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NRL's Deep Sea Floor Search ERA — A Brief History of the NRL/MIZAR Search System and Its Major Achievements

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

NRL's Deep Sea Floor Era began in 1963 when, in response to the loss of the nuclear submarine THRESHER, a small team began developing the instruments and methods to search the deep ocean floor. After photographing THRESHER in 1964 the team helped locate and recover an H-bomb in 1966. In 1968 the team located the sunken submarine SCORPION, in 1969 they found and helped recover the submersible ALVIN and in 1970 they found the French submarine EURYDICE. Five times between 1970 and 1974 they photographed the nerve-gas-laden LE BARRON RUSSELL BRIGGS and collected water samples above her deck at a depth of three miles.

The converted cargo ship MIZAR (T-AGOR-11) was the key surface platform in these missions. Her NRL-designed center well permitted towing a suite of instruments from the center of pitch and roll. Three hull-mounted hydrophones, a transponder on the sea floor and a responder on the instrument suite were the

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elements of an underwater tracking system. Cameras, strobe lights, magnetometer and side-looking sonar were the prime search instruments. A multiple water sampler and a biological trawl were added for environmental missions. A development of the search team called LIBEC, for Light Behind Camera, expanded the areal coverage of conventional underwater cameras by sixty times. The Era essentially ended when sponsorship for MIZAR was transferred to the Naval Sea Systems Command in early 1975.

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NRL'S DEEP SEA FLOOR SEARCH ERA — A BRIEF HISTORY OF THE NRL/MIZAR SEARCH SYSTEM AND ITS MAJOR ACHIEVEMENTS

INTRODUCTION

On April 10, 1963, the nuclear submarine THRESHER (SSN 593) sank in the North Atlantic. Because there was no clue to the cause of the sinking the Navy wanted to see what could be learned by examining the wreckage on the bottom. The event was a turning point in Navy and civilian oceanography because it called attention to the lack of any real capability to methodically search and inspect the deep ocean floor. Tremendous progress was made during the next decade with the Naval Research Laboratory taking the lead role. Under Chester L. Buchanan a small team of NRL ocean engineers and scientists, with unselfish cooperation from many organizations, developed the methods and instruments necessary to successfully search the deep ocean. The hidden abyss could at last be examined and mapped in great detail.

By 1970 NRL was able to routinely photograph an entire cargo ship (the 274-ft-long LE BARRON RUSSELL BRIGGS) while selectively capturing sea water samples several yards above her deck in water one whole mile deeper than at the TITANIC site.

The purpose of this report is to document the history of NRL's Deep Sea Floor Search Era. Highlights of the most important search missions have already been documented in articles written in laymens terms mainly for NRL's Annual Review. Reprints of these articles are assembled in chronological order here with new text that provides continuity and corroborative detail.

HISTORICAL OVERVIEW

Prior to 1970 Buchanan's team had photographed the THRESHER wreckage in 1964, helped locate and retrieve the H-bomb lost in the Mediterranean Sea in 1966, located and photographed the lost nuclear submarine SCORPION in 1968, and found and helped retrieve the research submersible ALVIN in 1969. A key element in those searches was the USNS MIZAR, an ex-Air Force cargo ship that was redesigned by NRL to serve as a unique research vessel. Long before THRESHER sank, Buchanan's researchers in NRL's Sonar Systems Branch were probing the ocean depths with huge sonars towed through a center well. Such a well was built into MIZAR's number two cargo hold; her second deck was converted into an operations center with staterooms added for the scientific crew. A heavy suite of instruments could now be lowered (or raised) in a controlled fashion on vertical rails to a tow-point near MIZAR's center of pitch and roll. This not only reduced the surface wave motions imparted to the tow cable but extended operations into periods of high sea state that would shut down operations aboard conventional research vessels.

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With the help of Dr. Stanley Murphy, Applied Physics Laboratory, University of Washington, Seattle, Buck's group installed three tracking hydrophones on MIZAR's hull - a new approach to deep-sea-floor navigation. The old Navy GERTRUDE (underwater telephone) then permitted MIZAR to also become a surface guidance system for submersibles such as the Navy's TRIESTE. MIT's renowned Dr. Harold T. Edgerton, explained the use of his underwater camera, strobe light and pinger. By adding a crude telemetry system to turn the cameras on and off crucial bottom time could be extended. The HRB Singer Company gave Buchanan an underwater magnetometer. It was a new model with a large donut-shaped sensor but its output was unstable. By making a smaller sensor from part of a childs toy the signal levels were brought under control and crisp magnetic anomalies were recorded as the towed system passed over parts of THRESHER. Hudson Laboratories of Columbia University sent blueprints of their latest side-looking sonar and a temporary circuit mounted on a 1" x 3" piece of wood. This permitted NRL's search swath width to be extended by hundreds of yards.

With the scuttling of the nerve-gas-laden cargo ship BRIGGS in 1970, the search system became a more scientific tool with the addition of a multiple water sampler. Water and photographs were collected in five annual visits to the site to answer environmental contamination questions. Additional Deep Water Dump Sites were investigated in the same time period with the addition of a biological trawl towed from the instrument package. Cameras oriented to look back at the mouth of the trawl monitored its performance, while bottom-oriented cameras photographed sea floor animals directly in its path.

During the early '70's efforts to extend bottom photo coverage culminated in the LIBEC (Light-Behind-Camera) system. By separating the camera from the region of intense backscatter near the light source photographs could be taken 20 to 25 meters above the bottom. The resultant image covered an area fifty times that of conventional cameras. In 1973 LIBEC was used to survey the Median Rift Valley of the Mid-Atlantic Ridge in support of Project FAMOUS (French-American Mid-Ocean Undersea Study). The additional perspective resulted in single images of linear fissures which paralleled the sides of the Rift Valley. The photographs added dramatic evidence for divergence of the crustal plates attached to the continents of North America and Africa.

During the time interval from June 1964 through September 1974, the NRL/MIZAR team participated in 39 Deep Sea Search missions. These are summarized in Table I which lists the date, location, depth, and objective for each. The table also documents the number of seafloor photographs collected on each mission. If the 1963 cruises on USNS GILLISS are included the total number of photographs exceeds three quarters of a million.

TABLE 1

NRL/MIZAR DEEP SEA SEARCH MISSIONS

CRUISE	MONTH	YEAR	MISSION	LOCATION LAT	LONG	DEPTH (M)	PHOTOS	OBJECTIVE
*	4 - 9	1963	THRESHER	41°44'N	64°56'W	2560	40,000	S/G
1-10	6 - 9	1964	THRESHER	41°44'N	64°56'W	2560	70,000	I/G
11	11	1964	BERMUDA	32°14'N	64°58'W	3750	3,000	I
12-13	2	1965	BAHAMAS	24°30'N	77°30'W	2000	26,000	S/I
14	2	1966	BERMUDA	32°14'N	64°58'W	4000	3,800	I
15	3	1966	H-BOMB	37°14'N	01°44'W	800	65,175	S/G/R
16	9	1967	AZORES	37°00'N	25°40'W	3000	18,900	I
17	5	1968	BLAKE PLATEAU	30° N	79° W	650	7,500	I
18-21	6 -11	1968	SCORPION			>3000	140,000	S/I
22	6	1969	CHASE 8/11	39°37'N	71°00'W	2130	2,000	S/I
22,23	6, 8	1969	ALVIN	39°52'N	69°12'W	1550	38,500	S/I/R
22	7	1969	THRESHER	41°44'N	64°56'W	2560	15,000	I
24	11	1969	ST. CROIX	17°50'N	64°50'W	3800	20,000	S/R
25	4	1970	EURYDICE	43°04'N	06°46'E	1100	50,900	S
26	5	1970	MINERVE	42°53'N	05°47'E	2200	52,100	S
27	10	1970	BRIGGS	24°23'N	75°58'W	5010	16,600	S/I
28	6	1971	BRIGGS	24°23'N	75°58'W	5010	7,500	I
29	11	1971	MONAHAN	31°40'N	76°56'W	2300	51,000	S
30,32	4, 7	1972	AREA "A"	39°37'N	71°00'W	2160	82,700	S/I/T/R
31	6	1972	BRIGGS	24°23'N	75°58'W	5010	2,700	I/T
33	3	1973	IRISH OPS	53°00'N	15°00'W	2500	16,000	B/I
34	6	1973	BRIGGS	24°23'N	75°58'W	5010	4,000	I/T
35	10	1973	FAMOUS	36°49'N	33°15'W	2500	5,250	I/T
36	11	1973	EASTLANT I	43°00'N	13°00'W	2000	28,400	B/I
37,39	4, 9	1974	EASTLANT II,III	43°00'N	13°00'W	2000	10,900	B/I
38	8	1974	BRIGGS	24°23'N	75°58'W	5010	200	I/T

* EPCER ROCKVILLE (SONAR SEARCH), USNS GILLISS (PHOTO SEARCH)
OBJECTIVES: S = SEARCH, I = INSPECT, R = RECOVER, G = GUIDE, B = BATHY, T = TEST

BEFORE THRESHER

Underwater sound research had been conducted at NRL since its inception in 1923. Spurred by the need to give the Navy better means to detect submarines, the Sound Division continued to grow and produce advances just as it does today as the Acoustics Division. In the early 1950's research was directed towards increased detection ranges. This called for lower frequency and larger transducers.

The effects of temperature and pressure in the ocean combine to form a sound channel at about 1000 meters [1] where sound speed reaches a minimum. This causes sound rays to bend in towards the channel trapping the rays and extending sonar transmission to maximum ranges. To fully explore the effect Buchanan's Sonar Systems Branch was funded to tow experimental acoustic arrays in the ocean's deep sound channel. In 1953 NRL was assigned the LSM, USS HUNTING (EAG-398) to tow such an array. Because the tow body housing the array was so immense (28 by 10 by 9 feet and 15 tons), it had to be launched and retrieved through a specially constructed center well. The Branch continued towed acoustic experiments in the ocean to as deep as 15,000 feet until 1959 [2]. Then an unfortunate error made during shipyard repairs caused an engine failure aboard HUNTING that was deemed too expensive to repair. This left Sonar Systems without a research vessel.

In the early '60's Buchanan's Branch shifted their attention to environmental effects on underwater sound. Towards that end, two underwater viewing systems were obtained during the early months of 1963. A conventional underwater system comprising a pinger, a strobe light and two cameras were purchased from Edgerton, Germeshausen and Grier, Inc. A slow-scan television camera was obtained from NASA.

Thus it was that a group assembled to perform one type of research was accidentally available and equipped to begin another. The few other laboratories that could have gone on to do much the same thing were already committed to other work. The early success of Buchanan's group and the flexible nature of NRL's mission were key elements in their continued support.

THE THRESHER SEARCH

One week before the tragic loss of THRESHER the NASA television camera was demonstrated to NRL's Commanding Officer Captain Bradley F. Bennett. The video signals were transmitted through 23,000 feet of cable wound on a big drum outside Buchanan's office. During a dinner party on 10 April Bennett learned that THRESHER had sunk in waters greater than 8,000 feet deep. That evening he telephoned Buchanan and suggested that his unique capability would probably be needed in the morning. Sleep was impossible for Buchanan that night. He stayed up planning a two-phase search operation and had a hand-written copy of the plan on the C.O.'s desk before 8 a.m. While a better copy was being typed the Captain called Buchanan with the short phone message, "Go!" ROCKVILLE (PCER 851), NRL's small acoustics research vessel, left the pier on the twelfth of April and headed for the search area 260 miles east of Boston. She was equipped with a unique trainable hull-mounted sonar. Five of Buchanan's researchers were aboard together with others borrowed from elsewhere at NRL and from Hudson Laboratories. The remainder of the Branch stayed behind to prepare instruments to be towed near the sea floor.

The ROCKVILLE joined three other research vessels the ALLEGHENY, MISSION CAPISTRANO, and PREVAIL to make a precise sonar exploration of the 10 by 10 nautical mile search area. Three other research vessels, ATLANTIS II, CONRAD, and GILLISS were assigned to investigate promising bottom contacts. Additional people from Sonar Systems Branch were aboard GILLISS where they joined other researchers from the Naval Oceanographic Office and the Naval Ordnance Laboratory. Details of the overall search for THRESHER in 1963 were described by F. N. Spiess and A. E. Maxwell [3]. The part played by NRL in both '63 and '64 is described in the first reprint, "Ocean Bottom Photography from a Deep Towed Camera System" [4]. It is reprinted here with permission from the Society of Photo-Optical Instrumentation Engineers.

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pp. 156-160, Vol. 4, No. 4

Ocean Bottom Photography from A Deep Towed Camera System

Walter L. Brundage, Jr. and R. B. Patterson, *U. S. Naval Research Laboratory, Washington, D.C.*

ABSTRACT

A towed deep ocean photographic system in continuous use and development at the U. S. Naval Research Laboratory has produced well over 100,000 bottom photographs. Details of this system, including the arrangement of lights and cameras, the use of longer ranged sensors to regulate camera operation, and the shipboard processing techniques, are described. Some proposed future improvements in the system are also presented.

Early attempts at remote photography of the deep ocean from the surface were made by Bontan[1] who published a book on his experiments in 1900. The first successful work was apparently done by Ewing, et al[2] in 1940. Important improvements since then include the use of a multi-exposure camera[3], a precise means of positioning the camera above the bottom[4], and the use of a corrected lens[5]. The standard Edgerton, Germeshausen & Grier, Inc. "Stereo Camera System" incorporates all of these features and represented the "state of the art" at the time of the THRESHER disaster in April of 1963.

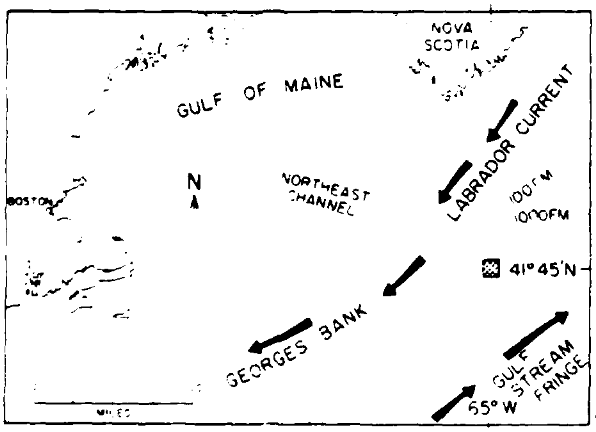

Figure 1. THRESHER Search Area

At the time, the most effective method of searching the 10 by 10 nautical mile area (cross hatched in Figure 1) was by precision echo soundings. Details of this and other portions of the first years operations are reviewed by Spiess and Maxwell[6]. By early May the Atlantis II had photographed bits of debris from the submarine near one of the more promising sonar contacts. Their camera system was typical of contemporary equipment which was lowered to the ocean floor on a simple strain cable. At a pre-set time the cameras automatically took pictures at about a 13 second interval until the film was expended.

EVOLUTION OF A MULTI-SENSOR PACKAGE

The advantage of searching with a number of sensors combined in one towed vehicle (or Fish) was recognized from the start. By early June, the U. S. Naval Research Laboratory aboard GILLISS (AGOR-4), was using an embryonic multi-sensor system. Probably for the first time in history, man was able to photograph selected objects of interest on the ocean bottom 2500 meters below. The fish was a ten foot rack, which contained two cameras mounted as a stereo pair, one modified strobe light, a pinger system, a battery, and a slow scan television system. This equipment was supplied by E.G.&G. except for the television which was built by Lear Siegler and modified for deep submergence used by NRL.

A new video picture was generated every four seconds on a shipboard monitor where it could be recorded with a Polaroid camera. By means of a telemetry control system, the observer could also photograph objects of interest with the E.G.&G. cameras. The control and video signals were telemetered through an insulated center conductor in the tow cable On 3 June 1963, this fish took pictures of nondescript debris that was later discovered to be protruding from THRESHER's sail. In retrospect, this incident emphasized the importance of the search technique of tilting the cameras to each side in order to obtain wider coverage.

Tilted cameras were used on the fish shown in Figure 2. This unit was used for the cruise which terminated the first year's search on 2 September 1963. A 100 watt-second strobe light was mounted on the streamlined nose and a proton precession magnetometer was added to the system. The toroidal sensing coil was mounted on a nonmetallic boom to separate it from the magnetic field of the fish and other equipment. Interference problems thwarted the simultaneous use of all the sensors but one remarkable photograph was obtained with this fish (see Figure 3).

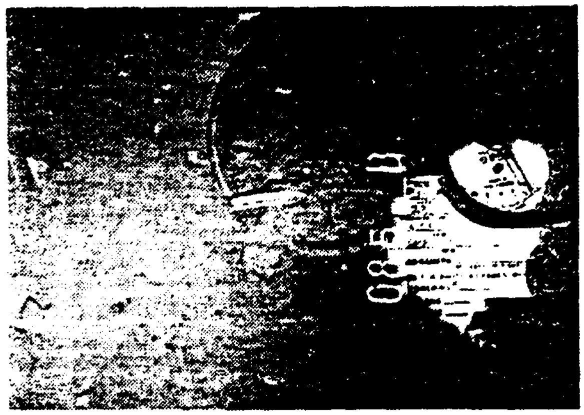

Figure 3 THRESHER's Anchor

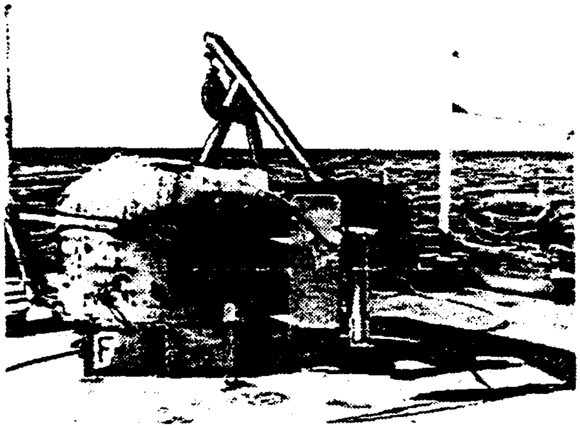

Figure 2. Fish used on THRESHER Search, 1963

This photograph of THRESHER's two ton mushroom anchor was taken in a debris strewn area some distance from the nearest significant part of the main hulk. Bottom markers called "fortune cookies" were placed on the bottom and helped establish the relative position of the anchor. The mud covered part of the anchor is on the side toward which the hulk was found. This dubious clue is still not considered valid by the investigators who believe that the anchor could maintain little trajectory before reaching a free settling condition.

Convincing photographs and pieces of material recovered by dredging and bathyscaph work had definitely established the fact that the submarine lay nearby. NRL was given the assignment of perfecting an improved system for deep ocean search which could be profitably tested in the same area the following season

THE 1964 FISH

Two fish like that shown in Figure 4 were designed and built for the 1964 operations in the THRESHER area. Two 200 watt-second strobe lights, built by NRL, were mounted on the nose tilting 14° from the vertical to each side. The simple reflectors are adjustable but it was found that greater tilt does not significantly increase coverage. The strobes were designed to cycle every two seconds, the normal scan rate of

Figure 4. Fish used during 1964

the television system. Simple filters help eliminate interference from the strobes which contain high voltage oscillators of nearly constant frequency

The cameras, both photographic and television, are mounted in the two sections under the tail fins. The photographic system is composed of three cameras, one vertical and one tilted to each side. The depression angle of the tilted cameras is adjustable and one configuration used is illustrated in Figure 5

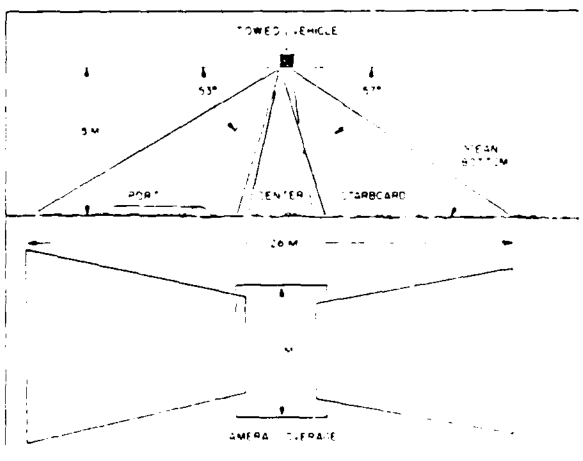

Figure 5 Camera Coverage

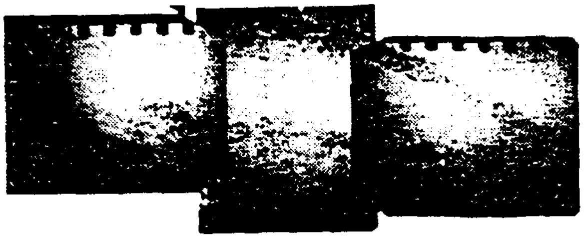

Figure 6. An Example of the Photographic Coverage

Keys fitted into the bottom end caps of the cameras assured uniformity on successive lowerings. An operating height of 8 meters was typical in the THRESHER work. This is a greater operating distance than is generally used and results in some loss of resolution. In searching for a large object, it was felt that greater coverage was needed at the expense of resolution. An example of coverage provided is shown in Fig. 6.

This unrectified photomontage of pictures taken simultaneously by the three cameras, shows a linear distribution of rocks found in the THRESHER area. The pattern depicted is about 16 meters long and oriented north-south. Brundage, et al[7] discussed the possible origin of this pattern.

NAVIGATION BY SONAR

Navigation relative to a fixed bottom reference was used successfully in the area. A transponder mounted on the fish returned a sound pulse automatically upon the reception of an interrogation pulse from the surface vessel. Three hydrophones mounted in a triangular array on the bottom of the ship feed the signal to a computer which is programmed to determine the relative position of the fish on the basis of difference in arrival time at the three hydrophones coupled with the elapsed time from the interrogation pulse. Another transponder anchored near the bottom is interrogated with a sound pulse of different frequency. The same system is thus used to locate the surface vessel relative to a fixed bottom reference. Figure 7 is a simplified sketch of this system. The NRL tracking system has been described by Van Ness, et al[3].

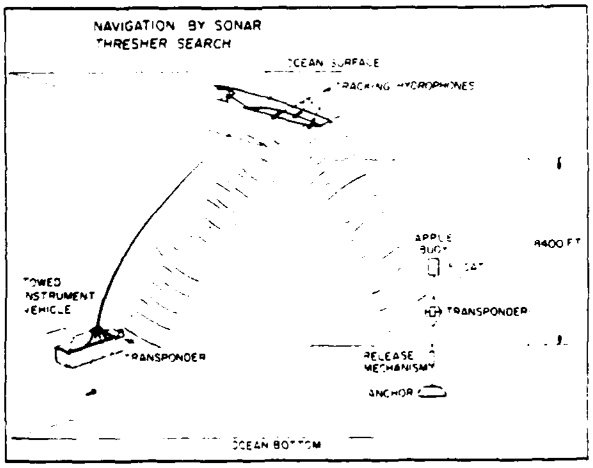

Figure 7 Acoustic Navigation System

The basic features of this tracking system are similar to a system devised by the Applied Physics Laboratory, University of Washington. At the 8th SPIE Technical Symposium H. E. Edgerton[4] described the method used to control the height of deep-sea cameras off the bottom. He also discussed transponders, calling them "sound houses," in describing another method of acoustic navigation. The precision of such a system can be improved if the signals from the transponders

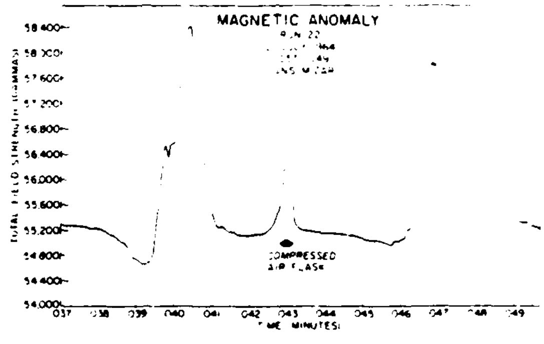

Figure 8 Typical Magnetic Anomalies

are received directly by the fish and then transmitted via the cable to the ship.

Patterson and Brundage[10] discuss other techniques by which a deep towed vehicle may be navigated. Particulars of the NRL telemetry and control system are presented by Flato[11].

PHOTOGRAPHY DIRECTED BY MAGNETOMETER

The success of the NRL 1964 THRESHER photography can be credited largely to the reliability of the magnetometer system. Cameras were generally operated only when the magnetometer indicated the presence of a magnetic target. Anomalies recorded on a typical lowering are shown in Figure 8.

The small peak in the center was caused by a compressed air flask. The larger peaks are associated with parts of the hulk itself. Similar anomalies were recorded when pictures of THRESHER's sail (Figure 9) and tail section (Figure 10) were taken.

Figure 9 THRESHER's Sail

The submarine's numbers 5, 9 and part of the 3 can be seen beneath the starboard dive plane in Figure 9. Draft markings on the upper rudder can be seen beneath the anchor light in Figure 10. Note the peculiar creature swimming just forward of the rudder near the vent on the hull. Many hundreds

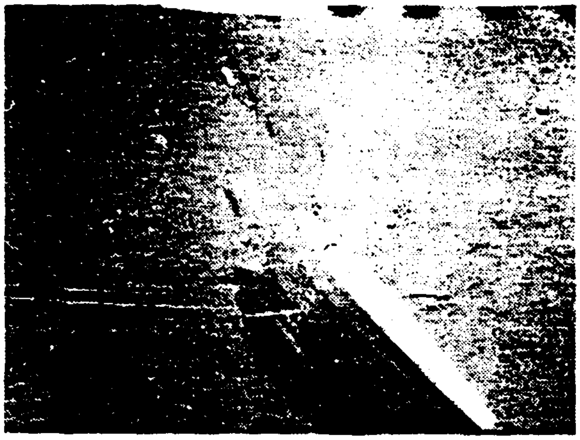

Figure 10. THRESHER's Tail Section.

of other photographs were also obtained showing these and other parts of the hulk. These are being used by the U. S. Naval Reconnaissance and Technical Support Center to make a photo-mosaic of the area. It is estimated that the photos obtained in a ten day period provide at least 75% coverage of a 1000 ft. dia. circle centered on the wreckage.

PHOTOGRAPHY DIRECTED BY SONAR

A side-looking sonar survey was made in the THRESHER area in 1963, the results of which were presented by Clay, et al[12]. Unfortunately the area was blanketed by so many targets (mostly rocks) that echoes from the submarine were obscured.

The uses of sonar as a target detector have, however, been demonstrated in other areas. During a camera lowering near Bermuda in November 1964 many curious side echoes and reverberations were recorded. Toward the end of the run, shipboard monitors indicated "all systems stop" except for the pinger which is a self-contained system. The fish was raised while the pinger record was studied. Figure 11 is a portion of this record.

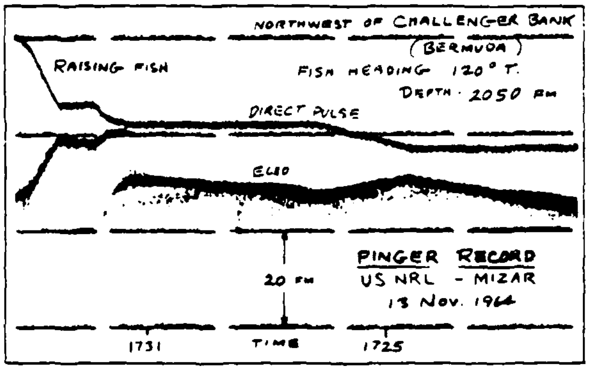

Figure 11. Pinger Record

Note that when the fish was raised, a second bottom echo appeared about 10 fathoms above the first. This record indicates that the fish passed over the lip of an almost vertical wall. When the fish returned to the surface the cause of the failure was evident. The strobe lights were damaged and flooded, resulting in a system short circuit. Most of the damage was sustained on the front and upper portions of the fish.

The film from the undamaged cameras was developed. The photographs showed outcropping rock surfaces that appeared to be vertical and even overhanging.

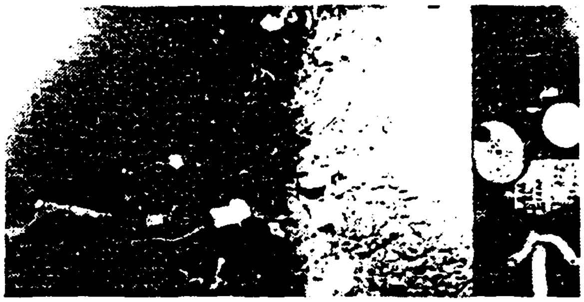

Figure 12. Final Photograph of Run.

The last photograph taken by the port camera just after the flooding occurred is shown in Figure 12. The scene is of an animal populated rock wall lit by the last flash from the starboard strobe. The light-colored animals on the long thin stalks may be some form of deep-sea ascidian or "sea squirt." The mark on the film points towards the front of the fish.

FILMS AND PROCESSING

Medium to high speed panchromatic films are generally used for ocean bottom photography. Dupont 331, a thin base film which allows a 25% increase in film load, was used during most of the 1964 operation. Recently color film experiments have been conducted using Anscochrome D/200, processed for a film speed of 400 by the manufacturer. This film has much less latitude than the black and white film used and can not handle the variations in illumination inherent in this type of photography. Therefore, the three camera array was loaded with conventional film and a fourth camera was mounted to test the color film. While the color film was generally underexposed, over 50% of the exposures contained additional information to supplement the black and white photographs.

It was necessary to process all black and white film aboard ship and the techniques used varied considerably during the two years. During 1963, all film was processed in rewind tanks using Acufine or Ethol UFG developer. This type of developer requires time and temperature controls which are difficult to maintain in a small shipboard installation. These difficulties can be overcome by the use of a two-solution developer[13,14], such as Diafine. This type of developer tolerates considerable variation in time and temperature and has the additional advantage of compensating for considerable variation in illumination.

This compensation is seen in Figure 13, where the left photograph which was processed with a conventional developer exhibits much more variation in illumination than the right photograph which was processed in Diafine. The use of this type of developer with a Morse G-3 tank, which costs less than $30 and can be loaded in a changing bag, provides an ideal solution to the processing problems of a low-budget photographic survey.

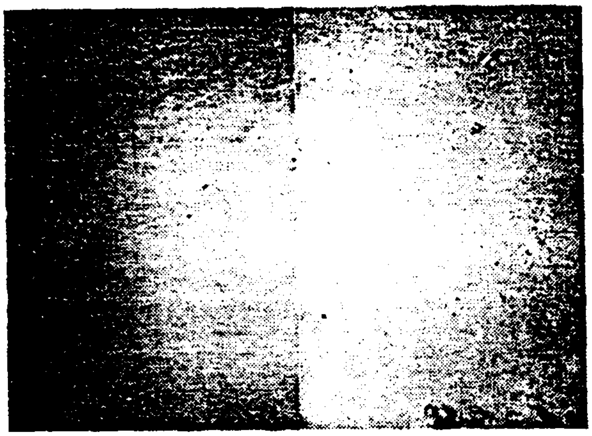

Figure 13. Comparison of Processing Techniques.

FUTURE SYSTEMS

The equipment and techniques presented here have given satisfactory results, but there is always room for improvement. In order to obtain the greater coverage required for search and survey missions, an attempt is being made to adapt a water corrected 160° wide angle lens to EG&G's new Survey Cameras which use 500 to 600 ft. film loads. It is not practical to process this length of film in a rewind type processor so a small continuous run processor is being adapted for use with a two-solution developer.

Probably the most needed improvements are in using the photographs after they have been obtained. Someone at the National Oceanographic Data Center estimated that at the time of the THRESHER disaster there was a total of about 50,000 deep ocean photographs. Since that time, NRL has taken three or four times that number. With the increase in organizations in the field and the new cameras with greater film loads, the number will soon be astronomical. Our photographs have generally been taken to obtain specific information but they contain a vast amount of other information which should be used. Some sort of a catalog, such as the IBM card system described by Cruickshank[15] would be useful in making the information available to interested parties. To reach its full potential in this regard, it must be expanded to cover information in all fields and be used by all organization engaged in deep ocean photography. In addition to this, there is a need for automatic viewers and printers capable of handling the various and sometimes unusual film formats used in underwater cameras.

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About the Authors . . .

Robert B. Patterson was born in Des Moines, Iowa. He received a B.A. degree in Physics from the University of Iowa at Ames, Iowa. He joined USNRL as a Physicist and is presently employed there as a Research Physicist in the Ocean Sciences and Engineering Div., Deep Sea Research Branch.

Walter L. Brundage was born in New York, N.Y. He received a B.S. and a M.S. degree in Oceanography from the University of Washington, Seattle, Washington. He joined USNRL as a Research Oceanographer and worked in that capacity until he accepted a two year appointment as a Research Oceanographer at SACLANT ASW Research Center in LaSpezia, Italy.

THE SURFACE PLATFORM MIZAR

Experience at sea aboard USNS GILLISS by NRL in 1963 strongly indicated that the AGOR-3 class was not adequate for deep sea search. Ever since the engine failure that retired HUNTING the Laboratory had been looking for a decommissioned ship having appropriate hull characteristics. Late in 1963 the USNS MIZAR was located in Seattle, Washington. With a length of 266 feet, a beam of 52 feet and a displacement of 3880 tons MIZAR was big for the job but available. As noted in [2] the structure and location of her number 2 hold straddling the ships middle made her an ideal choice for a center well installation. The following reprint describes Buchanan's initial impressions with MIZAR and presents a summary of the second year of the THRESHER search. It includes an account of the roll played by MIZAR in guiding the submersible TRIESTE II directly to the target. Many other important details of the 1964 operations were described by F. A. Andrews in [5].

Reprinted from 1973 Report of NRL Progress,
pp. 81-83, Naval Research Laboratory, Washington, D.C.

A LOVE AFFAIR

C. L. Buchanan

Mr. Chester L. Buchanan joined NRL in 1946 as an electronics engineer in the Sound Division. He has headed in succession the Sonar Systems Branch and the Deep Sea Research Branch of the Sound Division and the Ocean Engineering Branch of the Ocean Technology Division. Currently he holds the position of Associate Superintendent of the Ocean Technology Division. He is widely recognized for his accomplishments, and those of his group, in the THRESHER, H bomb, SCORPION, and ALVIN incidents.

I had to laugh—there she was, the funniest ship I had ever seen. With those big holds forward empty, her huge ice-strengthened bow pointed up toward the sky. The rat guards on the mooring hawsers looked like two big red eyes, and the mooring hawsers sloping sharply down to the dock looked for all the world like whiskers. At first impression, here was a huge gray rodent with red eyes and rust-colored whiskers staring curiously at the two intruders who strode down the dock.

On board the mood was different. She was a real lady. Her paintwork was clean—the furniture was of honey maple, freshly varnished. After we entered the strangely silent engine room, a huge lump raised in my throat. I was falling in love, but I was not the first. Taped to the engine was an ordinary sheet of paper torn from a writing tablet. Written across it were the words "Goodby Old Girl."

Jerry (J. J. Gennari) had recommended MIZAR to me, but neither of us had seen her before. Her 260-foot length and 50-foot beam, with a displacement of 3700 tons, made her big for an oceanographic research ship. Her ice-strengthened hull, twin screws with single rudder, and her deisel electric propulsion system promised excellent maneuverability at slow speeds. There were the characteristics we were looking for, the characteristics we must have to probe the 8000-foot depth of the North Atlantic and to locate and photograph the hulk of the submarine THRESHER, tragically lost on April 10th of that year, 1963.

It was November now, and our frustrations from the failures of that summer—due to inadequate ships and equipment—were giving way to a dogged determination to do it right, in 1964. The first requirement was a suitable ship and we quickly set about our task—to determine whether this ship could do the job.

We climbed and searched throughout every frame of this lonesome ship. At every turn it was the same story—her big forward holds would permit speedy modifications. Nothing would have to be torn out. The main operation center could be built in the after end of the second deck of the number-two hold, and on either side of the yawning hatch was room for staterooms for the scientists required to man the search gear. Towing would be no problem—a saddle could be built on the gunnel, one of the huge cargo booms could be used to lift the sensor vehicles over the side, and the boom secured in the saddle would provide a perfect towing arrangement.

It was with a sense of excitement that we flew back to Washington—our heads filled with plans and ideas—eager to commence the transformation of this freighter into an oceanographic research ship, specially equipped for deep-ocean search and inspection.

We were not the only group planning for the next summer's operations. At the Navy Electronics Laboratory in San Diego, an equally dedicated group was hard at work modifying the submersible TRIESTE in preparation for the search.

The winter months passed quickly. We planned, estimated costs, built equipment, and experimented, tested, and checked our gear. We even went to sea on ROCKVILLE (PCER 851) to test our equipment at sea. On the 10th of March, MIZAR sailed from Seattle for the long voyage to the east coast. The Military Sea Transport System (now Military Sealift Command) operated the ship for us. After a 3-week shipyard modification in Savannah, Georgia, we installed our equipment and sailed for Boston. After a few minor modifications, we sailed on our first short shakedown cruise.

Our faith in MIZAR was high, but we had not yet learned how to use her. First we practiced launching our "fish" without any instruments on it. The ship's crew soon learned how to launch the "fish" without crashing it into the side of the ship. Soon we started installing the sensors and testing them. At the same time we were trying out our Underwater Tracking Equipment (UTE). This equipment was designed to determine the location of transponders on the ocean floor and also to determine the location of our "fish." It also was intended for use in tracking the submersible TRIESTE.

After a week or so we were confident of our ability to "work" the ship. We headed back into Boston to make our final preparations.

Meanwhile the TRIESTE had been brought to Boston and was also being prepared. Since her preparation involved the safety of men, the work was more exacting and she was not ready for sea.

Admiral Coates was the Task Force Commander (CRF 168), and Captain Frank Andrew was Task Group Commander (CTG 168.1). Their little fleet consisted of the MIZAR (now classed as an oceanographic ship–T-AGOR-11), the USS HOIST (ARS 40), and the submersible TRIESTE. MIZAR sailed on June 25, 1964, to start the THRESHER search. In the incredibly short time of 2 days we located and photographed the hulk. By July 22 we had photographed almost the entire hulk which was broken into five major pieces.

Proudly, yet sadly, we sailed into Boston on July 23 with a broom displayed at the signal halyard.

By this time the TRIESTE was nearly ready, and we all turned to in preparation for the task of guiding TRIESTE to the wreckage to make a close-up inspection.

In early August the entire task force arrived in the area, and preparations were made for TRIESTE to dive. Her first dive on August 14 was unsuccessful, due to a fault in her gyrocompass. Her second dive also was thwarted by the same problem. During these dives we on MIZAR were gaining experience in tracking her and were very sure that once her gyrocompass was operational, we could direct her with ease.

The third dive proved to be one of the most amazing operations we could have imagined. Captain Andrew elected to make the dive as observer. The officer in charge and pilot were Lt. Commander J. B. Mooney and Lt. John Howard, respectively. As the dive progressed we all breathed a sigh of relief as it became evident that the gyrocompass was working. For a short time the TRIESTE rested on the ocean floor at 8400 feet, while we meticulously determined her position by use of the UTE. Lt. Denny Curtis was the dive director aboard MIZAR, and he was frequently in telephone contact with those aboard TRIESTE. Unfortunately, the telephone transmissions interfered with the UTE operations so that he had to restrain these communications.

We informed Captain Andrew of the course to steer and the distance to the THRESHER hulk, and wonder of wonders, the TRIESTE position moved slowly in the correct direction.

This had never been attempted before, and we really had no way to determine the accuracy of the system. Finally, the little pencil dots on our plotting board reached the point where we had previously judged the THRESHER hulk to lie. Lt. Curtis informed Captain Andrew that they were now so close that they were within our circle of confusion. Now Captain Andrew is an excellent mathematician and a great believer in statistics. He therefore immediately asked the pilot to set TRIESTE down on the ocean floor. He then informed Lt. Curtis that they saw nothing, and requested that we compile a lot of data and average it so we could vector them closer to the hulk. We did so but to no avail. The statistics always converged on the spot we had selected (and which by now we had begun to question).

TRIESTE is a pretty tight fit for three men. The third man, who is looking out of the viewport, is sometimes almost forgotten down on the bottom of the dark capsule as he peers out into the murky water.

As they sat still waiting, the observer said, "Say, how high are we above the bottom?" "Man, we're resting on the bottom," shot back the pilot, "we're just waiting for those clowns up there to tell us which way to go." Observer: "Well, then! Why can't I see the bottom?" Pilot: "You can't see the bottom?" Observer: "Heck no! I can't see anything!" Pilot: "Wait a minute, let me turn this thing around!" Observer: "Hold it! Holy cow, there's a piece of metal–and it's made of metal, it's–it's the hulk!"

Yes, stranger than fiction, all the while TRIESTE had been neatly balanced directly on top of one section of THRESHER, with the viewport looking over the end and too high above the bottom to see it.

Nine years ago, yet it seems like yesterday. Since then there have been many other memorable events. With MIZAR we assisted in the location and recovery of an H bomb, located and photographed the lost submarines SCORPION and EURYDICE, and located and actually recovered the research submersible ALVIN from a depth of 5100 feet (with an assist from the research submersible ALUMINANT). In all these years she has never let us down. MIZAR, I love you!

MIZAR'S CENTER WELL

The successful 1964 search mission at the THRESHER site was completed before a well could be installed in MIZAR. The towed instruments were lifted from the number two hold and out over the starboard side by means of a specially rigged cargo boom. The end of the boom was secured in a cradle and the shieve on the boom became the tow point. The drawbacks of this were that the ship could not turn to port, roll motions were imparted to the cable and the operation was dangerous to both equipment and personnel.

As previously noted the center well installation not only reduced the surface wave motions imparted to the cable but permitted operating in rough seas. Turning the ship presented no problems. Figure 1 is a cut-away drawing of the interior of the enclosure over the center well installation. The well doors are shown open with the elevator structure raised to its uppermost position. A towed suite of instruments can be seen beneath the elevator.

As noted in [2] many deficiencies of the HUNTING well were eliminated in the MIZAR installation. The ends of the well were rounded, for example, and a series of shelf-like wave baffles at each end reduced the turbulence of water surging in the well. The design produced no discernible reduction in MIZAR's top speed of 13 knots. Once the instruments had been retrieved the well doors were slid closed and the instruments were lowered to rest on the doors. The covered well deck then became a protected area where the instruments could be serviced in preparation for the next lowering and remote observers could not see what was taking place on deck. Much of the success of the research missions can be attributed to the excellence of MIZAR's center well installation. The completion of the well coincided almost exactly with loss of the H-Bomb on 17 January 1966.

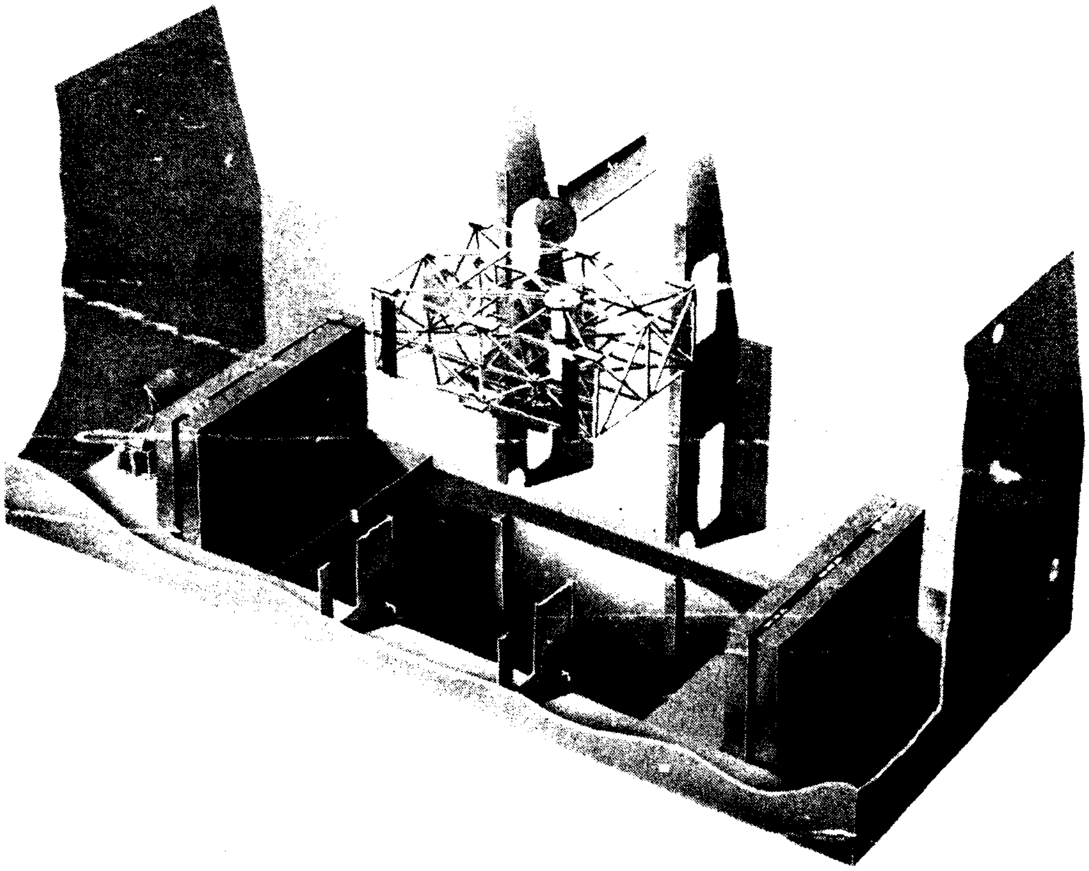
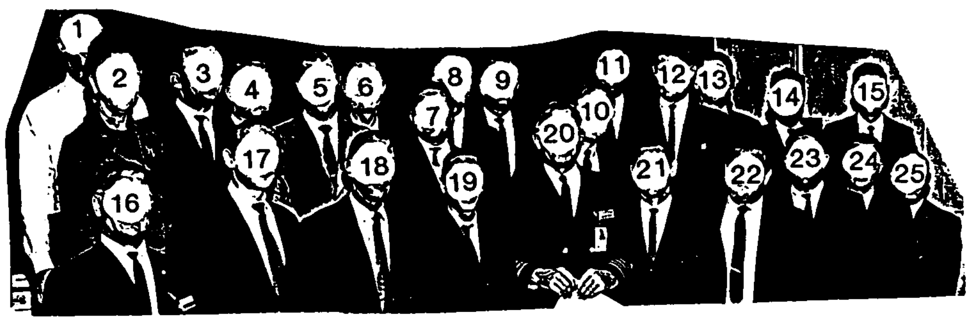


Fig. 1 — Artist's cutaway view of the interior of the well deck structure aboard USNS MIZAR.

HONORS AND AWARDS

The following reprint is an article from NRL's internal newspaper, LABSTRACTS. The article leads off with a commendation from the Marine Technology Society to Buchanan and his search team for their participation in the THRESHER search and the H-Bomb recovery. Each member of the team is listed by name within the three Branch Sections - Mechanical Engineering, Electronics and Oceanology. Figure 2 is a photograph of the Branch members taken when they were given the Navy Merit Award for Group Achievement.



1. Mort Smith
2. Hester M. Helms
3. Earnest C. Czul
4. Rick Love
5. H. Bernard Lindstrom
6. Howard E. Barnes
7. Peter Kaufman
8. Andrew M. Findlay
9. Mathew Flato
10. Daniel Friedman
11. Wilbur F. Jones
12. Robert L. Mills
13. Hollis Gibbs
14. John B. Humphrey
15. James A. Somerville, Jr.
16. Chester L. Buchanan
17. Frank W. Heemstra
18. Massis Davidian
19. Lloyd Greenfield
20. Thomas B. Owen
21. Walter L. Brundage
22. Robert B. Patterson
23. Kenneth R. Stewart
24. Hanford N. VanNess
25. Jervis J. Gennari

Fig. 2 — Members of NRL's Sonar Systems Branch were honored in 1965 with the Navy Merit Award for Group Achievement. The Commanding Officer (No. 20) presented the award, given for their success in finding the nuclear submarine THRESHER.

THE H-BOMB SEARCH AND RECOVERY

The article goes on to describe the NRL/MIZAR role in the H-Bomb search and recovery. During the search phase NRL was first to make use of a wide angle underwater camera. The design was completed during the two weeks between MIZAR's sailing and the flight of the search team to Spain. The parts for the new camera were carried on the flight as hand luggage.

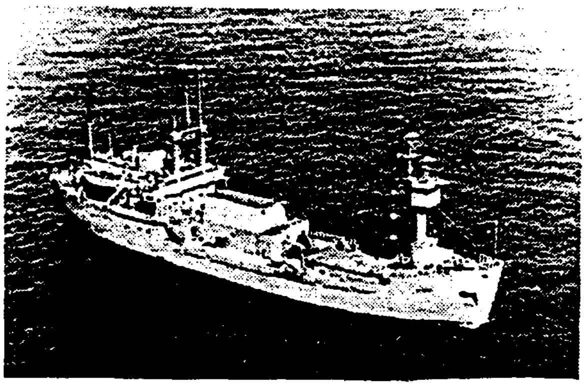
The wide angle bottom photographs lacked the detail seen in standard bottom photos but this lack was outweighed by their benefits. A single photograph from the wide angle camera covered an area equal to that in nine photographs from the three-camera array previously described. Film processing and viewing times were shortened by the same nine-to-one factor.

The 2,850 foot depth from which the bomb was finally recovered made it the first modern deep sea recovery operation. MIZAR's acoustic navigation system played a key element in both guidance for the manned deep submersible and for placement of recovery gear at strategic points on the bottom. Additional accounts of the operation designated SALVOPS/MED are in [6] and [7].

Reprinted from 1966 NRL Labstracts, pp. 1-2
Naval Research Laboratory, Washington, D.C.

AWARD TO C.L. BUCHANAN AND TEAM

Award to C. L. Buchanan and Team



Aerial photograph of the MIZAR on station off Palomares.

The Marine Technology Society Honors and Awards Committee has commended Mr. Chester L. Buchanan and his team of scientists and engineers for their outstanding work in the THRESHER search and in the recovery of the H-bomb off the coast of Spain. The presentation was made on Tuesday, June 28, at the society's annual banquet held during its second Annual Conference and Exhibit at the Sheraton-Park Hotel. Mr. Buchanan accepted the award on behalf of his branch, the Deep Sea Research Branch, Code 7540 (formerly the Sonar Systems Branch).

The commendation reads: "The Marine Technology Society takes pleasure in commending Mr. C. L. Buchanan and his team of scientists and engineers from the U.S. Naval Research Laboratory, who by their ingenuity and persistence under the most adverse conditions, made it possible to locate and identify the submarine THRESHER over eight thousand feet below the surface of the North Atlantic Ocean and to recover the hydrogen bomb from the bottom of the Mediterranean Sea off Palomares, Spain. Their ability, knowledge, and skill in adapting existing research equipment and methods and to pioneering new techniques not only contributed in large measure to the successful accomplishment of these two operations, but established a methodology for future ocean engineering."

Included in this team were Daniel Friedman, consultant; Jervis J. Gennari, Head of the Mechanical Engineering Section, and his associates, Wilbert H. Jones, Ernest C. Czul, Howard E. Barnes, David Halper, Bernard N. Lindstrom, Alan Scott Dam, James Somerville, and Richard Love; Matthew Flato, Head of the Electronic Section, and his fellow workers, Kenneth Stewart, Robert Mills, Hanford Van Ness, Roger Cooley, Frank Heemstra, Robert Patterson, Richard Bridge, Lloyd Greenfield, and Hollis Gibbs; John B. Humphrey, Head of the Oceanology Section, and his associates, Walter L. Brundage and Massis Davidian; Harry Merchant, Engineering Services Division; and Gloss Worthington, Technical Information Division.

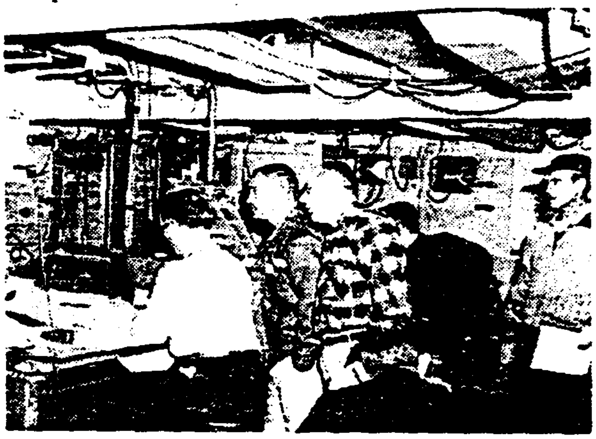
While the contributions of this group to the THRESHER search are well known, their prominent role in the search for and recovery of the hydrogen bomb off the coast of Spain early this year has not been well publicized. Mr. Buchanan and his team, aboard the MIZAR (NRL's oceanographic research ship), provided a deep water search capability and gave vital navigational guidance to the submersibles ALVIN (operated by Woods Hole Oceanographic Institution for ONR) and ALUMINAUT (privately owned).

When the authorities realized that one of the bombs ejected by a disabled U.S. bomber had fallen into the ocean, NRL made immediate preparations to assist in searching for it. The MIZAR departed Washington on February 4 with a small contingent of scientists aboard. They were joined by the remainder of the team upon the arrival of the ship in Spain on February 19. After a short period of shakedown operations, the search began in earnest.

The NRL group was assigned the job of searching an area near the place where a Spanish fisherman reported the bomb to have fallen. The MIZAR had completed, with negative results, a search in the initial assigned area and was about halfway through the second assigned area when the submersible ALVIN located the bomb a short distance southeast of the area in which the MIZAR was operating. The MIZAR was immediately sent to assist in determining the exact location of the bomb.

Since at this time ALVIN was not equipped with a transponder capable of operating with the MIZAR's tracking system, direct determination of the position of ALVIN and the bomb was not possible. Therefore, a transponder was mounted on the submersible ALUMINAUT. Using their sonars to determine each other's direction, the two submersibles were able to make an essentially unassisted rendezvous. After successfully making this submerged rendezvous, ALVIN was surfaced, leaving ALUMINAUT beside the bomb. The MIZAR was now able to determine the exact location of ALUMINAUT and hence the bomb.

Since ALVIN was the only submersible having a mechanical arm installed, she was required to attach equipment to the bomb for its recovery. The MIZAR's assignment was to direct ALVIN back to the exact location of the bomb. On the first search attempt only one hour and one minute elapsed from the time ALVIN submerged until she had the bomb in sight. This time was never bettered until ALVIN's final dive, in this area, when the evolution was performed in 47 minutes.



MIZAR control center during the lowering of the work table. (Left to right are Mr. Buchanan; LCdr Worthington; Mr. Gennari; Mr. Andrew M. Findlay, Sound Division; Mr. Flato; and Mr. Willis Raney, (back to camera), Woods Hole Oceanographic Institution.)

After the bomb was located, the first recovery attempt was made by Mr. Buchanan's group, aboard the MIZAR. Using her deep-sea winch, the MIZAR lowered a work table containing a number of devices which could be attached to the bomb and a transponder which enabled the MIZAR to determine the position of the work table. This feat was highly successful, and it was estimated that the work table was placed within 80 feet of the bomb. ALVIN successfully made fast the work table to the bomb by using the attachments provided but, unfortunately, it was not noticed that the lifting line was snarled about the work table anchor. When the line was strained in lifting the bomb, it was cut at the point of the anchor snarl, and the bomb was lost again.

The search was resumed in, of course, a very small and concentrated search area. During the daytime the MIZAR directed the search patterns of ALVIN and ALUMINAUT and at night conducted a search with her own towed cameras. When ALVIN again located the bomb, she was under control of the MIZAR, and therefore the exact location of the bomb was immediately known. The final contribution of Mr. Buchanan's group was to guide ALVIN back to the bomb once more so that a special transponder could be placed on the bomb to assist Navy's CURV (Controlled Underwater Research Vehicle), which had recently arrived on the scene, to locate and finally recover the bomb.

After the recovery was completed on April 8, the group hurried back to NRL to prepare plans for the research programs necessarily set aside by this important work. Thirty days later, some of the group were again at sea aboard the MIZAR conducting underwater acoustic experiments.

THE SCORPION SEARCH

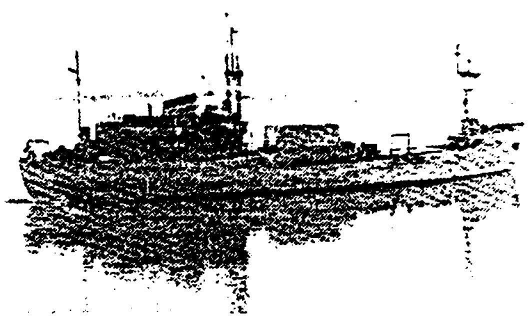
The most significant advance in the NRL search equipment following SALVOPS/MED was made by mounting the wide angle lens mentioned previously in a survey camera. The combination of increased bottom coverage in a single exposure together with greatly increased film capacity meant that a photo run could continue for 35 hours. During that span there was continuous overlapping photographic coverage of the sea floor. This system had just been tested over the Blake Plateau when news of the loss of SCORPION was radioed to the NRL search team.

Reprinted from 1968 Review, pp. 108-109
Naval Research Laboratory, Washington, D.C.

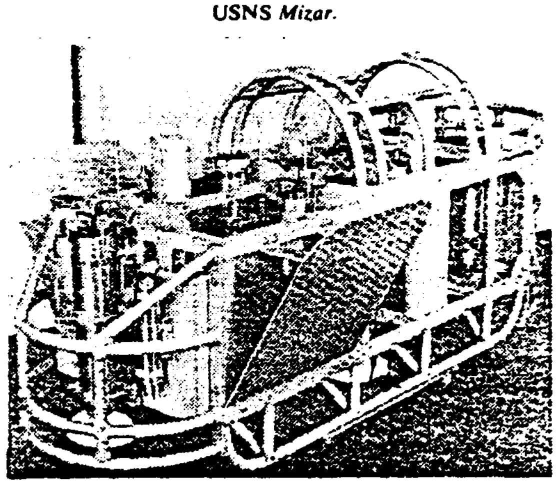
SCORPION SEARCH

Scorpion **Search.** The successful search for the lost submarine USS *Scorpion* was probably the longest continuous operation aboard a ship ever undertaken by a group from NRL. The search operations were conducted aboard USNS *Mizar* (T-AGOR 11), which steamed from Norfolk, Virginia, on June 2, 1968, and returned to New York on November 22. During this 172-day interval, *Mizar* steamed approximately 10,000 miles, of which 2,600 miles were traveled at a search speed of about one knot.

Once a month *Mizar* visited Prahia in Terceira, Azores, to take on supplies and exchange scientific parties. Each scientific party normally consisted of 12 personnel from NRL, 4 satellite navigation operators from the Naval Oceanographic Office, and one operations analyst from Wagner Associates. During the first two months there also were four ocean-bottom scanning-sonar operators from Westinghouse. The commodore of Task Group 42.2.1 and one officer from Submarine Development Group One were aboard during the last three months. Only 19 berthing spaces were available for scientific personnel, but there were times when the scientific party was as large as 25.



USNS *Mizar*.



Aluminum carriage ("fish") containing search instrumentation.

The towed search vehicle was an aluminum structure, called a "fish," which was built at NRL. Mounted in this structure was the integrated search system. The principal sensors used were the proton precession magnetometer, a wide-angle-lens survey camera, and a side-looking sonar. A transponder for determining the position of the fish relative to the ship, a frequency-multiplexing telemetry and command-control unit, two 200 watt-second stroboscopic lights, and a 28-volt battery power supply made up the remaining components mounted in the fish. An off-the-bottom depth indicator (essentially a pinger system) was used to maintain the fish at the desired height above the ocean floor.

A 20,000-foot-long armored, single coaxial cable provided the only electrical link for all information from the sensors to the ship and for commands from the ship to the fish. (Maintaining a full battery charge was also done through this same coaxial cable.) The fish was retrieved only when the camera ran out of film, which was after 35 hours of continuous photography. When searching at a speed of one knot, with the fish 30 feet above the bottom, a 100-foot-diameter view of the bottom was photographed each 30 seconds. Sufficient overlap of the photographed area was provided so that a continuous mosaic of the ocean bottom could be reconstructed. A total of 119,000 photographs was taken of the area. At times, two cameras were mounted in the fish. The second camera carried film for an additional 24,000 photographs. The total ocean bottom photographed equaled an area of 12 square miles.

Major shipboard navigational equipment included the acoustic tracking system, which computed the position of the fish relative to the ship, and a satellite navigation system, which indicated the ship's geographic position. When a systematic search of an area was desired, transponders were mounted on the ocean bottom and "fixed" geographically. The acoustic-tracking system also used these transponders to compute their position relative to the ship.

The first photographic evidence found of the whereabouts of *Scorpion* was a bent piece of sheet metal, which was detected after 18 days of operation. In that same area, there was a sharp geomagnetic outcropping that gave a signal from the magnetometer having characteristics similar to those of a man-made object. However, no further magnetic anomalies were recorded. The bent piece of metal could not be positively identified as being from the *Scorpion*, so the search was continued in other areas.

After five months of futile searching, it was decided to return to the general vicinity in which the metal had been found. Within a few days, on October 28, the magnetometer recorded a signal of the proper characteristics, and the side-looking sonar showed an object standing clear of the bottom. When the film was developed, the object was identified as being a large section of the hull.

On the following run, after the fish had been near the bottom but a few hours, the main drive-shaft coupling on the deep-sea winch failed. The fish plummeted to the ocean floor, but it was retrieved by the operation of a small auxiliary motor. After 4-1/2 hours of inhauling, the fish finally broke surface. Suddenly, the tow cable parted, and the fish (valued at $75,000) plunged 10,000 feet to the ocean bottom. This was a serious loss of equipment, but more so of search capability. Two days were spent preparing the spare fish and repairing the hoist. During the remaining three days, 10,000 photographs were obtained of parts of the hulk and debris from it.

NRL was charged with the responsibility for coordinating the analysis of all data. A large mosaic photograph of the ocean floor was completed, and pertinent data were made available to the Navy's Board of Inquiry.

Additional details about the SCORPION Search organization, special shipboard equipment and navigation were described by Buchanan [8]. A companion article [9] reported on the operational use of the towed sensors.

A systematic method for measuring the effectiveness of a search as it progressed [10] was first introduced during SALVOPS/MED and practiced during the SCORPION Search. Such operations analysis tools can aid in the decision-making process about where next to search. A major weakness of such tools is the value assigned to clues developed during the search. In the SCORPION Search the crumpled piece of metal mentioned in the above reprint was not accorded the high value it deserved [10] and five months were wasted.

ALVIN SEARCH AND RECOVERY

On October 16, 1968 Woods Hole Oceanographic Institution (WHOI) was operating the Research Submersible ALVIN about 90 miles south of Martha's Vineyard when she sank due to a handling accident. Before leaving the site the WHOI researchers had the foresight to make a bathymetric survey of the area. This furnished the NRL search team with a chart which helped in planning the orientation of towed vehicle runs the following year.

On the third run, an acoustic image of promising proportions was obtained. This marked the first time that side-looking-sonar provided a definitive clue in a deep search mission.

The subsequent salvage operation set a new record for the size and weight of an object recovered from such a great depth. The 9,000 pounds measured on the initial lift was only 200 pounds greater than was calculated had ALVIN's syntactic foam buoyancy material remained fully effective. Many additional details of the recovery operation can be found in [11].

The salvage of ALVIN from waters nearly a mile deep demonstrated a significant U.S. Navy capability for deep ocean engineering. Close cooperation between surface acoustic guidance elements and a deep submergence vessel (ALUMINAUT) was a key to the success. The value of the highly useful ALVIN and the value of the lessons learned on the mission far exceeded the cost of the search and recovery.

Reprinted from 1969 Review, pp. 118-119
Naval Research Laboratory, Washington, D.C.

LOCATION AND RECOVERY OF ALVIN

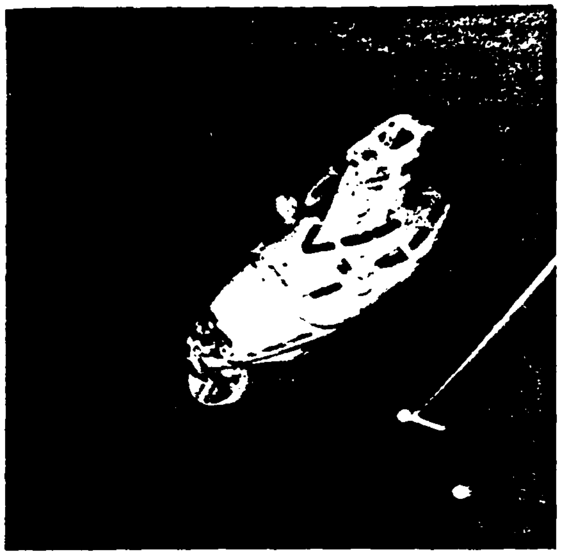
Location and Recovery of *Alvin*. Although the recovery of the submersible *Alvin* has been widely acclaimed as a spectacular accomplishment, NRL views her part in the undertaking as another demonstration of a growing capability to do important work on the deep ocean floor.

The search for *Alvin* began more as a practice mission than a full-blown salvage operation. Following the location of the *Scorpion* hulk in late October 1968, shakedown cruises were needed to test the search equipment which had been replaced and refurbished after five months of continuous service at sea. The first of these cruises, in June 1969, was conducted in the area in which *Alvin* was lost in the preceding October because that area was conveniently located for *Mizar* operations and because the submersible would present a target of challenging size for the ship's towed acoustic, magnetic, and optic sensors.

Alvin was located at a depth of 5100 feet after four days of searching and on the seventh lowering of the sensing system. Clear water permitted excellent photographs to be taken. They showed that the submersible had not been damaged by its impact with the bottom; the only visible damage was to the propeller assembly, which broke off as a result of the launching accident that caused the tiny submarine to sink.

Based upon *Alvin*'s upright attitude and apparently good condition, a decision was made to attempt recovery. The recovery team was staffed by the Office of the Supervisor of Salvage, Office of Naval Research, Woods Hole Oceanographic Institution, Reynolds Submarine Services, Naval Underwater Weapons Research and Engineering Station, Ocean Systems, Inc., and NRL. The vessels involved were the surface ships *Mizar* and *Crawford* and the submersible *Aluminaut* and her tender, *Stacey Tide*.

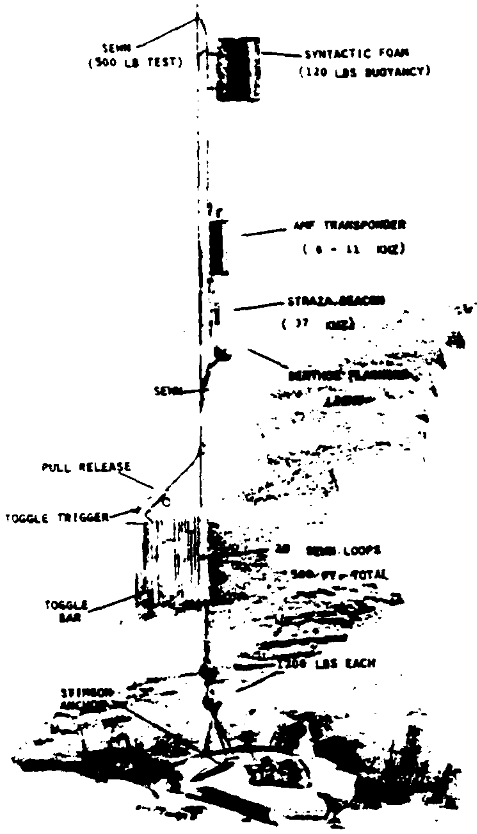
Unfortunately, all navigation markers were removed at the end of the first cruise, so it was necessary to relocate and mark *Alvin*'s position a second time. By then, the search system was essentially at peak performance. Nevertheless, four days were again required to locate *Alvin*.



Alvin was photographed many times as she lay on the ocean bottom at a depth of 5100 feet. This wide-angle photograph was obtained when the NRL "fish" was about 15 feet above the submersible's sail. The fact that Alvin had just barely penetrated the soft bottom sediment was puzzling in view of predictions that the craft might have been buried upon impact.

After appropriate navigational references had been installed, an 8-foot-long "toggle bar" was attached to the end of a 7000-foot-long, 4-1/2-inch-circumference nylon line aboard *Mizar*. Two 500-pound weights and an anchor were fastened 500 feet from the toggle bar. Beyond this were a flashing light and two navigational transponders. In addition, several hundred pounds of syntactic foam was attached to keep this part of the line taut. The 500-foot length of line between the toggle bar and the anchors was lightly tied to the lift line in 25 ten-foot-long loops, with the toggle bar suspended by a quick-release device. The lift line and attachments were lowered until the acoustic-tracking equipment indicated that the anchors were close to *Alvin*, at which time the anchors were lowered to the ocean floor and the remainder of the lift line reeved out and tied to a large surface float, which was then cast loose from the ship. It turned out that the anchors were positioned within 250 feet of the submersible.

Aluminaut, which dived immediately, was vectored to *Alvin* by NRL's tracking information. It made



Attachments at bottom end of line that lifted Alvin to the surface. By means of Mizar's underwater tracking instruments, NRL personnel positioned this equipment within 250 feet of the submersible.

repeated unsuccessful attempts to insert the toggle bar in *Alvin*'s open hatch before being forced to return to the surface. After a delay due to rough weather and the desirability of making minor equipment changes, *Aluminaut* submerged again, this time successfully inserting the toggle bar.

Mizar retrieved the lift line and raised *Alvin* without incident. The weather was very calm, and no increase in line tension occurred at "breakout." When *Alvin* was near the surface, divers attached additional lines and pontoons. The craft was then towed to calm waters near shore, where she was pumped dry and lifted onto a barge. An inspection showed that very little damage had occurred and that refurbishing was entirely feasible.

Of the many things learned from the recovery operation, perhaps the one most worthy of mention concerns the choice of 4-1/2-inch-circumference nylon for the lift line. No information had been available on the dynamics of a 27-ton virtual mass suspended on a mile-long line attached to a heaving vessel. NRL scientists used a computer to make appropriate computations for three possible lines—3/4-inch-diameter steel cable, 4-1/2-inch-circumference nylon, and 8-1/2-inch-circumference polypropylene. Results showed that prohibitively high peak loads would be reached if the lift was made over the side of a ship which rolled as little as 10 degrees. Resonance would occur in each line, but for the 4-1/2-inch nylon line it would occur at lengths of between 50 and 100 feet, while for the other lines it would occur at lengths of between 300 and 1200 feet. The decision to lift through *Mizar*'s centerwell was based on still other computations which showed that doing so would reduce dynamic loads at all lengths. The resonant length was not reached because the fairleads on deck required 80-100 feet of line and because *Alvin* was stopped about 85 feet from the surface, or nearly 200 feet from the end of the lift line.

SEARCH FOR EURYDICE AND MINERVE

In March of 1970 NRL was asked to search for two French submarines, the MINERVE and the EURYDICE both lost off Toulon in a 25 month period. Before sailing for the Western Mediterranean the NRL search team knew that the steep underwater topography in the EURYDICE search area would be a challenge. Fortunately the near-shore land geology and adjacent marine geology had been studied by Daniel J. Stanley of the Smithsonian Institution. Professor Stanley willingly loaned NRL geological and bathymetric charts that proved very helpful during the mission.

Even though care was taken to make camera runs downslope the sinuous nature of the submarine canyons was too abrupt and the towed system collided with a rock wall. The structural framework of the vehicle (1 1/2 in. diameter solid aluminum cylindrical stock) was badly bent and broken but it afforded adequate protection for the instrument housings.

Arrangements were quickly made and the damaged frame and a set of drawings were transferred to a French Naval escort that evening. After an overnight stay at the Toulon Naval Shipyard the frame was returned next morning in near mint condition.

A photograph of the stern section of EURYDICE is shown in Figure 3. Following the mission, French Vice Admiral Scitivaux de Greische sent his warm appreciation and congratulations were sent by the Secretary of the Navy. Special thanks were provided the NRL search team when the French Navy arranged a one day bus tour up the coast to Monaco.

Fig. 3 — Close-up underwater photograph taken April 29, 1970 shows the stern section of the French submarine EURYDICE which sank in the Mediterranean Sea near Toulon on March 4, 1970.

Reprinted from 1970 Review, pp. 139
Naval Research Laboratory, Washington, D.C.

SEARCHES FOR SUNKEN FRENCH SUBMARINES

Searches for Sunken French Submarines. In recent years, NRL has developed a unique ocean-floor search and inspection capability based on the use of visual (camera and slow-scan TV) and nonvisual (magnetometer and side-looking sonar) sensors towed by the oceanographic research ship USNS *Mizar*. This capability has been demonstrated in successful searches for the lost nuclear submarines *Thresher* and *Scorpion*, the nuclear weapon lost off the coast of Spain, the research submersible *Alvin*, and most recently in locating the ship *LeBarron Russell Briggs*, as noted in the article "Nerve Agent Disposal Site Investigation," which appears elsewhere in this annual review.

In the spring of 1970, NRL was again called upon to conduct a deep-ocean search—this time for the French Navy submarine *Eurydice*, which was lost on March 4, 1970, in the Mediterranean Sea near Toulon, France. One week after the submarine's disappearance, the Government of France requested U.S. assistance for about two months, at French expense, in finding the craft, and on March 13 the Chief of Naval Operations arranged for the NRL-*Mizar* search team to undertake the task, for which the termination date of June 1 was set. *Mizar* sailed from Washington, D.C., on March 25, and the search began on April 12 in an area of a few square miles and in water about 3000 feet deep approximately 8 miles southeast of Cape Camarat. The cameras and magnetometer were the primary search sensors, because typically the bottom was rough, with steep slopes and outcropping rocks, rendering the side-looking sonar ineffective.

Debris from *Eurydice* was first photographed on April 26. More debris and several magnetic anomalies were noted on April 27 and 28, and on the following day, pictures of the aft 70 feet of the hull were obtained. Later, additional portions of the ship, including the bow and possibly the sail, were photographed. Before leaving the area, a transponder was placed in the debris field of *Eurydice* to guide the French Navy's bathyscaphe *Archimede* to the location for further inspection.

On May 2, the French Navy requested that in the time remaining before the June 1 cutoff date the NRL-*Mizar* team conduct a search for *Eurydice*'s sister ship, *Minerve*, which had been lost about 20 miles southwest of Toulon on January 27, 1968. The U.S. Navy agreed, and the operation commenced on May 8.

Information on the disappearance of *Minerve* was not adequate to localize the search to a relatively small area, as was the case for *Eurydice*, so a fine-grained photographic coverage could not be made in the time available. Fortunately, however, the ocean floor in this region is relatively smooth and flat, permitting considerable use of the side-looking sonar. This device, whose search-sweep width is 1200 feet, provided maximum coverage at the relatively wide track spacing required by the size of the search area and the time limitation.

The search for *Minerve* lasted from May 8 until May 24, when the French Navy requested that it be terminated. An area of 13 square miles had been searched by sonar and an area of 1 square mile by camera. Although *Minerve* was not found and the only interesting debris photographed was the tail of an aircraft, as yet unidentified, a large number of potentially useful bottom photographs were collected.

These two search operations, one successful and the other not, were the first of their kind conducted jointly by two governments. In all essential aspects, this cooperative effort was well organized, operated smoothly, and was a source of satisfaction to all parties concerned.

[Supported by the Government of France]

THE LE BARRON RUSSELL BRIGGS

Deep ocean environmental research became a new objective of the NRL search team in 1970 with the scuttling of the LE BARRON RUSSELL BRIGGS and her cargo of obsolete munitions. The late '60's brought a heightened awareness of environmental pollution problems so new concerns were raised about ocean dumping practices that were largely ignored until then. Photographs were now used to observe animal life near and on the sea floor. By adding a remotely-controlled water sampler to the search instruments, chemical analyses could be made to look for contaminants at precisely controlled locations within dump sites.

Reprinted from 1970 Review, pp. 132-134
Naval Research Laboratory, Washington, D.C.

NERVE-AGENT DISPOSAL SITE INVESTIGATION

Nerve-Agent Disposal Site Investigation. Scientists from the Ocean Sciences and Ocean Technology Divisions participated in several phases of the operation involving the disposal on August 18 of Army nerve-agent munitions at sea. On that date the obsolete Liberty Ship *LeBaron Russell Briggs* was scuttled with her cargo of 418 steel-encased concrete vaults, each containing 30 GB nerve-agent rockets.

The controversial decision to dispose of this material at sea was reached by the Department of Defense after a year of studying alternative methods of disposal which would be both safe and technically feasible. The rationale for sea disposal was that the combined effects of the agent's rapid dilution to nonlethal concentrations and its chemical reaction with seawater to yield nontoxic products as the material slowly leaked into the water would prevent any significant damage to marine life, even in the immediate vicinity of the sunken hulk.

In anticipation of the disposal, NRL scientists planned and directed an oceanographic survey of the proposed dumping site, located in an enclosed basin about 240 nautical miles off the east coast of Florida. The survey, which was conducted by a combined NRL-Naval Oceanographic Office team, established that bottom currents and vertical mixing of the water are slow in the 16,000-foot-deep basin chosen for the disposal. Furthermore, the survey established base-line levels of the relatively sparse deep-sea marine life and of selected chemical parameters in order that possible changes resulting from the disposal could be evaluated.

NRL scientists provided testimony on behalf of the Department of Defense during the congressional hearings and court actions following public announcement of the intended disposal at sea. They also attended the disposal operation to test the surface water for nerve-agent toxicity immediately after the ship was scuttled and to serve as Navy spokesmen for the press.

In October 1970, scientists aboard the Laboratory's oceanographic research ship USNS *Mizar* conducted the first of a scheduled series of postdisposal inspections of the site. They obtained numerous photographs

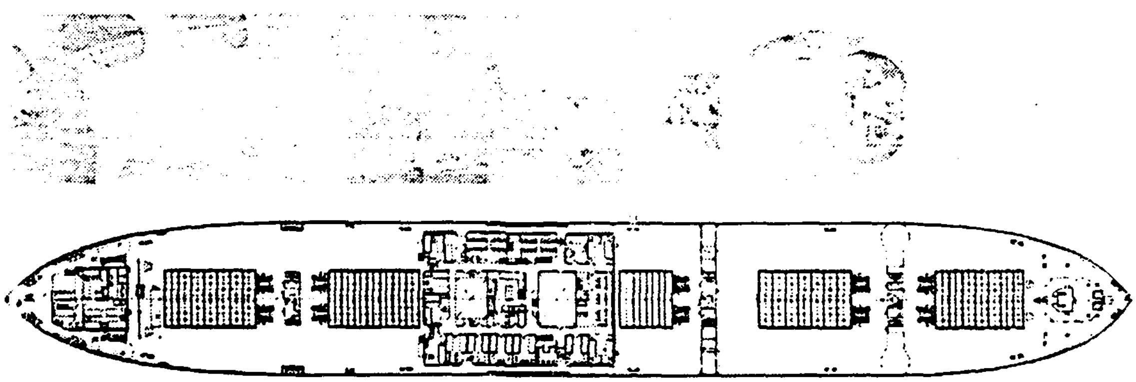


Figure 11. Underwater photomosaic of LeBarron Russell Briggs constructed by the Naval Reconnaissance and Technical Support Center from underwater photographs taken by NRL. The large differences in contrast are due to variations in camera range as the deep-towed "fish" passed over the 3-mile-deep hulk. The deck plan is shown to the same scale as the mosaic.

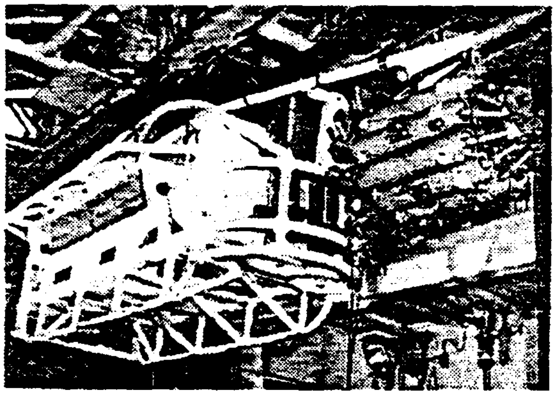


Figure 12. NRL's renowned deep-towed "fish" became a combined search and sampling vehicle with the addition of a multiple water sampler, seen here attached to the aft end of the fish. Signals telemetered down the towing cable activated the water sampler when other sensors on the "fish" indicated that the hulk containing the chemical-warfare munitions was nearby.

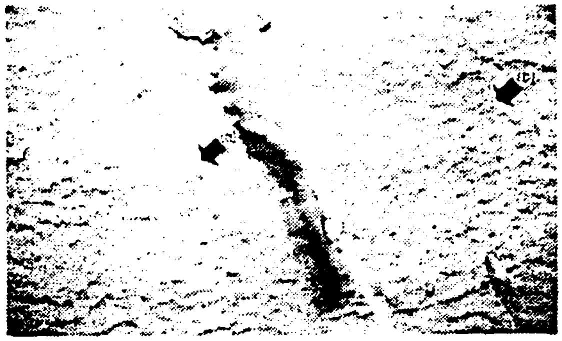


Figure 13. This bottom photograph was taken very close to the sunken nerve-gas-laden ship. The fish (lower right) is a typical representative of the deep-sea macrourid, or rat-tail, family. The vaned compass is suspended from the towed search vehicle. The arrows point to (a) marks in the sediment, presumably made by fishes, and (b) to sediment that was displaced when the ship hit the sea bottom.

and sonar traces which provided unambiguous proof that the hull had remained intact (Figure 11) with the vaults still in its cargo hold. The position of the sunken hulk was redetermined as 29°23.1'N. and 75°58.0'W., which was within 0.1 mile of the coordinates established at the time of the scuttling.

Water samples were obtained by the multiple sampler shown in Figure 12. All of these samples, including several taken over the open holds, gave completely negative results when tested chemically for the presence of nerve agents or fluoride, which is one of the agents' decomposition products. Fluoride concentration was measured by an NRL procedure capable of detecting 25 parts per billion of excess fluorides. The negative results suggested that either no GB agent had as yet leaked out into the surrounding water, or, if leakage had occurred, a rapid dilution to nontoxic concentrations had taken place.

Results of measurements of dissolved oxygen, pH, and salinity were identical to those obtained during the predumping survey. There was no evidence of dead or dying organisms in any of the more than 16,000 photographs taken in the vicinity of the hulk. In a number of bottom pictures, fish and other large animals were observed swimming within 300 feet of the Liberty Ship. Some photographs taken of the depression formed by the impact of the hulk reveal lebensspuren (life trails) similar to those seen in Figure 13, proving that benthonic creatures had frequented the site sometime in the previous eight weeks.

Additional surveys of the dump site are planned for the future. Close-up photographs will be carefully scrutinized for sponges, hydroids, and other animals, which should begin soon to affix themselves to the hull. Irregularities or gaps in the growth patterns may prove to be a sensitive indicator of nerve-agent leakage. Water samples will again be collected by means of the remotely controlled multiple sampler.

[Supported by the Dept. of the Army]

Four more times ending in January 1974, MIZAR returned to the BRIGGS site for photographs and water samples. In the final revisit, just as in all previous returns to the hulk, living animals were photographed and the water samples reflected no change above normal background conditions. In one series of three photographs a crab could be seen making progress across the deck of the liberty ship [12]. A more thorough discussion of conditions at the site, tests, and measurements is found in [13].

EXTENDING PHOTOGRAPHIC RANGE

In "The Face of the Deep" [14] the authors note a gap in the size of sea floor features between those inferred from echo soundings and those seen in bottom photographs. This, "Unknown Sea-Floor Morphology" in the size range between 5 and 100 meters is covered by the NRL-developed LIBEC technique described in the next reprint. Single LIBEC photos span 20 meters and a simple montage of a half dozen photos closes the entire gap noted in [14].

Hints that photographic range could be extended by increasing the distance between lights and cameras came when wide angle and normal angle cameras were simultaneously used to photograph the same subject. Often the image seen by the camera closest to the strobe light was obscured by light scattered from suspended particles. See, for example the simultaneous views of ALVIN in [15]. Such observations lead to a series of tests noted in the next reprint and described more thoroughly in [16].

Reprinted from 1970 Review, pp. 137-138
Naval Research Laboratory, Washington, D.C.

SEARCH PHOTOGRAPHY BY THE LIBEC TECHNIQUE

Search Photography by the LIBEC Technique. Since the loss of the submarine *Thresher* in 1963, NRL has strived to improve its capability to search the deep sea floor. This work led to the development of the three-camera array used to locate *Thresher* and the wide-angle camera used to locate *Scorpion, Alvin, Eurydice,* and *LeBarron Russell Briggs.* The backscatter of light in the water space between the camera and the bottom limited these systems to a maximum operating altitude of about 30 feet, which corresponds to a path width of roughly 90 feet. A study was conducted recently to determine if the lighting system could be modified to overcome these limitations caused by backscatter and thus allow greater photographic coverage.

In order to evaluate various lighting geometries, mathematical expressions were developed for the backscatter of light along any line of interest between the camera and a hypothetical target. The curve in Figure 16, derived from these expressions, predicts the backscatter along the optical axis of a camera when the light is mounted 3.5 feet to one side. It is evident from the curve that most of the backscatter comes from a region close to the camera which is more intensely illuminated than the volume nearer the target. If the camera's field of view were to be moved out of this highly illuminated volume close to the light source, the harmful backscatter could be reduced significantly. With narrow-angle systems this can be accomplished by a lateral separation of the light and camera. For the wide-angle cameras favored for ocean-floor search, locating the LIght BEhind the Camera (LIBEC technique) is more effective.

Predictions based upon a combination of theory and experience suggest that, with the light 30 feet behind the camera, operating heights of 120 feet are possible. At this height, a light source energy of as much as 50,000 joules is needed to maintain sufficient bottom illumination. While such powerful lights are available, they are generally too large to be adapted for use underwater. This made it necessary to design and build the one shown in Figure 17. This unit, which will withstand a pressure equal to that at a depth of about 16,000 feet, has an energy capacity of 8700 joules. Six units were used to provide the required 50,000 joules.

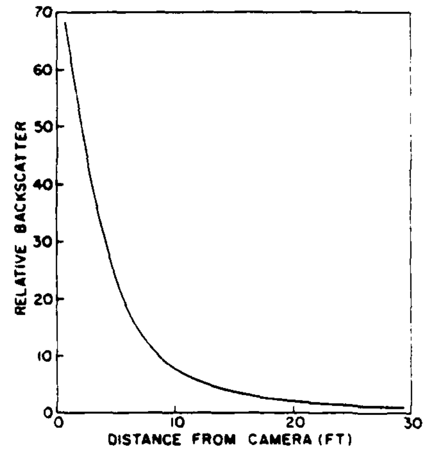


Figure 16. Relative backscatter of light as a function of range along the optic axis of a camera system in which the light and camera have a lateral separation of 3.5 feet. The zone of intense backscatter predicted by the curve seriously limits the range of underwater cameras.

These light sources and available cameras were used to photograph the ocean floor in an area east of Charleston, South Carolina. Photographs were taken at 10-foot intervals between heights of 10 and

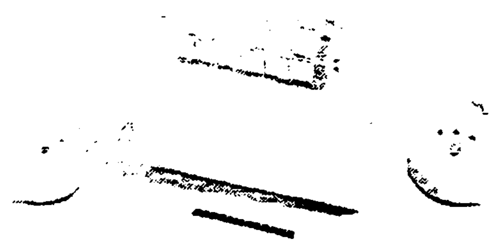


Figure 17. Underwater electronic flash unit and housing designed for a depth of more than 3 miles. The nominal 8700 joules of electrical energy stored by the NRL unit provides about 30 times the light output of commonly available models.

120 feet with vertical separations of light and camera of 30, 15, and 7-1/2 feet and with no separation. With the camera 30 feet below the lights, photographs

of the bottom were taken at distances up to 80 feet. Comparable photographs were taken with the presently used laterally displaced camera at about one-half this distance. Experience has shown that man-made objects on the sea floor generally can be photographed from greater distances than natural objects. To verify this by experiment, photographs of a 2-foot-diameter white disc were taken at ranges up to 120 feet (Figure 18). The contrast decreased with range but was sufficient to indicate that successful photographs could have been obtained at even greater ranges.

While further testing and development is needed, it is obvious that the LIBEC technique provides significant advances over NRL's current wide-angle photographic search system. For example, if the operating altitude can be raised to 80 feet, the photographic search width will be broadened to 240 feet, and the 150 hours now required to photograph a square mile will shrink to less that 60 hours. A fully operational LIBEC system would require only three overlapping photographs to cover the entire hulk of a bottomed Liberty ship, such as *Briggs*. The fact that a square mile of the sea floor could be imaged on a single roll of film illustrates the potential of LIBEC as a survey tool.

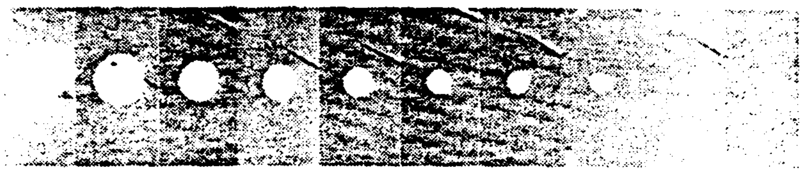


Figure 18. Experimental underwater photographs of a 2-foot-diameter white disc taken at ranges of from 30 feet (left) to 120 feet (right) with the light source 30 feet behind the camera.

Developmental and engineering aspects of the light source required for LIBEC photography were described in [17]. Three of NRL's 8,700 joule pulsed xenon light sources were loaned to the civilian oceanographic community in 1978. Unfortunately these were accidentally lost at sea. Even though such efforts were made to transfer the LIBEC technology, the system remains unused by the oceanographic community today.

SEA FLOOR NAVIGATION BY ACOUSTICS

Performing an effective sea floor search requires mapping the location of the deep towed sensor system and any significant clues that may lead to the target. The location of the surface vessel within an accuracy of meters can be measured today by means of satellite navigation. In water depths of a mile or two, however, the towed sensors can be as much as a half mile from the surface platform and in any direction depending on the last maneuver of the platform. The towed instruments will respond to a change in course by the towing vessel after a delay of as much as a half hour. Such mapping problems are solved by the acoustic tracking system described in the following reprint. The system is an extension of the technology described in [18] by the Applied Physics Laboratory (APL) at the University of Washington in Seattle. The NRL search team was assisted by Professor Stanley Murphy, APL Washington, who helped install a portable acoustic tracking system for NRL aboard USNS GILLISS in 1963 to search for the THRESHER.

Reprinted from 1971 Review, pp. 205-206
Naval Research Laboratory, Washington, D.C.

MIZAR'S UNDERWATER SEARCH SYSTEM

***Mizar's* Underwater Search System.** Searches of the deep-ocean floor require continuous and accurate knowledge of the positions of towed sensors and the towing ship relative to each other and to one or more fixed positions on the ocean floor. A deficiency in this knowledge causes duplication of search effort at considerable cost in time and money and may result in failure of the mission. To assure that the necessary data would be obtained, the Laboratory designed a special underwater tracking system and installed it aboard USNS *Mizar* (T-AGOR-11) in 1964. This system has been an important factor in the success of may NRL search operations, most notably those carried out to locate the lost submarines *Thresher, Scorpion,* and *Eurydice,* the submersible *Alvin,* and most recently the sunken ship *LeBuron Russell Briggs.*

The underwater tracking system (Figure 39) consists primarily of a triangular array of hydrophones mounted on *Mizar*'s hull, an acoustic transponder that can be placed in a fixed position on the ocean floor, and a responder that is mounted on the towed sensor platform. The hull-mounted hydrophones are positioned at the vertices of an isosceles right triangle having equal sides of 50 feet. A small shipboard digital computer automatically controls the system.

In operation, the responder on the towed sensor platform is interrogated electrically via a telemetry link in the towing cable. The responder replies acoustically, and the acoustic travel times between it and each of the three receiving hydrophones on the ship's hull are accurately measured and converted to radii of three spheres whose centers are the hydrophones. The computer then finds the unique point of intersection of the three spheres, this point being the location of the responder and, hence, of the sensor platform relative to the ship. Next, the sea-floor transponder is interrogated by an acoustic pulse from one of the hull hydrophones, to which the transponder replies acoustically. These travel times are measured and used to compute the transponder's position relative to the ship. Information as to the attitude of the plane of the three hydrophones, as affected by roll, pitch, and heading of the ship, is provided for inclusion in the computations. The computer furnishes a printout of the north-south and east-west distances to the responder and transponder and the depths of each relative to the ship, and it provides a printout, calculated by algebraic coordinate addition, of the position of the responder (sensor platform) relative to the transponder.

The recoverable transponder, anchored 30 feet above the ocean floor, serves as a reference point.

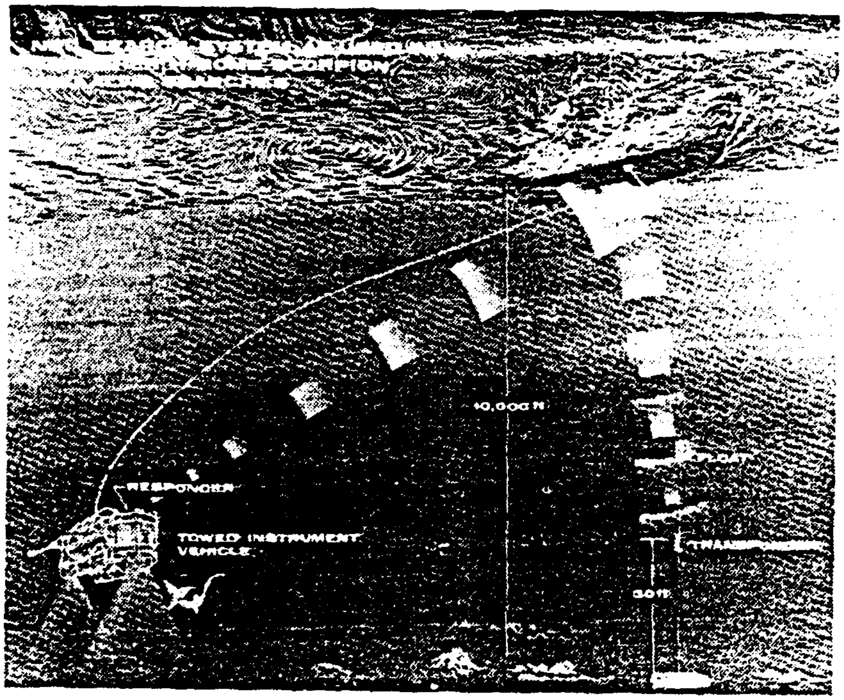


Figure 39 Depiction of the underwater tracking system in operation during a search mission Major components include three hull-mounted tracking hydrophones a responder mounted on the towed instrument platform and a fixed sea-floor transponder that serves as a bench mark

or "bench mark," for local navigation in the area. Its true geodetic position is fixed by correlating its location relative to *Mizar*, whose geodetic position is provided by satellite navigation.

The underwater tracking system requires very accurate measurement of acoustic travel time. The position error introduced by a timing error of 1 microsecond is about 1 foot for a water depth of 10,000 feet. The original system used "leading edge" detection in the time-measuring circuits. Timing errors occur with this type of threshold detection because noise bursts above a certain amplitude are treated as valid signals. In actual operation, standard deviations of 200-300 feet in position occurred at a depth of 10,000 feet even under the most favorable environmental conditions.

Efforts to improve the timing accuracy by use of more sophisticated signal-processing techniques have been underway at various research centers since 1965. For instance, the use of a matched-filter detector was studied at the Catholic University of America under ONR contract. NRL refined this concept and designed and built a practical receiver which incorporated a matched-filter detector. An evaluation of this receiver made at NRL in 1971 indicated that it is much superior to the earlier one. In addition, a limited test of the new system was conducted at sea. Under rather favorable conditions, the standard deviation of raw position data from a straight-line, least-squares fit was about 60 feet. Employment of a data-smoothing routine in the computer program reduced the standard deviation to about 25 feet, a marked improvement over the performance of the original system.

DEEP WATER DUMP SURVEYS

During a preliminary survey of a Deep Water Dump Site in 1969 (Table I, Cruise 22) concentrations of the dead sea urchin, Echinus affinis, were photographed. Within a few hundred meters along a camera run the number of dead urchins reached a peak just where the living population sharply decreased. Normal live populations were photographed on both sides of the zone in question. Echinus was known to be relatively fast moving and active so the observation suggested that whatever caused the death of the urchins might be keeping the live ones away. Because this, in turn, suggested a highly localized source of contamination a more detailed survey was mounted to settle the question. The following reprint describes some of the techniques used and results found. A very thorough description of the findings is given in [19].

Reprinted from 1972 Review, pp. 195-197
Naval Research Laboratory, Washington, D.C.

INVESTIGATION OF THE ABYSSAL BENTHIC ZONE

Investigation of the Abyssal Benthic Zone. Until the past few decades, the great world ocean had been regarded as too mighty and vast to be seriously altered by mere acts of man. Increasingly in recent years, man has challenged some of the uses he has made of the ocean as threats to his very existence. Since 1969, NRL has been equipped to study an important aspect of this problem—the potential contamination of the abyssal benthic zone, that part of the ocean near the bottom at depths greater than 1000 meters.

For a number of years obsolete munitions were being disposed of at sea in areas designated as Deep Water Dump (DWD) sites. In response to public concern over such disposals, the Navy initiated investigations to ascertain the environmental conditions at the sites. One such investigation was directed by NRL during 1972 at DWD Area A, located 150 nautical miles east-southeast of New York City on the slope between the continental shelf and the deep ocean bottom, where four surplus World War II ships loaded with obsolete munitions had been scuttled.

The search and survey mission was conducted by means of special equipment developed by NRL and operated aboard USNS *Mizar* (T-AGOR-11). This equipment had been used successfully in recent years to locate the sunken U.S. submarines *Thresher* and *Scorpion* and the sunken French submarine *Eurydice*. It includes underwater cameras having both wide-angle and normal-angle coverage, electronic flash lamps, a magnetometer, side-looking sonar, an acoustic responder, and associated power and command and control electronics. All are mounted on an unmanned towed platform. (See Figure 40.)

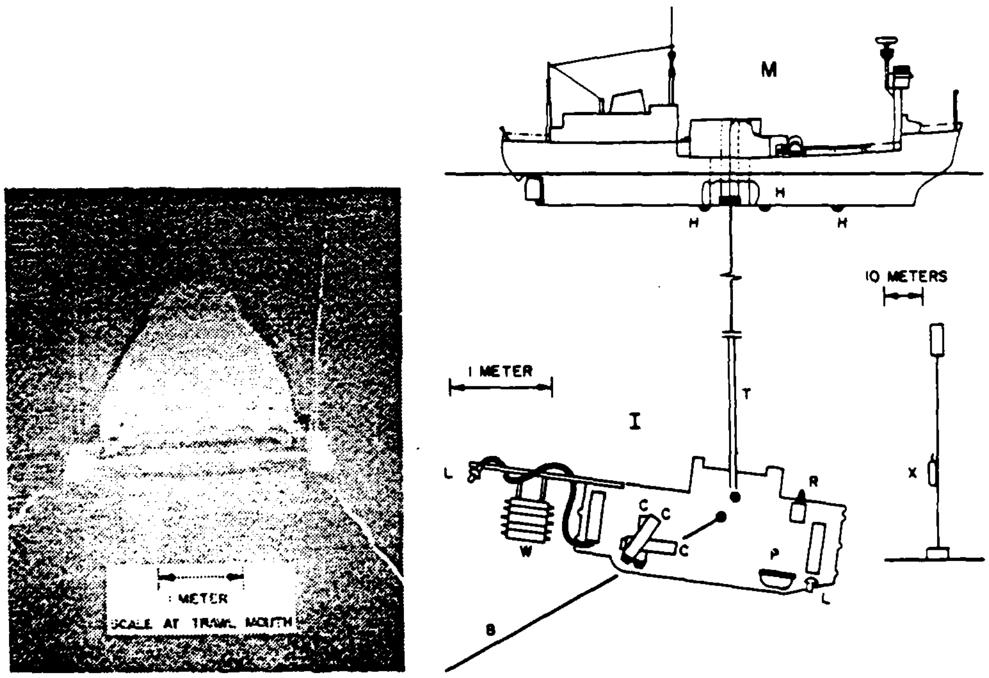


Figure 40. NRL's ability to investigate the abyss stems from elements in the system illustrated above. From the surface platform Mizar (M), the instrumented platform (I) is lowered through a well by electrical tow cable (T) to a position above the sea floor, which is monitored by acoustic pinger (P). Electronic flash lamps (L) provide light for cameras (C) which photograph the ocean bottom and instruments, such as the water sampler (W) and bottom dredge or trawl sampler (shown in photograph), which is tethered to the towed platform by bridle (B). Precise acoustic navigation is provided by the anchored reference transponder (X), the responder (R), and Mizar's hull hydrophones (H). The entire system is controlled from a laboratory aboard Mizar. Note difference in scale between the instrumented platform and the remainder of the illustration.

At DWD-A, the procedure was to tow the equipment near the bottom at a depth of 7000 feet (2300 meters) by means of a cable through which the equipment could both receive and transmit telemetry signals. Satellite and LORAN C navigation systems, together with an acoustic tracking system, were used to establish the location of the hulks and the towed instruments. Bottom photographs were taken to identify two of the hulks and record pertinent detail. Positive identification of the hulks was made by comparing unique features in photographs taken before and after the sinking. A debris field resulting from the explosive detonation of a third scuttled ship was also located and photographed. The fourth ship could not be located.

Teams of scientists from Florida State University, the Naval Oceanographic Office, the Naval Weapons Laboratory, and Edgewood Arsenal joined the NRL investigators from the Ocean Sciences and Ocean Technology Divisions for the final phase of the operation.

A commercially available water sampler was modified for use aboard the towed platform, and water samples were taken whenever the acoustic tracking system indicated that the search platform was very close to one of the hulks. A photograph of the sampler was taken at the same time that each water sample was taken to assure proper functioning of the equipment. Extensive biological sampling was done by "photo-trawling," a method whereby a large biological trawl net was towed and photographed simultaneously (Figures 40 and 41). Several tons of abyssal mud, rocks, and animals were recovered during the photo-trawling operations. Among the few artifacts brought to the surface was an ammunition box and its contents (Figure 41).

The new photo-trawling tool helped the NRL-directed team to map for the first time the distribution of surface-dwelling (epibenthic) bottom animals over several square miles of the deep sea floor. Additional data were gathered at two bottom stations farther up on the continental slope. From them it was learned that no food-chain links existed between the fauna at the dump site and the creatures nearer snore tnat form an important food source for man. Other. standard methods were used to obtain biological samples and to collect chemical and physical data. None of the samples of water, sediment, and benthic animals obtained showed evidence of contaimination.

[Supported by NAVORD]

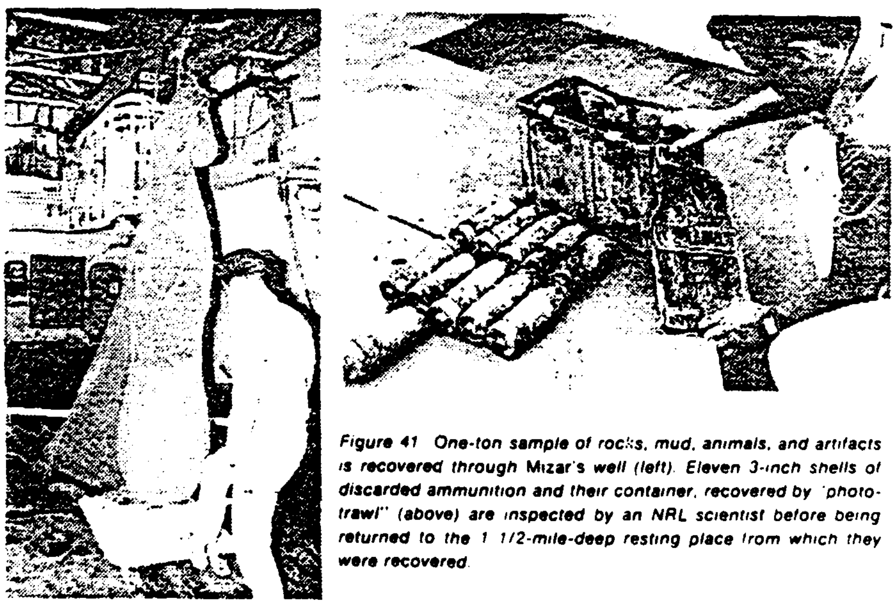


Figure 41 One-ton sample of rocks, mud, animals, and artifacts is recovered through Mizar's well (left). Eleven 3-inch shells of discarded ammunition and their container, recovered by "photo-trawl" (above) are inspected by an NRL scientist before being returned to the 1 1/2-mile-deep resting place from which they were recovered.

MID ATLANTIC RIDGE PHOTOGRAPHY

A key scientific role was played by NRL's LIBEC system in the French-American Mid-Ocean Undersea Study (Project FAMOUS). LIBEC was used to make a photographic survey of the Rift Valley between the North American and African Plates. Results of the survey are described in the next reprint. The 5,250 LIBEC images were equivalent in area to the coverage that would have been obtained by 300,000 conventional sea floor photographs. The resultant sea floor photomap was the largest ever assembled. It helped the Project FAMOUS geologists to carefully plan the dives they would make during the following summer.

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Naval Research Laboratory, Washington, D.C.

LIBEC AND FAMOUS

LIBEC and FAMOUS. The centermost feature of the largest single mountain range on earth, the underwater Mid-Atlantic Ridge, is a steep-walled slash called the median Rift Valley. The modern and basic unifying theory of plate tectonics holds that it was from there that the continents split apart some 200 million years ago. Today, the continents continue to drift apart, but at an incredibly slow rate which accounts for only a few centimeters of movement a year. Only in the past 10 years have several independent lines of evidence lent support to continental drift – a theory proposed early in the century, but endorsed strongly by relatively few scientists. In an attempt to learn more about the details of plate tectonics, NRL scientists recently obtained more than 5,000 photographs of the sea floor inside the median Rift Valley with the LIght BEhind Camera (LIBEC) system.

The LIBEC system permits photography of the ocean bottom at greater ranges than were previously possible (note size comparison of conventional and LIBEC photos in Figure 1). This advance is achieved by separating the camera from the zone of intense backscatter near the light source while directing most of the light towards the outer limits of the target area.

LIBEC is deployed from the research vessel MIZAR through the ship's center well and is towed by means of a cable-telemetry system developed at NRL. Figure 1 depicts the various elements of the system as they would appear from a position just above the sea floor.

Although the majority of the photos corroborate previous information that the Rift Valley is floored with pillow basalt, others reveal a wealth of additional detail. Many steep-walled scarps and fissures (Figure 2) were seen, some apparently continuous over distances of more than 3 kilometers (km). Further studies are planned to determine if these structures are related to volcanic or tectonic processes.

Steep rock surfaces were found to harbor a variety of sessile animals such as sponges, hydroids, and corals. Deposit feeders were noted in zones where pelagic sediment has accumulated. More active creatures

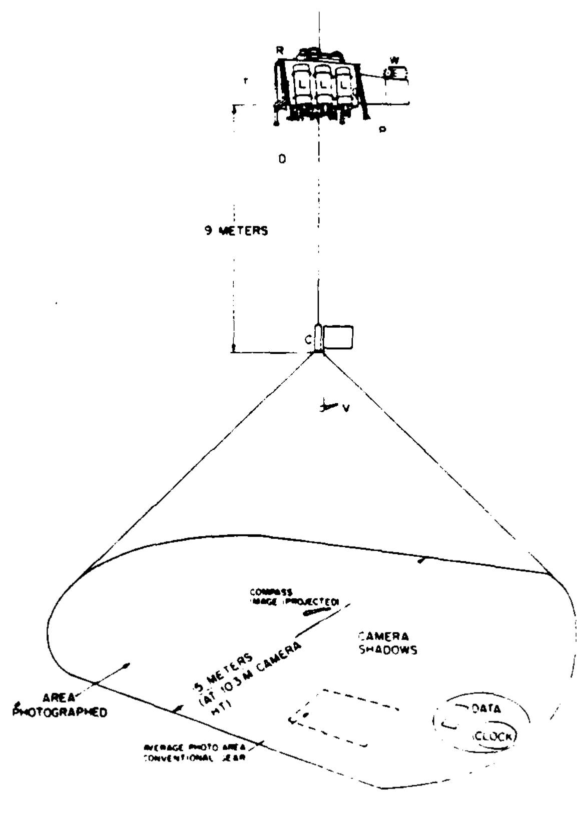

Figure 1. Spatial relationships of various components in NRL's Light Behind Camera (LIBEC) system. During operation of the deep-towed LIBEC system, 8000-joule electronic flash lamps (L) direct light via multiple cones (D) to the outer edges of the camera's field of view. The camera (C) is suspended well below the light source, thus avoiding the region of intense backscatter, which usually reduces the range of photography. (Note the dashed square, which represents the average area of coverage obtained using conventional gear.) Other elements in the LIBEC system, as it was configured during MIZAR cruise 73-11-10, were the responder (R), for acoustic positioning; pinger (P), for acoustic altitude; multiple water sampler (W); precision temperature sensor (T); and vaned compass (V), which is suspended from the camera.

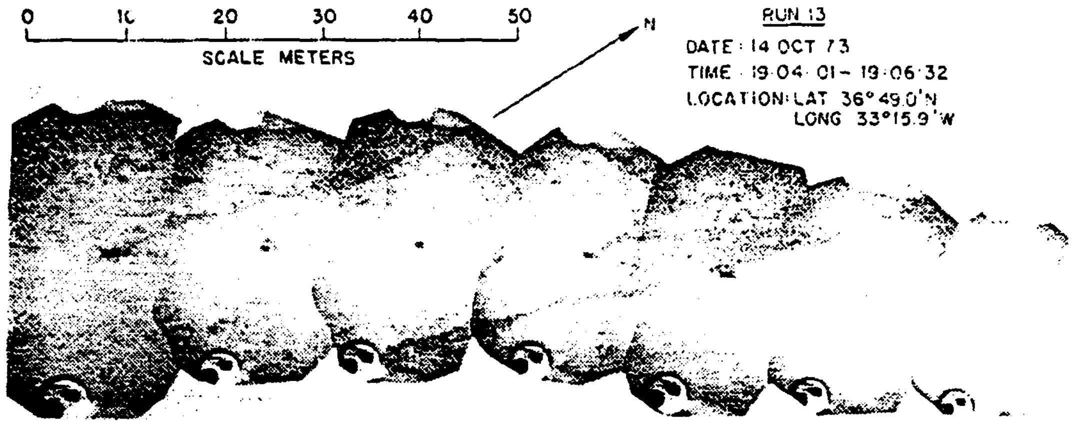

Figure 2. The two dark lines in this montage of seven LIBEC photographs are vertical openings or fissures which parallel the sides of the median Rift Valley in the Mid-Atlantic Ridge.

were present in a number of exposures, and the unusual cirrate octopod (umbrella octopus) appeared in at least two photographs.

Temperature was monitored continuously, and several water samples were collected on command during each photographic run. Although no anomalous salinity, oxygen, or temperature conditions were detected, further measurements of the water will be made to determine if microconstituents such as mercury are present in abnormal concentrations.

Researchers from the Acoustics, Ocean Sciences, and Ocean Technology Divisions took part in the mission, which was completed in cooperation with the Woods Hole Oceanographic Institution. The mission was part of the French-American Mid-Ocean Undersea Study (FAMOUS), the most comprehensive study of the Mid-Atlantic Ridge ever attempted. The FAMOUS area, a few hundred km southwest of the Azores, will be the site of further intensive studies (summer of 1974) when American and French observers will dive in submersibles to locations preselected on the basis of LIBEC and other data. The divers will provide "ground truth" for much of the information seen in the four-by-five km LIBEC study area. Such observations will be added to a giant 1:250 scale photo-mosaic map of the Rift Valley floor, the largest of its kind yet attempted.

Final results will aid in a better understanding of plate tectonics. This in turn should furnish clues about the new sources of certain dwindling natural resources. When the continents split apart, formations now known to contain oil deposits were severed; accordingly, a precise reconstruction of the previous land positions should lead to as yet undiscovered reservoirs. Additionally, the upwelling of materials from the deep earth along central ridges is thought to be the genetic process responsible for many metal ore deposits now found on land.

[Supported in part by National Science Foundation.]

FINAL IMPROVEMENTS

Even though NRL successfully used television to view the sea floor from USNS GILLISS in 1963 the many problems inherent in its use were not overcome until 1974. The following and last reprint describes how the video problems were solved. The account also describes the installation of stability and maneuvering propulsion on the deep towed instrument package.

Reprinted from 1974 Review pp. 278-281
Naval Research Laboratory, Washington, D.C.

RECENT IMPROVEMENTS TO THE NRL DEEP-OCEAN SEARCH SYSTEM

Recent Improvements to the NRL Deep-Ocean Search System. Activities at the Naval Research Laboratory in deep-ocean search, survey, and inspection received national prominence when NRL scientists aboard the USNS MIZAR located the resting places of missing nuclear submarines USS THRESHER and SCORPION and played a vital role in locating the lost hydrogen bomb off Palomares, Spain. Since those times, the unique capability for sea-bottom inspection developed at the Laboratory has been employed in other projects of national importance affecting defense, the civilian economy, and international goodwill.

In recent months, several significant improvements have been made to the NRL search system which have substantially increased its value both in direct support of Fleet requirements and as an instrument of basic oceanographic research. A listing of the improvements would include the development of a real-time, normal- or slow-scan underwater television capability; the construction and installation of a lateral thruster for the towed underwater instrumented vehicle; the addition of tail rotors capable of providing

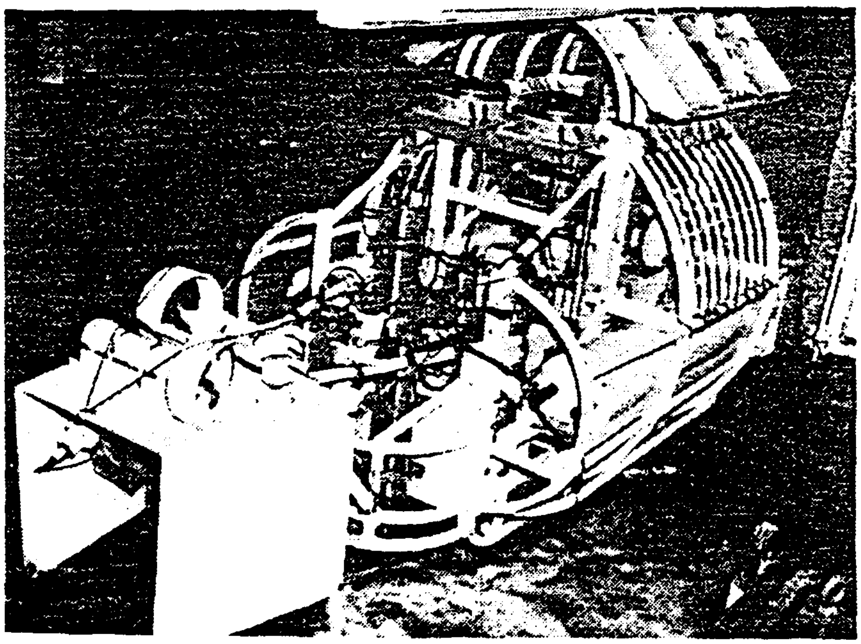

Figure 38. New NRL "fish," which features underwater television, lateral thrusters, yaw-control rotors, and many sensors, probes, and tracking devices

active yaw control to the vehicle; and the provision of a new wide-base-line acoustic tracking and navigation system, interfaced with automatic plotting of ship and instrument package.

Some of these changes can be seen in Figure 38. The two yaw-control rotor motors are clearly visible on the tail of the vehicle, while the thruster propeller can be seen within its protective box in the upper part of the structure. The thruster motor is capable of providing at least 450 Newtons of thrust in either direction. This motor will enable the fish to hover at operational depth with the aid of rotor control over any point within a 125-meter-diameter circle, without the need for maneuvering action by the surface ship.

Portions of the underwater television system were designed, developed, and tested entirely at the Laboratory. An entirely new modulation scheme was devised to multiplex the television signal onto the twin-conductor armored coaxial tow cable in such a way that no interference would take place with existing frequency-multiplexed command, control, and signal channels used for other sensors and probes.

For transmission purposes, the television channel was placed between 500 kHz and 4.25 MHz. The modulation scheme inverted the preamplified video signal, so that low frequencies were transmitted near the 4.25-MHz carrier frequency, while high-frequency video was transmitted just above

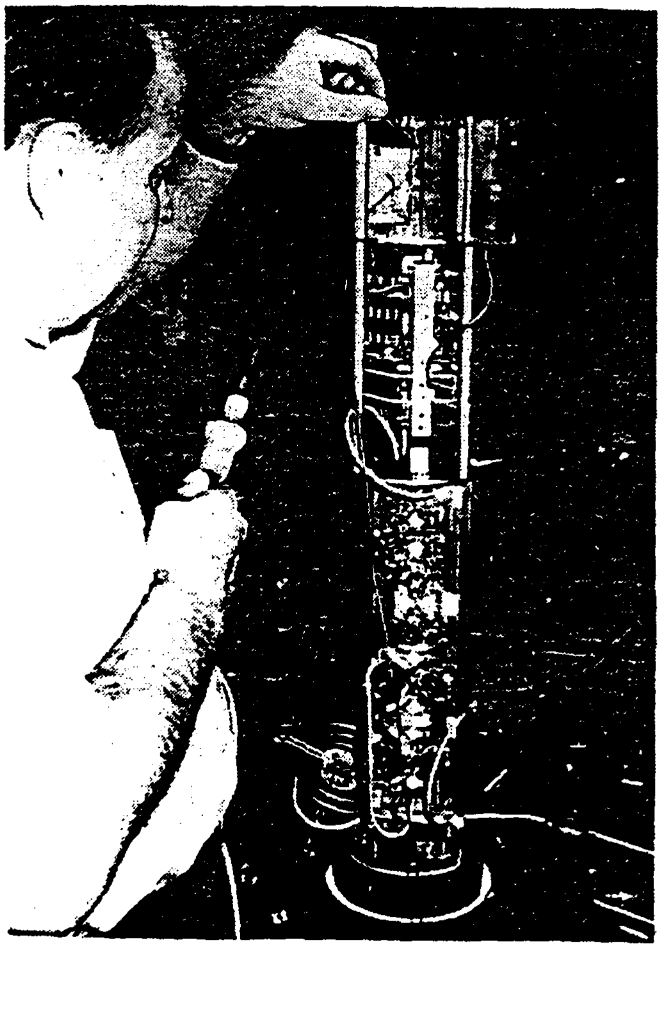

Figure 39. Underwater television electronics, showing filters, carrier generator, modulation device, and line driver: configured for insertion into a pressure-resistant housing

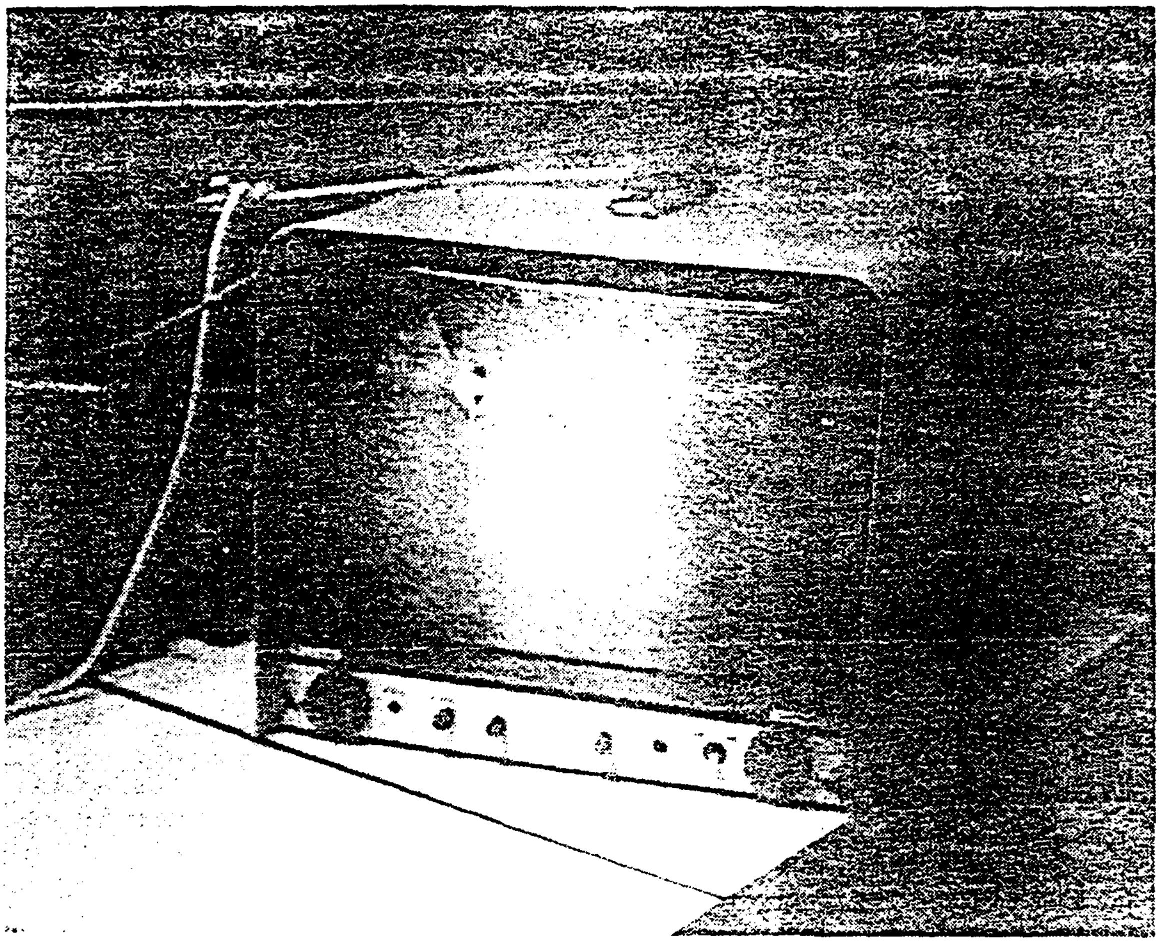

Figure 40. Shipboard monitor, showing a compass hanging 3 m below the television camera in 3600 m of water over a silting ocean bottom

the 0 to 200 kHz telemetry band. The carrier frequency was created by multiplying by 27 the television trigger command frequency of 157.5 kHz. Figure 39 shows the underwater television electronics package, which was mounted on the towed vehicle within a pressure housing. An illustration of the quality of picture provided by the topside television monitor is shown in Figure 40. Unfortunately, distinguishing ocean-bottom features are not visible in this region of the deep-sea floor. Evidence of picture contrast and resolution is seen in the picture, however, from the clarity of the compass suspended approximately 3 m below the television camera lens.

Microbathymetry operations in September 1974 called for improved navigational accuracy and control. Acoustic ranging information received at the ship from bottom-mounted transponders triggered from the ship and fish was processed via shipboard computer to provide the tracking information needed for automatic plotting. Tracking information from the short-base-line shipboard system for locating the fish was also integrated into the plotting routines.

Recent improvements to the deep-ocean search system are expected to have a significant impact on the operational readiness and capability of NRL to respond in future emergencies, or to perform other deep-ocean tasks of military or national significance. Future plans call for the development of new, high technology sensors and probes. These plans are discussed more fully in the article on pages 31-38 entitled, "Deep-Ocean Search, Survey, and Inspection—A Cooperative Venture".

LOSS OF MIZAR AND TRANSFER TO HAYES

During the early '70's increasing ship costs forced NRL to give up the use of one of its two research vessels, HAYES and MIZAR. Studies indicated that USNS HAYES (T-AGOR-16) should be retained and in early 1975 sponsorship of MIZAR was transferred to the Naval Electronics Systems Command. This however, did not terminate the deep search capability at NRL.

Under the direction of Geoffrey O. Thomas the Search and Inspection Group, as it was then called, developed the capability to operate the deep search system from HAYES. Launch and retrieval was from between the catamaran hulls. Tests were carried out in a series called DOSS (Deep Ocean Search System) I, DOSS II, and DOSS Plus, terminating in October of 1978. Although this series was totally successful the equipment handling procedures were more awkward than aboard MIZAR and after retrieval the towed instruments remained on an open weather deck. Because the DOSS series were experimental they will not be considered a part of NRL's Deep Sea Floor Search Era. The Era essentially ended therefore with MIZAR's final search and inspection missions in 1974.

CONCLUDING REMARKS

NRL's Deep Sea Floor Search Era was an exceptional period during which a small group at the Laboratory furnished a reliable means of finding lost objects of great value on the deep ocean bottom. Many of the missions were newsworthy at the international level. During the Era, technology similar to NRL's was being developed elsewhere. For example, Woods Hole Oceanographic Institution developed a towed unit called ANGUS (for Acoustically Navigated Geophysical Underwater Survey). The Marine Physical Laboratory at the Scripps Institution of Oceanography developed a similar system called Deep Tow. NRL's expertise was no longer unique. The Navy could turn elsewhere for help on deep sea floor missions and the Laboratory could turn its research and development elsewhere.

A TESTIMONIAL

Captain William F. Searle, Jr. was the Navy's Supervisor of Salvage at the time of the SCORPION Search. Although retired from the Navy he continues to be a prime resource person for expertise in deep ocean search and recovery. When the TITANIC was located in 1985 Captain Searle was asked by Congress to review the development of technology for deep ocean search and recovery. His remarks regarding NRL's contributions [20] appear to be a fitting way to end this report.

"The superb work of the scientific teams from the Naval Research Laboratory and under the direction of Mr. Chester Buchanan on board the USNS MIZAR in searching for the sunken submarine THRESHER, as well as the explosive-laden SS ROBERT LOUIS STEVENSON ..... and the nerve-gas container-laden SS LE BARRON RUSSELL BRIGGS ....., to name but a few, led the way for the search operation in the North Atlantic which is the subject of this hearing; namely, the apparently successful search and identification operation expedition of Dr. Bob Ballard and his French colleagues. Lest there be any doubt as to our intent by including this paragraph, we hasten to point out that the roots of this deep search/location/identification operation lie in the pioneering work generally associated with MIZAR and Buck Buchanan, pioneer of the ocean deep".

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