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A CATHODE RAY TUBE SUITABLE FOR VIEWING UNDER HIGH AMBIENT

Prepared by
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By Donald Amberger

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ACKNOWLEDGEMENTS

FOREWORD

This report summarizes the research and development accomplished during a program to investigate the feasibility of fabricating a cathode ray tube employing a re-emission technique, to provide very high contrast under high ambient light conditions. The work was performed, primarily by Mr. Donald Amberger, during the period from October, 1966 to March, 1967, for the National Aeronautics and Space Administration, Electronic Research Center, under contract Number NAS 12-97. The contract was administered by NASA-ERC with Mr. E. Hilborn acting as the technical Monitor.

The concept of high contrast displays, on which the program was based, originated in a Hartman-Huyck Systems Co. sponsored feasibility investigation resulting in a patent disclosure covering non-linear optical filters.

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Glossary

Symbol	Description
c	contrast
e	emitted intelligence
b	reflected background
$A_{//}$	incident electric field (parallel component to the plane of incidence)
$A_{\perp}$	incident electric field (perpendicular component to the plane of incidence)
$R_{//}$	reflected electric field (parallel component to the plane of incidence)
$R_{\perp}$	reflected electric field (perpendicular component to the plane of incidence)
$T_{//}$	transmitted electric field (parallel component to the plane of incidence)
$T_{\perp}$	transmitted electric field (perpendicular component to the plane of incidence)
n	index of refraction
θ_i	angle of incidence
θ_t	angle of (refraction) transmission
θ_r	angle of reflection
$\mathbf{R}_{//}$	reflectivity (polarization in the parallel direction)
$\mathbf{R}_{\perp}$	reflectivity (polarization in the perpendicular direction)
$\mathbf{T}_{//}$	transmissivity (polarization in the parallel direction)
$\mathbf{T}_{\perp}$	transmissivity (polarization in the perpendicular direction)
$J_{//}$	power density (parallel component to the plane of incidence)
$J_{\perp}$	power density (perpendicular component to the plane of incidence)

Glossary (continued)

Symbol	Description
θc	critical angle
$\propto$	ratio of the subtended cone to the sphere
h	Planck's constant (6.55×10^{-27} erg/sec)
c	Speed of light (3×10^{10} cm/sec)
E	energy
q	number (quantity)
γi	speed of incident photons
γo	speed of emitted photons
λ	wavelength
P	power
η	quantum efficiency
$S(\lambda)$	wavelength of incident radiation
d	thickness of ultra violet filter
D	diameter of spread spot
γ	ratio of d to thickness of filter to produce transmission (T)
T	transmission (output/input)
I	incident radiation
X	thickness of material
a	absorption (1-T)
σ	linear absorption coefficient
ϵ	epsilon (2.7183)
Z	atomic number
W	chemical atomic weight
No	Avogodro's number
ρ	mass density
C_{kl}	a transitional coefficient probability
Fl	foot lamberts

Glossary (continued)

Symbol	Description
μa	micro amperes
kv	kilo volts
mw	milli watts
V	electric field voltage/meter
M	magnetic field current/meter
L	luminous intensity
ω	solid angle
B	luminance

Abstract

A high contrast Cathode Ray Tube, employing non-reciprocal optical filtering techniques was developed.

The non-reciprocal filter design consists of a UV bandpass filter, a fluorescent film and a visible bandpass filter. All elements are transparent. The filter is between the observer and an ultra-violet emitting cathodoluminescent phosphor. Incident light (the observer's side) strikes the visible filter and is partially absorbed. The remaining ambient passes through the transparent fluorescent film and is absorbed by the UV filter. The two filter layers have no mutual bandpass. Return diffuse reflection or emission from the fluorescent film and any return reflection from the phosphor are therefore eliminated. Because of this feature, a cathode ray tube employing these principles maintains constant contrast and readability over a wide range of ambient illumination levels.

This program has concentrated on the problem of the elimination of diffuse reflection. Technology presently exists for reduction of specular reflection to low values through the application of interference filters.

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Introduction

The Cathode Ray Tube is currently the most widely used device for the display of complex information. The extension of its use in aerospace applications is limited by its failure to maintain readability under high ambient illumination levels.

Adequate readability may be achieved by increasing highlight brightness or by the control of contrast. Increased highlight brightness results in an increase of power requirements and reduced life which are undesirable.

The control of contrast as a means of achieving readability under high ambient illumination was the purpose of this program.

The methods described in this report show that a non-reciprocal filter can be used to achieve theoretically perfect contrast.

PROGRAM OUTLINE

The following tasks were established covering all phases of the program.

Task 1 — Develop a composite filter structure by investigating, analyzing, synthesizing, and testing UV-responsive fluorescent methods. The desired result is a filter that will transmit useful amounts of energy in the visible spectrum in one direction, and substantially absorb incident visible energy, without significant reflection, in the other direction.

Task 2 — Fabricate and test composite filters using UV emitting phosphor layers (Type P-16). Particular attention must be given to investigation of techniques, resulting in minimum degradation of image resolution.

Task 3 — Evaluate phosphor/filter composite screens and determine their suitability for use as display screens in CRT displays. Specific areas of evaluation are:

    a. Ability to perform under widely varying ambients.

    b. Ruggedness, reliability and life under the conditions of anticipated use.

Data will be developed from actual test in a sample CRT configuration and preliminary screening for fatigue of materials under simulated use.

Task 4 — Identify, by a literature search, cathodoluminescent materials which radiate energy at shorter wave lengths, and prove superior to P-16 phosphor in electron to UV photon conversion.

Task 5 — Evaluate selected fluorescent materials, determining their conversion efficiency.

Task 6   - Determine the effectiveness of previously selected fluorescent materials when used with P-16 phosphor and irradiated with shorter wavelength UV photons.

Task 7   - Develop optimum substrates for the fluorescent layer.

Task 8   - Develop optimum concentrations of fluorescent materials in the substrate.

Task 9   - Investigate the possible effects of different organic solvents on the brightness and hue of the fluorescent layer.

Task 10 - Specify appropriate filters, having no mutual bandpass, for use with the selected UV phosphor and fluorescent materials.

Task 11 - Fabricate, evaluate and deliver to ERC a cathode ray tube employing the results of the research.

Task 12 - Recommend areas for additional research based on the findings of Tasks 1 through 11.

All of the tasks outlined above were completed during the course of the program and are summarized in the technical report.

Tasks 1 through 3 consisted of initial trials and early assessments of the individual components.

After the initial acquisition of materials and equipment, a gross screening was set up for evaluation of various fluorescent samples with various binders. This phase was quite exhaustive, covering a multitude of known fluorescent compounds and a wide variety of plastic-solvent combinations. The results of these tests are tabulated in the Appendices to this report.

The best fluorescent materials were carefully evaluated to determine their absorption and emission characteristics. Based on this data, the passive visible filters and UV filters were selected for the best combination.

Various CRT envelopes with non-linear filters and removable faceplates were tested in a vacuum system. The ion gauge was kept within the 10^{-7} to 10^{-6} mm Hg range.

Under these conditions, the filters worked as predicted; that is, high contrast was achieved, even when the faceplate was illuminated with floodlamps approximating direct solar radiation intensity over the visible spectrum. At this point, only the specular reflections presented a contrast problem.

Various UV phosphors were tried with no one phosphor showing any outstanding performance.

Experimentation up to this point in time had been primarily devoted to the evaluation of organic fluorescent compounds in solid plastic solutions. It was anticipated that such materials could be employed successfully in a CRT environment, since an effective seal would be present between the fluorescent layer and the gun/vacuum environment, in the form of the solid UV bandpass filter, which is also the supporting structure for the cathodoluminescent phosphor. However, it was discovered that even though the fluorescent plastics did discontinue outgassing, a cold-pumped tube had extremely short life because of surface contaminants which are picked up at room temperature. CRT industry standards require a bake temperature of 410°C for thorough outgassing of the envelope and long life. The plastics used decomposed at this temperature and after several experiments, it was determined that there is no practical way of protecting the plastic from exposure to this temperature. The obvious conclusion is that organics cannot be usefully employed in a CRT. The solution is to use inorganic materials based on glass matrices.

There are new problems introduced with this method. Among the most outstanding is resolution, which is discussed at length in this report. However, initial experiments with the demountable apparatus showed that the fluorescent glass chosen performed nearly as well as the best organic system, if precautions were taken in matching the absorption edge with the cathodoluminescence spectrum.

A sealed off tube was fabricated in accordance with good industrial practice, using glass structures. The unit was then tested.

The performance was exceptionally good. The image, even under direct outdoor sunlight, was distinct and clear with high contrast.

TECHNICAL DISCUSSION

General Considerations - Visual images are perceived
as the result of differences in either color or intensity
of light reaching the observer's eye from each element of
the object or display. These differences, which we term
contrast, are the principal factors contributing to visi-
bility of a display. For high visibility, it is essential
that the contrast of the display be subject to control
solely by the operator and not subject to "wash out" by
ambient illumination.

The high ambient illumination conditions encountered
in an aerospace environment seriously degrade the contrast
of existing displays. This is caused by specular and dif-
fuse reflections from the display surface. Reduction of
these reflections is the first task in obtaining useful
contrast levels. Contrast is not the only image parameter
which must be considered in determining the visibility of
a cockpit display. Brightness must also be taken into
consideration, because of the light adaptation character-
istics of the human eye. If a pilot's eyes are adapted to
a bright sky background of several thousand foot lamberts,
a display having high contrast will be difficult to ob-
serve if the display brightness is below the threshold of
the daylight-adapted eye. Thus both brightness and
contrast are essential for high visibility.

The approach investigated is a unique method, simple
both in theory and actual operation.

The definition of contrast C, (Ref. 1) is similar to
that of signal to noise ratios when dealing with electrical
systems. Contrast is then a figure of merit by which an
observer can distinguish an image over the background.

Therefore, an image source

$$C = \frac{\text{Emitted Intelligence}}{\text{Emitted intelligence + reflected background}}$$

(Ref. 1) AFFDL-TR-66-6

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or more concisely,

$$C = \frac{e/b}{e/b + 1}$$

<div align="right">Eq. (1)</div>

which resembles the probability of correct data in receiver theory.

To achieve high contrast, either the emitted energy must be increased or the reflected background decreased or both.

Reference to Figure 1 illustrates the principle involved. If an observer looks at a visible filter cascaded with a UV, no reflected background will be seen except those specular in nature. The composite filter will appear black. The filter does not pass or generate visible radiation. An object placed behind the filter will not be seen. The reduction of reflected background has been accomplished. But, the emitted or intelligence has also been reduced. This filter is still linear and reciprocal.

By inserting a thin transparent fluorescent film as shown by Figure 1, the composite will remain black, but the image will become clear. The object or image is formed on the UV image plane and via Stokes' conversion principle, the fluorescent film becomes stimulated and converts the image from UV to visible radiation.

Background radiation is not reflected to the observer but absorbed by the filter and the image is radiated to the observer with the main loss due to the fluorescent conversion. A primary requirement is that the filter elements themselves introduce no diffuse reflections in the system; i.e., they must be transparent and possess a minimum of optical scattering.

The composite is non-reciprocal. Radiation passes slightly attenuated in one direction and completely absorbed in the other direction. From this simple model, contrast levels approaching 1.0 can be obtained in any ambient condition.
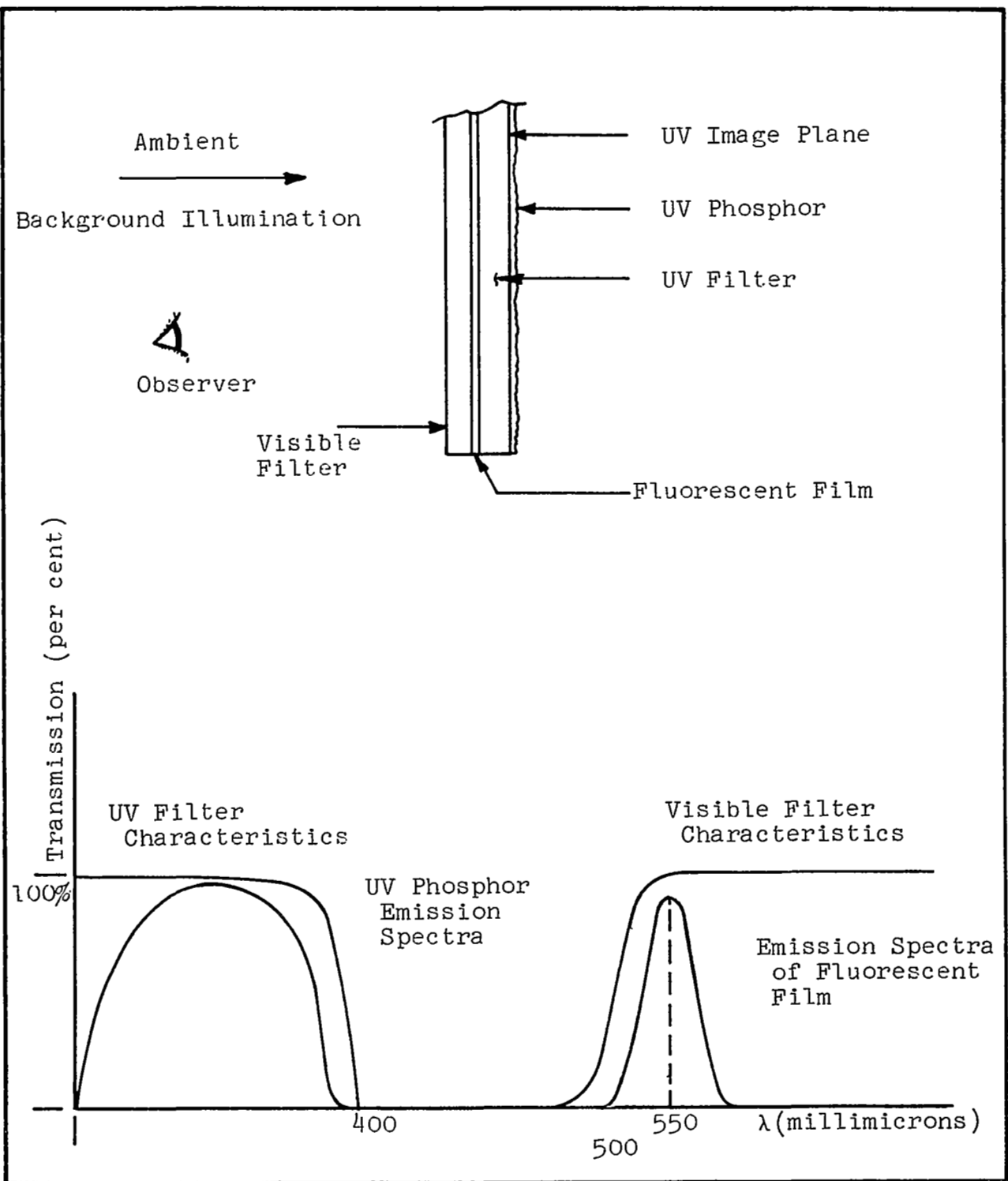
Figure 1.   Non-Reciprocal Filter

Theoretical Calculations for the Filter

The actual calculations of contrast of the filter will be made assuming the observer is in broad daylight.

Reflected Ambient - A worse case of illumination shows an intensity density of 150 mw/cm²/micron at 555 millimicrons or 102,000 Lumens/ft²/micron, due to direct sunlight. The sensed total intensity for the standard observer is then this value of intensity times the response of the eye integrated over the limits of the response of the eye. The net sensed intensity is then 16,000 lumens/ft². The intensity of radiation in the visible spectrum assuming approximately uniform distribution is about 30,000 ft.-candles.

A piece of ground glass which diffusely reflects 18% (Ref. 2) of the incident radiation would in this case reflect 30,000 ft.-candles x 0.18 = 5,400 ft.-candles.

Based on contrast, an image on this ground glass would have to be 5,400 ft.-candles in order to be "reasonably" visible (0.5 contrast). Based on data as outlined in Appendix II, it has been determined that composite filters reflect approximately 1/20 or less of the incident radiation than does ground glass. Experiments with improved reflections can be reduced to 1/100 of the incident signals.

An image of only 54 ft.-candles is now required to be clearly visible and distinguishable.

Expected Contrast in a CRT - The tube used throughout the research was a 5 CK type. Using this tube with a 5" diameter face and a 20 KV anode rated at 100 micro amps the electrical excitation is 2 watts.

The phosphor used is equivalent to P-16 which has an absolute efficiency of .049 watts radiated/watt excitation or a quantum yield of 0.015 photons/electron volt (Ref. 3). The electrical power density input is 14.7 watts/ft² or 10,000 lumens/ft². The aluminized phosphor then converts this to 490 lumen/ft² or 490 ft.-candles of net optical radiation. As will be shown in the section titled

(Ref. 2) Moon, "The Scientific Basis of Illuminating Engineering" p. 253, Dover Publications, Inc.
(Ref. 3) ITT response characteristics; Response of JEDEC phosphors.

"Conversion Losses", the net resultant conversion of the P-16 UV emission to visible fluorescent radiation is a minimum of 10%. Therefore, the visible optical radiation at the face of the tube is 49 ft.-candles.

The contrast (ignoring specular reflections due to index of refraction mismatch) is then:

$$C = \frac{Emitted}{Emitted + Reflected} \qquad\qquad Eq. \ (2)$$

$$C = \frac{49}{49 + 54} \ x \ 100$$

$$C = 47.5\%$$

Therefore, a comfortable viewing level (100 ft.-candles is usually accepted as a maximum intensity for comfort) is available for variations in ambient from complete darkness to bright sunlight. Detailed results are given in the section titled Results.

Losses due to trapping of emitted radiation - In addition to the photon conversion efficiencies, as previously mentioned, an additional loss mechanism exists due to index of refraction mismatch.

Physical observation of a fluorescing layer of dye shows very strong emission at the edge of the layer regardless of where the dye is stimulated. It is thus apparent from this standpoint that the stimulated color centers are radiating spherically and that total internal reflection exists for certain critical angles of emission. The following analysis assumes in the worst case that these internal reflection losses are not ameliorated by the use of anti-reflection coatings.

The model used for this computation is shown in Figure 2. Assuming that the fluorescent layer has been stimulated, the following questions arise. How much of the stimulated emission enters region 2 or the viewing area? What is the nature of the resultant radiation pattern?

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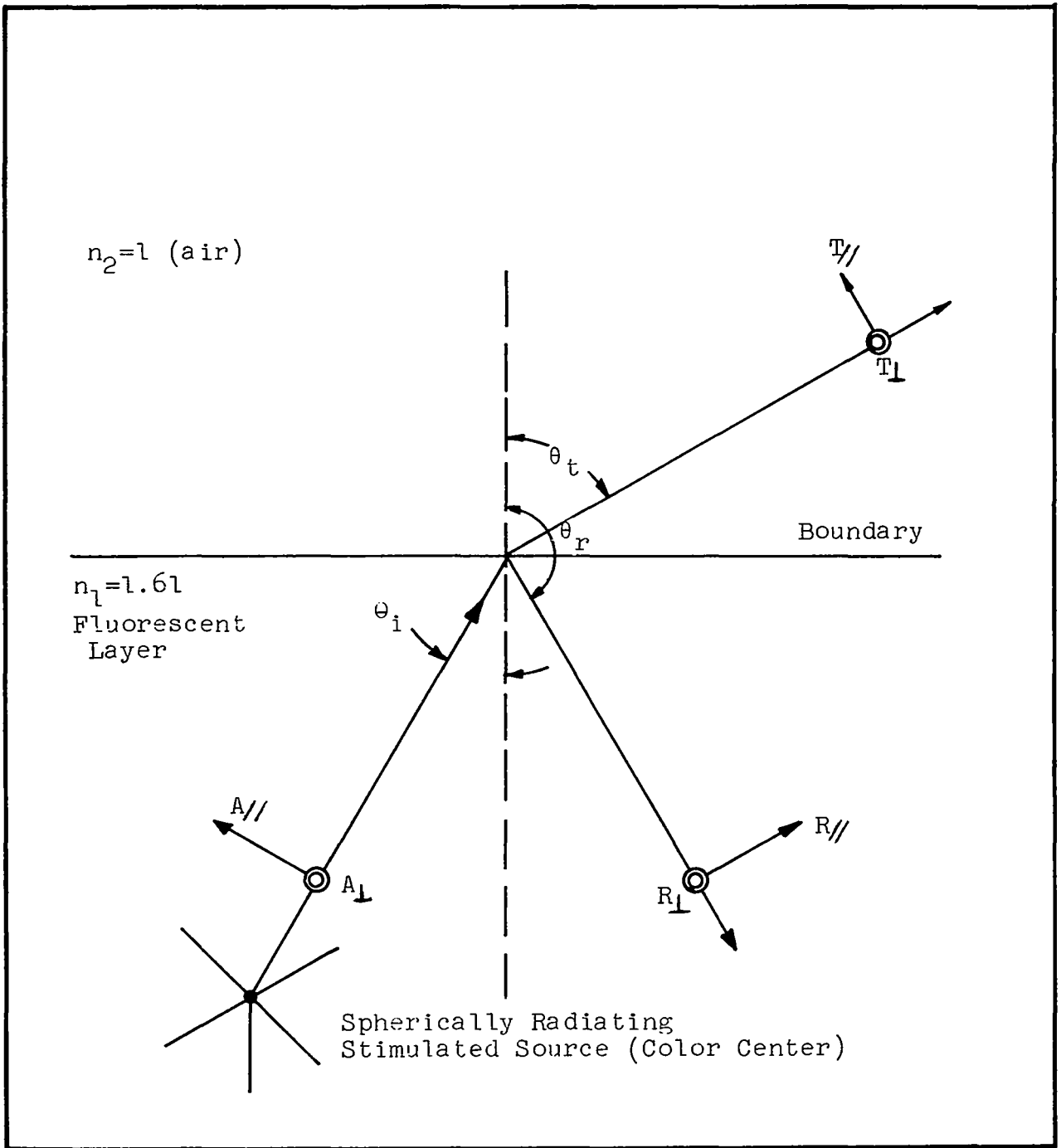
Figure 2.   Fresnel Diffraction Model

The problem is solved by utilizing the Fresnel Formula (Ref. 4). The vectors A, R and T represent the incident, reflected and transmitted electric fields. By solving the equations as outlined it is determined that:

$$T_{//} = \frac{2n_1 \, \cos\theta_i \, A_{//}}{n_2 \, \cos\theta_i + n_1 \, \cos\theta_t} \qquad \text{Eq. (3)}$$

$$T_{\perp} = \frac{2n_1 \, \cos\theta_i \, A_{\perp}}{n_1 \, \cos\theta_i + n_2 \, \cos\theta_t} \qquad \text{Eq. (4)}$$

and that

$$R_{//} = \frac{n_2 \, \cos\theta_i - n_1 \, \cos\theta_t}{n_2 \, \cos\theta_i + n_1 \, \cos\theta_t} \quad A_{//} \qquad \text{Eq. (5)}$$

$$R_{\perp} = \frac{n_1 \, \cos\theta_i - n_2 \, \cos\theta_t}{n_1 \, \cos\theta_i + n_2 \, \cos\theta_t} \quad A_{\perp} \qquad \text{Eq. (6)}$$

Figure 3 shows the plots of the various components of electric field, and their respective polarization. Figure 4 is a plot of the transmissivity and reflectivity. In the situation we are concerned with, i.e., trapping. Figure 5 shows the power density output from the surface as a function of θ_t. It is observed that θ_t of 90° coincides with a $\theta_i = 39°$, and that the components of J are reasonably flat over the range of θ_t, employing an isotropic source. Therefore, the power escaping can be assumed to be uniform over the exit cone, and the net power output per input is about 10% for the case cited.

Since the curves show a fairly uniform viewing power density, the net radiated power can be approximately computed by knowing the solid angle of emission or the critical angle. The cone into which the point source radiates is shown in Figure 6 and θ_i represents the critical angle. The area of the subtended cone is

$$A_{cone} = 4\pi \, r^2 \, \sin^2 \theta/2 \qquad \text{Eq. (7)}$$

(Ref. 4) Born and Wolf: Principles of Optics, p. 40, Pergamon Press
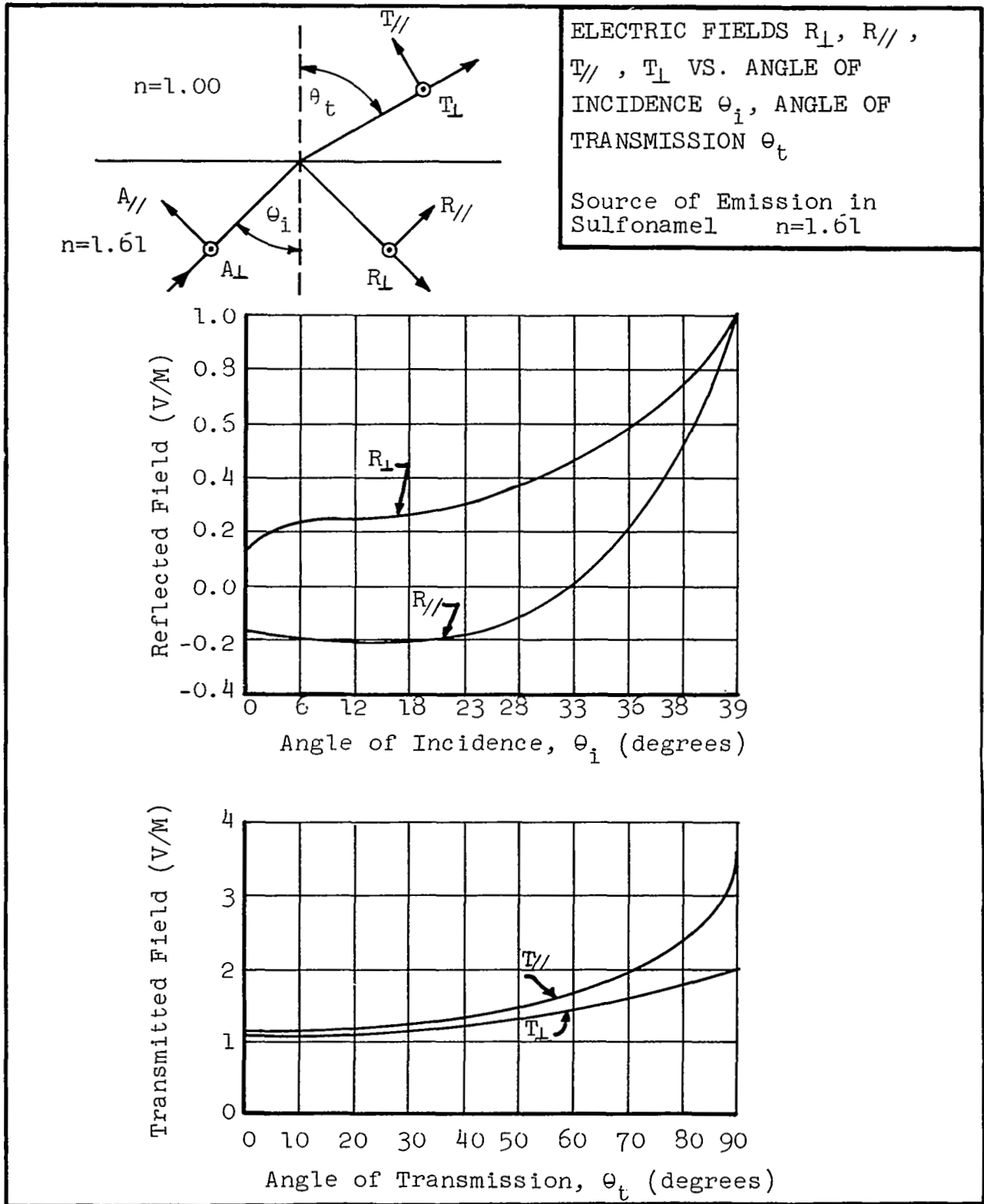
Figure 3.   Electric Fields VS. ∠Incidence and ∠Transmission
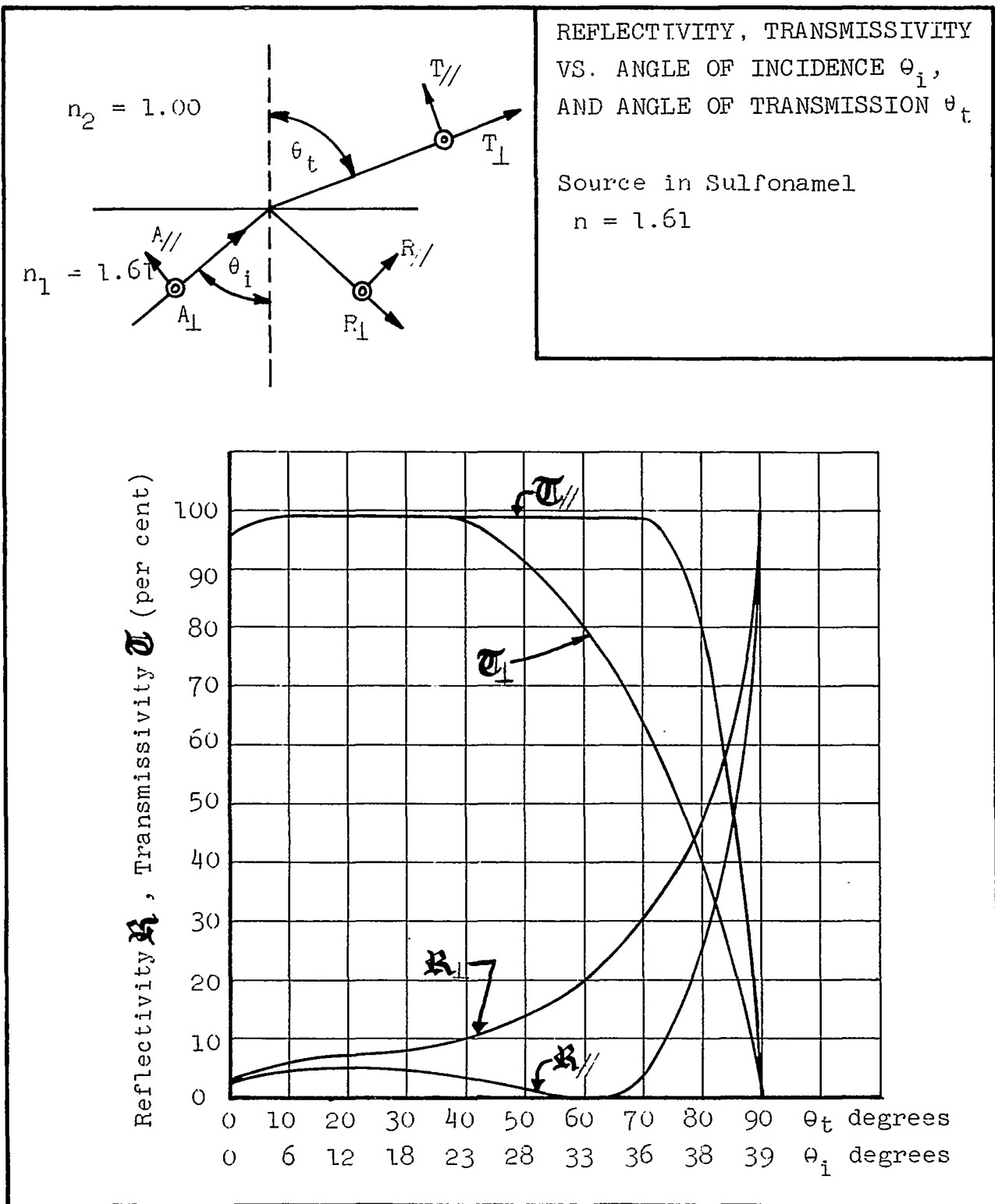
Figure 4.   Reflectivity, Transmissivity VS.
∠Incidence and ∠Transmission

Incremental Measuring Volume
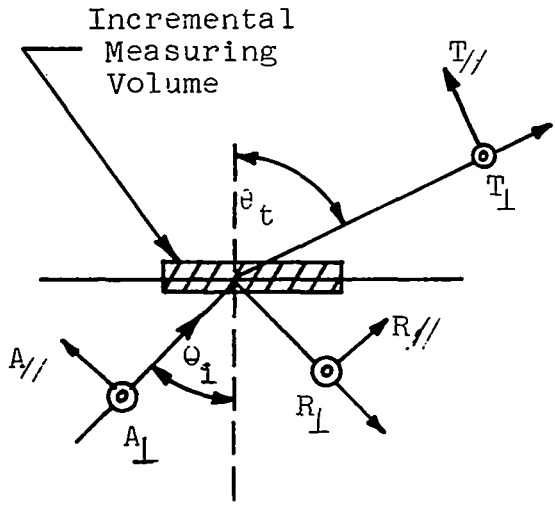
POWER DENSITY VS. ANGLE OF TRANSMISSION θ_t AT SURFACE.

Source of Emission in Sulfonamel , n = 1.61

Reference: Born & Wolf p. 41
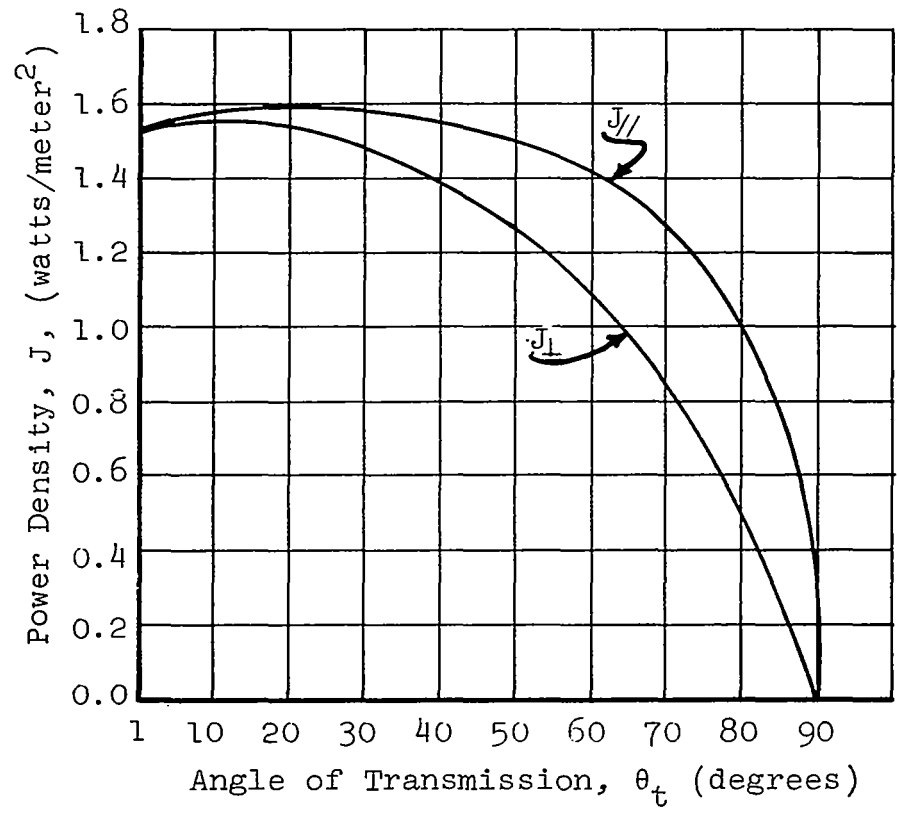
Figure 5.   Power Density VS. ∠Transmission at Surface

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and the ratio, α, of the subtended cone to the sphere is

$$\alpha = Sin^2 \, \theta/2 \qquad\qquad Eq. \ (8)$$

For an index of refraction of 1.61 for the source, a critical angle of $\theta_c = 38.4°$ is produced.
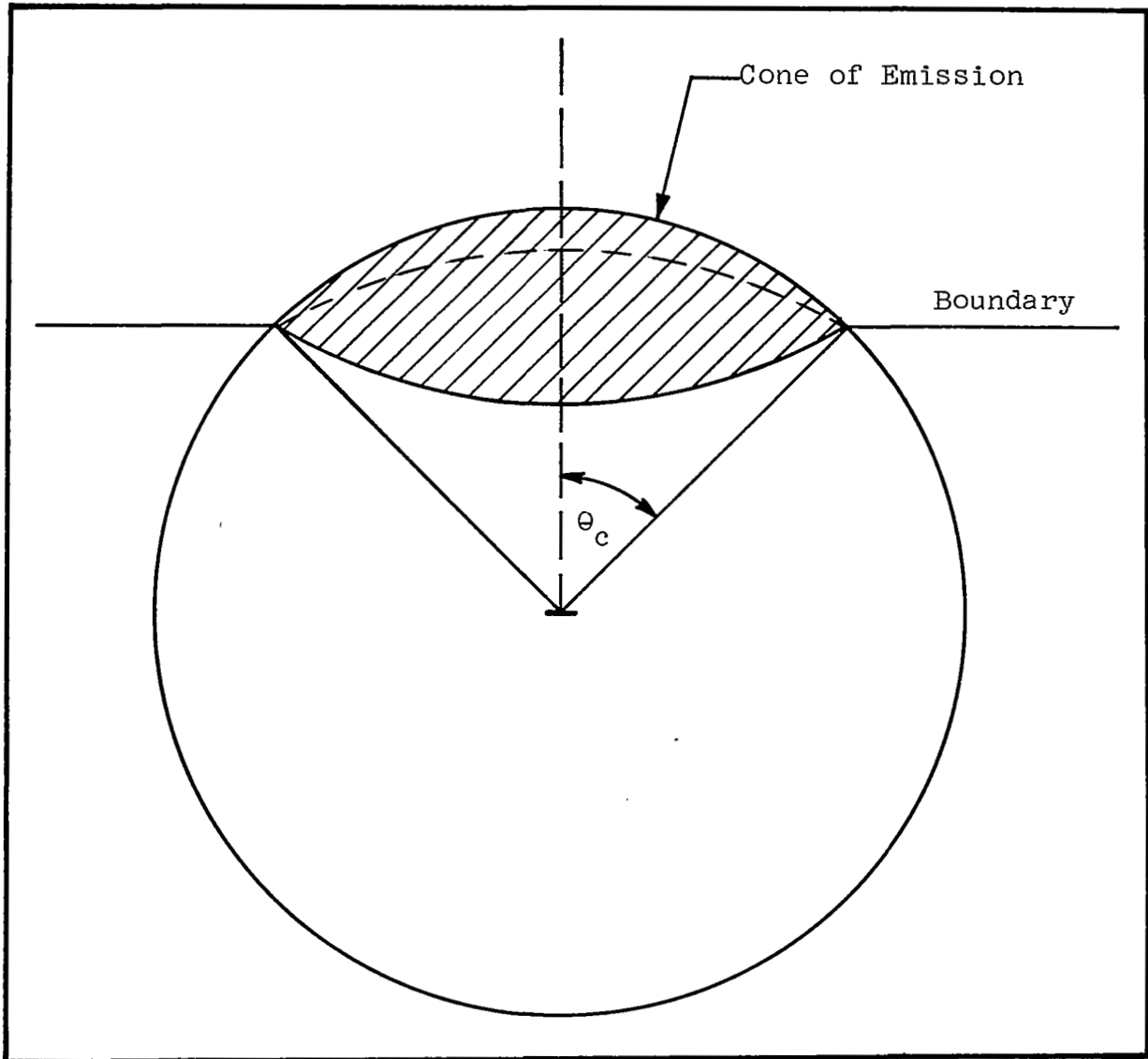
Figure 6.   Cone of Emission Model

Consequently, the output power from a source which radiates in an exit cone of 76.80° is 10.6% of the power of that source. The rest of the power is trapped.

It is noted from the curves that the output is not restricted to any particular viewing angle, but the pattern is generally uniform over a 140° x 140° field of observation.

Conversion losses - The major factors in determining the visible output quality are:

a)   conversion efficiency of fluorescent material

b)   "trapping" of radiation

c)   visible filter characteristics

d)   phosphors used.

Items (c) and (d) will be presented in the section titled "Passive Filters, Phosphors and Associated Research."

Conversion efficiency of fluorescent materials - It is known that numerous organic dyes exist which have quantum conversion efficiencies of between 50% to 100%. The most commonly known organics are:

Agent	Reported Quantum Conversion Efficiency
Boric Acid + phenathrene activator	100% (Ref. 5)
Salicylic Acid	100% (Ref. 6)
Benzene + anthracene activator	100% (Ref. 5)
Anthracene + pentacene activator	90-100% (Ref. 5)
Plastic + benzene ring dyes or salts	100% (Ref. 5)
Uranine + H_2O	70% (Ref. 7)
Rubrene + Hexane	100% (Ref. 7)

(Ref. 5)   J. DeMent, Fluorochemistry, Chemical Publishing Co., N. Y. 11945

(Ref. 6)   Allison, et al, J. Optical Society Am. pp. 54, 747, 1964

(Ref. 7)   Pringsheim & Vogel, Luminescence of Liquids and Solids, Interscience, New York 1955

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By experiment, it was determined that dyes obtained from the Switzer Co. have equivalent quantum efficiencies and possess very low optical diffusion. If one assumes that a practical quantum efficiency of 75% can be reproduced, the model predictions will be more conservative.

Various glasses were investigated and some quantum efficiencies were found to be as high as possibly 60% to 80% for uranium oxide doped glass. (Ref. 8)

Stokes' law states that if an incident photon whose energy is $h\gamma_i$, strikes a fluorescent structure, the photon will re-emit with an energy of $h\gamma_o$, where $\gamma_i > \gamma_o$, and the absorbed energy is $h(\gamma_i - \gamma_o)$. γ_o is usually fixed for a material and to obtain fluorescence, $\gamma_i > \gamma_o$ must be at least satisfied.

If the fluorescent material is stimulated by a photon whose energy is $E_i = h\gamma_i$, the net input energy $E_i(q)$ for q photons is

$$E_i(q) = qh\gamma_i = \frac{q_i hc}{\lambda_i} \qquad \text{Eq. (9)}$$

Energy input flow or power is then

$$P_i = \frac{dE_i(q)}{dt} = \frac{dq_i}{dt} \frac{hc}{\lambda_i} \qquad \text{Eq. (10)}$$

The emitted number of photons are q_o

where $q_o = \eta \, q_i$

where η = the quantum efficiency

Energy output is then

$$E_o = \eta \, q_i \, \frac{hc}{\lambda_o} \qquad \text{Eq. (11)}$$

(Ref. 8)   Private Communication: Dr. R. F. Reade, Corning Glass Co., New York

and the output power is

$$P_o = \frac{dE_o}{dt} = \frac{dq_i}{dt}\left(\eta\,\frac{hc}{\lambda_o}\right)$$

Since

$$\frac{dq_i}{dt} = \frac{P_i\lambda_i}{hc}$$

$$P_o = \frac{P_i\lambda_i}{hc}\frac{\eta\,hc}{\lambda_o}$$

If

$$\lambda_o = \lambda_i + \Delta\lambda$$

where $\Delta\lambda$ is the wavelength difference between the input and output

$$P_o = \frac{\lambda_i P_i}{\lambda_i + \Delta\lambda} \qquad\qquad \text{Eq. (12)}$$

So the overall power efficiency is then

$$\text{Eff} = \frac{P_o}{P_i} = \eta\left(1 - \frac{\Delta\lambda}{\lambda_o}\right) \qquad\qquad \text{Eq. (13)}$$

The power conversion efficiency for any material must be less than the quantum efficiency by the factor

$$\left(1 - \frac{\Delta\lambda}{\lambda_o}\right)$$

For example, uranium oxide glass emits at 550 mμ and is stimulated at 330 mμ. The quantum efficiency is 80%, and the overall power conversion is 48%.

Filter Requirements

The UV filter and the visible filter have no common pass band. As shown previously, the concept of the non-reciprocal filter is that visible or ambient radiation travels into the filter and is completely absorbed. Nothing remains to be reflected from the diffuse phosphor back to the observer. Due to non-ideal properties, the filters selected exhibited certain properties in the stop band, which produced ambient reflections from the phosphor back to the observer.

Two filters defined by T_{UV} and T_{VIS} transmission functions, as shown in Figure 7 are subjected to incident radiation whose spectrum is $S(\lambda)$. It is further assumed that the phosphor diffusely reflects 50% of the incident. The incident signal on the phosphor is therefore $T_{UV}(\lambda)\ S(\lambda)$ and the reflected signal to the observer $S_o(\lambda)$.

$$S_o(\lambda) = [\ T_{UV}(\lambda)\ T_{VIS}\ (\lambda)]^2\ S\ (\lambda)/2 \qquad \text{Eq. (14)}$$

It can be seen that $S(\lambda)$ is attenuated as though it passed through the filters twice. As an example, if in the stop bands $T_{UV} = T_{VIS} = 0.01$ an overall attenuation of 10^8 results. Thus, any pair of filters with reasonable attenuation in their "exclusive" band will suffice.

UV filter requirements - Based on a search of available commercial UV filters of the non-interference type made from glass, it was determined that basically only one class exists. depending primarily on the doping or coloring level. Typical filters are the Corning (Ref. 9) series as shown in Figure 8.

(Ref. 9)   Anon: Glass Color Filters, Catalog CF-3, Corning Glassworks.
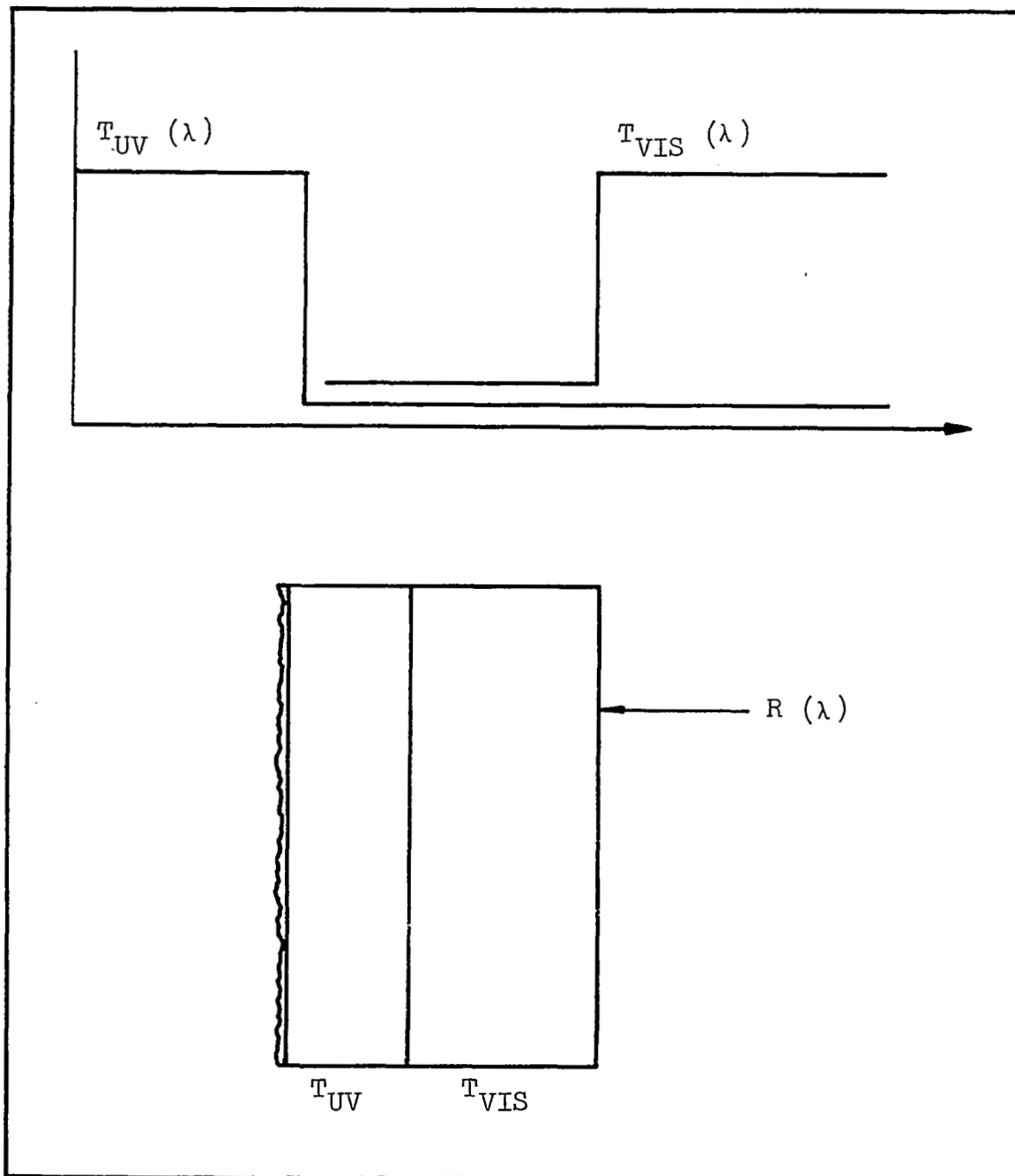
Figure 7.   Ideal Filter Transmission
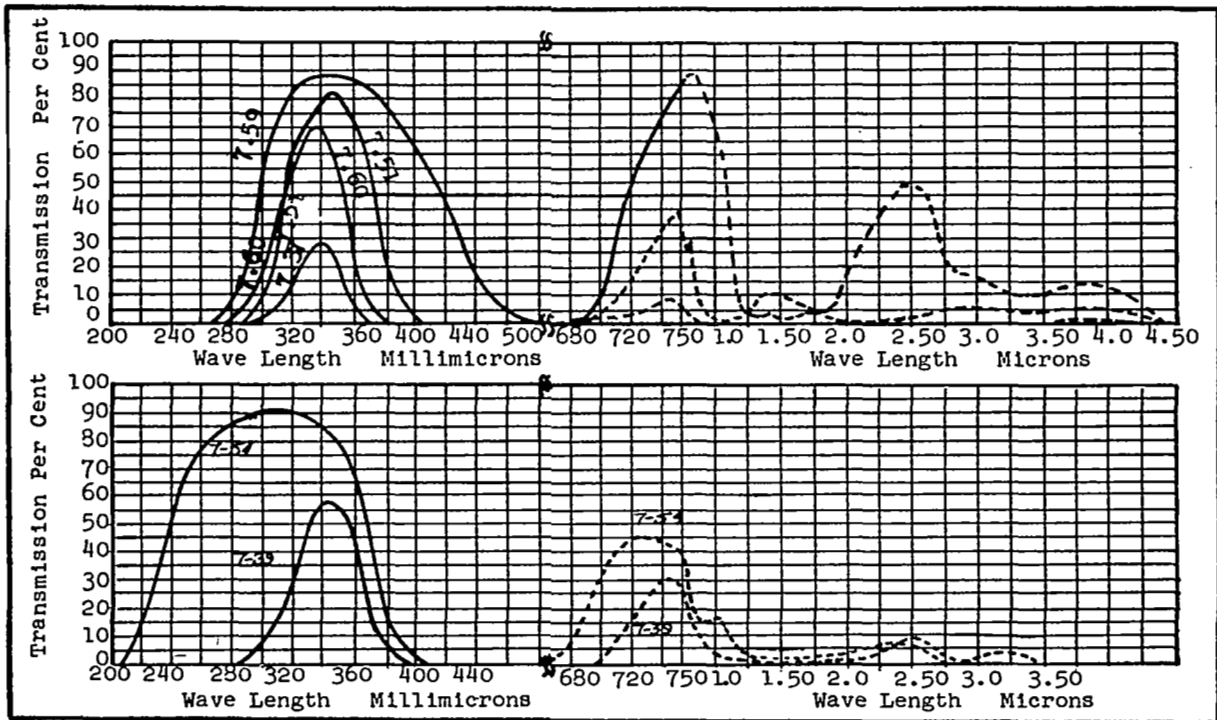
Figure 8.   UV Filter Data

Each filter has the undesirable feature of passing long wavelength red as well as UV. This is one reason why filtered UV sources, such as lamps, generally have a reddish tinge.

In our application, a focused point on the phosphor radiates through the thickness dimension of the UV filter and is spread. See Figure 9. The spread in spot size can be calculated, knowing the filter thickness d and the index of refraction. Using Snells' law,

$$n_1 \, Sin \, \theta_1 = n_2 \, Sin \, \theta_2 \qquad\qquad Eq. \ (15)$$

The maximum deviation of a ray, θ_2, in the filter is when $\theta_1 = 90°$.

Of course, the intensity is relatively low since (Ref. 10) the reflections become quite high, for grazing angles larger than the polarizing angle.
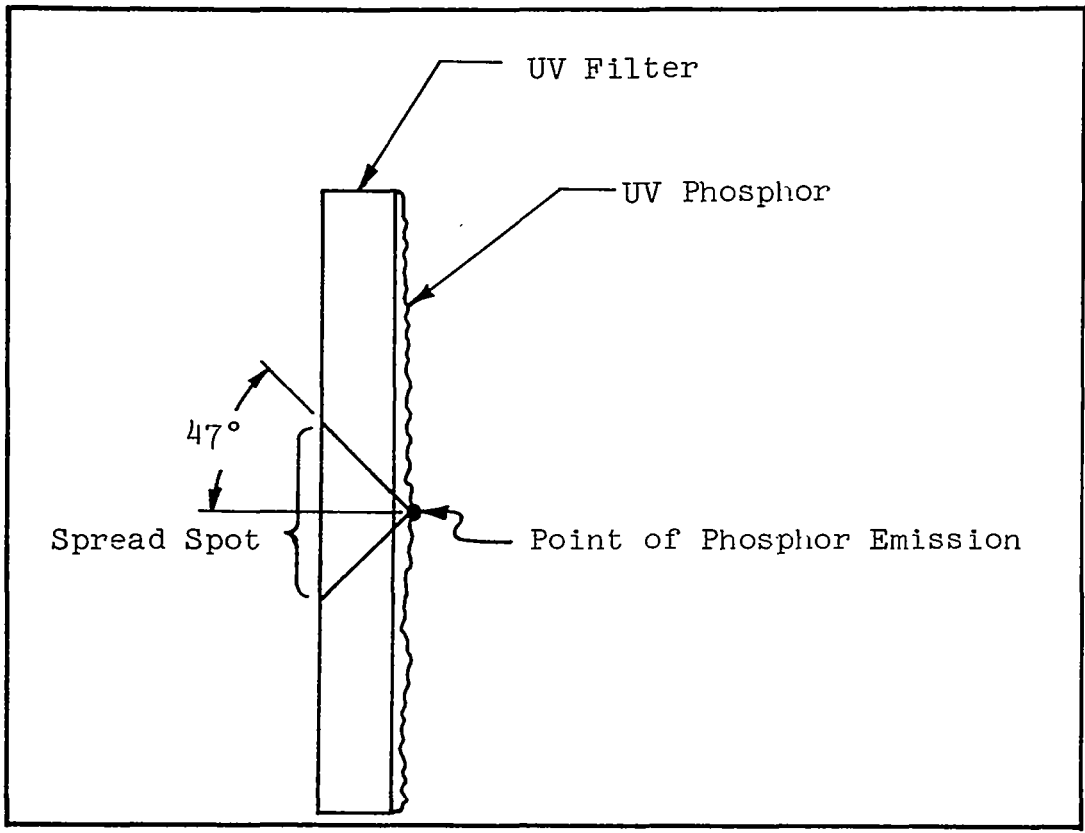
Figure 9.   Spreading Image Model

The point spread to a spot, as shown, has a size depending on the value d as

$$D = \text{spot diameter} = 2d \tan 47°$$

The normal ray for glass with an index of refraction of 1.47 is more intense than the ray at 47°. The distribution of intensity of the spot is not uniform. Where the total source reflectance is 50% (1/2 power point) the angle $\theta_1 \cong 80°$ and $\theta_2 \cong 45°$.

If a resolution of 100 lines/inch is chosen, D = .01" and

$$d = \frac{D}{2} \qquad \frac{1}{\tan 45°} = \frac{.01}{2 \times 1} = .005"$$

or

$$d = 0.127 \text{ mm}$$

(Ref. 10)   Jenkins & White, Fundamentals of Optics, p. 511, McGraw Hill Book Company Inc.

The transmission curves are significantly altered from the curves shown for filter 7-39, which are d = 5 mm. Using the same coloring, but making d = 0.20 mm, will produce a new transmission $T_N = T_o{}^r$ where r = ratio of d to thickness of filter to produce transmission T_o.

Filters used during this research effort were type 7-54 and type 7-39, lapped down to 0.5 mm.

Figures 10 and 11 illustrate the principle of using standard filters lapped down to 0.5 mm.
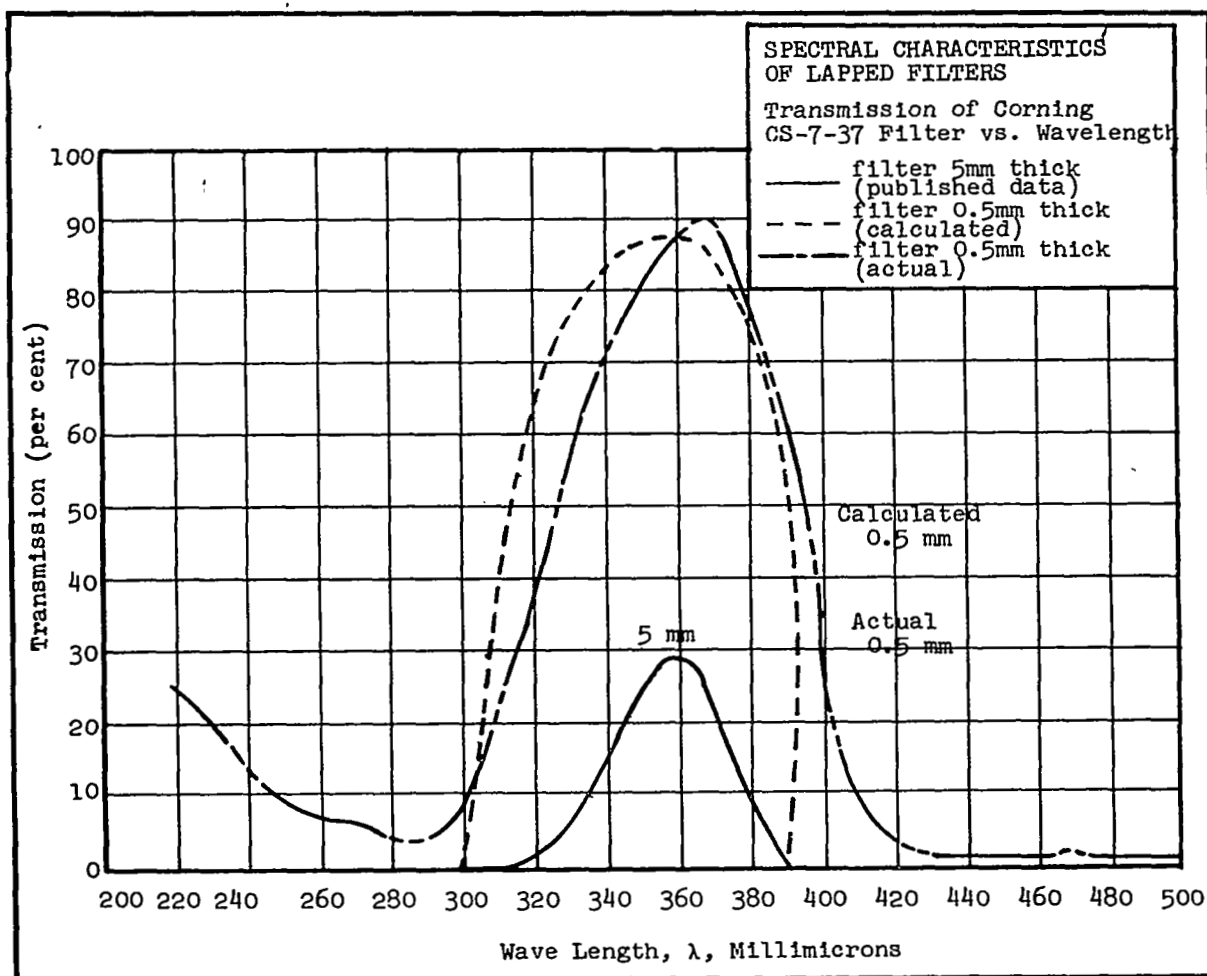
Figure 10.   Spectral Characteristics of Lapped Filters
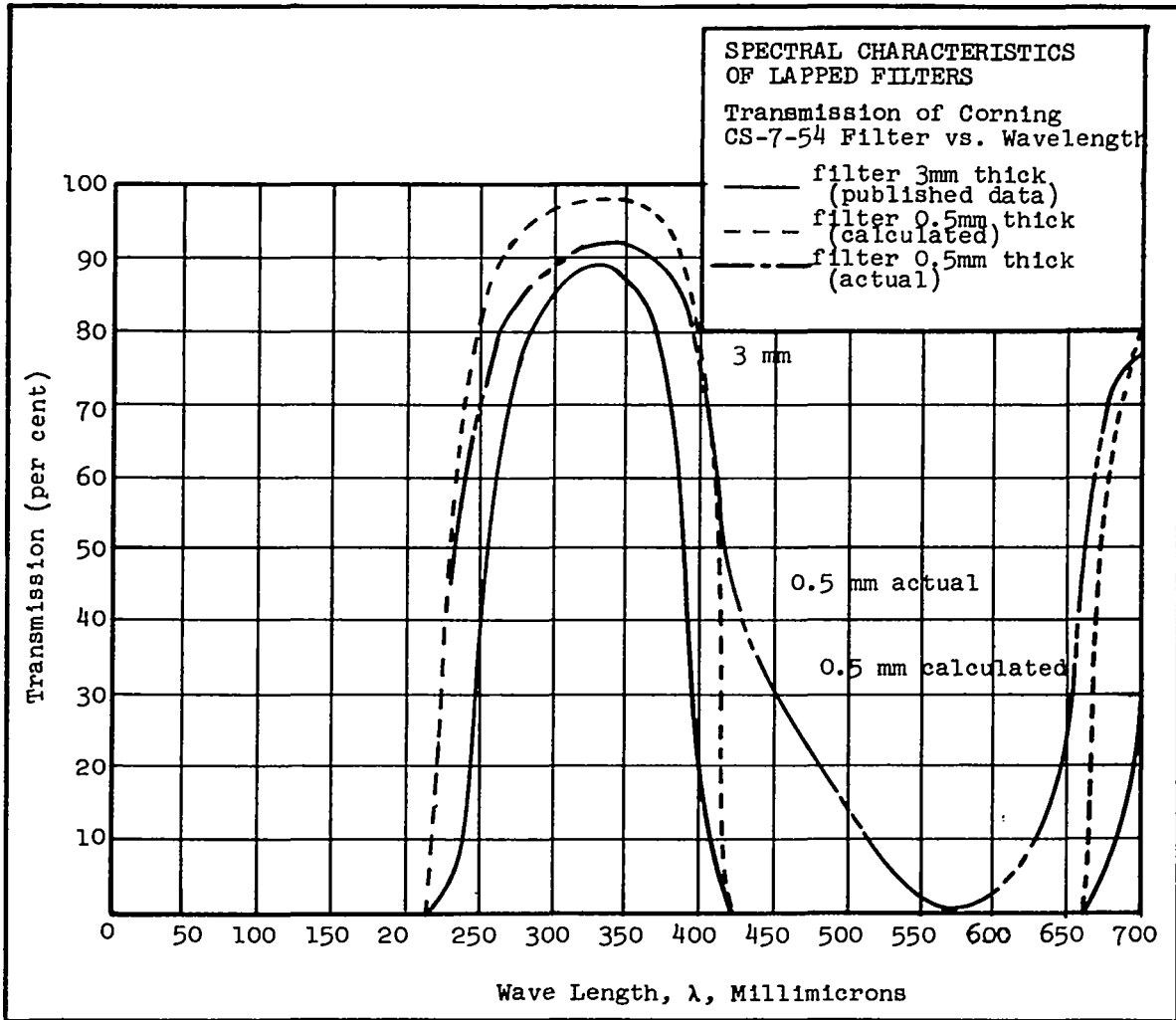
Figure 11.   Spectral Characteristics of Lapped Filters

The passband requirements are ideally that the filter provides 100% transmission in the UV and 0% in the visible. The filters shown will suffice with the exception of filter No. 7-54.

UV Phosphors and Associated Research

As previously illustrated, the composite filter must have a UV phosphor coating on the UV filter side in order to generate a UV image. The most commonly known UV phosphor is JEDC Type P-16.

A great deal of investigation has been done in the past and a literature search revealed the following phosphors to be better than P-16. The literature search is found in Appendix A.1. The best references were:

1. Contract No. 90449/AD 472680

2. Contract No. AF33(657)8985/AD 441857.

Name	Peak Emission	Brightness or Output Efficiency Compared to P-16
Calcium Silicate: lead	3380 Å	2
$CaSiO_3:Pb$		
Barium Silicate: lead	3520 Å	2
$BaSiO_3:Pb$		
Calcium Borate: lead	2700 Å	1
$Ca(BO_2)_2:Pb$		
Calcium Silicate: Cadmium	3550 Å	1
$CaSiO_3:Cd$		
Strontium Calcium Zinc Silicate: lead	3260 Å	.85
$SrCaZnS_{12}O_7:Pb$		

Report AD441857 lists a large number of UV phosphors and provides an excellent reference. AD 472680 provides detailed results of a few promising compounds.

The conclusions were that both the Calcium Silicate: Lead and Barium Silicate: Lead are superior to P-16 in terms of output, spectrum and life. Current tubes under study in fact employ the specially prepared calcium silicate: lead which is superior to P-16.

Materials Research

A substantial portion of this R & D effort was devoted to the study and selection of the best fluorescing material. Fluorescent compounds are generally divided into two distinct areas, organic and inorganic.

Organics - Superficially, it may appear that the organics have many advantages over inorganics; namely:

efficiency
variety
simplicity in manufacture
low cost
ease of handling

It was decided to conduct a full investigation on the various organic compounds.

It was ascertained that successful manufacture of a CRT requires the baking of the entire (Ref. 11) tube at 410°C to produce a useful life. Unfortunately, there is no known organic (excepting Teflon) which remains intact under these conditions. Nevertheless, the initial research effort devoted to organics was extremely useful in theoretical modeling and in the rapid setup of experiments.

The research provided a vast wealth of data on these compounds; the results and findings are summarized in Appendix A.2.

It should be noted that the fluorescent films referenced in the Appendix are all about 0.005" thick. It was observed that such a thin film will completely absorb the input UV up to the wavelength of emission. In employing such thin film organics as the active element, the image will not be spread and the UV will be completely absorbed for re-emission. In addition, the organic films are clear and do not diffusely reflect ambient illumination. This is discussed in greater depth in Appendix A.2.

(Ref. 11)   Private Communication: P. Seats, Thomas
            Electronics

Inorganics - Upon completion of the basic experimental work with organic fluorescence, glass systems were investigated for use in a sealed tube. In recent years, laser technology has created a new level of art in highly efficient fluorescent materials, as typified by rare earth doped glasses.

Cast 6" x 6" blocks of uranium oxide glass were procured from Corning Glass Works. Uranium oxide is reported to have quantum efficiencies of 75% (Ref. 12).

Initial tests with a long wavelength UV lamp showed that the entire cast slab fluoresced, which suggests that the UV is not absorbed in the first incident layer. To duplicate the organic thin film resolution, it was suggested that the Uranium Oxide glass be lapped down to a thickness of 0.005". The question is then, how thin should the slab be lapped down and yet absorb a high percentage of the UV?

In a method similar to those employed for investigating the thin film organics, an 8 mm section was evaluated in terms of transmission, spectral response and relative power output. The detailed data is plotted in Figure 12.

Further investigation into the fluorescent phenomenon produced an interesting result. The spectrofluorometer instrumentation used as a source of tunable narrow band energy produces essentially a narrow collimated beam. If the input wavelength is set for 380 millimicrons, a top view observation would show a green column of light in the glass along the same path as the UV path (Reference Figure 13). The fact that it is an observable indication means that the UV is stimulating the color centers which in turn emit isotropically. As the input wavelength is shortened, it is observed that the green column becomes a green cone. Finally, for $\lambda = 3300A$, the cone vanishes to a point.

(Ref. 12)   Private Communication: Dr. Dalton and Dr. Reade, Corning Glass Works, March 7, 1967
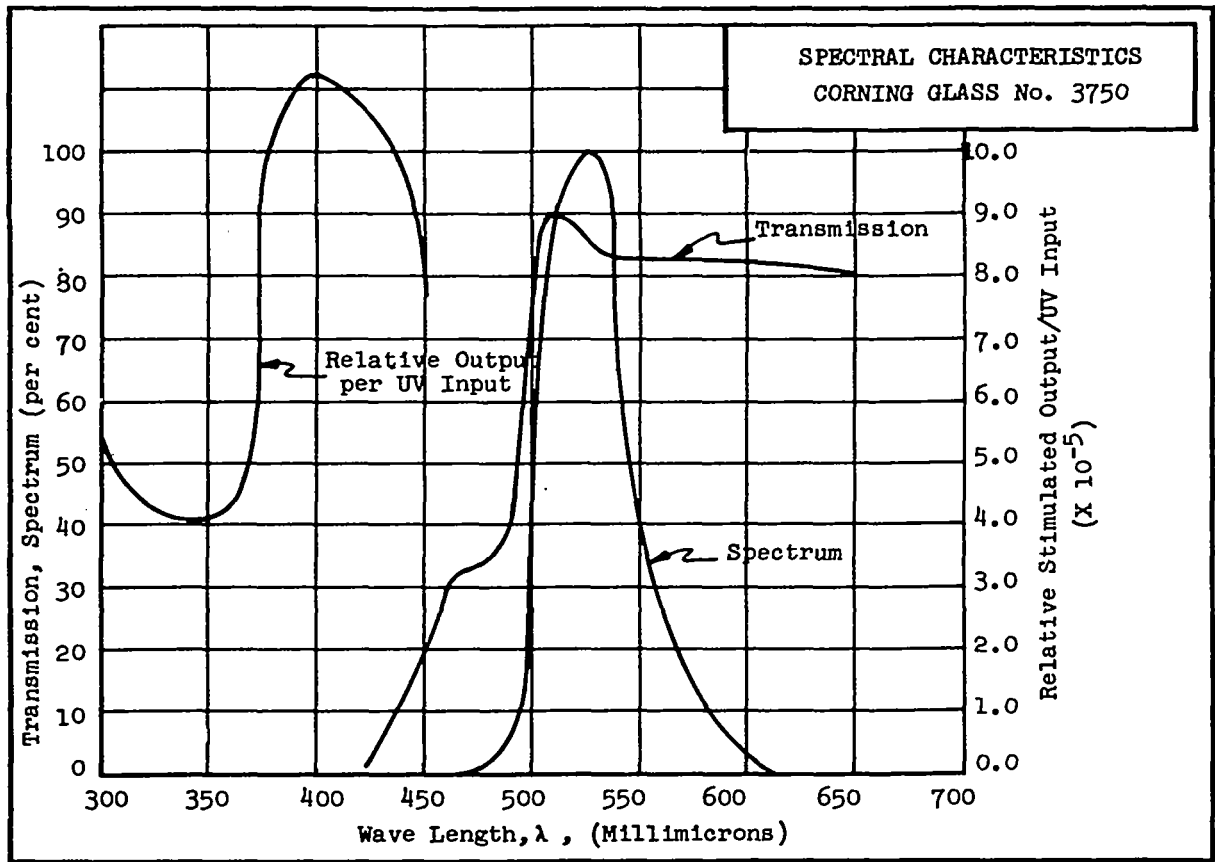
Figure 12.   Spectral Characteristics Corning Glass No. 3750
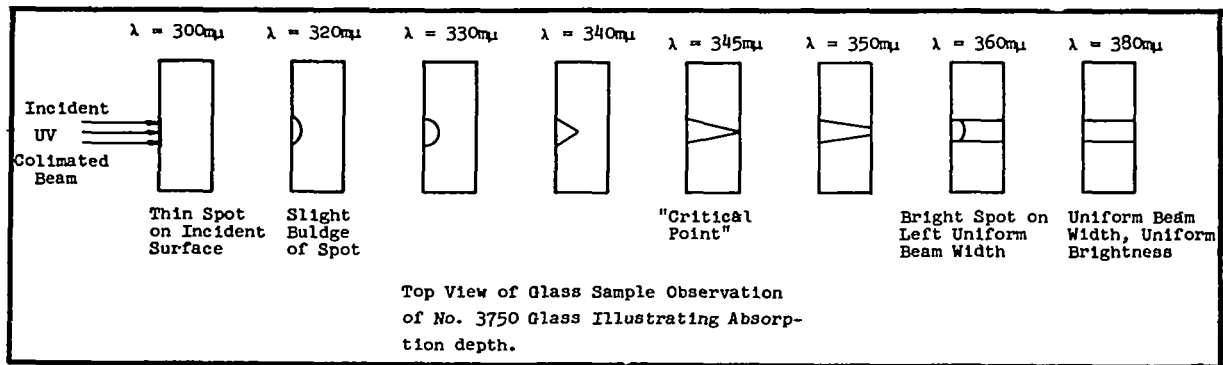
Figure 13.   Observation of Glass

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This observation shows that by using a short wave
UV phosphor, the image will be regenerated at fluorescent
wavelengths without spreading, as though the glass were
a thin film. This is a most useful property and an
analytical description is formulated.

According to relatively well known X-ray theory
(Ref. 13), it can be shown that similar results are ob-
tained with X-ray bombardment. We will assume that the
X-ray model can be extended to the longer wavelength such
as UV.

Assuming that a slab of non-scattering material, as
shown in Figure 14, has incident radiation I, the exit
radiation through a thickness of ∂X is then $I + \partial I$;
transmission T is defined as

$$T = \text{output/input} = \frac{I + \partial I}{I} \qquad \text{Eq. (16)}$$

and absorption $a = 1 - T$.
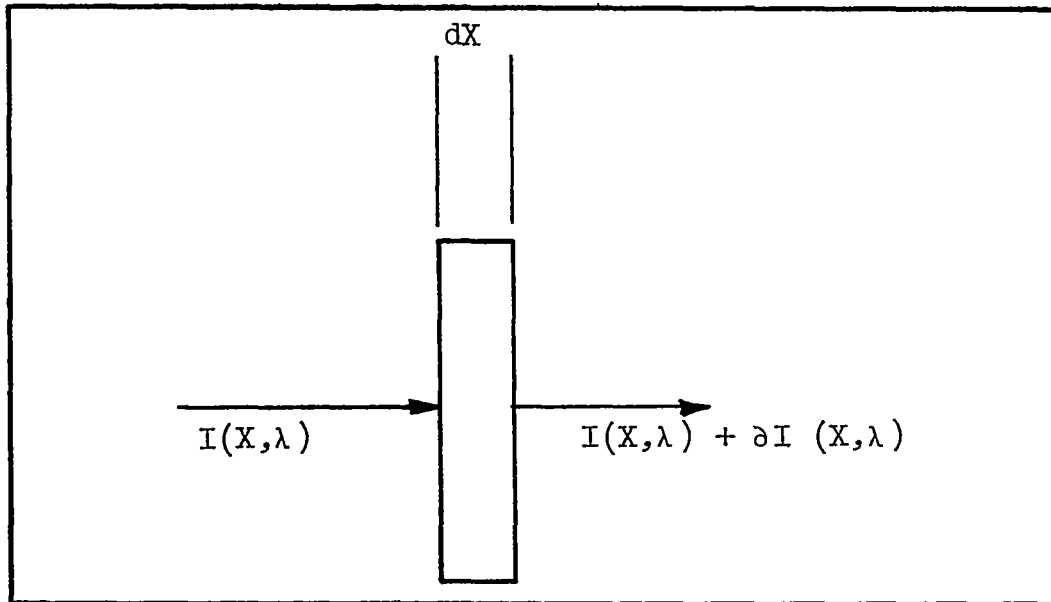
Figure 14.   Absorption Model

(Ref. 13)   Andrews - Optics of the Electromagnetic
            Spectrum, pp. 353, Prentice Hall, Inc.
            Hoag, Koff - Electron and Nuclear Physics,
            pp. 207, D.V. Van Nostrand Co., Inc.
            Leighton - Principles of Modern Physics,
            pp. 421, McGraw Hill Book Co., Inc.

In general,

$$T(\lambda,X) = \frac{I(\lambda,X) + \partial I(\lambda,X)}{I(\lambda,X)}$$ Eq. (17)

so

$$I(\lambda,X)\ T(\lambda,X) - I(\lambda,X) = \partial I(\lambda,X)$$

$$= W(\lambda,X)\ I(\lambda,X)$$

Therefore,

$$\partial I(\lambda,X) = I(\lambda,X)\ \partial W(\lambda,X)$$

$$\frac{\partial I(\lambda,X)}{\partial X} = \frac{-I(\lambda,X)\ \partial W(\lambda,X)}{2X}$$

$$= -\sigma(\lambda)\ I(\lambda,X)$$

Where $\sigma(\lambda)$ is defined as the linear absorption coefficient

$$\sigma(\lambda) = \frac{\partial W(\lambda,X)}{\partial X}$$

Therefore,

$$\frac{\partial I(\lambda,X)}{\partial X} = -I(\lambda,X)\ \sigma(\lambda)$$

The classical solution to this differential equation is

$$I(\lambda,X) = I(\lambda,0)\ \epsilon^{-\sigma X}$$ Eq. (18)

According to accepted X-ray theory, it was found that σ varies with wavelength as the third power. A normalized σ can be defined as an absorption cross section σ_a.

Therefore,

$$\sigma_a(\lambda) = \frac{\sigma(\lambda)W}{\rho N_o} \qquad \text{Eq. (19)}$$

W = chemical atomic weight

N_o = Avogadro's number

ρ = mass density

so

$$\sigma_a(\lambda) \cong C_{kl}\, z^4 \lambda^3$$

and

$$\sigma(\lambda) = \frac{\rho N_o}{W}\, C_{kl} z^4\, \lambda^3$$

The coefficient C_{kl} is a coefficient acting as a transitional probability coefficient and varies depending on the energy levels considered. This coefficient should remain constant over bands of wavelengths and then change abruptly.

So we let

$$\sigma(\lambda) = \sigma \lambda^3$$

We would expect σ to vary as described, since

$$\sigma = \frac{(\rho N_o\, z^4)}{W}\, C_{kl} \qquad \text{Eq. (20)}$$

Since

$$I(X,\lambda) = I(o,\lambda)\, \epsilon^{-\sigma(\lambda)x}$$
$$= I(o,\lambda)\, \epsilon^{-\sigma \lambda^3 x}$$

Therefore,

$$T = \epsilon^{-\sigma \lambda^3 x} \qquad \text{Eq. (21)}$$

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By knowing the transmission of the material, σ can be plotted as shown in Figure 15, and it is clear that the curve behaves as expected.
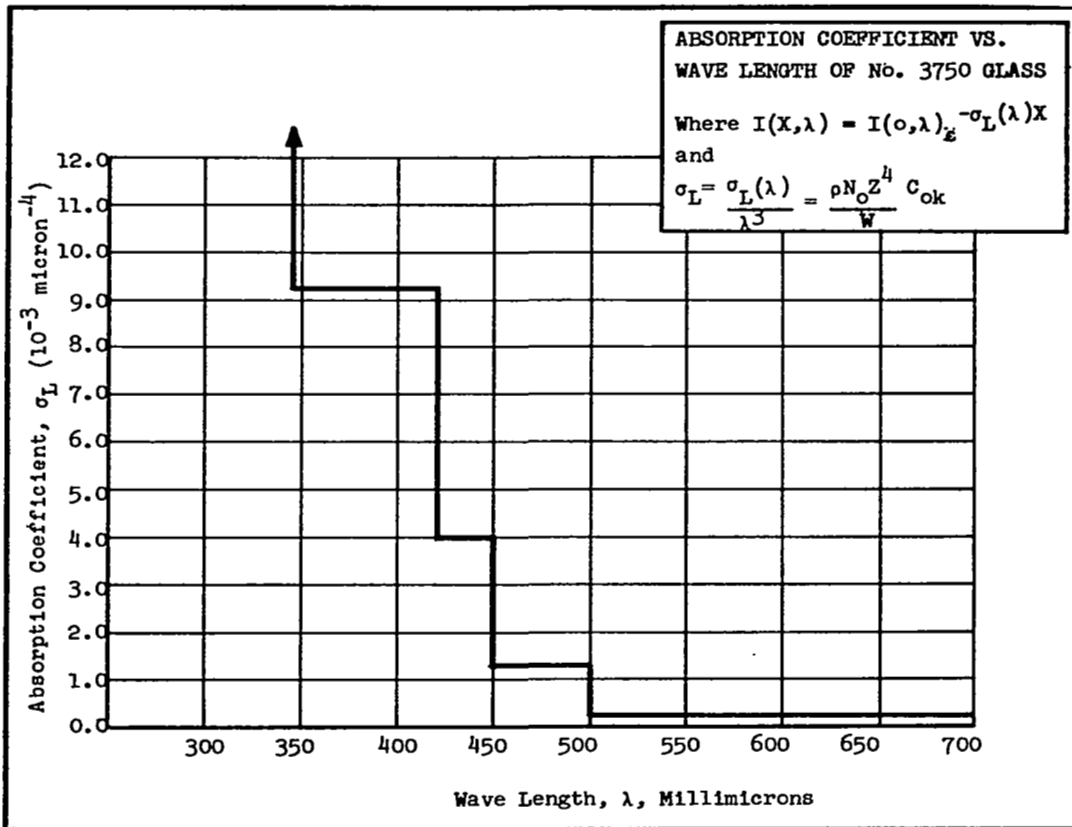
Figure 15.   Absorption Coefficient VS. Wavelength of No. 3750 Glass

The conclusion is that a thick glass may be used without degrading resolution, provided the excitation wavelength is far enough down into its intrinsic absorption band.

Passive or Visible Filter Requirements

The mechanism of the passive filter is fairly straightforward and its selection has been mainly that of a search of readily available materials.   The

requirements of the filter are summarized as follows:

1) pass the stimulated emitted output un-attenuated.

2) absorb wavelengths which stimulate the fluorescent material.

3) no scattering to incident radiation.

The simplest type is plastic base, such as pigmented acrylic, which may be brushed on the face of the tube.

The glass type of filter, particularly "sharp cut" filters, must be chosen with care, since the atomic absorption often possesses related tendencies towards fluorescence, which would defeat their purpose.

Figures 16, 17 and 18 plot typical plastic filters.

SPECTRAL CHARACTERISTICS
GREEN FILTER

Verdgreen - Allied Chemical
National Analine Division
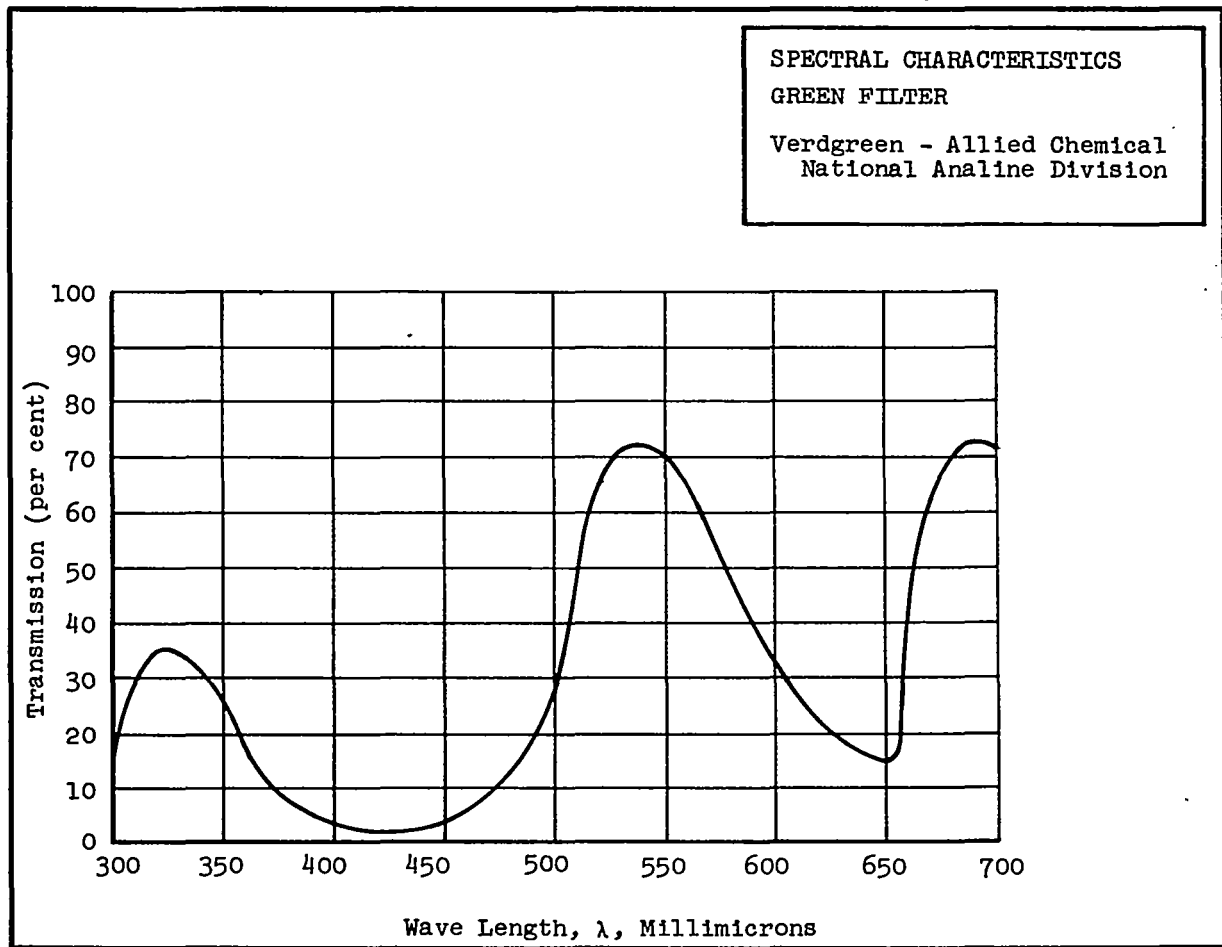
Figure 16.   Spectral Characteristics Green Filter

SPECTRAL CHARACTERISTICS
GLASS STAIN COLOR FILTER

Kelley Green
Glass Stain Products SSS28
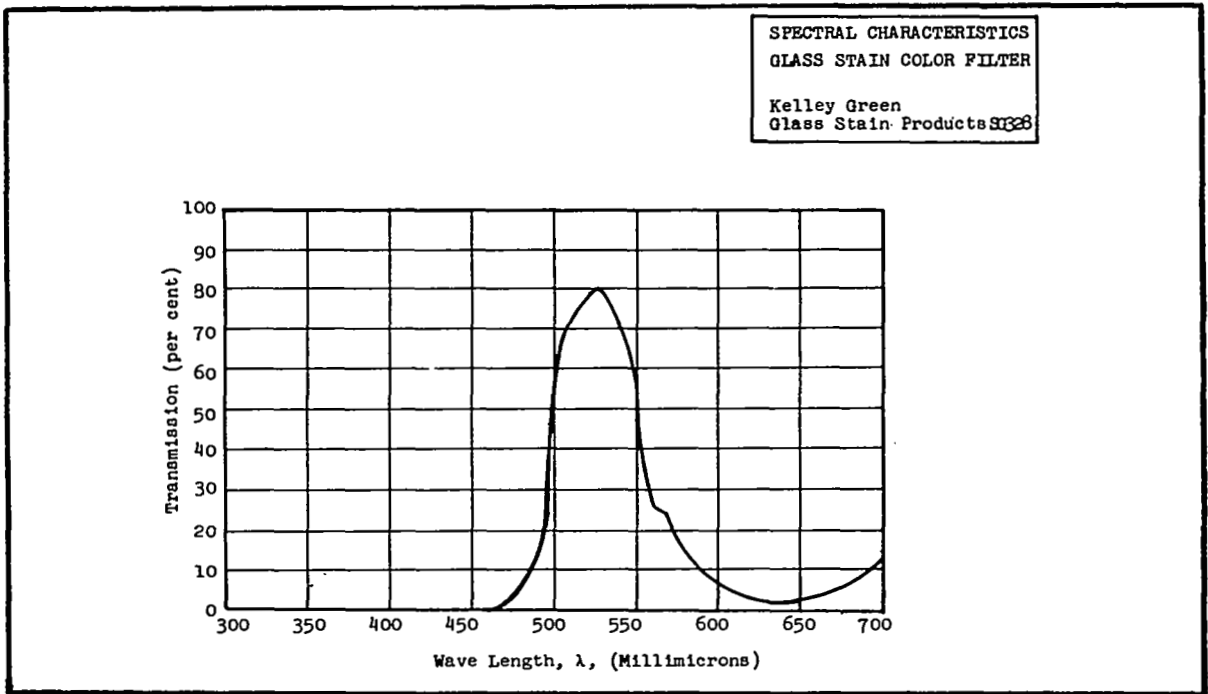
Figure 17.   Spectral Characteristics Glass Stain Color Filter

SPECTRAL CHARACTERISTICS
ACETATE COLOR FILTER

Medium Green, Roscolene 874
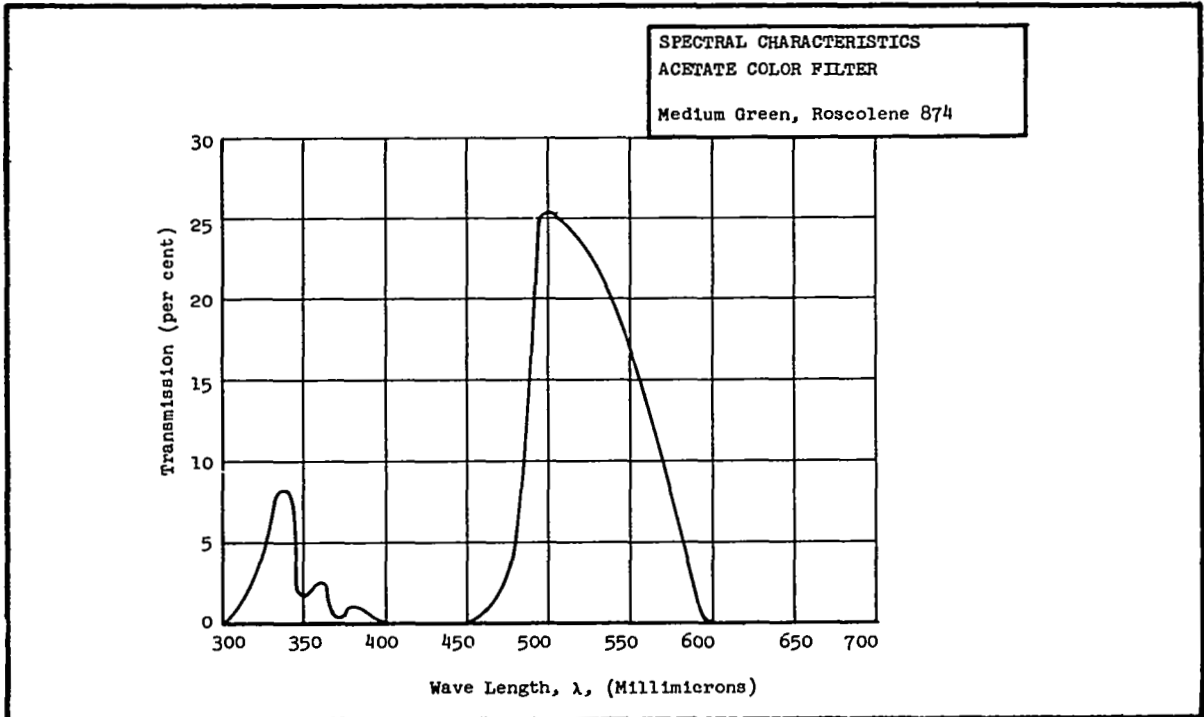
Figure 18.   Spectral Characteristics Acetate Color Filter

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Results of CRT Prototype Manufacture

The preceding sections dealt mainly with the technical requirements of individual components and related theories. The following section will describe the integrated results in an operating device.

Demountable Tubes

A demountable type vacuum system was obtained and set up to pump out the neck section of either a 5 AD or a 5 CK. The system is fitted with a 90° elbow, a straight nipple and a quick disconnect fitting which in turn fits over the pumping section of the tube. Figure 19 shows the apparatus completely set up. With the 4" CVC system as shown, an ion gauge reading pressures of 3×10^{-7} mm Hg were obtained with the baffle loaded with liquid nitrogen.

Tubes purchased had a pumping port and a cut off faceplate. The tube side and faceplate side were lapped down to provide a proper seal. The seal consists of the assembly shown in Figure 20. The seal proved extremely reliable and leak-proof in repeated assembly and disassembly.

Faceplate Configuration

The faceplates used consist of the assembly shown in Figure 21. The fluorescent materials used in the first experiments were organic, since baking is not required for a continuously pumped system. It was observed that the organics tended to initially outgas when they were pumped, but stabilized after a period of about two hours.

Tests were conducted in the following order:

Test No.	Sample-Composition	Observations
1	P-1 screen	Tube operated as CRT.
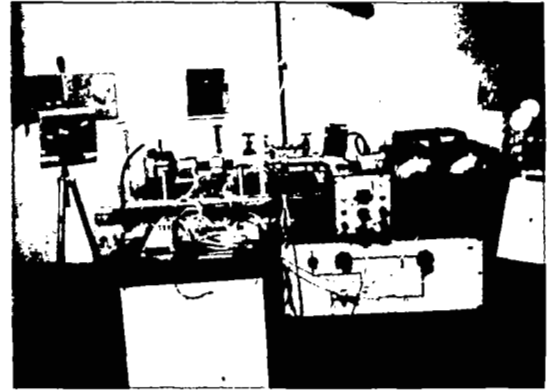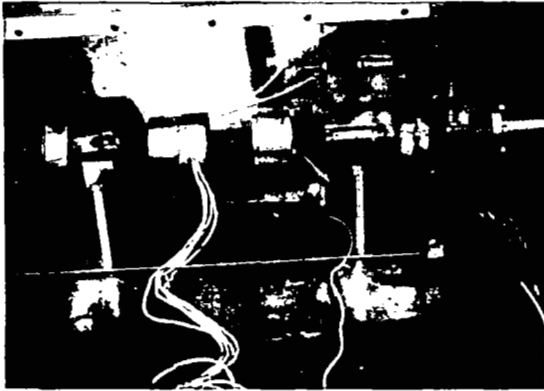
Figure 19.   Photo of Demountable Equipment
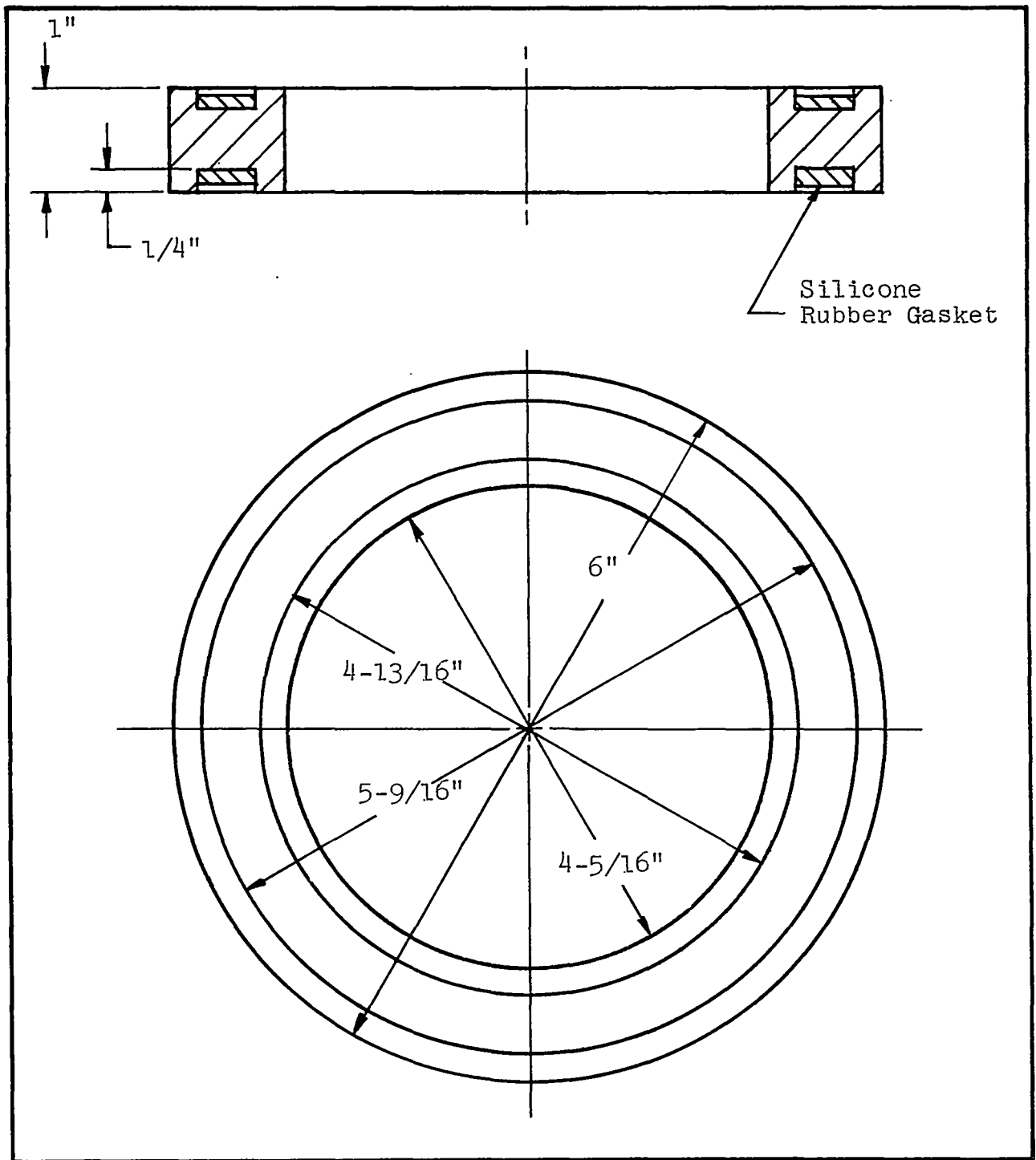
Figure 20.   Demountable Faceplate Vacuum Seal

Samples

Vacuum Cement

Inside View

UV Filter

UV Phosphor

Cross Section

Passive
Filter

Thin Fluorescent
Organic Film
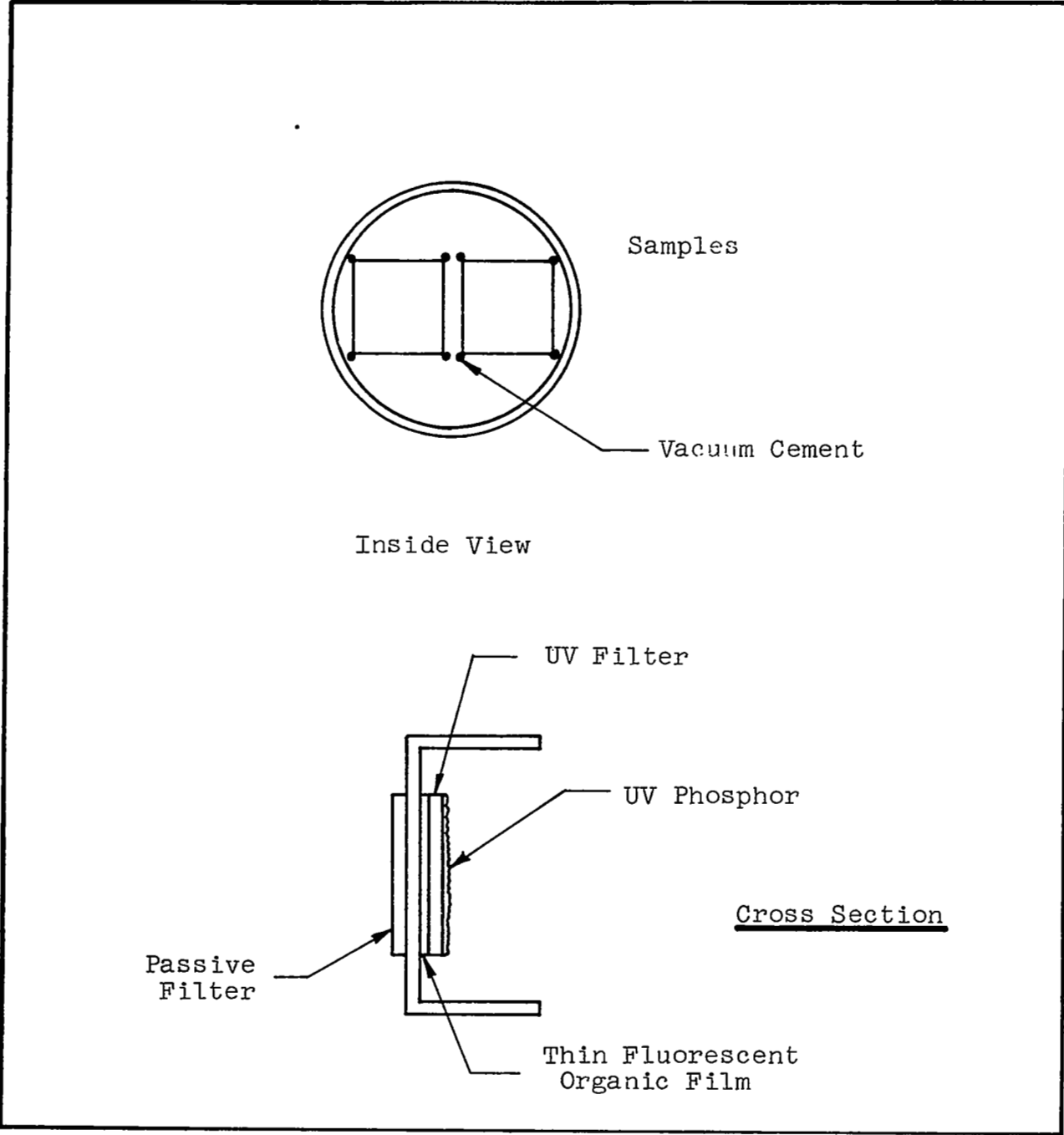
Figure 21.   Organic Faceplate Construction

Test No.	Sample-Composition	Observations

2	Screen a: P-1
	Screen b: Vycor slide
	  with P-16 + Q15
	Screen c: UV filter
	  with P-16 and Q15
	Screen d: UV filter
	  with P-16 and Q15
		P-1 section
		slightly brighter
		than P-16 screens
		(due to poor P-16
		deposition)

3	Screen a: UV filter
	  with P-16 strips of
	  Q13, Q15, Q17
	Screen b: UV filter
	  with calcium sili-
	  cate: lead strips
	  of Q13, Q15, Q17
	Screen c: P-1 slide
		Q17 brightest,
		P16 screen about
		equal to calcium
		silicate: lead in
		brightness, better
		than P-1, good
		contrast with right
		visible filter

It was observed that the emission of the various
tubes was much lower than expected, and that the grid had
to be driven to nearly 0 volts to obtain any emission at
all. This fact was confirmed as being typical of a cold-
demountable (Ref. 14) system.

It was also observed that the image would not become
brighter as the anode potential was increased beyond 6 KV,
due to space charge accumulation. Two methods exist to
eliminate this problem.

- Aluminizing the phosphor

- Employing a transparent conductive coating on the
  faceplate (tin oxide)

After the tube was stripped down for further experi-
ments, a tin oxide coating was applied to the UV filters.
The conductive surface is then tied back to the high
voltage anode by means of a graphite film (Aquadag). It
was found that additional brightness was obtainable by
then raising the anode to as high as 15KV. In general, as
is typical of silicate phosphors, high anode potentials

(Ref. 14)   Private Communication: P. Seats, Thomas
            Electronics, February 17, 1967

are desirable. The electrical schematic of the apparatus is shown in Figure 22.
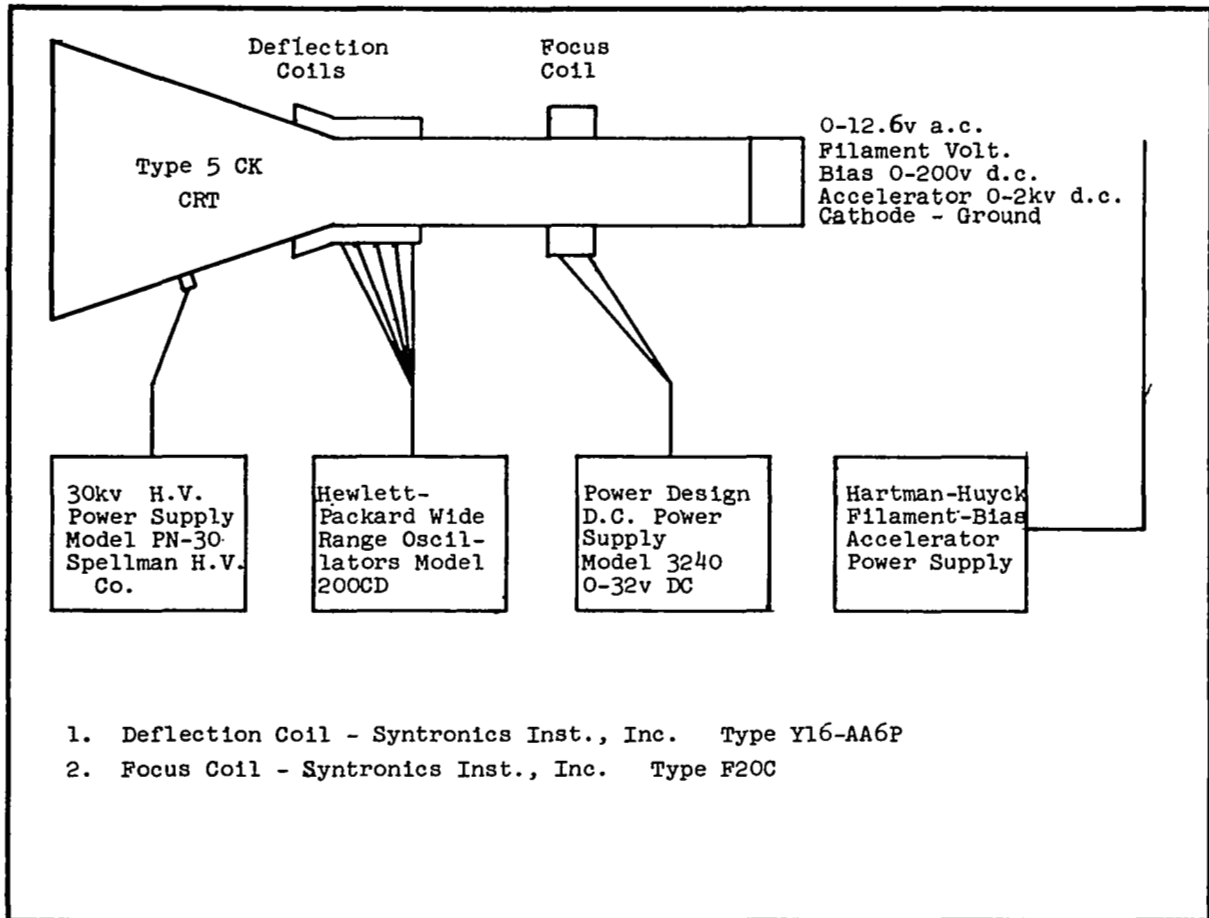
Figure 22.   Electrical Schematic

Inorganic Filters

To produce practical tubes, a completely inorganic system was constructed using the faceplate as shown in Figure 23.
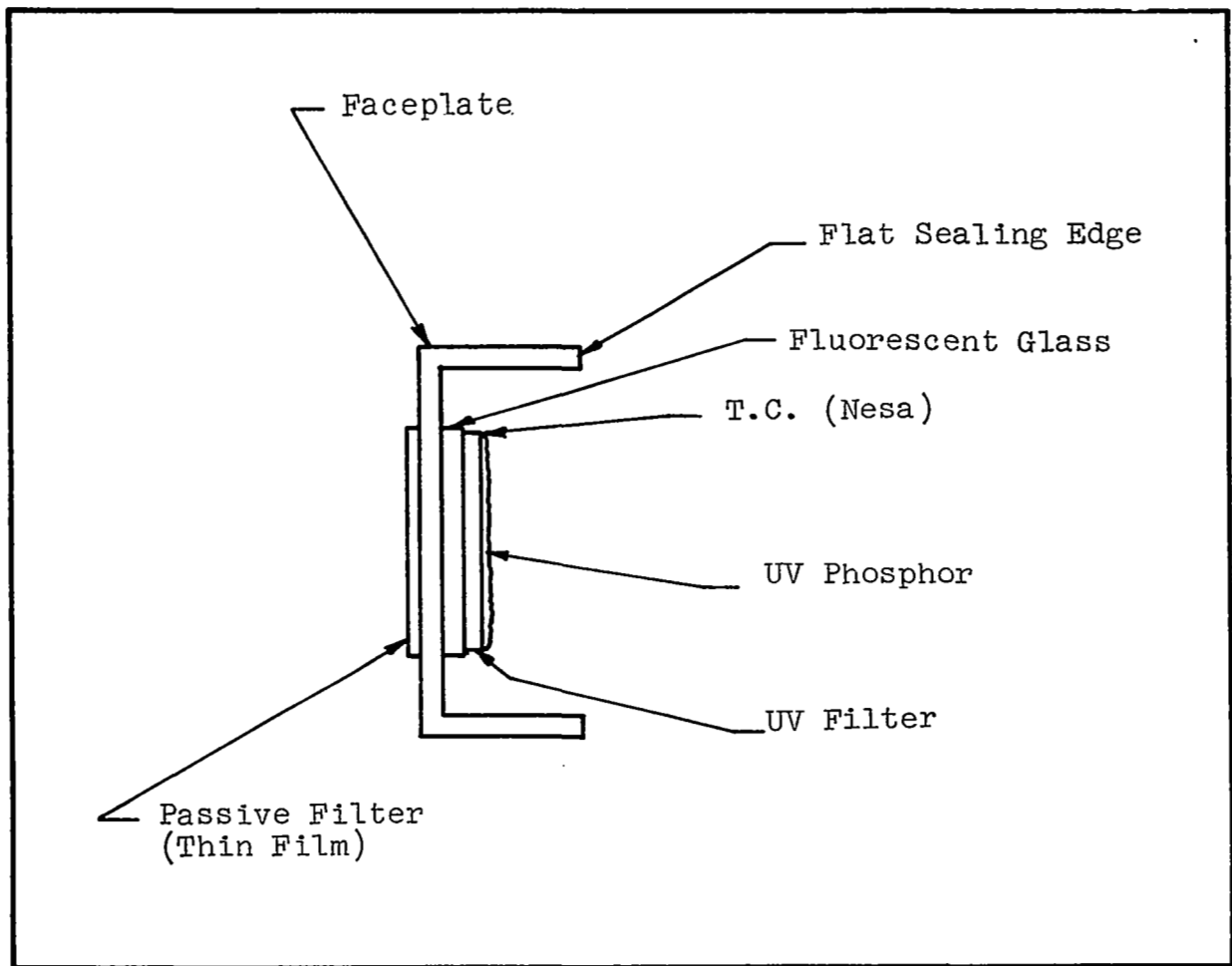
Figure 23.   Inorganic Faceplate Construction

Two phosphor samples were employed: P-16, which emits near 380 millimicrons and calcium silicate: lead which emits near 338 millimicrons. Both phosphors stimulated the uranium oxide glass and produced about equal intensities. The difference is that the P-16 spread the image as expected, whereas calcium silicate: lead phosphor retained the image resolution defined by the UV filter. This is in accord with the experiments and predictions shown in the section titled "Extended Theory of Glass and Results."

Sealed Off Tubes

To prove the entire theory and experiments, a sealed off tube was constructed, employing the above inorganic techniques. The tube was turned on and functioned immediately. An observational check was then made as a final test of contrast.

With the tube displaying a lissajous figure on the high contrast background, a 250 watt photoflood lamp was directed on the screen from 10 inches away. The image remained clearly visible. The only difficulty observed was the specular reflection which hides the pattern if observed in the direct path. Later tests with 650 watt photoflood lamps still yielded a clearly visible image. Measurements of contrast ratio yielded a figure of 0.70 under 650 watts illumination at a distance of 2 feet, approximating full sunlight conditions.

The following table compares the CRT as fabricated, to a Dumont oscilloscope under the following conditions:

TABLE I

CONTRAST COMPARISONS

LIGHTING CONDITION	CONTRAST	
	High Contrast CRT	Dumont Oscilloscope
Room Lighting	0.99	0.91
650 W iodine lamp at 4' (normal-sunlight equivalent)	0.75	0.13
650 W iodine lamp at 2' (max.-sunlight equivalent)	0.70	0.11

TABLE II

HIGH CONTRAST CRT CHARACTERISTICS

2nd Anode Potential (kv)	Beam Current (μa)	Screen Brightness (fl)	Beam Power (mw)	Beam Power Density (watts/in^2)	Area of Spot (cm^2)
15	10	15	150	7.8	124
15	20	25	300	10.9	178
15	30	30	450	12.0	243
15	40	40	600	12.2	316
15	50	40	750	12.1	400
10	10	5	100	3.6	178
10	20	8.5	200	4.1	316
10	30	10	300	3.9	495
10	40	11	400	3.1	838
10	50	12	500	3.8	838
5	10	.6	50	.65	495
5	20	.9	100	.90	716
5	30	1.1	150	1.00	966
5	40	1.1	200	1.02	1263
5	50	1.1	250	1.01	1600

The tube is rated for 1600 μa current, but only under scan conditions.

Recommendation

A number of areas now remain to be investigated in order to optimize and manufacture the CRT on a reasonable scale. The areas of most importance:

- Develop a method of fabrication of thin and large area UV filters.
- Study fluorescent glasses, particularly the rare-earth variety, to obtain color variations.
- Refine the UV phosphors for maximum efficiencies.
- Develop a selection of optimum visible filters for each glass studied.

Conclusion

A cathode ray tube has been developed, employing non-reciprocal optical filtering techniques, consisting of the best practical combination of phosphor, fluorescent material and passive filters.

High contrast was achieved even under direct sunlight, verifying all previous theories and experiments.

These methods and techniques of the high contrast ray tube will lend themselves to a brand new depth of displays.

APPENDIX A
UV PHOSPHOR REFERENCES

The literature searched is listed below:

1964	1965	1966
AD 426 563	AD 464 491	AD 482 235L
AD 418 207	AD 470 967	
AD 441 857	AD 470 059	
AD 430 462L	AD 458 561	
AD 447 132L	AD 465 036	
AD 425 170	AD 451 390	
AD 346 966L		
AD 353 222L		
AD 436 109		

Others

AD 602 188	AD 600 517
AD 433 584	AD 472 101
AD 409 871	AD 442 229
AD 415 446	AD 401 348
AD 414 930	AD 436 109
AD 605 261	AD 434 970
AD 609 034	AD 434 239
AD 418 207	AD 407 796
AD 277 793	AD 606 705

AL-TDR-64-94

Patents: #273367   #3227883   #3177082   #2924732   #3176574

Journal Optical Society of America, October 1951, pp. 702-708, "Fluorescent
    Sensitized Photomultipliers for Heterachromatic Photometry in the UV"

Journal Optical Society of America, June 1964, pp. 747-751, "Absolute Fluorescent
    Quantum Efficiency of Sodium Salicylate"

Journal Optical Society of America, December 1965, pp. 1628-1632, "Diffuse
    Reflection From a Plane Surface"

JEDEC Publication No. 16, "Optical Characteristics of Cathode-Ray Tube"

Bell Systems Monograph No. 3989, Sept. 1960, Vol. No. 5, pp. 204-208, "Aging
    of Electronic Phosphors in Cathode Ray Tubes"

Philips Res. Rep. 1952, Vol. No. 7, pp. 421-431

Journal Optical Society of America, 1947, Vol. No. 5

Journal Electrochemical Society, 1957, Vol. No. 104, pp. 104

Advanced Development Report No. BL-P-6-2049, 15 May 1964, pp. 1121-4,
    "Luminescence of Pyrosilicate Structures Activated by Lead"

Journal Optical Society of America, May 1947, Vol. No. 37, pp. 355-362,
    "Ultra-Violet Phosphors and Fluorescent Sun Tan Lamps"

Trans. Electrochemical Society, 1947, Vol. No. 91, pp. 241-263, "New Ultra-
    Violet Phosphors"

Journal Electrochemical Society, Feb. 1957, Vol. No. 104, pp. 93-100, "Ultra-Violet Fluorescence of Some Ternary Silicates Activated Lead"

Journal Electrochemical Society, 1952, Vol. No. 99, pp. 137-139, "Calcium Zinc Silicates Phosphor"

Journal Electrochemical Society, 1950, Vol. No. 97, pp. 29-32, "Ultra-Violet Emitting Phosphor"

Journal Optical Society of America, 1926, Vol. No. 13, pp. 573-588, "Note on the Rare Earths as Activators of Luminescence"

Journal of Electrochemical Society, 1951, Vol. No. 98, pp. 299-300, "Silver as an Activator of Halophosphate Phosphors"

Journal Optical Society of America, 1949, Vol. No. 39, pp. 655-660, "Optical Properties of Calcium Silicate Phosphors"

Ann. Chem. Phys., 1909, Vol. No. 18, pp. 289-292, "Cathodic Phosphorescence of the Rare Earths"

Chem. Tech (Berlin), 1958, Vol. No. 10, pp. 353-360, "Emission Characteristics of Inorganic Crystalline Phosphors Lead Activated Luminophors with Ultraviolet Emission"

Naturwissenschaften, 1958, Vol. No. 45, pp. 462, "Ultraviolet Luminescence of Tl-Activated Calcium Borates"

Naturwissenschaften, 1962, Vol. No. 49 (8), pp. 181, "Tl-Activated Ca Pyrophosphate Ultraviolet Emitters"

Z. Physk. Chem. (Leipzig), 1959, Vol. No. 211, pp. 307-323, "Ultraviolet Emission of Lead-Activated Borate Luminophors as a Function of Activator Content and Temperature"

APPENDIX B

ORGANIC MATERIALS

The data presented in this section was amassed during the course of the research effort. Although it was discovered that organics cannot be used in CRT work because it poses difficult problems, the data, compiled in the course of the work, is assembled and presented for reference purposes, since it may be useful to other researchers in allied areas.

Table B-I summarizes various properties of the most commonly known fluorescent dyes under five basic groups.

Table B-IIa and B-IIb summarize various plastic matrices with Auramine O and corresponding solvents.

Table B-IIIa summarizes the better plastics with a large number of solvents outlining the degree of solubility.

Table B-IIIb summarizes solubility of rare earths in solvents.

TABLE B-I

PROPERTIES OF FLUORESCENT DYES - SULFONAMEL *

Switzer Sulfonamel Plastic dissolved in a 1:1 solution of Diacetone Alcohol & Acetone (250 ml diacetone alcohol 250 ml acetone; 50 grams sulfonamel)

Name of dye sample	Fluorescent under UV	Ambient Color	Solubility
Group I:			
Rhodamine B Base	yes - red	rose	dissolves well in matrix
Auramine O	yes - yellow	yellow	some sediment
Fluorescein - Alkali & Alcohol Soluble	no	clear	dissolves well, but not enough dye
Primulin	yes - pale green	very pale green	some sediment
Fluorescein	no	pale orange	dissolves well
Naphthacene	no	clear	partially dissolves
Rhodamine 6B	yes - red	rose	some sediment
Group II:			
Anthracene	yes - lavender	clear	partially - some sediment
Chrysene	yes - lavender	clear	partially - some sediment peak excitation at 330µ
Pyrene	yes - pale blue	light amber	partially - some sediment
9-Methylanthracene	no	amber	dissolves well
4, Tetraphenyl - 1,3, Butadiene	yes - pale blue	clear	partially - quite a bit of sediment
2,5, Dephenyloxazole	yes - pale blue	clear	dissolves well

* Composition of Sulfonamel is a polymer mixture of melamine, formaldehyde. sulfonamide, manufactured by Switzer Bros., Cleveland, Ohio.

PROPERTIES OF FLUORESCENT DYES - SULFONAMEL (cont'd)

Name of dye sample	Fluorescent under UV	Ambient Color	Solubility
Group II:(con't)			
9, 10, Dichloroanthracene	yes - pale blue	pale yellow	partially - some sediment dissolves in diacetone alcohol
Quinoline	no	light amber	liquid to start with
Carbazole	yes - lavender	white	does not dissolve
Quinine Sulphate N.F.	no	clear	partially - some sediment
8, Hydroxyquinoline	no	light amber	partially - some sediment

The dye samples in Group II that only partially dissolved in the diacetone alcohol, acetone solution, were then mixed with other organic solvents in order to find a solvent that would completely dissolve the dye sample. Carbazole; 1,1,4, - Tetraphenyl - 1,3, - Butadiene; and Chrysene were each mixed individually with Methyl alcohol, Toluene, Xylene, Methyl Ethyl Ketone, Pentyl acetate and Hexane but none of these solvents dissolved the dye sample.

Group III:*

	Fluorescent under UV	Ambient Color	Solubility
I Acridine red	yes - red	red	dissolves well
II Pyronin "B"	yes - red	red	dissolves, slight sediment
III Methylene Blue	no	blue	soluble, slight sediment
IV Acriflavine Hydrochloride	yes - pale green	yellow-green	soluble
V Methylene Blue (Double ZN Salt)	no	blue	soluble, slight sediment
VI Acridine	yes (crystal form only blue)	colorless	soluble
VII Acridine Orange	yes - orange	orange	soluble, slight sediment
VIII Uranine (H₂0 sol.)(Na Fluorescein)	yes - yellow-green	orange	soluble
IX Safranin "0"	yes - pink	pink	soluble

Solvent used to test above dyes - Switzer Sulfonamel Plastic (80 grams) dissolved in 500 ml of 1:1 diacetone alcohol and acetone.

Name of Solvent	Fluorescent under U.V.	Solubility
Methylene Blue tested in the following solvents:		
Acetone	no fluorescent color	soluble
Diacetone alcohol	no fluorescent color	soluble
Xylene	no fluorescent color	soluble
Methyl Ethyl Ketone	no fluorescent color	soluble
H₂0	no fluorescent color	soluble

* Test slides made of all Group III except numbers III and V. Samples run with both long and short wave U.V. - fluorescent color more intense under short wave lamp.

PROPERTIES OF FLUORESCENT DYES - SULFONAMEL (con't.)

Name of Dye Sample	Long & Short Wave U.V. Used	Ambient Color	Under U.V.	Solubility
Group IV:				
p-Bis [2(5-Phenyloxazolyl)] Benzene	yes - blue	colorless	blue	Soluble-color is of greater intensity under long wave
p,p[1]- Diphenylstilbene	yes - blue	colorless	none	slightly soluble color greater under long wave
2-(1-Naphthyl) 5 Phenyloxazole	yes - pale blue	colorless	blue	soluble-greater under long wave
2,5 - Di Phenyloxazole	yes - pale blue	colorless	blue	soluble-slight sediment greater under long wave U.V.

Solvent - Switzer Sulfonamel Plastic

All four of Group IV gave greater fluorescent color in solution with long wave U.V. lamp. The solid crystals of all, about equal in fluorescent intensity under both long and short wave lamps. p, p[1] - Diphenylstilbene mixed with solvent and allowed to dry gave no reaction to either long or short wave U.V.

Test slide made of 2(1-Naphthyl) 5 Phenyloxazole.

Name of Chemical	Fluorescent Under U.V.*	Ambient Color	Under U.V.	Solubility
Group V:				
Europium Chloride	no	colorless	none	soluble in sulfonamel
Europium Ethylsulfate	no	colorless	none	soluble in sulfonamel
Samarium Chloride	no	colorless	none	soluble in sulfonamel-slight sediment
Samarium Acetate	no	colorless	none	soluble in sulfonamel
Samarium Sulfate	no	colorless	none	soluble in sulfonamel
Terbium Chloride	solution - no crystals - yes, yellow-green	colorless	none	soluble in sulfonamel
Terbium Sulfate	solution - no crystals - yes, green	colorless	none	soluble in sulfonamel

* Long and short wave lamps used to test samples. No test slides made.

TABLE B-I

PROPERTIES OF FLUORESCENT DYES - SULFONAMEL (con't)
Rare Earth Group Elements*

Name of Chemical	Fluorescent In Solid Form	Soluble Sulfonamel	Fluorescent In Solution	Remarks
TRIS (Salicylaldehydo) Samarium #920290	no	yes	no	
TRIS (2,4 Pentanediono) Terbium #920799	yes - green	yes - some sediment	yes - yellow-green	Test slide made
TRIS (1,3 Diphenyl 1,3 Propandediono) Samarium #920970	no	yes	no	
TRIS (8-Hydroxyquino-lino) Europium #921198	no	yes	no	
TRIS [4,4,4 Trifluoro 1-(Zfuryl) 1,3 Butanedi-ono] Europium #921179	yes - red	yes	yes - bright red-orange	Test slide made
TRIS (Salicyaldehydo) Neodymium #920447	no	yes - some sediment	no	
TRIS [4,4,4 Trifluoro 1 (2 Thienyl) 1,3 Butane-diono] Samarium #920783	yes - pale pink	yes	yes - pale orange	Test slide made
TRIS (1,1,1,5,5,5 Hexa-fluoro) 2,4 Pentanediono Europium #921186	yes - orange	yes	yes - very pale orange	
TRIS (2,4 Pentanediono) Thulium #921120	no	yes	no	
TRIS (1,1,1 Trifluoro) 2,4 Pentanediono Europium #921182	yes - pink	yes	yes - pale pink	
TRIS (2,4 Pentanediono) Europium #920969	yes - pale red	sediment	yes - very pale yellow	
TRIS (Salicyaldehydo) Europium #9100	no	yes - some sediment	no	
TRIS [4,4,4 Trifluoro 1-(2 Thienyl) - 1,3 - Butanediono] Europium #8990	yes - red	yes	yes - red	Test slide made
TRIS [4,4,4 Trifluoro 1-(2 Thienyl) - 1,3 Butanediono] Terbium #9553	no	yes	no	
TRIS (5-Nitrosalicyl-aldehydo) Europium #9550	yes - red-orange	yes	yes - orange	Test slide made
TRIS (1-Phenyl 1-3 Buta-nediono) Terbium #9113	no	yes	no	
TRIS (1-Phenyl 1-3 Buta-nediono) Europium #8989	yes - orange	yes	yes - very pale orange	
TRIS (Salicylaldehydo) Cerium #9031	no	yes - some red	no	

* Source - Eastman Organics Div.

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PROPERTIES OF FLUORESCENT DYES - SULFONAMEL (con't)

Name of Chemical	Fluorescent In Solid Form	Soluble Sulfonamel	Fluorescent In Solution	Remarks
TRIS (Salicylaldehydo) Praseodymium #9116	no	yes - some red	no	
TRIS (1 Phenyl 1-3 Butanediono) Samarium #9119	no	yes	no	
TRIS (Salicylaldehydo) Lanthanum #9117	no	slightly sol.	no	
TRIS (1,3 Diphenyl 1,3 Propanediono) Europium #920854	yes - red	yes	yes - pale orange	Test slide made
TRIS (1-Phenyl-1, 3 Butanediono) Dysprosium #921057	no			
TRIS (1 Phenyl - 1,3 Butanediono) Holmium #921058	no	slightly sol.	no	
TRIS (1,1,1 Trifluoro 2,4 Pentanediono) Samarium #921180	no			
TRIS (1,3 Diphenyl) 1,3 Propanediono Terbium #920853	no	yes	no	
TRIS (Acetoacetanilido) Terbium #921181	yes - green	yes - slightly sol.	yes - very pale green	Test slide made

ELVANOL

Elvanol (Dupont polyvinyl alcohol #71-30) mixed with some of the best fluorescent materials to obtain solubility and fluorescent quality in a plastic binding material other than Sulfonamel.

Elvanol prepared by addition of 5 grams of polyvinyl alcohol to 100 ml of hot H_2O, mixed, allowed to cool. Product of high viscosity.

Fluorescent Material	Soluble In Elvanol	Fluorescent In Solution	Remarks
Sample #5:			
Rhodamine "B"	yes	yes - pink	Weaker than Sulfonamel
Anthracene	no	-	-
Rhodamine "6B"	yes	yes - yellow	Sulfonamel better
Switzer Q15 Pigment	no	-	-
TRIS (5-Nitrosalicylaldehydo) Europium #9550	yes	yes - pale orange	Sulfonamel better
TRIS [4,4,4 Trifluoro 1 (2 Furyl) 1,3 Butanediono] Europium	no	-	Particles float on surface

Elvanol (polyvinyl alcohol) #71-30 diluted by the addition of:
TRIS (5-Nitrosalicylaldehydo) Europium	yes	yes - very pale	

TABLE B-I

PROPERTIES OF FLUORESCENT DYES (con't) - ACRYLIC

Liquid Acrylic, clear checked for fluorescent quality and some of best fluorescent materials.

Chemical	Soluble	Fluorescent	Ambient Color	Remarks
Rhodamine "B"	yes	yes - red-orange	red	Fluorescence fades rapidly as it dries
Blaze Orange Q15	yes	yes - pale orange	very pale orange	Fluorescence very poor
Rhodamine 6G	no	-	-	-
TRIS (5-Nitrosalicylaldehydo) Europium	no	-	-	-

Sample #1 & #2: Test slides of Rhodamine "B" made by dipping of slide into an almost concentrated solution of dye and plastic. A second slide made of lesser concentration to compare fluorescence.

METHOCEL H.G.

Methocel H.G. (Dow - Hydroxypropyl Methyl Cellulose) Water Soluble Gum. Max. clarity of solution at 5-10°C 1 gm of Methocel/40 ml of Ethyl Alcohol plus H_2O.

Rhodamine "B"	yes	yes - red-orange	pink	*Concentration 2 slides made
Q15 - Switzer	no	-	-	-
TRIS [4,4,4 Trifluoro 1-(2 Furyl) 1,3 Butanediono] Europium	no	-	-	particles float

Sample #3 & #4: *1 slide dipped in prepared Methocel and dye. Second slide dipped in 1:1 Methocel and Ethyl Alcohol.

SODIUM SILICATE

Sodium Silicate Solution

Chemical	Soluble	Fluorescent	Ambient Color	Remarks
Rhodamine "B"	yes	no	-	-
TRIS (Acetoacetanilido) Terbium	no	-	-	particles float

VINYL

Vinyl, Clear Spray, Bel-Art, F-24005 (PVC)*

Rhodamine "B"	yes	yes - red-orange		fluorescence of slide decreases
TRIS (Acetoacetanilido) Terbium	no	-		fluorescence of slide decreases

* Manufactured by BEL-ART Products, Pequannock, N. J.

TABLE B-IIa

PLASTIC MATRICES AND SOLVENTS - LIQUIDS

Matrix	Manufacturer's Data	Color	Auromine O soluble	Viscosity	Wetting Ability
Tetra Flex 990	National Polychemicals Inc. Wilmington, Mass.	dark amber	no	-	-
Catalina A-1167	Catalin Corp. New York, N Y.	clear	yes	may need thinning	good
Multifarius Liquid Acrylic	International Fiber-glass Corp. Woodside, N. Y.	amber	yes	no thinning necessary	good
Multifarius Vinyl	International Fiber-glass Corp. Woodside, N. Y.	clear	yes	must be thinned for dipping	good
Conap Polyure-thane 1127	Conap Inc. Alleghany, N. Y.	amber	yes	may need thinning	good
Santicizer 160	Monsanto Co. St. Louis, Mo.	clear	yes	no thinning necessary	good
Vikem PVC	Bel-Art Products Pequannock, N. J.	clear	yes	may need thinning	good
Humi Seal Silicone 1H34	Columbia Technical Corp. Woodside, N.Y.	clear	yes	may need thinning	good
Nylon in alcohol	General Dispersing, Inc., Bloomfield, N.J.	milky	yes	may need thinning	good
Sodium Silicate	Fisher Scientific New York, N. Y.	clear	no	-	-
Humi Seal Acrylic 1F18	Columbia Technical Corp. Woodside, N.Y.	clear	yes	may need thinning	good
Humi Seal Poly-urethane 1A27	Columbia Technical Corp. Woodside, N.Y.	light amber	yes	must be thinned for dipping	good
Humi Seal Acrylic 1B12	Columbia Technical Corp. Woodside, N.Y.	clear	yes	no thinning necessary	good
Clear gloss lacquer	Grant Paint & Varnish Co. Brooklyn, N.Y.	clear	yes	must be thinned for dipping	good
Quram 220 (organic ammo-mium silicate)	Philadelphia Quartz Co. Philadelphia, Pa.	clear	no	-	-

SOLIDS

Matrix	Manufacturer's Data	Solvent	Percent Solid	Auramine O Solubility	Viscosity	Wetting Ability
Polyethylene Grade 6	Allied Chemical Corp. Morristown, N.J.	Trichlo-rethylene	25%	yes	may need thinning	good
Methocel HG	Dow Chemical Co. Midland, Mich.	Distilled water	2%	yes	no thinning necessary	good.
Polysulfone	Union Carbide Corp. N.Y.,N.Y.	Chloro-benzene	25%	yes	may need thinning	good

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PLASTIC MATRICES AND SOLVENTS - SOLIDS (con't)

Matrix	Manufacturer's Data	Solvent	Percent Solid	Auramine O Solubility	Viscosity	Wetting Ability
Elvanol 71-30	DuPont Wilmington, Del.	Distilled water	2%	yes	no thinning necessary	poor
Elvanol 71-30 plus	DuPont Wilmington, Del.	Leconol wetting agent	2%	yes	no thinning necessary	good
Elvanol 72-60	DuPont Wilmington, Del.	Distilled water	2%	yes	no thinning necessary	poor
Elvanol 72-60 plus	DuPont Wilmington, Del.	Leconol wetting agent	2%	yes	no thinning necessary	good
Ethocel	Dow Chemical Co. Midland, Mich.	Xylene	2%	yes	no thinning necessary	good
Radel (water soluble film)	Union Carbide Corp. N.Y.,N.Y.	Water	2"x2"x .002"	yes	no thinning necessary	good
Sulfonamel	Switzer Bros. Inc. Cleveland Ohio	Dimethyl Formamide	60%	yes	no thinning necessary	good
Radel + Wetting Agent	Union Carbide Corp., N.Y.,N.Y.	Water	2"x2"x .002"	yes	no thinning necessary	good
Cellulose Acetate (Acetyl 40%)	Distillation Products Rochester, N.Y.	Acetone	5%	yes	no thinning necessary	good
Elvanol 52-22	DuPont Wilmington, Del.	Water	2%	yes	no thinning necessary	good
Cyanocel	American Cyanamid Co. Wayne, N. J.	Acetone	5%	yes	no thinning necessary	good
Resinox 755	Monsanto Co. St. Louis, Mo.	Acetone	5%	yes	no thinning necessary	good
VYHH-Vinyl	Union Carbide Corp. N.Y.,N.Y.	Diacetone Alcohol	5%	yes	no thinning necessary	good
VAGH-Vinyl	Union Carbide Corp. N.Y.,N.Y.	Dimethyl Formamide	5%	yes	no thinning necessary	good

TABLE B-IIb

PLASTIC MATRICES AND SOLVENTS - RESULTS

Auramine O in Matrix	Absorption peak - mμ	Fluorescent peak - mμ	Relative Fluorescence	Coating	Remarks
Clear cover glass	260	500	3%		
Sulfonamel	388	520	100%	Transparent	
Methocel	378	517	18%	Transparent	
Elvanol 72-60 + WA	385	519	53%	Transparent	
Elvanol 71-30 + WA	382	519	23%	Transparent	
Elvanol 52-22	386	528	45%	Transparent	

TABLE B-IIb

PLASTIC MATRICES AND SOLVENTS - RESULTS (con't)

Auramine O in Matrix	Absorption peak - mμ	Fluorescent peak - mμ	Relative Fluorescence	Coating	Remarks
Multi Acrylic	273	525	10%	Transparent	grainy
Acrylic 1B12	278	540	20%	Transparent	
Acrylic 1F18	270	515	4%	Transparent	
Gental 101 (Nylon in alcohol)	275 465	538 510	100%+ 100%+	Translucent	
Radel	260	509	12%	Transparent	
Radel + Wetting Agent	260	507	10%	Transparent	
Cyanocel	267	524	100%+	Translucent	
Ethocel	270	522	46%	Transparent	grainy
Cellulose Acetate	260	507	50%	Transparent	grainy
Polyurethane 1127	470 473	522 515	60% 89%	Transparent	
Polyurethane 1A27	450	500	7%	Transparent	grainy
Polysulfone	450	503	100%+	Transparent	grainy
Polyethylene	260	500	100%+	Translucent	grainy
Silicone 1H34	320	620	30%	Transparent	wet
Clear Lacquer	473	520	11%	Transparent	wet
Santicizer 160	260	507	4%	Transparent	wet
Multifarius Vinyl	263	505	6%	Transparent	wet
Vikem PVC	448 255	502 505	100%+ 100%+	Transparent	grainy
Catalin A-1167	375	478	23%	Transparent	grainy
Resinox 755	472	522	30%	Transparent	

TABLE B-IIIa

SOLVENT DATA - PLASTICS

	Auramine O	Sulfonamel	Cyanocel	Cellulose Acetate	Poly-ethylene	Ethocel
Ethyl Alcohol	C Sol.	PS	NS	PS	NS	CS
Methylene Chloride	C Sol.	PS	CS	PS	NS	PS
Methyl Isobutyl Ketone	P Sol.					
Toluene	P Sol.					
Dibutyl Phthalate	C Sol.	CS	NS	PS	NS	PS
Ethylene Glycol Monoethyl Ether Acetate	CS	CS	NS	PS	NS	CS

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TABLE B-IIIa
SOLVENT DATA - PLASTICS (con't)

	Auramine O	Sulfonamel	Cyanocel	Cellulose Acetate	Poly-ethylene	Ethocel
Ethylene Glycol Monoethyl Ether	CS	CS	CS	CS	NS	PS
Acetone	PS					
Isophorone	PS					
Petroleum Ether	NS					
Xylene	NS					
Hexane	NS					
Cyclohexanone	PS					
Trichlorethylene	PS					
Methyl Ethyl Ketone	PS					
Diacetone Alcohol	CS	CS	NS	CS	NS	PS
Acetonitrile	CS	CS	CS	CS	NS	PS
Dimethyl Formamide	CS	CS	CS	CS	NS	PS
Chlorobenzene	PS					
Isopropyl Alcohol	CS	NS	NS	NS	NS	CS
Methyl Alcohol	CS	NS	NS	PS	NS	PS
Butyl Alcohol	CS	NS	NS	NS	NS	CS
Tributyl Phosphate	PS					
Benzene	NS					
Pentyl Acetate	NS					
Pentane	NS					
Distilled Water	CS	NS	NS	NS	NS	NS
Perchlorethylene	NS					
Dimethyl Sulfoxide	CS	CS	CS	CS	NS	PS
Hexamethyl phosphoramide	PS	PS				

TABLE B-IIIb
SOLVENT DATA - RARE EARTHS

Solvent	Terbium Chloride	Terbium Sulfate	Terbium Chloride Solubility	Terbium Sulfate Solubility
Acetone	no fluorescence	no fluorescence	slightly soluble	
Toluene	no fluorescence	no fluorescence	not soluble	not soluble
Methyl Alcohol	no fluorescence	no fluorescence	soluble	not soluble
Methyl Ethyl Ketone	no fluorescence	no fluorescence	soluble	not soluble
Pentyl Acetate	no fluorescence	no fluorescence	slightly soluble	not soluble
Hexane	no fluorescence	no fluorescence	soluble	not soluble
Diacetone Alc.	no fluorescence	no fluorescence	soluble	not soluble

SOLVENT DATA - RARE EARTHS (con't)

Solvent	Terbium Chloride	Terbium Sulfate	Terbium Chloride Solubility	Terbium Sulfate Solubility
Xylene	no fluorescence	no fluorescence	not soluble	not soluble
Ethyl Alcohol	no fluorescence	no fluorescence	soluble	not soluble
Water, distilled	no fluorescence	no fluorescence	soluble	soluble
Benzene	no fluorescence	no fluorescence	not soluble	
Chlorobenzene	no fluorescence	no fluorescence	not soluble	
Tributyl Phosphate	no fluorescence	no fluorescence	soluble	

No test slides made to date.

Solvent Data	Solid	Solvent	Soluble	Fluorescent
TRIS (Salicylaldehydo) Europium #9100	No.	Toluene	No	No
		Acetone	Slightly	No
		C_2H_2OH	Slightly	No
		Diacetone Alcohol	Yes	No
		Methyl Ethyl Ketone	Slightly	No

All samples checked with both long and short wave UV lamps. Best results with long wave lamp.

Since contrast depends not only on how diffuse the coating is but on the fluorescent output as well, no general comment or evaluation can be associated with a given film based on either of the aforementioned quantities. Contrast depends on the ratio of fluorescent output to "diffusibility" and this figure of merit (B) then is the key to an optimum film. For any material under investigation with, concentration as a variable, the value of B must be measured before any quantitative judgement is formed regarding the particular sample.

A variety of plastics, solvents and dyes are readily available for evaluation. Of all the dyes, only a few were determined worthwhile investigating. Rare Earths are ruled out due to their marginal fluorescence. The Switzers show excellent emission properties but they cannot be used for a well controlled experiment. These dyes are clad with Sulfonamel. Since Auramine O has high emission, it is used as the test dye for substrate-concentration measurements.

The technique of measuring diffuse reflection is somewhat complicated and is discussed briefly. Incident light is disposed of in all of the following phenomenon:

- Specular reflection (due to index of refraction)
- Direct transmission
- Absorption (resulting in heat)
- Diffuse reflection
- Diffuse transmission.

The method of measuring diffuse reflection is to illuminate the sample and at an angle different from the angle of incidence. Measure over a cone, the reflected (diffuse) intensity. This is done by using the Farrand Spectrofluorometer. These results, when compared to ground glass at 6100 Angstroms, show that most films are 10 to 20 times less diffuse than ground glass.

TABLE B-IV

CONCENTRATION EXPERIMENTS

1. Sulfonamel - Dimethyl Formamide (60%) Solution

    0.1 grams of Auramine O per 30 ml of 60% solution

2.   0.2 grams of Auramine O per 30 ml of 60% solution

3.   0.2 grams of Auramine O per 60 ml of 30% solution

4. Cellulose Acetate-Diacetone Alcohol (5%) Solution

    0.1 grams of Auramine O per 30 ml of 5% solution

5.   0.2 grams of Auramine O per 30 ml of 5% solution

6.   0.2 grams of Auramine O per 60 ml of 2-1/2% solution

7. Cellulose Acetate-Acetone (5%) Solution

    0.1 grams of Auramine O per 30 ml of 5% solution

8.   0.2 grams of Auramine O per 30 ml of 5% solution

9.   0.2 grams of Auramine O per 60 ml of 2-1/2% solution

10. Polysulfone-Methylene Chloride (10%) Solution

    0.1 grams of Auramine O per 30 ml of 10% solution

11.   0.2 grams of Auramine O per 30 ml of 10% solution

12.   0.2 grams of Auramine O per 60 ml of 5% solution

13. Ethylcellulose-Isopropyl Alcohol (2-1/2%) Solution

    0.1 grams of Auramine O per 30 ml of (2-1/2%) solution

14.   0.2 grams of Auramine O per 30 ml of (2-1/2%) solution

15.   0.2 grams of Auramine O per 60 ml of (1-1/4%) solution

16. Ethylcellulose-Xylene (2-1/2%) Solution

    0.1 grams of Auramine O per 30 ml of (2-1/2%) solution

17.   0.2 grams of Auramine O per 30 ml of (2-1/2%) solution

18.   0.2 grams·of Auramine O per 60 ml of (1-1/4%) solution

19. Polysulfone-Chlorobenzene (10%) Solution

    0.1 grams of Auramine O per 30 ml of (10%) solution

20.   0.2 grams of Auramine O per 30 ml of (10%) solution

21.   0.2 grams of Auramine O per 60 ml of (5%) solution

22. Elvanol 52-22-Distilled Water (2-1/2%) Solution

    0.1 grams of Auramine O per 30 ml of (2-1/2%) solution

23.   0.2 grams of Auramine O per 30 ml of (2-1/2%) solution

24.   0.2 grams of Auramine O per 60 ml of (1-1/4%) solution

25. Elvanol 72-60-Distilled Water (2-1/2%) Solution

    0.1 grams of Auramine O per 30 ml of (2-1/2%) solution

26.   0.2 grams of Auramine O per 30 ml of (2-1/2%) solution

27.   0.2 grams of Auramine O per 60 ml of (1-1/4%) solution

CONCENTRATION EXPERIMENTS (con't.)

28. Zerlon-155-Methyl Isobutyl Ketone (15%) Solution

    0.1 grams of Auramine O per 30 ml of (15%) solution

29.   0.2 grams of Auramine O per 30 ml of (15%) solution·

30.   0.2 grams of Auramine O per 60 ml of (7-1/2%) solution

31. Zerlon-155-Acetone (10%) Solution

    0.1 grams of Auramine O per 30 ml of (10%) solution

32.   0.2 grams of Auramine O per 30 ml of (10%) solution

33.   0.2 grams of Auramine O per 60 ml of (5%) solution

34. Omitted

35. Cyanocel-Acetonirile (5%) solution

    0.1 grams of Auramine O per 30 ml of (5%) solution

36.   0.2 grams of Auramine O per 30 ml of (5%) solution

37.   0.2 grams of Auramine O per 60 ml of (2-1/2%) solution

38. Cyanocel-Acetone (5%) Solution

    0.1 grams of Auramine O per 30 ml of (5%) solution

39.   0.2 grams of Auramine O per 30 ml of (5%) solution

40.   0.2 grams of Auramine O per 60 ml of (2-1/2%) solution

Table V shows the results of diffusion measurements. Note that in almost all cases, the reference diffusion (ground glass) is about a factor of 20 higher than any given slide. All diffusion data was taken at λ = 610 millimicrons so that the slide would not fluoresce.

The most difficult part of the experiments deals with comparing the normal ray of fluorescent output of each slide. The problems lie in the fact that:

    a) the glass substrates show fluorescent tendencies.

    b) the 0th order of the filtered source leaks out of the source.

    c) the gratings only imperfectly reject other wavelengths.

TABLE B-V

RESULTS OF DIFFUSION MEASUREMENTS

Slide Identification Number	Reference Diffusion Reading (μa)	at 610 mμ Diffusion Reading (μa)	No Filter Visual Observations of Film
1	11.5	.55	Growing – Otherwise good
2		.91	
3		.56	
4		1.05	
5		1.31	
6	11.5	1.09	
7	9.1	.63	
8	11.5	1.71	
9		1.30	

TABLE B-V

RESULTS OF DIFFUSION MEASUREMENTS (con't)

Slide Identification Number	Reference Diffusion Reading (μa)	at 610 mμ Diffusion Reading (μa)	No Filter Visual Observations of Film
10		2.54	
11		4.89	Granular Coat
12		2.89	
13		.86	
14		1.54	
15		.90	
16	11.5	.75	
17	9.1	.73	
18		.83	
19		1.85	
20		1.23	
21		.63	
22		.50	
23		2.05	
24		.85	
25	9.1	.67	
26		.92	
27		1.15	
28		1.00	
29		1.79	
30		.91	
31		2.65	
32		3.69	
33		6.62	
34			
35		3.61	
36		6.15	
37		3.95	
38		3.05	
39		4.39	
40		2.63	

To obtain the purest possible data, it is required that a UV filter be used in front of the UV source and a visible filter after the UV filter. This essentially eliminates "stray" UV from striking the photomultiplier.

Table B-VI is an initial spectral calibration of the UV source and filter. The 1P28 phototube is within $\pm 10\%$ in this range.

TABLE B-VI

SPECTRAL CALIBRATION OF UV SOURCE AND FILTER

X Millimicrons	% Output
300	14%
320	29%
340	56%
350	70%
360	78%
380	100%
400	63%
420	7%

The results of all slides are shown in Tables B-VII and B-VIII. A noteworthy point is that the response is fairly uniform as a function of wavelength, indicating considering the lamp response that the dye peaks near 300 millimicrons.

TABLE B-VII

RESULTS OF SLIDES

Slide Identification Number	Fluorescent λ (mμ)	Normal* Fluorescent Power at 300 mμ (μa)	Normal* Fluorescent Power at 350 mμ (μa)	Normal* Fluorescent Power at 385 mμ (μa)
1	514	.045	.054	.0885
2	516	.037	.044	.0525
3	510	.043	.0445	.0615
4	493	.048	.046	.049
5	508	.041	.0415	.0415
6	467	.087	.0795	.0905
7	505	.041	.042	.045
8	507	.039	.040	.0325
9	490	.0435	.041	.0455
10	467	.054	.0495	.0615
11	470	.039	.0365	.0465
12	490	.034	.034	.0475
13	468	.075	.069	.0775
14	467	.070	.064	.072
15	468	.076	.0695	.0785
16	468	.095	.087	.097
17	464	.0262	.0232	.0237
18	468	.035	.0315	.0345
19	369	.074	.069	.0835
20	465	.0775	.0705	.083
21	466	.088	.080	.092

* Photo multiplier Current

RESULTS OF SLIDES (con't)

Slide Identification Number	Fluorescent λ (mμ)	Normal* Fluorescent Power at 300 mμ (μa)	Normal* Fluorescent Power at 350 mμ (μa)	Normal* Fluorescent Power at 385 mμ (μa)
22	493	.048	.045	.052
23	483	.042	.0385	.042
24	490	.0445	.041	.047
25	467	.059	.0545	.065
26	466	.053	.048	.053
27	483	.045	.041	.0455
28	467	.089	.0815	.0925
29	465	.077	.070	.0825
30	466	.0855	.0785	.0895
31	466	.041	.0395	.049
32	493	.021	.0215	.0285
33	470	.038	.0405	.056
34	No slide made			
35	515	.0174	.0235	.029
36	510	.0176	.0166	.0215
37	508	.017	.0209	.0256
38	508	.018	.023	.026
39	515	.0147	.0194	.0224
40	512	.0215	.0282	.034

$$S1 = 20 \text{ m}\mu$$
$$S2, S3, S4 = 5 \text{ m}\mu$$

The best materials for nominal concentrations are:

1 - Sulfonamel-Dimethyl Formide 6% solution - 0.1 grams dye to 30 ml solution.

2 - Ethyl Cellulose-Xylene 2-1/2% solution - 0.1 grams dye to 30 ml solution.

3 - Elvanol 52-22-Distilled Water 2-1/2% solution - 0.1 grams dye to 30 ml solution.

4 - Elvanol 72-60-Distilled Water 2-1/2% solution - 0.1 grams dye to 30 ml solution.

TABLE B-VIII

RESULTS OF SLIDES

Slide Identification Number	Fluorescent* Output at 385 mμ (Normal) μa	Diffuse* Reflection at 610 mμ μa	Ratio, B Normal Fluorescent Output ÷ Diffuse Reflection (x 10^{-3})
1	.0885	.55	161.0
4	.0490	1.05	46.6
7	.0450	.63	71.4

* Photo Multiplier Current

TABLE B-VIII
RESULTS OF SLIDES (con't)

Slide Identification Number	Fluorescent* Output at 385 mμ (Normal) μa	Diffuse* Reflection at 610 mμ μa	Ratio, B Normal Fluorescent Output ÷ Diffuse Reflection (x 10^{-3})
10	.0615	2.54	24.2
13	.0775	.86	90.2
16	.0970	.75	129.6
19	.0835	1.85	45.2
22	.0520	.50	104.0
25	.0650	.67	97.0
28	.0925	1.00	92.5
31	.0490	2.65	18.5
35	.0290	3.61	8.03
38	.0260	3.05	8.52
2	.0525	.91	67.5
3	.0615	.65	110.0
17	.0237	.73	32.5
18	.0345	.83	41.6
23	.042	2.05	20.5
24	.047	.85	64.7
26	.053	.92	57.6
27	.0455	1.15	39.5

The Sulfonamel in conjunction with the Switzer dyes are optimum, in comparison to all the plastic solvents tested. It was observed that the peak emission wavelength varied slightly as a function of matrix. Both of these facts were recognized earlier in the program.

Table B-IX shows the value of B for the Switzer Q15

TABLE B-IX
SWITZER Q15 SERIES

Concentrations	B (x 10^{-3})
Switzer Q_{15}/ADA sol.	
1 grm/2 ml	41.6
1 grm/5 ml	50
1 grm/7.5 ml	8
1 grm/10 ml	18.5
1 grm/15 ml	12.5
1 grm/20 ml	11.4
1 grm/25 ml	6.0
Nominal 1 grm/1 ml	67.0
2 dips 1 grm/1 ml	30.3
3 dips 1 grm/1 ml	43.7

* Photo Multiplier Current

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As was shown, the Switzer Q series proved to have the best figure of merit B for the materials tested. Preliminary trials, however, show that the rare earths are equally good, and have the added feature of optical clarity. The emission spectrum is well within the transmission band and the emission peaks are far removed from the absorption peaks. For each of the Q series dyes, the following data was obtained:

- Transmission
- Emission spectrum
- Relative output for various UV excitation

This amassed data is reduced and portrayed graphically in Figure B - 1 through Figure B - 7. The most interesting general feature as exhibited by Figure B - 3 and Figure B - 4 is that the transmission is drastically affected by the absorption band. Consequently, the output is greatly influenced by the concentration.

As shown, the worst wavelength for the dyes is in the vicinity of 350 millimicrons, and the best will be above 400 millimicrons or near 300 millimicrons. This points out that P-16 phosphor may be the best exciter.

It is suspected that the Sulfonamel has some effect on the dye at 350 millimicrons although the transmission characteristics of Sulfonamel do not reveal this.

SPECTRAL CHARACTERISTICS
AURAMINE O IN SULFONAMEL,
SPECTRUM, TRANSMISSION,
STIMULATED OUTPUT VS. λ
1gm AURAMINE O:25ml sol
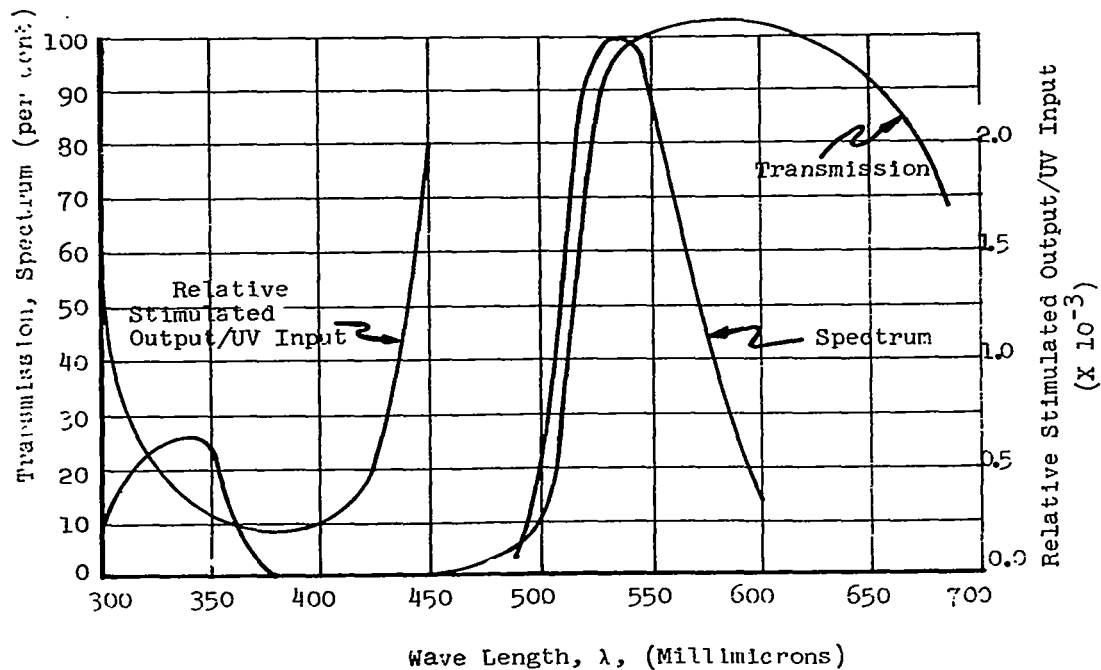50% SULFONAMEL IN DIMETHYL
FORMAMIDE BY WEIGHT

Wave Length, λ, (Millimicrons)

Figure B-1. Graphic Results of All Data

SPECTRAL CHARACTERISTICS Q_{13} SWITZER, SPECTRUM, TRANS-
MISSION, STIMULATED OUTPUT VS. λ, 5gm Q_{13}: 20ml 1:1 ADA
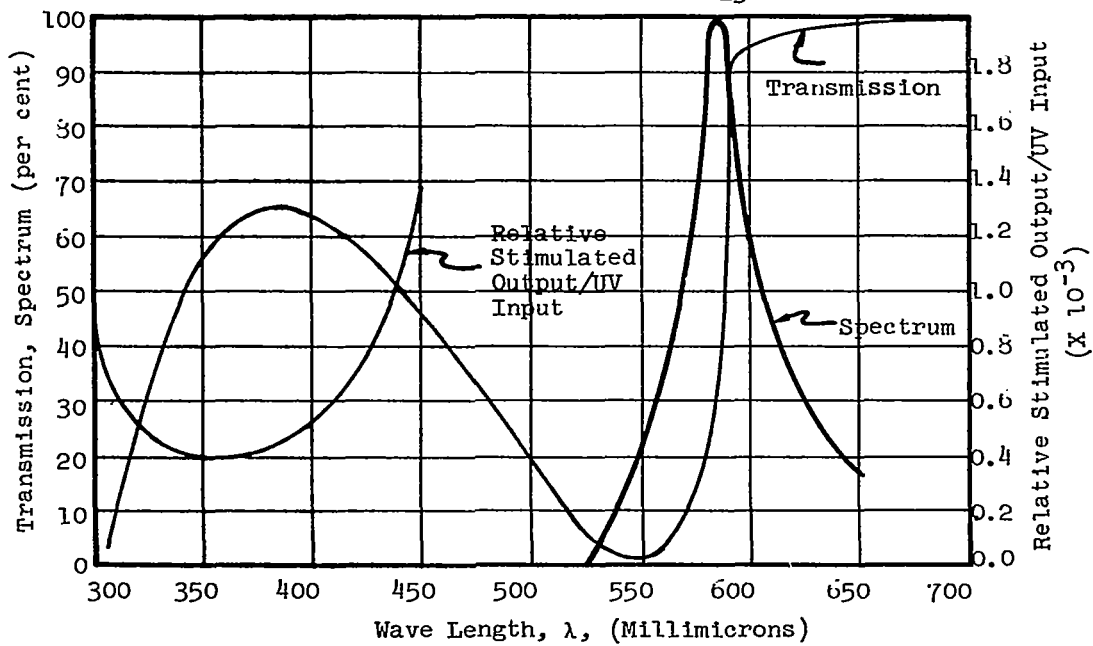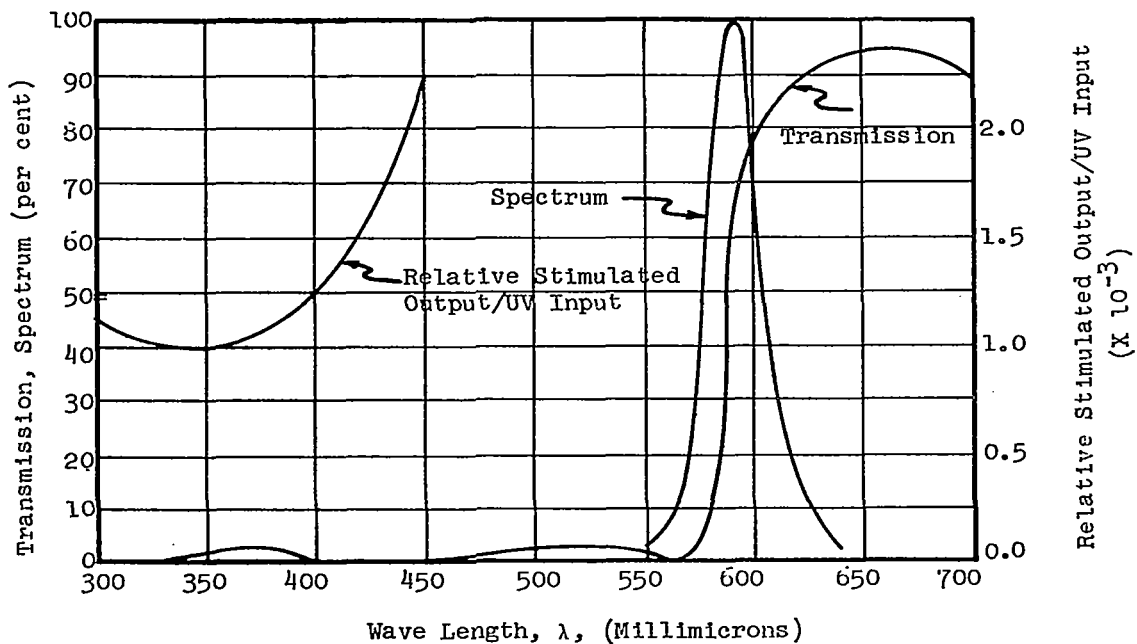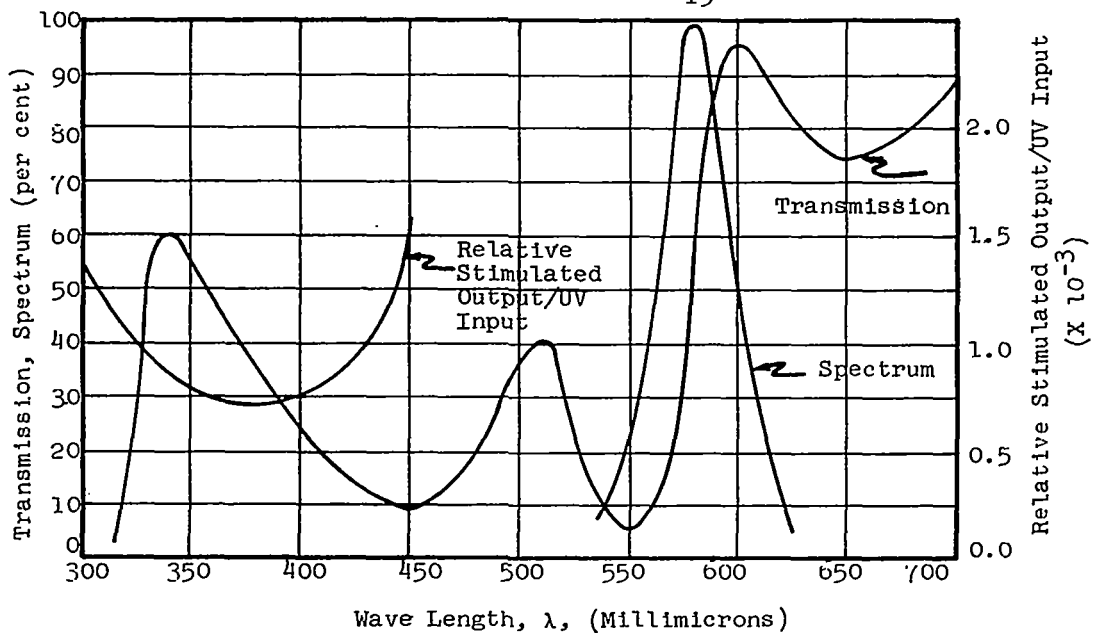

Figure B-2. Graphic Results of All Data

SPECTRAL CHARACTERISTICS Q_{15} SWITZER, SPECTRUM, TRANS-
MISSION STIMULATED OUTPUT VS. λ 5gm Q_{15} TO 10 ml 1:1 ADA

Figure B-3. Graphic Results of All Data

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SPECTRAL CHARACTERISTICS Q_{15} SWITZER, SPECTRUM, TRANS-
MISSION STIMULATED OUTPUT VS. λ, 5gm Q_{15} TO 20 ml 1:1 ADA

Figure B-4. Graphic Results of All Data

SPECTRAL CHARACTERISTICS Q_{17} SWITZER, SPECTRUM, TRANS-
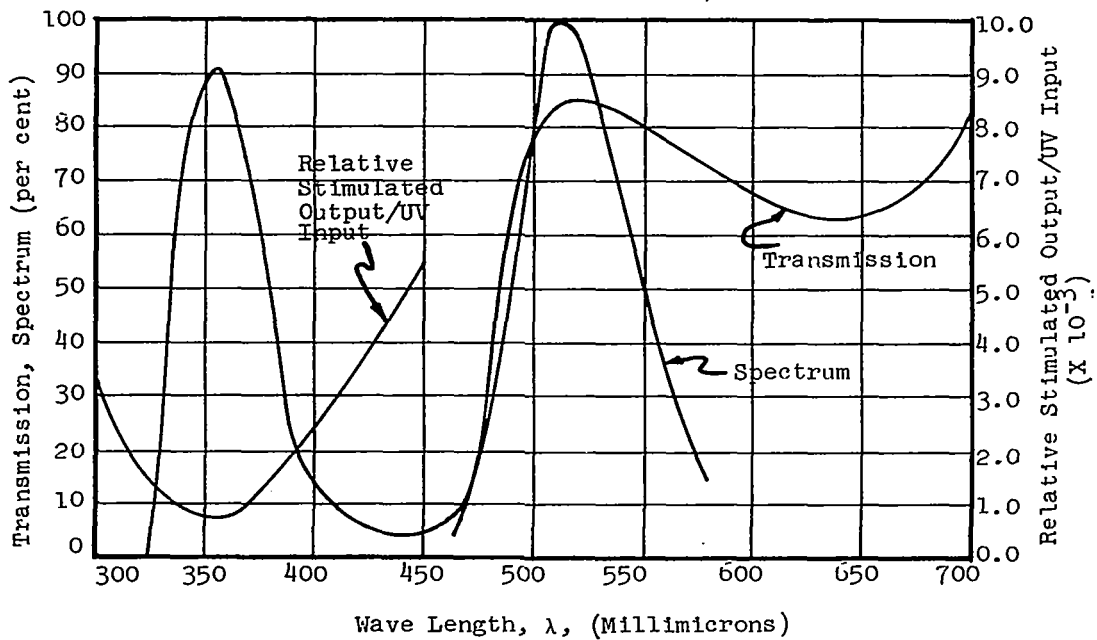MISSION STIMULATED OUTPUT VS. λ 5gm Q_{17} TO 20 ml 1:1 ADA

Figure B-5. Graphic Results of All Data

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SPECTRAL CHARACTERISTICS Q_{18} SWITZER, SPECTRUM, TRANSMISSION
RELATIVE STIMULATED OUTPUT VS. λ 5gm Q_{18} TO 20 ml 1:1 ADA

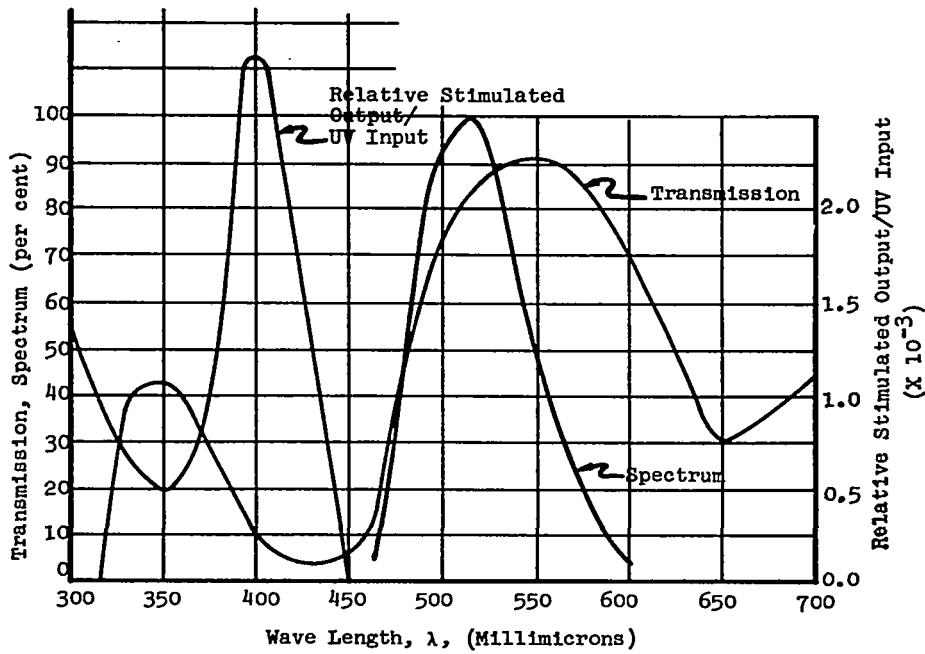Figure B-6. Graphic Results of All Data

SPECTRAL CHARACTERISTICS Q_{19} SWITZER, SPECTRUM, TRANS-
MISSION STIMULATED OUTPUT VS. λ, 5gm Q_{19} TO 20 ml 1:1 ADA
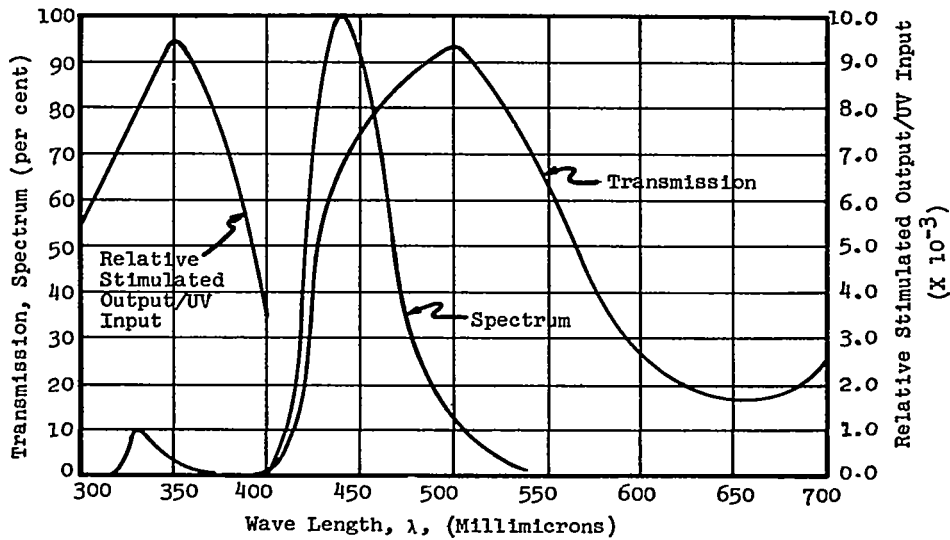

Figure B-7. Graphic Results of All Data

TABLE B-X

OPTIMUM COMBINATIONS

Dye and Concentration (gm/ml)	Corning Filter type		Peaks Millimicrons	Relative Intensity x 10-3		± 10% points milli- micron	Cutoff wavelength milli- micron
	Theoretical	Actual		400mμ	450mμ		
Auramine O	3-71	-	540	.2	2.0	490-610	490
Q13 (5:20)	3-68	3-66	580	.5	1.4	545-675	525
Q15 (5:10)	3-67	3-66	585	1.2	2.2	555-625	550
Q15 (5:20)	3-69	-	575	.8	1.6	545-610	525
Q17 (5:20)	3-72	3-71	510	2.5	5.5	460-590	455
Q18 (5:20)	3-72	-	510	3.0	0	460-590	450
Q19 (5:20)	3-74	-	440	3.3	0	410-500	400

APPENDIX C

MEASUREMENT DEFINITION

Throughout the course of this program it was felt that there exists a large discontinuity in definitions of photometric measurements. For example, the usage of Ft.-Lamberts was purposely avoided in favor of the usage of power/unit-area or power density.

The sensor or the human eye senses total power or power/unit area x size of the eye aperture. In fact, almost <u>any</u> sensor senses total power or total energy. Power and energy are fairly straightforward fundamental quantities where brightness or Ft.-Lamberts are artificial conveniences.

The purpose of this section is to clarify and define all of the various terminology. For this purpose, we consider two distinct clear-cut relationships:

    A) Relating to incident radiation.

    B) Relating to source radiation.

    A) <u>Relationships relating to incident radiations</u> - Plane electromagnetic waves behave according to Maxwell's equations

$$\vec{p} = \vec{V} \times \vec{M}$$

where V and M are electric field volts/meter and magnetic field amp/meter respectively. The quantity $\vec{p}$ is then watts/meter^2 or power density on power/unit area. For a given area A, the total power P is $P = \vec{p}A$, where P is watts. In the visible range, it is more convenient to speak of power (or flux) as lumens. By definition, 1 watt = 680 lumens, no matter what the wavelength.

It is not clear where the historical origin of the usage stems, however, it must be accepted that a lumen is a unit of power.

It is established that when one speaks of illumination, power density or power/unit, area is the corresponding basic quantity in the Maxwell sense.

Conventional units are watts/meter^2, lumen/ft^2, (foot candles)

where   1 lumen/ft^2 $\triangleq$ 1 foot-candle

    B) <u>Relationships relating to source</u> - Flux radiates in a pattern. Along any particular axis the incident power/solid angle subtended is a constant independent of the distance to the source. By definition then, Luminous Intensity

$$L = \frac{dP}{d\omega}$$

ω = solid angle subtended

P is taken over the solid angle.

The units are lumen/steradian and by definition

    1 Lumen/steradian = 1 candle.

Luminous intensity applies to any source, provided the observer is far enough away so that it appears as a <u>point</u> source. For an incoherent source, if the observer is five times the distance away as the largest source dimension, the source pattern appears as a point source.

Also note that, 1 candle = 1 candle power.

The last of the definitions to be expressed in basic units is luminance B, which also relates only to the source but considers the fact that the source has a finite area.

The shortcoming of the quantity $I = \frac{dP}{d\omega}$ is that if we used a large source, one gets a large I. The use of luminance is a way of rating sources considering the area.

$$B \triangleq \frac{dL}{dA \cdot \cos \theta}$$

where $\cos \theta$ relates the idea of projected area.

Since

$$L = \frac{dP}{d\omega}$$

so

$$B = \frac{dP}{d\omega dA \cos \theta}$$

or units of Lumens/Steradian/area of candles/area.

The two most commonly accepted definitions of Luminance in terms of known quantities is the foot-Lambert or the Lambert or Stilb (CIE).

Since 1 candle/area = 1 lumen/steradian/area = 680 watts/steradian/area a new unit as above can be defined as such

$$1 \text{ Lambert} = \left(\frac{1}{\pi} \right) \text{ candles/cm}^2$$

$$1 \text{ Ft.-Lambert} = \frac{1}{\pi} \text{ candles/ft}^2$$

$$1 \text{ Stilb} = 1 \text{ candle/cm}^2$$

An area source whose brightness is 3.14 candles/ft^2 has a brightness of 1 ft.-Lambert.

REFERENCES

Kodak Publication "Tech Bits" 1965 No. 1

Scientific Basis of Illuminating Engineering, Perry Moon p. 553

Applied Optics and Optical Engineering, Kingslake Vol. 1 p. 1

Fundamentals of Optics, Jenkins and White, p. 109

APPENDIX D

(REFERENCE: NOTEBOOK NO. 176)

PROCEDURE FOR APPLYING CONDUCTIVE COATINGS TO SUBSTRATES

Prior to heating the 0.5 mm thick U.V. filter it is good practice to have it thoroughly clean. The muffle furnace is then preheated to exactly 600°C. This temperature is critical and should be manually cycled between 590°C and 600°C. It was found that if the substrate is heated at too low a temperature the surface of the glass would not be receptive to the conductive coating. This would result in the conductance of the coating being poor. If the substrate is heated at too high a temperature the glass will melt and flow just enough that the surface of the substrate loses its flatness. It was found that if the UV filter was placed on a maronite block at room temperature, it would not be subject to any thermal shock prior to placing it in the furnace.

When the furnace is at exactly 600°C the block and substrate are inserted and the temperature manually controlled to maintain a uniform heat. The substrate is allowed to remain in the furnace just long enough to apply the TC (Tin chloride) solution.

Once the substrate has been coated both the maronite block and the substrate are removed and allowed to cool at room temperature.

PHOSPHOR SETTLING PROCEDURE

Phosphor settling is carried out in a one liter beaker. It is preferred that this beaker be of sufficient height to provide uniform dispersion of the phosphor. In order to obtain good screen uniformity, the phosphor suspension should be dispensed uniformly in the settling solution. At the end of the settling time the solution is either drained through a spout in the bottom of the container or siphoned out with an aspirator.

The preparation for settling consists of dissolving 0.3g of barium acetate in 1 liter of deionized water and placing it in an appropriate beaker. For best results this solution should be kept below room temperature during the settling process. A clean substrate is then placed in the bottom of a beaker upon an elevated holder which provides for easier removal. A separate beaker is prepared containing 40 ml of deionized water and 20 ml of a 30% potassium silicate solution. 0.4g of phosphor is added to this mixture. This will provide a screen weight of 5 mg/cm^2 when deposited on surface of 180 cm^2 area.

The phosphor is then dispersed in the solution by shaking for approximately one minute. After thoroughly shaking the phosphor mixture, it is dispensed into the acetate solution and allowed to settle undisturbed for 45-60 minutes. The beaker is then drained, the substrate heat dried in an oven.

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APPENDIX E

THE USE OF INORGANIC FLUORESCENT GLASS AS A SECONDARY EMITTER
RATHER THAN AN ORGANIC FLUORESCENT AGENT

The following list of pages deals specifically with the experiments and research involved in the development of a prototype High Contrast CRT which utilizes an inorganic fluorescent glass as a secondary emitter rather than using organic fluorescent agents. They are: page 5 and 28 through 46.

A feasibility investigation was sponsored entirely by Hartman Systems Company and has resulted in an application for patent consideration.