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OIL POLLUTION DETECTION AND DISCRIMINATION BY REMOTE SENSING TECHNIQUES

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ABSTRACT

Airborne remote sensing techniques were applied to the detection and discrimination of pollution by oil on the ocean surface. The tests were performed in the Gulf of Mexico during April, 1970. Pollutants investigated included #2 fuel oil, #6 fuel oil, 9250 lube oil, light crude oil, heavy crude oil, gasoline, and mixtures of gasoline and oil. A total of 103 oil slicks were produced as a function of spill rate and ship speed. Ship speeds were nominally 10, 14, and 17 knots and spill rates ranged from 0.02 to greater than 4.0 GPM (Gallons per Minute).

Sensors used during the airborne tests included; two dual polarized microwave radiometers operating at 10.2 and 30 GHz, an infrared scanner operated in both the 4-5.5μ and 8-14μ regions, a dual 70 mm camera sensing visible color and infrared color, a 4-lens camera employing filters from the mid-visible to ultraviolet wavelengths.

Oil was detected on the sea surface at spill rates as low as 0.2 GPM for long wavelengths sensors and at the lowest spill rates for photographic imagery using an ultraviolet filter. Anomalously warm infrared radiometric temperatures were recorded in the 4-5.5μ region for heavy crude oil while #6 fuel oil appeared radiometrically cooler.

PREFACE

This report presents the results of airborne multi-sensor tests of small oil slicks formed in the Gulf of Mexico during April, 1970. A total of 103 oil slicks were made by a U. S. Coast Guard cutter 50 miles off the coast of Alabama. Pollution types investigated were #2 fuel Oil, #6 fuel Oil, 9250 lubricating oil, gasoline, light crude oil and heavy crude oil. The oil slicks varied as a function of spill rate (from 0.02 to 4.57 GPM) and ship speed.

Remote sensors utilized in performance of the tests included: 4-lens camera operating in the ultraviolet and short wavelength visible, dual 70 mm visible color and infrared camera, an infrared scanner operating in the 4-5.5 and 8-14μ bands, and two microwave radiometers at wavelengths of 1 and 3 cm. Aircraft operating altitude was 2,000 feet throughout the six days of tests.

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I. INTRODUCTION

This report represents the results of a measurements and analysis program on airborne sensing of controlled oil spills under Contract DOT-CG-03532-A. The airborne tests were conducted approximately 50 miles off the Coast of Alabama, southeast of Mobile. All sensor measurements were conducted from a single aircraft so that all data could be correlated in space and time. The sensors on board the aircraft included two microwave radiometers, a visual multispectral color camera, an IR color camera, a multispectral 4-lens camera operating in the short wavelength visible and ultraviolet, and an infrared scanner. The airborne tests were secondary to other tests being conducted by the Coast Guard from the deck of the spill vessel, the chase boat, and the low altitude heliocopter photography. The multisensor aircraft photographic data were to supplement that data taken on board the ship and the heliocopter by providing width measurements and a history on spread rates versus flow rates over a period of time. The microwave radiometers and the infrared scanner data were to be used to determine the capabilities of these sensors in detecting oil from an airborne platform. Being primarily a photographic mission, the experiment was run to complement the photographic data and was not always optimum for the acquisition of microwave data.

In the discussion which follows, the data received by each sensor and the analysis thereof will be discussed separately and compared in a conclusion section. Since more than 7,000 photographs were taken and over 11 hours of microwave data were recorded this report cannot cover all aspects of the experiment. Instead, a representative sampling of each oil type spilled at various spill rates will be discussed. A major goal in the analysis of the data received from all sensors was to determine the detection threshold of that sensor and the relationship of the sensor responses to the various oil types and oil thicknesses. Tables which contain the airborne logs, detection data, and analysis data are included as appendixes.

II. EXPERIMENT DEFINITION

All oil spills were pumped from the deck of the Coast Guard cutter at a specified rate over a period of time which varied from approximately eight minutes to 16 minutes, dependent upon the speed of the ship. The ship's speeds were nominally 10 knots, 14 knots, and 17 knots; the spill rates varying from .02 gallon per minute to well over 4 gallons per minute. The oil types included No. 2 fuel oil, 9250 oil, No. 6 fuel, light crude oil, heavy crude oil gasoline, and mixtures of heavy crude and gasoline. In addition to the controlled spills, a static test was conducted wherein river mud was pumped overboard to determine if any visual or sensor similarities existed between it and oil. During all spills surface photo coverage and slick thickness measurements were conducted by the Coast Guard from a 210' cutter and an 82' Coast Guard vessel. Photographs were also taken from a Coast Guard heliocopter in the immediate area of the cutter. All multisensor measurements were made from the ship's stern with the aircraft returning after each run to that oil slick farthest away from the cutter which was detectible by the operator, either visually or by the sensors. This limitation turned out to be visual to the DC-3 multisensor aircraft pilot as it was necessary for him to align the single beam microwave sensors over the slick. It was seldom possible to fly the aircraft by the single beam sensor output, as the beam was aimed approximately 50° from nadir behind the aircraft.

In order to maintain a thousand foot spacing between the DC-3 multisensor aircraft and the heliocopter, the DC-3's altitude was fixed at 2,000 feet. This altitude was considered a minimum for the lowest frequency microwave sensor to assure that the antenna sampling was large enough to eliminate the effects of individual waves upon the radiometric response. Higher alittudes were not considered as the resolution of the photographic data would be impaired. Consequently, the high frequency microwave data were difficult to analyze because the antenna sampling size was small enough that individual wave effects and aircraft motion biased the data received. The measurements were conducted over a seven-day period with only one day of downtime because of weather. Operations were shortened during one day because of poor visibility.

III. TEST DETAILS AND ANALYSIS

All radiometer, scanner and photographic data were taken from a single DC-3 aircraft. A crew of six was required to operate the aircraft and equipment. The crew included an experiment coordinator, a radiometer operator, a scanner operator, a photographer, a pilot, and a co-pilot. The scanner and cameras were pointed at nadir, while the radiometers were looking 46° from nadir behind the aircraft. An angle of 50° was the desired nadir angle, but at 120 knots aircraft speed the pilot could not hold the plane exactly horizontal. As 46° could be maintained relatively constant, this angle was accepted as an alternate. The flight plan for taking data was to fly toward the ship from the fartherest visible oil spill. After passing over the ship, the course was reversed until oil again could not be detected with a microwave radiometer or a scanner.

The original intent was to fly in an "S" pattern over the oil to determine the minimum detection point. This method of return was found to be unsatisfactory because aricraft motion was too great without long approaches. Thus, after the first day a different approach was used; namely, to fly directly back down the ship's course following the oil spill visually as far as possible, maintaining a constant heading until the signal was lost with the microwave and infrared radiometers. Data was taken on the return flights with the microwave radiometers, which enabled comparison to be made of up-wind, down-wind, and cross-wind information. Minimal microwave data were obtained the first day as the shipboard radar or communication equipment and the boresight camera created considerable interference. The "X" band radiometer was particularly sensitive to interference when the aircraft was within one or two oil spills of the ship. The source of the interference has not been discovered to date, because all radars were turned off and communications held to a minimum on the Coast Guard cutter. It is expected that other on-board interference associated with the operation of the ship was the source of the interference. The first day's runs were short in duration as the light oil dispersed rapidly on the water's surface making it difficult for the pilot to fly a reverse course. While the first day's data were limited the operations were extremely valuable in training for the following day's measurements. Throughout the entire data flights, a log was kept on board the aircraft of each run, containing positional data and miscellaneous observations. The log run numbers are not related in number to the oil dumps. However, the dumps which were overflown, and the times at which they were overflown on each aircraft pass, were recorded. The flight-run numbers were recorded on the left margin of the flight data sheets between the stop and start indicators. The return flight was given the same number as the previous run with an "R". This departure from the planned approach of one run per oil spill was required because oil spills were detected at such long ranges from the ship that more than one spill was completed before the aircraft could pass over the ship again. This departure from the experiment plan did not create difficulties in the data analysis, since the times were synchronized with that of the ship, and, when possible, the time and footage readings on the tape recorders were noted in the aircraft log each time a new test came within the beam of the radiometer. In a similar manner the camera operator recorded the frame numbers and the time at which photographic coverage was started on each run, and the time when an oil spill was overflown. Since the aircraft speed and altitude remained constant throughout the entire run, the optical data and the microwave data could be readily correlated within the accuracy required. The major difficulties encountered in collecting both the optical data and the microwave data from the same aircraft resulted on those days in which the winds were high and the spills were made cross-wind. On those days the aircraft had to fly with a crab angle to maintain its course. As a result, when the cameras were directly over the oil spills the microwave radiometer antennas were looking at an angle to the side by several hundred feet. This problem was overcome by the coordinator visually sighting down the radiometer antennas and directing the aircraft's flight from that position. In general, crab angles were such that optical and microwave data could be obtained simultaneously in this manner. The major difficulty with this approach was that the pilot could not visually fly the spills and anticipate changes in spill direction, as his headings were based on a reference point approximately 2,000 feet behind the aircraft. Because of this difficulty, future tests should consider the possibility of using two separate aircraft or multibeam radiometers with fields of view similar to that of the cameras.

A typed copy of the flight log is included in the appendix as the reference for any future data reduction. The spill numbers are indicated in the lined columns with the aircraft run numbers indicated on the far edge of the paper and marked by a check in the Start and Stop columns. Data correlation logs and data analysis logs have also been included in the appendix. In the data analysis discussions which follow, the aircraft runs will not be referred to and discussions will be made only on a test or spill number. In this manner all sensor data aboard the aircraft can be easily correlated with data acquired by shipboard sensors.

An analysis of each spill on each aircraft run has been made for spread rate and detection capabilities. The results of this analysis have been recorded in tabular form in the appendix. A full discussion of each spill is not made within this text, as it would be too lengthy. However, representative samplings of spills at five flow rates are selected and discussed for each sensor herein. In certain instances, where other significant information was deemed important in the overall analysis, the discussion also covers those spills in a subsequent section. A matrix of those spills selected for analysis is presented in Table 1.

Oil Type	Ship Speed	Flow Rates 0.05 GPM	0.1 GPM	0.5 GPM	1.0 GPM	60 Liter/Mile
No. 2	14 Kt	-	9	7	6	-
9250	14	21	20	18†	17†	-
No. 6	14	85	86	87	88	90
Light Crude	10	36	35	33	31	39
Light Crude	14	48	47	45	43	40
Light Crude	17	-	49	51	52	56
Heavy Crude	14	64	65	67	68	98

†15 and 14 substituted at 17 knots in the following discussion.

Table 1 - Oil Spills Selected for Analysis

A table preceding the photographs lists the spills according to oil type. The figure numbers for the tests discussed are listed in that table.

In the analysis which follows, the prime considerations are the capabilities of the sensors to establish the type of oil and the flow rate, and to determine minimum detection capabilities of the sensors. The capability of each sensor in meeting these goals is discussed separately and a comparative summary follows the discussion of each sensor.

A. MULTISPECTRAL PHOTOGRAPHY

Multispectral photographs were taken simultaneously with a 4-lens camera. The 4-lens camera is a modified K-24 aerial camera equipped with four Schneider-Kreuznach Xenar 1:3.5/100 lenses. The shutter speed was 1/450 second at f.5.6 on all lenses except the 18A (UV) filter, which was f.4. The single lens field of view was 1220 feet at an aircraft altitude of 2,000 feet. Kodak Tri-X Aerecon film 8403 was used in the 4-lens camera. Filters provided images in the ultraviolet and short wavelength visible portion of the spectrum. A 0.5 to 0.6 micron filter was used to provide conventional black and white photographs from the middle portion of the visible spectrum. The remaining filters covered the 0.32 to 0.50 micron region in the 0.39 to 0.50, 0.32 to 0.48, and 0.36 to 0.40 micron bands.

During the first day of tests the film drive motor for the 4-lens camera failed, requiring the operator to use the manual hand crank throughout all but the last two days of operation. The use of the manual film advance did not appreciably degrade the quality or quantity of multispectral data. Data are sparse however, for the No. 2 fuel oil spills which took place on the first day of tests.

The data presented herein will be discussed on the basis of spill rate and oil type. A subsequent section will describe the effects of dispersion on detectability through a sequence of photographs of the same oil slick over an extended period of time.

The multispectral photographs reading from top to the right in the 4-frame photo are for filters of 0.39 to 0.50μ, 0.32 to 0.48μ, 0.5 to 0.6μ, and 0.36 to 0.40μ, as shown in Figure 1. All figures are for a ship speed of 14 knots unless otherwise noted.

0.39 to 0.54μ	0.32 to 0.48μ
0.5 to 0.6μ	0.36 to 0.40μ

Figure1- Location of Spectral Bands on 4-Lens Photographs

Flow Rate--0.05 GPM (Gallons per Minute)

The detection of oil spilled at 0.05 GPM is questionable for all pollutant types except heavy crude oil. Figures 2A and 2B are photographs of No. 6 fuel oil and light crude oil (ship speed - 10 knots) respectively. Although no oil appears in the photographs, it is assumed that the aircraft was over the oil slick and the oils were not detectable. As seen in Figure 3A, heavy crude oil at a spill rate of 0.05 GPM is detectable in the ultraviolet bands as a narrow irregular light streak across the center of the photographs. In the 0.5 to 0.6μ portion of the spectrum the oil slick is not apparent.

Flow Rate--0.1 GPM

The detection threshold for oils at a spill rate of 0.1 GPM is apparent for both refined and crude oils. Figure 3B shows the marginal detectability of No. 6 fuel oil eight (8) minutes after initiation of the spill. Note lighter irregular slick in lower right of 0.36 to 0.40μ photo. In the 0.32 to 0.48μ band the detection is marginal and the oil is not apparent in the 0.39 to 0.5 or 0.5 to 0.6μ bands. Both light and heavy crude oil slicks show up well in the shorter wavelength photographs, Figures 4A and 4B. The heavy crude shows a better contrast than the light crude, and can be discerned in the photographs using the visible portion of the spectrum. The intensity of contrast of the heavy oil in the ultraviolet region is higher but it is also interesting to note the effects of sun glitter in Figures 4A and 4B. The photograph of the light crude oil slick (Figure 4A) was made at 1430, while the heavy crude was flown at 1139. Sun glitter appreciably detracts from rapid identification of the presence of oil. A further fact to be noted is that crude oils appear to be more easily detected.

Flow Rate--0.5 GPM

All pollutants overflown with the 4-lens camera were detectable at a spill rate of 0.5 GPM. Figure 5A shows 9250 lubricant oil during spillage; note white water of wake in left center portion of photographs. Only the 0.36 to 0.40μ band photograph shows presence of oil. The effects of wake action on positive identification of oil spillage is displayed in this photograph. A No. 6 fuel oil slick (Figure 5B) is readily apparent in all of the short wavelength photographs as a lighter irregular ribbon in the center portion. In the visible portion of the spectrum the presence of oil on the water surface is indicated by the absence of sun glitter. The use of the absence of sun glitter as a method of oil slick detection leaves much to be desired and gives no indication of the type or thickness of the oil.

The presence of pollution by light crude oil with ship speeds of 10, 14, and 17 knots is presented in Figures 6A, 6B, and 7A. The slick formed at the slowest speed (Figure 6A) is readily apparent in the short wavelength photographs. Here, again, the slick is vaguely discernable as a decrease in sun glitter due to suppresion of surface roughness. The presence of oil in Figure 6B is seen as a very narrow light streak across the center of the photographs for the short wavelengths. The presence of oil is not apparent in the photograph using the visible portion of the spectrum. With a ship speed of 17 knots, the light crude oil (Figure 7A) appears as an irregular mass in the center of the short wavelength visible and ultraviolet photographs.

The presence of oil cannot be distinguished in the 0.5 to 0.6μ band due to under exposure. The presence of a heavy crude oil slick is readily apparent in Figure 7B. All wavelengths of investigation indicate the presence of oil, however, the shorter wavelengths produce much greater contrast.

At a spill rate of 0.5 GPM it again appears that heavier oils (lower API Gravity) are more easily detected than light weight oils. The sequence of photographs at a spill rate of 0.5 GPM also indicates that refined petroleum products are as readily detected as equivalent gravity crude oils.

Flow Rate--1 GPM

With a spill rate of 1 GPM all oil types overflown were readily detected. The 9250 lubricating oil was detected immediatley after spillage as shown in Figure 8A. The high viscosity oil remained as a narrow irregular slick apparent in the short wavelength visible and ultraviolet bands with a lighter appearance than the surrounding water devoid of pollution. The 9250 oil is not apparent in the 0.5 to 0.6μ band.

Number 6 fuel oil was detected through clouds 20 minutes after initiation of the spill. The slick is characterized by wind streaking and is best seen in the 0.36 to 0.40μ band (Figure 8B). The 0.39 to 0.5μ and 0.32 to 0.48μ band also show the oil, but the contrast is somewhat reduced. The visible portion of the spectrum does not detect the oil slick.

Figures 9A, 9B, and 10A show the detection of light crude oil at ship speeds of 10, 14, and 17 knots respectively. In all cases the shorter wavelength bands produce the best detection mechanism of the 4-lens camera. Figure 9A shows the effects of wind streaking, while Figure 9B shows a narrow ill-defined slick which appears lighter than the surrounding water. The effects of spreading are shown in Figure 10A, where the slick occupies the upper two-thirds of the photographs and is apparent as a mottled light mass with areas of varying oil thicknesses. Note there is also a suppression of sea surface roughness and a decrease in sun glitter in the area covered by oil.

Heavy crude oil at a 1 GPM spill rate is readily apparent in Figure 10B, 13 minutes after initiation of the spill. The average width of the slick is 300 feet. All wavelengths of investigation show the presence of oil, however, the shorter wavelengths show better contrast. It appears that thicker oil is present at the periphery of the slick because of the higher intensity response along the edges.

Flow Rate--60 liters/mile

All oil types investigated were detectable at a spill rate of 60 liters/mile. No. 2 fuel oil and 9250 lubricant were not spilled at a flow rate equivalent to 60 liters/mile. Figure 11A shows the presence of No. 6 fuel oil as a light hazy slick in the right center of the photographs for the short wavelength bands. The oil slick can be distinguished from clouds by comparing the ultraviolet frames with the 0.5 to 0.6µ frame (lower left) where the oil slick does not appear light and hazy.

Light crude oil slicks are shown in Figures 11B, 12A, and 12B. With ship speeds of 10 and 14 knots the slicks have similar appearances in the short wavelengths of investigation and are not apparent in the 0.5 to 0.6µ region. Slight variations in the thickness of the slicks is apparent in Figure 11B and

12A as darker streaks with their long axis parallel to the long axis of the slick. Similarities in the appearance of the two slicks is because they were formed in succession (Spills 39 and 40) and all conditions, such as glitter, roughness, etc., were the same.

In contrast to the uniform well-defined boundaries of the 10 and 14 knot light crude oil spills, the 17-knot spill the following day shows irregular boundaries and mottled appearance, (Figure 12B). Here, again, positive detection is limited to the 0.39 to 0.5μ, 0.32 to 0.48μ, and 0.36 to 0.40μ bands. A slight indication of oil is apparent in the 0.5 to 0.6μ portion of the spectrum but positive identification is marginal.

Heavy crude at a spill rate of 60 liters/mile appears as dark accumulations when thick, Figure 13A, and thin lighter streaks due to dispersion by wind action. This particular frame was taken 21 minutes after initiation of the spill. The oil slick is most pronounced in the short wavelength visible and ultraviolet bands, (right center of photograph). In the 0.5 to 0.6μ band the presence of oil is not apparent.

Effects of Wind Direction Perpendicular to Long Axis of Oil Slick

To determine the effects of wind on the dispersion of oil, a sequence of multispectral photographs showing the dispersion of light crude oil over a period of 90 minutes are presented in Figures 13B, 14A, 14B, and 15A. Figure 13B shows the light crude oil slick shortly after initiation of the spill at 0959 hours. Compare Figure 14A with 13B and note that the width of the thickest accumulation of oil has not appreciably changed. The time elapsed between Figures 13B and 14A was 8 minutes. The significant difference between Figures

13B and 14A is the development of the linear features extending down from the light colored oil slick in Figure 14A.

In Figure 14B the oil has been on the water for 38 minutes. The slick is discernable in the upper portion of the photographs in all wavelengths of investigation, except the 0.5 to 0.6μ portion of the spectrum. The linear features of alternating light and dark bands extend downward from the slick through the entire photograph.

The last photograph of the sequence, Figure 15A, shows the presence of a thin film of oil in the upper two-thirds of the 0.39 to 0.5μ, 0.32 to 0.48μ, and 0.36 to 0.4μ bands. Ncte the presence of the linear streaks which are most apparent in the right half of the slick. At the time of this photograph the oil slick had been on the water for one hour and 30 minutes; the width of the slick is indeterminable but is greater than 1000 feet.

<u>Sequence Photographs of Selected Oil Slicks</u>

The rates of dispersion of No. 6 fuel oil, light crude, and heavy crude oils with varying rates of spillage will be discussed in the following section. An oil slick of heavy crude oil at a rate of 0.1 GPM and a ship speed of 14 knots is presented in Figure 15B, twelve (12) minutes after initiation of the spill. The slick is well-defined and has a total width of 375 feet with a concentration of thicker oil on the upper edge approximately 40 feet in width. Figure 16A shows the characteristics of the slick 23 minutes after initiation of the spill. The width of the slick has not changed from those recorded in previous overflight 11 munutes earlier. The thicker, lighter portion of the slick appears to be slightly wider and the contact is more irregular. The lower boundary of the slick is less well-defined when compared with Figure 15B.

It is also interesting to note the presence of a wide oil slick of unknown origin running perpendicular to the slick under investigation in Figure 16A. Observers on board the spill vessel recorded crossing an unidentified oil slick during spillage of slicks 65 and 66. The presence of both slicks can be determined, and it does not appear that the detection of the later slick is degraded by the presence of older oil on the sea surface.

At a spill rate of 0.5 GPM a heavy crude oil slick was overflown five(5) separate times during an 89-minute interval. The dispersion rates and slick characteristics are described in Table 2.

The presence of oil is apparent throughout the entire interval, however, the width dimension became approximate due to thinning of the oil slick by the action of wind. The boundary on the windward side of the slick remains sharp after one hour on the water surface. Figures 16B, 17A, 17B, and 18A and B are representative photographs showing the dispersion detection characteristics over an 89-minute period.

Dispersion characteristics of heavy crude oil spilled at a rate of 2.6 GPM are similar to the 0.5 GPM rate. It appears that with higher spill rates the oil tends to remain coalesced for longer periods of time. Figure 19A shows the heavy crude oil slick (rate = 2.6 GPM) 18 minutes after initiation of the spill. Note the distinct boundaries and high contrast of the slick; average width of the slick in Figure 19A is 375 feet. After the oil has been on the water for 47 minutes the width had increased to only 400 feet, and the oil/water boundaries are not as well defined, Figure 19B.

The slick formed at the 2.6 GPM spill rate retained its complete coverage without breaking up after 66 minutes on the water, Figure 20A. (Note that the width dimension has not appreciably increased.) Compared with the 0.5 GPM

Frame Number	Time from Start of Spill in Minutes	Description	Width in Feet	Figure No.
845	0	Oil mixed with Water in Wake	50	16B
861	19	Well defined Slick, Sharp Boundaries, apparent on Visible	250	17A
873	38	Thicker on Windward Edge, Boundary conditions Vague on Leeward Side	430 - 460	17B
910	61	Contact Remains Sharp on Windward Side, Leeward Side Boundary not apparent in Photograph	875	18A
950	89	White Opaque oil apparent in Short Wavelength Photos; Thin oil film suspect in upper Portion of Photo.	250 Broken up	18B

Table 2 - Dispersion and Detection Characteristics of Heavy Crude Oil @ 0.5 GPM Flow Rate

spill rate slick (Figure 18A) it is noted that oil slicks formed at higher spill rates tend to remain coalesced for longer periods. This however is dependent upon the wind and sea conditions.

A No. 6 fuel oil slick at a spill rate of 3.96 GPM was overflown four times from initiation of the spill through an interval of 57 minutes. Figure 20B shows spilling of the oil. Identification of oil is marginal due to presence of disturbed water in the wake and clouds. However, a dark streak in the center of the white water appears to be oil. In the following photograph (Figure 21A) the presence of oil is apparent at all wavelengths of investigation. The oil slick has not dispersed appreciably during the 17 minutes since initiation of the spill. Thirty-five minutes after spilling the oil slick remained thick and narrow (maximum width = 125 feet). High reflectance in all wavelengths of investigation indicates the presence of oil, Figure 21B. The upper portion of the photograph indicates the presence of thin wind-streaked oil (Note the light semi-opaque steeaks in upper left, transversing obliquely across photo.) in the 0.32 to 0.48μ and 0.36 to 0.40μ bands.

Light crude oil spilled at 4.57 GPM (Spill 56) was initiated at 0935. Weather and sea conditions were reported at 0830 as wind out of the NE at 4 knots and the sea calm. Figure 22B shows the slick conditions six minutes after initiation of the spill. Boundaries are very irregular and the width varies from a maximum of 460 feet to a miniuum of 250 feet. The oil is irregularly distributed in the slick with a wide range of thicknesses apparent. Some areas within the slick appear to be devoid of oil or are covered by very thin films. The variation in thickness causes the slick to have a mottled appearance in the short wavelength visible and ultraviolet bands. Detection of the slick with the 0.5 to 0.6μ band is questionable.

After 27 minutes the slick had dispersed to a width ranging from 375 feet to 625 feet, Figure 23A. The contacts of the slick are not as sharp as the previous photograph. The mottled appearance remains dominant with areas of thin oil becoming slightly larger, which is consistent with the increase in width.

Spill 56 appeared hazy and mottled after 65 minutes on the water, Figure 23B. Boundaries are vague but still discernable in the 0.39 to 0.5μ, 0.32 to 0.48μ, and 0.36 to 0.40μ bands. Width of the slick had increased to approximately 650 feet. The only significant distinguishing feature for the differentiation of a light and heavy crude oil appears to be the mottled appearance, however, the mottled appearance may also be due to faster ship speeds.

To compare the effects of dispersion for light crude oil a 1.14 GPM spill rate (Spill 53) was monitored through a sequence of overflights which obtained data on the oil after the slick had been on the water for 91 minutes. After 31 minutes the slick has an average width of 500 feet, Figure 24A. Boundaries were irregular and the leeward boundary was less distinct than the windward. Characteristics of the slick did not change appreciably during the 23 minutes which elapsed between Figures 24A and 24B. In Figure 24B the width increased to greater than 875 feet, but the boundary conditions were similar to those of the previous photograph.

After 91 minutes on the water surface (Figure 25A) only the thicker oil which was on the windward side of the slick was discernable. There is, however, a slight indication of the presence of a thin oil film in the upper portion of the photograph which causes a minor decrease in sun glitter. Conditions for using suppression of sea state and associated decrease in sun glitter are not the best in Figure 25A, since the reflection is highest in the lower part of the photograph.

CONCLUSIONS

In the bands used for photographic imagery with the 4-lens camera, the 0.36 to 0.40μ band is the most useful for detection of oil on the sea surface. Heavy crude oil spilled at a rate of 0.05 GPM was detected with the short wavelength bands. At spill rates of 0.1 GPM and greater all oil types investigated were detectable with the 0.36 to 0.40μ band. The 0.39 to 0.50μ and 0.32 to 0.48μ bands indicate the presence of oil at the higher spill rates but the contrast between oil and water devoid of oil is more pronounced in the 0.36 to 0.40μ band.

Crude oils appear to be more easily detected than refined petroleum products, however, this may be due to the time of day and different sea conditions which existed during the formation of the slicks. For a comparison of the threshold of detectability of refined and crude oils the slicks must be observed during the same time of day under similar sea conditions.

B. VISUAL COLOR AND INFRARED COLOR CAMERAS

Simultaneous 70 mm color photos were made of the oil spills directly below the aircraft. The camera is a modified K-24 aerial camera equipped with Schneider-Kreuznach Super-Angulon 1:5.6/47 lenses. The shutter speed on the camera was 1/450 second with lens settings of f.8. Kodak Ektachrome Infrared Aero film (type 8443) and Ektachrome MS Aerographic film (type 2448) were used to produce infrared images and conventional color photography, respectively. Exposure settings were difficult because of the sun angle and reflections, but in most cases exposure did not mask the detection of oil as contrasts were perceptable. Coverage of the second and third day spills was not obtained because of a broken shutter.

Both visual and IR color are discussed simultaneously in this section as the results are similar. Unless differences are noted, the discussion herein applies to both types of color film. Evaluation of the color film will first be made on selected 14 knot runs at specified flow rates. When photos were not available of the selected spills, similar spills have been substituted and noted. Additional photos of the same spills later in time have been included in this discussion for spread rate evaluation. Photos of the spills to be discussed are shown in Figure 26 through 39 which have been arranged by fuel types to show comparisons by spill rate. It was felt to be more convenient to discuss the oil by flow rates, thus the discussion will refer to figure number, spill number, and photo number. In this manner both visual comparison at different rates for one oil type can be made simultaneously with comparisons between oils.

Whenever possible the same spills evaluated as to flow rate detection will be discussed also as to spread rate. In addition, other spills will be evaluated if it is felt that significant data can be presented. If the spill was only visible on one pass, no further discussion is presented. In general, no history on #2 fuel or 9250 oil could be obtained for more than one pass. The heaviest spill of 9250 oil of Spill 14 did remain visible for 3 passes and is the first series discussed.

Flow Rate--0.05 GPM

Flow rates of 0.05 GPM or less are extremely difficult to detect with the visual and IR color. Number 2 fuel was not visible at all and 9250 oil was questionable. Occasional photographs of the 9250 oil show a small area on the water surface which reflects light. Usually this area could not be definitely identified as the spill in question. Light crude photos were not available of the 0.05 GPM rate as the test was conducted at the time the color camera was inoperative. A photo of heavy crude oil is shown in Photo 823, of Figure 29. The oil appears as dark streaks on the edge of the wake shortly after the spill was started. This dark discoloration disappears rapidly. The heavy crude measurement was made during a period when intermittent cloud cover existed at altitudes below the multi-sensor aircraft altitude, thus light conditions compromised the color exposures.

Number 6 fuel, like heavy crude, appears as a narrow dark band in the water. Figure 27, Spill 85, Photo 1245, was taken nearly 30 minutes after the #6 fuel was pumped in the sea. Earlier overflights did not show this oil, which would indicate that the fuel had not fully surfaced or that it clumped together after some aging. No dispersion of the oil is noted in Photo 1245.

Flow Rate--0.1 GPM

The minimum reliable detection flow rate with color photography under the conditions flown is approximately 0.1 GPM. Number 2 fuel at 0.1 GPM appears very similar in appearance to the lower flow rates of #6 fuels. Time history would be required to distinguish the #2 fuel as it appears on the surface rapidly and disperses quickly. Number 2 fuel at 0.1 GPM is shown in Figure 26, Spill 9, Photo 63. The oil shown in the IR color of Photo 63 gives a sharper contrast than the oil in the visual color.

9250 oil detection is still questionable ot 0.1 GPM as shown in Figure 26, Spill 20, Photo 160. Consistent data was not received on 9250 oil, thus it must be assumed that detection is limited.

Number 6 fuel as it appears in Figure 27, Spill 86, Photo 1250 is quite easily detected at 0.1 GPM as dark thick appearing patches of oil. The spill has been in the water nearly 20 minutes at the time Photo 1250 was taken and is noticeably wider in width than the 0.05 spill of Photo 1245. Both visual and IR color seem equally satisfactory for detection purposes. Ill-defined boundaries make width determination difficult.

Heavy crude photos are shown in Figure 29 on Spill 65, Photo 837. The oil is readily detected on both color films and has been in the water nearly 32 minutes. It should be noted that at this flow rate heavy crude has a white appearance instead of black. The spread of the oil appears to be in one direction during this spill. It is not evident from the photo as to whether the oil is thicker on one side and spreading in one direction or if, instead, it is thicker on one side due to the mixing action of the ships screws. Heavier spills indicate that the spills are uniform unless there are heavy cross winds.

Flow Rate--0.5 GPM

As before, the #2 fuel was not detected with the color photos. 9250 oil was not detected at 14 knots but earlier runs at 17 knots were detected as shown in Figure 26, Spill 15, Photo 106. The major difference to note is that the oil in the IR color shows greater contrast than the visual color. The same contrast differential applies to the #6 fuel as shown in Figure 27, Spill 87, Photo 1254. The #6 fuel oil appears to spread more rapidly than does the 9250 oil.

The light crude oil shown in Figure 28, Spill 51, Photo 659, is not easily detected particularly in the IR color photos. The oil had just been spilled and the film was underexposed. The color of the light crude contrasts from the 9250 oil and the #6 fuel in that the light crude has a greyish cast instead of being black.

Heavy crude after being in the water a short while (20 minutes) can be readily detected as shown in Figure 29, Spill 67, Photo 863. Spill 67 was dumped with a ship speed of 17 knots. Photo 863 shows that the oil is thicker on the edges with most of the oil being on the edges of the 250 foot slick. This unevenness is probably the result of wake action, as it does not appear to be a function of wind direction.

Flow Rate--1.0 GPM

Number 2 fuel was not detected by the color film. It is suspected that the aircraft may not have been over the spill at that time as lower rates were detected earlier. The 14 knot spill of 9250 oil was not detectable, however, at 17 knots black streaks over a wide area were noted as shown in Figure 26, Spill 14, Photo 110. Number 6 fuel is easily detected at this high a rate but the boundaries are difficult to determine with low sun angles, Figure 27, Spill 88, Photo. 1271. Photos of the light crude at 10 and 14 knots were not taken because of camera problems, but at 17 knots, Figure 28, Spill 52, Photo 687, shows light crude after 25 minutes in the water. In this time duration the oil has spread to 350 feet. Large patches are shown which still have a swirl pattern but are starting to separate. Some brown or reddish colors are noted in the grey swirls which are probably due to thicker patches of oil on the surface. Heavy crude colors are similar to light crude colors. The major difference to be noted is that heavy crude does not spread as rapidly as light crude. The heavy oil does spread quite rapidly, however, as it is 250 feet wide in Figure 29, Spill 68, Photo 865, and has only been in the water less than 10 minutes.

Flow Rate--60 liters/mile

Number 2 fuel and 9250 oil were not spilled at the 60 liters/mile rate. Number 6 fuel at 3.6 GPM is shown in Figure 28, Spill 90, Photo 1290. Number 6 fuel is a black color and spreads slowly. Differentiating between #6 fuel and 9250 oil does not appear to be easy from the color photos; however, it is readily discernable from the light and heavy crude.

Light crude spill 56 is shown in Figure 28, Photo 717, at 4.57 GPM. The high rate was required to provide 60 liters/mile because the ship's speed was 17 knots. Light crude at the high rate is easily detected in both films. The reddish-brown rust color in the oil is throughout with spiral patterns. No break up is evident with the oil spreading 300 to 400 feet after 10 minutes.

Heavy crude at 3.5 GPM is shown in Figure 30, Spill 98, Photo 1450. This particular spill of heavy crude appears different than other heavy crude spills. The color is black like the #6 fuel. The spread rate appears slower at first although Photo 1450 was taken only a few minutes after the oil was spilled. Spread rates of heavy crude at other speeds will be evaluated later.

Spread Rate--9250--1.0 GPM

Figure 30, Photos 95, 99, and 110 show Spill 14 on three consecutive passes. Photo 99 is 12 minutes after Photo 95 and Photo 110 is 14 minutes later. Thus the oil has been spilled approximately 2, 16, and 20 minutes, respectively.

In this period, the black appearing oil spread from 150 to 200 to 300 feet, respectively. The overall length of the spill does not noticeably change. On the third pass the oil shows some signs of breaking up. The detection duration time could not be evaluated as Spill 14 was dumped later in the day and operations were terminated before the oil completely dispersed.

Spread Rate--#6 Fuel--0.15 GPM

Spill 86 at 0.15 GPM is shown in Figure 31, Photos 1250 and 1262. In both photos the boundaries were difficult to determine. The oil of Photo 1250 has been in the water 20 minutes and 34 minutes in 1262, thus it was starting to break up before spread rates could be determined. Previous photos were obscured by clouds. The major difference between the #6 and 9250 to be noted herein is in width only which is related to spill rates. Both types appear black on both color films.

Spread Rate--#6 Fuel--0.52 GPM

The next higher spill rate of #6 fuel to be compared is shown in Figures 31 and 32, Photos 1254, 1266, and 1277. Photo 1254 shows the oil 8 minutes after the spill started. Photo 1266 and 1277 are considerably later by 22 minutes and 38 minutes, respectively. Widths were difficult to measure as heavy swells and wind spread the oil rapidly. Close examination shows that the oil is bunched in the wave troughs and appear as black streaks. The major spill location maintains the densest concentrations; however, the time detection period of the oil could not be continued as clouds prevented visual tracking with the aircraft. It was believed that this was overflown later but identification could not be made without visual references.

Spread Rate--#6 fuel--1.16 GPM

A higher rate of #6 fuel spill rate at 1.16 GPM is shown in Figure 33, Photos 1271, 1281, and 1346. The oil spill in the three photos is approximately 10 minutes, 26 minutes, and 60 minutes later, respectively. Cloud cover made identification of this spill difficult. One run was made between Photos 1281, and 1346 which could not be identified by spill numbers because of clouds. Photo 1271 shows the oil to be black an shiny with both edges not sharply defined. Photo 1281, although not sharply defined because of the high percentage of cloud cover, indicates the start of oil break up and in Photo 1346, the oil appears only in patches. The fuel appears to be only bunching and spreading with little or no sinking or deterioration.

Spread Rate--#6 Fuel--3.67 GPM

Three passes were made over Spill 90 before operations were terminated for the day. The oil in Figure 33, Photo 1290, has been spilled only 5-6 minutes. The spill appears dark and is starting the breakup into the wave troughs. Photo 1334 of Figure 33 shows how the oil has spread 20 minutes after being spilled. The major portion which appears shiny has spread to nearly 400 feet in width. Close study shows longer streaks spreading out from the major spill area. Photo 1359 of Figure 33 was taken 42 minutes after the spill was started. Heavy clouds made it difficult to locate the center of the spill as the spill had broken into patches which are barely evident over the entire photo. IR color shows this break up the best as shiny patches.

Spread Rate--Light Crude--0.5 GPM

Two photos are shown in Figure 33 and 34 for light crude at 0.5 GPM. In photo 659, the oil immediately after being spilled is barely discernable in the visible color film as grey spirals just ahead of the chase boat. Other photos show the oil as light grey swirls which gradually dispersed. Photo 726 shows the same spill approximately 68 minutes later. The oil still appears as broken swirled patterns 100 to 200 feet apart. The slow spread rate is probably due to the light wind conditions that day.

Spread Rate--Light Crude--1.0 GPM

Spill 52 is shown in Figure 34 of Photos 687, 701, and 731. The oil has been in the water for each photo for 15 minutes, 38 mnnutes, and 60 minutes, respectively. The first photo shows the oil to be wide spirals with the oil in patches spread over nearly 350 feet. The oil appears hazy white with the visual color photo being somewhat clearer showing a red tint in the center of the spirals. In both Photos 701, and 731, the oil has spread to 400-450 feet with the spiral pattern being less distinct. The red tint tends to remain on the edges of the spills giving the impression that the oil is thicker on the edges. Later photos show only patches of oil which cannot be definitely related to this spill because of limitations in the camera's field of view.

Spread Rate--Light Crude--4.57 GPM

Spill 56 at 4.57 GPM is shown in Figure 35, Photos 717, 745, and 789. The oil in the photos have been in the water approximately 10 minutes, 42 minutes, and 72 minutes, respectively. As can be seen in the photos, it is very evident that this spill was at a high rate with little break up of the oil in over an hour. Photo 789 was made on the last run of the morning when the ship's course was changed, thus the spill's duration could not be determined. Spread rate from the photos are measured as 250 feet, 400 feet and 500 feet respectively. As in the lighter spill rates, the oil rapidly spreads to a width of 300-400 feet and then gradually spreads. Wind conditions for these photos are still such to give light wave action with some swells.

Spread Rate--Heavy Crude--0.5 GPM

Photo 863 of Figure 35 and Photo 881, and 914 and 954 of Figure 36 show consecutive photos of Spill 67. The age of the oil in the water in each photo is approximately 20 minutes, 39 minutes, 62 minutes, and 90 minutes, respectively. The major significance of these photos is to show how the distinct patches of oil and spiraled patterns of Photo 863 changes into a diffused, hazy white streak which does not spread significantly beyond 400 feet. It should be noted that with age the IR color detection degrades faster than the visual color, with the oil in the IR color photos turning black in the last photo. Operations for the day were ended before further photos could be taken; however, under the wind conditions at that time, it is estimated that detection would have been possible for several hours.

Spread Rate--Heavy Crude--0.94 GPM

A higher flow rate of Spill 68 is shown in Photo 865 of Figure 36 and Photos 888, 921, and 959 of Figure 37. The age of the oil in these photos is 10 minutes, 27 minutes, 50 minutes, and 79 minutes, respectively. The first photo, 865, shows the oil shortly after it was spilled and the chase boat apeears to have disturbed the oil in the upper portion of the spill. By comparing Photo 865 to 863, it is evident that the flow rate is greater in 865. As in the previous 0.5 GPM photos, little change is noted in the later photos except for the fading and diffusion of the oil. As before the IR color gradually changes from white to black with time while the regular color only fades. In this test the oil may have been discernable for a longer period had operations heen extended that day.

Spread Rate--Heavy Crude--3.5 GPM

The heavy spill rate of Spill 98 was continued on a different day and the results are compared herein to show the effects of higher seas. Only two photos were taken as the spill was made near the end of the day. The first photo is 1450 in Figure 37, taken approximately 3 minutes after the spill was dumped and Photo 1501 in Figure 38 which shows the spill aged by 54 minutes. Photo 1450 appears entirely different than the other heavy crudes spilled on previous days. The color is black instead of grey and the spiral pattern is not evident as it was before. In the later photo, the oil has diffused quite evenly but still has a black color with a highly reflective surface.

Spread Rate--Heavy Crude--2.64 GPM

Photos 935, 974, and 996 of Figure 38 show the heavy crude of Spill 71 which was spilled at a rate of 10 knots. The age of the oil in the three photos are respectively, 18 minutes, 47 minutes, and 66 minutes. The oil in these photos does not indicate any differences resulting from speed. The oil still spreads rapidly to 300 feet and gradually increases to 500 feet. As in earlier heavy crude runs, the spiral pattern appears and gradually diffuses.

Spread Rate--Heavy Crude--3.95 GPM

A high rate of spread (17 knots) for #6 fuel in Spill 96 is compared in Figure 39 in Photos 1391,,1410, 1431, and 1467. The ages of the fuel are 2 minutes, 17 minutes, 26 minutes, and 58 minutes. The first photo shows only a narrow stretch of oil followed by shiny patches of oil over a wide area which is difficult to measure. As in the heavy crude, speed does not appear to effect the oil spread rate.

Conclusions of Color Photography

Both visual multispectral color and IR color appear to be equally capable of detecting oil on the surface of the water under the weather conditions encountered during performance of this program. The major differences noted between the two was that the infrared film tends to give a slightly sharper contrast between the oil and the water with low sun angles. The multispectral visual color is more useful in evaluating flow rates as the oil thickness can be better inferred by seeing the wider range of colors that appear as oil thickens. Neither film was found satisfactory in the detection of #2 fuel, however, difficulties in operation on the days in which #2 fuel was spilled may compromise the conclusion. Detection of the other oils were possible with the color cameras at flow rates down to 0.05 GPM providing the oil had been in the water for a very short time period (less than 10 minutes). Reliable detection of oil for any extended period with visual and IR color film were only made at flow rates above 0.5 GPM. The lower flow rates remain on the surface of the water for a short period of time and if any wind is present or high currents exist, the oil quickly disperses and is not longer visible.

All of the spill rates were largely influenced by wind and the sea's condition. The break up of the oil does not appear to be due to gradual diffusion. In particular, heavy crudes and the heavier fuels break up into patches and spread over a wide area. Until this happens, almost all types of oil tested appear to spread quite rapidly to 300 feet and then gradually to 500 feet. Any spreading beyond 500 feet in width is usually accompanied by the break up of the oil into small patches or small streaks in the troughs of the swells. The speed of the ship does not appear to have any significant effect on the appearance of the oil in the water except for perhaps subtle differences in such things as the distance behind the ship at which the oil first surfaces. No attempts were made to analyze these sort of subtle differences.

Color photography does not appear to be a precise tool in determining the rate of oil spillage. However, an estimation of flow rates can be inferred. It also should be possible for an experienced operator to determine if the flow rates are above a certain value such as 0.5 GPM, 1 GPM, or 3-4 GPM. Of course, clouds and weather do have significant effects upon the color photography as noted in several photographs, during the days in which clouds and storm conditions existed.

C. INFRARED SCANNER IMAGERY

Infrared imagery of oil slicks was obtained in the 8-14μ and 4-5.5μ bands using a Bendix Scanner. Due to mechanical difficulty only limited data were obtained on the first day's test with the scanner operating with an 8-14μ detector. The thermal mapper was a Bendix TM/LN-3 scanner with a tri-metal 8-14μ detector cooled with liquid nitrogen. The instantaneous field of view is 2.5 milliradians with a total field of view of 120° of arc. A #2 fuel oil slick appears in Figure 40 as a dark stream of oil trailing the spill vessel. The rate of spill was 0.2 GPM with a ship speed of 18 knots. In the 8-14μ band the oil appears cooler (darker) than the surrounding water. Thicker oil at the boundary of the slick is cooler radiometrically than the center portion of the slick. The wake of the ship appears warm and it is not known if oil was being spilled at the time the imagery was made. If oil was being spilled its detection would undoubtedly be masked by the radiometrically warmer wake.

During the last two days of tests the scanner was operational using a 4-5.5μ detector. The instrument used was a Bendix TM/LN-2 equipped with a InSb 4-5.5μ detector. Figure 41 (Spill 98) shows the detection capabilities over a heavy crude oil slick spilled at a rate of 0.5 GPM and a ship speed of 14 knots. Contrary to expected results, the heavy crude oil appears radiometrically warmer than the surrounding water in the 4-5.5μ band. It was anticipated that the response of oils in the intermediate infrared would be similar to the 8-14μ region response. Further analysis on the 4-5.5μ scanner imagery of the heavy crude oil slick after it had been on the water for several minutes revealed that it remained radiometrically warmer.

In contrast to the response of heavy crude oil, Number 6 fuel oil, (Spill 90) appeared radiometrically cooler in the 4-5.5μ region, Figure 42. The spill rate was 3.67 GPM and the ship speed was 14 knots. The difference in the response of the crude and refined petroleum in the 4-5.5μ region is not fully understood. It may be due to inherent differences in the emittance and reflectance of the two oil types in the 4-5.5μ region. Previous measurements in the 8-13.5μ range* have shown that crude oil appears radiometrically cooler than the surrounding water.

The infrared imagery presently at hand is not sufficient to fully evaluate the capabilities of oil type differientiation using the 4-5.5 region of the intermediate infrared. To determine and evaluate the capabilities of sensors operating in or near these wavelengths, further tests should be performed. Specific data on the effects of oil thicknesses and types which can be distinguished must be quantified.

D. MICROWAVE RADIOMETER SENSORS

Two microwave radiometers were mounted in one of the two camera wells in the bottom of the DC-3 aircraft shown in Figure 43. The radiometers were mounted looking aft at 50° nadir when the deck of the aircraft is horizontal. The all solid-state radiometers, built by the Microwave Sensor Systems Division of Spectran, Inc., were designed for operation on airborne or ground based platforms. Both radiometers are dual polarized with analog read-outs directly in temperature. All radiometric temperature read-outs are automatically corrected for changes in ambient and hot load temperature. The electrical parameters of the radiometric systems are included in Table 3.

The look angle of the radiometers was selected to be at or near 50° to minimize the effects of sea state to the vertically polarized signals. It was felt that near the 50° nadir angle the vertical polarized signals would be affected primarily by the oil on the water alone, and not resulting from the

*Lowe, D. S., and P. G. Hasell, Multispectral Sensing of Oil Pollution, 6th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, 1969.

Table 3 - Radiometer System Specifications

Center Frequency	10.2 GHz	30.0 GHz
Bandwidth (min.)	450 MHz	450 MHz
ΔT (sensitivity/second) Single polarity Double polarity	 0.11° K 0.15° K	 0.21° K 0.30° K
Intercept Element	320 X 230 feet†	170 X 120 feet†
Antenna Beamwidth	4.6°	2.4°
Data Outputs	Horizontal Vertical Reference	
Recorded Integration Time	0.1 sec.	0.1 sec.

†Major and minor axes of ellipse from 2,000 feet altitude.

calmed sea condition. The final nadir angle of the radiometers during the actual flights was 46° instead of 50° and, as a result, all sea state effects were not ignored by the vertical channel as will be shown later.

The results of these measurements will be discussed differently than was the photographic data as the results, in general, apply equally to all spills. Whenever anomalies appear, that spill will be discussed separately.

The Microwave data was taken by flying from astern the Coast Guard cutter at an altitude of 2,000 feet. As the look angle in not at nadir, the intercept area of the antenna beams are elliptical in shape with major and minor axes of approximately 320 by 230 and 170 by 120 feet for the 10.2 GHz and 30 GHz radiometers respectively. Sample sizes of these areas are minimal for the 10.2 GHz system and below for the 30 GHz to obtain a good statistical average of the wave trains. As a result of the small sample size, most of the discussion to follow applies to the X-Band, (10.2 GHz) system. Data were compiled and analyzed for the K_a-Band (30 GHz) system, but the accuracy of the signal magnitudes are questionable.

During the tests, microwave data were recorded of a 4-channel tape recorder at a speed of 3-3/4 inch/second. In addition, both horizontally polarized signals were recorded at the input to the tape recorder on a dual channel strip line recorder at 2 inches/minute. A monitor station was available to sample any of one of the six outputs desired on a digital voltmeter. A check on the data and time log later showed that the aircraft invertor's output was 120 volts at 45 cycles, instead of 60 cycles, thus all recorders were running at 45/60 or 3/4 speed. All data have been corrected to reflect the true recording speed.

The data on the tape recorder have been recorded on a 6-channel strip chart recorder with the integration time increased to approximately 2 seconds. The data were run at 25 millimeter/second to make the length of the microwave data more closely correspond to the length of the photographs. In addition, a spike suppression curcuit was used to delete the boresight camera and interference spikes. The two extra channels record the difference in the horizontal and vertical polarized signals for each radiometer. The data in this format is too large for presentation, thus only the amplitude data has been tabulated and included in Appendix A.

Detection Limitations

The minimum detection level of the microwave radiometers was difficult to determine in these tests as visual acquisition was required to align the antenna beam with the oil spill. Tests during the first day gave little information because of the alignment difficulties. On other days when low level spills were visible, detection with the microwave radiometers was made down to 0.05 GPM.

The X-Band microwave signal level for the spills discussed earlier, in the color and ultraviolet sensors are as shown in Table 4.

	SPILL RATES 0.05 GPM	0.1 GPM	0.5 GPM	1.0 GPM	60 Liters/Mile
No. 2	-	-	-	-	-
9250	-	-	-	-	-
No. 6	-2°	-2°	-4°	-5°	-5°
Light Crude[†]	- -4° -	- - -	- -6° -6°	-3° -9° -6°	-4° -7° -5°
Heavy Crude	-	-6°	-5°	-1°	-10°

[†]Three series at 10, 14, and 17 knots are evaluated.

Table 4 - Microwave Radiometric Temperatures

The signal levels shown in the table by themselves are not significant as the alignment problem was always critical and the percentage beam fill is not always known. The most significant thing to be noted from the table is that the signals are all colder than the background. No pattern seems to be evident from the different ship speeds for light crude.

It would also appear from the table that heavier types of oil give colder recordings at lower rates, and that the heavier spills are colder than the light spills. These results are reasonable in that the oil spill rate was not great enough to reach a thickness where the warmer oil signal predominates over the reduced or cooler signal as a result of lower sea state. Some measurements do not follow this trend; the signals get warmer for some spills. It cannot be verified with the data available, but the effect might be due to the thickness of heavy patches of oil compensating for the cooler signal from sea state reduction. At K_a-Band, some warm signals were received but correlation between aircraft motion, wave effects, and oil is difficult. It is possible that many of the warm signals received at 30 GHz are patches of oil which are thick enough over a large enough area to give beam fills sufficient to create hot signals. Unless runs can be made at an altitude sufficient to smooth out or average the wave effects, sea state cannot easily be determined.

The runs from which the microwave data was analyzed are too numerous to present individually within this report. A typical run is shown in Figure 44, which was recorded on a strip chart at a slower speed. Both polarizations are shown for both radiometers. The areas between spills are evident in most cases in the X-Band recordings but are more difficult to see in the K_a-Band recordings. Careful integration with the eye shows an overall change from one spill to another. The effects of oil patches and aircraft motion are noted in the 30 GHz values as the beam fill changes. Aircraft motion was very difficult for the operators to detect and would not have been noted except for sun angle monitoring.

The increased temperature as the ship is approached is quite evident from Figure 45, and in the shorter integration recordings the noise is evident at least two spills behind the ship.

One spill was conducted in which no oil was dumped. The recordings for this run are shown in Figure 46. The spills prior to this test were extremely light and not visually acquired, thus it was difficult to align the aircraft to determine the presence or lack of oil in the beam. From the run and the return run, it can be noted that a lack of signal exists.

A second anomoly was noted in the microwave data which at this time is unexplained. Test 41 and part of Test 42 was extremely noisy, similar to that experienced when flying over the ship. This signal did not exist on the initial run shortly after it was spilled; however, on the next overflight and the return it was very evident. The ship's course changed after this and the spill in question was not overflown again. The anomoly was also noted on a non-experiment IR radiometer which was aboard the aircraft. To both the microwave and IR radiometers the signal was 8 - 10° warmer with 10° noise spikes.

Analysis of the V-H signals did not add any significant information to the data received. Theoretically, a difference should be noted because of sea state changes. As noted, 46° was not sufficient to remove sea state contributions to the vertically polarized signals, and may account for the lack of information in V-H. A large difference was noted in V-H for tests 41 and 42 where a great amount of noise was experienced. No reason is known at this time for the cause of the noise or the polarization difference.

Oil Type Detection

The ability of the microwave radiometers to discriminate among oil types in the quantities spilled for these tests is quite questionable. The rates of spill considered herein largely affected sea state only, thus the signals were primarily sea state readings. To detect oil type would require thicknesses whereby dielectric constants and absorption losses became significant ($>\frac{\lambda}{10}$). Inferences might be made from microwave data if runs were made from other angles such that spread rates and oil break up are noted. In general, such conclusions for oil type would be difficult and unreliable based upon tests to date.

Microwave Data Conclusion

The nature in which the microwave tests were conducted make it difficult to finalize any conclusions without further experiments. However, the conclusion can be made that microwave appears to be a satisfactory sensor in the detection of oil on the water's surface, even when the oil is not visible for reasons of oil quantity or weather. In any case, it is desirable that passes be made from a direction in which no oil is present to obtain a reference if quantity is to be determined. Higher spill rates could create some ambiguities in that oscillatory signals may exist with large changes in oil thickness.* The signals received by the 30GHz radiometer may indeed by a result of this fact as many of the larger signal changes cannot be explained by aircraft motion alone.

Detection or recognition of oil type with microwave radiometers does not seem feasible from the tests run; instead, a multi-sensor package including microwave radiometers shows the most promise.

It appears that for all weather conditions, microwave radiometers are desirable so as to not depend upon the visual or ultraviolet portions of the spectrum alone. Anomolies, such as those of Test 41, may provide significant information other than spill rate.

*Aukland, J. C., Conway, W. H., and Sanders, N. K., "Detection of Oil Slick Pollution on Water Surfaces with Microwave Radiometer Systems," Proceedings of the Sixth International Symposium on Remote Sensing of the Environment, University of Michigan, 1969.

IV. CONCLUSIONS

Analysis of the multisensor data presented in this report shows that each sensor has specific advantages for particular conditions of time of day, sea surface roughness, weather, and type of pollutant. In general, all sensors were capable of detecting oil slicks at spill rates of 0.5 GPM and greater. The express purpose of the program was to optimize photographic data, and, therefore, other sensor data such as that produced by the microwave radiometers and infrared scanner were compromised.

The imagery produced from the 4-lens camera operating in the short wavelength visible and ultraviolet regions shows the best detection capability of the photographic sensors. Detection of thin films of oil is inversely proportional to the wavelengths of investigation. That is, the shorter the wavelength, the better the contrast between oil and water. The 0.36 to 0.40μ band produces the best contrast of all filters used. The effects of sun angle (glitter) degrades the detection capabilities of the longer wavelength bands. The ability to discriminate oil types with the black and white multispectral photography does not appear feasible. However, the determination of spill rates and the oil's viscosity can be inferred by the slick's characteristics. The estimation of spill rates from dispersion characteristics is dependent on the wind and sea surface conditions.

Visual color and infrared color photography appear to be equally capable of detecting oil on the surface of the water under the weather conditions experienced during performance of this program. Detection of oil slicks formed at spill rates of 0.05 GPM was possible immediately after spillage, however, the small flow rate dispersed rapidly and was not discernable for extended periods of time. Color photographs in the visible portion of the spectrum were superior to the infrared in inferring flow rates by sensing a wider range of colors in the thicker slicks.

Infrared scanner imagery in both the 4-5.5 and 8-14μ bands shows good detection capabilities for the oil slicks investigated. Operating in the 8-14μ band the scanner produced imagery which clearly shows the presence of a No. 2 fuel oil slick. The detection of the low flow rate No. 2 fuel oil slick by the infrared scanner indicates the high sensitivity of the infrared region to oil on the water surface. The No. 2 fuel was the most difficult oil type to detect with other sensors on board the aircraft. Imagery produced using a 4-5.5 detector was of comparable quality to the 8 - 14μ data. However, an anomaly in the response for heavy crude oil and No. 6 fuel oil was observed. The heavy crude oil slick formed at a 0.5 GPM flow rate appeared radiometrically warmer than the surrouding water, whereas the No. 6 fuel oil slick (flow rate = 3.67 GPM) was radiometrically cooler than the water. The relationship between the infrared radiometric response in the 4-5.5μ region and the oil types, flow rates, etc., is not understood at the present. To ascertain the mechanism of radiometric temperature difference between heavy crude oil and No. 6 fuel oil in the 4-5.5μ region further experimentation is necessary.

Even though the experimental program was designed to optimize photographic sensors, the dual frequency microwave system detected oil slicks that were not discernable with camera systems operating in the visible portions of the spectrum. Data derived from this program indicate that further experimentation will be necessary to quantify the capabilities of microwave radiometry to discriminate oil types and to provide estimation of oil thickness. To fully ascertain the capabilities of microwave radiometry in detection of oil on the sea surface, experiments should be conducted during inclement weather and at night.

The dispersion characteristics of several oil types and various spill rates were investigated. It can be concluded from this investigation that the spreading and breakup of oil is dependent upon the wind and sea conditions. The break up of the more viscous oils (heavy crude and No. 6 fuel oil) is due to separation of the oil into discrete patches which spread over a wide area. In most instances the oils quickly spread to a width of approximately 300 feet and they gradually increase in width to 500 feet. Increases in widths of greater than 500 feet are generally accompanied by the breakup of the oil into small patches or streaks in the troughs of the swells. Streaking by wind action appears to be the predominant mechanism for rapid dispersion of oil slicks and variations in oil thickness within the slick.

Analysis and interpretation of the multisensor data derived from these tests has provided answers to many questions on the detection capabilities of the sensors used. In providing answers to some questions the results also stimulated many queries into the effects such variables as higher sea state conditions and inclement weather have upon oil pollution detection. To fully evaluate the detection capabilities, further experiments should be conducted to eliminate or fix the effects of as many parameters as possible.

TABLE 5 - FIGURE NUMBER INDEX

	Ship Speed	Flow Rate	Multispectral Figure Numbers	Color & IR Figure Numbers	IR Scanner	Spill #
#2 Fuel						
	10 kts	0.05 GPM				5
		0.1				4
		0.2				3
		0.5				2
		1.0				1
	14 kts	0.1		26		9
		0.2				8
		0.5				7
		1.0				6
	17 kts	0.1				13
	18 kts	0.2			40	12
		0.5				11
		1.0				10
9250						
	10 kts	0.1				23
		0.2				24
		0.5				25
		1.0				26
	14 kts	0.05				21
		0.1				20
		0.2				19
		0.5				18
		1.0				17
	17 kts	0.1				22
		0.2				16
		0.5	5A	26		15
		1.0	8A	26,30		14
Light Crude						
	10 kts	.02				37
		.05	2B			36
		0.1				35
		.2				34
		.5	6A			33
		.67				32
		1.0	9A			31
		2.0				38
		2.69	11B			39

Ship Speed	Flow Rate	Multispectral Figure Numbers	Color & IR Figure Numbers	IR Scanner	Spill #
Light Crude					
14 kts	0.05 GPM				48
	0.1	4A			47
	0.2				46
	0.5	6B			45
	0.94				44
	1.0	9B			43
	1.88				42
	2.00				41
	3.77	12A			40
17 kts	0.1				49
	0.2	7A			50
	0.5		28,33,34		51
	1.0	10A	28,34		52
	1.14				53
	2.0				54
	2.29				55
	4.57		28,35		56
Heavy Crude					
17 kts	0.1				63
	0.2				62
	0.5				61
	1.6				60
	1.14				59
	2.0				58
	2.29				57
14 kts	0.05	3A	29		64
	0.1	4B	29		65
	0.2				66
	0.5	7B	29,36		67
	0.94	10B	29,36,37		68
	1.88				69
	2.0				70
10 kts	2.64		38		71
	2.0				72
	1.35				73
	1.0				74
	0.67				75
	0.5				76
	0.2				77
	0.1				78
	0.05				79

	Ship Speed	Flow Rate	Multispectral Figure Numbers	Color & IR Figure Numbers	IR Scanner	Spill #
#6 Fuel						
	10 kts	0.05 GPM				80
		0.15				81
		0.52				82
		1.16				83
		2.46				84
	14 kts	0.05	2A	27		85
		0.15	3B	27,31		86
		0.52	5B	27,31,32		87
		1.16	8B	27,32		88
		1.83				89
		3.67	11A	28,33	41B	90
	18 kts	0.05				91
		0.15				92
		0.52				93
	17 kts	1.16				94
		2.46				95
		3.95		39		96
½ Gas & ½ Oil						97
Heavy Crude						
	14 kts	0.5	13A	30,37,38	41A	98
	17 kts	0.5				99
Gas & Oil						
	14 kts	0.1				100
2/1 Gas & Oil		0.1				101
4/1 Gas & Oil		0.1				102
Gas		0.1				103

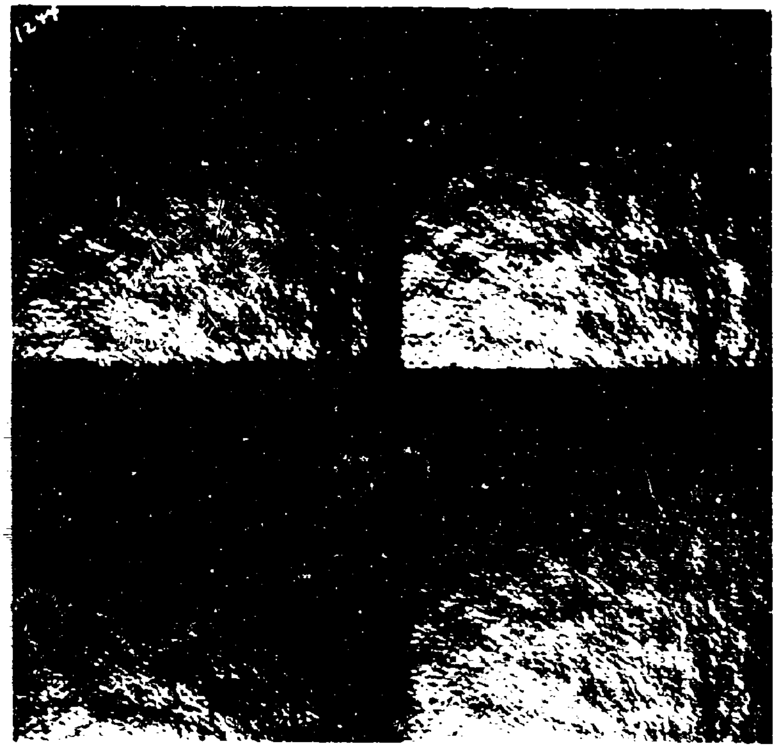


Figure 2A
Number 6 Fuel Oil
Spill Number 85
Flow Rate 0.05 GPM
Ship Speed 14 kts

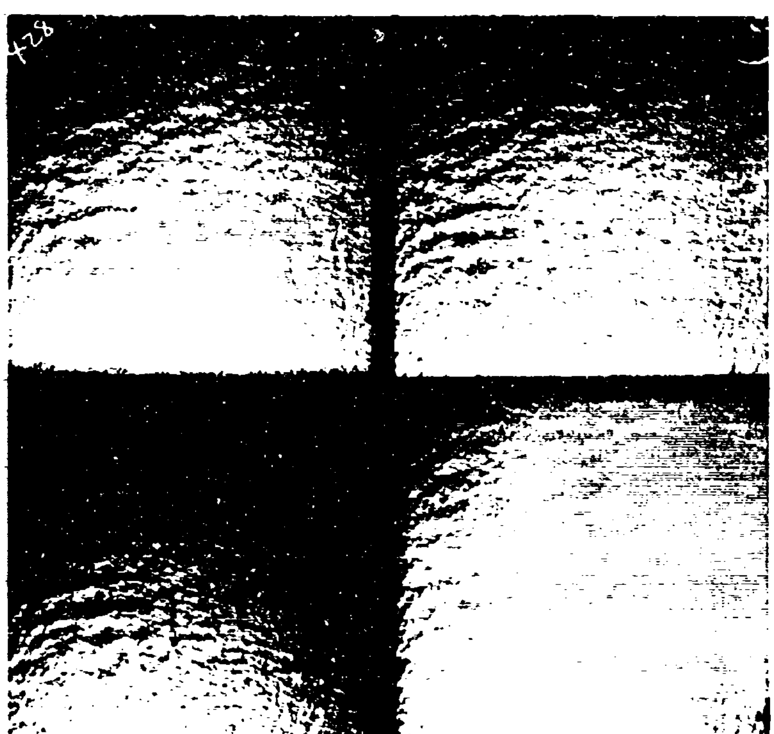


Figure 2B
Light Crude Oil
Spill Numcer 36
Flow Rate 0.05 GPM
Ship Speed 10 kts

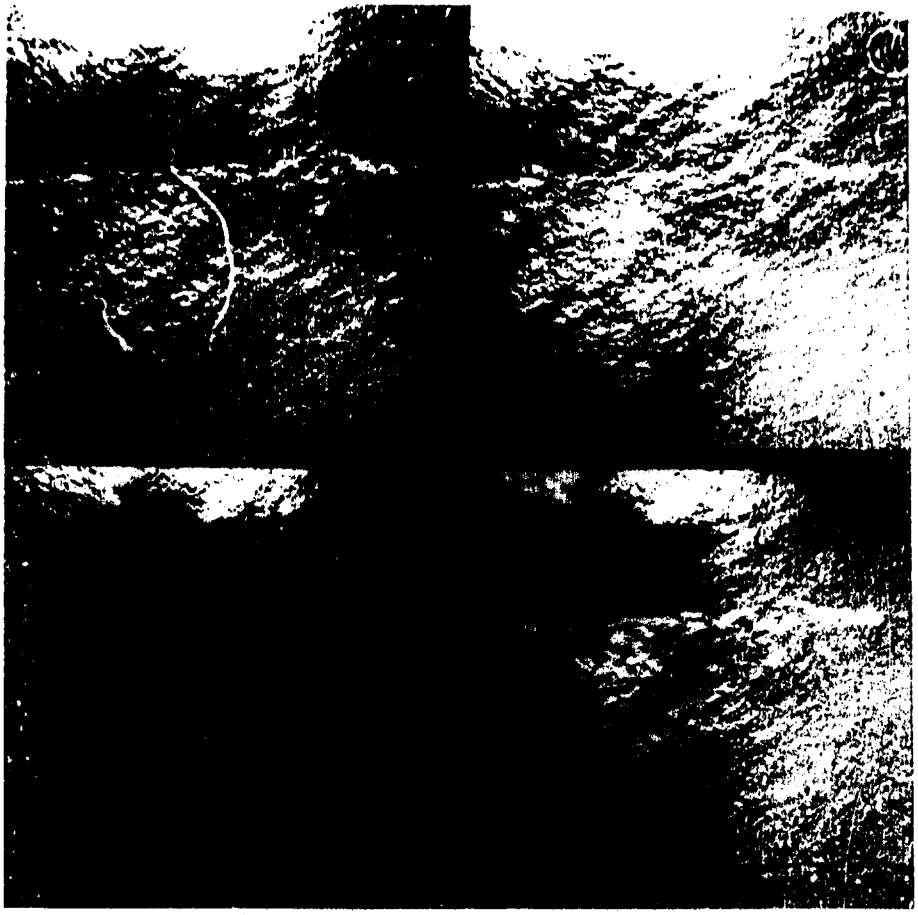


Figure 3A
Heavy Crude Oil
Spill Number 64
Flow Rate 0.05 GPM
Ship Speed 14 kts

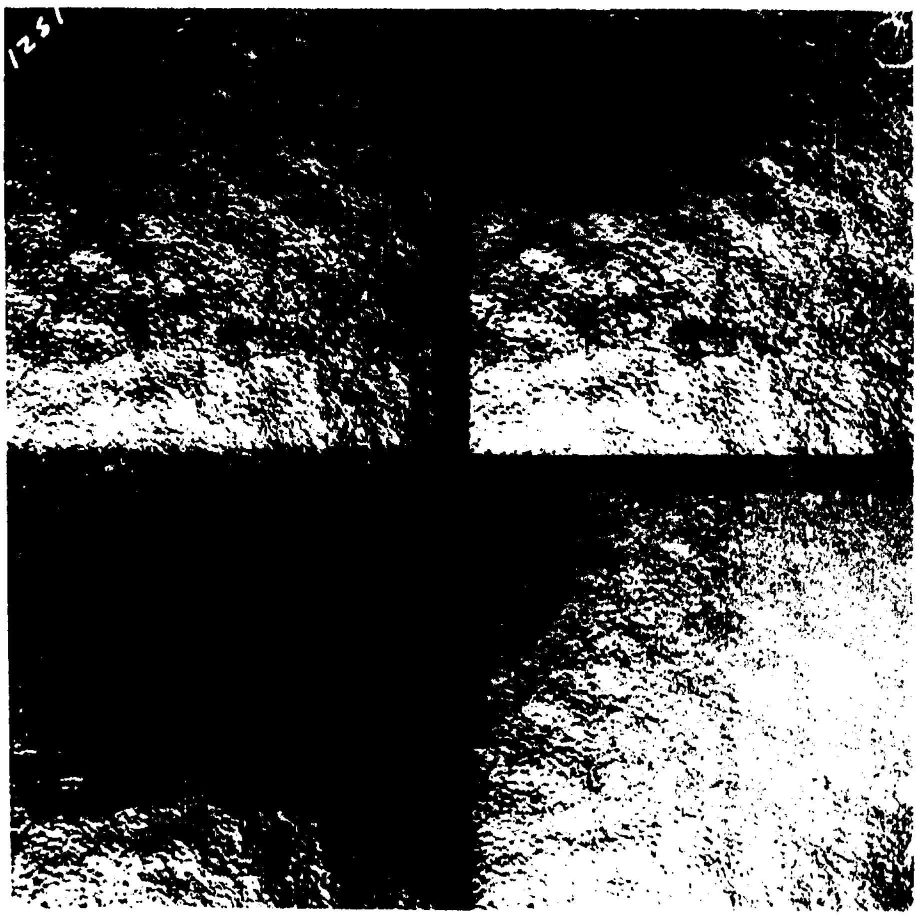


Figure 3B
Number 6 Fuel Oil
Spill Number 86
Flow Rate 0.1 GPM
Ship Speed 14 kts

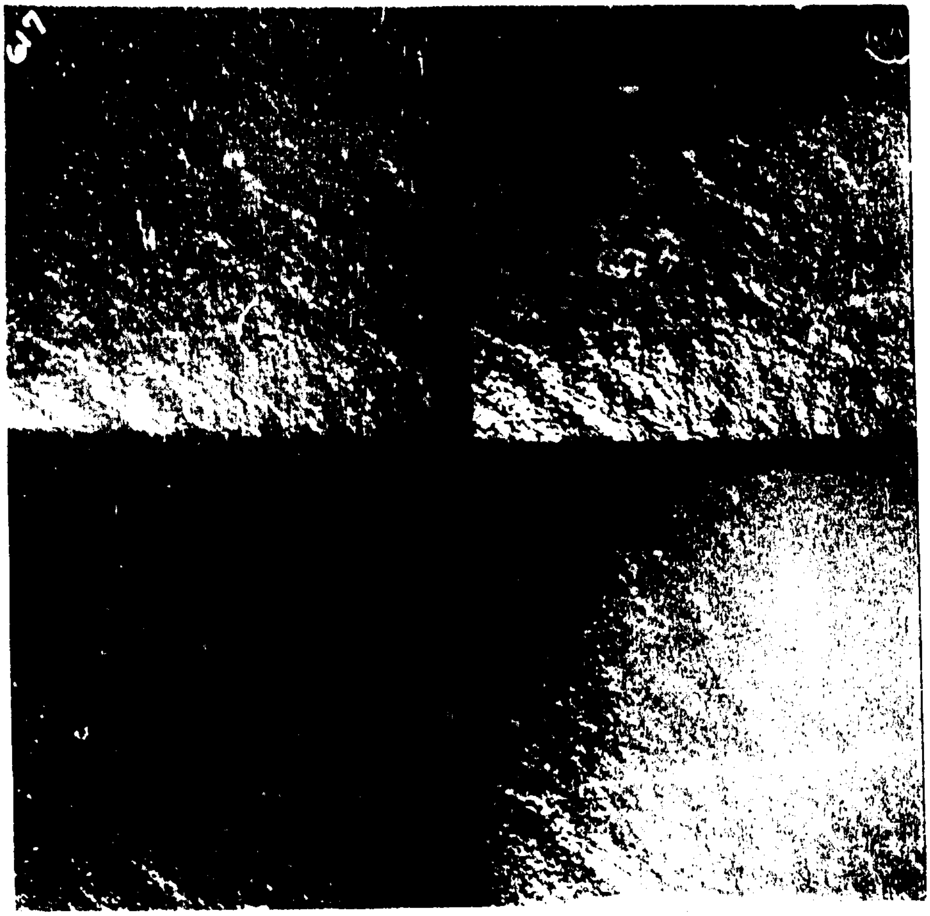


Figure 4A
Light Crude Oil
Spill Number 47
Flow Rate 0.1 GPM
Ship Speed 14 kts

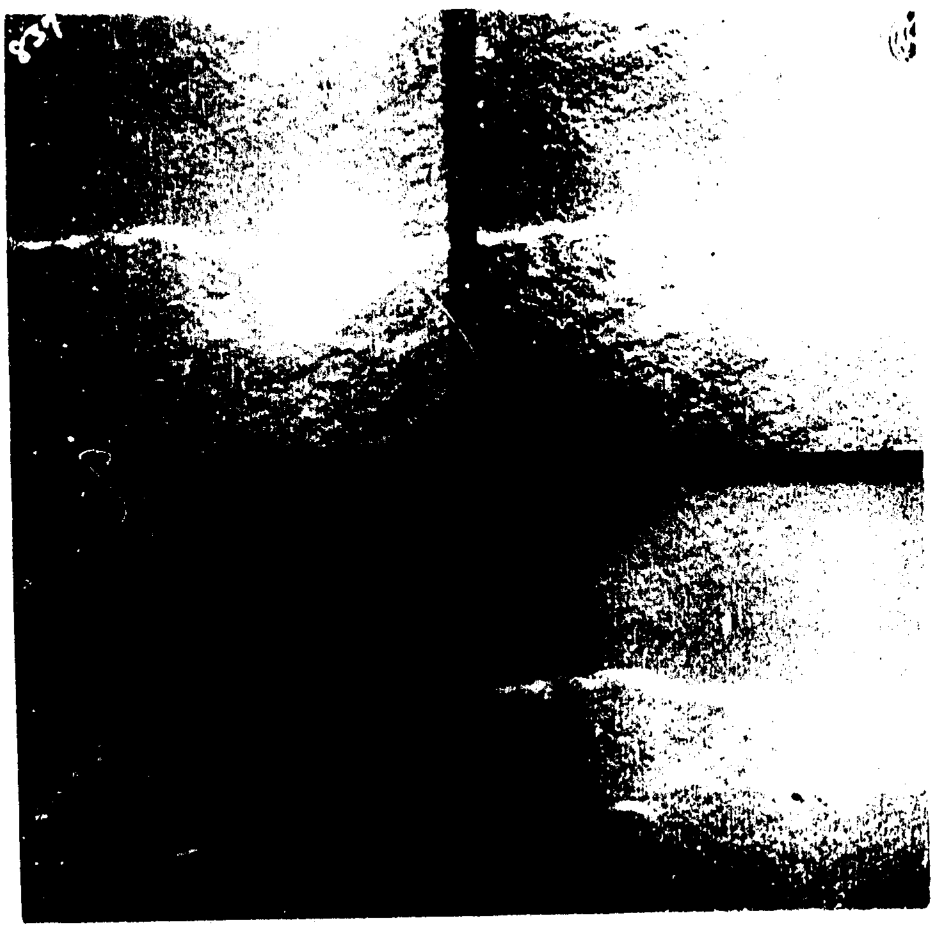


Figure 4B
Heavy Crude Oil
Spill Number 65
Flow Rate 0.1 GPM
Ship Speed 14 kts

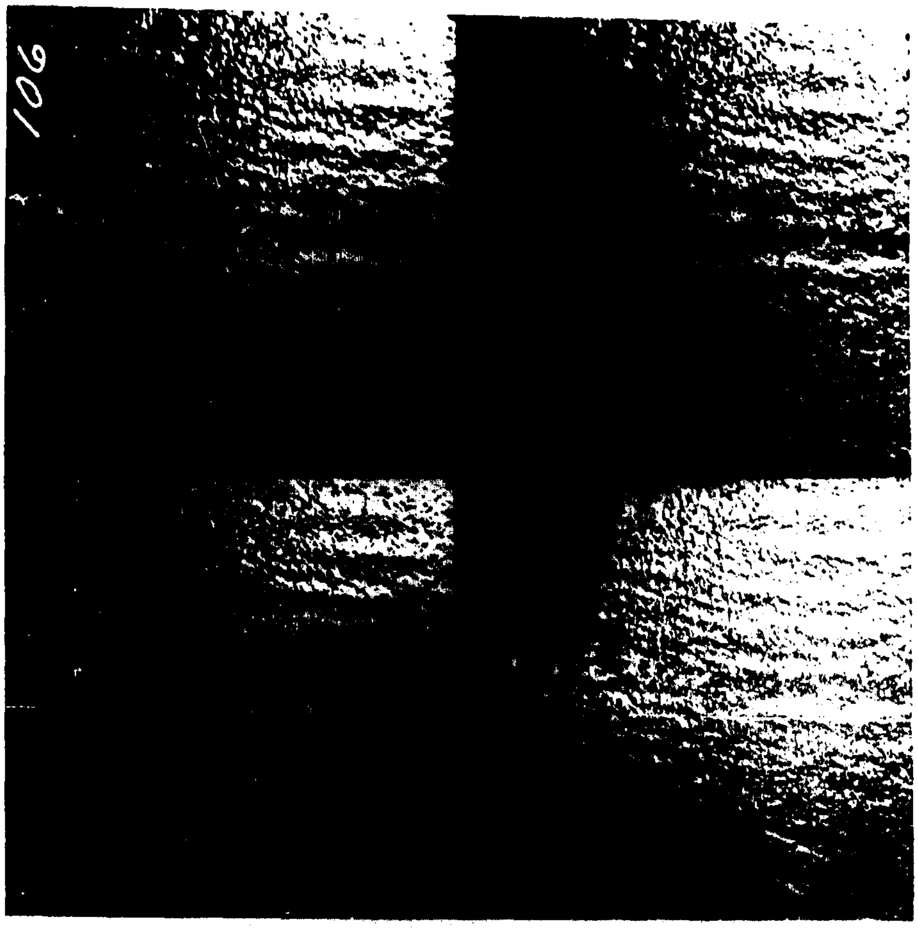


Figure 5A
9250 Lub Oil
Spill Number 15
Flow Rate 0.5 GPM
Ship Speed 14 kts

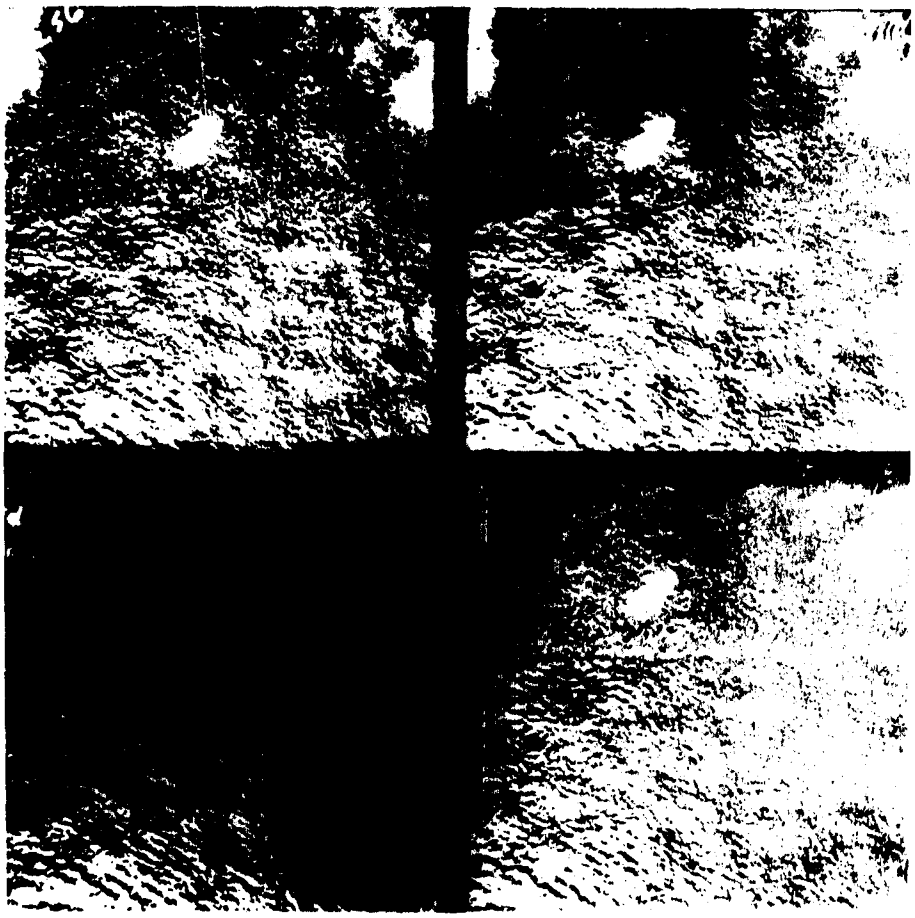


Figure 5B
Number 6 Fuel Oil
Spill Number 87
Flow Rate 0.5 GPM
Ship Speed 14 kts

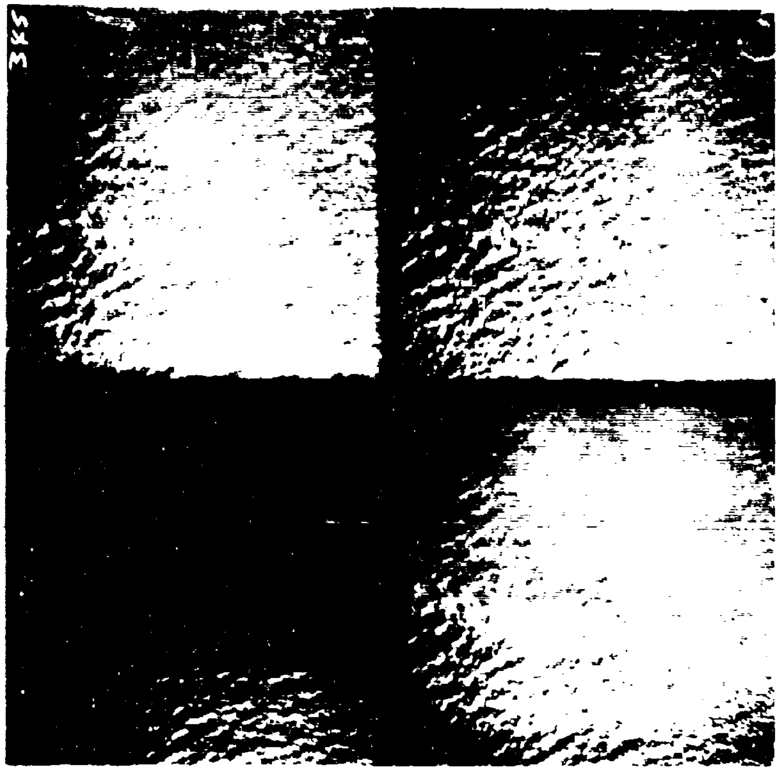


Figure 6A
Light Crude Oil
Spill Number 33
Flow Rate 0.5 GPM
Ship Speed

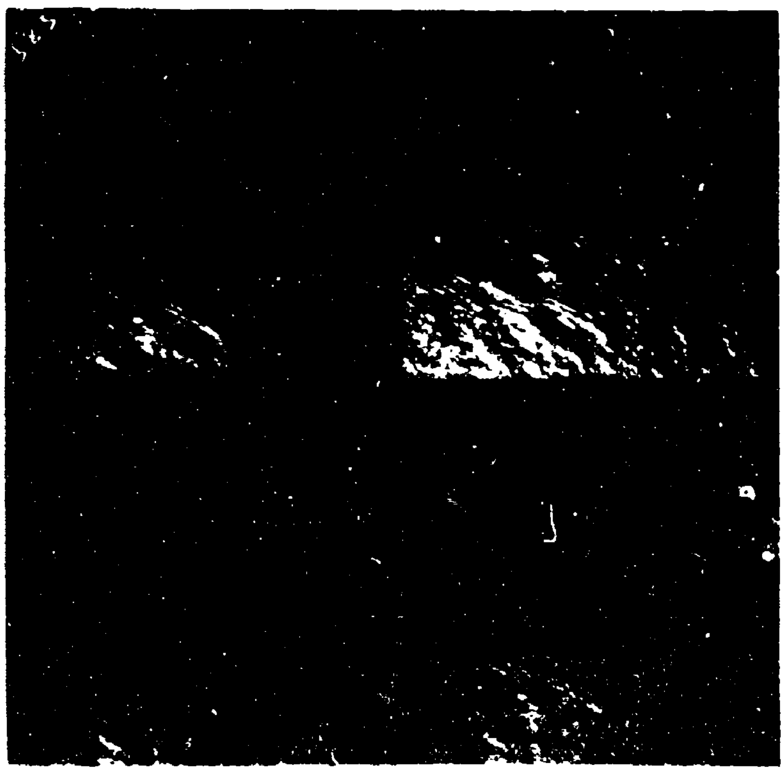


Figure 6B
Light Crude Oil
Spill Number 45
Flow Rate 0.5 GPM
Ship Speed 14 kts

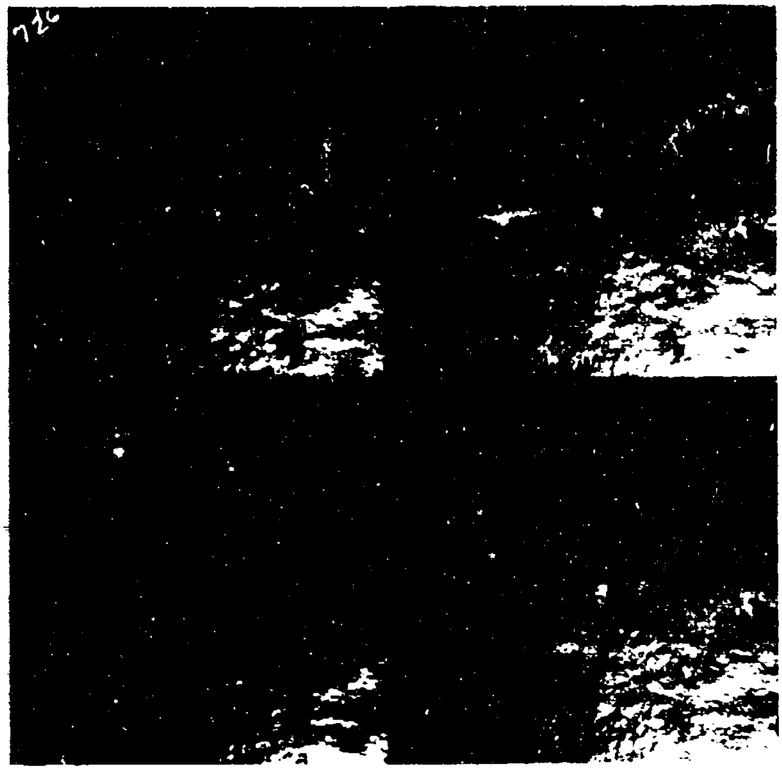


Figure 7A
Light Crude Oil
Spill Number 51
Flow Rate 0.5 GPM

Figure 7B
Heavy Crude Oil
Spill Number 67
Flow Rate 0.5 GPM
Ship Speed 14 kts

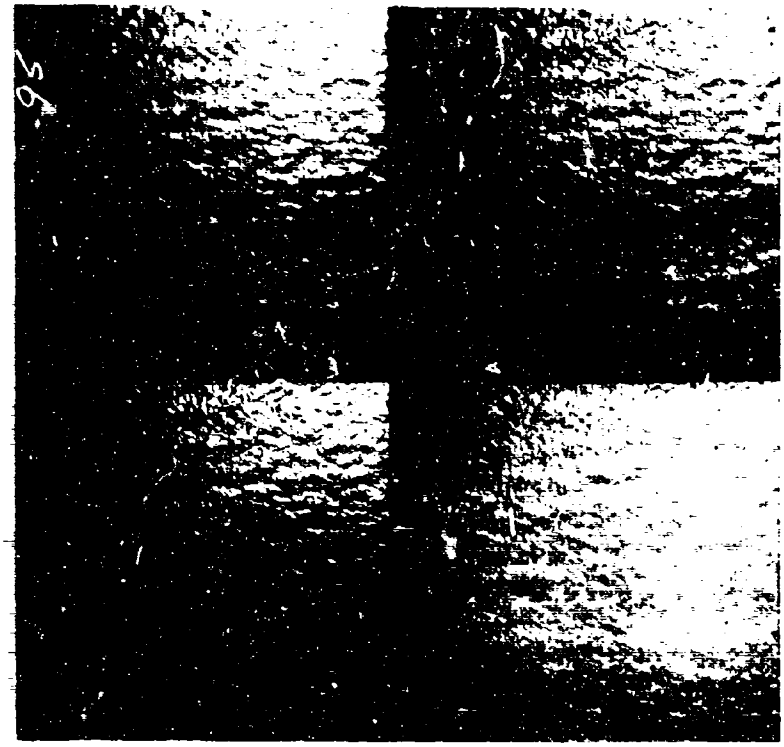


Figure 8A
9250 Lub Oil
Spill Number 14
Flow Rate 1 GPM
Ship Speed 14 kts

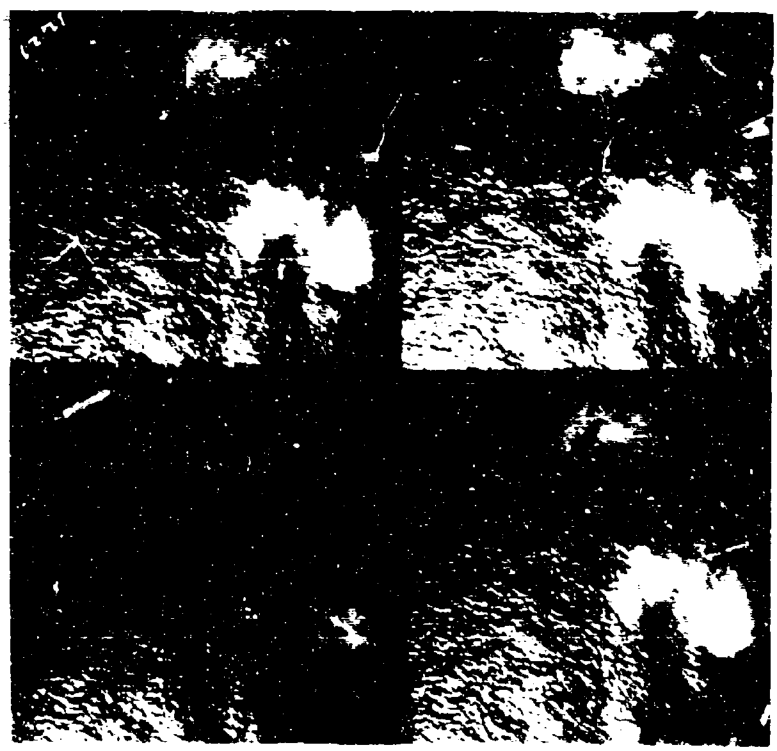


Figure 8B
Number 6 Fuel Oil
Spill Number 89
Flow Rate 1 GPM
Ship Speed 14 kts

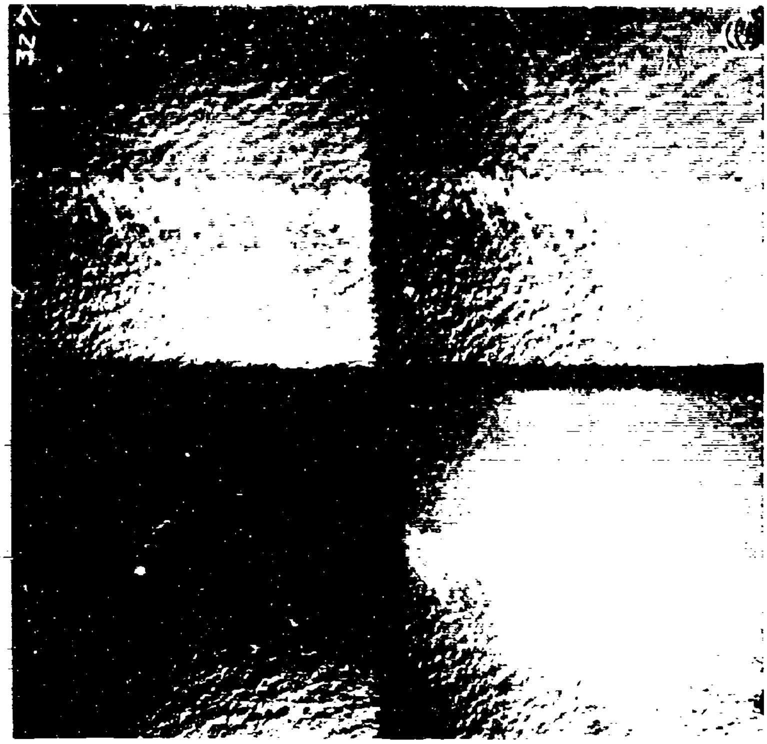


Figure 9A
Light Crude Oil
Spill Number 31
Flow Rate 1 GPM
Ship Speed 10 kts

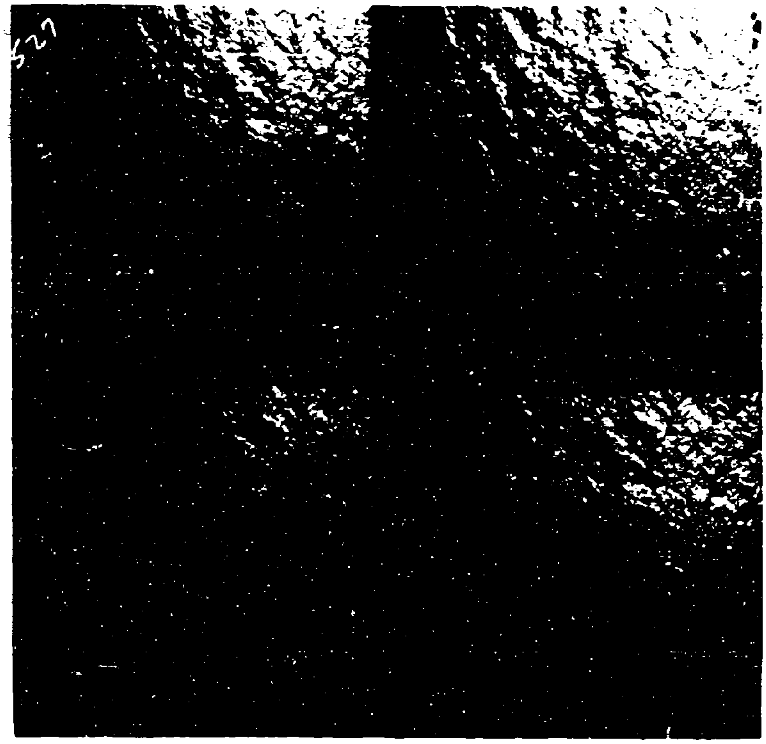


Figure 9B
Light Crude Oil
Spill Number 43
Flow Rate 1 GPM
Ship Speed 14 kts

Figure 10A
Light Crude Oil
Spill Number 52
Flow Rate 1 GPM
Ship Speed 17 kts

Figure 10B
Heavy Crude Oil
Spill Number 68
Flow Rate 1 GPM
Ship Speed 14 kts

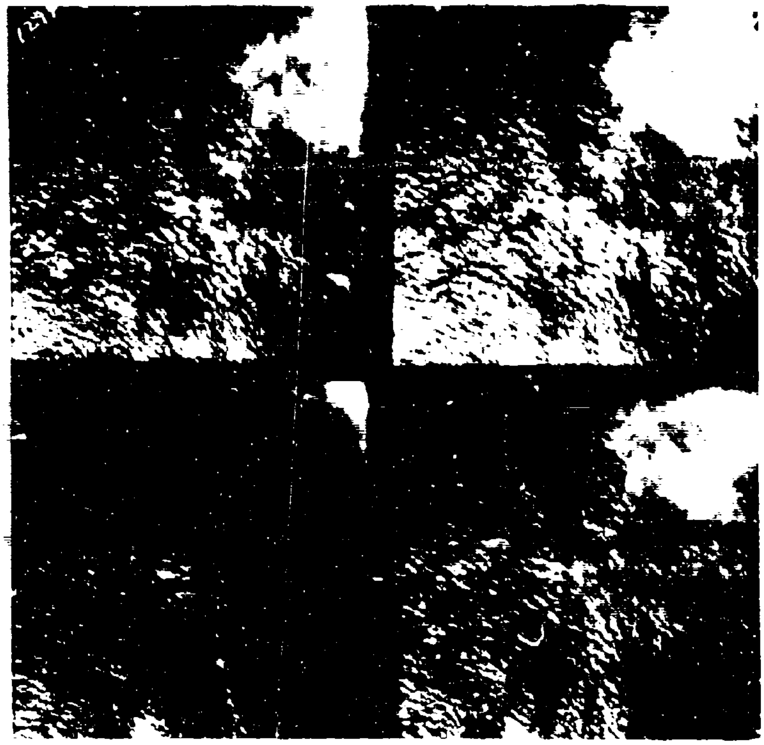


Figure 11A
Number 6 Fuel Oil
Spill Number 90
Flow Rate 60 liters/mi
Ship Speed 14 kts

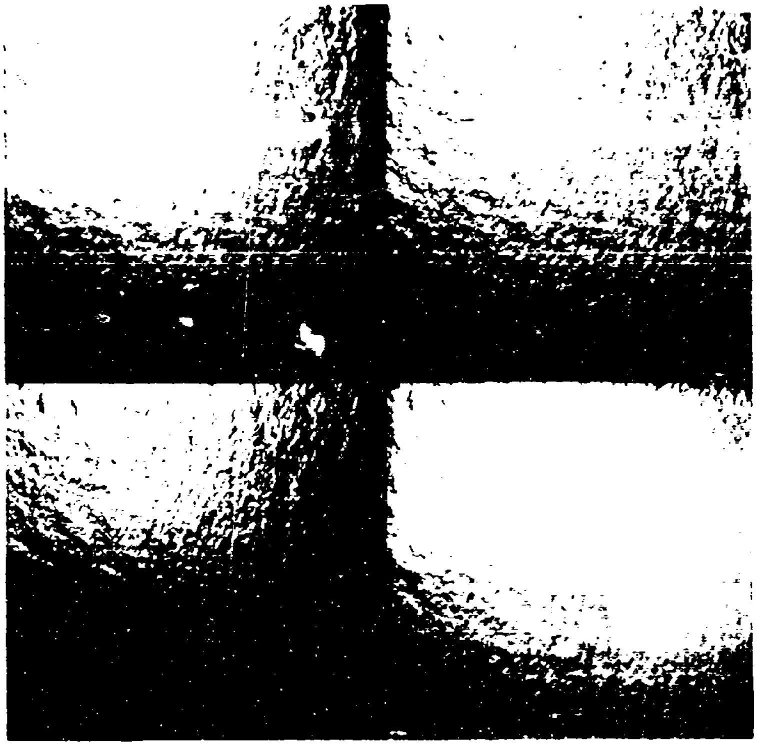


Figure 11B
Light Crude Oil
Spill Number 39
Flow Rate 60 liters/mi
Ship Speed 10 kts

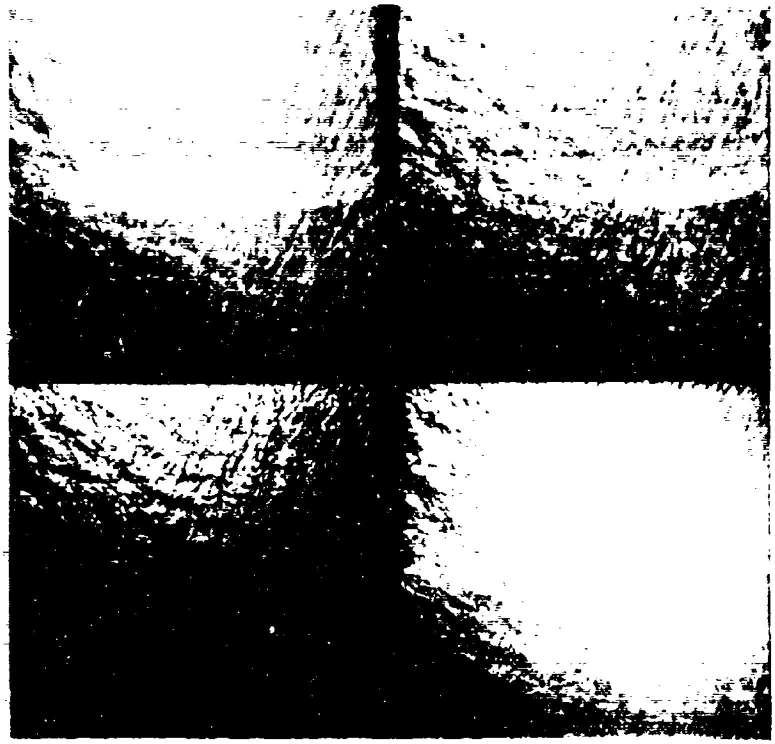


Figure 12A
Light Crude Oil
Spill Number 40
Flow Rate 60 liters/mi
Ship Speed 14 kts

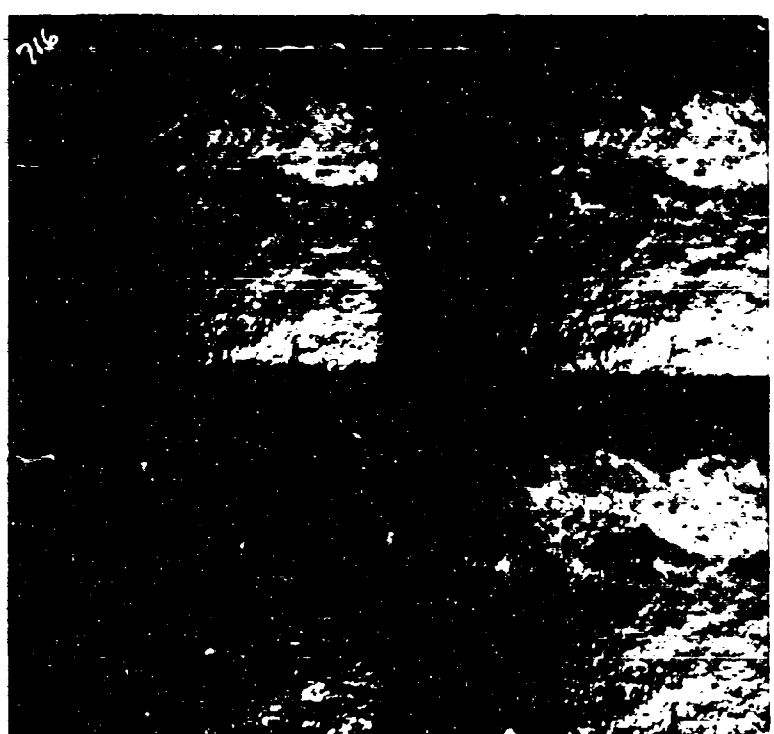


Figure 12B
Light Crude Oil
Spill Number 56
Flow Rate 60 liters/mi
Ship Speed 17 kts

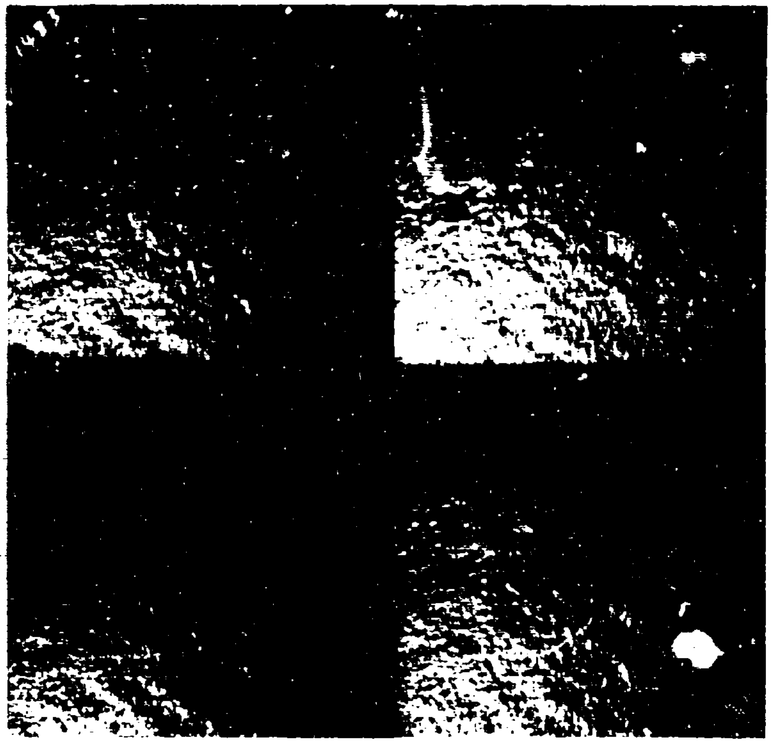


Figure 13A
Heavy Crude Oil
Spill Number 98
Flow Rate 60 liters/mi
Ship Speed 14 kts

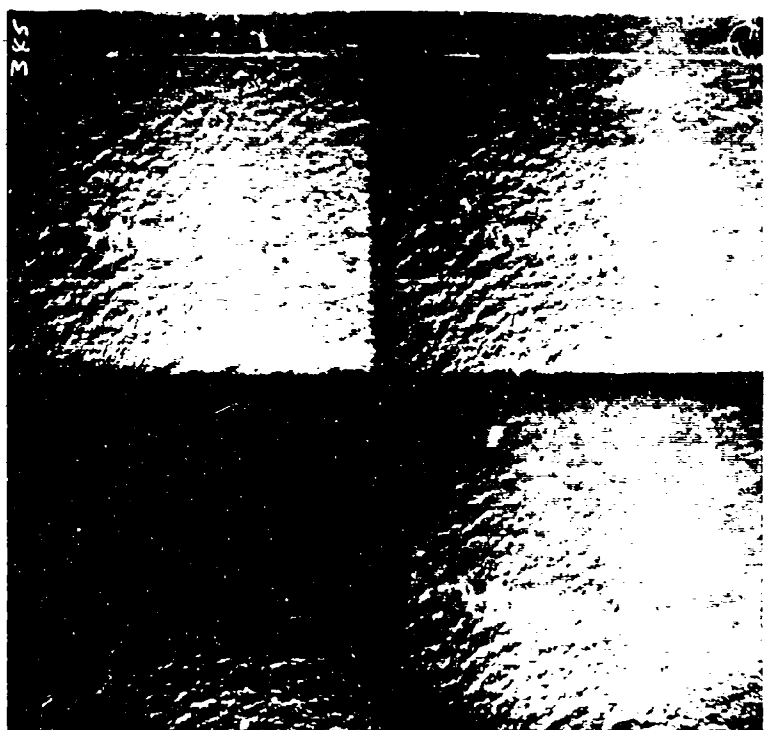


Figure 13B
Light Crude Oil
Spill Number 33
Flow Rate 0.5 GPM
Ship Speed 10 kts

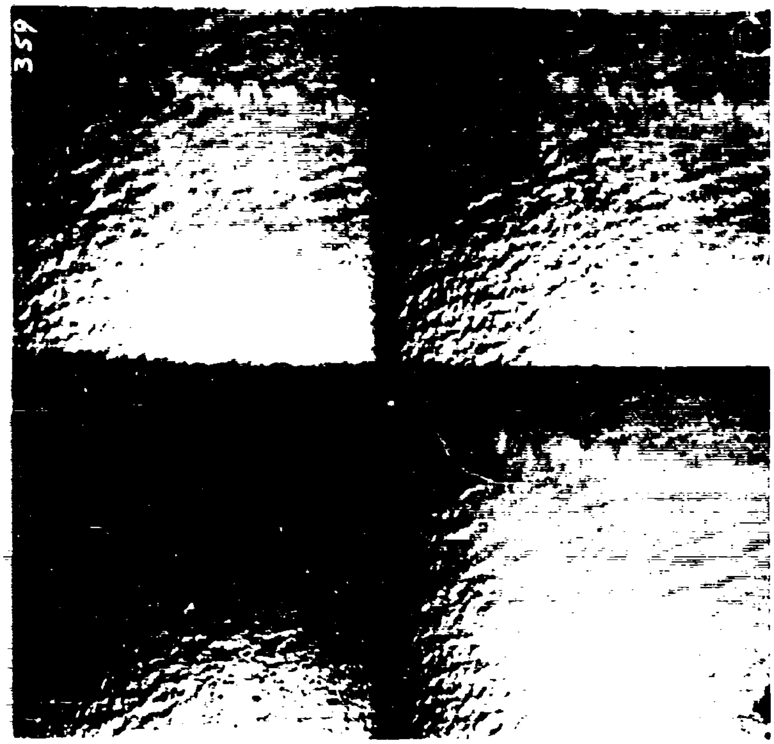


Figure 14A
Light Crude Oil
Spill Number 33
Flow Rate 0.5 GPM
Ship Speed 10 kts

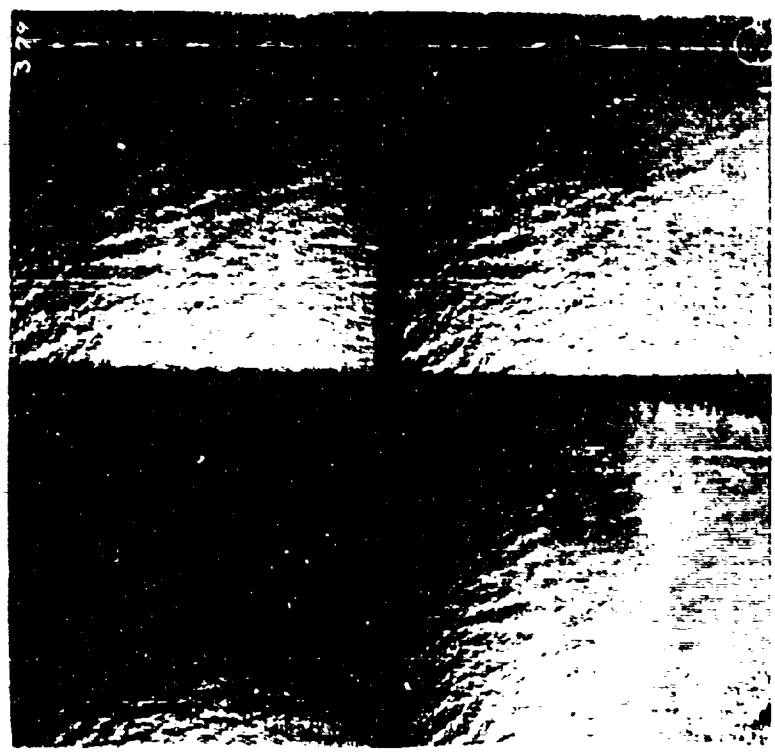


Figure 14B
Light Crude Oil
Spill Number 33
Flow Rate 0.5 GPM
Ship Speed 10 kts

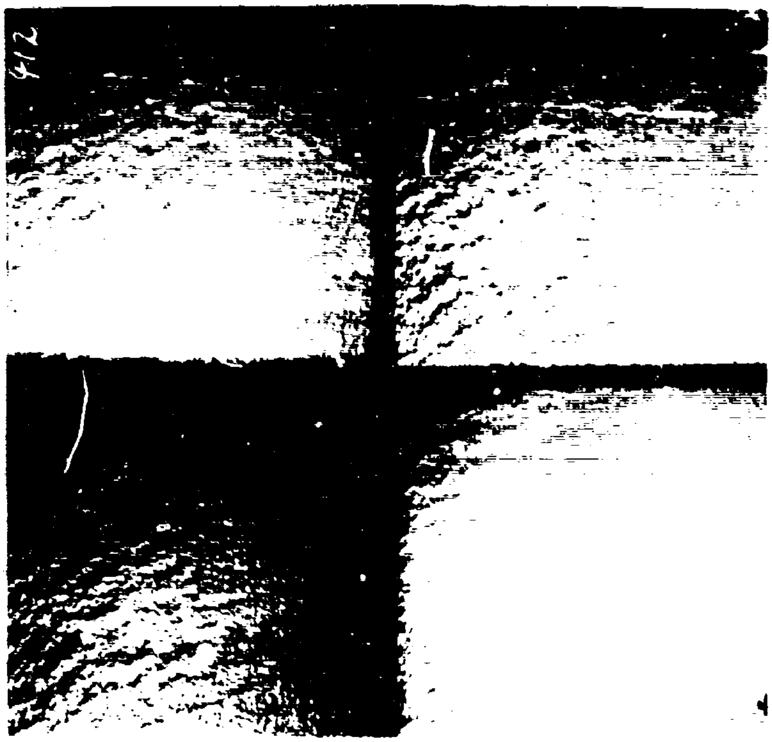


Figure 15A
Light Crude Oil
Spill Number 33
Flow Rate 0.5 GPM
Ship Speed 10 kts

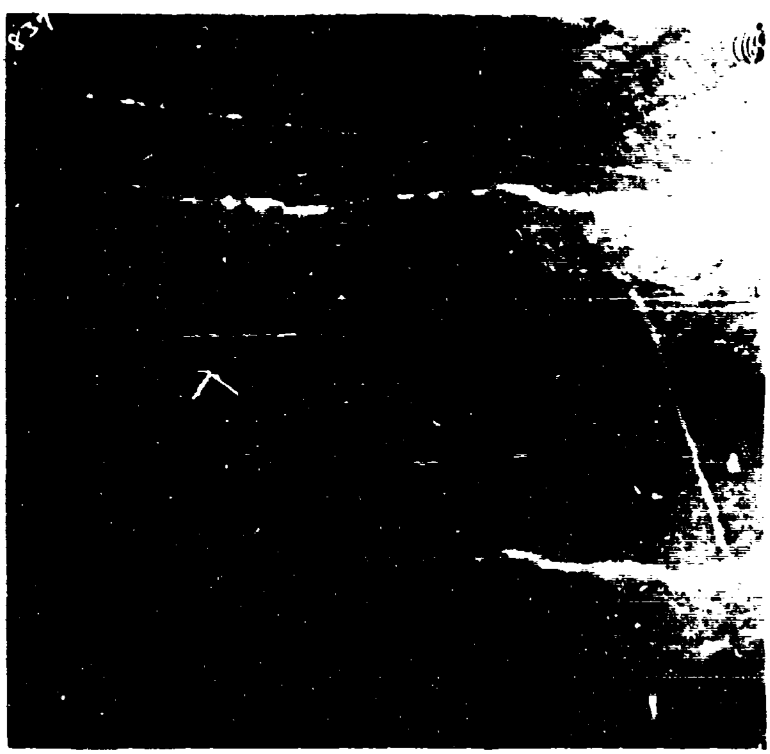


Figure 15B
Heavy Crude Oil
Spill Number 65
Flow Rate 0.1 GPM
Ship Speed 14 kts

Figure 16A
Heavy Crude Oil
Spill Number 65
Flow Rate 0.1 GPM
Ship Speed 14 kts

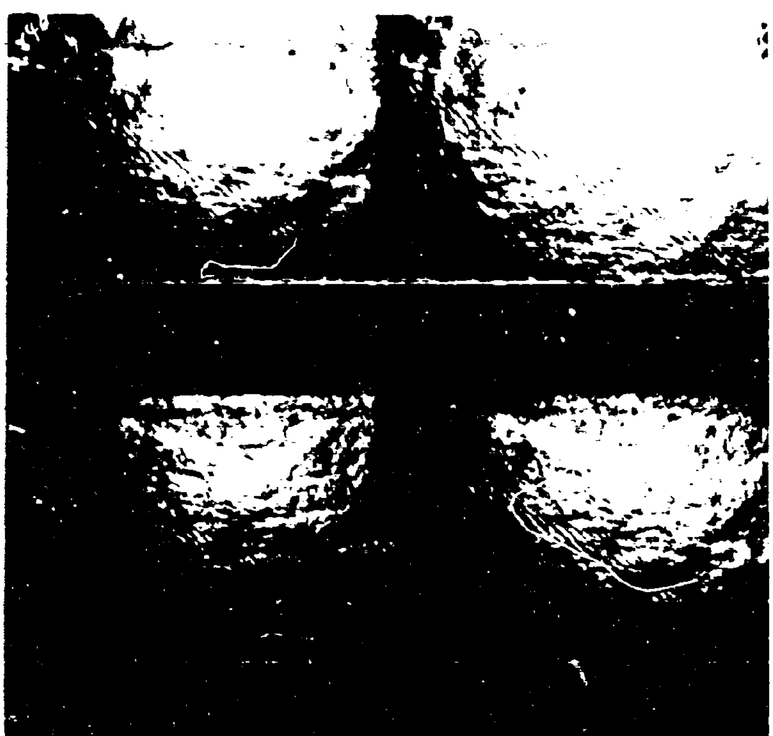


Figure 16B
Heavy Crude Oil
Spill Number 67
Flow Rate 0.5 GPM
Ship Speed 14 kts

Figure 17A
Heavy Crude Oil
Spill Number 67
Flow Rate 0.5 GPM
Ship Speed 14 kts

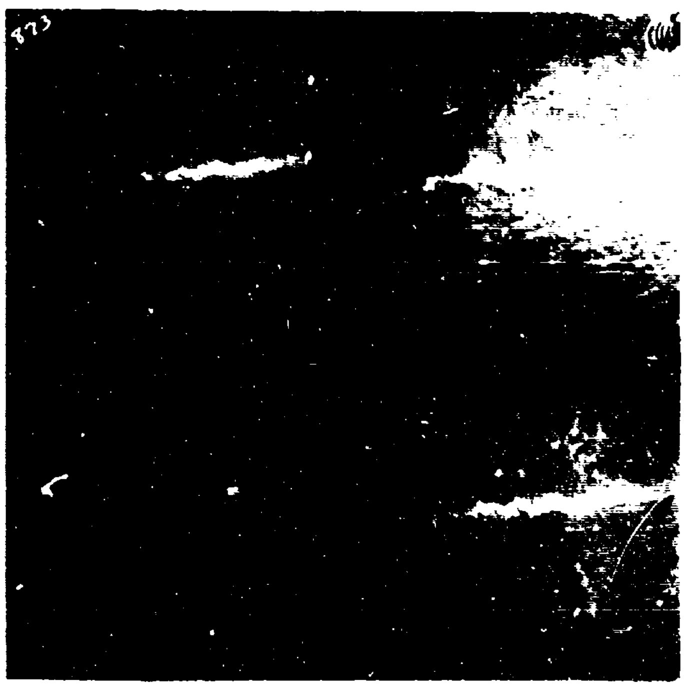


Figure 17B
Heavy Crude Oil
Spill Number 67
Flow Rate 0.5 GPM
Ship Speed 14 kts

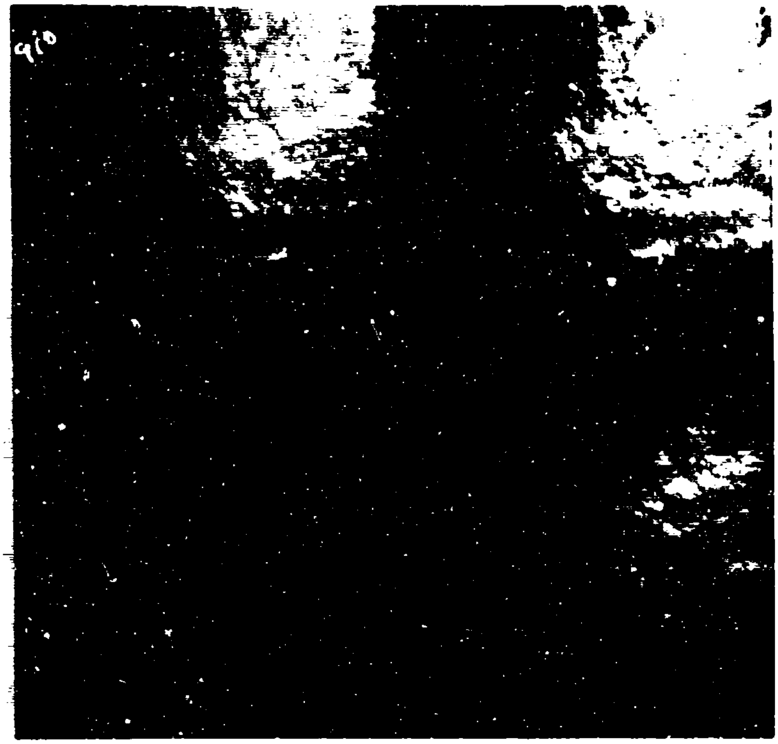


Figure 18A
Heavy Crude Oil
Spill Number 67
Flow Rate 0.5 GPM
Ship Speed 14 kts

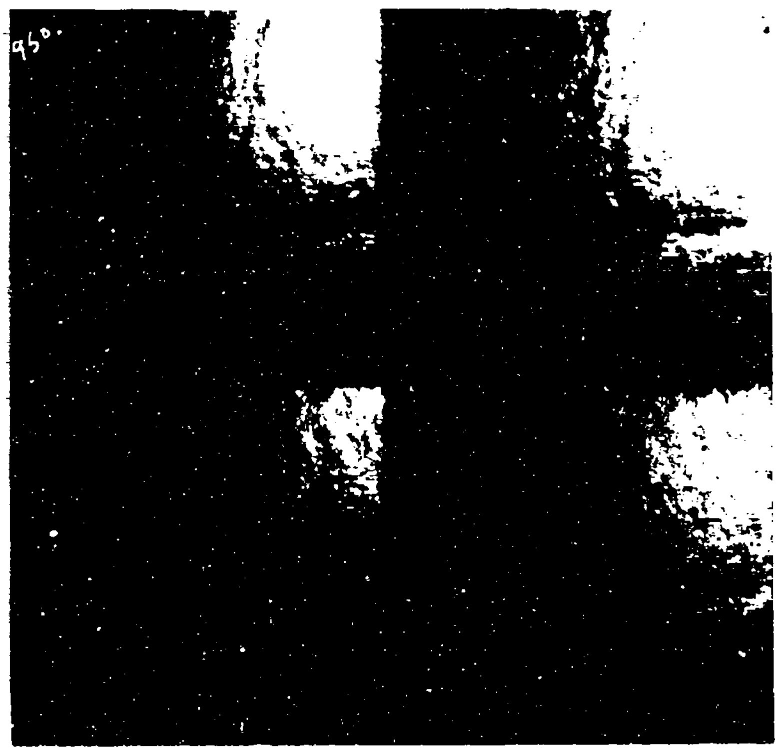


Figure 18B
Heavy Crude Oil
Spill Number 67
Flow Rate 0.5 GPM
Ship Speed 14 kts

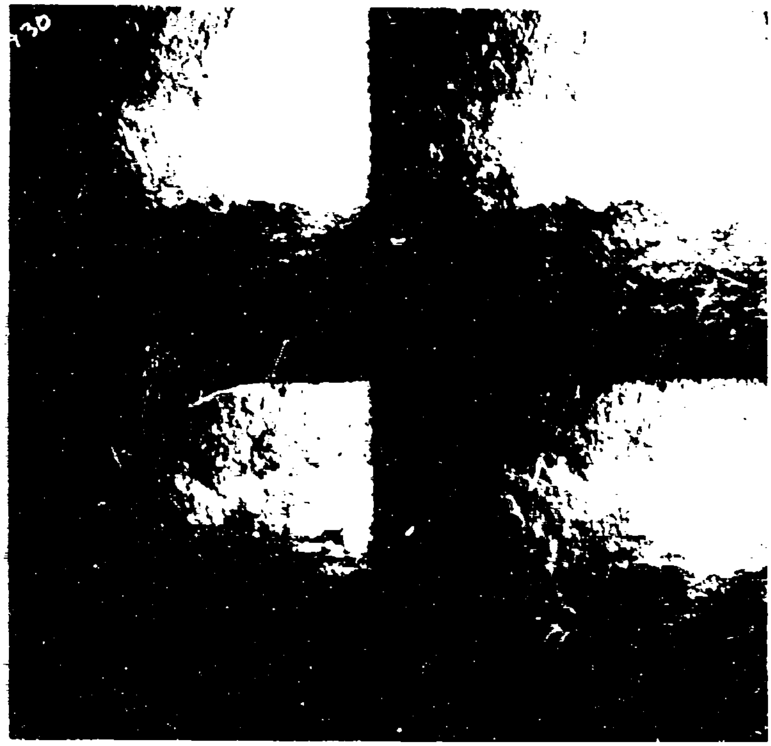


Figure 19A
Heavy Crude Oil
Spill Number 71
Flow Rate 2.64 GPM
Ship Speed 10 kts

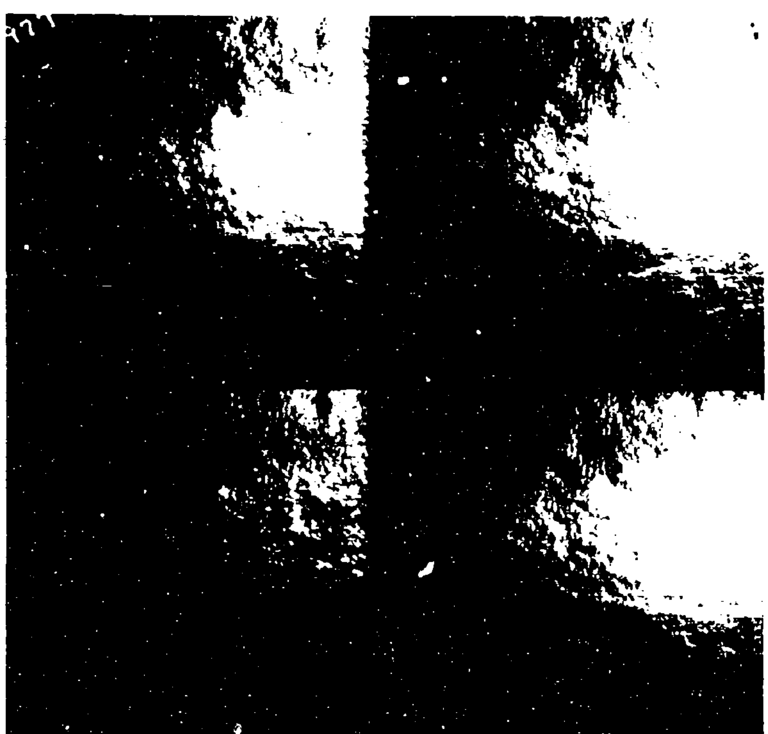


Figure 19B
Heavy Crude Oil
Spill Number 71
Flow Rate 2.64 GPM
Ship Speed 10 kts

Figure 20A
Heavy Crude Oil
Spill Number 71
Flow Rate 2.64 GPM
Ship Speed 10 kts

Figure 20B
Number 6 Fuel Oil
Spill Number 96
Flow Rate 3.95 GPM
Ship Speed 17 kts

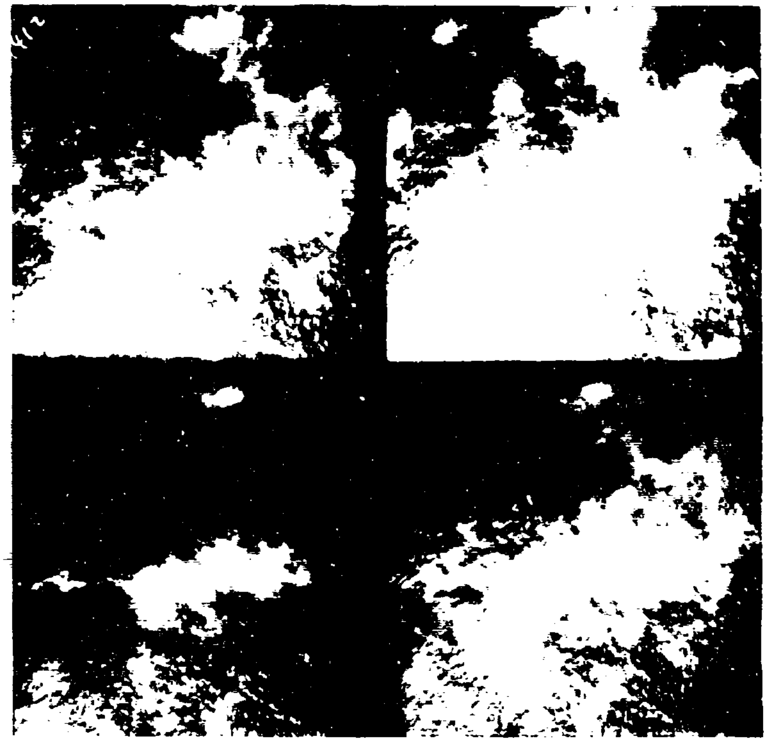


Figure 21A
Number 6 Fuel Oil
Spill Number 96
Flow Rate 3.95 GPM
Ship Speed 17 kts

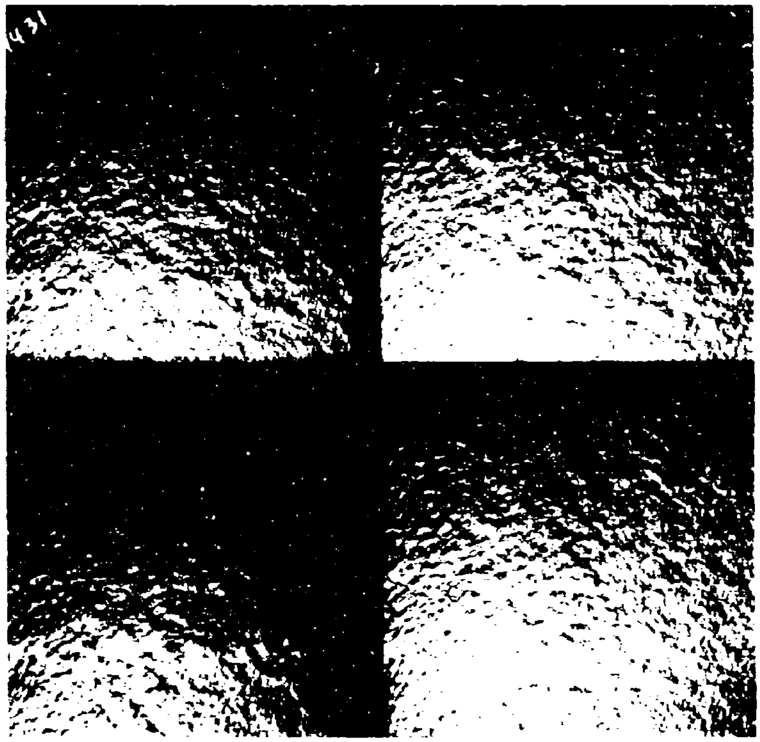


Figure 21B
Number 6 Fuel Oil
Spill Number 96
Flow Rate 3.95 GPM
Ship Speed 17 kts

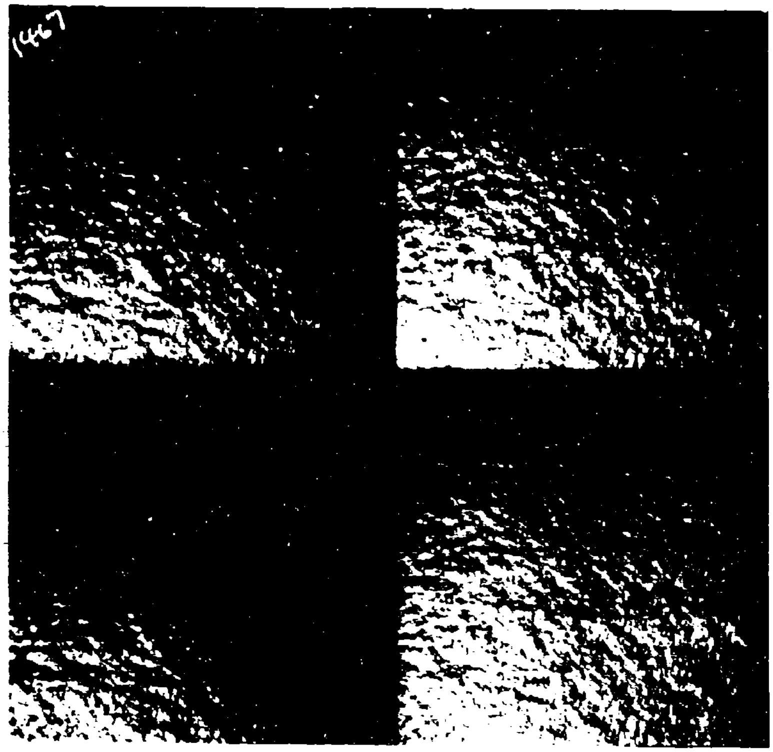


Figure 22A
Number 6 Fuel Oil
Spill Number 96
Flow Rate 3.95 GPM
Ship Speed 17 kts

Figure 22B
Light Crude Oil
Spill Number 56
Flow Rate 4.57 GPM
Ship Speed 17 kts

Figure 23A
Light Crude Oil
Spill Number 56
Flow Rate 4.57 GPM
Ship Speed 17 kts

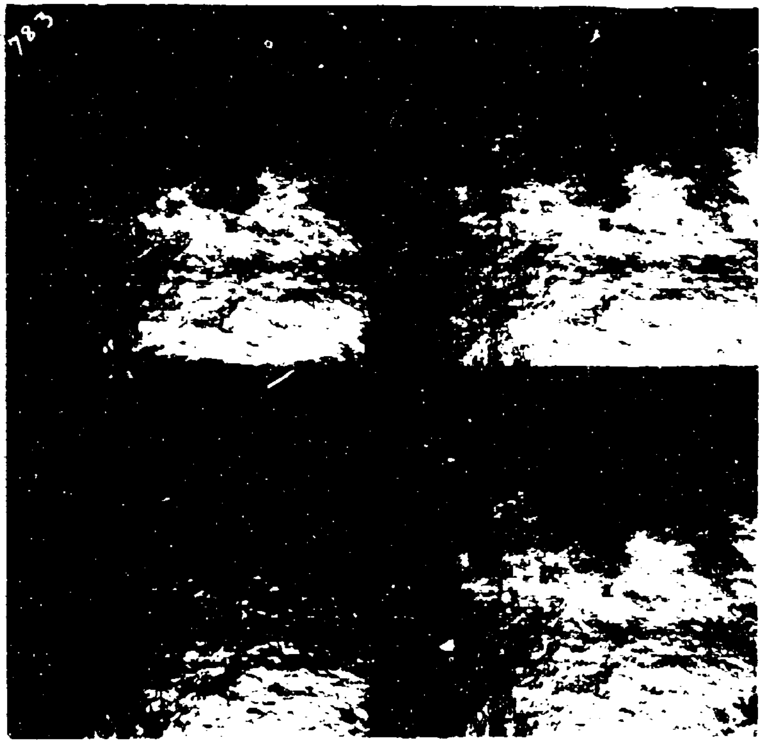


Figure 23B
Light Crude Oil
Spill Number 56
Flow Rate 4.57 GPM
Ship Speed 17 kts

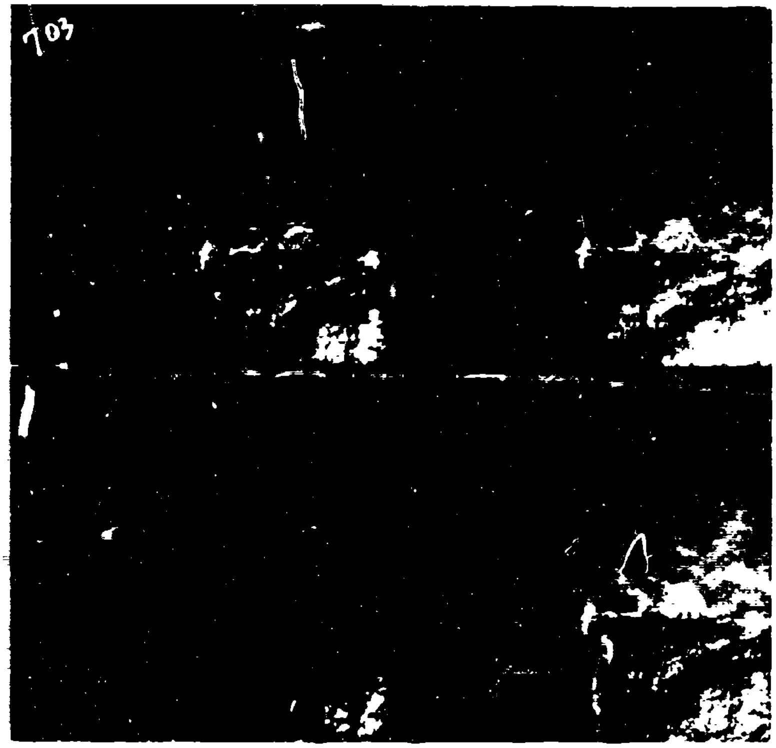


Figure 24A
Light Crude Oil
Spill Number 53
Flow Rate 1.14 GPM
Ship Speed 17 kts

Figure 24B
Light Crude Oil
Spill Number 53
Flow Rate 1.14 GPM
Ship Speed 17 kts

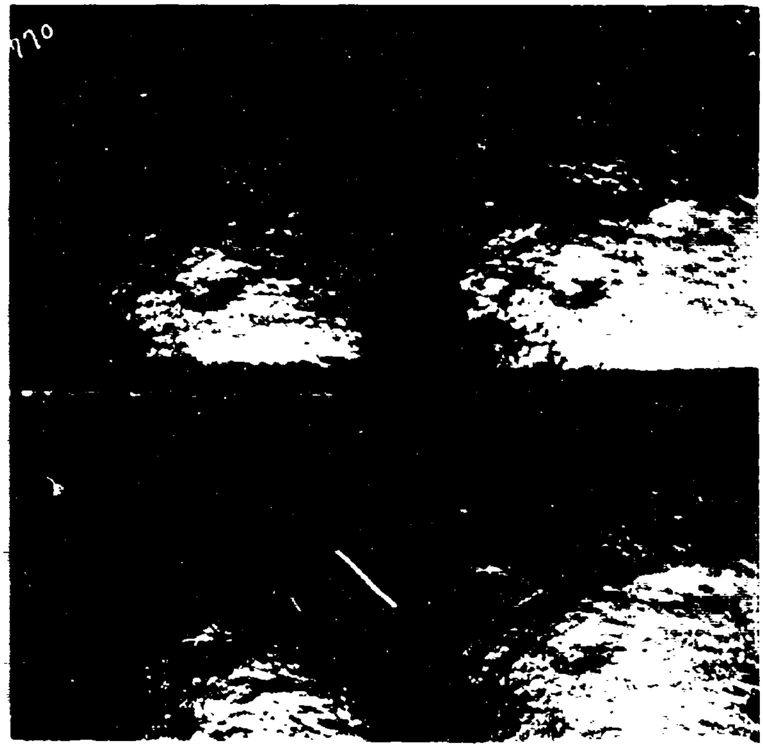
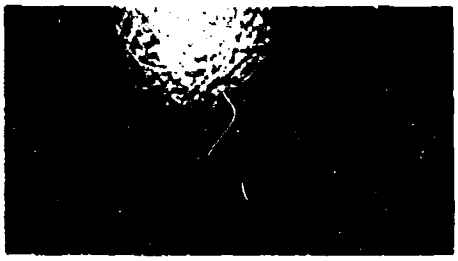
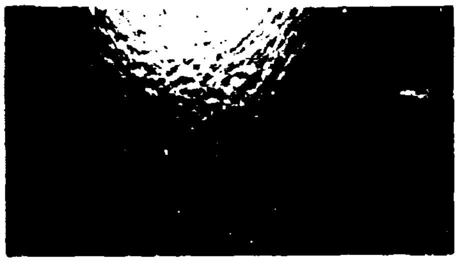
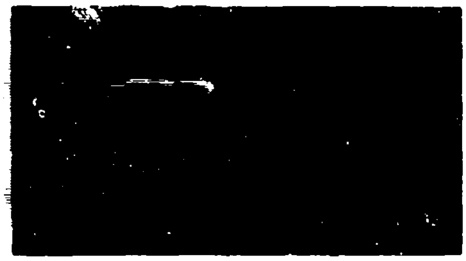
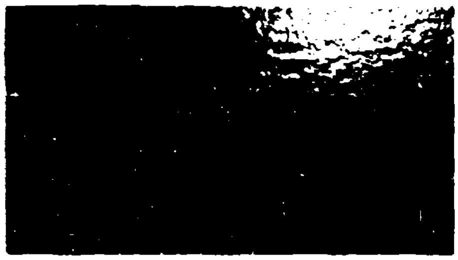
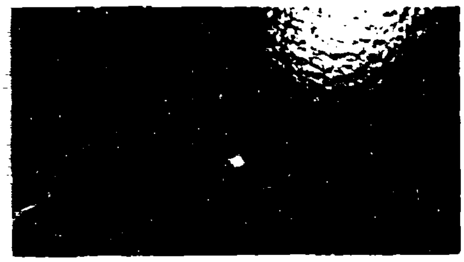


Figure 25A
Light Crude Oil
Spill Number 53
Flow Rate 1.14 GPM
Ship Speed 17 kts

IR COLOR	VISUAL COLOR
	
Oil Type #2 Fuel Flow Rate 0.1 GPM Time 1150	Ship Speed 14 knots Test No. 9 Photo No. 63
	
Oil Type 9250 Flow Rate 0.1 GPM Time 0913	Ship Speed 14 knots Test No. 20 Photo No. 160
	
Oil Type 9250 Flow Rate 0.5 GPM Time 1345	Ship Speed 17 knots Test No. 15 Photo No. 106
	
Oil Type 9250 Flow Rate 1.0 GPM Time 1357	Ship Speed 17 knots Test No. 14 Photo No. 110

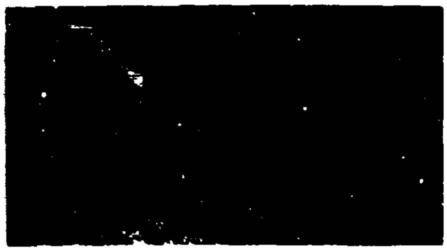
IR COLOR | **VISUAL COLOR**

Oil Type #6 Fuel
Flow Rate 0.05 GPM
Time 0943

Ship Speed 14 knots
Test No. 85
Photo No. 1245

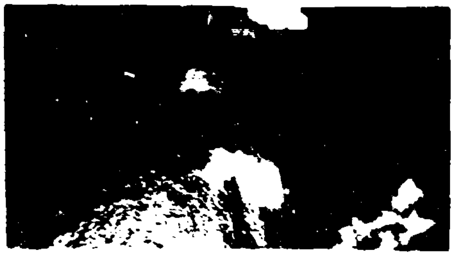
Oil Type #6 Fuel
Flow Rate 0.1 GPM
Time 0944

Ship Speed 14 knots
Test No. 86
Photo No. 1250



Oil Type #6 Fuel
Flow Rate 0.5 GPM
Time 0945

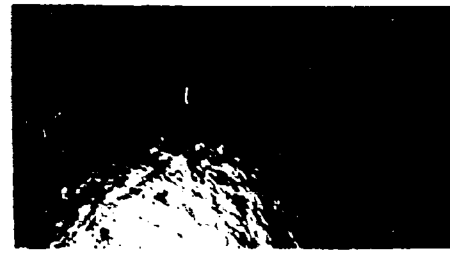
Ship Speed 14 knots
Test No. 87
Photo No. 1254



Oil Type #6 Fuel
Flow Rate 1.0 GPM
Time 1000

Ship Speed 14 knots
Test No. 88
Photo No. 1271

IR COLOR | VISUAL COLOR



Oil Type #6 Fuel
Flow Rate 3.67 GPM
Time 1018

Ship Speed 14 knots
Test No. 90
Photo No. 1290

Oil Type Light Crude
Flow Rate 0.5 GPM
Time 0855

Ship Speed 17 knots
Test No. 51
Photo No. 659

Oil Type Light Crude
Flow Rate 1.0 GPM
Time 0915

Ship Speed 17 knots
Test No. 52
Photo No. 687

Oil Type Light Crude
Flow Rate 4.57 GPM
Time 0939

Ship Speed 17 knots
Test No. 56
Photo No. 717

IR COLOR

VISUAL COLOR

Oil Type Heavy Crude
Flow Rate 0.05 GPM
Time 1134

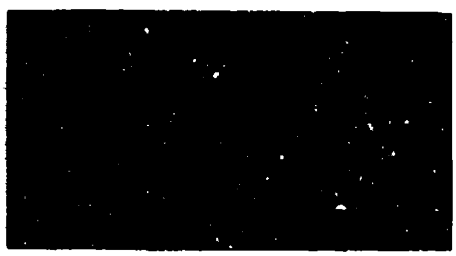
Ship Speed 14 knots
Test No. 64
Photo No. 823

Oil Type Heavy Crude
Flow Rate 0.1 GPM
Time 1159

Ship Speed 14 knots
Test No. 65
Photo No. 837

Oil Type Heavy Crude
Flow Rate 0.5 GPM
Time 1222

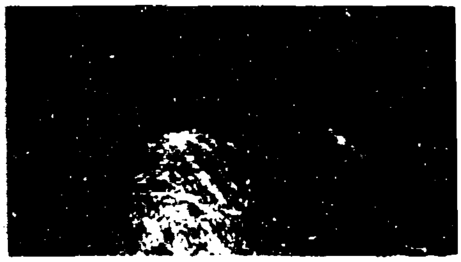
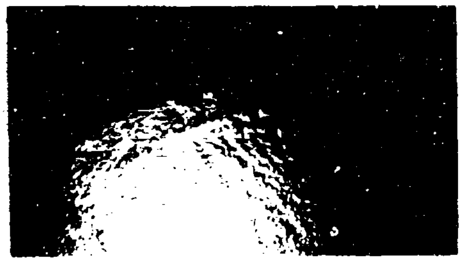
Ship Speed 14 knots
Test No. 67
Photo No. 863



Oil Type Heavy Crude
Flow Rate 1.0 GPM
Time 1224

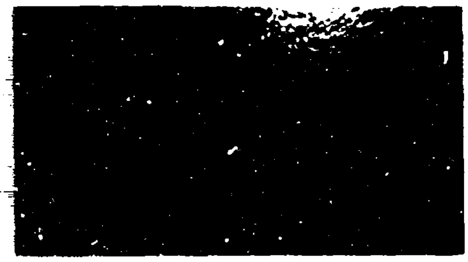
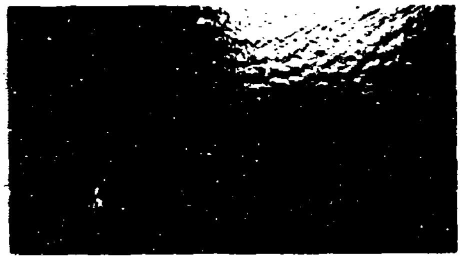
Ship Speed 14 knots
Test No. 68
Photo No. 865

IR COLOR **VISUAL COLOR**

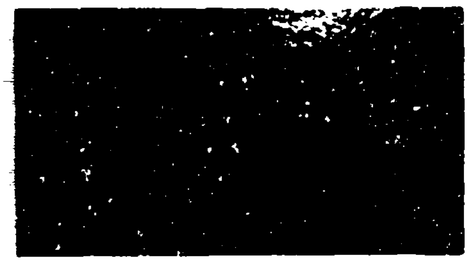
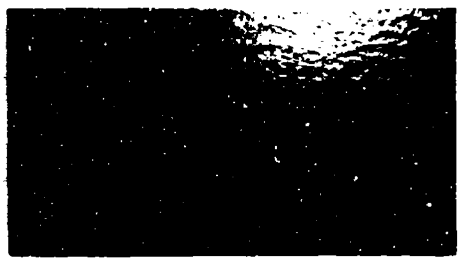
Oil Type Heavy Crude
Flow Rate 3.5 GPM
Time 1241

Ship Speed 14 knots
Test No. 98
Photo No. 1450

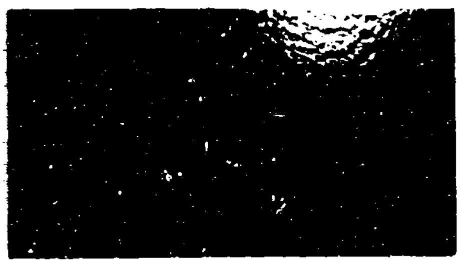
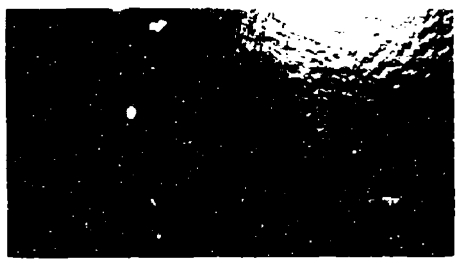
Oil Type 9250
Flow Rate 1.0 GPM
Time 1331

Ship Speed 17 knots
Test No. 14
Photo No. 95

Oil Type 9250
Flow Rate 1.0 GPM
Time 1343

Ship Speed 17 knots
Test No. 14
Photo No. 99

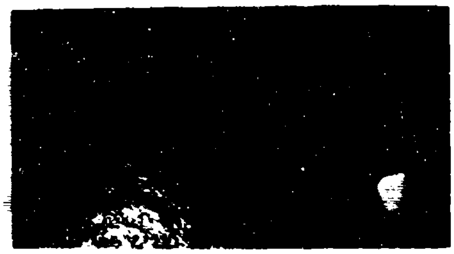
Oil Type 9250
Flow Rate 1.0 GPM
Time 1357

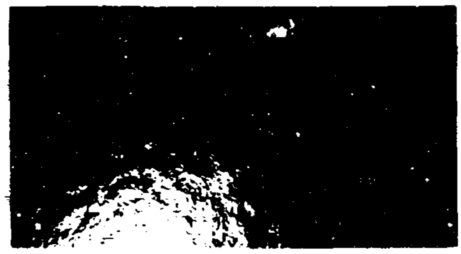
Ship Speed 17 knots
Test No. 14
Photo No. 110

IR COLOR | VISUAL COLOR

Oil Type #6 Fuel
Flow Rate 0.1 GPM
Time 0944

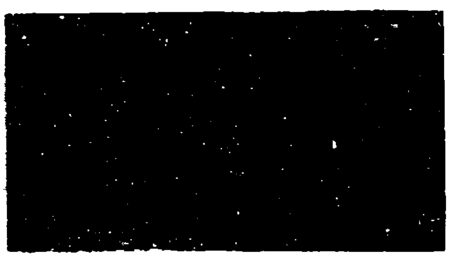
Ship Speed 14 knots
Test No. 86
Photo No. 1250

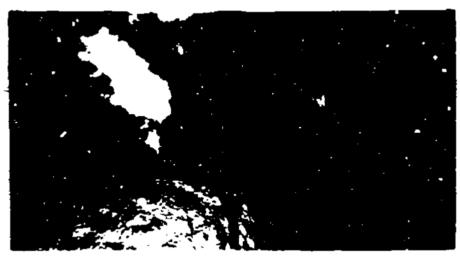




Oil Type #6 Fuel
Flow Rate 0.1 GPM
Time 0958

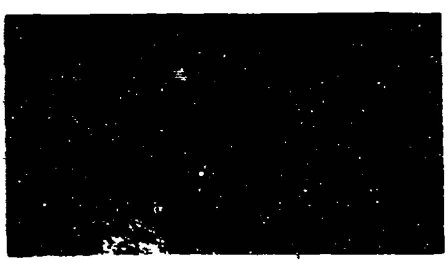
Ship Speed 14 knots
Test No. 86
Photo No. 1262

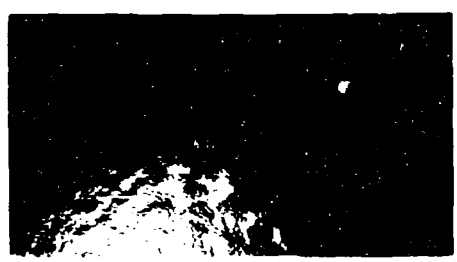




Oil Type #6 Fuel
Flow Rate 0.5 GPM
Time 0945

Ship Speed 14 knots
Test No. 87
Photo No. 1254





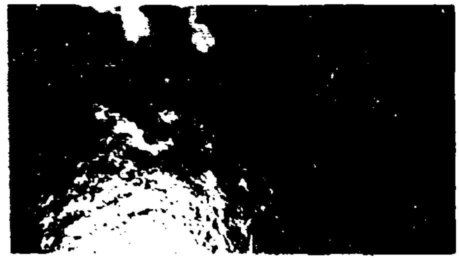
Oil Type #6 Fuel
Flow Rate 0.5 GPM
Time 0959

Ship Speed 14 knots
Test No. 87
Photo No. 1266

IR COLOR

VISUAL COLOR

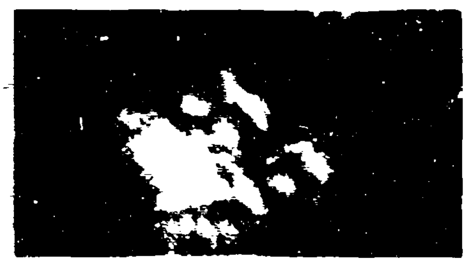
Oil Type #6 Fuel
Flow Rate 0.5 GPM
Time 1015



Ship Speed 14 knots
Test No. 87
Photo No. 1277

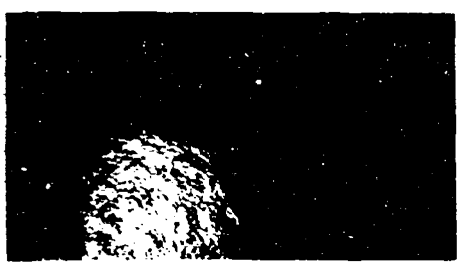
Oil Type #6 Fuel
Flow Rate 1.0 GPM
Time 1000

Ship Speed 14 knots
Test No. 88
Photo No. 1271

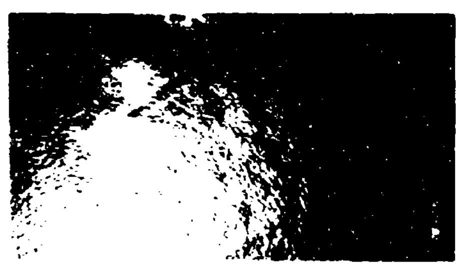


Oil Type #6 Fuel
Flow Rate 1.0 GPM
Time 1016

Ship Speed 14 knots
Test No. 88
Photo No. 1281

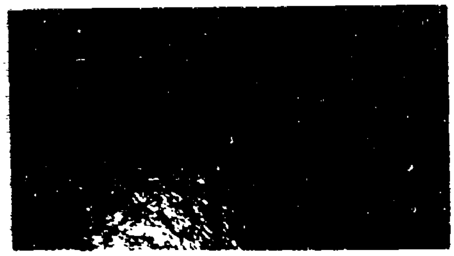


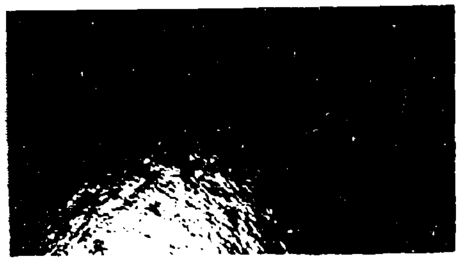
Oil Type #6 Fuel
Flow Rate 1.0 GPM
Time 1054



Ship Speed 14 knots
Test No. 88
Photo No. 1346

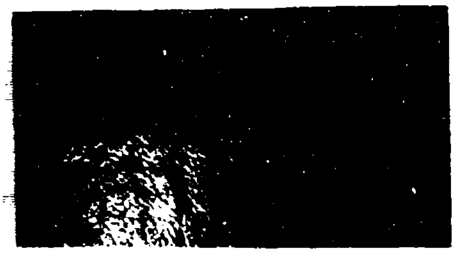
IR COLOR | VISUAL COLOR

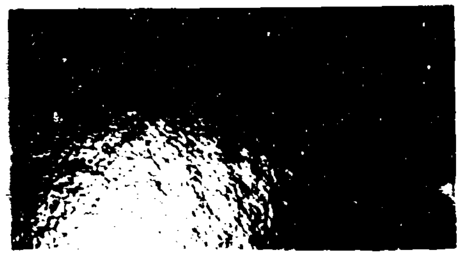




Oil Type #6 Fuel
Flow Rate 3.67 GPM
Time 1018

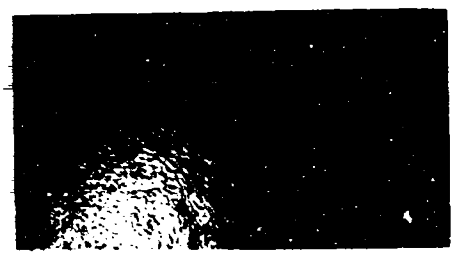
Ship Speed 14 knots
Test No. 90
Photo No. 1290

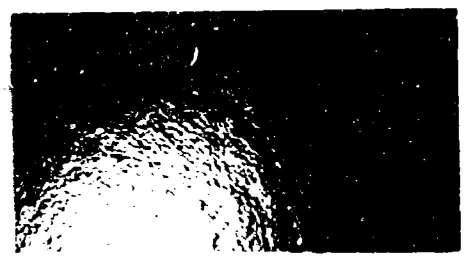




Oil Type #6 Fuel
Flow Rate 3.67 GPM
Time 1033

Ship Speed 14 knots
Test No. 90
Photo No. 1334





Oil Type #6 Fuel
Flow Rate 3.67 GPM
Time 1055

Ship Speed 14 knots
Test No. 90
Photo No. 1359

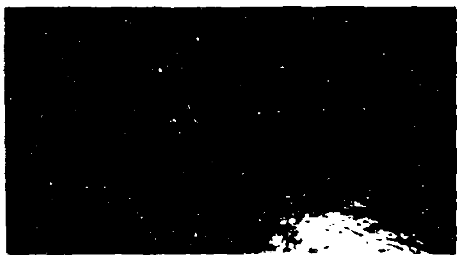
Oil Type Light Crude
Flow Rate 0.5 GPM
Time 0855

Ship Speed 17 knots
Test No. 51
Photo No. 659

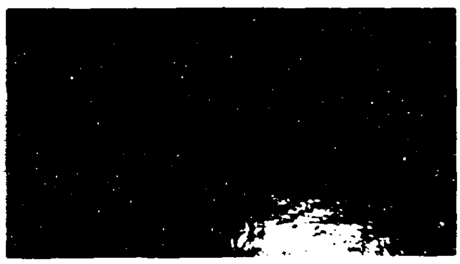
IR COLOR | **VISUAL COLOR**

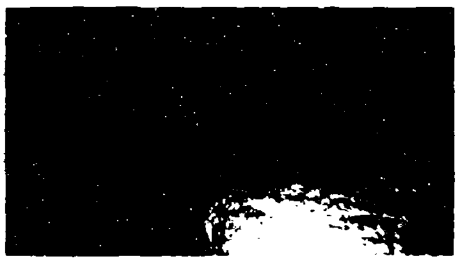
Oil Type	Light Crude	**Ship Speed**	17 knots
Flow Rate	0.5 GPM	**Test No.**	51
Time	0955	**Photo No.**	726

Oil Type	Light Crude	**Ship Speed**	17 knots
Flow Rate	1.0 GPM	**Test No.**	52
Time	0915	**Photo No.**	687



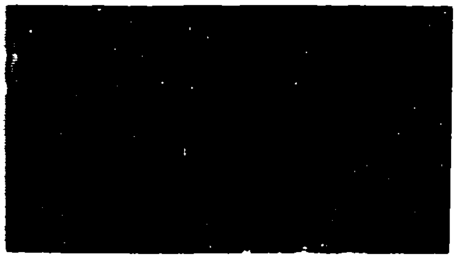
Oil Type	Light Crude	**Ship Speed**	17 knots
Flow Rate	1.0 GPM	**Test No.**	52
Time	0935	**Photo No.**	701





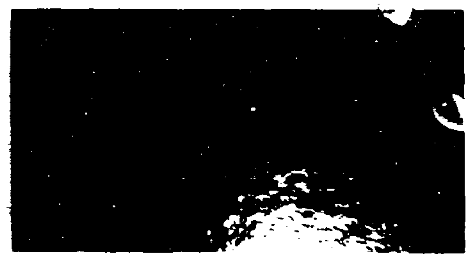
Oil Type	Light Crude	**Ship Speed**	17 knots
Flow Rat[illegible]	[illegible] 0 GPM	**Test No.**	52
Time	095[illegible]	**Photo No.**	731

IR COLOR | VISUAL COLOR



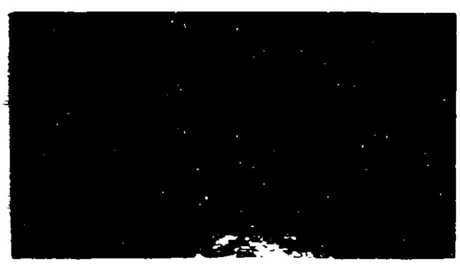
Oil Type Light Crude
Flow Rate 4.57 GPM
Time 0939

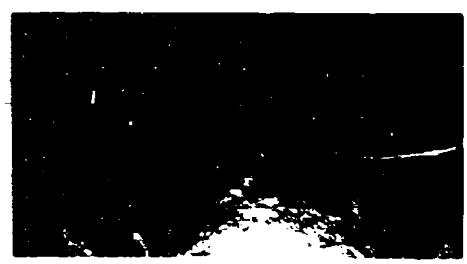
Ship Speed 17 knots
Test No. 56
Photo No. 717



Oil Type Light Crude
Flow Rate 4.57 GPM
Time 1002

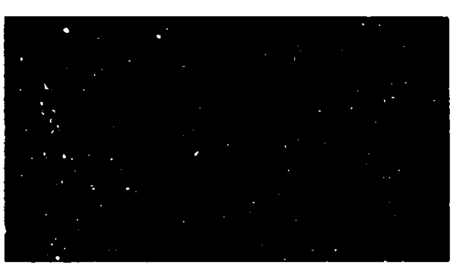
Ship Speed 17 knots
Test No. 56
Photo No. 745

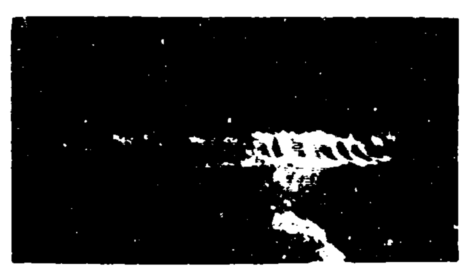




Oil Type Light Crude
Flow Rate 4.57 GPM
Time 1040

Ship Speed 17 knots
Test No. 56
Photo No. 789





Oil Type Heavy Crude
Flow Rate 0.5 GPM
Time 1222

Ship Speed 14 knots
Test No. 67
Photo No. 863

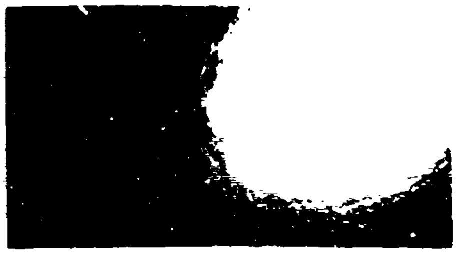
IR COLOR | VISUAL COLOR

Oil Type Heavy Crude
Flow Rate 0.5 GPM
Time 1241

Ship Speed 14 knots
Test No. 67
Photo No. 881

Oil Type Heavy Crude
Flow Rate 0.5 GPM
Time 1304

Ship Speed 14 knots
Test No. 67
Photo No. 914



Oil Type Heavy Crude
Flow Rate 0.5 GPM
Time 1332

Ship Speed 14 knots
Test No. 67
Photo No. 954

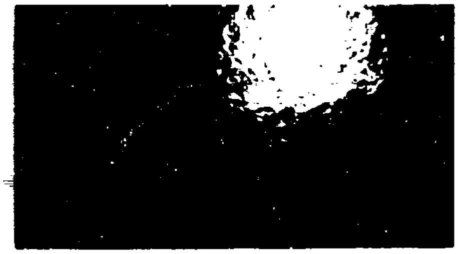
Oil Type Heavy Crude
Flow Rate 1.0 GPM
Time 1224

Ship Soeed 14 knots
Test No. 68
Photo No. 865

IR COLOR	VISUAL COLOR

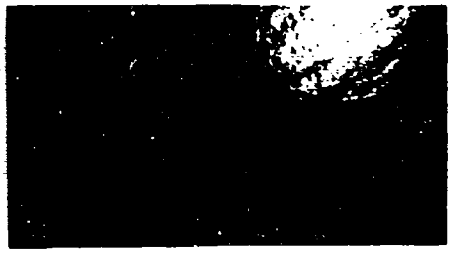

Oil Type Heavy Crude
Flow Rate 1.0 GPM
Time 1241

Ship Speed 14 knots
Test No. 68
Photo No. 888



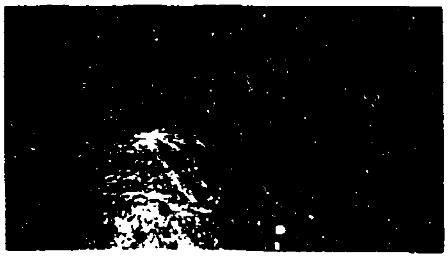
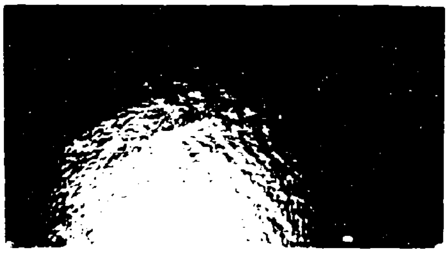

Oil Type Heavy Crude
Flow Rate 1.0 GPM
Time 1305

Ship Speed 14 knots
Test No. 68
Photo No. 921




Oil Type Heavy Crude
Flow Rate 1.0 GPM
Time 1333

Ship Speed 14 knots
Test No. 68
Photo No. 959

Oil Type Heavy Crude
Flow Rate 3.5 GPM
Time 1241

Ship Speed 14 knots
Test No. 98
Photo No. 1450

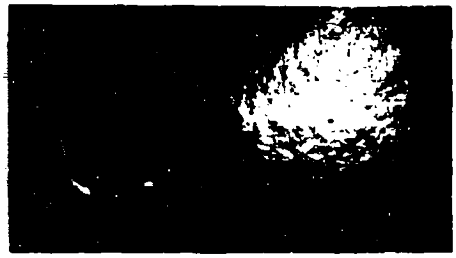
IR COLOR | VISUAL COLOR


Oil Type Heavy Crude
Flow Rate 3.5 GPM
Time 1329

Ship Speed 14 knots
Test No. 98
Photo No. 1501

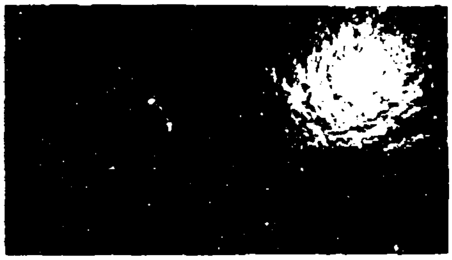
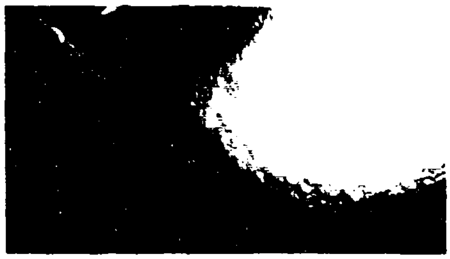

Oil Type Heavy Crude
Flow Rate 2.64 GPM
Time 1308

Ship Speed 10 knots
Test No. 71
Photo No. 935




Oil Type Heavy Crude
Flow Rate 2.64 GPM
Time 1337

Ship Speed 10 knots
Test No. 71
Photo No. 974

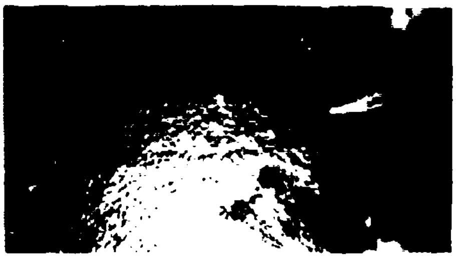



Oil Type Heavy Crude
Flow Rate 2.64 GPM
Time 1356

Ship Speed 10 knots
Test No. 71
Photo No. 996

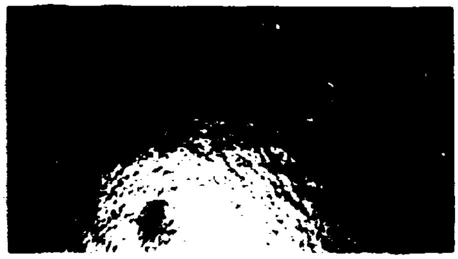
IR COLOR | VISUAL COLOR

Oil Type Heavy Crude
Flow Rate 3.95 GPM
Time 1205

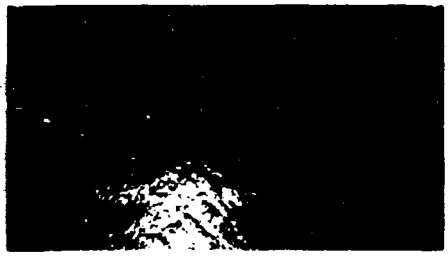


Ship Speed 17 knots
Test No. 96
Photo No. 1391

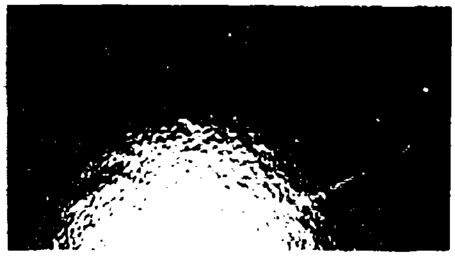
Oil Type Heavy Crude
Flow Rate 3.95 GPM
Time 1219



Ship Speed 17 knots
Test No. 96
Photo No. 1410

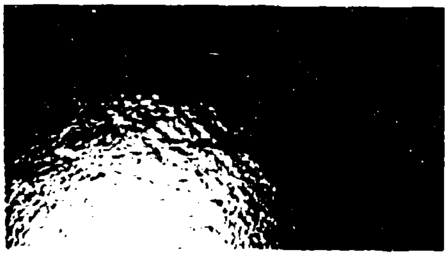


Oil Type Heavy Crude
Flow Rate 3.95 GPM
Time 1237



Ship Speed 17 knots
Test No. 96
Photo No. 1431

Oil Type Heavy Crude
Flow Rate 3.95 GPM
Time 1260



Ship Speed 17 knots
Test No. 96
Photo No. 1467

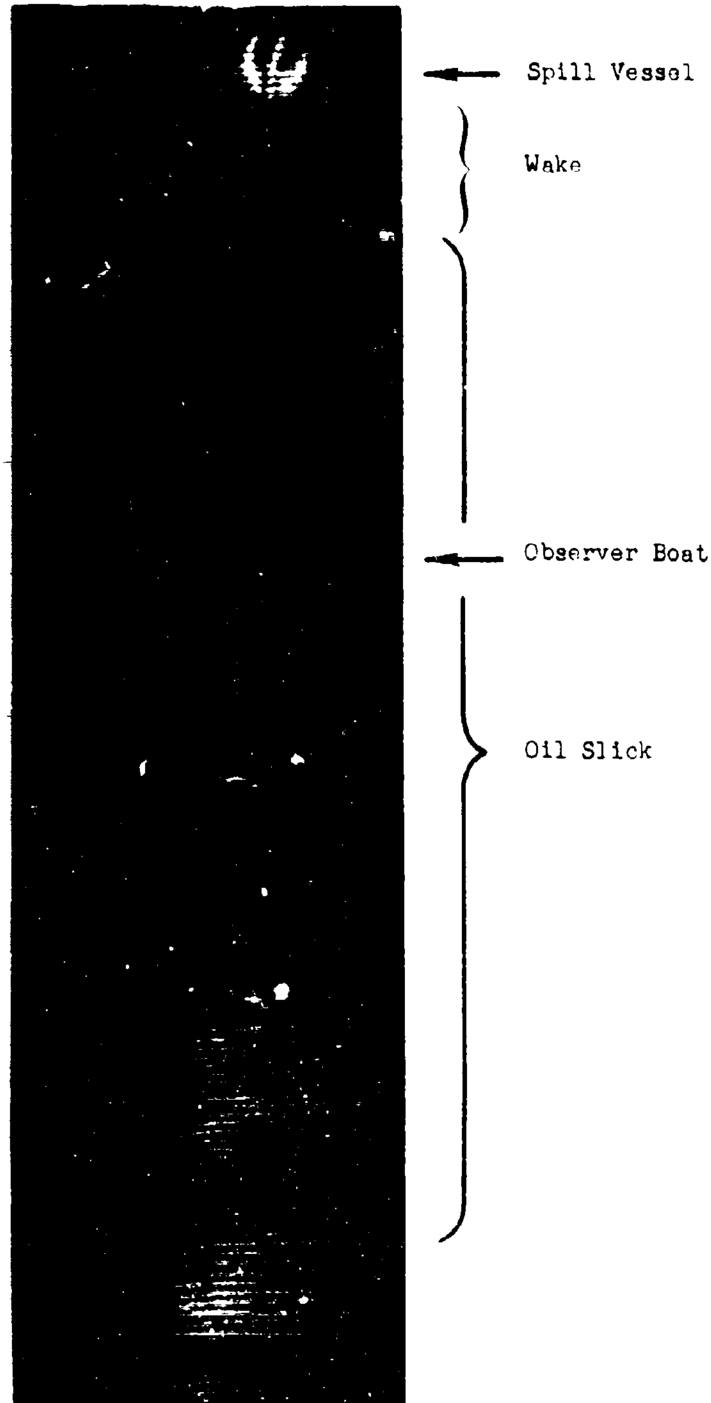


Figure 40
C-14 Imagery
Number 2 Fuel Oil
Spill Number 12
Flow Rate 0.2 GPM
Ship Speed 18 kts

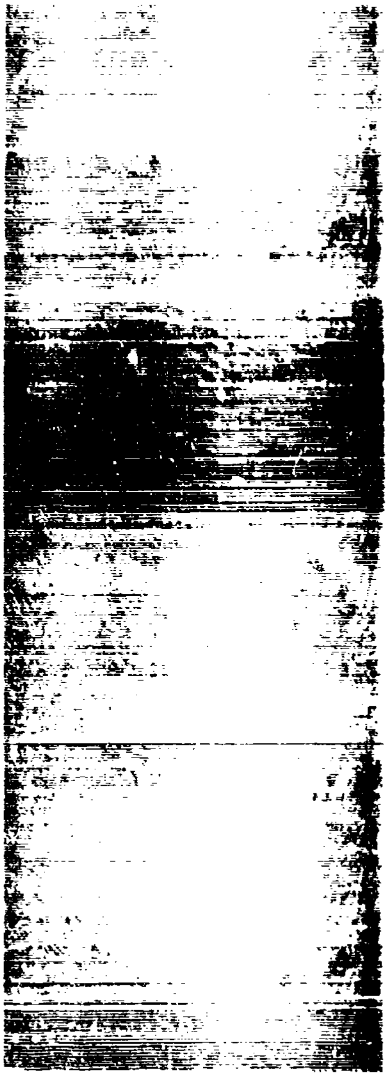


Figure 41
4-5.5μ Imagery
Heavy Crude Oil
Spill Number 95
Flow Rate 0.5 GPM
Ship Speed 14 kts

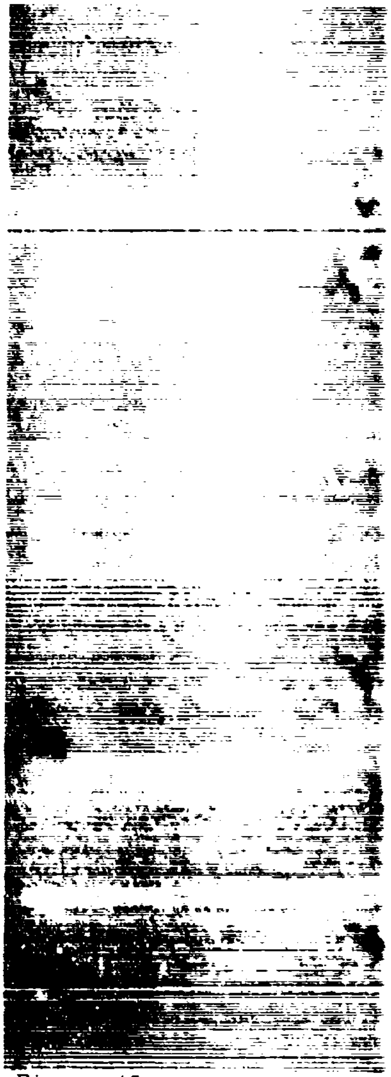


Figure 42
4-5.5μ Imagery
Number 6 Fuel Oil
Spill Number [illegible]
Flow Rate 3.67 GPM
Ship Speed 14 kts

Figures 41 & 42 4-5.5μ Imagery
of Heavy Crude Oil and Number 6 Fuel Oil.

Figure 43
DC-3 Equipment Installation

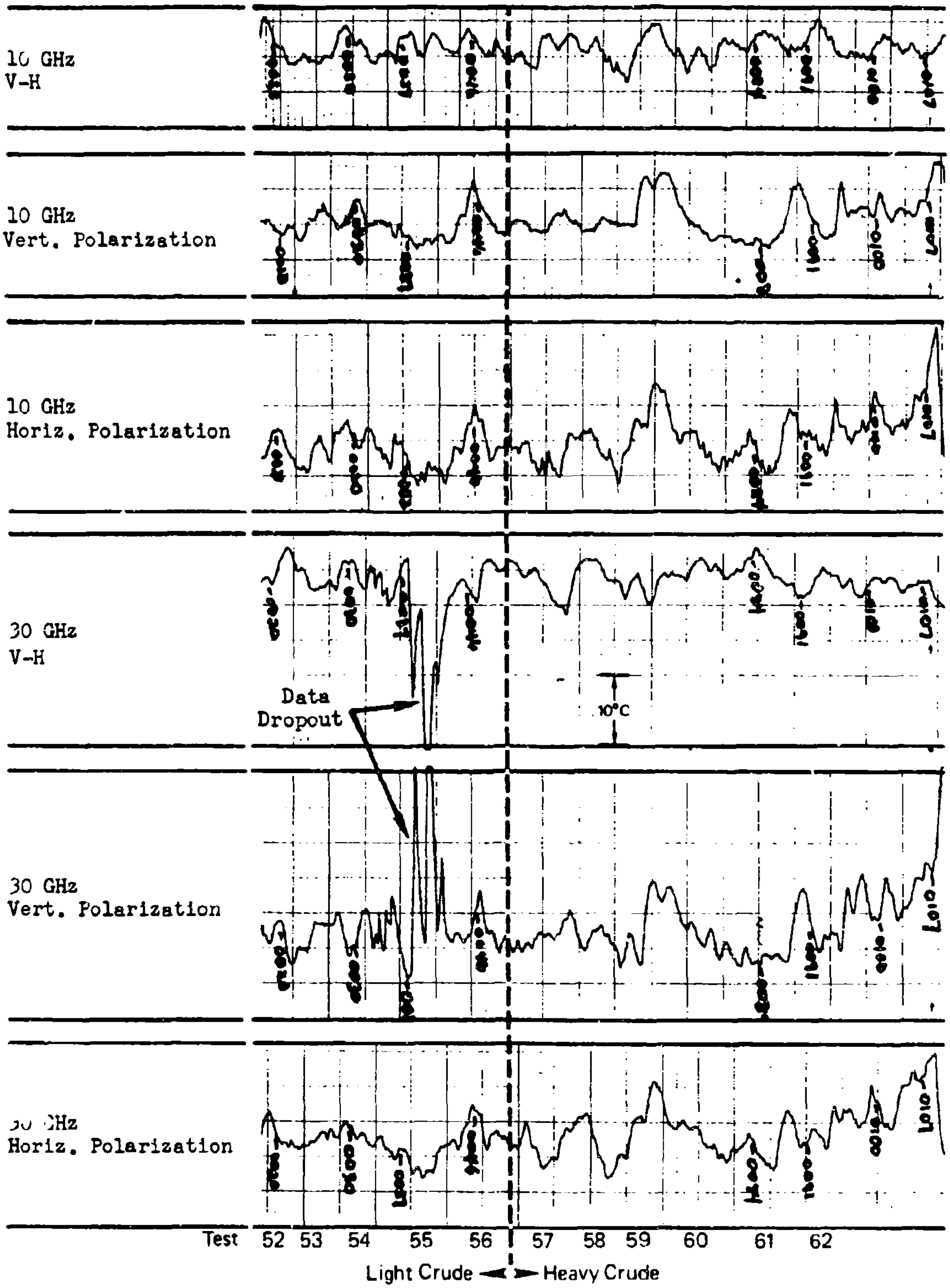


Figure 44 Typical Microwave Radiometric Response for Light and Heavy Crude Oil (Integration Time 1 second)

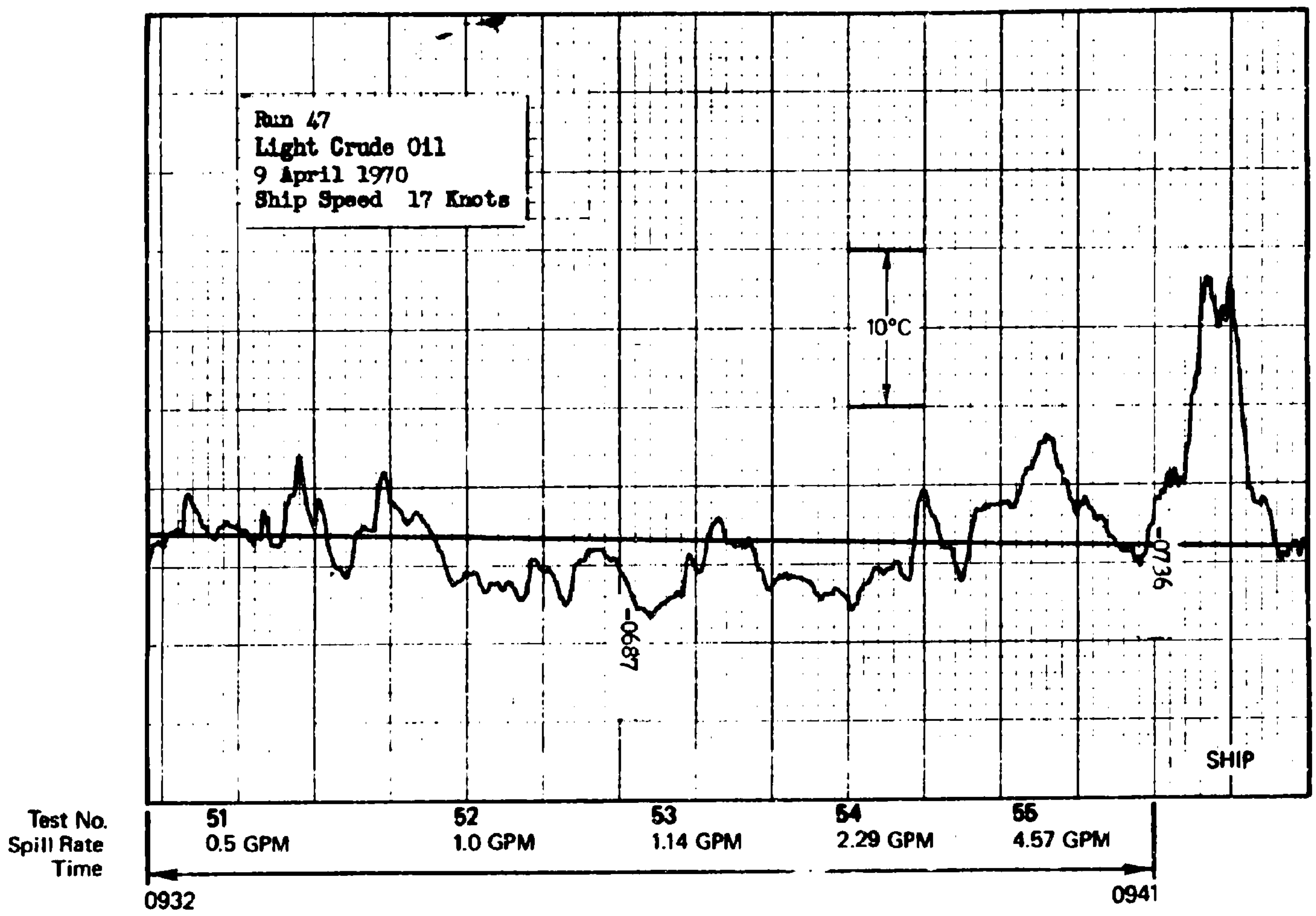


Figure 45 10 GHz Vertical Polarization Response for Light Crude Oil at a 1 Second Integration Time

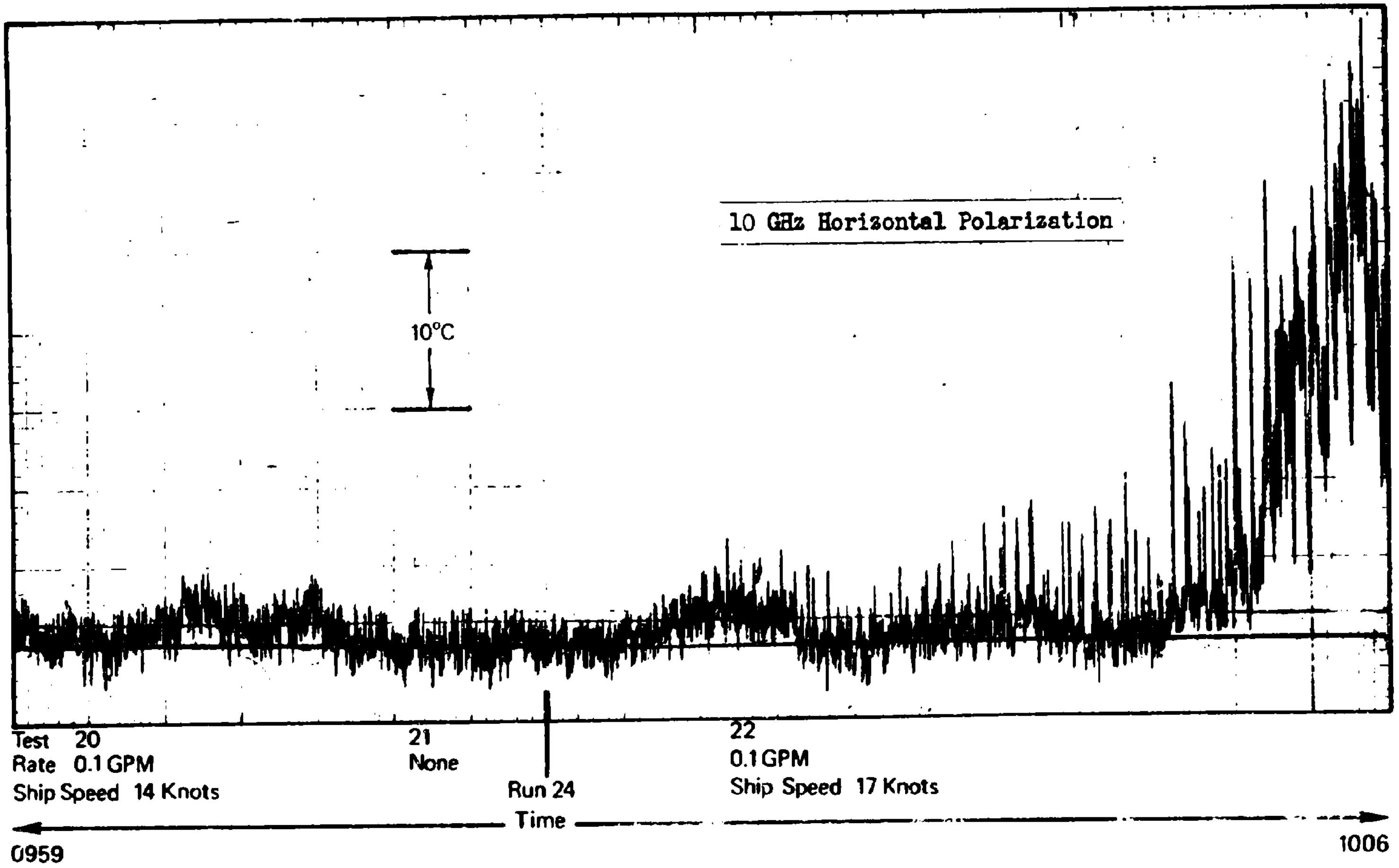


Figure 46 9250 Lubricating Oil Spills showing effects of Ship Noise on the 10 GHz Radiometric Response

APPENDIX A

MICROWAVE DATA

Microwave Data

RUN	SPILL	ΔT				V-H	SPILL LENGTH	COMMENTS
		30 GHz		10.2 GHz				
		V°	H°	V°	H°			
29	31	+2, ±5	+3	+7	+7			
30	31	---	---	+3	+5			
	32	---	---	---	3			
31	31	+2	+2	+3	+3	±10	~ 12K	
	32	+4	+3	+4	+3	?	~ 11K	
	33	+2	+3	?	?			Interference makes X band data questionable
32	31	---	+2	+2	+2			
	32	---	---	+1	+1			
	33	?	?	?	?			
	34	?	?	?	?			

Microwave Data

RUN	SPILL	ΔT				V-H	SPILL LENGTH	COMMENTS
		30 GHz		10 GHz				
		V°	H°	V°	H°			
39	39	+2	+3	+5	+4			
	40	-7	-3	+5	+7			
	41	-4	-4	-16	-16			
	42	+7	+4	+8	+4			
40	42	+4	+4	+4	+3			
	43	+4	+5	+7	+3			
	44	+2	+3	---	---			
41	41	+2	+3	+2	+1			
	42							
	43	?	+4	+6	+5			
	44	+4	+3	+7	+4			
	45	---	+4	+6	+6			
42	42	+5	+5	+7	+8			
	43	+3	+7	?	?			Very Short Run
	44	+4	+7	+4	+7			
	45	+3	+4	+4	+9			
	46	+5	+4	+5	+5			
43	---	---	---	---	---			
44	43	+6	+5	+4	+4			

Microwave Data

RUN	SPILL	ΔT 30 GHz V°	ΔT 30 GHz H°	ΔT 10 GHz V°	ΔT 10 GHz H°	V-H	SPILL LENGTH	COMMENTS
47	52	+5	+5	+6	+5	-2	16K	
	53	+1,±3	+9	+5	+6	-1	10K	
	54	+6	+5	+10	+7		16K	
	55	+6	+6	+7	+5			
	56	---	---	---	---			
	57	---	---	---	---			
48	51	---	+7	+3½	+6			
	52	+7,±2	+6,±2	+5,±1	+5,±1	10,+1 30,+5	12K	
	53							
	54	+5	+7,±1½	+4,±1½	+3,±1	10,+1 30,+4	8K	
	55	+3,±1	+7,±1	+5,±1	+4,±1½	?	?	
	56	+9,±2	+6,±2	+6,±2	+5,±1½	10,-1 30,+2	9K	
	57	+6,±3	+7,±3	+10,±2	+9	10,+3 30,+5	6K	
	58	---	---	---	---			Data problems
	59	10	6	7	6			
	60							
49	57	+9,±2	+12,±5	+9,±2	+5			
	58	+11,±2	+7,±2	+10,±2	+12,±3		10K	
	59	+7,±3	+11,±2	+9,±2	+9,±1½	10,±1 30,±4	10K	
	60	+7,±1	+9,±1	+9,±2	+6,±1	10,±1 30,±4	8K	
	61	+7,±2	+9.±1	+8,±2	+5,±1	10,-1 30,+2	6K	
	62	+7,±1	+9,±2	+7,±2	+6,±1½	10,±1 30,+3	10K	

Microwave Data

RUN	SPILL	ΔT 30 GHz V°	ΔT 30 GHz H°	ΔT 10 GHz V°	ΔT 10 GHz H°	V-H	SPILL LENGTH	COMMENTS
50	63	+6	+6	+8	+8	?	?	
51	63							
	64							
52	65	+15	+5	+13	+9	10, ±2 30, +4		
	66	+10	+9	+9	+9			
54	65	+3	+3	+7	+6			
	66	+7	+5	+6	+6			
	67	+5	+8	±2	+5			
55	65	+7	+4	+7	+3			
	66	+7	+9	+5	+5			
	67	+10	+10	+6	+12			
	68	+10	+10	+8	+10			
56	64	+6	+6	+3	+1			
	65	+6	+6	+3	+1			
	66	+6	+6	+5	+2			
	67							Tanker Spill
	68	+3	+6	+2	+2			
	69	+4	+6	+5	+3			
	70	+6	+6	+5	±2			
	71	+4	+4	+2	---			

Microwave Data

RUN	SPILL	ΔT 30 GHz V°	ΔT 30 GHz H°	ΔT 10 GHz V°	ΔT 10 GHz H°	V-H	SPILL LENGTH	COMMENTS
57	71	+3	+7	+4	+6	-+2	12K	
	72	+4	+7	+3	+1		12K	30V - Hot Areas (Thick Oil to -12°)
60	75	+2	+4	+3	+5			
61	75	+5	+6	+5	+6	30-+5 10-+2	11K	
	76	+5	+7	+6	+7	30+3 10+1	12K	
62	75	+8	+8	+8	+4	30-+2 -3 10-+2		
	76	+4	+6	+5	+6	30 +6 10 +2		
	77	+3	-6 -4	+9	+6			
65	81	+6	+7	+4	+1	30-+3 10·+1	14K	
	82	+6	+6	+7	+6	30-5		
66	81	+7	+3	+4	+4			
	32	+4	+4	+2	+4			
67	85	+6	+3	+1	+2			
68	85	+8	+4	+8	+4			
	86	+5	+6	+3	+2			
69	87	+6	+11	---	+4			
	88	+3	+2	+4	+6			
70	87	+6	+4	+5	+5			
	88	+4	+5	+5	+5			

Microwave Data

RUN	SPILL	ΔT 30 GHz V°	ΔT 30 GHz H°	ΔT 10 GHz V°	ΔT 10 GHz H°	V-H	SPILL LENGTH	COMMENTS
71	89	+5	+4	+2	+2			
	90	+4	+4	+4	+5			
72	89	+7	+6	+8	+7			
	90	+3	+4	+6	+3			
	91	+5	+5	+5	+5			
	92	+6	+8	+5	---			
73	---	---	---	---	---			
74	94	+3	+2	+4	+1			
	95	---	---	---	---			
75	94	---	+5	---	+6			
	95	+3	+4	+4	+7			
	96	+3	+3	+5	+5			

APPENDIX B

VISIBLE COLOR AND INFRARED COLOR PHOTOGRAPHY DATA

Reel #[illegible]

Photo Data

TYPE IR/MS

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
10	[illegible]	#2Fuel	50'	150'	Black	Parallel black trails	
11	10	#2Fuel	100'	5100'	Black	Black trail	
12	10	#2Fuel	50'	8200'	Black-IR	IR-Thin black trail	MS-unreadable
	11	#2Fuel	100'	7400'	Black	Black Trail	
13	12	#2Fuel	150'	4000'	Black	Wide black trail	
14	13	#2Fuel	50'	7100'	Black	Black Trail	
1[illegible]	14	9250	150'	8800'	Black	Black Trail	
16	14	9250	200'	3700'	Black	Wide Black Trail	
	15	9250	150'	7000'	Black	Black Trail	
17	14	9250	300'	8600'	Black	Wide Black Trail	
1[illegible]	S	Tanker Dump			Black	Black trails, large pools, parallel trails	Length & Width undetermined

Reel #4

Photo Data

TYPE IR/MS

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
44R	50	Lt Crude	50'		Black	Black Trail	Length undetermined
	51	Light Crude			Hazy white	Spiral Formation	Length & width undeter in IR-Unreadable
45	53	Light Crude	200'	13,800'	Hazy white	Wide spiral formation	
46	51	Light Crude	50'		hazy white MS-red tint	Spiral Formation	Length unreadable
	52	Light Crude	350'	9300'	hazy white MS-red tint	Wide spiral formation	
	53	Light Crude	200'	9100'	hazy white MS-red tint	Spiral formation	
	54	Light Crude	150'	8700'	hazy white MS-red tint	Tight spiral formation	
47	51	Light Crude	100'	4300'	Hazy white	Loose spiral formation	
	52	Light Crude	400'	9900'	Hazy white	wide cloudy trail	
	53	Light Crude	150'	8900'	MS-red tint Hazy white	Spiral Formation	
	54	Light Crude	300'	10,200'	Hazy white MS-red tint	Wide spiral formation	
	55	Light Crude	300'	10,100'	Hazy white MS-red tint	Wide spiral formation	
	56	Light Crude	250'	10,100'	Hazy white MS-red tint	Tight spiral formation	
	57	Heavy Crude	100'	2000'	Hazy white	Spiral formation	
48	51	Light Crude			Hazy white	Cloudy patches	Length & Width undetermined
	52	Light Crude	100'		Hazy white	Spiral formation	length unreadable
	53	Light Crude	100'		Hazy white	Cloudy Patches	length unreadable
	54	Light Crude	200'	9300'	Hazy white MS-red tint	Cloudy patches	
	55	Light Crude	300'	10,200'	Hazy white MS-red tint	Cloudy patches	
	56	Light Crude	400'	10,300'	MS-red tint	Spiral Formation	
	57	Heavy Crude	250'	8400'	Hazy white MS-red tint	Tight Spiral formation	
	58	Heavy Crude	300'	9600'	milky white MS-red tint	Wide, tight spiral formation	
	59	Heavy Crude	150'	9200'	Hazy white MS-red tint	Tight Spiral Formation	
	60	Heavy Crude	100'	6100'	hazy white MS-red tint	SPiral Formation	

Roll #1

Photo Data

TYPE IR/MS

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
49	52	Light Crude	50'		Hazy white	Cloudy Patches	Length Unreadable
	53	Light Crude	150'		Hazy white	Cloudy patches	Length Unreadable
	54	Light Crude			Hazy white	Wide cloudy patches	Length & width unreadable
	55	Light Crude	500'	10,500'	Hazy white	Wide, spiral, cloudy formation	
	56	Light Crude	500'	10,400'	Hazy white MS-red tint	Wide spiral formation	
	57	Heavy Crude	500'	8000'	Hazy white MS-red tint	wide spiral formation	
	58	Heavy Crude	400'	8900'	Hazy white MS-red tint	Wide spiral formation	
	59	Heavy Crude	350'	7700'	Hazy white	Wide spiral formation	
	60	Heavy Crude	450'	10,100'	Hazy white MS-red tint	Wide spiral formation	
	61	Heavy Crude	300'	9500'	Hazy white	Wide spiral formation	
	62	Heavy Crude			Hazy white	Cloudy traces	Length & width unreadable
52	65	Heavy Crude	25'		Hazy white	Thin white trail	Length unreadable

Photo Data

Reel #
TYPE IR/MS

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
52	65	Heavy Crude	25'	2800'	Hazy white	Straight Line pattern	
53	65	Heavy Crude	25'	9200'	Hazy white	straight line pattern spill end in hazy white spiral formation	
53	66	Heavy Crude	200'	9500'	Hazy white	wide spiral formation	
54	65	Heavy Crude	400'	9500'	Hazy white	Broken line pattern	
	66	Heavy Crude	450'	10,000'	extremely hazy white	Light spiral formation	
	67	Heavy Crude	250'	10,200'	Milky white	tight spiral deposit	
	68	Heavy Crude	150'	7900'	milky white	tight spiral formation	
55	65	Heavy Crude	100'	5600'	hazy white	Cloudy patches	
	66	Heavy Crude	500'	12,000'	hazy white	Wide spiral formation	
	67	Heavy Crude	400'	10,500'	hazy white	Wide hazy formation	
	68	Heavy Crude	300'	10,600'	milky white	wide spiral formation	
	69	Heavy Crude	300'	10,600'	milky white MS-red tint	tight spiral formation	
	70	Heavy Crude	150'	9000'	milky white MS-red tint	Tight spiral formation	
56	65	Heavy Crude	600'	12,000'	Blackish	Two distinguished parallel lines	
	66	Heavy Crude	400'	11,000'	Blackish white haze	white haze patches Black patches	Blackish-IR MS-white haze patches
	67	Heavy Crude	400'	9400'	white haze	wide spiral formation	
	68	Heavy Crude	400'	11,900'	white haze	wide cloudy patches	
	69	Heavy Crude	400'	12,300'	white haze MS-red tint	wide spiral formation	
	70	Heavy Crude	400'	12,300'	white haze MS-red tint	wide spiral formation	
	71	Heavy Crude	300'	11,700'	white haze MS-red tint	wide, tight spiral formation	
	72	Heavy Crude	200'	4400'	white haze MS-red tint	spiral formation	
57	66	Heavy Crude	500'	5600'	Blackish	Parallel lines	MS film Does not show in
	67	Heavy Crude	500'	12,000	IR-black MS-white haze	hazy wide formation black patches	Black-IR White haze-MS
	68	Heavy Crude	400'	13,000	milky white	wide hazy patches	black color-IR White haze-MS

Re-1 #5

Photo Data

TYPE IR/MS

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
57	69	Heavy Crude	400'	10,800'	white haze	wide spiral formation	
	70	Heavy Crude	450'	12,000'	MS-red tint white haze	wide spiral formation	
	71	Heavy Crude	400'	11,400'	white haze MS-red tint	wide spiral formation	
	72	Heavy Crude	250'	13,300'	white haze MS-red tint	spiral formation	
	73	Heavy Crude	250'	12,700'	white haze MS-red tint	spiral formation	
	74	Heavy Crude	150'	10,000'	white haze MS-red tint	spiral formation	
58	71	Heavy Crude	500'	9800'	white haze MS-red tint	wide spiral formation	
	72	Heavy Crude	200'	13,100'	white haze MS-red tint	spiral formation	
	73	Heavy Crude	300'	12,900'	white haze MS-red tint	spiral formation	
	74	Heavy Crude	150'	12,400'	white haze MS-red tint	spiral formation	

Reel #6

Photo Data

TYPE IR MS

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
59	75	Heavy Crude	150'	5000'	Milky white MS-red tint	spiral formation	Pic.#1100 not complete
60	75	Heavy Crude	150'	8300'	milky white MS-red tint	spiral formation	
	76	Heavy Crude	100'	12,400	milky white MS-red tint	spiral formation	
61	75	Heavy Crude	150'	7700'	milky white MS-red tint	spiral formation	
	76	Heavy Crude	150'	12,800	Milky white MS-red tint	spiral formation	
	77	Heavy Crude	150'	11,400	milky white	spiral formation	
62	77	Heavy Crude	150'	8200'	hazy white MS-red tint	spiral formation	
	78	Heavy Crude	100'	12,400	hazy white MS-red tint	spiral formation	
	Pictures 1138 through 1168 unreadable						
64	81	#6	100'	14,300	hazy white	spiral formation	
65	81	#6			hazy white	spiral formation	unreadable picture 1206-1207
	82	#6	100'	12,200	MS-hazy white IR-blackish	MS-spiral formation IR-blackish trail	
	83	#6	100'	5700'	hazy white	spiral formation	IR-unreadable
67	86	#6					Pic. 1240-42 unreadable
68	85	#6					Pic. 1245-46 unreadable
	86	#6	100'	11,400	Blackish	Blackish trail	MS-unreadable
	87	#6			MS-hazy white IR-blackish	MS-spiral IR-trail	Length & width unreadable due to cloud cove
69	86	#6					Pic. 1259-62 unreadable
	87	#6			IR-blackish	Blackish trail	MS-unreadable, length & width unreadable
	88	#6					Pic. 1270-74 unreadabl due to cloud cover
	89	#6					Pic. 1274-76 unreadable due to cloud cov
70	87	#6			IR-blackish	blackish trail	MS-unreadable
	88	#6					Pic. 1280-84 unreadable due to cloud cove

Reel 1

Photo Data

TYPE IR/MS

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
70	89	#6			IR-blackish	Blackish trail	MS-unreadable, length & width unreadable
	90	#6			IR-blackish	Blackish trail	MS-unreadable, length & width unreadable

APPENDIX C

VISIBLE COLOR AND INFRARED COLOR PHOTOGRAPHY SPREAD RATES

Photo Data

TYPE IR, MS

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
10	[illegible]	#2 Fuel	50'	150'	Black	parallel black trails	
11	10	#2 Fuel	100'	5,100'	Black	Black trail	
12	10	Fuel	50'	8,200'	Black-IR	IR Thin black trail	MS-unreadable
12	11	#2 Fuel	100'	7,400'	Black	Black trail	
13	12	#2 Fuel	150'	4,000'	Black	wide black trail	
14	13	#2 Fuel	50'	7,100'	Black	Black trail	
15	14	9250	150'	8,300'	Black	Black trail	
16	14	9250	200'	8,700'	Black	Wide black trail	
17	14	9250	300'	8,600'	Black	Wide black trail	
16	15	9250	150'	7,000'	Black	Black trail	
13	S	Tanker Dump			Black	Black trails, large pools, parallel trails	length & width undetermined
44R	50	Light Crude	50'		Black	Black trail	Length undetermined
44R	51	Light Crude			Hazy white	Spiral formation	IR-unreadable, length & width undetermined
46	51	Light Crude	50'		Hazy white MS-red tint	spiral formation	length unreadable
47	51	Light Crude	100'	4,300'	Hazy white	loose spiral formation	

Photo Data

TYPE

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
[illegible]	51	Light Crude			Hazy white	Cloudy patches	Length & width unreadable
46	52	Light Crude	350'	9,300'	Hazy white MS-red tint	Wide spiral effect	
47	52	Light Crude	400'	9,000'	Hazy white	Wide cloudy effect	
48	52	Light Crude	100'		Hazy white	Spiral formation	Length unreadable
49	52	Light Crude	50'		Hazy white	cloudy patches	Length unreadable
45	53	Light Crude	200'	13,800'	Hazy white	Wide spiral formation	
46	53	Light Crude	200'	9,100'	Hazy white MS-red tint	Spiral formation	
47	53	Light Crude	150'	8,900	Hazy white MS-red tint	Spiral formation	
4[illegible]	53	Light Crude	100'		Hazy white	Cloudy patches	Length unreadable
49	53	Light Crude	150'		Hazy white	Cloudy patches	Length unreadable
46	54	Light Crude	150'	8,700'	Hazy white MS-red tint	Tight spiral formation	
47	54	Light Crude	300'	10,200'	Hazy white MS-red tint	Wide spiral formation	
48	54	Light Crude	200'	9,300'	Hazy white MS-red tint	Cloudy patches	
49	54	Light Crude			Hazy white	Wide cloudy patches	Length & width unreadable
47	55	Light Crude	300'	10,100'	Hazy white MS-red tint	Wide spiral formation	
48	55	Light Crude	300'	10,200'	Hazy white MS-red tint	Cloudy patches	
49	55	Light Crude	500'	10,500'	Hazy white	Wide, spiral cloudy formation	
47	56	Light Crude	250'	10,100'	Hazy white MS-red tint	Tight spiral formation	
48	56	Light Crude	400'	10,300'	Hazy white MS-red tint	Spiral formation	

Photo Data

TYPE

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
49	56	Light Crude	500'	10,400'	Hazy white MS-red tint	Wide spiral formation	
47	57	Heavy Crude	100'	2,000'	Hazy white	Spiral formation	
48	57	Heavy Crude	250'	8,400'	Hazy white MS-redtint	Tight spiral formation	
49	57	Heavy Crude	500'	8,000'	Hazy white MS-red tint	Wide spiral formation	
48	58	Heavy Crude	300'	9,600'	milky white MS-red tint	Tight, wide spiral formation	
49	58	Heavy Crude	400'	8,900'	Hazy white MS-red tint	Wide spiral formation	
48	59	Heavy Crude	150'	9,200'	Hazy white MS-red tint	Tight spiral formation	
49	59	Heavy Crude	350'	7,700'	Hazy white	Wide spiral formation	
48	60	Heavy Crude	100'	6,100'	Hazy white MS-red tint	Spiral formation	
49	60	Heavy Crude	450'	10,100'	Hazy white MS-red tint	Wide spiral formation	
49	61	Heavy Crude	300'	9,500'	Hazy white	Wide spiral formation	
49	62	Heavy Crude			Hazy white	Cloudy traces	Length & width unreadable
52	65	Heavy Crude	25'		Hazy white	Thin white trail	Length unreadable
52	65	Heavy Crude	25'	2,800'	Hazy white	Straight line pattern	
53	65	Heavy Crude	25'	9,200'	Hazy white	Straight line pattern spill ends in spiral formation	
54	65	Heavy Crude	400'	9,500'	Hazy white	Broken line pattern	
55	65	Heavy Crude	100'	5,600'	Hazy white	Cloudy patches	

Photo Data

TYPE

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
[illegible]	[illegible]	Heavy Crude	[illegible]	1[illegible],000'	Black	Parallel Lines	
[illegible]	[illegible]	Heavy Crude	[illegible]00'	[illegible],500'	Hazy white	Wide spiral formation	
[illegible]	[illegible]	Heavy Crude	450'	10,000'	Hazy white	Light spiral formation	
[illegible]	[illegible]	Heavy Crude	500'	1[illegible],000'	Hazy white	Wide spiral formation	
[illegible]	[illegible]	Heavy Crude	400'	11,000'	Blackish White Haze	Black patches White hazy patches	IR-Black MS-white haze
[illegible]	[illegible]	Heavy Crude	500'	[illegible],600'	Blackish	Parallel Lines	Does not show in MS [illegible]
[illegible]	[illegible]	Heavy Crude	[illegible]50'	10,[illegible]00'	milky white	Tight spiral deposit	
[illegible]	[illegible]	Heavy Crude	400'	[illegible]0,500'	Hazy white	Wide hazy formation	
[illegible]	[illegible]	Heavy Crude	400'	[illegible],400'	White haze	Wide spiral formation	
[illegible]	[illegible]	Heavy Crude	500'	1[illegible],000'	White haze Black	White haze patches Black patches	white haze MS black-IR
[illegible]	[illegible]	Heavy Crude	150'	7,[illegible]00'	milky white	Tight spiral formation	
[illegible]	[illegible]	Heavy Crude	300'	10,600'	milky white	Wide spiral formation	
[illegible]	[illegible]	Heavy Crude	400'	11,[illegible]00'	Hazy white	Wide cloudy patches	
[illegible]	[illegible]	Heavy Crude	400'	13,000'	milky white Black	wide hazy patches Black patches	white-MS black IR
[illegible]	[illegible]	Heavy Crude	300'	10,600'	milky white MS-red tint	Tight spiral formation	
[illegible]	[illegible]	Heavy Crude	400'	1[illegible],300	white haze MS-red tint	Wide spiral formation	
[illegible]	[illegible]	Heavy Crude	400'	10,[illegible]00'	White haze	Wide spiral formation	
[illegible]	70	Heavy Crude	150'	[illegible],000'	milky white MS-red tint	Tight spiral formation	
[illegible]	[illegible]0	Heavy Crude	400'	1[illegible],[illegible]00'	white haze MS-red tint	Wide spiral formation	

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Photo Data

TYPE ..

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
[illegible]	70	Heavy Crude	450'	12,000	white haze MS-red tint	Wide spiral formation	
56	71	Heavy Crude	300'	11,700'	white haze MS-red tint	Wide, tight spiral formation	
57	71	Heavy Crude	400'	11,400'	white haze MS-red tint	Wide spiral formation	
58	71	Heavy Crude	500'	9,800'	white haze MS-red tint	Wide spiral formation	
56	72	Heavy Crude	200'	4,400'	white haze MS-red tint	Spiral formation	
57	72	Heavy Crude	250'	13,300'	white haze MS-red tint	Spiral formation	
58	72	Heavy Crude	200'	13,100	white haze MS-red tint	Spiral formation	
57	73	Heavy Crude	250'	12,700'	white haze MS-red tint	Spiral formation	
58	73	Heavy Crude	300'	12,900'	hazy white MS-red tint	Spiral formation	
57	74	Heavy Crude	150'	10,000'	hazy white Ms-red tint	Spiral formation	
58	74	Heavy Crude	150'	12,400'	hazy white MS-red tint	Spiral formation	
59	75	Heavy Crude	150'	5,000'	milky white MS-red tint	Spiral formation	Photo 1100 not complete
60	75	Heavy Crude	150'	8,300'	milky white MS-red tint	Spiral formation	
61	75	Heavy Crude	150'	7,700'	milky white MS-red tint	Spiral formation	
60	76	Heavy Crude	100'	12,400	milky white MS-red tint	Spiral formation	
61	76	Crude	150'	12,800'	milky white MS-red tint	Spiral formation	
61	77	Heavy Crude	150'	11,400	milky white	Spiral formation	

C-

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Photo Data

TYPE

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
[illegible]	[illegible]	Heavy Crude	150'	[illegible],[illegible]00'	hazy white MS-red tint	Spiral formation	
[illegible]	78	Heavy Crude	100'	1[illegible],400'	hazy white MS-red tint	Spiral formation	
[illegible]	81	#6	100'	14,300'	Hazy white	Spiral formation	
[illegible]	81	#6			Hazy white	Spiral formation	unreadable in photo
[illegible]	82	#6	100'	1[illegible],200'	MS-hazy white IR-Blackish	MS-spiral formation IR-blackish trail	
[illegible]	83	#6	100'	[illegible],700'	MS Hazy white	Spiral formation	IR-unreadable
[illegible]	85	#6					Photo 12[illegible] unreadable
[illegible]	86	#6					Photos 1[illegible]0-[illegible] unreadable
[illegible]	86	#6	100'	11,400'	IR-blackish	blackish trail	MS-unreadable
[illegible]	86	#6					Photos 12[illegible] unreadable
68	87	#6			MS-hazy white IR-blackish	MS-spiral IR-trail	Length & width un-readable due to clouds
[illegible]	87	#6			IR-blackish	IR-blackish trail	MS- unreadable L & W unreadable
70	87	#6			IR-blackish	IR-blackish trail	MS-unreadable
[illegible]	88	#6					Photo 1270-74 unreadable due to cloud cover
70	88	#6					Photo 1280-84 unreadable due to cloud cover
72	88	#6			IR-blackish	IR-blackish trail	L & W unreadable MS-unreadable

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Photo Data

TYPE _

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
[illegible]	70	Heavy Crude	450'	12,000	white haze MS-red tint	Wide spiral formation	
56	71	Heavy Crude	300'	11,700'	white haze MS-red tint	Wide, tight spiral formation	
57	71	Heavy Crude	400'	11,400'	white haze MS-red tint	Wide spiral formation	
58	71	Heavy Crude	500'	9,800'	white haze MS-red tint	Wide spiral formation	
56	72	Heavy Crude	200'	4,400'	white haze MS-red tint	Spiral formation	
57	72	Heavy Crude	250'	13,300'	white haze MS-red tint	Spiral formation	
58	72	Heavy Crude	200'	13,100	white haze MS-red tint	Spiral formation	
57	73	Heavy Crude	250'	12,700'	white haze MS-red tint	Spiral formation	
58	73	Heavy Crude	300'	12,900'	hazy white MS-red tint	Spiral formation	
57	74	Heavy Crude	150'	10,000'	hazy white Ms-red tint	Spiral formation	
58	74	Heavy Crude	150'	12,400'	hazy white MS-red tint	Spiral formation	
59	75	Heavy Crude	150'	5,000'	milky white MS-red tint	Spiral formation	Photo 1100 not complete
60	75	Heavy Crude	150'	8,300'	milky white MS-red tint	Spiral formation	
61	75	Heavy Crude	150'	7,700'	milky white MS-red tint	Spiral formation	
60	76	Heavy Crude	100'	12,400	milky white MS-red tint	Spiral formation	
61	76	Crude	150'	12,800'	milky white MS-red tint	Spiral formation	
61	77	Heavy Crude	150'	11,400	milky white	Spiral formation	

Photo Data

TYPE

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
[illegible]	[illegible]	Heavy Crude	[illegible]0'	[illegible], 00'	hazy white MS-red tint	Spiral formation	
[illegible]	78	Heavy Crude	100'	1[illegible],400'	hazy white MS-red tint	Spiral formation	
[illegible]	[illegible]1	#6	100'	14,300'	Hazy white	Spiral formation	
	[illegible]1	#6			Hazy white	Spiral formation	unreadable in photo
[illegible]	[illegible]	#6	100'	1[illegible],[illegible]00'	MS-hazy white IR-Blackish	MS-spiral formation IR-blackish trail	
[illegible]	83	#6	100'	[illegible],700'	MS Hazy white	Spiral formation	IR-unreadable
[illegible]	[illegible]	#6					Photo 124[illegible] unreadable
[illegible]	86	#6					Photos 12[illegible]0-[illegible] unreadable
6[illegible]	86	#6	100'	11,400'	IR-blackish	blackish trail	MS-unreadable
[illegible]	[illegible]6	#6					Photos 125[illegible] unreadable
6[illegible]	87	#6			MS-hazy white IR-blackish	MS-spiral IR-trail	Length & width unreadable due to clouds
6[illegible]	87	#6			IR-blackish	IR-blackish trail	MS- unreadable L & w unreadable
70	87	#6			IR-blackish	IR-blackish trail	MS-unreadable
6[illegible]	88	#6					Photo 1270-74 unreadable due to cloud cover
70	88	#6					Photo 1280-84 unreadable due to cloud cover
7[illegible]	88	#6			IR-blackish	IR-blackish trail	L & W unreadable MS-unreadable

Photo Data

TYPE ______

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
70	89	#6			IR-blackish	IR-blackish trail	L & W-unreadable MS-unreadable
71	89	#6	150'	12,500'	Black	Black trail	Trail visib[illegible] I& MS
72	89	#6	150'	11,900'	IR-black	IR-black trail	MS-unreadable
70	90	#6			IR-black	IR-black trail	L&W- unreadable MS-unreadable
71	90	#6	400'	13,500'	Blackish	Thick black trail	
71	91	#6	100'		Blackish	Thin black trail	Length unreadable due to cloud cover
72	92	#6			Blackish	Blackish trail	L&W-unreadable
72	93	#6	150'	9,700'	Blackish	Blackish trail	
73	94	#6	100'	12,300'	Black	Black trail	
74	94	#6			Blackish	Blackish trail	Length & Width unreadable due to clouds
75	94	#6	100'	10,600'	IR-Black	IR-Black trail	MS-unreadable
76	94	#6					IR & MS- Unreadable
74	95	#6	200'	10,600'	Blackish	Thin black trail	
75	95	#6	150'	11,700'	Blackish	Black trail	
76	95	#6	150'	11,600'	Blackish	Black trail	
77	95	#6			Grayish	Grayish broken trail	Length & width unreadable

Photo Data

TYPE

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
[illegible]	96	#6	150'		Black	Black trail	Length unreadable
[illegible]	96	#6	300'		Blackish	Blackish trail	" "
76	96	#6	150'	15,300'	milky white	White trail	
77	96	#6			Grayish	Grayish broken trail	Length & width unreadable
76	97	½ gas ½ oil			Black	Black splotches	
76	98	Heavy Crude	100'	5,000'	Black	Black trail	
77	98	Heavy Crude	250'	11,500'	MS-Grayish	MS-Grayish trail	IR stops at photo #1471
78	98	Heavy Crude	150'	11,000'	Grayish	Grayish trail	
77	99	Heavy Crude	400'	17,500'	MS-Grayish	MS-Wide grayish trail	No IR photo
78	99	Heavy Crude	200'	15,200'	milky white	White trail	
77	100	Gas & OIL					Unreadable

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APPENDIX D

4-LENS MULTISPECTRAL DATA

Roll #1,2, & 3

Photo Data

TYPE B & W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
10	[illegible]	#2 Fuel	100'	2,150'	Black UV-Gray	Parallel Trails	
11	10	#2 Fuel	150'	4,700'	Black with White	Black trail with white cloudy splotches	
12	10	#2 Fuel	50'	9,500'	UV-grayish with white	Grayish trail with white cloudy splotches	
	11	#2 Fuel	400'	7,500'	Black with white	Black trail with cloudy patches	
13	12	#2 Fuel	100'	2,500'	Hazy white	Spiral formation	unreadable in photo #83
14	13	#2 Fuel	150'	3,400'	hazy white	Spiral trail	
15	14	9250	250'	7,700'	Black with white	Black trail with white patches	
16	14	9250	350'		Black	Wide black trail	
	15	9250	200'		Black with white	Black trail with white cloudy patches	
17	14	9250	150'		Black	Black trail	
18	S	Tanker Dump	200'		Black	" "	most photos unreadable
24	24	9250	250'		Black	Wide black trail	

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Roll #4

Photo Data

TYPE B & W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
29	31	Light Crude			Black & hazy white	Black pools -white hazy spiral-black trails	photos 290-321 width unreadable
30	31	"	350'		hazy white	Wide spiral trail	
	32	"	200'		Black & hazy white	Black trail with hazy white spiral	
31	31	"	700'		Black	Extremely wide black pool	
	32	"	200'		Black UV-hazy white	Black trail UV-hazy white patches	
	33	"	200'		" " " "	" " " " " "	
32	31	"	200'		" " " "	Wide black trail UV-hazy white lines across trail	
	32	"	150'		" " " "	Black trail UV-hazy white patches	
	33	"	150'		" " " "	Black trail UV-hazy white lines across trail	
	34	"	150'		" " " "	Black trail UV-hazy white patches & lines	
33	31	"	300'		" " " "	Wide black trail UV-hazy white lines across trail	
	32	"	150'		" " " "	Black trail, UV-hazy white lines across trail	
	33	"	100'		Hazy white	Hazy white lines	

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Roll #5

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
[illegible]	[illegible]	Light Crude	200'		Black UV-hazy white	Black trail, UV-hazy white lines across trail	
	[illegible]	Light Crude	300'		" "	Wide black trail UV-hazy white patches in trail	
	33	"	200'		Black	Black trail	
	34	"	150'		"	" "	
	36	"					Unreadable
	37	"	150'		Black UV-hazy white	Black trail, UV-hazy white patches in trail	
	38	"	200'		" "	Black trail, UV-hazy white spiral in trail	
36	39	"	300'		" "	Wide black trail UV-hazy white spiral in trail	
	40	"	300'		" "	" "	
37	39	"	400'		" "	Wide black trail UV-hazy white trail	
	40	"	350'		" "	" "	
	41	"	250'		" "	" "	
	42	"	200'		" "	Black trail UV-hazy white patches in trail	
38	39	"	150'		" "	Black trail " " "	" "
	40	"	250'		" "	" " "	" "
	41	"	200'		" "	" " UV-hazy white trail over black trail	
	42	"	300'		" "	Black trail UV-hazy white patches in trail	

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Roll # 6

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
39	39	Light Crude	150'		Black UV-white haze	Black trail UV-hazy white patches in trail	
	40	"	400'		"	" " "	
	41	"	300'		"	" " "	
	42	"	400'		"	" " "	
	43	"	250'		"	" " UV-milky white patches in trail	
	44	"	250'		" UV-milky white	" " "	"
40	43	"	100'		" UV-hazy white	" " "	
	44	"	400'		" "	" " "	
	45	"	200'		"	" " "	
41	41	"	150'		"	" " "	
	42	"	100'		"	" " "	
	43	"	100'		"	" " "	
	44	"	250'		"	" " "	
	45	"			UV-hazy white	UV-hazy white patches	Width unreadable
	46	"			Hazy white	Hazy white patches	Width unreadable

Roll #7

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
41R	42	Light Crude	150'		Black UV-hazy white	Black, UV-hazy white patches in trail	
	43	"	150'		"	"	
	44	"	100'		Hazy white	Hazy white patches	
	45	"	50'		"	Hazy white trail	
	46	"	100'		Black UV-hazy white	Black trail, UV-hazy white patches	in trail
	47	"	50'		Hazy white	Hazy white trail	
47	52	"	100'		"	"	
	53	"	800'		"	Wide hazy white trail with splotches	
	54	"	500'		"	Wide hazy white trail lines across & dark patches in trail	
	55	"	400'		"	"	
	56	"	400'		"	Wide spiral pattern dark splotches(pools)	
	57	Heavy Crude	150'		"	Spiral trail pattern	
48	51	Light Crude			"	Hazy white patches	Width unreadable
	52	"	1,000		"	Wide trail with hazy white patches	
	53	"	200'		"	Straight lines milky white patches	
	54	"	150'		"	straight lines across hazy white patches dark pools	
	55	"	250'		Black with white haze	Black trail with hazy white patches in trail	
	56	"	450'		Hazy white gray	Hazy white trails with large gray pools	

Roll #

Photo Data

TYPE . B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
48	58	Heavy Crude	550'		milky white	Wide trail with tight spiral formation	
	59	"	250'		hazy white UV-gray	Hazy white trail with gray pools	
	60	"	250'		Milky white	Spiral formation	
49	53	Light Crude	300'		Black UV-hazy white	Black trail with hazy white patches in trail	
	54	"	300'		"	"	
	55	"	300'		"	"	
	56	"	150'		Hazy white Black	Hazy white patches across black trail	
	57	Heavy Crude	600'		Hazy white UV-gray	Hazy white patches straight lines & large gray pools in UV	
	58	"	400'		Hazy white Gray	"	
	59	"	700'		"	Wide hazy white trail straight lines, gray pools	
	60	"	800'		Hazy white	Wide trail, hazy white patches, straight lines	
	61	"	800'		Gray Hazy white	Wide hazy white pattern with straight line across gray pools	
	62	"	300'		"	Hazy white patches, straight lines, gray pools	
50	63	"	200'		Hazy white	Hazy white patches in trail	
51	64	"	50'		Black	Thin black trail	
52	64	"	50'		Hazy white	Thin hazy white trail	
53	65	"			"	Thin hazy white trail ending in wide spiral	trail 100' - wide spiral 500'
	66	"	200'		"	Spiral formation in trail	
	67	"	100'		Black	Thin black trail	
54	65	"	50'		Hazy white	Two thin parallel lines hazy white patches	
	66	"	50'		"	Thin hazy white trail	
	67	"	400'		Milky white	Wide hazy trail ending in spiral formation	
	68	"	300'		Milky white Gray	Wide spiral formation with gray pools	

Roll #9

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
55	66	Heavy Crude	50'		Black UV-hazy white	Thin black trail UV-hazy white trail	
	67	"	100'		Hazy white Gray	Hazy white trail with gray pools inside trail	
	68	"	400'		Hazy white	Two hazy white trails w/white patches between	
	69	"	500'		Hazy white Gray	Wide hazy white trail w/gray patches inside trail	
	70	"	300'		"	Milky white trail, spiral formation w/ gray pools inside	
56	66	"	150'		Black Hazy white	Black trail with hazy white trail inside	
	67	"	100'		Hazy white	Hazy white trail w/ white patches	
	68	"	400'		Black Hazy white	Black trail w/hazy white patches & trails inside	
	69	"	550'		Hazy white	Wide hazy white trail w/lines across & cloudy patches	
	70	"	600'		"	"	
	71	"	450'		"	Wide hazy white trail	
	72	"	150'		"	Hazy white trail, spiral formation	
57	66	"	100'		"	Hazy white trail, cloudy patches	
	67	"	100'		"	Hazy white trail ending in spiral	
	68	"	300'		"	Hazy white trail w/ white patches	
	69	"	200'		Hazy white UV-gray	Hazy white trail w/gray patches	
	70	"	600'		Black Hazy white	Wide black trail w/ white patches	

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
57	71	Heavy Crude	600'		Hazy white	Wide hazy trail	
	72	Heavy Crude	500'		Black Hazy white	Wide black trail-hazy spiral formation inside	
	73	Heavy Crude	400'		Hazy white Gray	Hazy white trail w/ gray pools inside	
	74	"	200'		Hazy white	Hazy white trail, Spiral formation	
58	70	"	200'		Hazy white	Hazy white trail, cloudy patches	
	71	"	300'		"	"	
	72	"	200'		Hazy white Gray	Hazy white trail gray pools	
	73	"	350'		Hazy white	Hazy white trail lines across	
	74	"	250'		Hazy white	Hazy white trail lines across	
59	75	"	250'		Milky white Gray	Milky white trail, spiral formation gray pools	
60	75	"	250'		"	"	
	76	"	200'		"	"	
61	75	"	300'		"	"	
	76	"	200'		"	Milky white trail line formation across gray pools	
	77	"	250'		Milky white	Milky white trail, loose spiral formation	
62	75	"	200'		Hazy white	Straight lines formation across	
	76	"	200'		"	Straight line across cloudy patches, gray pools	
	77	"	250'		"	Lines across, cloudy patches	
	78	"	300'		"	Loose spiral formation cloudy patches	
63	76	"	250'		"	Straight line across cloudy patches	
	77	"	200'		"	"	
	78	"	200'		"	"	

Roll #11
TYPE B&W

Photo Data

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
64	81	#6	100'		Hazy white	Thin spiral trail	
65	81	#6	50'		"	Thin trail, cloudy patches, straight lines across	
	82	#6	150'		Black UV-hazy white	Black trail, white lines across(UV)	
	83	#6	150'		"	Black trail, UV-hazy white spiral over trail	
68	86	#6	100'		"	Thin black trail with cloudy patches	
	87	#6	150'		"	Black trail with hazy spiral formation inside	
69	87	#6	100'		"	Thin black trail with white line across	
	88	#6	300'		"	Wide black trail with white lines across	
70	89	#6			"	Black trail w/white line across	
	90	#6	250'		"	Black trail with cloudy patches inside	

Roll #13

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
76	95	#6	200'		Black Hazy white	Black trail w/hazy white patches inside	trail
	96	#6	150'		"	"	
	98	Heavy Crude	100'		"	Thin black trail w/ hazy white clouds inside trail	
77	96	#6	250'		"	Black trail w/hazy white patches inside	
	97	½ gas ½ oil	150'		"	"	
	98	Heavy Crude	500'		"	Wide black trail w/hazy white line across trail	
78	98	"	300'		"	Black trail w/hazy white lines across trail	
	99	"	250'		"	"	
	101	2/1 gas & oil					Unreadable

Roll #13

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
76	95	#6	200'		Black Hazy white	Black trail w/hazy white patches inside	trail
	96	#6	150'		"	"	
	98	Heavy Crude	100'		"	Thin black trail w/ hazy white clouds inside trail	
77	96	#6	250'		"	Black trail w/hazy white patches inside	
	97	½ gas ½ oil	150'		"	"	
	98	Heavy Crude	500'		"	Wide black trail w/hazy white line across trail	
78	98	"	300'		"	Black trail w/hazy white lines across trail	
	99	"	250'		"	"	
	101	2/1 gas & oil					Unreadable

APPENDIX E

4-LENS MULTISPECTRAL SPREAD RATES

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
10	9	#2 Fuel	100'		Black UV-gray	Parallel trails	
11	10	#2 Fuel	150'		Black w/white	Black trail w/white cloudy splotches	
12	10	"	50'		UV-grayish with white	Grayish trail with white cloudy splotches	
12	11	"	400'		Black w/ white	Black trail w/cloudy splotches	
13	12	"	100'		Hazy white	Spiral formation	
14	13	"	150'		Hazy white	Spiral trail	
15	14	9250	250'		Black w/white	Black trail w/white patches	
16	14	9250	350'		Black	Wide black trail	
17	14	"	150'		"	Black trail	
16	15	9250	200'		Black w/white	Black trail w/white cloudy patches	
13	S	Tanker Dump	200'		Black	Black trails	
24	24	9250	250'		Black	Wide black trail	
29	31	Light Crude			Black & hazy white	Black pools-white hazy spirals-black trails	Width unreadable
30	31	"	350'		Hazy white	Wide spiral trail	
31	31	"	700'		Black	Extremely wide black pool	

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
32	31	Light Crude	200'		Black UV-hazy wh.	Black trail-UV, hazy white lines across trail	
33	31	"	300'		"	"	
34	31	"	200'		"	"	
30	32	"	200'		"	Black trail with hazy white spiral	
31	32	"	200'		"	Black trail, UV-hazy white patches	
32	32	"	150'		"	Black trail, UV-hazy white patches & white lines across trail	
33	32	"	150'		"	Black trail, UV-hazy white lines across trail	
34	32	"	300'		"	Wide black trail, UV-hazy white patches in trail	
31	33	"	200'		"	Black trail, UV-hazy white patches	
32	33	"	150'		"	"	
33	33	"	100'		Hazy white	Hazy white lines	
34	33	"	200'		Black	Black trail	
32	34	"	150'		Black UV-hazy white	Black trail, UV-hazy white patches & lines	
34	34	"	150'		Black	Black trail	
34	36	"					Unreadable
34	37	"	150'		Black UV-hazy white	Black trail, UV-hazy white patches in trail	
34	38	"	200'		"	Black trail, UV-hazy spiral in trail	

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
35	39	Light Crude	300'		Black UV-hazy white	Black trail, UV-hazy white spiral in trail	
36	39	"	300'		"	Wide black trail, UV-hazy white patches in trail	
37	39	"	400'		"	Wide black trail, UV-hazy white trail	
38	39	"	150'		"	Black trail, UV-hazy white patches in trail	
39	39	"	150'		"	"	
36	40	"	300'		"	"	
37	40	"	350'		"	Wide black trail UV-hazy white trail	
38	40	"	250'		"	Black trail, UV-hazy white patches in trail	
39	40	"	400'		"	"	
37	41	"	250'		"	"	
38	41	"	200'		"	Black trail, UV-hazy white trail over black trail	
39	41	"	300'		"	Black trail, UV-hazy white patches in trail	
41	41	"	150'		"	"	
37	42	"	200'		"	"	
33	42	"	300'		"	"	
39	42	"	400'		"	Wide black trail, UV-hazy white patches in trail	
41	42	"	100'		"	"	
41R	42	"	150'		"	"	
39	43	"	250'		"	"	
40	43	"	100'		"	"	

Photo Data

TYPE B/W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
41	43	Light Crude	100'		Black - UV Hazy White	Black trail - UV-Hazy white clouds in trail	
41R	43	Light Crude	150'		Black - UV Hazy White	Black Trail - UV Hazy white patches in trail	
39	44	Light Crude	250'		Black - UV Milky white	Black trail - UV-milky white patches in trail	
40	44	Light Crude	400'		Black - UV-Hazy white	Black trail - UV - Hazy white patches in trail	
41	44	Light Crude	250'		Black - UV Hazy white	Black trail - UV-Hazy white patches in trail	
41R	44	Light Crude	100'		Hazy White	Hazy white patches	
40	45	Light Crude	200'		Black - UV-Hazy white	Black trail - UV-Hazy white patches in trail	
41	45	Light Crude			UV - Hazy White	UV-Hazy white Patches	Width unreadable
41R	45	Light Crude	50'		Hazy White	Hazy white trail	
41	46	Light Crude			Hazy White	Hazy white Patches (traces)	Width Unreadable
41R	46	Light Crude	100'		Black -UV Hazy white	Black trail - UV - hazy white patches in trail	
41R	47	Light Crude	50'		Hazy white	Hazy white trail	
48	51	Light Crude			Hazy white	Hazy white patches	Width unreadable
47	52	Light Crude	100'		Hazy white	Hazy white trail	
4[illegible]	52	Light Crude	1000'		Hazy white	Wide trail with hazy white patches	
47	53	Light Crude	800'		Hazy white	Wide hazy white trail with splotches	
4[illegible]	53	Light Crude	200'		Milky white	Straight lines mily white patches	

Photo Data

TYPE B/W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
49	53	Light Crude	300'		Black - UV-Hazy white	Black trail with hazy white patches in trail	
47	54	Light Crude	500'		Hazy white	Wide hazy white trail-lines across-Dark patches in trail	
48	54	Light Crude	150'		Hazy white	Straight lines across-Hazy white patches dark pools	
49	54	Light Crude	300'		Black - UV-Hazy white	Black trail with hazy white patches in trail	
47	55	Light Crude	400'		Hazy white	wide hazy white trail-lines across, spiral pattern, Dark patches	
48	55	Light Crude	250'		Black with hazy white	Black trail with hazy white patches in trail	
49	55	Light Crude	300'		Black - UV Hazy white	Black trail with hazy white patches in trail	
47	56	Light Crude	400'		Milky white	Wide spiral pattern Dark splotches	
48	56	Light Cride	450'		Hazy white & Gray	Hazy white trails with large gray pools	
49	56	Light Crude	150'		Black hazy white	Hazy white patches across black trail	
47	57	Heavy Crude	150'		Milky white	Spiral trail pattern	
49	57	Heavy Crude	600'		Hazy white-UV-Gray	Hazy white patches straight lines-UV large gray pools	
48	58	Heavy Crude	550'		Milky white	wide trail with tight spiral formation	
49	58	Heavy Crude	400'		Hazy white & Gray	Hazy white patches & straight lines, gray pools	
48	59	Heavy Crude	250'		Hazy white UV-Gray	Hazy white trail with gray pools	
49	59	Heavy Crude	700'		Hazy white & Gray	Wide hazy white trail, straight lines across, gray pools	
48	60	Heavy Crude	250'		Milky white	Spiral formation	

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
49	60	Heavy Crude	800'		Hazy white	Wide trail, hazy white patches, straight lines	
49	61	Heavy Crude	800'		Hazy white & Gray	Wide hazy white pattern w/straight lines across gray pools	
49	62	Heavy Crude	300'		"	Hazy white patches, straight line across	gray pools
50	63	Heavy Crude	200'		Hazy white	Hazy white patches in trail	
51	64	Heavy Crude	50'		Black	Thin black trail	
52	64	"	50'		Hazy white	Thin hazy white trail	
53	65	"			Hazy white	Thin hazy white trail ending in wide spiral	Trail-100' Wide spiral-500'
54	65	"	50'		Hazy white	Two thin parallel lines hazy white patches between	
53	66	Heavy Crude	200'		Hazy white	A spiral formation in trail	
54	66	Heavy Crude	50'		Hazy white	Thin hazy white trail	
55	66	"	50'		Black UV-hazy white	Thin black trail,UV-hazy white trail	
56	66	"	150'		Black & hazy white	Black trail w/hazy white trail inside	
57	66	"	100'		Hazy white	Hazy white trail, cloudy patches	
53	67	"	100'		Black	Thin black trail	
54	67	"	400'		milky white	Wide hazy trail ending in spiral formation	
55	67	"	100'		Hazy white & Gray	Hazy white trail w/ gray pools inside trail	
56	67	"	100'		Hazy white	Hazy white trail w/ white patches	

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
57	67	Heavy Crude	100'		Hazy white	Hazy white trail ending in spiral	
54	68	"	300'		Milky white & Gray	Wide spiral formation with gray pools	
55	68	"	400'		Hazy white	Two hazy white trails w/white patches between	
56	68	"	400'		Black Hazy white	Black trail w/hazy white patches & trails inside	
57	68	"	300'		Hazy white	Hazy white trail w/ white patches	
55	69	"	500'		Hazy white & Gray	Wide hazy white trail w/ gray patches inside trail	
56	69	"	550'		Hazy white	Wide hazy white trail w/ lines across & cloudy patches	
57	69	"	200'		Hazy white UV-Gray	Hazy white trail w/ gray patches	
55	70	"	300'		milky white & gray	Milky white trail, spiral formation w/gray pools inside	
56	70	"	600'		Hazy white	Wide hazy white trail w/ lines across & cloudy patches	
57	70	"	600'		Black & hazy white	Wide black trail w/ white patches	
58	70	"	200'		Hazy white	Hazy white trail, cloudy patches	
56	71	"	450'		Hazy white	Wide hazy white trail	
57	71	"	600'		Hazy white	Wide hazy trail	
58	71	"	300'		Hazy white	Hazy white trail cloudy patches	
56	72	"	150'		Hazy white	Hazy white trail, spiral formation	
57	72	"	500'		Black hazy white	Wide black trail-hazy spiral formation inside	
58	72	"	200'		Hazy white & Gray	Hazy white trail gray pools	

Photo Data

TYPE B&W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
57	73	"	400'		Hazy white Gray	Hazy white trail w/ gray pools inside	
58	73	"	350'		Hazy white	Hazy white trail lines across	
57	74	"	200'		Hazy white	Hazy white trail spiral formation	
58	74	"	250'		Hazy white	Hazy white trail lines across	
59	75	"	250'		Milky white & Gray	Milky white trail, spiral formation, gray pools	
60	75	"	250'		"	"	
61	75	"	300'		"	Milky white trail, lines across gray pools	
62	75	"	200'		Hazy white	Straight line formation across	
60	76	"	200'		Milky white Gray	Milky white trail, spiral formation, gray pools	
61	76	"	200'		"	Milky white trail line formation across, gray pools	
62	76	"	200'		Hazy white	Straight line across cloudy patches, gray pools	
63	76	"	250'		Hazy white	Straight line across cloudy patches	
61	77	"	250'		Milky white	Milky white trail, loose spiral formation	
62	77	"	250'		Hazy white	Lines across, cloudy patches	
63	77	"	200'		Hazy white	Straight lines across cloudy patches	
62	78	"	300'		Hazy white	Loose spiral formation cloudy patches	
63	78	"	200'		Hazy white	Straight lines across & cloudy patches	
64	81	#6	100'		Hazy white	Thin spiral trail	

Photo Data

TYPE B & W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
65	81	#6	50'		Hazy white	Thin trail, cloudy patches, straight lines across	
65	82	#6	150'		Black-UV-Hazy white	Black trail, white lines across (UV)	
65	83	#6	150'		Black - UV-Hazy white	Black trail, UV-Hazy white spiral over trail	
68	86	#6	100'		Black Hazy white	Thin black trail with cloudy patches	
68	87	#6	150'		Black Hazy white	Black trail with hazy spiral formation inside	
69	87	#6	100'		Black Hazy white	Thin black trail with white line across	
69	88	#6	300'		Black Hazy white	Wide black trail with white lines across	
72	88	#6	50'		Black Hazy white	Thin black trail, cloudy patches inside	
70	89	#6			Black Hzy white	Black trail with white lines across	Width unreadable because of cloud cover
72	89	#6	100'		Black Hazy white	Black trail with cloudy patches inside	
70	90	#6	250'		Black Hazy white	Black trail with cloudy patches inside	
71	90	#6	600'		Black Hazy white	Black trail with cloudy patches	
71	91	#6	100'		Black	Thin black trail	
72	92	#6	100'		Black Hazy white	Black trail with cloudy patches inside	

Photo Data

TYPE B & W

RUN	SPILL	TYPE	WIDTH	LENGTH	COLOR	PHYSICAL DESCRIPTION	COMMENTS
72	93	#6	150'		Black Hazy white	Black trail with cloudy patches & lines inside	
73	94	#6	200'		Black Hazy white	Black trail with cloudy patches in-side	
74	94	#6	150'		Black Milky white	Black trail with cloudy patches inside	
74R	94	#6	200'		Black Milky white	Black trail with milky white patches	
74	95	#6	250'		Black Hazy white	Black trail with cloudy patches inside	
74R	95	#6	150'		Black Milky white	Black trail with milky white patches	
76	95	#6	200'		Black Hazy white	Black trail with hazy white patches inside trail	
74	96	#6	150		Black Hazy white	Black trail with cloudy patches end-ing in spiral formation	
74R	96	#6	350'		Black Hazy white	Wide black trail with hazy white lines across trail	
76	96	#6	150'		Black Hazy white	Black trail with hazy white patches inside trail	
77	96	#6	250'		Black Hazy white	Black trail with hazy white patches inside	
77	97	½ gas ½ oil	150'		Black hazy white	Black trail with hazy white patches inside	
76	98	Heavy Crude	100'		Black hazy white	Thin black trail with hazy white clouds inside trail	
77	98	Heavy Crude	500'		Black hazy white	Wide black trail with hazy white lines across trail	
73	98	Heavy Crude	300'		Black hazy white	Black trail with hazy white lines across trail	
73	99	Heavy Crude	250'		Black Hazy white	Black trail with hazy white lines across trail	
73	101	2/1 gas & oil					Unreadable

APPENDIX F

AIRCRAFT LOG

TEST DATA SHEET • AIRCRAFT	Date April 6 of 70 Operator Aukland Scarbrough

Location
Mobile Area - Gulf

Subject	Antenna Angle	Aircraft Type
Oil Slick Measurement	Nadir 46°	DC- 3 C-47

Weather	Sea State	Temperature
Wind - 010 @ 14 knots Clear	Some Breakers	18° Water, ° Surface

Tape Reel Number	Tape Speed	Camera Film Number	Frames per sec
1	Slow ips	1 & 2	1

Radiometer Frequency	Data	Channel Number
10.2 GHz	H	4
10.2 GHz	V	3
30 GHz	H	2
30 GHz	V	1
GHz		
GHz		
GHz		

Calibration Data

10.2 - HT 2.756K - 90.59 K @0745
10.2 - AT 5.326
30 - HT 2.475 - 2500
30 - AT 4.995
Turn on 30 Cal - 254 mv
V -283
H -210
Warm up { 10 H -173.1
V - 75.3
Cal -134

Comments

30 Hot load temp. ~ 103° 2.481K

10.2 Hot load temp. ~ 93°

Sea Temp

10.2 GHz V + 1.427v 30 GHz V + 1.190
H + 1.940v H +1.79

Camera Start # 4633 Ship 2° roll
MSS Int.# 2414 6° pitch

Problems on Recorder Readout

30 GHz H only good readout
Data OK on tape - Some bias

	Test	start	stop	Time	Target	Tape Indicator number	Camera Frame out mark	Aircraft speed	Aircraft altitude	Aircraft heading	Date April 6 of 70 Comments
	1					0018	2450	110	2000	270°	1 Gal/min 10 kts
				0904	start-1 gal						First Mark
				0907							Second mark
		X		0914							
1			X	0917	0.5 gal/min	0034	2568				
	2			0923	#2 Fuel						First mark
		X		0925							
2				0926							2nd mark
			X	0929		0054	2718				
	#2	X		0940							Again
3	#3			0944							First mark
	#2		X	0943		0082	2955				Second run complete
	#3			0944							Second mark
	#3			0953							Third Mark
	#3	X		0954		0084					Saw last of 2nd blank then #3
4			X	0957							
	#4			0958	#2 oil						First Mark
				1001	0.1 gal						Second Mark
	#4	X		1007		0101	3100				Over #3
5			X	1010		0124	3272				
	#5			1015	#2oil/.05 gal						First mark
				1018							2nd mark
	#4	X		1024							Run #4
				1026							Over #5
6			X	1027		0140	3389	Turned off pumps @ 1026			Over ship
							We saw #5	faintly			
	#6			1035	#2 1gal/mm						8 min/run 14 knots
				1037							2 nd mark
		X		1042							Start search over #4
7				1043							Saw #5 also Mark 3
			X	1044		0151	3471				

	Test	start	stop	Time	Target	Tape Indicator number	Camera Frame number	Aircraft speed	Aircraft altitude	Aircraft heading	Date April 6 of 70 Comments
	#7			1046	#2/ .5 gal						mark 1
				1048							Mark 2
		X		1052							Rod. Only
				1053		0171	3544	Cameras now			Over 6
8				1054	} Secured						Over Ship
			X	1054	} run and radiometer						Mark 3
					30 minute wait to refuel						
				Will	change approach here - Will take data with μ wave in both						
				directions.	No photo on return. Cannot visually acquire on return.						
				Gear	working beautiful - only problem is 30 GHz seemed to have fluxuation.						
	#8			1143	#2 fuel .2 gal/min		First	110 mark	200	95°	East run 14 knots
				1145							
		X		1149							No oil yet - μ tape only
9			X	1150							Turned on cameras
				1151		0187	3573				3rd mark
											cal run
	#9			1154	#2/ .1 gal	0190					First mark
	#8			1155							Return check
	#8			1156		0198					End of return
	#9			1156							Second Mark
	#9	X		1159							μ only
				1200							Everything
10			X	1201		0212	3621				Stopped
				1202							Mark 3
				1203		0214					Calibrate
				1205							Return check
				1206		0224					Lost signal
	#10			1208	1.0 GPM						First mark - 18 kts
				1210				110	200	110	2nd mark
		X		1211							Near #8
11				1212	?						Near #9/start camera
				1213							Over #10
			X	1214							20 sec early
				1215		0248	3751				Third mark

	Test	start	stop	Time	Target	Tape Indicator	Camera Frame number	Aircraft speed	altitude	heading	Date April 6 of 70 Comments
				1216		0250					Calib.
	#11			1217	0.05 GPM						First Mark
	#11			1218							2nd Mark
	#11	X		1221		0254					Over #10
12	#11			1222							Over #11
			X	1224		9271	3837				
	#11			1225		0273					Calib.
	#11			1226							Return
	#12			1228							First Mark
	#12			1229	.2 gal/min.						2nd mark
	#11			1230		0291					Secure return
	#12	X		1234							Can't see-Camera on
				1234							Over #11
13				1235							Mark 3 - com
	#12		X	1236		0315	3904				
				1237		0318					Calib.
	#13										
	#12			1240							Return
	#12			1242				MSS - Camera Diff			End Return
	#13					0335	4108	4073 - 6290			New film
	#13			1316	#2 /0.1 gal						Mark 1 17 kts
	#13			1318							Mark 2
		X		1322		0336					μ ww
				1323							Mark 3 end
14				1323							Cameras
			X	1324		0352	4153		#2 reel		Secured
				1325							Calib.
	#14			1326	9250 1.0 GPM	0354					Mark 1
				1328							Mark 2
	#13			1328							Return
	#13			1329		0362					End of return
	#14			1330							Over #13
15				1331							All camera go
			X	1332							Early.
				1333		0378	4220	0362			Mark 3

	Test	start	stop	Time	Target	Tape Indicator number	Camera Frame number	Aircraft speed	Aircraft altitude	Aircraft heading	Date April 6 of 70 Comments
				1333	9250 .5 gpm	0381					Calib
				1335							Return
				1336				0815 -			Over
				1338							End return
	#15			1338	9250/.5gpm	0403					Mark 1
	#15			1340							Mark 2
		X		1342		0404					Over #13
				1344							Overstart
16				1345							Mark 3
			X	1346							Last data to port
	#16			1347	9250/.2 gpm	0431	4369				Mark 1
				1347		0434					Calib.
	#16			1349							Mark 2
	#15			1349							Return of 15
	#15			1351							Over 14
				1352		0466					Complete rt.
	#16			1354							Mark 3
	#16	X		1356							Over 14
				1357							End of 14
17				1357							See start of 15
				1359							Over 16
			X	1400		0509					
					Tanker dumped oil - going to see						
		X		1400	Tanker oil	0510				140	2° signal
18			X	1405		0536	4770				Home
						0579					Tape Check

TEST DATA SHEET • AIRCRAFT

Date April 7 of 70
Operator Aukland Scarbrough

Location 29° 25'N 87° 15'W Gulf of M
out of Mobile

Subject Oil on water Coast Guard Tests	**Antenna Angle** 46° Nadir	**Aircraft Type** DC-3
Weather 310° wind	**Sea State** 10 knots Occasional white caps	**Temperature** ° Water ° Surface

Tape Reel Number 2	**Tape Speed** slow ips	**Camera Film Number** 2	**Frames per sec** 1

Radiometer Frequency	Data	Channel Number
10.2 GHz	H	4
10.2 GHz	V	3
30.0 GHz	H	2
30.0 GHz	V	1
GHz		
GHz		
GHz		

Calibration Data 2

10.2 HT-
10.2 AT-4.680°K 15°c
30.0 HT-2.486-2532-93.9-93.1°C
30.0 AT-4.350 16.5°C

Turn on - 10} cal -.305
reading V -.278
H -.372

30} cal -.444
V -.464
H -.416

30 HL-
10.2 HL-

Comments 0715 Take off time morning run 225° Mag.

Sea Reading @0745
10 GHz V- +1.575
H- +2.025

30 GHz V- +1.150
H- +1.720

Smooth
No white horses

On Station @0800

Changed to #2 data tape for today-check out data in last of #1

Tape start 010
Camera 4770

Scanner N.G. - No data 6th or 7th

Boresight camera - fouling data

	Test	start	stop	Time	Target	Tape Indicator	Camera Frame number	Aircraft speed	Aircraft altitude	Aircraft heading	Date April 7of70 Comments
	#17			0821	9250 1.0gpm crude					225	Mk #1 14 kts.
				0824							Mk #2
		X		0829		010	4770	110	2100	225	μ only
				0830							Cameras on
19				0831		0024	4834				Mk. #3
			X	0831							30 sec of film Secure run
				0832		0025					Calib
	#18			0834	9250 0.5 gpm						Mk. #1
				0836							Reverse Course
	#17			0837							Lost recorder drive
	#18	X		0841							Over 17 (all go)
				0842							End of 17
20				0842							Over 18
			X	0844							Cameras go off about 20 sec. before μ wave
				0844		0043	4949				Mk 3
				0845							Calib.
	#19			0847	9250 0.2 gpm						Mk 1
	#18			0348							Return over 18 & 17
	#19			0850							Mk 2
				0851		0065					Return complete
	#19	X		0849							Over #17
				0850							Over #18
				0850							Camera on go
21				0856							Over #19
			X	0859		0097	5080				
	#20			0900	9250 0.1 gpm						Mk #1
				0900		0100					Calib.
				0903							Mk #2
				0903							Return
				0906		0125					End return
		X		0910							Over #17 Everything go
				0911							See #18 clear all units
				0912							Over #19
22				0913							Over #20
	#21			0913	9250 0.05 gpm						Mk #1
	#20			0914							IR camera off
	#20		X	0915							Ran past ship
	#21			0916		0173	5331				Mk #2

	Test	start	stop	Time	Target	Tape Indicator	Camera Frame number	Aircraft speed	Aircraft altitude	Aircraft heading	Date April 7 of 70 Comments
	#20			0920							Return
				0921							Over #21
				0922							Over #20
	#21			0923							Mk 3
	#22				9250 0.0/gpm						
				0924							Cold Target
				0925		0211					End return for #21
	#22			0926							Mk #1
	#22			0928							Mk #2
	#21&#22	X		0928			Not time for each				Returning over 21 & 22
				0931							Over #20
23				0932							Mk #3 end
			X	0936		0271	5678				
	23			0936	9250 0.1gmp						Mk #1 Ship speed 10 knots
				0939							Mk #2
				0941							Return from 21 & 22
	23			0948							Mk #3-Still on return
				0950							Over #17
				0951			Saw all the way				End return
	24			0951	9250 0.2 GPM	0357					Mk #1
		X		0954							Over #17
	24			0954							Mk #2
				0957							Over #18
				0959							Over #20
24	24			1003							Mk #3
			X	1006							Completed
	25			1006	9250 0.5 GPM	0464					Mk #1
				1009							Mk #2
				1009							Return
				1010							Over ship
				1012							Over #22
				1015	Visual contact NG						Pick up oil on μw
	25			1018							Mark 3
				1018							Over 19
				1019							Ovear 18
				1021							Over 17
	26			1021	9250 1 gal pm						Mk 1

	Test	start	stop	Time	Target	Tape Indicator	Camera Frame number	Aircraft speed	altitude	heading	Date April 7 of 70 Comments
				1023	17 &	18 broken up					End return over 17
	26			1025							Mk #2
		X		1026		0596					Starting run for 25 & 26
				1027							IR & UV on over 17
				1028							Over 18
				1030							Over 19
				1031							Over 20
25				1033							Mark 3
				1035							Started BS camera
				1037							Turned off camera
				1037							Over 25
				1039							Over 26
			X	1040		0753					Over ship
					River Rouge Mud		Wind 12	knots		start	tests
	27			1132							Mk 1
				1134							
				1135		0761					Mk 2
26				1137		0774	A beam				
				1138							Mk 3
		X		1142		0774					From stern
27	27		X	1144		0789	A stern				
						Rerun on slick before securing					
	27a	X		1147						055	Over 26
				1148							Over 25
				1150							Over 24
				1152							Over 23
28			X	1153		0861					Over ship
				1153		0865					Calib.
				1307	Secure for day - Cutter takes on more oil						

TEST DATA SHEET • AIRCRAFT

Date April 8 of 70

Operator Aukland & Scarbrough

Location
29° 25N, 87° 15W Gulf of Mexico out of Mobile

Subject Oil on water Coast Guard Tests		**Antenna Angle** 46° Nadir	**Aircraft Type** DC-3
Weather Haze-Few clouds @2000 Wind @125° - 4-6 knots		**Sea State** 5 foot - occasional horse	**Temperature** ° Water ° Surface
Tape Reel Number 3 & 4	**Tape Speed** slow ips	**Camera Film Number** 2	**Frames per sec** 1

Radiometer Frequency	Data	Channel Number
10.2 GHz	H	4
10.2 GHz	V	3
30 GHz	H	2
30 GHz	V	1
GHz		
GHz		
GHz		

Calibration Data

10.2 HT - 2.624
10.2 AT - 4.134
30.0 HT - 2.442
30.0 AT - 3.767

Turn on readings

10	- C - .170	C
	V - .151	V
	H - .248	H
30	- C - .330	C
	H - .325	H
	V - .374	V

9745

Comments Will only fire boresight at intervals to avaid data interference.
IR scanner still NG, multi-spectral marginal - (awaiting parts)
0715 Take off

Sea State @ 0800 - 2-3'no. horses
10 V + 1.490 30 V +1.150
10 H +1.960 30 H +1.600
Cal - 94.0 Cal. -1.06v

125 @ 15K
10 H +1.980
V 1.490

More white caps here

30 H 1.600
V 1.05

	Test	start	stop	Time	Target	Tape Indicator	Camera Frame number	Aircraft speed	Aircraft altitude	Aircraft heading	Date April 8 of 70 Comments
						0010					Calib
						0013					Tape
	31			0928	L.C. 1.0 GPM			115	2K	237	Mk 1 - 10 Kts
		X		0934	Ov. 31						
29			X	0940	Ov. 31	0031	5751				
				0946	Ov. 31						E R
	32			0946	LC. 0.0.67gpm						Mk 2
		X		0951	Ov 31	0043					
30	32			0955							Mk 3
			X	0956	Ov 32	0068					
	33			0958	L.C.-.005gpm						Mk 1
				0959	Ov. 33						R T S
				1002	Ov 21						ER
		X		1005	Ov 31	0097					
31				1006	Ov 32						Start cameras
			X	1007	Ov 33	0131					
	34			1013	LC 0.2gpm						Mk 1
				1013		0133					RTS
				1020	Ov. 31	0175					ER
		X		1026	Ov 31						
32			X	1030	Ov. 34	0228					
	35			1035	L.C.-0.1 gpm						Mk 1
				1035	Ov. 35						RTS
				1036	Ov. 34						
				1037	Ov 33						
				1038	Ov 32						
				1039	Ov. 31						
				1040	Calib.	0277					ER
	36			1043	L.C.-.05gpm						Mk 1
		X		1044							
33				1051	Ov. 36						
			X	1052	Ov. ship	0346					
	36			1055							Mk 3
	37			1057	L.C.-.02gpm						Mk 1
				1059	Ov. 37	0367					RTS
				1100	L.C.-1.35gpm						Mk 1 ?
				1105	Ov. 31						
				1106	Ov. 13	0433	5755				ER
	37			1109							Mk 3

	Test	start	stop	Time	Target	Tape Indicator number	Camera Frame	Aircraft speed	Aircraft altitude	Aircraft heading	Date April 8 of 70 Comments
		X		1110	Ov. 31	0430					
34	38			1111	LC-2.0 gpm						Mk 1
			X	1121	Ov 38	0537					
				1125	Ov 38	0538					RTS
				1129	Ov. 33?	0568					ER
	39			1217	LC 2.69 gpm	0577		Reverse course 130T			Mk 1 - 10 Kts.
		X	1228		Ov. 38						
				1229							Mk 3
35			X	1232	Ov 39	0610					
	40			1232	LC - 3.77gpm						Mk 1 14 kts
				1234	Ov 40						RTS
				1237	Ov. 39	0620					ER
		X	1239		Ov 39	0631					
	40			1242							Mk 3
36	41			1245	LC - 2.0gpm						Mk 1
			X	1245	Ov. 40	0686					
				1248	Ov 41						RTS
				1252	Ov. 39						ER
		X		1255	Ov 39	0724					
37	41			1255							Mk 3
				1256	Ov 40						
	42			1257	L.C. -1.88gpm						Mk 1
			X	1302	Ov. 42	0797					
				1305	Ov. 42						RTS
				1305	Ov. 41						
				1306	Ov 40						
	42			1307							Mk 3
				1309	Ov 39	0858					
				1310	-						ER
		X		1313	Ov 39						
				1317	Ov 41	Both µ & IR					
38				1319	Ov 42	0963		Lots of noise			Hot
	43		X	1321	L.C.1.0 GPM						Mk 1
						Water temp check @ 10am 61 @ 1300 65°					
				1327	Ov 41						RTS @ 1324
				1328	Ov 40						
				1330	Ov 39	1039					
	43			1331							Mk 1
		X		1334	?	1040					

	Test	start	stop	Time	Target	Tape Indicator number	Camera Frame	Aircraft speed	Aircraft altitude	Aircraft heading	Date April 8 of 70 Comments
	44			1334	L.C.-0.94gpm						Mk 1
				1340	Ov. 39						
				1341	Ov. 41						Lots of noise
				1342	Ov. 42	1183					
	44			1344							Mk 3
	45			1347	L.C.-0.5 gpm						Mk 1
		X		1349	Ov. 42	.005			Reel 4		
				1351	Ov. 44						No RTS
40			X	1353	Ov. 45	.030					
				1356	Ov. 45						RTS
	45			1357							Mk 3
				1359	Ov. 44						
				1400	Ov. 43	0074					GR
	46			1400	L.C. -.2 gpm						Mk 1
		X		1405	Ov. 43						
41				1408	Ov. 46						
			X	1410	Ov. ship	0115					
	47			1413	L.C. -0.1 gpm						Mk 1
				1413	Ov. 46						RTS
				1415	Ov. 45						
				1417	Ov. 44						
				1419	Ov 43						
				1421	Ov. 42	0176					ER
	47			1423							Mk 3
		X		1424	Ov 43						
				1426	Ov. 44						
42				1427	Ov 45						
				1428	Ov 46						
			X	1430	Ov. 47	0238					
				1435		0242					Calib.
				1500	River mud	0242		110	2K	North	Mobile Bay outlet
				1502		0267					
				1503	Land & Water						
				1505	Land	0282			C .272		
							10	2	H .266		
									V .365		
							30		C .406		
									H .444		
									V .401		

TEST DATA SHEET • AIRCRAFT	Date April 9 of 70 Operator Aukland & Scarbrough

Location 29° 25'N 87° 15'W
Gulf of Mexico

Subject	Antenna Angle	Aircraft Type
Oil slick on water	n 46°	DC-3

Weather	Sea State	Temperature
Wind S@034 @ 4 knots Heavy haze @0800-Breaker -dark clouds n 2000-2500	swells-no breakers little ripple	° Water ° Surface

Tape Reel Number	Tape Speed	Camera Film Number	Frames per sec
4	slow ips		

Radiometer Frequency	Data	Channel Number
10.2 GHz	H	4
10.2 GHz	V	3
30 GHz	H	2
30 GHz	H	1
GHz		
GHz		
GHz		

Calibration Data

10.2 HT - 3.038
10.2 AT - 4.333
30 HT - 2.468 -2.503
30 AT - 4.218
Turn on reading

10	C - .16		C - .297
	V - .142		V - .277
	H - .238		H - .388
30	C - .220		C - .420
	V - .340		V - .454
	H - .290		H - .407

Comments

Take-off @0730

Sea States
@0745

10 - V - 1.350
H - 1.890
30 - V - +1.075
H - +1.690
Something in water

V - 1.385
H - 1.930
V - 1.075
H - 1.680
Light swells no horses

	Test	start	stop	Time	Target	Tape Indicator	Camera Frame number	Aircraft speed	altitude	heading	Date April 9 of70 Comments
						0283					Reel 4
						0289					Calib.
				0800							On station
	48			0818	L.C.-.05gpa	0290					Mk 1 - 17 knots
		X		0825	Ov. 48			115	2K	250	Ov. 48
43	48			0827							Mk 3
			X	0828	Run 48	0314					Ov. 48
	49			0830	L.C.-0.1gpm						Mk 1 - 17 knots
				0832	49 & 48						RTS
				0834	Ov. 48	0332					RE - Ov. 48
	49			0837							Mk 3
	50	X		0839	L.C.-0.2gpm						Mk 1 - 17 knots
44			X	0842	48, 49 & 50	0368					Couldn't visual see
				0846	Over 50						RTS
	50			0847							Mk 3
	51			0848	L.C.-0.5gpm						Mk 1 - 17 knots
				0850	Ov. 48						ER
		X		0852	Ov. 48	0397					
45	51			0855							Mk 3
	52			0856	L.C.-1.0gpm						Mk 1 - 17 knots
			X	0859		0454					Only visually on 51 & 52
				0902	Ov. 52			Cal.			RTS
	52			0903							Mk 3
	53			0904	LC 1.14 gpm						Mk 1 - 17 knots
				0905	Ov. 51						------
				0907	Ov. 50	0500					ER
		X		0910	Ov. 50				Multi-spectral Camera Only		
	54			0911	L.C.-2.0gpm						Mk 1 - 17 knots
46				0917	Ov. 54						Θ
	54		X	0919	Ov. 54	0581					Mk 3
	55			0920	L.C.-2.29gpm	0584					Mk 1 - 17 knots
				0923	Ov. 55						RTS
				0924	Ov. 54						
	55			0927							Mk 3
	56			0928	LC 4.57 gpm						Mk 1 - 17 knots
				0928	Ov. 51						ER
		X		0932	Ov. 50 or 51	0640					No visual
				0934	Ov. 51						Cameras on
47	56			0935							Mk 3

LC - Light crude
Mk 1 - start of flow
Mk 3 - stop flow

SR - Start Run
ER - End run
RTS - Return to start

RE- Return ended

	Test	start	stop	Time	Target	Tape Indicator	Camera Frame number	Aircraft speed	Aircraft altitude	Aircraft heading	Date April 9 of 70 Comments
				0935	Ov. 53	0687					Color & B & W cameras-all go
				0937	Ov. 54						
				0938	Ov. 55						
	57			0938	HC 2.29-gpm						Mk 1 - 17 knots
			X	0941	Ov. 57	0736					
				0945	Ov. 57						RTS
	57			0946	Ø						Mk 3
	58			0947	H.C.-2.0 gpm						Mk 1 - 17 knots
				0950	Ov. 52						
				0951	Ov. 51						
				0952	Ov. 50						
				0953	Ov. 49	0829					ER No visual-No signal
	58			0954							Mk 3
	59			0955	H.C. 1.14 GPM						Mk 1
		X		0955	Over 51						
				0958	Ov. 53						
				1000	Ov. 55						
	59			1002							Mk 3
48	60			1003	H.C.-1.6gpm						Mk 1
				1004	Ov. 57						
				1005	Ov. 58						
				1007	Ov. 59						
			X	1008	Ov. 60	0985					
	60			1010							Mk 3
	61			1011	H.C.-0.5 gpm						Mk 1
				1011	Ov. 61						RTS
				1012	Ov. 60						
				1015	Ov. 58						
				1016	Ov. 57						
				1017	Ov. 56						
	61			1018							Mk 3
	62			1019	H.C.-0.2gpm						Mk 1
				1020	Ov. 53						
				1021	Ov. 52						
				1022	Ov. 51						
				1023	Ov. 50	1159					
	62			1026							
		X		1032	Ov. 50	020	-----New Tape				Tape #5
49				1034	Ov. 52						

H.C. - Heavy Crude

	Test	start	stop	Time	Target	Tape Indicator	Camera Frame number	Aircraft speed	altitude	heading	Date April 9 of 70 Comments
				1035	Ov. 53	030					
				1036	Ov. 54	037					
				1038	Ov. 55	046					
				1040	Ov. 56						
49				1041	Ov. 57						
				1042	Ov. 58						
				1043	Ov. 59						
				1044	Ov. 60	084					
				1045	Ov. 61	091					
				1046	Ov. 62	0100					
			X	1047	Ov. 62	0107					Helo -Refuel
	63			1116	H.C. -0.1gpm			115	2K	088	Mk 1 - 17 knots
		X		1123	Ov. 63	0108					
	63			1123							Mk 3
50	64			1125	H.C.-.05gpm						Mk 1 - 14 knots
			X	1124	Ov. 63	0123					
				1128	Ov. 64						RTS
				1129	Ov. 63	0137					ER
		X		1133	Ov. 63						
	64			1135							Mk 3
51	65			1136	H.C.-.1gpm						Mk 1
			X	1136	Ov. 64	0156					
				1139	Ov. 65						RTS
				1140	Ov. 63	0166					
				1141	Ov. 63	0173					ER - No visual
		X		1145	Ov. 63						
				1146	Ov. 64	0183					
52			X	1148	Ov. 65	0202					
	66			1150	H.C. - 0.2gpm						Mk 1
				1152	Ov. 65	0209					RTS
				1153	Ov. 64						
				1155	Ov. 63						ER
		X		1159	Ov. 65	0239					
				1200	Ov. 66	0250					
53	67			1202	H.C.-0.5gpm						Mk 1
			X	1203	Ov. 67	0271					
				1207	Ov. 67						RTS
				1208	Ov. 66	0284					
	67			1212							Mk 3

	Test	start	stop	Time	Target	Tape indicator	Camera Frame number	Aircraft speed	Aircraft altitude	Aircraft heading	Date April 9 of 70 Comments
				1212	Ov 63	0315					ER - In blind
	68			1214	H.C. -0.94 gpm						Mk 1
		X		1215	Ov 62?						In blind
				1217	Ov 65?	0325					
				1218	Ov 65	0335					First visual siting
54				1219	Ov 66	0341					
				1220	Tanker spill	0350					Held dump for spill
				1222	Over 67	0360					
	68		X	1224	Over 68	0373			Milky looking		Mk 3
	69			1225	H.C.-1.88gpm						Mk 1
				1227	Ov 68 & 69	0380					RTS
				1230	Ov. 67	0400					Also 66
				1231	Ov. -ship spill						
				1232	Ov 65	0412					
				1233	Ov. 64	0424					ER
	69			1234							Mk 3
	70			1236	H.C.-2.0gpm						Mk 1
		X		1237	Ov. 64	0432					
				1239	Ov 65	0444					
				12440	Ov. 66	0456					
				1241	Ov. 68	0463					
55				1243	Ov 68	9475					
				1244	Ov 69	0484					
			X	1245	Ov 70	0490					
	70			1246							Mk 3
				1248	Ov 70	0498					RTS
				1249	Ov 70						
				1250	Ov 69	0521					
	71			1250	H.C.-2.64 GPM						Mk 1
				1252	Ov 68	0528					
				1253	Ov 67	0538					
				1254	Ov.66	0551					
				1255	Ov 65	0570					
				1257	Ov. 65 or 64	0576					ER
		X		1300	Ov 64						
				1301	Ov. 65	0583					
				1302							Mk 3
56				1302	Ov. 66	0599					
				1304	Ov. 67	0616					

	Test	start	stop	Time	Target	Tape Indicator number	Camera Frame number	Aircraft speed	altitude	heading	Date April 9 of 70 Comments
				1305	Ov 68	0630					
	72			1305	H.C. - 2.06gpm						Mk 1
				1306	Ov. 69	0645					
				1307	Ov. 70	0657					
				1308	Ov. 71	0669					
				1309	Ov. 72	0685					
			X	1311	Ov. ship	0693					
				1315	Ov. 7 2						RTS
	72			1317							Mk 3
				1318	Ov 70						
	73			1318	H.C.-1.35gpm						Mk 1
				1319	Ov 69	0746					
				1320	Ov 68	0754					
				1321	Ov 67	0768					
				1323	Ov. 66	0795					
				1325	Ov 65	0808					ER
		X		1329	Ov. 64						
	73			1330							Mk 3
				1330	Ov 65						
	74			1331	H.C. - 1.00gpm						Mk 1
57				1332	Ov 67	0849					Ov 67
				1333	Ov 68	0864					
				1335	Ov 69	0880					
				1336	Ov. 70	0901					
				1337	Ov 71						
				1339	Ov 72	0938					
				1341	Ov. 73						
				1342	Ov. 74	0969					
	74			1343							Mk 3
			X	1344	Ov 74	0986					
					End of days ops - will make run down further						
		X		1356	Ov. 71	0987					
				1357	Ov 72	1004					
58			X	1400	Ov 74	1060					
						Return to Mobile					
						1065					
						1079					Calib. tape
				1533							Land Mobile

TEST DATA SHEET • AIRCRAFT

Date April 11 of 70
Operator Aukland & Scarbrough

Location: Gulf of Mexico, off Mobile			
Subject: Oil on Water		Antenna Angle: 46°	Aircraft Type: DC-3
Weather: Haze-Over cast Dark broken clouds Few low slouds x 1000 feet		Sea State: Some white caps Wind 17 knts.	Temperature: 62° ° Water, ° Surface
Tape Reel Number: 6	Tape Speed: slow ips	Camera Film Number: 3	Frames per sec: 1

Radiometer Frequency	Data	Channel Number	Calibration Data
10.2 GHz	V	4	10.2 V - 90MV H - 77MV
10.2 GHz	H	3	
30 GHz	V	2	
30 GHz	H	1	
GHz			
GHz			
GHz			

Comments

Sea State @ 1005

10.2 V - 1.44
H - 1.890

30 V - 0.900
H - 1.390

Sky
Wind 17 knots

Date April 11 of 70

	Test	start	stop	Time	Target	Tape Indicator number	Camera Frame number	Aircraft speed	Aircraft altitude	Aircraft heading	Comments
				0900							Take off
				1015							On station
					H.C.-0.67 GPM			1	2000	270T	Sp. 10 kts.
	75	X		1056		0010	6567				Mk 1
	75			1108							Mk 3
59	76	X		1110	H.C.-.5gpm						Mk 1
			X	1111		0020					
				1114	Ov 76				Not over		RTS
				1115	Ov 75				target		
				1116		0034					ER
		X		1119	Ov. 75						
60			X	1121	Ov. ship	0049					
	77			1123	H.C.-.2gpm						Mk 1
				1125	Ov 77	0053			15° crab angle		RTS
				1127	Ov 75	0068					
				1128			6588				ER
		X		1131		0074					Sky is darker
61				1132	Ov 76	0083					
				1133	Ov 77	0091					
	77		X	1134		0097					Mk 3
	78			1136	H.C. -0.1gpm		6618		9265 on camera		Mk 1
				1137	Ov 78	0098					RTS
				1138	Ov 77	0106					
				1139	Ov 76	0114					
				1141	Ov 75	0123					
				1142	Calib	0129	6646				ER
		X		1145	Ov 75						3 - 4°C Colder
				1146	Ov 76	0139					
62	78			1147							Mk 3
				1148	Ov 77	0146					
	79			1149	H.C.-.05gpm						Mk 1
				1149	Ov 78	0154					
			X	1150	Ov ship	0163	6682				Raining
				1153	Ov 79						RTS
				1154	Ov 78	0178					
				1156	Ov 77	0180					
				1157	Ov 76	0190					
				1158	Ov 75	0198					

	Test	start	stop	Time	Target	Tape Indicator	Camera Frame number	Aircraft speed	altitude	heading	Date April 11 of 70 Comments
				1159		0206	6723				ER
	79			1200					Very dark		Mk 3
		X		1201	Ov 76						
	30			1202	#6 - .05 GPM						Mk 1 10 kts
63				1204	Ov 77	0224			Rain		
				1205	Ov 78	0233			Lightening		1
			X	1208		0255		etc	etc	- Ugh!	
				1403	Return						
				30 GHz into rain squall x H & V +.350V							
				X	Slight warmer						

	Test	start	stop	Time	Target	Tape Indicator number	Camera Frame number	Aircraft speed	Aircraft altitude	Aircraft heading	Date April 11 of 70 Comments
				0712	Mobile						Take off
				0800	On scene						
	81			0820	#6-.15gpm			120	2000	260	Mk 1 - 10 kts.
	81			0821		0236	6754				Mk 3
		X		0822							
	82			0823	#6 .52						Mk 1
64				0825	Ov. 81						
			X			0823	6768				
				0840	Ov 82						RTS
				0841	Ov 81						
				0842		0304	6783				ER
	82			0843							Mk 3
	83			0845	#6 1.16gpm						Mk 1
		X		0847							
				0848	Ov 81						
65				0850	Ov 82	0330					
				0851	Ov 83	0335					
			X	0851							
				0855	Ov 83	0341					Clouds RTS
				0356	Ov 82	0348					Broken to full
				0858	Ov 81	0362	6809	Gear off by accident			ER
	84			0900	#6 2.46GPM			120	2000	180	
		X		0903		0365					
				0904	Ov 82	0380					
66				0905	Ov 83						
			X	0906	Ov 84	0395					Clouds-No contact
	84			0911		0414					RTS - ER
	85			0914	#6 .05gpm		6841				Mk 1 14 kts
					Waiting on clouds						
				0923	Ov 85	0420					RTS
				0925	Ov 84	0428					
				0926		6432	6854				ER
	86			0924	.15gmp						Mk 1
		X		0929	Ov 84	0432					Cloud
67				0930	Ov 85	0438					
			X	0932	Ov 86	0454					
	86			0935							Mk 3
				0935							RTS
	87			0937	.52 gpm						Mk 1

	Test	start	stop	Time	Target	Tape Indicator number	Camera Frame number	Aircraft speed	altitude	heading	Date April 11of70 Comments
				0939		0480	6893		Clouds		ER
		X		0943	Ov 85	0485					Broken clouds
				0944	Ov 86	0495					
68				0945	Ov 87	0506					
			X	0947	Ov ship	0513	6917				
	87			0947							Mk 3
	88			0950	#6 1.16gpm						Mk 1
				0950	Ov 87	0518					RTS
				0951	Ov 86	0537					
				0953	Ov 85	0547					
				0954	Ov 85	0550	6935				ER
	89			0956	#6 1.83						Mk 1
		X		0957	Ov 85	0552					
	89			0959	Ov 87						Mk 3
69				1000	Ov 88	0577					
											Mk 1
				1001	Ov 89	0590					
			X	1002	Ov ship	6596	6969				
				1006	Ov 89	0600					RTS
				1007	Ov 88	0608					
				1009	Ov 86	0626					
				1010	Ov 85	0636	6985				ER - clouds
	89			1011							Mk 3
	90			1013	#6 -3.67 GPM						Mk 1
		X		1014	Ov 86	0644					
				1015	Ov 87	0653					
				1016	Ov 88	0660					Hard to
70				1017	Ov 89	0667					see
				1018	Ov 90	0676					
			X	1019	Ov ship	0685	7028				
	90			1021							MKB
				1022		0687					RTS
	91			1025	#6 .05gpm						Mk 1 18 kts
				1024	Ov 89	0704			Tough		
				1025	Ov 80	0713			to		
				1027	Ov ?	0732	7059		see		ER
		X		1032	Ov 88	0737				clouds	
71				1033	Ov 90	0749					

TEST DATA SHEET • AIRCRAFT

Date ~~April~~ 12 of 70

Operator Aukland and Scarbrough

Location
Gulf of Mexico

Subject	Antenna Angle	Aircraft Type
Oil on Water	46°	DC-3

Weather	Sea State	Temperature
In op-area-clear clouds to north & SW Wind 275° @ 11 knots	0755 1.5'-3 swells No white caps	Water ° Surface °

Tape Reel Number	Tape Speed	Camera Film Number	Frames per sec
6	slow ips	3	1

Radiometer Frequency	Data	Channel Number
~~10.2 GHz~~	~~V~~	4
~~10.2 GHz~~	~~H~~	3
30 GHz	V	2
30 GHz	H	1
GHz		
GHz		
GHz		

Calibration Data 0730

AT x - 4.298
30 - 4.180

HT - x-2.939
30-2.479

30 Cal. - .980
V - +1.550
H - +.990
Cal - -1.000

Amb ld
@745
x-H- -.0780
V- -.077

X- Cal - .850
V +1.235
H +1.690

Comments

Take off @ 0712

Turn on 30 H = -.287
V -.360
Cal -.284

Turn on 10 Cal -.174
V -.144
H -.235

Over clouds
30 - H-+1.520
V-+1.000
Cal- .992

No cloud @0755

30 H-1.550 V- .99 Cal-1.000

X H-1.885 V+1.350 Cal-93

	Test	start	stop	Time	Target	Tape Indicator number	Camera Frame number	Aircraft speed	altitude	heading	Date April 12 of 70 Comments
				1034	Ov 91	0764					
	92				#6/.15gpm						Mk 1
				1036	Ov 92						
			X	1037	Ov ship	0783	7102				
				1040	Ov 92			120			RTS
				1042	Ov 91	0803					
				1044	Ov 91	0824					
				1045	Ov 90	0833					
				1046	Ov 89	0844					
	93			1043	.52 gpm						Mark 1
				1047	Ov 88	0857					
				1048	Ov 87	0866	7146				ER
	93			1050							Mk 3
		X		1053	Over ?				Difficult		
				1055	?	0892			to		
				1058	Ov 93						
72			X	1100	End of 93	0943			see		
						Camera clock ≈ 1 min. fast for					
					morning runs - Reset @ 11:15						
											Wind 16 knots
										270	Dependable sp. 17 knots
	94			1145	#6 1.16gpm						Mk 1
		X		1152		011					Reel 7
				1153	Ov 99	016					
73			X	1154	Ov ship	023	7205				
	95			1153	#6/2.46 GPM						Mk 1
				1157	Ov 95	027					RTS
				1158	Ov 94	031					Clear .034
				1159	Ov 94	037	7215				ER
	95			1200							Mk 3
		X		1202							
	96			1202	#6/3.95 GPM						Mk 1
74				1203	Ov 94	0047					
				1204	Ov 95	0054					
				1205	Ov 96	0062					
			X	1206	Ov 96	0067	7248				
				1209	Ov ship						RTS

	Test	start	stop	Time	Target	Tape Indicator	Camera Frame number	Aircraft speed	altitude	heading	Date April 12 of 70 Comments
	96			1209							Mk 3
				1210	Ov 96	0073					
				1211	Ov 95	0800					
											Mk 1
				1212	Ov 94	0089					
				1213		0094	7273				ER
		X		1215	Ov 94						
				1216	Ov 94	1102					Cloud
75				1217	Ov 95	0109					
				1219	Ov 96	0122					Clouds
			X	1221	Ov ship	0141	7312				
	97			1223	½ Gas-½ Oil						Mk 1 14 kts 9250
				1225		0143					RTS
				1225	Ov ship	0146					
				1226		0149					No oil
				1227	Ov 97	0154					
				1228	Ov 96	0162					Oil everywhere
				1229	Ov 95	0170					
				1230		0182	7331				ER
					Cancelling	97 - Going to 98					
	98			1235	H. C. 3.5 GPM						14 knots Mk 1
		X		1233		0183					
				1235	Ov 94	0193					
				1236	Ov 94	0201					
76				1237	Ov 95	0215					
				1237	Ov 96	0223					
				1241	Ov 98	0243					
			X	1242	Ov ship	0247					
					HC/5 gal					270	96-98-97-99 Re-do
	93			1245							Mk 3
				1245	Ov 98	0251					RTS
				1247	about Ov 97	0263					spill
	99			1247	Ov 96						Mk 1
				1247	HC/5 gal.	0276					
				1248	Ov 96	0283					
				1250	96 in oil	0288					
				1250	Ov 95	0291					
				1252	Ov 94	0300					
				1253		0304	7419				ER

	Test	start	stop	Time	Target	Tape Indicator number	Camera Frame number	Aircraft speed	altitude	heading	Date April 12 of 70 Comments
	99			1254							Mk 3
	100			1256	G & 0/0.1						
		X		1255	Ov 94	0306					Don't see
				1257	Ov 95	0327					
				1259	Ov 96	0333					
				1260	Ov 96	0340					
				1300	97 abort	0345	Quite a few horses				Blank before 98
77				1303	Ov 98	0371					
				1305	Ov 99	0383					
				1306	Ov 100	0399					
	100		X	1306	Ov ship	0401	7482				Mk 3
	101			1308	2/1 oil/1.10						Mk 1
				1310	Ov ship	0405					RTS
				1311	Ov 101	0410					
				1312	Ov 100	0414					
				1313	Ov 99	0422					Big spill
				1314	Ov 98	0434					
				1315	Ov 98	0440					
				1316	97 abort	0446					
				1317	Ov 96	0463					
				1319	Ov 95	0481					
	101			1318							Mk 3
	102			1319	4G/10 .1						Mk 1
				1320	Ov 94	0486	7526				ER
		X		1325		0491					Still blind
				1328		0509					
				1329	Ov 98	0521					No scanner-change film
	102			1329							Mk 3
78				1330	Ov 99	0534					
	103			1330	Gas 0.1						Mk 1
				1331	99 end	0540					
					100 or 101	0554					
				1335		0561					Falling off
			X	1336		0578	7578	Secured			Still seeing
								before scan ship			
				1342		0583					RTS
				1345	Over 99	0612					

	Test	start	stop	Time	Target	Tape Indicator	Camera Frame number	Aircraft speed	Aircraft altitude	Aircraft heading	Date April 12 of 0 Comments
				1346	Over 100	0625					
				1347	Ov 99	0632					
				1348	Ov 98	0653	7620				ER
					Going to take a 500' pass for calibration of 3-5 μ scanner						
		X		1353	Over	0653		115	500		
79					Ov 98	0672					Ov
					Over 99	0677					Start
			X	1357		0694	7718				Climbing
					Calib. X - H - .070						
					V - .070						
					30 - H - .280						
					V - .290						
					Final Cal.						

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13. ABSTRACT

Airborne remote sensing techniques were applied to the detection and discrimination of pollution by oil on the ocean surface. The tests were performed in the Gulf of Mexico during April, 1970. Pollutants investigated included #2 fuel oil, #6 fuel oil, 9250 lube oil, light crude oil, heavy crude oil, gasoline, and mixtures of gasoline and oil. A total of 103 oil slicks were produced as a function of spill rate and ship speed. Ship speeds were nominally 10,14, and 17 knots and spill rates ranged from 0.02 to greater than 4.0 GPM (Gallons per minute).

Sensors used during the airborne tests included: two dual polarized microwave radiometers operating at 10.2 and 30 GHz, an infrared scanner operated in both the 4-5.5μ & 8-14μ regions, a dual 70 mm camera sensing visible color and infrared color, a 4-lens camera employing filters from the mid-visible to ultraviolet wavelengths.

Oil was detected on the sea surface at spill rates as low as 0.2 GPM for long wavelengths sensors and at the lowest spill rates for photographic imagory using an ultraviolet filter. Anomalously warm infrared radiometric temperatures were recorded in the 4-5.5μ region for heavy crude oil while #6 fuel oil appeared radiometrically cooler.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Oil Pollution Detection						
2. Oil Pollution Discrimination						
3. Remote Sensing						
4. Microwave Radiometers						
5. IR Scanners						
6. Multi-spectral & IR cameras						
7. UV Cameras						
8. Controlled Spills						
9. Gulf of Mexico						

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