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LABORATORY OF MARINE PHYSICS
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SPLASH SPOTTING
by
PASSIVE INFRARED TECHNIQUE

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Technical Report No. 51

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ABSTRACT

A previous study by the Laboratory of Marine Physics had indicated that the splash, casued by a mine or mine-like object entering the water when dropped from an appreciable height, could be detected by passive infrared techniques. Utilizing a commercially available radiometer, with a scanning mirror to sweep a twenty-degree sector area, equipment was designed to detect a splash occurring anywhere within such area. This report discusses tests conducted, in which the feasibility of detecting such splashes under various visibility conditions was demonstrated. Detection was obtained to a range of about 3500 yards; at shorter ranges under visibility conditions ranging from "bright and clear" to "darkness of night"; and under sea conditions ranging from "smooth" to "fairly rough with white-caps".

INTRODUCTION

Results of Previous Tests:

Experiments conducted [1] by members of this Laboratory, during the period April 1956 to January 1957, have shown that the splash due to the impact of a solid body on a water surface could be detected by infra-red techniques. In these tests, a Barnes Engineering Company infra-red radiometer (Model R-4B2) was used to measure the apparent temperature, as a function of time, of a region of the ocean surface during the entrance of a dummy mine (a weighted 50 gallon oil drum) into the water. When attempts were made to analyze the change in temperature during the splash, it was calculated that there was an insufficient release of energy by the dummy mine (the heating of the water due to the loss in kinetic energy of the mine) to explain the (usually) observed rise in temperature. Moreover, rises in temperature occurred even though the subsurface water was cooler than the surface water, so that the rise in temperature could not be due to mixing of water from below the surface.

The apparent rise in temperature which occurs has been successfully explained, in Reference 1, on the basis of the change in emissivity of water as a function of the angle of viewing of the water surface. The power per unit area radiated by a body at absolute temperature T is given by the Stefan-Boltzmann law:

$$R = \sigma \epsilon T^4$$

1. Withington, V., H.A. Fairbank, and C.S. Robinson, LMP Technical Report No. 48, Passive Infrared Mine Splash Spotting Preliminary Study, 8 February 1957, SECRET

where $\sigma = 5.67 \times 10^{-8}$ watts/square meter-°K; and ϵ is the emissivity, which is a characteristic of the radiating body. In the experiments performed, the radiation was measured by observation of the water surface at a glancing angle; when the splash occurs, the water is thrown up, forming an angle of almost 90° with the observation direction. The resultant change in the emissivity due to the change in angle of viewing completely explains the apparent temperature rises observed. Subsequent laboratory measurements of the emissivity of water as a function of angle were found to be in complete agreement with theoretical predictions based on Fresnel's laws of the reflection of light from a dielectric, and provides a firm basis for the explanation in terms of emissivity changes in the case of a mine splash.

While the studies resulting in T.R. 48 (Reference 1) definitely indicated that a splash was detectable by means of an infrared radiometer, the fact that the radiometer had to be positioned so as to observe the spot where the splash would occur made this particular equipment unsuitable as a device for detecting splashes of air-dropped mines; some form of scanning device would be needed. It was realized that, if the radiometer would sweep horizontally over an appreciable sector of the horizon, on apparent rise in temperature would occur whenever a splash appeared in the field of view of the radiometer. Since it is known that aircraft-dropped mines cause splashes which endure for about three seconds, this would allow for a method of discrimination against false targets as long as the scanning radiometer were able to get several "looks" at any splash. (From on analysis of numerous plots of radar data pertaining to observed splashes[(2)] it has been determined that the length of time that a splash persists varies from about one to eight seconds, with the majority lasting about three seconds). This problem was discussed with representatives of the Barnes Engineering Company, who undertook to design and construct a scanning radiometer head.

Objectives of the Program:

One of the principal problems of interest to this Laboratory is that of locating enemy mines placed in waters under control of our forces. Auxiliary to this problem, but of more particular concern to the armed forces, is that of removing, neutralizing, or marking for avoidance, the mines that have been located. The problem of locating the bottom (i.e. influence) mines is admittedly very difficult.

It seems probable that an enemy will employ the technique of mining waters of interest to the U.S. by dropping mines from aircraft. If the splashes caused by entry of such mines into the water can be observed, these positions can be plotted; the areas to be avoided by shipping, and to be searched (by various underwater methods) or swept can then be reduced to relatively small areas centered at

2. Beringer, E.R., M.C. Mertz, and C.S. Robinson, HPP Technical Report No. 10, Radar Studies of Mine Splashes in Operation MUD, 30 July 1952, CONFIDENTIAL

the plotted splash locations. The most promising methods thus far developed for obtaining data from which to plot splash locations have required reasonably good visibility or complicated radar or acoustic devices. The problem is therefore to find a reliable means for obtaining data necessary for plotting splash points, when visibility is less than good, particularly during darkness.

The studies at this Laboratory culminating in T.R. 48 led to the belief that splashes could be observed by means of infrared radiation, and thus data for their location plots could be gathered even in most areas of poor visual conditions. If a scanning radiometer should prove feasible, it should then be possible to mount two or more such instruments at strategic and accurately determined positions on shore (or even, in well protected locations, on small boats anchored in the harbor) and situated such that their scanning sectors would overlap. Should a mine splash occur in an area such that two or more radiometers would detect it, and such that the bearing from each could be determined, then the location of that splash could be plotted by the method of cross-bearings.

The objective of this study therefore became the investigation of the suitability of a scanning infra-red radiometer for detecting mine splashes.

The Radiometer

In view of the above, the Barnes Engineering Company of Stamford

Conn., designed and constructed a radiometer (Model R-811) containing an optical system for collecting and focusing infrared radiation; a detector which converts this radiation into electrical signals; and a preamplifier which amplifies the detector output signal to a level suitable for driving an external oscilloscope. Also contained is a scanning system for deflecting the detector field of view over a 20° arc of aximuth, and providing a synchronized horizontal sweep voltage for the oscilloscope; and a view finder which assists the user in pointing the radiometer at the desired overall field of view.

The optical system consists on an 8-inch Cassegrainian mirror telescope with a focal length of 12 inches; an effective focal ratio of f/1.9; and a resolution on the axis of 0.2 mils.

The detector is a Barnes Engineering #851 germanium-immersed flake thermistor, 0.4 mm wide by 1.5 mm high. This gives an effective instantaneous field of view of 20 mils high by 5 mils wide, which approximates the size of a splash at about 1000 yards range. The germanium lens serves as a heat sink for the active flake and provides a magnification of 4; it has a cut-off wavelength of 1.8 microns, thus eliminating all visible light. The compensating flake is identical to the active flake and each is biased by a 180 volt dry battery.

The preamplifier is a Barnes Engineering type DP-2A, modified to give a 1 to 1000 cycle per second bandwith. It uses two 6112 tubes, and with negative feedback has a gain of 1000. An Applegate 12 volt

DC supply heats the filaments, and plate voltage is supplied by a 300 volt, 20 ma Transpac unit with additional filtering.

Horizontal scanning is accomplished by oscillating a plane front-surface mirror, located directly in front of the telescope, about its vertical axis. A cam, driven by a 70 rpm Borg gearmotor and riding on a cam-follower attached to the mirror, provides a linear back-and forth-(azimuth) scan of 20°, thus producing two and one-third scans per second. A center-tapped potentiometer connected to the "B" supply is also driven by the motor to provide a sawtooth voltage wave synchronized with the mirror position for horizontal deflection of the oscilloscope trace.

The oscilloscope employed was a Dumont 304A modified by breaking the lead at one side of the internal "Y" center control and inserting an external shielded lead connected to a micropot shunted by a manually adjustable variable resistor. The micropot was driven by a 1/4 rpm clock motor, thus varying the vertical position of the azimuth scan trace so as to create a raster covering the full screen; thus, the horizontal axis of the oscilloscope screen represented the viewing azimuth of the radiometer, and the vertical axis represented time. The time necessary to complete a raster was adjustable from a few seconds to several minutes by means of the shunting resistor. In practice 45 seconds was found to be the most useful time to complete the raster (which was one inch high).

This presentation was then photographed by a Dumont Oscillo-record camera using a Polaroid-film back. The picture thus taken presented successive horizontal azimuth scans as a function of time. This presentation clearly indicated the location in azimuth of observed temperature discontinuities of as short as a few seconds duration. The short time between successive exposures of the Polaroid camera was of great assistance in optimizing performance of the equipment.

In practice, it was found that the azimuth scan departed considerably from a straight line due to slow changes in the background temperature and produced a confused raster which tended to obscure the transient phenomena in which we are interested. To correct this situation a Krohn-Hite model 330-A ultra-low frequency band-pass filter was inserted in the vertical deflection circuit. It was found that with a low frequency cut-off of 20 cps an acceptably straight line could be obtained without degrading the short time phenomena except for some distortion of the signal wave form. To further enhance the legibility of the data display, intensity modulation of the oscilloscope beam was used. An auxiliary resistance-coupled amplifier using two type 6AU6 pentodes with feedback and variable gain control was constructed to raise the signal voltage to a suitable level in order to accomplish this. It was found that a combination of both intensity and amplitude modulation provided the most meaningful presentation.

The intensity amplifier and its Lambda regulated power supply, the vertical scan mechanism, a function selector switch and necessary on-off

FIG. 1. RADIOMETER, SUPPORTED ON ADJUSTABLE TABLE TOP.

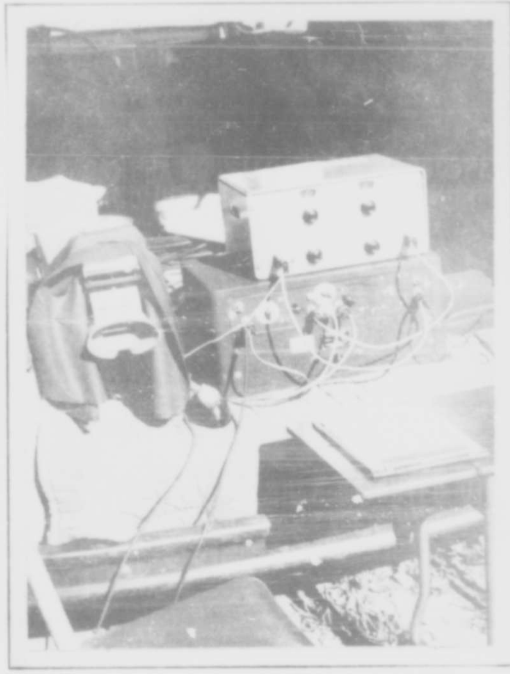

FIG. 2. CAMERA MOUNTED ON OSCILLOSCOPE, (LEFT) AND CIRCUIT CONTROL CASES, (RIGHT).

FIG. 3. IMPROVED SUPPORT FOR RADIOMETER. (TABLE ON TRIPOD).

FIG. 4. SPLASH FORMED WHEN WEIGHTED OIL DRUM WAS DROPPED FROM "A-FRAME."

switches were mounted together in a separate cabinet. Two Sola line voltage regulators were used to insure stable operation. In the field the radiometer unit was mounted on a heavy duty photographic tripod with a pan-head easily adjustable both in azimuth and elevation. A compartmented carrying case contained all connecting cables, film, log and spare parts. The result was a compact, readily portable system which performed in a most satisfactory manner under a wide variety of field conditions (see Figures 1-3).

TESTS AND RESULTS

Summary of Tests

The first phase of the tests consisted of bench-testing the equipment to determine optimum operating conditions using artificial targets (heated wires).

The second phase took place at the Fort Hale Naval Reserve Training Center located at New Haven harbor, where live splashes were produced either by dropping an oil drum into the water from a height of forty feet or by exploding dynamite charges just below the surface of the water. Splashes were observed at ranges up to 1500 yards. Here we confirmed or modified the operating techniques arrived at in the first phase of testing to conform to field conditions; a high incidence of splash observations was achieved both during the day and the night.

The third phase of tests involved detection of splashes caused by mine-like objects dropped from aircraft. The first part of this phase was conducted at Beavertail, Jamestown, R. I., where sixty pound practice bombs were dropped from Navy planes flying at about 500 ft. altitude. Later a series of mine drops were observed at the Chesapeake Bay Annex of the Naval Research Laboratory. For this series, regular mine cases, sand-loaded to give the same weight and weight distribution as service mines, were dropped from Navy planes flying at about 500 ft. altitude; splash indications were obtained at various ranges out to about 3400 yards.

Details of Tests

During the first field tests on April 18, 1958 no photographs of the oscilloscope face were obtained due to a light-leak occuring in the camera mounting. This fault was not located until examination in the laboratory the following day. During the delay thus involved, the sweep circuit control mechanism was completely overhauled to eliminate a slight jump in the scanned picture.

Throughout the Spring season, tests were frequently delayed by inclement weather conditions. During these periods numerous laboratory tests and experiments were conducted, and improvements were made in the circuitry. Among these was the insertion of the ultra-low frequency band pass filter to smooth out the sweeps in scanning, by eliminating low frequency signal components. Considerable improvement was obtained, but some scan-to-scan variations remained.

The next field test (May 9, 1958) was again conducted at Fort Hale. The equipment was set up on shore about thirty feet south of the pier, at the outer end of which was an "A" frame (Fig. 4), from which a weighted oil-drum was dropped to produce a splash, simulating that of a mine dropped from an aircraft. During this particular test a brisk on-shore breeze was blowing, causing some "white caps". Several drops were made but the pictures failed to show any positive indication of splashes. Part of the difficulty was due to poor splashes, scarcely distinguishable visually from the prevailing white caps; and part of the difficulty was due to camera trouble. The picture did show, however, positive indications of such objects as the end of the pier, navigational buoys, and passing vessels.

It was decided that for the next series of tests explosives should be suspended one or two feet below the surface of the water and detonated there to form more realistic splashes. While waiting for the acquisition of dynamite, obtaining permission to use explosives in the harbor, and for repairs to the camera, it was decided to redesign the auxiliary circuits completely. The sweep-circuit and the amplifier circuit were entirely dismantled and reassembled, to amplify the intensity or Z-axis of the oscilloscope indication rather than the amplitude or Y-axis alone. Following the reassembly there was an additional delay of tests owing to stormy weather.

On June 12th the equipment was again assembled at Fort Hale for further field tests, which proved to be the most satisfactory up to that date. The radiometer, (mounted on a turntable which permitted it to be rotated in azimuth and locked in any desired position, and also permitted some adjustment in a vertical plane) was located on shore about fifty feet south of the pier. A small reference buoy had been planted at a range of about 300 yards from shore and on a line of about 30 degrees south of the bearing of the end of the dock from the radiometer. The radiometer was adjusted in elevation such that the buoy appeared in the center of the vertical field of view, and such that the scanning mirror oscillated about 10 degrees on either side.

Two assistants in a boat managed the placing and detonating of the charges. Each charge consisted of two sticks of 40% dynamite suspended from a small expendable float; the dynamite would hang about 18 inches below the surface of the water. The supporting float was tethered to the marker buoy so that it would float about thirty feet "down-tide" from the buoy. The detonating caps were connected to a fine wire which was paid out from the boat as it took position about 100 yards up-stream (to avoid undue tension on the detonator wire) from the buoy. Communication between boat and shore was maintained by handy-talkie sets. Detonation was accomplished by an operator in the boat, on command from the oscilloscope observer ashore.

The pictures obtained on this test showed unmistakable indications of all splashes, as well as of other objects of infrared interest, such as buoys, boats, etc. It was interesting to note that indications of relatively fixed objects appeared as nearly straight vertical lines, while moving objects -- such as passing boats-showed lines at an angle to the vertical. Figures 5 and 6 are examples of the photographs obtained (although the resolution is somewhat poorer than the originals). In Figure 5, the splash occurs somewhat above the center of the photograph as two large white spots (the reason for the double spot will be discussed later) in azimuth it is at about 0° to the radiometer axis, along the vertical center line of the pictures and lasts for about four seconds. The straight vertical lines are due to the (stationary) reference buoy. In Figure 6, the splash occurs at about 1/2 inch to the right of the center of the photograph, and lasts for about 2 seconds. The straight vertical line is due to the reference buoy; the curved lines are due to moving craft.

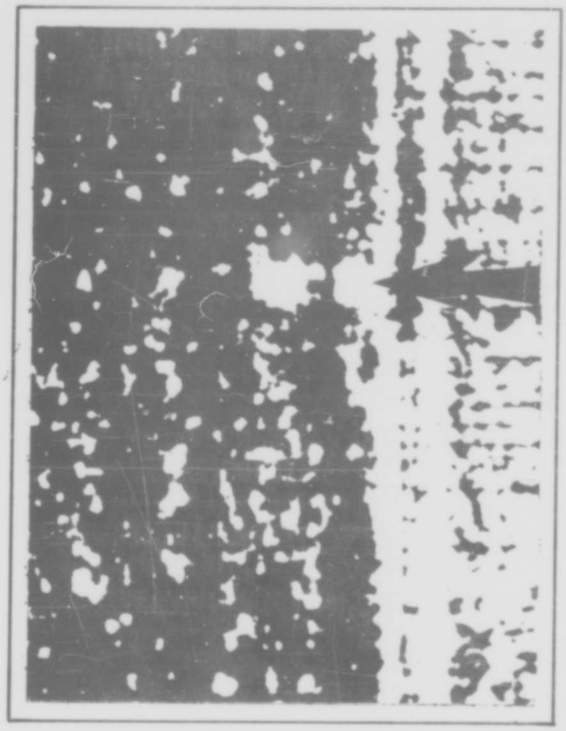

FIG. 5. (ENLARGED). SPLASH INDICATION IS LARGE DOUBLE SPOT, A LITTLE ABOVE CENTER OF PICTURE. DOUBLE VERTICAL LINE JUST TO RIGHT IS INDICATION OF REFERENCE BUOY.

FIG. 6. (ENLARGED). SPLASH INDICATION IS WHITE AREA RIGHT OF CENTER OF PICTURE. VERTICAL LINE AT RIGHT IS REFERENCE BUOY; VERTICAL LINE AT LEFT EDGE IS DYNAMITE TENDING BOAT; AND DIAGONAL LINE IS PASSING MOTOR BOAT.

(which are therefore changing azimuth with time); the vertical line at the far right is due to the dynamite boat.

Although not apparent in these reproductions, the indication of the splashes consisted of "double pips" instead of single ones, as had been expected. When the equipment was returned to the laboratory the suggestion was made that the focus of the radiometer should be checked. It had been set and locked by the manufacturers, and the instruction booklet stated that it was focused "at infinity". The locking screw was removed and by moving the focusing ring, it was determined that the instrument had, in fact, been set at a focal distance of about eight feet. The setting of the focusing adjustment for "infinity" was carefully determined. The radiometer was then taken back to Barnes Engineering Co., where the fact of the error in first setting was confirmed, and also the correctness of the setting for "infinity" focus. During this investigation the equipment was set up and directed toward a tall factory chimney and a water tower near by. The range was about one mile. The resulting picture Figure 7, showed a very distinct bright line indication of the (hot) chimney and a distinct dark line indication of the (cool) water tower. However, while the indication of the water tower showed as a broad black line, that of the chimney appeared as two vertical bright lines separated by a narrow dark line. (Fig. 7)

Intensity (or "Z" axis) amplification was being used in the oscilloscope circuit. It was believed that a transformer in this curcuit had failed, and that on each contact with the hot target the intensity

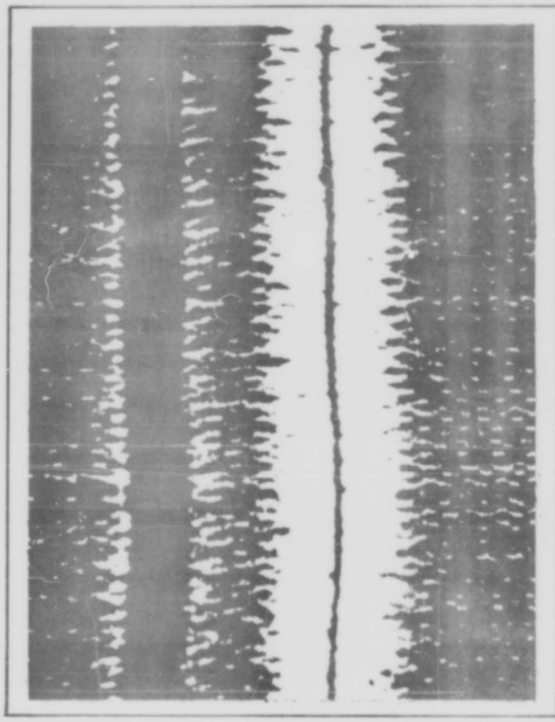

FIG.7. TEST. INDICATION OF FACTORY CHIMNEY (RIGHT), AND NEARBY WATER TOWER (LEFT), RANGE ABOUT ONE MILE.

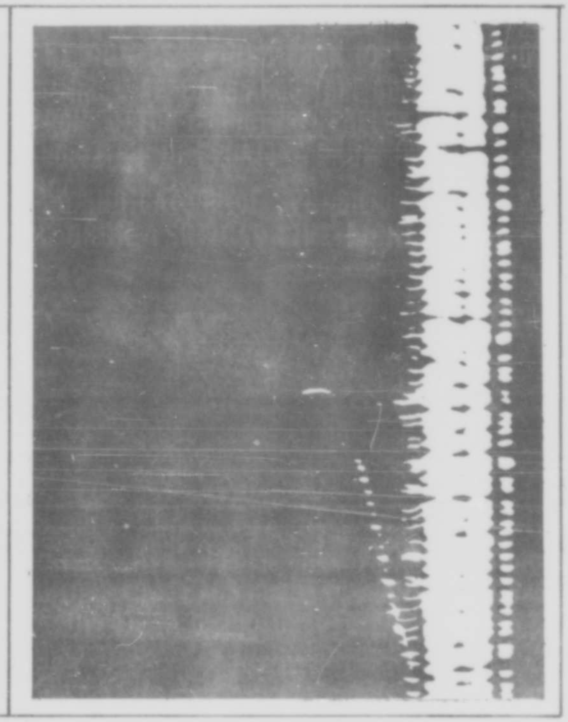

FIG.8. INDICATION OF SPLASH DUE TO DROPPED OIL DRUM. VERTICAL LINE RIGHT IS END OF PIER.

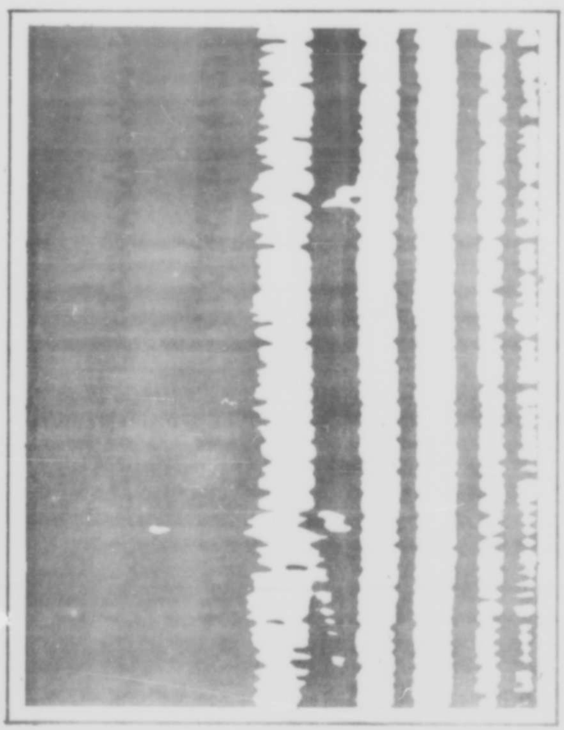

FIG.9. SPLASH DUE TO ROCK SHOWS ABOUT ONE QUARTER FIELD FROM TOP. SPLASH DUE TO OIL DRUM APPEARS ABOUT ONE QUARTER DISTANCE FROM BOTTOM OF PICTURE, FOLLOWED BY DIAGONAL INDICATION OF FLOATING DRUM DRIFTING TOWARD DOCK.

would build up then cut off suddenly to zero intensity. The scanning sweeps being alternately from left and from right, two bright lines would be formed instead of one relatively broad bright line. The equipment was returned to the laboratory, and considerable time was spent in tracing and correcting the defect. It is probable that this defect may be the cause of the double indications shown in Figs. 5 and 6. Again several days were lost due to rainy weather.

For the next field test, the oil-drum and A-frame at the end of the pier was again used for creating the splashes. With the focus of the radiometer correctly set, it was desired to determine whether the resolution was sufficient to distinguish a splash with such a small angular separation from the pier. The circuits were arranged for intensity amplification only. The picture showed clear indications of each drop, but with the vertical line only about 1 $^1/_2$ to 2 seconds duration; then a fainter diagonal line of about 8 to 10 seconds duration appeared, leading toward the larger vertical line indication of the end of the pier (Fig. 8) (Note that time increases in the downward direction in the photograph).

It was surmised that this diagonal line was an indication of the floating drum as it moved in toward the pier under the influence of the retrieving line. To test this assumption several drops were made, each following by about fifteen seconds a splash created by tossing a large stone into the water at about the same location where the dropped drum splash would occur. In each case the pictures showed the two distinct splash indications. Figure 9 is typical of these pictures (note again that time increases in the downward direction). The heavy vertical lines are the pier and various stationary objects. The splash due to the stone appears about one-quarter of the distance below the top of the photograph; the splash due to the oil drum occurs at about one-quarter distance above the bottom, with the floating oil drum indication below it. It should be noted that, upon entering the water, the oil drum drops some distance below the water surface, so that the first indication is due to the splash alone; the drum then reappears at a slightly different location and drifts off. No indication of the drum appears before it hits the water.

These tests provided an encouraging indication of the sensitivity of the equipment. It was desired then to conduct tests with more realistic splashes but with adverse visibility conditions.

Splashes formed by explosion of dynamite charges were the most realistic available. A two-conductor, underwater cable was laid from the shore to a buoy about 500 yards out in the harbor. By this means the service boat (which placed the charges and connected them to the cable) could move completely out of the field of scan of the radiometer for each detonation. The charges were detonated by a switch operated at the site of the radiometer. The pictures obtained showed clear indication of all splashes; in some, the drift of the spray in the wind was also evident.

Figure 10 is a typical splash taken when looking up-sun; the

FIG. 10. SPLASH LOOKING DIRECTLY IN BEARING OF BRIGHT SUN.

FIG. 11. INDICATION OF EXPLOSIVE-CREATED SPLASH. EXPERIMENT CONDUCTED SEVERAL DAYS AFTER FIG. 10.

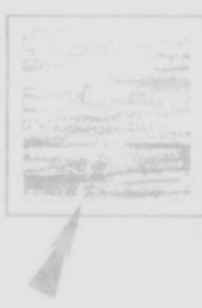

FIG. 12. RESULT OBTAINED DURING NIGHT TEST (INDICATION IS DIAGONAL LINE NEAR BOTTOM).

dark background indicates the "hot" sea surface, due to the sun's reflection; the splash appears as a white indication, showing that the splash appears cooler than the background. This "cold splash" phenomenon, due to shadowing of the water surface background is discussed in Reference 1. (An exaggerated y-axis modulation has been used in this photograph, giving the large vertical excursion of the trace.) These experiments were repeated several days later (Fig. 11).

Figure 12 shows results obtained during the night; before darkness settled, the radiometer was oriented in azimuth such that the buoy (supporting the sea end of the cable) was in the center of scan, and left in this position for the night operations. In the tests fired during darkness, the splashes could not be distinguished by visual means, but the indications given by the radiometer were clear. During the tests a stiff on-shore breeze sprang up, creating white-caps on the waves which grew to such condition as to endanger the small boat operations; the test was then discontinued. However, the rough surface conditions apparently had no ill effect upon the ability to detect splashes.

The tests up to this point showed quite conclusively that this infra-red radiometer was capable of detecting splashes under varied visibility conditions, out to a range of about 600 yards. It was desired to conduct tests observing splashes caused by real mine cases dropped from aircraft to simulate realistic conditions and also to determine the maximum range of reliability for its intended use.

The Office of Naval Research, Washington, D. C. (Code 463) arranged for a series of drops from aircraft, off Beavertail, Jamestown, R.I. The planes employed were from Fleet Air Wing 3, Based at Bangor, Maine. Sand-filled dummy practice devices, each weighing 50 to 100 lbs., were dropped from a plane flying about 300 ft. altitude at a speed of about 200 knots.

On each pass the plane flew directly over the observation station on a course toward Beavertail Buoy, and dropped a single device; the first range to splash was about 300 yards, and successive drops made at increased ranges in increments of about 150 yards, out to a range of about 1000 yards; (Figs. 13, 14). All the splashes were disappointingly small, being about the same size as splashes produced by the oil-drum drop at Fort Hale, New Haven, Conn.

Plans were made to repeat the series of drops the following day, but when the planes arrived, they carried no "bombs" larger than standard 10 pound "smoke bombs". These gave practically no visible splashes, but each emitted a very clear puff of bluish white smoke. The pictured indications obtained of these smokepuffs were very clear. (Fig. 15, (double drop)).

Encouraging as the results of field tests appeared, the fact remained that the device had not yet been used to observe realistic splashes created by dropping actual mine cases. Accordingly ONR code 463 arranged for observation of aerial drops of real mine cases off Solomon's Island, Maryland. The plans were completely disrupted

FIG.13. SPLASH FROM AIR DROPPED DUMMY PRACTICE MINE. (NOTE 15 SECOND DURATION OF SPLASH.) (TRANSPARENCY USED IN POLAROID CAMERA.)

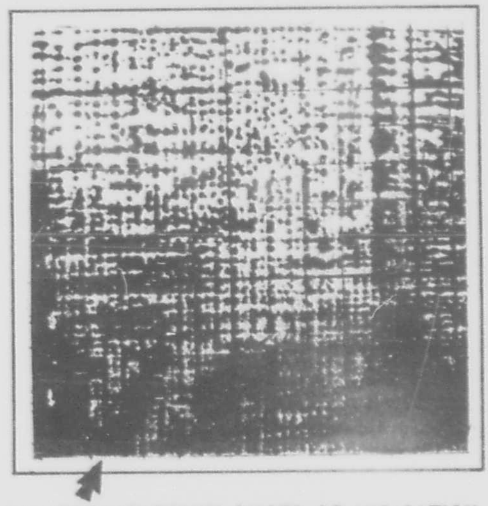

FIG.14. TRANSPARENCY PHOTO OF INDICATION OF SPLASH FROM AIR DROPPED DUMMY MINE.

FIG.15. INDICATION OF SMOKE FROM DOUBLE DROP OF SMOKE-BOMBS.

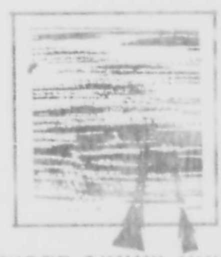

FIG.16. THREE DUMMY MINES DROPPED SIMULTANEOUSLY FROM AIRCRAFT.

due to the passage up the coast of "Hurricane Daisy". However, advantage was taken of an opportunity to observe two splashes caused by the detonation of two large "mine counter-measure" explosive charges. (This project was not being adversely affected by the hurricane). The visibility conditions were very poor, with completely overcast skies, and thick haze all around the horizon. The location of the charges was about 2.9 miles distant from the infra-red observation position, and yet distinct indications were obtained on the photograph which is not of sufficient quality to reproduce.

ONR Code 463 next arranged a program of mine drops off Chesapeake Bay Annex at Chesapeake Beach, Maryland. This program provided for two days of operations using two planes each day. A range had been prepared by placing two marker buoys: the first buoy at 1000 yards from shore, the second at 2000 yard range. Each plane carried three 1000 lb. concrete filled MK 36 mine cases. All mines were equipped with standard parachutes. The plan provided for the dropping plane to fly on course 350 degrees true at about 500 ft. altitude, and drop its mine such that its splash would be approximately on the line of marker buoys; i.e. on line bearing 080 degrees from observation point.

The first plane to drop was directed to drop three mines in succession such that the middle mine would land near the 1000 yard marker buoy, and the other two about 200 yards either side of the middle drop. Due to faulty release mechanism in the plane, all three were dropped simultaneously. They fell in a bunch and created what, to the eye, appeared to be a single broad splash. The picture obtained showed indications of three splashes, two very close together, the third very close by (Fig. 16). It was very gratifying to note the high resolution which this equipment possessed.

The second plane was directed to drop its mines singly at varying ranges. The first mine was dropped at 2000 yards range, but the "projection" film in the Polaroid camera failed and the faint indication on the torn film although distinguishable to a trained eye, was unsatisfactory. The 2000 yard drop was repeated and the last mine dropped at about 2500 yard range. These two drops did not give as clear indications in the picture as was anticipated. For the next day's operation the film was changed from the transparencies which had been used heretofore to regular Polaroid film.

The second day two planes were again used. One was loaded with three 2000 pound Mark 25 mines, the other with two Mark 25 mines. The first plane dropped single mines at ranges of 2000 yards (Fig. 17), 3000 yards (Fig. 18), and about 3500 yards (Fig. 19). All splashes were indicated in the picutres, but the splash indication for the 3500 yard range was faint. The second plane was requested to drop both its mines in quick succession at the 2000 yard range. On the drop the release mechanism failed and only a single mine was dropped (Fig. 20). The plane reported that the last mine would have to be released manually. In an effort to establish a maximum working range for the detection equipment, the plane was directed to drop the last mine at a range beyond 3500 yards. The plane made several passes, but the range was

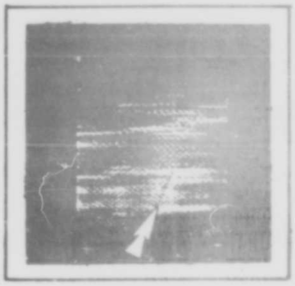

FIG.17. DUMMY MINE SPLASH AT RANGE 2000 YDS. AIR DROPPED.

FIG.18. DUMMY MINE SPLASH AT RANGE 3000 YDS. AIR DROPPED.

FIG.19. DUMMY MINE SPLASH AT RANGE 3500 YDS. AIR DROPPED.

FIG.20 DUMMY MINE SPLASH AT RANGE 2000 YDS.

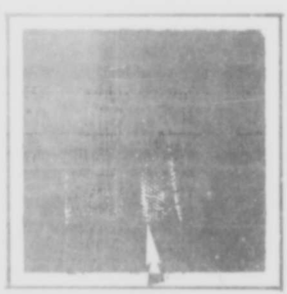

FIG.21. DUMMY MINE SPLASH, DROPPED AT RANGE OF 2000 YDS., NEARLY IN LINE WITH PASSING FISHING BOAT. (SPLASH IS SHORT LINE NEAR BOTTOM, LEFT OF BOAT INDICATION.)

then fouled by fishing vessels and therefore the last drop was made at a range of about 2500 yards (Fig. 21).

Conclusions and Recommendations

It is to be concluded from the results of these experiments that there is a high probability of mine-entry splash detection by means of an infrared single line scanning system.

Of the eleven air-dropped practice mines made available for observation all were detected at ranges between 1000 and 3500 yards. This is an admittedly small sample and no actual mine entry splashes were available during reduced visibility or darkness. However, the similarity of the response due to the mine splashes and the splashes produced by dynamite explosions, which have been successfully observed under poor visibility conditions, leads to the conclusion that mine splashes could be detected at night with equal success.

It must be kept in mind that the instrumentation employed in these tests was commercially available equipment with only the minor modifications necessary to adapt it to this application. Equipment designed specifically for this type of work would undoubtedly give far better results. It should be noted that the inclusion of the indium antimonide filter with a 7.5 micron cutoff would considerably reduce the sun's reflections from the sea. The germanium lens (2.8 micron cutoff) integral with the bolometer was sufficiently effective, however, to permit recording a dynamite-produced splash directly up the sun's path in the middle of the afternoon.

[redacted]

The ability of an infrared system to operate at night and in many other cases of limited visibility make it superior to optical or photographic techniques for spotting mine splashes. Its comparatively low cost, ease of maintainance, small power requirements, and transportability makes it preferable to radar for limited area coverage. Being a passive system, its presence cannot be detected by an enemy and it is immune to electronic countermeasures.

It is recommended, therefore, that the Navy proceed to have developed and evaluated a proto-type operational infrared mine-splash spotting system.

Since the simple infrared system described in this report promises to give a high degree of effectiveness at small cost, one phase of the work should emphasize the development of a system having the features of simplicity of equipment and presentation, and independence of external power supplies. There does not seem to be any other system presently envisaged for splash-spotting which combines these advantages of ease of transportability, of placement, and of maintainance, and with low cost and high effectiveness. Units could probably be built for under $10,000 each, 10 to 20 of these should be stockpiled to be flown to any areas in which they may be needed.

This system will consist of a scanning infrared radiometer, a self-contained power supply and an appropriate read-out mechanism. In its simplest form, each unit can be operated by one man; to conserve the (self-contained) power supply, this could be turned on only

[redacted]

[redacted]

when an "alert" is sounded; 35mm. photographs can be made of the oscilloscope face, and simultaneously of a clock (in order to distinguish between the various splashes). Subsequent development of the film and interpretation could then be preformed at a central station (harbor control post).

[redacted]

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