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THE DEEP OCEAN OPTICAL MEASUREMENT (DOOM) PROGRAM

Prepared by:  
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ABSTRACT: A ship borne system is described and results of in-situ measurements of the inherent optical properties of ocean water are presented. This Deep Ocean Optical Measurement (DOOM) system is designed to measure to any depth in the ocean spectral attenuation coefficients from 380 to 560 millimicrons, the volume scattering function at 436 millimicrons through an angular range from six to 92 degrees, and background illumination of both celestial and biological origin. Representative data obtained from December 1967 through January 1970 on six measurement cruises to various areas of the Atlantic are presented. Future cruises and plans are discussed.

NAVAL ORDNANCE LABORATORY  
WHITE OAK, MARYLAND

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The Deep Ocean Optical Measurement (DOOM) Program

The measurement program described in this report was conducted by the Optical Oceanography Section of the Radiation Physics Division (formerly the Infrared Group of the Solid State Division) of the Applied Physics Department. The work was performed for the Naval Ordnance Systems Command's ASW Oceanographic Research Program under Task Number ORD-03C-000/092-1/R104-03-01. This report is for information only and is not intended as a recommendation for action.

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By direction

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Chapter 1  
INTRODUCTION

Of the many physical problems confronting man's exploration of the sea, perhaps the most confining is the degradation of vision when venturing beneath the surface of the world's oceans. In the atmosphere man with his optical instruments may view past the horizon or probe into the far reaches of space, but on entry into the hydrosphere, even with the most sophisticated of optical instruments his visibility is limited to but tens of feet. At depths below several hundred meters the ocean becomes a realm of perpetual darkness, where sources of artificial illumination are a requisite even for marginal viewing. Although sonar systems, because of low attenuation losses in water, have been employed extensively and quite successfully in a large number of undersea applications, their performance is not to be confused with that of quality optical devices - in terms of information rate and imaging quality. The inherent nature of sound propagation in water limits the information rate and resolution of sonic devices by several orders of magnitude as compared to optical systems. Optical wavelengths unfortunately suffer severe transmission losses in aqueous media; thus very bright source lights at these wavelengths are required even for modest viewing ranges.

The recent development of the laser which holds promise of being an unexcelled source for underwater applications, has stimulated interest in light propagation through water and led to a number of studies at NOL and elsewhere (a, b, c). Laboratory measurements of the spectral attenuation coefficients at several wavelengths for tap, distilled, and filtered water were made at NOL during the mid sixties. Propagation of pulsed green laser light (530 m $\mu$ ) in water was investigated during field tests (a) in a 2500-foot model basin at the Naval Ship Research and Development Center, Carderock, Maryland. Further studies of lasers in water were conducted with both the pulsed green laser and a continuous wave gas laser operated in the red (632.8 m $\mu$ ) in the 100-foot vertical undersea weapons tank at NOL (d). The above studies confirmed the belief that coherent laser emissions are attenuated and scattered in the same manner and by the same mechanisms as conventional incoherent light sources. Thus measurements with conventional optical instruments may be validly applied to studies of laser systems for underwater naval use.

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A Deep Ocean Optical Measurement (DOOM) program was initiated at NOL in 1966 for the purpose of measuring in-situ the optical properties of the ocean which influence underwater light transmissions. Although many studies of absorption and scattering by natural waters have been made, (e, -k) these have lacked the cohesiveness which would provide an adequate picture of the attenuation phenomena in the sea. Some shortcomings of past studies are the following:

(1) Measurements were not made in-situ but with collected water samples either in the laboratory or aboard ship, thus disturbing the biological and dynamic physical processes occurring in the ocean.

(2) Only one optical parameter was measured either attenuation or scattering, without correlating the two.

(3) Information from the depths of the ocean basins is quite meager.

(4) Equipments were old and unsophisticated resulting in data of questionable accuracy. The objective of the DOOM program is to measure quantitatively under controlled optical conditions with modern instrumentation the optical properties at all depths of Atlantic and Caribbean ocean waters.

This report will describe in detail the instrumentation and techniques developed to fulfill this objective. Sea trials to date will be discussed briefly and examples of typical data will be presented.

## Chapter 2

### THEORY

Optical properties of the ocean may be divided into two separate classes, the inherent properties and the apparent properties<sup>(1)</sup>. The former are intrinsic physical properties of the medium and determine the manner in which a beam of light is propagated within that medium. They are independent of the orientation of the beam and of the existing light fields within the medium. Apparent optical properties depend in a rather complicated way on the inherent properties and are dependent on the geometric structure of the various light fields in the medium. Inherent properties measured by DOOM are the attenuation coefficient and the volume scattering function.

If a collimated beam of light is propagated through water over a path of length  $x$ , the radiant power of  $P_x$  remaining is given by

$$P_x = P_0 e^{-\alpha x}$$

where  $P_0$  represents the total flux initially in the beam. The total attenuation coefficient  $\alpha$ , defined by this equation, has the dimensions of reciprocal length and in this report will be expressed in units of reciprocal meters ( $m^{-1}$ ). In theory  $P_x$  excludes flux that has been deviated by any scattering process, but in practice all functional measuring devices do accept both single and multiple scattered flux from small forward angles that are within the receiver field of view.

Attenuation coefficients of electromagnetic radiation in all waters, both pure and natural, are a marked function of wavelength; the only real window in the entire spectrum falls in the visible near 480  $m\mu$ . Spectral attenuation coefficients of pure water prepared and measured in the laboratory by several investigators are presented in Figure 1. The pure water of Matlack was prepared by filtering demineralized tap water through 0.22  $\mu$  pore size millipore sieves, while multiple distillation was employed in the preparation of the other samples. In addition to the NOL measurement are the much referenced works of Hulbert (h) and a more recent effort by Sullivan (m) which exhibits a somewhat higher transmission in the blue-violet. The work of Sawyer (e) from the 1930's is typical of some of the earlier results which yielded lower

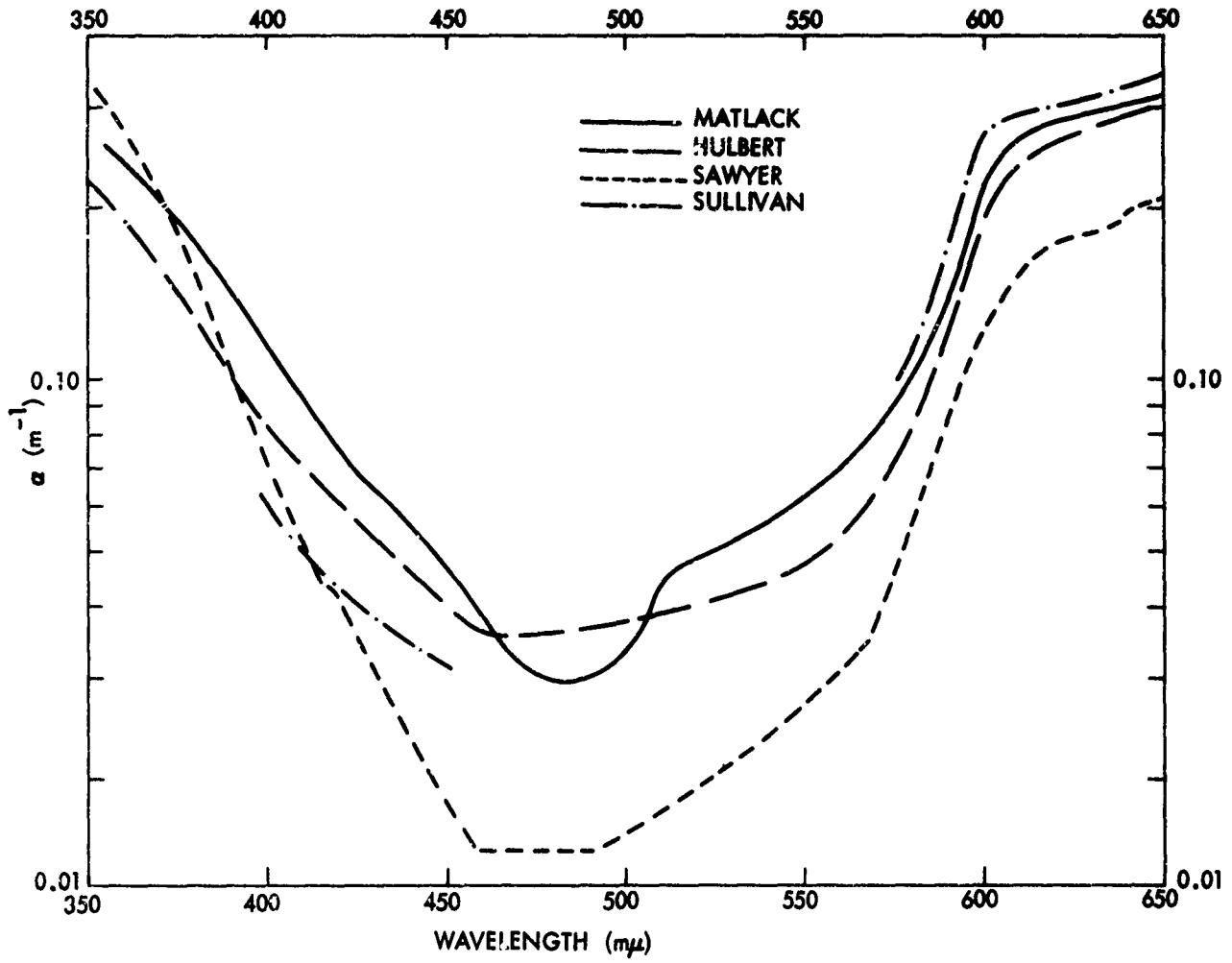


FIG. 1 OPTICAL ATTENUATION SPECTRA OF PURE WATER SAMPLES

coefficients and consequently higher water transmissions than are believed correct today. The curves of the other observers which in general agree in magnitude, shape, and location of the window, represent currently accepted levels of minimum attenuation in water.

Attenuation of light in water results from two independent mechanisms: absorption and scattering. Absorption includes all processes where radiant flux is converted into other forms of energy, such as the irreversible thermodynamic conversion to kinetic energy. Scattering is a random process by which individual photons are deviated and thus lost from the original beam of light. The attenuation coefficient  $\alpha$  is the sum of the absorption coefficient  $a$  and the total volume scattering coefficient  $s$ , thus

$$\alpha = a + s.$$

To determine that portion of the attenuation due to scattering, consider an elemental volume  $dv$  within a collimated beam of monochromatic light as in Figure 2. Let  $H$  be the irradiance input to  $dv$  and  $dJ(\theta)$  be the radiant intensity of light scattered in the direction  $\theta$ . The volume scattering function  $\sigma(\theta)$  is defined by the equation:

$$\sigma(\theta) = dJ(\theta)/Hdv$$

so  $\sigma(\theta)$  is a measure of the light from the beam that is scattered per unit volume of water per unit solid angle in the direction  $\theta$ . Its unit is commonly expressed in steradian<sup>-1</sup> meter<sup>-1</sup>. If  $\sigma$  is integrated over the entire solid angle ( $\Omega$ ) about  $dv$ , the total volume scattering coefficient  $s$  is obtained; thus

$$s = \int \sigma d\Omega = 2\pi \int_0^\pi \sigma \sin \theta d\theta$$

where it has been assumed that the scattering is symmetrical about the beam. Its unit is expressed in reciprocal meters ( $m^{-1}$ ).

Scattering in pure water must be considered on a molecular level and may be described by the Raleigh equation (n) or by the Smoluchowski Einstein fluctuation theory (o, p). Spectral distribution will vary as the inverse fourth power of the wavelength and the angular distribution as  $(1 + 0.835 \cos^2 \theta)$  (j). In practice however it is virtually impossible to obtain water completely free of particulate matter, so in all probability perfectly clean water has never been measured. The theoretical volume scattering function and those measured from pure water samples in the laboratory are presented in Figure 3. (h, q) Although the functions have been measured at different wavelengths, the shape of the curves show the departure from the theoretical thus indicating the presence of foreign particulate matter.

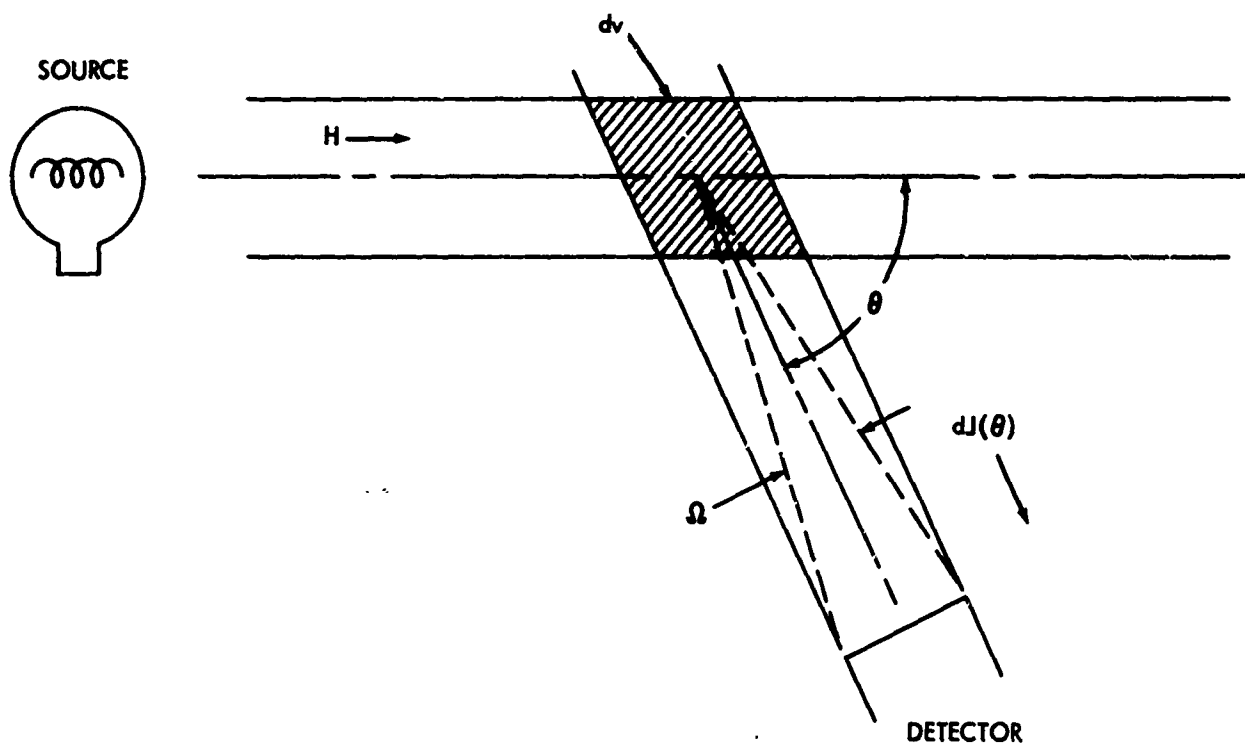


FIG. 2 SCHEMATIC DRAWING FOR DERIVING THE VOLUME SCATTERING FUNCTION  $\sigma(\theta)$

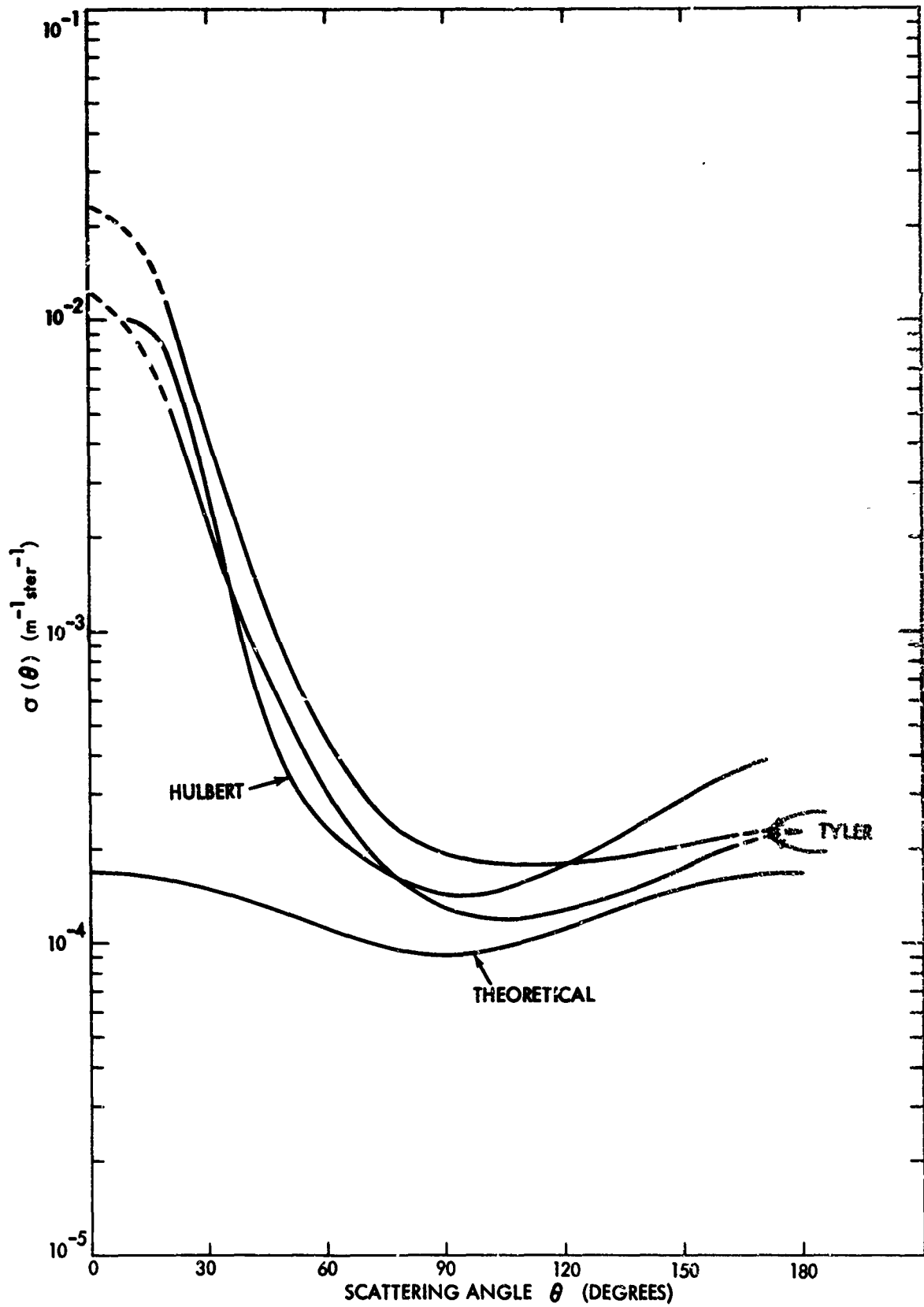


FIG.3 VOLUME SCATTERING FUNCTION OF DISTILLED WATER SAMPLES AS MEASURED BY HULBERT FOR TUNGSTEN LIGHT AND TYLER AT  $522.0 \mu$

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Since two independent mechanisms, scattering and absorption, govern water clarity, no single quantity can adequately specify the attenuation of light in natural water. Rather a combination is required such as the attenuation coefficient  $a$  and the total volume scattering coefficient  $s$ . A compilation for pure water of spectral  $a$  after Hulbert (h) and spectral  $s$  for the theoretical case from Le Grand (r) is presented in Table I. From the magnitude of the coefficients, it is evident that the spectral attenuation is much more strongly dependent upon selective absorption than the inverse fourth power wavelength scattering term.

The nature of the attenuation processes become much more complicated when natural waters are considered due to the presence of dissolved and suspended impurities within the media. Spectral attenuation of natural waters vary over wide ranges as indicated by the measurements of Figure 4 (h). Factors which may influence the transmission of light in sea water are (1) dissolved inorganic salts, (2) yellow substance, and (3) suspended particulate matter, both inorganic and organic. Studies by several observers (f, m) have substantially proved that dissolved salts in the sea exert virtually no influence on light transmission. Yellow substances are dissolved organic compounds, consisting of humic acid, melanoidins, and other compounds which result from the decomposition of plant and animal life. Attenuation by yellow substance, which is prominent in coastal and surface waters, increases towards the shorter wavelengths and when strong results in a shift of the transmission window at 480  $m\mu$  towards the longer wavelengths, (s). Inorganic particulate matter consists of opaque and transparent mineral particles such as silt which in general have diameters large relative to the wavelength of visible light. Organic particulate material includes the plankton populations, both zoo- and phyto-, of the surface layers and the associated detritus produced by the biological kingdom within the sea. Planktonic organisms, many of which are transparent and range in size from microns to centimeters, both scatter and absorb light thus increasing attenuation. Selective absorption by these organisms tends to increase attenuation towards the shorter wavelengths. Since the size of suspended particulate materials in natural waters is usually large compared to the wavelength of light, spectral scattering no longer follows the Einstein relationship as in the pure water case, but becomes essentially independent of wavelength.

Background radiant flux within the ocean may originate from two basic areas, (1) the atmosphere and celestial bodies in space and (2) from the luminescent organisms contained within the hydrospace itself. Illumination entering the ocean's surface from above is basically derived from the sun with some contributions from the sky, moon, and stars. The level of illumination at the surface, which varies both seasonally and diurnally, may change by as much as nine orders on magnitude during transition from full sunlight to the overcast night sky.

TABLE I

Measured Spectral Attenuation Coefficients  
and Theoretical Scattering Coefficients for  
Pure Water

$\lambda(m\mu)$	$\alpha(10^3 m^{-1})$	$s(10^3 m^{-1})$
400	80	5.03
425	57	3.89
450	40	3.05
475	36	2.43
500	38	1.97
525	41	1.60
550	47	1.33
575	75	1.11
600	197	0.93
625	273	0.78
650	308	0.67
675	390	0.58
700	576	0.49

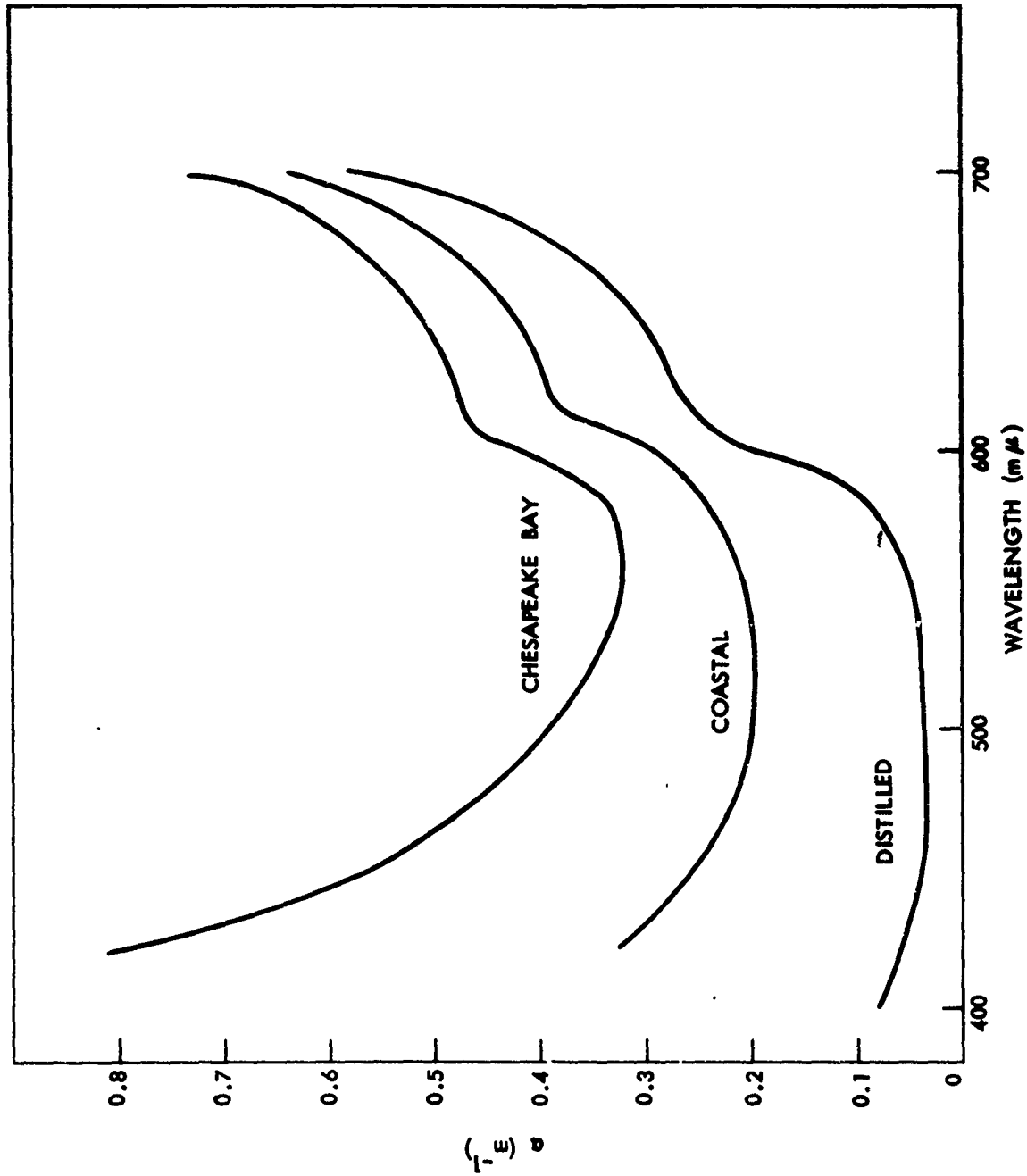


FIG. 4 SPECTRAL ATTENUATION OF DISTILLED AND NATURAL WATERS FROM HULBERT

Radiant flux entering the ocean is attenuated exponentially with depth as  $e^{-Kd}$  where  $K$  is the diffuse vertical attenuation coefficient and  $d$  is the ocean depth. The euphotic zone is the region where ample light is available for photosynthesis. Depending on water clarity, it extends to depths of from 60 to 150 meters. Below this zone the remaining light is blue-green due to selective attenuation and  $K$  approaches a nearly constant value. Although lower values have been recorded, the diffuse coefficient  $K$  nominally ranges from  $0.03$  to  $0.04 \text{ m}^{-1}$  for clear ocean waters and from  $0.05$  to  $0.15 \text{ m}^{-1}$  for surface and coastal waters. (s) Surface illumination in clear ocean waters has been detected by photoelectric devices at depths in excess of 800 meters.

Precise measurement of  $K$  at these depths is complicated by the presence of luminescence from marine organisms which may contribute at low light levels a significant portion of the total flux present. Bioluminescence, either spontaneous or stimulated, generally occurs as flashes of light ranging in duration from less than 0.2 seconds to more than one second. In all ocean areas thus far investigated by a number of observers (t, u), some bioluminescent flashing was recorded at every depth where it could be distinguished above ambient background illumination. The frequency of flashing reported varied from a maximum of 160 per minute in certain surface layers to one per minute at a depth of 3750 meters. Spectral emissions, peaked in the blue-green transmission window, have produced peak irradiances greater than  $10^{-2}$  microwatts per  $\text{cm}^2$ . (s)

Although a great many kinds of marine organisms are known to emit luminescent light, it appears that most flashing is produced by small organisms ranging in size from one centimeter to the microscopic unicellular forms. Continuous physical agitation of ocean water off Puerto Rico containing large populations of the tiny dinoflagellates stimulated a sustained irradiance of about  $10^{-2}$  microwatts/ $\text{cm}^2$ . (v) Optical stimulation, in the form of a pulse train from a Xenon arc lamp have similarly produced in-situ sustained luminescence that exceeds the background radiance by as much as a factor of  $10^4$ . (x)

Chapter 3  
INSTRUMENTATION

The Deep Ocean Optical Measurement (DOOM) system is a self-contained, internally powered research instrument designed to measure simultaneously to any depth in the ocean the spectral attenuation coefficient, total volume scattering coefficient, and levels of background illumination. As pictured in Figure 5, the DOOM system continuously samples and records optical data as it is lowered on a wire rope from the mother ship to the ocean bottom. The metal framework, which serves to support the system on deck as well as protecting it from impact during handling, contains the following basic components:

- (1) Instrument sphere
- (2) Optics cylinder
- (3) Pressure temperature probe
- (4) Abyssal pinger
- (5) External White mirror system
- (6) Stepping motor

This framework is eight feet in length, three feet wide, and the top of the sphere stands about four feet off the deck. Total weight in air is about 2200 pounds, in water some 600 pounds lighter. Both the instrument sphere and optics cylinder are watertight housings fabricated of inch-thick precipitated hardened stainless steel designed to withstand hydrostatic pressure to 20,000 psi. The sphere has an inside diameter of 29 inches, the cylinder an ID of 12 inches and a total length of 32 inches. Equipment within the sphere supplies the measurement system with necessary power, control, signal processing, and signal recording functions. Electrical continuity between the sphere and cylinder is provided by multi-conductor connector and cable assembly proof tested to 20,000 psi. The optics cylinder houses separate optical instruments for the measurement of attenuation, scattering and background. Light enters and emerges from the cylinder through a total of five windows of one inch thick fused quartz each of which provides a free aperture of 20.6 mm. An eight pass White mirror system provides a 7.5 meter folded external light path in water for the attenuation measurement section. Light emerging from the scattering section is deflected through varying angular increments by a mirror attached to a deep sea stepping motor thus providing a measurement of the scattering function  $\sigma(\theta)$ . Pressure and

**DEEP OCEAN OPTICAL  
MEASUREMENT SYSTEM  
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**FIG. 5 ARTIST'S RENIDION OF DOOM**

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temperature are continually recorded to all depths by the external PT probe. Signals from the abyssal pinger are used to determine the distance of the package from the bottom.

The spectral attenuation measurement section is shown schematically in Figure 6. Light from a coiled filament tungsten lamp, is imaged on the entrance slit of a Littrow type reflectance grating monochromator. Spectral slit width of the monochromator as determined by the 600 groove/mm grating, the 125 mm focal length collimating lens L2, and the 0.5 mm slit widths, is essentially constant at 6.6  $m\mu$  over the useful spectral range of the instrument. Wavelength scanning is accomplished by rotating the grating with an eighteen step cam driven by an AC synchronous motor at rates of either one or two RPM. A spectral interval of about 170  $m\mu$ , scanned in 10  $m\mu$  incremental steps, is positioned in the near UV and visible wavelength regions. The exit slit of the monochromator is imaged by the field lens L3 through the quartz window A into the water at the entrance plane I1 (Figure 7) of the White system. The field stop A1, also imaged by L3 but at the primary mirror M1 of the White system, restricts the light bundle diameter to 44 mm in air and 33 mm in water. Positions of these images are the same in air as in water because the quartz windows have been fabricated with a slight negative curvature. An eight pass White optical system, attached on the outside of the cylinder provides a 7.5 meter external water path. Three 76 mm diameter mirrors with radii of curvature 910 mm, aluminized on the front surface and overcoated with silicon monoxide for salt water protection, fold the light for eight water passes in the manner shown in Figure 7. Light leaving the White system enters the cylinder through window B, is collected by lens L4 and eventually imaged on the cathode of the photosensor, an S4 spectral response photomultiplier tube. Appropriate field and aperture stops limit the field of view of the sensor so it accepts only light reflected within the solid angle subtended by the third mirror M3 of the White system. The function of the Wratten filter Number CC50M is to modify the spectral content of flux received from the tungsten lamp so that the output signal of the S4 photomultiplier is more uniform with wavelength. Chopping of the light at the exit slit of the monochromator permits the receiver electronics to differentiate between the DC background light and that of the chopped AC source and also facilitates signal processing. In order to provide a reference signal in case of changes in system responsivity, a portion of the source energy is deflected by a beam splitter directly to the sensor optics. Mirrored and open segments of a reference wheel are positioned in the reference and  $\alpha$  signal beams by a stepper motor synchronized with the grating drive. During the normal  $\alpha$  measurement, light from the White system is allowed to pass to the photodetector. But once each spectral scan at a prescribed wavelength, the mirrored portions are rotated into the beam so as to block light from the exterior and deflect that from the reference beam onto the sensor. Separate mirror segments of two different reflectivities

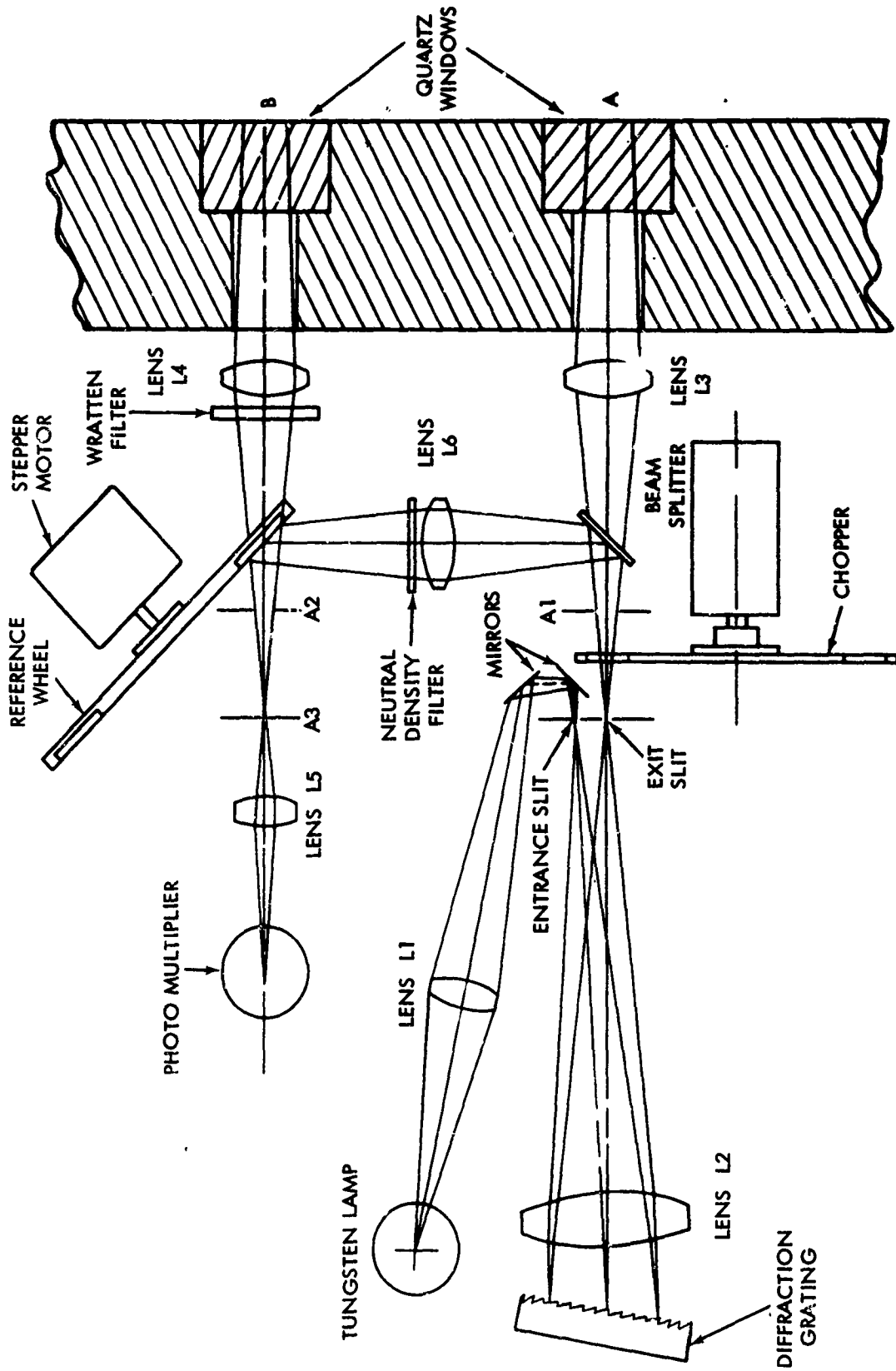


FIG. 6 SCHEMATIC OF ATTENUATION MEASUREMENT SECTION

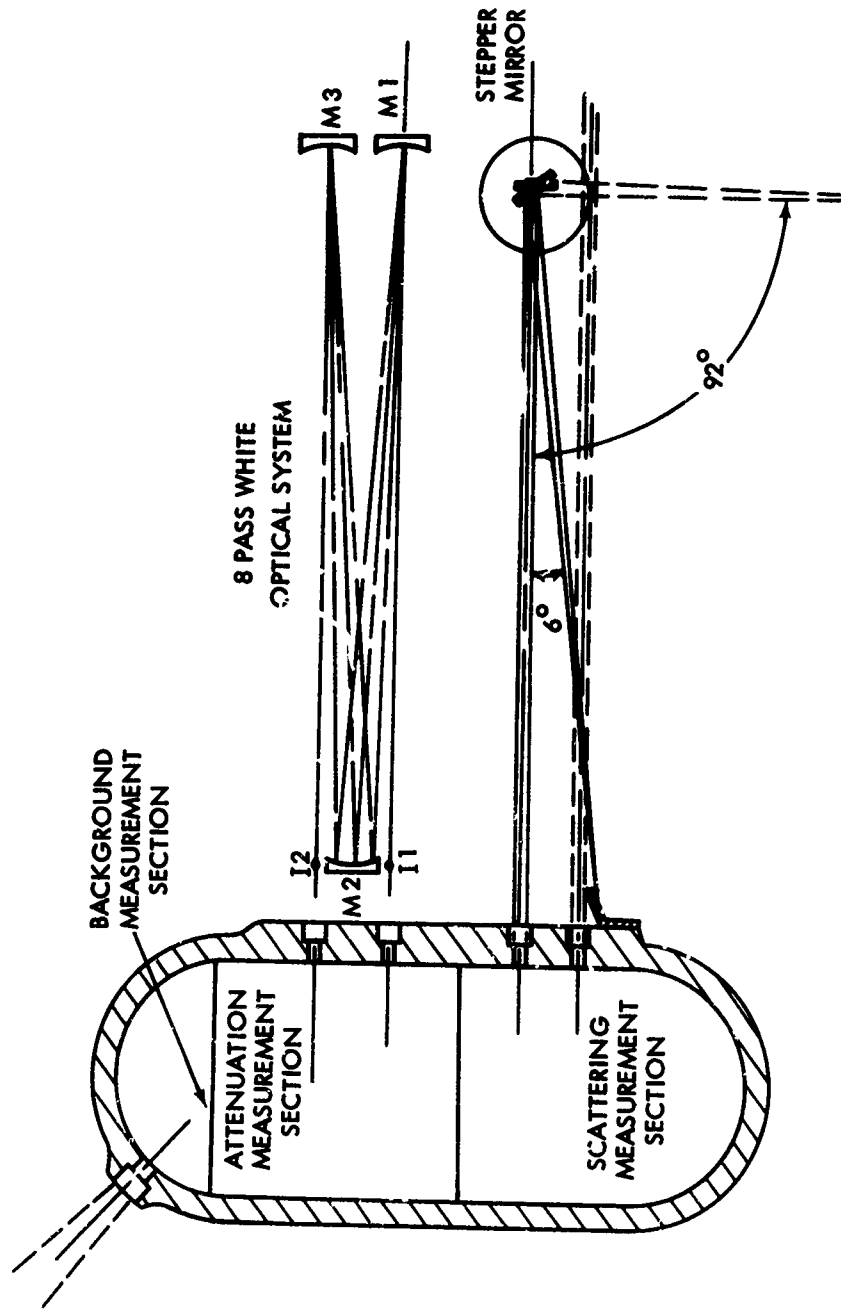


FIG.7 EXTERNAL OPTICS AND IN-SITU LIGHT PATHS OF THE THREE MEASUREMENT SECTIONS

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roughly 0.80 and 0.18, provide reference signals differing in magnitude by a constant factor of about 4.5. This difference serves as a monitor of system gain during a measurement drop.

The scattering measurement section is designed to measure through angles from six to 92 degrees, the volume scattering function of ocean water for 435.8 millimicron wavelength light. This section is shown schematically in Figure 8. Radiation from the 100 watt Mercury short arc lamp producing an average brightness of 140,000 candlepower/cm<sup>2</sup> over the 0.31 mm arc diameter, is imaged one to one by lens L1 in the 0.50 mm diameter aperture A1. This aperture is imaged by lens L2, f = 109.4 mm, in the water at a distance of 1.92 meters which corresponds to twice the distance from the exit window A to the stepper mirror. Source light is deflected by the stepper mirror, Figure 7, which is attached to the motor shaft of a reversible deep sea stepping motor. The motor is programmed to scan in nine individual steps over a predetermined angular range and then return to the original angle at a rate of one complete cycle per minute. The angular deviation of the reflected beam from the incident beam varies from minimum of six degrees to 92 degrees as shown in Figure 7. At the minimum six-degree angle, the image of A1, seven mm in diameter in water, falls on the rear of a black mask attached to the cylinder adjacent to the entrance window. This six-degree minimum angle is determined by geometrical considerations, such as the 962 mm distance to the stepping mirror, the 69.8 mm window separation, the image size, and the 20.6 mm free aperture of the window. The axis of the field of view of the optical receiver parallels at the 69.8 mm distance that of the source bundle. Aperture A2, 3.0 mm in diameter, located in the focal plane of collecting lens L4, f = 90.7 mm, determines the 33 milliradian circular field of view. Thus only flux scattered within the common volume of the reflected source beam and the solid angle subtended by aperture A2 and in the direction of A2 can enter the photo sensor compartment and contribute to the scattering signal. Accepted flux is reflected from 0.90 reflectivity beam splitter and filtered before falling on the cathode of an S11, 11 dynode photomultiplier. The interference filter which has a peak transmission of 65 percent and a half width of 11 m $\mu$ , passes only the 435.8 m $\mu$  line of the HG arc light. Since signal levels decrease by orders of magnitude as the scattering angle is scanned to larger angles, attenuation is required at the small angles in order to maintain a more nearly flat response. A filter wheel synchronized with the deep sea stepping motor, rotates appropriate neutral density attenuators into the light bundle within the receiver optics. As in the  $\alpha$  section, a high and a low reference signal recorded during each cycle provide periodic checks on system sensitivity and gain. When the reference mirror wheel is positioned to intercept the source beam, lens L3 images L1 through an attenuating filter, the beam splitter, and the

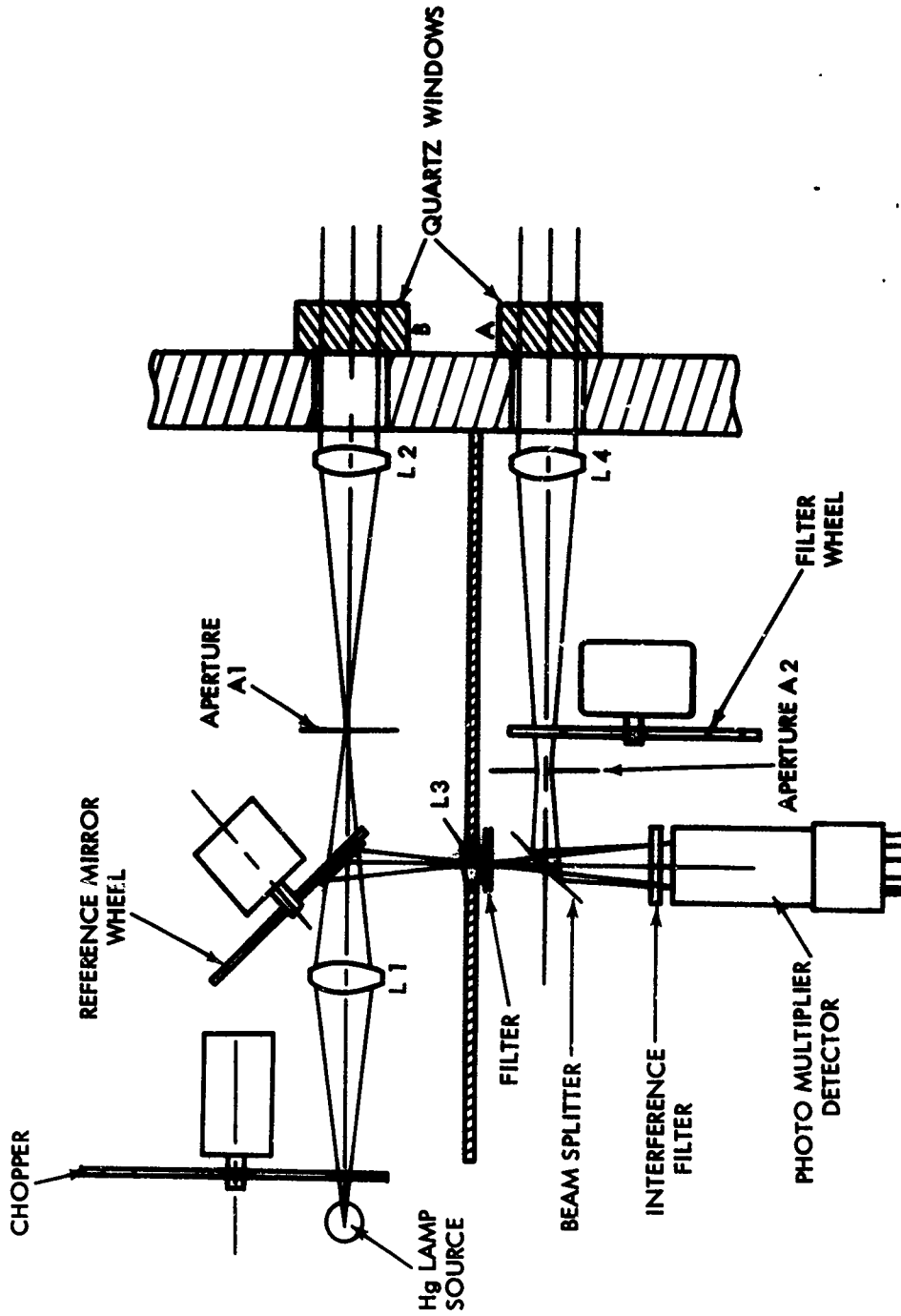


FIG. 8 SCHEMATIC OF SCATTERING MEASUREMENT SECTION

interference filter onto the photocathode of the sensor. Here again chopping is employed to facilitate background rejection and signal processing.

The background measurement section is housed within one of the hemispherical end caps of the optics cylinder. It is a passive receiver of light from the submarine radiance fields existing in the ocean. Accepted radiant flux is restricted to a moderately small horizontally oriented solid angle and to a narrow spectral band in the blue-green visible region of the electromagnetic spectrum. The background section is shown schematically in Figure 9. Light collected by the 82 mm focal length lens L1 is deflected by a 45 degree mirror to the variable aperture A1 located in the focal plane of L1. Aperture diameter is adjustable from 2.5 to 25 mm permitting fields of view for the 82 mm lens from  $2.3 \times 10^{-4}$  to  $2.3 \times 10^{-2}$  steradians in water. Lens L2 images the aperture on the cathode of an S11, 11 dynode photomultiplier tube. The interference filter passes a spectral band peaked at 485 m $\mu$  and 20 m $\mu$  wide at the one-half transmission level while the right angle prism serves simply to divert the light towards the optical sensor. An opaque shutter positioned by a rotary solenoid blocks incoming flux for a duration of five seconds out of every minute thus providing a zero signal level.

Solid state electronics employing operational amplifiers with logarithmic outputs are used to process signals from the three optical sections. Amplifiers are matched with photomultiplier current outputs which are linear from the noise level, about  $10^{-7}$  amp, to saturation at about  $10^{-3}$  amp, or over a dynamic range of  $10^4$ . Multiple decade log amps are required for the background and scattering section, because their output currents may encompass the full dynamic range. The  $\alpha$  section however manages with a two-decade range. Direct current outputs from the log-amps are then recorded on a light beam galvanometer recording oscillograph. Frequency responses for the three recorded signals from the attenuation, scattering, and background sections are respectively 120, 120, and 30 hertz.

Two equipments, a Ramsay Mk XI Deep Sea Probe and a Hydro products Abyssal pinger are attached externally to the pressure housings on the DOOM package. The Ramsay Probe simultaneously measures temperature and pressure to depths of 33,000 feet and converts these parameters to DC voltages. Temperature over a range from 0 degrees to 35 degrees is sensed by two thermistors connected in a DC bridge circuit. The pressure sensor is a 0 to 15,000 psi silicon strain gauge pressure transducer manufactured by Fairchild. A deep sea cable from the instrument sphere provides external power for operating the instrument and permits recording of sensor outputs in the sphere. The abyssal pinger is a self-contained unit providing 13 watts of peak acoustic power in pulses two milliseconds in length and at a frequency of 12 kilohertz.

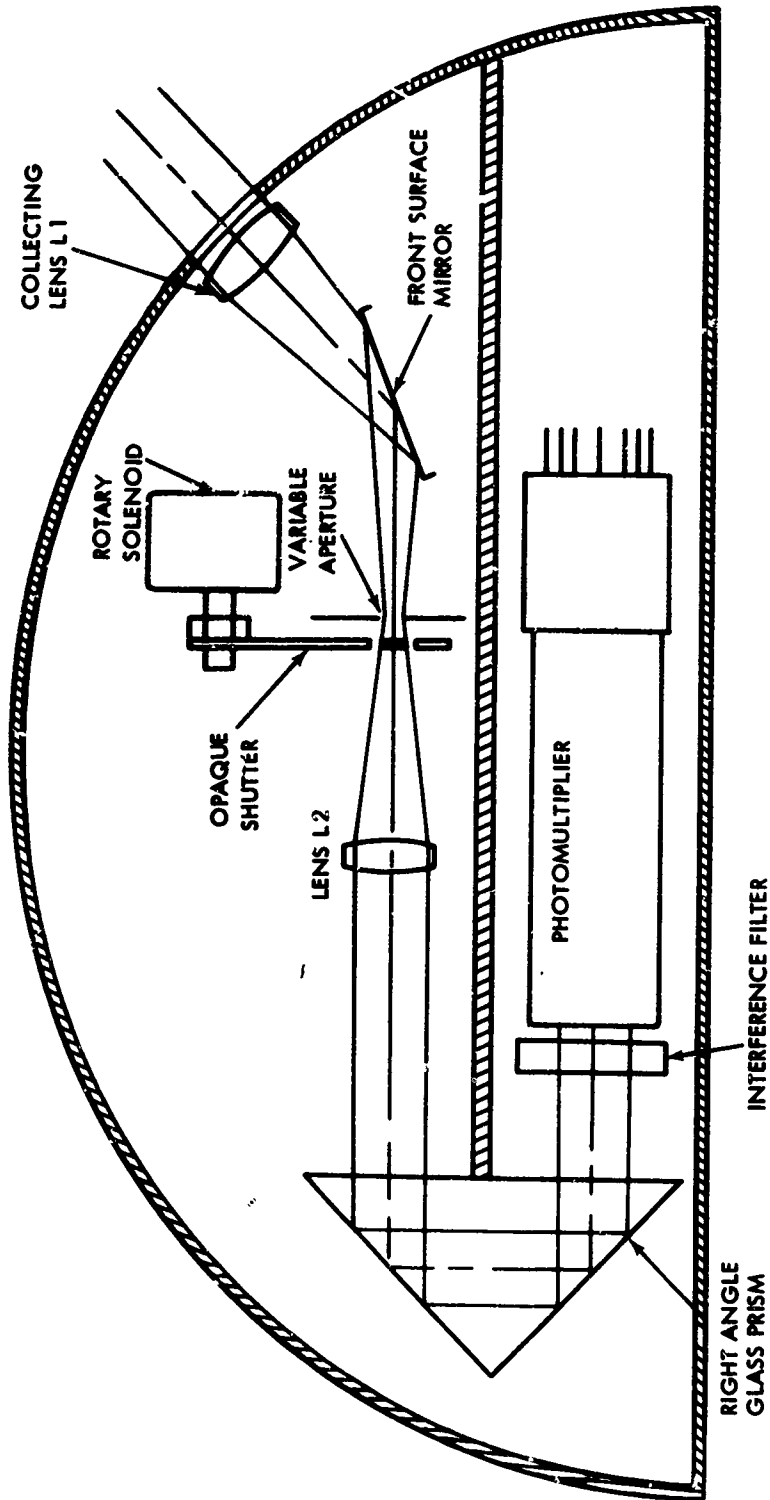


FIG. 9 SCHEMATIC OF BACKGROUND MEASUREMENT SECTION

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Pulse repetition rate is chronometer controlled at one pulse (ping) per second. The difference in time of arrival of the directly transmitted pings and those reflected from the bottom are recorded on the ship's conventional 12 Khz depth sounder and the resulting trace separation provides the means for determining the distance of the package off the bottom.

Power for the DOOM instruments is supplied by two rechargeable silver zinc batteries. The primary voltage at 28 VDC is used both directly and after conversion to regulated AC and DC voltages, i.e., 115 VAC,  $\pm 15$  VDC, 1200 VDC, etc. A separate 40V battery provides power for the mercury arc lamp. An internal timer automatically turns the system off after a maximum three-hour operating period as determined by the capacity of the batteries.

Seven channels of analog information are simultaneously recorded by a D. G. O'Brien, model 300 light beam galvanometer oscillograph on 3 5/8-inch photosensitive paper. These seven data channels consist of the three optical signals, the Ramsay probe outputs of pressure and temperature, a timing marker at two-second intervals, and a static reference trace provided by a fixed mirror.

## Chapter 4

### CALIBRATION AND DATA REDUCTION

Both spectral attenuation and volume scattering measurements are quantitative determinations of their respective coefficients while the background data are strictly relative in nature. The  $\alpha$  measurement is dependent upon the accurate relative measurement of the difference in received optical power for two cases, (1) when the attenuation is essentially zero, which occurs in air and (2) when the system is submerged in the attenuating medium. The scattering measurement requires a determination of the total power in the source beam relative to that received when in the scattering medium. Thus in the  $\alpha$  and  $s$  sections a calibration standard is not required since both sections contain their own sources of radiation and calibration involves only an accurate comparison of signals under two different conditions. Such is not the case for the background section which acts solely as a passive receiver of external light. Hence a standard radiation source would be required for an absolute quantitative calibration. Due to the difficulty of obtaining and operating such a standard in the field, in this case on a rolling spray-lashed deck at sea, only qualitative data on background lighting is recorded.

The quantitative  $\alpha$  calibration is made by comparing the respective radiant power,  $P_A$  and  $P_W$  transmitted through the two media, air and water. The power returning to the cylinder in the air case is

$$P_A = P_0 T_{QA}^2 \rho_m^2 e^{-\alpha_A x}$$

where  $P_0$  is the source power leaving the cylinder,  $T_{QA}$  is the transmittance of the quartz-air interface,  $\rho_m$  is the reflectivity of the folding mirrors,  $\alpha_A$  is the attenuation coefficient in air, and  $x$  is the external path length. Since attenuation in air is negligible the exponential term approaches unity and the equation becomes

$$P_A = P_0 T_{QA}^2 \rho_m^2$$

Recorder deflection produced after logarithmic amplification is

$$D_A = 1/B \log k P_A$$

where B is the slope of the logarithmic gain curve and k is a constant, involving receiver responsivity. For the water case

$$P_w = P_o T_{QW}^2 \rho_m^7 e^{-\alpha x}$$

where  $T_{QW}$  is the transmittance of the quartz-water interface,  $\alpha$  is the attenuation coefficient of water, and

$$D_w = 1/B \log k P_w$$

The difference in received signals for the two cases is

$$\Delta D = D_A - D_w = 1/B \log \frac{P_A}{P_w}$$

Substituting for the received powers

$$\Delta D = 1/B \log \left( \frac{P_o T_{QA}^2 \rho_m^7}{P_o T_{QW}^2 \rho_m^7 e^{-\alpha x}} \right) = 1/B \log \left[ \frac{T_{QA}^2 e^{\alpha x}}{T_{QW}^2} \right]$$

since the reflectivity of the front surface mirrors overcoated with SiO is the same in air as in water. Solving the above equation for  $\alpha$

$$\alpha = \frac{2.303}{x} \left[ \log \left( \frac{T_{QW}}{T_{QA}} \right)^2 + B \Delta D \right]$$

Substituting applicable values for the DOOM system,  $T_{QW} = .9980$ ,  $T_{QA} = .9644$ , and  $x = 7.444$  m, then

$$\alpha = 0.0092 + 0.3094 B \Delta D \text{ m}^{-1}$$

To calculate the magnitude of  $\alpha$ , it is only necessary to measure the difference in deflection for the two cases and to determine the slope of the gain curve of the log amp. This curve, a plot of relative source power versus recorder deflection is obtained by attenuating the source light with calibrated

neutral density filters. A typical gain curve linear over approximately two decades is shown in Figure 10.

A characteristic of a grating monochrometer is that the spectral dispersion is a linear function of wavelength. The DOOM grating is driven by a precision 18 step cam. From an accurate physical measurement of the radii of the cam steps and the length of the lever arm drive, the wavelength interval between steps can be accurately calculated. Quantitative setting of wavelength is accomplished by adjusting the grating angle until the 546.1 mμ line of a Hg lamp is passed through the exit slit for a specified cam step.

The scattering section measurement consists of measuring and recording a known portion of the total power of the source radiation leaving the cylinder and comparing it with that which is scattered by the water into the solid angle subtended by the optical sensor. Calibrating apparatus for determining source power is shown in Figure 11. A glass right angle prism is temporarily secured on the outside of the cylinder across the two quartz windows so that the source beam is deflected into the receiver optics in such a way as to pass geometrically the total source beam. Neutral density filters provide appropriate attenuation to prevent saturation of the photomultiplier. The power measured is

$$P_{CAL} = P_0 T_{AQ}^2 T_{GA}^2 T_F$$

where  $P_0$  is the power leaving the cylinder, and  $T_{AQ}$ ,  $T_{GA}$ , and  $T_F$  are the transmittance respectively of the air-quartz interface, the glass-air interface, and the attenuating filter. The recorder deflection produced is

$$D_{CAL} = 1/B \log (k P_{CAL})$$

where B is the slope of the log amp gain curve and k is a system responsivity constant. Scattered power collected by the optical receiver when submerged in water is

$$P_w = P_0 \sigma(\theta) C(\theta, \alpha) T_{wQ}^2 \rho_m$$

where  $\sigma(\theta)$  is the volume scattering function,  $T_{wQ}$  is the transmittance of the water-glass interface,  $\rho_m$  is the stepper mirror reflectivity, and the function  $C(\theta, \alpha)$  is given by the equation

$$C(\theta, \alpha) = e^{-\alpha(2b - a \cot \theta + a \csc \theta)} \int_{\Omega} dx / \sin \theta$$

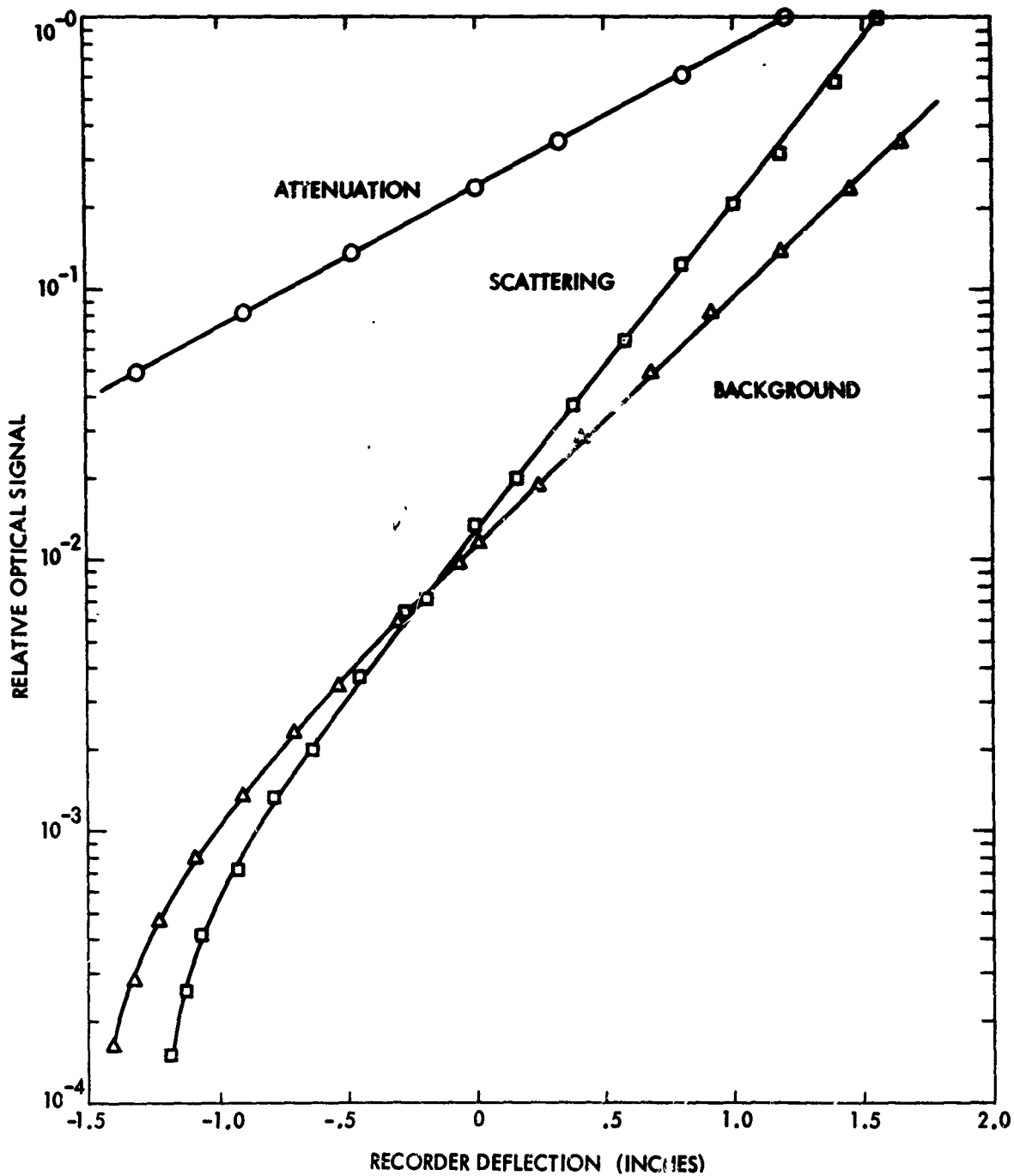


FIG. 10 GAIN CALIBRATION CURVES FOR THE THREE MEASUREMENT SECTIONS

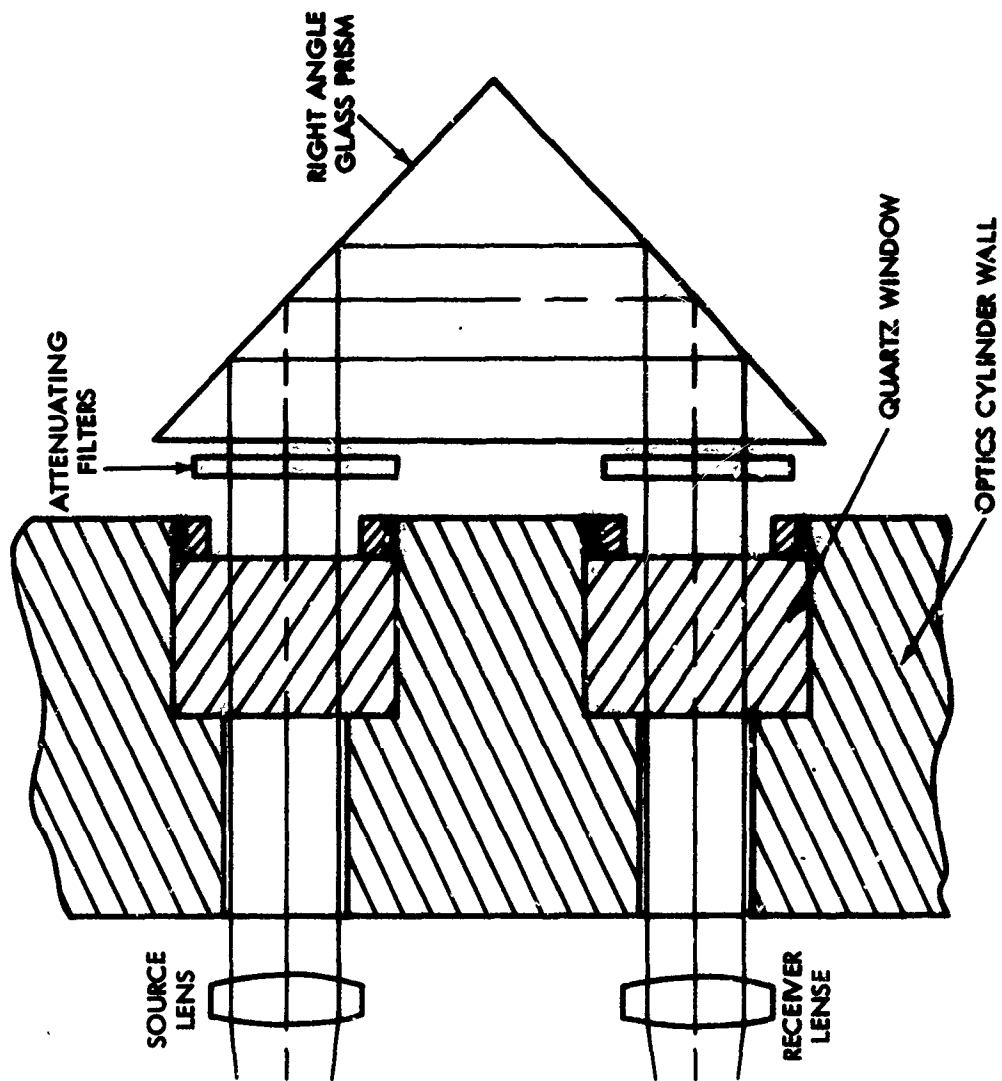


FIG. 11 SCATTERING SECTION CALIBRATION OPTICS

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The exponential term gives the attenuation loss over the traversed water path as determined by the scattering geometry,  $b$  being the distance to the stepper mirror and  $a$  the window separation. The integral computes the portion of the flux from the intercepted length of source beam ( $dx$ ) falling within the solid angle ( $\Omega$ ) of the receiver that is collected by the optical sensor. Deflection produced by the scattered light is given by

$$D_w = 1/B \log (kP_w)$$

Subtracting the two deflections

$$D_{CAL} - D_w = \Delta D = 1/B \log \frac{P_o T_{AQ}^2 T_{GA} T_F}{P_o \sigma(\theta) C(\theta, \alpha) T_{wQ}^2 \rho_m}$$

and solving for  $\sigma(\theta)$  yields

$$\sigma(\theta) = \frac{T_{AQ}^2 T_{GA} T_F}{C(\theta, \alpha) T_{wQ}^2 \rho_m} 10^{-B\Delta D}$$

Substituting values for the constants  $T_{AQ} = .9642$ ,  $T_{wQ} = .9980$ ,  $T_{GA} = .9561$ ,  $T_F = 1.71 \times 10^{-5}$  and  $\rho_m = 0.89$ , we obtain

$$\sigma(\theta) = \frac{1.64 \times 10^{-5} 10^{-B\Delta D}}{C(\theta, \alpha)}$$

To obtain the volume scattering function the relative difference in recorder deflection must be measured, the gain slope determined, and  $C(\theta, \alpha)$  evaluated as a function of the scattering angle. The gain curve of the log amp, also obtained by using calibrated neutral density filters, is linear over a range of three decades as shown in Figure 10. The value of  $\alpha$  in the exponential term is obtained from the  $\alpha$  measurement section and the integral of the solid angle is computed from the geometry and optical parameters of the system.

Since the background measurement is qualitative and passive in nature, its calibrations consist of those dealing with the response of the sensor system to external stimuli. System gain as measured using a tungsten source and calibrated neutral density attenuators, is linear over about three decades as shown in Figure 10. Frequency response is determined by chopping the source radiation with a continuously variable speed motor. Signal level was down by  $1/e$  at about 30 hertz.

All data, both calibration and in-situ measurements, are recorded on seven channels of the DGO oscillograph.

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Presented in Figure 12 are oscillograph traces of a calibration in air. Traces A and B, the pressure and temperature signals are inactive. A one minute record is presented which includes a complete scattering measurement, trace C, from 6 degrees to 92 degrees and two transmission spectra, trace D, one with high, the other with the low reference signals. Trace E is the dummy trace and trace F the timing marker producing pips at two second intervals. The background section is shuttered, so its signal, trace G, represents the dark current noise of the photomultiplier and associated electronics. The transmission spectra consisting of 20 cam intervals of 1.5 second duration each, are scanned at a rate of two per minute. Transmission data are recorded at 18 wavelengths, starting with the longest at step  $\lambda_{20}$  and driving to the shortest at step  $\lambda_2$ . Step  $\lambda_{12}$ , at the same wavelength as step  $\lambda_{11}$ , is used for the reference signal and step  $\lambda_1$  recycles the cam to the initial wavelength  $\lambda_{20}$ . The high reference signal (HR) is about a factor of 4.5 greater than the low reference (LR).

The 60 second scattering measurement cycle includes in addition to the nine angular measurement signals, a shuttered zero level signal (SHUT) and both high (SHR) and low (SLR) reference signals all of which are recorded as the stepper recycles back from the maximum 92 degree angle to the initial 6 degree angle. During calibration as in Figure 14, a constant radiant flux enters the receiver optics during the 47 second period allotted for angular measurements. At the two smallest angles, 6 degrees and 13.2 degrees, attenuators of the filter wheel attenuate the flux by factors of 0.11 and 0.33 respectively. The high and low reference signals differ by a factor of about ten. It should be remembered when viewing these records that the output signals of the three measurement sections have been logarithmically compressed.

An in-situ record is shown in Figure 13. Trace identification and signal notation are the same as for the previous calibration data, that is, A is the pressure signal, B temperature, C scattering, D- $\alpha$ , E-dummy, F time marker, and G background. Temperature and pressure transducers are functioning; the temperature near its maximum at about 25°C, the pressure reading very nearly atmospheric. In this case the package is near the surface, so attenuation is moderately high; the coefficient in the transmission window at  $\lambda_{11}$  (480  $m\mu$ ) being about 0.070  $m^{-1}$ . Scattering signals are also large and difference in signal levels at the nine angles are easily recognized. The background signal is riding at the noise level of the photomultiplier indicating an absence of luminescent spikes and an illumination level characteristic of a very dark night.

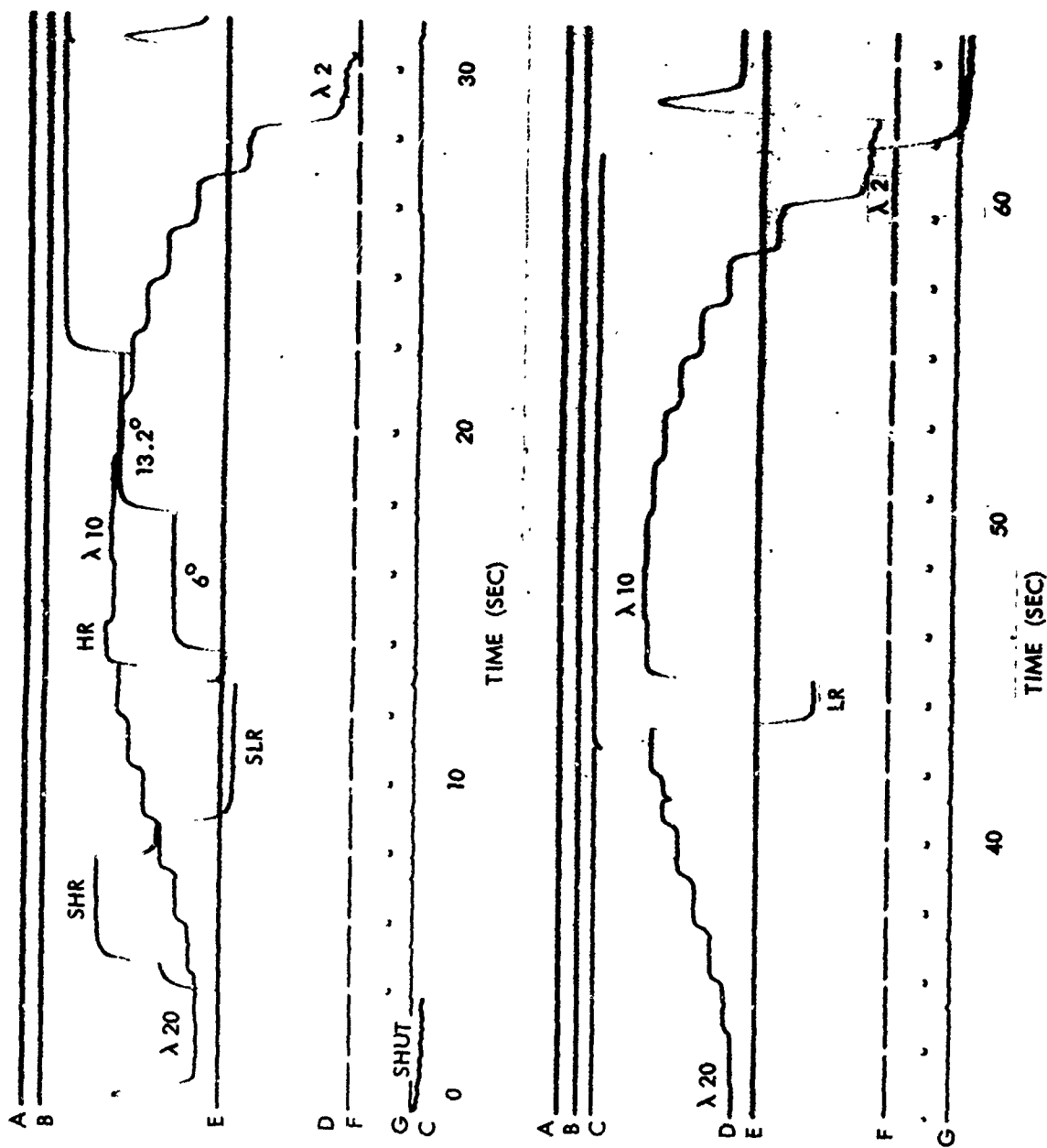


FIG. 12 RAW DATA FROM IN-AIR CALIBRATION RUN

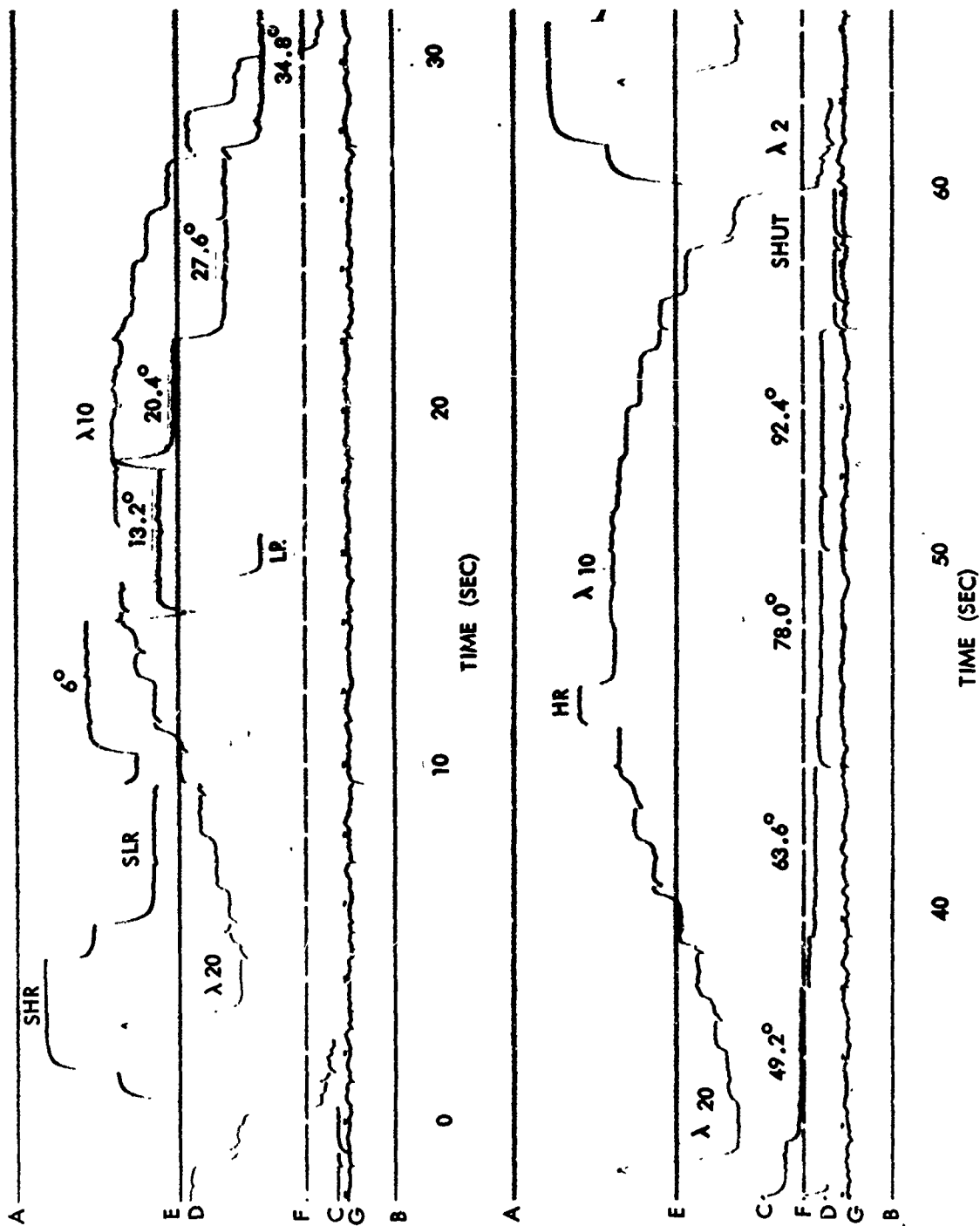


FIG. 13 RAW DATA FROM AN IN-SITU MEASUREMENT RUN

Chapter 5  
OPERATIONAL PROCEDURES

DOOM operations are conducted from aboard Auxillary Oceanographic Research (AGOR) ships which are under technical control of the U. S. Naval Oceanographic Office. The ships are equipped with conventional instruments for routine oceanographic studies and provide support for programs of the several east coast Naval Laboratories. A three ship east coast fleet consisted of the U. S. Naval Ships (USNS) GILLIS, SANDS, and LYNCH, T-AGOR's four, six, and seven respectively, prior to the de-commissioning of the GILLIS in the fall of 1969. Project DOOM has operated for both the GILLIS and the LYNCH, the latter being shown in Figure 14. The LYNCH, a 1320 ton displacement, 209 feet long vessel, has a cruising range of 12,000 nautical miles at a maximum speed of 12 knots and can accomodate a scientific party of 15.

Shipboard installation involves bolting the DOOM assembly to the deck under the A-frame located on the fantail, Figure 15, where it is secured at all times other than during actual measurement drops. The A-frame serves to lift and swing the package outboard for drops and for lifting the top half of the sphere for data removal and daily maintenance. Either of two winches may be used, a deep sea winch containing 45,000 feet of tapered 3/8 inch to 3/4 inch steel wire rope or the intermediate winch utilizing 30,000 feet of 1/2 inch steel wire rope. In order to provide an adequate safety factor, for oceanographic work a factor of 2.5 is considered sufficient, the deep sea unit must be used for depths in excess of 16,000 feet.

Operations at sea may be divided into three phases: (1) Pre-drop preparations and calibrations, (2) the measurement drop, and (3) post and between drop activities. The system, of course, has been completely checked out, calibrated and sealed in the laboratory prior to shipment to the port of embarkation. Either en route to or upon arrival at the first measurement station, the top of the instrument sphere is removed and the system connected for operation on external power. Performance tests on the entire system are conducted on external power and adjustments are made if necessary. Batteries are tested, fresh film is loaded in the recorder, and the interval timer which determines the length of operation is set. The system is now switched to internal power and the following calibrations

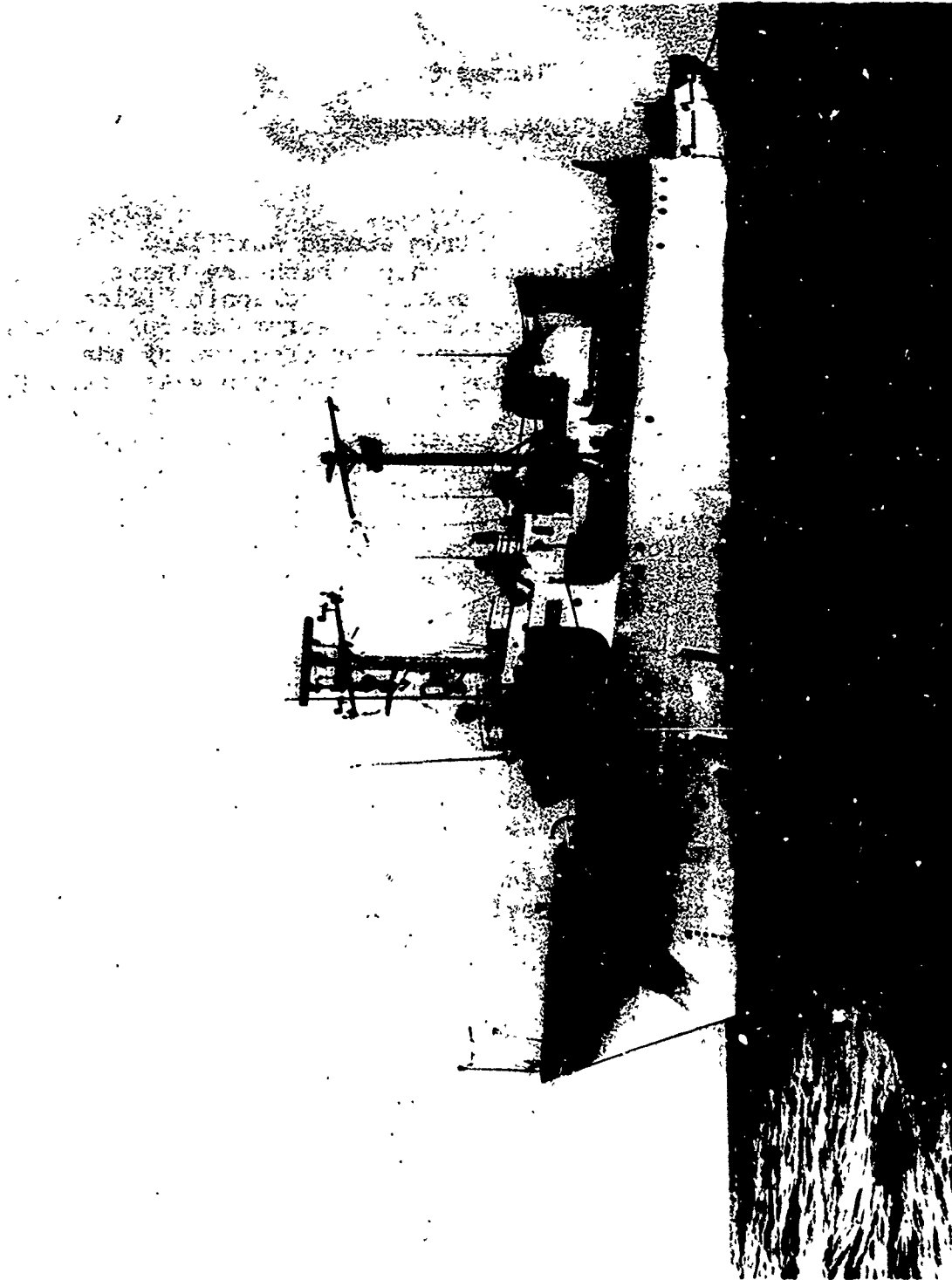


FIG. 14 THE U.S. NAVAL SHIP LYNCH, T - AGOR - 7

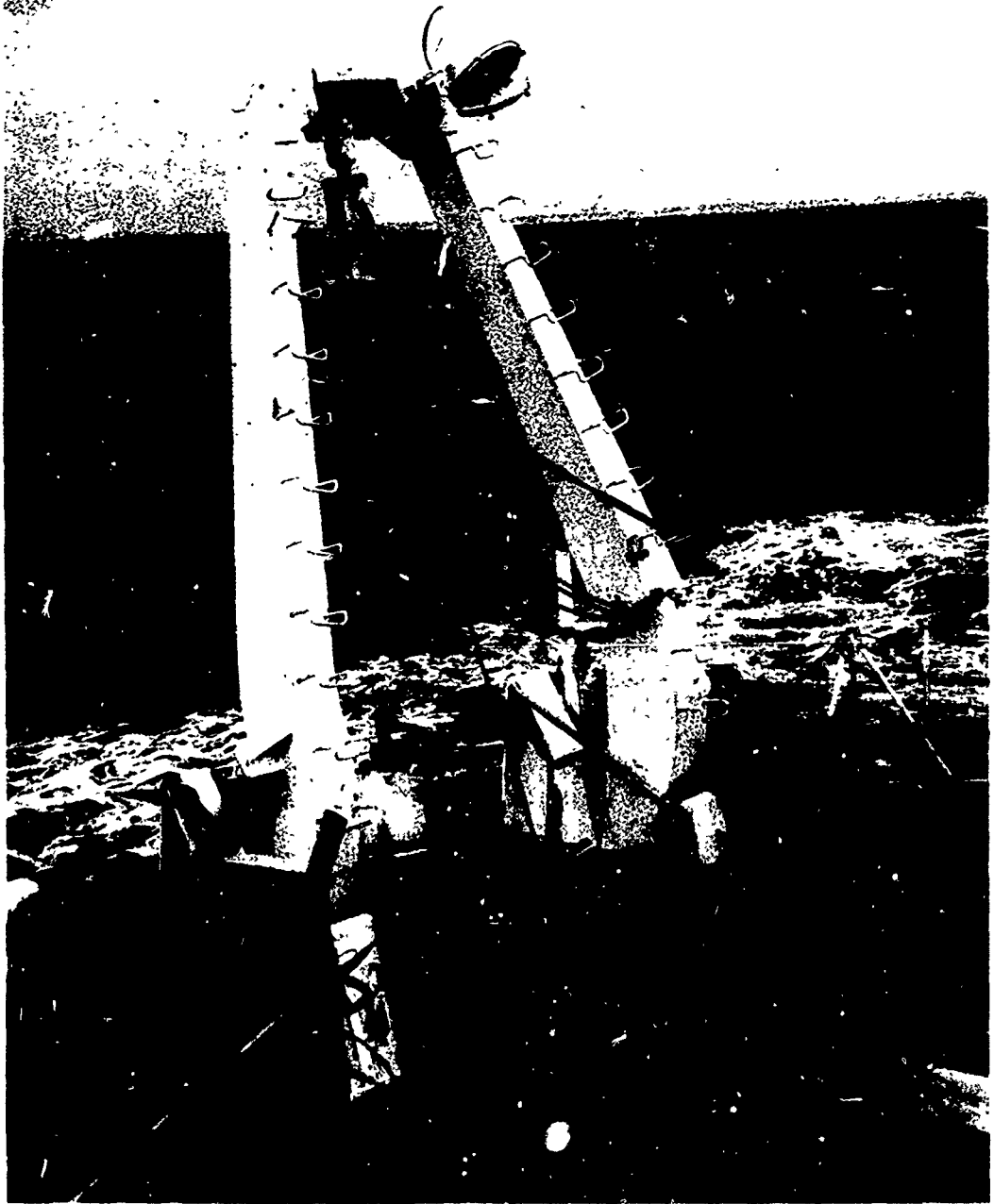


FIG. 15 DOOM ASSEMBLY AT SEA

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are run and internally recorded:

- (1) the attenuation section air calibration,
- (2) the attenuation section gain calibration with appropriate neutral density filters,
- (3) the scattering section calibration.

After this five to six minute calibration period, the system is shut down, the top of the sphere replaced, and DOOM is ready for the second operational phase, the measurement drop.

Because of the high ambient light levels during the day which tend to saturate DOOM's optical sensors, drops are made during the hours of darkness. Prior to each drop a bathythermograph (BT) is taken and examined for strong or rapid variations in the vertical thermal structure of the surface waters (to 1000 feet). Knowledge of the existence and depth of such thermal gradients are of value when planning a drop because they usually correspond to significant changes in optical characteristics. Both the DOOM system and the pinger are now started by mating electrical connectors located external to their pressure housing. After a short warm up period, and visual inspection of the light beams emanating from the cylinder, DOOM is hoisted and swung over the side into the water. Lowering rates, variable from about six to 70 meters per minute for the DOOM package, and length of wire out are constantly monitored from on-deck indicators. Very slow lowering rates with momentary stops are incorporated when it is suspected that the waters are so layered that small changes in depth will produce rather major changes in the optical signals. However, when a deep measurement is planned, lowering rates must be fast enough to place the package on the bottom within the time limit, a maximum of three hours, set on the interval timer. In the ship's laboratory, acoustic signals from the DOOM pinger and the ship's fathometer are recorded on a precision depth recorder. Two signals are received from the DOOM pinger, one propagated directly from the package to ship, and the other after reflection off the bottom and then to the ship. By measuring the difference in time of arrival of these signals, the distance of the package off the bottom is computed. This computation is used to stop the package at some height off the bottom, anywhere from 0 to 100 meters depending on factors such as sea state, wire angle, and bottom topography. After automatic shutdown of the DOOM instruments, the package is retrieved and secured on deck.

Post recovery operations consist of opening the instrument sphere, removing the recorder magazine with the data, and placing the batteries on a 12 hour charging cycle. An air calibration is deferred at this time until the next drop so that external mirrors may be cleaned and dried. The data recorded on photosensitive linowrit paper is developed and printed at sea. A cursory analysis of this data is made to determine if the DOOM instruments functioned properly during the drop.

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If the discrepancies are found, remedial repairs are made prior to the next evening's drop. Data are also examined for unique optical phenomena which would warrant further investigations and thus could be programmed into succeeding drops.

Factors determining the length of the total operational cycle are the 12 hour battery charge, the three to six hour measurement drop, and the constraint imposed by the night operation requirement. These factors combine to place DOOM operations on a 24 hour measurement cycle. Ship time when the DOOM package is not in the water may be spent steaming to a new station. Or it has been used by groups from other Navy Labs and universities on Navy contracts who "piggyback" and conduct independent research on a not-to-interfere basis.

## Chapter 6

### SEA TRIALS

The first successful sea trials of the DOOM system were conducted aboard the USNS GILLIS in December of 1967 in an operating area south of the Bermuda rise. Five subsequent cruises to various areas of the Atlantic, Table II, have resulted in a total of 39 measurement drops at 29 different stations as indicated in Figure 16. Measurement areas include coastal waters of the Virginia Capes, and East Florida, the basins of Northwest and Northeast Providence channels, the Gulf Stream in the Florida Straits, off the Virginia Capes, and further out at sea off New Jersey, the deep basin waters of the Hatteras Abyssal plain from the Bahamas north to New York, and the trench area from Cuba to Puerto Rico.

Cruises are nominally scheduled for about two weeks duration with perhaps 10 to 12 drops at from five to six stations. The remainder of the time is allowed for transit from port to stations, computed at the ships cruising speed of 10 knots. The number of drops per cruise has been generally less than scheduled due to a variety of reasons falling in three broad categories; (1) inclement weather (2) equipment failures, both DOOM and ship and (3) logistic difficulties. In order to prevent damage to or loss of the DOOM package during launch, lowering, or recovery, operations are conducted only when moderate to fair sea conditions prevail. Rough seas have restricted to some extent operations on all cruises. DOOM equipment failures have included the shorting of conductors in the deep sea cables, flooding of external electrical connectors, and a burnt out power inverter. The loss of a main engine and chronic problems with winches constitute the major ship equipment failures.

Each of the six DOOM cruises will be discussed separately below with regard to dates, areas, drops, data obtained and problems. Cruises are denoted chronologically by letter, the drops by number. Drop C5 would thus be the fifth drop of cruise C, the third cruise.

Cruise A departed Norfolk on 7 December 1967 aboard the GILLIS and after steaming through heavy seas arrived on station about 100 nautical miles south of Bermuda on 11 December 1967. Three drops were completed here in 4570 meters of water before

Cruise	Dates	Number of Stations	Drops	Operating Area
A	12-7-67 to 12-18-67	3	5	100 to 200 nautical miles southeast of Bermuda
B	9-15-68 to 9-27-68	4	6	450 nautical miles off New Jersey coast in and near the Gulf Stream
C	11-26-68 to 12-3-68	5	6	Florida Straits, Bahama Channels, and Atlantic Ocean just east off islands
D	3-17-69 to 4-2-69	6	6	Florida Straits, Bahama Channels, and Atlantic just east of islands
E	10-17-69 to 10-31-69	5	6	Virginia Capes, Coastal Area and Hatteras Abyssal Plain from 37N, 73W to 27N, 72W
F	1-6-70 to 1-20-70	6	10	Bahamas and south to Puerto Rico trench

TABLE II. DOOM Measurement Cruises December 1967 to January 1970

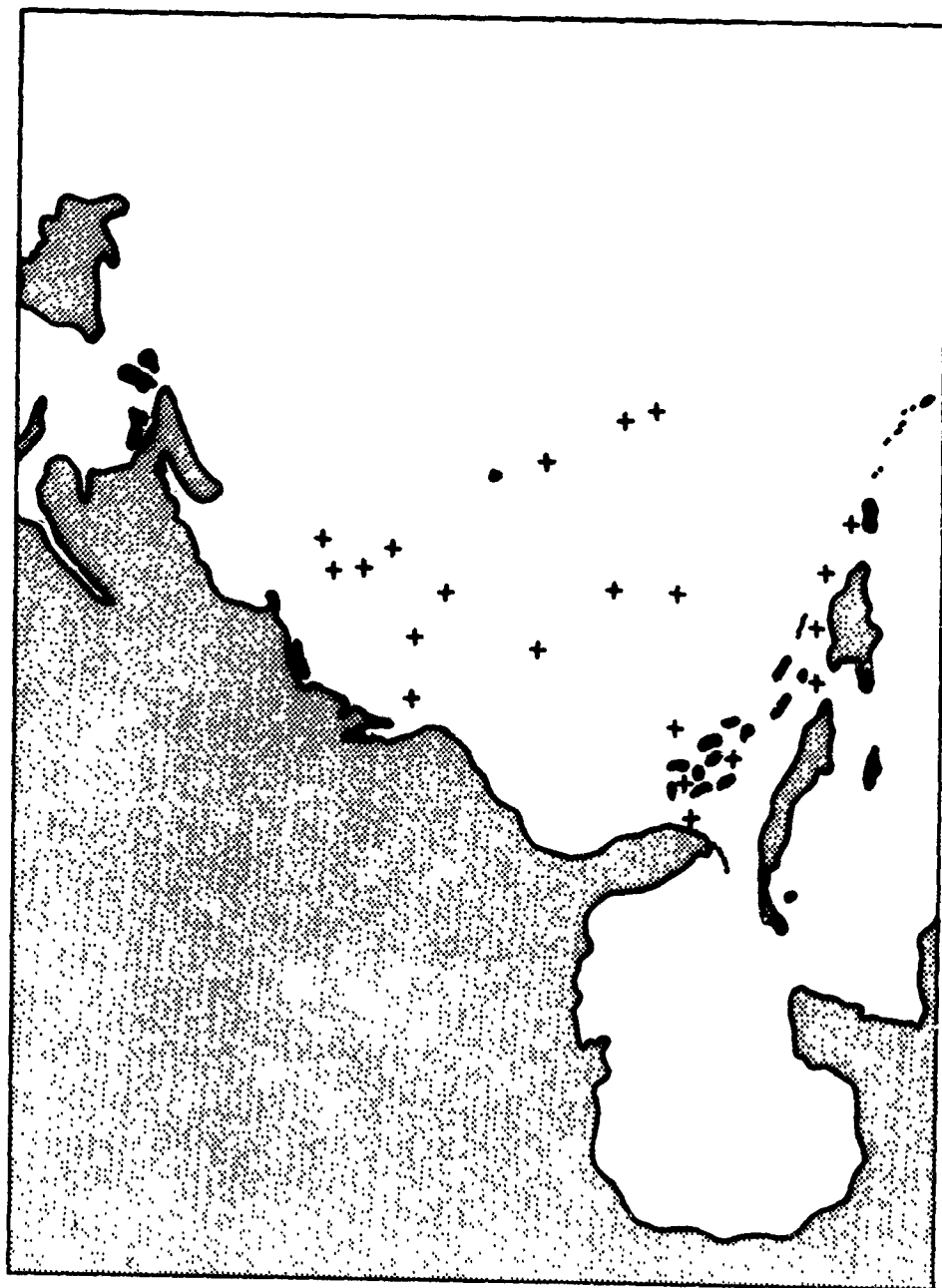


FIG.16 DOON. MEASUREMENT STATIONS THROUGH JANUARY 1970

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transiting on 14 December 1967 about 120 miles southeast to deeper water (5300 meters) where two more drops were made. A major storm blew up during the evening of the 15th forcing us to abandon the measurements and run for Bermuda, arriving on 18 December 1967.

The scattering section had not been completed in time for Cruise A so only spectral attenuation and background measurement were attempted. The first drop made in daylight resulted in receiver saturation due to the high ambient light levels for both  $\alpha$  and background signals when the package was near the surface. It was then decided to make all subsequent measurements at night. Further trouble developed during drop A1 at a depth of 800 meters when two cable conductors, carrying the background signal and +15 VDC between cylinder and sphere, were shorted, thus driving the background trace off scale on the recorder. Unfortunately this short developed only under large hydrostatic pressure so the source of this difficulty eluded us until after drop A3 when the short persisted after DOOM was surfaced. Luckily only these two conductors of the 16 in the cable were shorted. Therefore we were able to switch their signals to spare conductors allotted for the inactive scattering section and the background section was functioning again. Another casualty of DROP A1 was the pressure temperature probe which failed to function because of electronic problems in its regulated DC power supply. Repairs were trivial and the probe performed satisfactorily for the remainder of the cruise. In drop A3 during launch, the package was inadvertently slammed against the side of the ship which resulted in a shift of the  $\alpha$  section within the cylinder and a misalignment with the external optics. Thus  $\alpha$  data on this drop was lost.

Although a number of problems had developed during cruise A, it was felt that a reasonable amount of worthwhile data had been obtained. Spectral attenuation measurements had been moderately successful on all but drop A3, and significant background data was obtained on drops A4 and A5. However, reduction and analysis of this data back at the laboratory revealed that signals became markedly non-linear as the drops progressed resulting in an apparent decrease in  $\alpha$  as a function of operating time. This effect is quite evident when curves of attenuation coefficients are plotted versus depth both as the package is lowered and then raised to the surface. One would expect the "up" curve to essentially retrace the "down" curve. However, this does not occur. The measured attenuation continued to decrease after the bottom had been reached and the "up" curve tracked at a level appreciably below the "down" curve. Study of the non-linear effects failed to reveal the exact nature of the problem other than possible variations in amplifier gain as a function of temperature. Since cruise A data is subject to these errors, neither quantitative nor qualitative calculations of attenuation coefficients could be made with any degree of confidence.

A temporary manpower shortage, created when personnel were assigned to an urgent short term project, did not permit a thorough investigation of the DOOM electronic problems prior to the next cruise in September 1968, nor did it permit the completion of the scattering section. Some minor modifications were made on the electronics but it was not really expected that these would eliminate the non-linear effects. However, certain tests in-situ at sea were planned which, it was hoped, would shed some light on these difficulties. These were mainly concerned with the effect of temperature changes within the DOOM package which are induced by the inherent nature of the thermal structure of the ocean where temperature drops to near freezing at the ocean bottom. To minimize cooling effects, shallow drops were planned in the warmer surface waters. Deep drops would be made for comparison. Even if electronic problems recurred at depth, data of value would be obtained from the surface water measurements.

Cruise B was originally scheduled to depart Norfolk, Virginia on 13 September 1968 and operate at seven different stations from the shallow waters off the Virginia Capes to the depths of the abyssal plain some 450 miles east of New York, before returning to port at Bayonne, New Jersey on 27 September 1968. A group from the Naval Ammunition Depot, Crane, Indiana would piggyback on this cruise in order to test submarine markers for the USS DOLPHIN. At the last moment the port of embarkation was switched to Bayonne where sailing was delayed by two days until the 15th due to a breakdown of one of the ship's two main engines. Rough seas further delayed DOOM operations until the night of 20 September 1968. Since clearances to operate in Fleet Areas must be secured well in advance of planned operations, tests at the first three stations scheduled prior to 20 September had to be abandoned. Six drops were then made on successive days at stations about 450 nautical miles off the east coast, on both sides of and in the Gulf Stream. The ship, again the GILLIS, returned to port on 27 September.

The non-linear amplifier gain problem was still apparent and proved to be a strong function of depth (temperature) because shallow water drops remained quite stable. Repeatable attenuation data were collected during three drops to depths of 200, 300, and 600 meters. Of the remaining three drops, two were of the non-linear deep variety and the third failed due to a minor malfunction in the electronics. The background section was plagued with noise and drift problems. Perhaps half of the background data was lost due to either the signal drifting or the excessive noise which developed late in drops B4, B5, and B6.

Prior to the next cruise in November 1968, the electronics of the signal processing circuitry were completely rebuilt. The intent was to fabricate ultra stable circuitry that was

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insensitive to varying ambient parameters such as temperature and power voltages. Laboratory tests indicated that we had succeeded but the final trial remained at sea.

DOOM Cruise C departed Port Everglades, Florida on 26 November 1968, again with NAD Crane personnel aboard, for 13 scheduled days at sea. Cruise plans included stations in the Straits of Florida, the Northwest and Northeast Providence channels of the Bahamas, and two locations in the open sea due east of the islands. Drop C1 was attempted on the night of departure in shallow water just off the Florida coast in fairly heavy seas. In retrospect sea conditions were probably too rough in that the package was banged severely against the ship both during launch and recovery which resulted in misalignment of the  $\alpha$  section optics and a shift of the background zero level off scale. Although calmer seas prevailed for five subsequent drops, the DOOM system was not without misfortune. On the next drop when signal traces became quite noisy and amplifier gains non-linear, the new circuitry was immediately suspected. Post drop tests revealed that some minor adjustments were required but no gross malfunction was discovered which would account for such extreme behavior. When in-situ troubles persisted, attention was directed to the possibility of salt water leaks in the external cable assembly. Visual inspection for moisture on the face of connector inserts was inconclusive since, O-ring grooves trap water during immersion which may flow to the insert when plug and receptacle are disconnected. Connectors were cleaned, dried, and fitted with new O-ring seals, but the problems continued. Finally, the resistance from conductor to conductor within the cable decreased to measurable values, thus proving conclusively that either the cable or the connector was flooding and the source of our dilemma. Since no replacement cable was then carried on DOOM trips, operations were terminated.

After such a disastrous performance on Cruise C, it was felt imperative that all subsystems of DOOM function flawlessly in forthcoming sea trials in March 1969. The defective deep sea cable was replaced and a spare ordered which would be carried on all future tests. In addition to the normal laboratory preparations and calibrations prior to a cruise, additional tests in water were conducted in the 100 foot deep undersea weapons tank at NOL. All systems, including the completed scattering section, were performing satisfactorily until flooding occurred in the deep sea motor causing irreparable damage to that unit. Since a replacement could not be delivered before the next cruise, a fixed mirror was substituted producing a scattering measurement at a constant angle of six degrees.

Cruise D, essentially a repeat of Cruise C, was scheduled to depart Key West on 24 March 1969, proceed through the Straits of Florida and the Northwest and Northeast Providence

channels, and enter the open ocean on 28 March 1969 for deep measurements east of the Bahamas. About nine drops were planned, four in transit, four in the deep ocean, and one off the Florida coast the evening prior to entering Port Everglades on 2 April 1969.

Temporary loss of the DOOM equipment in shipment resulted in postponement of sailing until the afternoon of 27 April 1969. The initial drop that evening was aborted due to sudden mechanical failure of the A-frame. High seas in the Straits of Florida prevented operations until the calmer waters of the Northwest Providence Channel were entered in the early morning of the 29th. During pre-drop check out, the 40v battery supplying the mercury arc lamp was inadvertently shorted to ground, completely destroying the wiring to the lamp, but fortunately doing no harm to the rest of the circuitry. Consequently, only the attenuation and background sections were operating during the early morning drop D1. These, however, performed flawlessly showing no signs of electronic non-linearity which had plagued them previously. The Mercury lamp circuitry was rewired this time incorporating appropriate fusing. Three drops on successive nights of the 29th, 30th, and 31st, two in the Providence channels and the last in 3840 meter water at the mouth of the Northeast channel, resulted in good data from all three measurement sections from surface to bottom. On the night of 1 April two short drops were made off the coast of Florida opposite Fort Lauderdale, the first in the middle of the Gulf Stream, the other as close to shore as safety permitted. Both were successful.

DOOM Cruise E departed Norfolk, Virginia on 17 October 1969 aboard the USNS LYNCH for two weeks of tests in the Atlantic. Piggybacking on this trip were a group of graduate students and faculty from the Oceanography Department at the Florida State University who were to conduct on a not-to-interfere basis their own independent program of biological measurements. The only major equipment modification was the installation of the new stepper motor permitting scattering measurements from six degrees to 92 degrees. Seven stations were planned, the first in shallow water just off the Virginia Capes, the second further from shore in the Gulf Stream. From there we were to proceed southeast to a deep water station about 360 nautical miles east of Cape Fear and then track due south, occupying several stations in route, to the final operating area east of the Bahamas.

Although rough seas forced postponement of a drop the first night out, the weather cleared permitting successive drops on the following three evenings, the first in coastal waters and the succeeding two in the Gulf Stream. All sections performed quite well during drop E1. Drop E2 data was lost because of failure of the recorder lamp just prior to the package entering the water. Scattering data, now recorded as a function

of angle, looked good until a depth of about 2100 meters was reached during drop E3 where the stepping motion apparently missed a step thus confusing the angular orientation of the mirror. The torque of the motor proved to be insufficient to consistently drive the mirror when subjected to the large hydrostatic pressures of the deep ocean. On all subsequent drops during the cruise, the motor similarly malfunctioned when reaching depths of around 2000 meters. The background section also began having troubles as evidenced by a decrease in sensitivity and an increase in the noise level.

The next several days, 21 to 27 October, were characterized by rather high seas, which hindered operations to the extent that only three drops were completed at as many stations over the Hatteras abyssal plain. Minor shipboard modifications failed to correct the background and scattering problems. A peculiar accident befell the DOOM package during the final drop E6 on the 27th. At a depth of about 650 meters, it apparently struck a large object which momentarily inverted it, causing the lifting bridle wires to snarl on an appendage of the framework, thus tilting the package on its side for the remainder of the drop. The inversion also caused the misalignment of an  $\alpha$  section component and the consequent loss of data for the rest of the drop. Cruise E was terminated on 31 October at Port Everglades.

Since the next DOOM cruise was scheduled to embark from Port Everglades in early January, DOOM material was offloaded at the NOL Test Facility, Fort Lauderdale where pre-cruise maintenance and calibration were performed. Modification made at this time were (1) the replacement of the background section photomultiplier which appeared to solve our problems there and (2) increases in voltage and capacitance of the stepper drive circuitry in order to increase torque of the motor.

The primary operational area for DOOM Cruise F of January 1970 was the Brownson Deep located toward the western end of the deep trench just north of Puerto Rico. Four to Five measurement drops were planned at stations along the route during a one week transit to the trench area, via the Florida Straits and the channels north of Cuba and Hispanola. An additional five to six drops were anticipated in the Brownson Deep. Just prior to sailing on 6 January, NAVOCEANO operations requested that we not transit via our planned route due to delicate international relations prevailing in this area, but rather proceed through and swing east of the Bahamas, and enter the trough area through a passage east of Cuba. A further loss of one day was incurred when the ship was detoured to the port of Nassau to discharge a seasick technician.

A record high of ten DOOM drops were made on successive nights from 10 January 1970 through 19 January 1970 at five

different stations beginning in the sheltered sound south of Long Island in the Bahamas and terminating with five drops in the Brownson Deep. Three stations north of Hispaniola were sampled in route. A most unfortunate accident had occurred when the DOOM system was assembled for sea in Fort Lauderdale. As the end cap of the optics cylinder was replaced, several power wires carrying 28 VDC and 115 VAC were pinched and consequently shorted, resulting in seemingly catastrophic failure when DOOM was first run at sea. Although damage was repairable since fusing had protected the circuitry, some degradation of performance of certain components was evident. The background section was one of these casualties, producing virtually no usable data during the tests. Performance of the control circuit of the stepper motor was affected to the extent that on five drops a scattering measurement at only a constant six degree angle was attempted. The  $\alpha$  section functioned properly.

Only seven of the ten drops yielded usable data however due to a variety of component failures. External electrical cables flooded in one case, the recorder magazine failed to feed properly in another, and a DC power failure aborted the third. Of the seven successful measurements four were made in the deep trench and three in route. The stepper motor again failed to function properly when at depths in excess of 2000 meters.

In addition to normal surface to bottom studies, a plankton concentration - optical transmission correlation experiment was attempted on two drops. The Florida State University contingent deployed ten plankton nets, spaced every 20 meters, to a depth of 200 meters over a time interval of about 1.5 hours. DOOM was simultaneously lowered, taking care to pause for several minutes at the depths of the deployed nets. This test was performed late in the evening so that vertical migrations of the plankton with decreasing ambient light would be stabilized.

## Chapter 7

### SAMPLE DATA

The DOON program has produced moderate quantities of pertinent optical oceanographic data on transmission, scattering, and backgrounds in the ocean during five of the mix measurement cruises.

Types and amounts of reliable data obtained are summarized as follows:

(1) Spectral attenuation - surface waters during Cruise B, surface to bottom for Cruises D, E, and F.

(2) Scattering -  $\sigma(\theta)$  at six degrees during Cruise D and part of Cruise F;  $\sigma(\theta)$  from six to 90 degrees to depths of about 2000 meters for Cruise E and part of F.

(3) Background - Moderate success on Cruises A, B, and D. Illustrative examples of the above types of data which have been reduced, are now presented with comment on relevant features and some comparison to laboratory measurements.

Spectral attenuation coefficients at two wavelengths, 408  $m\mu$  in the violet and 482  $m\mu$  in the transmission window are plotted along with temperature as a function of depth in Figure 17. This data, taken in October at a station slightly north of the Gulf Stream some 450 nautical miles off the New Jersey coast, illustrates a typical attenuation profile for surface waters. Attenuation, which is fairly constant in the isothermal surface water to about 50 meters, changes quite dramatically at the thermocline, the coefficients increasing rapidly by about 40 percent before falling continuously with depth. This attenuation peak is attributed to plankton and detritus which tend to concentrate in layers above strong temperature gradients.

A deep water profile of attenuation and temperature is shown in Figure 18. This data was recorded at a station located in 3840 meter water in the Atlantic at the mouth of the Northeast Providence channel in April. After a slight peak, which again occurs at the top of the thermocline, the attenuation at 500  $m\mu$  drops to a minimum at about 500 meters and remains fairly constant at  $0.045 \pm .005 m^{-1}$  all the way to the bottom.

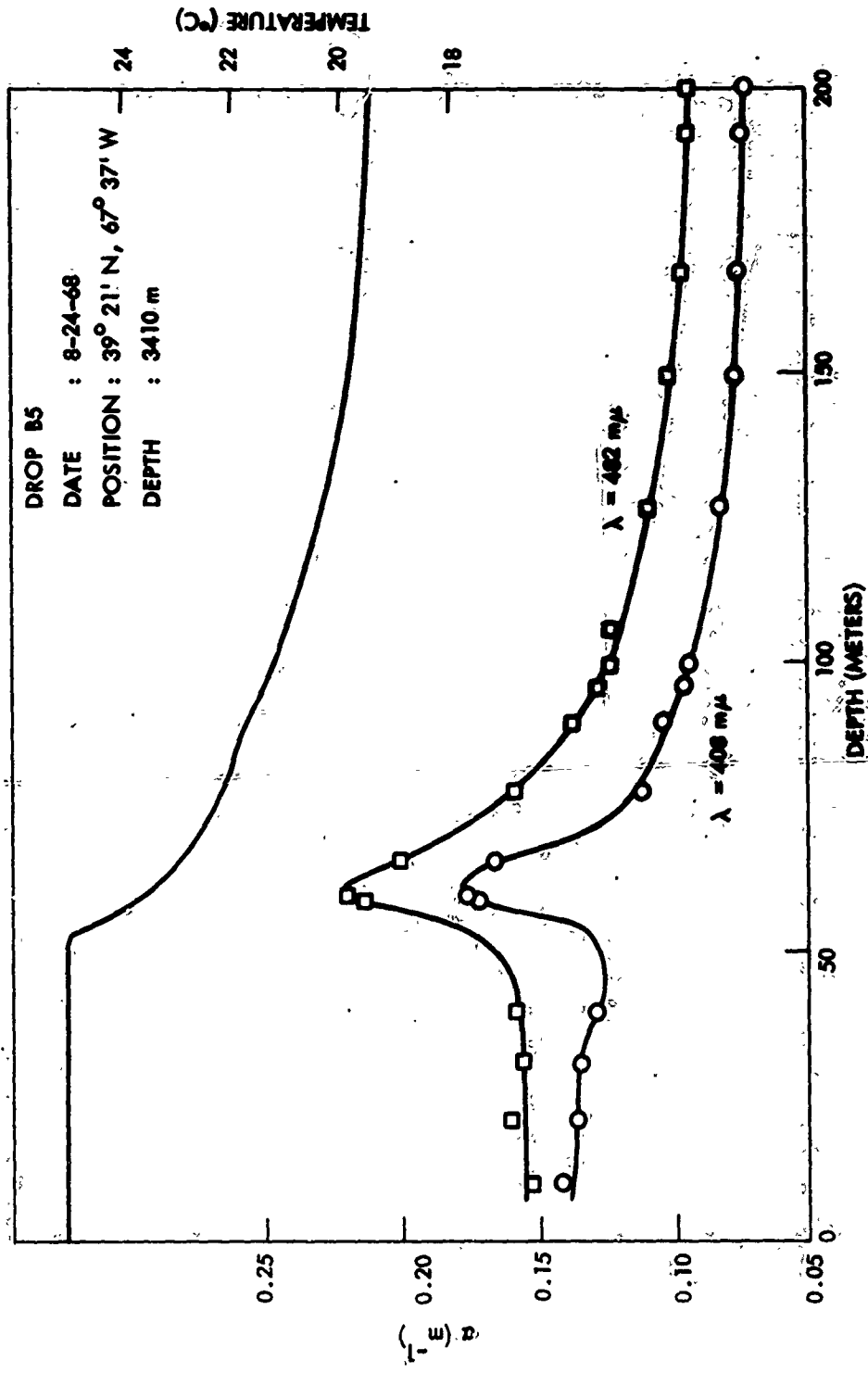


FIG. 17 OPTICAL ATTENUATION AND TEMPERATURE PROFILES OF SURFACE WATERS IN THE NORTH ATLANTIC

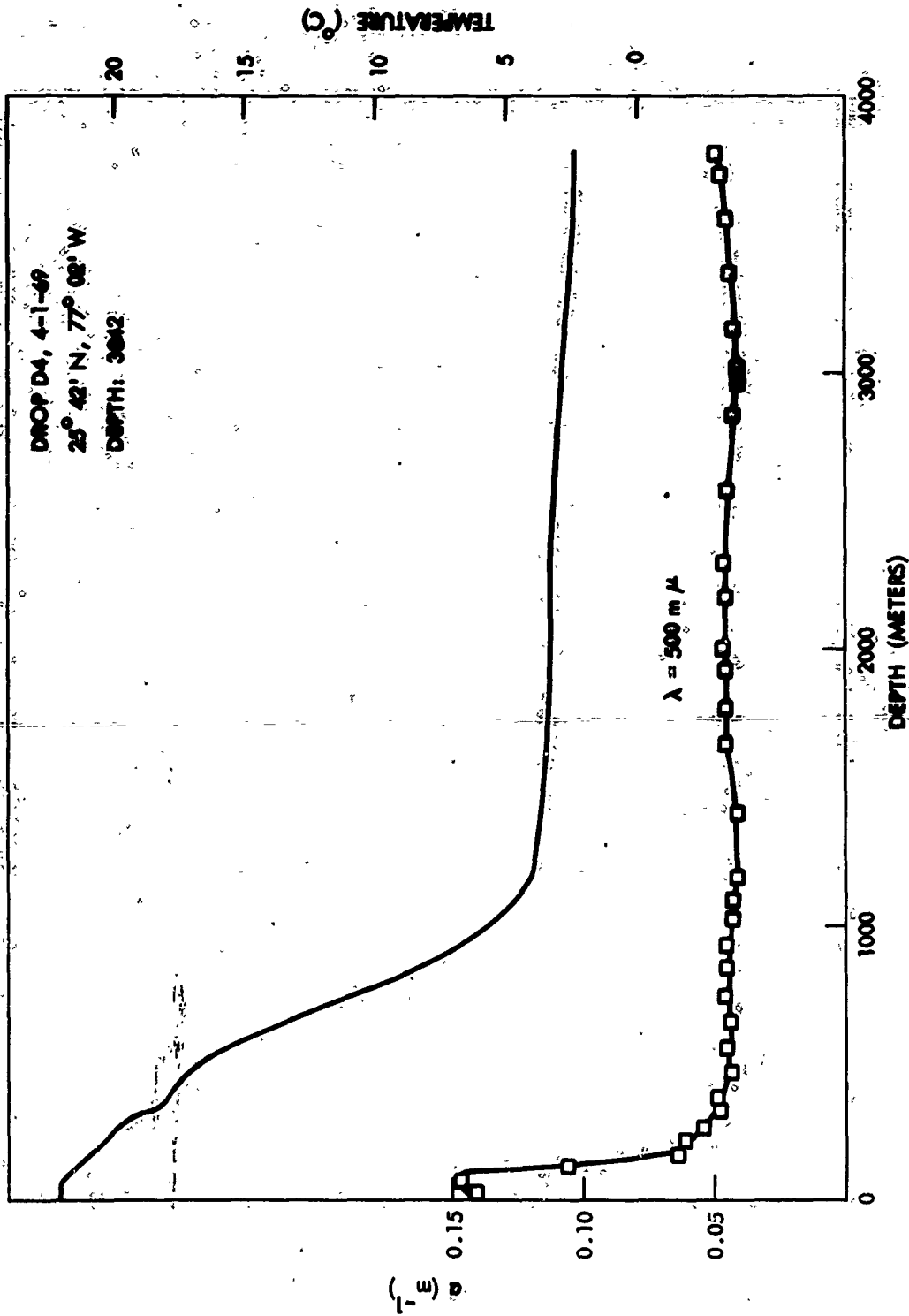


FIG. 18 OPTICAL ATTENUATION AND TEMPERATURE PROFILE EAST OF THE BAHAMAS

It is quite evident that the higher turbidity in the surface waters of the photic zone are the result of the concentration of living organisms here, primarily the phyto and zoo-plankton and their waste products.

A number of interesting features may be observed in the  $\alpha$  and temperature profiles of Figure 19 which were measured during drop E3 in the Gulf Stream off the Virginia Capes in October. Several temperature inversions were present in the stratified surface layers of the upper 150 meters shown here with an expanded depth scale. The correlation between optical clarity and temperature gradients is quite apparent. In fact on the slopes of the strongest inversion centered at about 80 meters, the transmission was so weak that the  $\alpha$  signal went off the low end of the scale of the recorder. Below the stream waters, the more or less regular temperature decrease with depth was accompanied by a similar slow decrease in  $\alpha$  reaching a minimum of  $0.048 \text{ m}^{-1}$  at about 2500 meters. At a depth of 2800 meters or about 345 meters off the bottom, the attenuation begins to increase and continually rises to  $0.066 \text{ m}^{-1}$  at 3065 meters when the package was stopped some 80 meters from the bottom. This increase in turbidity near the bottom is common in areas where deep currents stir up loose sediments and silt from the bottom.

Let us now consider the variation of attenuation as a function of wavelength. Spectra from the previously discussed Gulf Stream drop E3 are plotted at selected depths in Figure 20. Aside from the higher attenuation of the surface waters, two features of the spectra are worthy of note. There is a basic difference in the relative shape of the attenuation spectra for surface and deep water cases. For surface waters the attenuation in the blue-violet wavelength interval clearly exceeds that of longer wavelength in the yellow-green interval. The converse is true in the deep water where the coefficients at the shortest wavelength  $386 \text{ m}\mu$  are slightly below those of the longest  $555 \text{ m}\mu$ . This change in shape results in the second feature of note, the shift in location of the spectral transmission maxima. In clear waters, it falls near  $480 \text{ m}\mu$  but shifts to the longer wavelengths,  $490$  to  $500 \text{ m}\mu$ , in the more optically dense surface waters.

The most turbid waters of the ocean are found in the shallow coastal areas of the large continental land masses; those measured by DOOM were located about 35 nautical miles off the Virginia Capes during drop E1. Except for the magnitude of the attenuation which is considerably higher, the spectral curves, Figure 21, show a similarity in shape to the previous surface water measurement of the Gulf Stream. Transmission maxima are shifted to the longer wavelength, about  $500 \text{ m}\mu$ , and the short wavelength attenuation far exceeds that of the longer wavelengths. Values of coefficients at the extreme short wavelengths are not shown because signal levels, due to

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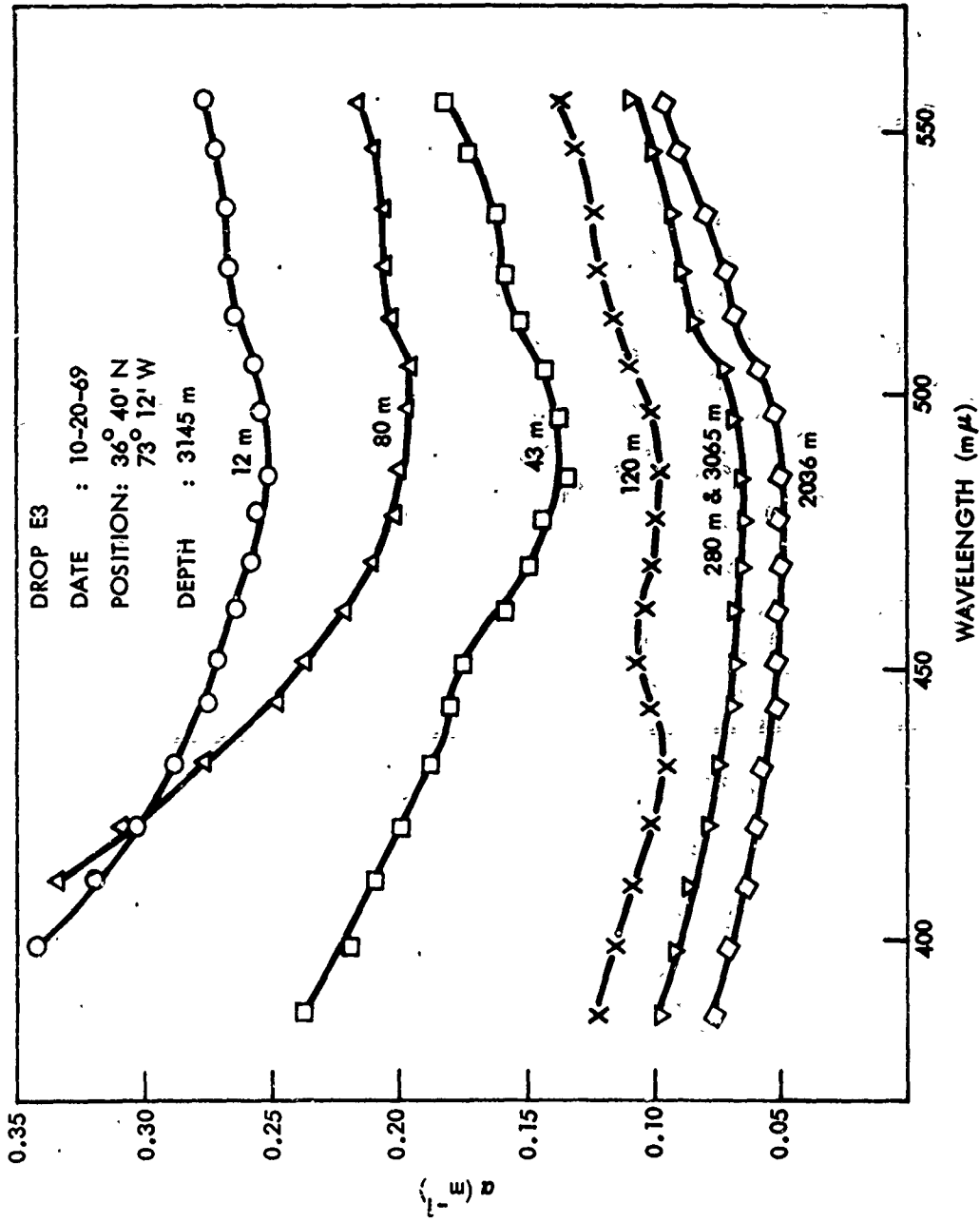


FIG. 20 OPTICAL ATTENUATION SPECTRA AT SELECTED DEPTHS IN THE GULF STREAM OFF THE VIRGINIA CAPES

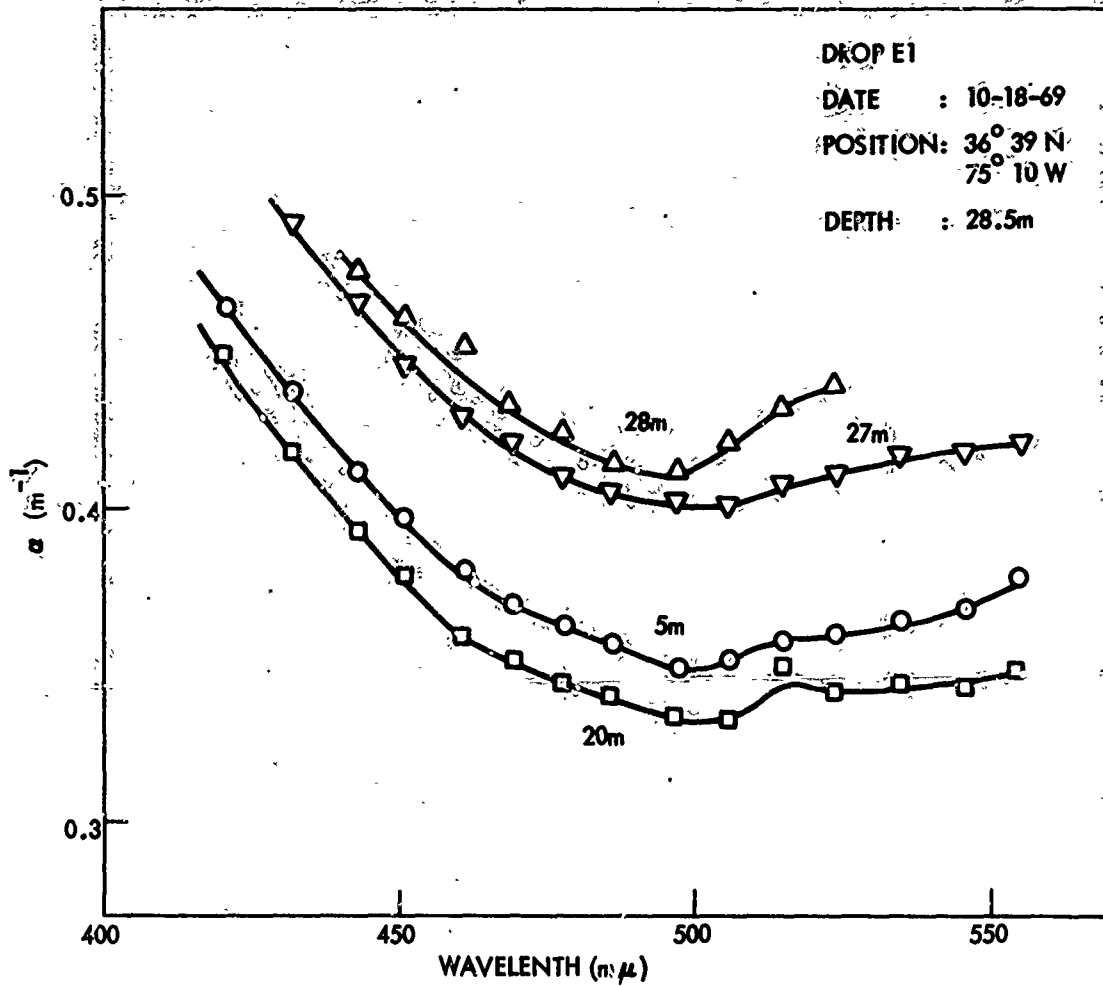


FIG. 21 OPTICAL ATTENUATION SPECTRA AT SELECTED DEPTHS IN COASTAL WATERS

high turbidity, were so low that they fell off the low end of the recorder scale.

In contrast to the coastal and surface waters, the intermediate layers extending to great depths in the oceans, are remarkably optically clean, surpassing in some spectral regions even the purest produced in the laboratory. In Figure 22 are contrasted spectra of deep in-situ measurements of drop E5 over the Hatteras Abyssal plain east of Cape Kennedy, Florida with those of pure water produced in the laboratory by three separate investigators. The in-situ spectrum at 2040 m, typical of the clear water column for this drop, falls below those measured in the laboratory at wavelengths shorter than the window region at  $480 \text{ m}\mu$ , indicating a clearer, more transparent medium from the ultraviolet through the blue than has been produced or at least measured in the laboratory. The only close measurement is that of Sullivan, of recent origin, and perhaps this points out the extreme difficulty of artificially producing scatter-free water. The trend of deep ocean waters to be relatively cleaner at the shorter wavelengths can also be seen in the spectrum recorded 300 meters from the bottom at 4660 meters. Although attenuation coefficients are from  $0.03$  to  $0.04 \text{ m}^{-1}$  higher than the clearer in-situ water, the spectral shape remains roughly the same and at the short wavelengths, below  $400 \text{ m}\mu$ , is below the laboratory measurements of Hulbert and Matlack.

Scattering data may be presented in a manner similar to the attenuation profile, as in Figure 23, where the volume scattering function at an angle of six degrees is plotted as a function of depth. Also included is a plot of  $\alpha$  at  $432 \text{ m}\mu$  near the wavelength ( $436 \text{ m}\mu$ ) of the scattering measurement which is used in the calculation of  $\sigma(\theta)$ . This data was taken during drop D3 in March in the Northwest Providence channel. An expanded depth scale is used in the first 400 meters. Since scattering is one of the mechanisms contributing to the attenuation process, one might expect the scattering function to vary in a manner similar to the attenuation. And indeed it does at most depths; the maxima, minima, and slopes of the two curves nominally following one another. The exception occurs between 400 and 600 meters where  $\alpha$  begins to slowly increase while  $\sigma(6^\circ)$  continues to decrease before starting a slight rise at 650 meters. It must be concluded then that this increase in  $\alpha$  is due to absorption by dissolved impurities rather than by an increase in scattering from particulate matter.

Scattering data may also be presented as a function of scattering angle as in Figure 24 where the volume scattering function at  $436 \text{ m}\mu$  is presented for an in-situ measurement from drop E1 in coastal waters off the Virginia Capes. For comparison laboratory measurements of regular and filtered tap water are also included. The angular range of the in-situ function extends only from six degrees to  $48^\circ$  because extremely low

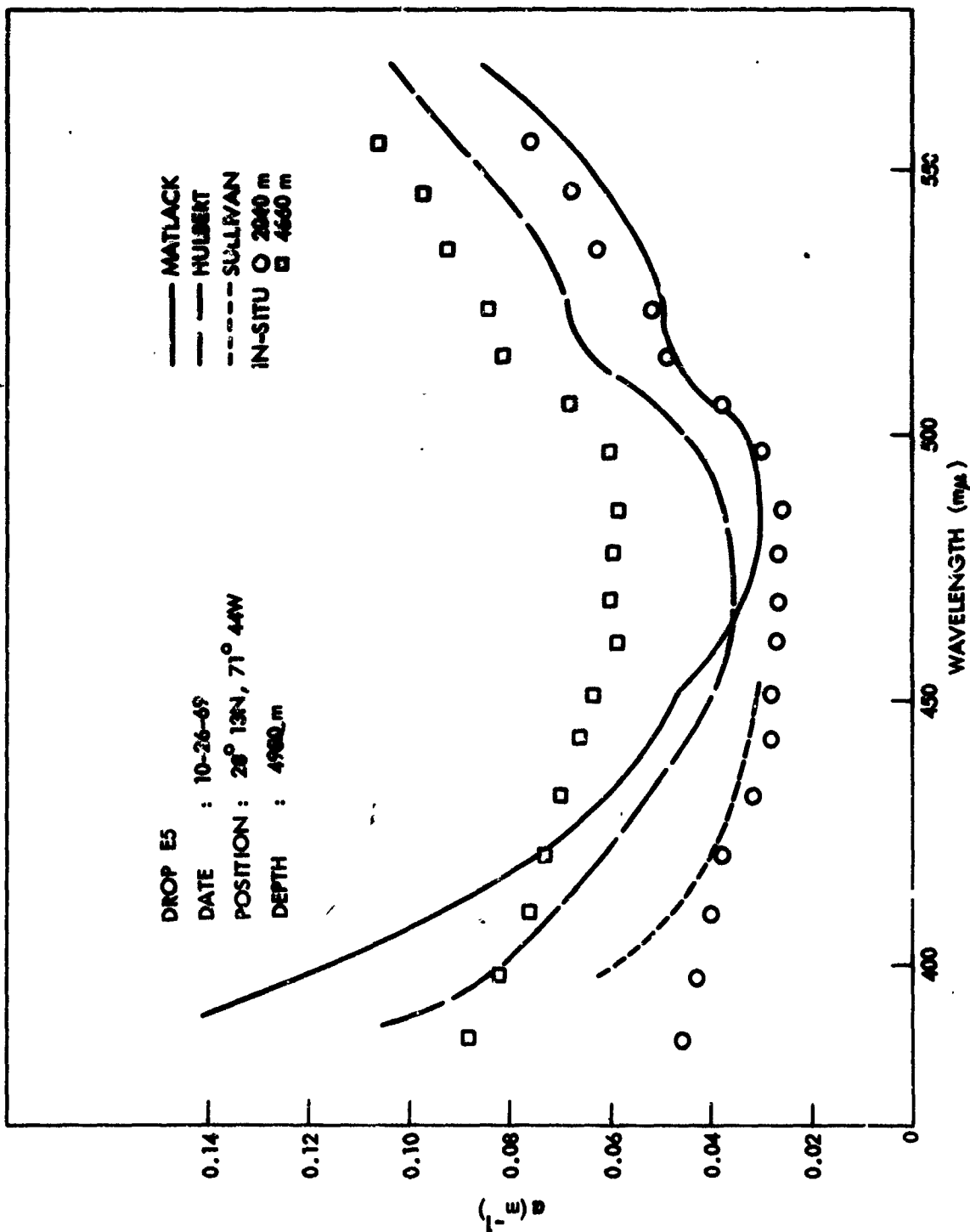


FIG. 22 COMPARISON OF SPECTRAL ATTENUATION COEFFICIENTS OF PURE AND NATURAL WATERS

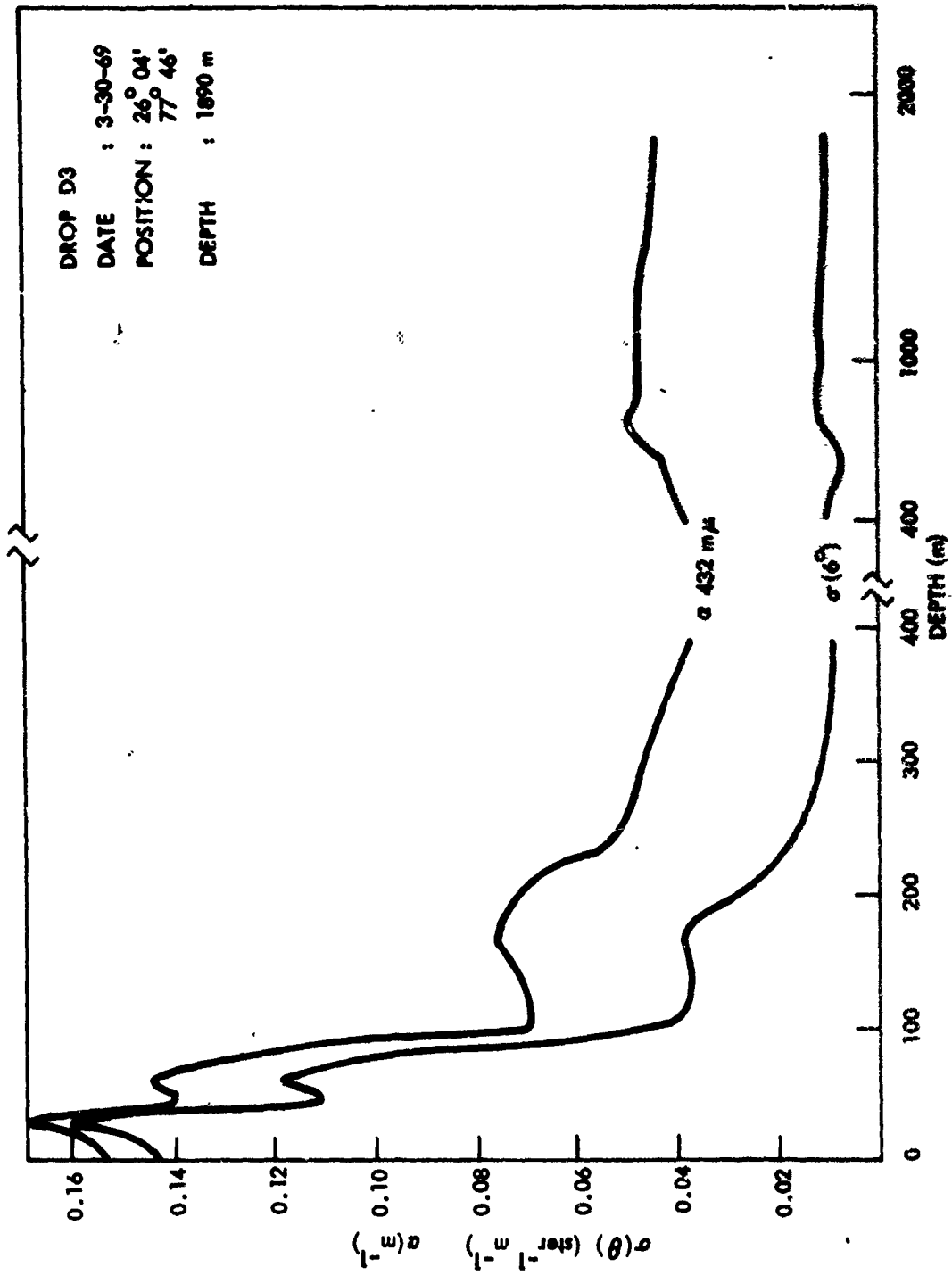


FIG. 23 OPTICAL ATTENUATION AND SCATTERING PROFILES IN THE NORTHWEST PROVIDENCE CHANNEL

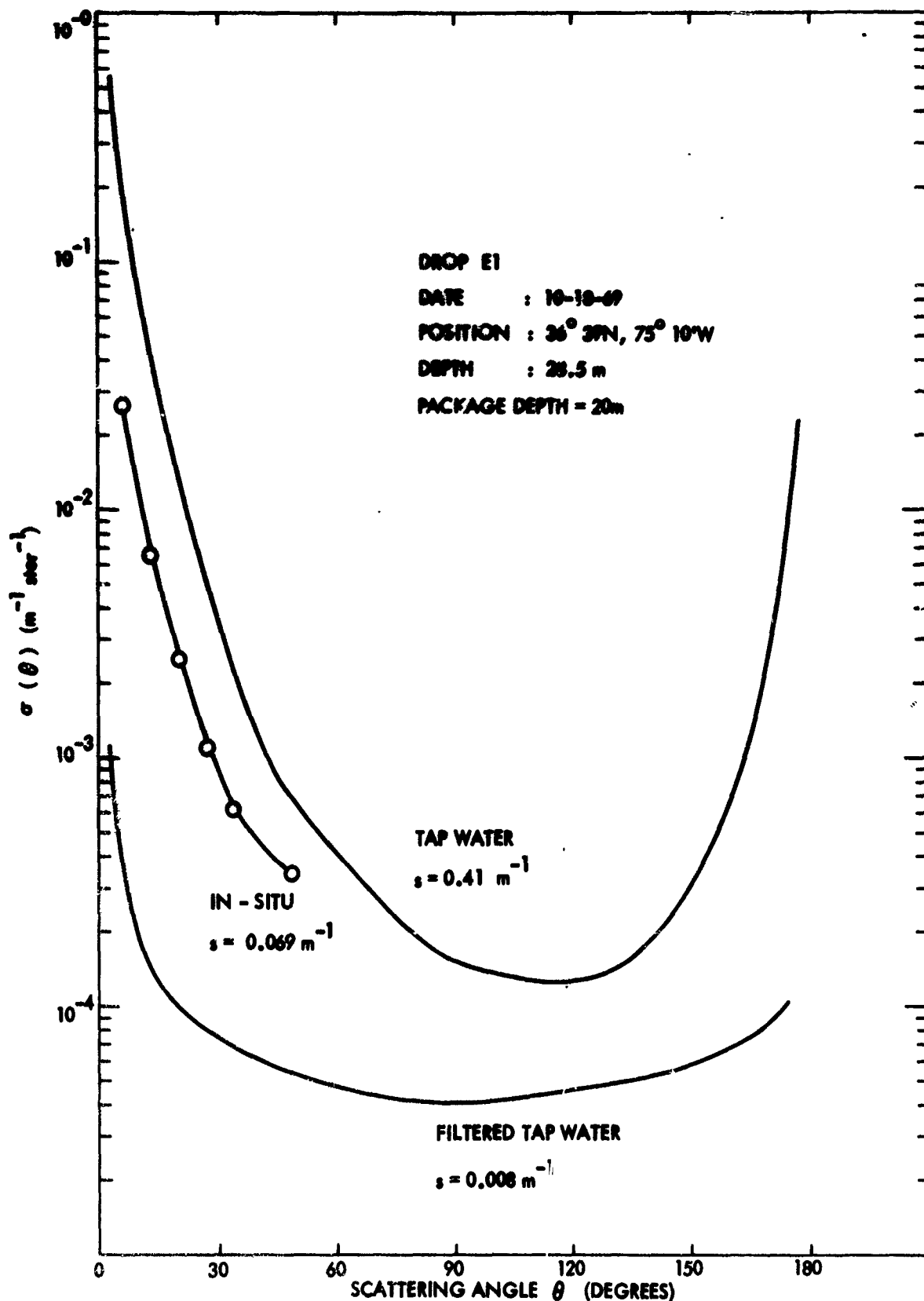


FIG. 24 COMPARISON OF IN-SITU AND LABORATORY MEASUREMENTS OF THE VOLUME SCATTERING FUNCTION AT 436 m $\mu$

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signal levels at larger angles fall below the linear range of the logarithmic amplifier. This rather turbid coastal water produces a curve which falls between regular and filtered laboratory samples, indicating perhaps very strong particulate scattering in city water supply. To obtain the total volume scattering coefficients the function must be integrated from zero to 180 degrees; but our measurement is from only six to 48 degrees. If we examine the function for tap and other natural water measurements, we find that the smaller angles below 48 degrees contribute over 90 percent of the total area beneath the curves. Applying a ten percent correction to the in-situ integration, an  $s$  of  $0.069 \text{ m}^{-1}$  is obtained. This constitutes about one-sixth of the attenuation coefficients which was measured at  $0.41 \text{ m}^{-1}$  and would lead to the conclusion that attenuation was due primarily to absorption by yellow substance or other dissolved impurities.

The background measurement is a passive qualitative reception of sporadic signals and, therefore, does not lend itself to concise analytical presentation. Rather, the data must be evaluated on a statistical basis and correlated with the other optical and physical parameters which are recorded. A sample of raw data showing a high incidence of luminescent flashing is presented in Figure 25. These traces were recorded during drop B5 in the Atlantic north of Gulf Stream about 450 nautical miles east of New Jersey. They are slightly over one minute in length in order to include the complete background data recording interval with two shutter closures and a complete  $\alpha$  spectrum which at this time was scanned at a one per minute rate. Real time is determined from the two-second markers, starting from the left at the  $\alpha$  spectrum turn-around at 1924:00. During the time interval of this record, the package was lowered a distance of about six meters, from a depth of 60 to 66 meters. A strong irregular temperature gradient is observed on the bottom temperature trace beginning around 1924:38.

Even though the measurement was made after dark, a sizable ambient background signal is present at this depth above the dark current level observed during the shuttered period. The rate of recorded flashings appears to increase somewhat from less than one to perhaps several spikes per second when the gradient is entered. Frequency of flashing is presumably proportional to the number of luminescent organisms within the field of view while the magnitude of the flashes will vary due to a number of factors, i.e., proximity, radiance, size, and position within the field of view. In this region of high luminescent activity, attenuation is severe and spectral signals fluctuate rather rapidly as can be seen from times 1924:45 to 1925:00. To illustrate the rippling effect that luminescent plankton have on the attenuation measurement, a second record taken nine minutes later at a depth of 100 meters is presented. Figure 26. Only occasional spiking is observed and the ambient illumination is at the dark current level.

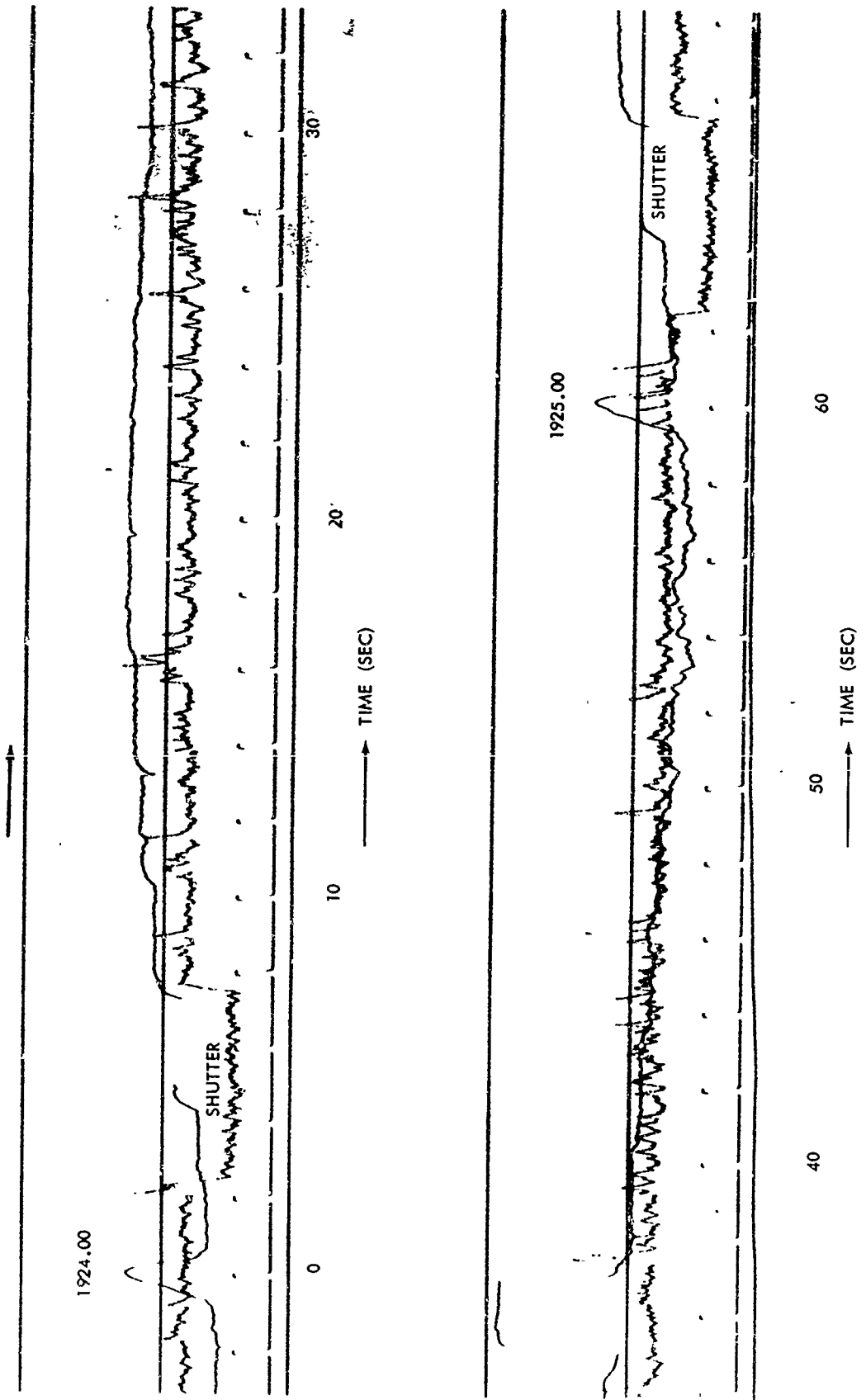


FIG.25 BACKGROUND DATA IN A TEMPERATURE GRADIENT SHOWING A HIGH INCIDENCE OF LUMINESCENT FLASHING

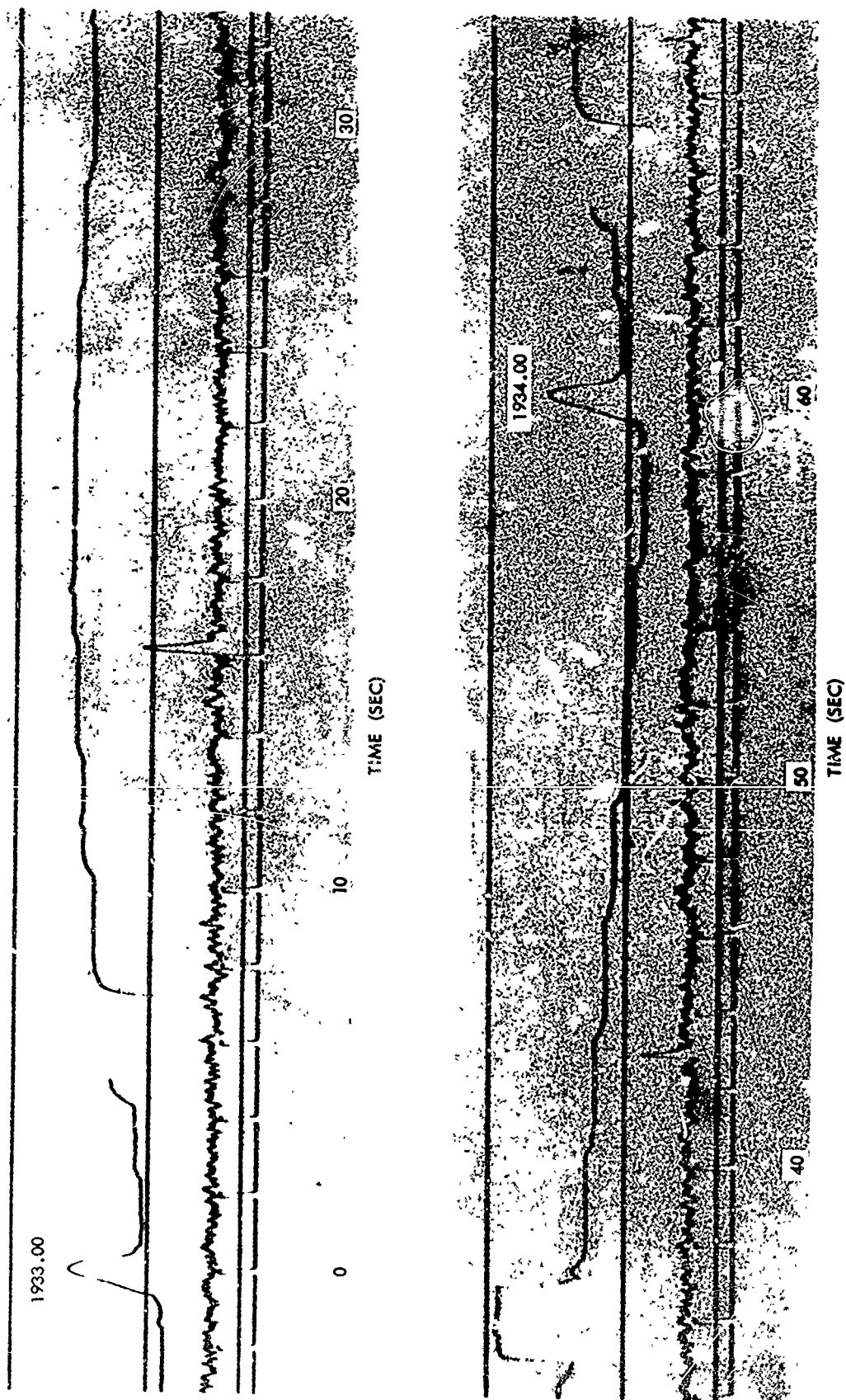


FIG. 26 BACKGROUND DATA FROM ISOTHERMAL WATER SHOWING A LOW INCIDENCE OF LUMINESCENT FLASHING

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It is seen that the  $\alpha$  signal is higher and much smoother. The coefficient at 482  $m\mu$  has a value of  $0.095 m^{-1}$  as compared to  $0.170 m^{-1}$  at 60 meters. A correlation is indeed established between attenuation and the population of luminescent plankton.

## Chapter 8

### FUTURE PLANS

This report has described and summarized the DOOM effort to date with emphasis on equipment and the data gathering processes rather than on data presentation and analysis. The reasons for this emphasis are two-fold:

(1) The DOOM effort has been concentrated on developing a seaworthy system that will reliably produce the quality of optical data which we desire and then on operating that system in the field so as to amass a representative sampling of transmission phenomena of ocean waters.

(2) Much of the raw data has not been processed due to manpower limitations and thus the quantity of data reduced to date is not sufficient for rigorous analysis and interpretation. Data reports with appropriate analysis, will follow as the processed results become available.

Field measurements will continue in FY 1971 and FY 1972 with three proposed cruises which should complete the survey of Atlantic Ocean waters. The first cruise will sample Caribbean waters in the vicinity of the Bartlett Deep in February and the second will investigate the plankton-rich waters south of Nova Scotia and Laborador in May-June 1971. Still in the planning stage is a final measurement cruise to the Mediterranean in March or April 1972. Although no commitments have been made past FY 1972, interest exists in exploring other ocean areas, namely the Arctic beneath the ice caps and possibly some regions of the Pacific or South Atlantic.

No major modifications to the DOOM system nor in measurement techniques are anticipated in future studies. However, additional physical and biological sampling of ocean parameters concurrent with DOOM operations may be desirable. Such data might include salinity and dissolved gas determinations, or chemical analysis of organic absorbing elements.

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REFERENCES

- (a) D. E. Matlack, H. A. Templin, and W. W. Talbert, "Transmission of Green Laser Light (5300Å) through Water," NOLTR 64-179, 18 Sep 1964
- (b) G. L. Knestrick, J. A. Curcio and A. G. Rockman, "Underwater Attenuation of Laser and Non-laser Light," NRL Report 6181, 1964
- (c) Howard J. Okoomian, "Underwater Light Measurements at David Taylor Model Basin," Ultrasonic Imaging and Pulsed-gated Light," Dec 1965
- (d) D. E. Matlack, "The Transmission of Laser Light Through Water," "Ultrasonic Imaging and Pulsed-gated Light," Dec 1965
- (e) R. W. Sawyer, "The Spectral Absorption of Light by Pure Water and Bay of Fundy Water," Contributions to Canadian Biology and Fisheries, New Series Vol. VII, No. 8 (1931)
- (f) G. L. Clarke and H. R. James, "Laboratory Analysis of the Selective Absorption of Light by Water," J. Opt. Soc. Am. 29:43 (1939)
- (g) Burt, W. V., "Selective Transmission of Light in Tropical Pacific Waters," Deep Sea Research, 5:51-61, 1958
- (h) Hulburt, E. O., "Optics of Distilled and Natural Water," J. Opt. Soc. Am., 35:698-705 (1945)
- (i) Tyler, J. E., "Scattering Properties of Distilled and Natural Waters," Limnology and Oceanography, 6:451-456, 1961
- (j) Jerlov, N. G., "Optical Oceanography," Elsevier Publishing Co., 1968
- (k) G. G. Neuymin, et al "Some Results of Optical Investigation in the North Atlantic," Soviet Oceanography Transactions, American Geophysical Union, 1964 Series, Issue No. 1
- (l) J. E. Tyler & R. W. Preisendorfer, "The Sea Volume 1, Physical Oceanography, Interscience Publisher, 1962
- (m) Sullivan, S. A., "Experimental Study of the Absorption in Distilled Water, Artificial sea Water, and Heavy Water in the Visible Region of the Spectrum." J. Opt. Soc. Am. 53:962-967, 1963
- (n) Rayleigh, "On the Scattering of Light by Small Particles," Phil Mag. 41:447-454 (1871)
- (o) Smoluchowski, M., 1908 "Molekulav-kinetisch Theorie der Opaleszenz von Gasen im Zustande," sowie einiger verwandten Erscheinungen. Am. Physik, 25:205 1908
- (p) Einstein, A. 1910 "Theorie der Opaleszenz von homogenen Flussigkeiten und Flussigkeitssystemen in der Nahe des Kritischen Zustandes," Am. Physik, 33:1275 (1910)
- (q) Tyler, J. E., "Measurement of the Volume Scattering Function of Hydrosols," J. Opt. Soc. Am., 50:505A (1960)
- (r) Le Grand, Y., "La Penetration de la Lumiere Dans la mer," Am. Inst. Oceanography, 19:393-436 (1939)

UNCLASSIFIED  
NOLTR 70-165

- (s) Seibert Q. Duntley, "Light in the Sea," J. Opt. Am. 52:214-233, 1963
- (t) Clarke, G. L. and Denton E. J. "The Sea," Vol. 1, Physical Oceanography, Interscience Publishers, 1962
- (u) Kampa, E. M. and Boden B. P. "Light Generation in the Sonic Scattering Layer" Deep Sea Research 4:73-92 (1957)
- (v) Clarke, G. L. & Hubbard, C. J. "Quantitative Records of Luminescent Flashing of Oceanic Animals at Great Depths," Limnol & Oceanography, 4:163-180 (1959)
- (w) Clarke, G. L. and L. R. Breslan "Studies of Luminescent Flashing in Phosphorescent Bay, Puerto Rico, and in the Gulf of Naples using a Portable Bathyphotometer."
- (x) Neshyba, S. "Pulsed Light Stimulation of Marine Bioluminescence in situ," Limnology & Oceanography 12(2):222-235 (1967)

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13. ABSTRACT  A shipborne system is described and results of in-situ measurements of the inherent optical properties of ocean water are presented. This Deep Ocean Optical Measurement (DOOM) system is designed to measure to any depth in the ocean spectral attenuation coefficients from 380 to 560 millimicrons, the volume scattering function at 436 millimicrons through an angular range from six to 92 degrees, and background illumination of both celestial and biological origin. Representative data obtained from December 1967 through January 1970 on six measurement cruises to various areas of the Atlantic are presented. Future cruises and plans are discussed.		

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Spectral attenuation measurement of ocean water Light scattering measurements of ocean water In-situ optical measurements Deep ocean optical measurements Underwater light transmission optical oceanography						

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It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).  
  
There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.
14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.