

Developments in Submarine and Small Vessel Lighting

By **DEAN FARNSWORTH**

THERE are today over 35,000 vessels in the Navy, Marine, Army and Coast Guard Services. Small vessels of 300 to 2,000 tons displacement account for the vast majority of these, to which we will add submarines, much larger, but with individual compartments which present similar design problems. In spite of their special lighting requirements such vessels received little attention until recent years. Lieutenant (now Captain) Robert T. Alexander published an excellent analysis of illumination requirements of small vessels in 1941.^{1, 2} However, no appreciable change occurred in their lighting installations.

It became increasingly apparent during the war years that the application of standard lighting methods to small vessels was producing unsatisfactory results. Naval and Marine lighting standards were lower than industrial practice; the actual installations were in fact even poorer. Ocular complaints increased and were frequently ascribed by the personnel to bad lighting conditions. Tests conducted in 1944-45 at the Medical Research Laboratory indicated that the visual acuity of submariners returning from several years' sea duty was lower than that of recruits to an extent which would not be accounted for by age differences. Personnel made comment to the effect that a third-rate factory would not tolerate the wretched lighting with which their boats were supplied.

Three new developments made the situation critical: first, the masses of new, specialized equipment which were crammed into all compartments—this made proper light distribution very difficult; second, the increased use of such instruments as radar, sonar and computing machines—this demanded close, continuous and fatiguing use of the eyes by most of the crew; and third, the advent of the snorkel (and now the atomic-powered submarine) — this permitted continuous living under-seas, perhaps for months, without the rest provided by daylight, fresh air and liberty ashore.

The problems were not to be solved simply nor

without the cooperation of more men and agencies than could be named in the space of a page. After a few years it became evident that the lighting of submarines and small naval vessels could not be modeled upon industrial, office, aeroplane or passenger vessel traditions but that it should be considered as an entirely new field to which original approaches would have to be made.

In order to appreciate some of the problems in lighting a submarine interior we should attempt a visualization of what the inside of a submarine looks like. It consists of a series of pressure tight cylinders fastened end to end. Imagine the inside of a boiler — a large boiler — congested with pipes, instruments, valves, meter panels, electronic gear, control handles, and cabinets of all sizes, under and between which are narrow passageways for the operators. There are bunks between the torpedoes, electronic gear between the bunks and controls which are operable from the mess tables.

The original approach to lighting this conglomeration of equipment was by way of the customary three or four centrally located and routinely spaced fixtures with wide angle reflectors. However, small spaces thickly filled with a variety of equipment are not responsive to the same rules of lighting practice as would be found elsewhere. The results were, first, unequal distribution of light due to the irregularity of the equipment layout. Second, there were high glare sources of all types — the low lamps were in the line of sight of the eye, there were high brightness areas because the lamps were necessarily placed so close to the equipment and overhead, and there was reflected glare from the many highly polished surfaces. Third, many of the working areas were so dark as to be hazardous, to make dials illegible and, in places, literally to require the use of flashlights.

With the advent of larger and more complicated items of electronic gear, the lighting situation became intolerable. The number of incandescent light sources could not be increased without taxing the generator capacity, their size made it difficult to find spaces to locate them, and the design of available fixtures was such that increase in the number of units actually increased the number of glare sources.

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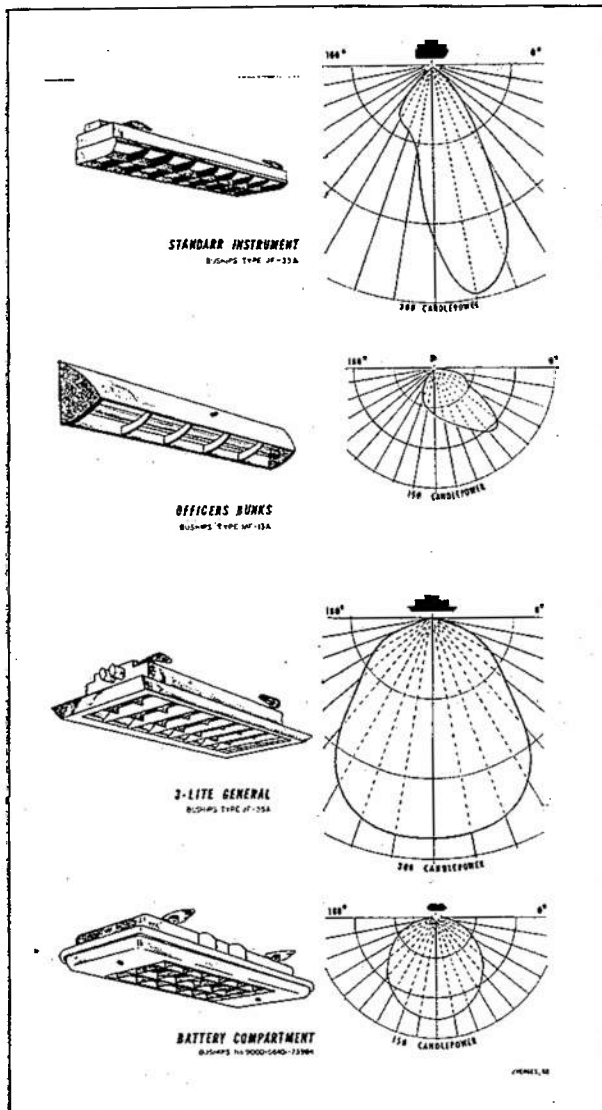


Figure 1. Some of the forty-two special luminaires, incorporating fluorescent lamps, designed for specialized shipboard applications.

All analyses showed that, in addition to such usual considerations as appearance, ease of cleaning and lamp replacement, waterproofness, resistance to salt, oil and chemical vapors, the following requirements were of special importance:

- (1) The units should be small, and of a shape that would fit between pipes and in narrow channels.
- (2) The light distribution should be efficient and directional, primarily in an angular plane.
- (3) Both the luminaires and the lamps should be highly shock resistant in order to sustain depth charging of extraordinary intensity.
- (4) A variety of specialized luminaires would be needed but the logistics of supply aboard submarines required that they should utilize as few types of lamps as possible.
- (5) They should be extremely efficient in current consumption in order not to put an unreasonable load upon the power supply.
- (6) The lamps should be long-lived and vibration-proof.

(7) In case of breakage the glass should not litter the compartment.

(8) The equipment should be simply adaptable to a complete dark-adaptation (red lighting) system.

(9) Heat radiation should be minimal.

The initiative and ingenuity of certain manufacturers created the first actual luminaires for testing. Experimental installations were made of several types of fluorescent, incandescent and low wattage systems before the emergence of the present solutions. While progress will not stop with these, it can be claimed that they now make possible the illumination of small vessels at levels which are comparable to recommended industrial practice. Illumination of working areas within modern submarines of the Killer and high-speed Attack classes measures between 10 and 30 footcandles, with localized lighting up to 40 footcandles. It is of even more significance that brightness contrasts have been generally reduced to ratios of the order of 1 to 40.

Eight-watt, 12-inch fluorescent lamps were the core of many of the successful solutions. These have proved superior in shock resistance to even rough service incandescent lamps. They permit the design of units which can be "tucked in" between pipes, have low current consumption and permit efficient fixture design with well controlled distribution. Some of the forty-two special luminaires incorporating fluorescent lamps designed by the L. C. Doane Company for specialized shipboard applications are shown in Fig. 1.

The most difficult problem was that of uniformly lighting high banks of dials from sources placed overhead and very close to the panel. This has been solved to the extent that ratios of better than 1 to 5 are now obtainable even under extreme conditions. A comparison is shown in Fig. 2 of a small group of dials illuminated by a 60-watt incandescent light in an old standard reflector with that provided by two 8-watt fluorescents in the new directional fixture. To correct for the length of throw and the angle of incidence on the lower dials it is necessary that some 30 times as much light be directed through the 10-degree plane (from the normal) as through the 60-degree plane. For the first time it is possible to provide reasonably uniform illumination over high banks of dials (Fig. 3) and to be able to find spaces for enough such units.

However, general compartment, instrument and dial illumination is but one part of the picture; "four hours on watch and four off" means that a man has hours for recreation, light reading, and naval correspondence courses. Recreational use is made of the mess compartment (now frequently referred to as the "dinettes") where special localized lighting is placed under the condiment racks in shallow reflectors of less than an inch and a half in

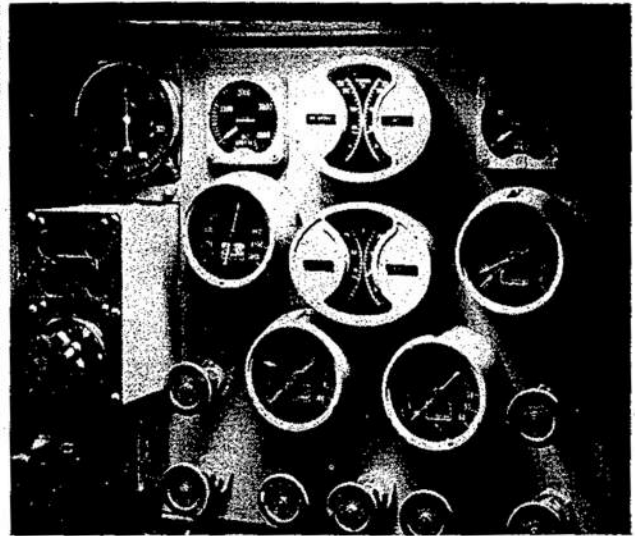
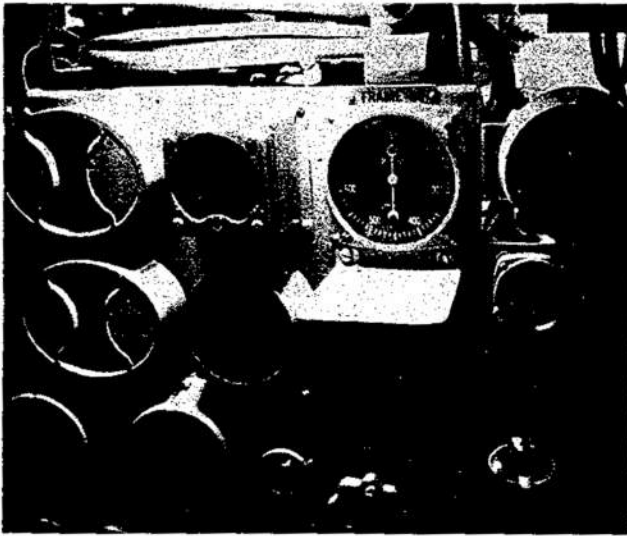


Figure 2. On the left is one of the Engine Room control panels showing the best distribution obtainable by a 60-watt incandescent lamp in an open reflector. On the right is a similar control panel relighted with two 8-watt fluorescents in a Doane overhead directional luminaire.

total depth. Standard white fluorescent lamps not only eliminate the shadow underneath the racks but make the food more attractive and provide a special illumination level for reading and card playing.

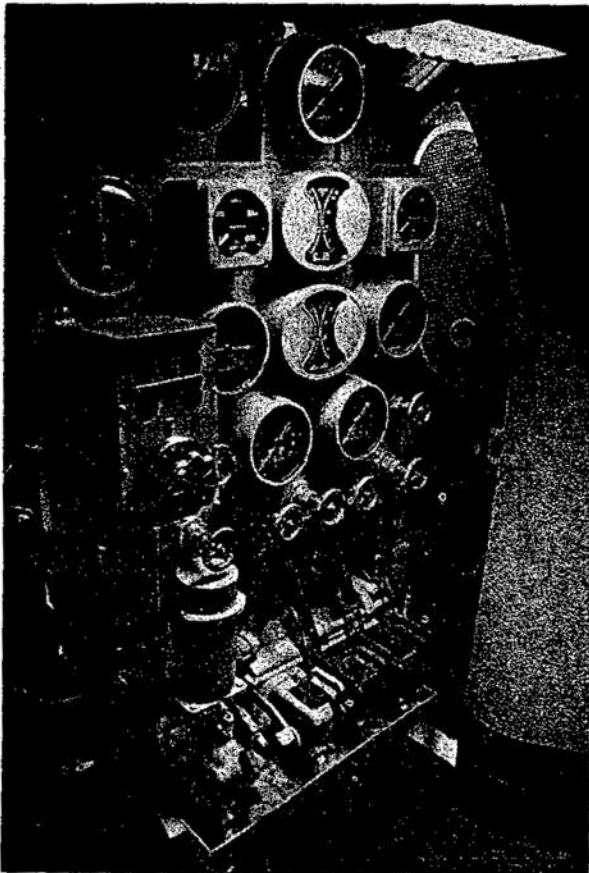


Figure 3. Vertical distribution over a 6½-foot operating panel where the luminaire must be placed within 8 inches of the panel.

Outside of the messing areas there are no special recreational rooms and a man has no castle for a home but his bunk. There he reads, talks, plays cards, and writes letters home. An individual bunk light has been the dream of every man in the service. The present unit is partially successful: an incandescent light with a protecting cover which raises to form the reflector is mounted on an arm which folds beneath the mattress when the bunk must be secured (Fig. 4).

Other specialized units are required for such locations as the battery compartments where there is headroom of only two or three feet, the officers' wardroom where most of the official business of the boat is conducted, officers' desks and bunks, the narrow passageways, the yeoman's desk and radio-man's shack, shaving mirrors, the galley and crew's mess.

Red Lighting for Dark Adaptation

A most critical phase of lighting aboard military vessels is one which is almost exclusive to them—that which concerns the need for dark adaptation. Attack and defense most often occur at night, late twilight and before dawn. At such times it is possible to see only by the use of the scotopic, or rod, mechanism of the eye. It has been found that red lighting will permit rapid subsequent dark adaptation if it meets certain specifications of quality and intensity, and that men can continue their regular duties under such lighting. In consequence there are areas aboard all military vessels in which planning must be made for total red illumination in the evening and during the night. The specification for spectral quality permits transmission of less than .001 of the visible energy at wavelengths below 600 mu.



Figure 4. Men's bunk light in use for reading. When not in use, units are folded beneath the mattresses.

In addition, these red light levels must be low in order to provide for rapid subsequent dark adaptation. Some of the red lighting levels recommended by the Visual Engineering Section of the Laboratory are given in Table I.

These might appear to be extremely low levels to those who are only familiar with curves derived from threshold data such as Lythgoe's. A threshold is a 50-50 point — 50 per cent of the time seen, 50 per cent not seen, or, 50 per cent right, 50 per cent wrong. Such data are not directly useful in daily occupations where we cannot afford to be right only 50 per cent of the time. It wouldn't be good for business. It is impossible in shipboard operations. Nor are daily tasks on the threshold level. Most of the things we are required to see are easy to see — that is, *supra-threshold*. Therefore a different psychophysical technique is required for determining the minimum lighting levels at which ordinary visual tasks can be accomplished with reasonable accuracy. One method consists in recording the per cent error scores made on a variety of supra-threshold tasks and adjusting the curves

TABLE I.—Red Lighting Levels for Dark Adaptation.

CONTROL ROOM	
Illumination on working areas01 - 0.4 ft-c
Illumination on black-and-white dials, figures, nameplates03 - .10 ft-c
Brightness of instrument faces (white portion)02 - .08 ft-L
Brightness of indicator lights (not to exceed 1 sq. in. area)10 - 1.00 ft-L
CREW'S MESS AND OFFICERS' WARDROOM (These are readiness areas)	
Illumination at table top height	0.5 - 2.0 ft-c
Brightness of any area in the visual field: not to exceed	2.0 ft-c

to coincide at the plateau of good performance recorded at the higher levels of illumination used in each experiment.

Seven such curves, from four investigators, are shown in Fig. 5. The tasks were various: perception of depth, identification of letters, addition and dial reading from small and large dials. Because of the variety of tasks, of stimuli, of methodology, of criteria and of scoring large differences are to be expected. However, in all studies a kind of break-point occurs in the log unit between 0.01 and 0.1 footlambert. Analysis of a number of such studies of supra-threshold tasks justified the specifications suggested in Table I.

It is not contended that such low brightnesses are most desirable but there is no doubt that they are sufficient for ordinary occupations involving clearly supra-threshold tasks.

The present method of achieving the specifications for spectral quality and intensity is by enclosing the fluorescent lamp in a red acrylic tube. Internal red lighting of instruments presents problems which have not yet been solved.

Coordination of Lighting With Compartment Design

At no time was it assumed that the redesign of the fixtures would be sufficient to establish a good visual environment. As we know, the design, color and reflectivity of the surroundings greatly affect the appearance of light in a room. The finding that standard lighting methods required drastic modification for small compartments was minor compared with the reversals of decorating principles which sometimes proved necessary.

Several specific effects were attempted in the coordination of lighting and compartment design.

1. Sense of space. The first plan was to paint practically everything in each compartment in one color in order to "pull together" the diversity of shapes, colors and textures of the equipment. This succeeded, but it succeeded better when one substantial contrasting color area was emphasized in each compartment so that the uniformly-colored but heterogeneous shapes could "fall away" from the accent area.

2. Change of pace. Working areas are specified in one color, living areas in another. This seems to be all that is necessary to provide variety and a sense of orientation. It was first thought that warm tones should be used in the living areas and cool tones in the working quarters. This formula has been deliberately reversed on some boats with equally acceptable results.

Another standard principle of decorating proved untrue when applied to small compartments with varied lighting. It has been generally accepted that

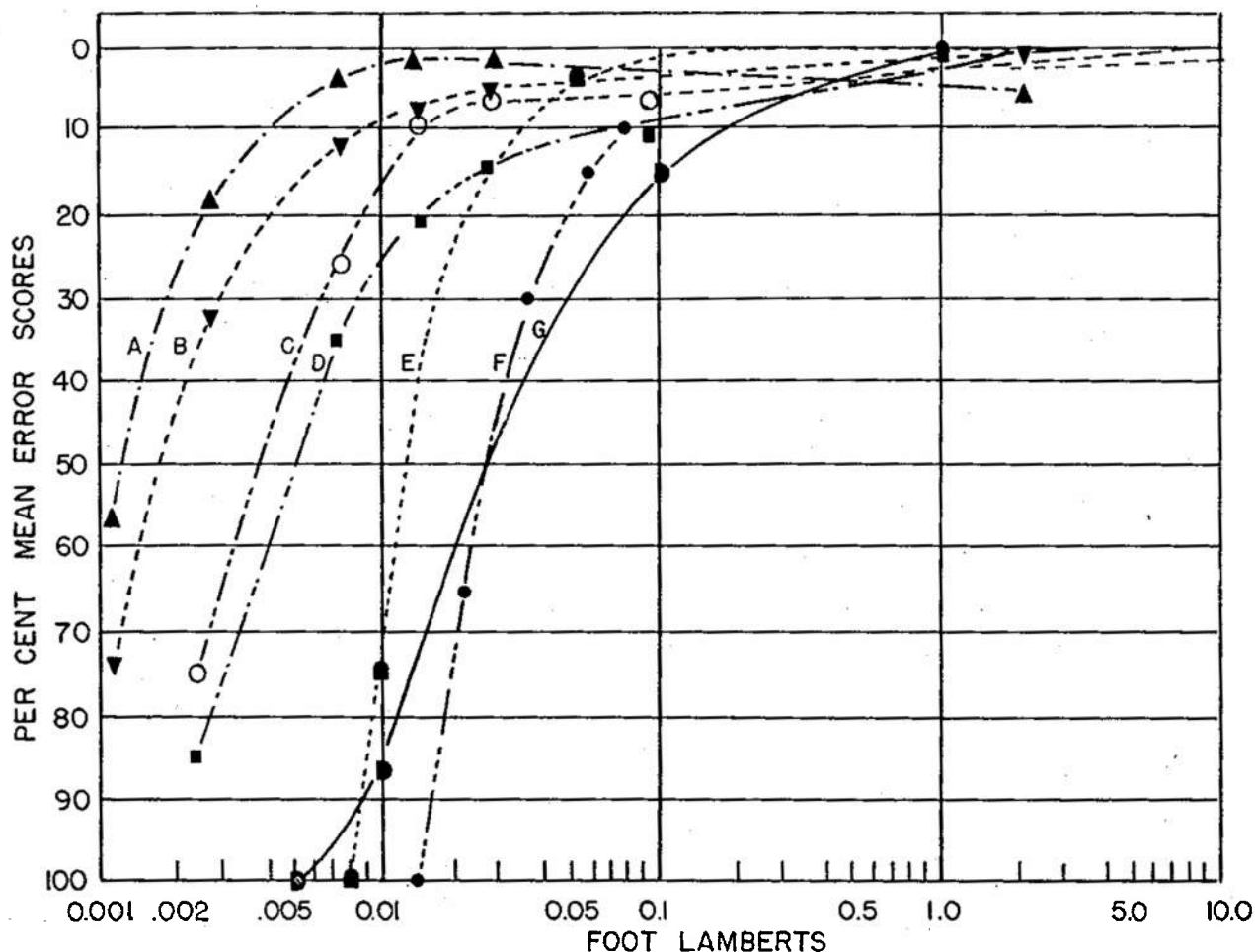


Figure 5. Visual performance at low brightness levels. Per cent mean error scores adjusted to best performance.

- A. Large dials — gross criteria
- B. Large dials — fine criteria
- C. Small dials — gross criteria
- D. Small dials — fine criteria

Chalmers, Goldstein and Kappauf, "The effect of illumination on dial reading," Wright-Patterson Air Force Base, Dayton, 1950.

E. Addition Problems — 20-pt. type. Rock, Milton L., "Visual performance as a function of low photopic brightness levels," Wright-Patterson Air Force Base, Dayton, 1950.

F. Legibility of letters — 20/40 size. Brown, Fred E. "A Study of the legibility of transilluminated markings in aircraft cockpits," Aeronautical Medical Equipment Laboratory, Philadelphia, 1949.

G. Depth perception — Rock, M. L., *op. cit.*

a sample color will appear more intense when applied to a whole room, and that color differences will be emphasized when applied to separate rooms. To the contrary, it was found that color differences were almost eliminated when applied to small compartments. It was therefore necessary to increase the chromatic contrasts of the colors in the scheme far beyond what would be normally acceptable.

3. Low background brightness. Paint reflectances are deliberately low. Backgrounds which are the same or of lower brightness than the object attended to are known to increase acuity and ease of seeing. Men in submarines look at instruments and each other. When a man looks another in the face, it should—for morale's sake—appear clear, healthy and lively. Therefore all background colors are chosen primarily to enhance and lighten skin color.

Reflectances of the standard colors range between 30 per cent and 50 per cent.

4. Spectral coordination of light and colorant. The original paint scheme on the *SS Permit* was designed for incandescent light—under which it was highly successful. The yellow-gray standard, however, turned to a dirty mustard on the next boat which had cool white fluorescent. This was remedied by the addition of light red to the formula, just in time to meet an installation of warm whites which produced a soft pink effect in the crew's quarters. The moral to this adventure was not the well-known fact that colors change with their illuminant but that the *spectral distribution* of paints must be specified in conjunction with the spectral emission of the sources.

5. Uniform instrument lighting. The best de-

signed luminaires cannot make light turn corners in mid-air, nor change its habit of reflecting at the angle of incidence. When instrument panels are designed so that the top dials are tilted forward and the lower dials tilted up, (1) more uniform distribution is obtained, (2) lamp reflection from the dial faces is eliminated, (3) the shadow of the dial rims is reduced, and (4) the direct view increases reading accuracy and reduces parallax.

6. Elimination of glare. Because of the narrow passageways, most surfaces are seen at oblique angles, which increases the intensity of reflected glare from the well-polished bright work which has long been the pride of the Navy. Louvered luminaires were the first step in glare elimination, but substitution of modern materials for polished brass and stainless steel has reduced reflected glare to a minimum. Paint gloss is limited to 30 units, and now covers all metals except hand controls. Satin-finished plastic laminates of low reflectance substitute for the CRS rub boards which formerly lined the passageways and compartments.

One of the chief sources of direct glare was formerly from the white overheads near the lamps. Attempts to use indirect lighting only increased

the glare because the overhead was so low. Both white paint and indirect units have been eliminated.

7. Eye-rest areas. It is believed by this laboratory that the pupils of the eye are naturally used to change of illumination and the opportunity to exercise, particularly to rest by dilation. Therefore each compartment should be provided with a low brightness area where this natural ocular rest is possible. One application is to panel the compartment at head height with dark, natural wood laminates; another is to paint one wall in a solid, dark color.

This is a tale of coordination of better lighting luminaire design with many other fields of human engineering. Lighting units alone could not have produced better vision, but without much better lighting luminaires we could not have achieved better visual conditions. Our common goal is to do all that illumination can do for the habitability environment of the Navy personnel of today.

References

1. Alexander, Robert T., Lieut., USCG: "Illumination of Coast Guard Vessels," *J. Am. Soc. Naval Engr.*, Vol. 53, No. 1 (February 1941).
2. ———: "Light Sources for Coast Guard Use," *J. Am. Soc. Naval Engr.*, Vol. 53, No. 2 (May 1941).