NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.

REPORT NUMBER 970

COLD WEATHER GOGGLES:
I. Optical Evaluation

by

S. M. Luria, D. F. Neri, J. A. S. Kinney
and
H. M. Paulson

Naval Medical Research and Development Command
Research Work Unit M0095-PN.001-1040

Released by:

W. C. MILROY, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

19 January 1982

Approved for public release; distribution unlimited

COLD WEATHER GOGGLES: I. OPTICAL EVALUATION

by

S. M. Luria, Ph.D.
David F. Neri, B.A.
Jo Ann S. Kinney, Ph.D.
Helen M. Paulson, B.A.

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

REPORT NUMBER 970

NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Research Work Unit M0095-PN.001-1040

Approved and Released by

W. C. Milroy, CAPT, MC, USN
Commanding Officer
NAVSUBMEDRSCHLAB

Approved for public release; distribution unlimited

Summary Page

PROBLEM

To determine the optimal specifications for goggles to protect the eyes in the cold.

FINDINGS

Thresholds for damage to the eye from ultraviolet, infrared, and the various parts of the visible spectrum have been assembled from the experimental literature and compared with the measurements of the magnitudes of radiant energy for these parts of the spectrum occurring in nature. This permits the calculation of the degree of filtering necessary to protect the eyes. Additional studies of the extent of the field of view, resistance to fogging and abrasion, optical properties, and comfort have provided additional criteria for setting specifications.

APPLICATION

The results are pertinent for the manufacture of improved goggles to protect the eyes of troops operating in the cold.

Administrative Information

This investigation was undertaken under Naval Medical Research and Development Command Work Unit M0095-PN.001-1040 - "Protective devices for the eye in cold weather." This report was submitted for review on 16 December 1981 and approved for publication on 19 January 1982. It was designated as NavSubMedRschLab Report No. 970.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

ABSTRACT

To compare the utility of a dozen protective goggles for the cold, their transmittance of harmful radiation, optical quality, resistance to fogging, and comfort were measured. The transmittances were discussed in terms of thresholds for damage to the eye from various bands of light radiation. The optical characteristics were evaluated against military specifications for aviators' visors. All the goggles except one screened out enough UV at sea level, and all but two screened out enough of the visible and infrared radiation. There were wide variations in optical quality, resistance to fogging, and comfort. A set of specifications was drawn up to meet the various requirements, but it was concluded that one set of goggles was unlikely to be satisfactory for the wide range of conditions which would be encountered.

CONTENTS

INTRODUCTION

The eyes need protection in cold weather. Visual problems under these conditions are more common and more critical than is generally realized. In a recent After-Action Report of Deployment to the Marine Corps Mountain Warfare Training Center,[1] statistics were presented of injuries sustained during the cold weather training. Thirteen men in the participating battalion suffered medical problems during the exercise which were severe enough to require evacuation by helicopter. They included one case of disease, two burn cases, three cases of exhaustion, and seven cases of snowblindness. Visual problems thus accounted for a large share of the emergency evacuations.

The effects on the eye of strenuous activity in the cold were studied by Kolstad and Opsahl.[2] They examined cross-country skiers who had competed in a 90-minute race in Norway. The temperature was 3°F with no wind and no snow falling. They reported that 26 of the 29 skiers, examined within 30 minutes of the completion of the race, were found to have damage to their eyes. The visual acuity of three of the men was reduced to 20/30 in one or both eyes. Thirteen of the men had experienced blurred vision and pain previously, and five had at some time been forced to drop out of a race for that reason. In such races, the use of goggles is impractical, since they fog and become encrusted with ice.

The eyes need protection not only against the cold, but against other factors as well. The first is, quite simply, the amount of light.[3] New snow reflects about 90% of the sunlight. Since the density of aerosol particles decreases with altitude and is virtually negligible at 5000 ft,[4] the effective illumination increases. This intense illumination may result first of all in severe discomfort due to glare. An individual's ability to tolerate glare decreases markedly with age; a 30-year-old becomes uncomfortable with only about 65% of the glare that a 20-year-old can tolerate, and, by the age of 40, this is reduced to about 40%.[5] Yet there is very little experimental data addressing the question of what is the brightest light level which remains comfortable.

In addition to severe discomfort, there is now considerable evidence that electromagnetic radiation can damage various parts of the eye. Damage to the retina can result from unexpectedly low levels of visible light, particularly the shorter wavelengths.[6]

Protection is needed also against ultraviolet (UV) rays,[7] the intensity of which doubles with approximately every 3500 feet of altitude. Excessive exposure to UV leads to swelling of the corneal epithelium, resulting in the malady called keratoconjunctivitis, popularly known as snowblindness. Ultraviolet radiation also enhances cataract development in humans.[8]

Finally, protection against infrared radiation (IR) should be considered. Long-term exposure to IR has long been reported to cause cataracts.[9] LeGrand[10] has calculated the amount of absorption of IR by the tissues of the eyes and concluded that this is, if not the essential factor, at least an important cause of injury to the lens. Although the levels of IR encountered in nature are probably too low to produce an injury, Pitts[11] has suggested that these levels of IR may, by increasing the temperature of the optical tissues, lower the thresholds for damage by UV. That is, IR acting in conjunction with UV, may increase the chance of injury to the eye by the UV. The amount of IR also increases with both altitude and cold weather, since how much reaches the earth's surface depends to a considerable extent on the amount of water vapor in the air.[12]

For these reasons, some sort of eyeglasses or goggles is often indispensable. They have, however, two disadvantages. First, it is possible that certain military tasks, such as aiming rifles or looking through optical instruments, may be seriously degraded. In addition, they tend to fog, and, in cold weather, to become encrusted with ice. Clearly then, the utility of such goggles depends on the extent to which they satisfactorily answer three questions. First, what are the optical properties of the various goggles? What is the total transmittance of the various components of radiation--visible light, UV, and IR? What is their optical quality, freedom from distortion, and the like? Obviously, different sunglasses are quite different in these respects. Second, how resistant are the goggles to fogging? Third, how are such things as acuity, target detection, vision through field glasses, and riflery affected by the goggles? The optimal characteristics of goggles should be designed with these criteria in mind.

In order to specify the optimal characteristics, it is necessary to determine first the range of variability exhibited by the sizeable number of commercial goggles and sunglasses already available for winter sportsmen. This range gives an indication of how well such goggles are typically manufactured. It can then be determined to what extent the variations in the goggle characteristics protect the eyes and affect the performance of the men wearing them.

This report deals with the physical characteristics of the goggles. The effect on performance will be presented in a subsequent report.

THE GOGGLES

Thirteen goggles were evaluated. All can be purchased commercially except for the military issue. They vary in a number of characteristics.

(1) All have plastic filters except one which has glass filters.

(2) Six of the goggles, including the glass, have a single layer of filter; seven have two layers of filter with an air space between them to reduce the possibility of fogging.

(3) All but three are similar "wrap-around" goggles with curved faces. The military issue and the glass goggles are more like spectacles. One of the goggles is a standard pair of machine-shop safety goggles with a filter inserted; it has a flat face.

(4) The goggle filters come in a variety of colors: neutral, yellowish-neutral, yellow, yellow-green, rose, and purple.

(5) Finally, two of the goggles have special characteristics. One has a polarizing filter; the other

has the "Photochromic" filter, developed by Corning, which changes density and color as the ambient illumination changes.

The goggles are identified in terms of their unique characteristics. Table I lists the characteristics and their abbreviations.

Table I. Abbreviations of goggle characteristics

F	Fog resistant
GL	Glass filter
GY	Green-yellow
M	Military issue
N	Neutral
P	Polarizing filter
PC	Photochromic filter
R	Rose
S	Safety goggles
Y	Yellow
YG	Yellow-green
YN	Yellowish-neutral
1	Single filter layer
2	Double filter layer

THE TESTS

Transmittance - The spectral transmittance of each goggle was measured from the UV (beginning at 200 nm) through the visible range and into the IR up to 1600 nm using a Cary Spectrophotometer, Model 14. The overall percent transmittances for visible light were calculated from these curves.

Spherical Power - Spherical power is the degree to which the focus of the light is changed by the filter. This was measured with a Bausch & Lomb vertometer which has .01 diopter divisions.

Prismatic Deviation - This indicates the degree to which the light rays are bent to one side by the filter. Horizontal and vertical prismatic deviations were measured with the goggles positioned before a transit. Each pair of goggles was first worn by one subject, and the area of the filter before each pupil was marked. The transit was then aligned with these points for the measurements. A target calibrated to indicate deviations from .06 to 1.0 prism diopters was set at a distance of 35 feet and viewed through the goggles with the transit.

Distortion in Area of Critical Vision - This was measured with the use of an Optical Tester manufactured by the Ann Arbor Optical Co. designed to test the quality of camera lenses. The tester presents a grating which is viewed through the optical medium to be tested. The resulting apparent distortion of the grating is matched to a series of comparison gratings which illustrate the various degrees of distortion. This series of comparisons is shown in Fig. 1. Military visors are rejected if their rating is greater than 5.

Field of View - A subject's field of view was measured with a Goldmann perimeter when he was wearing each pair of goggles.

Abrasion Resistance - This was measured by rubbing a standardized abrasive weight across the goggle a specified number of times and judging the relative amount of scarring to the face of the goggle.

Resistance to Fogging - This was tested by first chilling the goggles at a temperature of $0^{\circ}F$ and then having subjects put them on in ambient temperatures of 40, 50, 60, and $70^{\circ}F$. The goggles typically fogged immedi-

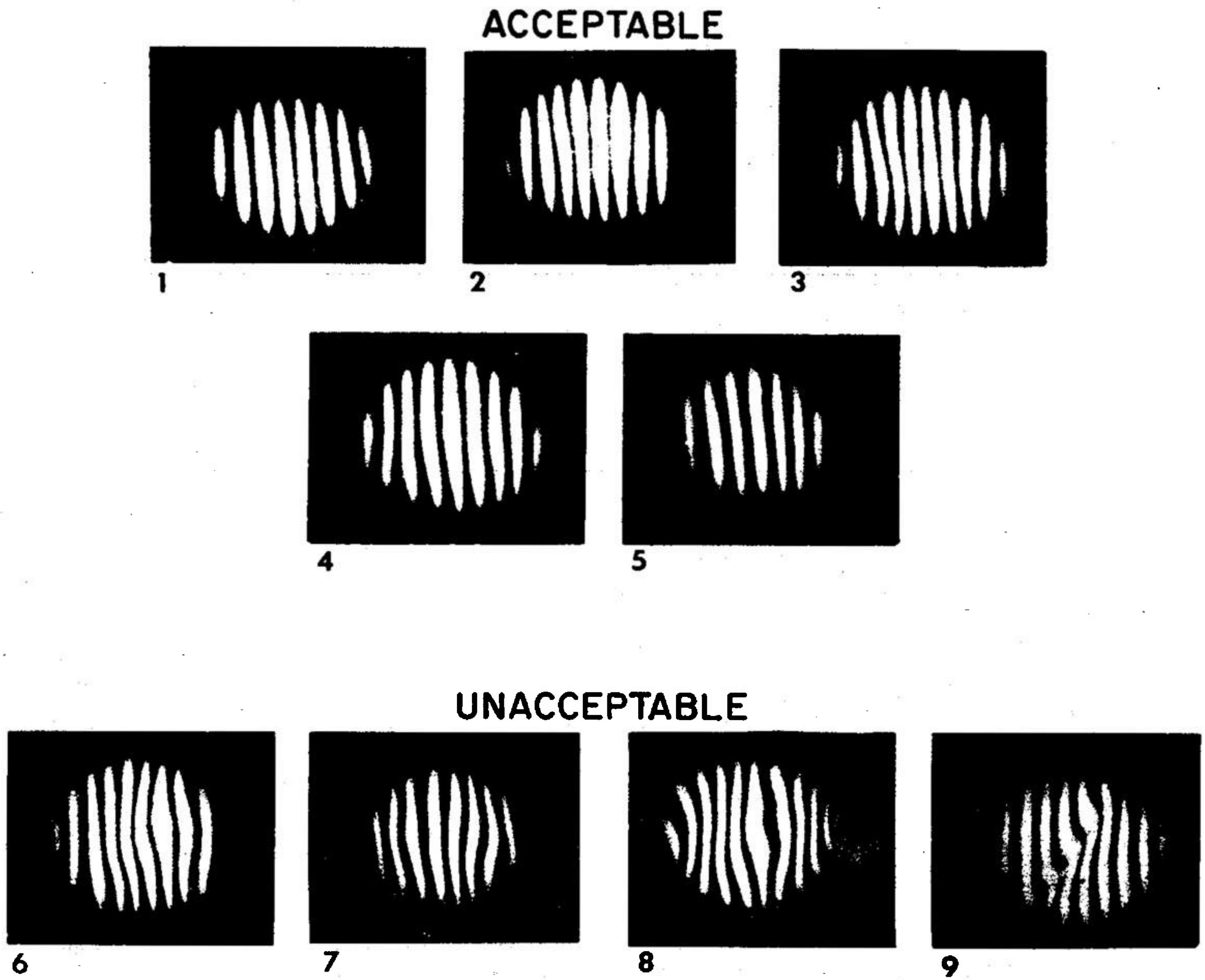

Figure 1. Critical vision area distortion standards. A standard grating is viewed through the optical medium to be evaluated, and its appearance is compared to these photographs. Numbers 6 through 9 are unacceptable.

ately in the warmer ambient temperatures and then gradually cleared. The time required for the fogging to dissipate was measured by timing how long it took for the subjects to be able to perceive each of three targets. The targets were gray circles subtending 2^{o} visual angle on a white background, with contrasts of .05, .08, and .15 according to the formula

$$C = \frac{L_B - L_T}{L_B}$$

where L_T is luminance of the target and L_B is that of the background.

Comfort - Subjects rated the goggles for comfort on a 10-point scale. The ratings were made by 10 subjects who do not wear glasses and 10 subjects who do wear glasses. The latter made their ratings while attempting to wear the goggles over their glasses.

RESULTS

Transmittance - The transmittances of the goggles are shown in Figs. 2 and 3 and Table II. There are clearly enormous differences between the various goggles in the amount of visible light which they transmit. This is to be expected, since different goggles have been designed for different applications. The Y-GL and the N-P transmit less than 20% of the visible spectrum, whereas the Y-S transmits about 80%. There are also great differences in the amount of UV and IR transmitted. The PC transmits 93% of the IR, whereas the Y-GL transmits only about 41%. As for the UV, the YG goggles transmit very little, whereas the R-2 transmits about 35% of the UV above 350 nm.

The Photochromic goggle (PC) is unique in this group; it changes color and transmittance with changes in the ambient illumination (Fig.3). In dim light, it is a distinctly yellow filter which transmits about 70% of the visible light; in bright light it turns blue and transmits only about 25%. Both its UV and IR transmittances remain unchanged, however.

Spherical power - The spherical powers of the goggles (Table II) range from virtually no power for the Y-S to -0.20 diopters for the YG-2. Most, however, show very little power.

Prismatic deviation - Table III gives both the horizontal and vertical prismatic deviation through the area of the filters directly in front of the pupils of one observer. The yellow safety goggles showed none at all. The YGs showed a relatively large amount of deviation.

The magnitude of prismatic deviation is clearly a function of the degree of curvature of the filter. The Y-S goggle has a flat filter and exhibits no prismatic deviation; the YG filters have a very curved filter and the most prismatic deviation. The magnitude of curvature, as measured by a Geneva Lens Measure, is given in Table II. These values are approximate, because the plastic filters are easily deformed during the measurements.

Critical vision area distortion- The test of visual distortion involves judgments of the appearance of a grid in the Optical Tester. Table II gives the ratings made by the authors. Five of the goggles, including the military issue, would be rejected if they were aviators' visors.

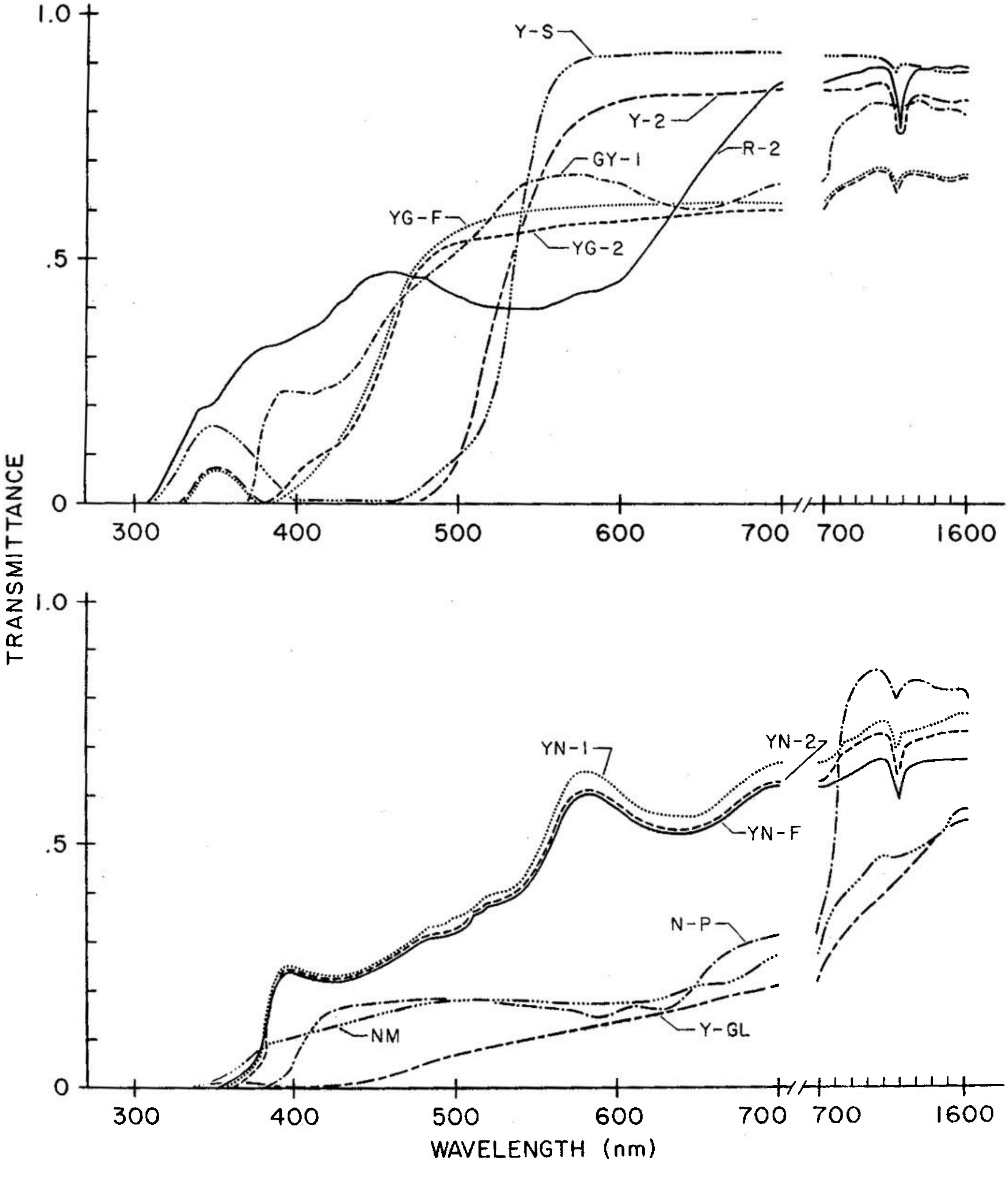

Figure 2. Transmittances of the various goggles

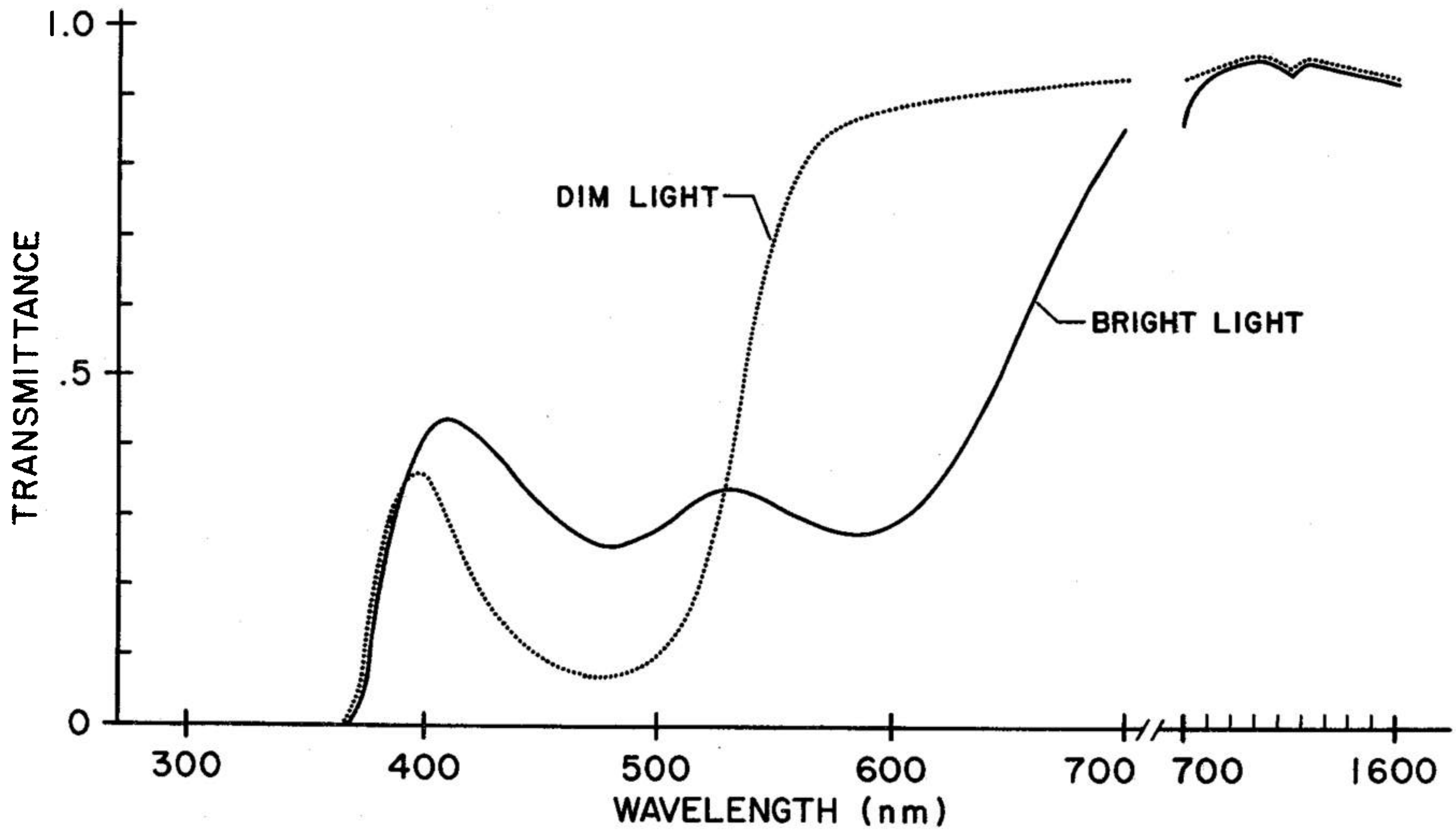

Figure 3. Transmittances of the Photochromic goggle under high and low illumination

Table II. Summary of optical measurements

Goggle	Total transmittance	UV	IR	Spherical power(D)	Curve	Viewing Distortion	Comfort*		Size (cm)	
							Without glasses	With glasses	Width	Max. Height
Y-2	.66	.03	.85	-.06	3.4	3	7.4	4.5	12.25	4.60
Y-GL	.12	.01	.41	-.05	6.1	1	4.7	1.2	12.75	4.75
Y-S	.80	.07	.90	-.02	0.9	6	5.1	6.7	14.25	6.50
YN-1	.55	.07	.73	-.01	4.9	1	7.6	1.7	11.75	5.50
YN-2	.42	.07	.71	-.05	4.9	6	6.6	1.6	11.50	5.50
YN-F	.42	.07	.68	-.08	7.2	4	7.3	2.4	10.75	5.50
YG-2	.51	.005	.66	-.20	6.6	4	6.8	1.2	11.00	5.50
YG-F	.55	.005	.66	-.12	6.4	1	6.8	1.2	11.00	5.50
GY-1	.67	.06	.79	-.07	5.3	1	7.9	4.0	12.75	4.75
R-2	.40	.21	.88	-.10	5.8	8	7.2	4.8	12.25	4.50
N-P	.17	.005	.75	-.14	6.0	9	6.8	1.2	11.50	6.00
N-M	.21	.05	.46	-.10	3.1	8	4.0	3.2	14.00	4.50
PC High Ill.	.25	.08	.93	-	-	3	-	-	16.50	4.75
Lo Illum.	.72	.08	.94	-.04	4.7	2.3	7.0	5.0	-	-

* 1 = low comfort; 10 = high comfort

Table III. Prismatic deviations in diopters

Goggle	Sum of Horizontal deviations	Difference between left and right horizontal deviations	Difference between left and right vertical deviations
Y-2	.19	.19	.00
Y-GL	.28	.02	.05
Y-S	.00	.00	.00
YN-1	.23	.03	.00
YN-2	.25	.09	.06
YN-F	.19	.19	.00
YG-2	.44	.12	.10
YG-F	.60	.16	.00
GY-1	.14	.02	.00
R-2	.46	.04	.07
N-P	.52	.08	.00
N-M	.12	.00	.00
PC (low illum.)	.12	.12	.00

Field of view - Figure 4 gives the limits of the right half of the visual field through each goggle. The YN-1 and the Y-2 are relatively small goggles. The Y-S are standard machine-shop safety goggles with an added filter. They have a complicating factor, since the sides of the goggles are also transparent; although there is considerable distortion, it is possible to see a considerable amount through the side panels. The field of view through the front surface of the safety goggle is relatively restricted, because the front surface is far from the eyes.

Abrasion resistance - Except for the glass Y-GL, none of the goggles would have passed the abrasion test for aviators' visors. The Y-S and the GY-1, however, were borderline.

Fogging - Figure 5 shows the times required for each pair of goggles to clear sufficiently to allow detection of the highest contrast target when the ambient temperature was 70^{o}F. The values are the means for three trials of each goggle for two of the authors. The Y-2 and the GY-1 scarcely fogged at all. It may be noted that the Y-2 is sold with a defogging cloth which is used to coat the goggle before use.

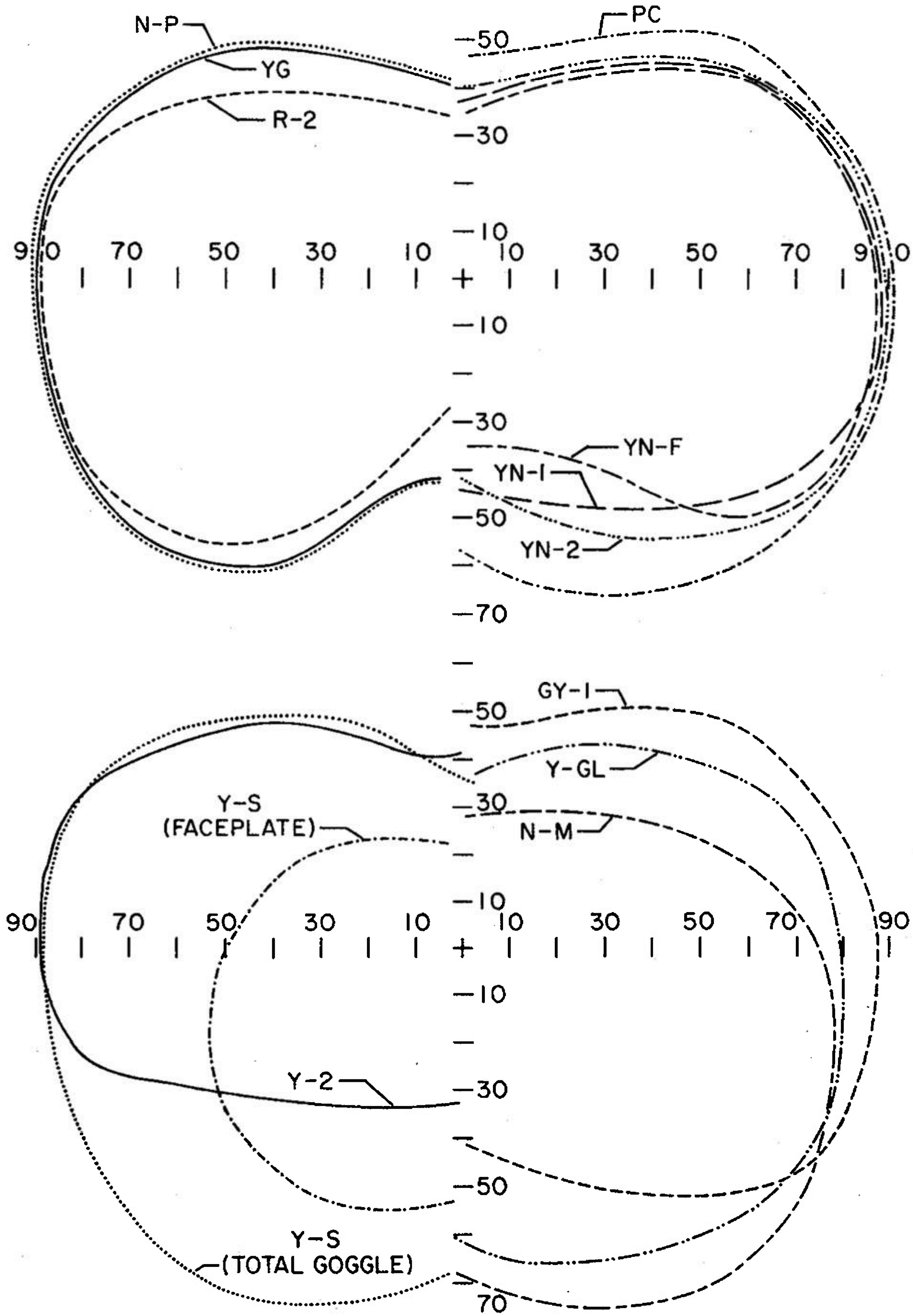

Figure 4. Half-field of view through each goggle

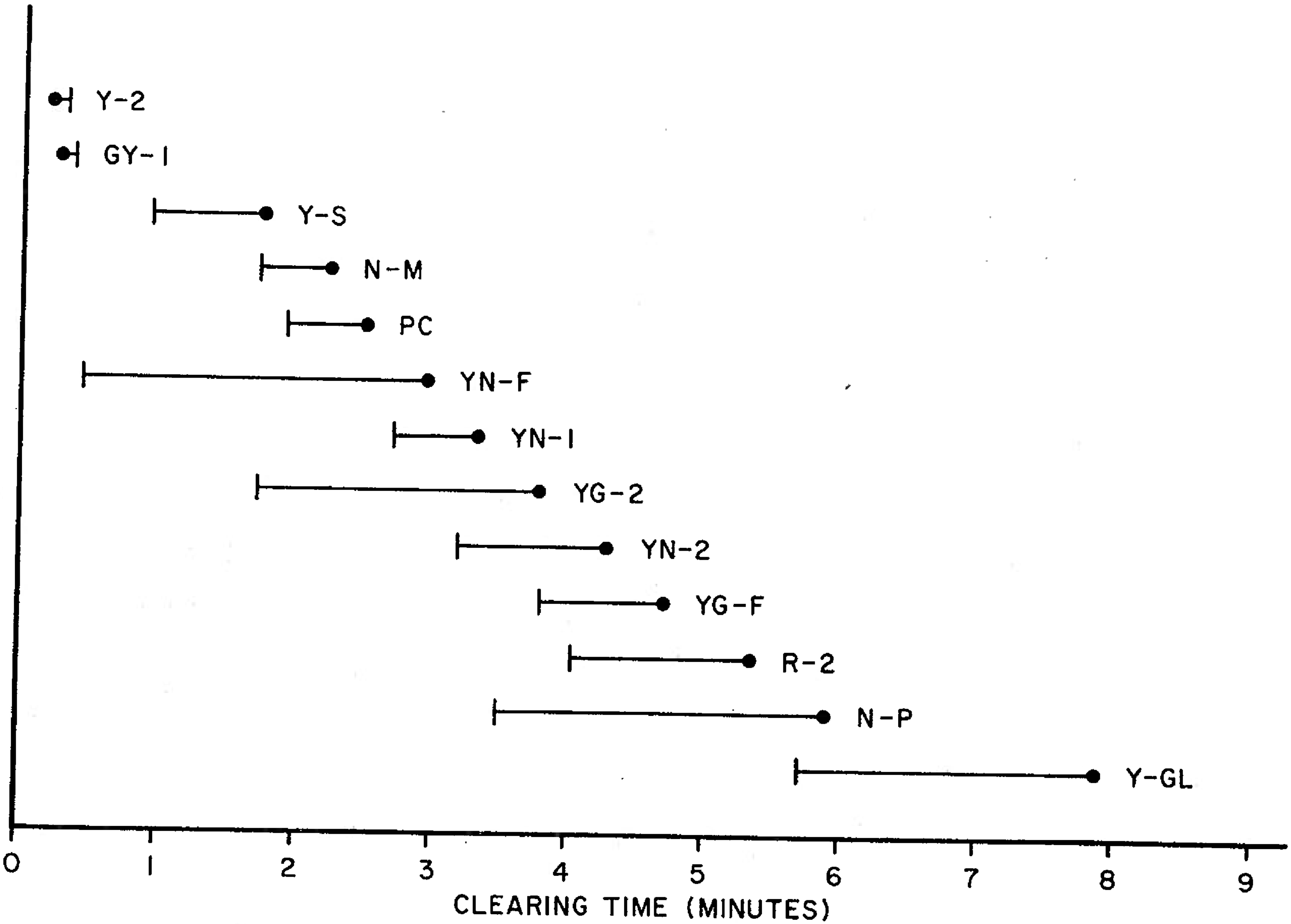

Figure 5. The mean times required for each goggle to clear sufficiently for the wearer to detect the highest contrast test-target. The dot indicates the mean; the bar indicates one standard deviation.

These tests did not determine how long the cloth application will last or how long the cloth itself will last. But initially and for short periods of time, at least, it is quite effective.

The same test was carried out in ambient temperatures of 40, 50 and 60°F in a cold chamber. Six observers wore the goggles in this experiment. Each pair of goggles was worn once at 40° and 60° and three times at 50°. Table IV lists the highest target-contrast which has not become visible through the goggles after a period of 10 minutes. The inability to see the high target-contrast of .15 is an indication of severe fogging. The table also gives the percentage of targets which were not seen (combined for all temperatures). The greater the number of targets not seen is, of course, another indication of how badly the goggles fogged. The GY-1 again proved to be a superior goggle in this respect. The Y-GL and the N-P goggles again proved to be the least resistant to fogging. The Y-2 did not score well in this series of tests, presumably because the anti-fogging cloth was not used. The correlation between the results of the two experiments, excluding the Y-2 was .48.

Table IV. Maximum target-contrast not detected at various ambient temperatures, and percent of targets not detected within 10 minutes for all temperatures

Goggle	40°F	50°F	60°F	Percent
Y-2	-	Med	Hi	17
Y-GL	Hi	Hi	Hi	30
Y-S	-	Med	Lo	10
YN-1	-	Med	Lo	10
YN-2	-	Lo	Lo	10
YN-F	-	Lo	Lo	7
YG-2	-	Lo	Med	10
GY-1	-	-	-	0
R-2	-	Lo	-	3
N-P	-	Hi	Med	17
N-M	-	Lo	Hi	13
PC	-	Lo	-	3

Lo = .05

Med = .08

Hi = .15

Comfort - Ten staff members who do not wear eyeglasses and ten who wear glasses wore each pair of goggles for a short time and rated them on a 10-point scale for comfort. Table II gives the mean ratings for both sets of observers. For those who wear glasses, it is clear that goggles are rated as being comfortable if they are simply large enough to fit over eyeglasses. The criteria for comfort among the observers who do not wear glasses are more difficult to define except for the N-M and Y-GL which are spectacles rather than goggles. There were far fewer very low ratings and more high ratings.

SELECTION OF OPTIMAL CHARACTERISTICS

This investigation set out first to evaluate the various commercially available goggles as protective devices. The ultimate goal, however, is to specify the optimal characteristics of protective goggles which are issued to troops operating in Arctic-like conditions. Two questions are central to this study. The first has to do with the extent to which the various goggles protect the wearer from the hazards of light radiation. The second deals with the degree of optical distortion and the degradation of vision.

Protection from Damage from Electromagnetic Radiation

The first question concerns the ability of the goggle to protect against damage and discomfort to the eyes by the high levels of radiation present on snowfields, particularly at high altitudes. In addition to keratoconjunctivitis, other types of injury can occur, including damage to the retina or lens, as well as sunburn of the skin around the eyes.

To answer this question we must estimate both the amount of incident energy and the quantity of radiation that is likely to be hazardous. This must be done separately for various portions of the spectrum of radiation--the ultraviolet regions, the visible, and the infrared--since both the sensitivity of the eye to damage and the type of damage inflicted vary with the type of radiation.

Standards for Protection of the Eye

The American Conference of Government Industrial Hygienists (ACGIH) has adopted detailed threshold limit values (TLVs) for a wide variety of physical and chemical agents.[13] Among them are standards for light radiation. Different TLVs have been set for the various parts of the spectrum, and different methods of measuring the radiation are employed in different parts of the spectrum. For some portions of the electromagnetic spectrum, the standards are in terms of the total sum of radiation, irrespective of wavelength. In these regions all wavelengths are presumed to have the same potential for producing damage and the TLV is calculated simply as a sum of the amount of energy at each wavelength in irradiance units, for example mW/cm^2. This type of standard is used in the near ultraviolet region, from 320 nm to 400 nm, and in the infrared region between 800 and 1200 nm.

The other type of standard is used for radiations for which the sensitivity of the human eye is known to vary significantly with the wavelength. In these cases the amount of radiation at each wavelength is evaluated according to its potential to produce damage. For example, in the far ultraviolet the most damaging wavelength is 270 nm, and the hazard decreases on either side throughout the region from 200 nm to 320 nm. In calculating the TLV, the amount of energy at each wavelength is integrated with the "hazard-producing function" to obtain the total sum. This sum is also specified in units of irradiance such as mW/cm^2. It should however be differentiated from the previous type of standard, and we will, therefore, refer to it as "hazard-effective irradiance." "Hazard-effective" thresholds have been set for both the far ultraviolet and the visible portions of the spectrum.

The standards set up thus far cannot be considered to be definitive. One authority, Pitts, has stated that we are "a long way from being in a position to set standards."[14,p.1196] Another, Delori, has pointed out that "the standards are appropriate for protection against short exposure (less than 10 sec) because these standards are based on exhaustive experimental and clinical studies.... However, for long exposure, the guidelines for protection against photic damage are based on only a few experimental studies on animals..."[14,p.1200] Despite these uncertainties, the present discussion is based on the current standards unless recent studies appear to be more appropriate.

Ultraviolet Light

Standards - Near UV - The maximum total irradiance permitted for a long exposure to the near ultraviolet (320 to 400 nm) is 1 mW/cm^2.

- Far UV - The permissible exposure to radiation from 295 to 320 nm is 1×10^{-4} mW/cm^2. This radiation is, however, expressed in what we call "hazard effective radiation." That is, the permissible exposure is calculated taking into account differences in the potential hazard from different wavelengths.

Level of natural environment - To estimate the degree of protection needed, we must know how much UV there is. The levels of radiation reaching the surface of the earth are affected by a bewildering variety of variables, such as the season of the year, the time of day, latitude, altitude, and the type and amount of matter suspended in the atmosphere. As Diffey[15] has pointed out, the "determination of the spectral distributions of global UVR is extremely complex if all the .... factors are to be considered."

We can, however, obtain an estimate of the level of radiation from the very accurate determinations of the intensity of solar radiation outside the earth's atmosphere (the so-called solar constant). Thekaekara[16] measured a value of 1.353 kW/m^2 and Willson et al[17] recently put it at 1.368 kW/m^2. Since about two-thirds of this energy reaches the surface of the earth and of this about 5% is in the UV,[18] a general estimate of the amount of UV reaching the earth is thus about 4 mW/cm^2.

Near UV (320-400nm) - Recently Kostkowski et al[19] published new measurements of the UV radiation below 340 nm on the surface of the earth. Assuming that the level of UV is relatively constant from 340 to 400 nm, as Diffey[15] and Bener[20] have indicated, then from these measurements we arrive at a terrestrial solar irradiance of 6.6 mW/cm^2 from 295 to 400 nm for the conditions under which the measurements were made; of this 0.4 mW/cm^2 is the total irradiance from 295 to 320 nm. This gives us an approximate level of 6.2 mW/cm^2 for 320-400 nm to which one would be exposed. The total permissible radiation for the day (1 mW/cm^2) is thus approximately 16% of the radiation which would occur naturally. A filter of 0.8 density is thus required to protect the eyes.

When we compare the transmittances of the various goggles, we see that all but one transmit less than 16% of the UV. Only the R-2 goggle transmits appreciably more--about 25% of the near UV. Thus, all but one are acceptable in this range.

Far UV(295-320 nm)- According to the data of Kostkowski et al[19] the total irradiation from 295 to 320 nm is about 0.4 mW/cm^2. A lower limit of 295 nm is taken because radiation below that wavelength is screened out by the atmosphere.[21,22] Since the damage thresholds for the far UV are given for a total exposure of 8 hours, the level of radiation should be adjusted to take account of changes during the day. (Such a correction was not made for the near UV, because that standard is based on a 16-minute exposure.) Bener[20] presents a graph of UV for various solar altitudes from 0 to 60° with a representative level of atmospheric ozone. If we assume that 0.4 mW/cm^2 is the maximum level of radiation at a solar altitude of 60° and that the level of radiation falls off as depicted by Bener, then the mean level of radiation for the day would be approximately 0.2 mW/cm^2.

This must be converted to hazard effective radiation using the formula

$$E_{eff} = \sum_{295}^{320} E_\lambda \, S_\lambda \, \Delta_\lambda$$

where E_{eff} is the irradiance that is effective in terms of producing damage, E_λ is the spectral irradiance in W/cm^2/nm, S_λ is the relative spectral effectiveness specified by ACHIH, and Δ_λ is the bandwidth in nm. When the naturally occurring irradiance at each wavelength is multiplied by the relative spectral effectiveness, we arrive at a hazard effective irradiance of 2×10^{-3} mW/cm^2. The permissible exposure of 1×10^{-4} is thus only 5% of the naturally occurring effective irradiance. That is, 95% of the radiation must be filtered out to meet current standards.

All the goggles filter out virtually all of the radiation below 320 nm. The R-2 transmits about 3%, but that is within acceptable limits. Thus, in terms of their UV transmittance, both near and far, all but one of the goggles are acceptable.

The Effect of Altitude - The preceding evaluations are based on data which were taken near sea level. A final question arises, however: How great is the increase in UV with increases in altitude, as the atmosphere becomes thinner? Sliney and Freasier[7] state that the amount of UV doubles with every 3500 feet of altitude. On the other hand, Gates[12] has published a graph of changes in radiation with altitude. His computations do not indicate any appreciable increase in the radiation below 290 nm up to an altitude of 5 km, although his curve for extraterrestrial radiation shows a very large increase. Buettner[23] has published measurements of the relative UVB (280-315 nm) radiation for three altitudes in the "tropics." At low solar altitudes, the differences in UV radiation from one altitude to another are quite small. Only at high solar altitudes do the differences become appreciable. In the Arctic, of course, the sun does not reach a high altitude. We do not know if Sliney and Freasier's rule of thumb holds for all latitudes and solar altitudes. It would be very useful to have precise measurements for various altitudes in the Arctic.

If the rule does hold, then, at an altitude of 7000 ft, for example, goggles would be required which transmit only 1.25% (ND=1.9) of the UV. Only the YGs, the Y-GL, and N-P would then be acceptable.

Visible Radiation

Standards - There are great differences in the hazards from different wavelengths of light. The work of such investigators as Ham et al[6] and Sperling[24] has shown that blue light is far more hazardous than other parts of the visible spectrum. To calculate the damage threshold, we again weight the radiance against the relative hazard for each wavelength according to the formula

$$E_{eff} = \sum_{400}^{1400} L_\lambda \, B_\lambda \, \Delta_\lambda$$

where E_{eff} is the irradiance that is effective in terms of producing damage, L_λ is the spectral irradiance in $W/cm^2/nm$, B_λ is the "blue light hazard function"--the relative spectral effectiveness of the wavelengths as specified by ACGIH-- and Δ_λ is the bandwidth in nm.

The current standard, based on this formula, is set at $10 mW/cm^2$ of hazard effective irradiance for an exposure lasting more than three hours. This standard takes into account the differential sensitivity of the retina to damage, but there is evidence that it may be too lax. The most recent investigation of damage to the primate retina by broadband light was conducted by Sykes et al.[25] They exposed monkeys to a uniform field of light from daylight fluorescent lamps at intensities as high as 2300 footcandles at the cornea (9 mW/cm^2) for periods up to 12 hours. These experimental conditions are quite analogous to the practical situation. Men working in a snowfield would be exposed to broadband light; they would spend a great deal of time looking down at the snow as they walked; their eyes would be exposed to rather uniform, wide fields of bright light; and they would probably be out in the snow all day.

Sykes et al found that the threshold intensity for morphological changes to the macular cones for a single 12-hour exposure was 2.1 mW/cm^2. As the intensity of the light increased, the amount of damage increased; at an intensity of 9 mW/cm^2 (about a log unit below the ACGIH standard) damage was extensive.

The daylight fluorescent lamps which Sykes et al used, however, do not duplicate sunlight. The spectral emission curve of this lamp is shown in Fig. 6a.[26] Superimposed upon the continuous emission curve of the lamp-

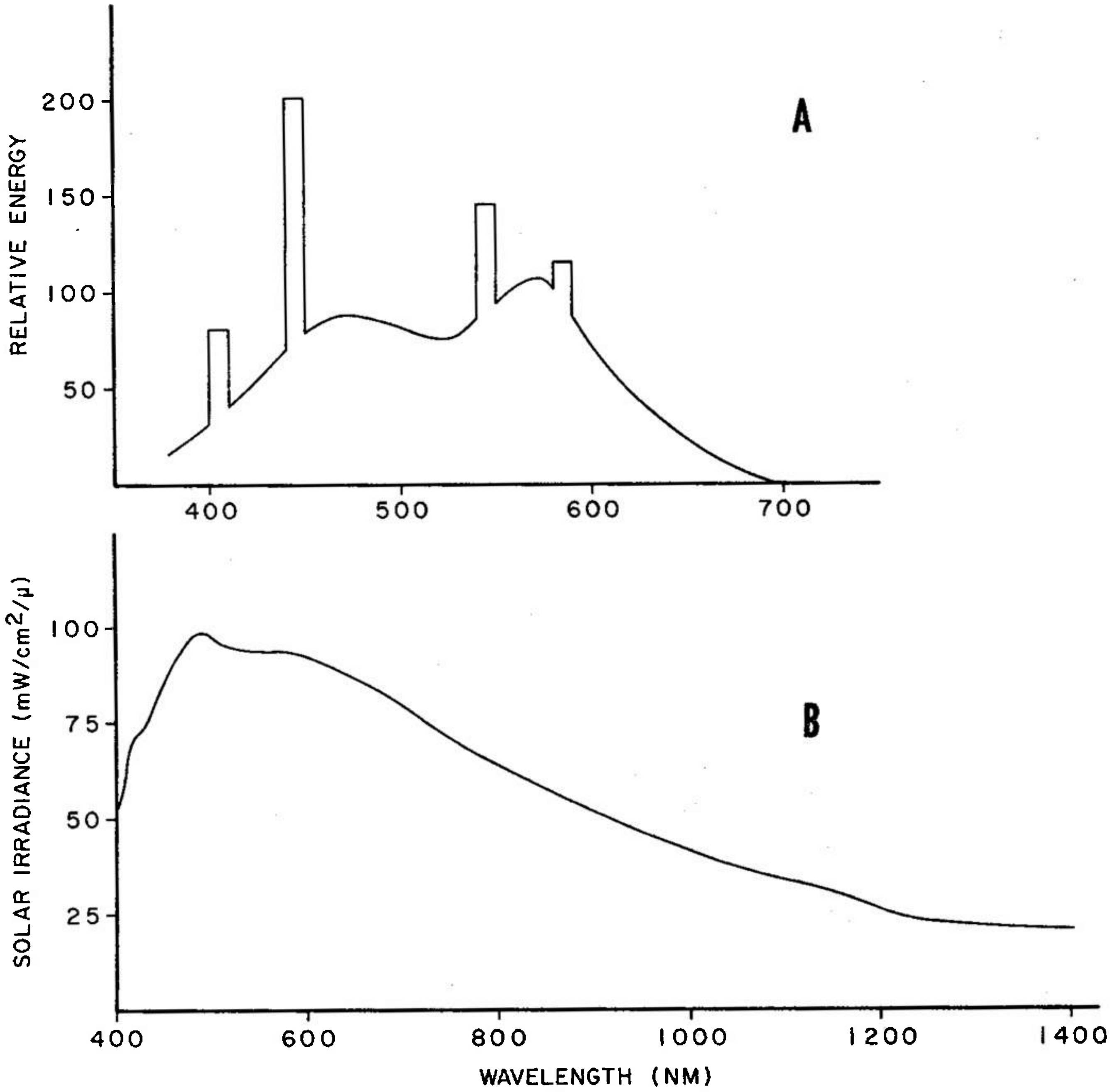

Figure 6. (a) The spectral emission curve of the daylight fluorescent lamp
(b) The spectral curve of sunlight reaching the earth through an air mass of 1.5

phosphor are four spectral lines produced by the mercury vapor. It is noteworthy that the most energetic of these spectral lines is at 436 nm; according to ACGIH, the most hazardous wavelength is 440 nm.

If we assume a total irradiation level from all wavelengths of 2 mW/cm^2 and then calculate the effective integrated spectral radiance of the lamp weighted against the blue light hazard function, we arrive at a value of 0.57 mW/cm^2, an intensity a little more than a log unit below the permissible standard.

Let us now take the spectral curve of sunlight reaching the earth through an air mass of 1.5[12,27] as shown in Fig. 6b. If we once again assume a total irradiation level of 2 mW/cm^2 and calculate the effective radiance, we arrive at a value of 0.41 mW/cm^2. Sunlight is, thus, only about 72% as hazardous as the daylight fluorescent lamp at the same total level of intensity. Presumably, then, had Sykes et al exposed their monkeys to sunlight rather than the fluorescent lamps, their radiation damage threshold would have been raised to about 2.9 mW/cm^2 for the 12-hour exposure. For an 8-hour exposure, the threshold for damage would presumably be less stringent, but for an increase in altitude, it would be more stringent.

Level in natural environment- It is very difficult, as noted above, to specify the total energy reaching the surface of the earth. The answer will depend on the specific conditions under which the measurements are taken. For typical concentrations of water vapor, ozone, and aerosols, Gates[12] calculates the total global energy reaching the horizontal surface of the earth at sea level through an air mass of 1.5 at 53 mW/cm^2. But if measured perpendicular to the sun's rays, he puts the direct solar radiation at 75 mW/cm^2. At an altitude of 10,000 feet, he calculates the total global radiation perpendicular to the sun's rays at 100 mW/cm^2.

One of the most recent actual measurements of globabl solar irradiance was by Kok and Chalmers.[28] Their results show that at Durban, South Africa, through an air mass of 2, the global solar irradiance from 300 to 770 nm was 26.5 mW/cm^2. Extrapolating to 1300 nm, in order to compare with Gates' figures, produces a total value of 46.5 mW/cm^2. Through an air mass of 1.0, the solar irradiance extrapolated to 1300 nm is about 105 mW/cm^2. Such figures are, again, highly dependent on the latitude and atmospheric conditions, but they are comparable.

How much filtering is needed to protect the eyes from this band of radiation? With estimates of solar radiation varying from around 25 to 100 mW/cm^2, let us assume the higher value. When the solar radiation is weighted by the blue hazard function[13] the effective irradiation from 400 to 1300 nm turns out to be 9.9 mW/cm^2. Of this total, 96% of the hazard lies in the range 400-500 nm. The effective irradiation above 500 nm is only .3 mW/cm^2. The level of radiation in the wavelengths above 500 nm, therefore, amounts to only one-tenth of the radiation which, according to Sykes et al, is needed to produce damage. If the short wavelengths were filtered out, the remaining radiation should pose no hazard.

The effective irradiation through each of the test goggles in the present sample was calculated for an initial solar radiance of 100 mW/cm^2 to see how effective each was in protecting the eyes from damage by the visible and infrared radiation. The results are given in Table V. The hazard effective irradiations vary widely. As expected, those goggles which filter out the short wavelengths transmit a very small hazard-effective irradiance. Only two goggles transmit more radiation than the damage threshold reported by Sykes et al; they are the GY-1 and the R-2. Three others are borderline.

It is of particular interest that one of the borderline goggles is the photochromic under high illumination. As noted above, in dim illumination the filter is essentially yellow while under bright light the filter turns blue. As Fig. 3 shows, this is accomplished not only by decreasing the transmittance of the longer wavelengths but also increasing that of the shorter wavelengths. The result is that under bright light, the blue light hazard is greatly increased. In Table V the blue light hazard is tabulated for 100 mW/cm^2 for both forms of the filter (although, of course, the filter would not remain yellow at that high light level). The hazard-effective irradiation is negligible when the filter is yellow but increases when it is blue, despite the fact that the total amount of transmittance is reduced. It would be desirable, of course, to reduce both the total transmittance and the blue light hazard. The development of a filter which will change its transmittance according to the amount of light present but without increasing the hazardous radiation at short or UV wavelengths would be optimal.

Table V. Hazard-effective irradiance in the visible and IR (mW/cm^2) through the various goggles

Goggle	Total Effective Irradiation
Y-2	0.2
Y-GL	0.2
Y-S	0.3
YN-1	2.2
YN-2	2.0
YN-F	2.0
YG-2	2.8
YG-F	2.9
GY-1	3.4
R-2	3.9
N-P	1.7
N-M	1.5
PC (blue form)	2.9
(yellow form)	0.8

Infrared Radiation

Standards - The standards for visible radiation discussed in the previous section included IR radiation. These damage thresholds were primarily concerned with blue-light hazard and showed the relative hazard for retinal injury for the wavelengths from 400 to 1400 nm. There are, in addition, other IR standards to protect against other injuries, such as thermal injury and the development of cataracts. The latter is generally thought to be the most usual hazard from prolonged exposure to IR. It has been determined[29] that IR between 800 and 1200 nm produces cataracts. The ACGIH sets a limit of 10 mW/cm^2 of IR through the 7 mm pupil to preclude this. If we conservatively assume that in bright light the mean pupil size will be 3 mm, then the permissible limit would be higher than 10 mW/cm^2, perhaps by as much as a factor of $(7/3)^2$, giving 54 mW/cm^2 as the new limit.

Wolbarsht and his colleagues have been attempting to determine the threshold for cataractogenesis as a result of IR exposure.[30,31] Their approach has been to determine the threshold for protein changes in the rabbit lens as measured by electrophoresis after exposure to a 1064 nm laser radiation. Although the results so far have not been conclusive enough to specify safe ocular levels,[32] currently the investigators believe that lenticular changes begin to appear at an exposure of about 100 joules. This indicates that the ACGIH threshold is quite safe, assuming we can generalize findings produced in rabbits by a narrow-band laser to man in sunlight.

It is also possible to produce thermal lesions on the retina with IR. The ACGIH has published a Burn Hazard Function[13] analogous to the Blue Light Hazard Function (both of which are reprinted by Sliney et al. [33]). The danger from IR is clearly far less than that from short wavelengths radiation. Indeed, DeMott and Davis[34] determined that the threshold for such lesions was about 3500 mW/cm^2.

<u>Level in natural environment</u>- If the total global radiation on a surface perpendicular to the sun at an altitude of 10,000 ft is about 100 mW/cm^2, then from Fig. 6b, we see that about 45% of the radiation exceeds 770 nm, or about 45 mW/cm^2. The mean daily radiation would be about 25 mW/cm^2. The level of IR to which the eye would be exposed is, therefore, within that permitted by the ACGIH standards, and far short of the levels required to produce a lesion according to DeMott and Davis.

It appears, therefore, that IR radiation is not a serious hazard under natural conditions. Indeed, Sliney et al,[33] in their analysis of the requirements for a protective shield for viewing welding processes, concluded that "While it may be intuitively desirable to attenuate wavelengths longer than 660 nm which contribute little to vision, such filtration is unnecessary for retinal hazard protection." (p. 2361)

Such a conclusion may seem surprising in view of the reports of glassblowers' cataracts which have long had wide currency. But Dunn[35] found no evidence of cataract in workers with many years of exposure to intense IR. Ham[36] has concluded that glassblowers' cataracts presupposes extremely long years of work--often beginning with childhood apprenticeship--and workdays exceeding current 8-hour standards.

In a test of the effect of IR on a visual discrimination task, Laxar[37] found no decrements of performance. He did report that his monkeys often rubbed their eyes or appeared to be trying to shield their eyes from the radiation, but he was exposing them to levels of radiation slightly higher than that found outside the atmosphere, which would be considerably higher than what men would naturally be exposed to. It appears that the small amount of IR filtration obtained from the goggles is satisfactory.

Other Characteristics

Color

Tinted sunglasses are often said to be undesirable, because they may distort color perception.[38] However, if identification of colors is not a task which is used extensively by Marines, then there are two reasons for prescribing yellow goggles. First, it is important to screen out the short wavelength portion of the spectrum; both the UV and the blue, pose a hazard to the eye, whereas the long wavelengths are relatively benign.

Second, recent investigations have demonstrated that yellow filters can improve vision in certain respects. Kinney et al[39] found that depth perception in the snow, as measured by the ability to discriminate the depth of depressions, was improved through yellow filters. In a related laboratory study, it was shown that yellow goggles improved reaction time to low contrast frequencies in the middle range of human sensitivity.[40] Thus, the use of yellow filters will at the same time reduce the blue light and UV hazard and improve perception of large, low-contrast targets.

Glare

A final consideration relating to transmittance is the maximum amount of light which one can comfortably look at. The level of light on a sunny snowfield will be very high. Most individuals will find it uncomfortable without sunglasses, and the level of discomfort can be expected to increase with age.[5] Although there has been a considerable amount of experimental work on the problems of glare, nearly all of it has involved small light sources whose intensity is above that of the background to which the observer is adapted.[41,42] Moreover, the measure of visual impairment has typically been some form of acuity. This is not the problem at hand.

The problem for men in snowfields is not the presence of a small glare source but rather the total illumination. Although Marines may at times be required to exhibit good resolution acuity, their main problem will be simply keeping their eyes open for long periods of time in light of very great intensity. Thus, we need to know the maximum intensity of ambient illumination to which most individuals can adapt and view with reasonable comfort.

A number of references specify requirements for sunglasses, but the specifications related to total transmittance appear to be based on trial and error in various practical situations.[38,43] For example, Farnsworth[43] noted a commander's report after an arctic operation which stated that sunglasses transmitting 12-15% of the light were inadequate on bright days and recommending transmittance of no more than 4%. The basis for this figure was not given. Further, Farnsworth noted that during World War II German submarines were furnished with progressively denser glasses for the lookouts until by 1944 transmittances were reduced to less than 3%.

Farnsworth[43] concluded that a

transmittance of 10% was most desirable for the average situation, but the recommendation appears to

Viewing distortion - Military specifications permit no greater distortion than that illustrated by

18. Koller, L. R. Ultraviolet Radiation. New York, Wiley, 1952.

19. Kostkowski, H. J., R. D. Saunders, J. F. Ward, C. H. Popenoe, and A. E. S. Green. New state of the art in solar terrestrial spectroradiometry below 300 nm. Optical Radiation News, No. 33, National Bureau of Standards, Oct 1980.

20. Bener, P. Spectral intensity of natural UV radiation and its dependence on various parameters. In F. Urbach (Ed.) The Biological Effects of Ultraviolet Radiation. New York, Pergamon Press, 1969, pp 351-358.

21. Jagger, J. Introduction to Research in Ultraviolet Photobiology. Englewood Cliffs, NJ, Prentice-Hall, 1967.

22. Diffey, B. L. Ultraviolet radiation physics and the skin. Phys. Med. Biol. 1980, 25, 405-426.

23. Buettner, K. J. K. The effects of natural sunlight on human skin. In F. Urbach, The Biological Effects of Ultraviolet Radiation. New York, Pergamon Press, 1969 pp 237-249.

24. Sperling, H. G. Functional changes and cellular damage associated with two regimes of moderately intense blue light exposure in rhesus monkey retina. ARVO meeting, Sarasota, FL, May 5, 1978.

bara. Damage to the monkey retina by broad-spectrum fluorescent light. Invest. Ophthal. Vis. Sci. 1981, 20, 425-434.

26. Wyszecki, G. and W. S. Stiles. Color Science, New York, Wiley, 1967.

27. Moon, P. The Scientific Basis of Illuminating Engineering. New York, McGraw-Hill, 1936.

28. Kok, C. J. and A. N. Chalmers. Spectral irradiance of daylight at Durban. Natl. Phys. Res.Lab., Research Rep. FIS 187, Pretoria, 1978.

29. Langley, R. K., C. B. Mortimer and C. McCullough. The experimental production of cataracts by exposure to heat and light. Arch. Ophthalmol. 1960, 63, 473-488.

30. Wolbarsht, M. L., M. A. Orr, B. S. Yamanashi, J. S. Zigler, and I. B. C. Matheson. The origin of cataracts in the lens from infrared laser radiation: Annual Progress Rept, 1977, U. S. Army Med. Res. & Dev. Command, Contract DAMD-17-74-C-4133.

31. Wolbarsht, M. L. Safe ocular levels for IR occupational exposures. Final Report, 1978, Natl. Inst. Occup. Health and Safety, Grant No. OH 0053-04

32. Wolbarsht, M. L., M. A. Orr, and I. B. C. Matheson. The origin of cataracts in the lens from infrared laser radiation: Progress report, 1979,U. S. Army Med. Res. & Dev. Command,

33. Sliney, D. H., C. E. Moss, C. G. Miller, and J. B. Stephens. Semitransparent curtains for control of optical radiation hazards. Appl. Optics 1981, 20, 2352-2366.

34. DeMott, D. W. and I. P. Davis. Irradiance thresholds for chorioretinal lesions. Arch. Ophthalmol. 1959, 62, 653-656.

35. Dunn, B. L. A preliminary study on "glass-worker's cataract" exposures. Indust. Ophthal. May-June 1950, 597-604.

36. Ham, W. T. Jr. Personal communication (1981).

37. Laxar, K. A preliminary investigation of the effects of near infrared radiation on visual performance. NSMRL Rep. No. 588, Jul 1969.

38. Matthews, J. L., D. Farnsworth, E. V. Kinsey, and V. A. Byrnes. Tinted optical media. Trans. Am. Acad. Ophthalmol. 1952.

39. Kinney, J. A. S., S. M. Luria, C. L. Schlichting, and D. F. Neri. Depth perception with yellow goggles. NSMRL Rep. No. 960, Aug 1981.

40. Kinney, J. A. S., C. L. Schlichting, D. F. Neri, and S. W. Kindness. Various measures of the effectiveness of yellow goggles. NSMRL Rep. No. 941, Oct 1980.

41. Bennett, C. A. Discomfort glare: concentrated sources--parametric study of angular small sources. J. Illum. Eng. Soc. 1977, 7, 2-15.

42. Pulling, N. H., E. Wolf, S. P. Sturgis, D. R. Vaillancourt, and J. J. Dolliver. Headlight glare resistance and driver age. Hum. Fac. 1980, 22, 103-112.

43. Farnsworth, D. Standards for general purpose sunglasses. NSMRL Rep. No. 140, Sep 1948.

44. Borish, I. M. Clinical Refraction (3rd Ed.) Chicago, Professional Press, 1970.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NSMRL Rep. No. 970	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) COLD WEATHER GOGGLES. I. OPTICAL EVALUATION		5. TYPE OF REPORT & PERIOD COVERED Interim report
		6. PERFORMING ORG. REPORT NUMBER NSMRL Rep. No. 970
7. AUTHOR(s) S. M. Luria, David F. Neri, Jo Ann S. Kinney, and Helen M. Paulson		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Submarine Medical Research Laboratory Naval Submarine Base New London Groton, Connecticut 06349-0900		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 63706N M0095PN001-1040
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Submarine Medical Research Laboratory Naval Submarine Base New London Groton, Connecticut 06349-0900		12. REPORT DATE 19 Jan 1982
		13. NUMBER OF PAGES 27
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office) Naval Medical Research and Development Command National Naval Medical Center Bethesda, Maryland 20014		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Goggles; Cold Weather; Eye-protection; Solar Radiation; Optical Standards

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

To compare the utility of a dozen protective goggles for the cold, their transmittance of harmful radiation, optical quality, resistance to fogging, and comfort were measured. The transmittances were discussed in terms of thresholds for damage to the eye from various bands of light radiation. The optical characteristics were evaluated against military specifications for aviators' visors. All the goggles except one screened out enough UV at sea level, and all but two screened out enough of the visible and infrared radiation. There were wide variations in optical quality, resistance to

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-014-6601 |

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20 cont'd:

fogging, and comfort. A set of specifications was drawn up to meet the various requirements, but it was concluded that one set of goggles was unlikely to be satisfactory for the wide range of conditions which would be encountered.