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TECHNICAL REPORT - SDC 641-2-2

ILLUMINATION IN THE ATTACK CENTER AND PERISCOPE AREA OF THE SS 563/564

(Human Engineering System Studies)

Dunlap and Associates, Inc.
10 East 49th Street, New York, N.Y.
22 August 1949

SDC Human Engineering Project 20-F-2
Contract N8onr-641, T.O. II
Project Designation NR-784-002

SPECIAL DEVICES CENTER

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96

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TABLE OF CONTENTS

I. SUMMARY

1. This report evaluates the room and instrument illumination required for efficient performance in the Attack Center and Periscope Area of the Class 563/564 submarine. Cognizant Navy personnel were interviewed to determine probable operational procedures in the Attack Center and Periscope Area. The implication of these procedures for illumination was considered. Then, provisional lighting specifications were developed for these areas. In doing so, attention was paid to the current Navy specifications and to the relevant literature.

2. Certain recommendations are made in this report:

a. Quantitative Lighting Specifications

Tentative specifications for general and instrument illumination are given for the Periscope Area and Attack Center, both for day and night conditions.

b. Functional Organization of Periscope Area and Attack Center

Location of the Captain in the Attack Center and a subordinate at the periscope during night maneuvers is a desirable arrangement. By this means, the Periscope Area can be isolated for dark adaptation at night while normal illumination can be used elsewhere. During the day, these two areas will be visually accessible to each other and the Commanding Officer can occupy whatever position he prefers. Other possible arrangements are also discussed.

3. Visits were made to some manufacturers to examine the lighting of equipment for this class of submarine. A report on these visits is included. Certain instruments were examined to determine the adequacy of illumination. The Macbeth Illuminometer was used to measure the brightness level and special goggles were used to determine the adequacy of red filters and the presence of stray ultra-violet light. It is urged that information regarding good instrument lighting practice and apparatus (brightness meter and test goggles) be made available to the designers of instruments.

II. PROCEDURE

This report presents an evaluation of the room and instrument illumination necessary for efficient performance in the Attack Center and Periscope Area of the Class 563/564 submarine. The design of these submarines differs considerably from that of the current fleet type. One compartment extends from frames 42 to 55 and is divided along the center line of the boat into two areas. The starboard area, to be called the Attack Center, is to contain the radar, sonar, fire control, and plotting equipment. The port area, to be called the Control Room, contains the diving controls, power switchboards, and air, trim, and hydraulic manifolds. The Periscope Area, with the periscopes and helm, is at the forward end of the Control Room-Attack Center compartment, at about the mid-line of the boat. Both periscopes are on the mid-line in the Electric Boat Co. model and athwartships on the Portsmouth Naval Shipyard model.

This boat does not have a conning tower. The Control Room, Attack Center, and Periscope Area are all next to each other in the center of the boat. The original plan called for bulkheads to separate the three areas. In present mock-ups, the bulkhead around the Periscope Area extends only to shoulder height (about 42 inches above the deck). The deck of the Periscope Area is 31 inches higher than that of the rest of the compartment, and it is possible to look from there into the Attack Center. There is a bulkhead on the portside with a door to the Control Room.[1]

In order to determine illumination requirements, it was important to consider the procedures which would probably be employed in the operation of this

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[1] Further details concerning the arrangement of equipment in the Attack Center are presented in another report. See Tolcott et al. (24).

submarine. Accordingly, interviews on this subject were held with submarine operating personnel at ComSubLant (New London) and with qualified representatives of BuOrd, BuShips, Electric Boat Co. (Groton), and Portsmouth Naval Shipyard. Small scale models were used to demonstrate the layout of the various areas. An attempt was made to ascertain whether the Captain prefers to remain at the periscope at all times during an attack, and whether it is important at night to maintain conditions for dark adaptation in the vicinity of the periscope.

In addition, some recently collected and still unpublished research data were made available by the Medical Research Laboratory of the U.S.N. Submarine Base (New London) and by the Institute for Cooperative Research of the Johns Hopkins University (Baltimore). This information relates to dark adaptation, and the illumination of submarines, instruments, and cathode ray tubes.

Visits were made to the plants of companies preparing equipment for these submarines. Although much of the equipment existed only at the planning stage, it was often possible to examine completed instruments or mock-ups at several companies. A report on these visits is presented in Chapter VI.

III. CURRENT NAVY SPECIFICATIONS FOR ILLUMINATION ABOARD SUBMARINES

Comprehensive specifications for illumination aboard submarines do not exist at present. However, some specifications, to which reference is often made, have been published by various Navy agencies. For example, the Bureau of Ordnance gives the following illumination requirements:

> General - The illumination shall fulfill the following requirements:
>
> (a) illuminate adequately the dials, scales, etc., so that they may be read easily and without fatigue,
> (b) provide an even distribution of light,
> (c) avoid objectionable shadows,
> (d) obtain suitable contrasts,
> (e) reduce glare to a minimum,
> (f) limit emission of stray light in exposed units,
> (g) where dark adaptation of the operating personnel is required in exposed or protected locations, the light shall be of such wave length as not to impair the vision of the operator or observer - O.D. 4640 (34, Sheet 44).
>
> Nature of Supply - ...Each optical instrument shall be provided with an independent dimming control, which includes a variable resistance, to permit close adjustment of the cross-light conditions. If a dimming switch is required in an individual instrument, it will be specified in the applicable Procurement Specification (34, Sheet 46).

Other detailed requirements are available from the Air Force-Navy Aeronautic specifications (29):

> Contrast - There shall be a maximum contrast between the white lettering, numbering, and marking and the background of the plastic lighting plate when viewed in daylight. The value of contrast when measured under diffused illumination with a Luckiesh-Taylor Brightness Meter or equivalent shall not be greater than -20. Contrast 'C' is defined as:
>
> $$C = \frac{B_1 - B_2}{B_1}$$
>
> where B_1 is the brightness of the background and B_2 is the brightness of the lettering, numbering, and marking.
>
> NOTE: A contrast of -19 would be unacceptable, while a contrast of -21 would be acceptable.

It may be noted that the definition of contrast, as given in the specification, refers strictly to white markings on a black background. All markings in the Attack Center and Periscope Area should be white on black in order to reduce the amount of light under dark-adapted conditions. For equal degrees of contrast, legibility is about the same for white on black as for black on white numerals.

> Gloss - The outer surface of the plastic lighting plate shall have as low a specular gloss as practicable, but in no event shall the gloss exceed 5 units when measured by the American Society for Testing Materials Standard Method D52 3.
>
> Illumination - The light assembly shall be located so that the brightness of all illuminated markings is relatively uniform over the range of lamp voltage from 7-volts to 28-volts. When the lamps are operated at 28-volts without a filter the brightest markings shall be no greater than seven times the dimmest markings of the plastic lighting plate. The dimmest markings shall be not less than 0.50 footlambert. Measurements shall be with a Luckiesh-Taylor Brightness Meter, or equivalent. Stray light leakage from any surface of the plastic lighting plate will not be permitted (p. 3f).

These specifications are inadequate in the sense that the instrument engineer does not find here sufficient information for the design of a proper lighting system. For example, a brightness level for dark adaptation is not described. (The value of 0.50 footlambert is given as a minimum for daylight illumination.) Nor is a wave length of light (i.e., red) given as adequate to protect dark adaptation. One could specify "Wratten filter No. 29 or its equivalent," as is done on some contracts. In 1942, Weinbach and Lee (26) published a report which appears to be the first statement of the specification used by the Navy during the war. Perhaps the greatest shortcoming in these specifications is the failure to recognize that the illumination of instruments must be related to the illumination of the room in which the instruments will be located. A coordinated specification for room and instrument illumination makes it possible to control brightness ratio and glare for day and night conditions. A Navy conference meeting in 1946 recommended that illumination standards be established (32). The suggestion has been made that several brightness levels from day to night conditions be established as reference standards for illumination (30). The proper room and instrument illumination could then be defined more readily.

It is interesting to note that data relevant to this problem are available in the engineering, medical, and psychological literature. But these data have not been summarized in a form which makes them useful to the instrument designer. An attempt to bridge this gap has been made in the following section where provisional specifications for instrument and room illumination are presented.

IV. PROVISIONAL LIGHTING SPECIFICATIONS FOR THE ATTACK CENTER AND PERISCOPE AREA

It is impractical, if not impossible, to deal separately with instrument and general room illumination. Some instruments, which do not have self-contained lighting, can be read only if the general illumination is adequate. The self-illuminated instruments and the cathode ray tubes may raise the over-all brightness level of a compartment in which dark adaptation must be maintained. Since the protection of dark adaptation requires that there be as little light as possible, the brightness of both the room and the instruments must be reduced together. In all cases, instruments can be observed most effectively only if the brightness of the dials is equal to or a little more than that of the surrounding areas. Instrument and room illumination, therefore, are closely related and require common specifications.

It is well-known that the best visual performance occurs at high brightness levels. Visual acuity increases as brightness increases up to about 1000 millilamberts; the rate of improvement with increased brightness is greatest up to about 10 millilamberts (15).[2] Since electric current must be conserved aboard

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[2]Millilambert - A measure of the brightness of a surface which emits or reflects light. A perfectly reflecting surface illuminated by one footcandle has a brightness of one footlambert (fl), i.e., footlamberts = footcandles x reflection factor of surface. Footlamberts (fl) x 1.076 = Millilamberts (ml); ml x 0.929 = fl. Several representative brightness values are given below:

white surface in bright sunlight	12,000 ml
fluorescent lamp	900-3000
clear blue sky	500-1,250
black cloth in sunlight	225

Footcandle - A measure of the intensity or level of illumination. One footcandle (fc) is the intensity of illumination at a point on a surface one foot from a uniform point source of one standard candle. The approximate intensity of illumination from certain sources is given below:

direct sunlight	12,000 fc
daylight, in shade	100-1000
good office lighting	50-100
street lighting	0.6-1.2

submarines, it is reasonable to specify a moderate rather than a high brightness level provided that useful work can be done at the moderate level. The selection of 10 millilamberts, rather than some lower brightness, as a suitable level for submarines is based on the fact that it is the brightness level beyond which further brightness increases provide diminishing returns in improvement of acuity.

Provisional specifications are given in this section both for room and instrument illumination, during day and night lighting conditions. However, before proceeding to these, it might be helpful to consider the various brightness levels that may be encountered and their effect upon vision.

Table I provides convenient reference levels of sky brightness at night.

Table I. Brightness of the Sky Horizon at Night*

Sky Condition	Brightness Range - Millilamberts
Full Moon	.005 - .020
Half Moon	.001 - .004
Clear Starlight	.000 100 - .000 200
Overcast Starlight	.000 010 - .000 020

*Adapted from (33) p. 38.

Half moon brightness will be encountered for about one half of the month, and full moon and clear starlight each for about one quarter of the time. An overcast sky would appreciably reduce all of these brightness levels.

In terms of the human eye, daylight vision is performed by the cones, which are in the center of the retina. These cells make it possible to perceive sharp details and to differentiate colors. But they fail to respond when the light diminishes below about .001 millilambert (half moon sky brightness). That is why one may barely recognize colors in full moonlight, but not under darker conditions.

The ability to see at lower brightness levels is due to other cells in the retina. These are the rods, which can respond to amounts of light as low as .000 005 millilambert, well below overcast starlight. The maximum concentration of rods is found surrounding the central cones in a band 10 to 20 degrees from the center of the eye. "Off-center" vision, or looking off to the side, places the image on the retinal area where the rods abound, and thus one can detect objects under very dark conditions. The visual image, however, is crude and practice is required in order to know whether or not one actually sees a real object.

Off-center vision would be required to see anything at all through the periscope on many nights of the month. It is therefore important to know whether useful work at a periscope is possible on a dark night by means of off-center vision. If a target can be seen, identified, and tracked, then it is necessary to protect the periscope officer's dark adaptation down to the lowest brightness level at which this work can be performed successfully. Dark adaptation below this level would be superfluous. The level down to which dark adaptation should be preserved is not precisely known, although an exact experiment might be designed to find a satisfactory answer. It is urged that such an experiment be carried out because the findings can be of worth in deciding whether or not the involved procedures required to maintain dark adaptation produce a useful return.

The time required to adapt from one brightness level to another must also be considered. The adaptation process is primarily a chemical reaction in the retinal cells and takes time. The adjustment from a dim to a bright level occurs within less than 30 seconds. However, the crucial shift from a bright to a dim level may take up to 30 minutes, depending upon the initial and final brightness levels.

The amount of time required to adjust from one brightness level to a lower one is shown in Figures 1 and 2, drawn from curves in two reports issued by the Medical Research Laboratory, U. S. Submarine Base, New London. Figure 1 shows the time in the dark required to reach lower brightness levels following initial adaptation (20 minutes exposure) to 6 footlamberts of white light (one 60 watt bulb at 115 volts, mounted in a chandelier) and to the same light while the subject wore the standard red Navy dark adaptation goggles (17). Figure 2 shows another subject in a similar experiment except that the white light was 140 footlamberts (18). Table II has been derived by interpolation from these curves to show the approximate time required to reach certain lower brightnesses after exposure to these experimental levels. The brighter level (140 footlamberts) is higher than the minimum of the best type of office lighting; the lower brightness (6 footlamberts) approximates that found in submarines.

Table II. Time in the Dark Required to Reach Certain Lower Brightness Levels, After 4 Conditions of Exposure*

(Time is given in minutes and seconds, e.g., 0:0)

Initial Brightness Level (fl)	Final Brightness Level (ml)					
	.1	Full Moon .01	Half Moon .001	Clear Starlight .000 1	Overcast Starlight .000 010	.000 005
140 fl, white light, no goggles	0:2	0:12	4:36	8:24	16:34	22:36
140 fl, white light, plus red goggles	—	—	0:15	1:51	12:30	20:1
6 fl, white light, no goggles	—	0:1	0:11	2:24	8:33	16:48
6 fl, white light, plus red goggles	—	—	—	0:10	2:0	5:15

*These values interpolated from curves in two reports from the Medical Research Laboratory, U. S. Submarine Base, New London (17, 18). The blank spaces in the table signify that adaptation occurs in less than one second.

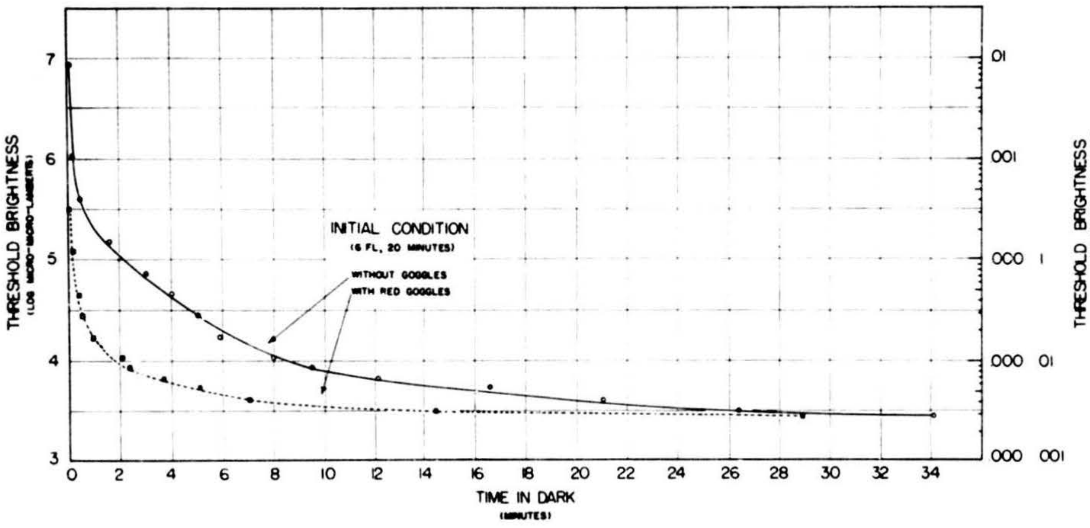

Figure 1. Time in the dark required to reach lower brightness levels, after 20 minutes exposure to 6 footlamberts white light, with and without red goggles. From Mitchell (17).

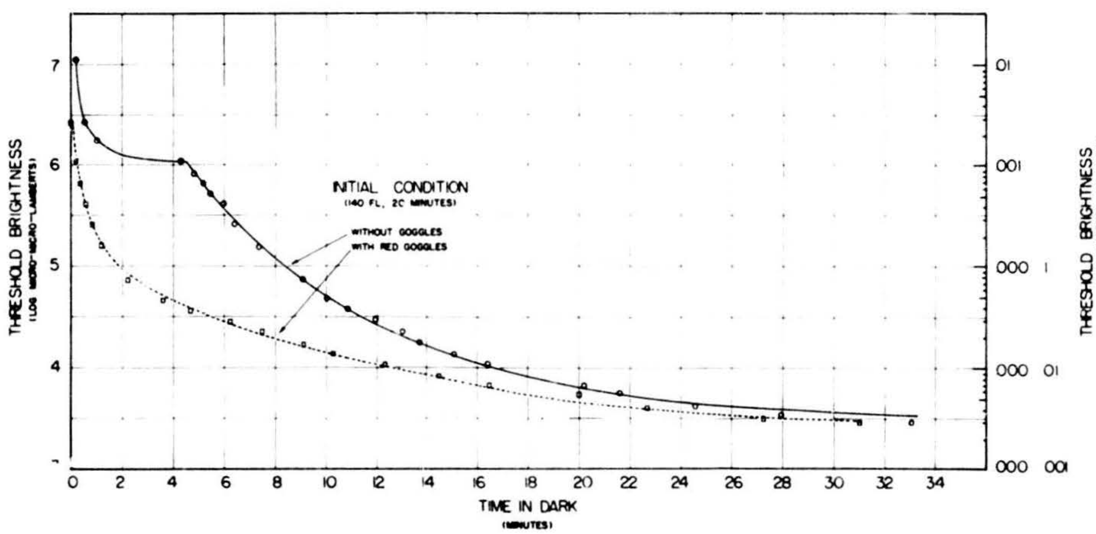

Figure 2. Time in the dark required to reach lower brightness levels, after 20 minutes exposure to 140 footlamberts white light, with and without red goggles. From Mitchell (18).

Six conditions of darkness have been selected as reference levels, i.e., final brightness levels. These extend from a level brighter than full moonlight to one darker than that probably ever met at sea. The "final" level in this table may be reached after adapting for about 25 minutes. Of course, adaptation does not cease at that time. A slightly greater sensitivity develops when dark adaptation continues up to 24 hours. For all practical purposes, however, maximum sensitivity is reached within one-half hour. Excluding the first and last columns, then, the other columns approximate the brighter levels of full moon, half moon, starlight, and overcast starlight.

The significance of the data in Table II may be demonstrated by an example. After exposure to 6 fl, without goggles, the table shows that 2 minutes and 24 seconds are required to detect light at a brightness level of clear starlight. Provided that red goggles have been worn, only 10 seconds are required before one can see under the same conditions. Other comparisons can readily be made. Obviously, one adapts more rapidly after exposure to a moderate (6 fl) than to a high (140 fl) level of daylight brightness; the wearing of red goggles always makes it possible to see in dim light more rapidly than when goggles have not been worn. The time taken to dark adapt is wasted time in the sense that nothing can be seen until adaptation has proceeded to the brightness level at which one wishes to observe.

Attention may be directed to the fact that the light loss through the optical system of a periscope may amount to more than 50 percent. Also, these dark adaptation curves refer to the ability to detect a spot of light, and not to the ability to recognize an obscure shape as a potential target. When corrections have been made for these factors, it is doubtful whether effective sighting can occur at the periscope when the horizon sky brightness is lower than that of half moonlight.

The above facts were considered in establishing the tentative specifications for lighting given in Table III. A discussion of the many researches upon which these specifications are based appears in the Appendix. Many values in Part C of Table III represent compromises between dark adaptation required for sighting through the periscope and the illumination needed for reading the instruments. For example, legibility is poor and performance is inadequate when, in order to protect dark adaptation, the brightness of the instrument markings is less than .02 ml. On the other hand, although legibility improves when the brightness of instrument markings is more than .10 ml, dark adaptation is always affected adversely by any increase of brightness. Illumination lower than .10 ml can be employed satisfactorily in working areas where instrument reading is not required.

One central fact in the table is that the optimal operating brightness for a cathode ray tube is .10 ml. While visual performance improves as brightness increases above this level, the efficiency of the tube decreases. The value of .10 ml is well established by many investigations of the Systems Research Laboratory (9,27). Since CRT's should be operated at this level, the area surrounding them should also be illuminated at this or a slightly lesser level. Of course, it may then become necessary to isolate such instruments, by means of shields, from the view of those whose dark adaptation for lower levels must be preserved. Also, it will be noted that for daylight conditions, higher values have been chosen for room and instrument lighting than for the CRT's. This is due to the fact that these values provide greater visibility in the general working area and are readily achieved. Here again, the CRT's should be protected by shields from the higher room brightness. The following comments with respect to illumination supplement the facts presented in the table.

Table III. Provisional Specifications for General (Area) and Instrument Illumination*

	Desired	Permissable From	To
A. General Lighting Requirements for Both Bright and Dark Conditions			
1. Brightness ratios:			
Various dial markings within a given instrument	1:1	1:1	3:1
Instrument to background	2:1	1:1	10:1
Various instruments within a given panel	1:1	1:1	3:1
Cathode ray tube to background	2:1	1:1	10:1
2. Instrument characteristics:			
Brightness ratio of markings to background	100:1	15:1	400:1
Reflectance of instrument markings (with external illumination)	100%	75%	100%
Central viewing angle to read instrument dials	160°	120°	180°
B. Lighting Requirements for Bright Conditions			
1. Illumination on working areas	10 fc	1 fc	10 fc
2. Brightness of markings on instruments	10 ml	2 ml	20 ml
3. Brightness of indicator lights	50 ml	40 ml	100 ml
4. Brightness of cathode ray tubes	.10 ml	.10 ml	1.0 ml
C. Red Lighting Requirements for Dark Adapted Conditions**			
1. Illumination on working areas	.02 fc	.01 fc	.03 fc
2. Brightness of markings on instruments	.04 ml	.02 ml	.06 ml
3. Brightness of indicator lights	.08 ml	.04 ml	.10 ml
4. Brightness of cathode ray tubes	.10 ml	.10 ml	1.0 ml

*See the Appendix for a discussion of the studies from which these values have been drawn.
**See the Appendix for the specifications of red light.

1. It may be noted that desirable brightness levels (in millilamberts) are given for instrument markings whereas only illumination (in footcandles) has been specified for working areas. The illumination for <u>working</u> areas does not, of course, refer to illumination for the instrument area. The separate specification of brightness for instruments and illumination for working areas is meant to simplify the tasks of various groups of designers in meeting the requirements.
2. External overhead lighting should be shielded so as to minimize the disturbing effects of bright patches of light.
3. It should be possible to vary instrument brightness to achieve the levels required for day or night operations.
4. It is desirable to have intensity controls designed in such a way that the operator cannot adjust them above or below certain predetermined values.
5. Any system of illumination which satisfies the general and specific characteristics detailed in Table III would appear to be acceptable. As is well known, instrument illumination systems have employed various techniques, such as back-lighting, false panel, lucite inter-panel, and ultra-violet excitation of phosphors. No attempt will be made here to evaluate the relative merits of the several systems because an excellent treatment of this subject is contained in Fordyce's paper, to which reference has already been made. Attention will be directed here only to some recent developments and to a few points which always require special emphasis. Special care must be taken with ultra-violet lighting systems. Sudden blackout may occur when the current is interrupted momentarily or when the voltage drops below a critical level. Small amounts of stray ultra-violet light may interfere seriously with dark adaptation. In the past, it has been difficult to find a satisfactory fluorescent paint for the dials and numbers. Where

dark adaptation must be maintained, the fluorescent paint should be deep red (600 mu or more).[3] Some organic fluorescent pigments (such as the Switzer pigments), whose color is acceptable, deteriorate upon continued exposure to ultra-violet light. An interesting plastic material for panel lighting has just been developed by Plasteck, Inc. (East Port Chester, Connecticut). This is a clear lucite panel to which are laminated, first, a thin sheet of white and then a thin sheet of black plastic. Engraving through the black surface yields white letters and markings with a high degree of contrast; the black surface is very dull and durable. Small light bulbs with a red filter are inserted in holes drilled through the panel to provide red-illuminated figures for night lighting. This plastic panel probably can be applied to instrument illumination.

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3 Such pigments were not available during the war. Some recently developed pigments may be satisfactory, but they have not been sufficiently tested. These are Fluorescent 2125, of the New Jersey Zinc Company, Phosphor 1818 of the DuPont Company, and magnesium-germanate fluorescent of RCA.

V. OPERATIONAL PROCEDURES IN THE ATTACK CENTER AND PERISCOPE AREA

Lighting values for normal and dim (dark adapted) levels of illumination have been offered in the previous section. However, lighting practice must serve the required operational procedures. The present arrangement of the 563/564 attack submarine provides direct visual access from the Periscope Area to the Attack Center. An important factor, therefore, is the functional relationship between these two areas.

To ascertain the procedures which might be used in this new type submarine, interviews were held with submarine officers at ComSubLant from 30 May to 11 June 1949. The group interviewed included submarine Commanding Officers, Executive Officers, Squadron Commanding Officers, Engineering Officers, and senior officers on the ComSubLant staff. All these men were experienced submariners. These officers were asked to consider the arrangement of equipment in the Periscope Area and Attack Center. A small scale model of the floor area and of the equipment was employed to facilitate the discussions. The men were asked to arrange the equipment in such a way as to produce the most efficient operation of the submarine. They were also asked such questions as, "Where would you, as a Commanding Officer, prefer to be stationed most of the time?" and "Should the Periscope Area be separated from the Attack Center?" A full report on these interviews appears in another study (24).[4] In this report, we are concerned only with the responses which concern the problem of <u>illumination</u>.

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[4] This investigation (24) was concerned with determining the best location of equipment in the Attack Center and Periscope Area. As the interviews indicated, the Commanding Officer generally preferred to be located near the periscope a large part, if not all, of the time. The placement of the equipment was therefore based on this premise and recommendations were made for repeaters in the Periscope Area. The present study, concerned with the role of illumination, considers also the possibility that the Commanding Officer may be located in the Attack Center. In the latter circumstance, there may be no need for repeaters in the Periscope Area.

The interviews, each lasting two to three hours, were held with twelve officers. The pertinent results are noted in Table IV.

Table IV. Preferred Location of the Commanding Officer

No. of Officers	Periscope Area	Attack Center	Sonar Area
6	Day and night		
2	When periscope observations are possible	When periscope observations are not possible	
2	Attack	Approach or evasion	
2			Day and night

As the data show, six individuals believe the Commander should be in the Periscope Area at all times, while two prefer that he remain near the sonar gear (in the Attack Center). The remaining four officers would vary the practice, according to day or night and attack or approach conditions. Most officers wished to isolate the Periscope Area to protect their dark adaptation during night operations. Some wanted to isolate this area at all times by a fixed bulkhead; about 50 per cent preferred an adjustable light-proof curtain.

It is important to note that almost all officers desired that certain equipment be placed in the Periscope Area: 11 officers desired a position indicator; 9 the QHB and 5 the radar scope. If repeaters are observed at night in the Periscope Area, there may be a time delay, due to the loss of dark adaptation, before effective sighting can occur at the periscope.

While comparatively few officers were interviewed, there were two Group Commanders (Captains) among them. A much larger group could be interviewed in order to test whether or not these opinions are typical. In any case, the findings are adequate for the present purpose: they indicate that authoritative opinions differ concerning the location preferred for the Commanding Officer. Although most officers prefer to stay at the periscope when such observations are possible, this attitude is not universal. Some officers prefer to use the Attack Center as their battle station. An illumination problem occurs because of the substantial request for repeaters in the Periscope Area. Three main operational procedures must, therefore, be evaluated in terms of their effect upon illumination requirements.

1. The Commanding Officer remains at the periscope and has visual access at all times to the Attack Center. The Periscope Area and the Attack Center both are illuminated brightly during the day and dimly in red at night.[5]

   With regard to efficient performance at all stations, this is not the best arrangement. Dim light in the Attack Center imposes a penalty: i.e., makes it difficult, though not impossible, to read instruments and maps. Furthermore, looking at instruments bright enough to read interferes with the dark adaptation required on dark nights. Also, it is doubtful that visual access from the Periscope Area to the Attack Center is useful; one cannot see CRT blips, for example, at any distance much greater than that which separates the operator from the instrument. This procedure, at best, follows current practice; at worst, it overlooks the fact that the SS 563/564 is a new type boat.

2. The Commanding Officer stays at the periscope but at [illegible] does not have visual access to the Attack Center. During the day, both the Attack Center

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[5] There is another technique by which one may observe at the periscope at all times. The Commanding Officer could wear a blackout blinder to protect one eye for use at the periscope. He would use the other, unprotected, eye to observe repeaters or equipment in the Attack Center. The use of general red illumination would provide partial protection for the Commanding Officer in case the periscope eye were accidentally exposed to general illumination. This technique is difficult to comply with and, hence, is not recommended.

and the Periscope Area are illuminated brightly and the Commanding Officer can move freely between the two areas. At night, the Periscope Area is closed off by an adjustable blackout curtain and bright white light is used in the Attack Center. Any illumination required in the Periscope Area is dim red, and the Commanding Officer remains here in order to preserve his dark adaptation. If repeater radar scopes are located in this area, they should not be observed by the Commanding Officer on very dark nights (e.g., overcast starlight) unless he is willing to allow certain useless time at the periscope. Information from the Attack Center, or any other area, is relayed to the Commanding Officer by voice communication.

This procedure is preferable to the first in that it permits maximum lighting of the instruments in the Attack Center and minimizes the amount of interference with the periscope operator's dark adaptation.

3. The Commanding Officer stays in the Attack Center and another officer is assigned to duty at the periscope. The conditions of illumination are identical with those described immediately above. The Periscope Area can be open during the day but it must be isolated to maintain dark adaptation on dark nights.

This procedure, like the second one, permits adequate instrument illumination at all times in the Attack Center. However, the operational concept underlying this final alternative is more advanced. It recognizes the fact that, in the new type submarine, the Commanding Officer can now place greater reliance upon the effectiveness of radar and sonar. The periscope, in short, is considered as one of several sources of information which the Commanding Officer will use to arrive at his decisions. These new submarines and their novel equipment permit new operational concepts to be tested. In this way, full advantage of their potentialities may be realized.

VI. EVALUATION OF SPECIFIC INSTRUMENTS

The following establishments were visited:

Arma, Brooklyn, N. Y.
Bell Laboratories, Whippany, N. J.
Electric Boat Company, Groton, Conn.
Hazeltine, Little Neck, L. I.
Seaboard Electric, Glen Cove, L. I.
Submarine Signal Corporation, Boston, Mass.
Portsmouth Naval Shipyard, Kittery, Me.

Complete examination of the illumination system was made wherever finished apparatus was available. Tests were made of the quality of red illumination and of the control of stray ultra-violet light; the brightness level of the instrument markings was measured with a Macbeth Illuminometer. Where equipment was not available, discussions of lighting problems were held with the instrument engineers, and some of the ways such visits can be of assistance are illustrated below.

Two special goggles and a brightness meter were employed to make various tests of illumination. The first set of goggles was used to indicate whether or not the red color on instrument dials and numbers was sufficiently deep, i.e., 600 mu or greater, in order to protect dark adaptation. This goggle contains a special green filter[6] which passes a broad band of colors from violet to orange but excludes all reds at 590 mu and beyond. A proper red for dark adaptation cannot pass through this filter and appears black when viewed through the goggles. Any light, even a "red," which can be seen through the goggles must, therefore, contain orange, yellow, or blue wave lengths. The test is simply demonstrated and easily understood.

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6 The green filter is an experimental filter supplied to order by Eastman Kodak and designated as No. 1104. It was furnished in goggles by Lt. Cdr. Dean Farnsworth, H (S), USNR of the Medical Research Department, U. S. Submarine Base, New London. Note that the 590 mu cut-off provides more lee-way than the 600 mu standard followed in this paper. The filter was the best available for the present purpose.

The second set of goggles was used to test for the presence of stray ultra-violet light. Ultra-violet, or invisible light, has been used to activate certain phosphors, as one method of instrument illumination. It is imperative, however, that the ultra-violet sources be mounted so that no ultra-violet "light" shines, directly or by reflection, into the observer's eyes. Ultra-violet light causes fluorescence of the eyeballs which appears to the observer as a smoky haze. It interferes with the contrast required to see and with the maintenance of dark adaptation. The retina of the eye may be damaged by prolonged exposure to ultra-violet light.

The ultra-violet detecting goggles contained two special glass filters. The outer one is a dark glass (Corning No. 5874, "red purple ultra") which rejects all visible light and passes only the ultra-violet ("black light") end of the spectrum. The second glass (Corning No. 3750, "fluorescent canary") is the detector. It is a normally clear glass which fluoresces yellow-green upon exposure to ultra-violet. Thus, when one wears these goggles, the appearance of a pale yellow-green color signifies that ultra-violet light is present. The desirable condition would be for the observer not to see anything in the goggles, i.e., no "ultra-violet."

The brightness level of the instrument markings was measured quantitatively with a Macbeth Illuminometer. This is a brightness meter which incorporates a standard lamp. Measurements are made by varying the known brightness in the instrument until it equals that of the surface to be measured. In the hands of an experienced observer, it is much more precise than an ordinary photo-electric cell. The quantitative measurements and evaluations of equipment at Arma and the Bell Laboratory are summarized in Table V. The brightness values which exceed those in the tentative specifications (Table III) have been considered undesirable.

Table V. Brightness Measurements of Several Instruments

Mfr.	Equipment	Brightness (ml)	Comments* Specific	Comments* General	Type of Lighting
Arma	**Position Keeper**				
	(several versions of target ship dial)				
	a. Figures (red)	.012-.016	Slightly dim		
	Arrow tip (yellow) wide line	.367	Too bright		
	b. Ship (yellow and green)			Undesirable stray	
	Arrow tip (yellow) thin line	.048		u-v; undesirable	
	Center line (yellow)	.032		fluorescence of	
	Side line (green)	.016		black background	
	c. Ship (red)			paint.	Ultra-violet il-
	Arrow tip (red)	.030			lumination of
	Side line (green)	.016			fluorescent
	Position Keeper (other details)		Max.acceptable		paints. Red,
	a. Neon light switch plate (red)	.061	brightness		yellow, and green
	b. Pointers on Clock (yellow)	.022			pigments manu-
	c. Four lower switch plates	.005,.005	Too dim		factured by
		.123,.126	Too bright		Switzer Bros.
	Predictor Section of Angle Solver				
	a. Letter "F" (red)	.126	Too bright	Inadequate con-	
	b. External neon bull's eye	.126	Too bright	trol of stray u-v	
Bell	**SV-3 Radar Set Control**				
	a. Pilot light (red)		Much		
	Segment at maximum	23.8	too bright		
	Center	.95	Too bright		
	b. Dial surface - minimum	.07	Too bright		
	maximum	.18	Too bright		Edge lighting by
	AN/BPS-1 Indicator Console		Too small		concealed bulbs.
	a. Neon pilot light (red) minimum	.00	for reading		
	maximum	.118	Too bright		
	b. Dial surface (3 V, grain of		Too small		
	wheat) minimum	.00	for reading		
	maximum	.146	Too bright		
	c. Neon warning light (yellow)	10.4	Too bright		
G.E.	**VK Remote PPI Radar Repeaters**				Edge lighting by
	a. Range unit dial	.028			concealed bulbs.

*Brightness acceptable unless otherwise noted.

1. Arma

Several visits were made to this plant to inspect mock-ups of the Position Keeper and Angle Solver (with Predictor and Control panels). Comments on the equipment may be made under several headings.

a. Control of stray ultra-violet light

Three instrument panels were illuminated by ultra-violet light. The Control Section of the Angle Solver was covered with plain glass. The Position Keeper and the Predictor Section of the Angle Solver were covered with different types of ultra-violet absorbing filters. As tested by the ultra-violet detecting goggles, the plain glass panel on the Control Section was unacceptable; the panel on the Predictor Section was inadequate. All observers, including the Arma personnel, agreed that the only acceptable panel was on the Position Keeper. This panel is composed of two glass sheets separated by a plastic filter. One sheet is ordinary clear plate glass and the other is called "golden plate glass," manufactured by the Pittsburgh Plate Glass Company. The plastic is a sheet of Butycite Acetal Polyvinal dyed by Arma with a Du-Pont ultra-violet absorbing powder mixed with acetone. The entire panel was assembled by the Pittsburgh Plate Glass Company. It was noted that exposed wires on the mock-up fluoresced considerably in the presence of ultra-violet and they should be carefully hidden.

b. Fluorescent paint

For experimental purposes, Arma was testing two types of paint activated by ultra-violet: germanium red and Switzer Neon Red. Examination of the dials through the test goggles showed that the germanium red, which must include considerable yellow, was inadequate to protect dark adaptation. The Switzer Neon Red appeared to have an acceptable red

*Brightness acceptable unless otherwise noted.

color as tested by the goggles. Such clear-cut evaluation of color is impossible by direct examination, but is readily accomplished with the test goggles. Mention may be made of the fact that the Switzer pigment is an organic compound and it may be expected to deteriorate upon continued exposure to ultra-violet light. Red fluorescent paints which would not deteriorate are DuPont phosphor No. 1818, New Jersey Zinc Company fluorescent No. 2125, and R.C.A. magnesium-germanate fluorescent.

The Arma Position Keeper panel contained a clock whose dials fluoresced yellow-green; a fleur-de-lis to show zero degrees on a bearing dial fluoresced yellow; the starboard sides of two "ships" fluoresced green. It was pointed out that the use of red pigment on most of the dials, to protect dark adaptation, could easily be defeated by the use of other colors. In addition, it is not essential to use other colors, since the yellow and green devices are readily distinguished by shape alone. It is believed that Arma will eliminate the use of other colors than red.

It was noted that the black background paint on the Angle Solver fluoresced in the presence of ultra-violet light. This is undesirable and Arma indicated that a non-fluorescing paint could be substituted.

c. Brightness measurements

Most of the dial markings are adequate in terms of brightness level and evenness of illumination. The variation in brightness due to the use of various phosphors can be reduced provided that only red phosphors are used. Several pilot lights are too bright; these can be reduced by inserting neutral filters. Some of the large red, transilluminated "letters" fluoresced when the ultra-violet sources were active. There were no intensity controls on any of the panels or pilot lights.

2. Hazeltine

The instruments at this corporation were still in the design stage and the illumination system had not as yet been developed. The engineers demonstrated a prototype (from their design for airplane cockpits) which they were going to adapt to the submarine project. This was an ultra-violet and fluorescent paint system.

The project engineers stated that color requirements were not given in their specifications (BuShips Interim Specs. 16 E (RE) 15 May 1946). They intend to follow the requirements given in the aeronautic specifications for the control panel (AN-C-176, 23 November 1948) and cockpit (AN-P-89, 10 November 1948). They plan to use an amber filter over the cathode ray tube and to use edge-lighting. All brightness controls are to have variable resistors.

A receiver is to be used in conjunction with the relay radar tracking repeater (AN/SRR-4). Except for blown-fuse indicators, no internal illumination is planned. There will be a number of legends on the face of the receiver. Since these must be read by the operator, it appears that external illumination will be required. It may be difficult to read these legends if this instrument is located in a dimly illuminated area. The Hazeltine engineers had not yet reached a decision on how to handle this problem.

Information concerning fluorescent paint was presented to them and there was a general discussion of the probl m of ultra-violet lighting. Demonstrations were made of the way in which the special goggles could be used to test ultra-violet and red lighting.

3. Seaboard Electric

The recording unit of the Bathythermograph (AN/BSH - 1 & 2) uses a translucent viewer with rear illumination provided by one red-painted 6.3

volt bulb (GE 210). Brightness is varied by a rheostat which permits an off-position. The instrument itself was not available, but a bulb to be used in it was demonstrated.

Examination with the test goggles showed that the color of the bulb was not "red." The designer said, "We had never thought of what red really is." They had simply procured a Mazda lamp and had a local store paint it "red." They indicated that an adequate red paint would be procured and that they would consider the possibility of inserting two bulbs in parallel, for protection, should one fail.

4. Bell Laboratories

The A-scope and an antenna control unit for the SV-3 radars were available for inspection. Two VK units, borrowed from General Electric, were also shown.

The equipment was located in a laboratory where it was not possible to secure adequate darkness to observe the instruments. The measurements, therefore, are close to but do not represent self-illumination of the instruments. Obviously, however, some of the pilot lights are too bright.

The Bell Laboratories follow the requirements set forth in BuShips specification CS-755, 15 May 1947. The Bell equipment was found to have adequate red illumination. There were intensity controls for all instruments and pilot lamps. The latter are dimmed by mechanical diaphragms which always permit a small amount of light to be seen. In a few cases, the Bell equipment uses a yellow neon pilot lamp which only goes on as a warning that some equipment is out of order. All other lights, as required, are red.

The two General Electric VK remote PPI's (radar repeaters) showed certain undesirable features. The pilot lights were in three colors: red, green, and yellow; the illumination was quite strong, and there was considerable variation in brightness. In one or two cases, there was very uneven illumination with glaring focal points. The red pilot light had no intensity control.

Unless there is some reason to the contrary, it would appear desirable to use red pilot lights with a minimum intensity. The yellow pilot lights on the Bell and General Electric equipment were excessively bright and should be reduced in intensity. The GE units, of course, are not a problem for the Bell Company, which simply had the equipment on a loan basis.

5. Submarine Signal Corporation

The instruments at this company were still at the blue-print stage. Therefore, the discussion of illumination was restricted to problems of design. The test goggles were demonstrated on other finished equipment for the information of the engineers. The project engineers appeared to be cognizant of proper design features for good illumination.

6. Electric Boat Company and Portsmouth Naval Shipyard

The visits to Electric Boat Company (Groton) and the Portsmouth Naval Shipyard (Kittery, Me.) concerned the layout of equipment rather than the illumination of specific instruments. Full scale models were being prepared at both places and the main concern was how to locate the equipment for operational purposes. The illumination problem was considered in connection with the layout. It was agreed that a blackout curtain could be readily incorporated in order to isolate the Periscope Area if this were required.

7. General Comment and Recommendation

Considerable equipment for the SS 563/564 is still to be constructed by various companies. In a surprising number of instances, the engineers fail to have adequate information concerning good lighting requirements and how to attain them.

It would appear to be most urgent and useful, therefore, to make available to the equipment designers some guiding principles and practical techniques to aid them in preparing satisfactory equipment. Attention may be directed to the fact that a provisional specification has been provided in Table III of this paper. On the assumption that the values in Table III are acceptable, this information should be issued to instrument designers with instructions to meet the specified conditions. Where equipment has already been completed, it should be inspected by competent personnel to make certain that the best features of lighting design have been incorporated. Test goggles (to detect stray ultra-violet light and to assure a proper red light to protect dark adaptation) could be made available at very slight cost. It may also be suggested that a brightness meter, such as the Macbeth Illuminometer or the Luckiesh-Taylor Brightness Meter, be made available by the technical officer on instrument contracts.

APPENDIX

There will be presented in this Appendix a brief exposition of the facts which are the basis for the provisional specifications for illumination given in Table III, page 14 of this report. Table VI in this Appendix is a duplicate of Table III and identifies the research reports from which the various values have been derived. These studies are just a few in the large literature on the functioning of the visual mechanism.

An attempt has been made in these specifications to satisfy certain conditions which exist aboard submarines. One condition, for example, is that electric current should be conserved. This leads to the conclusion that, for bright conditions, one should specify the lowest level of illumination at which an adequate performance may be achieved. Another condition is that the dark adaptation of certain personnel should be protected. This requires some type of red illumination.[7] Finally, the specifications are considered "provisional" in the sense that they should be evaluated by competent authorities before being adopted as official.

The specifications are grouped in three sections: The first section establishes certain measures which would insure good lighting practice with regard to such factors as contrast, glare, and evenness of illumination. The second and third sections describe the brightness levels that should be achieved for bright and dark adapted conditions.

No attempt will be made to summarize all of the pertinent literature. Good summaries of the known facts about instrument illumination may be found

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[7] The reduction of lamp voltage from 115 to 35 volts, as a means of inducing dark adaptation and conserving current aboard submarines, has been found to result in dark adaptation definitely inferior to that which develops in red light (17).

Table VI. List of References for the Specifications Shown in Table III (Page 14)

	References
A. General Lighting Requirements for Both Bright and Dark Conditions	
1. Brightness ratios:	
Various dial markings within a given instrument	Fordyce (7); Bromer (1)
Instrument to background	Luckiesh & Moss (13); Lythgoe (15)
Various instruments within a given panel	Fordyce (7); Bromer (1)
Cathode ray tube to background	Williams (27); Hanes & Williams (9)
2. Instrument characteristics:	
Brightness ratio of markings to background	Luckiesh (11)
Reflectance of instrument markings (with external illumination)	Luckiesh (11)
Central viewing angle to read instrument dials*	
B. Lighting Requirements for Bright Conditions	
1. Illumination on working areas	Crouch (6)
2. Brightness of markings on instruments	Crouch (6); Luckiesh (11)
3. Brightness of indicator lights*	
4. Brightness of cathode ray tubes	Williams (27); Hanes & Williams (9)
C. Red Lighting Requirements for Dark Adapted Conditions	
1. Illumination on working areas	Lee & Finch (10); Luckiesh & Taylor (14)
2. Brightness of markings on instruments	Bromer (1); Verplanck (25) Spragg & Rock (22)
3. Brightness of indicator lights*	
4. Brightness of cathode ray tubes	Williams (27); Hanes & Williams (9)

*Survey of the literature did not reveal any studies directly relevant to these items.

in Fordyce (7) and in McFarland's book (16). More general discussions with background information appear in books by Moon (19) and Luckiesh (11), and there is an excellent summary in an article by Crouch (6).

1. General Lighting Requirements

One of the primary requirements of any lighting system, whether for use under bright or dark adapted conditions, is to provide even illumination, free from glare and from marked variations in brightness. This may be controlled by specifying certain brightness ratios. A number of studies have established the general principle that the brightness of the background should be equal to or slightly less than the brightness of the task; it should never be higher. Cobb and Moss (5), for example, showed that the greatest visual sensitivity exists when the brightness of the task is the same as that of the background, as measured by the minimum perceptible brightness difference. Luckiesh and Moss (13) found that the blink-rate was least on a reading task when the task and its background had the same brightness. Also, it was found that a reading task presented alternately on light and dark backgrounds results in increased response time (12). Similarly, Lythgoe (15) showed that visual acuity increases progressively as the background brightness is increased up to 1/10 that of the test object. Thereupon, as the background brightness is increased further, visual acuity drops slightly and the decrease becomes accentuated when the background becomes brighter than the task. A standard on brightness contrast, prepared by the Illuminating Engineering Society (31), may be consulted for the purpose of comparison.

The brightness of all dial markings (pointers, scales, and numbers) on any instrument should be the same. This statement also applies to the various instruments on the same panel. Brightness ratios between instrument markings, or between one instrument and another on a given panel, should not exceed 3:1 (7). On the other hand, instruments may be slightly brighter than their background in order to increase their value as an attention-getting device (3). Thus, a brightness ratio of 10:1 between the instrument and the panel is permissable (7). In the case of cathode ray tubes, the Systems Research group (9,27) reports that background brightness should be equal to or below screen brightness.

Proper instrument illumination requires that the instruments possess certain characteristics which will be described briefly:

a. Contrast, or brightness difference, between an object and its background

Contrast is defined in the formula:

$$C = \frac{B_1 - B_2}{B_1}$$

where B_1 is the brightness of the background and B_2 is the brightness of the object. Contrast may be expressed either as a percentage or a ratio. Of course, the best visibility (visual acuity) occurs with high contrast (11), as in the case of white numbers on a black background.

b. Design of pointers, numerals, and scale divisions on a dial

Sharp and clear numbers are desirable, but other factors must also be controlled in order to achieve maximum legibility. The reader is directed to three references which evaluate the results of many experiments and derive general principles which should be followed to insure good dial design (4,8,21).

c. The central viewing angle

The specification given in Table III expresses the importance of being able to read the numbers on a dial even when they are viewed from the side. Any dial that could be read from all positions within a 160 degree arc would, undoubtedly, appear distorted from some positions. Nevertheless, an attempt should be made to insure that a dial be readable from a wide angle. This particular requirement has not been based upon any specific research.

2. Lighting for Bright Conditions

Considerable evidence exists to demonstrate that visual performance, as measured by such indices as visual acuity, contrast sensitivity, speed of vision, and rate of blinking, improves as brightness increases (6,11). The data show that visual performance continues to improve as brightness increases up to the highest levels tested (100 to 10,000 footlamberts). Above 10 to 100 footlamberts, the improvement is slight compared with the improvement below that level.[8]

The present study recommends an illumination of 10 footcandles on working areas. Assuming that the reflectance of most surfaces will be within the range of 20 to 80 percent, this will result in a brightness range of approximately 2 to 8 millilamberts. The effect of this level of illumination may be judged by the fact that 10 footcandles on 8 point Bodoni type (slightly larger than newspaper type) at a reading distance of 14 inches provides 3.7 times the minimum visibility for normal 20/20 vision (11). The 10 footcandles intensity is not necessarily the ideal illumination. It is, however, a conservative value which provides a reasonable safety factor. Only moderately high values of illumination are

[8]This is shown very clearly by plotting the increases in visual acuity for each 100 percent increase in brightness as in Figure 1 of Dean Farnsworth's paper (6a).

specified because of the desirability of conserving electric power aboard submarines. The general illumination of 10 footcandles on passageways and work benches can readily be supplemented with special lights where a task involves the discrimination of fine details (50 to 100 footcandles are recommended).

Instrument markings should be illuminated so that their brightness is 10 millilamberts. Most instruments contain their own illumination system and any system which satisfies the specifications should be acceptable. It may be noted that an instrument marking brightness of 10 millilamberts and a general illumination of 10 footcandles provide brightness ratios of the order of 2:1 to 3:1, providing the average room reflectance is in the 30 to 50 percent range. The brightness level of 10 millilamberts may best be evaluated by reference to such studies as those of Crouch (6), Lythgoe (15), and Luckiesh (11). It may suffice to say, at present, that visual performance at 10 millilamberts is far above threshold on all commonly used tests.

The specification of 40 millilamberts as the minimum brightness of indicator lights is double the maximum specified brightness of instrument markings. This minimum value is stipulated primarily because such lights often serve as warning signals and they should be noticeably brighter than the instrument markings; a value of 50 millilamberts is desirable.

The optimum brightness of cathode ray tubes is specified as 0.1 millilambert. According to the extensive studies of the Systems Research group (9,27), this is the optimum brightness of the tube for almost all conditions of room illumination. Higher screen brightness would result in greater sensitivity for the detail on radar scopes. However, with brightness levels of 1 to 10 millilamberts, the responsiveness of the phosphor to incremental excitation is reduced. Thus, until better phosphors than the P7 and P10 become available, the practical limit of screen brightness is 0.1 millilambert.

Ambient illumination in the radar area should be kept at or slightly below the level of screen brightness (28). Thus, the radar area should be partly shielded since the surrounding areas are likely to be somewhat brighter. Adaptation to darkness may be damaging to scope visibility because of the short period of light adaptation required to come up to 0.1 millilambert. The ambient illumination may exceed the screen brightness by 10 times or slightly more, provided the scope itself is hooded or shielded.

3. Lighting for Dark Adapted Conditions

The general principle which must be followed to maintain the dark adaptation of personnel is that there should be the least amount of illumination compatible with adequate performance. The various methods of accomplishing the dim illumination of instruments are well described in the previously cited work by Fordyce (7).

Red light must be used since it interferes less with dark adaptation than does light of any other color. Following exposure to light, the time required to recover visual sensitivity increases as the wave length decreases in the following order, starting with the shortest recovery time: red, orange, yellow, green, blue-green, and violet. The superiority of red (in causing less interference with dark adaptation) becomes more pronounced when the effect of the various colors is compared at higher brightnesses. These facts have been demonstrated in many studies, most recently by Peskin (20).

It is important to specify precisely the spectral characteristics of the "red" light. If a red filter be used, it is suggested that the total transmission be not more than 1 percent below 600 mu and not more than 0.1 percent below 590 mu. A detailed specification for "red" may be found in AN-L-28, Lamps, red coated miniature incandescent, 29 July 1944. Filters which appear to be satisfactory are Wratten Nos. 29 and 88, Corning Nos. 243, 2403, 2404, and 2408, and the Polaroid Navy dark adaptation goggle. Where ultra-violet excitation is employed, the phosphor should fluoresce red with the same spectral characteristics as the red filters; in addition, there must be no stray ultra-violet light.

It is interesting to note that the use of red light for purposes of dark adaptation does not result in a loss of visual efficiency. Spragg and Rock (23) show that dial reading performance under red light is as effective as under yellow, green, and orange lights. Luckiesh and Taylor (14) report that visual acuity and readability are slightly better under red light than under either white incandescent or variously colored fluorescent lights.

Instruments should be illuminated to an intensity just sufficient to insure a minimum of reading errors. The brightness level required to accomplish this purpose has been considered in several studies, as summarized in Table VII.

These studies show that a variety of visual tasks can be performed at brightness levels as low as .01 to .04 millilambert. Bromer (1) demonstrated that instruments in a Link Trainer can be read well enough for purposes of navigation when the brightness level is from .01 to .02 millilambert. Verplanck (25) reports that the Torpedo Data Computer in a conning tower can be read easily at a brightness level of .06 millilambert. The

Table VII. Brightness Required for Various Reading Tasks Performed Under Dark Adapted Conditions

Study	Task	Criterion	Required Brightness (ml)*	Comments
Lee and Finch (10)	Reading numbers (visual angle 14-18')	Legibility	.01 - .03	Recommended for submarines.
Verplanck (25)	Reading TDC dials	Speed and accuracy	.06	Dials read easily; lower brightness levels not studied.
Spragg and Rock (22)	Dial reading	Speed and accuracy	.02	No improvement in performance at higher levels.
Brown (2)	Reading letters trans-illuminated (visual angle 5-15')	Accuracy	.04	No improvement with increased brightness for largest and smallest letter sizes; slight improvement above .04 ml for intermediate letters.
Luckiesh and Taylor (14)	Reading letters (visual angle 8-19')	Threshold readability	.00014- 014	Multiply brightness to improve ease of seeing; suggest 3 times.
Bromer (1)	Instrument on a Link Trainer panel	Ease of reading	.01 - .02	Faster detection of airplane "targets" with red than with u-v system.

*Red light used by all investigators except Spragg and Rock (22), who used white.

job of instrument reading is simulated in various ways in the other studies which, taken together, indicate that letters, numbers, and pointers can be read at brightness levels of .01 to .04 millilambert. Spragg and Rock (22) report that dial reading performance does not improve significantly as brightness increases beyond .02 millilambert. Luckiesh and Taylor (14) show that letters can be read at much lower intensities (.00014 millilambert) but, as might be expected, errors occur frequently. In conclusion, then, the specification recommends that instrument dials and markings be illuminated to a brightness of .04 millilambert; a range of .02 to .06 millilambert is given as acceptable.

Lee and Finch (10) suggest that for dark adapted conditions, the brightness of working areas may reach .003 millilambert provided that the illuminated areas are not large; for the same purpose, Luckiesh and Taylor (14) suggest a brightness range of .002 to .01 millilambert. This may be used to derive a value for illumination. The reflectance of common objects may be judged to vary from 20 to 80 percent. White paint and white paper have reflectances of 80 percent; unfinished walnut and mahogany woods have reflectances of about 20 percent (11). An illumination of .01 footcandle would produce a brightness range of .002 to .008 millilambert on these surfaces. The specification recommends .02 footcandle with .01 to .03 footcandle as acceptable. Under these conditions, the brightness of surfaces might range up to .024 millilambert which is close to the brightness of the instrument markings.

It is recommended that indicator lights have a brightness of .08 millilambert. In doing so, the rule suggested previously for bright conditions is followed again. That is, indicator lights should be noticeably brighter than instrument markings. The suggested brightness range for indicator lights extends from a value equal to that of instrument markings (.04 millilambert) to a level 2.5 times that value. Thus, an attempt is made to keep indicator lights brighter than any instrument markings but not by a very large amount.

As was pointed out earlier, present type cathode ray tubes should be operated at a screen brightness of .1 millilambert for maximum efficiency of detection (9,27). This level must be maintained in order to achieve the results for which the various radar and sonar sets were designed. These tubes, especially if the green, blue, and yellow phosphors remain in use, must be shielded in order to protect the dark adaptation of other personnel in the vicinity. Furthermore, personnel who use the cathode ray tubes should not be expected to perform duties which require dark adapted sensitivity unless time is allowed for adaptation.

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