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# Corning Glass Works

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# A

# TECHNICAL PROPOSAL

# BY

# CORNING GLASS WORKS

# TO

# THE UNITED STATES GOVERNMENT

# FOR

# Investigation of Improved Screens for Rear Projection Viewers.

March 1965

Corning Glass Works
Electronic Products Division
3900 Electronics Drive
Raleigh, North Carolina 27604

IV. RECOMMENDED PROGRAM

V. PERSONNEL

VI. FACILITIES

# I. INTRODUCTION

## A. Objective

Corning Glass Works wishes to propose that a study be made of the various glass and glass ceramic materials which may prove of value as basic materials for constructing improved rear projection screens. The work that will be done will include only available materials and processes. Thus, whatever success is achieved will be transferable with little delay to practical screens. Small excursions into variations of existing materials will be made as necessary to point the directions for further work.

This proposal is written in response to the "Development Objectives, Improved Screens for Rear Projection Viewers" dated March 17, 1964.

## B. Background in Optical Technology

Corning has a broad background in optics stemming from over a half century experience as a supplier of optical glass for scientific, signal, and ophthalmic applications. Some recent projects which have required an excellent knowledge of optical technology are the production of massive optics for Schlieren windows and for aerial camera lenses. Currently, work is being conducted in the Electronics Laboratory at Raleigh in the field of holographic images. This has led to the generation of a high degree of competency in handling coherent light as well as the acquisition of some highly precise optical apparatus. This is discussed more fully in a later paragraph on "Facilities".

## C. Materials Background

While Corning's demonstrated abilities in optical technology are important to the success of this project, perhaps the greatest contributions the Company can make is in the field of materials technology. Prior work, as reported by Bausch and Lomb (1), has consisted of evaluating conventional diffusing surfaces. Part of the work proposed herein will also consist of evaluation but it will be on surfaces and bodies which are unique and which are created by selective molecular changes in the material itself. It is recommended that this initial study be limited to available materials which have never been examined for their optical and diffusion properties. The conventional and exotic optical glass are obvious candidates for such a study. In addition there are other Corning materials whose optical properties can be altered by what might be called molecular manipulation. There are two general categories of such glasses and glass ceramics which would seem to offer the most promise.

## 1. Photosensitive Glass

### a. Unique Characteristics

Photosensitive glass, as the name implies, is sensitive to light. In compounding such glasses, the photosensitive metals, gold, silver or copper are introduced. In addition, other materials known as "optical sensitizers" and "thermal-reducing agents" are included. Such compositions typically respond to exposure to certain wave lengths by forming small colloidal metal particle nuclei. Subsequent heating of the glass then encourages the growth of small crystals around the nuclei.

### b. Processing

Practical glasses of these types have their greatest sensitivity in the ultra-violet. Exposure through UV transmitting negatives can result in the formation of latent images in the glass with photographic accuracy and resolution. Since the glass sections generally employed have significant thickness, and because the nucleating process takes place throughout the entire volume, it is for most applications essential to have parallel light. The latent image is then "developed" by heat treating for minutes or hours at several hundred degrees centigrade.

Depending on the combination of exposure and thermal treatment, a variety of property changes can be created. If the integrated treatment forms only colloidal metal particles in the glass, a range of transparent colors from red to blue will result. The colors may be made so saturated that transparency is lost.

Another result of certain combinations of treatments is the growing of crystals around the nuclei which, by light diffusion, form a white opaque phase. In addition to promising interesting optical possibilities, this phase is also comparatively soluble in hydrofluoric acid. Since the opal phase formation is a volume effect it is possible to selectively etch it away creating cavities or holes with accuracy and resolution limited mainly by the negatives used for exposure.

Detailed studies have been made of the formation of the opaque etchable phase. For practical consideration in processing, the optimum sized crystal is 4 - 5 microns. Recognizing now that subsequent cycles of exposure, heat treatment and etch may be employed, it is evident that one can create an unlimited combination of optical paths through the screen.

2. Porous Silica Glasses

Certain glass compositions in the borosilicate family, upon heat treating, will separate into two phases; one, a silica network and the other a composition soluble in hydrochloric acid. This soluble phase can be leached away leaving a rigid cellular permeable structure.

The pores in this leached body are twenty to forty angstrom units in diameter. The void volume amounts to about 30% of the total. The whole body need not be leached. Interesting optical effects have been produced by leaching only a thin surface layer and impregnating with other substances.

3. Sintered Glass

Glasses of many compositions can be finely powdered, pressed into desired shapes, and reconsolidated by sintering. The resulting articles are vitreous and can be clear or opaque, depending on the method of firing. Again, depending on processing, the bodies may be completely impervious or may have a degree of porosity. Pore sizes can be controlled to maximum values ranging from 1.4 to 220 microns.

D. Company Experience

1. Photosensitive Glass

While present automatic processing equipment limits one dimension of any article to 16", large aperture masks for 21" color TV tubes were one-time made. These contained hexagonal holes of 0.008" diameter on 0.028" centers. The 21" mask had over 500,000 holes. Fine

12 mm$^{-1}$

40 mm$^{-1}$ screens of 300 mesh have been made routinely and 1000 mesh has been made on a laboratory basis. Since these required through holes they were necessarily quite thin, limiting their overall dimensions to about a 2" circle. If only surface indentations were required, the overall size would be limited only by the glass forming and handling equipment. A concurrent project at the Bradford facility involves photosensitive glass in the half tone printing process. Reticulated surfaces of 150 line pairs per inch are being used. This does not in any way tax the capability of the material.

2. Porous Silica Glass

Corning has manufactured and sold porous glass, for a number of years, for use in applications where moisture gettering is required. Some experience has been gained in impregnating with various materials but there are no standard products manufactured.

3. Sintered Glass (MULTIFORM)

Products made by this process have been marketed for over ten years. A plant in Corning, New York, is devoted entirely to MULTIFORM. A great range of glass properties and geometries can be realized.

4. Optical Glass

Hundreds of glass compositions of a great range of optical properties are melted in the Company's Herrodsburg, Kentucky, plant. Sizes range from blanks for opthalmic lenses to radiation shielding windows weighing tons.

E. Attack to be Followed

The project will be divided into three phases, the first of which will be a study of all available literature. The second part will be the theoretical investigation in which the many theories of light scattering are reviewed for applicability and related to the properties of available materials. Finally, the most feasible approaches will be tested experimentally.

Throughout the course of the work documentation will be maintained and periodic reports will be submitted.

While the major effort will be on the applications of available materials, the need for, and properties of new materials will be given attention. Concepts for active screens will also be considered, should they arise.

At the conclusion of the first two phases, it would be considered desirable to confer with the contracting agency before going on to the next step.

## II. RESULTS EXPECTED

The theoretical study is expected to indicate what features of the available materials will be of the greatest value in achieving the objectives. The experimental part of the project will provide the opportunity to test the theoretical conclusions. It is entirely possible, too, that the experimental work may yield some unexpected beneficial properties that can be used to enhance the theoretical approach.

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It is expected to be possible to combine the desirable properties to optimize the performance against the objectives for appearance, efficiency, contrast and resolution. It is impossible, at this time, of course, to predict with great accuracy how closely all the objectives will be met and what trade-offs may have to be made. It would be desirable to discuss this with the contracting agency at the proper time.

In the course of the experimental work, samples will be built for evaluation which later can be turned over to the contracting agency. Where exceptionally good results are realized every effort will be made to provide the agency with a practical sized sample.

It is not unreasonable to expect that new concepts for active screens will evolve as the work progresses. The materials requirements would very probably be beyond the scope of the present project. Due note will be made should such an occasion arise which could serve as the basis for Corning initiating new materials research and possibly providing the base for a subsequent project.

## III. TECHNICAL DISCUSSION

### A. Introduction

Rear projection is a technique employed in visual presentations, where an observer is located on one side of a translucent and diffusing screen, and the optical image projector on the other. Well-known examples are view cameras, reflex cameras, microfilm readers, background scenes in motion pictures and certain electronic data displays. The observer has a certain amount of freedom to move around while observing the display and does not run the risk of interposing himself between the projector and the screen, which would cause a shadow and loss of the display.

However, the advantages of rear projection over front projection, in which observer and projector are on the same side of the screen, are obtained at the expense of reduced brightness, viewing angle, picture definition, contrast and tolerance of ambient illumination. Except for a recent study carried out by Bausch and Lomb (1), relatively little quantitative data are available about the diffusion characteristic of available rear projection screens. This is an area where empirical techniques have yielded good results for some specialized applications in the past, but where a thorough scientific study of new materials may still be expected to yield significant improvements.

#### 1. Definitions

The following two subsections deal with the projection of light and some general relationships encountered in the measurement of light intensity and brightness.

##### a. Projection and Measurement Units of Light

The function of a light projector is to gather as much light as possible from the light output of a suitable source and to project this light into a desired direction. Since an imaging capability is also required, the optical system is somewhat more complicated than that of a simple light collimator. A typical projection system (2) is shown schematically in Fig. 1.

The intensity of the projected light is

measured in terms of foot-candles. This is the most commonly used photometric unit. To gain a quantitative feeling for this intensity, or illumination, it is helpful to recall that the maximum illumination outdoors due to both sunlight and sky light is approximately 10,000 foot-candles. This may range down to 1,000 and 100 foot-candles for dark or very dark days (3). Indoor levels of illumination are of the order of 10-20 foot candles.

The foot-candle is derived from the basic unit for the lunimous output of a lamp, the candela, which in turn is defined as the sixtieth part of the intensity of a square centimeter of a black body radiator at the the temperature of freezing platinum (2047° K).

A light source of one candela output, which radiates light equally in all directions, will produce an illumination of one foot-candle, or one lumen per square foot, at the surface of a sphere which is concentric with the source, and which has a radius of one foot. At a distance of one meter, the illumination will be one lumen per square meter, or one lux. These relationships are shown graphically in Fig. 2.

Since the concept of light involves the sensitivity response of the human eye, there is no one-to-one equivalent between light intensity and power density as one is accustomed to in other portions of the electromagnetic spectrum. Futhermore, light is almost never monochromatic, as microwave radiation, for example, usually is. However, it is useful to remember the relationship at the wavelength of peak visual sensitivity, namely 555 millimicrons, where one watt corresponds to approximately 682 lumens.

The light projector is used in conjunction with some screen which intercepts and displays the image contained in the projected light beam. The total amount of light thus intercepted is the product of the average illumination in foot-candles and the screen area in square feet, i.e.,

Total light (lm) = Avg. Illum, (ft-c) x Illum, Area (s/ft).

### b. Brightness

The human eye does not see light or illumination itself. Rather, it sees reflected or emitted light from area sources. Unlike illumination, brightness does not change with distance from the surface whose brightness the eye is perceiving. This is so because the eye is not only an imaging system, but also the optical equivalent of an extremely high-gain (in excess of 80 db) antenna through its resolving power of less than one minute of arc. Thus, although the power received from an elemental area of the surface decreases as the square of the distance, the area on the retina corresponding to that elemental surface portion also decreases in the same measure. Hence, the power density, or illumination, on that part of the retina remains the same.

The measure for brightness is the foot-lambert. It is the brightness of a surface which emits or reflects perfectly diffuse light at the rate of one lumen per square foot of area. In the case of the perfectly reflecting and diffusing screen, this means a brightness of one foot-lambert per foot-candle of incident illumination.

The term "perfectly diffuse" light refers to the light emitted or reflected by a surface which obeys the Lambert Cosine Law. The light intensity is proportional to the cosine of the angle between the direction of emission and the normal to the surface. An element of a surface which obeys this law will appear equally bright when observed from any direction.

Minimum brightness for good pictorial representation is of the order of 10 foot-lamberts for the brightest spots of the image, and 0.1 foot-lamberts for the darkest spots, corresponding to a contrast ratio of 100 to 1. Non-image (background or ambient) illumination should result in a brightness not exceeding 0.02 foot-lamberts. A contrast ratio of 25 to 1 is sufficient for positive printed or line material, and a ratio of 5 to 10 to 1 for negative (white letters on black background) print.

For higher ambient brightness such as the 5 foot-lamberts mentioned in the development objectives, the contrast ratio will have to be considerably higher.

## 2. Rear Projection Screens

### a. State of the Art

Most of the work which has thus far been done to develop high-quality rear projection screens has been in the area of large displays. The best known example of this nature are the very large (up to 40 x 80 ft.) screens used for background scenes during the filming of motion pictures. Wide use is made of such techniques as Fresnel screens and lenticular screens (6). Optimum procedures have been worked out to arrive at solutions fitting the sometimes conflicting requirements regarding screen brightness, contrast, reflection factor, gain, bend angle and picture size, to the limitations dictated by ambient light, projection lens focal length and projector lumen output (5).

The field of small display rear projection systems with its different requirements has received much less attention. This encompasses primarily view cameras and microfilm readers. The requirements in these display systems have been not nearly as demanding as in large displays. Among the reasons for this are:

a) lower power, and hence lower efficiency requirements, because of the small screen size.

b) lower tolerance to ambient light was required, because the equipment could be operated in a darkened room (film reader), or special measures could be taken to eliminate ambient light (e.g., photographer's cloth used in view cameras).

c) less stringent requirements in terms of uniform diffusion and large bend angle, because the screen was usually viewed by only one observer who could adjust his position to attain optimum location and view angle.

The main concern in the technical perfection of these small screens has been to provide uniform brightness in the direction of the observer across the entire screen. This is usually done with a thin Fresnel lens in contact with the back surface which has the effect of bending the gain lobe of the diffused light toward the observer. A good deal of development work still remains to be done to achieve higher efficiency and uniform diffusion over a larger angle. In most conventional screens these requirements conflict, but this need not be so from a theoretical view point. Some analysis work is required to better understand and improve the scattering process and will be carried out in the course of this study.

b. Performance

In rear projection screens one is primarily interested in the diffusely transmitted light, rather than in the diffusely reflected light which is important in front projection screens. Aside from that, the technical considerations are quite similar. The overall efficiency of rear projection screens is significantly lower due to transmission and scattering losses, as well as due to the portion of the light reflected from the front surface, which is completely lost for the rear projection display.

The concept of a perfectly diffusing reflector may also be applied to the case of rear projection. There, the ideal case would be a surface which exhibits a uniform brightness of one foot-lambert regardless of viewing angle for each foot-candle of incident illumination from the other side. Such a perfectly diffusing screen is said to have a gain of unity. In practice, most surfaces have a higher brightness when viewed from certain directions, with a necessarily lower brightness when viewed from other directions. The gain in each direction is defined as the ratio of observed brightness in foot-lamberts to incident illumination in foot-candles:

Gain = foot-lamberts/foot-candles

This is illustrated for a typical rear-projection screen in Fig. 3.

The observers, depending on whether they are in a direct line with the projector (Observer 1), or looking at the screen at a more or less large angle with this principal axis, see a brightness corresponding, in this example, to a screen gain of 3, 1.4 and 0.4 for Observers 1, 2, and 3, respectively. The gain falls off with increasing angles from the principal axis because of imperfect diffusion in the screen. This is indicated by the length of the arrows. The distribution lobe for a perfectly diffusing screen would be a circle. The illumination at point A in this example was assumed to be 10 foot-candles. The angle between the observer's direction of view and the principal axis is called bend angle. The gain as a function of the bend angle is shown for a number of practical screens (5) in Fig. 4.

The lowest curve in Fig. 4 shows almost uniform gain, hence this screen is an almost perfect diffuser. However, the fact that the gain is much less than unity indicates the losses which are invariably present in the rear projection case. These are due to reflection on the projector side, and to absorption in the screen. Usually, low absorption, or high transmission (80-90%), is accompanied by low diffusion (high gain) and vice versa. Thus, the desirable goal of both high transmission and high diffusion is usually not attained in one and the same screen. Some useful development work toward reaching a compromise between these two usually conflicting requirements can still be done, and will constitute one of the major aspects of the task to be carried out.

A useful figure of merit for rear projection screens is the bend angle at which the gain has fallen to 50% of its peak value. This is similar to the half-power beam width familiar from microwave and optical collimation systems. Similarly, the one-third power angles can be established. Usually, the higher the peak gain, the lower the 50% and 33% bend angles. These relationships are plotted for typical screens in Fig. 5, which also contains a typical graph of reflection factor vs peak gain. The latter is the ratio of re-radiated to incident ambient illumination on the observer side of the screen. Hence, the lower the reflection factor, the greater the tolerance of the screen to ambient (room) light.

## 3. Theoretical Considerations

The proposed development study on new or improved rear projection screens will involve not only experimental work, but also, and perhaps more importantly, a thorough theoretical investigation of the basic mechanisms involved in the transfer of the image from the projector to the observer side of the screen, and the diffuse reradiation of the image on the observer side. In addition, a literature and patent search will be conducted. The mechanism of diffusion may be brought about in two principally different ways: First, one may consider the case of a material which is heterogeneous throughout. A simplified model is that of a clear, transparent host material, which has suspended in it a random arrangement of spherical particles of a refractive index different than that of the host material. The resulting scatter properties are governed by turbidity of the material has been investigated by Mie (7) for a density of N spheres of radius R per unit volume:

$$\tau = N\pi R^2 f(x)$$

where

$$x = \frac{2\pi R}{\lambda^1}$$

and $\lambda^1 = \lambda/n_o$, the wavelength of the light in the medium. The expression f(x) in Equ. (1) is a complicated function for which the following extreme cases are of interest:

$$f(x) \propto x^4 \quad \text{for } x \ll 1 \qquad (3)$$

$$f(x) \propto x^2 \quad \text{for } x \sim 1 \qquad (4)$$

$$f(x) \rightarrow 2 \quad \text{for } x \gg 1 \qquad (5)$$

Equ. (3) is the well-known result for Rayleigh scattering by particles small compared to the wavelength. The scattering is proportional to the inverse fourth power of the wavelength.

For the diffusing screens considered in this study, cases (4) and (5) will be of greater interest. The latter is usually referred to as Mie scattering, caused by particles large compared to the wavelength. Its principal characteristic is the fact that it is non-dispersive, i.e., the scattering does not depend on the wavelength. As a consequence, color information is preserved.

The other main diffusion mechanism is through treatment of the surface (front or back, or both). Frosted glass is one example. The scattering or diffusion here depends on the so-called Rayleigh Criterion concerning the diffuse reflection from rough surfaces as a function of the incident angle.

An analytical method to describe screen properties has been proposed by Hill (8). Following the notation of Sears (9) one may state the following definition and formulae.

Definitions:

F, luminous flux;

I, luminous intensity or flux per unit solid angle;

B, luminance (brightness);

E, illuminance or flux per unit area received at a surface; and

L, luminous emittance or total flux emitted per unit area

Defining equations:

$I = \frac{DF}{dw}$ where w is solid angle with vertex at source;

$E = \frac{df}{da} = \frac{I_{\theta} \cos \theta}{r^2}$, where $\theta$ is angle with normal to surface;

$B = \frac{\Delta I_{\theta}}{\Delta A \cos \theta}$ ; and

$L = \frac{\Delta F}{\Delta A}$ , F is total emitted flux.

The essence of Hill's method is the use of an empirical "shape factor" s to modify Lambert's law. The following equations compare intensity and brightness for a surface which follows Lambert's law, with one which is directional but for which the intensity falls off in proportion to some power s of the cosine of the angle with the normal to the surface.

| Lambert Surface | Directional Diffuser |
|---|---|
| $I_{\theta} = I_o \cos \theta$ | $I_{\theta} = I_o \cos^s \theta$ |
| $B_{\theta} = B_L$ | $B_{\theta} = B_D \cos$ |

Here $B_L$ represents the brightness of the Lambert surface, and $B_D$ the normal brightness of the directional surface.

The illuminance of flux received per unit area at a point not on the screen illuminated by a circular area of the screen whose center is at the foot of the perpendicular from the point and whose radius subtends an angle $x$ at the point is found by integration to be:

Lambert Surface

$$E_L = \pi B_L \sin^2 \alpha$$

Directional Diffuser

$$E_D = \frac{2\pi}{s+1} B_D (1-\cos^{s+1} \alpha)$$

and the luminous emittance or total flux emitted by a unit area of the screen surface is:

Lambert Surface

$$L = \pi B_L$$

Directional Diffuser

$$L = \frac{2\pi}{s+1} B_D$$

If we neglect any differences which may exist in absorption or other screen losses, we can compare maximum normal brightness by assuming that the total luminous emittances are equal, in which case we see that

$$B_D = \frac{s+1}{2} B_L$$

This shows clearly why the "brightness" of a directional screen in foot-lamberts may often be several times the intensity of the incident radiation in foot-candles.

The "shape factor", s, provides a convenient index to the diffusing characteristics of the screen. For a perfect diffuser, it is of course, unity, while for a nondiffuser (free transmission or specular reflection) it becomes infinite. For practical screens it lies somewhere between 1 and 50. The requirement of a view angle of 90° will necessitate a shape factor only very slightly higher than unity. The attainment of this requirement will be one of the major goals of the proposed development program.

B. Materials approach to the problem

From what has gone before it is evident that many of the theoretical ways of manipulating light to solve the problem are dependent upon chemical manipulation of the light transmitting media. What follows now is a discussion of the different categories of materials that should produce the desired optical effects and how Corning's materials should meet these requirements.

In the design and development of new types of rear projection screens one may classify the possible methods into the following categories:

A) Passive Screens

B) Active Screens

C) Hybrid Screens

The screens and their properties described in Section III 2 are of the passive type, i.e., no amplification of the incident light takes place in them, and no power source is required. The concept of "gain" refers to directional preference, in the rediffusion pattern of the illumination and does not imply gain in terms of total radiated power. The present proposal deals with screens of the passive type.

Active screens are a type which, if technically feasible, would involve some kind of image or light intensification process. These could be logical follow-on based on the present work on passive screens and materials development now in progress in the Corning Research Laboratory.

Hybrid screens involve the use of auxiliary power or light sources but make no use of direct image intensification as such. In this type of screen, the incident light modifies the light transmission and dispersion properties of the screen material in such a way that auxiliary light, in transmission through or reflection by the screen, is similarly affected. Hence, a net image intensification may result. Certain phototropic materials, under development by Corning Glass Works, may lend themselves to this kind of application.

Another distinction that may be made between different types of rear projection screens is in the method by which the image is transferred from the front of the screen to the back. Usually the light is accepted on the front (projector) side of the screen, and then redistributed by diffusion or scattering in the screen material, to exit at the rear (observer) side in a manner which is a compromise between the desired amount of diffusion and the permissible loss of brightness and pictorial detail. However, diffusion is not required as an end in itself. It is merely used to accomplish an acceptable gain pattern (the half-power bend angle must not be too small) to permit a certain amount of freedom in the position of the observer. Also, it is often desired to have more than one observer. In addition, it serves to reduce the glaring "hot spot" which the observer perceives when he looks, through the screen, in the direction to the projector.

The specifications of the screen to be developed in the course of this work call for uniform brightness (± 15%) over a solid angle of 90°. It is quite clear that conventional screens of frosted glass do not even approach these requirements.

However, the same effect may be accomplished by means other than random scattering or diffusion. The image may be divided into elements and each element may be transferred individually from the front of the screen to the back. There, the light from the picture element may be made to emerge from the screen in the desired distribution pattern. One possible way that comes to mind is the use of fiber optics if the economics were not prohibitive.

Thus we may make the distinction:

I Randomizing Screens

II Nonrandomizing Screens

The former type is the conventional, diffusing screen, while the latter is nonconventional and has thus far been used only for applications involving extremely small image sizes. Both concepts may be active, passive or hybrid as outlined before, but it is likely that passive screens will be predominantly of the randomizing type, while active screens will be primarily nonrandomizing. Of particular interest finally is a possible classification of the screens from a materials viewpoint, in terms of how randomization (fiber optics, lenticulation) are accomplished, as follows,see Table I:

a) Homogeneous Screens

b) Heterogeneous Screens

The category of heterogeneous screens may further be subdivided into either:

$b_1$) Macroscopically Heterogeneous Screens

$b_2$) Microscopically Heterogeneous Screens or

$b_a$) Permanently Hetergeneous Screens

$b_b$) Temporarily Hetergeneous Screens

Homogeneous screens consist of one basic material only, and achieve their diffusion characteristics either through their fundamental material properties (e.g., paper) or geometrically through suitable surface treatment or shaping (e.g., frosted glass).

Heterogeneous screens combine materials of different properties, for example sandwiches of different materials (macroscopic case). The term "microscopic" refers to dimensions comparable or small compared with the desired resolving capability of the screen. Thus, a fiber optics screen would be considered microscopically heterogeneous, as would be a screen which uses separate small diffusing or scattering particles embedded in glass or plastic.

Finally, the terms "permanently" and temporarily" heterogeneous screen refer to the duration of the randomization or elementization properties. Fiber optics, cloudy glass, etc., would be examples of permanently heterogeneous screen materials, while reversibly phototropic versions would be called "temporarily heterogeneous".

In the following, a number of possible new rear projection screen types will be discussed. The major emphasis is in all cases on the use of Corning materials which are available at present. Some attention will be given to defining areas where there exists reasonable likelihood of successful development of new useful materials. The list of possibilities is by no means complete. Indeed, a portion of the proposed work will be devoted specifically to the search for new possibilities. The work will encompass both theoretical as well as experimental studies.

1. Passive Screens

Design objectives in this area will be the improvement of existing techniques through the use of available Corning materials and processes. This will be accomplished after a theoretical and experimental study.

a) Photosensitive Glass

This type of glass can be used in two ways:

1) A permanent image can be formed on the glass as on photographic

film. This permits the forming of rasters, grids or lines on the surface of the glass to modify its reflection characteristics. Also, since the darkening can be made to penetrate the glass, grids can be established throughout the bulk of the screen, producing an effect somewhat like fiber optics, although no total internal relection takes place at the "fiber" boundaries. Since this type of screen would have to be quite thin, it would be sandwiched onto a clear supporting substrate (Fig. 6). This is an example of screen classification A, II, $b_1$, $b_2$, $b_a$. (see Table I)

Another possibility would be the use of photographically formed Fresnel Zones (which, to a certain extent, act like convex lenses) to form a "lenticulated" screen, as in Fig. 7. This screen is of the type A, I, $b_2$, $b_a$. (see Table I)

2) Photosensitive Glass can also be given a very closely controlled surface shape through Corning's Fotoform process with the result that a number of possible screen patterns can be visualized (Fig. 8).

The serrations can be made so as to control the exit angle to give preference to a particular direction, or to yield different half-power angles in the horizontal and vertical. Also, serrations could be on both front and back, and turned 90° with respect to each other. These screens would be of type A, I, a. (See Table I). The question which will have to be investigated theoretically as well as experimentally in most of these screen versions is that of color fidelity. A serrated surface acts as a grating, and color dispersion may be expected. Furthermore, the color will be dependent on the view angle.

A front-viewing version of the screen could be made with suitable surface shaping. Observer and projector could be both circa 45° off the normal.

b) Heterogeneous Materials

Although in some of the previous examples the screen material was made heterogeneous after fabrication (photographic techniques), one may start with dissimilar materials, such as a suspension of microscopic ceramic particles in glass. The diameter of these particles would be smaller than the expected resolution but larger than the wavelength of light, hence the Mie scattering theory would apply (no dependence on wavelength, i.e., color fidelity). Also, the wide variety of available Corning materials will be an asset (see Fig. 9). This type would be classified as A, I, $b_2$, $b_a$. (See table I).

✓c) Polarizing Materials

One may investigate the possibility of using polarizing material for the reduction of ambient light reflection. This is particularly important in brightly lit rooms, where an observer may see the reflection of his own face more brightly than the desired display. The technique is currently employed in self-luminous alpha-numerical displays and uses a sheet of Polaroid in conjunction with GRENAR a quarter-wave plate. This permits light to come out of the display, while light that enters the display from the observer side cannot be reflected back. If the polarizing and retardation property can be made integral with the screen, a saving of interfaces with attendant reduction in losses may result. Such a screen would be of class A, b, with I or II and the subclassification of b depending on the design of the remaining portion of the screen. (see Table I)

d) Opal Glasses

Similar to (b), these glasses are produced by the introduction of small particles into the transparent glass. They can be made photosensitive and surface treated as discussed earlier, to yield a variety of possible screen materials. The more opaque versions may be preferred for the front (90° offset) view case.

e) MULTIFORM Glass

Possibilities similar to those discussed in connection with the Fotoform process are offered by MULTIFORM glass. Either the clear or the translucent form, in conjunction with some of the techniques discussed earlier, may be suitable for screens whose surface geometry is critical.

f) Fiber Optics

It is generally agreed that the nonrandomizing and virtually lossless image transfer from front to back afforded by fiber optics would be the optimum solution of the problem. However, cost becomes prohibitive for screens larger than a few millimeters in diameter. Nevertheless, the possibility of using fiber optics will be investigated. Some correction caps may have to be provided for each fiber to achieve the desired spreading angle. Classification would be A, II, $b_2$, ($b_1$), $b_a$. (see Table I)

g) Porous Vycor

The porous form of Corning's 96 per cent silica glass contains sub-microscopic holes in vast numbers. This material, although it has been developed for quite different purposes, may lend itself very well for use as a diffusing screen. Different leaching and firing processes could yield a variety of front and back surface combinations. Fig. 10 illustrates some of these. Also, there is a possibility of filling or partially filling the pores with a material of different index of refraction. Obviously, there are many possibilities that may be investigated. Classification of these porous Vycor sandwich screens is A, I, a. (see Table I)

2. Hybrid Screens

The recently developed photochromic glasses, of which there are already at least 2 dozen different types under laboratory investigation, open the possibility of developing an entirely new type of screen display system, with possible light amplification properties.

The display is called hybrid inasmuch as the screen material itself is not active and no image intensification as such takes place. Rather, the incident light is used to modify the transmission properties of the screen in such a way that an auxiliary light will be more or less preferentially transmitted. Such a method may also be termed (rather loosely) as "parametric" or "adaptive".

Typical photochromic glass, as shown by extensive laboratory investigations, has the property of becoming darker under the influence of blue or near-ultraviolet light, while red light has the opposite effect, viz., it is capable of bleaching the darkened glass. The responses, shomewhat over-simplified, are as shown in Fig. 11.

At the crossover wavelength, ca. 500 m$\mu$, the net effect is zero. Thus one may speculate on an adaptive glass rear projection screen. (see Fig. 12)

The photochromic glass may have suitable surface lenticulation or serration to achieve the desired viewing angle. Color content of the original image would be lost, but a net image intensification may be achieved.

This last method may be quite promising, but will require a rather long period of development work. Classification: C, II, $b_2$, $b_b$. (see Table I)

## IV. RECOMMENDED PROGRAM

The following R & D program is proposed for the work on rear view screens as required by the Government Agency:

### A. Literature Search

This includes a familiarization with the proper literature in periodicals and reports as well as patent descriptions. A time of three months will be sufficient for one engineer.

### B. Theoretical Investigation

1. Statistical approach concerning the variation of light distribution as a function of surface roughness and material characteristics.
2. Theoretical studies based on the scattering of particles (by Mie) followed up by experimental investigations where elemental blocks of different shapes will be prepared.
3. The influence of dielectric coatings on minimizing and maximizing transmission where rejection of light will be investigated.

This phase of the program will be done by one engineer over a time period of six months.

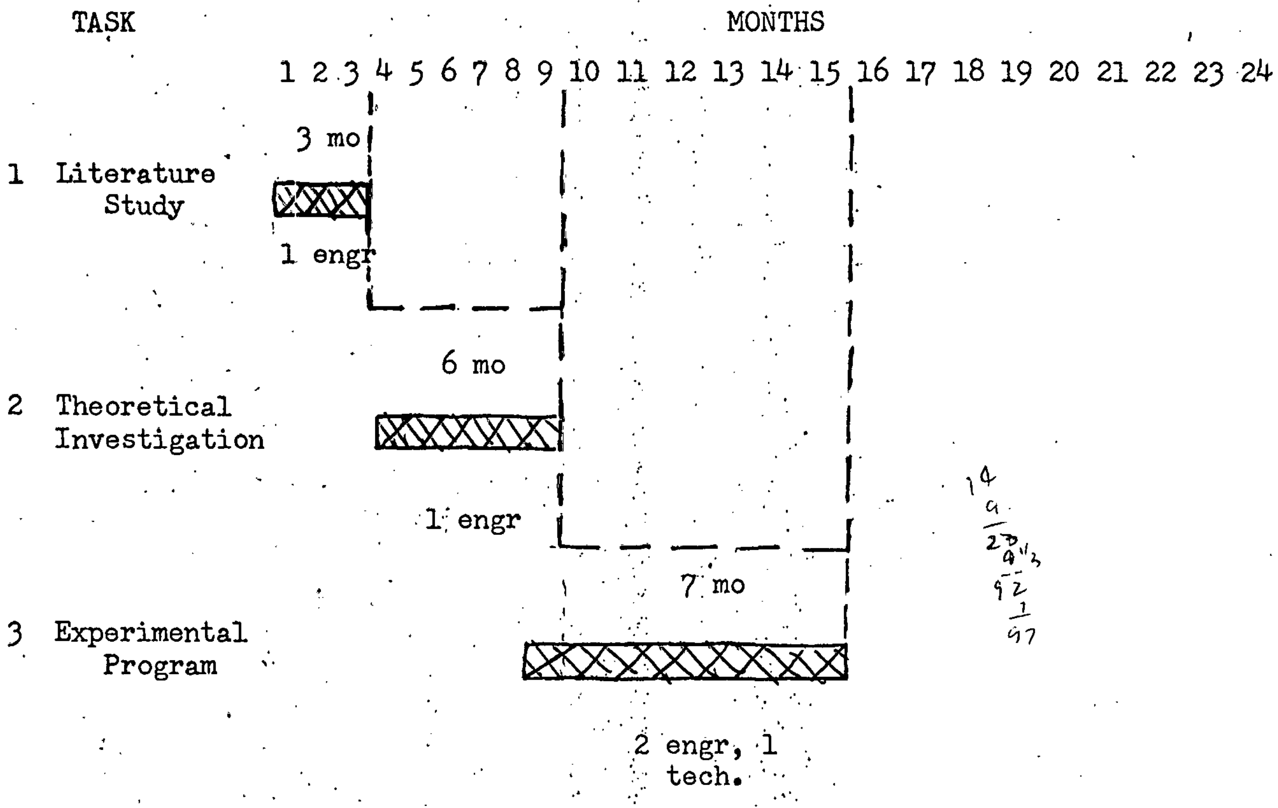
### C. Experimental Program

After the individual parameters are known as described under B an optically passive screen will be designed from theoretical and practical investigations. This design work will be mainly restricted to the presently available CGW materials with minor modifications as required. For this phase two engineers and one technician are required for a time period of seven months.

### D. Proposed Continuation of the Program

As a result of the work described in Sections A through C, it may well prove worth while to continue the work in one of several directions. At that time Corning would appreciate receiving advice from the Agency on the relative importance of these various approaches. This would enable Corning to determine what the Company had to offer and hence the advisability of preparing a follow on proposal.

## RECOMMENDED PROGRAM



14
9
23
9 1/3
92
1
97

## POSSIBLE FOLLOW ON PROGRAM

## V. PERSONNEL

Work on the proposed project will be performed by the Electro-Optics Group of the Electronic Research Laboratory located in Raleigh, North Carolina. At present, it is expected that [redacted] will be the primary investigators on the project with [redacted] available as primary consultants. Their resumes follow:

STAT
STAT

## VI. FACILITIES AND EQUIPMENT

The necessary equipment and instruments for studies of the optical properties and characteristics of existing and new materials as well as advanced experimentation and the evaluation of test samples will be provided.

### A. Facilities

The experimental work of the Electro-Optics Group is conducted in two laboratories. The larger of the two which has been made light-tight and bisected by a light-tight curtain. The purpose of this curtain is to offer the choice of one large optics laboratory or two smaller ones. Along the walls of this work area are laboratory benches which contain drawers and shelves for storage of optical hardware. Also in this laboratory is a massive granite surface plate mounted on a concrete footing which is mechanically isolated from the laboratory building. On this granite block (which measures 5' x 6' x 18") rather delicate interferometric experiments can be performed free of damaging vibrations from the work area and the building itself.

Adjacent to the large laboratory is a smaller laboratory which is also bordered by work benches and storage areas. Since this smaller area is not completely light tight, electronic and optical experiments not requiring absolute darkness are performed here.

### B. Equipment in the Electro-Optics Laboratories

Photometric Instrumentation:

1 EG&G 3/20 580/585 Spectroradiometer System w/ Quartz Input Optics
1 Baird-Atomic Densitometer Comparator Model CB-1
1 Dumont Photomultiplier w/ S-1 response
1 Dumont Photomultiplier w/ S-11 response
1 Lead Sulfide IR Detector

Sources

1 Watkins-Johnson Model WJ-291 He:Ne DC Pumped Gas Laser w/ Collimator (WJ-902-2), 2 Spherical Mirrors and 1 Plane Mirror for operation at 6328 A, 2 Spherical Mirrors for operation at 1.16
1 Pulsed Laser (400 Joule input) to excite ruby and Neodymium Rods
2 Corning Neodymium Glass Laser Rods
1 Ruby Laser Rod
1 General Electric Sun Gun

1 Gallium Arsenide Diode
2 Amglo HD-A Flashtube
3 Osram Super Pressure Mercury Lamps H930 200 W L/2
1 PEK 202 Mercury Arc Lamp w/ M-701 Power Supply
2 PEK Special Fill Cylindrical Flash Lamp XE-7-3-$\frac{1}{4}$
2 PEK 150 Watt Xenon Hi-Pressure Arc Lamps X150M
1 PEK Power Supply for 150 Watt Burner # 701-1480
1 PEK 118-7E Nanosecond Light Source

Filters

5 Schott and Genossen Filters

Spectral Range: 3000-4000A
Width of Passbands: 80A

10 Optics Technology Inc. Filters

Spectral Range: 4000-7000A
Width of Passbands: 120A

1 Optics Technology Inc. Linear Wedge Filter

4000-7000A

10 Optics Technology Inc. Filters

Spectral Range: .8-1.7
Width of Passbands: .25

10 Optics Technology Inc. Filters

Spectral Range: 1.8-2.7
Width of Passbands: .5

4 Corning Narrow-Band Filters

Spectral Range: 3600-4600 A
Width of Passbands: 400A

3 Corning UV Transmitting Filters

3100-4400A
3200-3900A
2500-3900A

1 Corning Bandpass Filter

4200A-2.75

2 Corning Infrared Transmitting Filters

.9 -1.75

## Optical Hardware

| | |
|---|---|
| 3 | 6 inch diameter 1/10 Wave Mirrors |
| 1 | 13.2 x 10 cm ½ Wave Mirror |
| 1 | Concave Spherical Mirror 4" dia. Focal Length = 48" ¼ wave |
| 2 | 6 inch diameter, 1/10 wave Beamsplitters |
| 4 | 6 inch diameter, Mirror and Beamsplitter Mounts |
| 1 | Ealing Triangular Cross Section Optical Rails (4 meters long) |
| 1 | Ealing Triangular Cross Section Optical Rail (2meters long) |
| 1 | Ealing Triangular Cross Section Optical Rail (1 meter long) |
| 1 | 5' x 6' x 18" Granite Gage Block on Spring Isolators and Isolated Footing |
| 4 | .0005 inch dia. pinholes |
| 13 | Wedge Prisms of Different Powers |
| 2 | Image Conduits |
| 2 | Light Transmitting Clad Rods |
| 3 | Bausch and Lomb Achromatic Objective Lenses (2X magnification) |
| 3 | Bausch and Lomb Achromatic Objective Lenses (10X magnification) |
| 4 | Pairs of Ronchi Rulings (100, 200, 300 lines/inch) |
| 1 | American Optical Cycloptic Microscope w/ Base, Illuminator, Eye Pieces, and Camera Adaptor |
| | Large Assortment of Inexpensive Lens of Various Diameters and Focal Lengths |

## Photographic Equipment

| | |
|---|---|
| 1 | Polaroid MP-3 Camera w/ Lighting Assembly |
| 1 | Bausch and Lomb "Balomatic 705" Slide Projector |
| 1 | Darkroom |
| 72 | 12" x 1½" High-Resolution Spectroscopic Plates |
| 72 | 4" x 5" High-Resolution Spectroscopic Plates |

## Electronic Equipment

| | |
|---|---|
| 1 | Tektronix 588 Oscilloscope |
| 1 | Hewlett-Packard 130C Oscilloscope |
| 1 | Hewlett-Packard 196B Oscilloscope Camera |
| 1 | Tektronix 564 Storage Oscilloscope |
| 1 | Hewlett-Packard 200 CD Signal Generator |
| 3 | ERA Model TR 040M DC Regulated Power Supplies |

To carry out the work contemplated in this proposal, Corning Glass Works would purchase approximately $10,000 of additional equipment. This would not be charged to the contract.

## REFERENCES

1. Final Report - "Rear Projection Screen Materials Study".
2. B. K. Johnson, "Optics and Optical Instrucments", Dover, 1960
3. Hardy and Perrin, "The Principles of Optics", McGraw-Hill, 1932, p. 160
4. "Light Measurement and Control", General Electric Company, Brochure No. TP-118
5. P. Vlahos, "Selection and Specification of Rear-Projection Screens," J. SMPTE 70, 89 (1961)
6. C. R. Daily, "High Efficiency Rear-Projection Screens", J. SMPTE 65, 470 (1956)
7. G. Mie, Annalen Der Physik 25, 377 (1908)
8. A. J. Hill, "A First-Order Theory of Diffuse Reflecting and Transmitting Surfaces", J. SMPTE, Vol 61, 18 (1853)
9. E. W. Sears, "Principles of Physics, Vol. 3 - Optics, Addison - Wesley, Cambridge, Mass. (1948)

A Passive Screens

B Active Screens

C Hybrid Screens

I Randomizing Screens

II Nonrandomizing Screens

a Homogeneous Screens

b Heterogeneous Screens

Volumetric Diffusers

Surface Diffusers

$b_1$ Macroscopically heterogeneous Scr.

$b_2$ Microscopically heterogeneous Scr.

$b_a$ Permanently heterogenous screens

$b_b$ Temporarily heterogenous screens

Table I Classification of Varous Screen Types

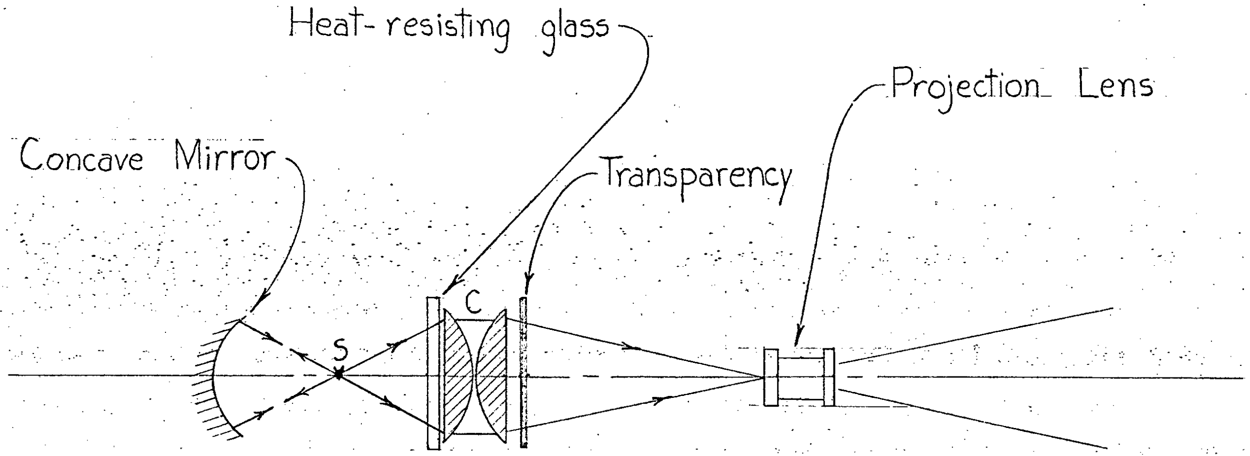


Fig. 1 : Typical Image Projection Optics

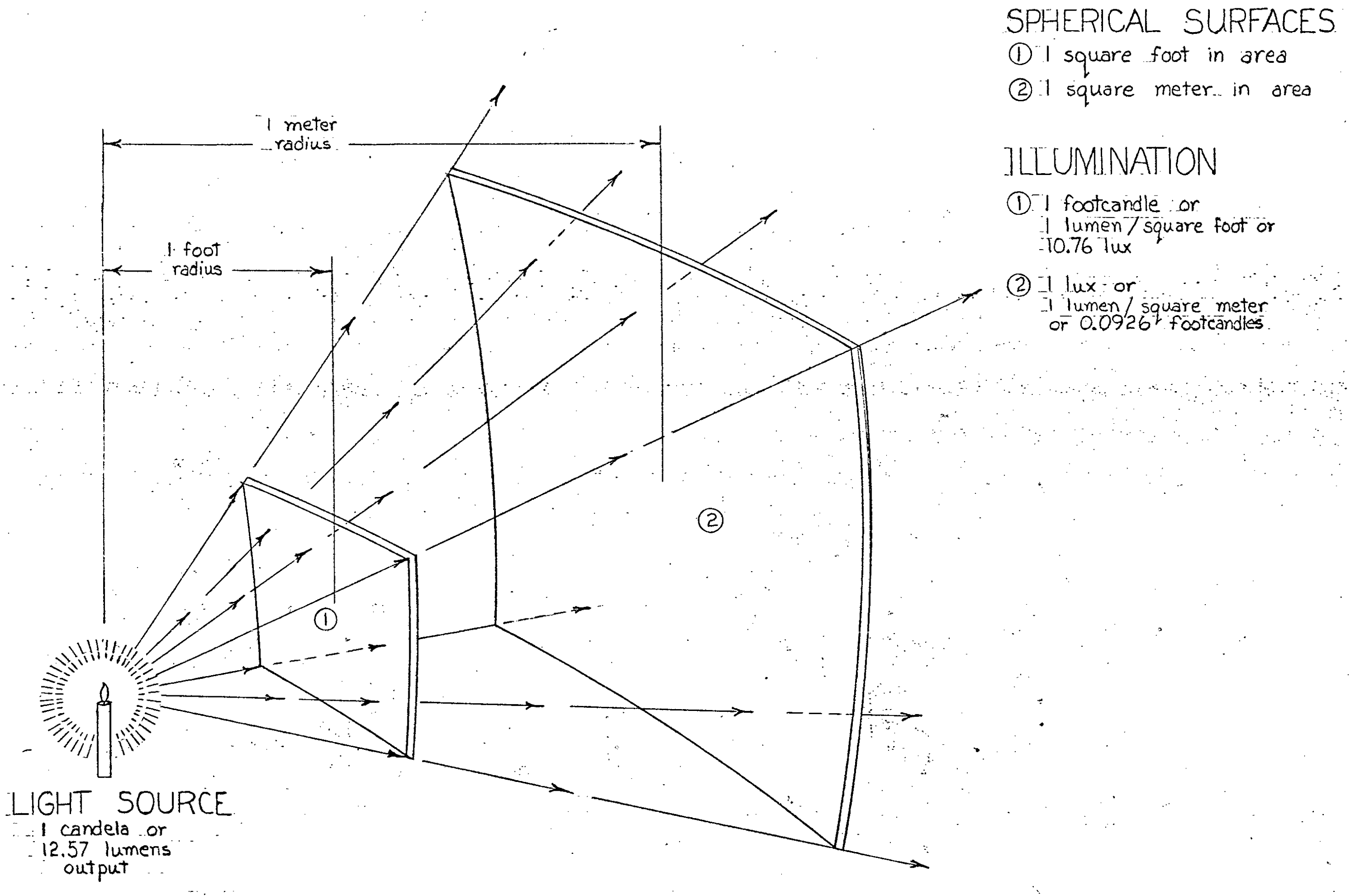


FIG. 2: ILLUSTRATION of SOME PHOTOMETRIC RELATIONSHIPS [4]

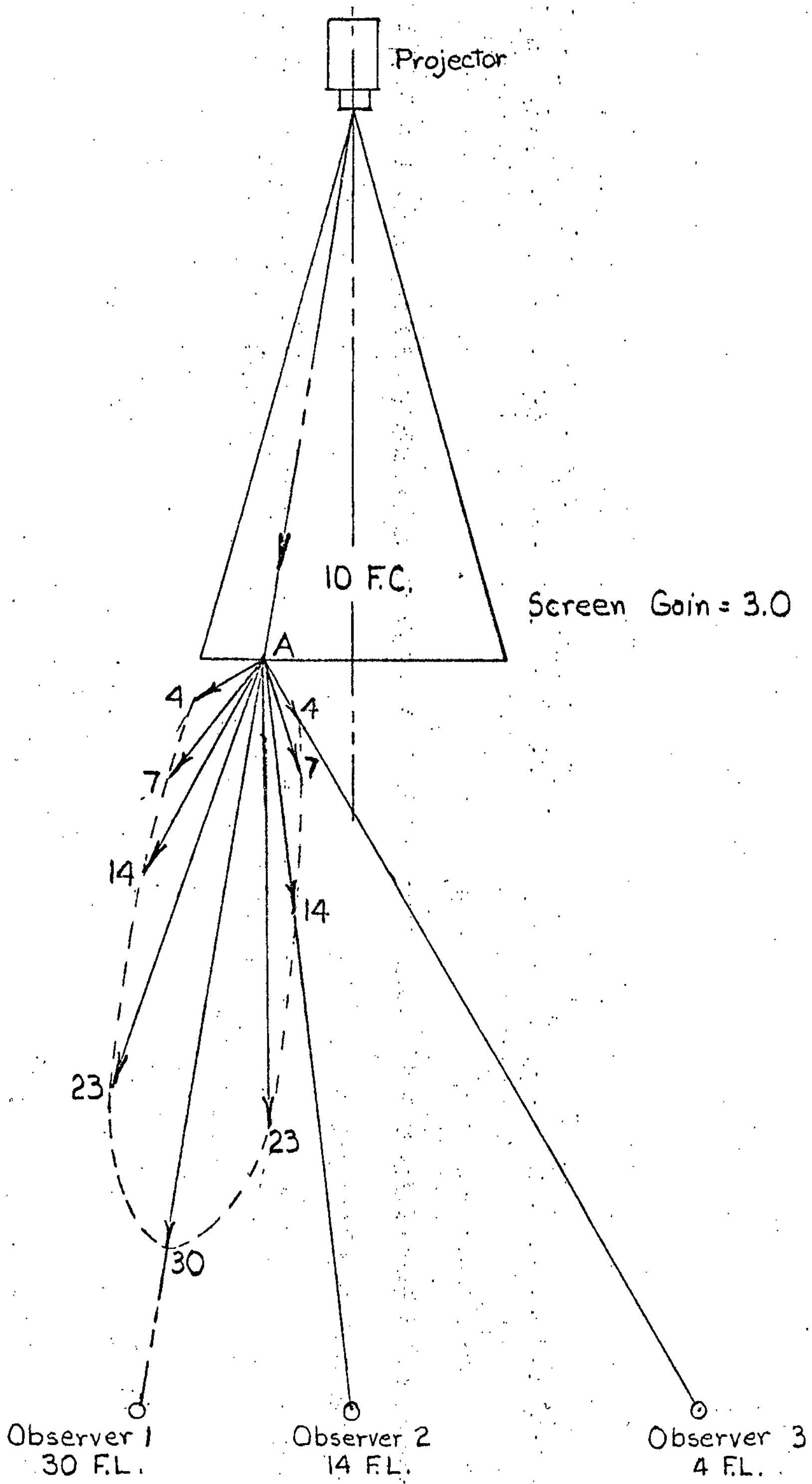


FIG. 3: BRIGHTNESS DISTRIBUTION LOBE FOR SCREEN GAIN OF 3.0 (EXAMPLE)

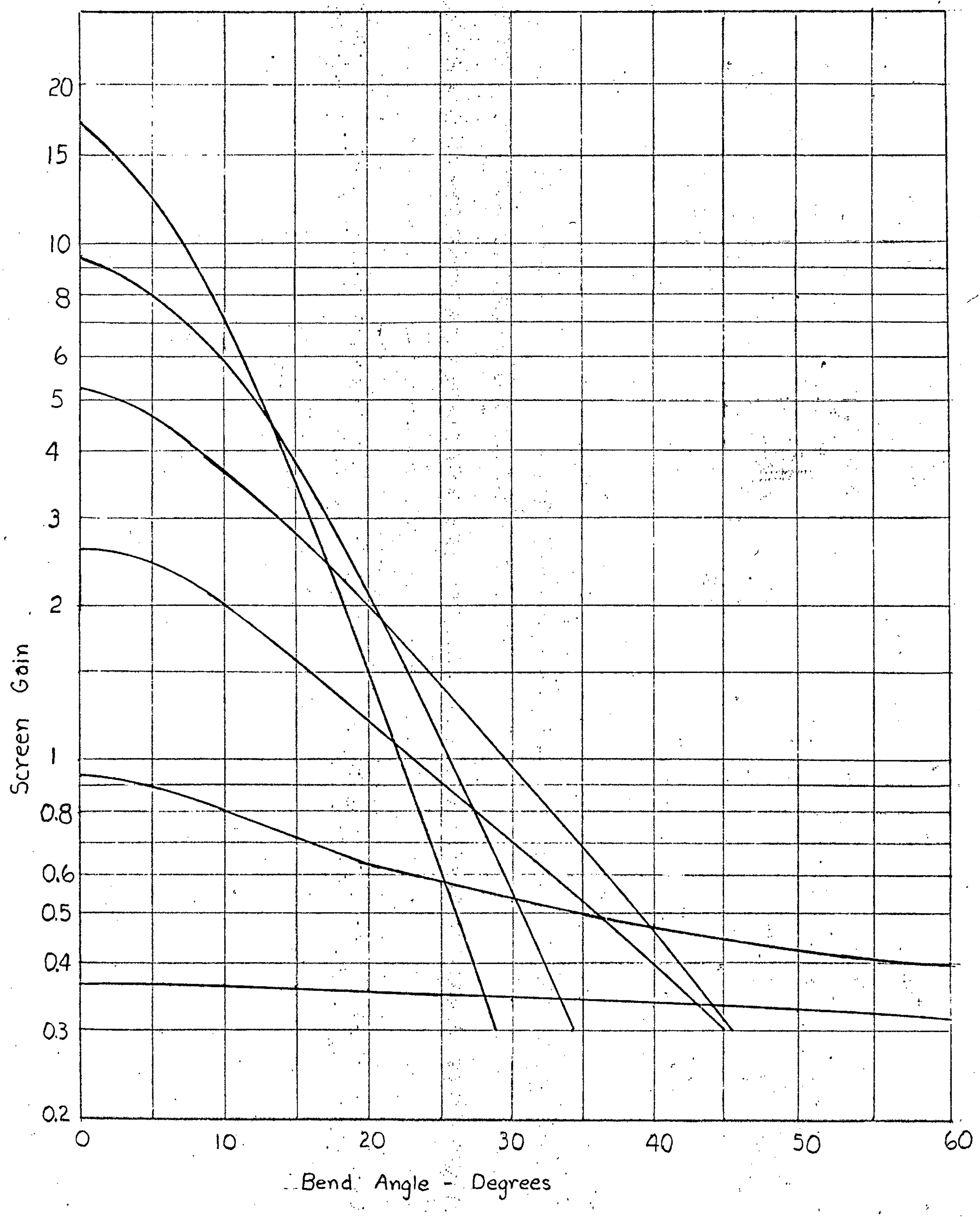


FIG. 4: SCREEN GAIN AS A FUNCTION OF BEND ANGLE FOR SEVERAL TYPICAL SCREENS

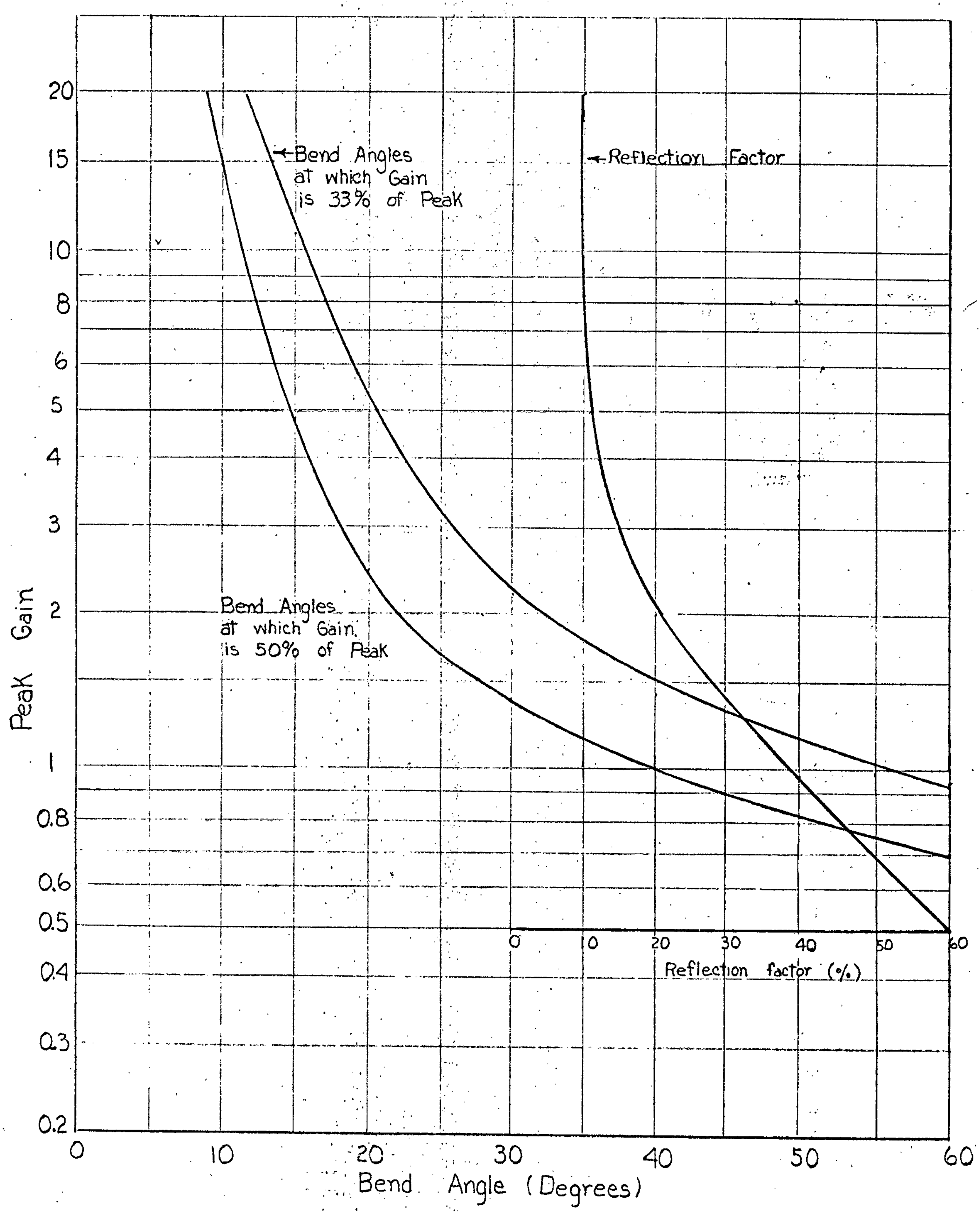


FIG. 5: BEND ANGLES FOR 50% AND 33% GAIN, AND REFLECTION FACTOR VS PEAK GAIN

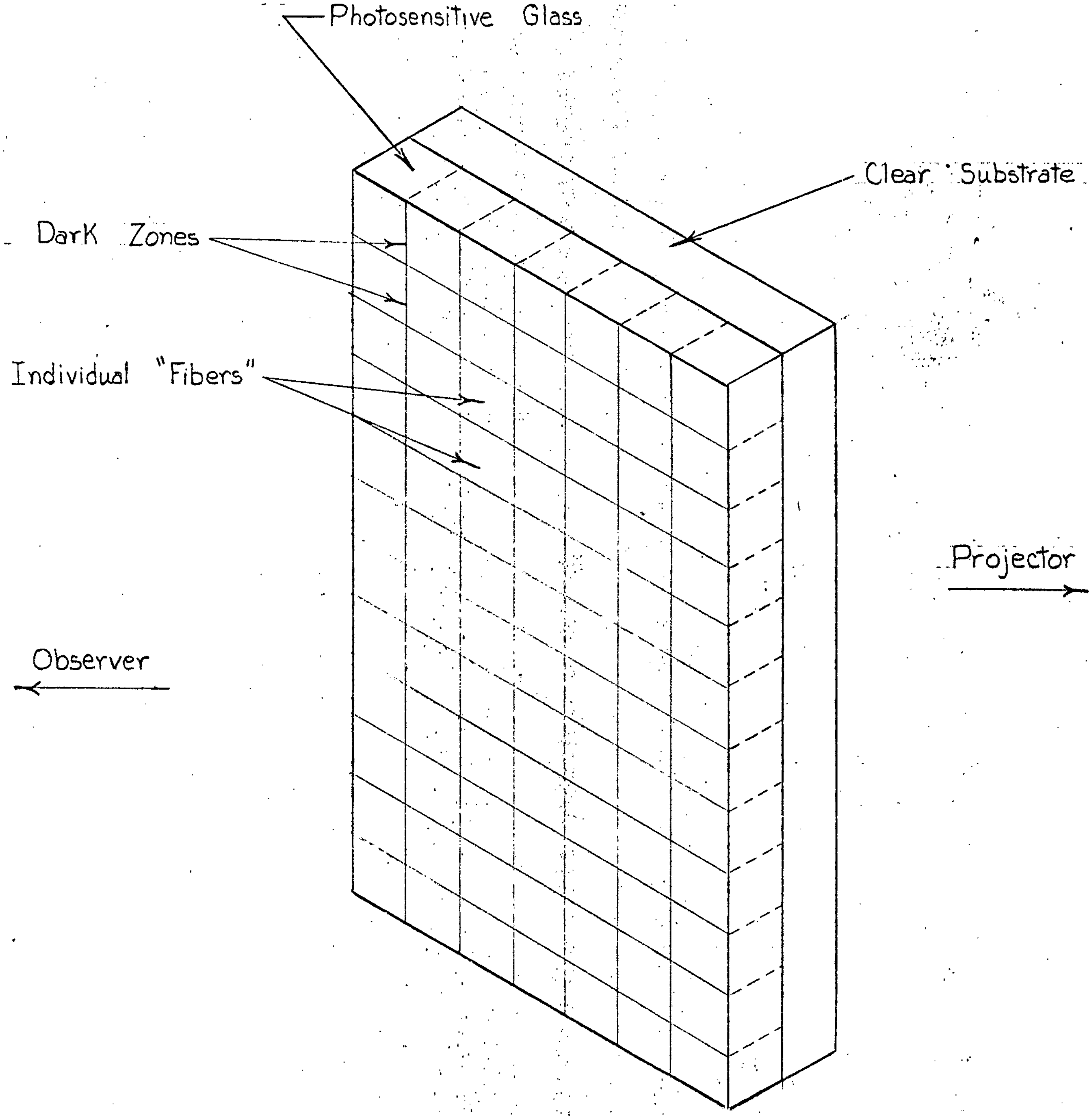


FIG. 6: ILLUSTRATION FOR PHOTOSENSITIVE GLASS

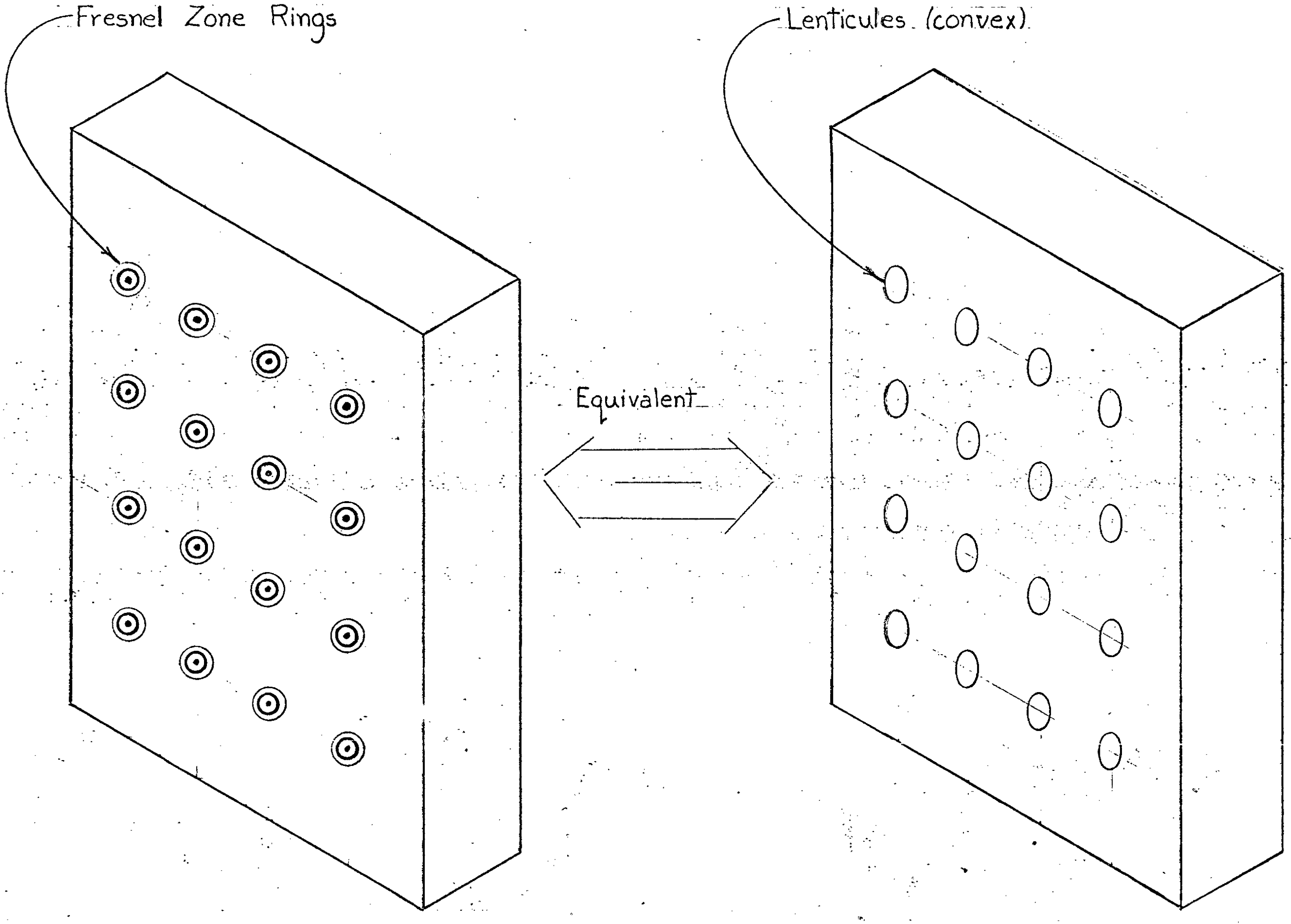


FIG. 7: PHOTOGRAPHICALLY CREATED FRESNEL ZONES

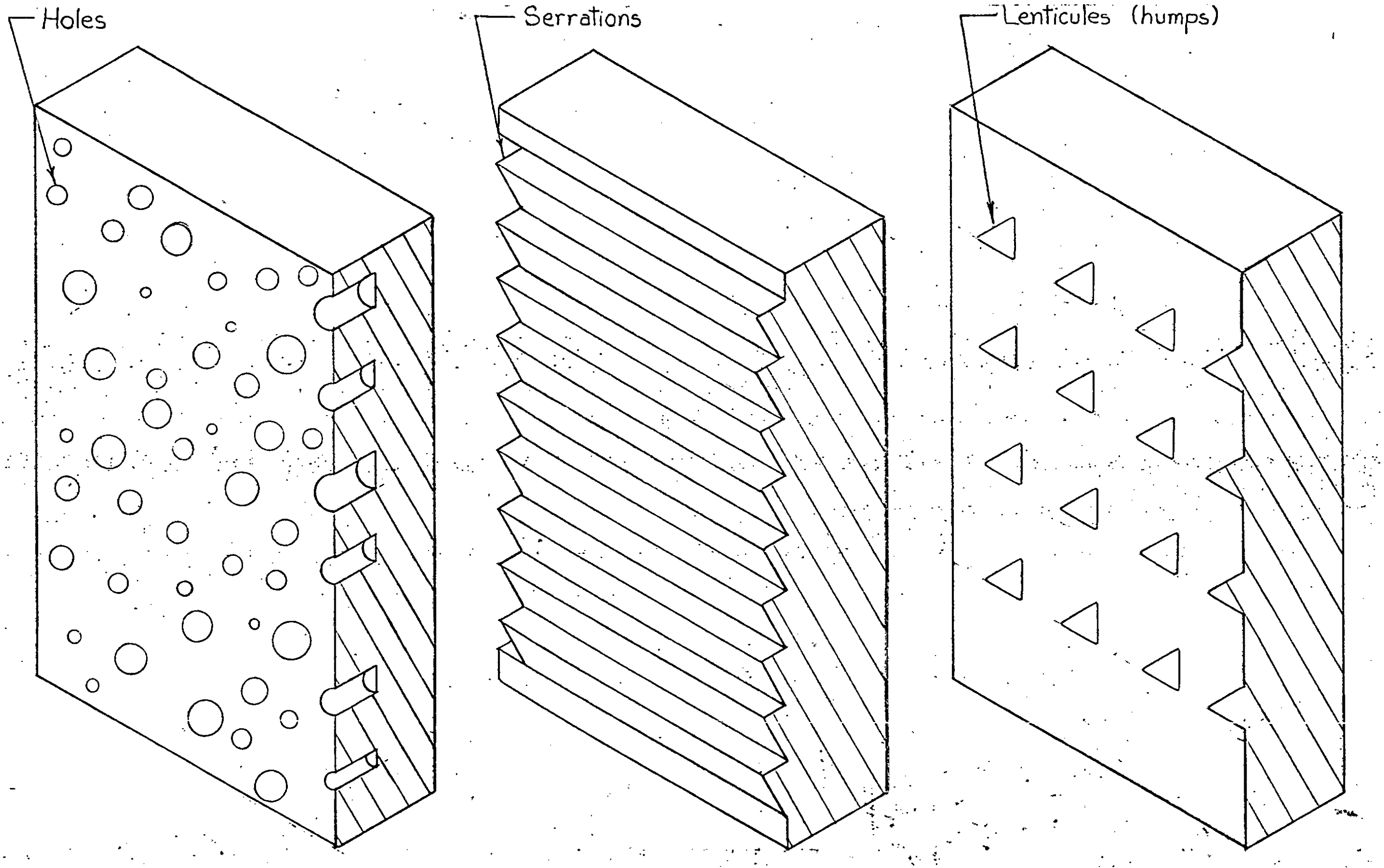


FIG. 8: VARIOUS POSSIBLE SHAPES OF FOTOFORM SCREENS

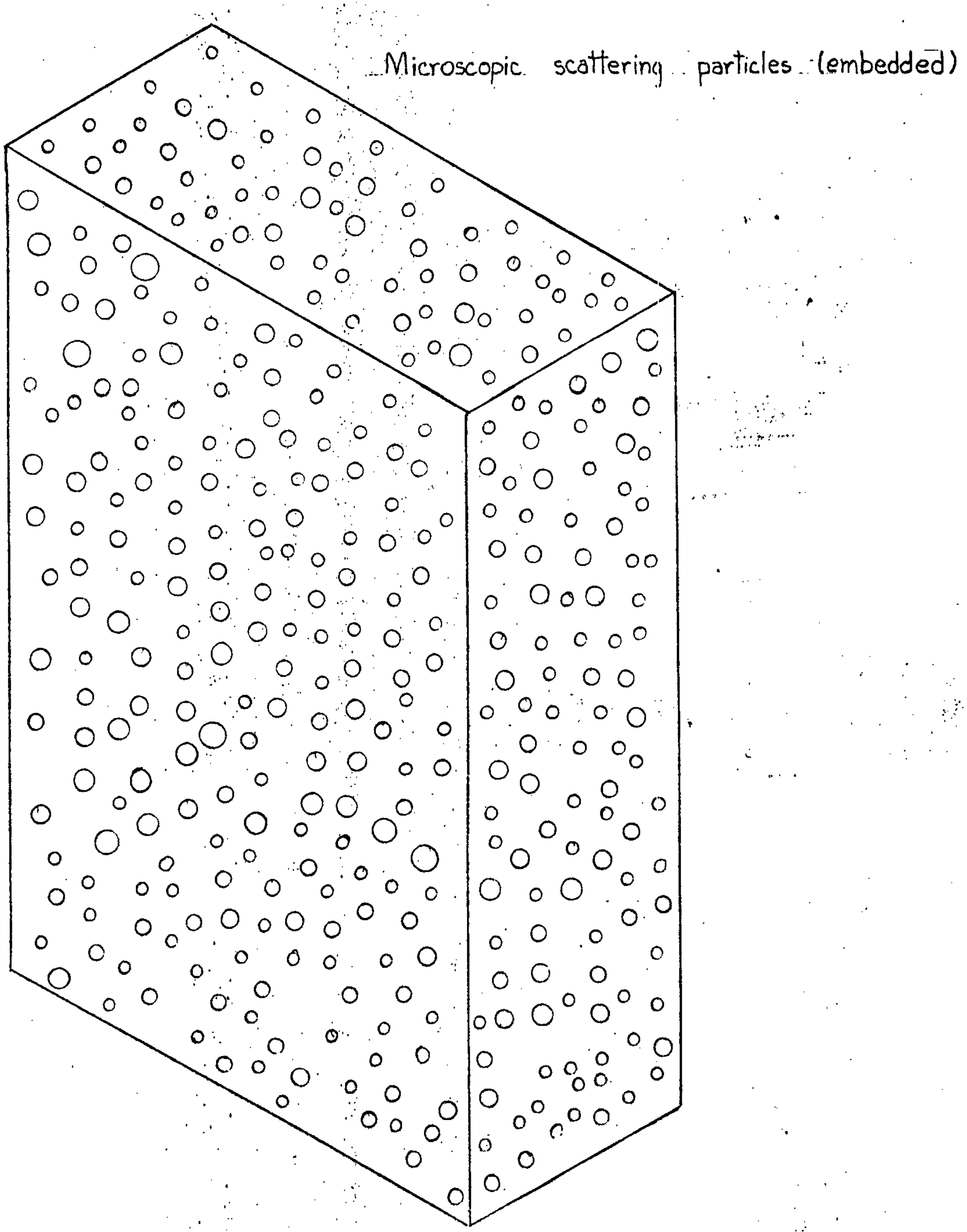


FIG.9 : HETEROGENEOUS SCREEN WITH SMALL SCATTERING ELEMENTS

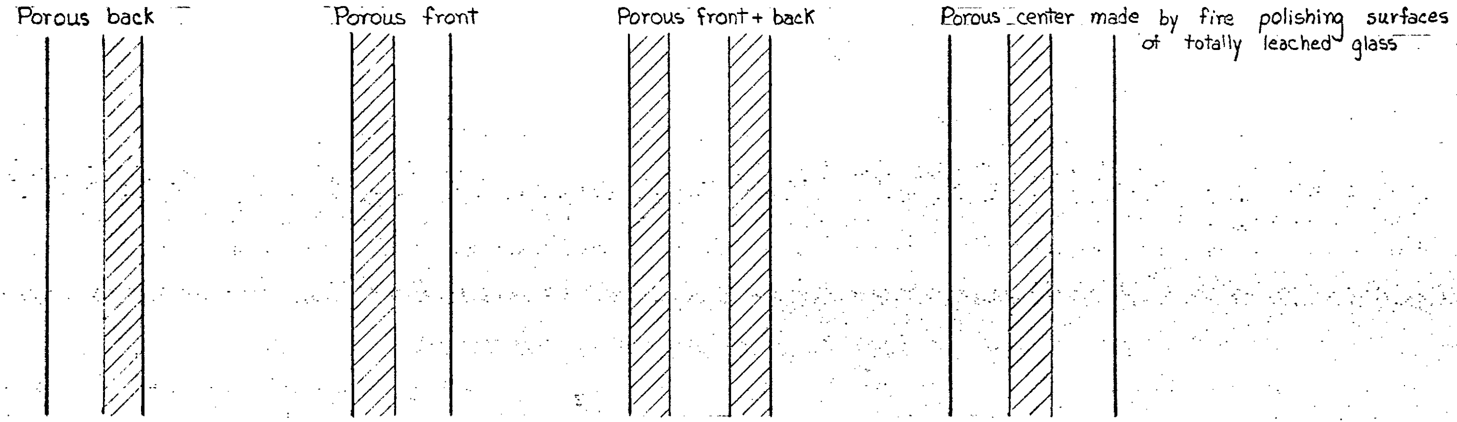


FIG. 10: EXAMPLES OF VARIOUS COMBINATIONS OF POROUS AND SOLID VYCOR

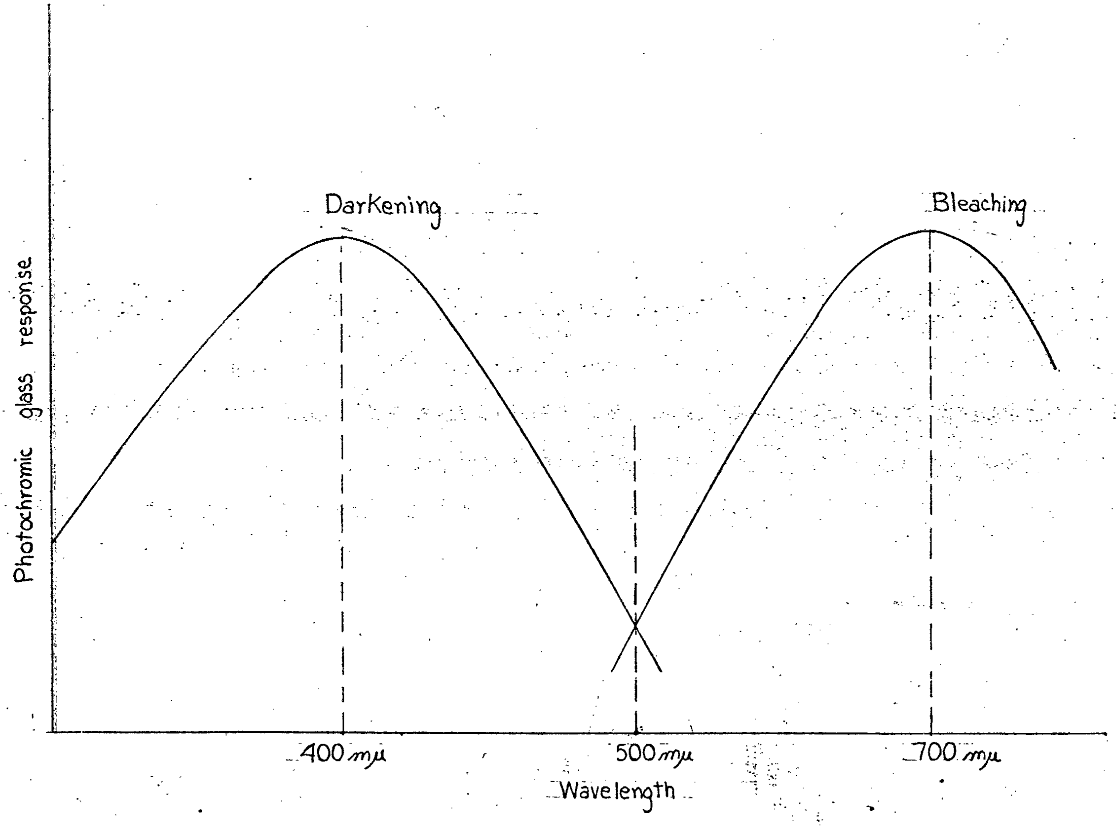


FIG 11 : DARKENING AND BLEACHING OF TYPICAL PHOTOCHROMIC GLASS AS A FUNCTION OF WAVELENGTH

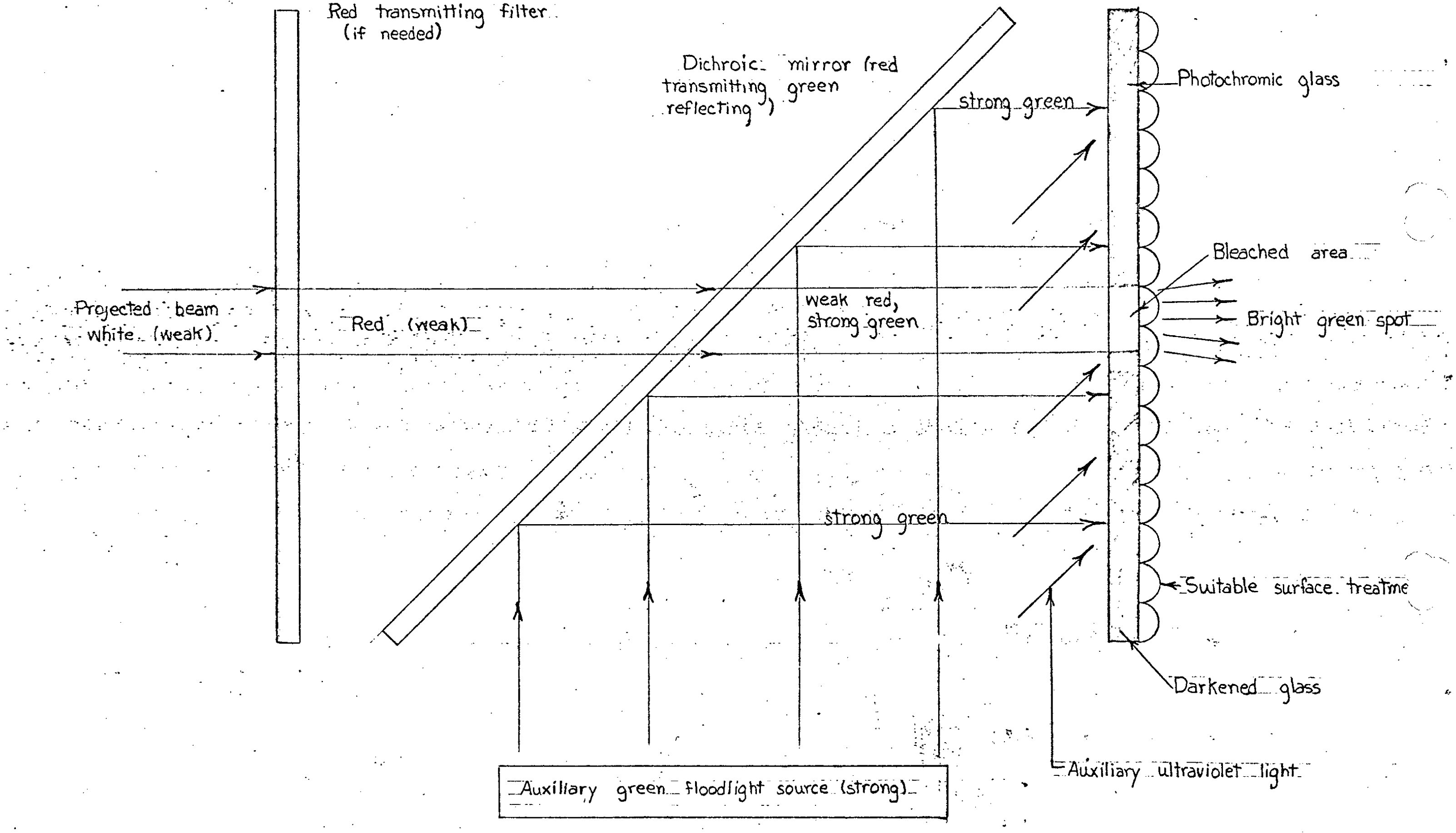


FIG. 12: A POSSIBLE ADAPTIVE PHOTOCHROMIC REAR-PROJECTION IMAGE INTENSIFIER (SCHEMATIC)