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# Focusing the Fresnel Lens Optical Landing System

W. F. Mullis, I. Nimeroff, and E. L. Walters

Illuminating Engineering Group
Optical Radiation Section
Heat Division
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**Department of the Navy**
**Naval Air Engineering Center**
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U.S. DEPARTMENT OF COMMERCE, Rogers C.B. Morton, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

May 21, 1975

Commander
Naval Air Systems Command
Washington, D. C. 20360

Attn: AIR 53722

Dear Sir:

Enclosed are four copies of National Bureau of Standards Report No. 75-644 entitled "Focusing the Fresnel Lens Optical Landing System".

Copies of this report are being sent to the agencies listed below.

Sincerely,

A. T. Hattenburg

A. T. Hattenburg
Illuminating Engineering Group
Optical Radiation Section
Heat Division
Institute for Basic Standards

Enclosures

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## PREFACE

At the request of the Naval Air Engineering Center of the U. S. Department of the Navy, the National Bureau of Standards conducted a study of various methods of focusing the Fresnel Lens Optical Landing System (FLOLS). This work involves both visual and instrumental procedures by which the correct focus position of the light source relative to the lens may be determined. The opinions, findings, and conclusions in this report are those of the authors and are not necessarily those of the Naval Air Engineering Center. Certain commercially available equipment, instruments, or materials are identified in this report to specify adequately the experimental procedures used. In no case should such identification be inferred as recommendation or endorsement by the National Bureau of Standards, nor does the identification imply that the materials or equipment are the best available for the purpose.

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ABSTRACT

The Naval Air Engineering Center requested the National Bureau of Standards to develop a method of evaluating the performance of lenses of the Fresnel Lens Optical Landing System (FLOLS). In the course of this work, it was found that focusing of the cells of a FLOLS unit varied considerably. This led the NBS to examine the various focusing techniques used in the past and to develop a more precise method for focusing a cell. The focusing methods studied include the following:

1. Photometric
2. Peep Sight
3. Parallax
4. Auxiliary Image-Forming Lens
5. Pattern Matching

In addition, in the study of these focusing methods, several other factors that affect the light-beam-forming characteristics of a cell were investigated. These include the effects of,

1. Lenticular Lens
2. Lens Temperature
3. Slit Width
4. Slit Alignment
5. Lamp Dimming and Source Color

The results of this study indicate that visual methods of focusing the FLOLS system have inherent difficulties that lead to improper focusing. Photometric procedures developed at NBS, however, can give adequate focusing precision.

## 1. Introduction

This report covers work completed to date in reference to various methods of focusing the Fresnel Lens Optical Landing System (FLOLS). Also attached, is an appendix relative to other factors affecting FLOLS performance. The work is a part of a larger effort to determine quantitatively the optical quality of the Fresnel lenses used in this system in terms of their acceptability (or unacceptability) for projecting a light beam pattern that has the appropriate parameters. Factors affecting the beam pattern in the system include such items as optical and mechanical alignment, slit width, lens distortion, lens temperature, and focusing. Because focusing of the system is the most critical parameter, a decision was made to report separately the data obtained to date by various focusing methods. It is recognized that proper focusing does not necessarily remove all of the problems associated with the formation of the light beam. However, when the system is properly focused, the other problems become less significant.

## 2. Description of FLOLS Unit and Cells

The Fresnel Lens Optical Landing System is a method for assisting pilots in establishing and maintaining the proper glide path for safe landing. The system provides a horizontal bar of light that when viewed with respect to a set of fixed horizontal datum lights indicates to the pilot whether he is above, below, or on a correct glide slope. The bar of light is formed by each of the FLOLS cells. The unit consists of five cells arranged as shown in Figure 1a. The individual FLOLS cells in the unit are placed so that these optical axes intersect at a point 150 feet behind the Fresnel lenses.

A FLOLS cell, schematically shown in Figure 1b, consists of a lenticular lens, a Fresnel lens, a light source, light-source mount, and mount-support rods. The lenticular lens, which spreads the beam horizontally, is placed outside an egg-crate type grille and the Fresnel lens. The grille consists of two sections between which the Fresnel lens is placed. The source consists of three lamps, each of which has a ground-glass covered slit. Focusing, as used in this report, consists of positioning the light source along the support rods of the cell until the proper beam spread (beam divergence or angle) is achieved. The support rods are parallel to the lens axis, so that the source can be moved along the lens axis.

## 3. Fundamentals for Focusing

The Gaussian lens equation quantitatively relates the distances between the lens and the source, the image, and the foci, F and F'

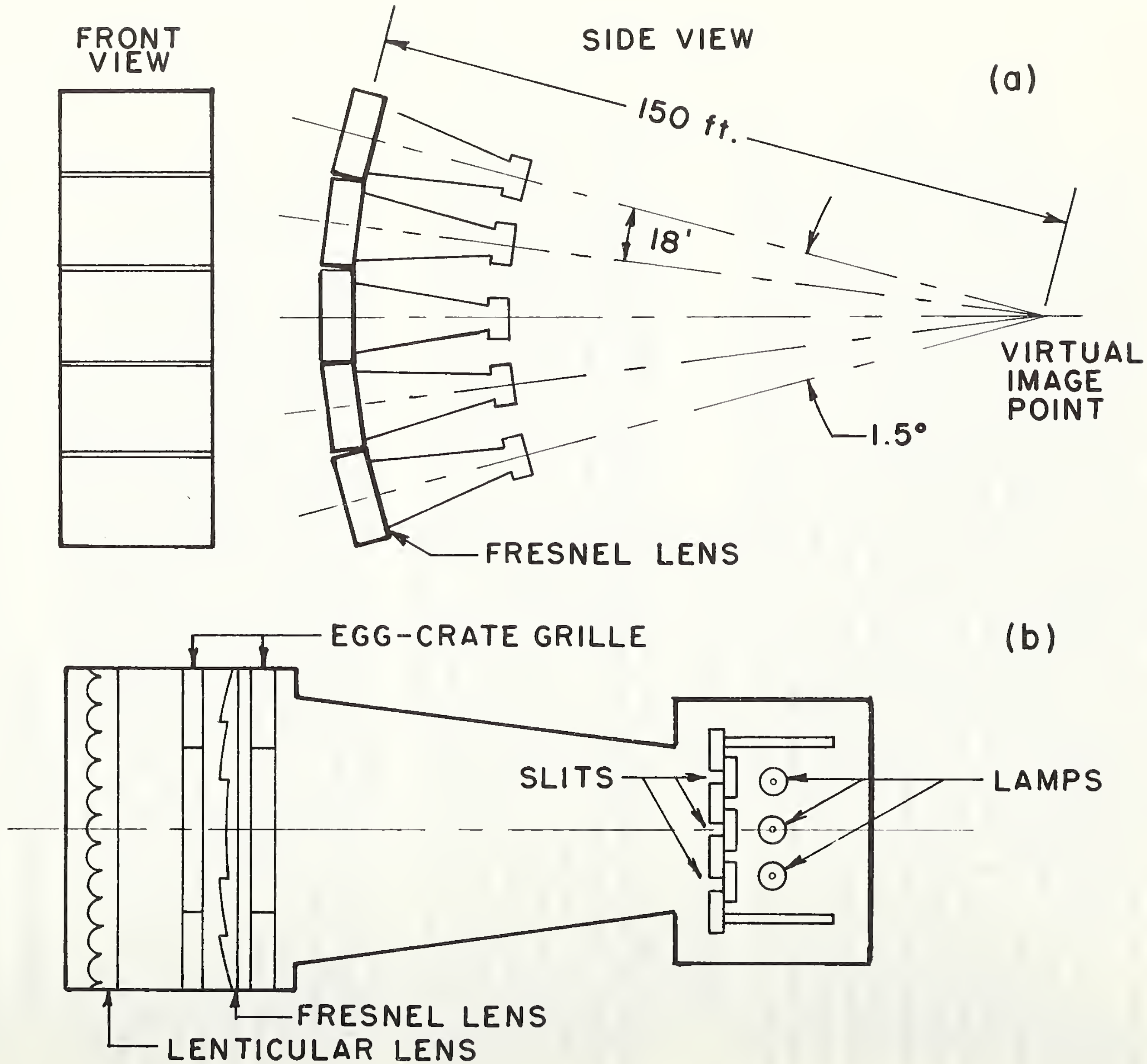


Figure 1. Fresnel Lens Optical Landing System: a. FLOLS unit, front and side views. b. Cell detail (not to scale).

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of any simple thin lens system. See Figure 2. If p is the distance from the source to the lens, q the distance from the image to the lens, and f the distance from the foci to the lens, then the equation is written,

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}. \tag{1}$$

In addition, it can be shown from Figure 2(a) that the ratio of the source size, S, to the image size, i, is equal to the ratio of their respective distances from the lens. This relationship is stated thus,

$$\frac{S}{i} = \frac{p}{q} \tag{2}$$

With this minimal background in the lens equations, the light-beam characteristics of the FLOLS can be examined. It can be seen from equation (1) that if the source is placed at the focus, then p is equal to f, the image distance q is infinite, and the emerging beam is collimated. This is shown in Figure 2(b). If the source is placed between the lens and the principal focus, a diverging beam will emerge and a virtual image is formed behind the lens. See Figure 2(c). As the source is moved closer to the lens the virtual image moves toward the source, and the closer the source is to the lens, the wider will be the diverging light beam.

It can be seen from Figure 2 that a lens will form either a real or a virtual image. To judge whether an image formed by the FLOLS cell is real or virtual, a diffusing screen in placed at the position from which the light appears to originate. If light falls on the screen the image is real, otherwise it is virtual. In either situation this image, so far as the optics are concerned, acts as the source for the optical system and light may be considered as if it were effectively diverging or spreading from that location. The virtual image is called a virtual source.

The spread of the beam from the image may be described in terms of the angular divergence θ about the optical axes or in terms of extent X together with the distance d along the axis from the image. In this report, if beam spread is given in angular units the former is meant, if beam spread is given in distance units the latter is intended.

The term beam spread is here defined as the divergence where the intensity distribution of the beam decreases to 50% of the maximum illuminance on either side of the optical axes. The decrease to 50%

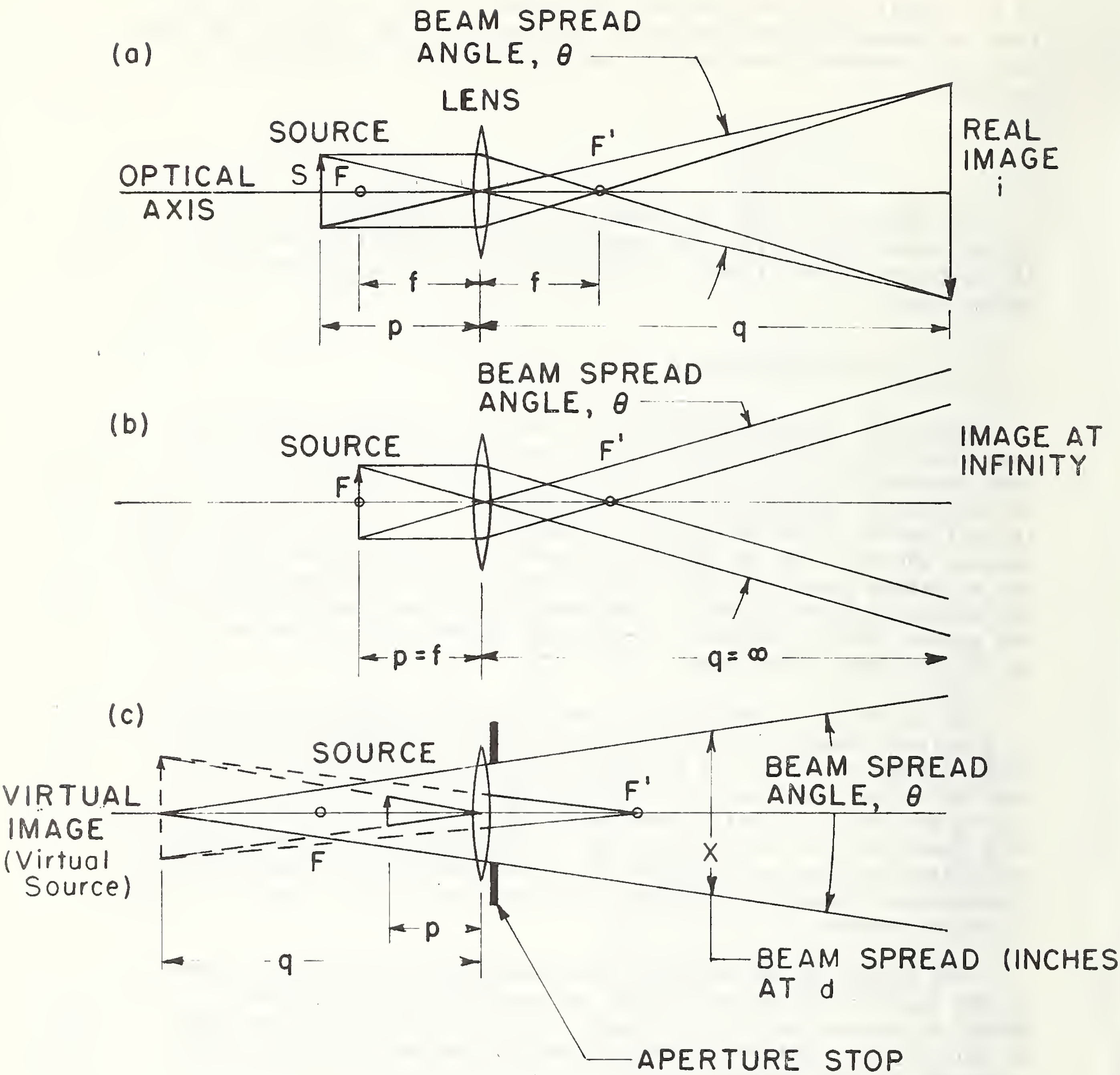


Figure 2. Image formation by a thin lens: a) Source S at distance p from lens, outside focus F forms real image i at distance q from lens, outside focus F'; b) Source at p = F, image at q = ∞; c) Source at p between lens and F, image at -q, outside F.

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occurs when the light from one half of the virtual image is occluded by the aperture stop. The beam illuminance drops to zero when the image is totally occluded by the aperture stop. This effect is shown in Figure 3 for an ideal lens and its virtual image.

Although the virtual image distance can not be measured directly, the FLOLS has been described in terms of this distance. It can, however, be determined indirectly by computation from the thin lens equation if the light source position and the focal length of the Fresnel lens are precisely known. The virtual image distance can also be determined from measurements of the beam spread.

A curve plotted to show the relation between the beam spread angle (angular width of the beam) of a particular lens and the source position inside the focus, can be used to find a position of the light source relative to the focus to obtain the exact beam spread angle desired. Since the beam spread is inversely proportional to the distance from the lens to the virtual image (the narrower the beam the greater the distance from the lens to the virtual image) a position of the light source can be found that will produce the required distance from the lens to the virtual image. This latter relation is shown in Figure 4 for a lens with a 24-inch focal length. It must be pointed out at this time, however, that with a lens of a given focal length and cell aperture, only one of the parameters needs to be specified (beam spread or virtual image distance) as one is inversely proportional to the other. If the distance from a lens to the virtual image is specified, the beam spread is thereby determined for that lens. Conversely, if the beam spread is specified, the distance to the virtual image is thereby determined. Measurements indicate that for a cell of the Fresnel lens optical landing system (FLOLS) equipped with an egg-crate grille having an effective aperture of 8.8 inches and a lens having a focal length of 24 inches the following values of beam spread angle and virtual image distance will be obtained:

1. for a virtual image distance of 150 feet, the maximum beam spread angle is 16.8 minutes of arc, and

2. conversely, if the beam spread angle is 18 minutes of arc, the lens to image distance is about 140 feet, where maximum beam spread angle is the angle between the points at which the beam illuminance drops to 50% on either side of the peak illuminance, with the virtual image at the vertex of the angle. Also, if a cell is used without the egg-crate grille (9-inch aperture) the corresponding values for the cell would be 17.2 minutes of arc for 150-foot image distance. With a 9-inch aperture and an 18-minute beam spread, the image distance would be 143 feet.

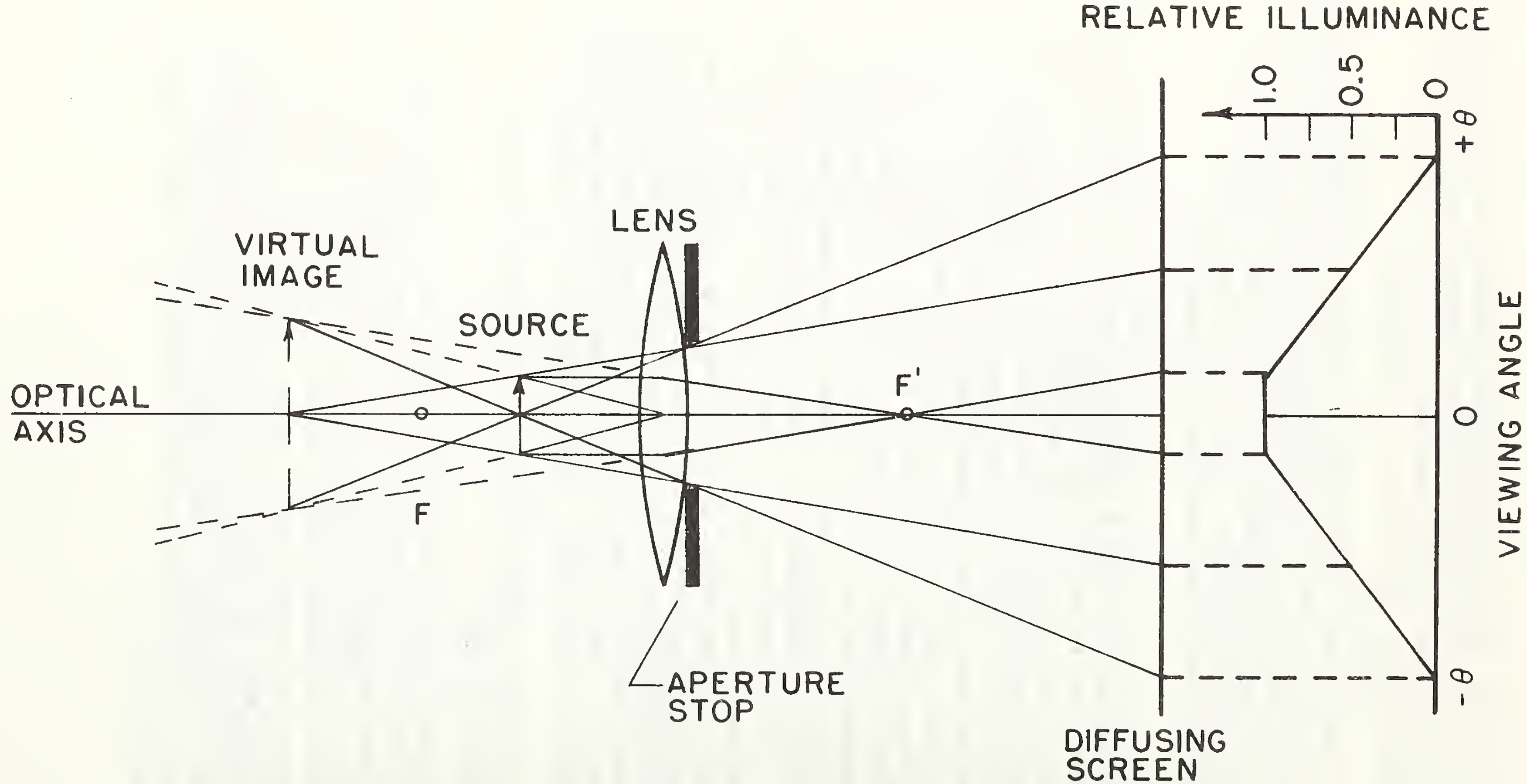


Figure 3. Ideal formation of beam distribution (at right) from virtual image (at left) by aperture stop occlusion.

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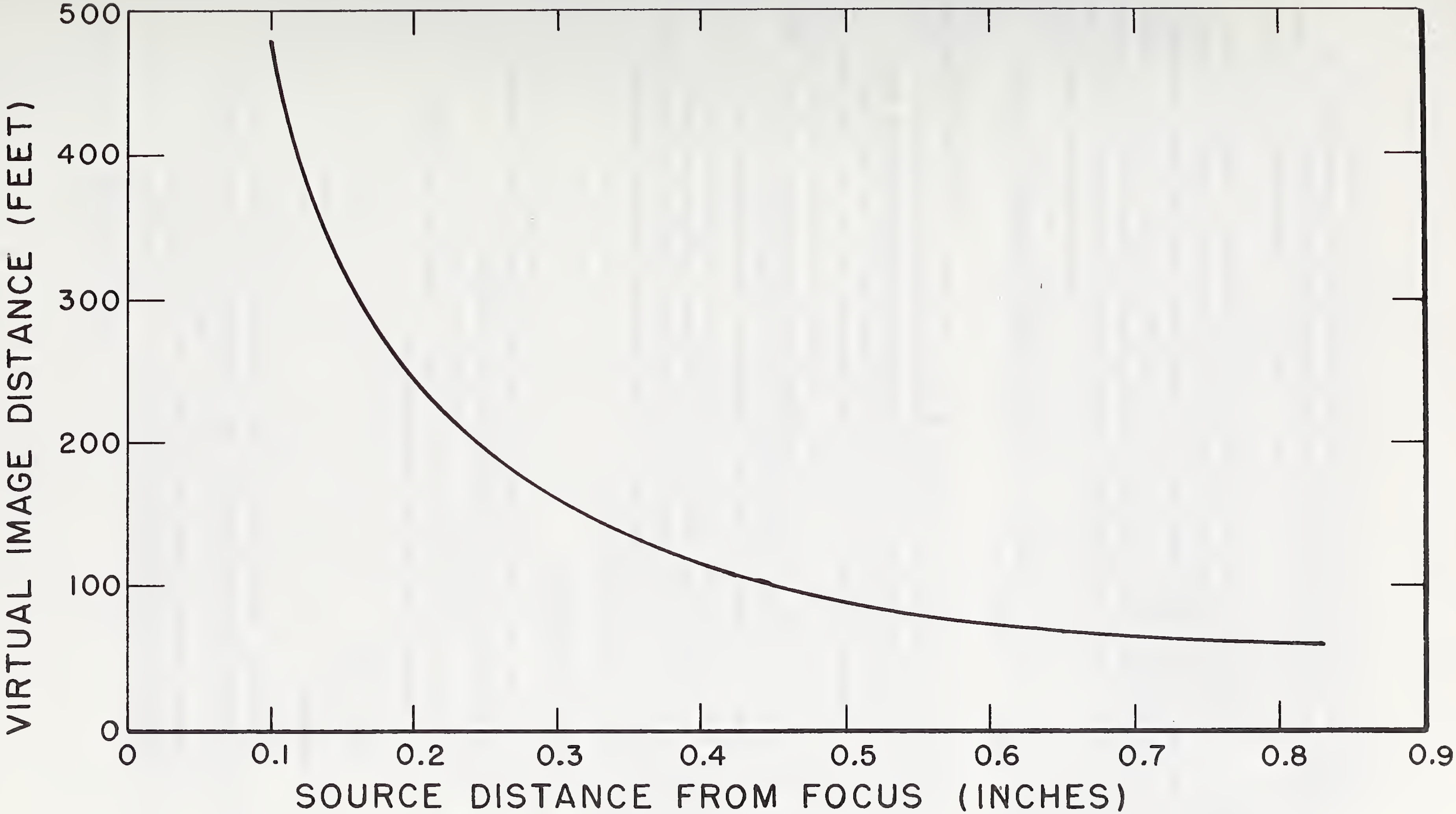


Figure 4. Virtual image distance versus source distance from focus for ideal lens having a 24-inch focal length.

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Since the beam spread angle can be measured photometrically to an accuracy of a few seconds of arc (method explained later) and since the position of the source can be measured mechanically to a couple of thousandths of an inch, the problem of focusing becomes primarily a matter of how much precision is required. The precision required, in turn, determines which of the available focusing methods should be employed. Computations indicate that a 0.010 inch movement of the light source for a nominal lens, in the region of proper beam spread, changes the distance to the image about 5 feet. Correspondingly, the 0.010 inch movement changes the beam spread in this region about 1 minute of arc. These effects reduce the problem of focusing to two considerations: (1) what focusing precision is required and (2) which parameter, virtual image distance or beam spread, should be specified.

The overall FLOLS unit is mounted in the rack with five individual cells stacked in such a way as to project a total beam spread of 1.5 degrees or 90 minutes of arc. This arrangement suggests that each cell is intended to cover an angle of 18 minutes. To cover this angle with a smooth transition of light between cells, an 18-minute beam spread (measured to the one-half maximum illuminance level) is required so that there be no illuminance decrease between cells. The cells are placed so that their optical axes intersect at a point 150 feet behind the Fresnel lenses. However, as seen from the discussion above, the beam spread angle is 16.8 minutes to the 50% points for a virtual image distance of 150 feet. It is probable that an angle smaller than 18 minutes per cell (0.3 degree) has been used in practice, as a comparison of the various focusing methods described below will demonstrate.

## 4. Methods of Focusing

Listed below are the various methods of focusing the Fresnel Lens Optical Landing System included in this study.

1. Photometric (photometer and either a graphic recording or a meter readout of beam spread)

2. Peep sight

3. Parallax

4. Auxilliary image-forming lens (observing face of cell or observing beam pattern as projected onto white card)

5. Pattern matching (matching cell beam pattern to a standard film pattern)

Five lenses were used in focusing by the photometric method. In the intercomparison of the other methods only two lenses were used, one designated No. 2117 and the other (furnished by NAEC) designated "Bad Lens".

Repetitive measurements were made with each method to determine the precision obtainable. Normally, 10 such measurements were made (five for each of two operators or observers) with each method. However, if the settings by a particular method were very widely dispersed, work with this method was stopped with fewer than 10 measurements. A description of the test procedure for each method utilized is given below.

## 5. Description of Focusing Methods

### 5.1 Photometric

The photometric focusing method is based on the principle of measuring photometrically the illuminance in a vertical plane at a stated distance from the cell and finding the width of the beam at which one-half peak illuminance occurs.

5.1.1 Photometer with Graphic Recorder. These measurements can be made by directly illuminating the photodetector of a photometer, used as an illuminance meter. Alternatively, with the photometer used as a luminance meter, measurements can be made by scanning the light beam pattern as projected onto a diffusing screen (ground glass or milky plastic). The photometer scans the pattern formed after the light from the cell has passed through the screen. The alternate arrangements of cell and photometer, with and without diffusing screen are shown in Figure 5. The scanning is accomplished by traversing the beam pattern with the photometer rather than by rotating the cell so that its beam traverses the photometer. Rotation of the cell results in a small angular error in that the virtual light source is not at the axis of rotation but rather 150 feet beyond it. Because the travel involved is small and would result in an extremely small error, rotation of the cell could have been used. In these measurements, however, the traversing procedure was used for convenience.

In photometric focusing the light source (lamps, slit and ground glass of the cell) is moved along the optical axis until the correct beam spread is obtained for the particular distance selected for the measurements. The geometric principle is shown in Figure 6 where

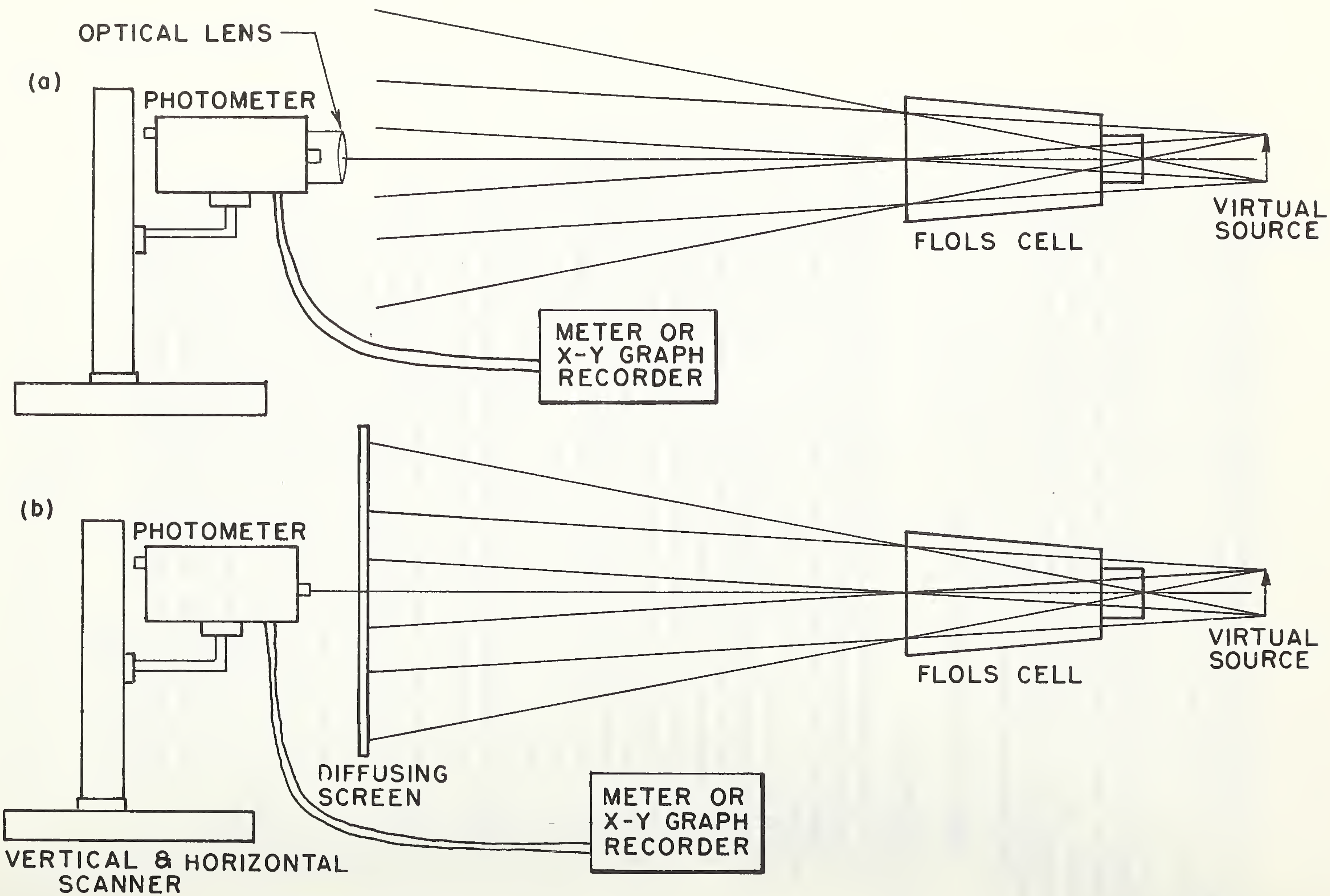


Figure 5. Focusing by measuring the width of the light beam by alternate photometric methods, a) without, and b) with diffusing screen.

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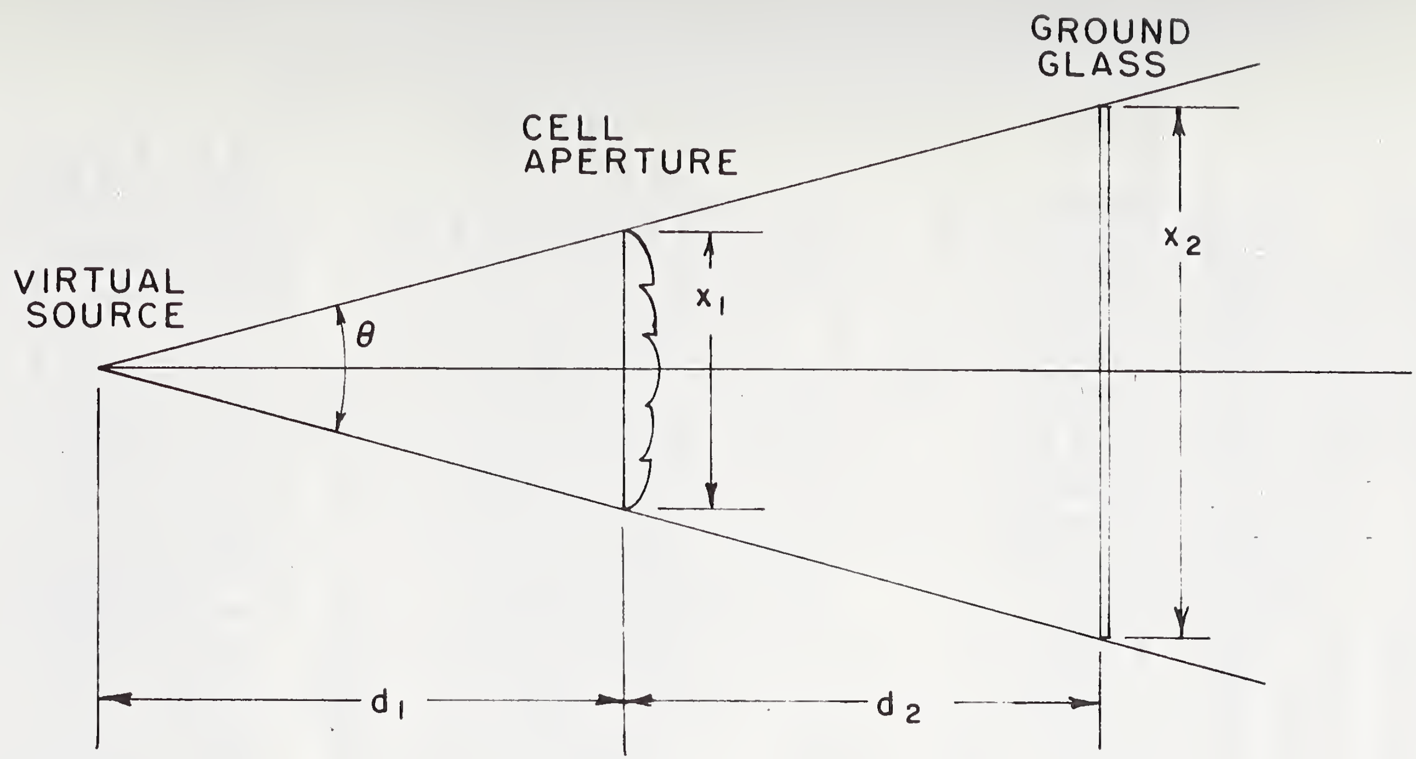


Figure 6. Geometric principle of beam spread, $\theta$ in degrees, or $X_2$ in inches, at distance of $d_1 + d_2$ in feet.

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$X_1$ is the cell aperture or opening

$X_2$ is the beam spread in inches at the 50% luminance level

$d_1$ is the distance to the virtual image from the cell aperture

$d_2$ is the distance from the cell aperture to the plane selected for the measurement.

From Figure 6, because the source can be considered a point in the plane of the figure, it is apparent, that the beam spread in inches at a given distance from cell aperture can be computed from the relation

$$\frac{X_1}{d_1} = \frac{X_2}{d_1 + d_2}, \text{ or} \tag{3}$$

$$X_2 = \frac{X_1(d_1 + d_2)}{d_1}.$$

It can be seen from Figure 3 that the beam does not cut off sharply, but gradually tapers off, hence the 50% illuminance points are used to define the beam spread. Use of a diffusing screen is a means that permits visual estimate of the beam spread. As an example of the beam spread at a diffusing screen distance of 20 feet from a a cell that has an effective aperture of 8.8 inches (cell with egg-crate grille) and a virtual image distance of 150 feet would be,

$$X_2 = \frac{8.8(150 + 20)}{150} = 9.97 \text{ inches.}$$

For a cell aperture of 9 inches (as for a cell without the egg-crate) the beam spread under the same distances as the example above would be 10.2 inches. Thus increasing the aperture increases the beam spread if the distances are not changed. Furthermore, the accuracy of the computed beam spread depends on how accurately the cell aperture is measured, on the assumption that no lens effect in the vertical plane is caused by the lenticular lens which covers the Fresnel lens. Actually, a lens effect is introduced by the lenticular lens which spreads the beam slightly. (This effect is discussed in the Appendix.)

A variation of this photometric technique involves measuring the beam spread at two different distances instead of at one distance from the virtual source. The results obtained by this procedure are independent of cell aperture or the effects of the lenticular lens. The procedure is simply to measure the distance, d, between the two positions of the ground glass, the second beam spread, $X'_2$, the beam spread increase, x, and the distance from the virtual source to the second ground glass position, $D'_2$, because ratios of corresponding parts of similar triangles are equal,

$$\frac{X}{d} = \frac{X'_2}{D'_2}. \qquad (4)$$

The geometry demonstrating the principle is shown in Figure 7. With this procedure it has been found expedient to make two or more measurements at each distance and from these data calculate the position of the source that gives the proper beam spread. With this technique, a set of measurements, one at each distance, is made with the light source positioned to give a beam spread wider than normal followed by a second set of measurements with the source positioned to give a beam spread narrower than normal. A graph is then made from the data for source position versus beam spread for the two different distances. Then from a line connecting the data points on the graph, the position of the source can be read which will give the exact beam spread desired. When the light source is positioned to produce a virtual image of 150 feet behind the cell lens, the unit is properly focused.

5.1.2 Photometer with Meter Readout. This method is essentially the same as the photometer with graphic recorder, described above, in which the beam spread from the cell is measured with a scanning photometer and recorded manually. It differs primarily in that the scanner, photodetector, and readout equipment are simpler. The method is rapid, accurate, and adaptable to laboratory and field use and the results obtained are independent of the cell aperture. The system consists of a simple barrier-layer type photocell, a manually operated scanning device, and a suitable operational amplifier feeding a meter readout.

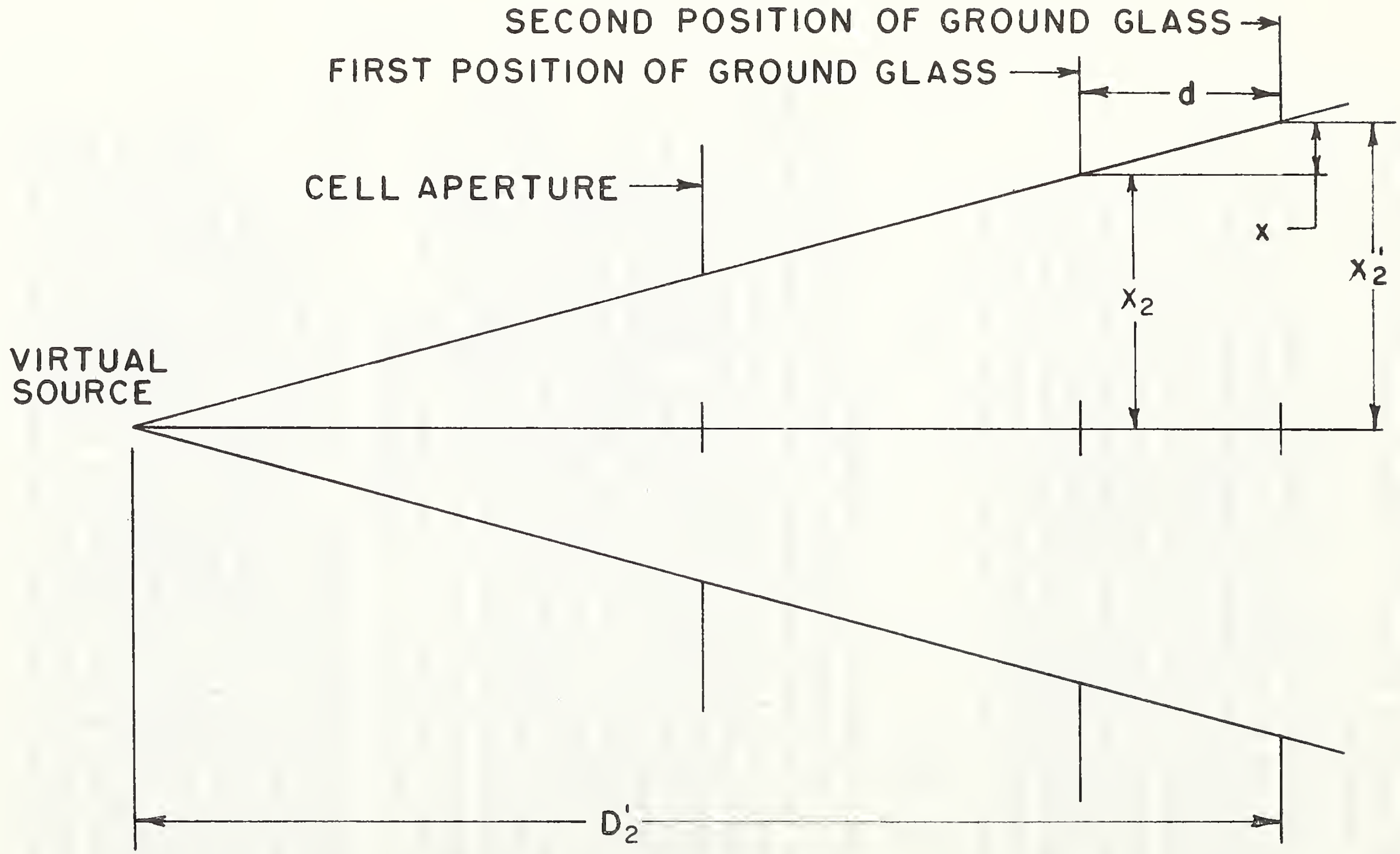


Figure 7. Geometric principle of beam spread increase x, in inches, with increase of test distance d, in feet, from virtual source.

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A diagram of the equipment is depicted in Figure 5. Photographs of the equipment are shown in Figures 8 and 9. The equipment used in this method was as follows:

| | | |
|---|---|---|
| Photocell | -- | Selenium, Weston Model 856, Type 1* |
| Scanner | -- | NBS constructed, having a total scan of 18 inches with graduations in 1/10th of an inch |
| Amplifier | -- | Pacific photometer, Model 17, with integral meter readout. |

There is nothing unique about the equipment except that the sensitive surface of the photocell is masked down to a horizontal slit 1/16 inch or smaller. This is done so that a more accurate measure of the beam spread limits can be obtained. In operation, the photocell is scanned across the light beam projected onto a diffusing plastic material until the position of peak intensity is found. The sensitivity of the meter is then adjusted so that the meter reads 100% at this position. The photocell is first moved toward one edge of the light beam (vertical plane), and then toward the other edge until readings of 50% of the peak intensity are obtained on either side of the optical axis. The positions of the two edges are noted. The distance between the two positions is the beam spread. For a cell equipped with an egg-crate grille and measured at a distance of 20 feet from the lens, the beam spread should be 9.97 inches, when a virtual image is produced at a distance of 150 feet behind the Fresnel lens. If the cell is not equipped with the egg-crate grille, the beam spread is 10.2 inches when a virtual image is produced at a distance of 150 feet. A suitable linear scale mounted on the slider-type scanner with graduations of 0.1 inch is convenient for reading the beam spread in inches. Hundredths of an inch can be estimated from the scale.

The data obtained by this method are used to place the lamp in its proper position. From the focal length of the Fresnel lens the proper source position is computed to give the expected beam spread (50% of maximum illuminance at a specified distance). With the source set near or at the proper position the illuminance distribution is measured. If the beam spread is not that which the computations indicate it should be, the source is moved until the expected spread is obtained.

*Use of a silicon photodetector is preferable.

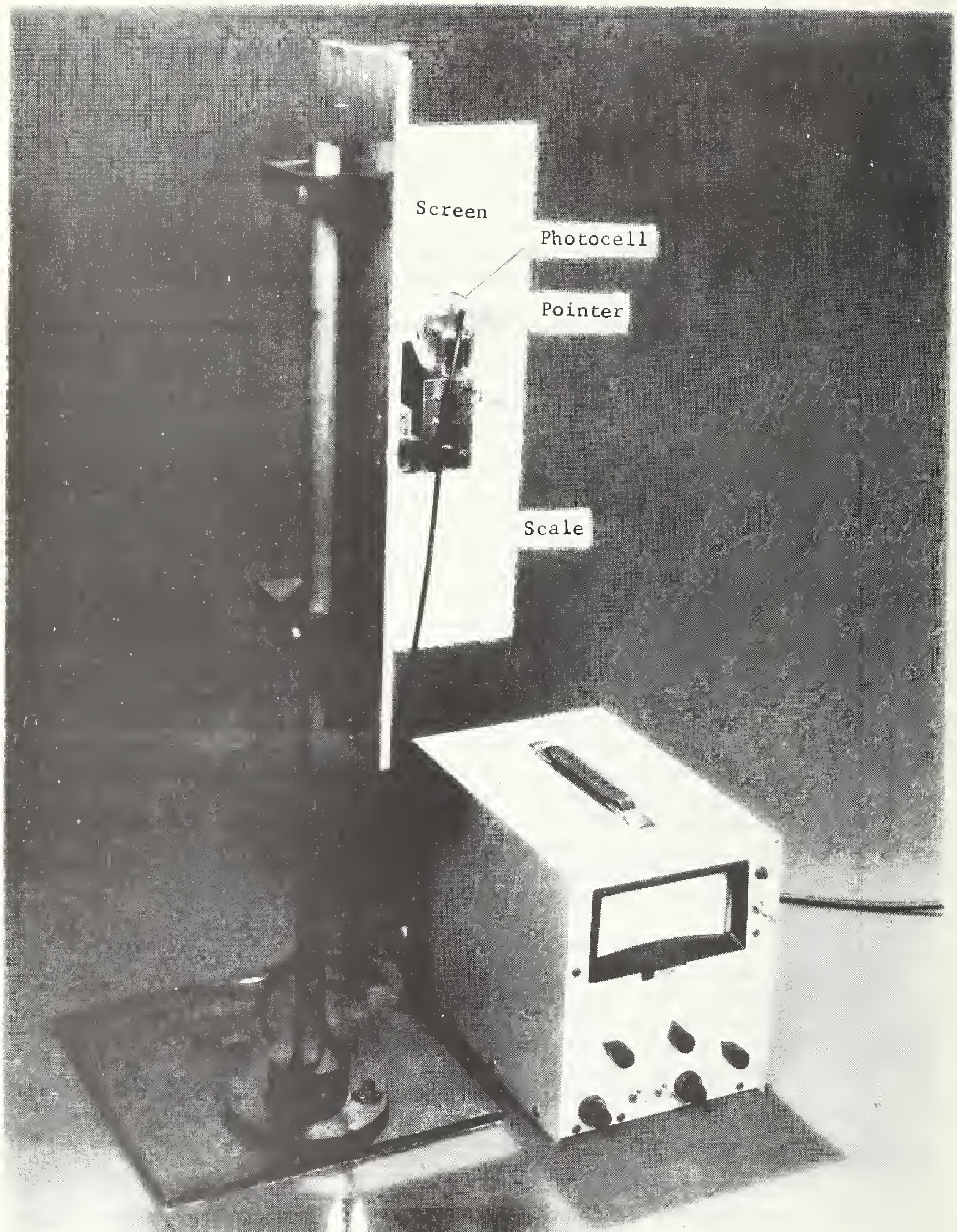


Figure 8. Manual scanning photometer with diffussing screen and meter readout.

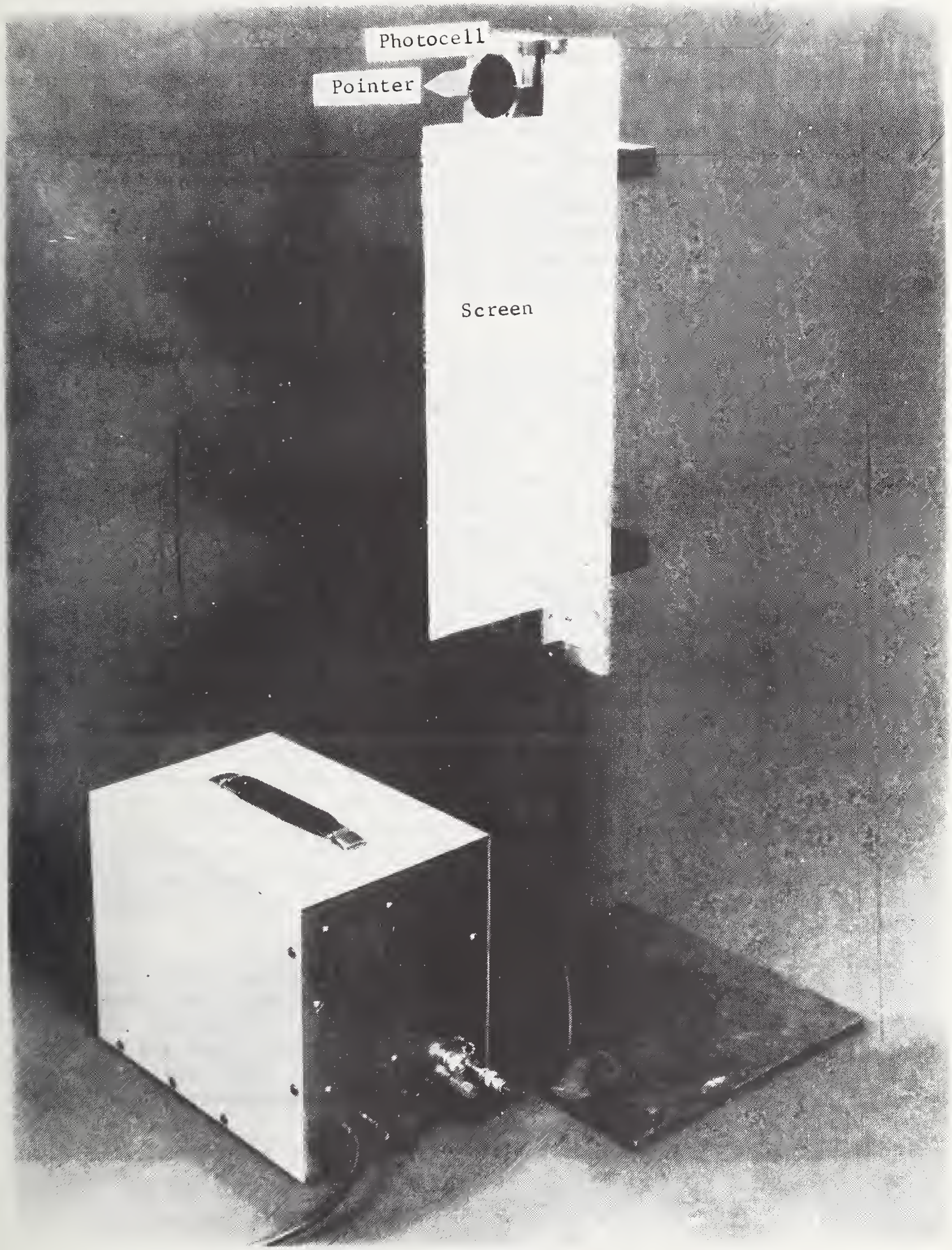


Figure 9. Manual scanning photometer with diffusing screen and meter readout

## 5.2 Peep Sight

The peep sight method measures, at a given test distance from the Fresnel lens, the vertical displacement, from the optical axis of the cell, of the bar of light ("meat ball") emanating from the virtual source. When the displacement is such as to indicate that the virtual source is at a distance of 150 feet from the Fresnel lens, the unit is properly focused. The geometry of the method is as shown in Figure 10. The procedure for focusing by this method is described in the Naval Air Engineering publication, NAEC-MISC-08668, Revision A, "Acceptance Requirements for Fresnel Lens Cell Assembly, N2562/42534."

This method was executed by means of a hole-alignment kit furnished by NAEC, Philadelphia, Pa. The kit consists of a "focus plate" with three tiny holes through which the light emanating from the cell is viewed and a "lens-alignment plate", consisting of a vertical plate and three horizontal bars, which fastens to the face of the cell, simultaneously. The vertical spacing of the holes in the plate together with the spacing of the bars of the lens alignment plate are chosen to position the virtual image at a distance of 150 feet when the light bar of the cell is successively aligned with the proper peep hole and bar of the focusing device. The device used was designed for a test distance of 10 feet. Thus, the outside hole spacing in the focus plate was 6.4 inches while the outside bar spacing of the lens alignment plate was 6 inches.

In using the equipment, the height of the focus plate is adjusted so that its center hole is at the same height as the center grid of the egg-crate of the cell face. Then while alternately viewing through the other two holes (upper and lower) of the plate, the source is moved along the optical axis of the cell until the correct setting, in the judgement of the observer, is achieved. Figure 11 depicts the equipment set-up for the measurements while Figure 12 shows the appearance of correct and incorrect settings.

For the measurements reported here two persons were used to make the settings; one served as operator while the other served as observer. While the operator moved the source, the observer sighted through the holes of the focus plate and made the judgements as to the correct focus. Then they exchanged roles until a total of ten such measurements (five by each observer) were made.

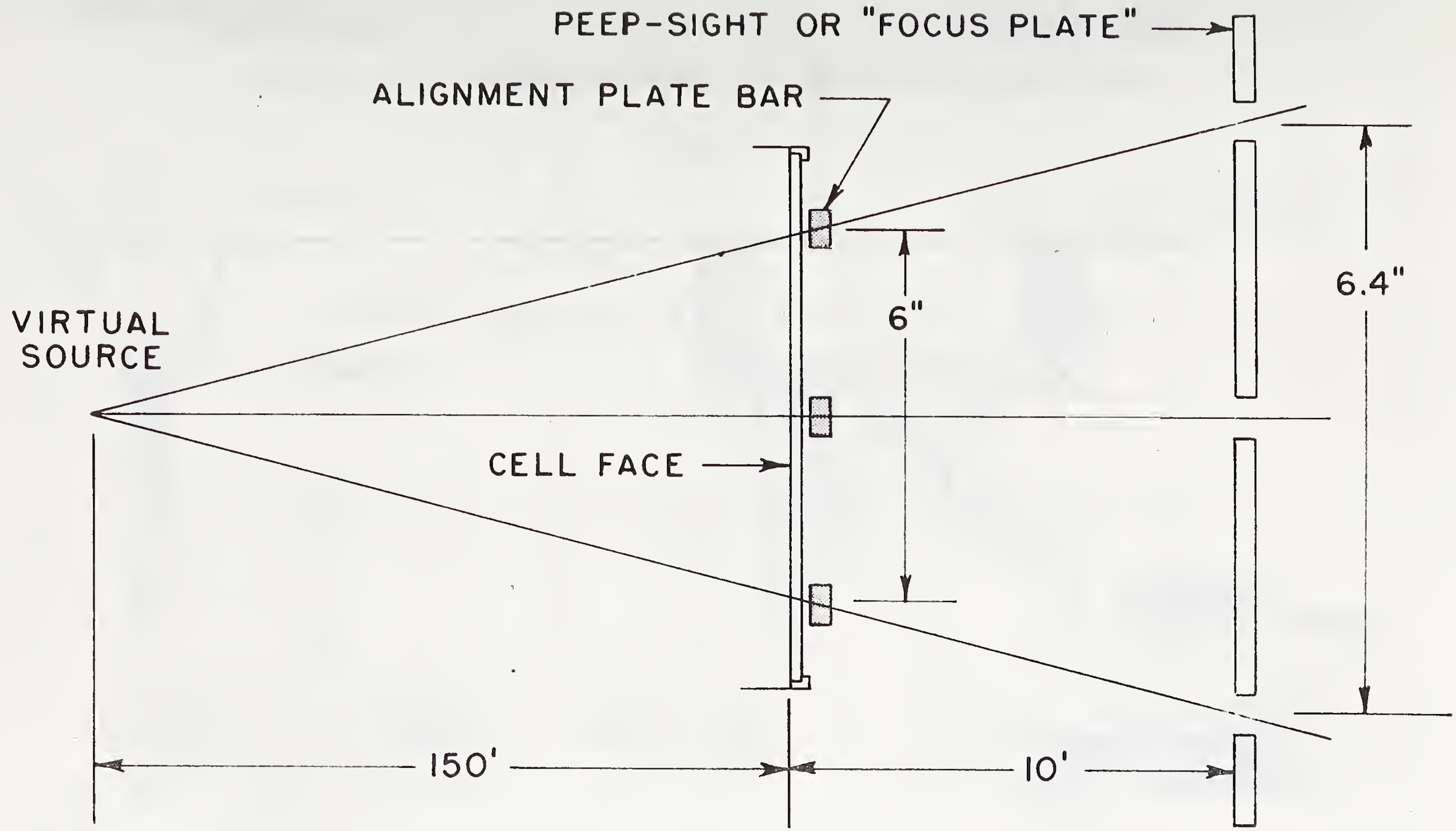


Figure 10. Geometry of peep-sight focusing device.

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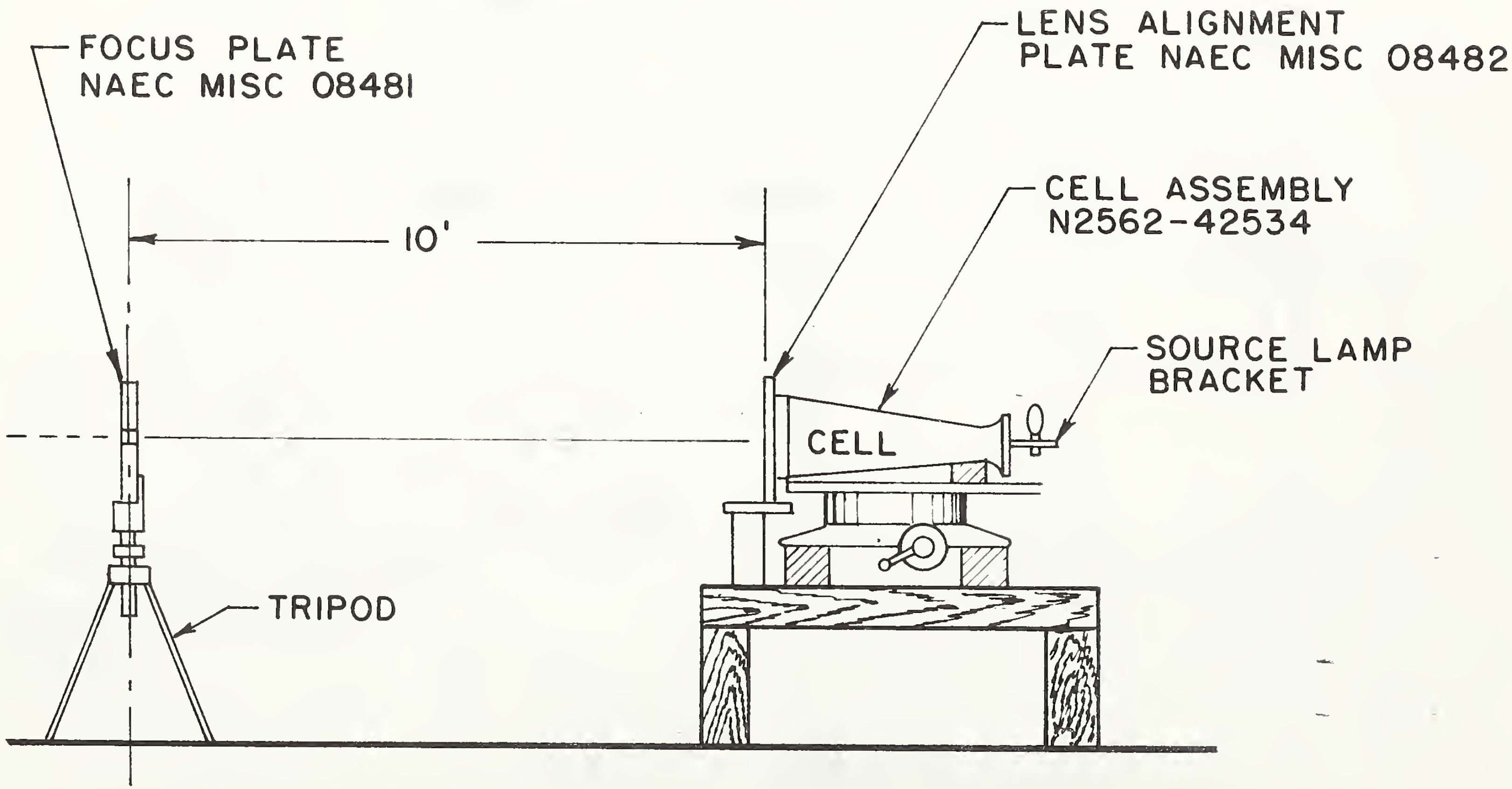


Figure 11. Equipment arrangement for focusing with peep-sight.

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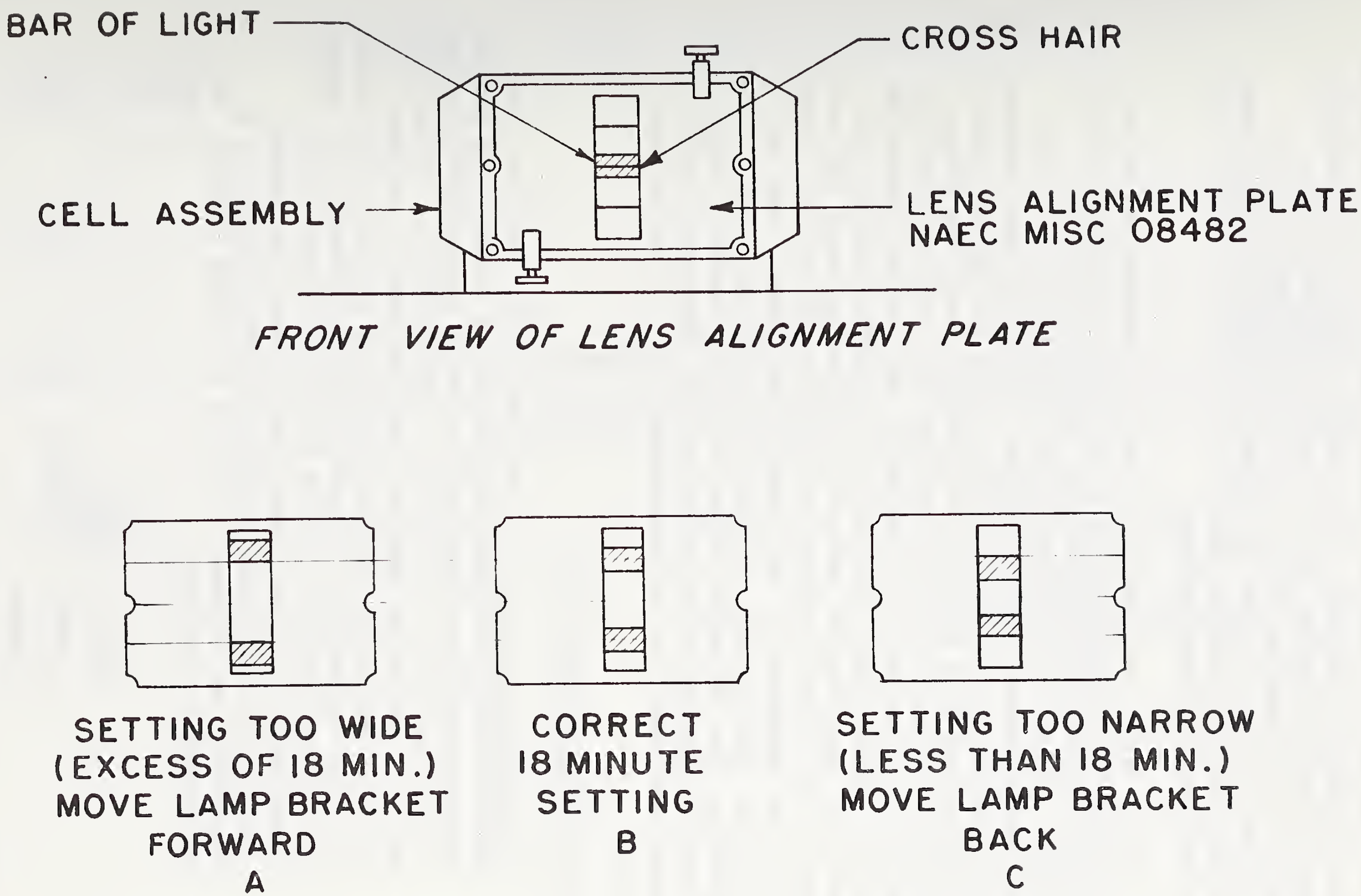


Figure 12. Appearance of correct and incorrect settings of source when using the peep-sight focusing method.

## 5.3 Parallax

This method is based on an established principle of optics in which relative positions of an object closer to an observer appears to shift relative to an object further from the observer as the observer moves across the line joining the two objects. This is shown in Figure 13. Although this principle was used on the first feasibility models, it later came to be known as the Xerox method.

In this method an observer visually compares the motion of the light bar of the cell with that of a stationary object positioned 150 feet behind the cell as he moves his eye vertically across the projected beam from the cell. In the present measurements, a light source with a slit type aperture 1/4 inch in height and approximately 1 1/2 inch in the horizontal plane was used to help the observer judge the proper alignment. Two small rods are mounted from the cell face and to the side of the unit. A diagram of the set-up is shown in Figure 14. As had been done with the preceding method, two persons were used for the measurements, one operator and one observer. The operator varied the position of the cell source until in the judgement of the observer the correct rate of movement was observed and alignment was achieved. The operator and observer then exchanged roles until each observer made five such judgements of the coincidence of the light bar and extension rods near the extreme movement for a total of ten readings.

## 5.4 Auxiliary Image-forming Lens

5.4.1 Observing Face of Cell. Focusing by the auxiliary lens method employs the quantitative law of lenses that relates distances of the source and the image to the focal length as was explained in Section 3. This method is accomplished with the use of an auxiliary hang-on lens. The lens used in this investigation, furnished by NAEC, Philadelphia, is plano-convex with a diameter of approximately 15 inches, and a focal length of about 32.35 feet. The virtual image formed by the Fresnel lens acts as the virtual source of the auxiliary lens and forms an image at a distance q as is shown in Figure 15. This distance can be computed from eq. 1

$$\frac{1}{q} = \frac{1}{32.35} - \frac{1}{150.2}$$

$$= 0.030912 - 0.006658$$

$$= 0.024254$$

or

$$q = 41.23 \text{ feet}$$

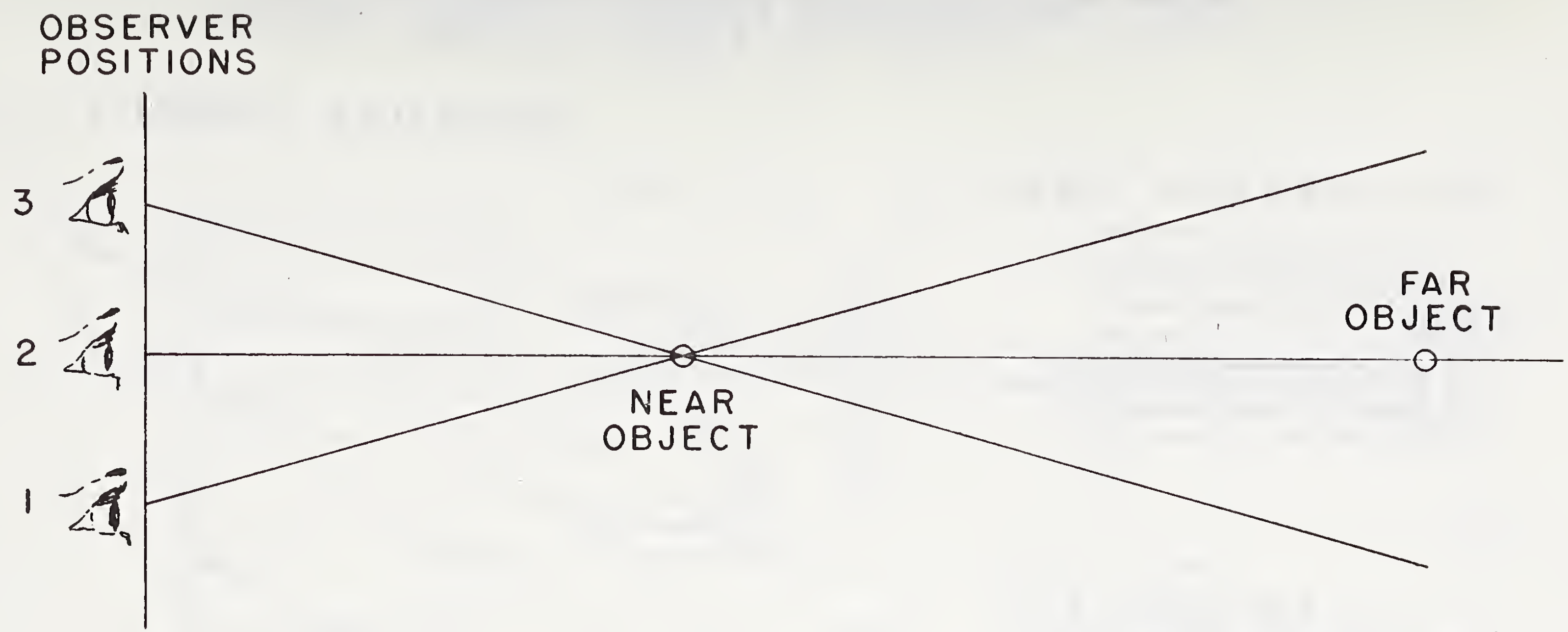


Figure 13. Principle of parallax, showing that at 1 near object appears to left of far object, at 2 near object appears in front of far object, at 3 near object appears to right of far object.

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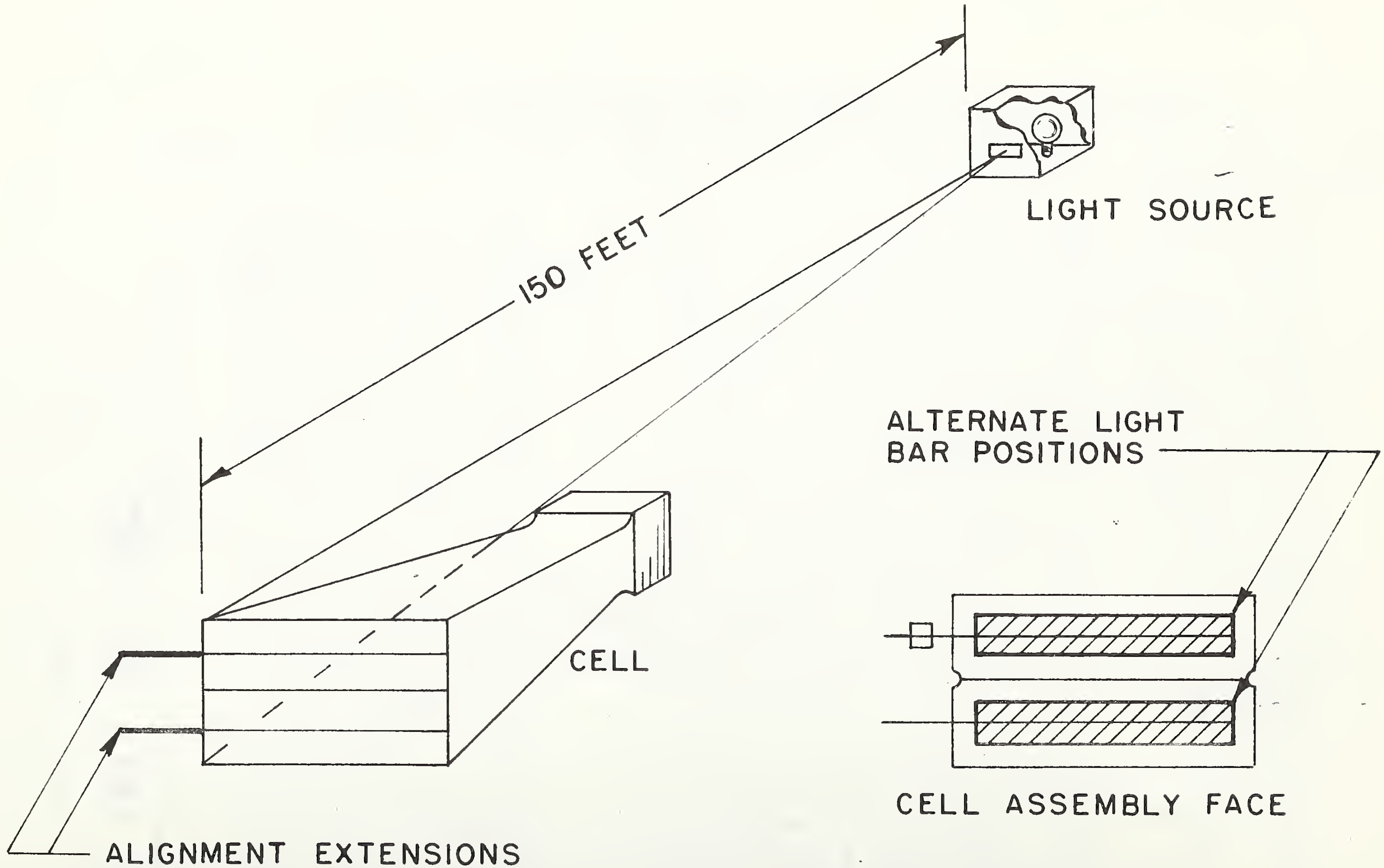


Figure 14. Equipment arrangement for parallax focusing method.

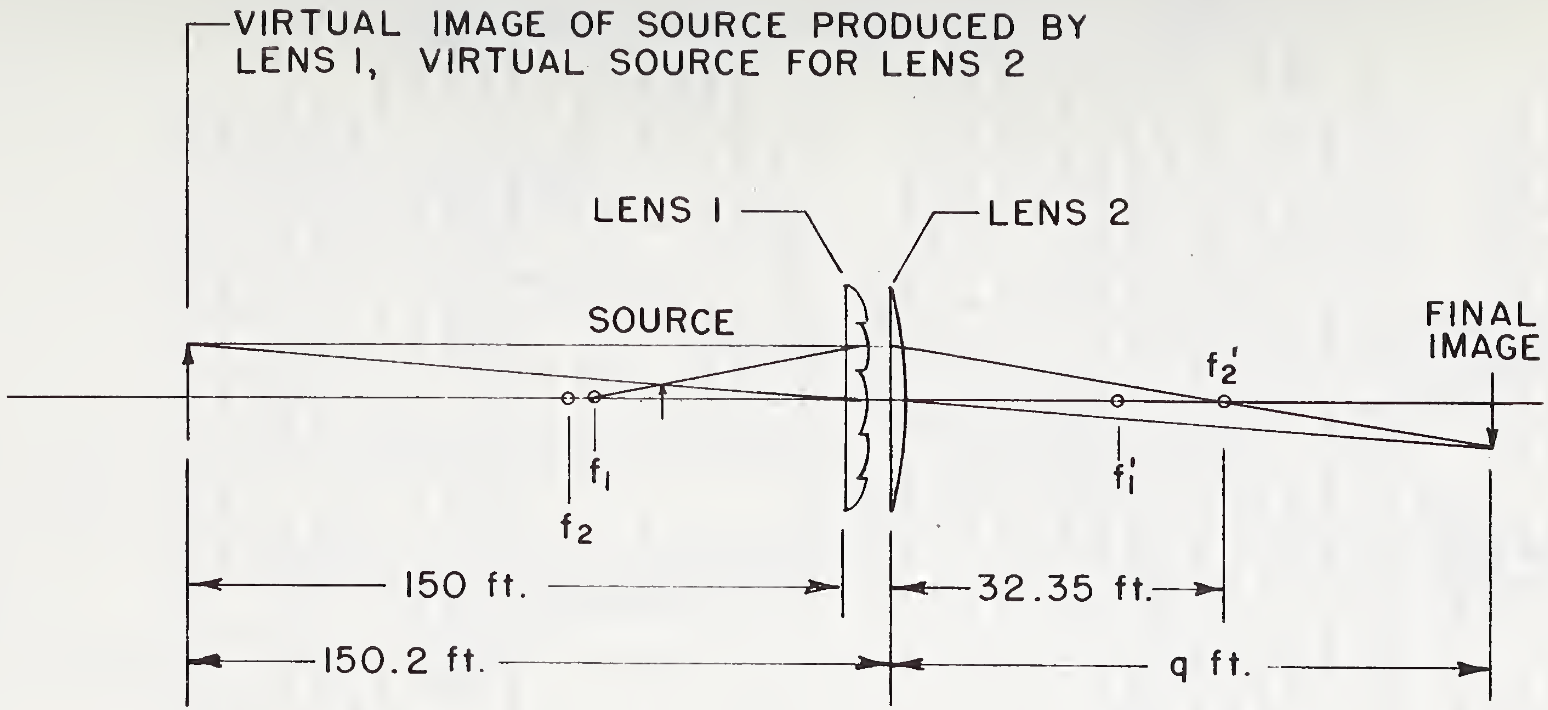


Figure 15. Image formation by auxiliary lens with focal point $f_2$ and $f_1$.

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Therefore, when the auxiliary lens is mounted over the face of the cell, 0.2 foot from the Fresnel lens, the image can be observed at a distance of 41.23 feet from the auxiliary lens. To make the focus determinations, an observer looks into the cell while an operator adjusts the source position.

In this study the yellow lenticular lens was in place in front of the Fresnel lens. The lenticular lens is intended to spread the beam horizontally without affecting the vertical spread. A yellow lenticular lens additionally absorbs the blue light and part of the green light yet passes enough of the green light so that longitudinal chromatic aberration may be used in focusing as described below. The principle of chromatic aberration, shown in Figure 16, is used to determine the proper position of the source. With improper settings of the source, colored fringes (green, red, or red and green, depending on setting) are obtained at the upper and lower edges of the beam. Proper focus occurs when all colored fringes are eliminated and a uniform yellow-orange image is obtained. Ten such determinations of source position were made with one lens and seven such determinations were made with a second lens.

5.4.2 Observing Beam Pattern Projected on White Card. This procedure employs a slight variation of the method described in Section 5.4.1. With this method, instead of looking at the cell face, the observer looks at the beam pattern projected onto an opaque white card placed at a distance of 41.23 feet from the cell. The source is then moved until the colored fringes disappear from the edges of the pattern. If the white card is moved closer to the cell than the proper focus requires, red fringes will appear. If the white card is moved further from the cell than proper focus requires, green fringes will appear. For the measurements reported here, a second white card was utilized. The first white card was placed at the 41.23-foot distance, while the second white card was held in hand and moved back and forth until the distance was found at which "no colored fringes" were observed. If this distance differed from the card at 41.23 feet, the cell source was moved until the two cards coincided. As with the other methods, 10 such source position determinations were obtained in this manner.

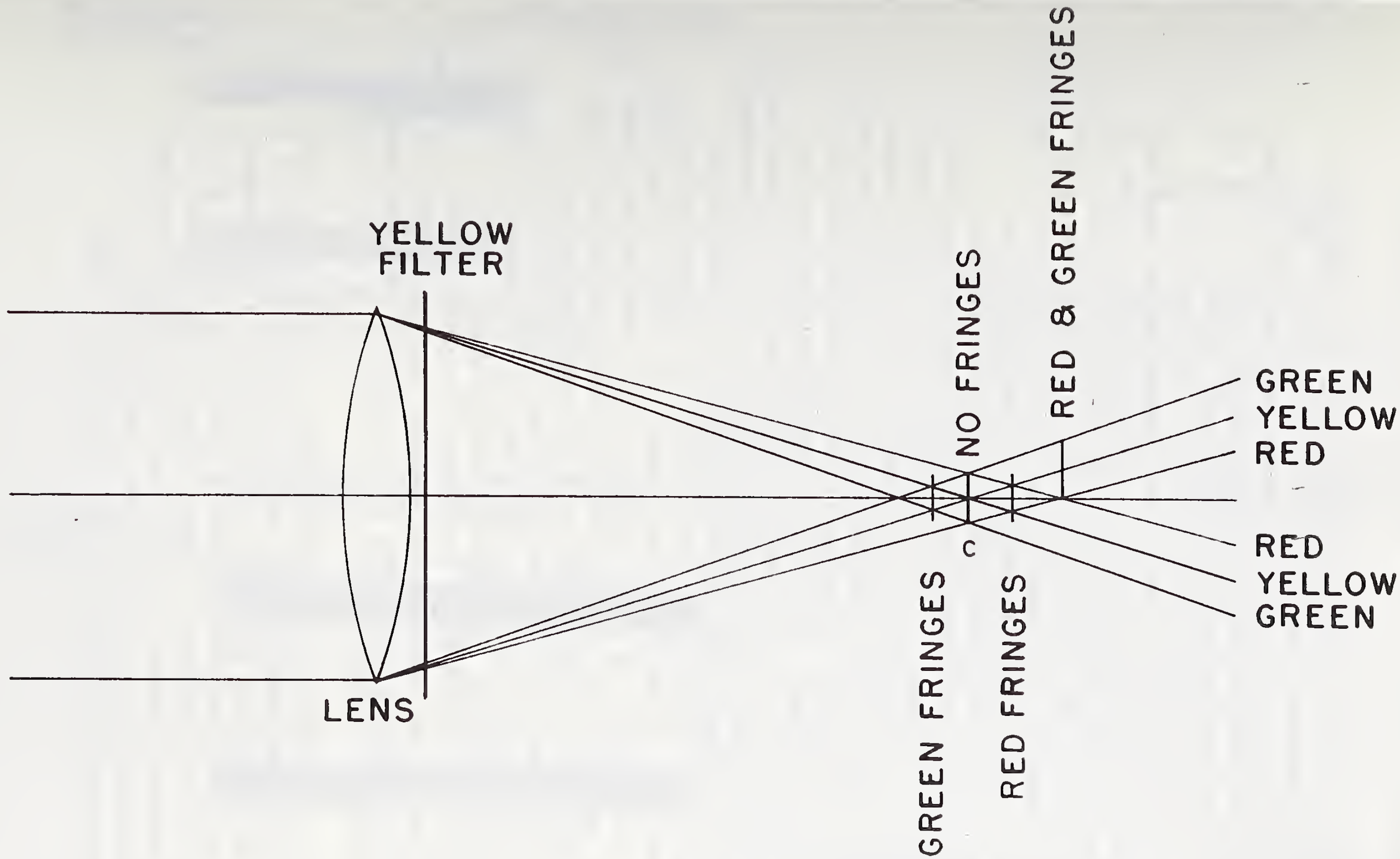


Figure 16. Principle of chromatic aberration, showing that with a yellow filter (lenticular lens) images can have green, red, and green and red fringes, or, at circle of least confusion, c, no fringes.

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## 5.5 Pattern Matching (Matching cell beam pattern to a standard pattern)

The principle of the pattern matching method is to judge when, at a given distance from the cell being focused, the beam pattern formed on a translucent screen matches a "standard pattern" placed at that distance. The standard pattern is a photographic color transparency of a cell beam pattern properly focused on a transmitting diffuser. The vertical and horizontal bars of the grille cause shadows in the beam and form the pattern. The lenticular lens tends to diffuse light into the shadows of the vertical bars and leaves only distinct horizontal shadows in the pattern. To obtain the transparency a photograph is made of the beam pattern after being transmitted by the diffuser. For the measurements here reported, the photograph was made at a distance of 20 feet from the face of the cell. Similarly, the pattern-matching determinations were made at the 20-foot distance. At this distance the beam spread (at 50% points) of a properly focused cell is about 9.97 inches in the vertical plane. The transparency for the standard pattern is made to actual size by using appropriate dimension markers in the initial photograph. To display the transparency for the matching determinations, a box, painted white inside, is constructed and equipped with a translucent plastic window and an incandescent lamp mounted in the box. The window is made of the same milky plastic material as the initial photograph. The plastic material not only covers the window but extends about 12 inches to one side of the box. The purpose of the extension is to receive the light beam from the cell for the pattern matching determinations. This arrangement places the beam pattern and the standard pattern side by side for convenient pattern matching. Only a very thin dark strip separates the two patterns. The window and the extension plastic material are made in two sections. Their abutting edges are painted black to prevent light spillage from one section to the other by diffusion. The arrangement of the equipment is depicted in Figure 17. Figure 18 is a photograph of the pattern display device.

In use, the equipment is placed in front of the test cell at the distance prescribed for the pattern. The light source of the cell is then moved along the optical axis of the Fresnel lens as was done for the other focusing procedures until, in the judgement of an observer, an exact match of the beam pattern and standard pattern is obtained. Particular attention is paid to matching the respective beam widths as this parameter determines the proper focus of the cell. This

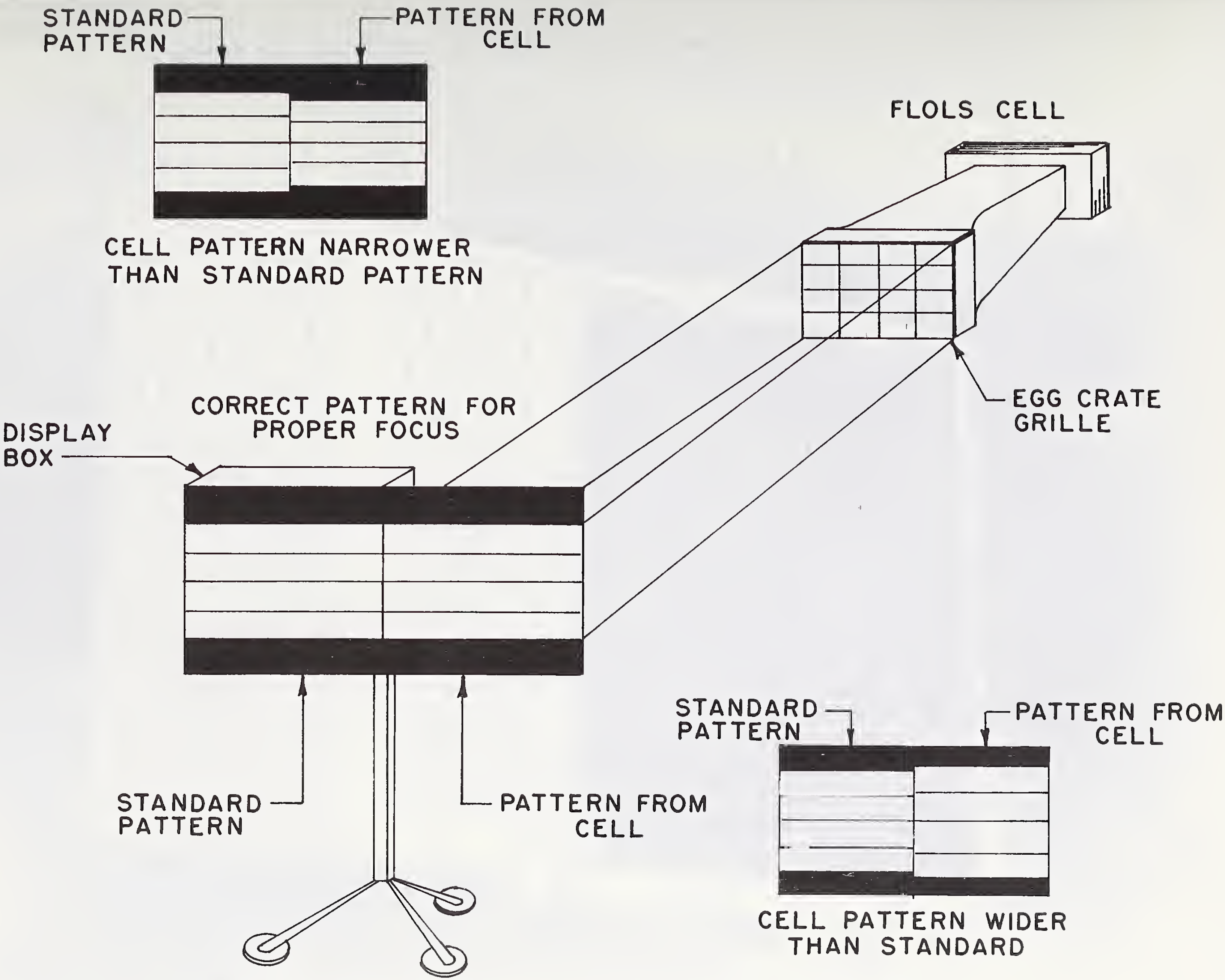


Figure 17. Equipment arrangement for focusing by matching cell pattern to standard pattern.

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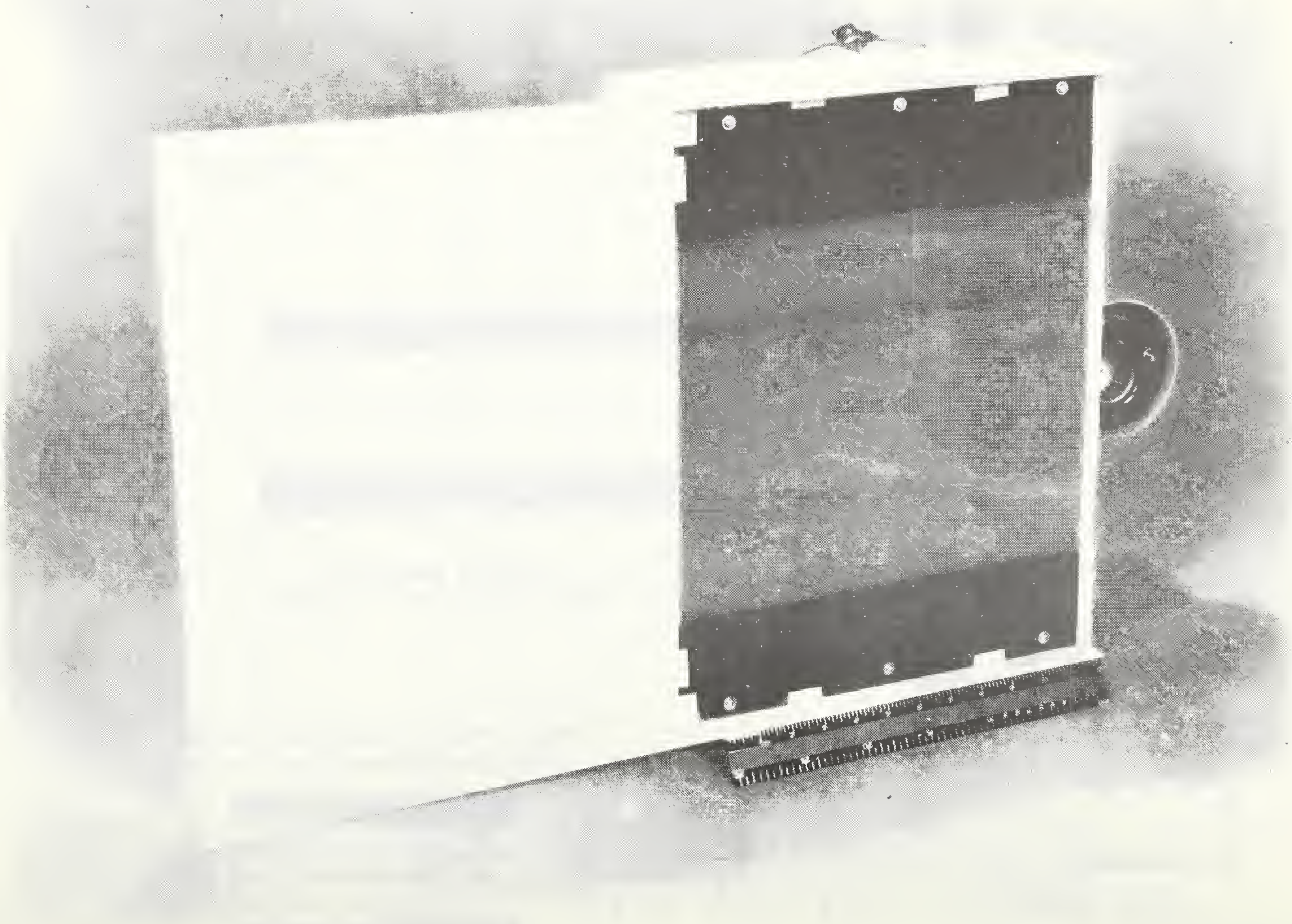

Figure 18. Photograph of pattern display device

procedure was used for the measurements reported here. Ten such determinations were made with approximately half starting with the pattern wider and half starting with the pattern narrower than the standard pattern.

## 6. Results

### 6.1 Photometric Procedures

The results of the focusing measurements of the five lenses utilizing the photometric method of measurement are given in Figures 19, 20, 21, 22 and 23. These figures give the beam spread, in inches, as measured at photometric distances of 20 feet and 50 feet from the cell lens, for a cell equipped in turn with each of the lenses as a function of the source distance from an arbitrarily fixed reference point. All the curves were made with respect to the same reference. These data for the lenses and the FLOLS cell aperture were used to compute the virtual image distance in feet and the beam spread in degrees. Figure 24 shows the relation of source position to virtual image distance and to the beam spread in degrees. Lenses 247 and 331 are sufficiently similar that their curves coincide.

It is apparent from curves of the type shown in Figures 19 to 23 that a source setting can be obtained to provide any desired beam spread and that the accuracy of the setting can be made to within about two thousandths of an inch. This uncertainty in source position results in a virtual image distance uncertainty of less than two feet. Only one of the two curves relating beam spread to source distance is needed if the cell aperture is utilized in calculating the normal beam spread at a given distance. Both curves are required, however, in cases where the aperture size is unknown, or uncertain.

The differences in focal length of the lenses are also apparent from the curves as indicated by the point of intersection of the two curves in Figures 19, 20, 21, 22 and 23. When the source is at this intersection point the light beam from the cell emerges collimated and a near-zero beam spread is obtained. Figure 2b shows that if the source is placed exactly at the focal point of a lens, a collimated beam will emerge and the virtual image will be at infinity. Notice that the curves for lenses 704 (Figure 22) and the "Bad Lens" (Figure 23) furnished by NAEC were extended to the point of intersection.

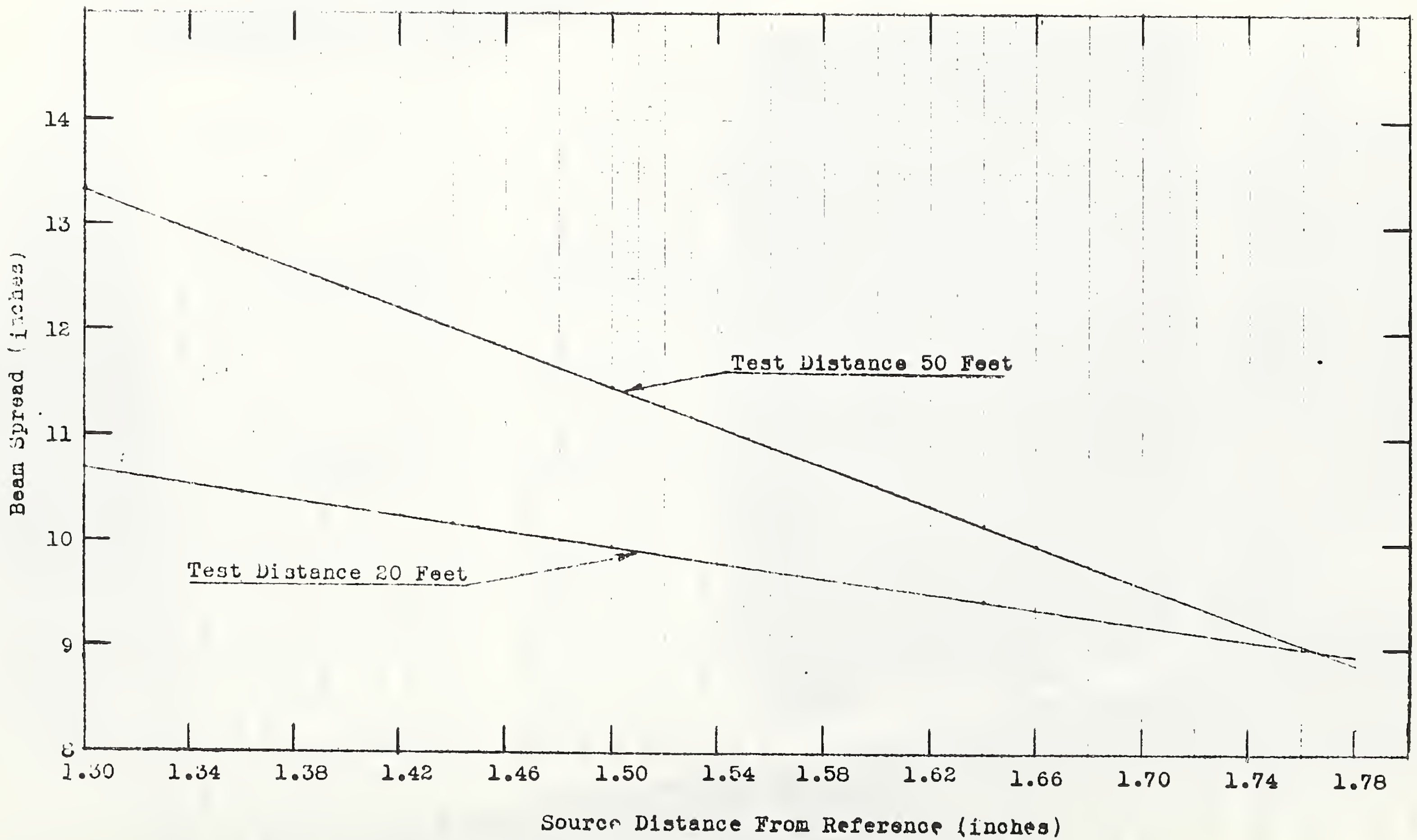


Figure 19. Beam spread of FLOLS cell as a function of source distance from reference at the indicated test distances. (Lens #2117)

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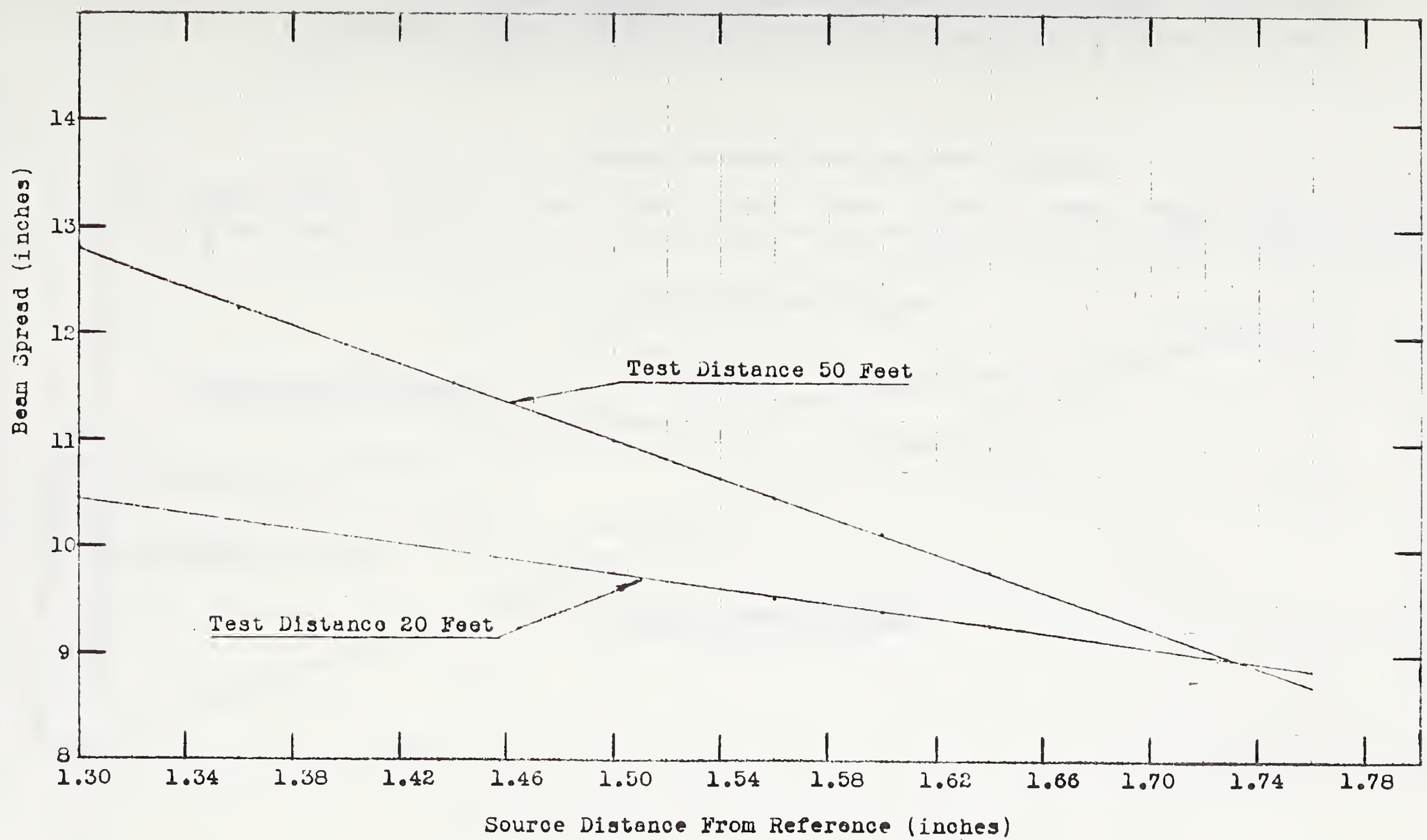


Figure 20. Beam spread of FLOLS cell as a function of source distance from reference at the indicated test distances. (Lens #331)

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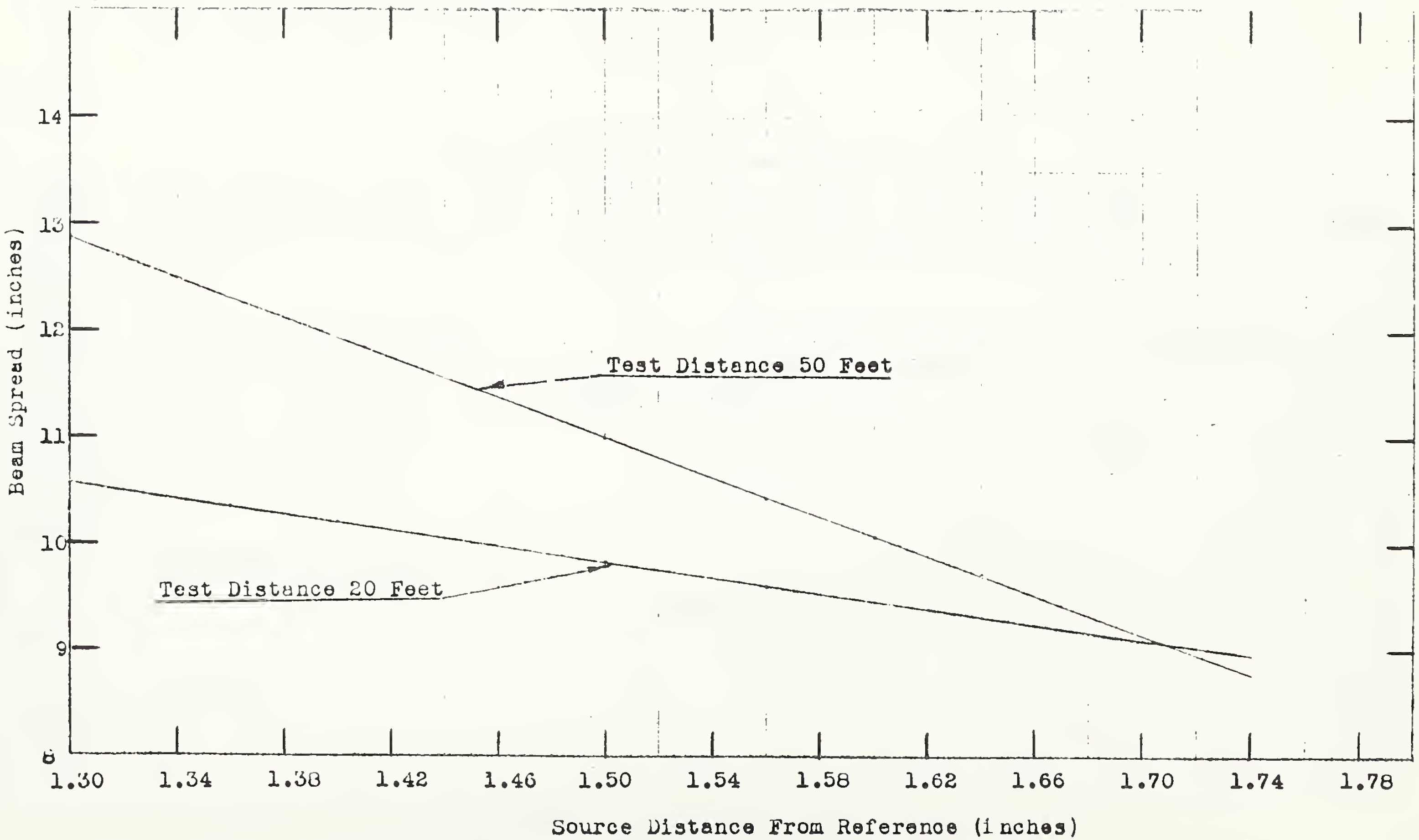


Figure 21. Beam spread of FLOLS cell as a function of source distance from reference at the indicated test distances. (Lens #247)

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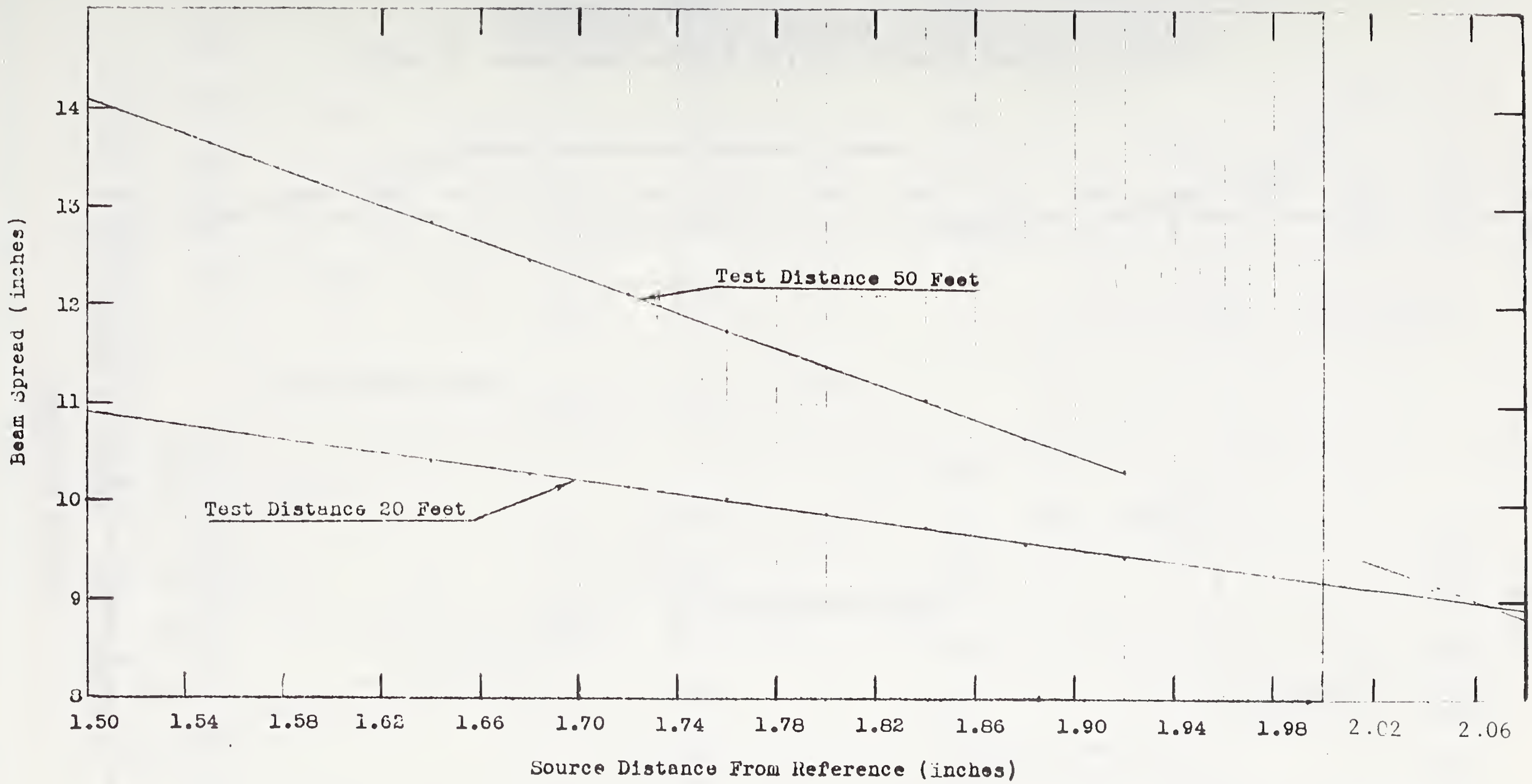


Figure 22. Beam spread of FLOLS cell as a function of source distance from reference at the indicated test distances. (Lens #704)

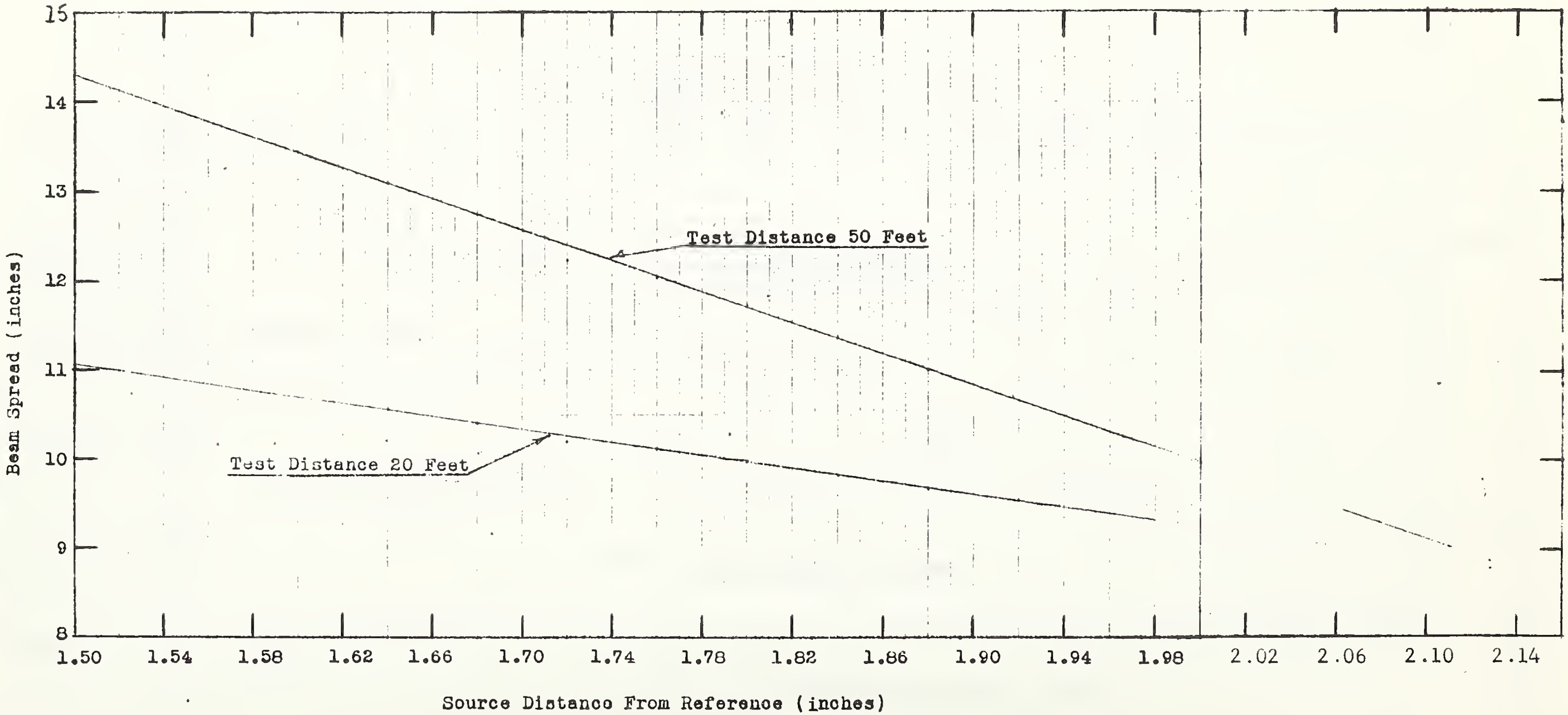


Figure 23. Beam spread of FLOLS cell as a function of source distance from reference at the indicated test distances. ("Bad Lens" furnished by NAEC).

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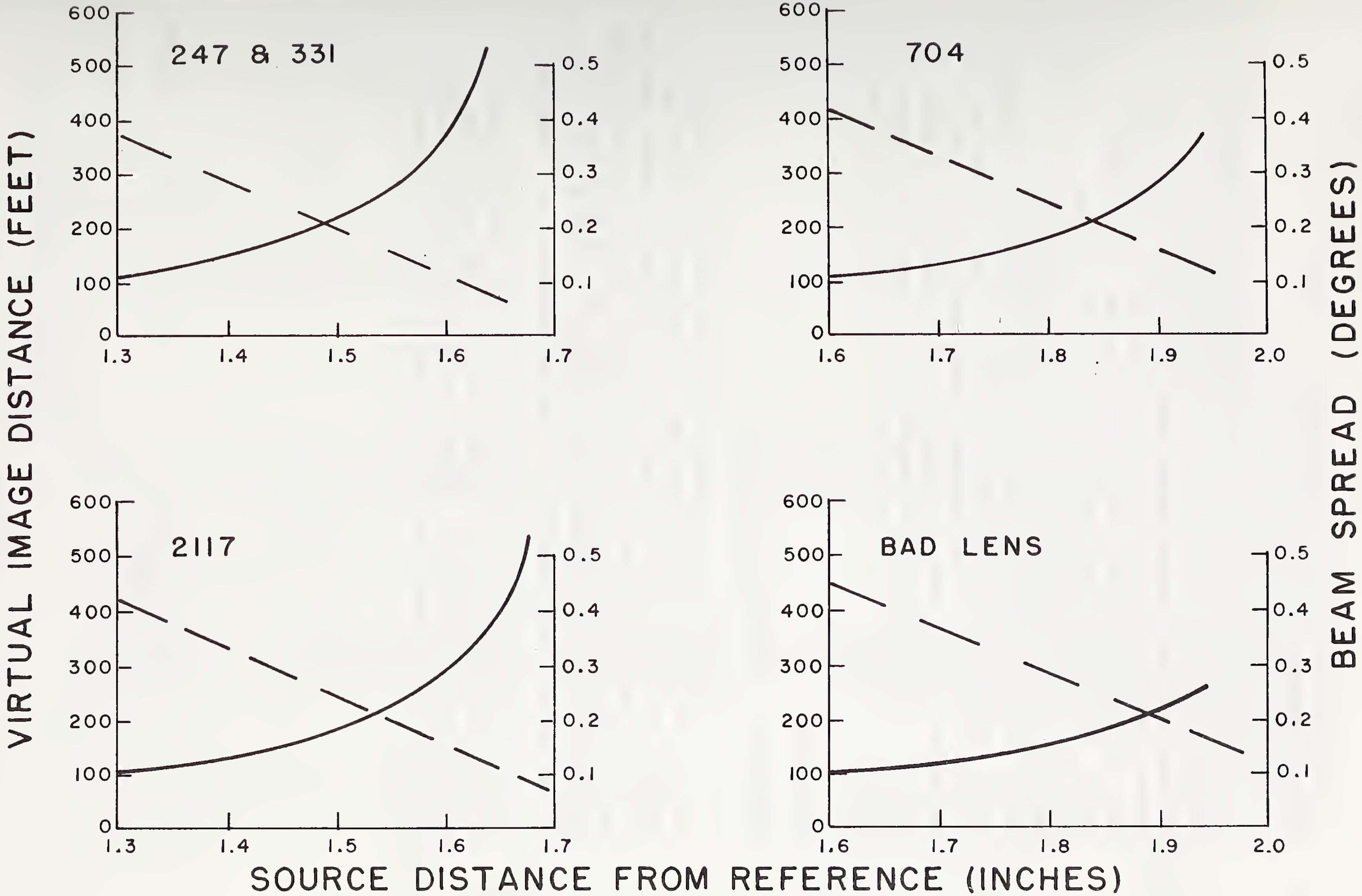


Figure 24. Virtual image distance (solid line) and beam spread in degrees (dashed line) as a function of source distance from reference for FLOLS cell equipped with indicated lens. Computations for all lenses with the same cell aperture are based on beam spread in inches shown on Figures 19, 20, 21, 22, and 23.

## 6.2 Other Procedures for Focusing

The results of the comparison focusing measurements of other procedures for focusing the FLOLS System are given in Tables I, II, and III. Only two of the lenses (No. 2117 and the Bad Lens) listed above were used for these measurements. Table I gives the individual readings as obtained for the various focusing methods on lens No. 2117, while Tables II and III separate the data into the maximum, minimum and average readings, the reading variation, and the calculated beam spread and image distance represented by these readings for each lens. Note that one setting is given in the tables for the photometric methods using a recorder or a meter readout as these settings were based not on visual judgements but on readings from spatial distribution graphs for the lenses. The source was thus set to the known image distance (150 feet), as calculated for the cell without the egg-crate grille.

# 7. Uncertainty

## 7.1 Photometric Procedure Uncertainty

An estimate of the uncertainty in the location of the virtual image position by means of the photometric method was obtained for lens 2117 and "Bad" lens. The beam spreads observed at 20 feet and at 50 feet for the condition of the virtual image computed to be at 150 feet from the lens and the beam spreads obtained for these distances from readings, fitted the curves shown in Figure 19 for lens 2117 and in Figure 23 for "Bad Lens".

The beam spread $X_1$, in inches, at 20 feet from the lens and the beam spread $X_2$, in inches, were used to locate the virtual source position q, in feet, following equation, based on ratios of corresponding parts of similar triangles shown in Figure 25.

$$\frac{20 + q}{50 + q} = \frac{X_1}{X_2}, \qquad (5)$$

or

$$q = \frac{50\ X_1 - 20\ X_2}{X_2 - X_1}$$

TABLE I. MEASUREMENTS OF SOURCE DISTANCE FOR THE INDICATED FOCUSING METHODS TO PRODUCE VIRTUAL IMAGE AT 150 FEET

| | Readings of Source Distances to Reference Point (inches) | | | | |
|---|---|---|---|---|---|
| | (a) Lens No. 2117 (Required setting, 1.440 inches)* | | | | |
| | Peep Sight | Auxiliary Lens With Target Screen | Auxiliary Lens with Observer Looking At Cell | Parallax | Pattern Matching |
| | 1.474 | 1.509 | 1.567 | 1.465 | 1.453 |
| | 1.490 | 1.490 | 1.536 | 1.490 | 1.412 |
| | 1.482 | 1.484 | 1.560 | 1.515 | 1.460 |
| | 1.518 | 1.500 | 1.496 | 1.535 | 1.467 |
| | 1.559 | 1.520 | 1.560 | 1.564 | 1.475 |
| | 1.538 | 1.495 | 1.519 | 1.689 | 1.450 |
| | 1.545 | 1.506 | 1.531 | 1.640 | 1.428 |
| | 1.535 | 1.513 | 1.520 | 1.450 | 1.446 |
| | 1.555 | 1.514 | 1.504 | - | 1.444 |
| | 1.550 | 1.506 | 1.552 | - | 1.430 |
| Average | 1.525 | 1.504 | 1.534 | 1.544 | 1.447 |
| Std. Deviation, σ | 0.030 | 0.011 | 0.024 | 0.079 | 0.018 |
| | (b) "Bad Lens" from NAEC (Required setting, 1.795 inches)* | | | | |
| | 1.817 | 1.860 | 1.803 | Not used | 1.742 |
| | 1.744 | 1.838 | 1.864 | | 1.755 |
| | 1.800 | 1.817 | 1.800 | | 1.774 |
| | 1.800 | 1.826 | 1.786 | | 1.740 |
| | 1.747 | 1.857 | 1.894 | | 1.786 |
| | 1.758 | 1.809 | 1.905 | | 1.813 |
| | 1.800 | 1.818 | 1.715 | | 1.812 |
| | 1.806 | 1.817 | - | | 1.809 |
| | 1.790 | 1.829 | - | | 1.766 |
| | 1.788 | 1.818 | - | | 1.779 |
| Average | 1.785 | 1.829 | 1.824 | - | 1.778 |
| Std. Deviation, σ | 0.025 | 0.017 | 0.063 | - | 0.026 |

*From photometric measurements.

TABLE II. COMPUTED BEAM SPREAD AND VIRTUAL SOURCE DISTANCE AT THE MAXIMUM, MINIMUM, AND AVERAGE SOURCE POSITION READING AS OBTAINED BY THE INDICATED FOCUSING METHODS FOR LENS 2117

| Focusing Method | Source Position: Readings Max. (Inches) | Source Position: Readings Min. (Inches) | Source Position: Readings Ave. (Inches) | Source Position: Reading Range Max-Min. (Inches) | Computed Virtual Source Distance (Feet) | Beam Spread at 50% Intensity Level (Degrees) |
|---|---|---|---|---|---|---|
| Peep Sight | 1.559 | 1.482 | 1.525 | 0.077 | 218<br>168<br>199 | 0.196<br>0.255<br>0.215 |
| Auxiliary Lens With Target Screen | 1.520 | 1.484 | 1.504 | 0.036 | 193<br>169<br>177 | 0.221<br>0.253<br>0.240 |
| Auxiliary Lens When Looking Into Cell Face | 1.567 | 1.496 | 1.534 | 0.071 | 238<br>174<br>203 | 0.180<br>0.245<br>0.204 |
| Parallax | 1.689 | 1.450 | 1.544 | 0.239 | 584<br>151<br>220 | 0.073<br>0.283<br>0.194 |
| Photometric with Recorder | Set at 1.440* | | | - | 150* | 0.287 |
| Photometric with Meter Readout | Set at 1.440* | | | - | 150* | 0.287 |
| Pattern Matching | 1.475 | 1.412 | 1.447 | 0.063 | 164<br>134<br>148 | 0.261<br>0.318<br>0.288 |

*See Section 6.1

TABLE III. COMPUTED BEAM SPREAD AND VIRTUAL SOURCE DISTANCE AT THE MAXIMUM, MINIMUM, AND AVERAGE SOURCE POSITION READING AS OBTAINED BY THE INDICATED FOCUSING METHODS FOR "BAD LENS" FROM NAEC

| Focusing Method | Source Position: Readings Max. (Inches) | Readings Min. (Inches) | Readings Ave. (Inches) | Reading Range Max-Min. (Inches) | Computed Virtual Source Distance (Feet) | Beam Spread at 50% Intensity Level (Degrees) |
|---|---|---|---|---|---|---|
| Peep Sight | 1.817 | 1.744 | 1.785 | 0.073 | 160<br>133<br>147 | 0.263<br>0.318<br>0.286 |
| Auxiliary Lens With Target Screen | 1.860 | 1,809 | 1,829 | 0.051 | 184<br>158<br>167 | 0.228<br>0.268<br>0.253 |
| Auxiliary Lens When Looking Into Cell Face | 1.905 | 1.715 | 1.827 | 0.190 | 215<br>118<br>165 | 0.196<br>0.357<br>0.255 |
| Parallax | NOT MEASURED | | | - | - | - |
| Photometric with Recorder | Set at 1.795* | | | - | 150* | 0.287 |
| Photometric with Meter Readout | Set at 1.795* | | | - | 150* | 0.287 |
| Pattern Matching | 1.813 | 1.742 | 1.778 | 0.071 | 158<br>131<br>144 | 0.268<br>0.323<br>0.293 |

*See Section 6.1

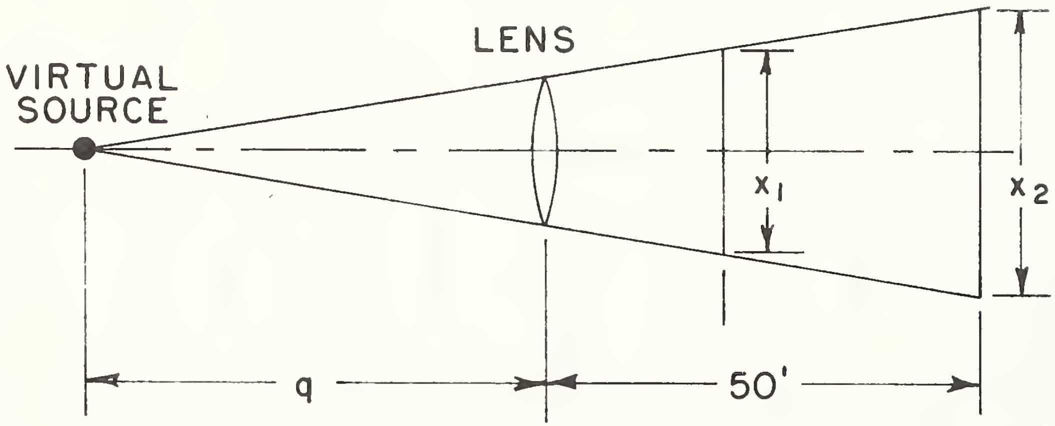


Figure 25. Location of virtual source $q$ from beam spread at 20 feet, $x_1$ and at 50 feet, $x_2$.

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Differences in virtual source position obtained from beam spreads by direct observation and by the fitted curves are considered to be an estimate of the range of measurements by the photometric methods. These ranges are located in Table IV for lens 2117 and the "Bad Lens".

## 7.2 Uncertainty in Other Procedures

The maximum and minimum virtual source positions obtained by means of the other procedures are listed in Tables II and III and give the range for those procedures. These ranges are also listed in Table IV for comparison with the photometric method.

## 8. Discussion

Generally, results obtained with all focusing methods where visual judgements were required differed greatly from the results obtained photometrically. Large variations in individual readings were obtained also; although some readings within a group were close, they tended to give much longer image distances than the specified 150 feet. For example, for Fresnel lens No. 2117, the peep sight method gave image distances from 168 feet to 218 feet. Similarly, the two procedures that use an auxiliary lens gave virtual image distances much too long for this Fresnel lens. The only visual method that gave reasonable results for this lens was the pattern matching method. Here again, however, the spread between individual readings is considered too great. The same trend is seen for the measurements of the "Bad Lens", except that the set of measurements with the peep sight method gave much closer tolerances. An image distance spread from 133 feet to 160 feet was obtained during the ten individual readings. This again, is considered greater than desired but does show what results this method might achieve from lens to lens. Again, the other methods (except the pattern matching method) gave results that tend to place the image at too great a distance. The pattern matching variation was the same order of magnitude for this lens as for the previous lens.

## 9. Recommendation

In conclusion it is recommended that the precision of a focusing method be sufficient to determine the virtual image distance to 5 feet, consistently. To achieve this precision the source needs to be positioned within 0.010 inch. Of the focusing methods tested only the photometric method appears to meet this criterion. It is recommended also that no method that requires visual judgements be used.

TABLE IV. RANGE OF VIRTUAL SOURCE POSITION FOR LENS 2117 AND "BAD LENS" BY MEANS OF SEVERAL PROCEDURES

| Procedure | Range, in feet, of Virtual Source Position | |
|---|---|---|
| | 2117 | "Bad Lens" |
| Peep Sight | 50 | 27 |
| Auxiliary Lens: | | |
| 1) With target screen | 24 | 26 |
| 2) Looking into cell face | 64 | 97 |
| Parallax | 433 | - |
| Photometric: | | |
| 1) With recorder | 5 | 2 |
| 2) With meter readout | 5 | 8 |
| Pattern Matching | 30 | 27 |

Of the two photometric methods, the procedure that uses a meter readout would appear to lend itself better to field use. It is simple, precise and will give fairly rapid results. Further, this method would require only a short period of training in its use.

# APPENDIX

## A-1 OTHER FACTORS AFFECTING CELL PERFORMANCE

In conducting the focusing investigations, certain other factors were observed relative to the FLOLS system that are of interest. These include:

1) Effect of the lenticular lens on beam spread.

2) Effect of lens temperature on beam spread.

3) Effect of slit-width on beam spread.

4) Effect of slit alignment on beam distribution.

5) Effect of lamp dimming and source color on beam spread and image distance.

In addition, certain operational and mechanical design features of the FLOLS cell were noted where improvements are considered desirable. The first section below treats the operational features while the second section treats the design features.

## A-2 OPERATIONAL FEATURES

### A-2.1 Effect of the Lenticular Lens on Beam Spread.

Beam spread measurements were made of a cell with and without the lenticular lens installed. The measurements were made with a 1980 Pritchard recording photometer by scanning the light beam pattern as projected from the cell onto a diffusing plastic plate at a test distance of 20 feet. The temperature of the cell was allowed to stabilize at approximately 35°C prior to the measurements. The results of the measurements are given in Figure A-1. As will be noted, the lenticular lens increases the beam spread of the cell by about 0.21 inch at this distance. The increase amounts to approximately 0.06 degree or 3.6 minutes of arc in the vertical plane. Instead of being neutral, the lenticular lens exhibits some "lens effect" in the vertical plane as well as its intended function of spreading the beam in the horizontal plane.

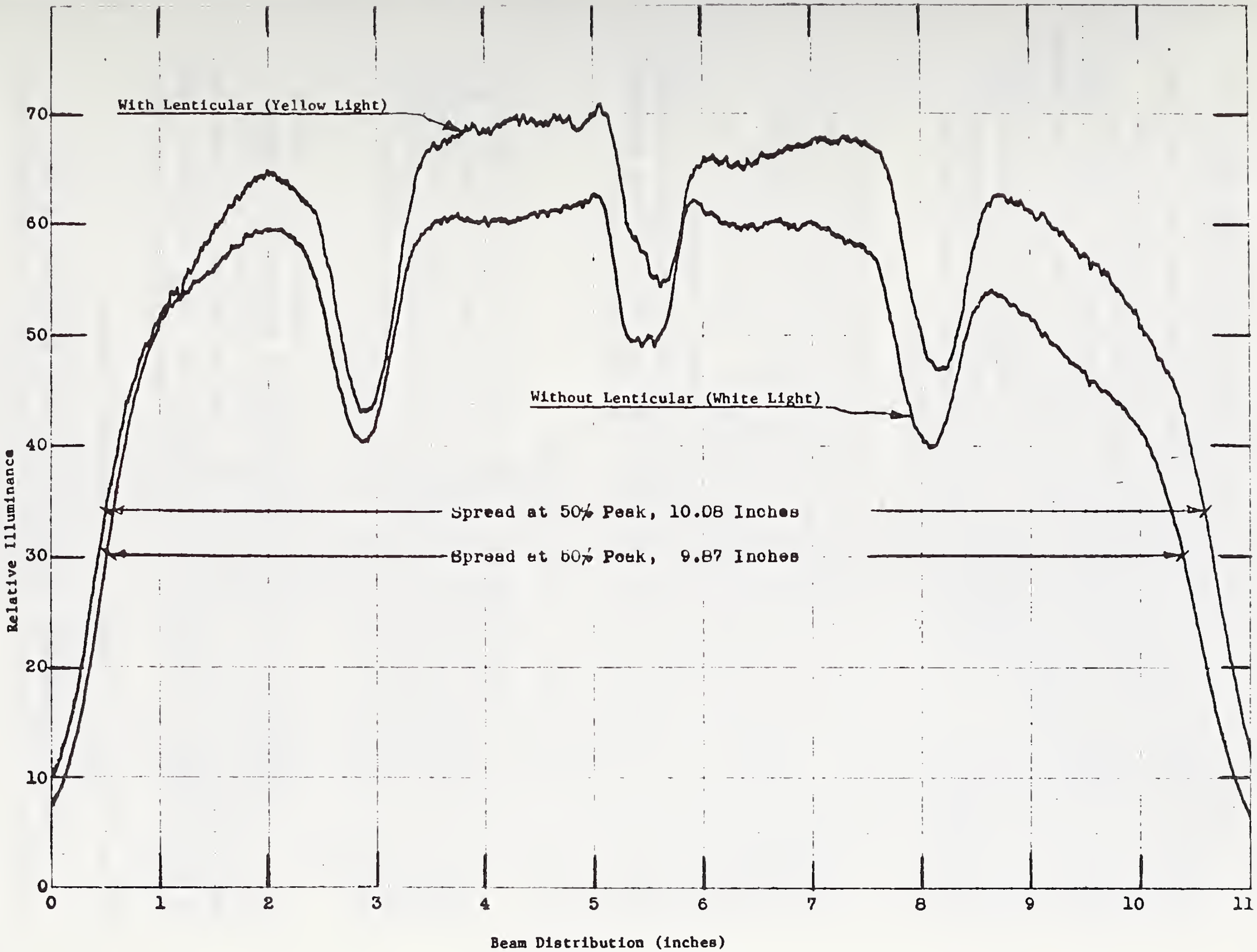


Figure A-1. Effect of lenticular lens on beam spread. (Beam was measured at a distance of 20 feet from the lens. Photometer gain was adjusted to obtain curves of comparable settings on the graph.)

A-2.2 Effect of Lens Temperature on Beam Spread.

A series of measurements were made of the beam spread at lens temperatures of 22°C and 35°C as a function of source distance from a fixed reference point. The cell was equipped in its usual configuration with a lenticular lens and egg-crate grille. The measurements were made photometrically in a manner similar to that described in paragraph 5.1, except that for these measurements the heater circuit of the cell was turned off during the first set of measurements and turned on during the second set of measurements. Air temperature inside of the unit adjacent to the lens was monitored with a thermocouple arrangement. The temperature was allowed to stabilize for about 30 minutes prior to the measurements.

Results of the two sets of measurements are shown in Figure A-2. The beam spread of the cell increases with lens temperature. The increase has the effect of decreasing the distance to the virtual source. Conversely, if the heaters become disabled during operation and the lens cools, the distance to the virtual source increases. For example, at a given point near proper lens setting (source setting 1.71 inch) the distance to the virtual source changes approximately 12.8 feet for a temperature change from 35°C to 22°C. This amounts to an approximate change of 1 foot per degree Celsius.

A-2.3 Effect of Slit-Width on Beam Spread.

Beam spread measurements were made of a cell equipped in turn with two slit-widths, namely: 0.055 and 0.070 inch. All other parameters were held constant during these measurements. Again, the beam spread measurements were made photometrically at a test distance of 20 feet with a recording photometer similar to the one described in paragraph 5.1.

The results of the measurements are presented in Figure A-3. As indicated, the slit width had no appreciable effect on the beam spread.* Although the wider slit gave a curve which appears to be slightly wider, its relative peak intensity is also higher and when the two curves are read at 50% of their respective peaks, their beam spreads are essentially the same.

A-2.4 Effect of Slit Alignment on Beam Distribution.

Beam distribution measurements were made of the cell as a function of the slit alignment relative to the optical axis

*Note the width of the "meat ball" is not directly related to the beam spread, but is increased with increase in slit width.

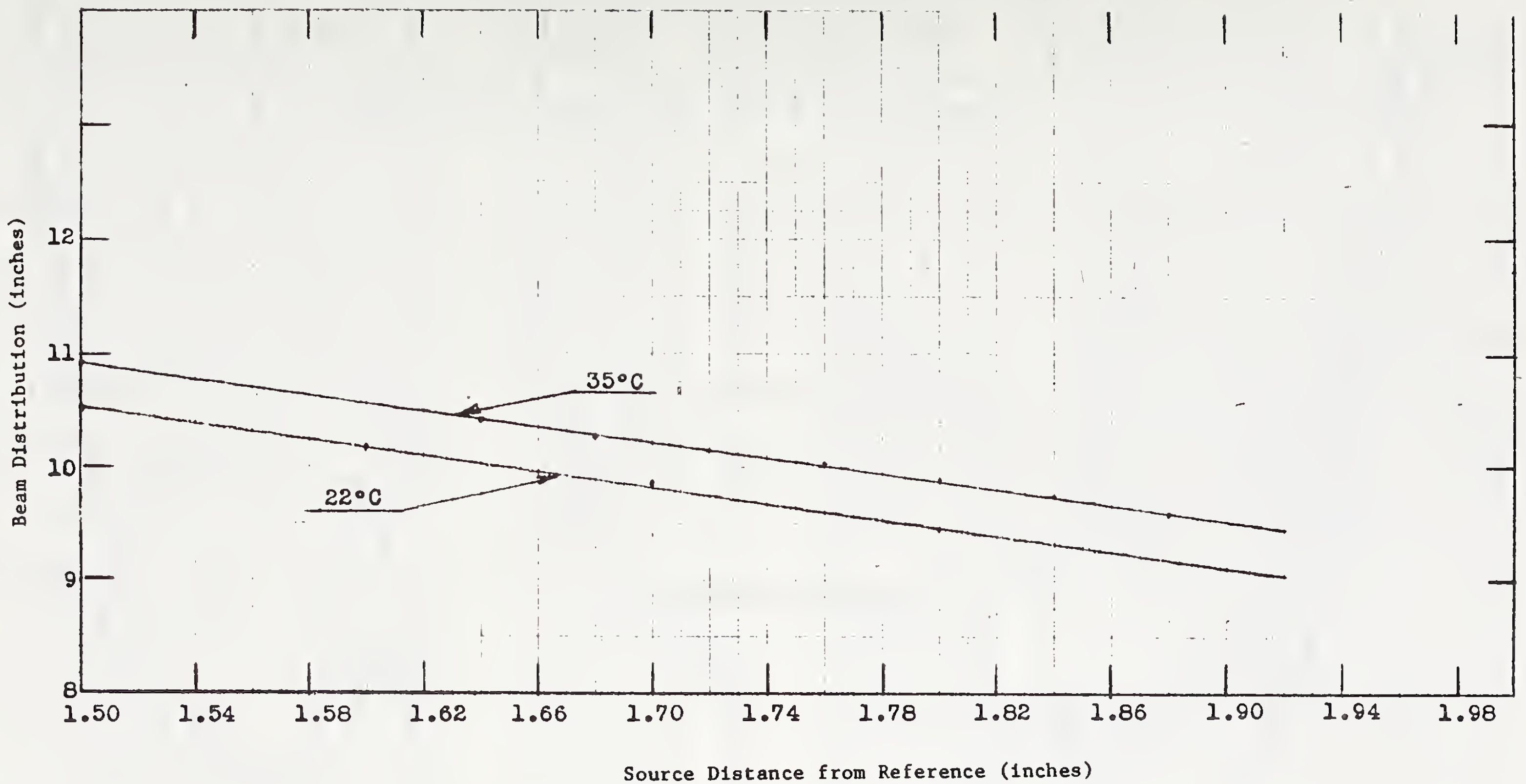


Figure A-2. Effect of lens temperature on beam spread measured at 20 feet from lens.

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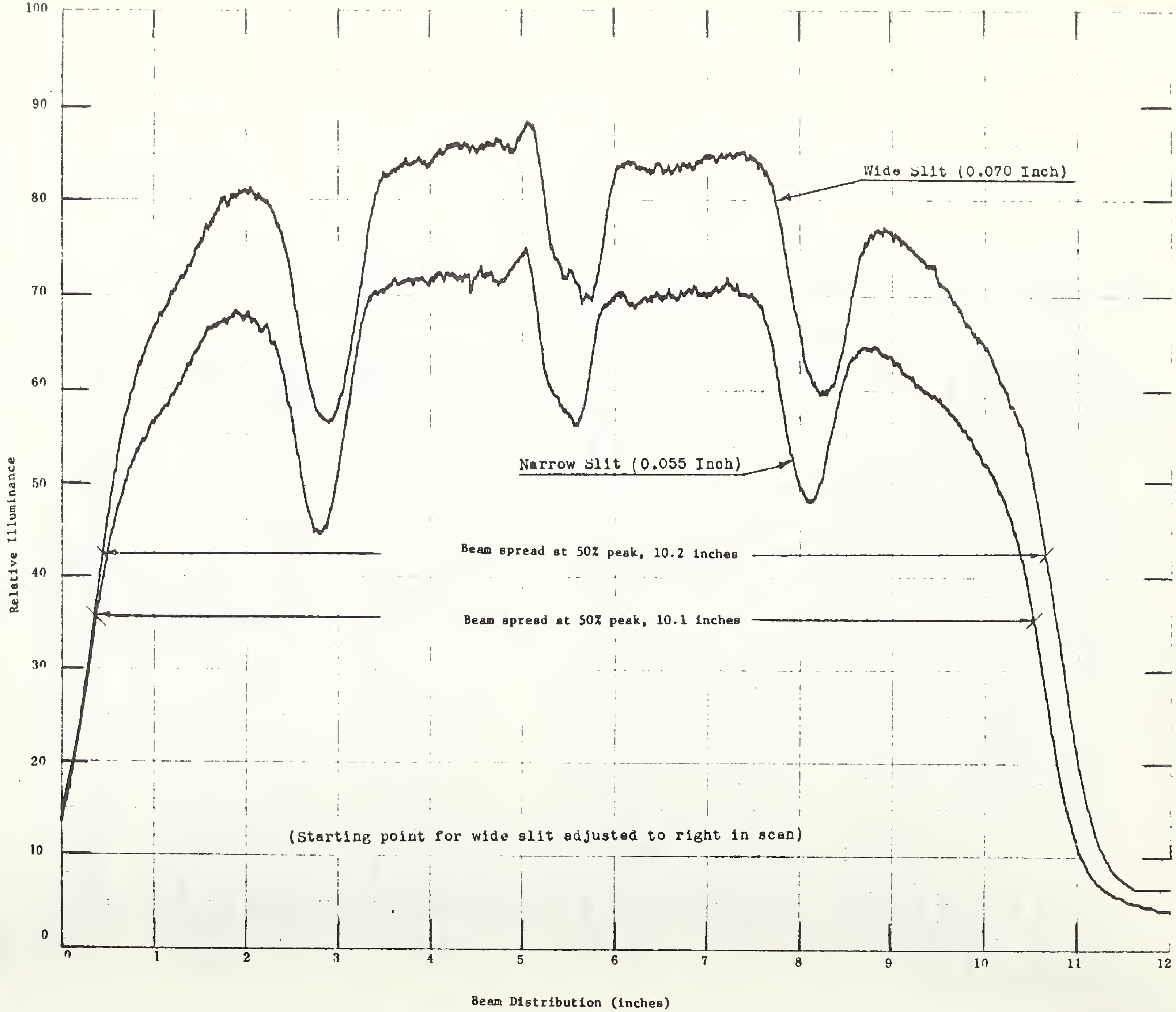


Figure A-3. Effect of slit width on beam spread measured at 20 feet from lens.
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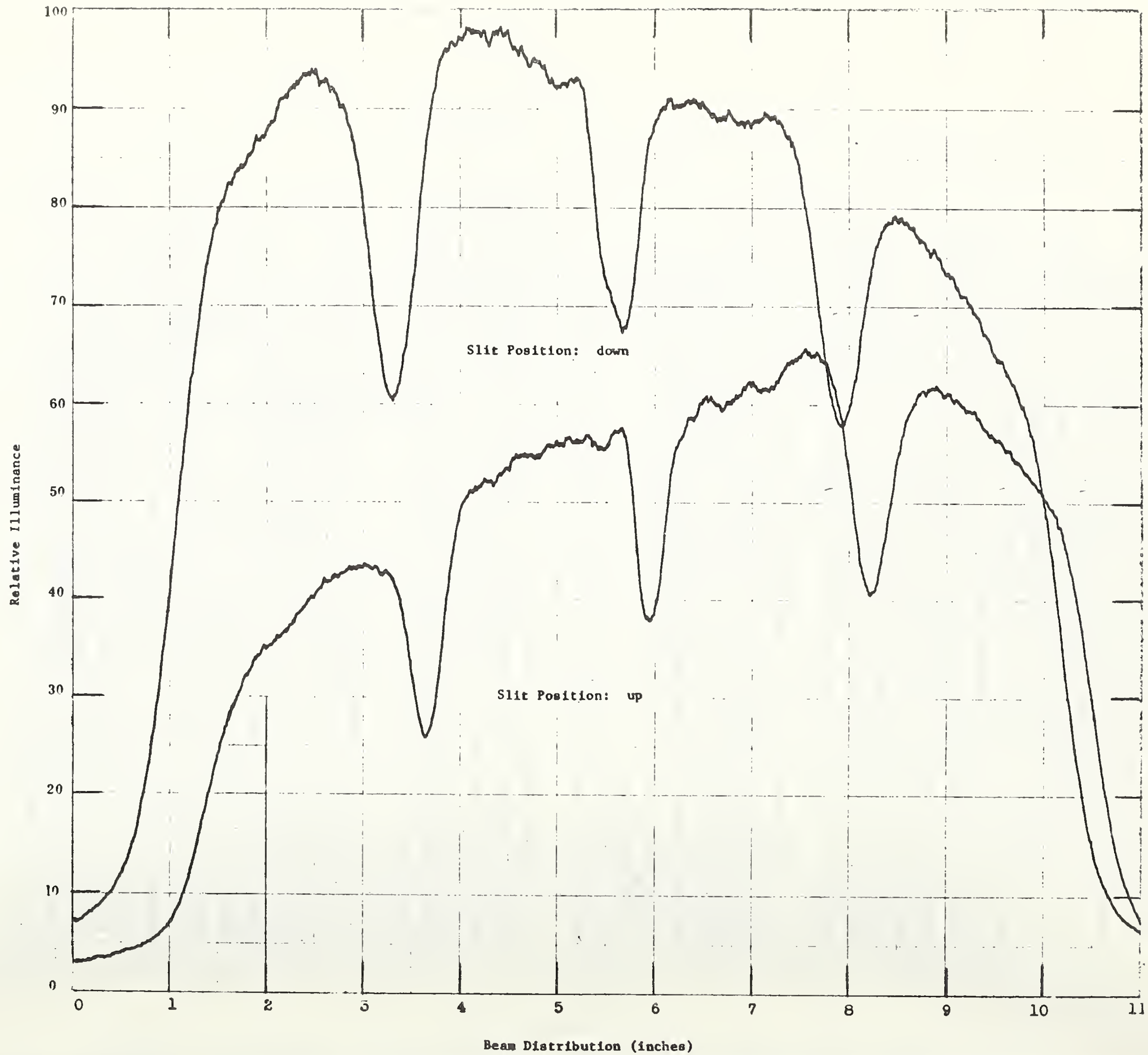
of the lens. For this measurement, only the 0.055 inch slit was used. For the cell in use, the mounting holes of the slit plate were oversized so that the slit plate is not pinned in a fixed position. The extreme movement of the slit plate amounts to approximately 3/32 inch up and down or side-to-side. Because of the slit dimensions and the effects of the lenticular lens, the up and down movement is critical and significant while the horizontal movement is not significant. Therefore, measurements were made of the cell only as the slit movement affects the projected beam distribution in the vertical plane. The first measurements were made with the slit shifted to the extreme upward position while the second measurements were made with the slit shifted to its extreme bottom position. In positioning the slit, attempts were made to maintain a horizontal position although the slit can be tilted slightly at the two extremes.

The results of the measurements are shown in Figure A-4. It is evident that the two distributions differ considerably. The need for pinning the slit in a fixed position once the cell is properly aligned is evident. The pinning should be accomplished at the factory during the initial alignment to prevent any likelihood of slippage or maladjustment at a later time.

### A-2.5 Effect of Lamp Dimming and Source Color on Focusing.

Measurements of beam spread as a function of lamp dimming and of source color were made of a FLOLS cell equipped in turn with a yellow and a clear lenticular lens. Measurements were also made of the cell equipped with the clear lenticular lens and sources of several colors. The beam spread measurements were made photometrically as described under the section 5.1.

During the measurements, the three lamps of the cell were operated in series and the cell temperature was allowed to stabilize prior to obtaining the successive readings. For the dimming measurements, the lamps were operated at 54, 20 and 12.5 volts when the cell was equipped with the yellow lenticular lens and operated at 54, 20, 12.5, and 10 volts when equipped with the clear lenticular lens. The latter voltage range corresponds to an intensity range from approximately 100% to 0.3%. The voltage was held constant at 54 volts when making the measurements of the effects of source color on the beam spread. For the latter measurements, the color was changed by inserting colored glass filters in turn between the source (lamps) and the frosted glass covering the slit of the cell.




NBSIR 75-644 Figure A-4. Effect of slit alignment on beam distribution

The results of the lamp dimming measurements are given in Table A-I and the results for the source color measurements are given in Table A-II. For both types of measurements the distance to the virtual source was calculated from the beam spreads obtained and the aperture of the cell egg-crate grille. The geometrical theory for the calculations is as explained in Section 5.1 of the report under the title "Description of Focusing Methods". As will be noted, dimming of the lamps has very little effect on beam spread, and hence, distance to the virtual source. Notice that a very small change was obtained at extremely low levels of intensity. Chromatic aberration of the Fresnel lens as the lamp becomes redder probably accounts for the small change. This effect is more pronounced in the source color measurements discussed below.

Referring to Table A-II, it will be noted that source color changes do affect the beam spread and image distance significantly. For example, with a red filter in front of the source the beam spread was 10.33 inches and with a blue filter the beam spread was 9.53 inches under otherwise identical conditions. The corresponding image distances for these two beam spreads are 114 feet and 237 feet, respectively. The effect then is the redder the source, the shorter the image distance, for a given position of the source. Consequently, it becomes necessary to focus a cell for the color with which it will be used. If the color is changed, the unit must be refocused. (Similar differences in image distance would be expected when cells of various colors are focused by means of any of the visual focusing methods, although these were not performed during this series of measurements.)

## A-3 MECHANICAL DESIGN FEATURES

### A-3.1 Lamp Mount Assembly.

Focusing of the FLOLS cell requires that the assembly which carries the lamps, frosted glass and slit be moved along the two support rods in the focal plane of the lens until the proper beam spread and/or distance to the virtual image is achieved. In moving the assembly, it was difficult to keep the two sides equi-distant from a given reference point on the support rods. One side of the assembly was usually moved first along one support rod. The other side was then brought abreast of the first and so on until proper adjustment was obtained. A feeler gage or calipers was used to determine when both sides of the assembly were moved the same distance from a given reference point. Movement of both sides an equal distance cannot be achieved visually. Since

TABLE A-1

EFFECTS OF LAMP DIMMING ON BEAM SPREAD
AND VIRTUAL SOURCE DISTANCE

| Lenticular Color | Lamp Volts | Beam Spread* (Inches) | Beam Spread (Degrees) | Virtual Source Distance (Feet) |
|---|---|---|---|---|
| Yellow | 54 | 10.13 | 0.318 | 131 |
| | 20 | 10.13 | 0.318 | 131 |
| | 12.5 | 10.20 | 0.334 | 126 |
| Clear | 54 | 9.73 | 0.222 | 187 |
| | 20 | 9.76 | 0.229 | 183 |
| | 12.5 | 9.81 | 0.241 | 173 |
| | 10.0 | 8.82 | 0.241 | 173 |

*At 20 feet.

TABLE A-II

EFFECTS OF SOURCE COLOR ON BEAM SPREAD
AND VIRTUAL SOURCE DISTANCE
(Clear Lenticular)

| Source Color (Filter between Source & Slit) | Lamp Volts | Beam Spread* (Inches) | Beam Spread (Degrees) | Virtual Source Distance (Feet) |
|---|---|---|---|---|
| Clear | 54 | 9.73 | 0.222 | 187 |
| Blue | 54 | 9.53 | 0.174 | 238 |
| Yellow | 54 | 10.05 | 0.298 | 140 |
| Red | 54 | 10.33 | 0.365 | 114 |

*At 20 feet.

satisfactory results were obtained by using the method described, accurate calipers should be available at each repair or alignment facility. Further, because this procedure complicates the focusing of a cell, consideration should be given to redesigning the lamp mount so that the two sides of the assembly can be moved simultaneously on the mount.

A-3.2 Fresnel Lens Mounting.

The Fresnel lens is held in place against its seating studs by four spacer-type 90° angle clamps. The clamps are padded with a rubberized sponge material on the surface that bears on the lens. When first installed, the material is resilient and provides sufficient pressure to hold the lens securely in place. After prolonged use, however, the material becomes compressed or packed and no longer holds the lens securely. With the clamp padding compacted, slight movement of the lens can occur. The effect of the lens movement, of course, is to change focus position with respect to the slit and, hence change the location of the virtual source. Consequently, consideration should be given to replacing the present rubber pads by a more stable material.

A-3.3 Lens Temperature.

The temperature of the lens of a FLOLS cell is normally held constant to within a few degrees by circulating the internal air over thermostatically-controlled heating elements. When the system is operating normally, temperature control appears adequate. However, of the four cells on hand, three were found to have wiring failures at the point where the power terminal lugs are connected to the heater element. A form of corrosion develops at this location that may cause electrical failure over a long period of time. It appears advisable, therefore, that a different type of heater be used or at least a more permanent type of connection to the heater be substituted for the one currently in use. Cognizant Navy officials indicated orally that changes to avoid heater failures are currently being implemented. The defects are mentioned here solely to report the failures noted in the cells at the National Bureau of Standards and to confirm that similar type failures had been found.

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15. SUPPLEMENTARY NOTES

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

The Naval Air Engineering Center requested the National Bureau of Standards to develop a method of evaluating the performance of lenses of the Fresnel Lens Optical Landing System (FLOLS). In the course of this work, it was found that focusing of the cells of a FLOLS unit varied considerably. This led the NBS to examine the various focusing techniques used in the past and to develop a more precise method for focusing a cell. The focusing methods studied include the following: 1. Photometric, 2. Peep Sight, 3. Parallax, 4. Auxiliary Image-Forming Lens, 5. Pattern Matching.

In addition, in the study of these focusing methods, several other factors that affect the light-beam-forming characteristics of a cell were investigated. These include the effects of, 1. Lenticular Lens, 2. Lens Temperature, 3. Slit Width, 4. Slit Alignment, 5. Lamp Dimming and Source Color.

The results of this study indicate that visual methods of focusing the FLOLS system have inherent difficulties that lead to improper focusing. Photometric procedures developed at NBS, however, can give adequate focusing precision.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Beam spread; Fresnel lens; focusing methods; photometric focusing; visual landing system.

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