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DAZZLING GLARE: PROTECTION CRITERIA VERSUS VISUAL PERFORMANCE

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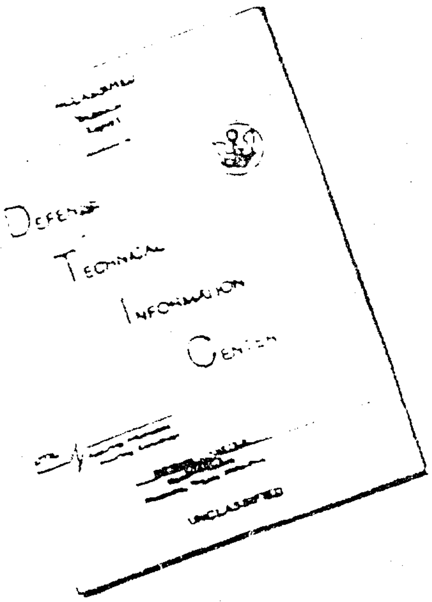

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Laser eye protection was first introduced into the U.S. Fleet when the need arose to protect aviators and aircrew from our own neodymium systems. This protection was designed to reduce the incident energy below the maximum permissible exposure level established by the American National Standards Institute. Since range finders used an infrared wavelength, as defined and therefore not visible to the eye, there was no possibility of glare. With time more systems were developed employing lasers in both the visible and infrared portion of the spectrum. When the lasing of the police helicopter in Los Angeles was first reported in 1981 it immediately became apparent that for wavelengths in the visible portion of the spectrum substantial losses in visual performance could be encountered at "safe" exposure levels. The incident emphasized the need to develop laser eye protection based on criteria that encompassed both transient (glare) and permanent (burns, hemorraghic lesions) effects. The goal of this research project has been to establish protection levels based on performance rather than damage criteria. Keywords:

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INTRODUCTION

The goal of this independent research (IR) project was to define the parameters of laser exposures in terms of visual performance rather than permanent damage criteria, and then to transition this information into laser eye protection. The ability to dazzle and disorient someone with low intensities of glare was demonstrated by a technician in Los Angeles who, after repairing a small, air cooled argon laser, decided to go outside and see how well it worked. His target was a police helicopter. The pilot and copilot suddenly found themselves deprived of all outward and inward vision as the energy from the laser radiated and reradiated through the canopy of their helicopter. As they tried evasive maneuvers the technician easily tracked them with the laser. Their pilot radioed for help and was able to maintain the aircraft's attitude until ground support personnel arrived to arrest the technician and impound the laser. The pilot had no permanent retinal damage from the exposures, but did indicate that while he was being lased he could see nothing except a bright, blue-green light. If he had been in a densely populated or unknown territory the outcome might have been different. The purpose of this IR project has been to define the parameters governing these transient glare effects in order to design more effective protective eyewear and to ensure that those who might be exposed in an operational setting know what to expect and how to react. The project is described in the following sections as it progressed from low intensity exposures through high intensity, operationally realistic exposures.

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CONTRAST SENSITIVITY

The initial series of three experiments assessed human contrast sensitivity functions of young, emmetropic (visual acuity 20/20 uncorrected) observers. Contrast sensitivity functions are analogous to the modulation transfer function of an optical system. System resolution is a function of the highest spatial frequency transmitted by the device, but overall fidelity of the image is also a function of the system's ability to relay lower frequencies. The human visual system is similar in the sense that it also processes information into discrete channels differing in spatial frequency. Low object frequencies subserve object detection, e.g., "there is something out there," while the higher object frequencies support object identification, e.g., "that something is a tank and it's not ours." Retinal summation and overall sensitivity also differs as a function of spatial frequency. As spatial frequency increases, the summation area decreases and contrast becomes more critical in determining whether or not the pattern will be perceived.

Sinusoidal gratings were generated using standard electronic techniques on the face of a 608 Tektronix monitor. A von Bekesy procedure was used to assess threshold sensitivity. The observers modulated the contrast of the gratings, which differed in spatial frequency, around the point where the grating went from visible to no longer visible. Each threshold consisted of the average of six reversals. A minimum of three thresholds were measured per spatial frequency under each condition. The subjects viewed the monitor from a distance of 1.2 meters, and all laser exposures were intrabeam. The surround was matched in brightness and color to the monitor in order to provide a uniform field of view. The glare intensities used were the maximum permissible exposure (MPE) level for a given viewing duration reduced by a factor of ten. Since MPE is a function of intensity and duration, as the duration of the exposure increases, the permissible exposure intensity decreases. Because the experimental paradigm required a substantial amount of time to complete, exposure duration was set at 10,000 seconds. As a result, for the first series of experiments glare intensity varied from 1 nanowatt up to a fraction of a microwatt.

The first experiment assessed the effects of glare eccentricity, intensity, and ambient illumination. The 528.7 nanometer (nm) line of an argon laser was used as the glare source. Glare intensity was either 1 or 10 nanowatts/CM^2. Figure 1 shows a progressive return in visual performance as glare eccentricity increased from zero degrees (foveal exposure) to 5 degrees (parafoveal exposure) of visual angle. The overall effect decreased when glare intensity was reduced by one log unit, but increased dramatically as ambient illumination was reduced by 1 log unit while glare intensity was maintained at the higher level. At the lower ambient illumination with the higher glare intensity, the spread of the glare function completely encompassed the area of the retina capable of processing the higher spatial frequencies. If both ambient illumination and glare intensity were reduced by 1 log unit, then the functions resembled the data collected with the higher ambient illumination and glare intensity. This indicated that the ratio of glare intensity to ambient illumination was very important in determining overall loss in visual performance. The results also demonstrated that the glare had a finite spread once it entered the eye and was affected little by the ocular media and nerve cells it passed through before reaching the retina.

The results demonstrated the effectiveness of very low intensities of glare in disrupting visual performance, however, the question of whether or not the observed decrement in sensitivity differed as a function of wavelength remained to be addressed. A wavelength difference would directly impact required protection levels. Intraocular scatter has been a controversial topic since the mid 1950s. Depending on the experimental approach, sometimes the degree of scatter appeared to be wavelength dependent, while at other times it did not. The question addressed by this experiment is, "If two wavelengths are equated for photopic efficiency, will the shorter wavelength scatter more in the eye

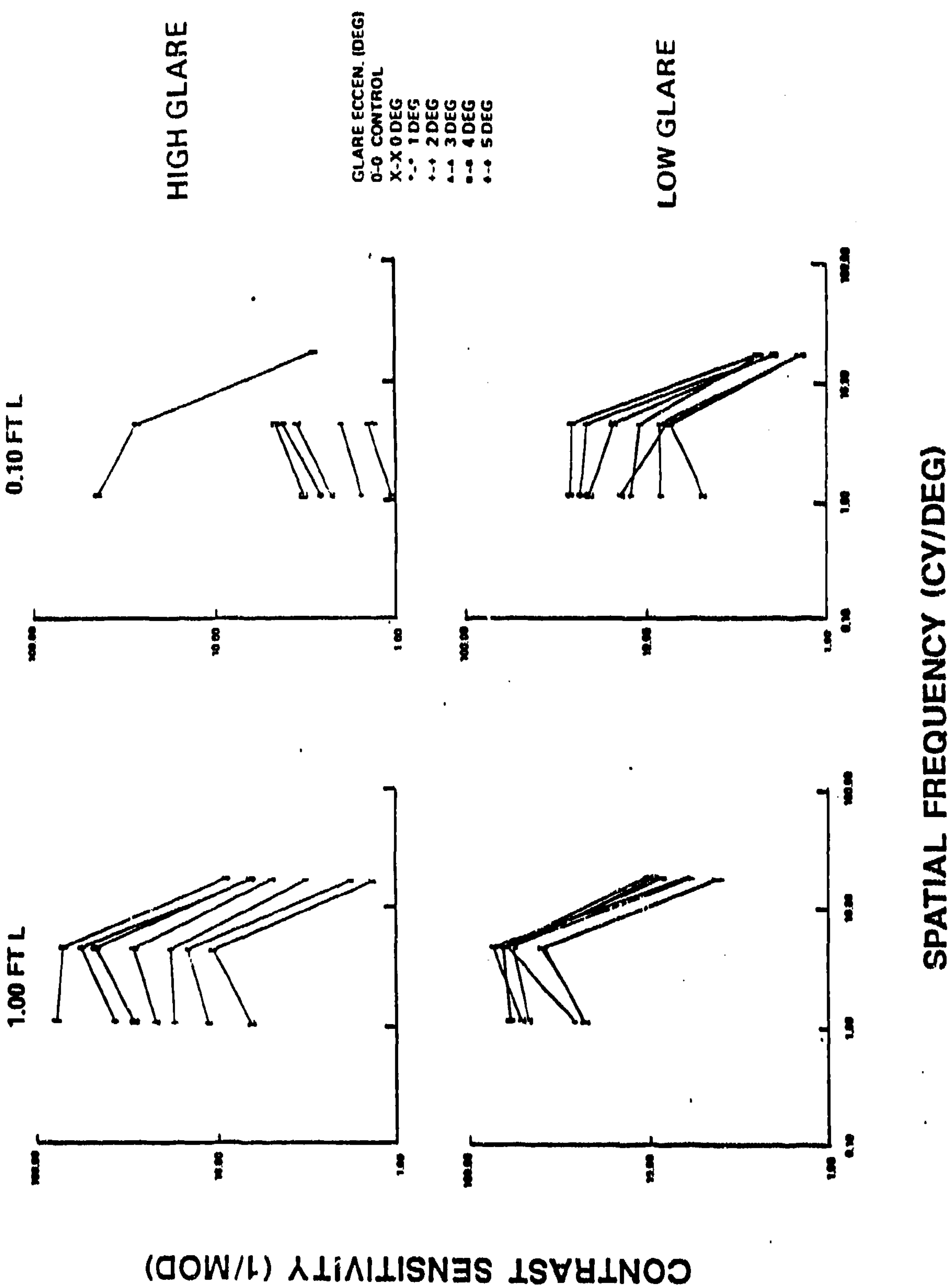

Figure 1. Contrast Sensitivity as a Function of Glare Intensity and Eccentricity.

and therefore cause a greater decrement in contrast sensitivity?"

The experimental paradigm was modified to exclude eccentricity, all viewing would be foveal and include glare from both an Argon and a helium neon laser (632.8 nm). In addition to assessing sensitivity with the 608 monitor (green phosphor), sensitivity was also assessed using a Tektronix 620 monitor (blue phosphor). In the original paradigm if a difference in sensitivity was observed, it would be impossible to determine if the difference was due to greater scattering, color contrast between pattern and glare source, or saturation of the green photoreceptors since both the pattern and the glare source affect the same photoreceptors (green laser and pattern vs red laser, green pattern). By comparing sensitivity with blue and green phosphor monitors there would be color contrast between both the argon and helium neon lasers and the gratings, and different color receptors would be involved for the glare and resolution of the gratings. If a difference was observed between glare sources when gratings were generated on the 604 but not the 620 monitor, then saturation of photopigments would be the causative factor. However, if a difference was observed in sensitivity between the photopically matched glare sources regardless of monitor type, then the cause could be attributed to differential scattering.

As shown in Figure 2, there was a consistent difference in sensitivity regardless of monitor type. Although glare intensity was equated for photopic efficiency, glare from the argon laser caused a greater loss in contrast sensitivity than the helium neon laser. The difference was observed for the lower spatial frequencies, but not the higher frequencies. At first this seems odd, but if the glare covers a finite area of the retina, and this area differs as a function of wavelength, then one would not expect a difference in the higher frequencies. The reasoning behind this hypothesis is that the retina sums sensitivity to a given spatial frequency over a finite area and the area of summation increases as spatial frequency decreases. Therefore, one would expect to see a difference in the lower spatial frequencies, but not the higher frequencies if the glare profile of both wavelengths exceeds the critical summation area for the higher spatial frequencies. The difference only for the lower spatial frequencies also indicates that although there appears to be a greater degree of scatter for the shorter wavelength, the size difference in glare profiles is small.

The third experiment assessed the difference between coherent and noncoherent glare while varying whether the glare was viewed intraocularly (glare and resolution same eye) or interocularly (glare right eye, resolution left eye). A collimated xenon arc lamp provided the noncoherent glare while a helium neon laser was used as the coherent glare source. The intensity of the xenon was measured across the visible spectrum and then normalized. By convolving this information with the spectral sensitivity of the eye, an intensity match could be achieved for the two different glare sources. The maximum glare intensity was 1.75 uW/CM^2, and was reduced by a factor of 10 and 100 for the medium- and low-glare intensities. As shown in Figures 3 and 4, there was a significant difference between the coherent and noncoherent glare sources when viewed intraocularly but not when viewed interocularly. When the subjects were exposed to the coherent glare many could not see the higher spatial frequencies (indicated by dotted lines in the figure; the number in parentheses indicates how many subjects of the original six could resolve the grating), while all could see even the highest spatial frequency when exposed to noncoherent glare. It seemed that the scintillation in the coherent glare preferentially masked higher spatial frequencies while the noncoherent glare cast a uniform glare. In the interocular condition the glare from the nonresolving eye seemed to add noise to the signal from the other eye. The change in sensitivity was no longer strictly a function of glare intensity. Similar to the previous experiments, the largest factor in determining the overall loss in sensitivity was the ratio of glare intensity to ambient illumination.

A possible reason for the difference between the two glare sources is that the xenon arc lamp was

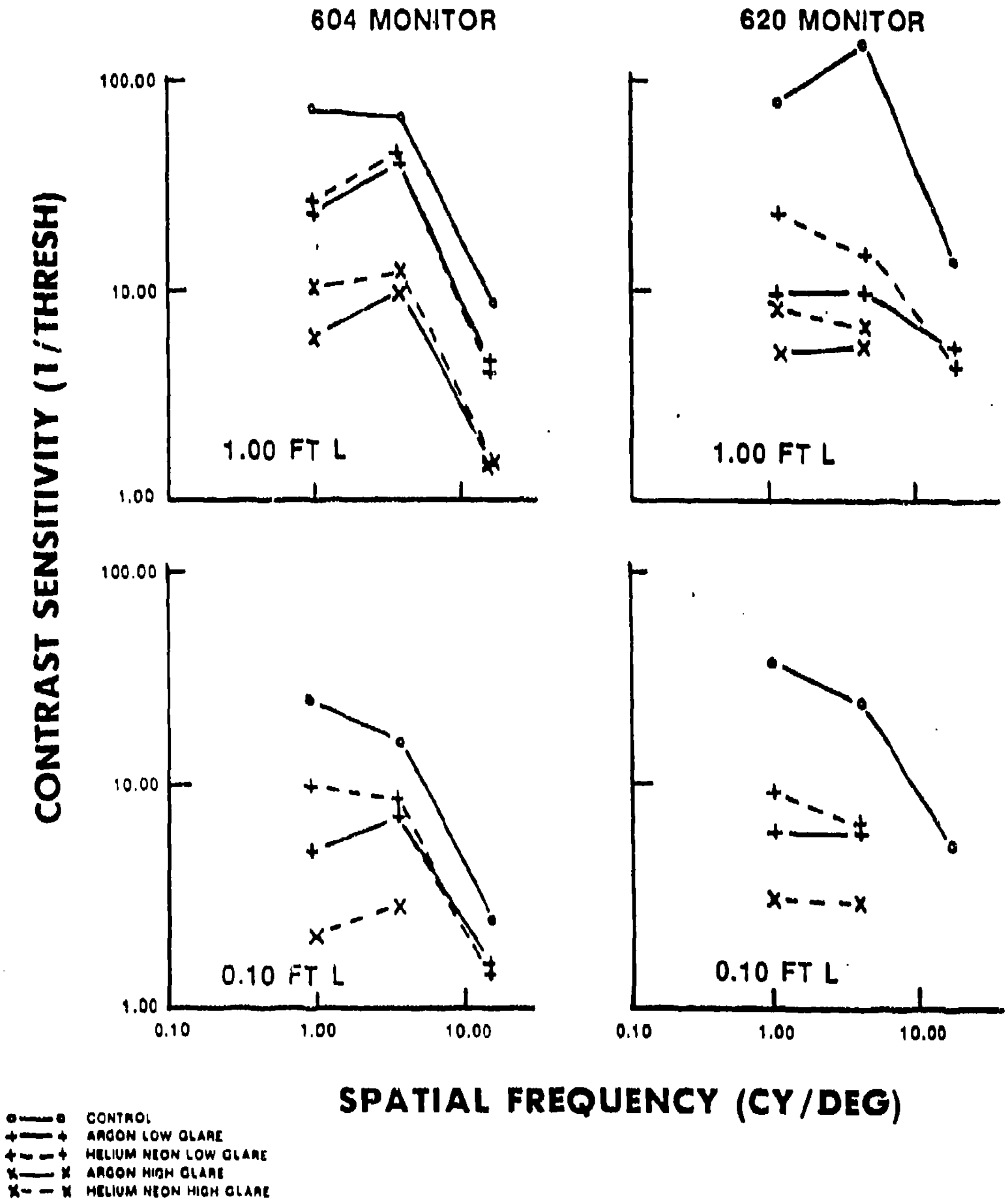

Figure 2. Contrast Sensitivity as a Function of Glare Intensity and Monitor Type.

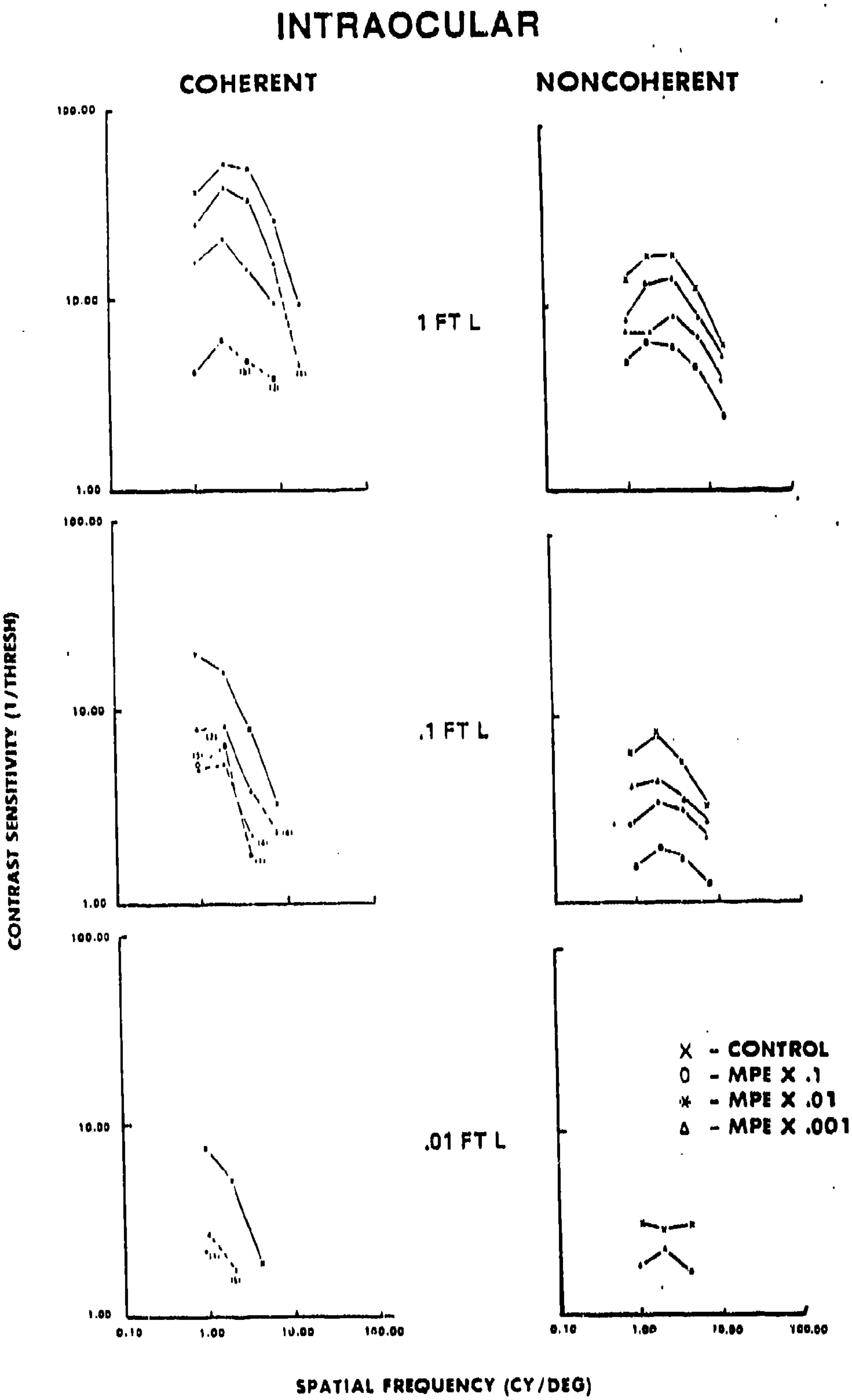

Figure 3. Coherent vs Noncoherent Intraocular Glare.

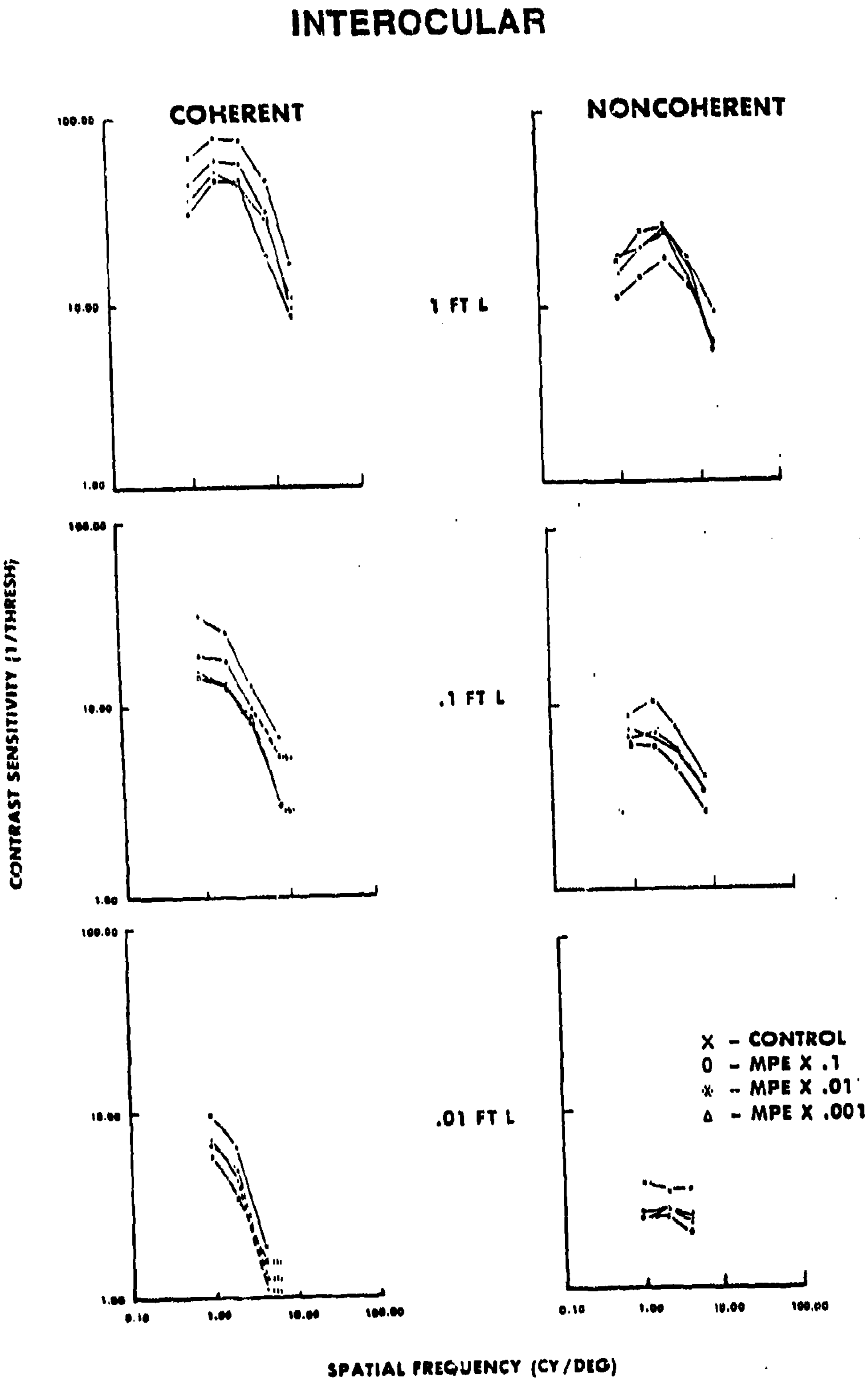

Figure 4. Coherent vs Noncoherent Interocular Glare.

not properly matched in intensity to the helium neon laser. To assess this possibility, the xenon arc lamp was filtered with a 35-nm interference filter peaking at 632.8 nm. The maximum intensity achievable from the xenon arc lamp was 0.44 uW/cm2. The results shown in Figure 5 demonstrate that the difference was not due to a difference in intensity, but rather the scintillation of the coherent source preferentially masking the higher spatial frequencies. The overall results demonstrate that a laser is more effective in disrupting visual performance, and that if one wants to simulate glare from a laser then use a laser. If a noncoherent, broadband source such as an arc lamp is filtered, the maximum obtainable irradiance will be greatly reduced.

CONCLUSIONS

The series of experiments demonstrated that the primary determinant of whether or not glare will disrupt visual performance is the ratio of glare intensity to ambient illumination. The degradation in performance will be greater for tasks requiring identification or detection of objects at great distances, i.e., targets with high object frequencies and/or of low contrast. The coherent vs noncoherent study demonstrated the superiority of coherent glare in disrupting performance while the intraocular vs interocular portion of the study defined the return in visual performance if one eye can be shielded from the glare.

The ability to severely disrupt visual performance with only a fraction of a microwatt of glare conclusively demonstrated the need to protect against transient losses in visual performance. This information was immediately transitioned into the required levels of optical density for laser eye protection currently under development. In some cases density was increased by as much as two log units. The results also indicated the direction for future research. The relationship between glare intensity and ambient illumination was not linear or exponential. This unfortunately precluded generalizations to bright ambient light levels from the present data base. However, the results of this series of experiments did identify the key independent variables.

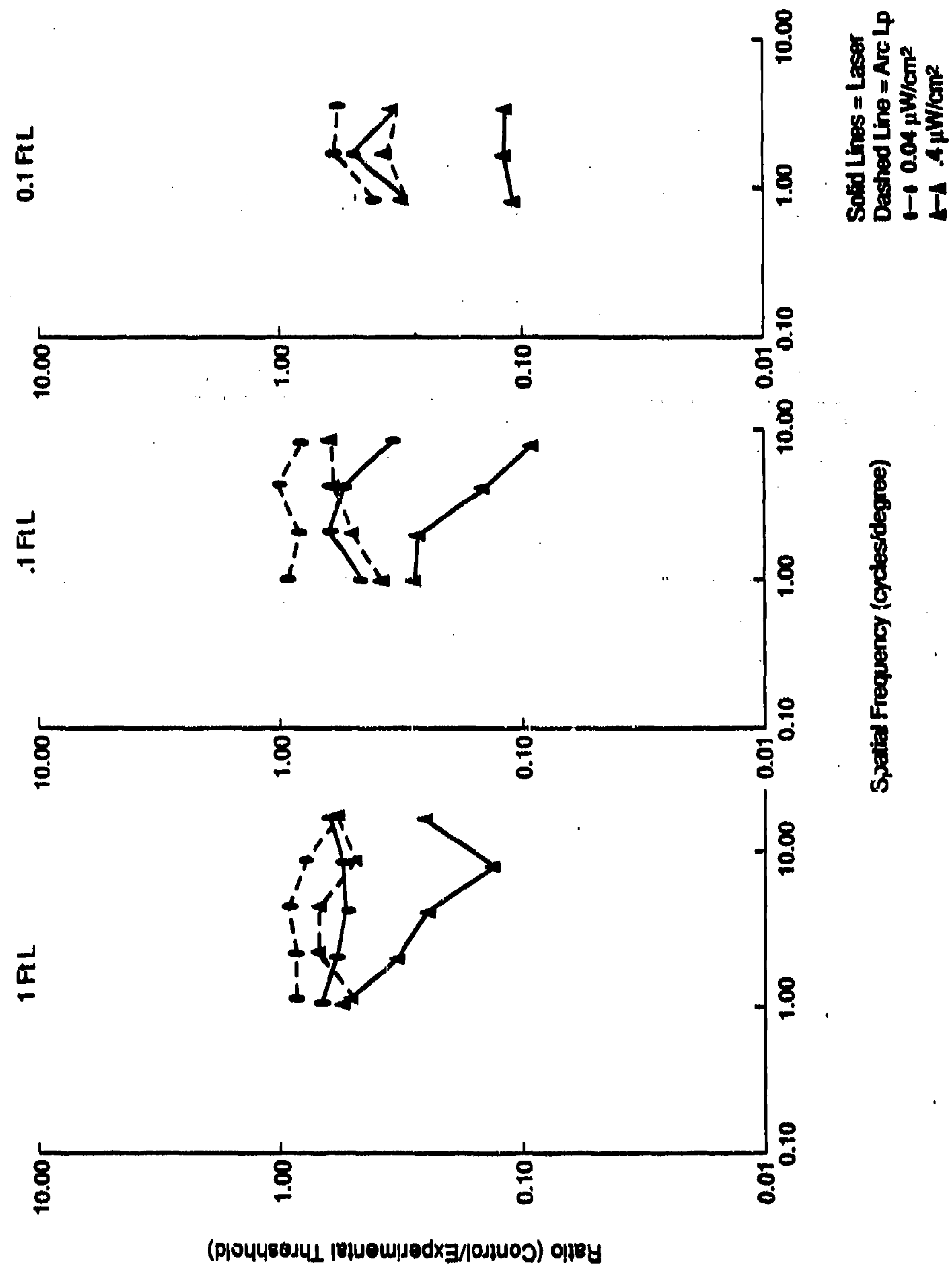

Figure 5. Filtered xenon arc lamp vs helium neon laser.

KINETIC PERIMETRY

In order to accurately predict performance decrements at high levels of ambient illumination, high intensities of glare are required. However, as glare intensity increases exposure duration decreases. As the permissible exposure duration decreases it becomes very difficult to collect enough data in a given session to minimize unwanted variability. By using kinetic perimetry the goal outlined above can be accomplished while varying the important independent variables identified during the contrast sensitivity portion of the project. Specifically, perimeter brightness can be varied continuously from an ambient illumination equivalent to a full moon up to an overcast day. The probe spot used to map the visual field can be varied in size, contrast, and color. The location of the probe spot within the visual field can be varied in order to create some spatial uncertainty, and most importantly, a visual field can be defined by mapping six meridians in approximately 1 minute.

This set of experiments explores the contribution of color contrast and its relationship to brightness contrast in determining the area of the visual field occluded when varying intensities of glare are present. By shifting the dependent measure to kinetic perimetry, glare intensities that are realistic for operational exposures can be used. The MPE for this experiment is 75% of the intensity permissible for a 50 minute exposure. Glare intensities were 2.4, 0.24, and 0.02 uW/CM^2. The 543 nm line of a tuneable helium neon laser was used as the glare source. Visual fields were assessed using a Topcon perimeter. The background brightness was 0.1, 1, or 10 FtL. The probe spot brightness contrasts were 10, 20, and 30%, while the probe spot colors were green, yellow, and red. Probe spot size was either 4 or 16 MM^2.

The results are shown in Figures 6, 7, and 8. The baseline visual fields are shown on the left for the different size and contrast probe spots, while the graphs on the right illustrate the percent of the base visual field occluded by glare for the different size and color probe spots (e.g., G4 is a green probe spot 4MM^2 in size) as a function of glare intensity. Overall, the results indicate that as glare intensity exceeds 2 uW/CM^2 in the green portion of the spectrum an operationally significant portion of the visual field is occluded at moderately high levels of ambient illumination (i.e., 10 FtL). The size of the occlusion at a given ambient illumination and glare intensity, as would be expected from the earlier experiments, depends on the size and contrast of the probe spot. Color contrast does reduce the amount of the visual field occluded, but only when brightness contrast is marginal for that particular viewing condition. As ambient illumination is reduced there is a corresponding increase in the amount of the visual field occluded, up to the point where visual performance is prohibited over 100% of the functional field at very low ambient illuminations.

CONCLUSIONS

The results to date have established protection criteria based on the prevention of transient losses in visual performance. These new protection criteria, based on both transient and permanent effects, are currently embodied in the Navy's multiple wavelength eye protection and the requirements for agile protection. The data also define, from a visual performance standpoint, what levels of glare are tolerable for various types of tasks under different ambient conditions and serve as the basis for threat models currently being developed in both the United States and Britain.

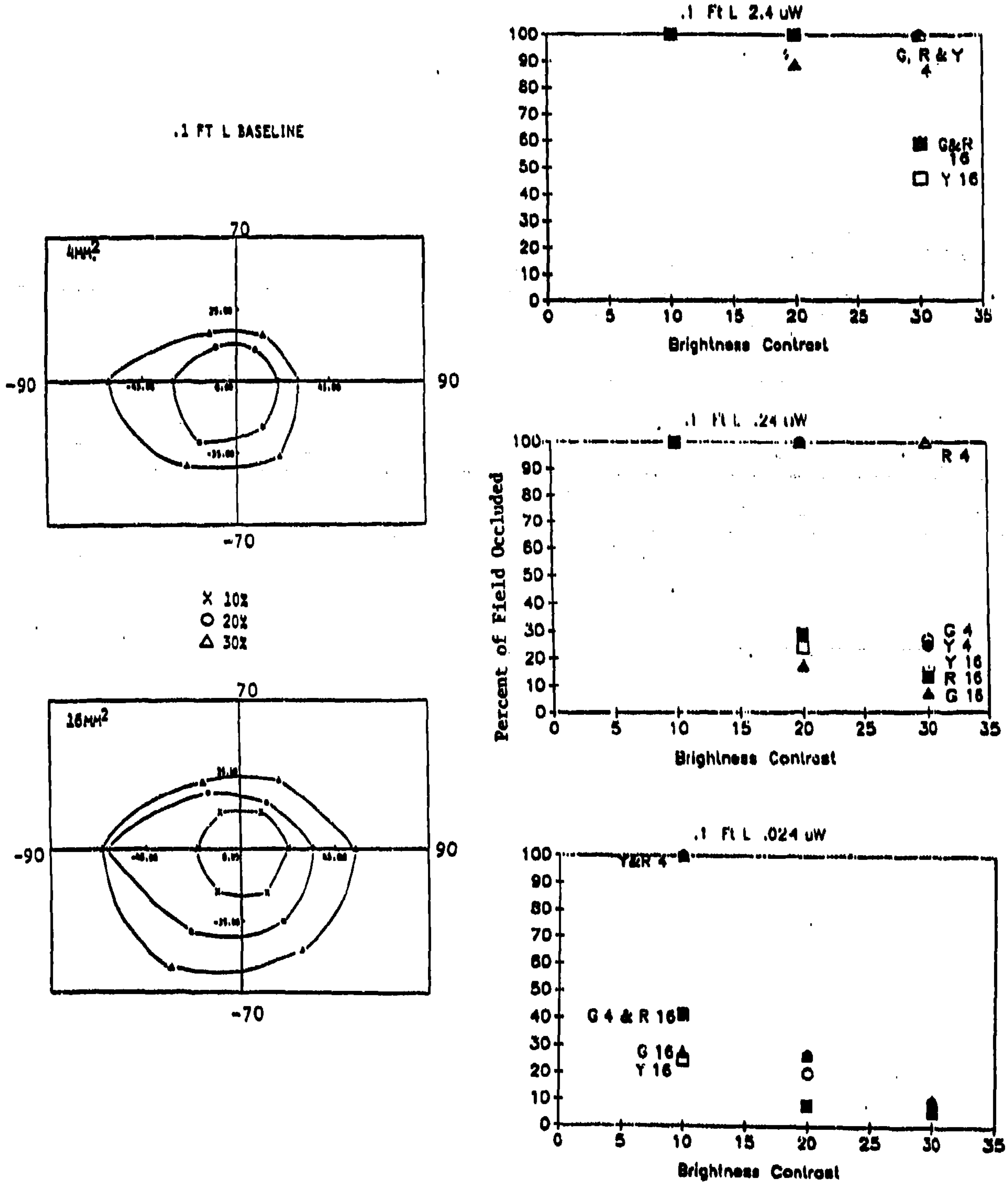

Figure 6. Baseline Visual Fields and Percent of Field Occluded — 0.1 FtL.

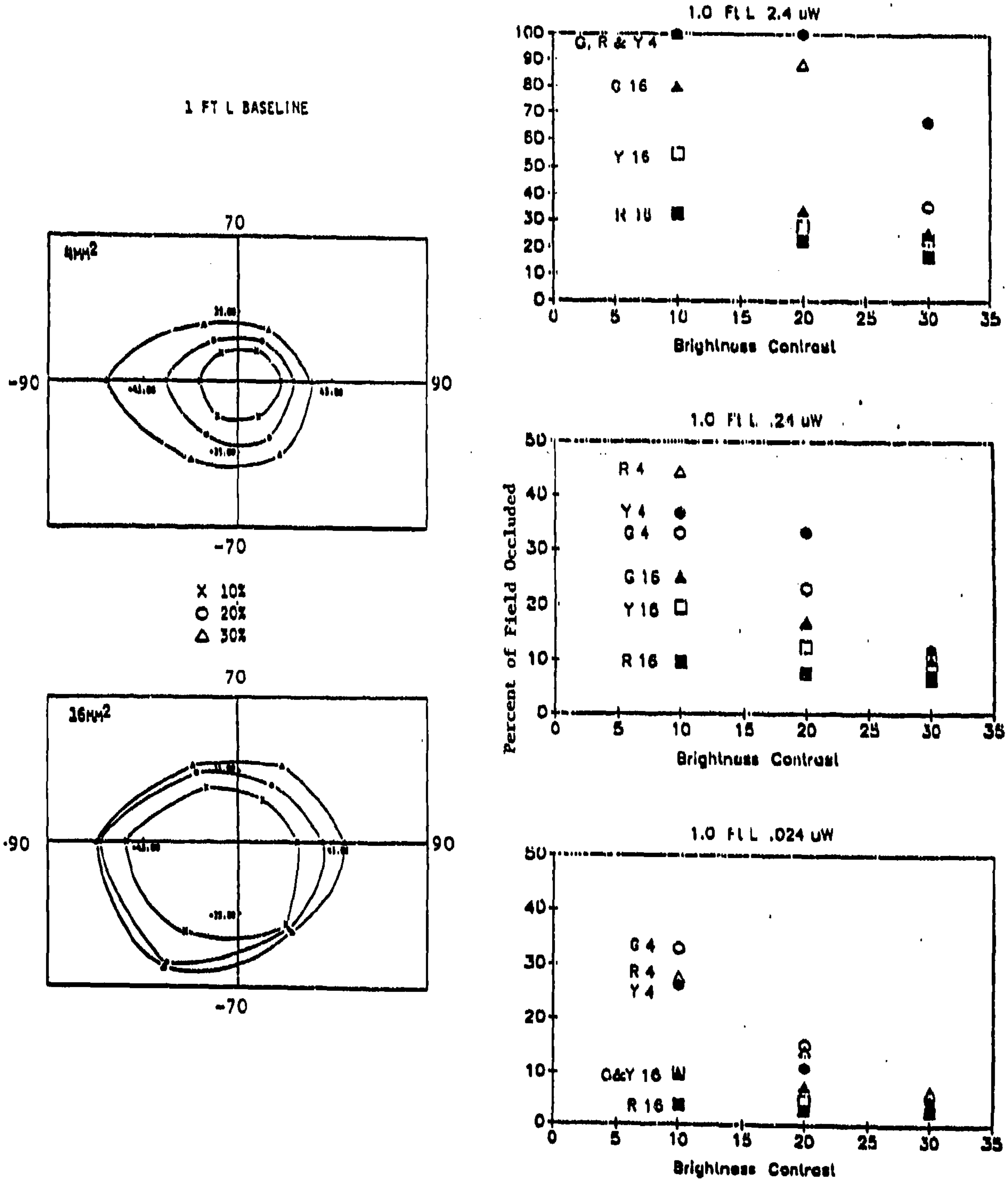

Figure 7. Baseline Visual Fields and Percent of Field Occluded — 1 FtL.

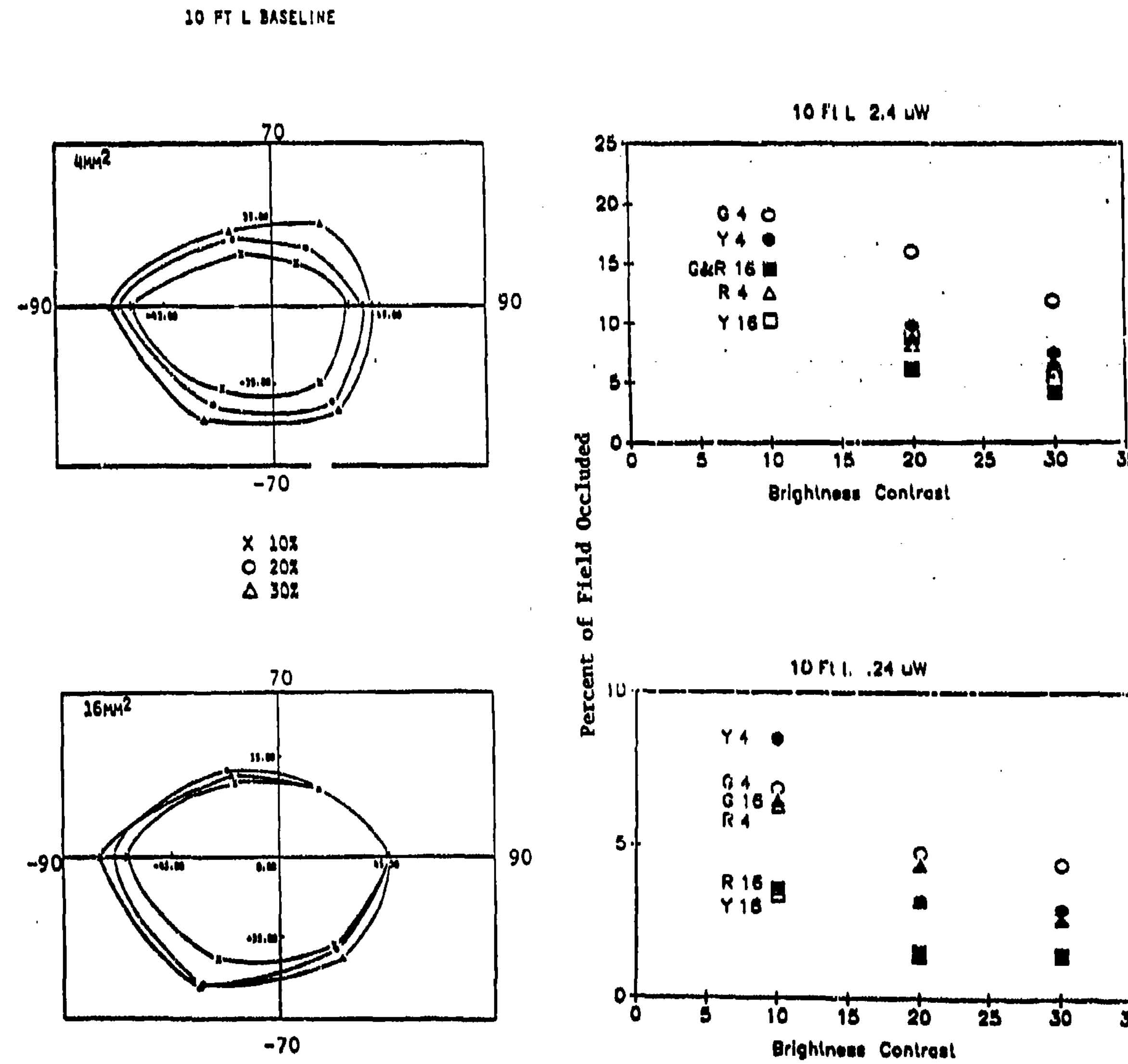

Figure 8. Baseline Visual Fields and Percent of Field Occluded — 10 FtL.

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