. When the volume of oil is different than 50 ml or 100 parts, calculate the percent sediment and water as follows:

Sediment and water, % = $(S/V) \times 100$

where:

S = volume of sediment and water, ml or parts and

V = volume of oil tested, ml or parts.

2. If two tubes are used, record the final volume of water and sediment in each tube and report

the sum of these two readings as the percentage of water and sediment. Report results lower than 0.05% either as zero or 0.05, whichever is closer. With 200-part tubes, report the average of the two percentage readings.

H. PRECISION AND ACCURACY

See Quality Assurance section.

I. REFERENCES

1. ASTM D96-73

2. ASTM D1796-75

DETERMINING A RESPONSE AMPLITUDE OPERATOR AND CREATING A SEA SPECTRA BOOM RESPONSE MODEL FROM TANK TEST MEASUREMENTS

In order to model a boom's motion in a harbor chop or random sea, responses to monochromatic wave forms in the test tank are mathematically combined. The first step is to measure the monochromatic responses and either (1) determine numerical values to describe the responses or (2) digitally record the response. The first option is suitable for classifying the response and report presentations. The second option is useful for constructing models.

An analytical model was developed using Lotus 1-2-3® to predict the Oil Fence response to a four component sea spectra. Four wave periods from thirteen used in tank tests were selected. They were 7, 3.6, 2.4 and 1.7 second period waves. The model was set for the user to assign wave heights to each of the four waves. The model would then calculate the contrived water surface wave form and the response of the boom apex to that water surface over a 150-second time period. The wave patterns of the water surface and boom are presented graphically as in Figure A-1. Although the water surface wave pattern portrays a sea surface wave pattern with respect to a fixed reference, the boom wave pattern is with respect to the model sea surface. The model also provides the user with maximum and minimum boom depth values. The user quickly knows if the model sea spectra has caused the boom to come out of the water or submerge at times.

The water surface wave pattern and boom response pattern are determined using the principal of superposition. The water surface wave height model is:

$$H_T = H_1 (\text{Sin } \alpha t) + H_2 (\text{Sin } \beta t) + H_3 (\text{Sin } \delta t) + H_4 (\text{Sin } \epsilon t) \tag{3}$$

Where α, β, δ, and ϵ are the encounter frequencies in radians per second (rotational frequency) of each component waves. The user specified wave heights are : H_1, H_2, H_3, and H_4. t is lapsed time in seconds. The boom depth amplitude response model is:

$$h_T = (B_1 * W_1) + (B_2 * W_2) + (B_3 * W_3) + (B_4 * W_4) \tag{4}$$

Where:

$$W_1 = H_1 (\text{Sin } \alpha t)$$
$$W_2 = H_2 (\text{Sin } \beta t) \ldots \tag{5}$$

and the measured boom depth amplitude response values are B_1, B_2, B_3, and B_4 for the four component waves respectively.

The values of B_1, B_2, ...B_n combined are the response operator and are reported in table or graphical form. Values for B, the amplitude of the boom response, can be determined manually from a stripchart trace as in Figure A-2.

The easier way is to computer analyze digitally-recorded data using a Fourier Transform program and get a frequency magnitude response. The Fourier Program, Protocol Basic, transforms the time-based pressure data into frequency-based or periodicity-based data. The process begins with the output signal from pressure transmitters through data logging, file conversion, analysis and document printing.

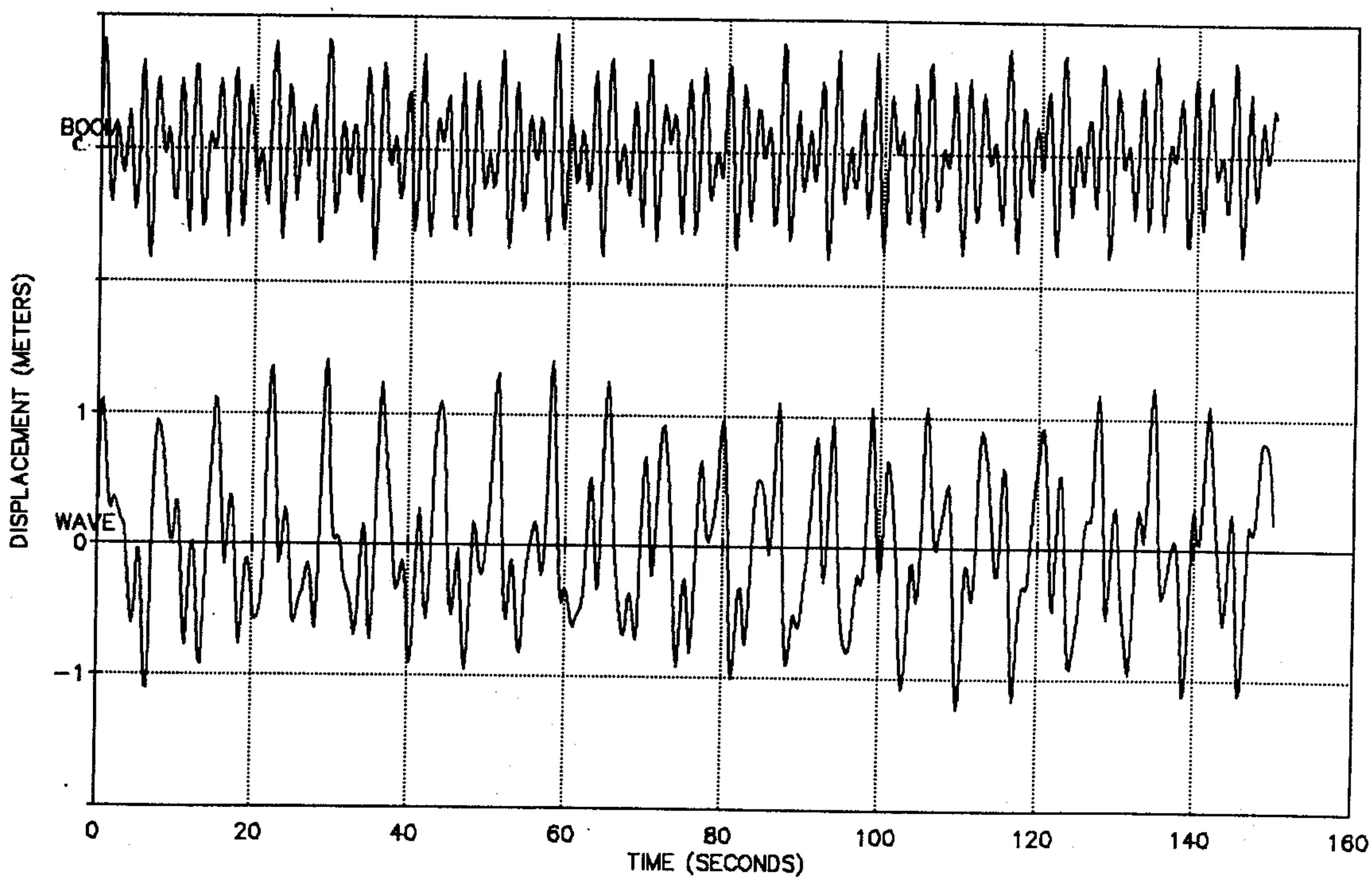


FIGURE A-1 - Boom Response Model predictions based on a four component wave spectra. The lower trace represents the surface wave the upper trace represents the boom skirt depth over the same time period.

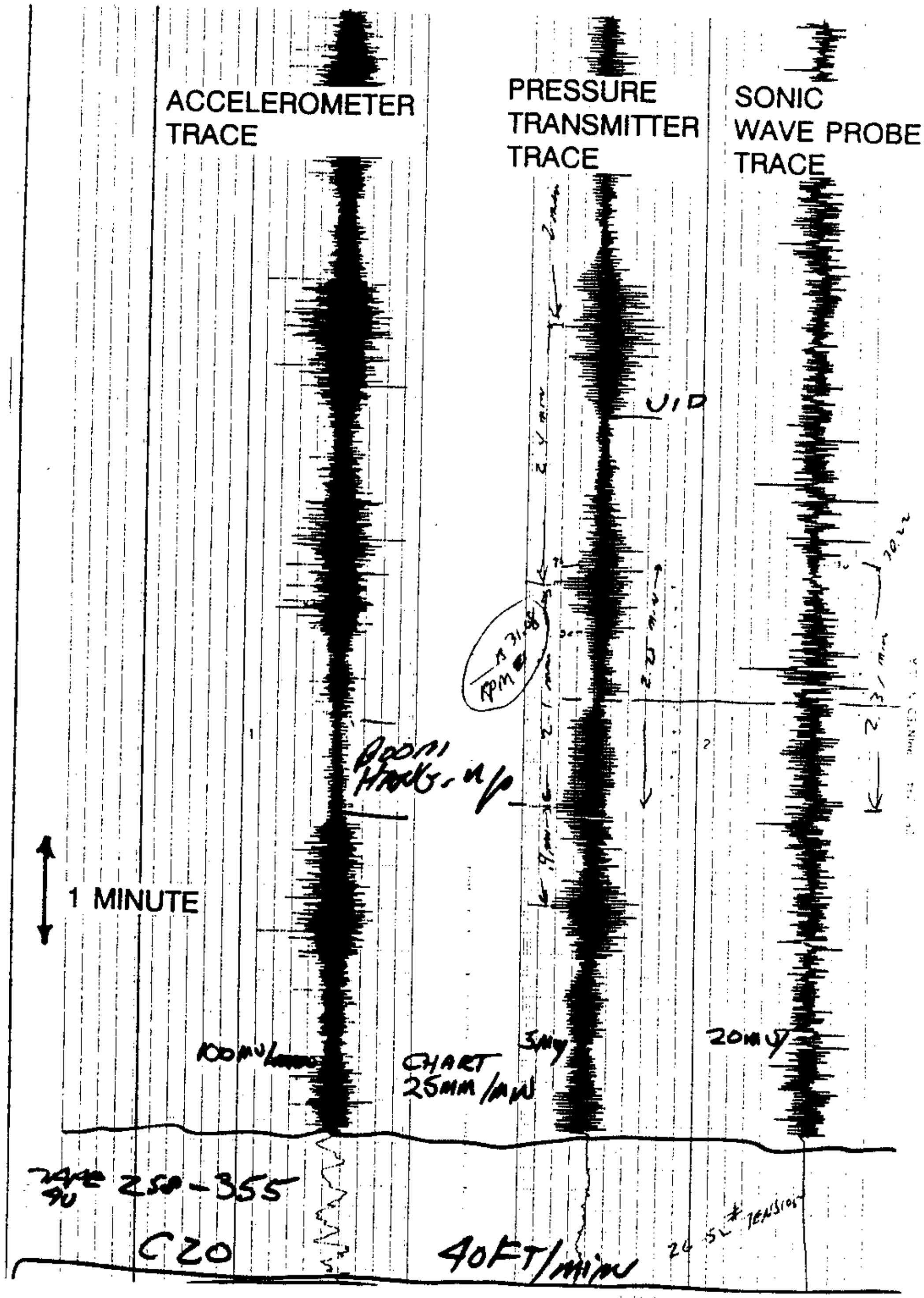


FIGURE A-2 - A recorder trace of accelerometer and pressure transmitter signals during wave tank boom testing. The value B, used for modeling, is the ratio of depth wave amplitude to the surface wave amplitude.

Figures A-3, A-4 and A-5 were generated from a system calibration exercise. A pressure transmitter was attached to a shaft that oscillated up and down in a water tank. This simulated a boom skirt rising and falling in the water column. The milliamp output signal was recorded on a Rustrak Ranger II datalogger. At the completion of several more tests, the data was downloaded to a personal computer in a "PRN" format file and then "imported" into a Lotus 1-2-3® spreadsheet to generate the time-based graph. Due to the nature of the Ranger II format, the original PRN file required editing so it could be used by the Protocol Basic program. The editing was done on the spreadsheet and a second PRN file was created by "printing" a file to disk. In the case of boom motion in a monochromatic wave, the data manipulation process will result in a monochromatic response near the same frequency of the wave. The value for B is the ratio of the response magnitude to the wave magnitude at the wave frequency.

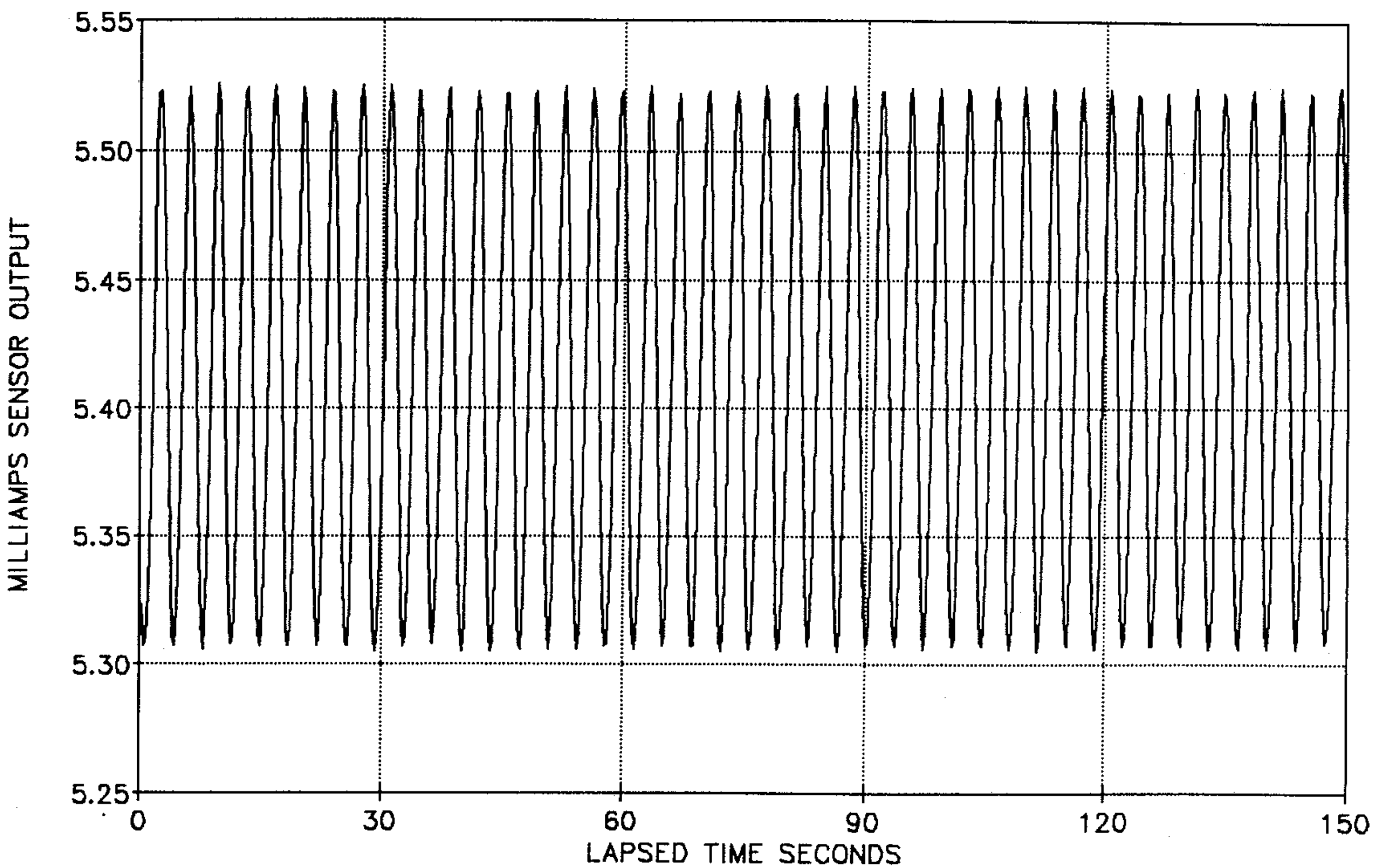


FIGURE A-3 - Time-based monochromatic signal variation from a pressure transmitter calibration exercise.

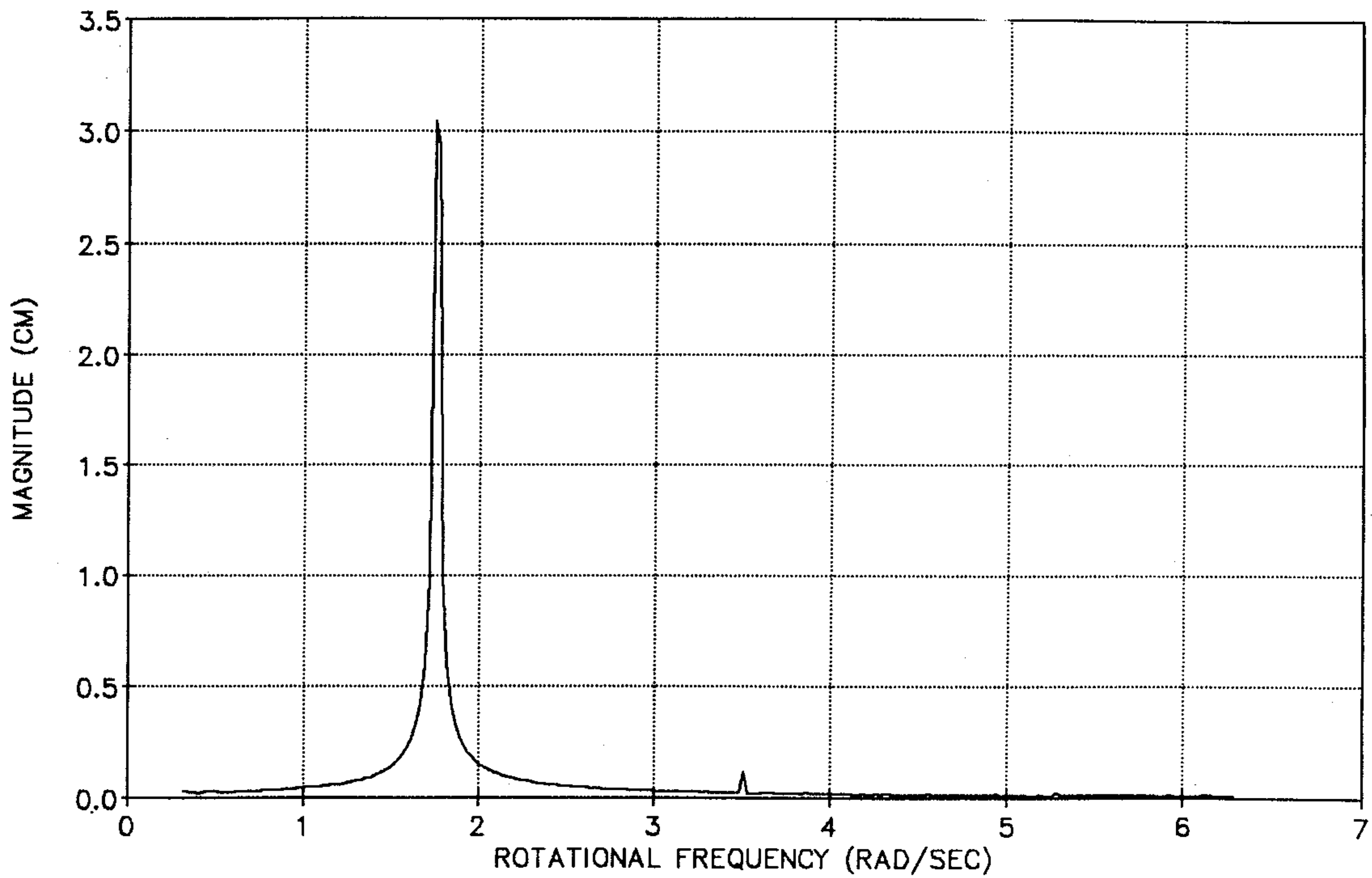


FIGURE A-4 - Frequency-based monochromatic signal graphed from Protocol Basic output.

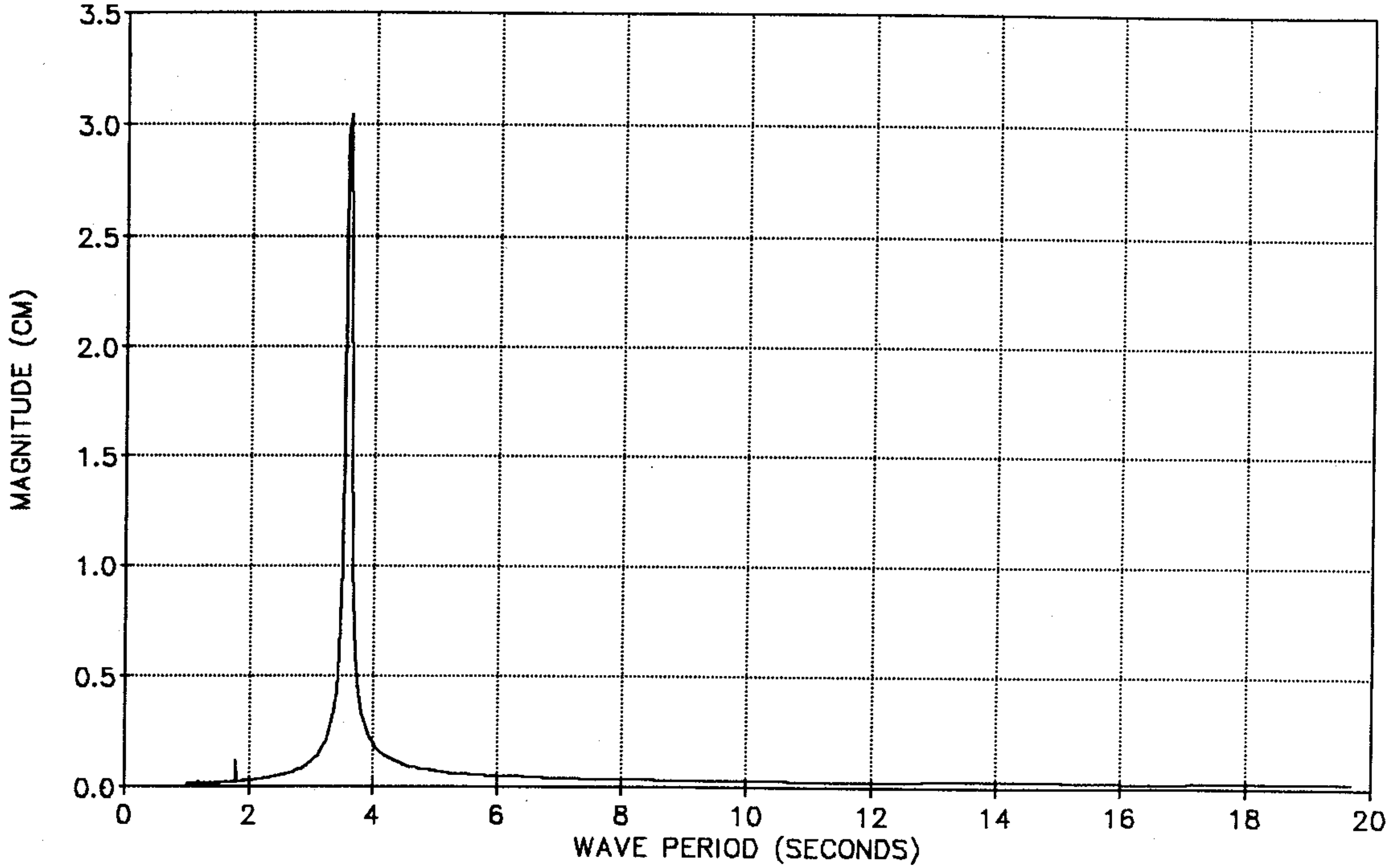


FIGURE A-5 - Periodicity-based monochromatic signal graphed from Protocol Basic output.

```
10  '   PROTOCOL.BAS (PROTO4.BAS)
20  '
30  '   BASIC PROGRAM WRITTEN TO PERFORM DATA QUALIFICATION
31  '   CALCULATING IN CONJUNTION WITH BOOM TEST PROTOCOL
32  '
33  '   THIS PROGRAM IS BELIEVED TO BE CORRECT AND FUNCTIONAL
34  '   AS WRITTEN.  IT HAS NOT BEEN REVIEWED BY AN EXTERNAL
35  '   SOURCE.  NO GAURENTEE OF CORRECTNESS OR COMPLETENESS
36  '   EXPLICIT, IMPLICIT OR OTHERWISE SHOULD BE ASSUMED.
50  '
60  '   WRITTEN FREBRUARY 1985 REVISED AUGUST 1987
70  '                 MICHAEL BORST
80  '                 MASON & HANGER - SILAS MASON CO., INC
90  '                 USEPA OHMSETT FACILITY
100 '                 POST OFFICE BOX 73
110 '                 LEONARDO, NJ  07737
 120 '                (201) 291-0680
120 '                 (201) 291-0680
130 '
131 '                 REVISIONS MADE AFTER JULY 1987 ARE
132 '                 MADE UNDER THE AUSPICES OF
133 '                 ROY F. WESTON INC.
134 '
140 '   WRITTEN TO BE USED WITH THE IBM PERSONAL COMPUTER
150 '   USING ADVANCED BASIC (MICROSOFT VERSION 1.10).
160 '   PROGRAM REQUIRES DATA TO BE STORED IN DISC FILE
170 '   IN DIMENSIONAL FORMAT. PROGRAM REQUIRES APPROXIMATELY 60K BYTES RAM.
180 '   FILE MUST CONTAIN AT LEAST 1024 DATA POINTS LOGGED AT EQUAL TIME
190 '   TIME INTERVALS FOR COMPLETE ANALYSIS, DATA MUST BE GREATER"
200 '   GREATER THAN -9999 AND LESS THAN 9999.  DATA NEED NOT BE INTIGER
210 '
220 '   DATA FILE IS SUBJECTED TO ALL REDUCTIONS OUTLINED IN
230 '                 ------PROPOSED------
240 '   TEST PROCEDURES FOR THE EVALUATION OF OFFSHORE OIL-SPILL
250 '   CONTROL BOOMS.  MB. VERSION 0. DATED 16 SEPTEMBER 1985. 40 PAGES.
260 '   PROGRAM IS APPLICABLE TO SECTIONS 3.4.4.2 THROUGH 3.4.4.3.2 INCLUSIVE
270 '
280 '   PROGRAM AND STANDARD WRITTEN UNDER THE AUSPICES OF THE
290 '   OHMSETT INTERAGENCY TECHNICAL COMMITTEE.  THE COMMITTEE IS COMPRISED
300 '   OF THE US MINERALS MANAGEMENT SERVICE, THE US COAST GUARD, THE US EPA,
310 '   THE US NAVY, AND THE CANADIAN ENVIRONMENTAL PROTECTION SERVICE.
320 '
330 '   BASED ON INFORMATION IN:
340 '
350 '   BENDAT, J.S. AND PIERSOL R.G., RANDOM DATA: ANALYSIS AND
360 '   MEASUREMENT PROCEDURES, WILEY-INTERSCIENCE NEW YORK, NY.,
370 '   1971 407 PAGES.
380 '
390 '   COMSTOCK, JOHN P. (PRINCIPLE EDITOR), PRINCIPLES OF NAVAL
400 '   ARCHITECTURE, SOC. OF NAVAL ARCHITECTS AND MARINE ENGINEERS,
410 '   NEW YORK, NY., 1980 827 PAGES.
420 '
430 '   MASON, R.D. et. al.,STATISTICS an introduction, BRACE
440 '   HARCOURT JOVANOVICH INC., NEW YORK, NY., 626 PAGES.
450 '
460 '   BAUMEISTER AND MARKS, STANDARD HANDBOOK FOR MECHANICAL ENGINEERS,
470 '   7th EDITION, McGRAW HILL, NEW YORK, NY., 1967
480 '
490 '   STANLEY, W.D., AND PETERSON, S.J. "FAST FOURIER TRANSFORMS ON
500 '   YOUR HOME COMPUTER", BYTE MAGAZINE VOL 3 NUMBER 12 DEC. 1978
510 '   PP 14-25.
520 '
530     COLOR 15,1,1 :CLS : KEY OFF : OPTION BASE 1 : WIDTH "LPT1:",130
540 '
550 '   DIMENSION ARRAYS
560 '
```

```
570     DIM DAT(1024),ANO(16,64),COLTOT(16),COLSTD(16)
580     DIM HALPHA(32),HLOWER(32),HUPPER(32),HCOUNT%(32)
590     DIM IMG(1024),MAG(513), PWR(513),RCOUNT(100)
600     DIM SIMP%(513)
610 '
620 'INTIALIZE VARIABLES
630 '
640     NPOINT=0 : SUMDAT=0 : SUM2DAT=0 :SUMTIM=0 :SUM2TIM=0 : MINDAT=9999
650     MAXDAT=-9999 :MIXUM=0 : CHISQR=0 : PI=3.14159 :PCOUNT=0
660     MAXMAG=0 : MAXPWR=0 : MXPWRF=0 : MXMAGF=0 :PRUNS=0 : NRUNS=0
670     MAGARO=0 : MAGAR2=0 : MAGAR4=0 : NPOINTS=0
680     FMT1$="\                \ ##########      ####          ####.###        ####
.####         ####.####"
690     FMT2$="      ###         #####.##      #######.###     #####.###"
700     FMT2$=FMT2$+"      #####        #####.###" : WARNING$="" : MED$=" -MEDIAN"
710     DETREND1$="":DETREND2$="":ANS$="":ANSWER$="":FORCE$=""
720     FMT3$=SPACE$(12)+"####.##" :FMT3$="          ##    "+FMT3$+FMT3$+SPACE$(7)+
"####"
721     FMT4$=FMT1$+"   ####.####" :HFIL$="" : HANS$="" : OUT1$="" :HMT$="Y"
730 '
740 '
750     INPUT "WHAT DISC DRIVE HAS THE DATA FILE ";DRIVEO$
760     IF ASC(DRIVEO$)>90 THEN PRINT "CAPS PLEASE" : BEEP
770     IF RIGHT$(DRIVEO$,1)<>":" THEN DRIVEO$=DRIVEO$+":"
780     INPUT "WHAT IS THE NAME OF THE DATA FILE ";FILEO$
790     DUMMY=INSTR(FILEO$,".")
800     IF DUMMY=0 THEN INPUT "WHAT IS THE EXTENSION";EXTO$
810     IF EXTO$<>""AND LEFT$(EXTO$,1)<>"." THEN EXTO$="."+EXTO$
820     FILEO$=DRIVEO$+FILEO$+EXTO$
821     INPUT "IS THIS A HERMIT FILE ";HMT$
830     INPUT "AUTOMATIC DETREND (Y/N) ";DETREND1$
840     DETREND1$=LEFT$(DETREND1$,1)
850     IF DETREND1$<>"Y" AND DETREND1$<>"N" THEN BEEP: PRINT "Y/N":GOTO 830
860     IF DETREND1$="N" THEN 900
870     INPUT "DO YOU WANT TO FORCE DETRENDING (Y/N)";FORCE$
880     FORCE$=LEFT$(FORCE$,1) : IF FORCE$="Y" OR FORCE$="N" THEN 900
890     PRINT "TO FORCE DETRENDING ENTER 'Y' OTHERWISE 'N'":GOTO 870
900     INPUT "DO YOU WANT TO CONVERT DATA PRIOR TO PROCESSING (Y/N) ";ANS$
910     ANS$=LEFT$(ANS$,1) : IF ANS$="N" THEN 1020 ELSE IF ANS$<>"Y" THEN 900
920     PRINT "CONVERSION AVAILABLE IS LENEAR ONLY"
930     PRINT "OUTPUT = CONSTANT + SLOPE*INPUT"
940     PRINT :INPUT "INPUT CONSTANT : ";CINTER
950     INPUT "INPUT SLOPE : ";CSLOPE
960     PRINT :PRINT "CONVERSION FUNCTION"
970     PRINT "OUTPUT = ";CINTER;
980     IF SGN(CSLOPE)<0 THEN PRINT " "; ELSE PRINT " + ";
990     PRINT CSLOPE;" * INPUT"
1000    INPUT "VERIFY AS CORRECT (Y/N) ";ANSWER$ : ANSWER$=LEFT$(ANSWER$,1)
1010    IF ANSWER$="Y" THEN 1020 ELSE IF ANSWER$="N" THEN 940 ELSE 1000
1020    INPUT "WHERE SHALL THE OUTPUT BE ROUTED ";OUT1$
1021    IF OUT1$="" THEN OUT1$="PRN"
1029    PRINT "IF EITHER OUTPUT FILE IS NOT WANTED TYPE 'NONE'"
1030    INPUT "WHAT IS THE NAME FOR THE MAGNITUDE SPECTRUM FILE ";MAGFIL$
1040    IF MAGFIL$="NONE" THEN 1140
1050    DUMMY=INSTR(MAGFIL$,":") : IF DUMMY <>0 THEN 1090
1060    PRINT "THE DEFAULT DISK DRIVE IS ASSUMED "
1070    INPUT "CORRECT (Y/N) ";ANSWER$
1080    ANSWER$=LEFT$(ANSWER$,1) : IF ANSWER$<>"Y" THEN 1030
1090    DUMMY=INSTR(MAGFIL$,".")
1100    IF DUMMY=LEN(MAGFIL$)-3 AND DUMMY<>0 THEN 1140
1110    PRINT "EXTENSION MISSING OR LESS THAN 3 CHAR'S"
1120    INPUT "CORRECT AS IS (Y/N) ";ANSWER$
1130    ANSWER$=LEFT$(ANSWER$,1) : IF ANSWER$<>"Y" THEN 1030
1140    INPUT"WHAT IS THE NAME FOR THE POWER SPECTRAL DENSITY FILE ";PWRFIL$
1150    IF PWRFIL$="NONE" THEN 1260
1160    DUMMY=INSTR(PWRFIL$,":")
```

```
1170     IF DUMMY<>0 THEN 1210
1180     PRINT "DEFAULT DRIVE ASSUMED ";
1190     INPUT "IS THIS CORRECT (Y/N) ";ANSWER$
1200     ANSWER$=LEFT$(ANSWER$,1) : IF ANSWER$<>"Y" THEN 1140
1210     DUMMY=INSTR(PWRFIL$,".") : IF DUMMY=LEN(PWRFIL$)-3 AND DUMMY<>0 THEN 125
0
1220     PRINT "EXTENSION MISSING OR LESS THAN 3 CHAR'S "
1230     INPUT "CORRECT AS IS (Y/N) ";ANSWER$ : ANSWER$=LEFT$(ANSWER$,1)
1240     IF ANSWER$<>"Y" THEN 1140
1250     ON ERROR GOTO 4720
1260     INPUT "DO YOU WISH TO SAVE HISTOGRAM DATA TO THE DISK ";HANS$
1261     HANS$=LEFT$(HANS$,1)
1262     IF HANS$="N" THEN 1269 ELSE IF HANS$<>"Y" THEN PRINT "Y/N ONLY" : GOTO 1
260 ELSE INPUT "FILE NAME ";HFIL$
1263     DUMMY=INSTR(HFIL$,".")
1264     IF LEN(HFIL$)-DUMMY=3 THEN 1267
1265     INPUT "EXTENSION IS MISSING OR LESS THAN 3 CHAR'S. OK?";HANS$
1266     HANS$=LEFT$(HANS$,1) : IF HANS$="N" THEN HANS$="" : GOTO 1262
1267     DUMMY=INSTR(HFIL$,":")
1268     IF DUMMY=0 THEN PRINT "DEFAULT DRIVES ASSUMED"
1269     OPEN FILEO$ FOR INPUT AS #1
1270     IF HMT$<>"Y" THEN 1279
1271     FOR I=1 TO 19
1272         LINE INPUT #1,A$ : PRINT A$
1273         NEXT I
1279     IF EOF(1) THEN 1310
1280     IF HMT$<>"Y" THEN INPUT #1,DUMMY ELSE INPUT #1,DUMMY,DUMMY
1290     NPOINT=NPOINT+1
1300     GOTO 1279
1310     CLOSE
1320     PWR2=LOG(NPOINT)/LOG(2) : IPWR2=INT(PWR2)
1321     IF IPWR2>10 THEN IPWR2=10
1322     NPOINTS=INT(2^IPWR2)
1330     INPUT "WHAT IS THE TIME SPACING (SEC) ";DT
1340     INPUT "WHAT IS THE UNIT OF THE DATA SET ";UNIT$
1350     IF UNIT$="FEET" OR UNIT$="FOOT" OR UNIT$="FT" THEN G=32.174
1360     IF UNIT$="M" OR UNIT$="METER" THEN G=9.810001
1370     IF UNIT$="CM" OR UNIT$="CENTIMETER" THEN G=981
1380     IF UNIT$="BCD" THEN G=1
1390     IF G<>0 THEN 1420
1400     PRINT "WITH UNITS OF ";UNIT$;" I DO NOT KNOW THE VALUE OF G"
1410     INPUT "WHAT IS THE VALUE OF G (1 FOR NOT IMPORTANT)";G
1420     TOTTIM=NPOINTS*DT : RES=1/NPOINTS/DT
1430     IF NPOINT=NPOINTS THEN 1650
1440     PRINT "THIS PROGRAM WILL ANALYZE ONLY AN EXACT POWER OF 2 DATA POINTS"
1441     PRINT " TO A MAXIMUM OF 1024 DATA POINTS"
1450     PRINT "THE SPECIFIED FILE (";FILEO$;") CONTAINS ";NPOINT
1460     PRINT "THE MAXIMUM POWER OF 2 IS ";INT(PWR2);" OR ";NPOINTS
1480     PRINT "PROGRAM REQUIRES APPROXIMATELY 8:30 FROM THIS POINT"
1490     IF NPOINT=NPOINTS THEN NSKIP=0 : GOTO 1650
1500     PRINT "THE PROGRAM REQUIRES EXACTLY ";NPOINT;" DATA POINTS "
1510     PRINT "THE SPECIFIED FILE CONTAINS ";NPOINT
1520     PRINT "YOU CAN (1) SELECT DATA STARTING WITH #1"
1530     PRINT "           (2) SELECT DATA ENDING WITH #";NPOINT
1540     PRINT "           (3) CHOOSE THE MIDDLE MOST POINTS "
1541     PRINT "           (4) SPECIFY THE NUMBER OF DATA POINT TO SKIP AT THE START
 OF THE FILE"
1550     PRINT "           (5) TERMINATE THE PROGRAM HERE ";
1560     INPUT "SELECTION : ";ANSWER
1570     IF ANSWER <> INT (ANSWER) OR ANSWER<1 OR ANSWER>5 THEN CLS : GOTO 1500
1580     IF ANSWER=1 THEN NSKIP=0 : GOTO 1650
1590     IF ANSWER=2 THEN NSKIP=NPOINT-NPOINTS-1 : GOTO 1650
1600     IF ANSWER=3 THEN NSKIP=(NPOINT-NPOINTS)\2 : GOTO 1650
1601     IF ANSWER=5 THEN PRINT "TERMINATED AT USERS REQUEST ";END
1610     IF ANSWER=4 THEN INPUT "SKIP HOW MANY POINTS ";NSKIP
1620     IF NPOINT-NPOINTS=>NSKIP THEN 1650
```

```
1630     BEEP : PRINT "IMPOSSIBLE REQUEST.  MAXIMUM SKIP IS ";NPOINT-NPOINTS : GO
TO 1610
1650     OPEN FILEO$ FOR INPUT AS #1
1651     BEGIN$=DATE$+" "+TIME$
1652     IF HMT$<>"Y" THEN 1660
1653     FOR I=1 TO 19 : LINE INPUT #1,DUMMH$: NEXT I  'SKIP HERMIT HEADER
1660     IF NSKIP=0 THEN 1700
1670     FOR I=1 TO NSKIP
1680         IF HMT$<>"Y" THEN INPUT #1,DUMMY ELSE INPUT #1,DUMMY,DUMMY

1690         NEXT I                                          'SKIP DATA AS SPECIFIED
1700     FOR I=1 TO NPOINTS
1710         IF EOF(1) THEN 1750                             'INPUT DATA FROM FILE
1730         IF HMT$<>"Y" THEN INPUT #1,DAT(I) ELSE INPUT #1,DUMMY,DAT(I)
1740         NEXT I
1750     CLOSE
1760     IF ANS$<>"Y" THEN 1810
1770     FOR I=1 TO NPOINTS
1780         DAT(I)=DAT(I)*CSLOPE+CINTER                     'USER-DEFINED CONVERSION
1790         NEXT I
1810     FOR I=1 TO NPOINTS
1820         SUMDAT=SUMDAT+DAT(I)                            'SUM OF DATA
1830         SUM2DAT=SUM2DAT+DAT(I)^2                        'SUM OF SQUARES OF DATA
1840         SUMTIM=(I-1)*DT+SUMTIM                          'SUM OF ELAPSED TIMES
1850         SUM2TIM=SUM2TIM+((I-1)*DT)^2                    'SUM OF SQUARES OF TIMES
1860         MIXSUM=MIXSUM+DAT(I)*(I-1)*DT                   'MIXED SUM
1870         IF MINDAT>DAT(I) THEN MINDAT=DAT(I)             'DATA MINIMUM
1880         IF MAXDAT<DAT(I) THEN MAXDAT=DAT(I)             'DATA MAXIMUM
1890         NEXT I
1900     AVEDAT=SUMDAT/NPOINTS                               'DATA AVERABE
1910     VARDAT=(SUM2DAT-SUMDAT^2/NPOINTS)/(NPOINTS-1)  'DATA VARIANCE
1920     STDDAT=SQR(ABS(VARDAT))                             'DATA STANDARD DEVIATION
1930     RANDAT=MAXDAT-MINDAT                                'DATA RANGE
1940     RMSDAT=SQR(SUM2DAT/NPOINTS)                         'ROOT MEAN SQUARE
1950     MSQDAT=SUM2DAT/NPOINTS                              'MEAN SQUARE
1960     SLOPE=(NPOINTS*MIXSUM-SUMTIM*SUMDAT)/(NPOINTS*SUM2TIM-SUMTIM^2)
1970     INTER=(SUMDAT-SLOPE*SUMTIM)/NPOINTS
1980     DUMMY=(NPOINTS*SUM2TIM-SUMTIM^2)*(NPOINTS*SUM2DAT-SUMDAT^2)
1990     COCOR=(NPOINTS*MIXSUM-SUMDAT*SUMTIM)/SQR(ABS(DUMMY))
2000     TSTAT=SQR(NPOINTS-2)*COCOR/SQR(ABS(1-COCOR^2))
2001     OPEN OUT1$ FOR APPEND AS #1
2010     PRINT #1, CHR$(12);CHR$(15);                        'NEW PAGE, COND PRINT
2011     PRINT #1, "      PRELIMINARY ANALYSIS PER OHMSETT TECHNIQUES" : PRINT #1,
2020     PRINT #1, "      PRELIMINARY STATISTICS ";DETREND2$
2030     PRINT #1, "      FILE NAME                                  ";FILEO$
2040     PRINT #1, USING "      POINTS AVAILABLE                ####";NPOINT
2050     PRINT #1, USING "      POINTS ANALYZED                 ####";NPOINTS
2060     PRINT #1, USING "      LEADING POINTS SKIPPED          ####";NSKIP
2061     PRINT #1, USING "      TRAILING POINTS SKIPPED         ####";NPOINT-NPOINTS-
NSKIP
2080     PRINT #1, USING "      DATA AVERAGE                    ####.###";AVEDAT
2090     PRINT #1, USING "      DATA MAXIMUM                   #####.###";MAXDAT
2095     PRINT #1, USING "      DATA MINIMUM                   #####.###";MINDAT
2100     PRINT #1, USING "      DATA RANGE                     #####.###";RANDAT
2120     PRINT #1, USING "      DATA STANDARD DEVIATION         ####.###";STDDAT
2130     PRINT #1, USING "      DATA VARIANCE                  #####.###";VARDAT
2140     PRINT #1, USING "      DATA MEAN SQUARE               #####.###";MSQDAT
2150     PRINT #1, USING "      DATA ROOT MEAN SQUARE          #####.###";RMSDAT
2151     PRINT #1, USING "      DATA ANALYSIS BEGAN            \              \
";BEGIN$
2160     PRINT #1, SPACE$(5);:FOR I=1 TO 65 : PRINT #1, "_";:NEXT I : PRINT #1,
2170     PRINT #1, SPACE$(5);:FOR I=1 TO 65 : PRINT #1, "_";:NEXT I : PRINT #1, :
 PRINT #1,
2180     PRINT #1, "      LEAST-SQUARES REGRESSION RESULTS (TIME ON DATA)"
2190     PRINT #1, SPACE$(5);:FOR I=1 TO 33 : PRINT #1, "_";: NEXT I : PRINT #1,
2200     PRINT #1, USING "         SLOPE                      ####.####";SLOPE;
```

```
2210     PRINT #1, " ";UNIT$;" /SEC"
2220     PRINT #1, USING "          INTERCEPT                                   ####.####";INTER;
2230     PRINT #1, " ";UNITS
2240     PRINT #1, USING "          COEFFICIENT OF CORRALATION       ##.####";COCOR
2250     PRINT #1, USING "          STUDENT T-TEST STATISTIC        ###.####";TSTAT
2260     PRINT #1, : PRINT #1, "        LEAST-SQUARES REGRESSION SHOWS THAT LINEAR
TREND ";
2270     IF ABS(TSTAT)>1.96 THEN PRINT #1, "IS "; : GOTO 2300
2280     IF ABS(TSTAT)<1! THEN PRINT #1, "IS NOT ";: GOTO 2300 ELSE PRINT "MAY BE
 ";
2300     PRINT #1, "SIGNIFICANT"
2310     IF FORCE$="Y" THEN PRINT #1, "      FORCED"; :GOTO 2320 ELSE IF DETREND1$
="N" OR ABS(TSTAT)<1! THEN 2400
2320     PRINT #1, "      AUTOMATID DETREND IS ON --- RECOMPUTING" : FORCE$=""
2321     CLOSE 1
2330     FOR I=1 TO NPOINTS
2340         DAT(I)=DAT(I)-(INTER+I*DT*SLOPE)              'REMOVE TIME TREND
2350         NEXT I
2360     SUMDAT=O : SUM2DAT=0 : SUMTIM=0 : SUM2TIM=0 : MAXDAT=-9999
2370     MINDAT=9999 : MIXSUM=0 : DETREND1$="" : DETREND2$="DE-TRENDED DATA"
2380     GOTO 1810
2400 '
2410 '   ANALYSIS OF VARIANCE
2420 '
2430     FOR J=1 TO 16
2440         FOR I=1 TO INT(NPOINTS/16)
2450             ANO(J,I)=DAT((J-1)*INT(NPOINTS/16)+I)
2460             NEXT I
2470         NEXT J
2480     FOR J=1 TO 16
2490         COLTOT(J)=0
2500         COLSTD(J)=0
2510         FOR I=1 TO INT(NPOINTS/16)
2520             COLTOT(J)=COLTOT(J)+ANO(J,I)
2530             COLSTD(J)=COLSTD(J)+ANO(J,I)^2
2540             NEXT I
2550         NEXT J
2560     FOR I=1 TO 16
2570         SSQTRT=SSQTRT+COLTOT(I)^2/INT(NPOINTS/16)
2580         COLSTD(I)=SQR(ABS((COLSTD(I)-COLTOT(I)^2/INT(NPOINTS/16))/INT(NPOINT
S/16)-1))
2590         NEXT I
2600     SSQERR=SSQTRT
2610     SSQTRT=SSQTRT-(SUMDAT)^2/NPOINTS
2620     SSQERR=SUM2DAT-SSQERR
2630     ANOVAF=(SSQTRT/15)/(SSQERR/(NPOINTS-16))
2640     SSQTOT=SUM2DAT-(SUMDAT^2/NPOINTS)
2650     PRINT #1, SPACE$(5);:FOR I=1 TO 65 : PRINT #1, "_";:NEXT I : PRINT #1,
2660     PRINT #1, SPACE$(5);:FOR I=1 TO 65 : PRINT #1, "¯";:NEXT I : PRINT #1,
2670     PRINT #1, "      ANOVA TEST RESULTS ";DETREND2$
2680     PRINT #1, "      SOURCE          SS           df                MS
F"
2690     PRINT #1, SPACE$(5);:FOR I=1 TO 65 : PRINT #1, "_";:NEXT I : PRINT #1,
2700     PRINT #1, USING FMT1$;"     TOTAL      ",SSQTOT,NPOINTS-1,SSQTOT/(NPOINTS
-1)
2710     PRINT #1, USING FMT4$;"     TIME       ",SSQTRT,15,SSQTRT/15,ANOVAF
2720     PRINT #1, USING FMT1$;"     RESIDUAL   ",SSQERR,(NPOINTS-16-1),SSQTOT/(NP
OINTS-16-1)
2730     PRINT #1, :PRINT #1, SPACE$(5);:FOR I=1 TO 65 : PRINT #1, "_";:NEXT I :
PRINT #1,: PRINT #1,
2740     PRINT #1, "      ANALYSIS OF VARIANCE INDICATES THAT THE DATA SETS ARE ";
2750     IF ANOVAF=>1.67 THEN PRINT #1, "NOT ";
2760     PRINT #1, "EQUIVELANT"
2761     PRINT #1, "      THERE WERE ";16*INT(NPOINTS/16);" POINTS USED IN THE ANO
VA TEST"
2762     PRINT #1, "      THERE WERE ";INT(NPOINTS/16);" POINTS IN EACH OF THE 16
```

```
SUBSETS"
2770    PRINT #1, SPACE$(5);:FOR I=1 TO 65 : PRINT #1, "_";:NEXT I:PRINT #1,
2780    PRINT #1, "      SET STATISTICS "
2790    PRINT #1, SPACE$(5);:FOR I=1 TO 14 : PRINT #1, "_";: NEXT I : PRINT #1,
2800    PRINT #1, USING"\           \   \      \    \      \";"       SET","AVERAGE"
,"STD.DEV"
2810    FOR I=1 TO 16
2820         PRINT #1, USING "      ##       ####.###      ###.####"; I,COLTOT(I)/INT
(NPOINTS/16),COLSTD(I)
2830         NEXT I
2840 '
2850 '  NORMALITY TEST
2860 '
2870    DATA -100,-1.862,-1.534,-1.318,-1.151,-1.01,-.887
2880    DATA -.776,-.675,-.579,-.489,-.402,-.319,-.237,-.157
2890    DATA -.078,0,.078,.157,.237,.319,.402,.489,.579,.675
2900    DATA .776,.887,1.01,1.151,1.318,1.534,1.862
2910    FOR I=1 TO 32
2920         READ HALPHA(I)                             'CUMULATIVE NORMAL VALUES
2930         HUPPER(I)=AVEDAT-HALPHA(I)*STDDAT          'LOWER LIMITS OF RANGES
2940         NEXT I
2950    FOR I=2 TO 32
2960         HLOWER(I-1)=HUPPER(I)                      'UPPER LIMITS OF RANGES
2970         NEXT I
2980    HLOWER(32)=AVEDAT-100*STDDAT                    'EXTREME LOWER LIMIT
2990    FOR J=1 TO NPOINTS
3000         FOR I=1 TO 32
3010              IF DAT(J)<=HLOWER(I) THEN 3050        'GROUP DATA
3020              IF DAT(J)>HUPPER(I) THEN 3050
3030              HCOUNT%(I)=HCOUNT%(I)+1
3040              GOTO 3060
3050              NEXT I
3060         NEXT J
3070    PRINT #1, CHR$(12);"      NORMALITY RESULTS ";DETREND2$
3080    PRINT #1, SPACE$(5);:FOR I=1 TO 18 : PRINT #1, "_";: NEXT I : PRINT #1,
3090    PRINT #1, "      INTERVAL","      ALPHA","      LOWER","      UPPER","      C
OUNT","CHI"
3100    PRINT #1, "      NUMBER","","      LIMIT","      LIMIT","","SQUARE"
3110    PRINT #1, SPACE$(5);:FOR I=1 TO 75 : PRINT #1, "_";:NEXT I:PRINT #1,
3120    DUMMY=0
3130    FOR I=1 TO 32
3140         DUMMY=DUMMY+HCOUNT%(I)
3150         PRINT #1, USING FMT2$;I,HALPHA(33-I),HLOWER(I),HUPPER(I),HCOUNT%(I),
(HCOUNT%(I)-(NPOINTS/32))^2/(NPOINTS/32);
3160         IF DUMMY>NPOINTS/2 THEN PRINT #1, MED$;: MED$=""
3170         IF HLOWER(I)<AVEDAT AND HUPPER(I)=>AVEDAT THEN PRINT #1, " -AVERAGE"
;
3180         PRINT #1,
3190         IF HCOUNT%(I)<5 THEN WARNING$="ONE OR MORE RANGES HAVE LESS THAN FIV
E --- CHI-SQUARE TEST MAY BE MISAPPLIED
3200         NEXT I
3210    PRINT #1, SPACE$(5);:FOR I=1 TO 75 : PRINT #1, "_";:NEXT I : PRINT #1,
3211    HEXPECT=NPOINTS/32                              'EXPECTED POINTS PER DIVIS
ION
3220    FOR I=1 TO 32
3230         PCOUNT=PCOUNT+HCOUNT%(I)
3240         CHISQR=CHISQR+(HCOUNT%(I)-HEXPECT)^2/HEXPECT
3250         NEXT I
3260    PRINT #1, "      CHI SQUARE IS ";CHISQR;" AND ";
3270    PRINT #1, "TOTAL POINTS ACCOUNTED FOR ";PCOUNT
3280    PRINT #1, "      DATA ";
3290    IF CHISQR>26 THEN PRINT #1, "FAILS "; ELSE PRINT #1,"PASSES ";
3300    PRINT #1," CHI-SQUARE TEST FOR NORMALITY " :PCOUNT=0
3301    PRINT #1,"       EXPECTED NUMBER OF POINTS PER DIVISION IS ";HEXPECT
3310    PRINT #1, SPACE$(5);WARNING$ : MED$=" -MEDIAN"
3320    PRINT #1, SPACE$(5);:FOR I=1 TO 75 : PRINT #1, "_";:NEXT I : PRINT #1,
```

```
3330    IF CHISQR<26 THEN 3560
3340    FOR I=1 TO 32
3350        HCOUNT%(I)=0 : HLOWER(I)=(I-1)*RANDAT/32+MINDAT
3360        HUPPER(I)=I*RANDAT/32+MINDAT
3370        NEXT I
3380    FOR I=1 TO NPOINTS
3390        DUMMY=INT((DAT(I)-MINDAT)*32/RANDAT)+1
3400        IF DUMMY>32 THEN DUMMY=32
3410        HCOUNT%(DUMMY)=HCOUNT%(DUMMY)+1
3420        NEXT I
3430    PRINT #1, CHR$(12);"      HISTOGRAM DATA ";DETREND2$
3440    PRINT #1, SPACE$(5);:FOR I=1 TO 14 : PRINT #1, "_";: NEXT I : PRINT #1,
3450    PRINT #1, "      INTERVAL","                 LOWER","     UPPER","      COUNT"
3460    PRINT #1, "      NUMBER","                 LIMIT","     LIMIT"
3470    PRINT #1, SPACE$(5);:FOR I=1 TO 55 : PRINT #1, "_";:NEXT I : PRINT #1,
3471    IF HFIL$<>"" THEN OPEN HFIL$ FOR APPEND AS #2
3480    FOR I=1 TO 32
3490        PRINT #1, USING FMT3$;I,HLOWER(I),HUPPER(I),HCOUNT%(I);
3491        IF HFIL$<>"" THEN PRINT #2, USING FMT3$;I,HLOWER(I),HUPPER(I),HCOUNT
%(I)
3500        PCOUNT=PCOUNT+HCOUNT%(I)
3510        IF PCOUNT>NPOINTS/2 THEN PRINT #1, MED$;:MED$=""
3520        IF HLOWER(I)<AVEDAT AND HUPPER(I)=>AVEDAT THEN PRINT #1, " -AVERAGE"
;
3530        PRINT #1,
3540        NEXT I
3541    IF HFIL$<>"" THEN CLOSE 2
3550    PRINT #1, SPACE$(5);:FOR I=1 TO 55 : PRINT #1, "_";:NEXT I : PRINT #1,
3560 '
3570 ' RUN TEST
3580 '
3590    FOR I=1 TO 100
3600        FOR J=1 TO INT(NPOINTS/100)
3610            RCOUNT(I)=RCOUNT(I)+DAT((I-1)*INT(NPOINTS/100)+J)^2
3620            NEXT J
3630        RCOUNT(I)=RCOUNT(I)/INT(NPOINTS/100)
3640        NEXT I
3650    FOR I=1 TO 100
3660        RCOUNT(I)=SGN(RCOUNT(I)-MSQDAT)
3670        NEXT I
3680    FOR I=2 TO 100
3690        IF RCOUNT(I)=RCOUNT(I-1) OR RCOUNT(I)=0 THEN 3710
3700        IF RCOUNT(I)>0 THEN PRUNS=PRUNS+1 ELSE NRUNS=NRUNS+1
3710        NEXT I
3720    TOTRUN=NRUNS+PRUNS
3730    PRINT #1, : PRINT #1, "      STATIONARITY TEST RESULTS ";DETREND2$
3740    PRINT #1, SPACE$(5);:FOR I=1 TO 25 : PRINT #1, "_";: NEXT I : PRINT #1,
3750    PRINT #1, "      RUN TEST SHOWS ";TOTRUN;"RUNS"
3760    PRINT #1, "      THERE WERE ";PRUNS;"POSITIVE RUNS AND ";
3770    PRINT #1, "AND ";NRUNS;" NEGATIVE RUNS"
3780    PRINT #1, "      STATIONARITY SHOULD ";
3790    IF TOTRUN>61 OR TOTRUN<40 THEN PRINT #1, "NOT ";
3800    PRINT #1, "BE PRESUMED IN THE DATA SET"
3810    PRINT #1, "      STATIONARITY TESTED USING MEAN SQUARE OF ";INT(NPOINTS/1
00);" POINTS"
3830    PRINT #1, CHR$(12);"      PERIODICITY TEST RESULTS"
3840    PRINT #1, SPACE$(5);:FOR I=1 TO 23 : PRINT #1, "_";: NEXT I : PRINT #1,
3850 '
3860 ' FOURIER TRANSFORMATION
3870 '
3880    FOR I=1 TO NPOINTS
3890        DAT(I)=(DAT(I)-AVEDAT)/NPOINTS              'FFT OF DIFFERENCES FROM
3900        IMG(I)=0                                    'FROM AVERAGE SO THAT OC
3910        NEXT I                                      'COMPONENT EQUALS ZERO
3920    I1=NPOINTS/2 : I2=1 : NU=2*PI/NPOINTS
3930    FOR I=1 TO IPWR2
```

```
3940        I3=0 : I4=I1
3950        FOR K=1 TO I2
3960            X=I3/I1
3970            GOSUB 4540
3980            I5=Y
3990            Z1=COS(I5*NU) : Z2=-SIN(I5*NU)
4000           .FOR M=I3+1 TO I4
4010                A1=DAT(M) : A2=IMG(M)
4020                B1=Z1*DAT(M+I1)-Z2*IMG(M+I1)
4030                B2=Z2*DAT(M+I1)+Z1*IMG(M+I1)
4040                DAT(M)=A1+B1 : IMG(M)=A2+B2
4050                DAT(M+I1)=A1-B1 : IMG(M+I1)=A2-B2
4060                NEXT M
4070            I3=I3+2*I1 : I4=I4+2*I1
4080            NEXT K
4090      I1=I1/2 : I2=I2*2
4100      NEXT I
4101   CLOSE 1
4110   IF MAGFIL$<>"NONE" THEN OPEN MAGFIL$ FOR APPEND AS #1
4120   IF PWRFIL$<>"NONE" THEN OPEN PWRFIL$ FOR APPEND AS #2
4130   FOR I=1 TO NPOINTS/2+1
4140       X=I-1 : GOSUB 4630
4150       MAG(I)=2*DUMMY
4160       IF MAG(I)>MAXMAG THEN MAXMAG=MAG(I):MXMAGF=I*RES
4170       PWR(I)=2*(DUMMY)^2/NPOINTS*DT
4180       IF PWR(I)>MAXPWR THEN MAXPWR=PWR(I) : MXPWRF=I*RES
4190       IF MAGFIL$<>"NONE" THEN PRINT #1,I-1,MAG(I)
4200       IF PWRFIL$<>"NONE" THEN PRINT #2,I-1,PWR(I)
4210       NEXT I
4220   CLOSE
4221   OPEN OUT1$ FOR APPEND AS #1
4230   SIMP%(1)=1 :SIMP%((NPOINTS/2)+1)=1
4240   FOR I=2 TO NPOINTS/2 STEP 2
4250       SIMP%(I)=4 : SIMP%(I+1)=2
4260       NEXT I
4270   FOR I=1 TO NPOINTS/2+1
4280       MAGARO=MAGARO+SIMP%(I)*MAG(I)^2/6
4290       MAGAR2=MAGAR2+SIMP%(I)*MAG(I)^2/6*((I-.5)*RES*2*PI)^2
4300       MAGAR4=MAGAR4+SIMP%(I)*MAG(I)^2/6*((I-.5)*RES*2*PI)^4
4310       NEXT I
4320   PRINT #1, "       MAGNITUDE SPECTRUM FILE : ";MAGFIL$
4330   PRINT #1, "       POWER DENSITY SPECTRUM FILE : ";PWRFIL$
4340   PRINT #1, "       ";NPOINTS;" DATA POINTS ANALYZED WITH ";DT;"SECOND SPACI
NG"
4350   PRINT #1, "       RESULTING INTERNAL SPECTRAL RESOLUTION ";RES;" HZ"
4360   PRINT #1, "       RESULTING NYQUIST FREQUENCY ";(NPOINTS/2-1)*RES;" Hz"
4370   PRINT #1, "       OTHER HARMINICS WITH POWER MAGNITUDES > MAX/3"
4380   PRINT #1, "       HARMONIC","FREQUENCY","MAGNITUDE"
4390   FOR I=1 TO NPOINTS/2
4400       IF PWR(I)<MAXPWR/3 AND PWR(I)<>MAXPWR THEN 4420
4410       PRINT #1, "       ";I-1,(I-1)*RES,PWR(I)
4420       NEXT I
4430   PRINT #1, "       MAXIMUM MAGNITUDE LOCATED AT  ";MXMAGF;" Hz"
4440   PRINT #1, "       MAXIMUM POWER DENSITY LOCATED AT  ";MXPWRF;" Hz  ";MAXPW
R;" ";UNITS$;"^2-SEC"
4450   PRINT #1, USING "       ZERO-TH MOMENT = ####.###";MAGARO
4460   PRINT #1, USING "       SECOND MOMENT = ####.###";MAGAR2
4470   PRINT #1, USING "       FOURTH MOMENT = ####.###";MAGAR4 : PRINT #1,
4480   PRINT #1, : PRINT #1, "      4.0*";CHR$(251);"E =";4!*SQR(MAGARO);UNIT$
4490   PRINT #1, "      2";CHR$(227);CHR$(251);"(E/M2) = ";2*PI*SQR(MAGARO/MAGAR
2);" SEC
4500   PRINT #1,"     2";CHR$(227);"g";CHR$(251);"(E/M4) = ";2*PI*G*SQR(MAGARO/M
AGAR4);UNITS$
4510   PRINT #1,"       ***** g= ";G ;" ";UNIT$"/SEC^2"
4520   PRINT #1, "      DATA ANALYSIS COMPLETE AT ";DATE$;"  ";TIME$
4521   CLOSE #1
```

```
4530    END
4540 '
4550 'SCRAMBLER CUBROUTINE
4560 '
4570    Y=0 : N1=NPOINTS
4580    FOR W=1 TO IPWR2
4590        N1=N1/2
4600        IF X=>N1 THEN Y=Y+2^(W-1) : X=X-N1
4610        NEXT W
4620    RETURN
4630 '
4640 ' MAGNITUDE SUBROUTINE
4650 '
4660    GOSUB 4560
4670    DUMMY=SQR(DAT(Y+1)^2+IMG(Y+1)^2)
4680    RETURN
4690 '
4700 '  ERROR TRAPPING SUBROUTINES
4710 '
4720    BEEP : CLS : BEEP : BEEP
4730    IF ERR-76 THEN PRINT DRIVEO$;" IS NOT VALID"
4740    IF ERR<>61 THEN 4770
4750    PRINT "DISK FULL -- OUTPUT FILE NAMES CHANGED TO NONE"
4760    MAGFIL$="NONE" : PWRFIL$="NONE" : CLOSE: RESUME
4770    IF ERR<>71 THEN 4790
4780    PRINT "DISK DRIVE NOT READY -- FILE OUTPUT DELETED" : GOTO 4760
4790    IF ERR<>70 THEN 4820
4800    PRINT "DIST IS WRITE PROTECTED -- FILE OUTPUT DELETED " : GOTO 4760
4810    IF ERR=53 OR ERR=76 THEN 4830
4820    PRINT "ERROR NUMBER ";ERR;" DETECTED IN LINE ";ERL : END
4830    RESUME 750
```

OIL SAMPLING FROM RECOVERY TANKS

Samples are taken from the recovery tank sections using a stratified sample thief (See Figure A-6). Developed at OHMSETT, the thief is designed to simultaneously capture representative samples from a fluid column in three-inch (76.2 mm) segments (See Figure A-7). This eliminates the necessity of mixing the immiscible oil and water to obtain samples representative of the whole fluid column.

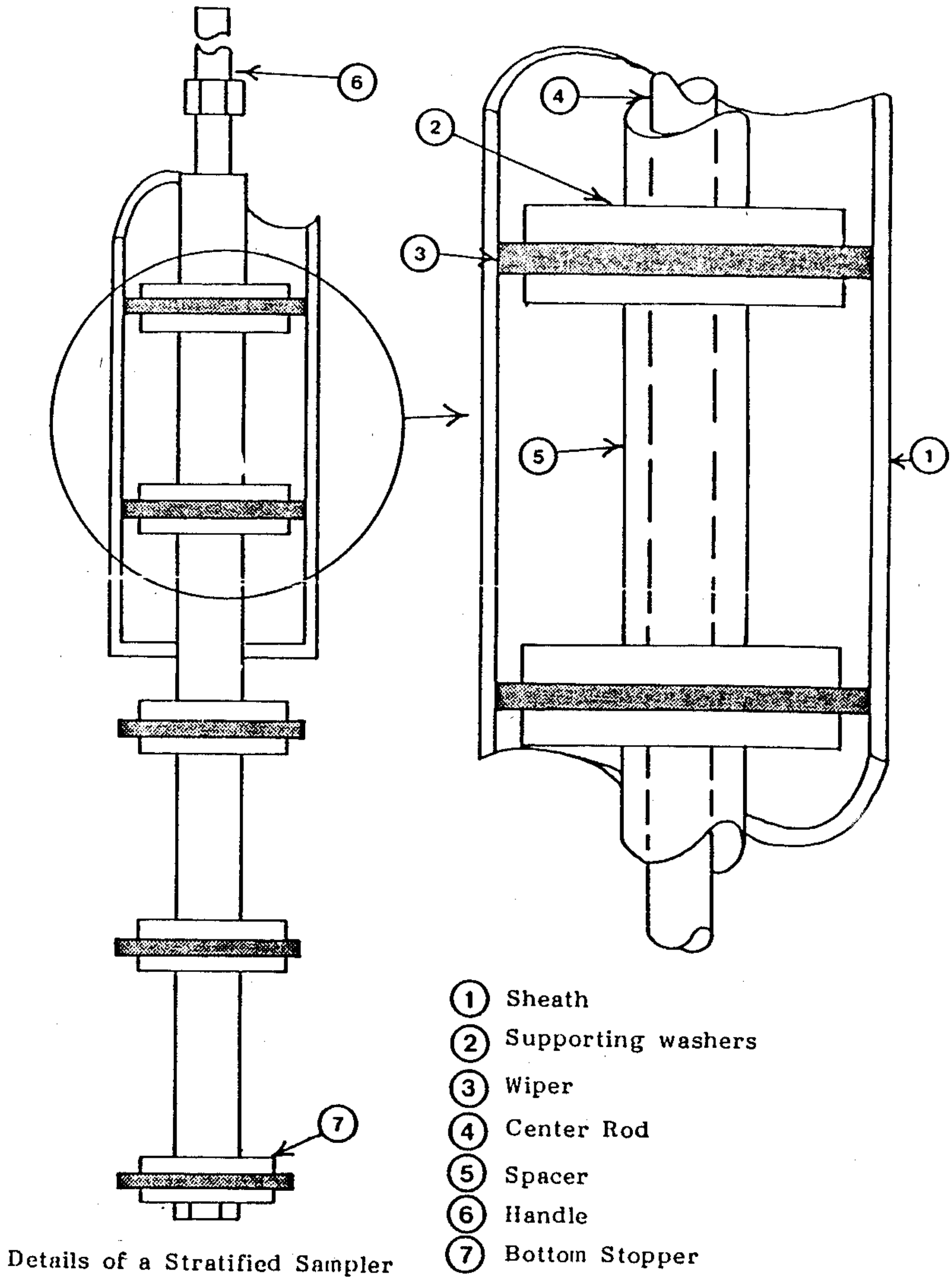


FIGURE A-6 - Details of a Stratified-sampler.

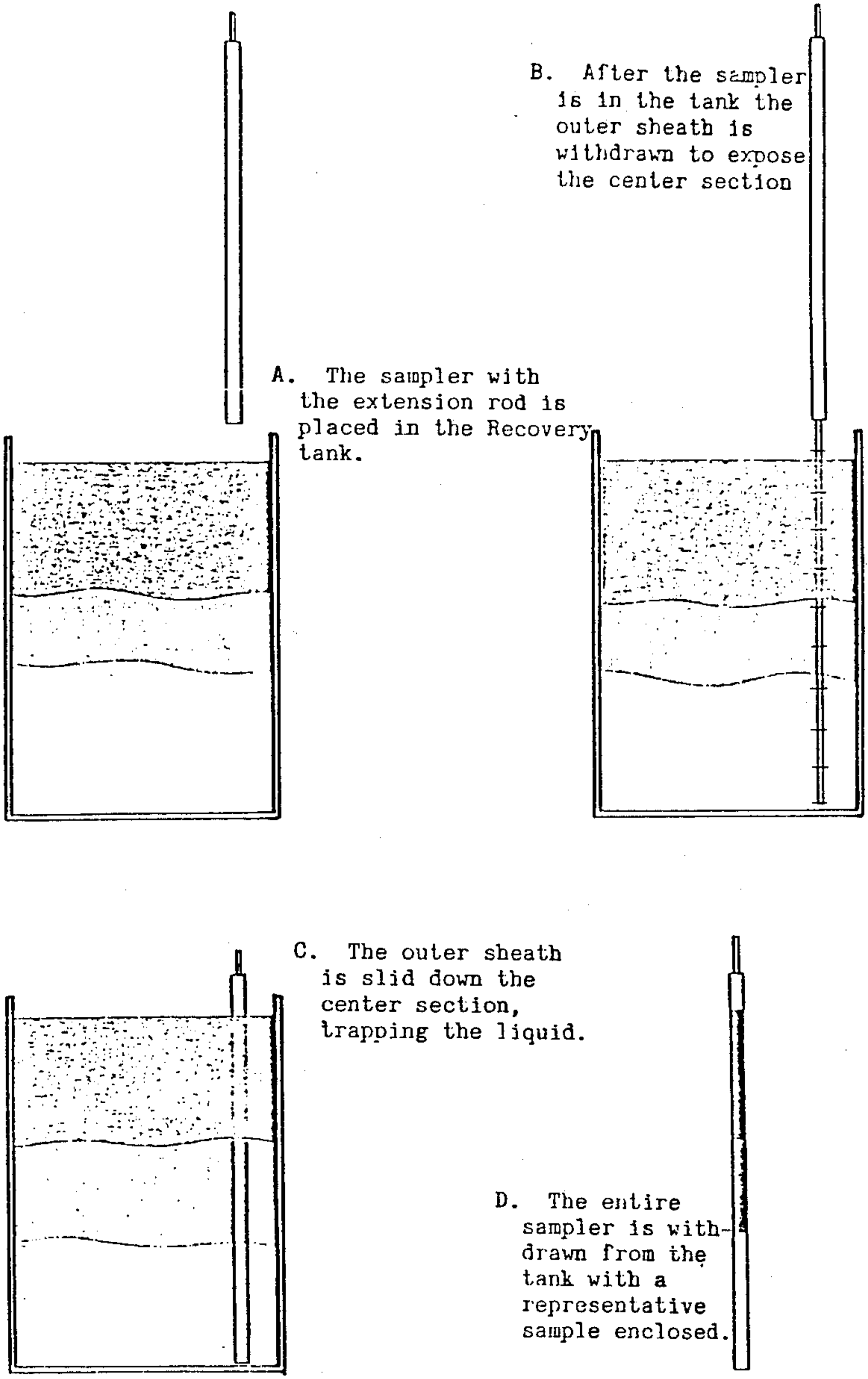


FIGURE A-7 - How to use the stratified-sampler.

APPENDIX B

QUALITY ASSURANCE

QUALITY ASSURANCE PLAN FOR
THE OFFSHORE BOOM AND SKIMMER TEST PROTOCOL

1.0 INTRODUCTION

1.1 Introduction and Purpose

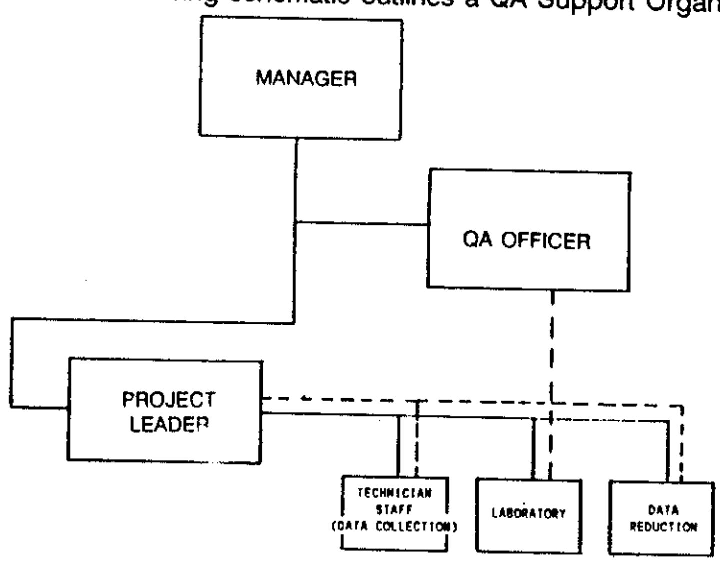
In measuring the boom and skimmer performance, the investigator is attempting to precisely measure processes that are being influenced by random events. Each instrument and each individual method can achieve high precision. However, the final data is often characterized by large standard deviations caused by waves. Long test durations reduce the standard deviations, but long tests, especially tank tests involving oil are often not considered practical. This Quality Assurance and Quality Control (QA/QC) Program has been designed to:

- Provide a management structure and report system that insures adherence to the accepted procedures for performing tasks described in the Offshore Boom and Skimmer Test Protocols.

- Obtain documented mechanical and analytical data of known data quality.

2.0 DATA QUALITY MANAGEMENT

Quality work depends upon the procedures activated for monitoring and control and support personnel responsible for each function. The following schematic outlines a QA Support Organization.



2.1 Project Manager

- Develop the specific work plan from the protocol.

- Have overall responsibility for meeting the protocol objectives.

- Have overall responsibility for assuring work force and technical expertise is provided.

- Be available to take action on any problem requiring additional management or technical support.

- Review program reports, directives, QA plans, Health and Safety Plans, progress reports, and financial reports prior to release.
- Prepare periodic reports (overviews) and final reports as requested by MMS.
- Keep client informed of all aspects of the program activity including expenditures, progress, problems, and recommended solutions.
- Assure that all raw data, documentation, protocols, and reports are transferred to the archives at the close of each test program.

2.2 Test Director

- Ensure that the test equipment is assembled according to specifications and that it is working properly.
- Ensure that all chemicals, equipment, instrumentation, and standards needed for the test are acquired on schedule.
- Ensure that experimental work is performed in strict compliance with the selected test methods, the QA plan, and all the SOP's documented in the Work Plan.
- Direct all labor force operations from preparation and initiation to conclusion and demobilization.

2.3 QA Officer

The Quality Assurance Officer should be independent from the project team and will often report directly to a General Manager to maintain an objective function. In small organizations, this is not always possible. He will monitor and document the adherence of the facilities, equipment, methods, practices, records, and controls to the appropriate regulations. He will ensure that the data quality meets or exceeds the objectives. He will receive administrative and technical support, as needed, from the other members of the organization.

A summary of the QA Officer's responsibilities follows:

- Maintain copies of the master schedules, protocols (with up-dated amendments), program plans, and current standard operating procedures (SOP's).
- Audit the work project plan for adherence to the protocol.
- Inspect critical phases of work plan at the required frequency.
- Ensure that the work plan and standard operating procedures are followed by project personnel.
- Submit periodic reports to management.

- Review all interim and final reports.
- Issue standard operating procedures.
- Audit and keep records of calibration and traceability of standards.
- Audit data validation and analysis procedures.
- Oversee archiving operations.

2.4 Technicians

These individuals will rig the test hardware and carry out the work plan under direction of the test director.

3.0 DATA QUALITY OBJECTIVES

Every quantitative measurement contains sources of inaccuracy and imprecision, both of which have variable components. These have been recognized as Systematic and Random errors. Systematic errors affect the accuracy by giving a net bias to all of the measurements in the set. Random errors also make a noticeable contributions by reducing precision. Such variations arise due to instrument precision limits, sample size variability, residual sample heterogeneity, instrumental noise, and other technical limitations. Their effects are minimized by better engineering controls and a larger, well-defined database.

There are two basic indicators of measurement quality: precision and accuracy. When experimental measurements are first carried out by use of reliable working standards, excessive measurement variability provides a good reason to search for uncontrolled systematic errors. When evaluating results by validated methods, the final estimate of precision will usually rely on the assumption that all practicable steps have been taken to control (ie., suppress, eliminate, or compensate) the systematic errors. The remaining fluctuations are considered random and will determine the experimental precision.

3.1 Precision

Precision of a data set is measured as the standard deviation of that set using the calculation:

$$S = \frac{\sqrt{(Xi-X)^2}}{N-1}$$

where:

S = Standard Deviation

Xi = Each member of a data set

X = Mean of the data set

N = Number of values in the data set

Initially, the averages of all the replicates is obtained and then, the standard deviation of each mean is calculated. This gives a measure of data dispersion for future comparisons. If any individual measurements in a 3 run set is more that+/-2 standard deviations away from the mean then another measurement must be performed for confirmation. The outlier in the set may then be discarded. In addition, the maximum number of replicates is always considered with the understanding that precision is directly proportional to the square root of that number; ie., 25 replicates result in a 5-fold improvement in precision and 100 replicates result in a 10-fold improvement in precision.

Precision is also expressed in terms of "repeatability" and "reproducibility". Duplicate tests are compared and a percent difference from the average value is calculated. Repeatability values are specified where large numbers of tests to determine standard deviations are not justified.

3.2 Accuracy

Accuracies of the measurements made in the protocol are supported by calibration procedures using traceable standards or lab-made standards following good laboratory procedures. Data accuracy objectives of some reported values are calculated from component measurement accuracies.

3.3 Completeness

The amount of data taken will depend on the specifications in the work plan. At a minimum, additional tests will be run only to replace outliers and examine nonconformance. Sufficient samples or tests will be done to ensure initial, middle and ending coverage.

3.4 Boom and Skimmer Test Protocol Quality Assurance Objectives.

See Table B-1 and Figure B-1.

TABLE B-1 - BOOM AND SKIMMER TEST PROTOCOL QUALITY ASSURANCE OBJECTIVES

MEASUREMENT	TEST	INSTRUMENT(S)	PRECISION	ACCURACY	CAL. STANDARD
Oil in Water	Oil and Grease, Total Recoverable (Infrared)	Infrared Spectrophotometer Quartz cells: 10, 50 and 100 mm Volumetric flask, 100 ml	Percent Standard Deviation in the 20 ml/liter range is 10%	Bias is +2.5%	Solvent extracts of blanks & "Spiked" dispersions of the test oil in tank water at: 1, 10 and 50 mg/liter oil Solutions of the test oil in CCl_4 at: 0,10, 100, 500 mg/liter.
Water in Oil	Water and Sediment in Petroleum (Centrifuge)	Centrifuge with relative centrifugal force (rcf) equal to 500 at the fluid surface and 800 at the bottom. Centrifuge tubes, graduated.	Repeatability is dependent on the % water and sediment. At 7% water in oil: duplicate results by the same operator should be considered suspect if the standard deviation is greater than 0.4% water in oil.	There is no data available at present to determine accuracy.	Test oil with 1,5, and 10 % tank water blended in at high shear.
Specific Gravity	Hydrometer Method	Set of hydrometers Thermometer	Repeatability: Duplicate results by the same operator should be considered suspect if the results differ by more than 0.0006 grams/ml. Reproducibility: Results submitted by each of two laboratories should not be considered suspect unless the results differ by more than 0.0012 grams/ml.	+/- 0.1%	Distilled water Solutions of methyl alcohol and distilled water as needed over the range 0.79577 through 0.99727
Surface Tension & Interfacial Tension	Interfacial Tension of Oil Against Water by the Ring Method	Torsionwire tensiometer Platinum Ring	Repeatability: Same operator and apparatus, 2% of mean Reproducibility: Different operators and apparatus, 5% of mean	+/-1.5%	Distilled water Toluene NBS Class S fractional weights

TABLE B-1 - BOOM AND SKIMMER TEST PROTOCOL QUALITY ASSURANCE OBJECTIVES

MEASUREMENT	TEST	INSTRUMENT(S)	PRECISION	ACCURACY	CAL. STANDARD
Viscosity	Viscosity - Brookfield (Rotary Spindle Viscometer)	Viscometer Temperature Bath Thermometer	Repeatability: +/-0.2% FS	+/- 1% Full Scale	Cannon-Fenske Viscometer(s) calibrated according to ASTM D 2162, sizes: 150, 200, 300, 350, and 400. OR Brookfield calibration standard fluids.
Oil Flow Rate (Distribution Manifold)	Positive Displacement, Rotary Gear	Flow Meter, Totalizer Stopwatch, +/-0.01 seconds			Measured 500 gallon container, AND Stopwatch, +/-0.01 seconds
Tow Speed	Over Ground Tow Speed, Tank Testing	Tow Drive coupled to a: Rotating Light Chopper OR Magnetic Induction Sensor	+/-0.05 knots	+/-0.05 knots	Surveyors tape AND Stopwatch +/-0.01 seconds OR Time Logger with external triggering.
	Relative Current Speed	Knot Meter or other flow sensor attached to the device or the tow vessel	Tank Testing: +/-0.05 knots Off-Shore: +/-0.2 knots	+/-0.05 knot	Tank Testing: Measuring Tape AND Stopwatch +/-0.01 seconds OR Time Logger with external triggering. Off-Shore Testing: Calibrate in calm water pier-side as in tank OR calibrate in tank.
Wave Height and Period	Electronic Measurement of Wave Height and Period From a Fixed Platform	Sonic Meter mounted above the water surface. OR Resistance Wire, Pressure Gauge, Capacitance Probe mounted in the water	+/- 2.0 centimeters	98% responsiveness to a 1.0 meter/second depth change rate.	Measuring Tape Stopwatch +/-0.01 seconds

TABLE B-1 - BOOM AND SKIMMER TEST PROTOCOL QUALITY ASSURANCE OBJECTIVES

MEASUREMENT	TEST	INSTRUMENT(S)	PRECISION	ACCURACY	CAL. STANDARD
Wave Height and Period (Continued)	Electronic Measurement of Wave Height and Period Using a Tethered Buoy	Wave buoy with accelerometers OR Spar-buoy with resistance wire	+/- 2.0 centimeters	98% responsiveness to a 1.0 meter/second depth change rate.	Measuring Tape Stopwatch +/-0.01 seconds
Slick Thickness	Calculated - average, for tank testing. No method has yet been identified for off-shore that can be relied on.	Oil Distribution Flow Meter Tow Speed Meter or knot meter Measuring tape Stopwatch +/-0.01 seconds	At 3.0mm slick thicknesses previous tank test data shows reproducibility to be +/-0.2mm	The accuracy of this measurement is dependent on the spreading/distribution of the oil over the water surface and the portion of the slick the device encounters. At 100% encounter accuracy, based on the individual accuracies of the component measurements, is +/- 5%	See standards for the individual instruments
Throughput Efficiency (%TE) The amount of oil skimmed from the water versus the amnount encountered, expressed as a percent.	Calculated from: Total Oil Distribution Percent Encountered Recovered Oil	Visual estimate of percent encountered Oil Distribution Flow Meter Water in Oil analysis of recovered fluid. Depth Measurement of oil/water emulsion recovered	In calm water, throughput efficiency relative standard deviations for sets of six tests at 1.0 to 1.5 knots were 8.2 to 9.8%. In Harbor chop the relative standard deviations were 13.3 to 20.2%	+/- 5%	See standards for the individual instruments
Oil Recovery Rate (ORR)	Calculated from: Recovered Oil Duration of Recovery	Water in oil analysis of the recovered fluid Stopwatch Depth Measurement of oil/water emulsion recovered	No specific data available to support ORR precision. (See precision for %TE)	+/- 5%	See standards for the individual instruments

TABLE B-1 - BOOM AND SKIMMER TEST PROTOCOL QUALITY ASSURANCE OBJECTIVES

MEASUREMENT	TEST	INSTRUMENT(S)	PRECISION	ACCURACY	CAL. STANDARD
Recovery Efficiency (%RE) The ratio of oil to water collected by the skimmer during the test.	Calculated from: Total volume of fluid collected Total volume of oil collected	Water in oil analysis of the recovered fluid. Depth Measurement of oil/water emulsion recovered. Depth Measurement of total fluid recovered.	No specific data available to support %RE precision. (See precision for %TE)	+/- 5%	See standards for the individual instruments
Boom Wave Conformance	Dynamic Measurement of Boom Skirt Depth	Pressure Transmitters Wave Meter/Buoy Tow Speed Meter/Knot Meter	Standard deviations of minumum depths measured for sets of five tests, each 4.3 minutes long, in wind waves and swell, range from 2 centimeters to 14 centimeters. Standard deviations for pressure transmitters at the sides of a catenary (P1 and P3) and at the apex P2 are presented in graphical form in Figure B-1.	Accuracy of boom wave conformance is dependent on maintaining a constant tow speed. In tank testing accuracy is calculated to be +/- 10% based on the combined instrumental accuracies. At sea tow tests are influenced by the coupling of boom and tow vessel(s) responses and test accuracy is reduced.	See standards for the individual instruments

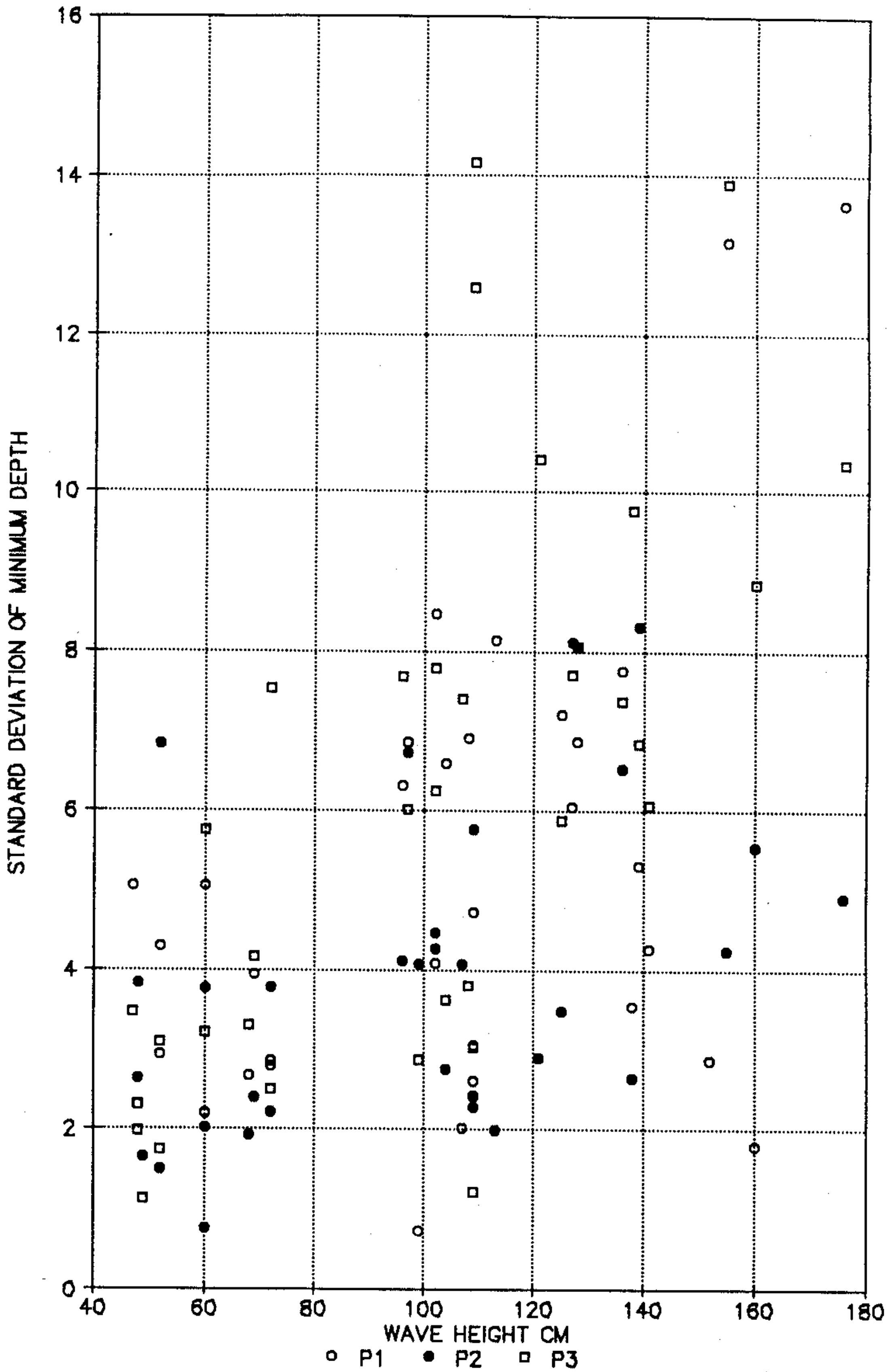


FIGURE B-1 - Standard deviations for minimum depth measurements. These values result from statistical analyses of off-shore boom evaluations. A three pressure transmitter array measured depths at the arms, P1 and P3, and at the apex P2.

4.0 CALIBRATION FREQUENCY

Each instrument should be calibrated prior to a test program and each day a two point calibration check should be performed. A two point check consists of a "zero" (baseline) reading and one other value in the top 25% of the measurement range of interest.

Some instruments such as pH meters, conductivity meters and surface tension balances are given a two point check with each sample.

5.0 PROCEDURES

5.1 The actual process of sampling just as the processing of the samples collected requires planning and quality control. Quality Assurance enters the picture with the selection of the sampling method, sample containers, preservation and holding times and covers the tracking of the samples or measurements from collection through analysis to data report. The key is sample identification to facilitate data traceability and summarization.

Samples are taken using a stratified sample thief. Developed at OHMSETT, and called the "Johnson Sampler", the thief is designed to simultaneously capture representative samples from a fluid column in 76.2 mm segments. This eliminates the necessity of mixing the immiscible oil and water to obtain samples representative of the whole fluid column. See Methods: Oil Sampling from Recovery Tanks.

5.2 Sample Custody - Oil and Water Analysis

A Chain of Custody Record has to be maintained for all of the samples generated on a daily basis. This form must follow the samples from generation through reporting of the analytical data. The Chain of Custody Record form duplicates most of the information recorded on the sample label and cross-referenced in the QA Log Book and goes further to document sample transfers. The sample collector fills in Part II and surrenders the sample and form to the QA Officer. At this point, the sample gets a QA reference number and enters the lab for analysis. The final step is the release of the data by the analyst, and the submission of the original Chain of Custody Record to the QA file and a copy with the written report.

5.3 See Appendix A for selected analytical methods used to obtain measurements necessary for the final data.

5.4 Data Collection

All data and measurements should have the following information recorded:

- Date of Analysis/Measurement
- Instrument Calibration/Standard Curves displaying:
  - Date/Time
  - Test performed and standard utilized
  - Initials of analyst
  - Test conditions/Instrumental Parameters

- Analytical data of oil or water must be recorded in a fixed-leaf notebook with the following information noted:

  - Initial of analyst
  - Test performed
  - Test conditions
  - Dilution factors
  - Visual observations (ie., significant differences)
  - Sample identity
  - Time sample was analyzed.
  - Person report sent to

6.0 DATA ANALYSIS, VALIDATION AND REPORTING

6.1 Data Sheets and Validation

The data sheets used for the collection of raw data must be prepared prior to testing to document all of the variables identified in each work plan. All critical data such as the dependent and independent variables listed in the test plan will be recorded on the data sheets each time a run is performed. Records will be kept in compliance with the guidelines given above. The accuracy of the data and calculations will be re-checked by the person performing the tests and by one other qualified person. In addition, the QA Officer will check the precision of the raw data and the equations or calculation methods used to calculate the dependent variables. The calibration, detection limits and recoveries will be evaluated. The data will be qualified for holding time exceedences (where applicable), blank contamination, spike recoveries, and detection levels.

6.2 Outliers

In order to obtain a complete data set, outliers must be identified in time to re-run specific tests

6.3 Reporting

Data sheets should be maintained during the rest program and at the end of each day reviewed for outliers and completeness. After validation, the data sheets will be submitted to the QA Officer who will maintain all raw data in notebooks. At the end of the study all data books will be bound and stored in a safe, accessible location.

7.0 INTERNAL QUALITY CONTROL CHECKS AND FREQUENCY

Spikes and conventional analytical standards must be analyzed.

7.1 Spike Sample Frequency and Procedure

Spike Sample Frequency and Procedure

Spike samples are to be submitted in a quantity equal to ten percent of the respective samples to be analyzed. This procedure is conducted as follows:

1. Known amounts of oil or water should be added to actual samples at concentrations where the precision of the method is satisfactory. It is suggested that amounts be

added to the low-concentration sample sufficient to double that concentration, and that an amount be added to one of the intermediate concentrations sufficient to bring the final concentration in the sample to approximately 75% of the upper limit of application of the method.

2. Two to five replicate determinations should be made at each concentration for instrumental analysis.

3. Accuracy should be reported as the percent recovery at the final concentration of the spiked sample. Percent recovery at each concentration should be the mean of the replicate results.

4. For convenience, samples selected to be spiked should be chosen from a set of samples previously analyzed for the desired spike constituent. This methodology will allow the contaminant level to be measured and the appropriate spike concentration to be added.

7.2 Duplicate Sample Frequency and Procedure

Duplicate samples should be obtained and considered in accord with the following stipulations:

1. They may be obtained from either of two sources:

   - Remaining portion of sample previously considered.
   - New sample obtained from same source, batch and sample point, mixed well and split.

2. The number of duplicates must depend on the analytical results but should be no less than 10% of the total number of samples tested.

   In addition, the duplicate samples should be kept under the same conditions and run under the same parameters used for the original samples.

8.0 PERFORMANCE AND SYSTEM AUDITS AND FREQUENCY

Normally the QA Officer conducts a performance audit on 10% of the runs. The first time, the QA officer will notify the operators that he will observe as they perform the tests and record the data. Subsequent observations will be unannounced.

As discussed in Section 10.0, all raw data sheets will be checked for accuracy and for compliance with test plan specifications.

9.0 PREVENTATIVE MAINTENANCE PROCEDURES AND SCHEDULES

A log book is maintained for every scientific instrument. The complete maintenance record is kept in each log book. Preventative maintenance checks and operations on a regular schedule will be performed. The QA officer will audit the records in order to insure that all necessary maintenance functions have been performed.

10.0 SPECIFIC ROUTINE PROCEDURES TO BE USED TO ASSESS DATA PRECISION, ACCURACY AND COMPLETENESS OF SPECIFIC MEASUREMENT PARAMETERS

As discussed in Section 11.0, the QA plan for monitoring work in progress is to introduce spikes, surrogate samples and other standard sample analysis techniques. However, in studies where the former are not feasible the data quality is insured by checking for outliers.

11.0 CORRECTIVE ACTION

The QA officer conducts regular performance and data audits and relies on the test directors for corrective action deemed necessary. Both the performance audits and the data (record) audit require observation of the work in progress and annotation of the following information:

- Date
- Audit No.
- Auditor
- Project No.
- Phase of Study Inspected
- Test Material
- Procedure
- Procedural Step
- Findings
- Corrective Action Required
- Deadline for Correction
- Responsible Individuals Briefed
- Re-inspection Plan
- Corrective Action Taken
- Date Correction Finished
- Person Responsible for Correction

The completed statement is returned to the QA Officer for subsequent circulation to the Test Director, and Project Manager. The case is closed as long as the corrections follow the audit expeditiously and cause no noticeable effects on the data produced. Any discrepancy or trend outside the control limits will be closely examined and may require repeat of the questionable test.

12.0 QUALITY ASSURANCE REPORTS TO MANAGEMENT

As described in Section 15.0 all audit reports are circulated to the Test Director and to the Project Manager. In addition the QA officer will write a periodic QA Report to the Project Manager, upon his request, to summarize the status of ongoing projects.

APPENDIX C

ASTM STANDARDS

Standard Practice for Describing
ENVIRONMENTAL CONDITIONS RELEVANT TO SPILL CONTROL SYSTEMS FOR USE ON WATER[1]

This standard is issued under the fixed designation F 625; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice creates a system of categories that describe environmental conditions relevant to the control of spills of oil and other substances that float on or into a body of water.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Significance

2.1 This practice is to be used as a guide to describe natural environmental conditions. These environmental descriptions may be utilized in formulating standards for design, performance, and standard practice for spill control systems.

2.2 Relatively few parameters of broad range have been used in Tables 1 and 2 in order to enable the user to readily identify general conditions under which spill control systems are used.

2.3 Satisfactory operation of any specific spill control system may not extend over the full range of conditions identified by Tables 1 and 2. Detailed discussion with systems suppliers is recommended.

3. Summary of Practice

3.1 General environmental conditions for spill control systems are grouped into 11 major types of water bodies, Table 1, each combined with one of 5 different environmental descriptors, Table 2, to provide 55 significantly different sets of environmental conditions.

4. Definitions

4.1 *wave height*—height difference between the wave crest and the preceding trough.

4.2 *current*—water speed relative to a fixed point.

4.3 *water depth*—mean vertical distance measured from the surface of the water to the top of the continuous solid surface below.

4.4 *water temperature*—average or point temperature of a water body as measured within the top 300 mm (12 in.).

4.5 *air temperature*—average or point temperature of the air measured at or near the ground or water surface.

4.6 *debris*—any solid or semisolid substance that could interfere with the operation of a spill control system.

5. Use of Tables

5.1 The use of Tables 1 and 2 in describing a given set of environmental conditions is illustrated by the following example: A given environment is characterized by the following: waves, 0.3 m; current, 0.5 m/s; water depth 3 m; air temperature, 20°C; sea water temperature, 15°C; wind velocity, 12 km/h; no ice, but a slight amount of kelp (debris). From Table 1 the description of the water body is seen to be Type VII. From Table 2 the set of environmental descriptors that best describe the above conditions is seen to be Type D. Therefore, the shorthand notation describing the above conditions is Type VIID. With the same conditions except for a wind velocity of 40 km/h, the notation would be Type VIIDw.

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[1] This practice is under the jurisdiction of ASTM Committee F-20 on Spill Control Systems, and is the direct responsibility of Subcommittee F20.10 on Oil Spills.
Current edition approved July 16, 1979. Published October 1979.

TABLE 1 Types of Water Bodies

Type	Wave Height,[A] m(ft)[B]	Current, m/s(kn)	Depth, m(ft)	General Category of Water
Rivers and Protected Waters				Shallow Water
I	0–0.3(0–1)	≤0.8(1.5)	0–0.5(0–1.5)	low/moderate current; low waves
II	0–0.3(0–1)	>0.8(1.5)	0–0.5(0–5.5)	moderate/fast current; low waves
				Moderately Deep Water
III	0–0.3(0–1)	≤0.8(1.5)	0.5–1.5(1.5–5)	low/moderate current; low waves
IV	0–0.3(0–1)	>0.8(1.5)	0.5–1.5(1.5–5)	moderate/fast current; low waves
V	0–1(0–3)	≤0.8(1.5)	0.5–1.5(1.5–5)	low/moderate current; moderate waves
VI	0–1(0–3)	>0.8(1.5)	0.5–1.5(1.5–5)	moderate/fast current; moderate waves
				Deep Water
VII	0–0.3 (0–1)	≤0.8(1.5)	>1.5(5)	low/moderate current; low waves
VIII	0–0.3(0–1)	>0.8(1.5)	>1.5(5)	moderate/fast current; low waves
IX	0–1(0–3)	≤0.8(1.5)	>1.5(5)	low/moderate current; moderate waves
X	0–1(0–3)	>0.8(1.5)	>1.5(5)	moderate/fast current; moderate waves
Open Water—Inland or Ocean				Very Deep Water
XI	1–2.5(3–8)	≤0.8(1.5)	6(20)	low/moderate current; high waves

[A] May include breaking waves. The ratio of wave height to wave interval ratio should also be considered.
[B] Conversions from metric to inch-pound units are approximate, rounded to a preferred number.

TABLE 2 Environmental Descriptors

Type[A]	Air Temperature, °C(°F)	Water Temperature, °C(°F)	Water Condition	Debris	General Category
A	>0–40(>32–105)	>0–30(32–85)	clean	none	moderate
B	≅0(≅32)	≅0(≅32)	clean	solid or slush ice	cold
C	>40(105)	>30(85)	clean	none	hot
D	>0–40(>32–105)	>0–30(>32–85)	clean	slight/dense	debris
E	>0–40(>32–105)	>0–30(>32–85)	silt	slight/dense	silty with debris

[A] If wind is significant, approximately 35 km/h(20 kn) or more, append "w" to the descriptor type, as "Bw."
[B] Conversions from metric to inch-pound units are approximate, rounded to a preferred number.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103.

TABLE 1 Data Sheet for Skimmer Testing in Uncontrolled Environments

Conditions	Time Recorded	Method/ Equipment Used
Environmental Conditions:		
Wave height (Section 6)		
Wave length and direction (Section 7)		
Skimmer forward velocity (relative to the water) (Section 8)		
Skimmer velocity (relative to the oil slick (Section 10)		
Skimmer motion relative to waves (Section 9)		
Wind speed (Section 11)		
Wind direction (Section 11)		
Surface water temperature (Section 12)		
Air temperature (Section 13)		
Current speed and direction (relative to the bottom) (Section 15)		
General weather description (14.1)		
Oil Slick Conditions (Where applicable):		
Oil type and source (17.1)		
Oil viscosity at skimming temperature (17.2)		
Oil/water content of oil slick (17.3)		
Slick thickness (at entrance to skimmer (17.4)		
Slick thickness (free slick) (17.4)		
Slick temperature (17.5)		
Oil slick surface tension (18.2)		
Oil/water interfacial tension (18.3)		
Oil slick specific gravity (17.8)		
Oil slick width (17.6)		
Debris description (17.7)		
General description of slick continuity (18.4)		
Slick boundary conditions (18.5)		
Recovered Fluid Conditions:		
Recovery rate (19.1)		
Total amount collected (19.2)		
Oil/water content (19.4)		
Viscosity (20.1)		
Specific gravity (20.2)		
Debris amount (19.3)		
Skimmer Control Settings (As Applicable):		
Pump rate		
Engine speed		
Speed of oil slick pickup device		
Weir depth		
Hydraulic fluid flow rate/pressure		
Pneumatic flow rate/pressure		
Electrical current/voltage		
Door openings, etc.		
Other controllable parameters		
Description of performance limiting variables		
Significant non-controllable variables		
Calculated Results:		
Oil slick encounter rate		
Oil encounter rate		
Oil recovery rate		
Oil slick recovery rate		
Oil slick throughput efficiency		
Throughput efficiency		
Oil slick recovery efficiency		
Recovery efficiency 4.2		
Storage efficiency		
Geographical Description of Operations Area List charts prepared, and attach		
Photographs. Describe and attach		

Standard Definitions of Terms Relating to SPILL RESPONSE BARRIERS[1]

This standard is issued under the fixed designation F 818; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This document defines the terminology used in the field of spill response barriers. Only those terms commonly used or peculiar to this field have been included; no attempt has been made to list all terms used.

1.2 Design, engineering, and performance terms are listed separately: barrier design terminology (1.3), barrier engineering terminology (1.4), and barrier performance terminology (1.5).

1.3 *Barrier Design Terminology*—Terms associated with Spill Response Barrier Design:

accessories—*optional* mechanical devices used on or in conjunction with a boom system but not included with the basic boom and end connectors; that is, lights, paravanes, drogues, buoys, anchor systems, storage bags, boxes or reels, bulkhead connectors or repair kits, etc.

anchor point—a structural point on the end connector or along the length of a boom section designed for the attachment of anchor or mooring lines.

ancillary equipment—those mechanical devices *essential* to the operation of a given boom system; that is, air pumps, hydraulic power supplies, control manifolds, etc.

ballast—weight applied to the skirt to improve boom performance.

boom—a floating mechanical barrier used to control the movement of substances that float.

boom section—the length of boom between two end connectors.

boom segment—repetitive identical portion of the boom section.

boom weight—dry weight of a fully assembled boom section including end connectors.

control draft—the minimum vertical depth of the membrane below the water line.

"curtain type" boom—a boom consisting of a flexible skirt supported by flotation.

end connector—a device permanently attached to the boom used for joining boom sections to one another or to other accessory devices.

"fence type" boom—a boom consisting of a self-supporting or stiffened membrane supported by flotation.

float—that separable component of a boom that provides buoyancy.

flotation—that portion of a boom which provides buoyancy.

freeboard—the vertical height of the boom above the water line.

handhold—any strap, handle, depression or other provision for grasping the boom by hand.

hinge—a location between boom segments at which the boom can be folded back 180 deg upon itself.

lifting point—a structural point on the end connector or along the length of a boom section designed for the attachment of a lifting device, such as a crane.

membrane—the continuous portion of a boom which serves as a barrier to the movement of a substance.

overall height—the maximum vertical dimension of the boom.

skirt—that continuous portion of the boom below the floats.

stiffener—a component which provides sup-

[1] These definitions are under the jurisdiction of ASTM Committee F-20 on Hazardous Substances and Oil Spill Response and is the direct responsibility of Subcommittee F20.11 on Control.

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port to the membrane.

tension member—any component which carries horizontal tension loads imposed upon the boom.

total draft—the maximum vertical dimension of the boom below the water line.

1.4 *Barrier Engineering Terminology*—Terms associated with Spill Barrier Engineering:

catenary drag force—the tension on a boom that results from towing it in a "U" configuration.

current response—change in freeboard or draft due to current forces acting to displace the boom from rest.

gross buoyancy—the weight of fresh water displaced by the boom totally submerged.

gross buoyancy to weight ratio—gross buoyancy divided by boom weight.

heave response—the ability of the boom to react to the vertical motion of the water surface.

reserve buoyancy—gross buoyancy minus boom weight.

reserve buoyancy to weight ratio—reserve buoyancy divided by boom weight.

roll response—rotation of the boom from rest due to wave, wind, or current forces.

straight line drag forces—the tension on a boom that results from towing it from one end.

wind response—change in freeboard or draft due to wind force acting to displace the boom from rest.

1.5 *Barrier Performance Terminology*—Terms associated with Spill Response Barrier Performance:

conformance—the ability of a boom to maintain freeboard and draft when subjected to a given set of environmental conditions.

containment mode—the placement of a boom to prevent free movement of a floating substance.

diversion mode—the placement of a boom to redirect the movement of a floating substance.

performance—the ability of a boom to contain or deflect oil under a given set of environmental conditions.

sweeping mode—movement of a boom relative to the water for the purpose of controlling or collecting a floating substance.

towing—transportating a boom from one place to another by pulling from one end.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa 19103.

Standard Guide for
INCINERATING OIL SPILL WASTES AT TEMPORARY FIELD LOCATIONS[1]

This standard is issued under the fixed designation F 873; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide addresses incineration as a means of waste disposal and specifically discusses incinerating oil spill wastes at temporary field locations.

1.2 The purpose of this guide is to provide the user with general information on incineration as a means of disposal, not to define a rigid set of standards. It is intended as a reference to plan or execute disposal by incineration.

1.3 This guide outlines procedures and describes some equipment that can be applied to a land-based field incineration process. Included in the guide is a description of typical oil spill wastes that can be incinerated; an outline of procedures to select, prepare, operate, and restore a temporary site; and a summary of general site safety considerations.

NOTE—Additional information about oil spill disposal techniques can be found in the documents listed in Section 2.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary information is given in Section 8.

2. Applicable Documents

2.1 *Department of Energy:*
DOE/EV-1830-1, PNL-2929 Combustion: An Oil Spill Mitigation Tool[2]

2.2 *Department of Transportation.*
CG-D-35-79 Disposal Systems and Techniques for Oil and Hazardous Chemicals Recovered from Marine Spills[2]

3. Descriptions of Terms Specific to This Standard

3.1 *field*—a location designed during an oil spill cleanup for incinerating oil spill waste material.

3.2 *incineration*—controlled burning of waste products or other combustible material.

3.3 *incinerator*—a device constructed for the purpose of containing a material for thermal oxidization.

3.4 *landfarming*—a controlled method of spreading a known amount of oil in a nominally uniform layer thickness onto a designated land area for the purpose of biological decomposition. This decomposition process is accelerated by mixing the oil layer with the top few inches of soil, aerating the soil by occasional plowing and adding fertilizers that include nitrogen and potassium to increase the oil decomposition rate.

3.5 *landfill*—a land disposal technique that uses excavated pits to contain the oil spill waste material. The waste is placed in the excavation, covered over, and left to degrade.

3.6 *oil spill*—An uncontrolled discharge of petroleum materials into the environment.

3.7 *on-scene coordinator*—the person in charge of oil spill countermeasures.

3.8 *open burning*—the process of burning a material without the aid of an incinerator.

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[1] This guide is under the jurisdiction of ASTM Committee F-20 on Hazardous Substances and Oil Spill Response and is the direct responsibility of Subcommittee F20.14 on Disposal.
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[2] Available from the National Technical Information Service, U.S. Dept. of Commerce, 5285 Port Royal Rd., Springfield, VA 22160

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