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EXPERIMENT FOR THE SELECTION OF REFLEX-COLLIMATING SIGHT COMPONENTS

N. William Doss
Richard R. Kramer

August 1976

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U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland

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An evaluation and selection of certain optical components of the reflex-collimating sight for the Improved M16 was conducted at the U.S. Army Human Engineering Laboratory for Frankford Arsenal. The measurements were obtained in units of visibility levels thru the Blackwell Visual Task Evaluator for three calibrated operators, as were the ambient light levels. The data were analyzed, weighted, and the selection was made for recommendation of two beamsplitters and three reticle patterns to the Infantry School at Ft. Benning, GA.

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EXPERIMENT FOR THE SELECTION OF REFLEX-COLLIMATING SIGHT COMPONENTS

N. William Doss
Richard R. Kramer

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APPROVED: JOHN D. WEISZ
Director
U. S. Army Human Engineering Laboratory

U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland 21005

CONTENTS

EXPERIMENT FOR THE SELECTION OF

REFLEX-COLLIMATING SIGHT COMPONENTS

INTRODUCTION

An experimental investigation was conducted by the U.S. Army Human Engineering Laboratory (HEL) in order to assist in the selection of the reticle and beamsplitter for a reflex-collimating sight for use with small arms such as the M16 rifle. Dichroic beamsplitters with different spectral and transmittance characteristics, and aiming reticles of different patterns were provided by Frankford Arsenal, Philadelphia, PA, as part of a coordinated effort by the U.S. Army Armament Command, Rock Island, IL, HEL, and the U.S. Army Infantry School, Ft. Benning, GA.

A field test was designed to evaluate the visual characteristics of the five reticles and six beamsplitters with the aid of the Blackwell Visual Task Evaluator No. 3 (VTE). This device provides quantitative "visibility" readings while the subject-operator is looking at real-world scenes (2). It establishes a scale of visibility, units of which are called visibility levels (VL), now recognized and adopted for use by the illuminating Engineering Society (IES) (4).

Three calibrated subject-operators determined threshold-visibility levels of roughly man-size targets up to 400 meters through the beamsplitters and reticles in a telescope configuration.

A telescope having a reticle in a focal plane in the optical system is commonly known as a telescopic sight, or military telescope. A telescopic sight is advantageous in that it permits the reticle and target to be both in focus, and may not require precise alignment of the eye with respect to the line of sight. Alignment of the eye need be only within the exit pupil diameter. In comparison, iron rifle sights induce the eye to attempt an actual impossibility—the focusing simultaneously on rear sight, front sight, and target. The eye, furthermore, must be in good alignment with all three (7).

A collimator sight is a relatively simple sighting device that has many of the advantages of a telescopic sight. It permits observation of a reticle with the eye focused at infinity, or with the same eye accommodation as required to view a target, and it does not require that the eye be precisely positioned. Ambient light, or light from an internal illuminator, passes through the reticle, sometimes concentrated by a condensing lens or lens system. The reticle may be either a pattern etched on glass, or a transparent area in an opaque surround. Light from the illuminated reticle passes through a collimating lens placed one focal length from the reticle rendering the light rays leaving the reticle parallel. The collimated light from the reticle is combined with the light from the target scene by the use of a coated glass plate (beamsplitter), which permits light both to pass straight through from one face and reflect the light striking the opposite face (Fig. 1).

This surface-coated beamsplitter is essentially a half-light mirror, and is an important component of the reflex collimating sight (3 & 7). It is designed to reflect approximately half of the light that falls upon it; the other half of the available light passes through. The reflectance of the beamsplitters used in this test varies with wavelength. This characteristic, which was achieved by using dichroic filters for the beamsplitters, allows a color discrimination to be made between the target and the reticle. Dichroic filters essentially reflect what they don't transmit, and the ratio of reflectance to transmittance can be made to vary widely with wavelength.

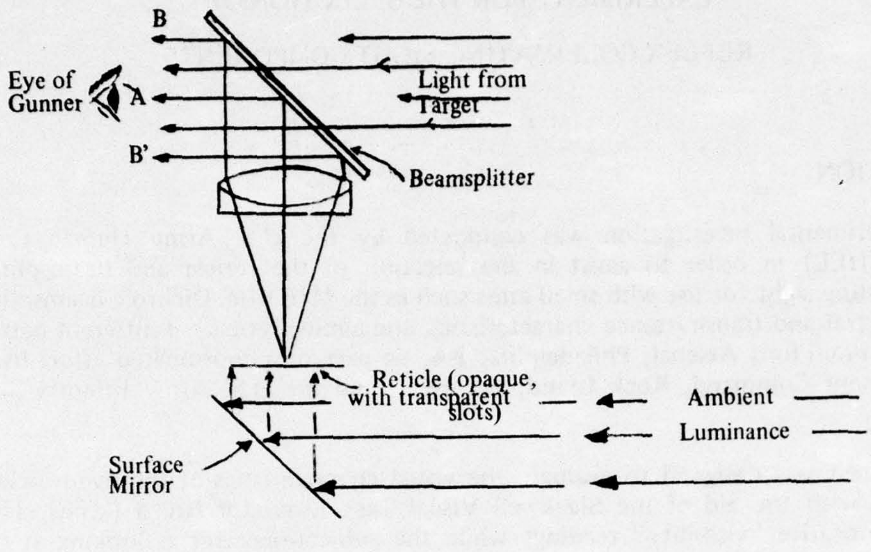

Fig. 1a. Transmitted mode.

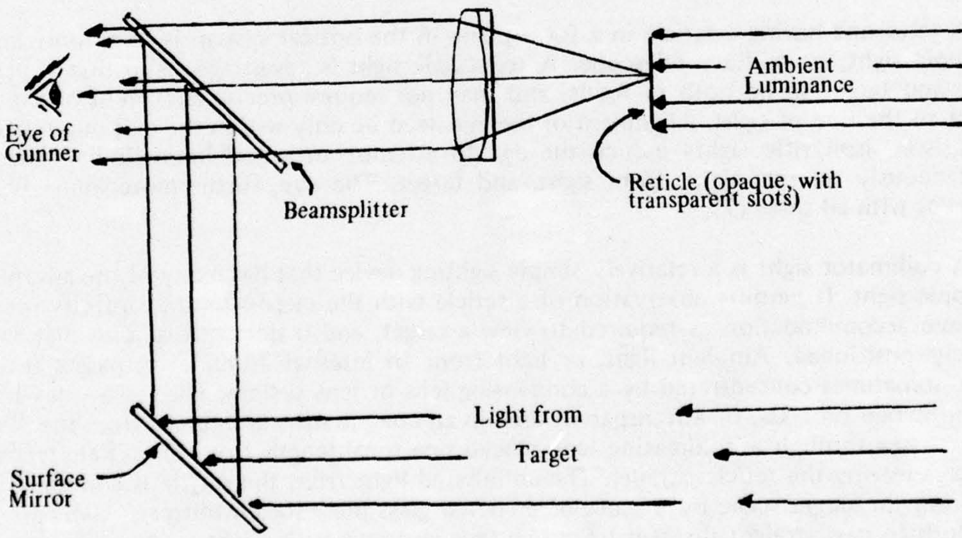

Fig. 1b. Reflected mode.

Fig. 1. Schematic of a reflex-collimating sight.

The selection of reflective coatings that are designed to enhance color contrast is part of a trade-off that must be dealt with in terms of target versus background contrast and visibility.

The user's view through the sight is dominated by the color of the beamsplitter. The superimposed reticle is generally a different color; however, its relative brightness must be greater than that of the background in order to be usable. The reticle can be made several times brighter than the background, by selection of beamsplitter color and transmittance value, with a corresponding decrease in target/background visibility. The target/background resolution can be enhanced by beamsplitter selection toward a lighter color with a greater relative brightness, but only if the reticle is made dimmer. The relative brightness of the scene will impose additional problems to the user that must be dealt with. In order to achieve contrast against sunlit clouds and snow (up to 10,000 fL.), for example, image brightness would need to be 2,000 fL. for only 20 percent contrast. In providing adequate brightness, allowance must be made for only partial reflectance by the transparent mirror (beamsplitter). Use of a colored image maximizes contrast against anticipated backgrounds. In addition, excessive reticle-pattern brightness interferes with target-background contrast. Contrast may be enhanced by either dark on light background or vice versa. The use of colored markings against colored backgrounds of comparable brightness should be avoided (3).

All of the reticles are visible against a dark color, but we must determine which reticle pattern interfaces best with a brighter background. This means accepting a lighter color which lowers the contrast with the reticle. Those conditions, combined with target acquisition and interference problems, are the basis for the experiment designed around the visual-task evaluator.

A reticle aiming pattern, such as a crosshair, was placed in a condition of focus on the optical bench-VTE arrangement, and presented to the viewer as a bright-colored image, superimposed on the view of the target. The reticles used in this study were of five different patterns, ranging from the conventional crosshair to concentric aiming circles (Fig.2).

To remove parallax from this type of optical system, either the collimating lens or the reticle must be moved until the reticle pattern is sharply focused when viewed through the collimating telescope (1).

The test fixture, a special-purpose holder for the optical components and the VTE device, was fabricated so that the collimating lens and the reticle could be reoriented to either transmitted or reflected mode of view. The reason for using both modes is that the color properties of the beamsplitters can be "flipped". For example, if in the normal, or transmitted mode, the target and surround appear bluish and the reticle reddish; in the reversed, or reflected mode, the target will now be reddish, while the reticle is bluish.

METHOD

Three of the personnel from HEL acted as operator-subjects (Ss). Based on their calibration curves obtained from the operator sensitivity calibration procedures, described in Reference 2, the Ss were assigned a baseline performance value from VL_1 to VL_3 (Appendix A). Cross-checks were run on the calibration equipment to ascertain that operator variability was acceptably low.

All of the Ss had 20-20 vision or corrected-to-20-20 vision; none were impaired by color-defective vision.

The ages of the Ss were 18, 25, and 34 years.

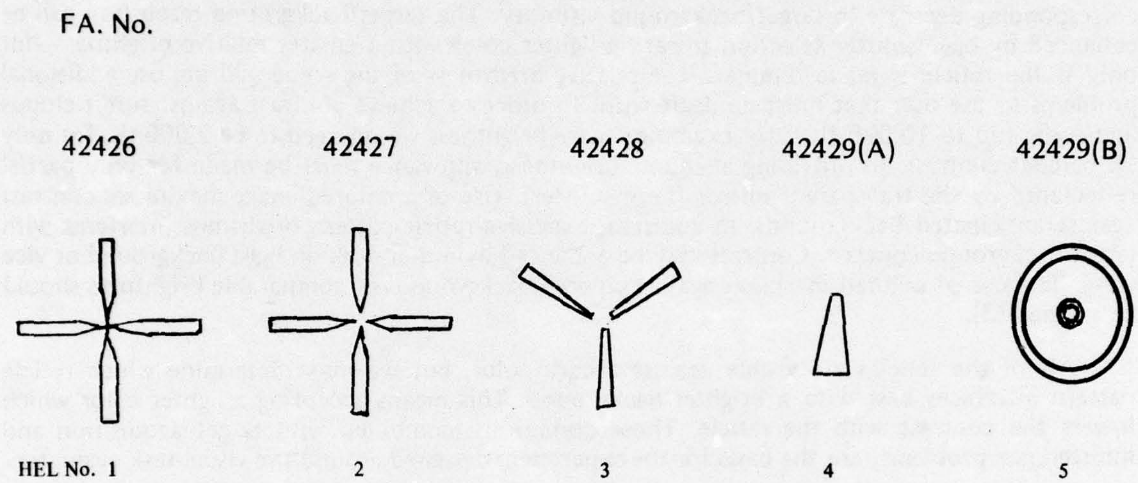

Fig. 2. Reticle patterns as used in the experiment.

This study was designed as a factorial experiment. There were five independent variables in a 3 x 6 x 5 x 3 x 2 design arranged in the following order: Subject x Beamsplitter x Reticle x Range x View.

The sequence followed by the Ss for the complete experiment is shown in Figure 3.

For the evaluation of the beamsplitter and reticle, the VTE was placed in a viewing position that presented an unobstructed field of view of a field from zero to 400 meters.

E-type silhouettes were placed at 100, 200, 300 and 400 meters—offset from the centerline left and right. The targets were placed against various backgrounds; the 100- and 200- meter targets were against light-colored grass that varied from light to dark, and the 300- and 400- meter targets were against normal tree foliage (dark green). The 400-meter target was positioned to bisect a relatively light grass background and dark foliage. It was shaded from noon to evening, whereas the other three targets were exposed to the changing sun angles throughout the day.

The E-type silhouette is a dark olive-drab color which approximates a soldier's uniform in color but not in texture. To prevent bright reflections and more closely approximate real targets, the silhouettes were covered with olive-drab fatigue shirts, except for the 400-meter target, which was covered with a khaki-colored shirt to enhance detection.

The VTE was set up to look through the beamsplitter as a rifleman would. A precision photometer (8) was introduced into the test to measure the light level of the target and the area immediately surrounding it. Each reading consisted of the mean of three samples.

The optical components were placed in front of the VTE in a test fixture that duplicated the essential features of the proposed sight (Fig. 4).

Each of the four targets was viewed by a pair of Ss working as a team, and each member acted as a data recorder for the other to preclude the possibility of bias from reading his own results on the VTE output and contrast controls. The two S teams obtained readings through six optical beamsplitters, viewed in the transmitted and reflected modes, each of which was viewed in conjunction with five aiming reticles (Fig. 3).

Photometric readings were taken simultaneously with the first, third, and fifth readings of the output (f1) and contrast (VL) controls of the VTE in order to determine any gross variance in ambient light level that might occur during the time taken obtaining a reading.

A datum obtained through the VTE represents a mean of five readings per S, for: (1) brightness level—in foot-lamberts—and (2) visibility levels—in VL units. The readings of visibility levels were weighted by the S's individual calibration curve.

It soon became apparent that a level had to be established for the low limit of task luminance. A reading obtained of the background luminance, as measured by the VTE, had to be greater than 250 fLs in order to see the 300- and 400- meter targets at all. Readings from 500 fLs down to 250 fLs were marginal. These readings occurred under extremely cloudy, dark conditions. Brighter readings were usable even with moderate precipitation.

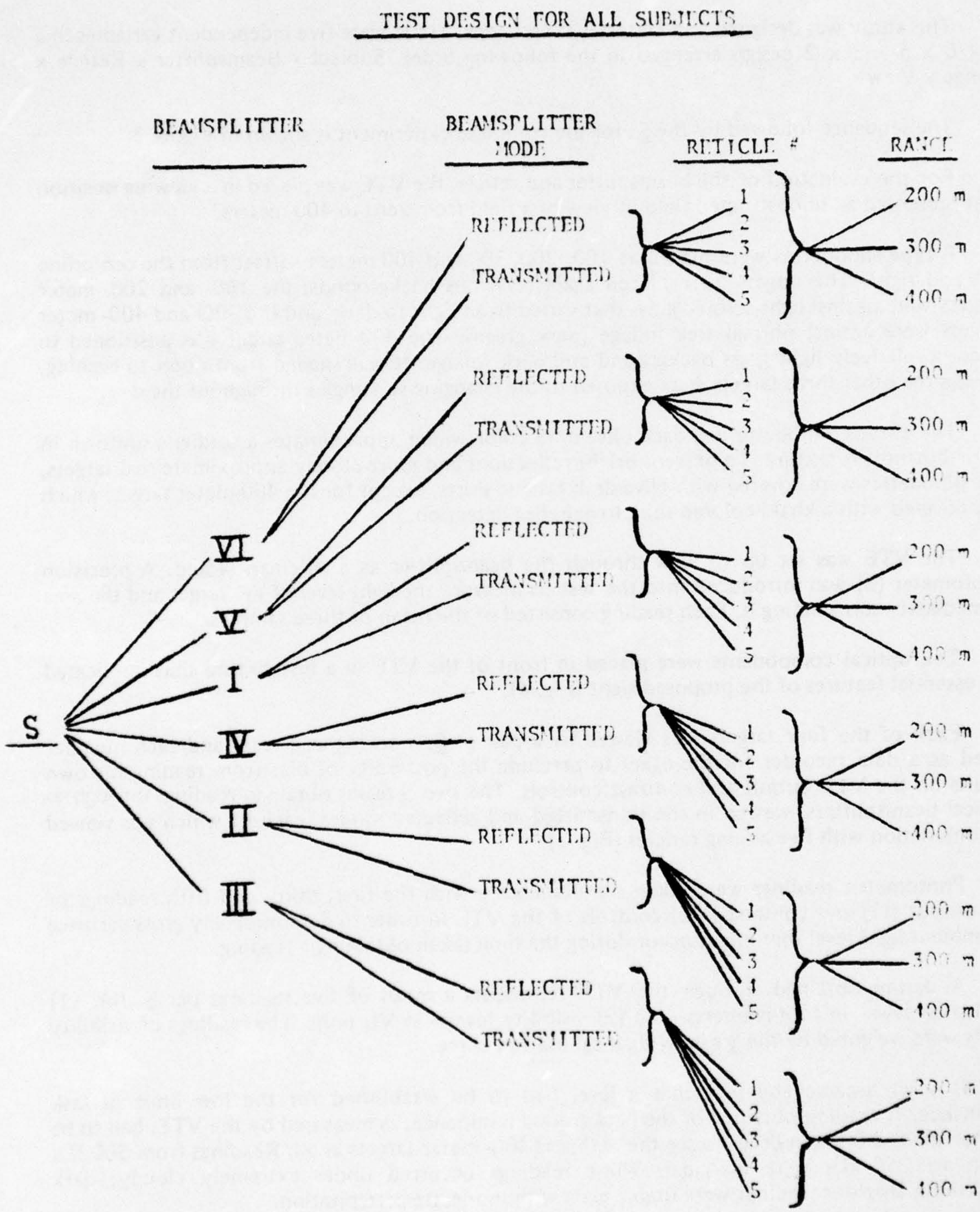

Fig. 3. Table of test design.

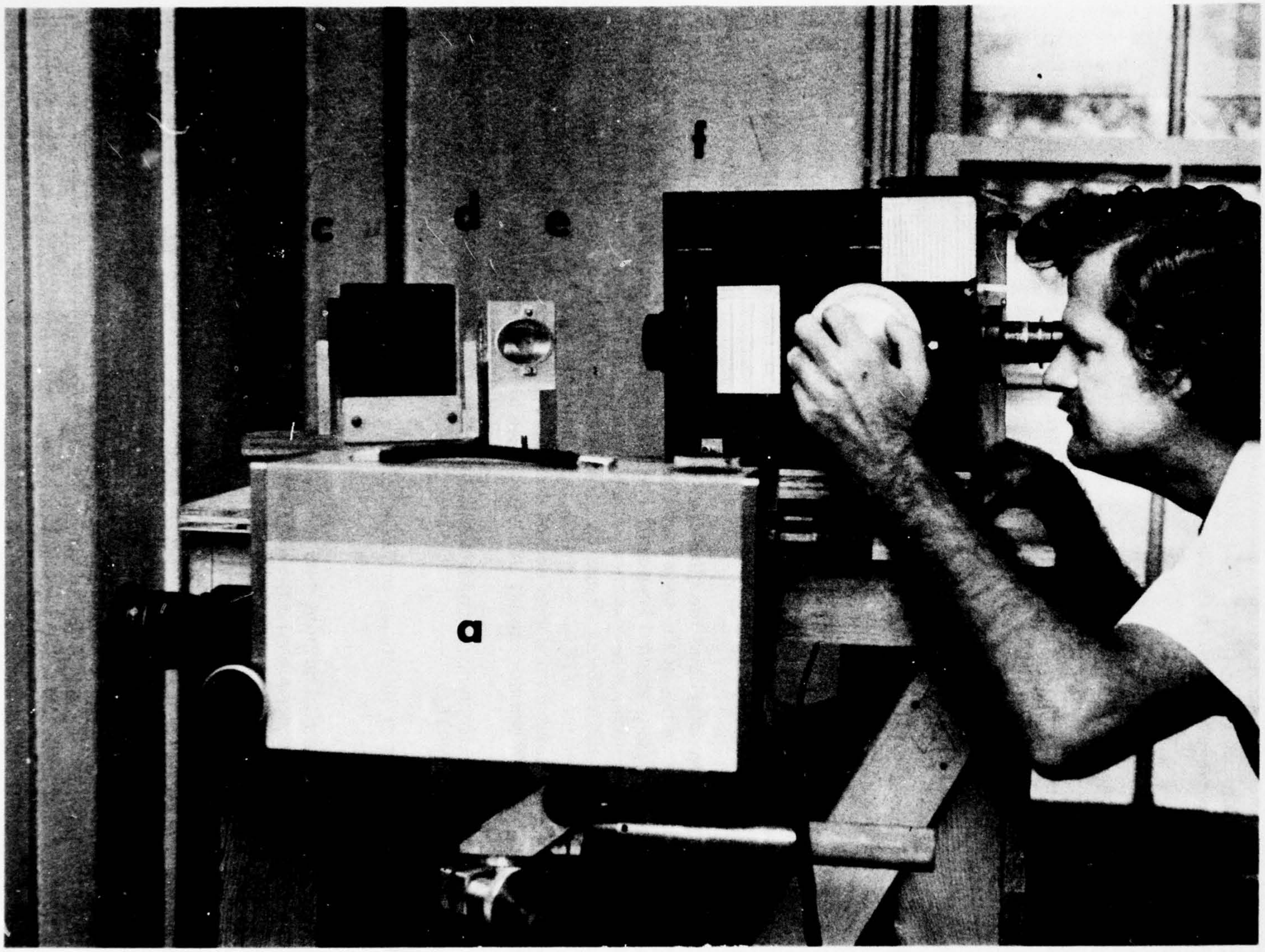

Fig. 4. Test apparatus (a-photometer, b-reticle, c-surface mirror, d-coll. lens, e-beamsplitter, f-VTE).

The 100-meter target remained easily visible under all conditions of light levels and optical component arrangements. Since the time required for the experiment turned out to be longer than expected, and the perception of the 100-meter target did not appear to be affected much by the test conditions, we removed it from the test.

RESULTS AND DISCUSSION

Means and standard deviations of the dependent variable, as measured in units of visibility level, were grouped by test condition.

The results of the test indicate that the visibility levels were influenced by the combined effects of the beamsplitters, reticles, and range.

The results (Figs. 5-18) represent readings of 200-, 300-, and 400-meter targets taken at luminance levels greater than 250 fLs.

The effect of range on the visibility levels for all beamsplitters, reticles, views, and Ss indicate little difference between 300 and 400 meters. For analysis purposes, the results of the 300- and 400- meter targets were summed over the frequency of their readings and designated as "Range 2." The 200-meter data are referred to as "Range 1."

Differences between khaki and the olive-drab target colors seemed to have little effect on the results. Luminance readings of the target surfaces taken at the same time of the VL readings indicate differences typically about 17 percent. The VTE operator variability of 25-30 percent would easily mask the luminance variance which makes up the key components of both color-contrast and threshold visibility. Research concerning the effects of neutral density filters used in conjunction with the VTE in bright daylight indicates that colors or their respective wavelengths are altered toward the darker end of the visible spectrum. Consequently, a dull color such as khaki or olive-drab will not exhibit an easily discernible color-difference.

All beamsplitters' performance in combination with each reticle across all test conditions are shown in Figures 5 through 16.

The combined effect of all reticles, in VL units, for each beamsplitter for all test conditions are shown in Figures 17 and 18.

Varying ambient light conditions had no consistent effect on the VL readings. The combined effects of the independent variables show that, for mean VLs, the best performing beamsplitters were:

HEL 6 (red)

HEL 3 (yellow-orange)

HEL 1 (blue)

HEL 5 (blue-green)

In the reflected mode, range 1 treatment:

Beamsplitter 6, viewed in conjunction with reticles 1 through 4, produced VLs of > 20, reticle 5 produced a VL of > 10 (Fig. 10). The I.E.S. recommended visibility level for 99 percent visual accuracy is 8 (Appendix A).

In the transmitted mode, range 1 condition:

Beamsplitter 3, used in conjunction with reticles 3 and 5, produced VL readings of 25 or greater, and reticles 1 and 2 produced VLs approaching 15 (Fig. 13).

Beamsplitter 5 produced VLs of 10 to 20 across all reticles (Fig. 15), and Beamsplitter 6 produced VLs of 12 to > 25 across all reticles (Fig. 16).

It should be noted that some reticle-caused differences of VL readings were a result of obscuration and not because of relative brightness of the reticle-background interface.

For example, a bright reticle pattern such as HEL Test No. 1 (Fig. 2) could yield good color contrast against a moderately bright background. However, the broad lines as well as the horizontal arrangement would interfere with target search or acquisition; the converging lines that make up the main sight picture all but obscure a man-like target at ranges greater than 200-meters. Reticle No. 2, while having the same thick line and pattern orientation as No. 1, does not suffer from the obscuration of the target by the center of the converging lines. Reticle No. 3 has three thin, tapered lines oriented 120 degrees apart; it offers good target acquisition with little interference. The center is open, resulting in a positive sight picture on small or distant targets. Reticle No. 4 consists of a large, vertical, tapered post, similar to a front blade sight picture; however, the top is as broad as a man-sized target at 300-400 meters. This would obscure most of the target and add to the aiming error. Reticle No. 5 consists of two concentric aiming circles that have a slight interference effect on target acquisition. This reticle has a good sight picture out to 200-meters, but beyond that the center circle obscures the defined edges of the target.

The effect of range on reticle performance across all independent variables in units of visibility level was: 13 to 17 VLs for range 1; for range 2, the only reticles that came close to visual performance criterion of VL_8 (Appendix A) were reticles 1 and 2.

The mean of the $\underline{S}$s' performance for the complete test agreed with the visual performance criterion of VL_8:

8.8 for $\underline{S}$ No. 1

7.4 for $\underline{S}$ No. 2

8.8 for $\underline{S}$ No. 3

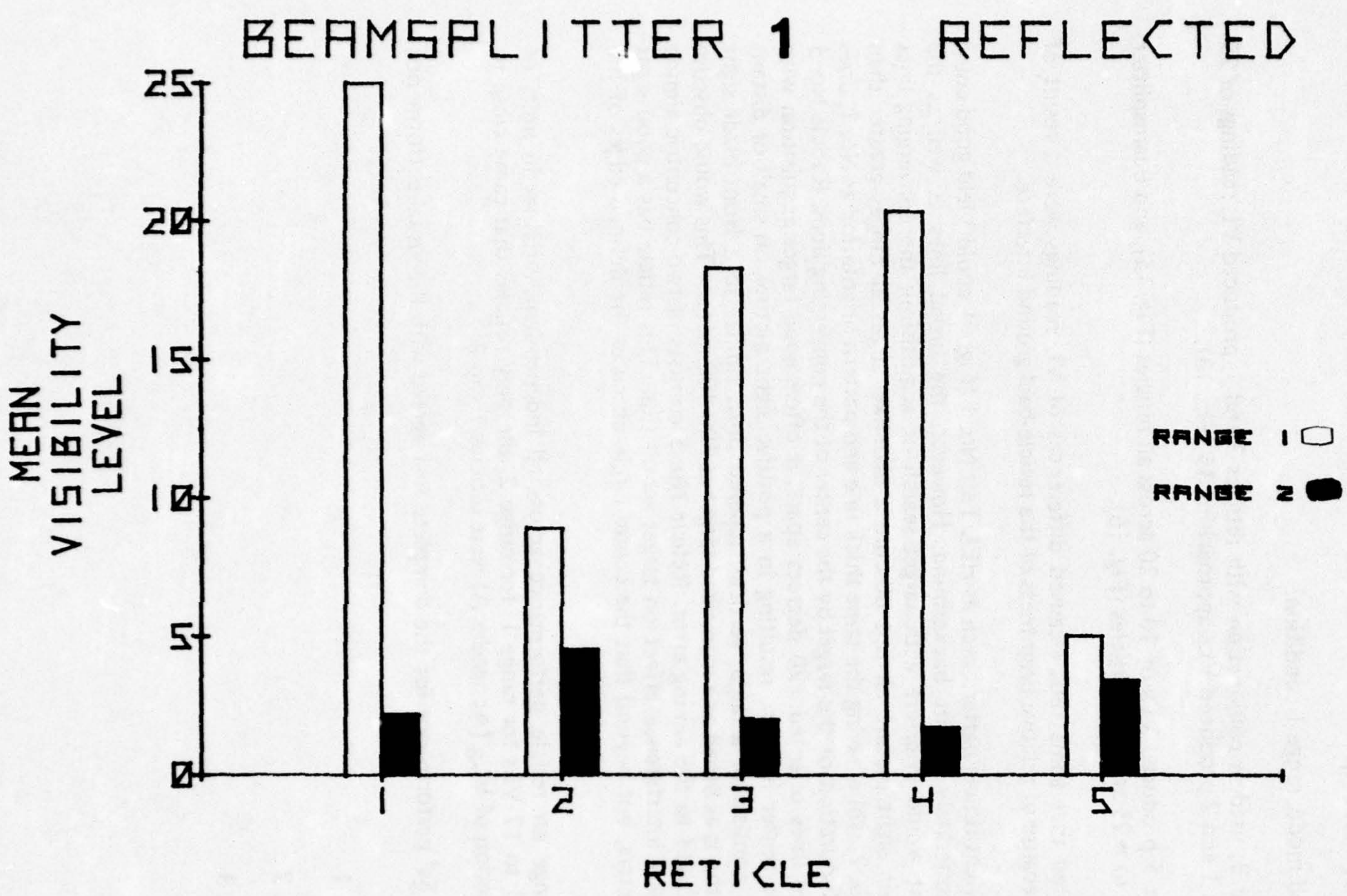

Fig. 5. Mean visibility levels of individual beamsplitter as affected by reticles and range in the reflected mode—Beamsplitter 1.

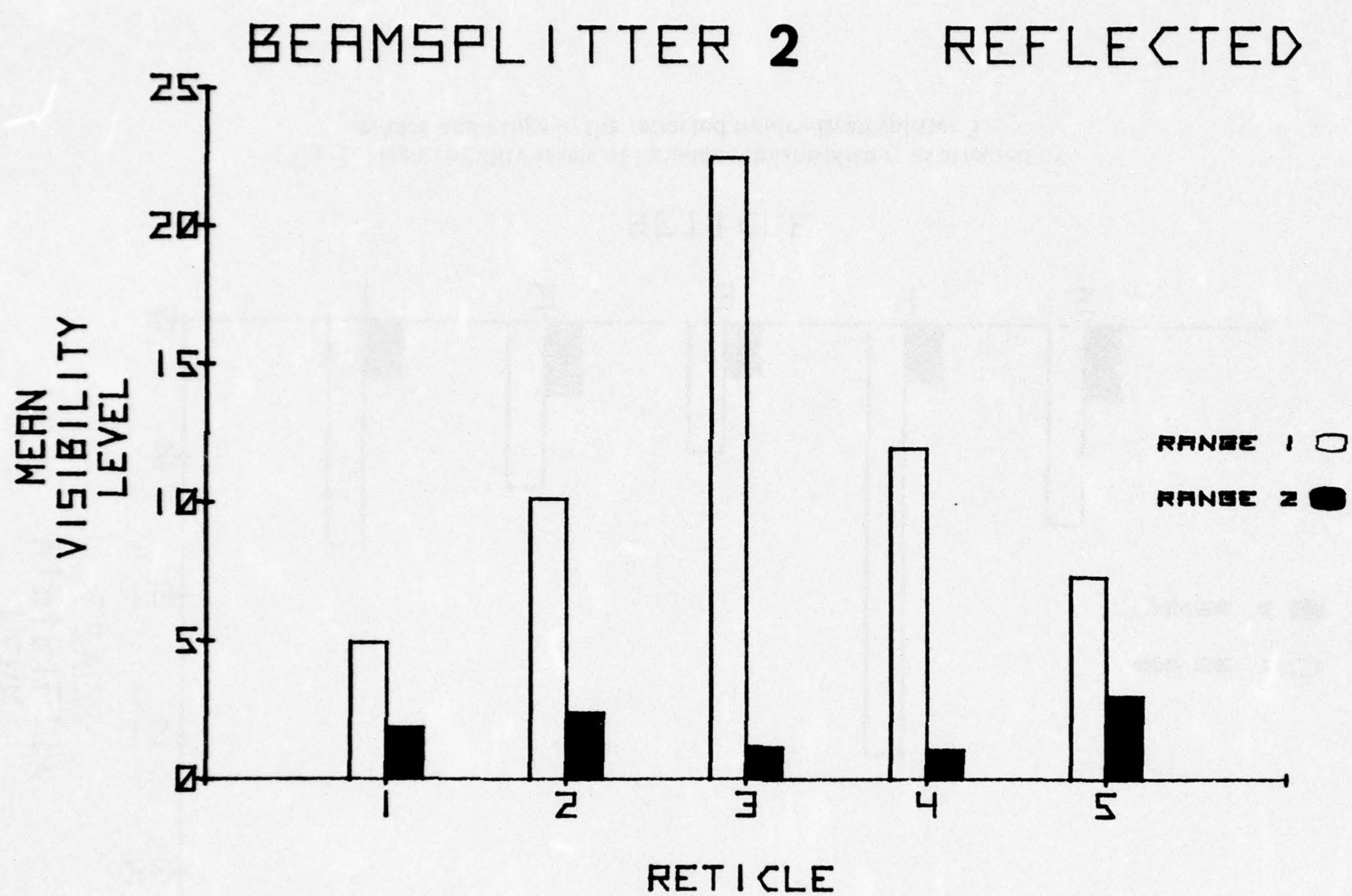

Fig. 6. Mean visibility levels of individual beamsplitter as affected by reticles and range in the reflected mode—Beamsplitter 2.

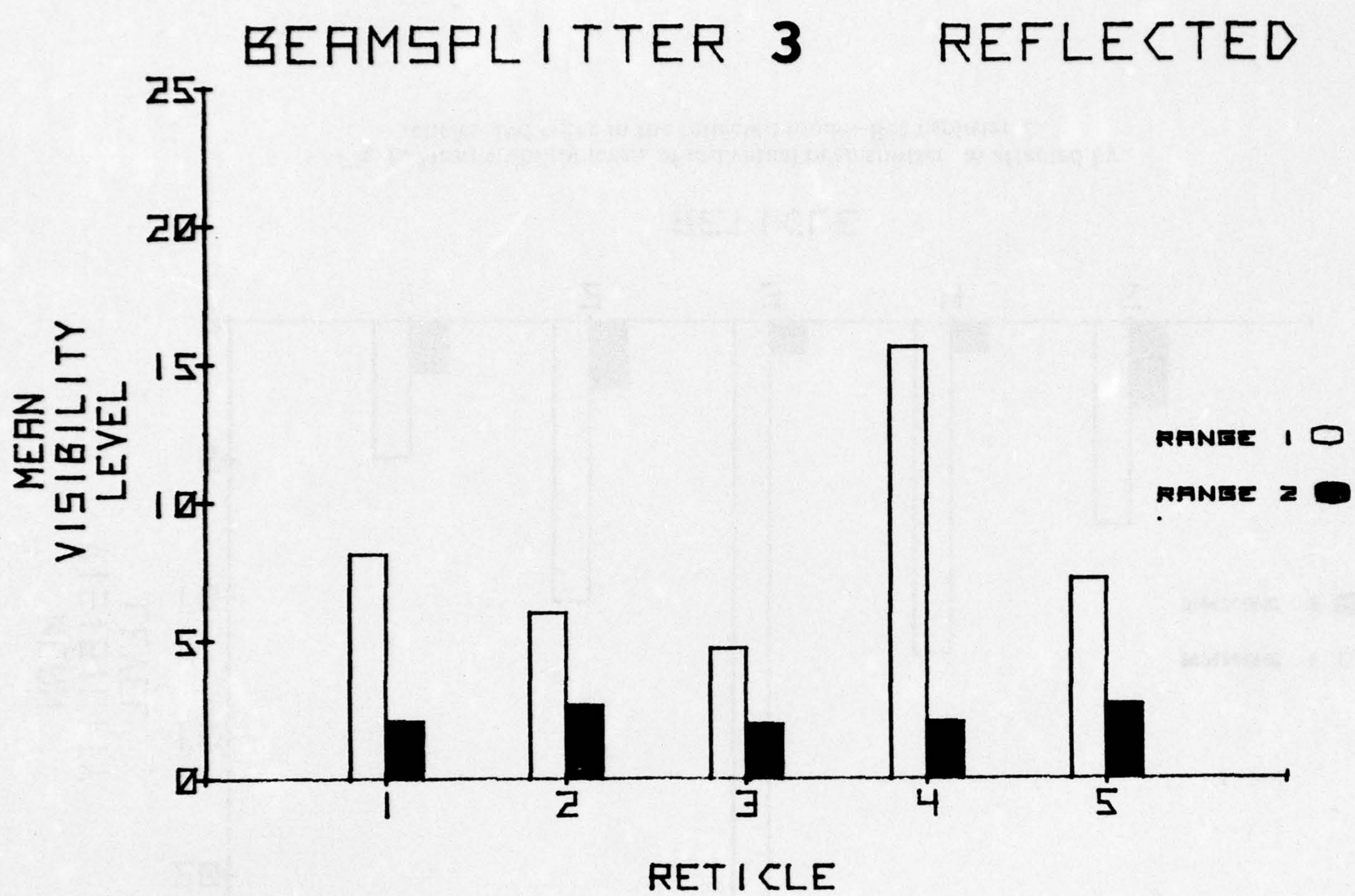

Fig. 7. Mean visibility levels of individual beamsplitter as affected by reticles and range in the reflected mode—Beamsplitter 3.

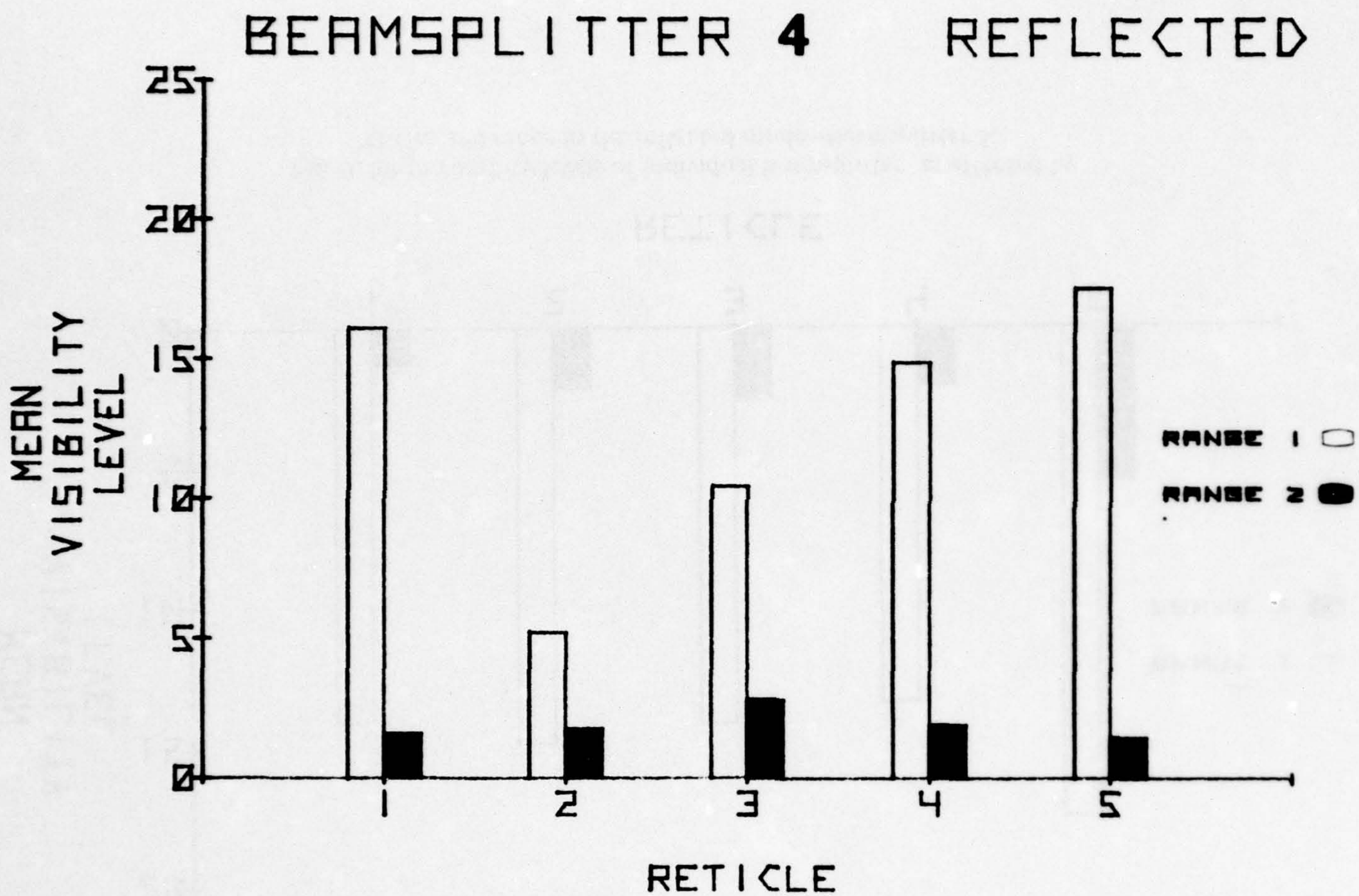

Fig. 8. Mean visibility levels of individual beamsplitter as affected by reticles and range in the reflected mode—Beamsplitter 4.

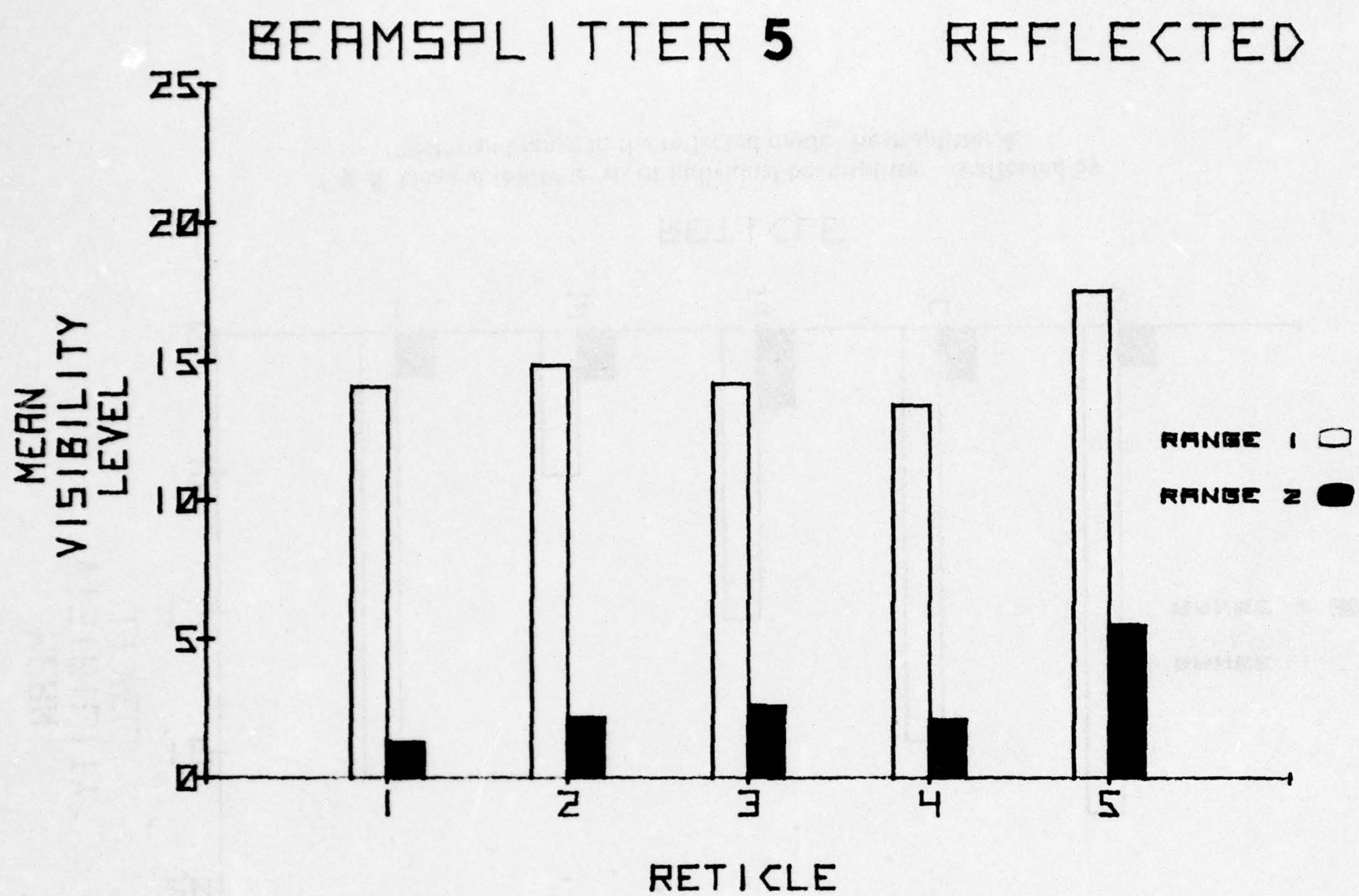

Fig. 9. Mean visibility levels of individual beamsplitter as affected by reticles and range in the reflected mode—Beamsplitter 5.

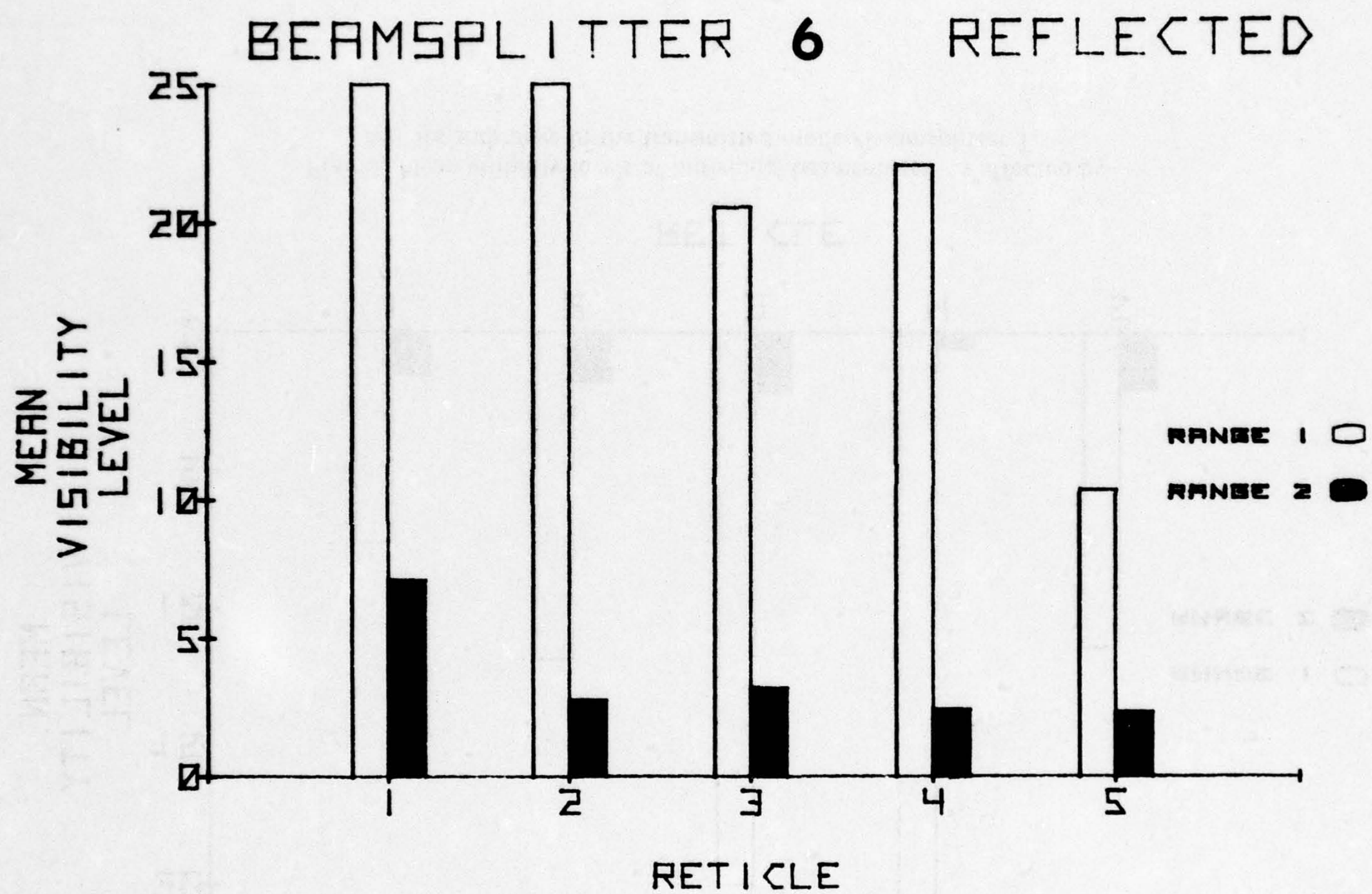

Fig. 10. Mean visibility levels of individual beamsplitter as affected by reticles and range in the reflected mode—Beamsplitter 6.

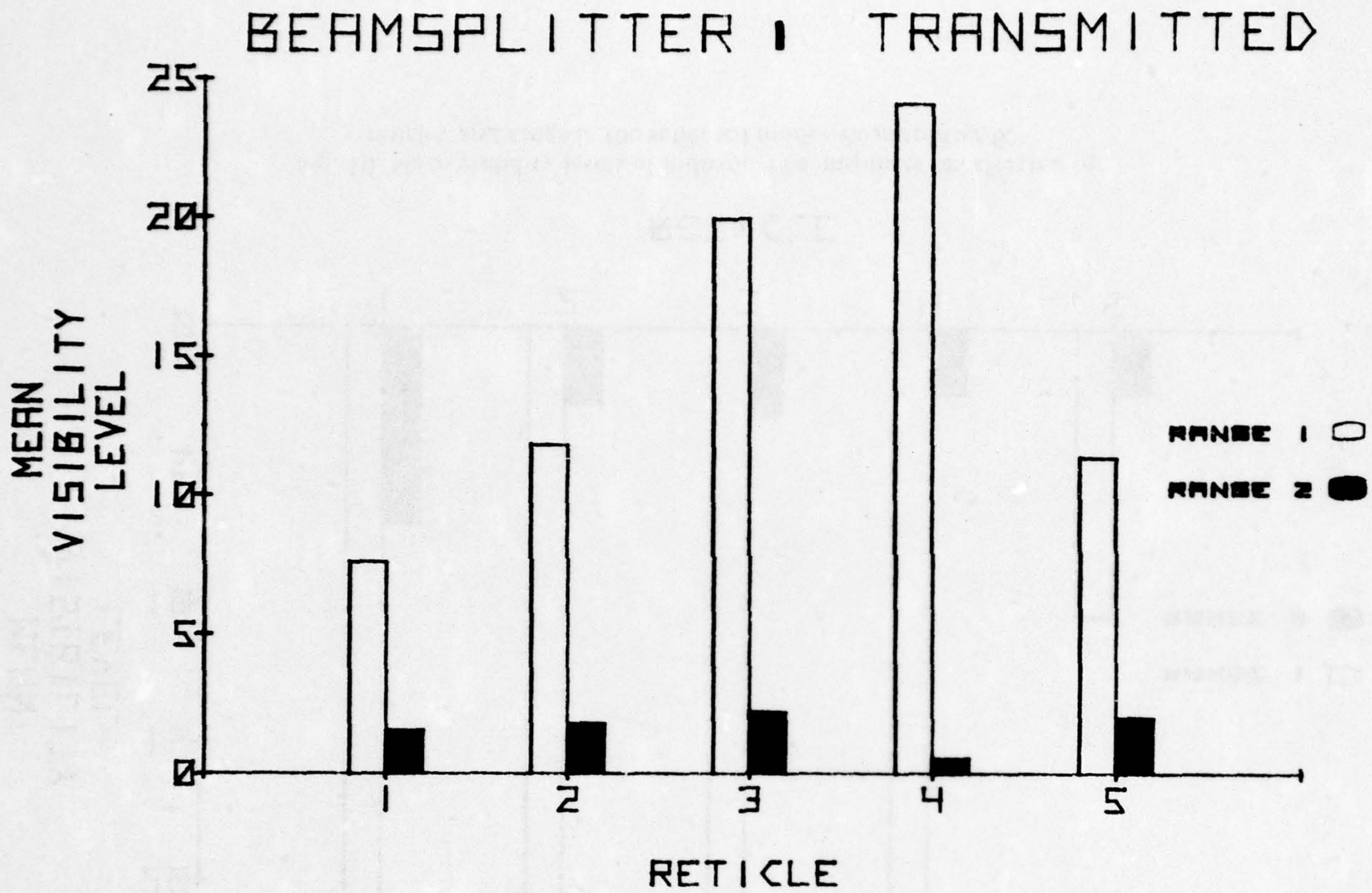

Fig. 11. Mean visibility levels of individual beamsplitter as affected by reticles and range in the transmitted mode—Beamsplitter 1.

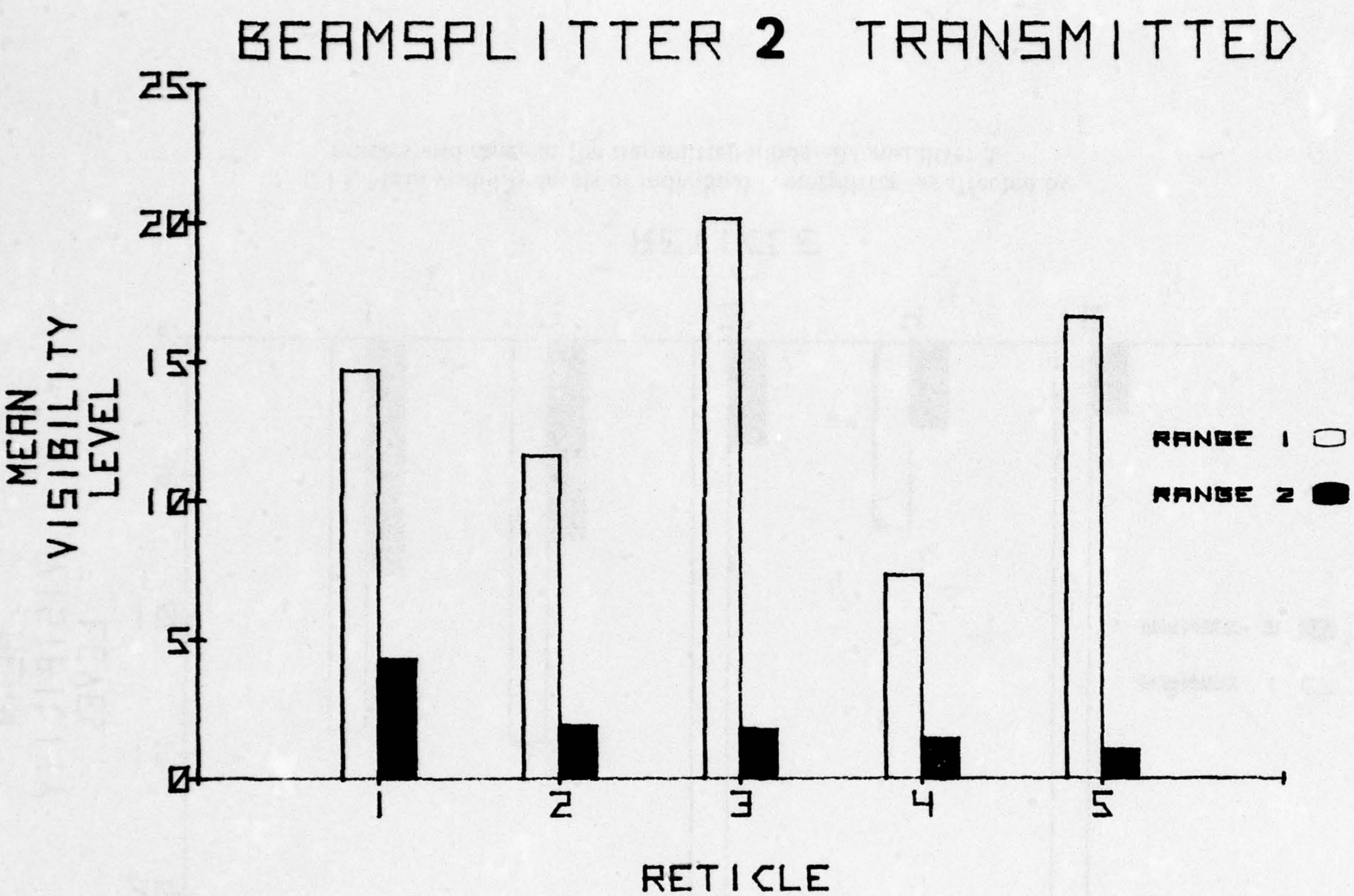

Fig. 12. Mean visibility levels of individual beamsplitter as affected by reticles and range in the transmitted mode–Beamsplitter 2.

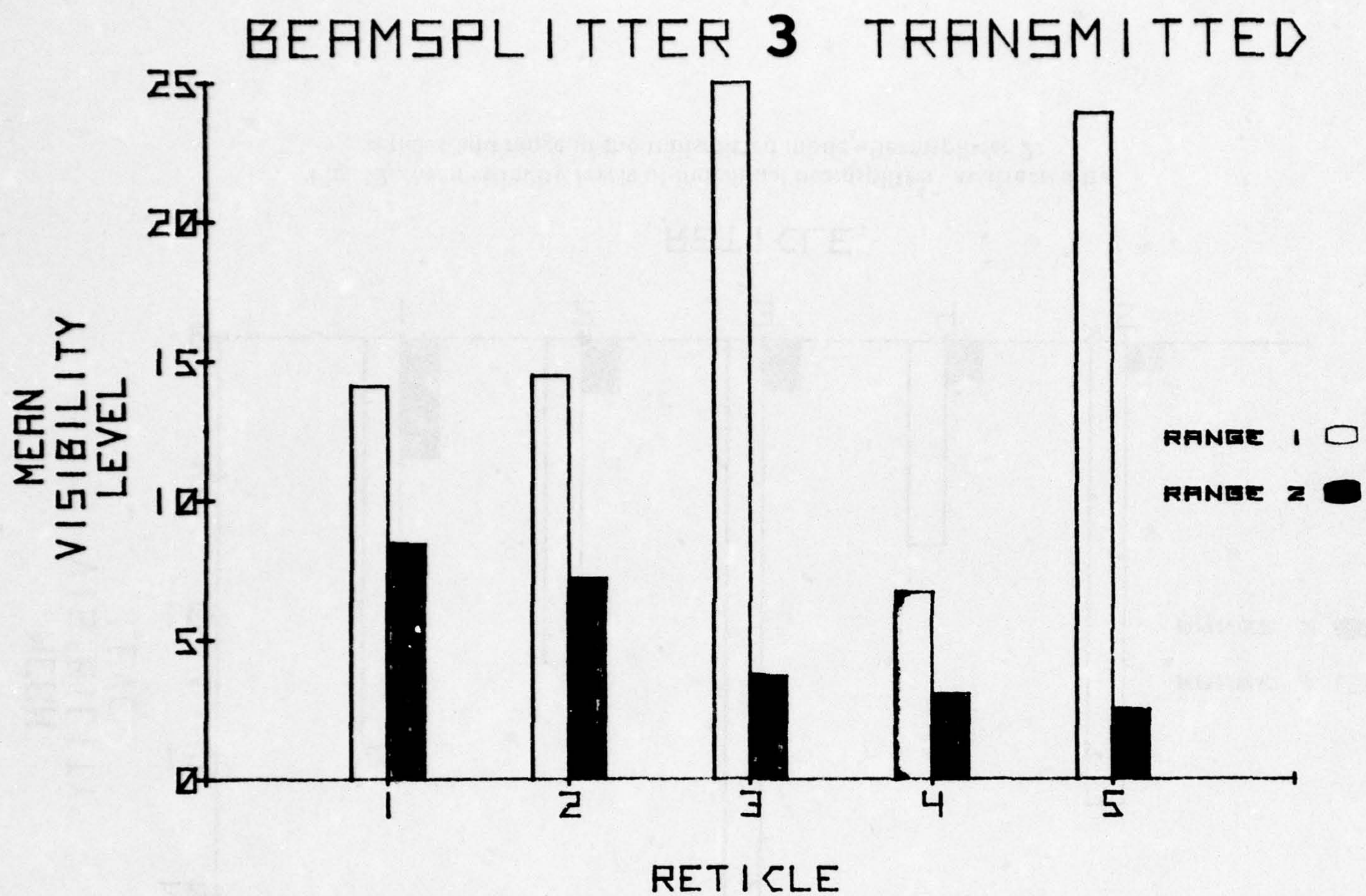

Fig. 13. Mean visibility levels of individual beamsplitter as affected by reticles and range in the transmitted mode—Beamsplitter 3.

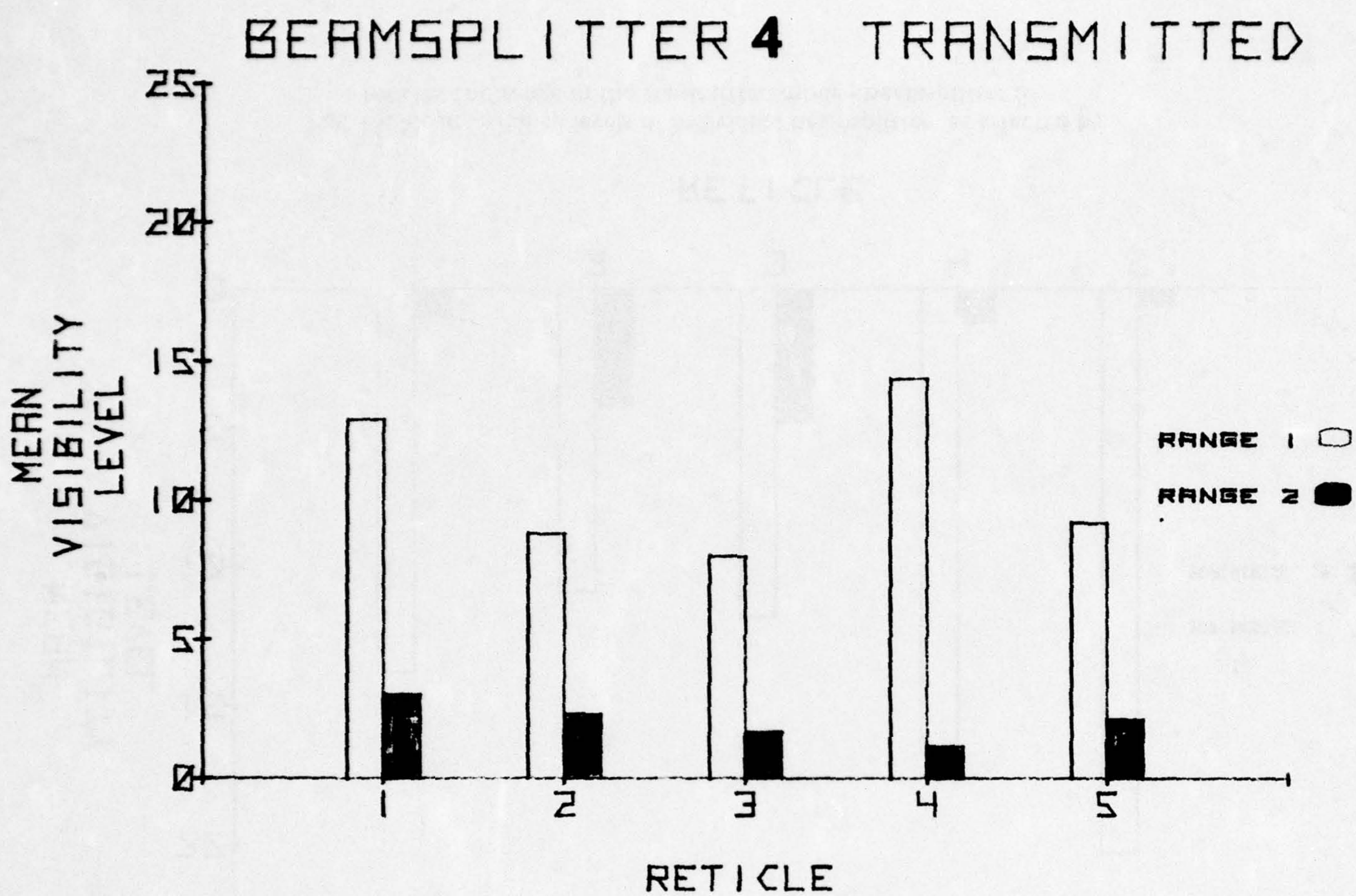

Fig. 14. Mean visibility levels of individual beamsplitter as affected by reticles and range in the transmitted mode—Beamsplitter 4.

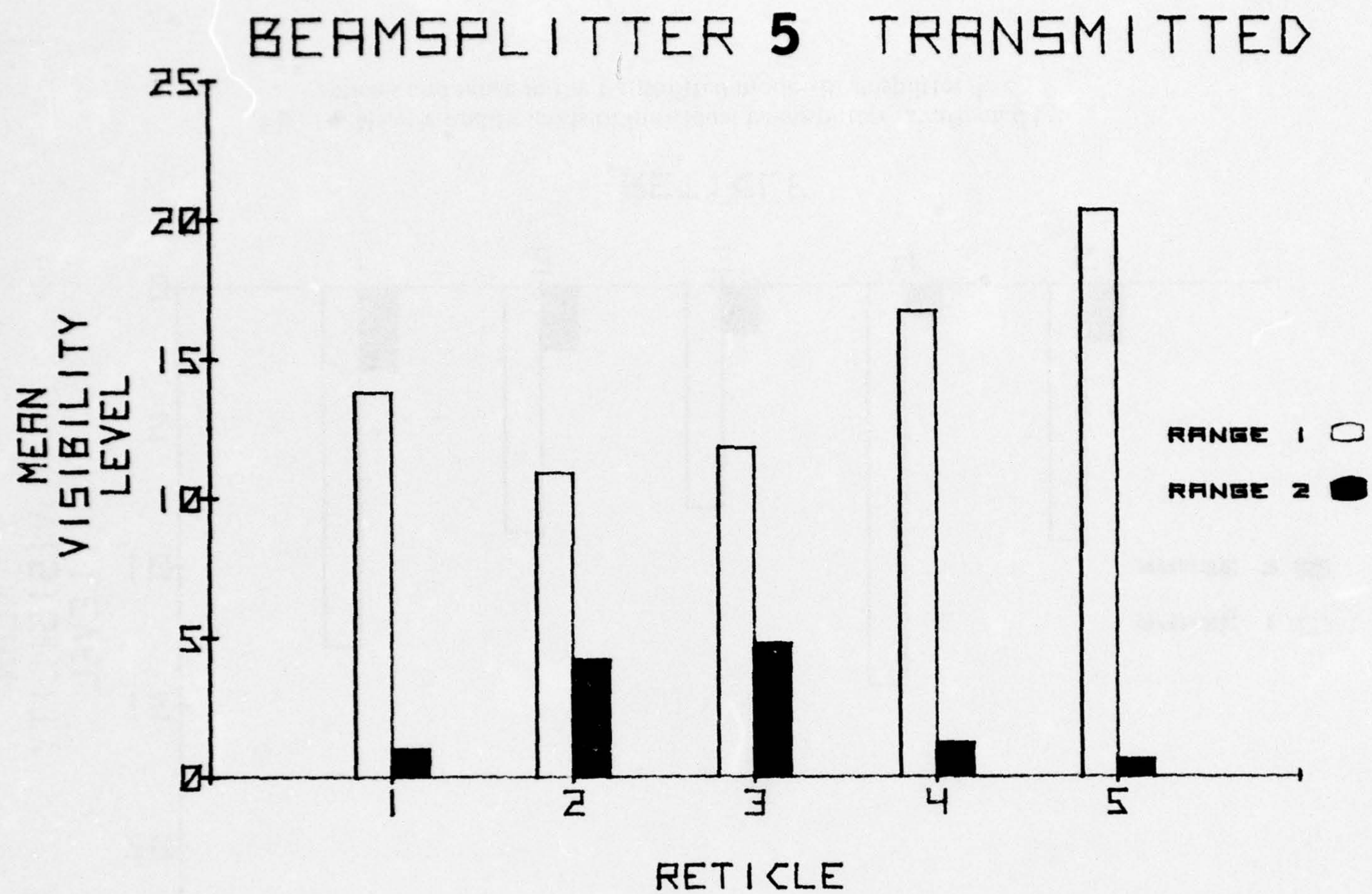

Fig. 15. Mean visibility levels of individual beamsplitter as affected by reticles and range in the transmitted mode—Beamsplitter 5.

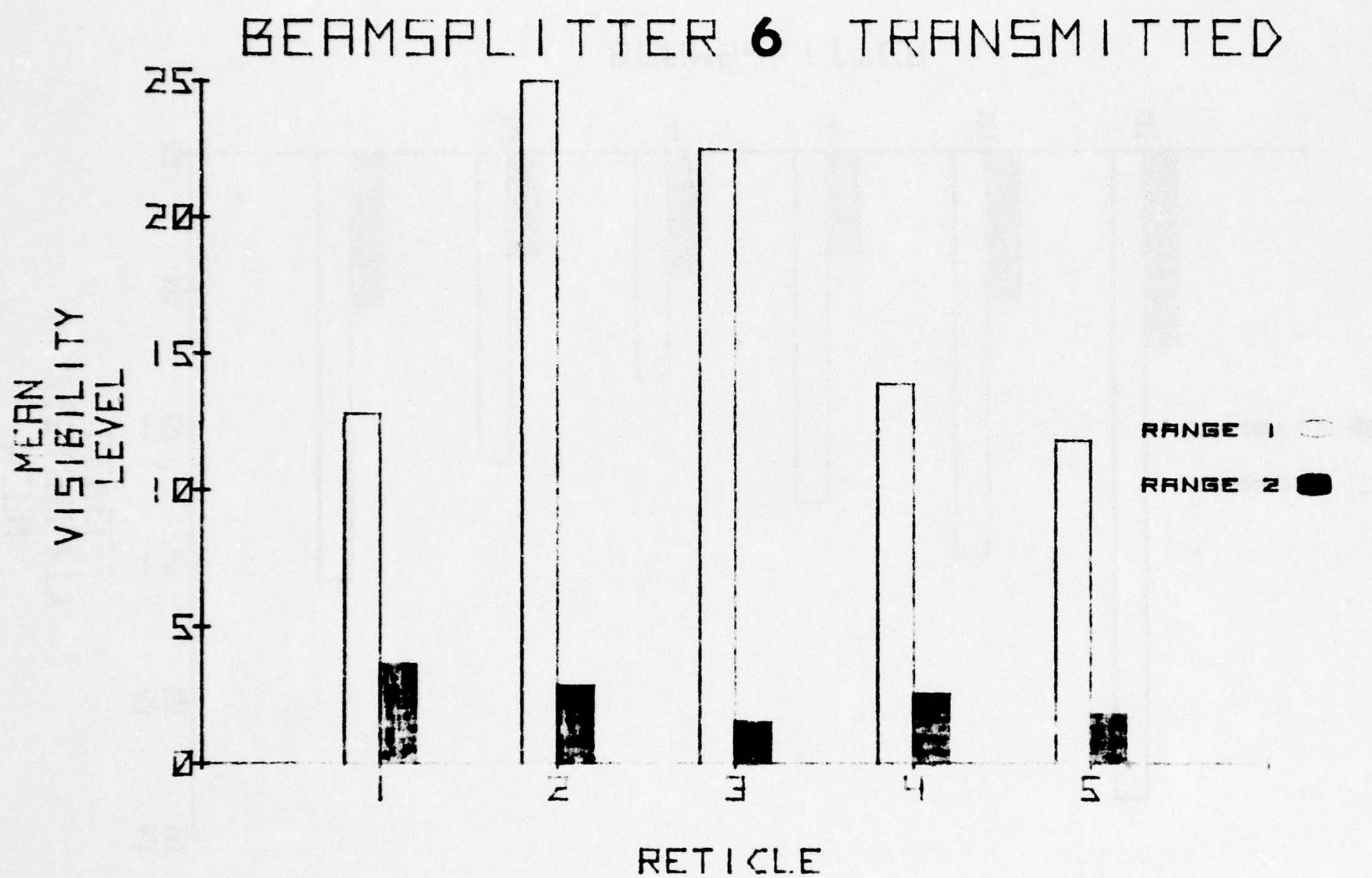

Fig. 16. Mean visibility levels of individual beamsplitters as affected by reticle and range in the transmitted mode—Beamsplitter 6.

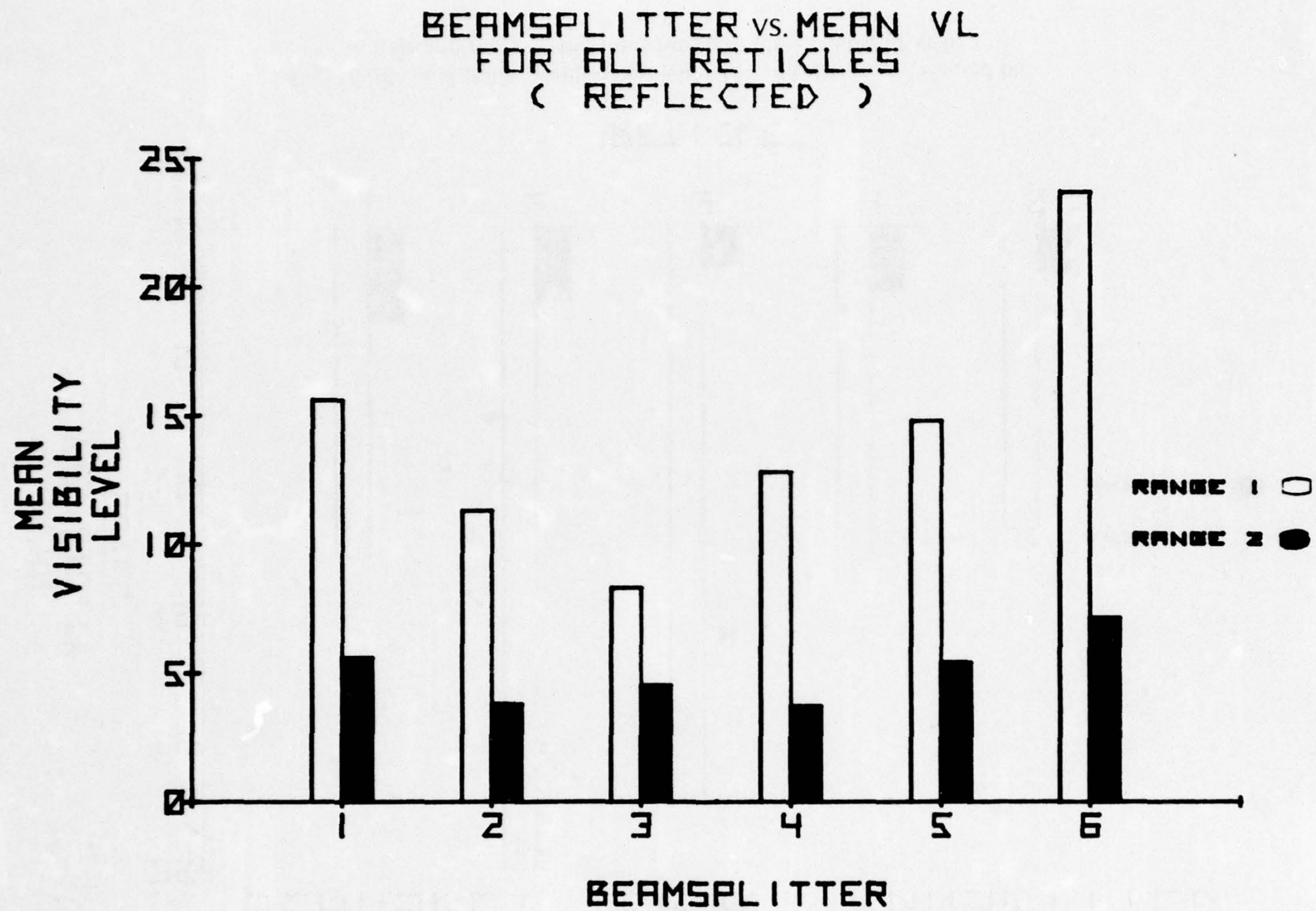

Fig. 17. Mean visibility level versus beamsplitter for all reticles by range (reflected).

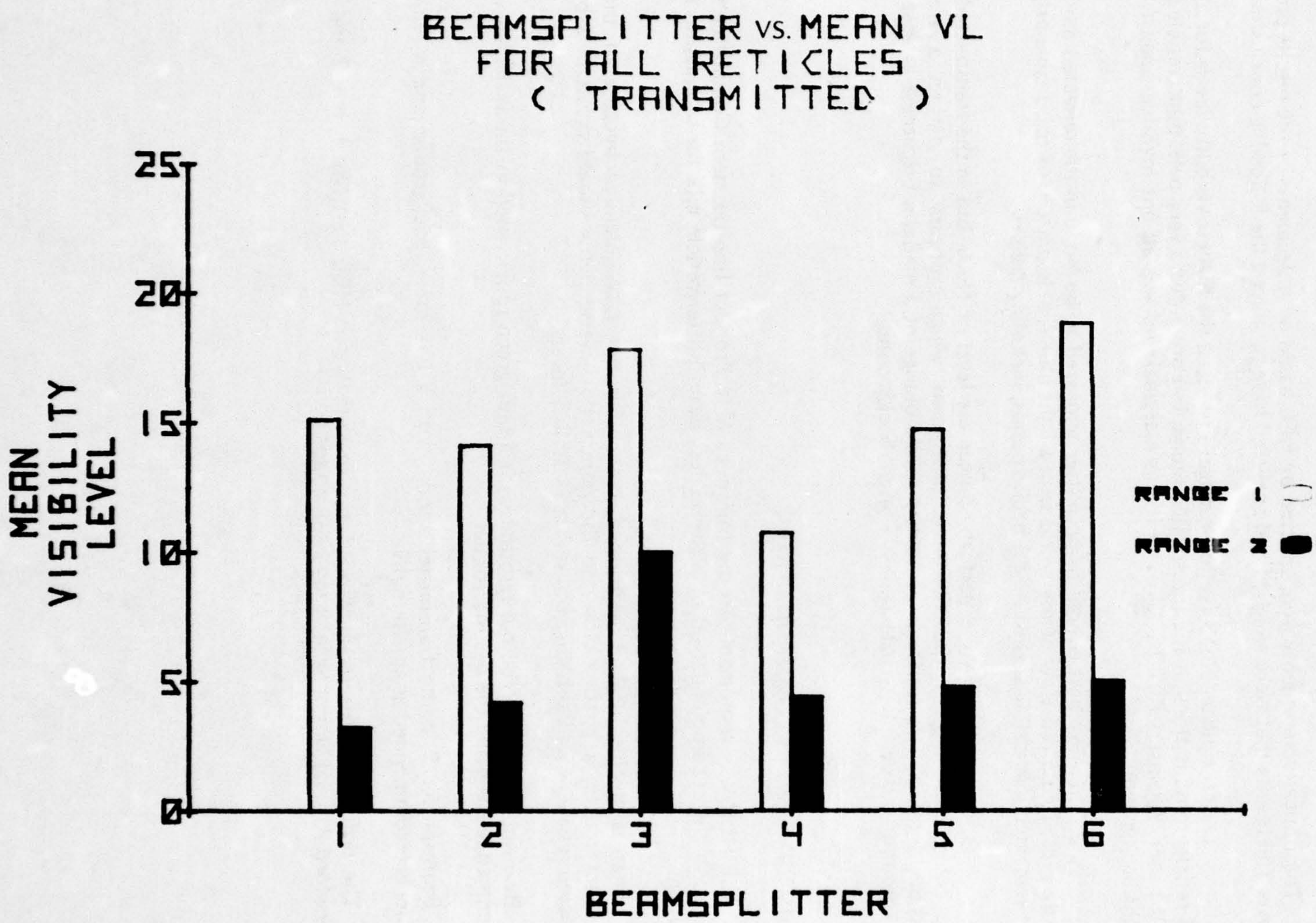

Fig. 18. Mean visibility level versus beamsplitter for all reticles by range (transmitted).

CONCLUSIONS

The optical components were selected by HEL based on judgements of the results presented above. The results that were weighed and analyzed have produced the following conclusions:

1. Beamsplitter No. 3 (yellow-orange) produced the highest visibility levels for all range and reticle combinations in the transmitted mode, but presented a very pale pink reticle pattern to the user. Against a dark background it was marginal and was all but invisible against a light, bright background.

2. The next best overall beamsplitter appeared to be No. 6 in the reflected mode. This mode presented a red view of the world with a light blue reticle pattern of reasonable brightness that remained just visible against bright backgrounds, including the sky.

3. Beamsplitter No. 5 performed near the level of No.6, but in the transmitted mode. The color presented to the viewer is blue-green which appears to darken a tree- and grass-background. The reticle is presented as red-orange of a medium brightness against a dark background, and definitely pale against a bright background.

SUMMARY AND RECOMMENDATIONS

The HEL was responsible to the Improved M16 Product Improvement Committee for the evaluation and recommendation of a five or less beamsplitter/reticle mix for submission to Fort Benning.

Whereas Beamsplitter 3 performed best, it is not recommended because of the pale, indistinct reticle; a coating closer to the pure yellow wavelengths should result in a brighter reflected reticle as well as higher transmitted visibility levels.

Beamsplitter 6, the red background with a blue-green reticle used in the reflected view, is recommended as being the best performer.

Beamsplitter 5 in the transmitted mode, with a blue-green background and a red-orange reticle, is recommended as an alternative.

The reticle patterns recommended are, in rank order: HEL Test No. 1, No. 2 and No. 3. (Frankford Arsenal Nos. 42426, 42427 and 42428).

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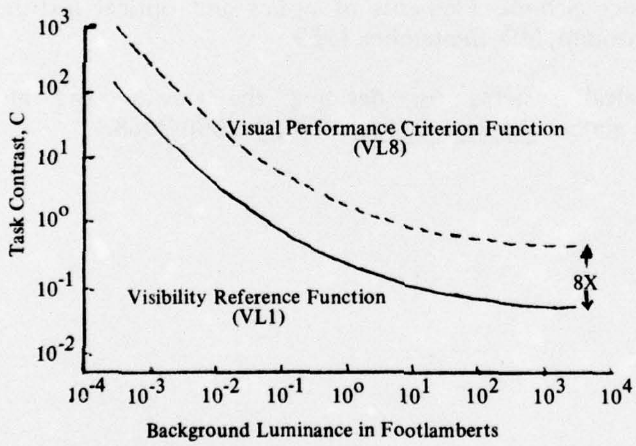
APPENDIX A

THE UNIT OF VISIBILITY, VL

Values of VL units obtained by the VTE are called visibility levels. By definition, the visibility level of an object describes its degree of super-threshold visibility, with threshold taken as unity, VL_1. Threshold visibility is the point at which the presence of the object of interest (the visual task) is just detectable.

The visibility level is a function of two variables—task contrast and background luminance. All visibility levels are defined relative to the Visibility Reference Function shown by the solid line in Figure 1. This curve is the data for observers in the 20-30 year age group and shows the task contrast they required at different levels of task background luminance to achieve threshold visibility for a 4-minute-of-arc luminous white disk exposed for one-fifth second against a gray background. This curve is called VL_1 and serves as the absolute reference. All other levels are represented by curves constructed parallel to the reference curve and are displaced along the vertical axis by the Visibility Level Numeral. For example, VL_8 (8 being the numeral of contrast multiplier) is the dashed curve constructed parallel to VL_1 and displaced up the vertical scale by a factor of 8. The locus of all points of VL_8 represent 8 times the task contrast of threshold visibility.



The visibility level of VL_8 corresponds to the task in which all the potential for completing a visual task exists, if humans could perform as a perfectly efficient "seeing machine." Under the actual conditions of seeing, we seldom fully utilize the capacity of our eyes. The visibility level of VL_8, as defined by the IES, is the criterion level of Visual Performance Potential and, as such, is the minimum prescribed for "good" visibility.