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A REVIEW OF THE DEVELOPMENT OF VISUAL AIDS FOR OPERATIONS IN NIGHT REPLENISHMENT AT SEA

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ABSTRACT

The Navy has been interested in the problems associated with replenishment at sea for many years. Recently, interest has shifted to night replenishment. One of the greatest disadvantages in night replenishment is, of course, the low light levels under which the work must be performed.

The visual problems encountered in such an operation are enumerated and analyzed, and the experiments performed by others in past years toward the development of light sources to aid in night replenishment operations are summarized. An account is given of recent work performed by NRL and COMSERVLANT on the use of a zinc sulfide phosphorescent paint to illuminate the projectile and heaving line in the line-throwing rig. It is suggested that phosphorescent paints also replace red flashlights on the fueling rig.

AUTHORIZATION

NRL Problem N95-01
Project NS 674-100

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

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INTRODUCTION

Replenishment at sea may be defined as the process of transferring men and materials from one ship to another at sea. At the present time, probably the most important material transferred during such a replenishment exercise is fuel. In the nuclear-powered Navy of the future, transfer of fuel at sea will become unnecessary; however, the problem of transferring food, ammunition, and other items from one ship to another will remain with the Navy.

In the future, the Navy may be required to perform replenishments under cover of darkness, and the difficulties which are encountered in daylight will be magnified tremendously. These difficulties are present throughout the entire operation, from coming alongside, rigging lines between the ships, station keeping, maintaining correct tension on the rigging, passing materials between the ships, to finally leaving the replenishment ship safely. All of these operations require the fine judgement of skilled seamen. It is evident that a seaman's skill depends very strongly on his ability to see, and when this ability is diminished under nighttime conditions his skill as a seaman also diminishes.

VISION UNDER NIGHTTIME CONDITIONS

As a rough approximation, a person's "ability to see" under different background luminances* can be defined as the product of illumination at the eye and the sensitivity of the eye at that illumination level. This product is greater numerically for daylight than for starlight conditions. The "ability to see" definition given above, however, suffers from at least two serious defects which detract from its usefulness. In the first place, the eye can only act as a null instrument in quantitative measurements of lighting conditions. The eye can judge that one lighting condition is better than another but cannot judge how much it is better. In the second place, the manner in which the eye functions under daylight and starlight conditions is quite different. The human eye has two different types of receptors in the retina. One type of receptor is used mainly in daylight and the other principally in starlight. With this in mind, the eye may be considered as composed of a nighttime eye and a daytime eye. Characteristic differences of the two types are given in Table 1.

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*Many words used in describing visual phenomena evolve from the word "lumen." Since these words are quite similar in sound as well as in spelling but have quite different meanings, a glossary of terms is included at the end of this report.

TABLE 1
Characteristics of the Daytime and Nighttime Eye

Property	Daytime Eye	Nighttime Eye
Sensitivity	Very low	Very high
Color sense	Highly developed	Absent, or at least very poorly developed
Visual acuity	Very good	Very poor
Field of view	Very narrow	Very wide
Best observing method	Direct vision, through center of the eye	Indirect vision, through corner of the eye

Illumination from the sun at the earth's surface on a clear day is approximately 10^4 foot-candles; on a clear, moonless night this value of illumination decreases to roughly 8×10^{-5} foot-candles. On the other hand, the eye increases in sensitivity over a wide luminosity range while becoming dark adapted. Figure 1 shows the relative sensitivity of the eye for different wavelengths of light over eye adaptation levels ranging from essentially a black background to a background of luminance 100 millilamberts. There are two principal conclusions to be drawn from this figure: (a) If the eye looks at a scene having a luminance, for example, of 100 millilamberts until it becomes adapted to this level of luminance (this is roughly the luminance of a piece of white paper illuminated by 100 foot-candles) its sensitivity to the different wavelengths of visible light will be given by the bottom curve in Fig. 1. If the scene luminance is now reduced to 0.001 millilamberts (this corresponds to twilight conditions), the eye sensitivity will have increased for all wavelengths at this luminance level compared to the 100-millilambert scene. (b) At a scene luminance of 100 millilamberts the maximum of the relative sensitivity curve occurs at 0.55 microns (5500A or, yellowish-green light). However, when the field luminance is reduced to 0.001 millilamberts, the eye is most sensitive to 0.53 microns (blue-green light). At threshold (this condition is realized in a perfectly dark room — not a starlit sky), the eye shifts its maximum sensitivity to about 0.51 microns (blue light). It is to be noted that the change in sensitivity of the eye which accompanies a change in scene luminance viewed by the eye is not constant throughout the visible spectrum. This change in sensitivity of the eye to different wavelengths of light due to dark adaptation of the eye is known as the Purkinje shift.

Figure 2 compares the visual acuity of the two different eyes. The light-adapted eye can easily resolve fine details in a scene. The dark-adapted eye can see very well that an object exists in the field of view but cannot see details of the object very clearly, that is, things appear blurred when viewed from out of the corner of the eye. In order to see details in a night scene, the eye automatically tries to focus the image on the part of its retina where visual acuity is highest in daylight vision. In other words, the instinctive thing to do is to look directly at the object. When this is done, the daytime eye is being used under nighttime conditions. The result is that details are seen much better if the illumination level is high enough but many objects which would be readily detected by the nighttime eye are not seen at all.

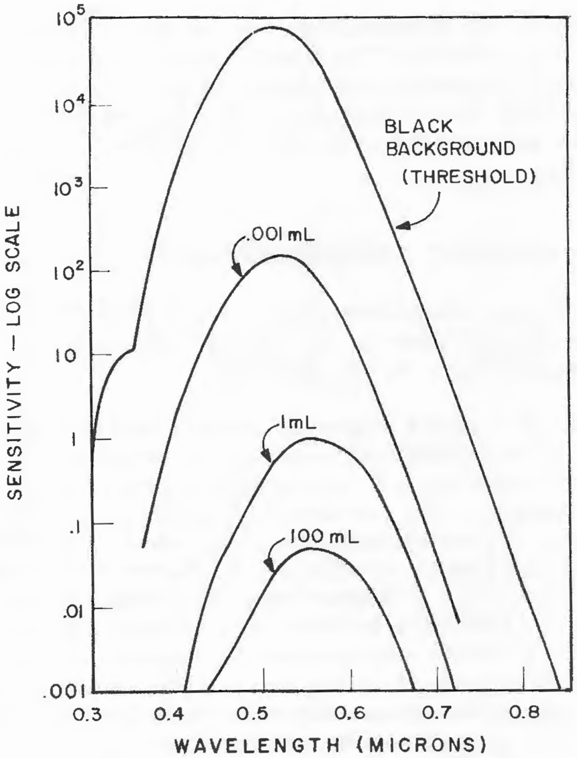

Fig. 1 - Relative sensitivity of the eye vs wavelength at adaptation levels from threshold to 100 millilamberts (adapted with permission from Forsythe, W. E. and Adams, E. G., J. Sci. Lab. Denison Univ. 39, Dec. 1945)

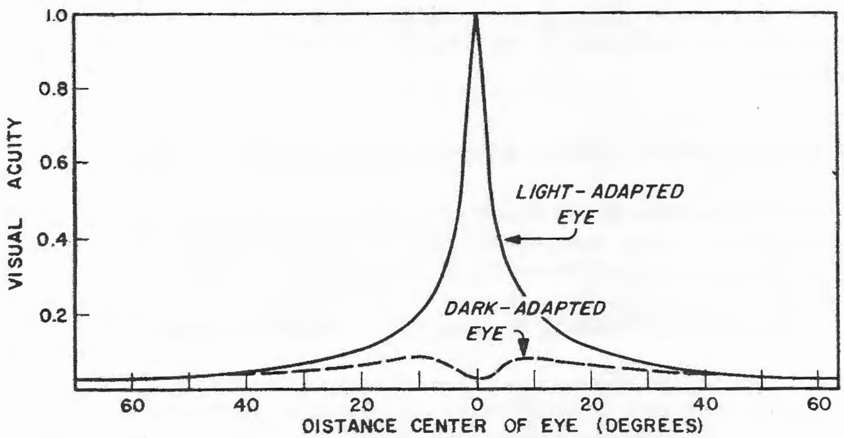

Fig. 2 - Visual acuity of the daytime and nighttime eye (adapted with permission from Walsh, J. W. T., "Photometry," [London, Constable], N.Y., The Macmillan Co., 2nd ed., rev., 1953, p. 59)

Another property of the daytime eye which is very useful in vision is its sensitivity to color differences. The nighttime eye is color blind. With its ability to detect color differences, the daytime eye is capable of seeing color contrast in a scene where the illumination level is sufficiently high. Color contrast is a valuable aid in obtaining visual information from an operation such as night replenishment.

VISUAL PROBLEMS IN NIGHT REPLENISHMENT

A consideration of the characteristics of the nighttime and daytime eyes shows what everyone knows: one can see better and most easily carry out a replenishment at sea operation in the daytime.

Since the success of a night replenishment exercise at sea depends to a great extent on seamanship, and seamanship in turn depends very much on the intelligent use of the human eye, it is considered essential to aid the eye in this operation if at all possible. The conning officer of each ship and the men engaged directly in the replenishment exercise subconsciously use their daytime eyes to perform their duties while at the same time lookouts of the watch are using their nighttime eyes. Under these circumstances, it is worthwhile to raise the illumination in the area between the ships to a level such that the daytime eye is able to function but not to such an extent that dark adaptation of the eye is destroyed. In this respect, it is more advantageous to have many low-level luminous sources rather than only relatively few high-level ones. For example, in order to show the contour of fuel lines, it is more satisfactory to paint several stripes on the lines with luminous paint than it is to place tungsten lamps with red filters as markers at three or four places on the line. As another example, heaving lines having the first 6 or 7 fathoms painted with luminous material are picked up at night on the receiving ship much more quickly than those having a tungsten lamp attached to the line as a light source. In general it may be said that the primary need is to increase the visibility of several vital points by only a slight amount rather than increasing the visibility of fewer points by a great amount.

It is worthwhile at this point to list the properties of some luminous materials which are available for use in military operations at night. These materials may be divided into three broad classes having characteristics as shown in Table 2.

PAST EXPERIMENTS ON NIGHT REPLENISHMENT AT SEA

It was logical that the first attempts to aid a night replenishment at sea operation would involve the use of electrically powered lamps. From experience the Navy gained in the use of red-adaptation goggles and red-filtered flashlights during World War II, it was also logical that similar devices would be used in an attempt to increase the visibility during night replenishment exercises.

The first accounts of experiments performed by COMSERVLANT beginning about 1950 mention the use of such red flashlights and some experiments designed to see whether other materials might be more satisfactory. In particular, COMSERVRON TWO wrote a brief summary of its work in 1952. One-foot strips of green fluorescent cloth were used on fuel hose saddles, riding line hooks, and hose couplings, and on the distance line at 40, 60, 80, 100, and 120 foot intervals. Three ultraviolet "black lights" were located to illuminate the fluorescent cloths and avoid blinding effects to personnel. Night replenishments utilizing this method were reported as having been favorably tested on various occasions prior to 1952. During the Type Training Cruise, tests were conducted to compare the effectiveness and visibility range of the standard method (red flashlights) and this method.

TABLE 2
Properties of Luminous Materials

Property	Phosphorescent Material	Fluorescent Material	Radioactive Luminous Material
Source of energy for emitted light	Ultraviolet black light and, to a lesser extent, tungsten light	Ultraviolet black light and daylight	Radioactive material enclosed in the phosphor
Order of time for light to decay to half of its initial value after excitation	A few minutes (See Fig. 3)	Varies from microseconds to milliseconds	Varies from a few years to thousands of years
Luminance value obtainable	Dependent upon intensity of excitation source and the type material. (See Fig. 3, for example.)	Greater than a perfectly white plaque in daylight	About same order of magnitude as initial luminance of phosphorescent materials
Form of material available	Paint, adhesive tape, and baked on enamel	Cloth, paint, and tapes	Service markers and flexible tubing
General uses	Under darkened conditions where low-level light sources are worthwhile	Daytime and nighttime where an exciting source may be used continuously	As markers of important pieces of gear under nighttime conditions

The maximum visible range of the standard method (1000 - 1500 yards) was considered acceptable as compared with 300 feet using black lights and fluorescent cloth. COMSERVRON TWO also pointed out that at this time (1952) the red filters for the flashlights had different types of dyes which caused wide variation in the light intensity from different flashlights. They recommended that the standard method be retained and the black light-fluorescent method be used only for experimental purposes. They also recommended that uniform red filters be obtained for the flashlights. The Bureau of Ships was requested to investigate procurement of luminous paint which could be seen 150 feet on a dark night 12 hours after application.

In 1953 COMSERVRON TWO indicated that it had experimented with fluorescent cloth and paint excited by ultraviolet light to illuminate working areas during night replenishment at sea. This was considered particularly important to winch operators of ammunition ships in judging heights above deck when landing ammunition loads.

Tests were made using the standard red flashlight method during Service Training Exercise 1-53 on a dark night with 3 cargo ships fueling from 3 oilers. Each oiler burned a dimmed wake light during the approach stages. The operation was considered a success, but three objections to the system were raised by COMSERVRON TWO:

1. When the rig is passed during daylight hours and fueling is continued into the night, the lights are required to be previously rigged in anticipation of such an occurrence.

2. Replacement during fueling of lights on the rig that become extinguished while the rig is connected is a practical impossibility.

3. There is no general illumination of the working areas.

At this time, COMSERVRON TWO considered the standard method to be acceptable to meet security requirements but intended to study the problem to remove the three objections cited above. They proposed the use of phosphorescent lacquer Shannon Glow 11-116-1 with an ultraviolet spotlight as exciter. An experiment was performed in the Norfolk, Virginia, Naval Operating Base Theatre which was completely darkened. The lacquer and standard stock phosphorescent tape (calcium sulfide) were both illuminated by an ultraviolet spotlight with the following results:

1. Neither tape nor lacquer was visible 5 minutes after the ultraviolet light was turned off.

2. The lacquer was brighter than the tape.

3. When the light was on, the tape and lacquer could be seen at well over 200 feet.

4. The lacquer was not considered suitable unless the ultraviolet light remained on it almost continuously.

5. The spotlight could be seen at a distance of at least 1500 yards.

Officers conducting the test reported optical discomforts. It might be worthwhile to digress and explain this "optical phenomenon." Fluorescence of the eyeball is common when an ultraviolet light is viewed in the darkness. Although the Bureau of Medicine and Surgery has indicated that it considers a medical problem exists, it can be shown that the problem is more properly termed an annoyance, and that damage to the eye does not occur. For example, if a mercury lamp filtered by a glass transmitting between 3000A and 4000A with a maximum transmission at about 3600A is viewed directly in a darkened room the eyeball will fluoresce. The observer is usually annoyed and directs his view elsewhere. With the eyes still looking into the ultraviolet light beam, if the room lights are now turned on, the fluorescence of the eyeball is not noticed even though the same amount of ultraviolet light from the lamp plus the additional ultraviolet light from the room lamps is now entering the eye. If the room lights are turned off after the eyes have become light adapted, the eyes immediately fluoresce again showing that the phenomenon is not due to a dark-adapted condition of the eye. On an average day, more ultraviolet light in the spectral range 3000A to 4000A enters the eye from sunlight than from a mercury lamp with filter as described above, even if the lamp is looked at directly from moderate distances. As used in the replenishment exercise it is not usual that anyone stares directly into the ultraviolet lamp (black light). It should be pointed out, however, that unfiltered light from a low-pressure mercury arc with a quartz envelope which emits mainly at 2537A should not be viewed directly at any time. In such cases, it is possible to damage the retina on prolonged exposure. Anyone who is further interested in this matter should read the comments of Luckiesh*.

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*Luckiesh, M., "Applications of Germicidal, Erythemal and Infrared Energy," New York:D. Van Norstrand, 1946, pp. 346-348

Another night replenishment exercise was performed 25 May 1953 in the Virginia Capes Operating Areas with the CHIPOLA and GREENE (DDR 711) participating. The equipment tested was a cluster of three enameled reflector floodlights equipped with 60-watt bulbs and steam-tight diffusing globes with the bottom half blocked out. These floodlights were used to illuminate the control winch on the CHIPOLA and working spaces. The intensity of the lights was controlled with a Variac. Colored flashlight bulbs were rigged in accordance with the then existing instructions. The sky was overcast and the night relatively dark. The floodlights were suspended about 8 to 10 feet over the working area at station three of the CHIPOLA. The GREENE determined the visible distance of the red flashlights. The floodlights were then diminished to a level satisfactory for fueling operations. The following conclusions were reached by COMSERVRON TWO:

1. Limit of visibility of red flashlights was 1500 yards.

2. With floodlights of 4 candle-power each, visibility range of lights was no greater than 1500 yards, and illumination of working areas was more than required.

3. Under the test conditions, a light of 2 candle-power was adequate with no loss in darken ship security.

4. Time required for rig handling was reduced from that usually required without the illumination from floodlights.

5. Safety of personnel and equipment was greatly increased.

6. Ship control personnel reported no difficulties.

7. The practice of night replenishment can be expedited and made safer without loss of security by providing low-level general illumination at replenishment stations.

COMSERVRON TWO continued the experiments with floodlights and red flashlights during 1954. An entirely new lighting system based on recommendations of the Atlantic and Pacific Commanders was added to the naval warfare plan on replenishment at sea. This system included the lights mentioned above to assist ships in coming alongside, maintaining position alongside, and handling the gear and stores on deck and in the holds. The system was considered to be an improvement over previous ones but a continuous study of the replenishment lighting problem was to be maintained by COMSERVRON TWO.

During 1955 the system described above was more or less shaken down and COMSERVRON TWO offered the following conclusions:

1. The use of colors other than red should be avoided.

2. Hooded red cargo-type lights were satisfactory for illumination of handling areas. Development of a red filter for this light was required.

3. Red single-cell flashlights in pairs should be used on running rigging. These flashlights should be ruggedized and have a more positive means of being secured to rigging.

4. Dimmed red lights should be used to mark replenishment stations.

5. One dimmed red range light should be fixed atop each after king post to assist the ship alongside in keeping proper fore and aft station. This light should be hooded and reflect down and outward at an angle of 45 degrees.

6. The approach lights should consist of two shaded red lights to show the contour of the ship. One of these lights should be located aft by the king post and one forward at the turn of the bow.

7. The illuminated projectile used with the line-throwing gun is unsatisfactory.

The Bureau of Ships planned to issue Shipalts for installing red lights for general illumination of cargo handling about 1 June 1955. It was expected that other Shipalts dealing with station keeping and approach lighting would follow in six months. The project was considered dormant until installation of lights was accomplished in accordance with proposed Shipalts.

NRL-COMSERVLANT EXPERIMENTS ON NIGHT REPLENISHMENT AT SEA

Early in 1955 the Force Development Officer of COMSERVLANT with personnel from the Optics Division of the Naval Research Laboratory began work on this night illumination problem. In particular, it was decided to concentrate time and effort on two phases of the problem which seemed important and for which very little success had been attained. As noted by COMSERVRON TWO the illuminated projectile used with the line-throwing gun is unsatisfactory. Also there were objections to the use of red flashlights on fueling rigs because:

1. The lights had to be rigged during daylight hours for a night refueling.

2. Replacement of burned-out lights was a practical impossibility.

3. There was no general illumination of the working area.

The requirements for a satisfactory line-throwing rig at night are (a) that it be safe to personnel and (b) that the line be found as quickly as possible after being shot over. The first experiment at NRL involved the use of water-soluble fluorescent dye on the line. After being shot over, a portable ultraviolet light was used to find the line. This method was considered successful but has some disadvantages:

1. The line cannot be seen in flight and is therefore not safe to personnel.

2. An ultraviolet light must be available to find the line.

3. The line cannot be seen at great distances even when illuminated by ultraviolet light.

The line was next painted with phosphorescent paint which continues to emit visible light after the ultraviolet exciting light is removed (a typical decay curve for this paint is shown in Fig. 3). The projectile and/or bolo and about the first 10 fathoms of line were painted. This line was then coiled in a bucket free to run and excited with ultraviolet light just previous to being thrown or shot. This line is followed very easily with the naked eye and is almost immediately found on deck by the crew. Such a line-throwing rig meets all the requirements outlined above and has been approved by CNO for all underway replenishment-type ships as a replacement for the illuminated projectile as prescribed in the naval warfare plan.

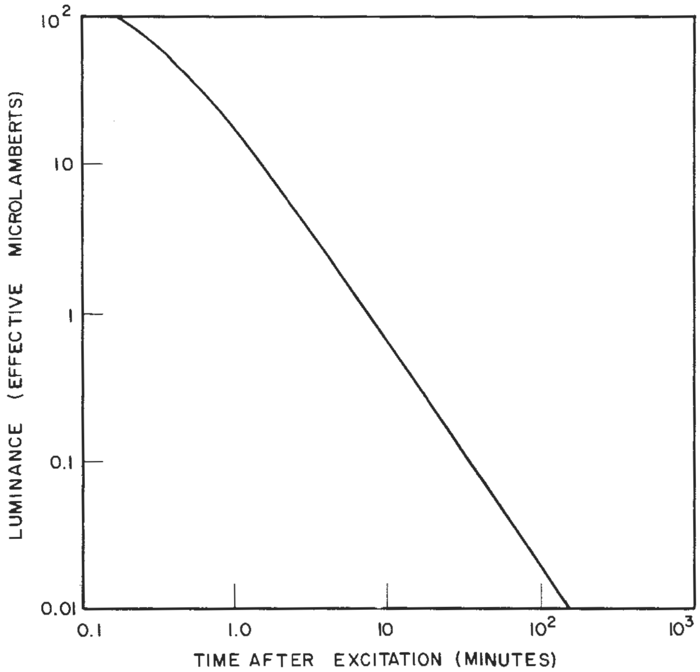

Fig. 3 - Typical decay curve of zinc sulfide phosphorescent paint excited by a tungsten light of 100 foot-candles illumination

The second part of this problem considered by COMSERVLANT and NRL was an improvement of lighting on the replenishment rig to correct the faults noted by COMSERVRON TWO. Phosphors which emit visible light when excited by infrared radiation were tested in the laboratory. These phosphors were found to be insufficiently bright and to require a continuous source of infrared energy in order to be visible. These laboratory experiments showed that infrared phosphors would be useless for the mission.

It was then decided to experiment with phosphorescent and fluorescent materials excited by ultraviolet radiation. The first experiment was performed on the USS CHUKAWAN (AO 100) in the summer of 1955 while the ship was at anchor in Hampton Roads, Virginia. Phosphorescent paint and tape together with fluorescent cloths were tested. The cloth was tied to the refueling hose and the tape was pasted on to the hose through its adhesive backing. The paint was applied to the hose on top of an undercoat of white paint which had been allowed to dry. The rig was illuminated by a 100-watt filtered ultraviolet light and viewed from a small boat at various distances away. The fluorescent cloth and phosphorescent tape were not considered satisfactory on the basis of this experiment, but the phosphorescent paint showed enough promise to be evaluated in an underway replenishment exercise.

This replenishment exercise was carried out in early 1956 between the USS ELOKOMIN (AO 55) and the USS LIND (DD 703). The fueling hose was painted with bands of phosphorescent paint about 6 inches wide with approximately 2 feet between bands. These bands covered the top and bottom loops of the hose for a distance of about 10 or 12 feet. The saddles and 4 or 5 feet of the receiving end of the hose were also painted with the same paint. With this painting scheme, the contour of the hose could be distinguished quite well, and the winch operator could judge when the bottom loops of the hose were too near the water or too taut, which is very important information for him. These bands of phosphorescent paint were excited to luminescence by a 12-inch mercury-xenon searchlight covered by an ultraviolet transmitting filter. It was necessary to excite the paint periodically since its luminescence decays in time after the exciting light is removed from it (Fig. 3).

CONCLUSIONS

Enough work has been performed on night replenishment at sea exercises to arrive at a few conclusions as to the best lighting system available. Where low-level illumination is required for operating machinery and handling gear on decks, the best lighting system is tungsten lamps with red filters whose intensity may be set by means of a Variac. The distance line should be marked at 20-foot intervals by pieces of canvas painted with phosphorescent material. It is not necessary that numerals be painted on these markers since the conning officer can count the number of markers and multiply the number by 20. The projectile and heaving line question has been settled by the use of phosphorescent paint. The replenishment rig lighting question is still unsettled. There is doubt that the use of red flashlights on this rig will be satisfactory because of the objections raised by COMSERVRON TWO. The use of phosphorescent paints seems to be a more satisfactory solution.

ACKNOWLEDGMENTS

The work performed by the Naval Research Laboratory and COMSERVLANT in the experiments reported herein was assisted to a great extent by LCDR J. J. Jachimowicz, USNR, and Mr. Carey M. Whitfield, Jr. both of the Naval Research Laboratory. We are greatly indebted to them for their ideas and help. The officers and men of the above mentioned ships were very cooperative and helpful with ideas in the experiments conducted by NRL personnel aboard their ships.

GLOSSARY

Candela – the unit of luminous intensity. It has such magnitude that the luminance of a "blackbody" (full radiator) operating at the solidification temperature of platinum is 60 candelas per square centimeter

Candle-power – the light-radiating capacity of a source in terms of its luminous intensity expressed in candelas

Dark adaptation of the eye – changes in visual properties of the eye due to its being kept in the dark. These changes are an increase in sensitivity to radiation of all wavelengths, and a shift of the spectral sensitivity peak to shorter wavelengths.

Eye sensitivity – ability of the eye to obtain information from a scene

Fluorescent material – material which emits visible light of longer wavelength than the exciting light but for all practical purposes only while the exciting light illuminates it

Foot-candle – a unit of illumination. A surface placed 1 foot away from a source of luminous intensity equal to 1 candela will have an illumination of 1 foot-candle. This is true regardless of whether the surface is black or white.

Illumination – the ratio of luminous flux incident on an infinitesimal surface element to the area of the surface element

Lambert – a unit of luminance. A surface which is a perfectly white diffuser when illuminated by 1 candela from a distance of 1 centimeter will have a luminance of 1 lambert. The same surface illuminated from a distance of 10 meters will have a luminance of 1 microlambert.

Luminance – ratio of luminous intensity of an infinitesimal surface element in a given direction to the orthogonally projected area of the element on a plane perpendicular to the direction considered

Luminosity – the attribute of a visual perception in accordance with which a part of the visual field appears to emit more or less light

Luminous intensity – ratio of luminous flux emitted in an infinitesimal cone to the solid angle of the cone

Phosphorescent material – material which emits visible light of longer wavelength than the exciting light for varying periods of time after the exciting light has been extinguished. These periods may vary from minutes to hours depending on the type of phosphorescent material used.

Radioactive luminous material – material which has a radioactive substance incorporated in it causing it to emit visible light. Light output is roughly a function of the life of the radioactive material.

Retina - that part of the eye containing the material which is directly sensitive to the visible spectrum

Ultraviolet black light - a source of ultraviolet light with a filter transmitting energy of shorter wavelengths than visible light. Such light is not visible to the eye directly but will excite certain materials in such a manner that these materials emit visible radiation.

Visual acuity - a property of the eye which enables the person to see details of a scene. Formally, visual acuity is defined as being inversely proportional to the resolving power of the eye.

Visible spectrum - that part of the electromagnetic spectrum lying between roughly 4000A and 7000A

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