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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Visual Acuity Testing of Radiographic Inspectors in Nondestructive Inspection

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Visual Acuity Testing of Radiographic Inspectors in Nondestructive Inspection

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Visual acuity tests for radiographic inspectors should be correlated with the type of tasks encountered in real world radiography. The testing procedures should be capable of assessing differences in day to day performance of a given inspector as well as the performance of one inspector relative to other inspectors. Single line targets with specific parametric values for contrast, width, and blur are recommended to provide a means for testing a radiographic inspector for visual acuity. These targets may be used for periodic tests by the employing organization or for more frequent self testing by the inspector. Statistics from the National Health Survey, procedures recommended by the NAS-NRC Committee on Vision and real world radiographs have been utilized in arriving at recommended test configurations.

Key Words: Acuity tests; nondestructive testing; quality testing; radiograph evaluation; visual inspection; visual testing.

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1.0 Introduction

In assessing the acceptability of mensurative techniques, two basic uncertainty (reliability) measures are involved: the repeatability of measurements with a given instrument and the agreement between different instruments or installations. Similar performance assessments leading to consistent performance should be required of visual inspections in nondestructive evaluation.

1.1 Visual Inspection

The lack of precision in radiographic inspections has been discussed and documented in several studies.[1-4] The sources of unreliability in radiographic inspections may be due to any of several causes, among them being differences in the components and procedures for taking of the radiographs, and differences in visual capacity among the inspectors reading the radiographs. This paper shall be concerned with the latter. By reliability, we mean the precision of inspections, that is, agreement between different observers within a unit, between units within an installation, and between installations within an industry as well as the repeatability (consistency) in the performance of a given inspector. To achieve this end, procedures, apparatus, and reference materials should be standardized to minimize sources of variability.

In visual inspections, the human eye is the key component. Visual capacity must therefore be calibrated and reference materials necessary for calibration must be available. The complete evaluation of the inspector involves the calibration of the inspector's sensory capacity and the level of experience and knowledge that person brings to the task.

1.1.1 Detection - The inspector must first detect the possible presence of a defect, generally indications of a discontinuity in the radiograph. This resolution of a nonhomogeneity in the radiograph is primarily dependent on the visual sensory capacity of the inspector, i.e., the psychophysiological capacity of the inspector.

1.1.2 Interpretation - Having detected the presence of a discontinuity, it is necessary to interpret this discontinuity to determine whether it is a defect and, if so, to classify it as to the type of defect.

1.1.3 Evaluation - The final inspection involves the determination of the magnitude and importance of the defect. Should the object be rejected, repaired, or passed?

1.2 Scope

All three of the above inspector performances involve visual sensory discrimination ability, the proportion of sensory involvement being maximal for detection but decreasing as we go from interpretation to evaluation. As the role of sensory discrimination decreases, the role of information processing increases, i.e., the role of experience and knowledge in interpreting the visual cues become importance sources of differences in performance between observers. Inspectors can improve their knowledge by training, but visual capacity, which includes corrective devices the inspector brings to the job, is fixed. This report deals with visual acuity tests for radiographic inspectors that are simple to administer and uses standardized procedures and reference tasks. It does not treat the cognitive (experience) factors in visual inspection of radiographs, although a significant source of variability between inspectors may be the lack of good training criteria.[1]

2.0 Background

2.1 Variability

Measurement variability may exist within an instrument and/or between different instruments. Within instrument variability is generally called precision or repeatability. Between instruments variability is the agreement between different instruments, generally assessed by laboratory intercomparisons of a reference material. We have these same sources of variability with visual inspection of radiographs.

2.1.1 Intra (within) Observer Variability -

Consistency or repeatability of measurements is of primary concern in any mensurative technique, including measures relying on the performance of the human eye. Will the same inspector be able to detect targets of the same difficulty equally often on different days? Psychophysical experiments indicate that even experienced observers display variability in visual capacity that may vary from day to day.[5]

These changes can be due to physiological or psychological factors. In some cases performance at the prescribed level can be achieved by following recommended procedures, for example, spending more time adapting to the darkened environment of the inspection room.

For critical inspections or for the purposes of minimizing variability, a test is needed that inspectors can use for self calibration. They can then determine whether they are performing at a prescribed sensitivity level (or better) at the time that the test is taken.

2.1.2 Inter (between) Observer Variability -

No matter how consistent an inspector may be in performing at the same level day after day, unless the performance meets some specified level, that performance is unacceptable. An analogy in instrumental measurements is the agreement between different instruments and/or different laboratories. A given instrument in a given laboratory may give high repeatability, but the measurements may be inconsistent with those from other instruments or laboratories.

This second source of inconsistency, the variability between observers, is commonly observed in visual psychophysical experiments.[5] The observer must be calibrated so that the performance of one person approximates that of other observers in the same unit. But it is just as important that the performance of those in one unit be comparable to that of inspectors in other units or installations. These and other physiological considerations have been discussed by Yonemura.[6]

The visual capacity of radiographic inspectors can be evaluated in terms of an "absolute" score (meeting minimum requirements) or a relative ranking procedure (ranking the inspector's performance relative to other inspectors). The author believes that specifying minimum requirements based on radiographic inspection needs with consideration of national norms is the preferred criteria.

2.2 National Norm

The National Center for Health Statistics conducted a survey of binocular visual acuity during the years 1960-1962.[7] The Center examined a total of 6,672 individuals, ages 18-79 years. Figures 1 and 2 present the number of examinees who were able to identify letters whose stroke widths were equal or larger than the angular subtense given in the abscissa. There appears to be a separation between those over and under 45 years of age. This separation is more clearly demonstrated in figure 1, the results for persons with uncorrected vision, but is also clearly evident in figure 2 for persons with corrected near vision (14 in). In the National Health Survey, the examinees were not optimally refracted, but tested with whatever correction they were using. Since acuity tests for nondestructive inspectors should be performed with whatever corrections they are using, the results shown in figure 2 are those most applicable to this study. These data will be considered in the determination of visual acuity requirements for radiographic inspectors. Differences between the National Health Survey methodology and optotype (characters used as test objects for measuring visual acuity) from those adopted in this study will be discussed under the pertinent variable headings. In general, the inclusion of other variables (different levels of contrast and blur) has a net effect of making the nondestructive inspection acuity requirements stricter. The National Health Survey used high contrast details with sharp edges.

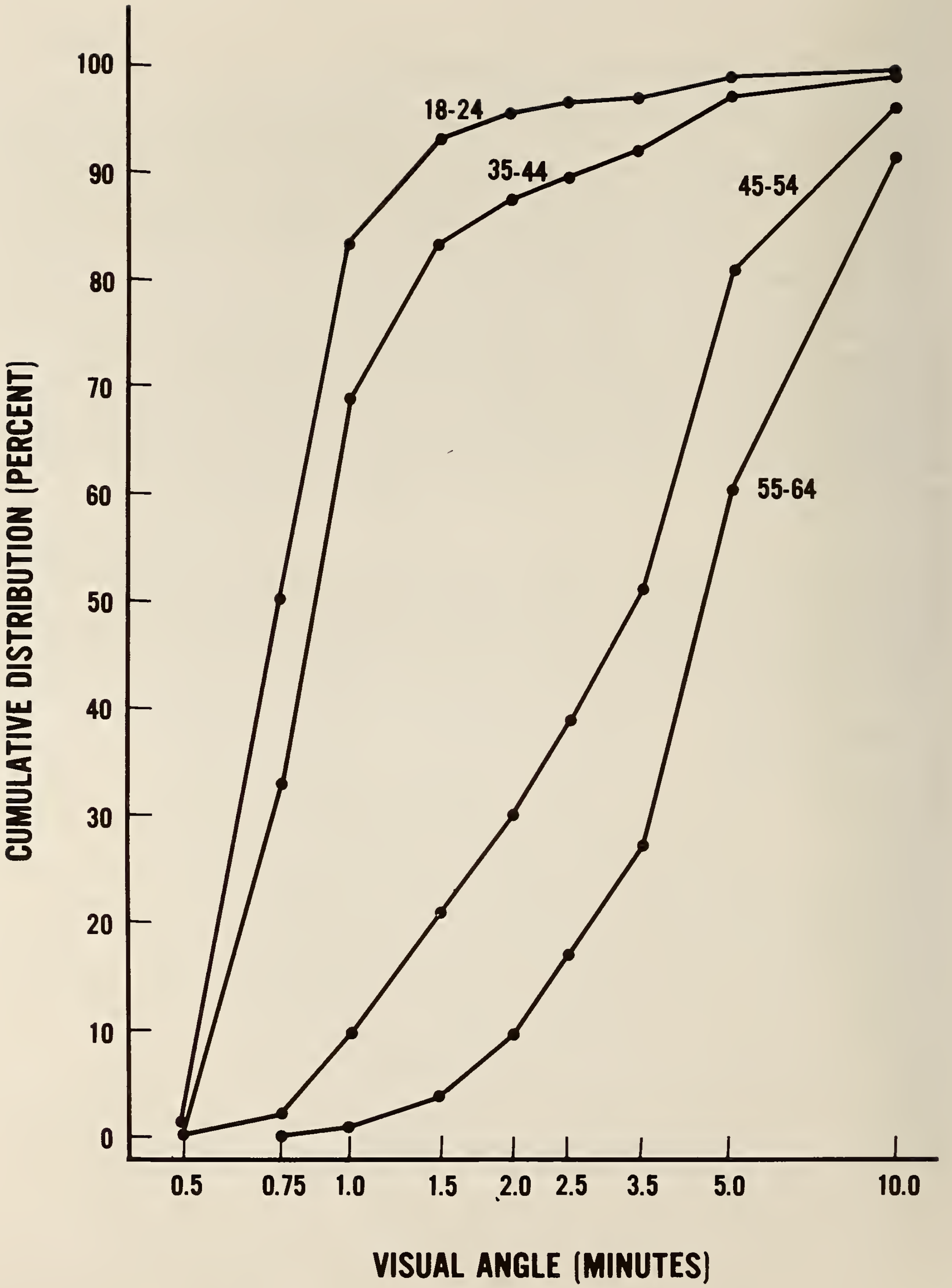

Figure 1. Percent of testees identifying letters as a function of stroke width for uncorrected near vision. The age groupings are given for each curve. Data from the National Center for Health Statistics.[7]

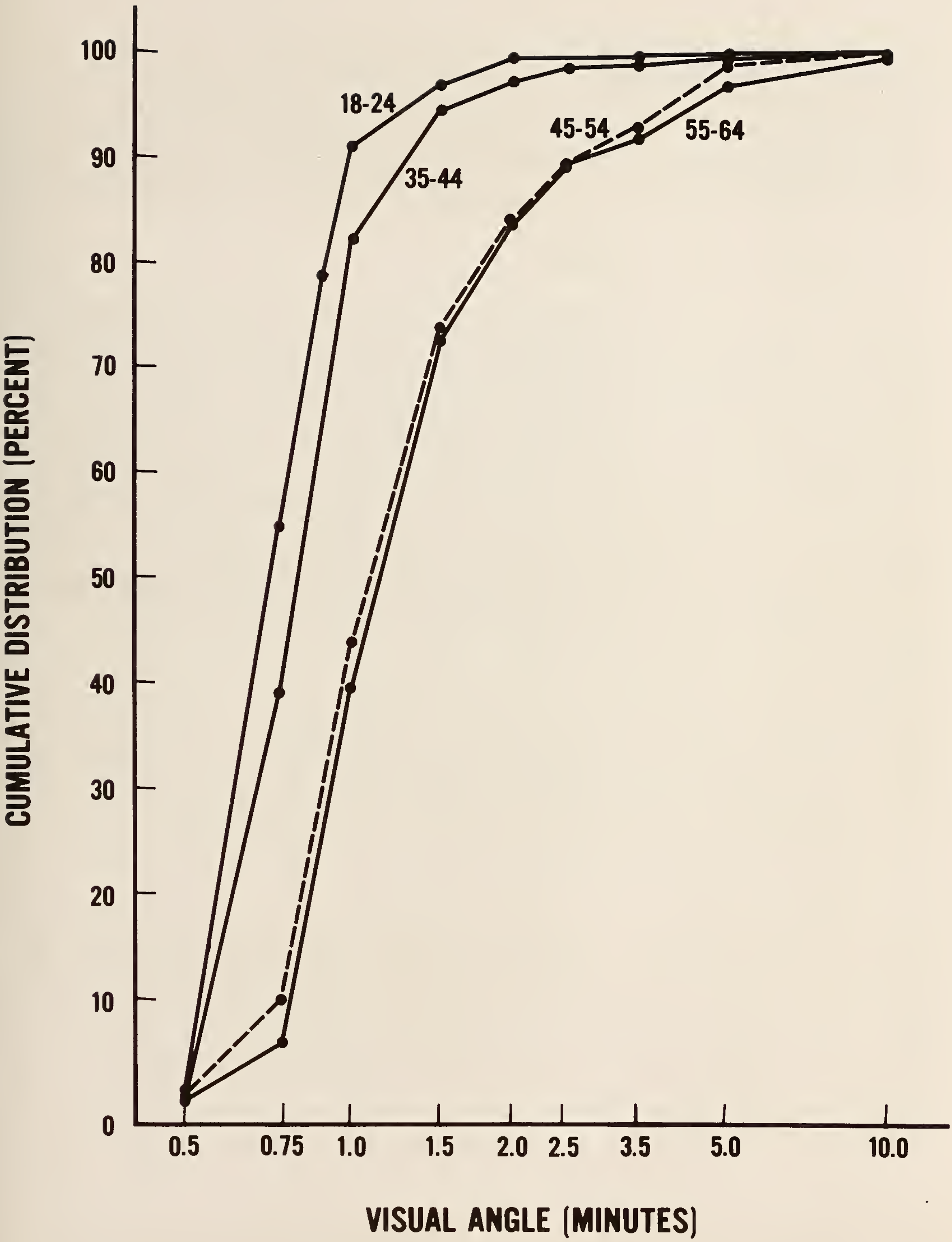

Figure 2. Percent of testees identifying letters as a function of stroke width for corrected near vision. The age groupings are given for each curve. Data from the National Center for Health Statistics.[7]

The Committee on Vision, National Academy of Sciences - National Research Council (NAS-NRC) has recently published "Recommended Standard Procedures for the Clinical Measurement and Specification of Visual Acuity".[8] Although their recommendations are for clinical applications, they will be utilized in our study where applicable, since the committee report will serve as the basis for nationally standardized procedures for testing visual acuity.

3.0 Reference Target Parameters

A valid basis for standardizing the sensory capacity of the human eye should be based on the circumstances under which this capacity is to be utilized. We must know what the eye is expected to see and the conditions under which the discriminations are to be made. Quantitative measures describing the physical correlates of what the eye is expected to detect should be the basis for designing visual acuity test targets. In radiographic inspections, dimensional descriptions of the defect measured on the material have limited value. The individual is asked to look at the radiograph, consequently the physical measure of interest for visual acuity testing is the defect as displayed on the film, regardless of how much it may differ from the actual defect. Microdensitometric scans of the defect taken directly from the radiograph are required. Table I describes fatigue cracks obtained by microdensitometric scans of radiographs. The radiographs show C-130 wing samples used in the Lockheed study for the Air Force,[4] "Reliability of Nondestructive Inspection on Aircraft Structure".* Although they represent only a fraction of possible defects, they do serve as indicators of the levels of difficulty for the various defect parameters that may be expected in radiograph inspections. The data in table I will be referred to during the discussions of task variables that must be considered in standardized tests for visual acuity testing.

3.1 Size

The dimensions of visual targets are generally expressed in angular terms, more specifically, in minutes of arc. Visual acuity is the reciprocal of the minimum resolvable line, or separation between two lines, expressed in minutes of arc. For purposes of this paper, where we are interested in specifying target dimension, the measure should be an angular one. For example, in figures 1 and 2, the frequency of subjects identifying letters with visual angles subtending X minutes of arc are presented, instead of the Snellen or decimal acuities given in the original source.

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*The radiographs were supplied by W.H. Sproat of Lockheed-Georgia Co. and B. Boisvert of the San Antonio Air Force Logistic Center.

Table I. Description of Defects Measured on Sample Radiographs

Target Number (A)	Density Bkgd (B)	Density Detail (C)	Transmittance Bkgd (D)	Transmittance Detail (E)	Contrast (F)	Width of Detail μm (in) (G)	Visual Angle* (minutes) (H)
101A	1.58	2.17	0.0263	0.0068	0.741	121.9(0.0048)	1.05
101B	1.04	1.42	0.0912	0.0380	0.583	207.2(0.0082)	1.78
101C	0.99	1.14	0.1023	0.0724	0.292	146.3(0.0058)	1.26
101D	1.56	1.60	0.0275	0.0251	0.087	85.3(0.0034)	0.73
102A	1.69	1.73	0.0204	0.0186	0.088	54.9(0.0022)	0.47
102B	1.67	1.84	0.0214	0.0145	0.322	158.5(0.0062)	1.36
111	1.80	1.83	0.0158	0.0148	0.063	195.0(0.0077)	1.68
134A	2.22	1.59	0.0061	0.0257	0.763	158.5(0.0062)	1.36
134B	2.19	1.61	0.0065	0.0245	0.735	170.7(0.0067)	1.47
141A	1.88	1.93	0.0130	0.0117	0.100	134.1(0.0053)	1.15
141B	1.80	1.90	0.0158	0.0126	0.203	280.4(0.0110)	2.41

*For a 40 cm (16 in) viewing distance

3.1.1 Width of Target - In figure 2, about half of the subjects under 44 years old will be able to identify a letter with a stroke width of 0.75' and about 85 percent can identify a stroke width of 1.0'. In acuity testing a 1.0' stroke width is taken as normal acuity.[7] We should compare these values with typical acuity required in inspection of radiographs.

The visual angles given in table I (column H) were obtained from microdensitometry scans of defects. The width of the defect was taken as the distance between those two edges, where the rate of change was less than 0.005 in density per micrometer, as recommended by Higgins and Jones.[9] The microdensitometry scans are also presented in figures 3-5. These defects are critical cracks that are expected to be detected. Since the purpose of this study is to recommend minimum acuity requirements, the more difficult images (subtending smaller visual angles) are of greater significance. Target no. 102A subtends the smallest visual angle (0.47') and target no. 101D subtends (0.73'). Although the rest of the targets are larger than one minute of visual angle, the blurriness and low contrast of the targets render them more difficult to detect than similar sized letters used in the Health Statistics Survey. Unless the validation of the proposed reference acuity tests indicates otherwise, the 1 minute angular subtense currently being used appears to be a reasonable value.

3.1.2 Length of Target - In the stimulus used in the National Health Survey, the height of the letters was 5 times the stroke width of the letters. Since the stroke width was the critical dimension from which acuity measures were obtained, the target length varied, but was always 5 times the critical dimension. In the Landolt C, the gap in the C determines acuity. The gap is always equal to the stroke width of the C, therefore for the Landolt C, the length of the detail is the same as the width. In both cases target length is a multiple of the threshold angular measure of acuity.

Hecht et al,[10] report that for detecting a single line under high luminances (6,300 cd/m^2) the best estimate of the critical length is about 1 degree i.e., the length beyond which increases in length do not improve acuity. For a 40 cm (16 in) viewing distance, a line length of about 0.7 cm (0.28 in) subtends 1 degree. Therefore, for a single line target, the length should be equal to or greater than 0.7 cm in order to eliminate target length as a variable.

3.2 Contrast

Luminance (L) contrast is defined as:

$$(L_b - L_d)/L_b,$$

where the subscripts b and d refer to brighter and darker, respectively. In visual acuity tests, the contrasts of the targets are large, 0.9 or larger. But the contrasts encountered in radiographs are signficantly

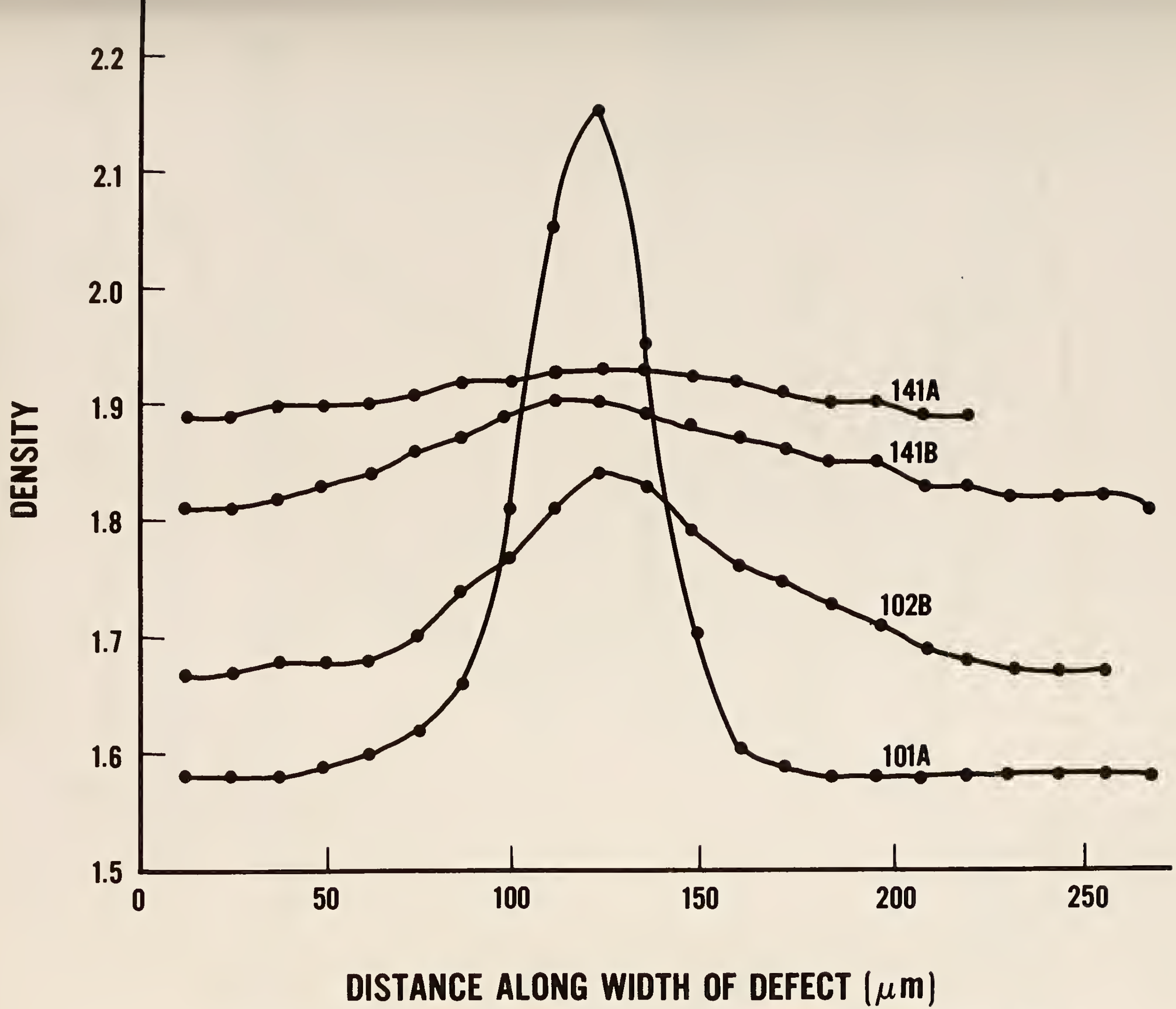

Figure 3. Density distribution of cracks from real world radiographs of aircraft wing samples.

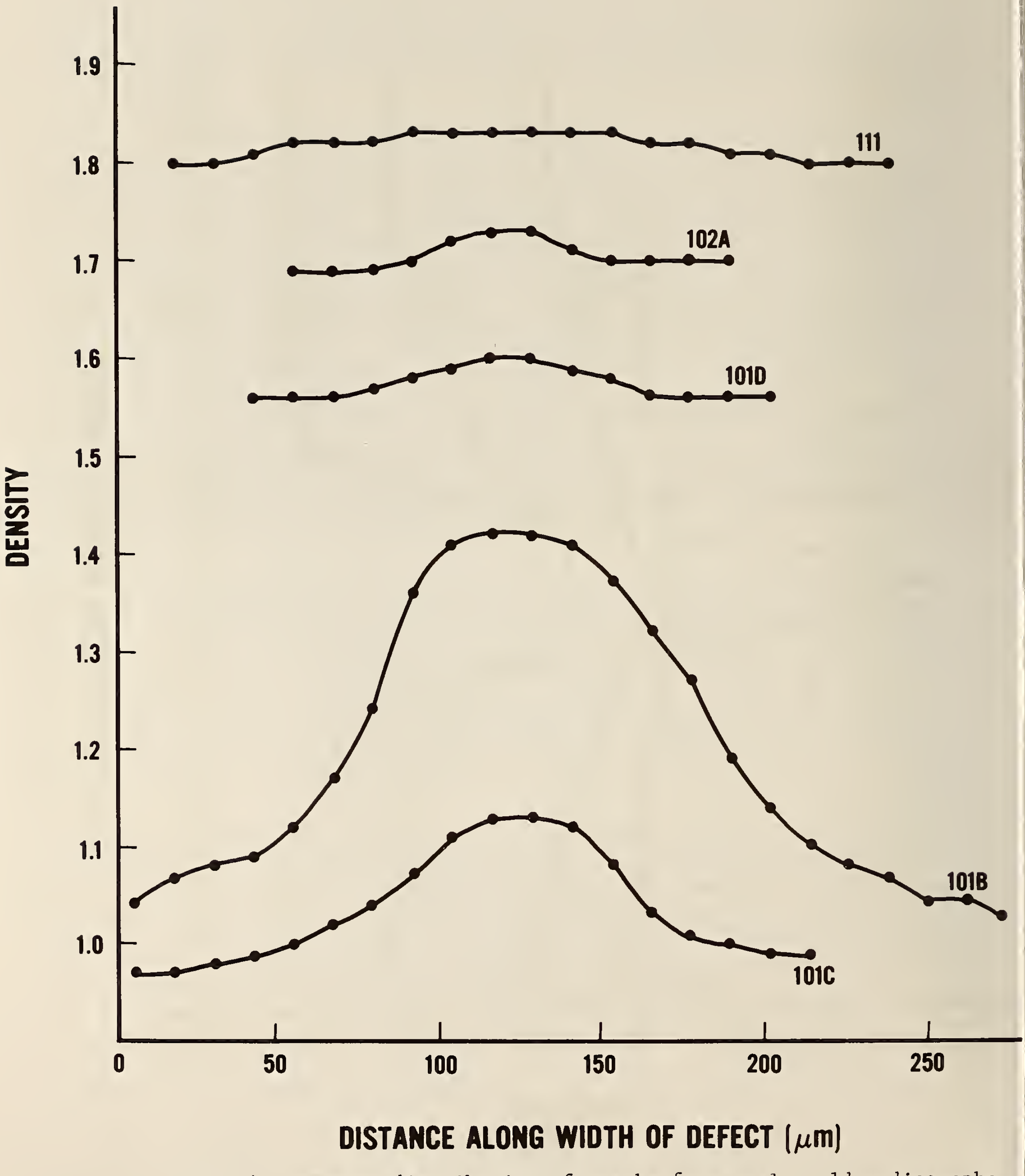

Figure 4. Density distribution of cracks from real world radiographs of aircraft wing samples.

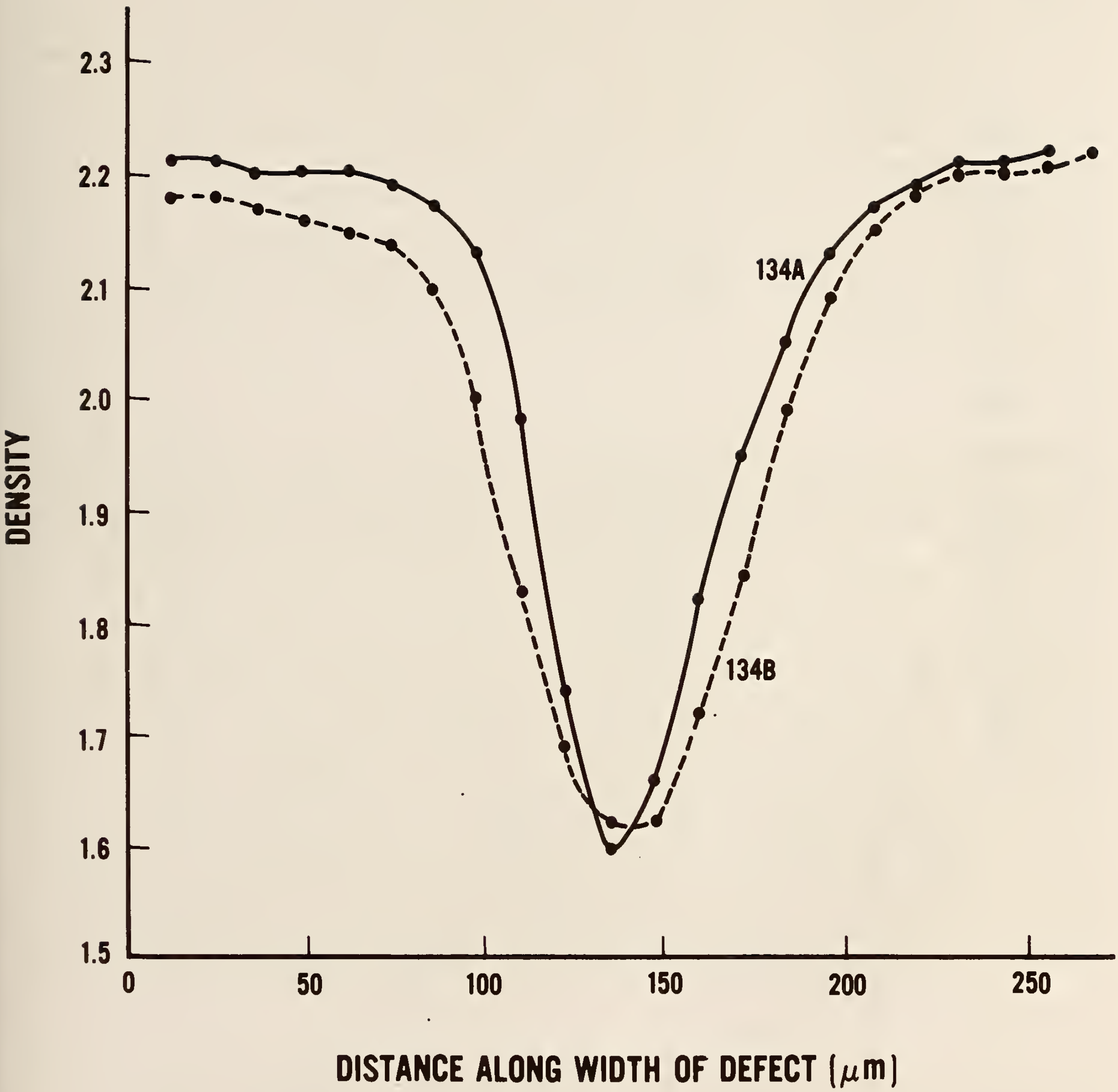

Figure 5. Density distribution of cracks from real world radiographs of aircraft wing samples. Defect lighter than background.

less as can be seen in table I, column F. The contrast of a target importantly affects the visual acuity.

Graham & Bartlett[11] have shown that the diameter of a circular detail has to be increased as contrast is decreased for the disc to be detected. (See figure 6.) High contrast targets are the exception rather than the rule in radiographs, therefore the reference acuity tests should include this real world variable (contrast). Although there is no definitive basis for recommending specific contrast values, the sample radiographs that were measured indicate that contrasts of 0.1, 0.3, and 0.85 may be reasonable estimates. (See table I.) The highest contrast complies with the NAS-NRC Committee on Vision's recommendation that the contrast of the test targets should not be allowed to fall below 0.85. The use of lower contrast levels has the effect of setting a stricter criterion for radiographic inspection acuity tests if the size dimensions are retained.

3.3 Blur

In standard acuity tests the optotypes have sharp edges, whereas in most real world radiographs, the details have fuzzy or blurred edges. Figures 3, 4, and 5 indicate the degree of blurriness to be expected in radiographs. Blur here applies only to the edge density distribution of the detail measured on the radiograph, and does not include the blur resulting from the spread function of the eye. As figures 3 and 4 indicate, the rate of density changes can range from a highly blurred image (sample 111) to defects that have a steep gradient (specimen 101). These variations in the sharpness of the images should be considered in reference visual acuity tests for radiographic inspections. Following standard practices in acuity testing, one level of sharpness can be similar to that of sample 101A i.e., a steep edge gradient. Since real world radiography involves less sharp defects, a test target with a flatter slope should be included, one approaching specimen 101C. This specification can be given in the form of discrete empirical values for the edge gradient. If radiographic image evaluation is expressed in terms of modulation transfer functions (MTF), it may be desirable to express the blur as line spread functions (also as discrete values).[12]

3.4 Form

The optotype used in the National Health Survey was letters. The optotype considered in this paper (and probably the acuity requirement most frequently encountered in radiograph inspections) is thin lines. The form of the optotype can affect acuity. Figure 7 presents the results for a Landolt C (open circles) and for a square wave grating pattern (filled circles).[13] For clinical purposes, the Committee on Vision, NAS-NRC recommends that equivalence in acuity scores with the Landolt C as the reference standard be demonstrated for other optotypes.

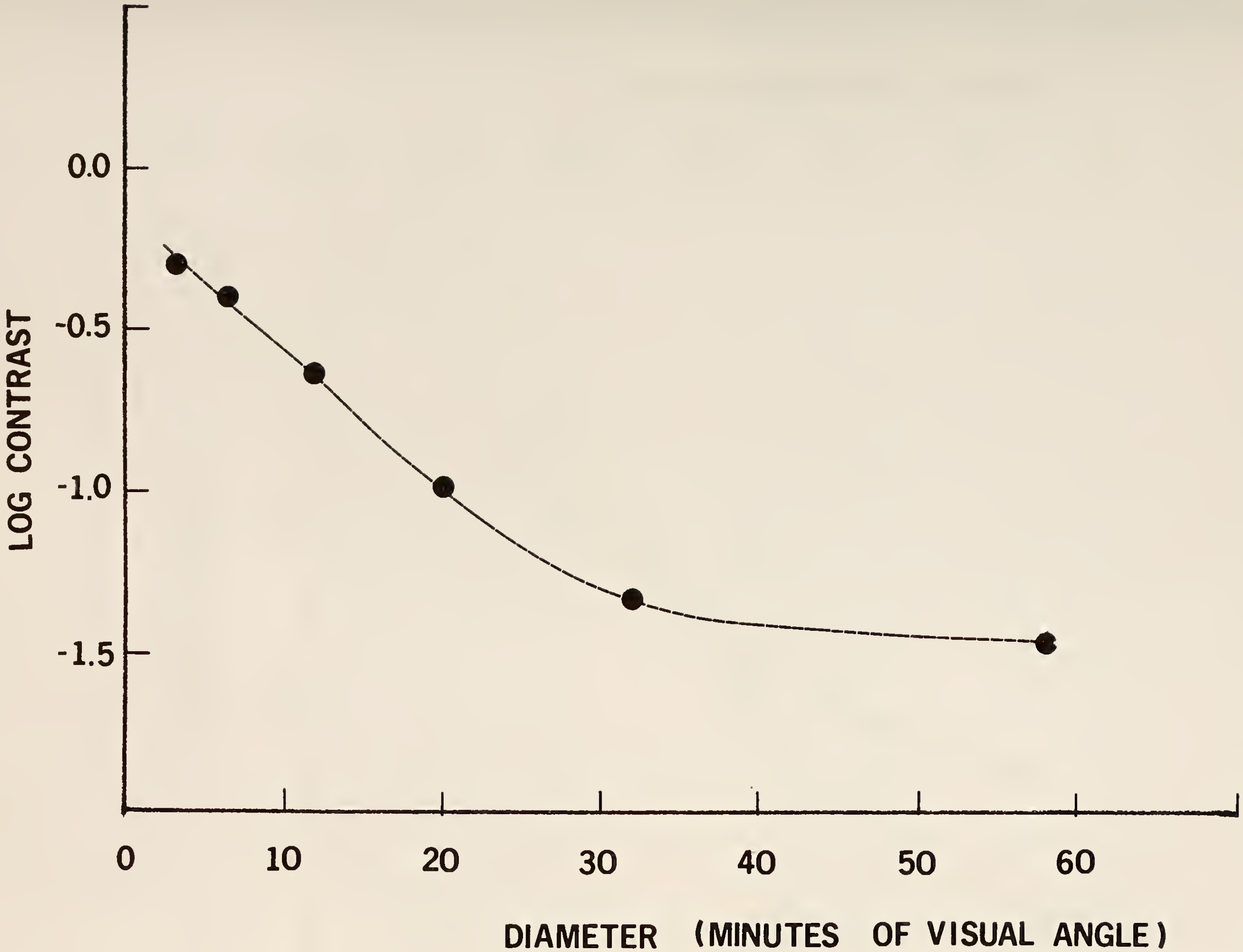

Figure 6. Contrast threshold as a function of the diameter or the test field. Adapted from Graham and Bartlett.[22]

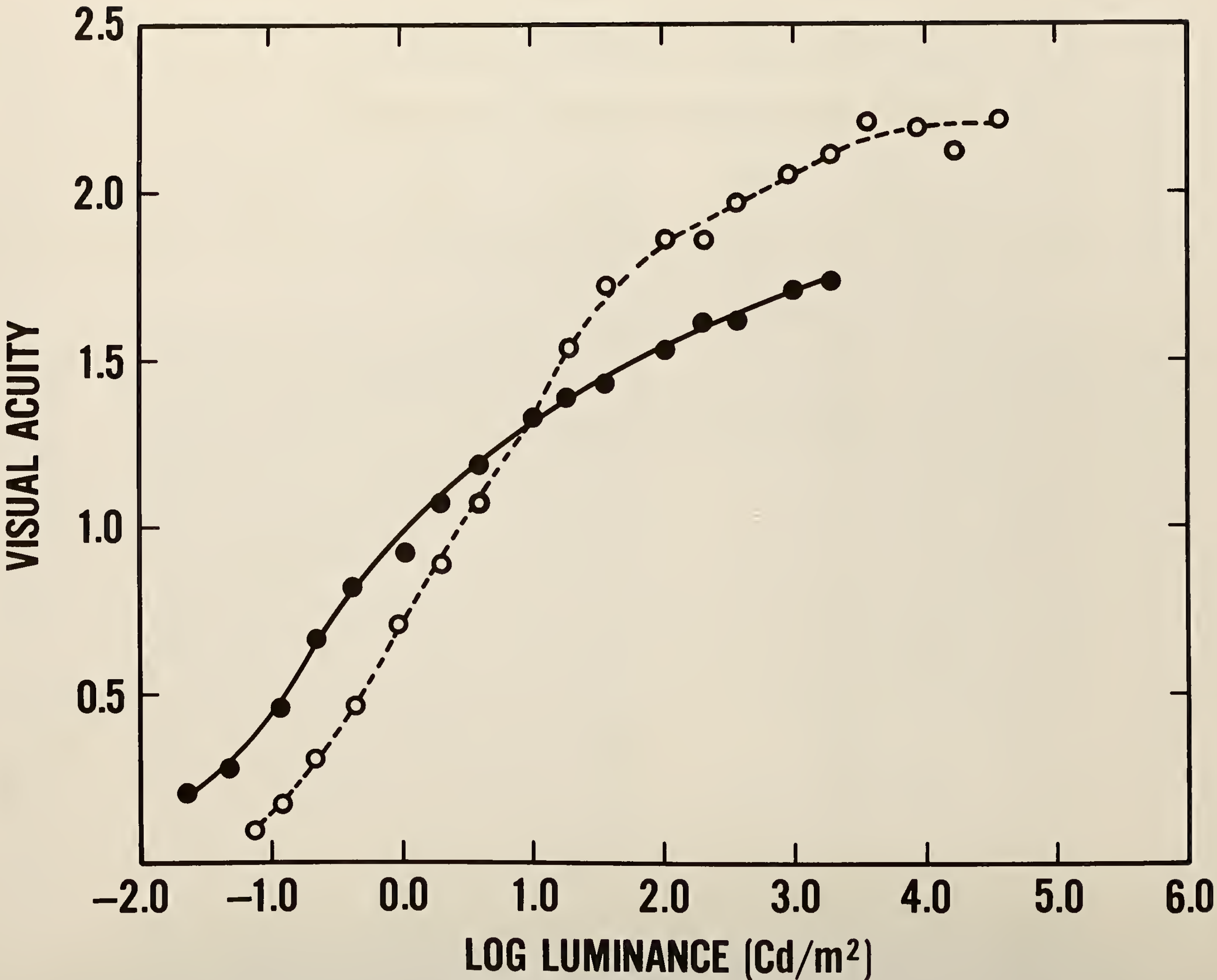

Figure 7. Visual acuity as a function of luminance. Open circles are for a Landolt C and filled circles for grating pattern test stimuli. Adapted from Shlaer.[12]

The standard acuity tests considered in this paper are not for diagnostic purposes, but it is recommended that an equivalency between single thin lines and Landolt C be established and/or the line targets be tested with a random selection of inspectors.

3.5 Luminance-Density

Figure 7 indicates that visual acuity increases as luminance is increased. This finding suggests the need to recommend a standard luminance level to be used in testing. The Committee on Vision, NAS-NRC recommends a background luminance of 85 $\pm$ 5 nits (25 $\pm$1.5 fL). With a background transmittance of 2 percent (density = 1.7) the desired 85 cd/m^2 should be within the range of most radiographic viewers.

3.6 Figure-Background Brightness Relationship

The National Health Survey optotypes were black letters on white background of high contrast.[7] The Committee on Vision, NAS-NRC also assumes that all optotypes are black figures on a white background. In radiographs, dark lines on a bright background and bright lines on a darker background are encountered but with the former occurring more frequently. The above conisderations indicate that the reference acuity standard should be one with dark lines on a brighter background.

4.0 Other Considerations

4.1 Viewing Distance

In acuity testing of radiographic inspectors we are interested in near acuity. The exact viewing distance is not critical, but once a viewing distance is specified, it is important that all tests be conducted at the specified distance, since the angular subtense of the target is calculated for a given viewing distance. The National Health Survey used a viewing distance of 35.6 cm (14 in). The Committee on Vision, NAS-NRC recommends a near acuity test viewing distance of 40 cm (16 in) primarily to be compatible (simple multiple) with the 4 m distance recommended for distance acuity. The author recommends the 40 cm viewing distance in order to minimize differences from standard practice.

4.2 Light Source

The wavelength composition of the light sources can affect acuity.[14] The primary consideration of the light source is the spectral centroid (the wavelength for which the eye must be focused). The spectral centroids of the commonly used lamps in viewers, incandescent and fluorescent lamps, when operated at designated voltages, are satisfactory.

4.3 Test Room

The only visual variable of significance in the test room is the ambient light level. We must avoid a high luminance space. Practical considerations would dictate a space with low ambient light levels. The luminances as seen by the testee should not be higher than the background luminance of the test target. The luminance of the surround affects pupil size and the amount of stray light in the eye. We recommend that the standard condition be one in which the space is darkened, with a portable light source for the testing examiner's use, making certain that it is placed so as to minimize the light being directed toward the testee.

4.4 Scoring

The performance requirement should be closely related to the performance of the average human observer. But for tasks in which the visual capacity is an important component of job performance, the criterion level may be set higher than that required for tasks where visual capacity is not as important. This is a policy decision that must be made by the users of the test.

It is estimated that the acuity test to be recommended in this paper, calling for a 70 percent performance score, will be slightly stricter than that for the general population, where the criterion for average vision is 1 minute of arc for a high contrast target with minimal blur. It is recommended that whatever value is decided on, a validation test with radiographic inspectors be performed, since the base level (average acuity) should reflect the performance of active radiographic inspectors.

5.0 Recommendations

Based on the preceding discussions, the recommended parameters are summarized in table II. The optotype should be a thin line darker than the background. The background luminance of the test target is kept constant at 85 $\pm$ 5 nits (25 $\pm$ 1.5 fL). Three contrast levels are recommended. The highest level, 0.85, is recommended by the Committee on Vision, NAS-NRC. The transmittance-density values for obtaining these contrasts are given in table III. The line widths recommended are 0.75, 1.0, and 1.5 minutes of arc. The length of the lines is kept constant at 107 minutes of arc. These angular measures are based on a viewing distance of 40 cm (16 in). The corresponding dimensions in inches and centimeters are given in table IV. Two levels of line sharpness should be considered--one with a sharp edge that will be similar to most optotypes used in visual acuity testing, and one with a blurred edge conforming to real world radiographs. The blurred line will be described by discrete empirical values, the one recommended being that which describes the edge gradient of sample 101C, figure 4.

Table II. Visual Acuity Test Parameters

Variable	Number of Conditions	Conditions
Figure-Ground	1	Dark on light
Background Luminance (nit/ftL)	1	85 ± 5/25 ± 1.5
Contrast	3	0.1, 0.3, 0.85
Line Width (minutes)	3	0.75, 1.0, 1.5
Line Length (minutes)	1	107
Viewing Distance (cm/in)	1	40/16
Blur	2	Sharp, blurred
Line Orientation	4	Perpendicular/horizontal oblique right/left
Light Source (viewer)	1	Incandescent, fluorescent
Total (combinations)	72	

Table III. Transmittance-Density of Visual Acuity Test Targets

	Line		Background	
Contrast	Transittance	Density	Transmittance	Density
0.1	0.018	1.74	0.02	1.70
0.3	0.014	1.85	0.02	1.70
0.85	0.003	2.52	0.02	1.70

Table IV. Dimensions of Line Target

Minutes*	Width Inches	Centimeter
0.75	0.0035	0.0087
1.0	0.0047	0.0116
1.5	0.0070	0.0175
	Length	
107	0.5	1.24

*Viewing distance = 40 cm (16 in)

Samples of the reference test targets are presented in figure 8. The relevant parameters of the reference test have been described, except for line orientation. Line orientation as a parameter serves two important functions: (1) it increases the number of possible responses (two with no orientation to four with the orientations recommended in this report), and (2) it includes astigmatic effects. The four orientations are horizontal (H), vertical (V), oblique-right (R), and oblique-left (L). Contribution by guessing can be decreased by dividing the targets into four quadrants with the subject being required to denote which quadrant the line is in, in addition to the orientation of the line. This additional precaution should not be necessary, but serves the purpose of decreasing the probable contribution by guessing from 1/4 to (1/4)(1/4) = 1/16.

These targets will be used for self testing (intra-inspector assessment) as well as testing by designated examiners (inter-inspector differences). The front of the slide (see figure 8) will be blank with all necessary information given on the reverse side. This procedure assumes that for self testing the examinee will not cheat, and will look at the side giving the correct response (H, V, R, or L) only after evaluating the target orientation. When used by professional examiners, they will be looking at the side with the target information.

These slides are to be used with a standard dimmable radiographic viewer, masked so that only a 5 cm (2 in) square is exposed. The light source for the viewer would be incandescent or fluorescent lamps.

The test room should be darkened with a portable light source for the examiner but in no case should the luminance be higher than 85 nits (25 fL) within the testee's field of view.

The actual performance by experienced radiographic inspectors cannot be predicted at present. It is recommended that a validation test with radiographic inspectors be performed, the passing score based on the performance for the above test, and the actual scoring including policy considerations. For example, since visual acuity is an important job-related requirement, how severe should we make the acuity requirements?

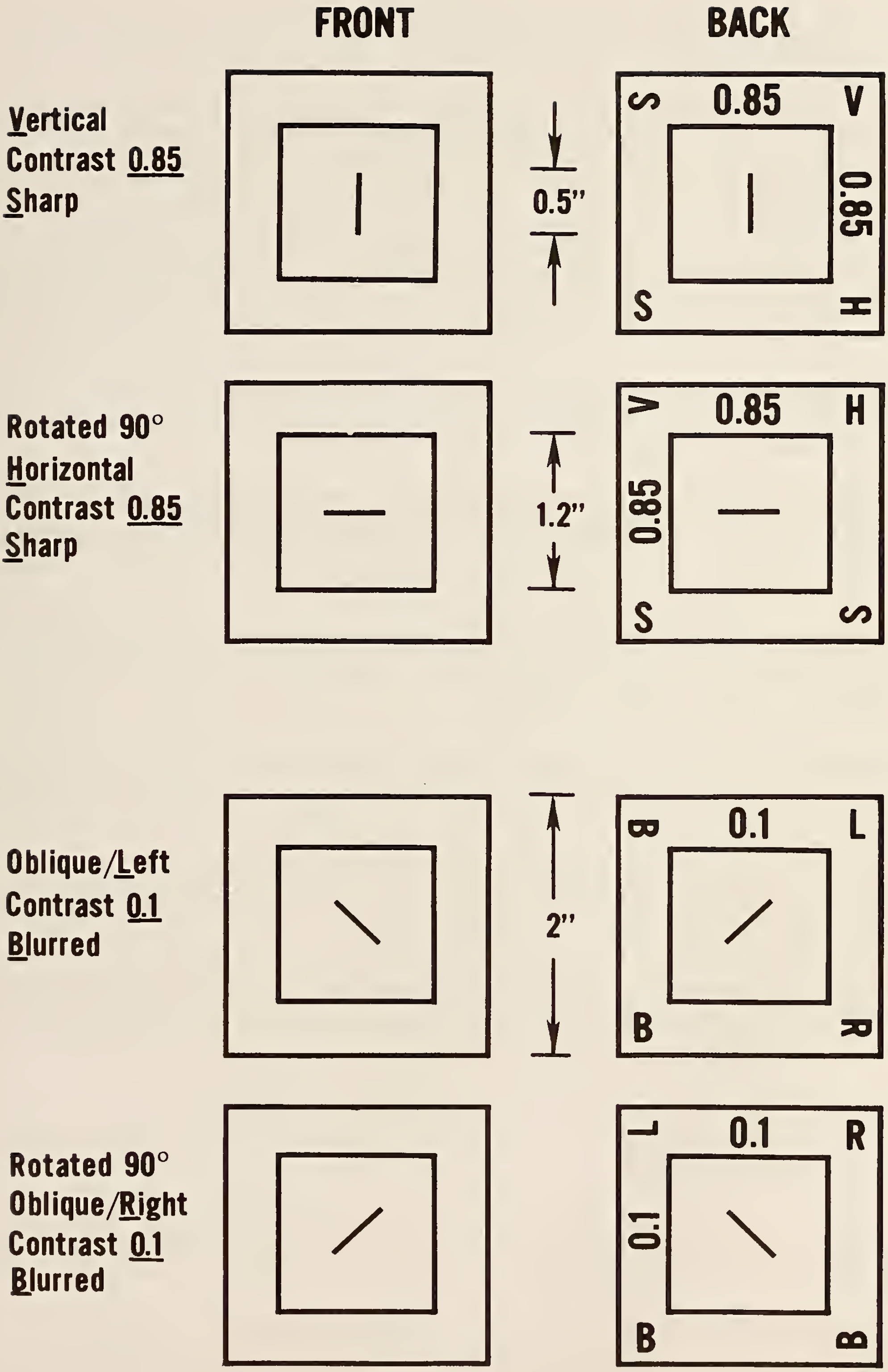

Figure 8. Examples of reference acuity tests showing line orientations and dimensions. See text for complete description.

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Visual acuity tests for radiographic inspectors should be correlated with the type of tasks encountered in real world radiography. The testing procedures should be capable of assessing differences in day to day performance of a given inspector as well as the performance of one inspector relative to other inspectors. Single line targets with specific parametric values for contrast, width, and blur are recommended to provide a means for testing a radiographic inspector for visual acuity. These targets may be used for periodic tests by the employing organization or for more frequent self testing by the inspector. Statistics from the National Health Survey, procedures recommended by the NAS-NRC Committee on Vision and real world radiographs have been utilized in arriving at recommended test configurations.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Acuity tests; nondestructive testing; quality testing; radiograph evaluation; visual inspection; visual testing

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