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MAY 1974

LAW ENFORCEMENT STANDARDS PROGRAM

SIMPLIFIED PROCEDURES FOR EVALUATING THE IMAGE QUALITY OF OBJECTIVE LENSES FOR NIGHT VISION DEVICES

NILE & CJ
STANDARDS PROGRAM

U.S. DEPARTMENT OF JUSTICE
Law Enforcement Assistance Administration
National Institute of Law Enforcement and Criminal Justice

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SIMPLIFIED PROCEDURES FOR EVALUATING THE IMAGE QUALITY OF OBJECTIVE LENSES FOR NIGHT VISION DEVICES

prepared for the
National Institute of Law Enforcement and Criminal Justice
Law Enforcement Assistance Administration
U.S. Department of Justice

by

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FOREWORD

Following a Congressional mandate* to develop new and improved techniques, systems, and equipment to strengthen law enforcement and criminal justice, the National Institute of Law Enforcement and Criminal Justice (NILECJ) has established the Law Enforcement Standards Laboratory (LESL) at the National Bureau of Standards. LESL's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

In response to priorities established by NILECJ, LESL is (1) subjecting existing equipment to laboratory testing and evaluation and (2) conducting research leading to the development of several series of documents, including national voluntary equipment standards, user guidelines, state-of-the-art surveys and other reports.

This document, LESP–RPT–0304.00, Simplified Procedures for Evaluating the Image Quality of Objective Lenses for Night Vision Devices, is a law enforcement equipment report prepared by LESL and issued by NILECJ. Additional reports as well as other documents will be issued under the LESL program in the areas of protective equipment, communications equipment, security systems, weapons, emergency equipment, investigative aids, vehicles and clothing.

Technical comments and suggestions concerning the subject matter of this report are invited from all interested parties. Comments should be addressed to the Program Manager for Standards, National Institute of Law Enforcement and Criminal Justice, Law Enforcement Assistance Administration, U.S. Department of Justice, Washington, D. C. 20530.

Lester D. Shubin, *Manager*
Standards Program

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*Section 402(b) of the Omnibus Crime Control and Safe Streets Act of 1968, as amended

1. INTRODUCTION

The purpose of this document is to describe two methods for determining the comparative image quality of objective lenses intended for use on night vision devices (NVDs) for law enforcement applications. Rankings produced by these tests on a sample set of lenses of various types have correlated well with the corresponding rankings obtained by modulation transfer function (MTF) methods. These test methods are not being proposed as replacements for the MTF methods. They are intended to be simple tools by means of which the ultimate user of NVDs can compare lenses supplied on NVD units to other lenses which he contemplates using on NVDs. An example of the use of these methods would be the determination of the suitability of a particular photographic lens for use with a particular NVD which has an NDV lens. In this case, the test procedures provide methods for comparing the image quality produced by the NVD when using the photographic lens to the image quality produced with the NVD lens. The test data will allow the user to rank the image quality of the photographic lens with respect to the NVD lens, thereby providing an indication of the suitability of the photographic lens for use on that particular NVD.

The simpler of the two tests is a single target test, designated the "low contrast resolution test" (LCRT). It is simple to perform, informative, and ranks lenses by the same initial criterion as the more complex test. The latter is an eight target "variable contrast resolution test" (VCRT) which provides better overall evaluation and can assess the relative image quality of lenses which show the same level of performance on the single target LCRT test. The criterion for evaluating the lenses in these tests is the limiting resolution at a particular contrast level or the limiting resolution as a function of contrast. The tests do not address other factors that could influence image quality such as veiling glare, lens transmittance, lens distortion, and curvature of field.

The principle of the variable contrast resolution test (VCRT) is identical to that of the low contrast test method (LCRT) except for the differences in the test targets and in the procedures for evaluating the test data.

The LCRT test was modified from the VCRT test when the data indicated that the much faster LCRT single-target test would produce the same ranking of NVD lenses with large differences in image quality as the more time consuming VCRT test. The VCRT test is better in ranking relative performance of NVD lenses which show small differences in image quality (resolution figures which differ by less than 10 to 12 percent).

The tests are designed for testing lenses for their suitability for one use: as objectives on NVDs with S–20 extended red response (ER) photocathodes. These are the types used on first generation NVDs commercially supplied to law enforcement agencies.

There are three classes of lens which may be used with night vision devices: NVD lenses, photographic lenses, and television lenses.

True NVD lenses are those which have been specifically achromatized for use at the longer wavelengths which predominate in NVD lighting conditions. Their performance has been optimized for use at maximum aperture. They provide flat fields of view which subtend relatively restricted angles. Veiling glare has been minimizee and performance has been maximized at spatial frequencies between zero and 40 line pairs per mm.

Photographic lenses have design requirements which are quite different from those of true NVD lenses. Their superficial similarities arise from common focal length, aperture, and in some cases, mechanical mounting requirements. Photographic lenses in general are not achromatized for use at NVD wavelengths, but at 432 and 589 nanometers. They are not designed for optimum performance at maximum aperture, but at about three steps smaller than maximum aperture. In general, they have much larger values of veiling glare and provide maximum performance at high resolution frequencies. Such lenses, while often recommended for NVD use, may suffer very drastic reductions in performance with the S–20 ER photocathode. Most photographic lenses cover much larger angular fields than are required by NVDs and performance near the center of the field may be sacrificed to achieve this. In general, photographic lenses must be assumed to provide poor performance on NVDs unless tests have shown otherwise.

Television lenses are designed for use on relatively low resolution camera tubes with S–10 response. As such, they suffer all of the defects of photographic lenses in general, plus the fact that original design requirements on resolution were not as stringent as on photographic lenses. Their achromatization will be different than for NVD lenses. They should be considered as not suitable for NVD use unless appropriate tests of performance have shown otherwise.

2. DEFINITIONS

2.1 Curve, Contrast

A graph showing the relation between target contrast percent and image resolution in line pairs per millimeter.

2.2 Curve, Focus

A graph showing the relation between image plane position and lens resolution for a particular target. The graph is used to positively show that the resolution test has been performed with the film in the position providing maximum lens, resolution for the target distance used.

2.3 Contrast, Percent (C%)

Percent contrast of the target is defined by the following equation, where T is the transmittance of a transparent bar target. T_{min} is the bar transmittance, and T_{max} is the background transmittance.

$$C\% = \frac{T_{max} - T_{min} \times 100}{T_{max} + T_{min}}$$

2.4 Emulsion 3414

A high definition aerial reconnaissance film, whose resolution is so high that the resulting image resolution is primarily a function of lens performance. Its spectral sensitivity is a reasonable match to that of the S–20 ER photocathode. Eastman Kodak Emulsion 3414 has been found to have a combination of spectral sensitivity, resolution, modulation transfer function, and lack of processing sensitivity which is adequate for this use. Any other film being considered as a substitute must be carefully tested to ensure its suitability.

2.5 Illuminant A, CIE

An easily obtained standard source of luminous and radiant energy with characteristics known to a high degree of accuracy. It has been widely used as the illumination source for testing night vision devices and is the source specified for the tests in this document. From such a source, the illumination includes all of the radiation (luminous and radiant) emitted by a glass bulb incandescent tungsten filament lamp operated at a color temperature of 2856 Kelvin. In addition to its luminious output, it is high in infrared energy and thus approximates the natural sources of light which provide the energy for NVDs when used under normal nocturnal natural illumination.

Currently available 100 watt inside frosted tungsten filament lamps, commonly used for interior lighting, approximate this source when operated at the proper filament temperature.

2.6 Magnification

The ratio of the image length to the object length.

2.7 f-Number

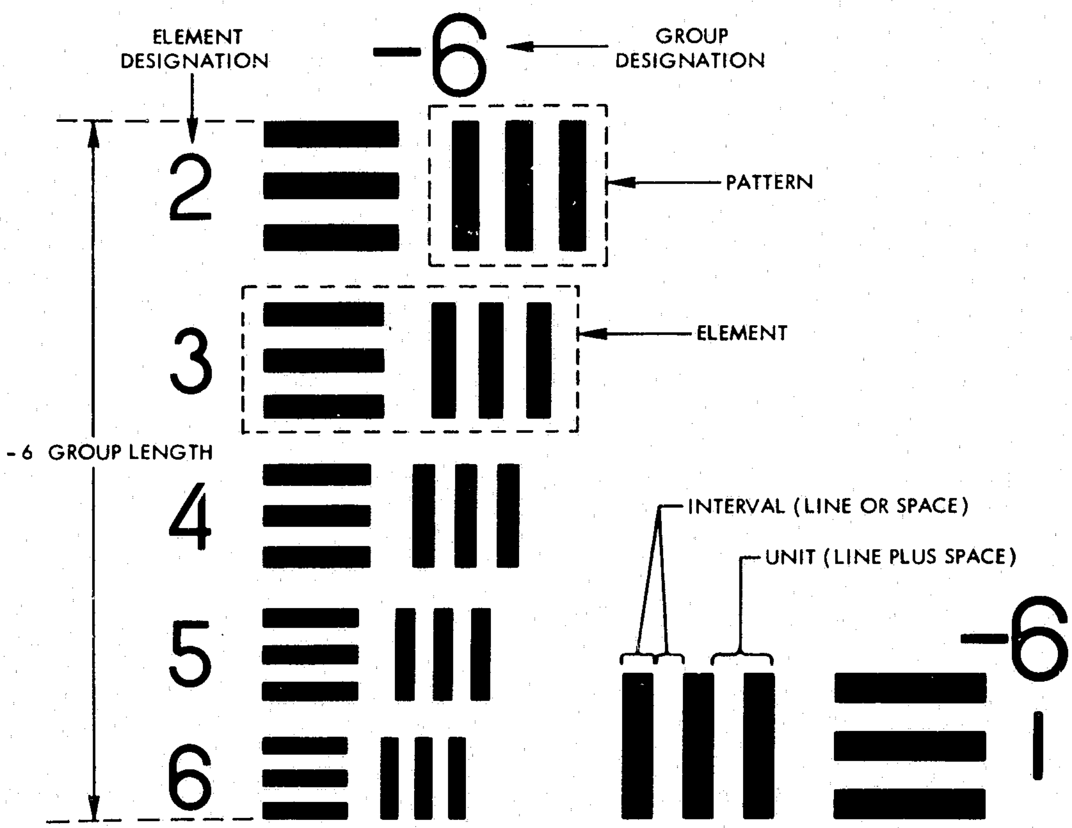
The ratio of the focal length of a lens to the diameter of its entrance pupil (apparent size of the diaphragm opening).

2.8 T-Number

The f-number of the theoretical perfect lens (which has no transmission or reflection losses) which produces the same image brightness as the subject lens. An f/2.0 lens which transmits one-half of the total energy it receives (because of absorption and reflection losses) has a T-number of f/2.8 and produces the same energy in the image as a "perfect" f/2.8 lens.

2.9 Target, Bar (Resolution)

A type of pattern used as a subject when performing resolution tests according to the methods outlined in this document. The chart consists of a three bar pattern, with the nomenclature indicated in figure 1. The standard Air Force 1951 type target is used. A pattern consists of three lines and two spaces of equal width with the line length equal to five line widths. An element consists of two patterns, one of vertical lines and one of horizontal lines. A group consists of six elements with the width of each unit (line plus space) in adjacent elements varying by the factor of the sixth root of two. The largest element of any group will have a two to one size ratio to the largest element of the next higher or



RESOLUTION GROUP MINUS SIX SHOWING APPLICABLE TERMINOLOGY

FIG. 1. Terminology Applicable to Air Force Type Resolution Chart.

lower numbered group. The actual spatial frequency of any element on the target is given by the formula:

$$R = 2^{(K + (N-1)/6)}$$

where R is the number of lines per mm on the target (one line comprises one line plus one space), K is number of the pattern, and N is the element number of the pattern.

2.10 Test, Low Contrast Resolution (LCRT)

A variation of the VCRT which makes use of only one chart of 25 percent contrast. The relative performance of lenses on subjects of this contrast has been found by test to have a significant correlation to the overall performance of the lens as judged by the total area under the MTF curve between zero and 40 line pairs/mm.

2.11 Test, Variable Contrast Resolution (VCRT)

A modified form of the traditional photographic resolution test. It makes use of a series of eight negative transparencies of the resolution test chart, with the contrast of the charts varying in uniform steps from 6 percent to 98 percent. The test output is a curve of subject contrast versus resolution in line pairs/mm.

3. LOW CONTRAST RESOLUTION TEST (LCRT)

The low contrast resolution test consists of recording and evaluating the image of a standard three-bar resolution chart, having contrast of 25 to 30 percent, and containing groups from −4 to +1, inclusive. The recording and evaluating conditions are standardized. The procedure is primarily intended as a comparison test to be performed by the lens user for evaluating his own equipment and judging the result by reference to the performance of a lens known to be satisfactory.

3.1 Comparative Performance

Due to the comparative nature of the LCRT, lenses to be tested should have focal lengths and maximum apertures that are not widely different. The focal length of the lens being tested should not differ by more than ±30 percent from the focal length of the reference lens. The maximum aperture of the lens being tested should not differ by more than one stop from the maximum aperture of the reference lens. All tests and resolution figures should be based on using the lens at its maximum aperture.

For the LCRT test, a reference NVD objective lens which is known to provide satisfactory performance is useful as a starting point. This should be tested initially by the same procedure used for the sample lens to be tested. Comparison of the results of the two tests will show whether the sample lens has a performance poorer than, equal to, or better than that of the standard used for comparison.

3.2 Test Sensitivity

For resolution differences to be considered significant, the measured difference must exceed 10 percent of the resolution of the reference lens.

3.3 Test Equipment

3.3.1 Test Target

The test target geometry is the standard three bar, Air Force 1951 pattern. The nomenclature shown in figure 1 applies and will be used in all references to the target.

The target size is based upon the requirements for testing lenses with focal lengths of 50mm to 300mm, designed to produce images on 18mm intensifier tubes. The target will have resolution groups −4 through +1. A target with these specifications will require a 28 × 28 cm (11 × 11 inch) area (figure 2). The patterns provide a maximum frequency of 3.6 line pairs/mm and a minimum frequency of .062 line pairs/mm.

The image resolution range available will equal the target frequency divided by the magnification factor. At the required distance this provides image frequencies of 540 line-pairs to 9 line pairs/mm. By using two test distances, this can be varied over the range of 540 to 4 line pairs/mm. This will cover all probable conditions of lens image quality and all of the commonly used focal lengths from 50mm (tested at 150 times the focal length) to 600mm (tested at 75 times the focal length).

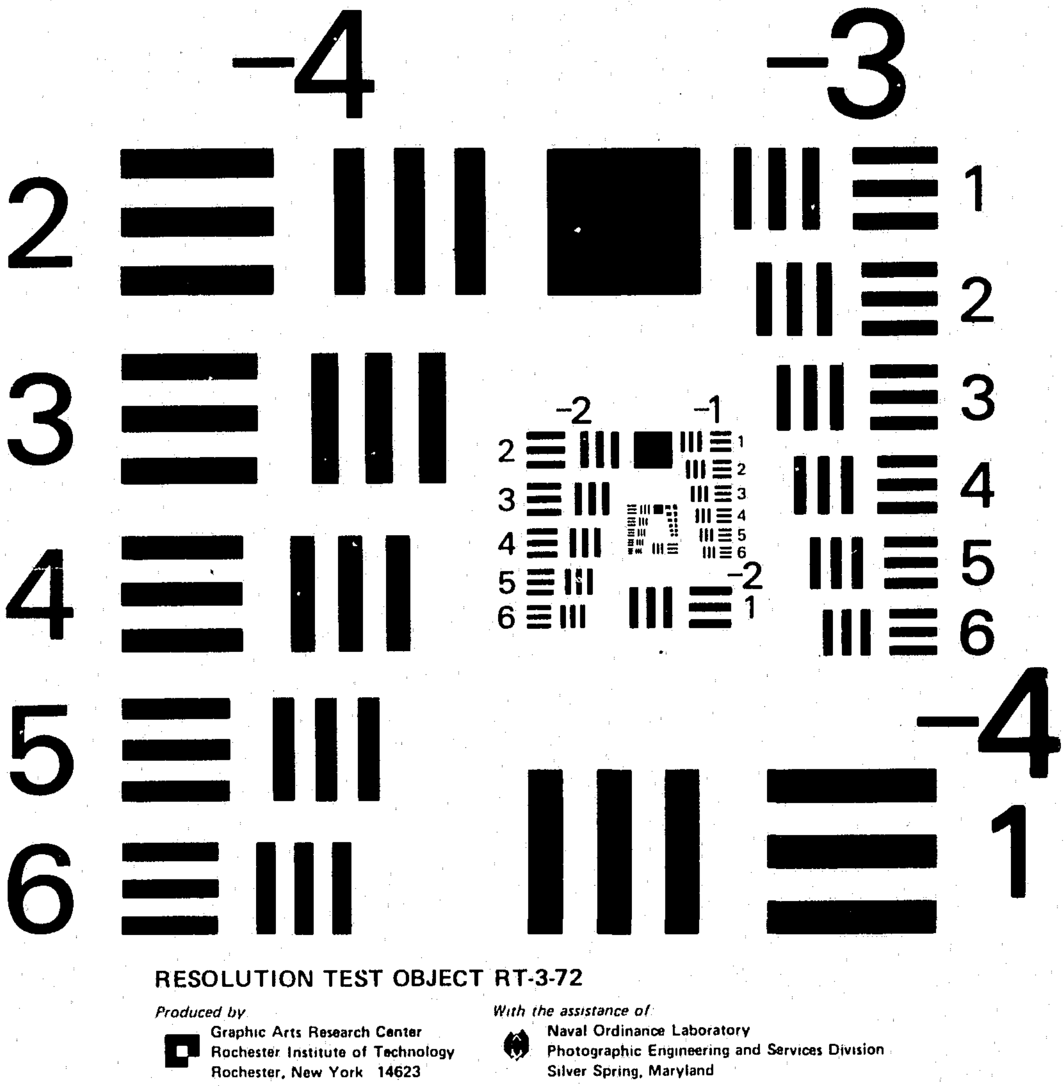


FIG. 2. Air Force Style 1951 resolution target as used for the single target Low Contrast Resolution Test and the eight target Variable Contrast Resolution Test. (Reproduction size is not correct for the group and element numbers.)

The test target should be a negative of the chart shown in figure 2, that is, it should have transparent bars on a denser background and should preferably be on a glass plate with rear illumination. The diffuse density difference between the bars and the background should be approximately 0.22–0.27 to provide a contrast to 25–30 percent when calculated by the formula in 2.3.

The orientation of the identifying numbers on the target element should read correctly when viewed from the glass side of the target. The target should be mounted with the emulsion in contact with the smooth (unground) side of a sheet of photographic quality, fine ground glass and the edges bound with mounting tape. The ground glass should have a density uniform over the full face to within ±.02 to assure uniform target illumination.

3.3.2 Illumination Equipment

The target should be uniformly illuminated with a tungsten source whose effective output is equivalent to CIE Illuminant A, Color Temperature 2856 K. This can be accomplished by proper use of filters, by controlling the filament current, or by a combination of these methods. The color temperature requirement assumes no serious attenuation of the long wave output of the tungsten lamp by the filter or target. Liquid filters must not be used to control color temperature.

The level of target illumination is not critical but should be uniform to ±15 percent. The level should provide convenient exposure times on the recording film at the apertures normally encountered. For apertures ranging from f/1.0 to f/4.0 (a 16:1 range in exposure), light levels of 0.5, 2.0 and 8.0 foot lamberts (measured at the transparent portions of the target) are convient, keeping exposures in the 15 second range. Neutral density filters of the photographic type should not be used as a means of light level control. Any filter used must have uniform attenuation between 300 and 1000 nanometers. Gelatin and many photographic filters do not. An inside frosted lamp approximately 76 cm (30 inches) from the target, with a variable size aperture in front of the lamp, permits a 30:1 change of illumination level without color temperature change. Change in wattage rating of the lamp (i.e., lamp exchange), while

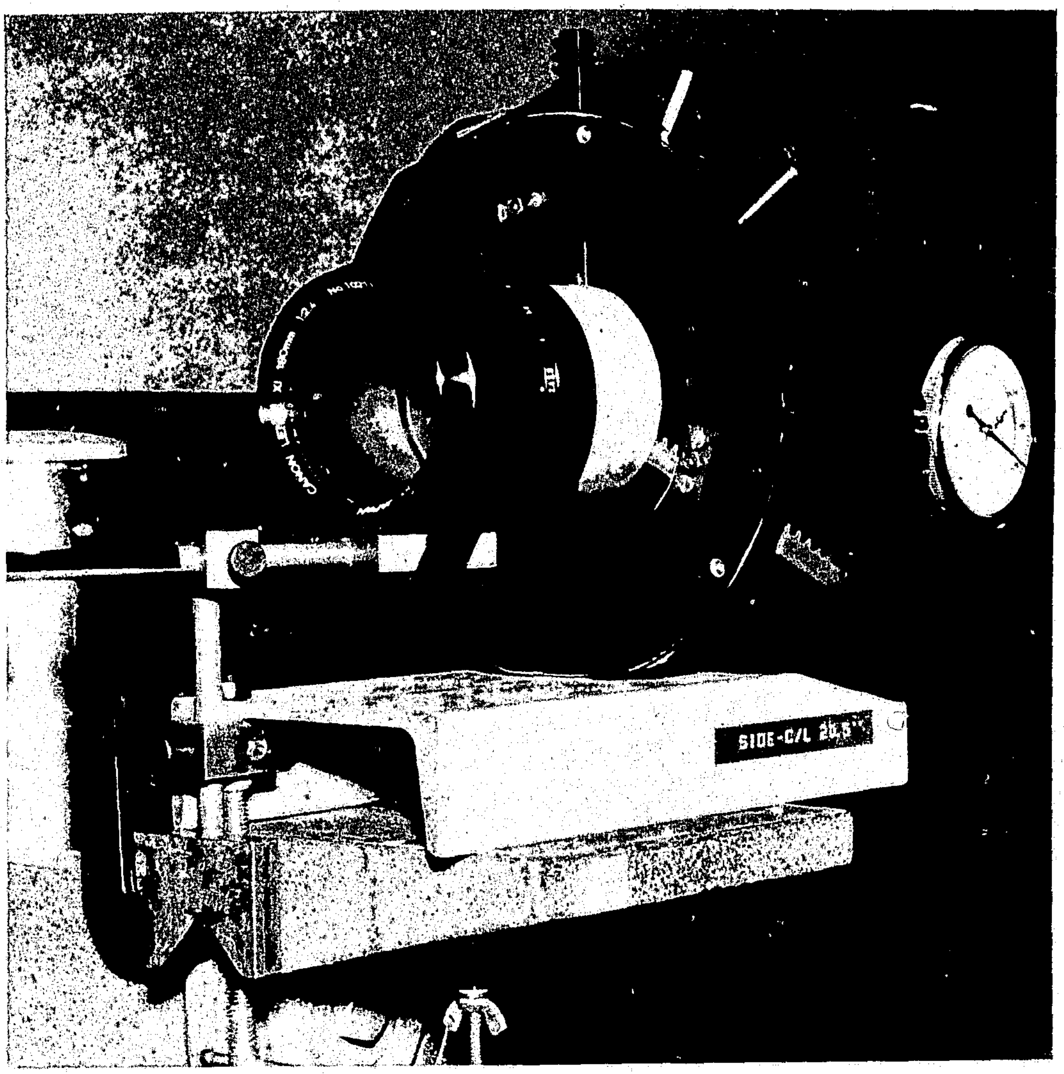


FIG. 3. Front View: Universal Lens Holder. Takes all NVD lenses up to approximately 4" Diameter.

keeping color temperature at 2856 K, can also be used.

The level of illumination should be controlled at all times. It should not vary in value by more than ±10 percent during the total period required to perform the test, or from test to test. The color temperature of the illumination must be controlled and should not vary by more than ±50 K. This control can be accomplished by the use of a power supply regulator which stabilizes the line voltage to within ±0.1 percent.

3.3.3 Lens Holder

The lens to be tested must be located with its optical axis perpendicular to the recording film. It must be capable of precise movement along the optical axis in small increments of known amount.

Figures 3 and 4 show a universal lens holder, built from an optical bench universal lens chuck, a 4 × 5 inch camera back with ground glass focusing panel, a dial indicator and a commercial 35mm film holder. Any convenient arrangement

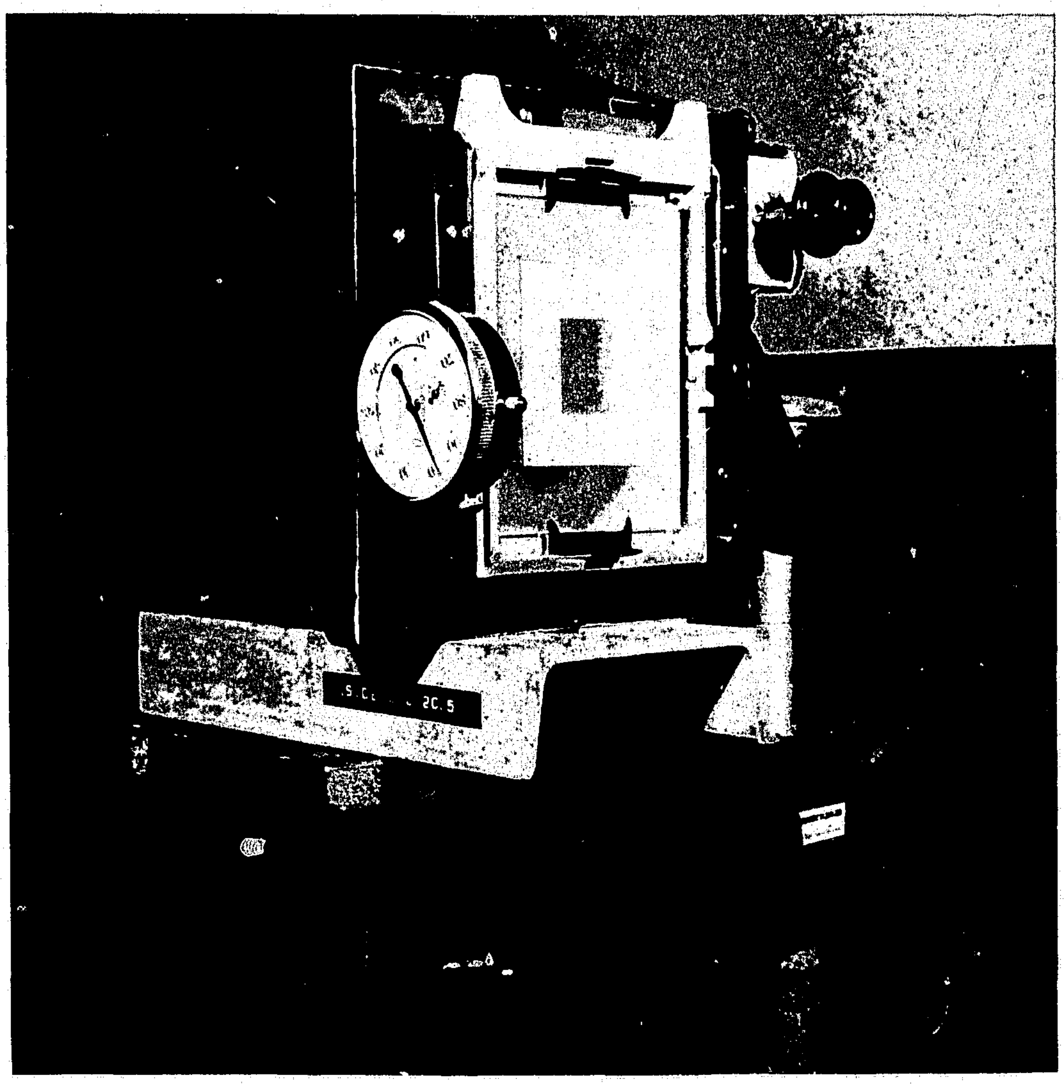


FIG. 4. Rear View: Universal Lens Holder. Dial shows focus movement from any reference position. Focussing control at upper right. Focus panel shows lens axis position for properly positioning target image.

which allows rapid interchange of the wide variety of lenses encountered, holds the lens solidly, and provides accurately known and repeatable focusing movement will be satisfactory.

3.3.4 Film Holder

The film holder must hold 35mm film in cartridge (36 exposure) or roll [30.5 meters (100 feet)] form (see figure 5).

The film must be held flat to within 0.001 inch (25 microns) over the total length of film used on each exposure. This is normally 38mm (1-1/2 inches) for most 35mm film holders.

There must be no change in lens-to-film distance between successive film frames.

The total image distance in the complete system of lens, lens holder, film holder and focus adjustment must remain constant within 13 microns (0.0005 inch) from frame to frame during the test.

3.3.5 Film and Film Processing Equipment

Eastman Kodak High Definition Aerial Reconnaissance film, Emulsion 3414 has been found to be suitable (see 2.4). This film has sufficient

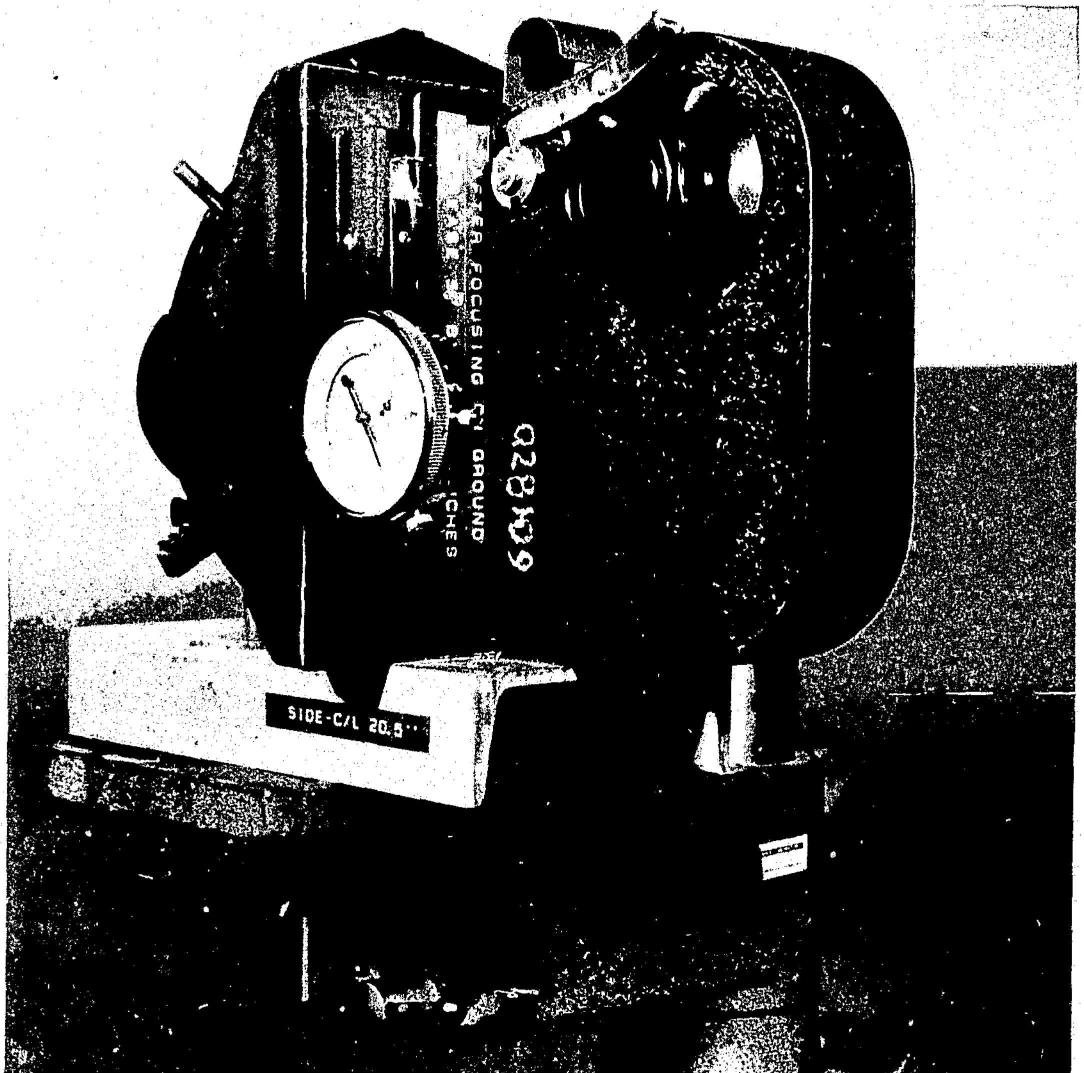


FIG. 5. Rear View: Universal Lens Holder. Film holder in place for exposing.

resolution capability that the image resolution will be substantially that of the lens and not be film limited.

Test film is to be processed to provide an average density gradient, as measured from sensitometric strips, of 1.34 ± 0.1. Machine processing with the Eastman Kodak Versamat processor, chemistry Type A, one developing tank at a speed of 3.5 meters/minute (10 feet/minute) at 27°C (80°F), produces this result. Hand processing in the manufacturer's recommended D–19 developing is acceptable as long as the finished negative is within the stated limits.

3.3.6 Exposure Measuring Equipment

The exposure during the test will be adjusted to provide an average target density on the film of 1.5 to 1.7. This density reading is based on a total target image size of 1.1 to 1.5mm (.043 to .059 inch), read with a standard photographic densitometer with a 1.0 mm aperture.

The only variables available to control film density are exposure time and light level. Lenses must be tested at maximum aperture. Exposure in most cases will have to be determined by trial, because of the wide variation in T stop for lenses of the same f-stop. Do not use aperture to control exposure.

3.3.7 Film Reading Equipment

The resolution of the recorded image must be determined by viewing the processed film with a standard laboratory microscope having a 10× objective and a 5× to 10× eyepiece.

Total magnification should be 50–100×. The light source used must be completely diffuse to eliminate coherency effects. This can be accomplished by supporting the film, emulsion side up, on a standard 50 × 75mm microscope slide cut from fine photographic ground glass of the type used for mounting the resolution target. The glass is used with the ground side down, and is thick enough to prevent bringing the grain into focus. The light source should be adjusted to be imaged on the ground side of the film slide when the sub-stage condenser is wide open and focused. Light intensity on the recorded image can then be easily adjusted over a wide range by changing the focus of the condenser.

The overall image size of the resolution target must be measured accurately to determine the image magnification. This can be done by providing an eyepiece micrometer for the film reading microscope and calibrating it with a stage micrometer. Alternatively, a toolmaker's microscope or a traveling microscope can be used separately for this measurement.

3.4 Test Procedure

3.4.1 Test Area

The area in which the test is conducted must have sufficient room to permit separating the test target and the lens holder by a distance of 150 times the focal length of the lens to be tested. The test area must be capable of being completely darkened. The only light affecting the film must come through the test target. Direct reflection from the illuminated test target into the test lens (from walls, floors, etc.) should be eliminated.

3.4.2 Test Target

The image of the test target should be located on the camera focusing screen at a point off the optical axis of the lens by an amount equal to 1/3 of the diameter of the image intensifier with which the test lens will be used. For the popular 18mm NVD tube, the center of the image should be approximately 6mm (.23 inch) from the axis of the test lens. Test target and camera film should be parallel at all times.

3.4.3 Focusing

The target image is carefully focused on the focusing screen, using at least 20× magnification. Note whether the vertical and horizontal patterns of the target require different focus positions. If so, average the two positions and record as the point of best visual focus.

After the point of best visual focus is determined, a schedule of not less than 5 different focal planes is calculated. The increment between each focal plane should be .0005 times the focal length of the test lens for lenses with f-numbers smaller than two and 0.001 times the focal length for those with f-numbers larger than two.

The five focal planes to be used (as a minimum) are the plane of best visual focus and those which are respectively, minus two, minus one, plus one, and plus two increments from that plane.

A minimum of five exposures should be made at each focal setting with no change in the test conditions (color temperature of light, exposure, aperture. focal distance, image location, processing).

3.4.4 Film Processing

The test film should be processed as detailed in 3.3.5.

3.4.5 Selecting Best Exposure

The first series of test strips should be checked for proper exposure. Exposure is correct when the average density of the target, when read on a densitometer having an aperture which covers between 50 and 76 percent of the total area of the target, is between 1.55 and 1.75. Do not exceed 1.75. In most cases, the first test strip on a new lens serves merely to bracket the correct focal plane and exposure time.

3.4.6 Determining Resolution

An image is considered resolved only when the following conditions are met:

A. A total of three lines and two spaces can positively be identified in both the vertical and the horizontal patterns for the element picked as the smallest resolved.

B. All elements with images larger than the one selected in A (above) can also be identified as three lines and two spaces in both horizontal and vertical patterns.

"Spurious" resolution effects, common in some lenses, may cause smaller elements than those selected properly for "A" to appear sharp and resolved. When spurious images are carefully examined, they will be found to have a different number of lines and spaces than the original subject. Always examine the large patterns first and work down to the smallest correct pattern. The lines and spaces may be considerably distorted (no sharp corners, line-space ratio changed, length-width ratio changed) but the essential correctness of the image geometry will still be intact for the correct, smallest element resolved.

Record the smallest element resolved in terms of group and element numbers [(−2,3) or (0,2) for instance].

The group-element designation is then converted to line pairs/mm. Table 1 lists the line pairs/mm at the target, for each group and element on the specified target.

TABLE 1

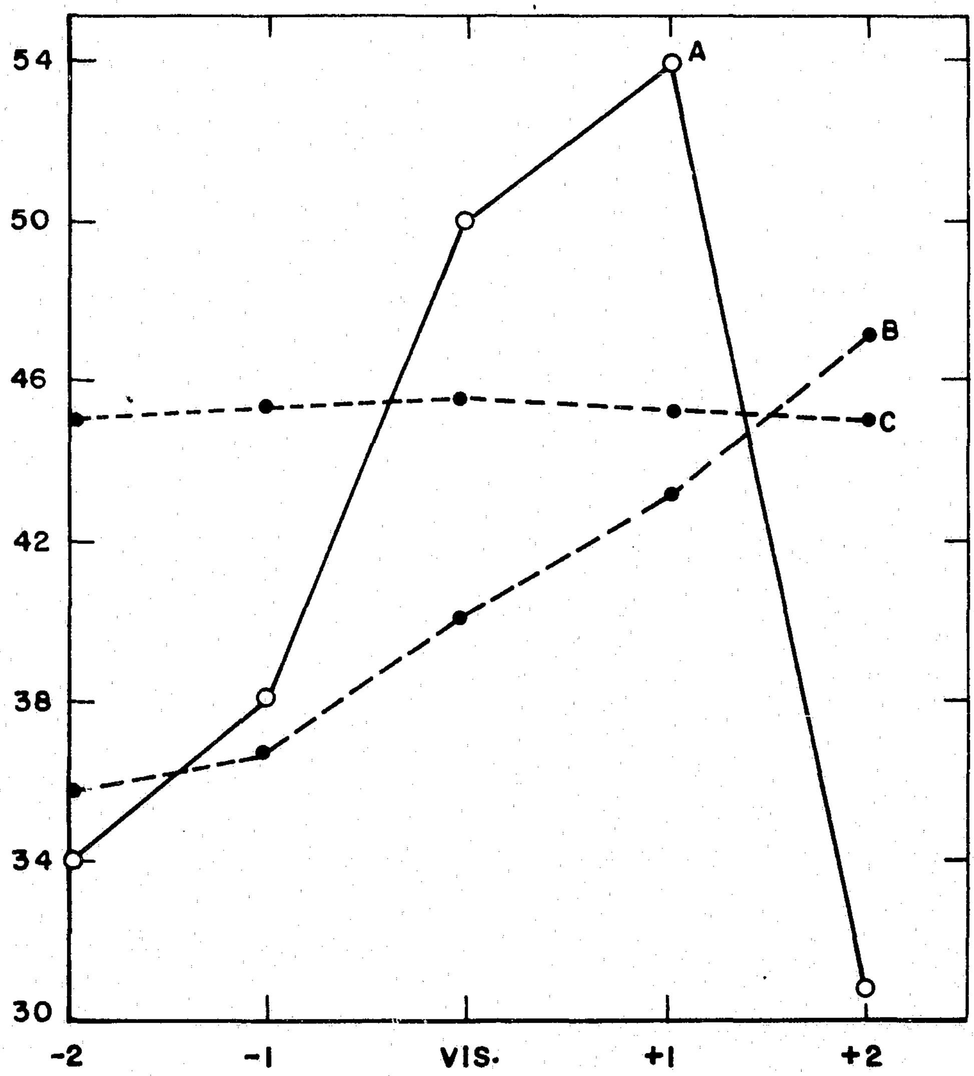
TARGET PATTERNS: LINE-PAIRS/MM

ELEMENT	GROUP					
	−4	−3	−2	−1	0	+1
1	.0625	.1250	.2500	.5000	1.0000	2.0000
2	.0702	.1403	.2806	.5612	1.1225	2.2449
3	.0788	.1575	.3150	.6300	1.2599	2.5198
4	.0884	.1768	.3536	.7072	1.4142	2.8284
5	.0992	.1984	.3968	.7937	1.5874	3.1748
6	.1114	.2227	.4454	.8909	1.7818	3.5636

The image resolution is obtained by taking the target resolution of the smallest element resolved and dividing it by the image magnification. The image magnification M is defined as the ratio of image length to target length. M is best determined by selecting for L the length of the total illuminated area of the target, inside the tape binding the target to the ground-glass diffuser. This should be approximately 267mm (10.5 inches). The length of the corresponding image in the negative (at best visual focus) is also measured. At 150 focal lengths distance this will be approximately 1.8mm (0.07 inch). M would then equal $0.07/10.5 = 6.67 \times 10^{-3}$.

The best image resolution is averaged for the five separate exposures taken at each focal plane. This gives five separate figures of average image resolution, one for each of five different focal planes. The figures are plotted on a curve of resolution vs. focal position. An example of this curve is shown in figure 6. Examine the curve to see if a definite maximum is indicated. The maximum occurs at the plane of best film resolution. If a maximum is present, the test is valid as far as focal position is concerned (see curve A in figure 6). If the curve does not show a well defined maximum, one of two situations exists.

1. The plane of best focus has not been included in the test. This produces a curve of the type shown at B, figure 6. The resolution continually increases but does not go through a maximum. This is normally caused by differences in visual and photographic focus, due to lens design, or by differences in focal plane location on the film holder and the focusing screen. For a curve like B, select the focal plane with next to the highest resolution and re-test at focal planes one increment lower, and one, two and three increments toward the higher resolution direction.
2. The focal planes are too close together to produce the changes in resolution required to



Focus curves from typical tests. A: Maximum resolution at +1 increment from visual focus. B: Maximum resolution not reached at maximum focus displacement. C: Focus increments too small to define plane of maximum resolution.

define a maximum (see curve C, figure 6). This may occur with poorly corrected lenses or lenses with relatively large f-numbers. In this case, double or triple the increments of movement for each focal plane and re-test. It is essential that the plane of maximum resolution be identified and closely approached in the test.

3.5 Lens Ranking

When a test strip has the required density and average resolution plots to a well defined maximum, the average resolution for the five samples of the best focal position is the low contrast resolution rating of that lens. This figure is then compared with the low contrast resolutions of the lens or lenses with which the subject lens is being compared.

The lens which resolves the highest number of line pairs/mm is judged to be the best lens of the group tested. Lenses which provide resolving powers which differ by less than 10 percent are considered to have equal resolutions.

4. VARIABLE CONTRAST RESOLUTION TEST (VCRT)

The variable contrast resolution test consists of recording and evaluating the image of eight standard three-bar resolution charts, having contrast from 6 to 98 percent. The recording and evaluating conditions are standardized. The procedure is primarily intended as a comparison test to be performed by the lens user for evaluating his own equipment and judging the result by reference to the performance of a lens known to be satisfactory. The VCRT provides limiting resolution performance data as a function of eight contrast levels as opposed to the LCRT which provides limiting resolution performance data for one contrast level.

4.1 Comparative Performance

Due to the comparative nature of the VCRT, lenses to be tested should have focal lengths and maximum apertures that are not widely different. The focal length of the lens being tested should not differ by more than ±30 percent from the focal length of the reference lens. The maximum aperture of the lens being tested should not differ by more than one stop from the maximum aperture of the reference lens. All tests and resolution figures should be based on using the lens at its maximum aperture.

For the VCRT test, a comparison NVD objective lens which is known to provide satisfactory performance is useful as a starting point. This should be tested initially by the same procedure used for the sample lens to be tested. Comparison of the two tests will show whether the sample lens has a performance poorer than, equal to, or better than the standard used for comparison.

4.2 Test Sensitivity

The VCRT test has the same test requirements and basic test sensitivity as the LCRT test with respect to a single contrast level of evaluation. However, since it provides more than one contrast level for evaluation, it is superior to the LCRT when judging image quality of lenses which produce insignificant differences in performance when tested according to the LCRT method.

4.3 Test Equipment

4.3.1 Test Target

All parts of 3.3.1 apply except that instead of a single target of 25–30 percent contrast, an array of eight targets with contrasts varying by equal steps from 6 percent to 98 percent are used. The eight targets, their contrasts, and their density differences (line and background) are as follows:

Target No.	Density Difference	Target Contrast %
1	.05	6%
2	.09	10%
3	.16	18%
4	.22	25%
6	.31	34%
7	.46	48%
8	.72	68%
9	1.92	98%

Note that target No. 5 would be in the axial image position and is not used (see figure 7).

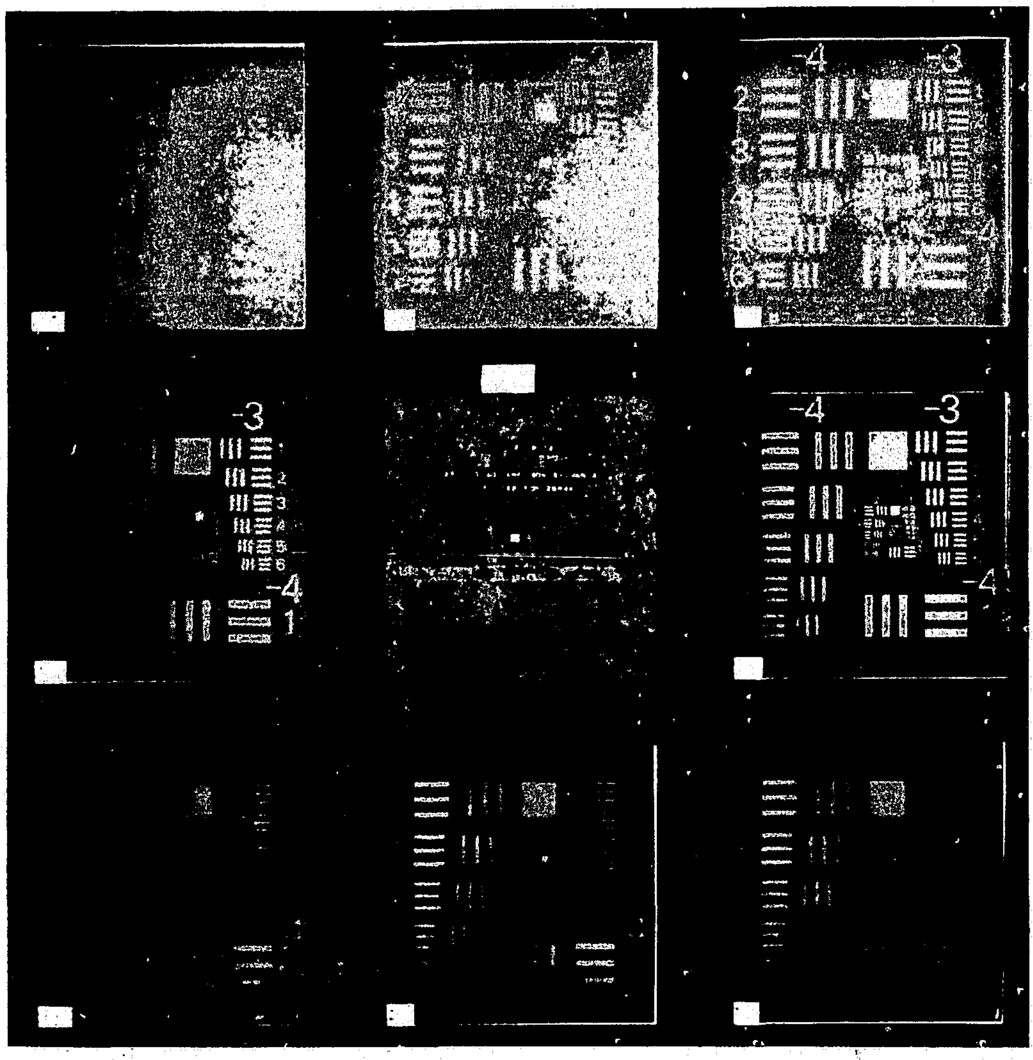


FIG. 7. Eight target array used for variable contrast resolution test.
Top row (left-to-right) targets number 1, 2, and 3.
Center row: Targets number 4, 5 (blank), and 6.
Bottom row: Targets number 7, 8 and 9.

4.3.2 Illumination Equipment: See 3.3.2

For the VCRT test, the illumination requirements apply to the complete array of eight targets as well as to the individual targets in the array.

The problem of uniformly illuminating the array of eight targets can be solved by combining eight, single-target and illuminator assemblies into one unit, using eight separate bulbs. An alternate method is to use a single, higher wattage inside-frosted bulb as a "small" source. This is combined with a sheet of 5mm (3/16 inch) translucent white "lucite" for diffusion. The lucite is mounted 30.5cm (12 inches) behind the targets, with the shielded light bulb mounted in the center of the lucite sheet and pointing away from the targets. The light from the bulb is reflected back through the lucite to the targets by a 60 × 60 cm (24 × 24 inch) front surface mirror mounted in the box enclosing the targets and illuminator. This assembly is shown in figure 8. A small black paper mask is required in the center of the mirror to eliminate a hot spot in the center area of the target array. Its size is found by trial. If the mirror is parrallel to the diffuser sheet, and the light source centered, the mask is square (like the individual targets) and is centered on the mirror.

4.3.3 Lens Holder: See 3.3.3

4.3.4 Film Holder: See 3.3.4

4.3.5 Film and Film Processing Equipment: See 3.3.5

4.3.6 Exposure Measuring Equipment: See 3.3.6

4.3.7 Film Reading Equipment: See 3.3.7

4.4 Test Procedure

4.4.1 Test Area

The area in which the test is conducted must have sufficient room to permit separating the test target and the lens holder by a distance of 150 times the focal length of the lens to be tested. The test area must be capable of being completely darkened. The only light affecting the film must come through the test target. Direct reflection from the illuminated test target into the test lens (from walls, floors, etc.) should be eliminated.

4.4.2 Test Target Array

The eight target array for the VCRT test is arranged in a 3 × 3 matrix as shown in figure 7. The center element of the matrix (target 5) is left blank.

The size of the eight target array is about 1 × 1 meter (40 × 40 inches). The individual targets are the same size as the single target used in the LCRT and at the same distance, producing individual target images on the film of the same size.

4.4.3 Focusing: See 3.4.3

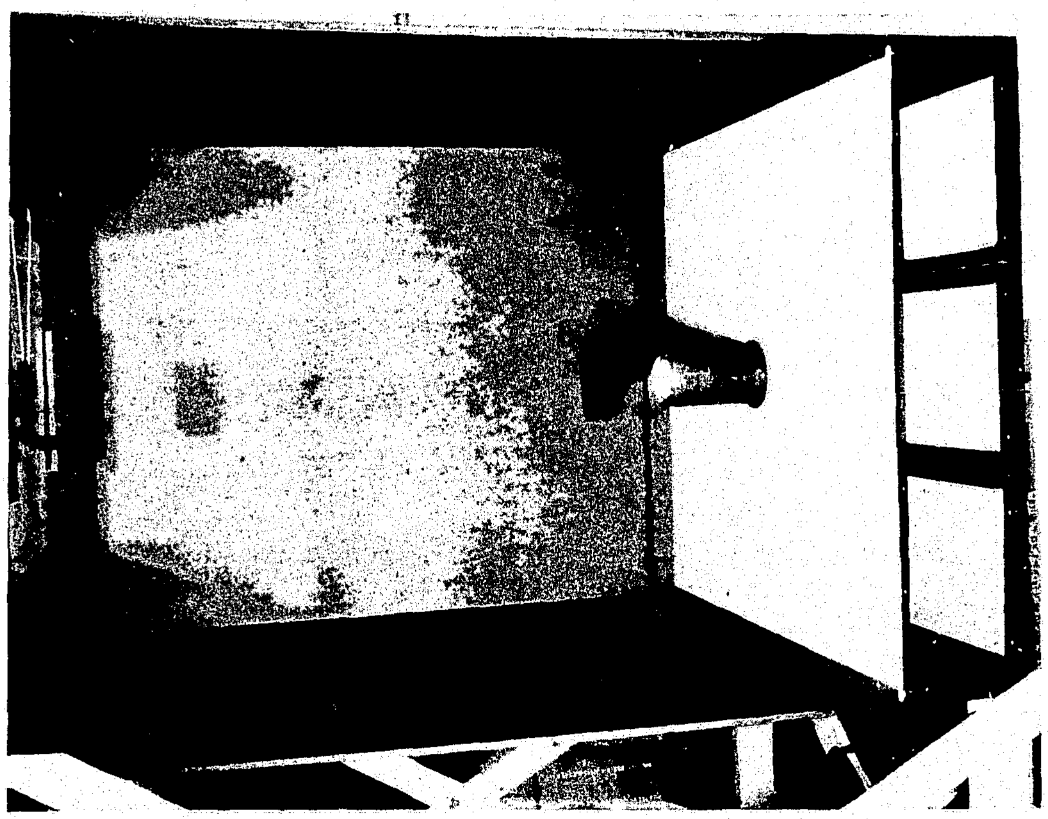


FIG. 8. Inside of single bulb, 8 target array illuminator, showing folded light path to reduce overall length of illuminator. Left (A): Front surface folding mirror with light mask in center. Right (B): 100 watt inside frosted bulb in light shield. (C) Lucite diffuser. (D) Array of eight resolution targets individually backed with ground-glass diffusers. Target number 6 at lower right.

4.4.4 Film Processing: See 3.4.4

4.4.5 Selecting Best Exposure: See 3.4.5

For the VCRT test, it is more convenient to tabulate the average densities on targets 1, 2, 3 and 4. Target 1 should have a maximum average density of 1.8–1.91 Do not exceed 1.9.

4.4.6 Determining Best Focal Plane

For the VCRT test, the plane of best resolution should be determined by plotting the resolution obtained on target 8 and following the criteria and procedure given in 3.4.6.

4.5 Lens Ranking

When a test strip has the required maximum density of 1.8–1.9, and the data plot to a well defined resolution maximum on target 8, the mean resolution for the five samples (from the maximum resolution focal plane) is computed separately for each of the eight targets in the array. A sample tabulation is shown in table 2.

The eight values of mean resolution are plotted on graph paper with percent target contrast as the ordinate and line pairs/mm as the abscissa. The lens is ranked for image quality from the graph.

In the VCRT test the initial and the major lens ranking is determined in the same manner as for the LCRT (see 3.5). The overall contrast-resolution curve gives a much better picture of total lens performance than does the single target point in the LCRT test.

Lenses are compared for performance by comparing their 25 percent contrast resolution. Lenses which differ in resolution by more than 10 percent of the resolution of the higher resolving of two lenses will in general show differences in actual performance.

When competing lenses produce resolutions which differ by less than 10 percent from each other, the relative performance at the 10 percent and 18 percent contrast targets should be com-

TABLE 2

Focal Plane: −2 Image Magnification (M): 0.00599

TARGET NO.	FRAME						Mean
	*A	B	C	D	E	Mean	M
*1	.1575	.1575	.1575	.1403	.0788	.13832	23.09
2	.2807	.2227	.2227	.1984	.3150	.24790	41.38
3	.3968	.3536	.3968	.3536	.3968	.37952	63.36
4	.4454	.4454	.4454	.2807	.4454	.41246	68.86
6	.5612	.5612	.5000	.3968	.5612	.51608	86.16
7	.6301	.5612	.7936	.5000	.7072	.63842	106.58
8	.7936	.7936	.8913	.6301	.8913	.79998	133.55
9	1.1223	1.1223	.8913	1.0000	.8913	1.00544	167.85

Figures under frame number are line-pairs/mm on the target, example:

*1–A = .1575 line-pairs/mm = group −3, element 3 (See table 1)

$$\text{Target 1 mean} = \sum_{A}^{E} \frac{x}{n} = \frac{.69116}{5} = .13832$$

$$\frac{\text{MEAN}}{\text{M}} = \frac{.13832}{5.99 \times 10^{-3}} = 23.09 \text{ line-pairs/mm in image.}$$

pared. If there are significant differences in resolution (not less than 10 percent of the reference resolution at the contrast being compared) at targets of lower contrast than 25 percent, the lens providing the highest low-contrast resolution in line pairs/mm is judged to be the best lens.

In the case of lenses producing no significant difference in resolution on the 6 percent, 10 percent, 18 percent, or 25 percent charts, resolution on the higher contrast charts should be considered, working upward from 25 percent to 34 percent, 48 percent and 68 percent. The ability of NVD lenses to resolve high contrast charts (48 percent and higher) is not of great significance since NVDs have a resolution limit of 30–40 line-pairs or less. Lenses which produce very poor NVD performance may have very high resolution values on high contrast charts.

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