NASA CONTRACTOR REPORT

NASA CR-1597

HIGH CONTRAST CATHODE RAY TUBE ENGINEERING REPORT

by D. Bolum

Prepared by
HARTMAN SYSTEMS CO.
Huntington Station, N. Y.
for Electronics Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JULY 1970

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ABSTRACT

A high contrast cathode ray tube, employing an integrated faceplate filter, was developed. The improved non-reciprocal filter design consists of fabricating a 5-inch CRT faceplate, with integrated composite filters, utilizing the principles developed on Contract NAS 12-97 (phase I of the total project effort) the results of which have been reported in the NASA contractor report CR-1185. Specifically, the faceplate developed during phase II is constructed of fluorescent glass with a very thin U.V. transmitting glass laminated or bonded to the interior and a spectrally matched passive color filter laminated to the exterior or viewing side. The non-reciprocal filter is constructed as an integrated part of the faceplate and, compared to the phase I prototype, exhibits improved image resolution, more efficient heat transfer, and minimum specular and diffuse reflection while maintaining uniform contrast and readability under widely varying levels of ambient illumination. This program has concentrated on the problem of laminating the filter components into a single composite filter structure suitable for incorporation into a CRT as a high contrast faceplate.

FOREWORD

This report summarizes the results attained during a research and development program to develop a composite filter structure suitable for utilization as a high contrast CRT faceplate for viewing under high ambient illumination with TV resolution capability. Work on this project was performed under the direction of Mr. K. Lally, Chief of Advanced Development, during the period from January 1968 to July 1969, for the National Aeronautics & Space Administration, Electronics Research Center, under contract number NAS 12-605. The contract was administered by NASA-ERC with Mr. H. Bullinger acting as the technical monitor.

The engineering personnel assigned to this project were: Mr. D. Amberger, Senior Staff Engineer and Mr. D. Bolum, Engineer. The assistance of Mr. G. Schaefer, who performed most of the laboratory experimentation and filter fabrication, is gratefully acknowledged.

Preparation of this report was the responsibility of Mr. D. Bolum.

TABLE OF CONTENTS

Section Page

Appendix Page

TABLE OF CONTENTS (cont)

TABLE OF CONTENTS (cont)

Appendix Page

LIST OF ILLUSTRATIONS

Figure Page

LIST OF ILLUSTRATIONS (cont)

LIST OF TABLES

LIST OF TABLES (cont)

SECTION I

INTRODUCTION

The high contrast CRT, shown in Figure 1, is unique in that it maintains readability under varying levels of ambient illumination. The extention of this concept into systems areas, however, is circumscribed by the thickness of the ultraviolet filter.

Since the thickness of the U.V. pass band filter determines the amount of degradation in resolution, which is due to the degree of spreading of light between the U.V. emitter and the fluorescent converting layer, it becomes an essential factor for consideration in the fabrication of the faceplate. This limitation can be alleviated by the employment of a thinner U.V. glass possessing the same absorption density. However, the inherent characteristics of thin glass structures present problems in handling and physical size which are undesirable fabrication features.

The purpose of this program (phase II of the total project effort) was to minimize these undesirable features by applying a very thin U.V. filter to the surface of a fluorescent base glass, thus achieving high resolution and mechanical strength.

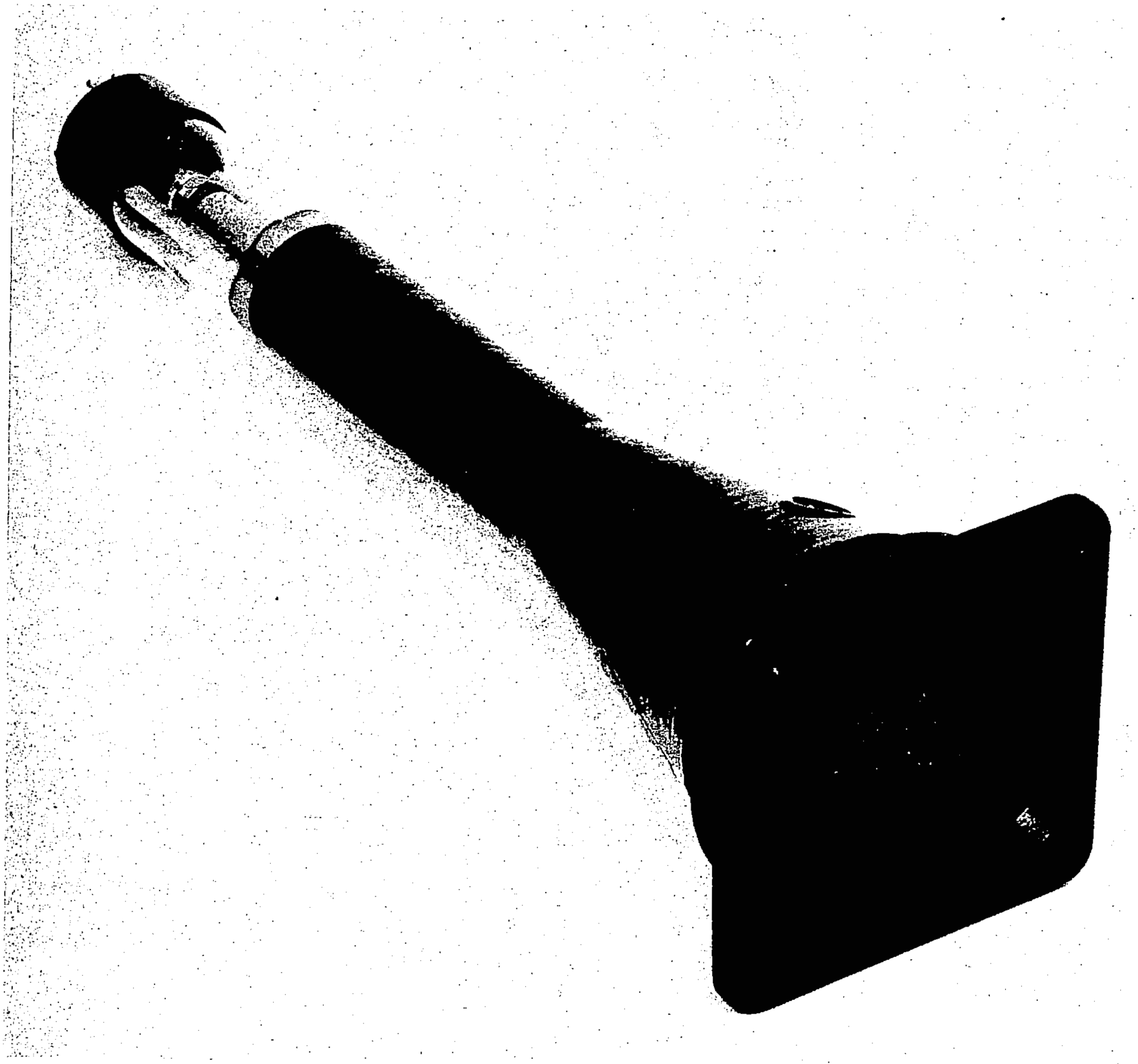


Figure 1. 3-Inch CRT

SECTION II

SUMMARY

Extensive investigation into several approaches of fabrication of thin U.V. filters on a fluorescent base glass resulted in pursuing two methods in depth, to a successful conclusion. One was Corning's lamination process and the other was Hartman Systems Co. high temperature diffusion of cobalt compounds into a fluorescent base glass. Both processes provided adequate U.V. film thickness of 5 mils; however, the H.S.C. faceplate was selected for incorporation into the deliverable tube.

The fluorescent glass investigation failed to provide any glass possessing an improved conversion efficiency over the uranium oxide doped borosilicate glass.

In the U.V. phosphor area, success was obtained in improved, more efficient, calcium silicate: lead, and barium silicate: lead phosphors, the latter being incorporated into the delivered CRT.

Finally the faceplate was mechanically mounted internal to the CRT bulb, assembled, and performance tested. The contrast and resolution were found to be superior to any of previous fabrications and, in addition, provided more efficient heat transfer and minimized specular and diffuse reflection.

SECTION III

PROGRAM OUTLINE

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

Task 1 - Identify, by a literature search, vendor search, and in-house experimentation, feasible methods of forming a thin ultraviolet filter, integrally, with a fluorescent glass substrate.

Studies included alkali-metal films, flame spray of glass compounds, R.F. sputtering of metallic oxides, vapor deposition of inorganic materials, and high temperature diffusion of nickel-cobalt compounds into fluorescent glasses.

From the investigations and studies, develop a composite filter structure 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.

In addition, design the filter structure for minimum degradation of image resolution.

Task 2 - Perform further investigation and evaluation of fluorescent glasses, other than the uranium oxide doped glass, such as the rare earth type glasses, in order to obtain various colors and/or higher output.

Task 3 - Perform further investigation and evaluation of ultraviolet phosphors in order to obtain an optimum match with the absorption bands of the fluorescent glasses.

Task 4 - Fabricate, evaluate, and deliver to ERC a fully operational cathode ray tube employing the best principles determined under the above tasks, and incorporating suitable interference filters to reduce specular reflection. The goal of this task will be the fabrication of a tube of sufficient size to allow demonstration of 525-line resolution capability.

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

The pre-experimental activities were devoted to the planning of tasks and to the requisitioning of materials necessary to perform the forthcoming experimental stages of the program. Several technical conferences with glass and equipment manufacturers followed to explore the practicality of various approaches to the lamination of a thin U.V. filter onto a fluorescent substrate.

In-house glass formulation experiments were initiated, to observe the characteristics of the various glass batches, select the more suitable samples, and then to perform additional cobalt oxide saturation experiments with these select glasses. The results of these tests are tabulated in the appendices of this report.

Utilizing the selected glass the saturation limit of the cobalt oxide was ascertained. These tests substantiated the fact that a thin U.V. filter may have the same optical density as an equivalent thicker filter by increasing the percent of doping proportionally.

Low-melt vitreous fluxes were then introduced into the selected cobalt oxide doped glasses to further provide a "wetting" effect on the surface and thereby induce a better bond between the filter and base glasses.

The low melt material was then optimized with regard to thermal expansion, matching, bonding, and dispersion of the metallic oxide material throughout the glass. The ultraviolet film thickness was measured at less than 15 microns, which is significant in regard to the inherent resolution of the composite filters. Faceplates were then fabricated to 1-inch, 3-inch and 5-inch diameters to verify that there was no intrinsic size limit.

In addition, contacts were established with Corning Glass Works, Corning, N.Y., Metco Inc. Westbury, N.Y. and the Consolidated Vacuum Corp. Rochester, N.Y. for the purpose of defining and verifying methods of producing a thin U.V. filter employing other techniques.

Various fluorescent glasses were investigated, including a white luminescent glass and several rare earth type glasses. However, none of these provided or improved conversion efficiency over the uranium oxide-doped borosilicate glass.

Several ultraviolet phosphors from various sources were evaluated by settling them on screens, mounting on a faceplate, and placing them in a demountable CRT. The results of this investigation are listed in Appendix V of this report.

The faceplate fabricated by Hartman Systems Co. was incorporated into a sealed tube which was assembled in accordance with standard industrial practices.

The cathode ray tube was then performance tested with regard to brightness, contrast, and resolution.

SECTION IV

TECHNICAL DISCUSSIONS

1. GENERAL CONSIDERATIONS

The most useful electro-optic displays for aerospace applications also possess characteristics which tend to degrade their performance under high ambient light levels. One example of this degeneration is the phosphor screen of a CRT which is diffusely reflecting and optically near-white (forming a highly reflective surface for incident ambient illumination). Here, the observer must often cope with an intolerable light level in trying to perceive information of critical value for proper tactical or navigational decisions. Increasing the display brightness as one solution has its limits, due to increasing visual fatigue over extended periods. Balanced solutions are found only by manipulation of both brightness and contrast.

However, many of the techniques which have been implemented in the past to increase contrast possess severe limitations which curtail their general utility. The non-reciprocal filter is the most practical solution to this problem to date.

At the conclusion of the previous contract (NAS 12-97), the feasibility of employing "non-reciprocal" optical filters to achieve high gains in contrast in a CRT was clearly substantiated. Figure 2 is a cross sectional view of this filter showing its component parts and optical functions.

In brief, the light from a U.V. source is transmitted through a visible absorbing, U.V. transmitting filter (A) to excite a transparent fluorescent material into emission at a longer visible wavelength, such as green. The output filter (B) is then chosen to be green so that only this emission band will be passed and subsequently the stimulated fluorescent emission may be readily viewed. Proceeding from the opposite direction, however, broad-spectrum ambient light first encounters the green filter which removes all wavelength components except green. This green band is transmitted through the active layer but its wavelength is too long to stimulate fluorescence. If the active layer is transparent, no diffuse reflection will occur and since the remaining ambient light is within the emission band of the fluorescent material, it will merely be transmitted through the active layer and then totally absorbed in the bisible absorbing filter. Thus, all incident ambient components are absorbed before they have an opportunity to illuminate any subsequent diffuse surfaces such as the phosphor screen.

Due to the degree of spreading of the emitted light from the phosphor surface through the U.V. filter, and thus the increase in spot size, it is essential to obtain as thin a U.V. filter as possible in any composite filter fabrication when high resolution

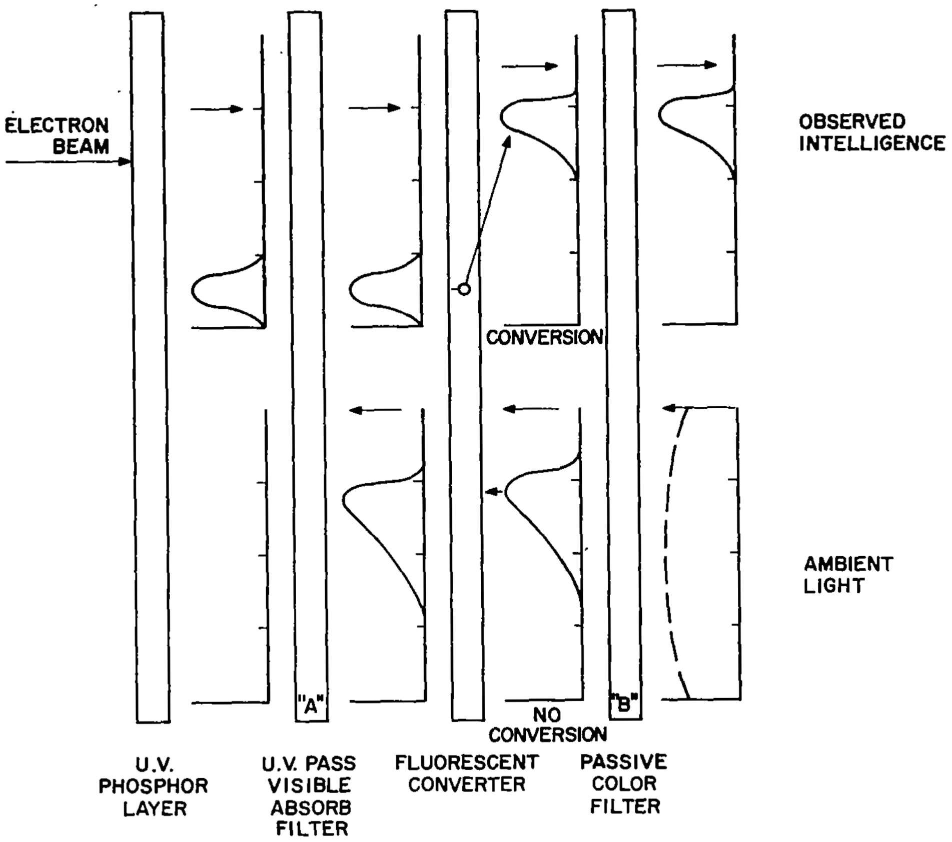


Figure 2. Exploded View of Non-Linear Filter

is required. Referring to Figure 3, the spread in spot size can be calculated if the filter thickness (d) and the index of refraction (n) are known.

A stimulated point in the phosphor layer radiates through the U. V. filter and is thereby spread to a spot of Diameter D which strikes the fluorescent layer. The visual image of the stimulated phosphor point therefore appears unfocused.

All the light radiating from the point of phosphor emission enters the U. V. filter and is refracted or reflected at the U. V. fluorescent glass interface. Here, the critical angle is the limiting angle of refraction and all rays beyond this angle are totally reflected. Since at the critical angle θ = 90° it follows from Snell's law that sin

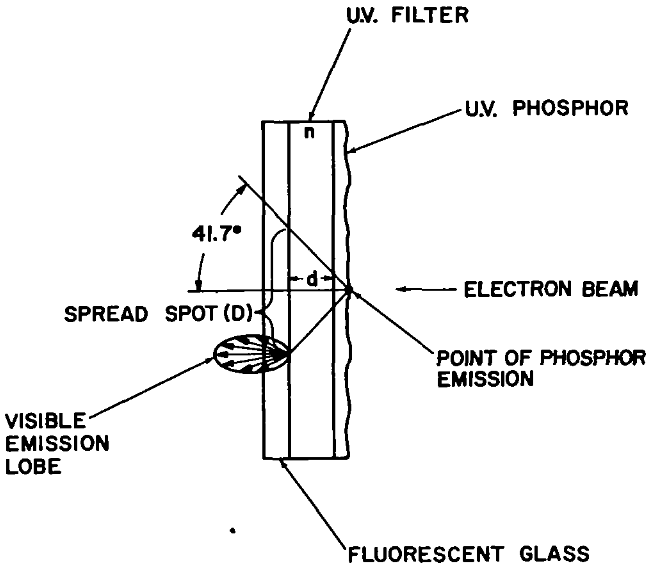


Figure 3. Spreading Image through U.V. Filter

$\theta c = \frac{1}{n}$ where n is the index of refraction of the optically denser medium with respect to air. If the index of refraction (n) of the U.V. filter was 1.37, then the critical angle would be 41.7° as indicated in Figure 3. Now that the critical angle, the thickness of the U.V. filter, and the index of refraction of the filter are known, the spot diameter (D) can be calculated, where $D = 2d \operatorname{Tan} 41.7^\circ$.

If a resolution of 100 lines/inch is chosen, then:

$$D = 0.01 \text{ inch and } d = \frac{D}{2 \operatorname{Tan} 41.7^\circ} = \frac{0.01}{2(0.89)} = \frac{0.01}{1.78} = 0.00562 \text{ inch}$$

or the thickness of the filter would be 0.1455 mm. Such an extremely thin piece of glass would be very difficult to handle. Another method would be to fuse a heavier piece of glass to the thicker fluorescent glass and then polish it to 0.1 mm.

A CRT identical in construction to the tube delivered under contract NAS 12-97 but reduced in size and with a 3-inch diameter faceplate, was completed during a company funded program. This CRT is shown in Figure 4. The tube employed a 20 mil thick ultraviolet filter in close proximity to a fluorescent faceplate and exhibited a spot resolution of about 30 mils with extremely high contrast. The sole factors, limiting both resolution and ultimate tube diameter, were the characteristics of the

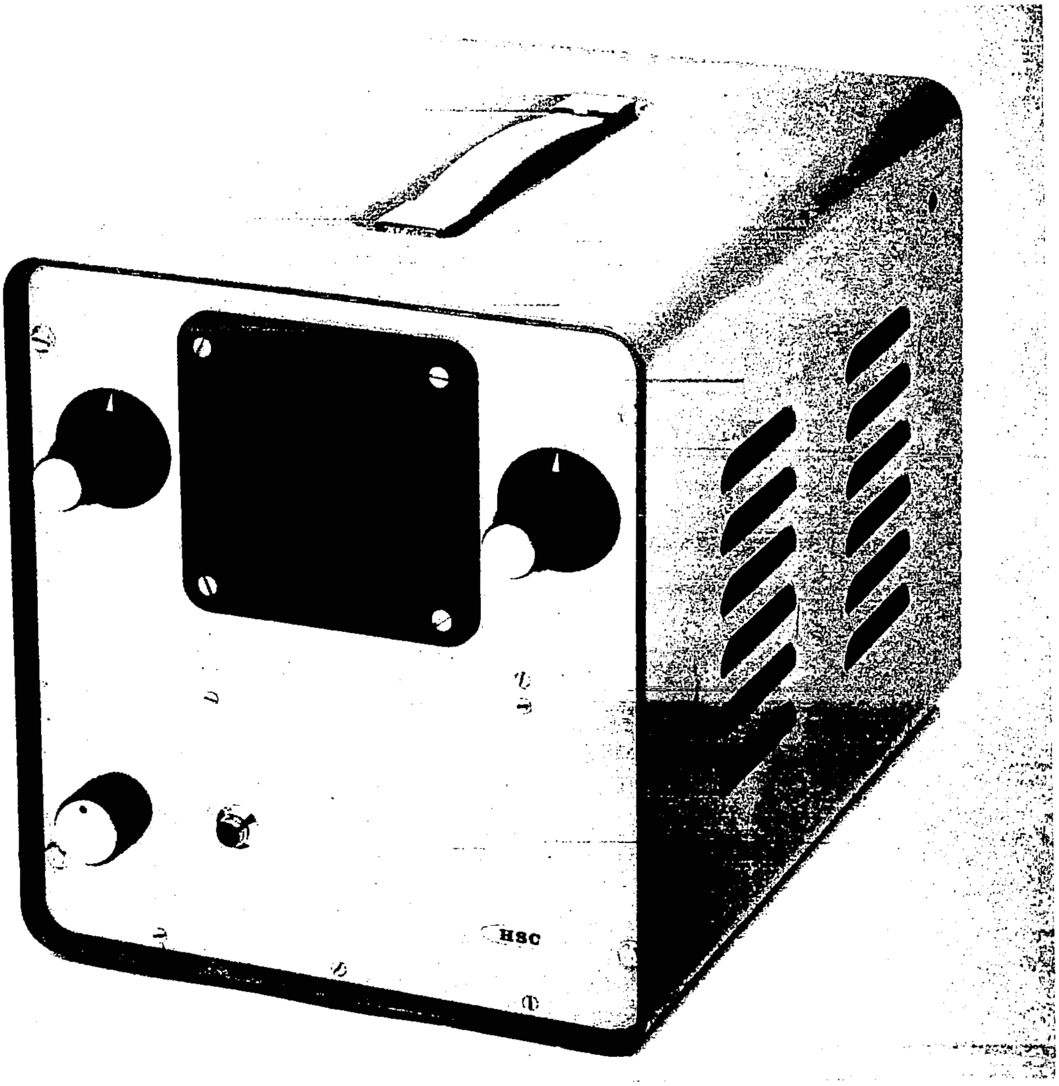


Figure 4. 3-Inch High Contrast CRT Demonstrator

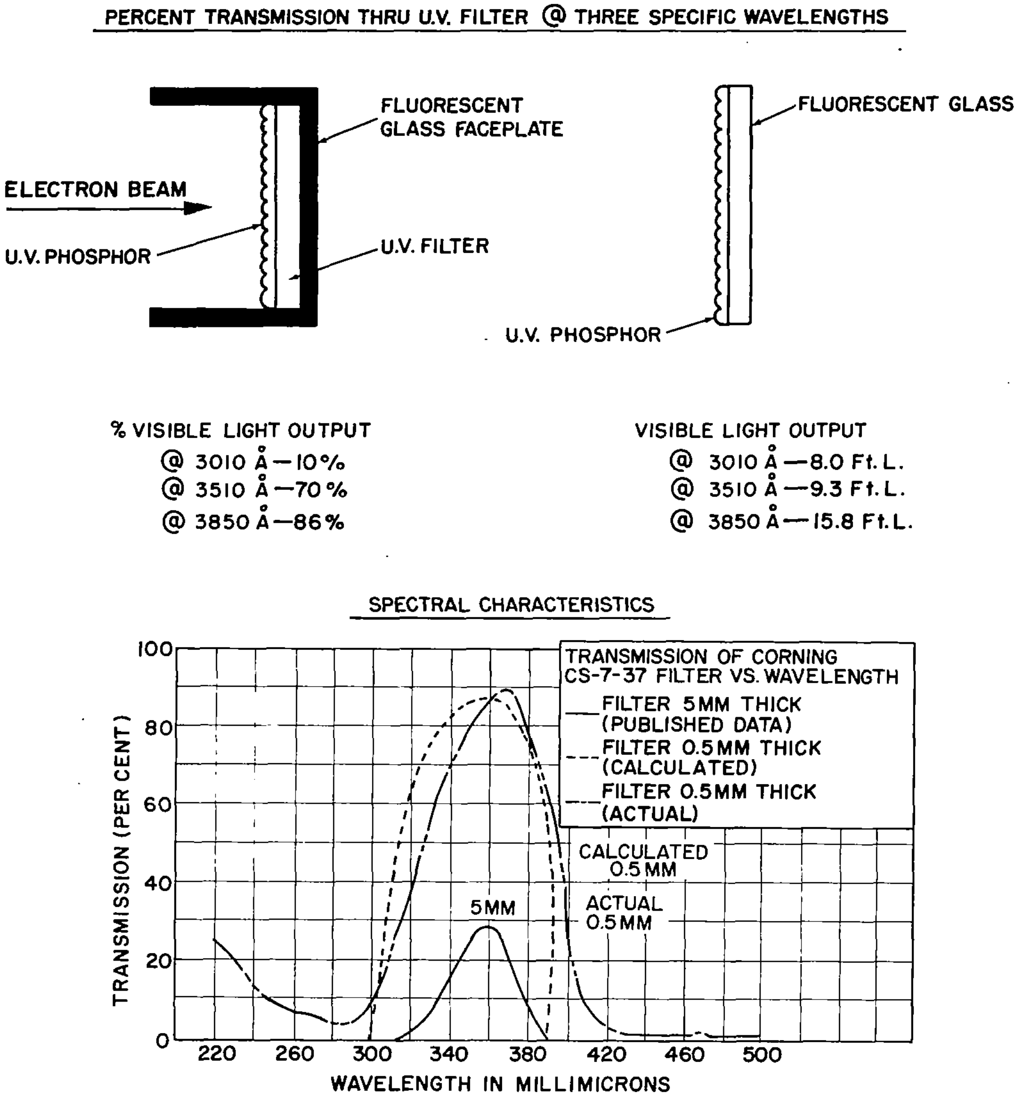


Figure 5. Spectral Characteristics of the Lapped Filter

ultraviolet filter glass. The particular glass system employed was brittle and fragile and could not be worked by conventional blowing and rolling methods. This necessitated lapping and polishing the glass to the desired thickness. Figure 5 shows the spectral characteristics of the lapped filter. Fabricating filters in this manner resulted in poor yield, due to breakage, limited physical size, and difficult handling characteristics. In addition, the limited thermal mass imposed constraints on the maximum allowable beam power to a greater degree than the phosphor screen. There was no way to thermally sink this assembly to dissipate the localized heat.

The specific goal in the present contract was to devise a means of fabrication which would result in thinner U.V. filters having the same or higher optical density than previous units, and which would be integrally laminated or bonded to the fluoresent glass. This would yeild a composite filter with no intrinsic size limits, no mechanical support problem, sufficient thermal mass to dissipate localized heat, and high enough resolution for all anticipated aerospace applications. To accomplish these goals, several approaches were initially considered.

To form an integral and thin U.V. filter on the fluorescent glass, the following approaches were considered:

1. Use of the alkali-metal films which have unique inherent transmission characteristics in the ultraviolet;

2. Employment of the flame spray process which would deposit hot glass particles onto a fluorescent glass substrate;

3. The R.F. sputtering of metallic oxides;

4. Utilization of a vacuum deposition system to vapor deposit selected inorganic materials on a glass substrate;

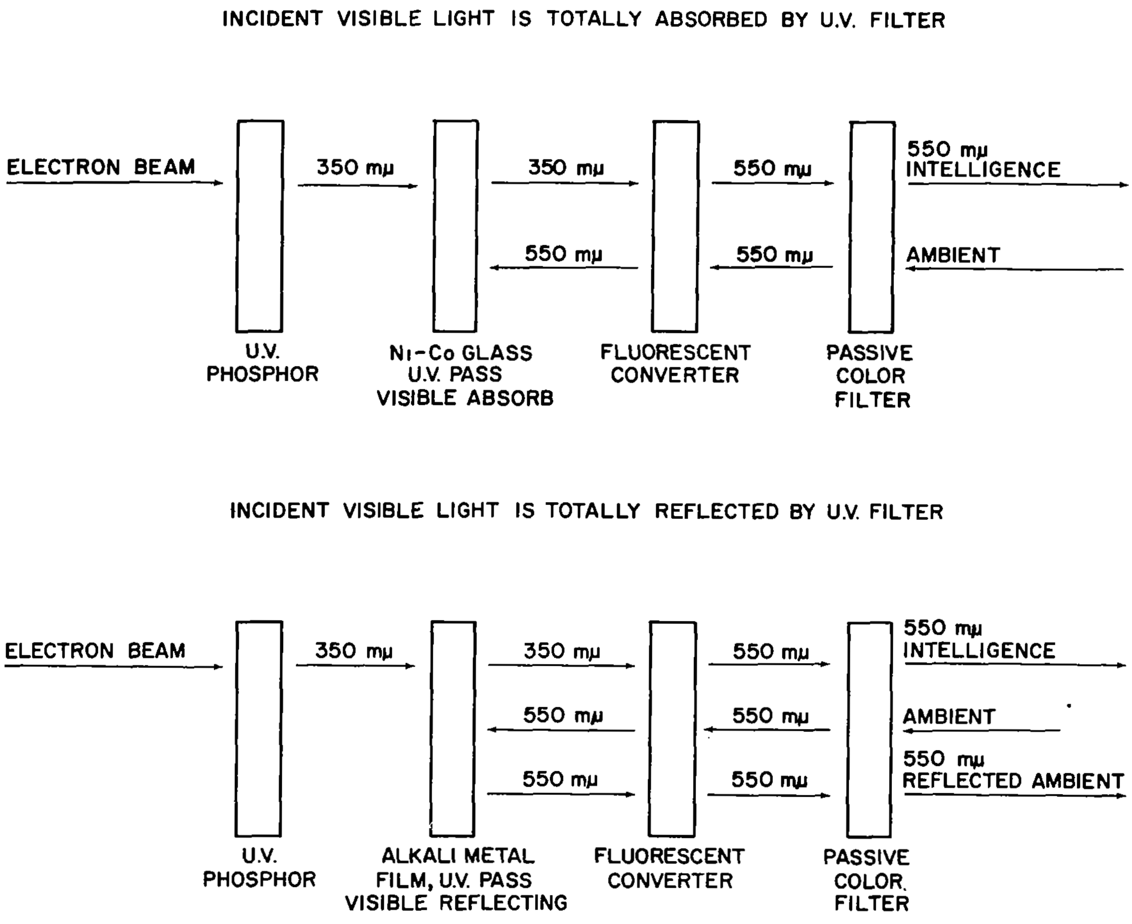
5. The high temperature diffusion of nickel-cobalt compounds into the surface of a fluorescent glass substrate.

2. ALKALI - METAL FILM STUDY

The fact that the alkali-metal film is highly reflective at visible wavelengths prohibits its use as a thin U.V. filter. The film must be able to absorb incident radiation in the visible in order to provide a high contrast, non-reciprocal filter. A reflecting U.V. filter will reduce the contrast by creating an overall brighter background, the color of which will correspond to the color of the passive filter employed. Figure 6 clarifies this fact.

Investigation of the alkali-metal film as a possible solution to the requiste thin U.V. filter was initiated because of the unique inherent characteristics of these metals. At thicknesses less than one microm they are opaque in the long wavelength region and at some critical wavelength in the visible or ultraviolet they become transparent and show comparatively low absorption. However, our study on the subject showed that even though the alkali metals were opaque to wavelengths in the visible they were almost totally reflecting at these wavelengths. In addition, when a film thin enough to show appreciable transparency in the ultraviolet is warmed to room temperature the unique optical properties of these metals tend to disappear. Potassium shows high reflecting power from the red down to a wavelength of 3150Å, bleow which point the reflection falls rapidly and the metal becomes very transparent. Caesium shows high transmission beginning at wavelength 4400Å, rubidium at 3600Å, sodium at 2100Å, and lithium at 2050Å. Thus it can be observed that as the atomic numbers decrease, the point where transmission commences moves toward shorter wavelengths.(1)

Multi-layer interference filters that are constructed to pass a narrow band of U.V. and reflect all other wavelengths are also of the type that would not be suitable for a high contrast filter of this design.



INCIDENT VISIBLE LIGHT IS TOTALLY ABSORBED BY U.V. FILTER

INCIDENT VISIBLE LIGHT IS TOTALLY REFLECTED BY U.V. FILTER

Figure 6. Comparison of Reflecting and Absorbing U.V. Filters

3. FLAME SPRAY INVESTIGATION

Utilization of the flame spray process was an additional possibility for attaining a composite fluorescent glass and thin U.V. filter; namely, flame spray of fritted or powdered U.V. material.

The term "thermospray" describes that type of flame spray equipment which involves the application of metals or other materials in powder form. The powder is gravity fed through a spray gun and nozzle, continuously melted in an oxygen fueled gas flame and atomized by compressed air which carries the metal particles to a previously prepared surface.

Observation of the flame sprayed substrates indicated that the U.V. material was deposited on the surface of the substrates as a thin film which had not entered into ionic bonding with the base glass. As a result, transmission of the material does not possess U.V. pass/visible absorb characteristics as was intended.

The particular experiments involved the spraying of three compounds; cobalt oxide ($CO_3\ O_4$), Corning No. 9863 powdered glass, and Corning No. 5860 powdered glass onto a uranium oxide-doped, fluorescent glass.

The intention was to form a thin U.V. structure on the surface of the fluorescent substrate by spraying hot molten particles of material onto the preheated prepared surface.

The experiments performed are outlined below:

- Flame spray cobalt oxide, black (CO_3O_4), on each of the following substrates (four samples per substrate).
    - Soda lime cover glass (2 inches x 2 inches x 1/16 inch)
    - Borosilicate (pyrex) glass (1 inch x 2 inches x 1/16 inch)
    - Vycor glass (1 inch x 2 inches x 1/8 inch)
    - Uranium oxide-doped, borosilicate glass (1 inch x 2 inches x 1/14 inch)
- Flame spray ground-up U.V. filter (Corning No. 9863 glass) on four pyrex substrates.
- Flame spray ground-up U.V. filter (Corning No. 5860 glass) on four pyrex substrates.

The vycor, soda lime, and pyrex glass substrates were cleaned with alcohol and then preheated to a temperature of 500 F prior to the thermospray application. The substrates were then flame-sprayed with cobalt oxide, black (CO_3O_4) at a distance of approximately 3 inches. The thickness of the sprayed film was between 1 and 2 mils. The uranium glass substrates (Corning No. 3750) were cleaned and then preheated to a temperature of 350 F. However, the substrates tended to crack during the spraying process due to the molten particles of cobalt oxide striking the surface. This situation was alleviated by increasing the substrate temperature prior to spraying.

The second set of experiments that were performed consisted of flame spraying powdered U.V. pass/visible absorb glass on the substrates. The Corning No. 5860 and No. 9863 U.V. glasses were utilized for this purpose. However, the powders would not flow through the feeder of the gun at a steady rate and consequently, the coverage obtained on the substrates was poor. In some cases, the powder passages within the gun clogged. It was necessary to introduce additives to increase the flow of the powder. Both Cabo-Sil and calcium stearate were tried and the latter provided better flow characteristics for the glass powders. The substrates were then cleaned and preheated to 500° F prior to being sprayed with the molten U.V. glass. After spraying, the substrates appeared as if the powder had been settled onto the surface. Actually, the glass particles were fused to each other as well as to the glass. Even though the metallic oxide was in a glass solution, the film material deposited on the surface of the substrates appeared coarse, diffuse and opaque.

A review of these experiments with Metco has proved inconclusive. The fact that there are numerous variables involved precludes any initial experimental conclusions. This process may still be the most expeditious method of fabricating the composite faceplate filter. An intensive experimental investigation in this area would be required to rule out the feasibility of this process.

4. R.F. SPUTTERING INVESTIGATION

R.F. sputtering inorganic compounds in a glass solution onto the surface of a fluorescent substrate required excessive sputtering time and resulted in too thin and transparent a film. Sputtering of inorganic compounds in their natural state indicated that the material was deposited on the surface of the glass and did not bond into the substrate. In addition, the highly reflective layer is undesirable since the film must be able to absorb incident radiation in the visible in order to provide a high contrast, non-reciprocal filter.

A cobalt oxide sputtering disc 4 inches in diameter and 1/4 inch thick was fabricated by Cerac Inc., Wisconsin. This material was hot-pressed from CO_3O_4 powder, under Argon and without binder. The initial sample films had a thickness of 750Å, 350Å, and 250Å respectively. The rate of deposition was 50 Å per minute. The results of these tests indicated that the cobalt oxide was deposited on the surface of the fluorescent substrate as a thin film of material which did not enter into ionic bonding with the glass. The transmission of this film is a function of the transmittance of the material itself and is not related to the transmission of the film material in a glass solution.

Attempts to locate a material which is compatible with CRT processing and environment and which possesses U.V. pass/visible absorb characteristics when not in the ionic state have not proved fruitful to date.

The next approach was to obtain a material in solution that would exhibit U.V. pass/visible absorb characteristics and sputter this material onto a glass substrate. The target material selected was a Corning No. 9863 filter blank which possessed transmission characteristics suitable to the requirements. This material was then sputtered onto glass substrates for evaluation. The material was sputtered for one hour and a film thickness of only about 1/10 of a fringe of sodium light was deposited on the substrate. This was an extremely thin, highly transparent layer.

The excessive sputtering time required to obtain a thin film of this material indicated that it was not a suitable target for this type of deposition. The material must contain an increased metallic oxide content to show an appreciable film thickness on the substrate.

5. VAPOR DEPOSITION OF FILMS

Attempts at vapor depositing certain inorganic materials onto glass substrates resulted in disassociation of the compounds. Therefore, use of an inorganic material which had suitable inherent optical properties, possessed a low melting point, and was compatible with CRT processing was dictated. To date a material that would provide the desired evaporated film has not been found.

By vapor depositing inorganic material onto both pyrex and soda lime substrates the feasibility of fabricating thin U.V. filters utilizing this process was ascertained. One such experiment consisted of mixing equal parts, by weight, of cobalt oxide and sodium borate and placing this mix in a quartz crucible. The crucible was then placed in a tungsten filament basket within a vacuum deposition system. The bell jar was evacuated sufficiently and the filament was "fired" to provide a slow steady heat to the material in the crucible. After a short period of time there was a very noticeable boiling of the material. This continued for five minutes and then the system was turned off and returned to atmospheric pressure. Inspection of the substrates revealed a deposit of sodium borate with no trace of cobalt oxide. Disassociation occurred whereby the sodium borate was separated from the cobalt oxide, transported, and deposited on the pyrex substrate. This further suggested that an inorganic material with suitable optical properties, a melting point in excess of 400°C and compatibility with CRT processing would provide the desired evaporated film.

In searching for inorganic materials possessing these necessary characteristics a list of prospective materials for vapor deposition was compiled. The potential films are listed below:

cobalt aluminate
cobalt orthoarsenite
cobalt orthosilicate
cuprous sulfide
cuprous iodide
cupric formate
cupric ammonium chloride
barium permanganate
bidmuth trioxide
chromium nitrate
chromium sulfate
cobalt bromide
chromium ammonium sulphate
ferric ammonium sulfate
silver sulfide
thorium
tungsten pentabromide
stannous oxide
stannous sulfide
uranium iodide
germanium tetranitride
iodine
nickel iodide
potassium permanganate
cobalt silicide
palladium sulfide
neodymium chloride
chrome chloride
bismuth selenide

6. CORNING GLASS FACEPLATE

An effort by Corning Glass Works directed toward laminating a fluorescent substrate to a very thin U.V. glass was attempted. By developing a new uranium glass with an expansion compatible to both the U.V. glass and the CRT funnel, Corning was able to fuse these two glasses together and then polish down the U.V. glass to the required thickness.

Corning's objective was to provide a composite filter with uniform expansion that would also be compatible with the 0120 glass used in the CRT envelopes. This accomplishment would simplify the sealing of the faceplate onto the envelope, in addition to eliminating costly sealing procedures necessitated by expansion mismatch.

Corning developed a new uranium glass with an expansion coefficient of $90 \times 10^{-7}/°C$ which was compatible with either the 5840 ultraviolet glass which has an expansion of $92 \times 10^{-7}/°C$ of the 5860 glass which has an expansion of $90 \times 10^{-7}/°C$. This new fluorescent glass matched both the U.V. and CRT glasses.

Corning Glass Works completed a 1-1/2 inch by 3/8 inch by 1/4 inch laminated composite filter with an expansion coefficient compatible with the 0120 glass used in the fabrication of CRT envelopes. This sample substrate had an ultraviolet layer with a thickness of from 6 to 8 mils fused to the fluorescent base glass. It was observed that the fluorescent uranium glass emitted at the surface of immediate ultraviolet incidence only when the excitation wavelength was less than 3300 Å. Fluorescent emission of this nature provides optimum resolution. Increasing the wavelength above the absorption edge resulted in the incident energy penetrating deeper into the uranium glass before being completely absorbed. Although the magnitude of the fluorescence increases with longer wavelengths (to a maximum when the excitation is 3700 Å), the resolution of the spot size spreads from its initial value when emitting from the surface of the glass to a new larger dimension which is inversely proportional to the square of the depth of penetration of the incident ray. The resolution of this composite filter is a function of the peak emission from the ultraviolet phosphor with 3300 Å being the optimum wavelength. The spectral characteristics of the Corning fluorescent and U.V. glass employed in the fabrication of the composite filter are shown in Figures 7 and 8, respectively.

7. H.S.C. FACEPLATE

The technique investigation into thin U.V. filter fabrication performed in our laboratory resulted in the successful development of a laminated filter compatible with CRT processing. Expansion matching of the fluorescent and ultraviolet glasses was perfected on 1- and 3-inch samples, resulting in a satisfactory bond and adequate dispersion of the metallic oxide material. The measured thickness of the U.V. film averaged less than one-half mil, thus significantly improving the inherent resolution of the composite filter. In addition, these filters were successfully subjected to thermal extremes and reduced pressures which might prevail during operation.

An effort was directed toward fabricating a laminated faceplate composed of a fluorescent substrate and a very thin U.V. transmitting-visible absorbing glass, fused together. The critical area of concern was the differential thermal expansion of the glasses to be utilized in the filter.

Glass formulation experiments were initiated for the purpose of developing a thin film glaze that would be compatible with a borosilicate glass. Experiments were performed to observe what effect the addition of 2% cobalt oxide would have on four typical glass batches; tests were also performed varying the constituents of a typical borosilicate formulation individually.

Utilizing the selected glass the saturation limit of the cobalt oxide was ascertained. Experimental data determined that the saturation limit of COO_2 in this glass batch was 20% by weight. These tests are of particular importance since they substantiate the fact that a thin U.V. filter may have the same optical density as an equivalent thicker filter by increasing the percent of doping proportionally. A typical commercial filter contains only a 1/2% dopant level and is approximately 3 mm in thickness. Our goal was a 0.25 mm thick U.V. filter or 1/2 the thickness of a commercial filter. This required a minimum dopant level of approximately 6% which was found experimentally to be feasible.

After additional experiments the data was re-evaluated and the conclusion was that by employing a low melting vitreous flux which, in its liquid state, would absorb the cobalt oxide, a filter could be formed in the first few molecular layers of the base glass surface. This fluxing agent would have to further provide a

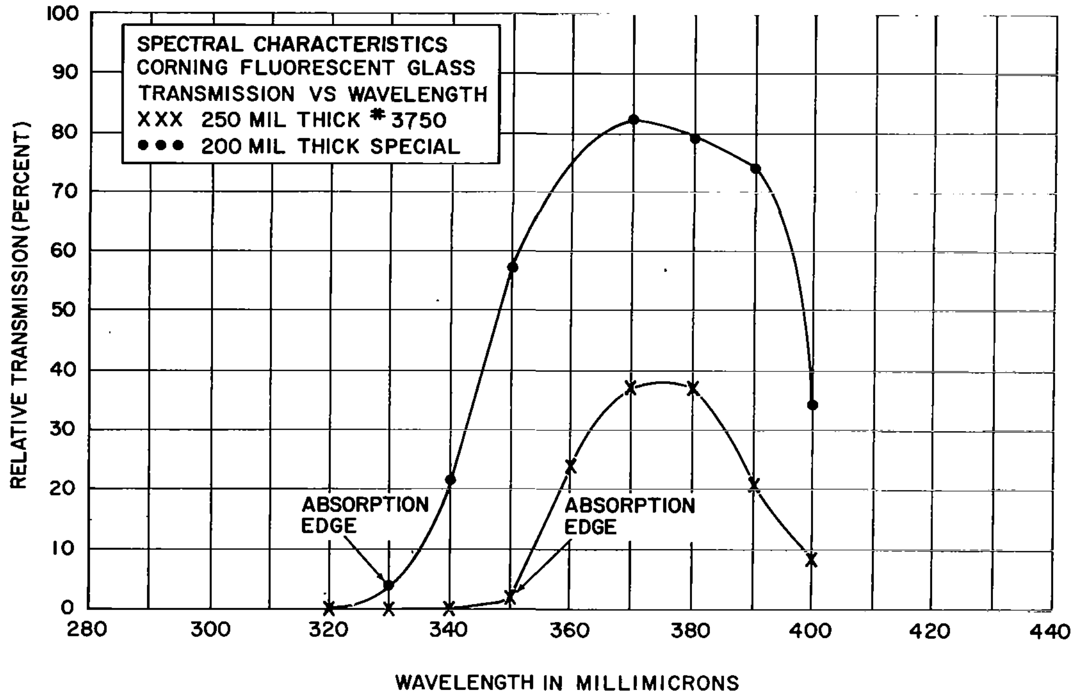


Figure 7. Transmission Characteristics of Corning Filter Sample-Fluorescent Glass Component

"wetting" effect on the surface that would induce the cobalt oxide doped flux material into integral molecular bonding within the base glass. Experiments were conducted to determine which vitreous media, loaded with 2% cobalt oxide, would accomplish this effect. These tests showed that sodium tetraborate and sodium perborate provided the best results. By lightly sand-blasting the surface of the uranium oxide glass with a fine grit sand prior to spraying the cobalt oxide and fluxing agent, improved dispersion and increased adhesion of the film after firing

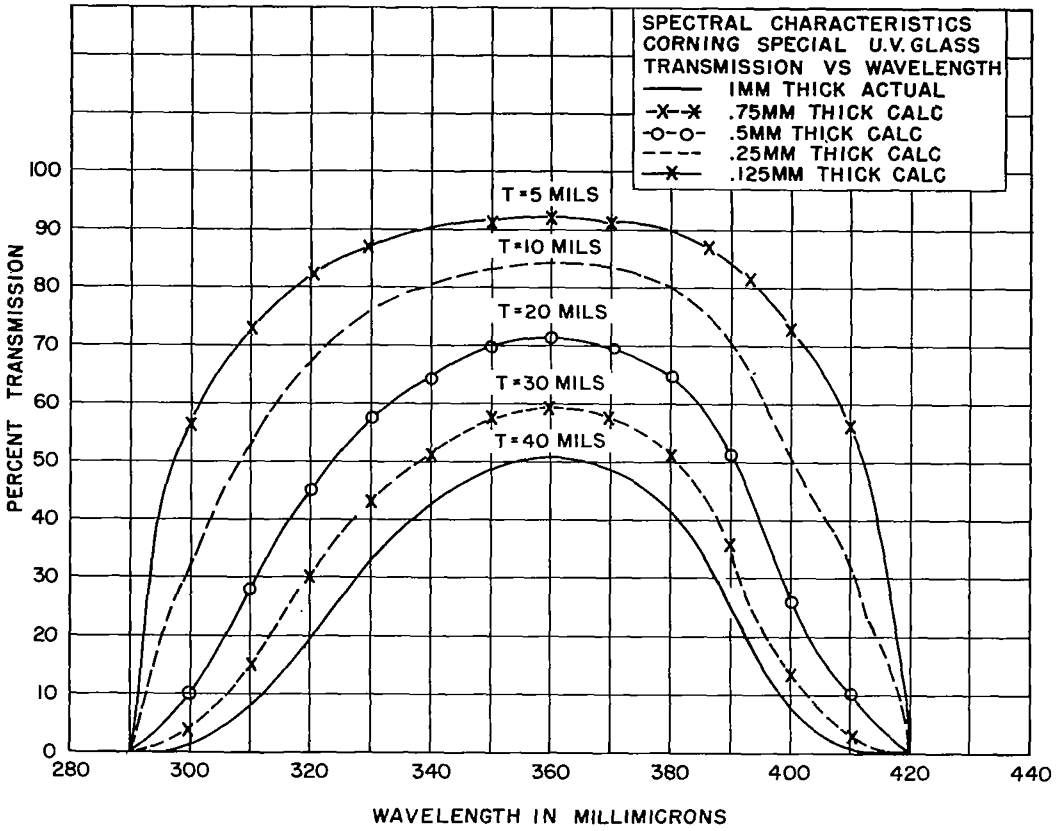


Figure 8. Transmission Characteristics of Corning Filter Sample-
U.V. Glass Component

was obtained. Cobalt oxide concentrations of from 30 to 40% seem best. The determination of the proper heating, soaking, and cooling cycles were strong factors in controlling crazing, distribution, and fusing of the glasses. Further experiments were performed increasing the cobalt oxide to sodium borate content. These tests, show that the cobalt oxide content could be increased to at least 30% and still obtain a uniform film whose expansion matched that of the uranium glass.

Further experiments were conducted employing samples which approximated an area of one square inch. These experiments resulted in an improved cobalt oxide doped, low melting, vitreous flux. This newly developed low melt material provided the required "wetting" effect on the surface of the fluorescent glass, thereby inducing the cobalt oxide doped flux into molecular bonding with the base glass. Expansion matching of two glasses was perfected on the initial 1-inch samples, resulting in a satisfactory bond and adequate dispersion of the metallic oxide material. Spectral transmission measurements of the U. V. film component of the composite 1-inch filters were recorded, employing the Bausch & Lomb Spectrographic 600 spectrophotometer and are compiled in the appendix of this report. Measurements of these U. V. films, using a comparator microscope indicated that the thickness averaged one-half a mil or less than 15 microns. The present reduction in U. V. film thickness is a significant accomplishment in improving the inherent resolution of the composite filter. The limiting parameters governing the spot size of the generated intelligence in the CRT will now be a function of the electron gun geometry and the phosphor screen structure and not the thickness of the U. V. film.

Samples whose area approximated two square inches were fabricated in order to ascertain the problems which would become evident by an increase in the size of the filter. One of the primary areas of concern was the uniform dispersion of the cobalt oxide within the glass matrix. Several experiments were performed to determine the requisite percentages of the sodium borate, zinc oxide and cobalt oxide necessary for proper thermal expansion, compatibility, optical density, flow characteristics, and dispersion of the metallic oxide in the glass matrix. A mixture of 28% zinc oxide, 57% sodium borate, and 15% cobalt oxide produces a frit that exhibited the best compromise of these indicated characteristics. The particle size of the frit was reduced from 100 to 300 mesh so that the cobalt oxide would dissolve more easily into the glass matrix. In addition, the 300 mesh particle size improved the dispersion of the metallic oxide throughout the glass matrix. The reduced particle size in conjunction with utilizing a settling technique enhanced the dispersion of the cobalt oxide and markedly improved the distribution of the frit particles over the surface of the glass.

A series of experiments were initiated to observe the effects of varying the quantity of the frit settled on a given substrate. The results indicated that the variation of frit by weight affected the degree of expansion mismatch and the uniformity of the metallic oxide dispersion.

When a piece of glass reaches room temperature after having been cooled from the viscous state, internal strains and stresses are found to exist within the body. The magnitudes of these stresses and strains, referred to as "residual," are determined largely by the rate of cooling within the transformation range of temperatures, the coefficient of expansion of the glass, and the thickness of the section involved. Because of these stresses, high expansion glasses will often break spontaneously after being allowed to cool in the open air. When the glass is homogeneous, the stresses and strains can be reduced to low values by cooling it gradually in an annealing operation. If the glass is not homogeneous, for instance, when it contains striae or cords or if it comprises a structure fabricated from two glasses, or a glass and a metal, of different expansion properties, these stresses cannot be reduced below some minimum level by slow cooling. (2)

The conclusion from these experiments was that the thinner films are more elastic and can tolerate a slight mismatch in the thermal coefficient of expansion. This necessitates a more exact thermal matching of the thicker films to prevent any crazing. Since these thicker layers are inherently denser, their color distribution appears more uniform. Continued investigation revealed that by temperature cycling the fluorescent glass substrate to 885° C prior to settling the cobalt oxide doped frit, minimizes the effects of any variation in the quantity of material deposited. By heat treating the glass prior to deposition of the film, the stress lines are reoriented in a more coherent manner relative to the structure of the matching film.

In experiment No. 173 a glass frit compound of cobalt oxide, sodium borate, and zinc oxide was settled onto a fluorescent glass substrate and elevated to a temperature of 870° C. The substrate was held at this temperature for two hours and then the furnace was shut down and the sample was allowed to cool slowly. There was no observable crazing at the glass interfaces; however, the cobalt oxide did not dissolve properly and failed to provide uniform dispersion. As a result, a higher percentage of zinc oxide was added since this material cuts the melting time, lowers viscosity, decreases the softening temperature, imparts elasticity, and provides a low coefficient of expansion. Experiment No. 178 employed a glass frit compound containing additional zinc oxide which resulted in the two glasses being fused together without any apparent expansion mismatch at the interface. These experiments are tabulated in the appendices. Next, sample No. 178 was environmentally tested to determine its resistance to reduced pressure and thermal extremes since some of these conditions prevail during normal CRT processing and others during its operation. The substrate was temperature cycled between -50° F and 212° F and exhibited no degenerative effects. In addition, the sample was subjected to a pressure of 25 microns of mercury and again there was no effect on the substrate. Subsequent experiments were then performed in an effort to repeat the results obtained in experiment No. 178. These attempts were unsuccessful until an annealing schedule was incorporated. Raising the temperature to a specified point and maintaining this temperature for a sufficient period of time relieved existing strains and stabilized the glass. Then by cooling the glass at a slow enough rate, the residual stresses would not reappear when the glass temperature had reached equilibrium. One such schedule was determined as a result of experiment No. 190 where the sample was near perfect with regard to stress strain and expansion compatibility. [1]The glass resulting from experiment No. 178 was incorporated into the faceplate filter. The spectral characteristics of this glass are shown in Figure 9. Refer to Appendix III for firing and annealing schedule and Appendix IV for specifics on the U.V. glass.

a. FLUORESCENT GLASS INVESTIGATION

To date the most efficient energy converter evaluated is the 1% uranium oxide doped borosilicate glass (Corning No. 3750) which has an expansion coefficient of 80 cm/cm° C x 10^{-7} over a temperature range of 0° to 300° C. Corning has modified this glass in order to provide an expansion match with the 0120 funnel glass whose coefficient of expansion is 90. This modification of the uranium glass has resulted in a shift of the absorption edge from 3500Å to 3300Å which necessitates the utilization of a U.V. phosphor having a spectral peak in this new range.

Experiments have indicated that when two rare earth oxides with fluorescent monochromatic components are dispersed in the same glass matrix and excited at a U.V. wavelength the fluorescent light output is a mixture of the two components. It

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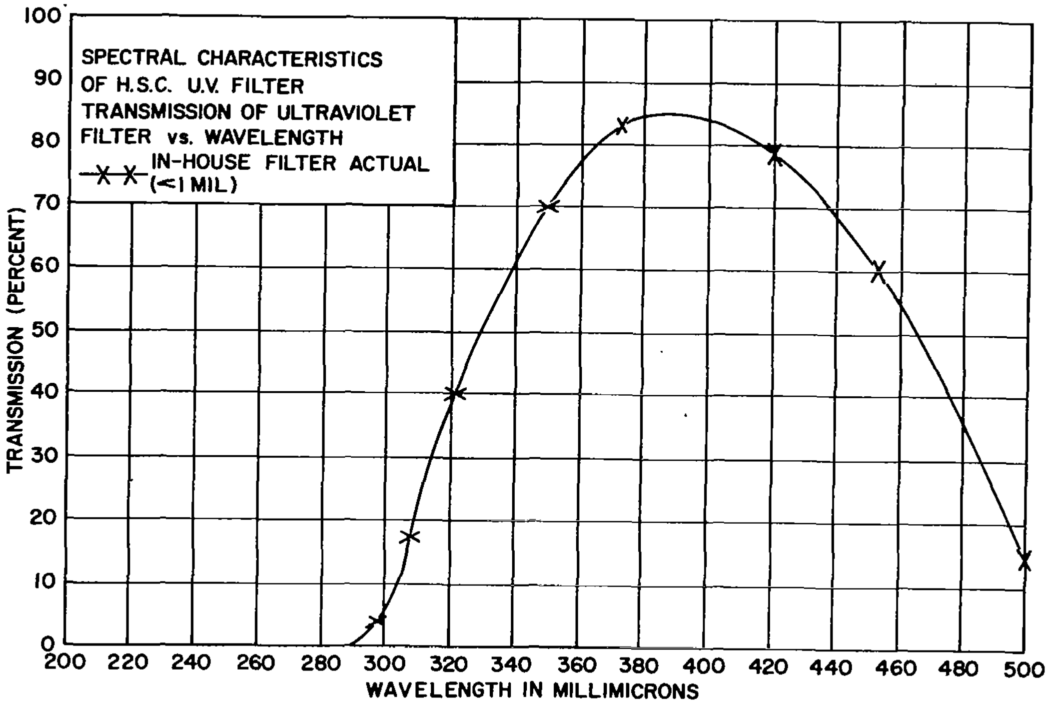

Figure 9. Spectral Characteristics of H.S.C. U.V. Filter

has also been observed that rare earth doped glasses are water white and transparent under ambient lighting conditions.

Incorporation of a rare earth doped white fluorescent glass into the filter system would enable it to display a white fluorescent output on a black background. A U.V. to visible fluorescent converter of this type would also extend the versatility of the non-reciprocal filter since the passive filter could be either clear glass, if a white output is required, or monochromatic to provide any color output desired. Figure 10 illustrates this principle.

An exhaustive investigation was previously performed on photoluminescent transparent glasses under Contract NAS 12-97, and therefore, studies in this area were of a supplementary nature only. Relative to this investigation, observation of the spectral characteristics and fluorescense of both the Corning No. 3750 glass and the modified #3750 glass was performed. The results of these observations are shown in Figures 11 through 14.

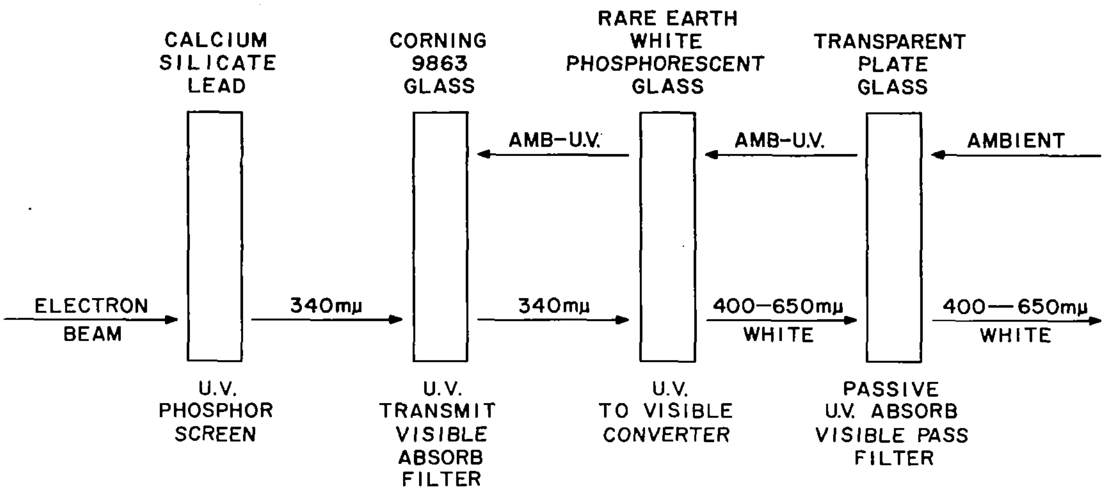

Figure 10. Functional Diagram of CRT High Contrast Filter Incorporating Rare Earth Fluorescent Glass

Owens-Illinois, Toledo, Ohio, has performed much research on the luminescence of glass and the factors affecting the luminescence of a wide range of compositions of multi-component, completely vitreous materials made by ordinary glass-melting methods. The work has been principally concerned with responses of these materials to irradiation by long and short wavelength ultraviolet light.

Investigations to date with glasses of this type received from Owens-Illinois, Ohio indicate that the peak absorption band are between 290 mu and 300 mu. This absorption band of the fluorescent glass is too low in wavelength to be excited by U.V. phosphors presently used in the CRT.

b. U.V. PHOSPHOR RESEARCH

An analysis of a cross section of available U.V. phosphors was initiated with the preparation of sample screens for evaluation in a demountable CRT. The following phosphors were considered: Sylvania P16 (peak 3850 Å), Semi-Elements Calcium Silicate: Lead (peak 3380 Å) and Barium Silicate: Lead (peak 3520 Å), four special ITT U.V. phosphors designated H1, H2, H3 and H4 which reportedly peak at 3000 Å, and a Sylvania U.V. lamp phosphor No. 2011 which is also a barium silicate: lead phosphor with a peak spectral output at 3500 Å.

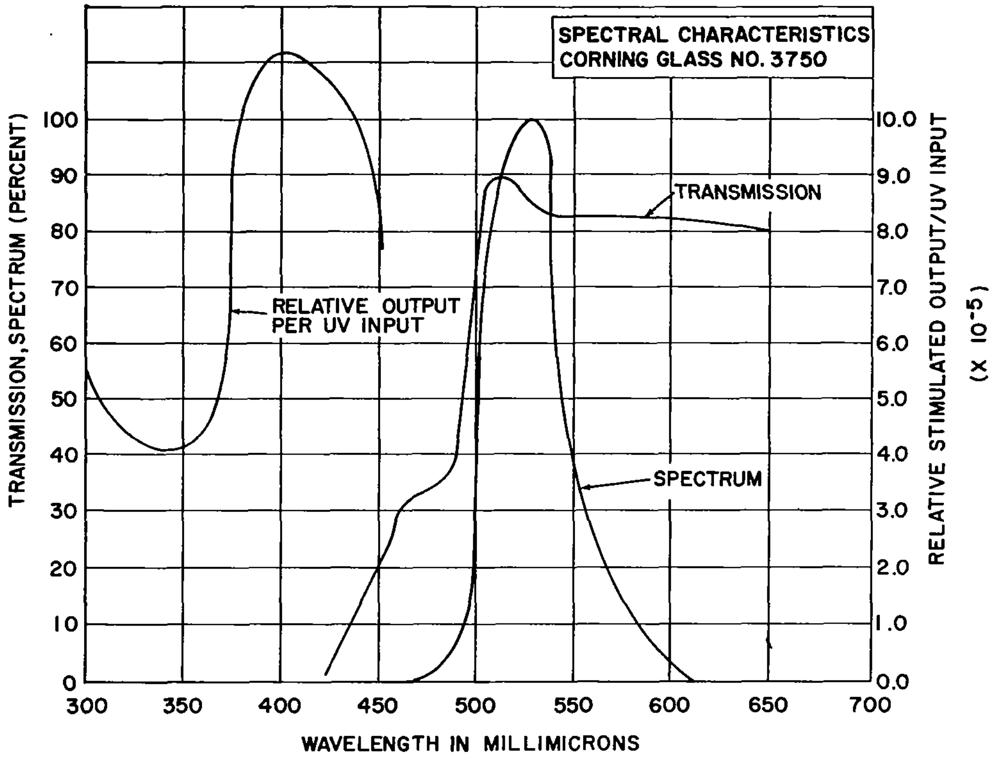

Figure 11. Spectral Characteristics Corning Glass No. 3750

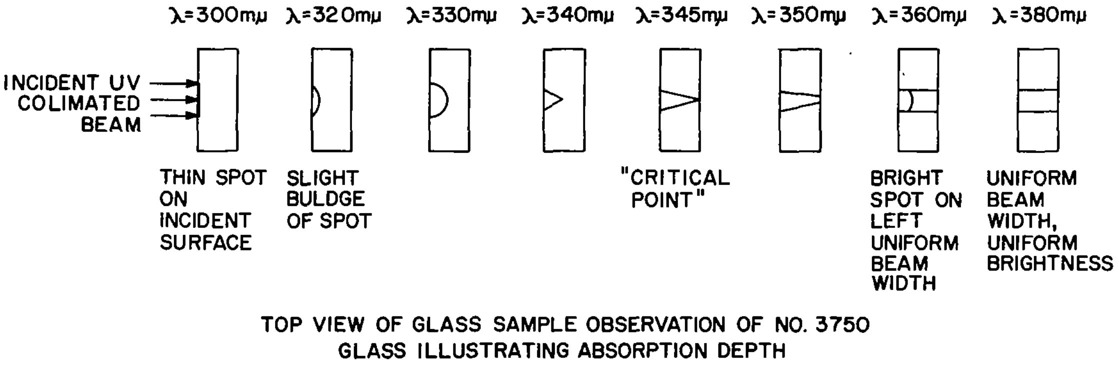

Figure 12. Observation of Fluorescence of Corning Glass No. 3750

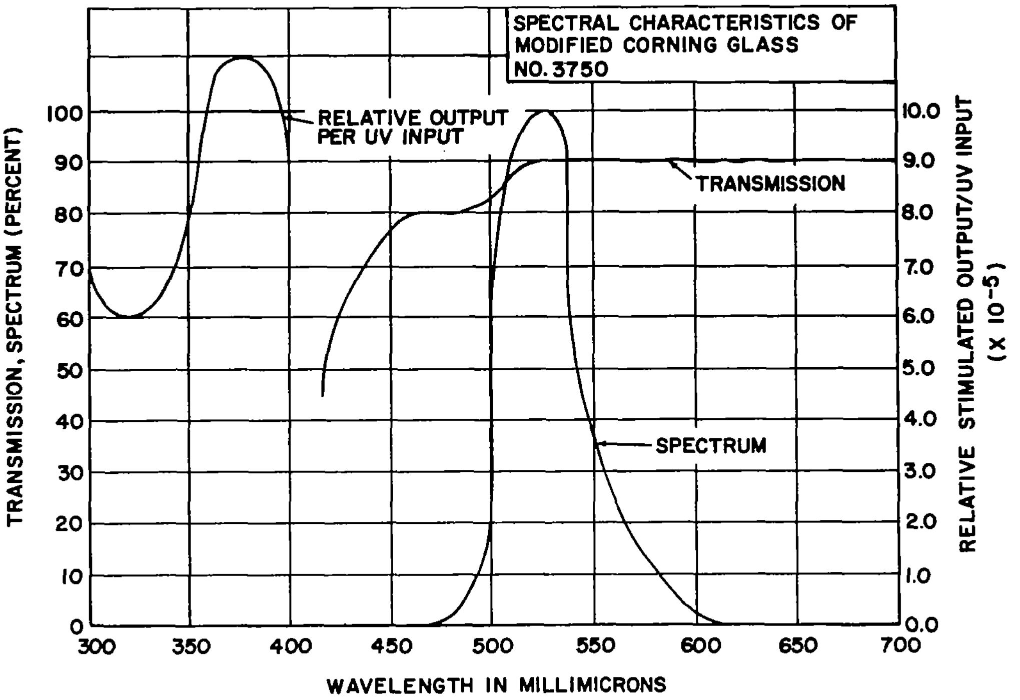

Figure 13. Spectral Characteristics of Modified Corning Glass No. 3750

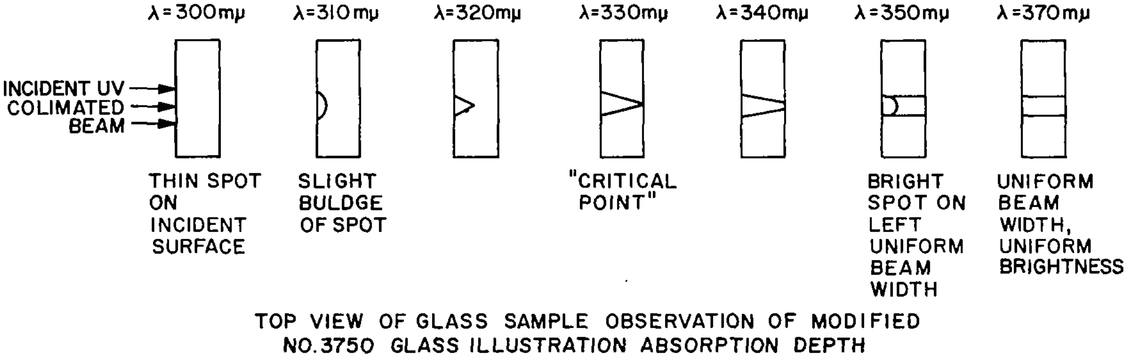

Figure 14. Observation of Fluorescence of Modified Corning Glass No. 3750

A continued literature search complementing previous work completed under Contract NAS 12-97, was directed toward improving the present calcium silicate: lead ($CaSiO_3$:Pb), and barium silicate: lead ($BaSiO_3$:Pb) U.V. phosphor compounds. These two phosphors peak at 3380 Å and 3520 Å, respectively.

Eleven phosphors were settled onto 1-inch square vycor substrates and then mounted to the faceplate of the demountable CRT for evaluation. These phosphor samples are listed in Appendix, VI, Table XXVII.

A great deal of investigation and search of literature has been done under the previous NASA contract. However, a manufacturer search revealed the U.V. phosphors listed in Table I to be presently available in addition to P16.

Several U.V. phosphors were observed including the barium silicate: lead, calcium silicate: lead, strontium borate: lead and barium zinc magnesium silicate: lead. The results of these observations are shown in the spectral energy distribution curve of Figure 15.

c. PHOSPHOR ALUMINIZATION

The brightness of a CRT is determined by the phosphor and the total energy per unit area delivered to the CRT screen. New developments in phosphors and aluminizing of the screen have increased the CRT brightness and increased the phosphor resistance to burning. The aluminum coating has improved the brightness of CRTs by reflecting toward the viewer most of the phosphor light output which was previously lost inside the CRT.

A number of advantages are to be gained from the use of an aluminized coating.(3)

- Since aluminum is a good reflector, the output of the ultraviolet phosphor is increased by a factor of two.
- No charge accumulation occurs because of the electrical conduction characteristics of the aluminum.
- Aluminized coatings provide a physical barrier against phosphor poisoning from foreign materials remaining in the evacuated tube. As a result, the phosphor life is increased.
- The aluminum backing may also be useful as a heat sink, thereby increasing the thermal capacity of the phosphor by uniformly distributing the heat over the entire faceplate.

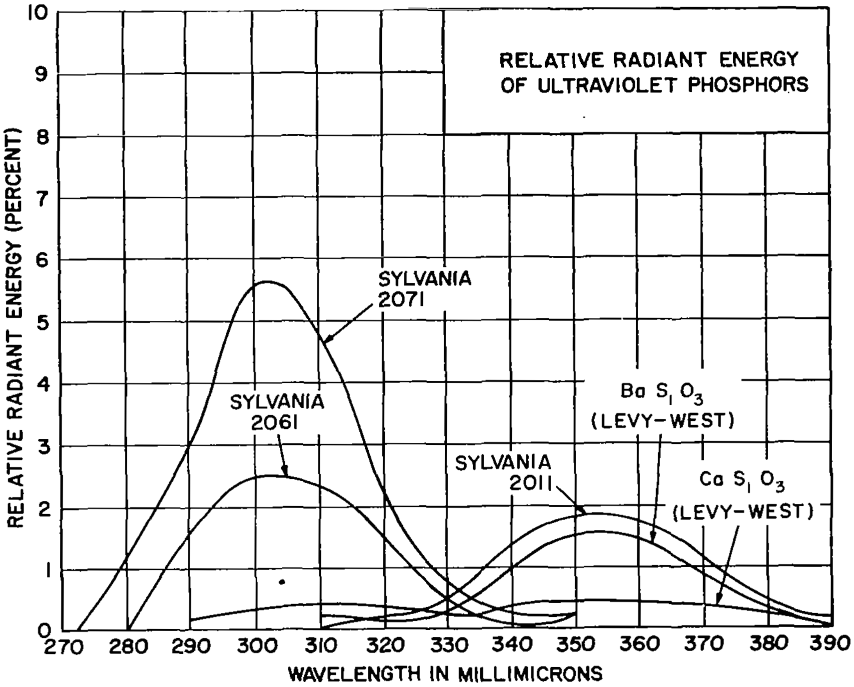

Figure 15. Relative Radiant Energy Curves of Phosphors(4)

8. FABRICATION RESULTS

The preceding sections dealt mainly with the discussions of filter fabrication techniques and individual related components that were investigated during the course of the program. The following paragraphs will describe the integrated results of the non-reciprocal filter in an operational device.

a. FACEPLATE CONSTRUCTION

The faceplate used consists of the assembly shown in Figure 16. To produce practical tubes, a completely inorganic system was constructed. Refer to Appendix IV for specifics on the faceplate fabrication techniques.

b. FACEPLATE TO BULB SEAL

Prior investigations and conferences with CRT manufacturers in regard to sealing the faceplate to the funnel of the bulb indicated that there would be no problem.

TABLE I. AVAILABLE PHOSPHORS

Name	Composition	Manufacturer	Manufacturer Designation	Peak Emission In Å	Peak Intensity Relative To P16
Barium Silicate: Lead	$BaSi_2O_5$:Pb	General Electric	1079-10	3500	100
Barium Zinc Silicate: Lead	$BaZnSi_2O_6$:Pb	General Electric	x 80	3010	100
Barium Silicate Suphate: Lead	---	Derby Lum. LTD	UVC/155E	3500	100
Zinc Barium Silicate: Lead	---	Derby Lum. LTD	UV 30	3000	100
Barium Lead Silicate	---	Sylvania	2011	3510	190
Strontium Borate: Lead	---	Sylvania	2061	2990-3030	250
Barium Zinc Magnesium Silicate: Lead	$BaZnMgSi_2O_5$:Pb	Sylvania	2071	2960-3000	550

NOTE: The conclusions were that the Sylvania Barium Zinc Magnesium Silicate: Lead No. 2071 was superior to P16 in terms of output and spectrum. Current tubes under study in fact employ this phosphor.

Either a conventional frit seal, a graded frit seal, or at worse a gold seal could be employed. However, sealing attempts by these cathode ray tube specialty houses failed due to the thermal coefficient of expansion mismatch of these glasses.

In-house experiments were initiated to determine what combination of available sealing frits would provide a vacuum tight bond between faceplate and funnel of the CRT. In addition, a parallel effort was instituted aimed at locating qualified companies that possess facilities and techniques necessary to effect the required seal. The prime companies contacted in this regard were:

Video Color, El Segundo, Calif.
Corning Glass Works, Corning, N.Y.
Fusite Corp., Cincinnati, Ohio
Bendix Mosaic, Strubridge, Mass.
Vitro Dynamics, Rockaway, N.J.
O. Hommel, Pittsburgh, Pa.
Thomas Electronics, Wayne, N.J.
Vitta Corp., Wilton, Conn.
Owens-Illinois, Toledo, Ohio

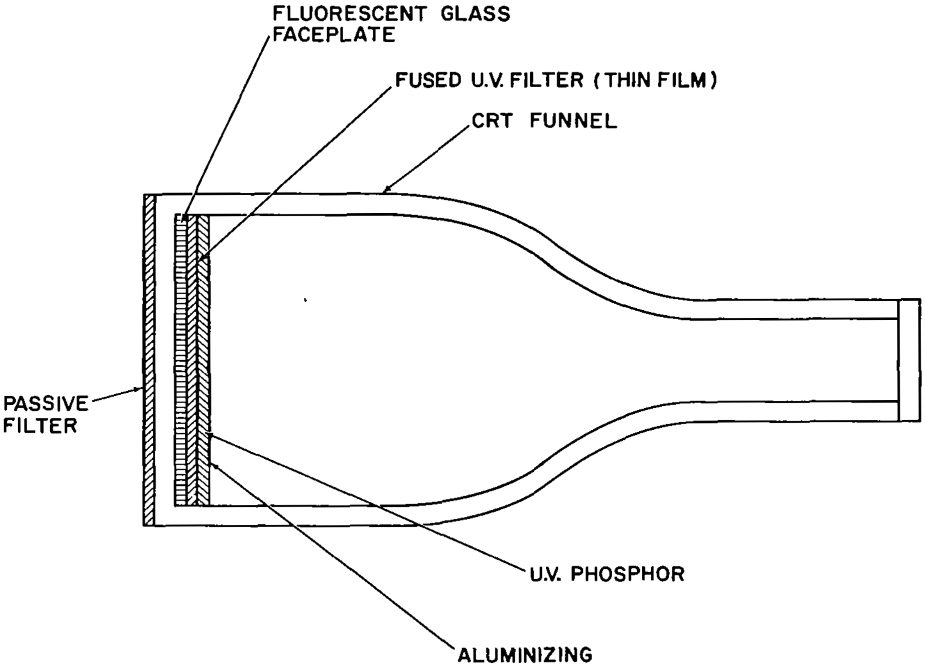

Figure 16. Cross Sectional View of Faceplate Construction

Neither the in-house experiments nor the outside manufacturers could effect a relatively stress free seal. Every seal combination that was investigated failed within a matter of a week. Conventional crystalizing frits, graded seals, vitrifying frits, and glass to metal seals were tried unsuccessfully. Refer to Appendix III for sealing techniques and experimental results.

To complete the investigations into the contrast, brightness under scan conditions, and resolution, the composite filter was mechanically mounted internal to a standard J40L1-A bulb as shown in Figure 16.

c. PASSIVE OR VISIBLE FILTER

Filter requirements are as follows:

- To transmit the emitted output from the fluorescent energy converter unattenuated.
- To absorb all wavelengths which may stimulate the fluorescent energy converter.
- To provide minimum spectral and diffuse reflection to incident radiation.

Filter data are presented in Figure 17 and 18 and Tables II and III.

The 2 mm thick Corning #4010 glass was selected as the passive filter in the deliverable unit.

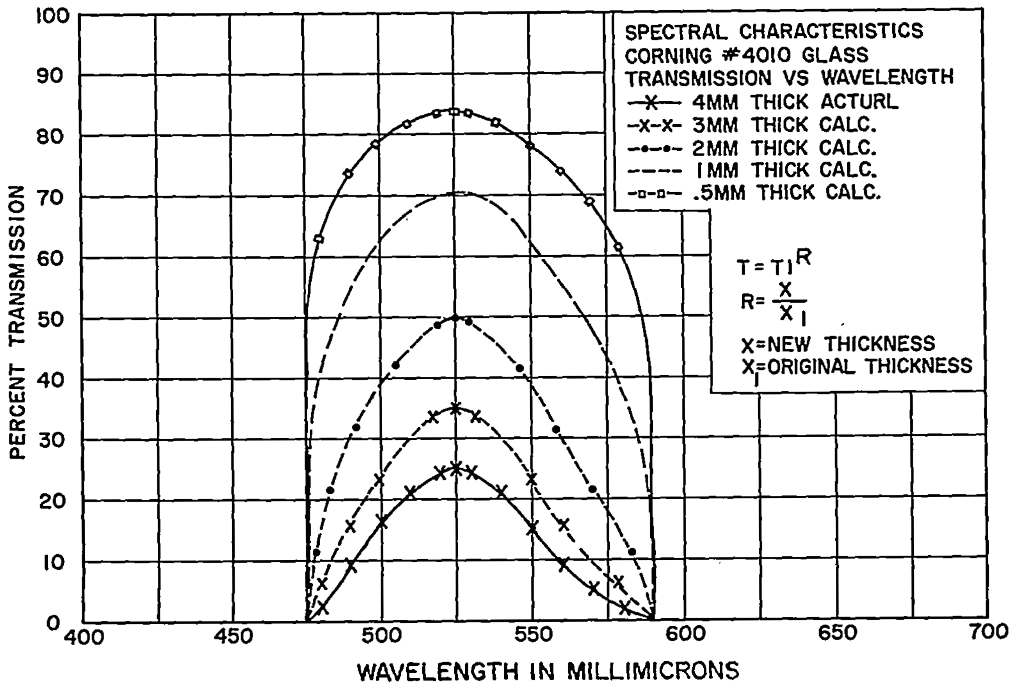

Figure 17. Calculated Data for Spectral Response of Lapped Down Corning Filters CS4-64

TABLE II. CALCULATED DATA FOR SPECTRAL RESPONSE OF LAPPED DOWN CORNING FILTER CS4-64

W (WAVELENGTH)	T1	T	
475	0	0	CS4-64 No. 4010 glass 0.5 mm thick
480	.025	.630583	
490	.09	.740083	
500	.15	.788881	
510	.2	.817765	
520	.24	.836616	
525	.25	.840896	
530	.24	.836616	
540	.21	.822768	
550	.15	.788881	
560	.09	.740083	
570	.05	.687656	
580	.02	.613238	
590	0	0	
W	T1	T	
475	0	0	CS4-64 No. 4010 glass 1 mm thick
480	.025	.397635	
490	.09	.547723	
500	.15	.622333	
510	.2	.66874	
520	.24	.699927	
525	.25	.707107	
530	.24	.699927	
540	.21	.676947	
550	.15	.622333	
560	.09	.547723	
570	.05	.472871	
580	.02	.37606	
590	0	0	
W	T1	T	
475	0	0	CS4-64 No. 4010 glass 2 mm thick
480	.025	.158114	
490	.09	.3	
500	.15	.387298	
510	.2	.447214	
520	.24	.489898	
525	.25	.5	
530	.24	.489898	
540	.21	.458258	
550	.15	.387298	
560	.09	.3	
570	.05	.223607	
580	.02	.141421	
590	0	0	

TABLE II. CALCULATED DATA FOR SPECTRAL RESPONSE OF LAPPED DOWN CORNING FILTER CS4-64 (cont)

W (WAVELENGTH)	T1	T	
475	0	0	
480	.025	6.28717 E-2	CS4-64 No. 4010 glass 3 mm thick
490	.09	.164317	
500	.15	.241029	
510	.2	.29907	
520	.24	.342893	
525	.25	.353553	
530	.24	.342893	
540	.21	.310216	
550	.15	.241029	
560	.09	.164317	
570	.05	.105737	
580	.02	.053183	
590	0	0	

T1 = original transmission at 4 mm

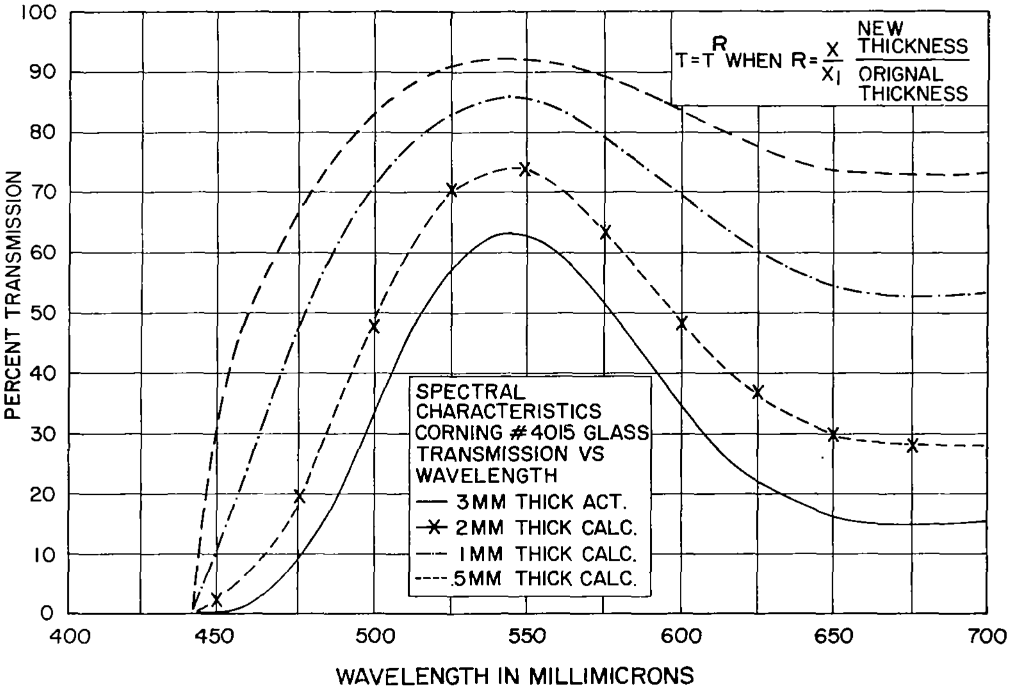

Figure 18. Plot of Spectral Response of Lapped Down Corning Filter CS4-65

TABLE III. CALCULATED DATA FOR SPECTRAL RESPONSE OF LAPPED DOWN CORNING FILTER CS4-65

W	T1	T	
440	0	0	Thickness = 1 mm CS4-65 No. 4015 glass
460	.02	.271796	
480	.12	.493591	
500	.33	.691298	
520	.53	.809439	
540	.62	.852838	
550	.63	.857394	
560	.6	.843576	
580	.48	.783165	
600	.34	.698204	
620	.24	.621742	
640	.18	.564944	
660	.15	.531665	
680	.15	.531665	
700	.15	.531665	
W	T1	T	
440	0	0	Thickness = 3 mm CS4-65 No. 4015 glass
460	.02	.073873	
480	.12	.243632	
500	.33	.477893	
520	.53	.655191	
540	.62	.727332	
550	.63	.735124	
560	.6	.711621	
580	.48	.613348	
600	.34	.487489	
620	.24	.386563	
640	.18	.319162	
660	.15	.282668	
680	.15	.282668	
700	.15	.282668	
W	T1	T	
440	0	0	Thickness = 0.5 mm CS4-65 No. 4015 glass
460	.02	.522361	
480	.12	.703306	
500	.33	.831904	
520	.53	.899974	
540	.62	.923713	
550	.63	.92617	
560	.6	.918699	
580	.48	.885291	
600	.34	.836037	
620	.24	.789069	
640	.18	.752273	
660	.15	.729846	
680	.15	.729846	
700	.15	.729846	

T1 = original transmission at 3 mm

d. ANTI-REFLECTIVE COATING

The anti-reflective coating incorporated into the deliverable tube to reduce the specular reflection was provided by Metavac, Flushing, N.Y. The reflection of the coated surface is less than 0.5% maximum average over the visible spectrum at normal incidence and will meet MIL-C-675 specifications. See Figure 19 and refer to Appendix IV for details.

e. BRIGHTNESS AND CONTRAST

Brightness is determined by the electrical energy applied per unit area. Electrical energy is the product of accelerating potential, beam current, and the duration of the phosphor excitation.(5)

$$B = f\,(E) = f\left(\frac{VIt}{A}\right)$$

Where E = electrical energy
V = accelerating potential
I = beam current
t = duration of excitation (exposure time, writing speed)
A = area

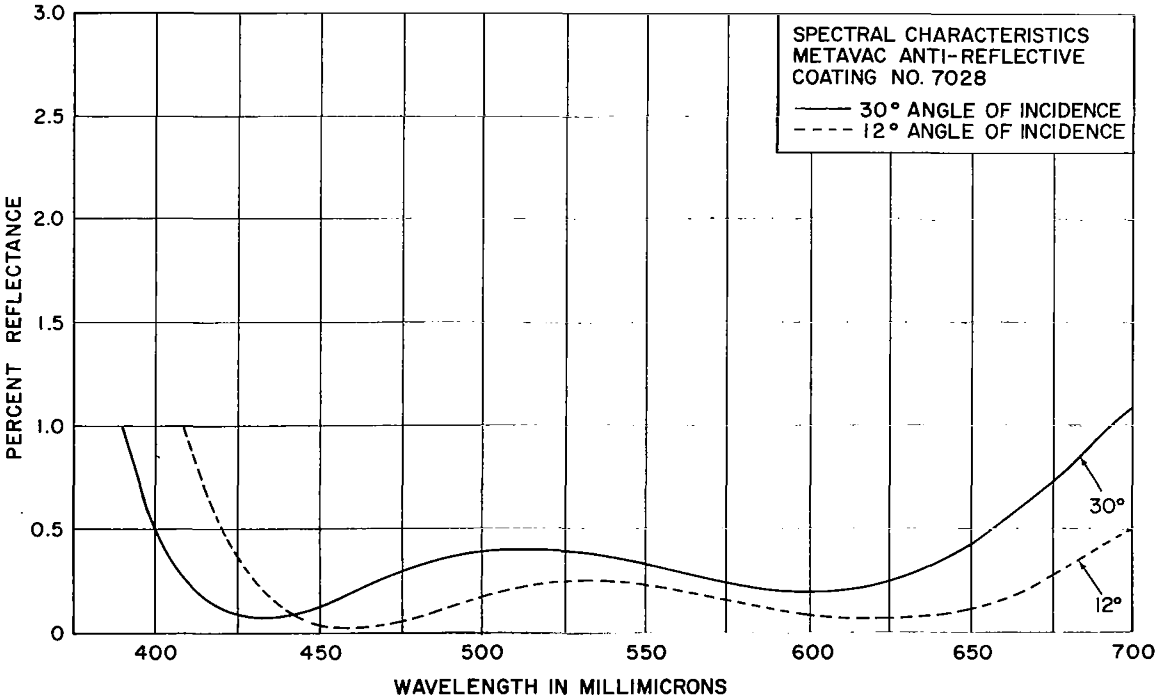

Figure 19. Characteristic Curve of Anti-Reflective Coating Across the Visible Spectrum

It can be observed from the equation that an increase in accelerating voltage, beam current, or the duration of the phosphor excitation (slower writing speed) will increase the light output of a CRT.

The most desired brightness level for complex displays is in the 20 to 70 foot lambert range, providing sufficient contrast is available. In high ambient brightness locations, more display brightness is required to provide adequate contrast. However, if the background brightness can be reduced sufficiently, display brightness of 1 to 10 foot lamberts may be used.

In the display field, contrast has several meanings. However, the term "contrast" is usually reserved for brightness differences in displays.

Two types of contrast definitions are commonly employed, contrast ratio and percentage contrast. The former is the ratio of the brightest portion of the display to the darkest and is used in applications such as TV, where gray scale rendition is important. The latter definition, percentage contrast, is used most often for display system installations which have an ambient brightness level that is a significant portion of the display brightness. (6)

$$C_r = B\ \text{max}/B\ \text{min}$$

$$\%C = \frac{\text{Emitted Intelligence}}{\text{Emitted Intelligence} + \text{Reflected Background}} \times 100\%^{(7)}$$

The maximum contrast ratio for cathode ray tubes is typically 20 to 1. However, in defining the display system the allowable ambient lighting level usually becomes a limiting parameter.

The high contrast CRT which HSC has developed is readable independent of variations in ambient lighting level and maintains its high contrast capability even under direct sunlight. Refer to Table IV.

Subdued lighting in operation centers and CIC areas, to provide for CRT readability, is eliminated. The normal lighting level will now be adequate for reading both the printed matter and the CRT display.

TABLE IV. HIGH CONTRAST CRT CHARACTERISTICS

2nd Anode Potential (kv)	Beam Current (μa)	Screen Brightness (Ft. L.)	Beam Power (watts)	Beam Power Density (watts/in^2)	Area of Spot (in^2)
5	120	0.32	0.6	1.15	0.520
5	120	0.8	0.6	5.43	0.111
10	140	28	1.4	2.83	0.495
10	140	18	1.4	9.27	0.151
15	150	36	2.25	80.30	0.028
15	160	46	2.4	185.00	0.013

f. SEALED OFF TUBES

To prove the entire theory, a sealed off tube was constructed, employing the improved filter 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 raster scan 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 percent contrast yielded a figure of 0.70 under 650 watts illumination at a distance of 2 feet, approximating full sunlight conditions.

Table V compares the CRT as fabricated under the conditions specified.

TABLE V. CONTRAST COMPARISONS

NORMAL CONDITION				
Lighting Condition	Ambient Brightness	Reflected Background	Emitted Intelligence	Percent Contrast
Room Lighting	500 Ft. L.	.22 Ft. L.	8.5 Ft. L.	97.6%
650 W quartz iodine lamp at 1 1/2 ft.	10,000 Ft. L.	3.0 Ft. L.	4.0 Ft. L.	57%
650 W quartz iodine lamp at 3 ft.	3,600 Ft. L.	1.0 Ft. L.	3.5 Ft. L.	70%
650 W quartz iodine lamp at 4 1/2 ft.	1,600 Ft. L.	0.8 Ft. L.	3.2 Ft. L.	80%
650 W quartz iodine lamp at 6 ft.	900 Ft. L.	0.7 Ft. L.	3.0 Ft. L.	81%
45° CONDITION				
Room Lighting	500 Ft. L.	.35 Ft. L.	2.0 Ft. L.	85%
650 W quartz iodine lamp at 1 1/2 ft.	10,000 Ft. L.	8.0 Ft. L.	9.5 Ft. L.	54%
650 W quartz iodine lamp at 3 ft.	3,600 Ft. L.	3.2 Ft. L.	4.5 Ft. L.	58.5%
650 W quartz iodine lamp at 4 1/2 ft.	1,600 Ft. L.	2.0 Ft. L.	3.0 Ft. L.	60%
650 W quartz iodine lamp at 6 ft.	900 Ft. L.	1.0 Ft. L.	2.6 Ft. L.	72%

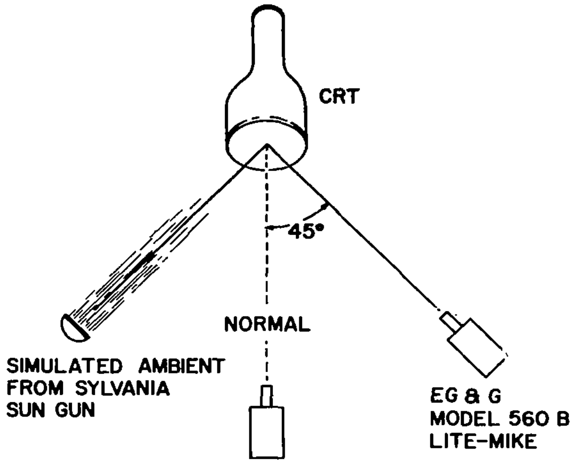

Figure 20. Spectral Reflection Measurement

A first surface mirror was placed in front of the CRT face and the lite-mike was aligned for a maximum reading (assume 100% reflection). See Figure 20. With no intelligence emitted from the CRT, the mirror was removed and the reflected light from the CRT faceplate was recorded. From this data the relative percent reflection was calculated. These measurements were taken under several ambient lighting conditions which were varied by placing the sun-gun at various predetermined distances. In addition, the lite-mike was positioned normal to the CRT faceplate and at a 45° angle to the faceplate. This data is tabulated in Table V.

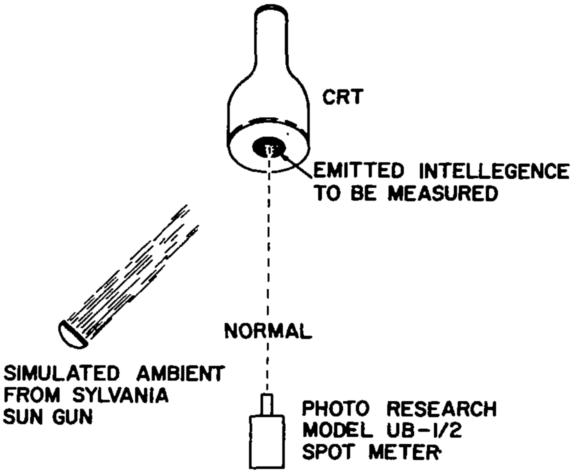

Figure 21. Brightness Measurements

Brightness measurements were recorded with the spot meter perpendicular to the plane of the cathode ray tube faceplate. See Figure 21. By proper placement of the sun gun, various ambients were simulated on the face of the CRT.

SECTION V

CONCLUSION

The critical area of concern under this contract was whether adequate resolution could be obtained employing our non-reciprocal filter technique. The deliverable CRT is proof that the limiting parameters governing the spot size of the generated intelligence in the CRT will now be a function of the electron gun geometry and the phosphor screen structure and not the thickness of the U.V. film. An operational high contrast cathode ray tube has been developed employing the non-reciprocal optical filtering techniques and exhibiting improved image resolution, more efficient heat transfer and minimum specular and diffuse reflection.

The generated intelligence from the CRT is less than anticipated under TV scan rates but adequate for displaying alphanumerics, symbols and vectors. The principles and techniques of the high contrast cathode ray tube offers a new generation of display devices capable of maintaining readability under high ambient illuminations.

Continued investigation into effective sealing techniques and location of compatible fluorescent glasses, under company sponsorship, has resulted in the recent uncovering of a glass that is fluorescent and has the same thermal expansion characteristics as the bulb glass.

This new fluorescent glass was sealed to both a 3-inch and a 5-inch funnel using conventional frit seal techniques. Observation under a polariscope showed near zero stress conditions in both cases.

The discovery of this new glass was made possible by a recent investigation into all available yellow glasses produced by major glass companies. It was found that Corning Glass Works manufactures a complete line of sharp cut yellow, signal yellow, and uranium yellow filters. Furthermore, it was discovered that they also manufacture one other highly fluorescent glass which is listed as a yellow color filter. This is Corning #3718 glass which has a coefficient of expansion of $96 \times 10^{-7}/°C$.

Evidently, Corning does not consider this yellow glass highly fluorescent and therefore, in all conferences with them, it was never mentioned as an available fluorescent glass compatible with their #0120 bulb glass. However, it is highly fluorescent and can be successfully sealed to cathode ray bulbs.

An operational tube has not yet been fabricated by Hartman Systems Co.; however, it is scheduled to be constructed in the near future, under company sponsorship.

SECTION VI

RECOMMENDATIONS

A number of areas now remain to be investigated in order to bring the CRT to a product level. The areas of most importance are:

- Determine best available ultraviolet phosphor to energize No. 3718 fluorescent glass.
- Adjust components of U.V. filter so that it will pass the U.V. light output from the phosphor with minimum attenuation.
- Optimize and finalize the entire composite high contrast filter.

The next logical step would be a continued effort directed toward producing, evaluating, and environmentally testing eight (8) cathode ray tubes employing the non-reciprocal filter.

APPENDIX I

GLASS, FILTER, AND PHOSPHOR REFERENCES

An extensive literature search was made to locate all information pertaining to ultraviolet phosphors, materials for U.V. transmission filters, fluorescent glasses, and ceramic glazes. The areas covered were technical journals, AD documents, and recent texts, generally after 1960. These references not only performed vast experimental work but provided some very excellent secondary references.

The literature being searched or to be searched is listed below:

AD 470 381
AD 470 767
AD 472 680
AD 425 107
AD 432 185
AD 441 298
AD 657 589
AD 450 206
AD 454 884
AD 457 390
AD 458 561
AD 464 315
AD 600 724
N67-40133
AD 619 009
AD 606 705
AD 419 123

Patents: 3109820

Journal Optical Society of America

"Optical Properties of Zinc Sulphide in U.V."	1956 Vol. 46 p. 1013
"Zinc Silicate Phosphors"	1951 Vol. 41 p. 644
"Zinc Sulphide Phosphors"	1951 Vol. 41 p. 718
"Calcium Silicate Phosphors"	1953 Vol. 43 p. 318
"Calcium Silicate and its Optical Properties"	1952 Vol. 42 p. 360
"Transparency of Optical Materials in Schumann Region"	1952 Vol. 42 p. 783
"U.V. Transmission of Barium Fluoride Crystal"	1956 Vol. 46 p. 362
"U.V. Transmission of Transparent Coatings on Glass"	1958 Vol. 48 p. 857
"Optical Constants of Cobalt Films"	1963 Vol. 53 p. 604

Journal Optical Society of America (cont)

"U.V. Transmission of Ammonium Dihydrogen Phosphate Crystals"	1960 Vol. 50 p. 865
"U.V. Transmission of Potassium Dihydrogen Arsenate"	1960 Vol. 50 p. 865
"U.V. Transparent Alkali Metal Filters"	1959 Vol. 49 p. 724
"U.V. Transmitting Silicate Glass"	1961 Vol. 51 p. 702
"U.V. Transmittance of Lithium"	1963 Vol. 53 p. 851

Journal Applied Physics

"Optical Properties of Cuprous Sulphide"	1965 Vol. 36 p. 3882
"Optical Properties of Gold"	1965 Vol. 36 p. 2571
"Optical Properties of Indium Oxide"	1966 Vol. 37 p. 299
"Structural & Optical Characteristics of Thin GaAs Films"	1966 Vol. 37 p. 1507
"Optical Properties of Anodic Oxide Films"	1966 Vol. 37 p. 1821
"Optical Properties of Thin Metallic Films in Island Form"	1966 Vol. 37 p. 2775
"Optical Properties of Thin Films of Molybdenum Trioxide"	1966 Vol. 37 p. 4818
"Preparation & Characterization of Evaporated Boron Film"	1966 Vol. 37 p. 1992
"Optical Properties of Copper Oxide Films"	1966 Vol. 37 p. 184

Journal American Ceramic Society

"Reactions between Metallic Iron & Cobalt Oxide bearing Sodium Disilicate Glass"	1967 Vol. 50 p. 61
"Activity-Composition Relationship in Orthosilicates & Metasilicate Solid Solutions in the System $MnO-C_0O-SiO_2$"	1967 Vol. 50 p. 230

Transactions Electrochemical Society

"New Ultraviolet Phosphors" 1947 Vol. 91 p. 241

Proceedings, I.R.E.

"Measuring Phosphor Resolution" 1962 Vol. 50 p. 95

Proceedings, Physics Society

"The Penetration of Electrons in Luminescent Materials" 1963 Vol. 81 p. 751

Journal, Electrochemical Society

"Spectral Properties of Rare Earth Oxide Phosphors" 1964 Vol. 111 p. 311

Applied Physics, Letters

"Electron Beam Aging of Silicate Phosphors" 1965 Vol. 6 p. 128

Ceramic Glazes

Cullen W. Parmelee "Ceramic Industry"
Pub. by Indust. Pub. Inc., Ill. 1951

Glass

1956 G. O. Jones, John Wiley & Sons Inc., N.Y.

Glass Eng. Handbook, E. B. Shand, 1958,
McGraw-Hill Book Co., N.Y.

Glass - Its Industrial Applications - Charles J. Phillips
1960 - Reinhold Publishing Corp., N.Y.

Clay & Glazes for the Potter - Daniel Rhodes
1959 - Chilton Co. Book Div., Publishers

Optical Properties of Thin Solid Films - O. S. Heavens
1965 - Butterworths Pub. Ltd., London, England

Specific References

1. R.W. Wood & C. Lukens
Physical Review 1938 Vol. 54 pp. 332-337

2. E.B. Shand
Glass Engineering Handbook
McGraw Hill 1958 p. 103

3. Data Display Study
AD 419 123 Report No. 2
National Cash Register Co. 1 March - 1 June 1963

4. Private communication:
P. Seats - Thomas Electronics 1 January 1969

5. Analysis of Pictorial Displays
AD 606 705 1st Quarterly Rpt.
Hughes, Culver City, Calif. Sept. 1964

6. H.H. Poole
Fundamentals of Display Systems
Spartan Books 1966 p. 283

7. Development of High Contrast
Electroluminescent Techniques for
Aircraft Displays Technical Report
AFFDL-TR-66-6
AD 619 009 April 1966 p. 28

8. C.W. Parmalee
Ceramic Glazes
Industrial Publications 1951 p. 12

9. Daniel Rhodes
Clay and Glazes for the Potter
Chilton Books 1957 p. 131

10. Daniel Rhodes
Clay and Glazes for the Potter
Chilton Books 1957 p. 69

11. C.W. Parmalee
Ceramic Glazes
Industrial Publications 1951 p. 23

12. Sylvania Electric Products Inc.
Chemical and Metallurgical Division
Towanda, Penna. June 1958

Specific References (cont)

13. Superior Electronics Co.
Div. of Howard Aiken Indust. Inc.
Clifton, N. J.
Cathode Ray Tube Processing
Information Rcvd. Oct. 1966

14. Owen Illinois
Kimble Glasses
Technical Data 1969

APPENDIX II

U.V. FILTER GLASS MATERIALS

1. BORAX ($Na_2O \cdot 2B_2O_3 \cdot 10H_2O$)

The composition of this compound, called sodium tetraborate, is:

Sodium oxide	16.3%
Boric oxide	36.5
Water of crystallization	47.2

Since the water of crystallization content is susceptible to variation in local temperature, care should be taken to store the material in a place where the temperature does not fluctuate much. Where precision is required in the use of the substance, the water content should be determined carefully. The total water content may be expelled at a low temperature (735° C.), and this product is known as fused borax. Fifty-three pounds of this is equivalent to 100 pounds of the hydrated salt. One of the advantages of the use of the dehydrated compound is the avoidance of intumescence, i.e., the swelling of borax during the fritting. It is claimed that the use of the fused salt lessens the need for greater space for storage of the raw material as well as in the crucibles or furnaces required for the melting of large frit batches.(8)

Borax is a very strong flux and solvent for all the materials used in glaze batches. It has specific action on color oxides, making possible the preparation of certain colors and shades. It reduces the viscosity, assisting in the healing of defects due to the formation of scratches, cracks, or pitting in the glaze surface prior to the maturity. This useful remedial action, due to the increase of the fluidity of the glaze melt, is sometimes employed by adding very small amounts of borax (about 10%) to the very viscous, high-fire glazes, e.g., the porcelain type. An excess may cause the formation of pinholes and blisters.

2. COBALT OXIDE

Cobalt oxide is the most stable and reliable glaze colorant. It gives a similar shade of blue in almost all types of glazes and under various firing conditions. The usual forms employed are cobalt carbonate, a light purple powder with the formula $CoCO_3$, or black cobalt oxide, CoO. The carbonate is usually preferred because of its fine particle size.(9)

Cobalt oxide is the most powerful of the coloring oxides in tinting strength. One-fourth of 1 percent in a glaze is sufficient to give a medium blue. One-half percent gives a strong blue, and 1 percent ordinarily gives a very dark blue. Amounts of more than 1 percent produce dense blue-black or black.

Glazes containing cobalt oxide may need to be thoroughly ball-milled to eliminate a speckled or mottled appearance in the finished glaze.

3. ZINC OXIDE ZnO

Zinc oxide is a very useful flux in the middle and higher range of temperature. Used in small amounts, it may be a very active flux, and when added in larger quantities, it may produce matness and dryness. It is little used in glazes fired at temperatures below 1110°C, because at the lower temperatures it does not have much fluxing power.

Although zinc oxide is not nearly as strong a flux as lead oxide, it has been employed as a substitute for lead. The so-called Bristol glaze was developed in England to avoid the use of lead. It is a type of glaze which employs zinc as the principal flux, with calcium, magnesium, and barium used as auxiliary fluxes. (10)

As an additional flux in glazes which contain lead, feldspar or boric acid, zinc is a very valuable material. It is an aid to smooth, even, trouble-free glazing. However, glazes which rely mostly on zinc for flux are apt to crawl and may be subject to pitting and pinholing, and the colors may be mottled and broken. A little zinc is a good thing and a lot of it is likely to cause trouble.

Zinc oxide is an important constituent of several types of glazes, functioning as a flux, improving the gloss, modifying the action of chromophores, and sometimes contributing to the opacity. Excessive amounts will render the melt too refractory, i.e., too viscous, without greatly lessening the glossiness. As is usual in glazes the effects obtained will be dependent in some degree upon the character and amount of the other bases present, as well as upon the content of silica and alumina. For example, in the Bristol type of glaze, the replacement of part of the calcia with zinc oxide is said to give a greater fusibility than that had with either constituent used alone. Zinc oxide has the greatest effect of any of the bases (excepting calcia and magnesia), in increasing the elasticity. It is second only to magnesia in its power to lower the coefficient of expansion of some glasses, but rates a little lower than calcia. With the exception of calcia it ranks first in increasing the strength. (11)

There are several grades, depending upon the purity which in turn depends upon the method of preparation. The best grade is prepared by the volatilization of metallic zinc and the oxidation of the vapors which are classified into various size groups during the process of condensation. The cheaper grades, prepared from the ores by a simpler process, may be contaminated with the oxides of iron, cadmium and lead. Inferior grades may contain considerable lead sulfate. Calcination of the zinc oxide has long been practiced to minimize the tendency of the oxide to cause shrinkage during the firing of the glaze and the consequent tendency to crawl and bead.

Zinc oxide has some effect upon colors, assisting in spreading a few and modifying others. For example, it benefits blues and tends to prevent the formation of greens with chromium oxide. It has been found that zinc oxide imparts to glazes a greater brilliancy, and also that it is a valuable constituent in correcting crazing.

4. COMPONENTS OF U.V. FILTER GLASS

Name: Sodium (Tetra) Borate

Composition: $Na_2B_4O_7 \cdot 10H_2O$ (Fused-Ground Borax Glass)

Manufacturer: Fisher S-252

Name: Cobalt Oxide (Cobaltous and Cobaltic Oxide)

Composition: Co_3O_4

Manufacturer: Fisher C-382

Name: Zinc Oxide (Dry Process)

Composition: ZnO

Manufacturer: Fisher Z-52

APPENDIX III

FIRING AND ANNEALING SCHEDULE

The Firing and Annealing Schedule in Figure 22 shows the required temperature cycling of the sprayed U.V. faceplate.

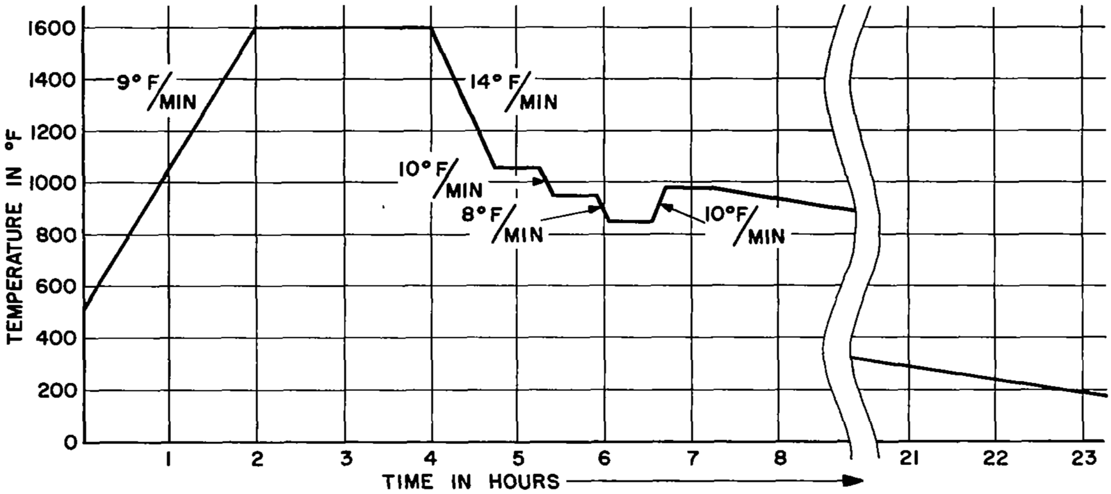

Figure 22. Firing and Annealing Schedule

APPENDIX IV

PROCEDURES FOR H.S.C. FILTER FABRICATION

The following procedures are necessary for H.S.C. filter fabrication:

- U.V. glass lamination procedure
- Phosphor type and screening information
- Lacquering and aluminizing data
- Sealing
- Passive filter
- Anti-reflection coating

1. U.V. GLASS LAMINATION PROCEDURE

The U.V. glass lamination procedure is as follows:

a. Mix ingredients

$$\left.\begin{array}{lll} \mathrm{ZnO} & - & 24\% \\ \mathrm{C0_2O_3} & - & 34\% \\ \mathrm{Na_2B_4O_7} & - & 42\% \end{array}\right\} \text{By weight}$$

b. In a zirconium coated ladle fire with a torch hot enough to reduce to molten state (propane-oxy) pour onto a hot plate and press into thin sheets.

c. Refire the cool mix again until molten press and cool.

d. Grind up mix into a 300-mesh powder using mortar and pestle.

e. Spray the powder onto glass at 45 to 50 pound pressure, thickness variable. Dry using heat lamp.

f. Spray vehicle is made up of the following:

50 ml xylene
25 ml amyl alcohol
10 ml plastic binder

The plastic binder consists of:

200 parts xylene
100 parts dibutylphtalate
18 parts ethocel
8 parts butyl alcohol

g. Place glass between two blocks of marinite separated by walls of marinite; the glass to lay on a thin bed of flint.

h. Furnace to be set at 1650° F brought up to full heat in about 2 hours. Held at high heat for 1 hour. Then cooled over a period of 12 hours.

2. PHOSPHOR TYPE

The screen employed on the deliverable CRT is a Sylvania Type 2071 barium zinc magnesium silicate: lead ultraviolet phosphor. The U.V. phosphor has a peak emission of 296 millimicrons and is readily available from Sylvania Electric Products Inc., Towanda, Penna. 18848.

3. CATHODE RAY TUBE SCREENING INFORMATION(12)

a. ELECTROLYTE OR GELLING AGENT

Barium acetate is the most widely used gelling agent. It can be used at various concentrations and mixed for use in the dilute or concentrated form. If mixed in the dilute form it can be funneled directly into the bulb, with good mixing being important. For example, take a 21-inch bulb, and say you would use 20 liters of .300 gms/ liter concentration, this would be 6.0 gms of $BaAc_2$; therefore, the same results can be obtained by using 19.4 liters of water and 600 ml of a 10 gms/liter solution of $BaAc_2$.

b. POTASSIUM SILICATE - SYLVANIA PS-6

Potassium silicate is always used in the diluted form with a specific gravity reading being a good control check. The degree of dilution varies throughout the industry from 1 part potassium silicate to 1 part deionized water, to 1 part potassium silicate to 4 parts water. The degree of dilution depends mainly upon the manufacturer's equipment. For obtaining good wet and dry screen adherence 40 to 60 ml of potassium silicate should be used for each gram of $BaAc_2$ used. For example, take the 21-inch bulb mentioned above containing 6.0 gms of $BaAc_2$; to this bulb would have to be added 240 ml of potassium silicate. Now, if the potassium silicate was diluted 1 part potassium silicate to 2 parts water, it would require 720 ml of the diluted potassium silicate.

c. PHOSPHOR

Phosphor is sometimes used in the dry form, but normally it is slurried with deionized water, using 25 gms of phosphor per liter of water. The phosphor is normally coated at 3.7 - 4.2 mg/sq. cm. for aluminized tubes and approximately 5 mg/ sq. cm. for nonaluminized tubes.

d. SCREENING PROCEDURE

First, the electrolyte cushion is inducted into the clear bulb, keeping the turbulence and swirling motion at a very minimum. The phosphor (either dry or slurried) and potassium silicate are then dispensed into the bulb simultaneously with a small amount (1/2 to 1 liter) of deionized water added to prevent the silicate from gelling in the dispensing equipment. The phosphor and silicate solution should be well mixed while entering the bulb and the funnel through which this phosphor-silicate solution is dispensed should be equipped with some type of spray tip so as to disperse the phosphor out to the edge of the bulb as well as the middle.

e. SETTLING TIME

The settling time varies throughout the industry from 10 to 40 minutes, but 25 minutes settling time seems to give good results.

f. LACQUERING

Any one of several lacquering processes can be used, all with equal success. The two most common being flotation and spray. The flotation process consists of floating the lacquer on a water cushion, and the spray process consists of spraying the lacquer on a rewetted screen.

g. ALUMINIZING

The suggested weights of aluminizing slugs for 21-inch bulbs are 200 to 250 mgs and for 17-inch bulbs 150 to 175 mgs. The slugs should be cleaned in very dilute solutions of sodium hydroxide and acetic acid before using. After aluminizing, the bulbs are baked in a lehr, maintaining the bulb temperature at 410°C to 430°C for 30 minutes.

h. SCREENING FORMULATIONS

The screening formulation used is determined by the particular lacquering process to be used. A typical screening formulation for a 21-inch bulb when lacquering is done by the flotation process would be the example mentioned in paragraphs a and b under electrolyte and potassium silicate. This particular formulation will give 0.03% $Ba(Ac)_2$ and 0.42% potassium silicate solids.

The total settling volume used for 21-inch bulbs is from 18 to 25 liters. Screen distribution is the main criteria for determining the settling volume to use because screen distribution improves as the total settling volume is increased.

i. GENERAL

This information is based on data acquired using Sylvania PS-6 potassium silicate, and Sylvania phosphor, and is intended to be used only as a guide because it is known that the optimum screening conditions differ from one plant to another.

4. LACQUERING AND ALUMINIZING DATA(13)

a. FLOTATION AND SPRAY

The two commonly used lacquering processes are flotation and spray. The flotation process consists of floating the lacquer on a cushion of water. Currently, the more popular method is the spray process. This method consists of spraying the lacquer onto a re-wetted screen, and is the process which will be discussed here.

Screened bulbs should be re-wet with deionized water (at 85 to 90°F) from a constant pressure source. Best results seem to be obtained with the bulb spinning at 30 rpm. Re-wet may be accomplished by approximately 5 seconds of water followed by 15 seconds of after spin.

Spinning during re-wet and lacquering should be carried out with the bulb running true, since bulbs running out of alignment can lead to aluminizing shrinkage.

Spray nozzles should be located approximately 7-1/2 to 8 inches from the inside of the face plate for most types. Bulb temperatures should be set to provide best results with the type of lacquer used. Generally speaking, a bulb that is too cold results in a process which is prone to producing thin centers. A bulb which is too warm tends to produce thin edges. Certain brands of viscous lacquer provide best results with warm bulbs while others of higher viscosity give optimum performance with room temperature glass. As the lacquer gets thinner, water-drain time may also be increased to compensate for it. Normally the required water drain time prior to lacquer spraying runs from 30 to 45 seconds. Some processors extend drain times to as much as 5 minutes when used in conjunction with very low viscosity lacquers.

Lacquer drain time will vary from 5 to 20 minutes depending upon the type of lacquer used and the surrounding conditions of temperature and humidity. During cut-off, water should be used from a constant pressure source and adjusted to prevent splashing on the screen. After cut-off, the bulb should be dried in a level position with care taken not to tilt bulb until drying is complete. Drying may be accomplished by forced warm air similar to the process described for screen drying. Drying times average 10 to 15 minutes and all air used should be filtered by at least a 100 micron filter. Application of heat such as infra-red to the faceplate may be used to speed up the drying process and keep more of the lacquer on the screen. This might help reduce the tendency towards thin edges.

Prior to dag coating, necks should be cleaned with ammonium bifluoride to remove all traces of silicate, a thorough water rinse should follow this operation. After neck is cleaned and dried, the dag should be applied with care taken to obtain the required smooth coverage without forming heavy spots which will eventually flake or peel. Excess dag should be wiped clean with a soft cloth. Neck cleanliness established at this point will prevent many types of failure mechanisms from occuring during final testing and operation.

Prepared bulbs are flashed in standard aluminizing units. Aluminizing slugs should be cleaned thoroughly prior to use. Very dilute solutions of sodium hydroxide and acetic acid make good cleansers. Typical weights of slugs are 150 to 175 mg. for 17-inch bulbs and 200 to 250 mg. for 21-inch bulbs.

After flashing, bulbs should be examined for aluminizing quality and thickness. Thickness can be measured by utilizing a suitably calibrated "Q" meter or other similar instrument.

b. SCREEN BAKE

Properly coated and cleaned bulbs should be baked out in air to insure removal of all traces of contaminating elements. Bulbs should reach inside face plate temperatures of 410°C and should be kept there for approximately 45 to 60 minutes. Typical oven temperature rise times are 25°C/minute for the heating portion and 10°C/minute for cooling. Bulbs should be loaded into the oven in a manner which will provide the most uniform temperature distribution. It is important to note that temperature stratification exists in most ovens and that placing bulbs on different levels will normally result in heat variations from bulb to bulb. Adherence to a strict bakeout schedule at the mentioned temperatures is one of the most important items in good process control. Failure to reach proper temperature in a bulb, especially one which has been aluminized, can easily cause pump contamination which may eventually lead to random low emission, poor shelf emission characteristics, and short life.

5. SEALING

The original intention was to seal the ultraviolet laminated fluorescent glass to the funnel of the CRT bulb. However, the Corning No. 3750 fluorescent glass proved incompatible with the Corning No. 0120 CRT bulb glass. All possible seal attempts failed between these two glasses and the special filter was finally mounted internal to a conventional CRT bulb as close to the face as possible.

6. PASSIVE FILTER

The spectral characteristics of Corning Glass No. 4010 used as a passive filter is shown in Figure 23.

7. FILTER BONDING CEMENT

The optical cement employed to bond the component filters into one single composite is a synthetic polyester resin adhesive manufactured by Summers Laboratories, Inc., Fort Washington, Pa.. The type F-65 cement selected is supplied with a liquid organic peroxide as a catalyst and bonding can be produced at or above room temperature. The operational temperature of this material is from -54°C to +100°C and the refractive index is approximately 1.55 when cured.

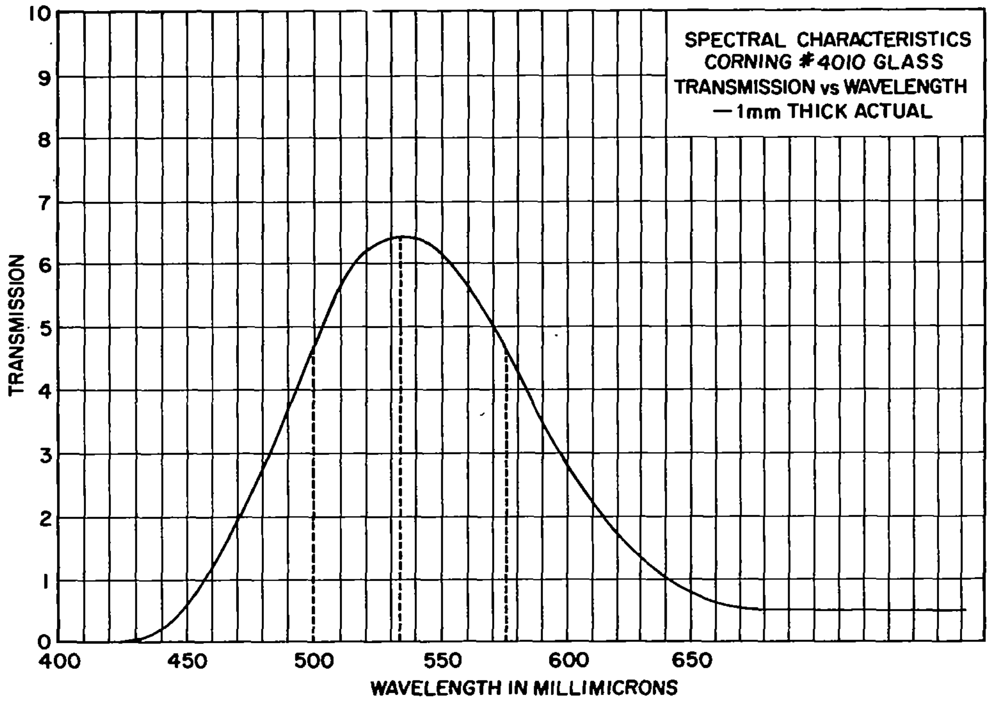

Figure 23. Spectral Characteristics of Corning Glass No. 4010

8. ANTI-REFLECTION COATING

Metavac Coating No. 7028, high efficiency reflection reducing multilayer coating meets the requirements of MIL-C-675, except that the following reflectance tolerances shall apply.

Wavelength Range	Angle of Incidence	Percentage Reflectance
450-675 mu	0°	0.6 maximum
425-700 mu	0°	0.5 maximum (average)
450-625 mu	30°	1.0 maximum
425-700 mu	30°	0.5 maximum (average)

Metavac Coating No. 7028 shall be capable of withstanding the following environmental tests:

- Solubility - The coated optical elements shall be immersed for a period of 24 hours in a solution of water and common table salt. The mixture shall be 6 ounces of salt per gallon of water at room temperature.
- Humidity - The coated optical elements shall be exposed for a period of 24 hours in a thermostatically controlled humidity chamber having a relative humidity of between 95 and 100 percent of 120° ± 4°F.
- Durability - The eraser shall be rubbed across the surface of the element from one point to another over the same path for 20 complete cycles with the force of 2.0 to 2.5 pounds continuously applied.
- Adhesion - Scotch Tape Test per MIL-M-13508A.
- Salt Spray - Test for 50 hours per MIL-STD-810A, Method 509.1.

APPENDIX V

TRANSMISSION CHARACTERISTICS OF COBALT OXIDE

The following figures illustrate the technical characteristics of cobalt oxide.

Figure 24. Cobalt Silicide Vapor Deposition Transmission Characteristics - Single Layer

Figure 25. Cobalt Silicide Vapor Deposition Transmission Characteristics - Double Layer

Figure 26. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 110)

Figure 27. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 114)

Figure 28. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 115)

Figure 29. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 116)

Figure 30. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 117)

Figure 31. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 118)

Figure 32. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 119A)

Figure 33. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 119B)

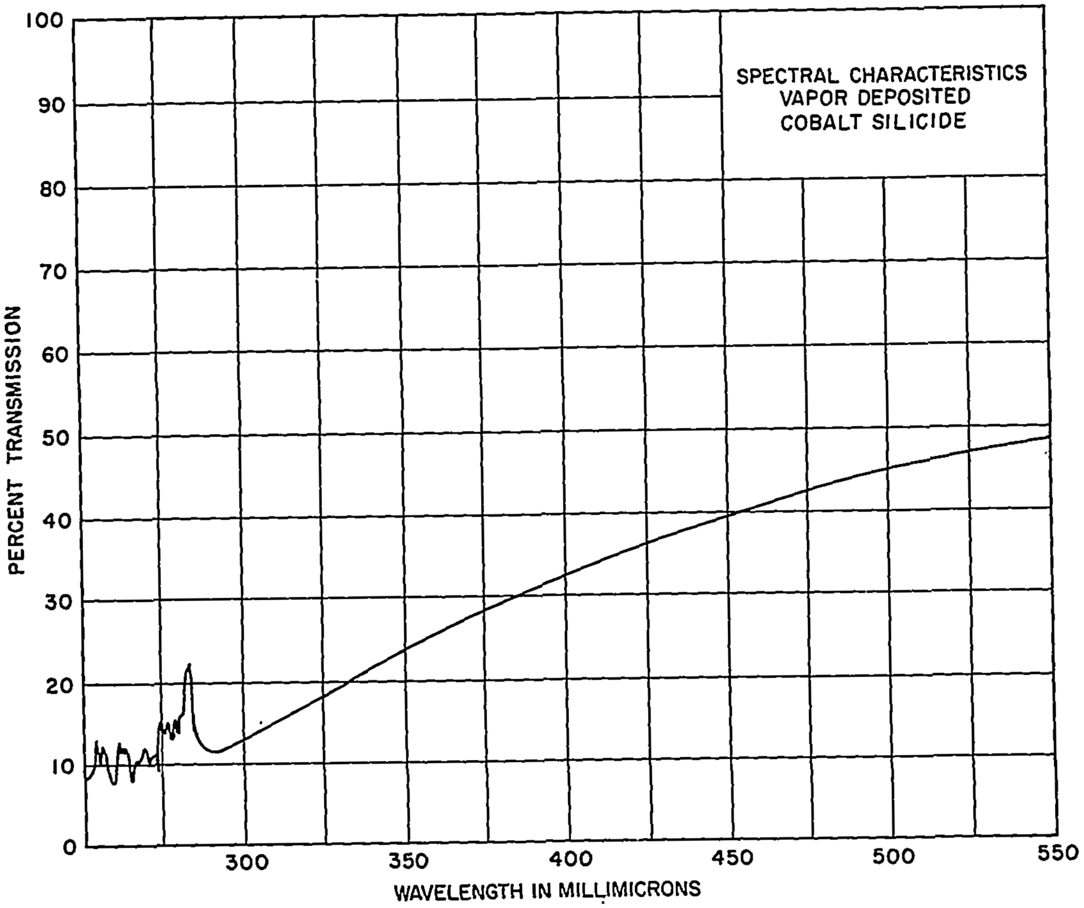

Figure 24. Cobalt Silicide Vapor Deposition Transmission Characteristics - Single Layer

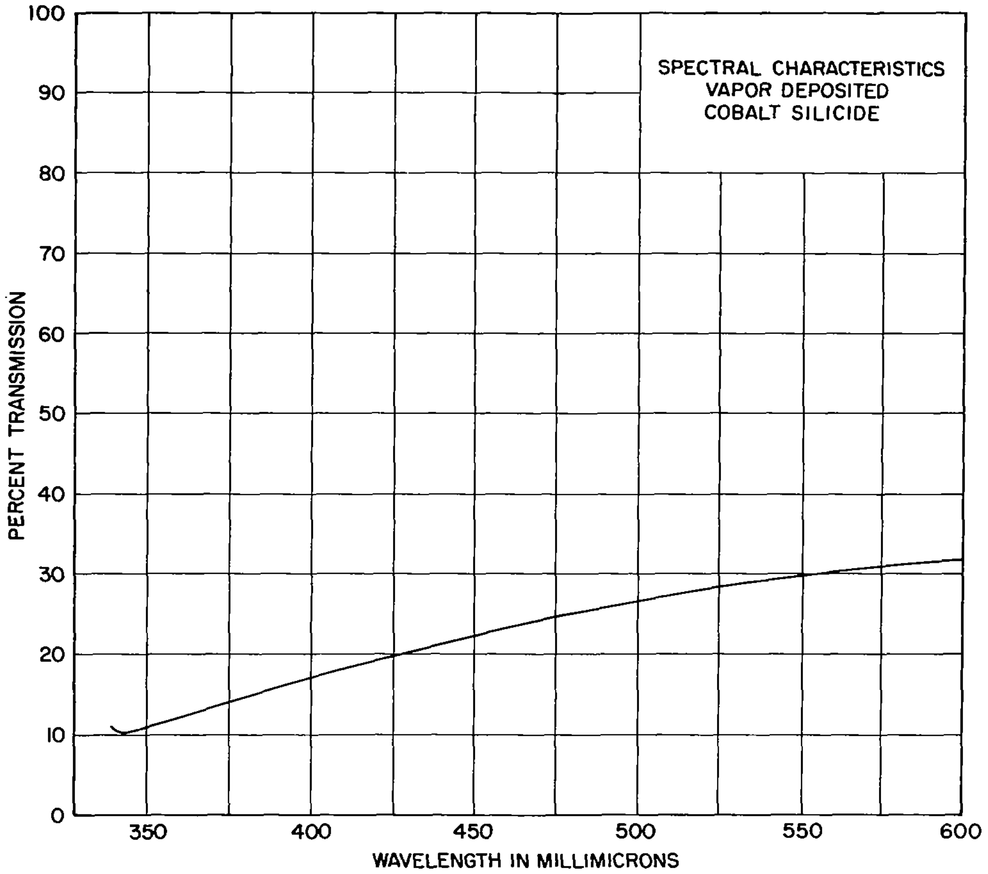

Figure 25. Cobalt Silicide Vapor Deposition Transmission Characteristics - Double Layer

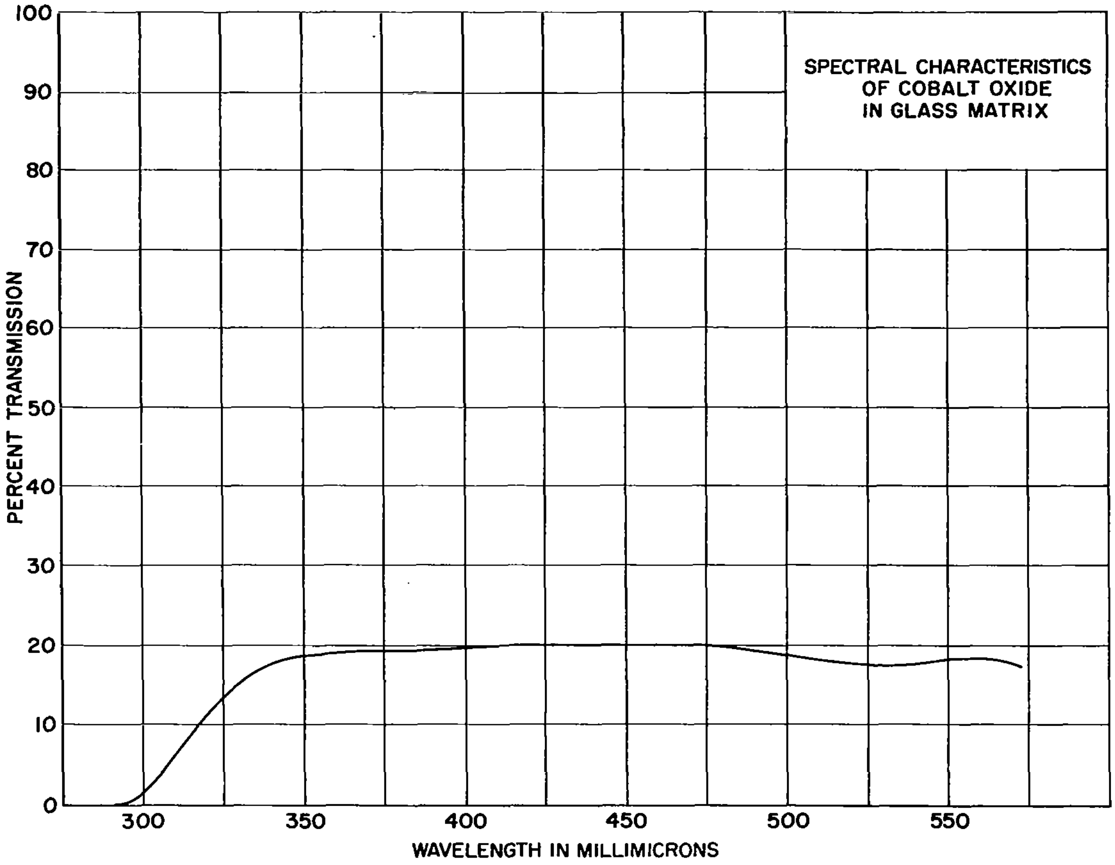

Figure 26. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 110)

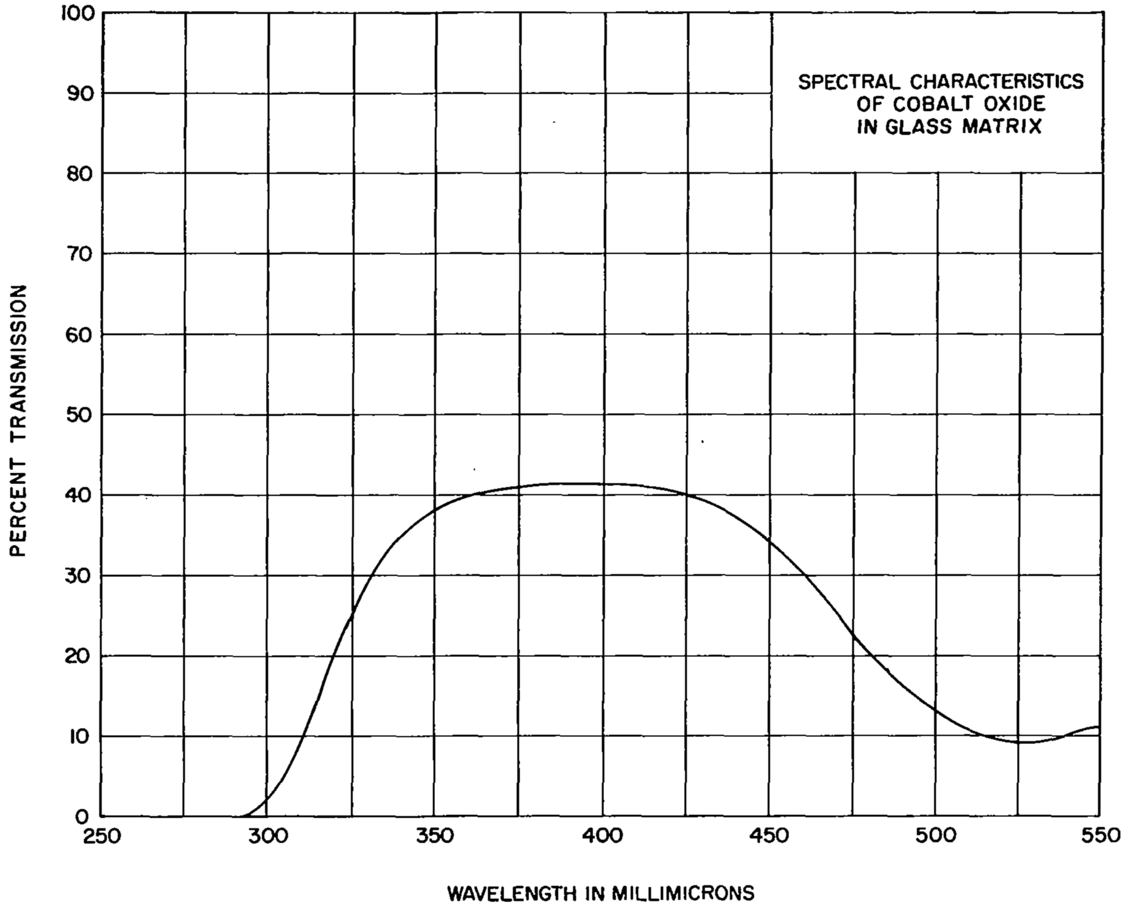

Figure 27. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 114)

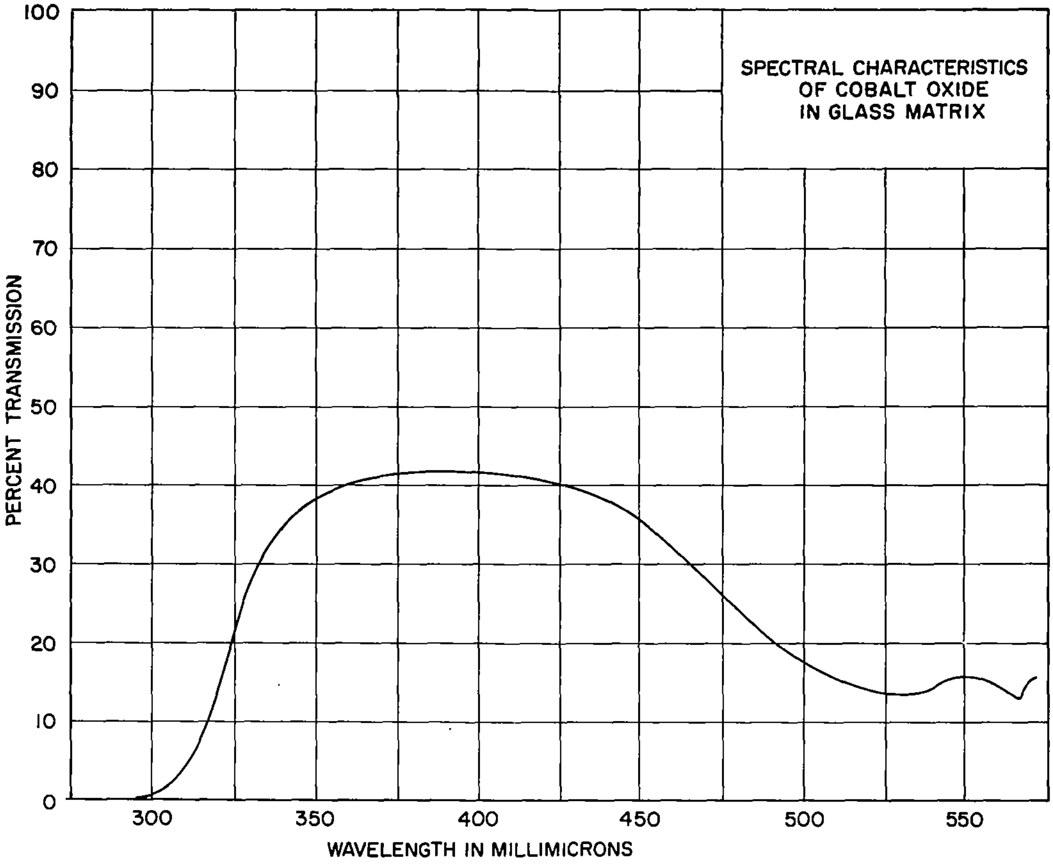

Figure 28. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 115)

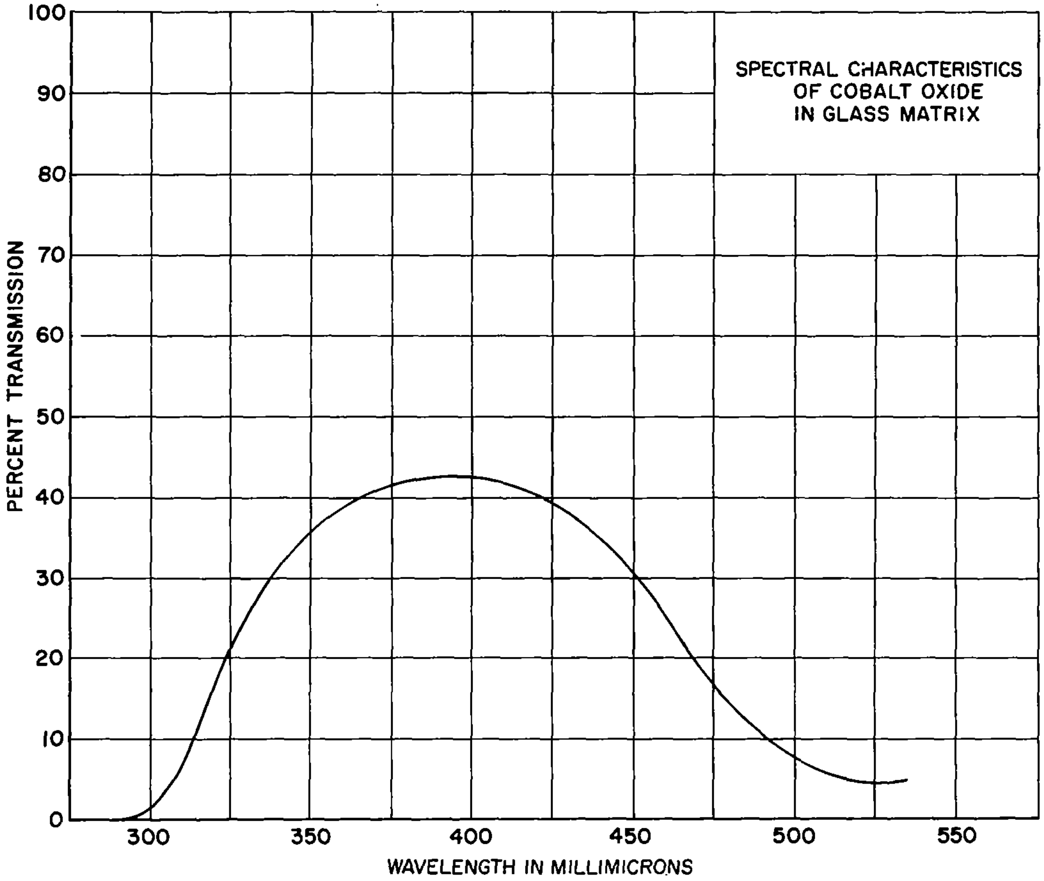

Figure 29. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 116)

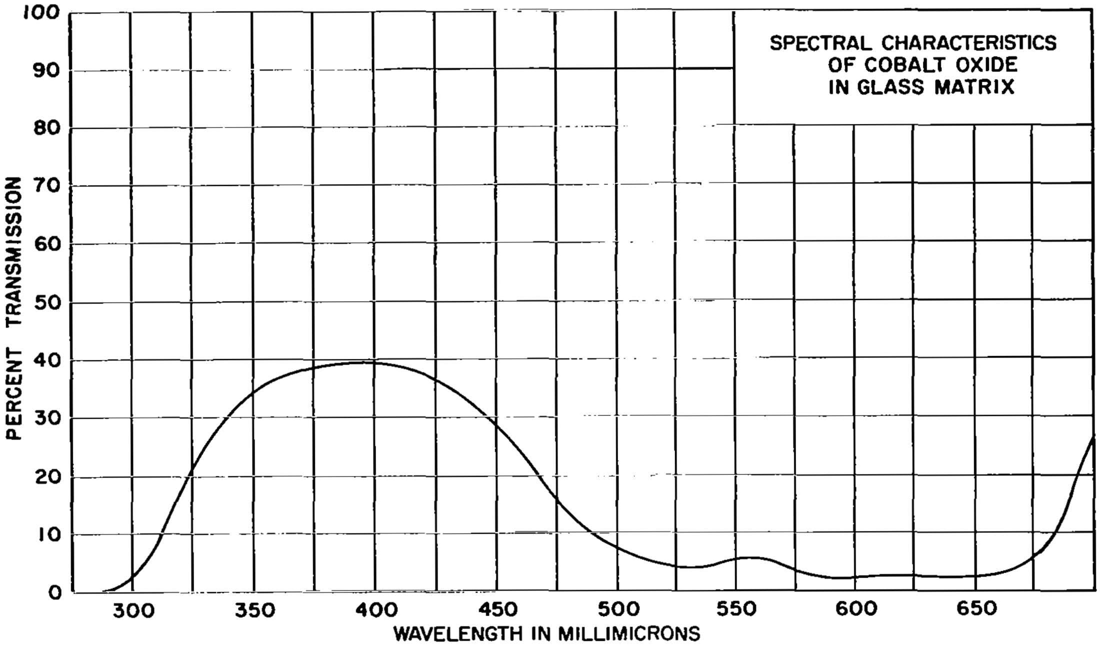

Figure 30. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 117)

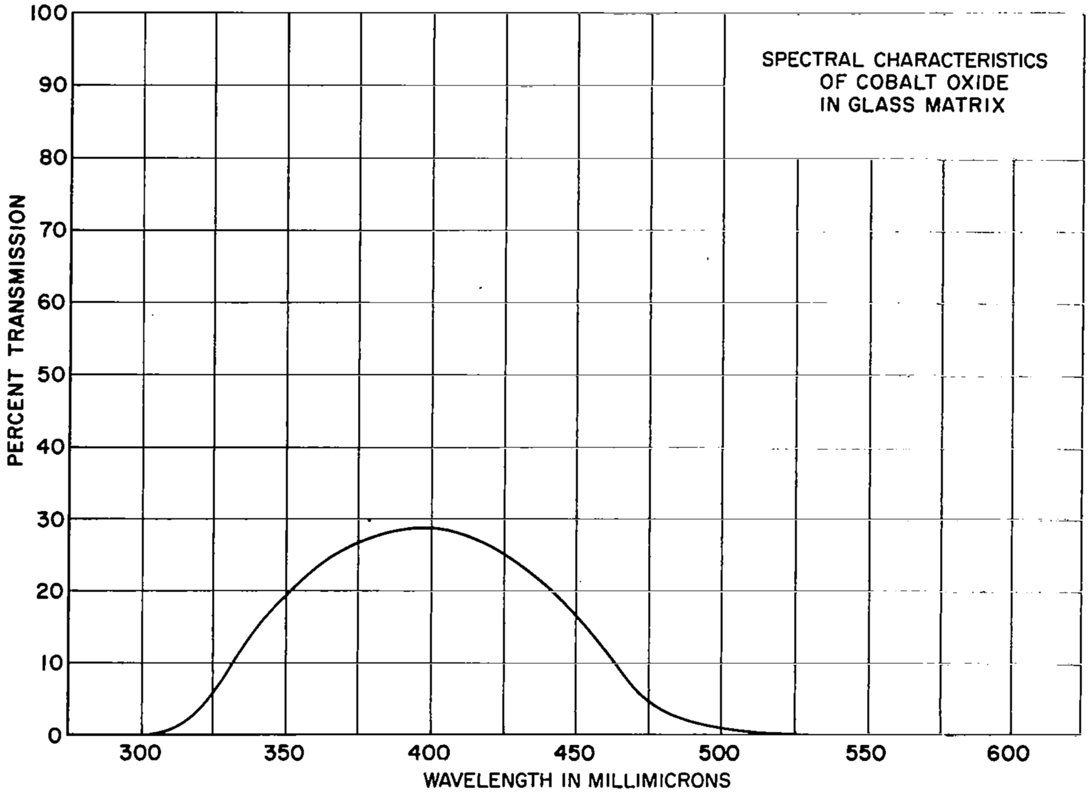

Figure 31. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 118)

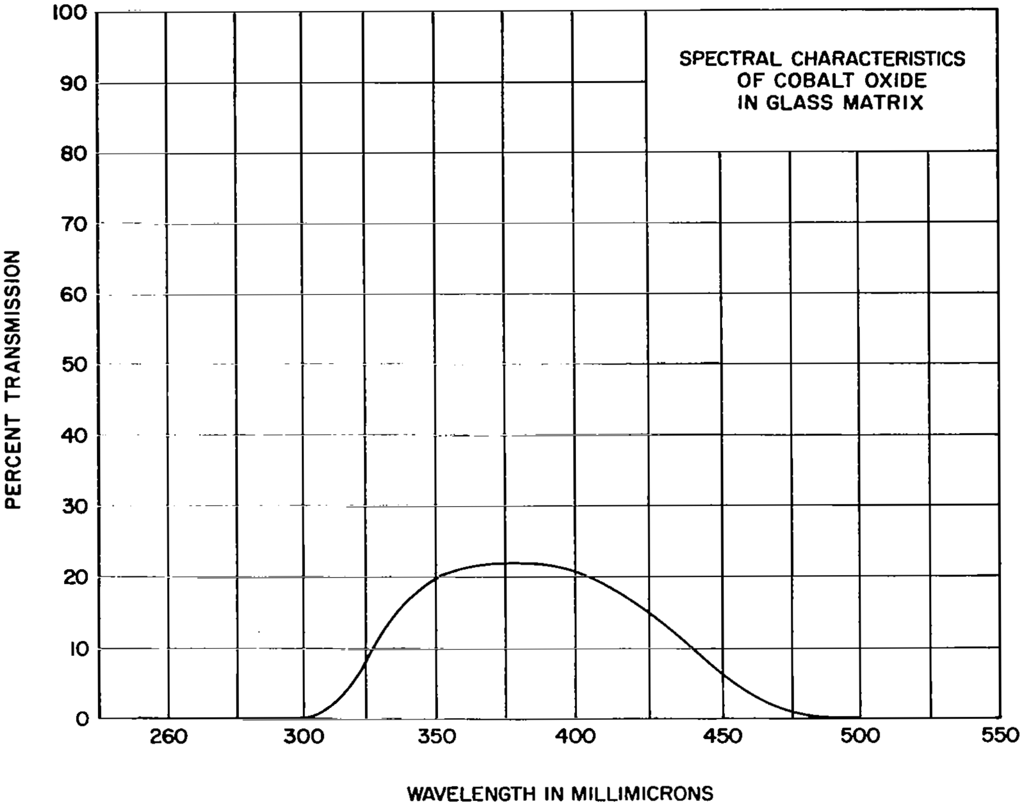

Figure 32. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 119A)

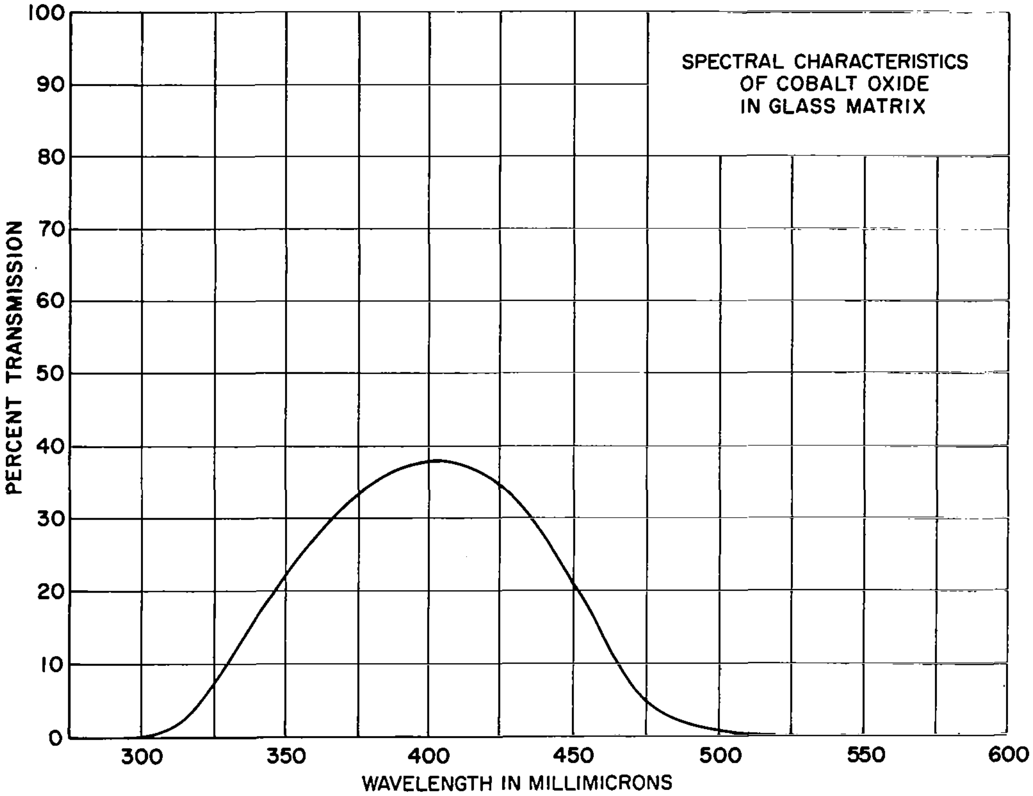

Figure 33. Transmission Characteristics of Cobalt Oxide Doped Glass Matrix (Sample No. 119B)

APPENDIX VI

TABLE OF EXPERIMENTS

Tables VI through XXX list the results of experiments.

TABLE VI. BASIC GLASS FORMULATION EXPERIMENTS

Sample No.	Glass Formulation		Firing Method	Melt Temperature	Optical Clarity	Crazing	Remarks
1	Na_2CO_3 $Ca\ CO_3$	11.4g 5.94g	Muffle Furnace	1500°F	Poor	Heavy on cooling	After further heating with oxy-propane burner batch still did not melt completely.
2	SiO_2 Na_2CO_3 $Ca\ CO_3$	2.5g 8.55g 4.46g	Oxy-Propane Burner	Above 1600°F	Good	Shattered on cooling	Flowed well. Mix ball milled for one hour.
3	SiO_2 Na_2CO_3 $CaCO_3$	5.0g 5.81g 2.85g	Oxy-Propane Burner	Above 1600°F	Opaque	Very heavy on cooling	Flowed fairly well. Mix ball milled for one hour.
4	SiO_2 Na_2CO_3 $CaCO_3$	7.5g 2.91g 1.43g	Oxy-Propane Burner	Above 1600°F	Air bubbles	Heavy on cooling	Spread and flowed well. Mix ball milled for one hour.
5	Feldspar Whiting	10.0g 10.0g	Oxy-Propane Burner		Poor	Heavy on cooling	Surface glaze only. Mix ball milled for one hour.
6	Feldspar Whiting	15.0g 5.0g	Oxy-Propane Burner		Air bubbles	Little on cooling	Surface glaze only.

TABLE VI. BASIC GLASS FORMULATION EXPERIMENTS (cont)

Sample No.	Glass Formulation	Firing Method	Melt Temperature	Optical Clarity	Crazing	Remarks
7	Feldspar 5.0g Whiting 15.0g	Oxy-Propane Burner		Poor white appearance	None	Batch not melting. Mix ball milled for one hour.
8	White Lead 12.9g Whiting 3.0g Feldspar 11.1g Kaolin 1.3g Flint 4.8g	Oxy-Propane Burner		Poor black appearance	None	Surface glaze only. Poor flowing. Mix ball milled for one hour.

TABLE VII. BASIC GLASS FORMULATION EXPERIMENTS

Sample No.	Glass Formulation	Firing Method	Melt Temperature	Optical Clarity	Crazing	Remarks
9	Sodium Borate 20.0g ($Na_2B_4O_7 10\ H_2O$)	Oxy-Propane Burner		Good	Heavy	Very good flow. Ball milled for one hour. Baked at 220°F until dry.

TABLE VII. BASIC GLASS FORMULATION EXPERIMENTS (cont)

Sample No.	Glass Formulation	Firing Method	Melt Temperature	Optical Clarity	Crazing	Remarks
10	Flint 15.0g Sodium Borate 5.0g	Oxy-Propane Burner		Opaque	Little	Surface glaze only. Batch did not melt entirely. Ball milled for one hour. Baked at 220°F until dry.
11	Flint 10.0g Sodium Borate 10.0g	Oxy-Propane Burner		Fair	Moderate	Good flow, better glaze. Ball milled for one hour. Baked at 220°F until dry.
12	Flint 5.0g Sodium Borate 15.0g	Oxy-Propane Burner		Good	Heavy on cooling	Good glaze on all surfaces. Flowed well. Ball milled for one hour. Baked at 220°F until dry.
13	Flint 20.0g	Oxy-Propane Burner		Opaque	Little	Batch not melted. Ball milled for one hour. Bakes at 220°F until dry.

TABLE VII. BASIC GLASS FORMULATION EXPERIMENTS (cont)

Sample No.	Glass Formulation	Firing Method	Melt Temperature	Optical Clarity	Crazing	Remarks
14	Boric Acid 20.0g	Oxy-Propane Burner		Very good	None	Very good flow. Ball milled for one hour. Baked at 220°F until dry.
15	Boric Acid 15.0g Flint 5.0g	Oxy-Propane Burner		Opaque white appearance	Little	Batch not melted. Ball milled for one hour. Baked at 220°F until dry.
16	Boric Acid 10.0g Flint 10.0g	Oxy-Propane Burner		Opaque	Little	Surface glaze only. Ball milled for one hour. Baked at 220°F until dry.

TABLE VIII. EFFECTS OF COBALT OXIDE IN TYPICAL GLASSES

Sample No.	Glass Formulation		Firing Method	Optical Clarity	Crazing	Sintering Temperature	Percent Cobalt Oxide	Remarks
17	Boric Acid Flint	5.0g 15.0g	Oxy-Propane Burner	Poor	None	---	---	Batch not melted. Ball milled for one hour. Baked at 220° F until dry.
18	Boric Acid	20.0g	Oxy-Propane Burner	Poor	None	800°C for one hour in Muffle Furnace	2	Batch not melted. Ball milled for one hour. Baked at 220° F until dry. Ball milled dry to a fine powder.
19	SiO_2 Na_2CO_3 $CaCO_3$	2.5g 8.5g 4.4g	Oxy-Propane Burner	Good	Heavy on cooling	800°C.for one hour in Muffle Furnace	2	Flowed well, cobalt oxide evenly distributed. Ball milled for one hour.
20	Feldspar Whiting	10.0g 10.0g	Oxy-Propane Burner	Good	Little	800°C for one hour in Muffle Furnace	2	Good flow rate. Light blue in color. Ball milled for one hour. Baked at 220° F until dry.

TABLE VIII. EFFECTS OF COBALT OXIDE IN TYPICAL GLASSES (cont)

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Crazing	Sintering Temperature	Percent Cobalt Oxide	Remarks
21A	Flint 10.0g Sodium Borate 10.0g	Oxy-Propane Burner	Good	Very little	---	2	Good flow rate. cobalt oxide evenly distributed. Deep blue in color. Ball milled for one hour. Dried and ground up in mortar and pestle.
21B	Flint 10.0g Sodium Borate 10.0g	Oxy-Propane Burner	Poor	Heavy on cooling	---	2	Batch did not completely melt. Batch was melted on uranium glass. Fairly good bond to uranium glass.

TABLE IX. VARIATION OF CONSTITUENTS IN TYPICAL BOROSILICATE GLASS

Sample No.	Glass Formulation	Firing Method	Base Substrate	Optical Clarity	Crazing	Glaze Adhesions to Base Substrate	Remarks
22	Flint 20.0g B_2O_3 8.0g Al_2O_3 1.3g Na_2CO_3 4.3g	Oxy-Propane Burner	Vycor	Very good except for bubbles	Slight	Fairly good	Wet ball milled for one hour. Baked at 220° F until dry. Fairly good flow rate.
23	Flint 23.3g Boric Acid 6.3g Al_2O_3 1.0g Na_2CO_3 3.3g	Oxy-Propane Burner	Vycor	Very good	Minimum	Good	Wet ball milled for one hour. Baked at 220° F until dry. Good flow rate.
24	Flint 26.6g Boric Acid 4.3g Al_2O3 1.0g Na_2CO_3 3.0g	Oxy-Propane Burner	Vycor	Good	None	Fair	Batch not completely melted. Wet ball milled for one hour. Baked at 220° F until dry.
25	Flint 23.3g B_2O_3 5.3g Al_2O_3 1.3g Na_2CO_3 4.3g	Oxy-Propane Burner	Vycor	Fair	Moderate on cooling	Very good	Good surface glaze. Wet ball milled for one hour. Baked at 220° F until dry.

TABLE IX. VARIATION OF CONSTITUENTS IN TYPICAL BOROSILICATE GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Base Substrate	Optical Clarity	Crazing	Glaze Adhesions to Base Substrate	Remarks
26	Flint 23.3g B_2O_3 7.0g Al_2O_3 1.0g Na_2CO_3 2.7g	Oxy-Propane Burner	Vycor	Very good	Minimum	Very good	Best glass batch thus far. Flowed away very well, good glaze. Some air bubbles at interface. Wet ball milled for one hour. Baked at 220° F until dry.
27	Flint 26.6g B_2O_3 3.7g Al_2O_3 1.0g Na_2CO_3 2.7g	Oxy-Propane Burner	Vycor	Very good some bubbles at interface	Slight	Good	Best of high content flint glass. Good glaze. Wet ball milled for one hour. Baked at 220° F until dry.
28	Flint 26.6g B_2O_3 4.7g Al_2O_3 0.8g Na_2CO_3 2.0g	Oxy-Propane Burner	Vycor	Cloudy	Slight	Fair	Did not flow well. Surface glaze only. Wet ball milled for one hour. Baked at 220° F until dry.

TABLE IX. VARIATION OF CONSTITUENTS IN TYPICAL BOROSILICATE GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Base Substrate	Optical Clarity	Crazing	Glaze Adhesions to Base Substrate	Remarks
29	Flint 21.6g B_2O_3 8.0g Al_2O_3 1.0g Na_2CO_3 3.3g	Oxy-Propane Burner	Vycor	Fair	Heavy	Fair	Flow rate was fair. Surface glaze only. Wet ball milled for one hour. Baked at 220° F until dry.

TABLE X. VARIATION OF CONSTITUENTS IN TYPICAL BOROSILICATE GLASS

Sample No.	Glass Formulation	Firing Method	Base Substrate	Optical Clarity	Crazing	Glaze Adhesion to Base Substrate	Remarks
30	Flint 23.0g B_2O_3 4.0g Al_2O_3 2.0g Na_2CO_3 6.0g	Oxy-Propane Burner Muffle Furnace	Pyrex 7744 glass	Molten very diffuse opaque	Minimum	Good	Dry ball milled for one hour. Made into frit. Closest match of glass so far. Sintered at 900° C in furnace.

TABLE X. VARIATION OF CONSTITUENTS IN TYPICAL BOROSILICATE GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Base Substrate	Optical Clarity	Crazing	Glaze Adhesion to Base Substrate	Remarks
31	Flint 23.0g B_2O_3 7.0g Al_2O_3 2.0g Na_2CO_3 3.0g	Oxy-Propane Burner Muffle Furnace Oxy-Propane Burner	Pyrex 7744 glass	Molten very diffuse poor	Heavy	Fair	Dry ball milled for one hour. Made into frit. Sintered at 900° C in furnace. Batch not completely melted.
32	Pyrex (7744) Glass 10.0g Sodium Borate 10.0g	Muffle Furnace Oxy-Propane Burner	Pyrex 7744 glass Pyrex 7744 glass	Glazed Good except for bubbles	None	Good	Pyrex glass ground, mix sintered at 900° C in muffle furnace. Color also darkened.
33	Flint 2.0g B_2O_3 3.0g Al_2O_3 3.0g Na_2CO_3 6.0g	Oxy-Propane Burner Muffle Furnace Oxy-Propane Burner	Pyrex 7744 glass	Molten very diffuse opaque	None	Fair	Mixed dry in mortar and pestle, fired, made into frit. Sintered at 900° C in muffle furnace. Base substrate melted, batch did not.

TABLE X. VARIATION OF CONSTITUENTS IN TYPICAL BOROSILICATE GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Base Substrate	Optical Clarity	Crazing	Glaze Adhesion to Base Substrate	Remarks
34	Flint 20.0g B_2O_3 3.0g Al_2O_3 3.0g Na_2CO_3 8.0g	Oxy-Propane Burner Muffle Furnace Oxy-Propane Burner	Pyrex 7744 glass	Glazed sintered cloudy	Heavy	Good	Mixed dry in mortar and pestle, fired, made into frit. Sintered at 900° C in furnace. Poor compatibility.
35	Flint 20.0g B_2O_3 2.5g Al_2O_3 4.0g Na_2CO_3 7.0g	Oxy-Propane Burner Muffle Furnace Oxy-Propane Burner	Pyrex 7744 glass	Molten sintered good	Moderate	Good	Mixed dry in mortar and pestle, fired, made into frit. Sintered at 900° C in furnace.
36	Flint 10.0g B_2O_3 2.0g Al_2O_3 0.8g Feldspar 3.0g Whiting 1.0g	Oxy-Propane Burner Muffle Furnace Oxy-Propane Burner	Pyrex 7744 glass	Frit sintered good	None	Good	Mixed dry in mortar and pestle, fired, made with frit. Sintered at 900° C in furnace

TABLE X. VARIATION OF CONSTITUENTS IN TYPICAL BOROSILICATE GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Base Substrate	Optical Clarity	Crazing	Glaze Adhesion to Base Substrate	Remarks
37	Pyrex (7744) Glass powdered 4.0g Whiting 2.0g	Oxy-Propane Burner	Pyrex 7744 glass	Opaque	None	Poor	Pyrex base substrate melted while glass batch did not.

TABLE XI. VARIATION OF CONSTITUENTS IN TYPICAL BOROSILICATE GLASS

Sample No.	Glass Formulation	Firing Method	Base Substrate	Optical Clarity	Crazing	Glaze Adhesion to Base Substrate	Remarks
38	Pyrex (7744) Glass powdered 4.0g Na_2CO_3 2.0g	Oxy-Propane Burner	Pyrex 7744 glass	Opaque	None	Poor	Pyrex base substrate melted while glass batch did not.
39	Pyrex (7744) Glass powdered 4.0g Boric Acid fused 2.0g	Oxy-Propane Burner	Pyrex 7744 glass	Opaque	None	Poor	Pyrex base glass melts before mix does.

TABLE XI. VARIATION OF CONSTITUENTS IN TYPICAL BOROSILICATE GLASS (cont)

Sample No.	Glass Formulation		Firing Method	Base Substrate	Optical Clarity	Crazing	Glaze Adhesion to Base Substrate	Remarks
40	Pyrex (7744) Glass powdered	4.0g	Oxy-Propane Burner	Pyrex 7744 glass	Opaque	None	Poor	Pyrex base glass melts before mix does.
	Al_2O_3	2.0g						
41	Pyrex (7744) Glass powdered	4.0g	Oxy-Propane Burner	Pyrex 7744 glass	Opaque	None	Poor	Pyrex base glass melts before mix does.
	Feldspar	2.0g						
42	Pyrex (7744) Glass powdered	4.0g	Oxy-Propane Burner	Pyrex	Opaque	None	Poor	Pyrex base glass melts before mix does.
	Sodium Borate	2.0g						

TABLE XII. SATURATION LIMIT OF COBALT OXIDE IN A TYPICAL GLASS MATRIX

Sample No.	Glass Formulation		Percent Cobalt Oxide Added	Firing Method	Base Substrate	Optical Clarity	Crazing	Remarks
43	Flint B_2O_3 Al_2O_3 Na_2CO_3	69% 20% 3% 8%	1	Oxy-Propane Burner	Vycor	Good	Heavy	Color very light blue.
44	Flint B_2O_3 Al_2O_3 Na_2CO_3	69% 20% 3% 8%	1-1/2	Oxy-Propane Burner	Vycor	Good	Heavy	Color light blue. Cobalt well absorbed in glass.
45	Flint B_2O_3 Al_2O_3 Na_2CO_3	69% 20% 3% 8%	2	Oxy-Propane Burner	Vycor	Good	Very heavy	Mixed dry in mortar and pestle. All cobalt oxide went into glass.
46	Flint B_2O_3 Al_2O_3 Na_2CO_3	69% 20% 3% 8%	2-1/2	Oxy-Propane Burner	Vycor	Fair	Very heavy	Mixed dry in mortar and pestle. All cobalt oxide went into glass.
47	Flint B_2O_3 Al_2O_3 Na_2CO_3	69% 20% 3% 8%	3	Oxy-Propane Burner	Vycor	Good	Very heavy	Mixed dry in mortar and pestle. Melt temperature seems to rise with the increase of cobalt oxide.

TABLE XII. SATURATION LIMIT OF COBALT OXIDE IN A TYPICAL GLASS MATRIX (cont)

Sample No.	Glass Formulation		Percent Cobalt Oxide Added	Firing Method	Base Substrate	Optical Clarity	Crazing	Remarks
48	Flint B_2O_3 Al_2O_3 Na_2CO_3	69% 20% 3% 8%	4	Oxy-Propane Burner	Vycor	Good	Very heavy	Mixed dry in mortar and pestle. All cobalt oxide went into glass.
49	Flint B_2O_3 Al_2O_3 Na_2CO_3	69% 20% 3% 8%	5	Oxy-Propane Burner	Vycor	Good	Very heavy	Mixed dry in mortar and pestle.
50	Flint B_2O_3 Al_2O_3 Na_2CO_3	69% 20% 3% 8%	6	Oxy-Propane Burner	Vycor	Good	Very heavy	Mixed dry in mortar and pestle. All cobalt oxide went into glass.

TABLE XIII. SATURATION LIMIT OF COBALT OXIDE IN A TYPICAL GLASS MATRIX

Sample No.	Glass Formulation		Percent Cobalt Oxide Added	Firing Method	Base Substrate	Optical Clarity	Crazing	Remarks
51	Flint B_2O_3 Al_2O_3 Na_2CO_3	69% 20% 3% 8%	7	Oxy-Propane Burner	Vycor	Good	Very heavy	Mixed dry in mortar and pestle. All cobalt oxide went into glass. Color very deep blue.
52	Flint B_2O_3 Al_2O_3 Na_2CO_3	69% 20% 3% 8%	10	Oxy-Propane Burner	Vycor	Good	Very heavy	Mix dry in mortar and pestle. All cobalt oxide went into glass.
53	Flint B_2O_3 Al_2O_3 Na_2CO_3	69% 20% 3% 8%	15	Oxy-Propane Burner	Vycor	Good	Very heavy	Mix dry in mortar and pestle. Heat required so high that vycor started to melt. Very little air bubbles. Color deep blue.

TABLE XIII. SATURATION LIMIT OF COBALT OXIDE IN A TYPICAL GLASS MATRIX (cont)

Sample No.	Glass Formulation	Percent Cobalt Oxide Added	Firing Method	Base Substrate	Optical Clarity	Crazing	Remarks
54	Flint 69% B_2O_3 20% Al_2O_3 3% Na_2CO_3 8%	20	Oxy-Propane Burner	Vycor	Poor dull appearance	Very heavy	Mix dry in mortar and pestle. Batch did not completely melt. Some cobalt oxide did not go into glass.
55	Sodium Borate 99% Nickel (1c) Oxide 1%	--	Oxy-Propane Burner	Vycor	Poor	Heavy on cooling	Mix dry in mortar and pestle. Nickel did not flow into glass.
56	Sodium Borate 99% Nickel (ous) Oxide 1%	--	Oxy-Propane Burner	Vycor	Opaque	None	Mix dry in mortar and pestle. Mix did not melt.
57	Sodium Borate 99% Manganese Dioxide 1%	--	Oxy-Propane Burner	Vycor	Good	Slight	Mix dry in mortar and pestle. Manganese flowed into glass completely. Color is tan, brown, red.

TABLE XIV. EXPERIMENTS IN VAPOR DEPOSITION OF ULTRAVIOLET FILMS

Sample No.	Deposition Material	Filament	Source Type	Minimum Pressure	Base Glass	Mixture Ratio	Remarks
58	Cobalt Chloride Magnesium Fluoride	Tungsten	Coil	2 X 10^4	Pyrex	1 to 1 by weight	Mixture did not heat properly and therefore no deposition took place.
59	Magnesium Fluoride	Tungsten	Coil	2 X 10^4	Pyrex	1 to 1 by weight	Mixture did not heat properly and no deposition took place.
60	Cobalt Oxide Sodium Borate	Tungsten	Coil	2 X 10^4	Pyrex	1 to 1 by weight	Mixture was evaporated but deposit on glass crystalized. The sodium borate disassociated from the cobalt oxide and none of the cobalt oxide evaporated.

TABLE XV. FLUORESCENCE OF RARE EARTH AND URANIUM OXIDES IN GLASS MATRIX

Sample No.	Glass Formulation	Percent Fluorescent Oxide	Firing Method	Ambient Color	Fluorescent Color	Crazing	Remarks
61	Sodium Borate Terbium Oxide	2	Oxy-Propane Burner	Water white (clear)	Green	Heavy	Heated on pyrex substrate until molten and flowing well then cooled.
62	Sodium Borate Europium Oxide	2	Oxy-Propane Burner	Water white (clear)	Dull red	Heavy	Heated on pyrex substrate until completely flowing then cooled.
63	Sodium Borate Terbium Oxide Europium Oxide	 1 2	Oxy-Propane Burner	Water white (clear)	Orange, red	Heavy	Mixed two rare earth oxides in order to ascertain feasibility of color mixing.
64	Sodium Borate Uranium Oxide (UO_2)	2	Oxy-Propane Burner	Pale yellow	Dull green	Heavy	Heated on pyrex substrate until completely flowing then cooled. Very poor fluorescence.

TABLE XV. FLUORESCENCE OF RARE EARTH AND URANIUM OXIDES IN GLASS MATRIX (cont)

Sample No.	Glass Formulation	Percent Fluorescent Oxide	Firing Method	Ambient Color	Fluorescent Color	Crazing	Remarks
65	Sodium Borate Uranium Oxide ($U_3 O_8$)	2	Oxy-Propane Burner	Pale yellow	Green	Heavy	Heated on pyrex substrate then cooled. Good fluorescence with a bright output.
66	Sodium Borate Uranium Oxide (UO_3)	2	Oxy-Propane Burner	Pale yellow	Green	Heavy	Heated on pyrex substrate and then cooled. Good bright fluorescent output.

TABLE XVI. EXPANSION MATCHING OF U.V. FILM TO CORNING NO. 7740 GLASS

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Crazing	Percent Cobalt Oxide Frit	Adhesion to Base Substrate	Remarks
67	Sodium Borate 20g Flint 2g	Oxy-Propane Burner	Good	Minimum	20	Good	Sodium borate plus cobalt oxide is fired into frit and then passed through a 40 mesh screen. Slurried with flint and fired into substrate.
68	Sodium Borate 20g Flint 4g	Oxy-Propane Burner	Poor	Heavy	20	Good	Same firing procedure as sample No. 67. This mix separated on cooling into blue and white areas. It appears the silicon oxide did not flow.
69	Sodium Borate 20g Whiting 2g Kaolin 0.6g	Oxy-Propane Burner	Fair	Minimum	20	Good	Same firing procedure as sample No. 67. Slurried with Whiting and Kaolin. Mix flowed well with good dispersion of the cobalt oxide.

TABLE XVI. EXPANSION MATCHING OF U.V. FILM TO CORNING NO. 7740 GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Crazing	Percent Cobalt Oxide Frit	Adhesion to Base Substrate	Remarks
70	Sodium Borate 20g Whiting 2g Kaolin 0.2g	Oxy-Propane Burner	Poor	Heavy	20	Poor	Same firing procedure as No. 67. Good flow but after cooling U.V. film flaked off surface of base glass.
71	Sodium Borate 20g Whiting 4g Kaolin 1.6g	Oxy-Propane Burner	Poor	Heavy	20	Good	Same firing procedure as No. 67. Good flow, good glaze, but crazing very bad on cooling.

TABLE XVII. EXPANSION MATCHING OF U.V. FILM TO CORNING NO. 7740 GLASS

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Crazing	Percent Cobalt Oxide Frit	Adhesion to Base Substrate	Remarks
72	Sodium Borate 20g Whiting 9g Kaolin 4g	Oxy-Propane Burner	Poor	Heavy	20	Fair	Same firing procedure on No. 67. Good glaze but crazing and air bubbles appeared on cooling.
73	Sodium Borate 50g Powdered Glass 10g Cobalt Oxide 1.5g Whiting 1.0g Aluminum Oxide 0.5g	Oxy-Propane Burner	Good	None	-	-	Dry mixed in mortar and pestle. Fired in platinum crucible. Good color distribution.

TABLE XVIII. EXPANSION MATCHING OF U.V. FILM TO CORNING NO. 3750 GLASS

Sample No.	Glass Formulation	Firing Method	Firing Temperature	Crazing	Adhesion to base Substrate	Optical Clarity	Remarks
74	Sodium Borate 50g Powdered Glass 10g Cobalt Oxide 1.5g Whiting 1.0g Aluminum Oxide 0.5g	Muffle Furnace	800°C	Heavy	Good	Good	Glass from sample No. 73 was placed on uranium substrate and fired. Flow was good but the base glass split probably due to thermal shock.
75	Sodium Borate 60g Powdered Glass 10g Cobalt Oxide 4g Whiting 2g Aluminum Oxide 1g	Oxy-Propane Burner Muffle Furnace	1500° C 800° C	Excess compression	Poor	Good	Mix fired in platinum crucible. Frit then placed on uranium substrate and fired in furnace. Mixed flowed well but U.V. film was forced out of base glass on cooling.

TABLE XVIII. EXPANSION MATCHING OF U.V. FILM TO CORNING NO. 3750 GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Firing Temperature	Crazing	Adhesion to base Substrate	Optical Clarity	Remarks
76	Sodium Borate 40g Powdered Glass 10g Cobalt Oxide 2g Whiting 2g Aluminum Oxide 1g	Oxy-Propane Burner Muffle Furnace	1500° C 820° C	Excess compression	Poor	Good	Same firing procedure as sample No. 75. Mix flowed well and was cooled slowly but the film was forced out of base glass.
77	Sodium Borate 35g Powdered Glass 10g Flint 5g Whiting 2g Cobalt Oxide 1g Alunimum Oxide 1g	Oxy-Propane Burner Muffle Furnace	1600° C 820° C	Slight compression	Poor	Good	Same firing procedure as No. 75. Expansion match was close. Film was removed by forcing out of base glass.
78	Sodium Borate 60g Cobalt Oxide 1.5g Powdered Glass 10g Aluminum Oxide 2g Whiting 4g Flint 10g	Oxy-Propane Burner Muffle Furnace	1500° C 800° C	Slight compression	Poor	Poor	Same firing procedure as No. 75. Some sodium borate did not fire.

TABLE XIX. LOW MELTING VITREOUS FLUX EXPERIMENTS

Sample No.	Vitreous Flux	Base Glass	Percent Cobalt Oxide	Wetting Affect	Crazing	Firing Method	Remarks
79	Sodium Salicylate	Corning No. 3750	2	Slight	None	Furnace - 960°C	
80	Magnesium Acetate	Corning No. 3750	2	None	None	Furnace - 960°C	Oxide formed on surface of glass.
81	Sodium Silicate, Meta	Corning No. 3750	2	Slight	None	Furnace - 960°C	Wet in separate islands only.
82	Sodium Perborate	Corning No. 3750	2	Very good	Heavy	Furnace - 960°C	
83	Sodium Potassium Tartrate	Corning No. 3750	2	Slight	None	Furnace - 960°C	Only surface adhesion.
84	Hydroxlamine Hydrochloride	Corning No. 3750	2	None	None	Furnace - 960°C	No flow, no adhesion.
85	Sodium Acetate	Corning No. 3750	2	Slight	None	Furnace - 960°C	Flux separated and bonded poorly.

TABLE XIX. LOW MELTING VITREOUS FLUX EXPERIMENTS (cont)

Sample No.	Vitreous Flux	Base Glass	Percent Cobalt Oxide	Wetting Affect	Crazing	Firing Method	Remarks
86	Potassium Bisulphate	Corning No. 3750	2	Slight	None	Furnace - 960°C	Poor flow, no adhesion.
87	Sodium Phosphate	Corning No. 3750	2	Slight	None	Furnace - 960°C	No flow, no adhesion.
88	Hydroxlamine Sulfate	Corning No. 3750	2	Slight	None	Furnace - 960°C	Poor flow, no adhesion.

TABLE XX. COBALT OXIDE DOPING OF LOW MELTING FLUX MATERIALS

Sample No.	Vitreous Flux	Base Glass	Percent Cobalt Oxide	Crazing	Furnace Temperature	Remarks
89	Sodium Borate 2g Cobalt Oxide 0.04g Distilled water 20 ml	Corning No. 3750	2	None	860°C	Small amount of fine particles that did not disperse well imbedded in surface of glass.
90	Sodium Borate 2g Cobalt Oxide 0.08g Distilled water 20 ml	Corning No. 3750	4	None	860°C	Small amount of cobalt oxide dispersed in glass. About 2% of surface covered.
91	Sodium Borate 2g Cobalt Oxide 0.12g Distilled water 20 ml	Corning No. 3750	6	None	860°C	Cobalt oxide well imbedded and dispersed in glass. Surface coverage about 5%.
92	Sodium Borate 2g Cobalt Oxide 0.16g Distilled water 20 ml	Corning No. 3750	8	None	860°C	Cobalt oxide well imbedded and dispersed in glass. Base substrate has green appearance.
93	Sodium Borate 2g Cobalt Oxide 0.2g Distilled water 20 ml	Corning No. 3750	10	Very slight at edges	860°C	Cobalt oxide well distributed in glass. Surface coverage about 50%.
94	Sodium Borate 2g Cobalt Oxide 0.24g Distilled water 20 ml	Corning No. 3750	12	Heavy	860°C	Cobalt oxide well distributed in glass. Surface coverage from 50 to 60%.

TABLE XX. COBALT OXIDE DOPING OF LOW MELTING FLUX MATERIALS (cont)

Sample No.	Vitreous Flux		Base Glass	Percent Cobalt Oxide	Crazing	Furnace Temperature	Remarks
95	Sodium Borate Cobalt Oxide Distilled water	2g 0.28g 20 ml	Corning No. 3750	14	Moderate	860°C	Insufficient flow.
96	Sodium Borate Cobalt Oxide Distilled water	2g 0.32g 20 ml	Corning No. 3750	16	Moderate	860°C	Insufficient flow.
97	Sodium Borate Cobalt Oxide Distilled water	2g 0.4g 20 ml	Corning No. 3750	20	None	850°C	Sprayed onto base glass. Cobalt oxide dispersed well in glass. About 50 to 60% of surface covered.
98	Sodium Borate Cobalt Oxide Distilled water	2g 0.6g 20 ml	Corning No. 3750	30	None	850°C	Cobalt oxide only partially dispersed in glass.
99	Sodium Borate Cobalt Oxide Distilled water	2g 0.8g 20 ml	Corning No. 3750	40	None	850°C	Sprayed onto base glass. Cobalt oxide dispersion was very poor.
100	Sodium Borate Cobalt Oxide Distilled water	2g 0.6g 20 ml	Corning No. 3750	30	Slight	860°C	Sprayed onto base glass. Multiple firings to build up thickness of film. Fired finally for one hour with good dispersion.

TABLE XX. COBALT OXIDE DOPING OF LOW MELTING FLUX MATERIALS (cont)

Sample No.	Vitreous Flux	Base Glass	Percent Oxide	Crazing	Furnace Temperature	Remarks
101	Sodium Borate 2g Cobalt Chloride 0.6g Distilled water 20 ml	Corning No. 3750	30	None	850° C	Light blue green in color, good dispersion.
102	Sodium Borate 2g Manganese Dioxide 0.6g Distilled water 20 ml	Corning No. 3750	30	None	850° C	Yellow in color. MnO2 only slightly dispersed in base glass.
103	Sodium Borate 2g Nickel (ous) Oxide 0.6g Distilled water 20 ml	Corning No. 3750	30	None	850° C	Green in color. Very poor dispersion.
104	Sodium Borate 2g Manganese (ous) 0.6g Carbonate Distilled water 20 ml	Corning No. 3750	30	None	850° C	Deep brown color, good dispersion.
105	Sodium Borate 2g Nickel (ic) Oxide 0.6g Distilled water 20 ml	Corning No. 3750	30	None	850° C	Green in color. Very poor dispersion.

TABLE XXI. EXPERIMENTS TO DETERMINE OPTIMUM FLUXING AGENT

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Flow or Wetting	Firing Temp.	Adhesion	Remarks
106	Cobalt Silicide on Kodak Slide Glass	Evaporation (Boat) at 5x -10^5	Good			Poor	Thick film formed no adhesion. Apparently only cobalt oxide is leaving the boat.
107	Flint 11.5g Aluminum Oxide 0.5g Sodium Carbonate 1.5g Sodium Borate 3.5g Manganese Dioxide 1.5g	Oxy-Propane Burner	Poor	Poor	1500°C	Poor	No flow at all; small crystals formed.
108	Flint 11.5g Aluminum Oxide 0.5g Sodium Carbonate 1.5g Sodium Borate 3.5g Cobalt Oxide 1.5g	Oxy-Propane Burner	Fair	Fair	840°C	Fair	Mix formed into clear solid but flow is only fair.
109	Flint 11.5g Aluminum Oxide 0.5g Sodium Carbonate 1.5g Sodium Borate 3.5g Cobalt Carbonate 1.5g	Oxy-Propane Burner	Poor	Poor	1500°C	Fair	Small particles are scattered all through the mass that will not melt.
110	Cobalt Oxide 10% Zinc Oxide 36% Sodium Borate 54%	Oxy-Propane Burner	Good	Very good	860°C	Good	This mix melts and flows very readily at about 820°C.

TABLE XXI. EXPERIMENTS TO DETERMINE OPTIMUM FLUXING AGENT (cont)

Sample No.	Glass Formulation		Firing Method	Optical Clarity	Flow or Wetting	Firing Temp.	Adhesion	Remarks
111	Flint Aluminum Oxide Sodium Carbonate Sodium Borate Cobalt Chloride	1.5g 11.5g 0.5g 3.5g 1.5g	Oxy-Propane Burner	Poor	Poor	1500°C	Fair	Small crystals are formed but do not fuse together.
112	Flint Aluminum Oxide Sodium Carbonate Sodium Borate Manganese Carbonate	11.5g 0.5g 1.5g 3.5g 1.5g	Oxy-Propane Burner	Poor	Poor	1500°C	Poor	Manganese became small crystals in the molten glaze.
113	Flint Aluminum Oxide Sodium Carbonate Sodium Borate Nickel Oxide	11.5g 1.5g 3.5g 1.5g 0.5g	Oxy-Propane Burner	Poor	Poor	1500°C	Poor	Failed to melt totally as particles were still in solid crystals after firing.

TABLE XXII. VARIATION OF SODIUM BORATE TO ZINC OXIDE RATIO

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Firing Temp	Crazing	Adhesion	Remarks
114	Zinc Oxide 25% Sodium Borate 55% Cobalt Oxide 20%	Oxy-Propane Burner Muffle Furnace	Good	860° C	None	Good	Groundup frit was sprayed on. Very good glaze was formed. Ratio here is 2.2:1.
115	Zinc Oxide 19% Sodium Borate 50% Cobalt Oxide 31%	Oxy-Propane Burner Muffle Furnace	Fair	860° C	Spotty	Fair	Flow was poor and glaze spotty with small unfired crystals; ratio is 2.63:1.
116	Zinc Oxide 25% Sodium Borate 45% Cobalt Oxide 30%	Oxy-Propane Burner Muffle Furnace	Good	860° C	Very little	Good	Flow is good and just a small amount of spottiness; ratio is 1.8:1.
117	Zinc Oxide 20% Sodium Borate 45% Cobalt Oxide 35%	Oxy-Propane Burner Muffle Furnace	Fair	860° C	Very little	Good	Good flame and very little mottling; ratio is 2.25:1.

TABLE XXII. VARIATION OF SODIUM BORATE TO ZINC OXIDE RATIO (cont)

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Firing Temp	Crazing	Adhesion	Remarks
118	Zinc Oxide 25% Sodium Borate 45% Cobalt Oxide 30%	Oxy-Propane Burner Muffle Furnace	Good	860° C	None	Good	Glass powder settled on slide glass. Film thickness of 0.7 mils, good glaze and no mottling.
119	Zinc Oxide 25% Sodium Borate 55% Cobalt Oxide 20%	Oxy-Propane Burner Muffle Furnace	Fair	860° C	Fair	Fair	Glass frit of 100 mesh settled on slide glass; crazing may be due to cooling too fast.

TABLE XXIII. MATCHING EXPANSION TO 3750 GLASS USING 2 PARTS OF SODIUM BORATE TO 1 PART ZINC OXIDE AS CONSTANT

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Crazing	Adhesion	Firing Temp.	Remarks
120	Zinc Oxide 23% Sodium Borate 47% Cobalt Oxide 30%	Oxy-Propane Burner Muffle Furnace	Poor	Very bad	Poor	860° C	Surface glass broken by contracting pressure.
121	Zinc Oxide 27% Sodium Borate 53% Cobalt Oxide 20%	Oxy-Propane Burner Muffle Furnace	Poor	Badly	Poor	860° C	Flow was spotty; crazing of uranium glass caused by contracting pressure of cobalt oxide on cooling.
122	Zinc Oxide 28% Sodium Borate 57% Cobalt Oxide 15%	Oxy-Propane Burner Muffle Furnace	Fair	Small area strains	Good	860° C	Fairly good flow crazing at a minimum. It seems the surface is still contracting faster than substrate glass.

TABLE XXIII. MATCHING EXPANSION TO 3750 GLASS USING 2 PARTS OF SODIUM BORATE TO 1 PART ZINC OXIDE AS CONSTANT (cont)

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Crazing	Adhesion	Firing Temp.	Remarks
123	Zinc Oxide 26% Sodium Borate 54% Cobalt Oxide 20%	Oxy-Propane Burner Muffle Furnace	Fair	Badly	Bad	860° C	Flow was very good, but contracting rate mismatched uranium glass again.
124	Zinc Oxide 27% Sodium Borate 55% Cobalt Oxide 18%	Oxy-Propane Burner Muffle Furnace	Fair	Badly	Poor	860° C	Good flow but surface shattered on cooling due to mismatch.
125	Zinc Oxide 28% Sodium Borate 56% Cobalt Oxide 16%	Oxy-Propane Burner Muffle Furnace	Fair	Badly	Poor	860° C	Large areas pulled out of uranium glass.
126	Zinc Oxide 29% Sodium Borate 57% Cobalt Oxide 14%	Oxy-Propane Burner Muffle Furnace	Fair	Very small craze lines	Good	860° C	This matches the coefficient the best of the lot. But flow is poor.

TABLE XXIII. MATCHING EXPANSION TO 3750 GLASS USING 2 PARTS OF SODIUM BORATE TO 1 PART ZINC OXIDE AS CONSTANT (cont)

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Crazing	Adhesion	Firing Temp.	Remarks
127	Zinc Oxide 29% Sodium Borate 59% Cobalt Oxide 12%	Oxy-Propane Burner Muffle Furnace	Fair	Badly	Poor	860° C	Flow was poor; glaze good but crazing occurred on surface.
128	Zinc Oxide 30% Sodium Borate 60% Cobalt Oxide 10%	Oxy-Propane Burner Muffle Furnace	Fair	Badly	Fair	860° C	Spider crazing on surface. It seems cobalt oxide is not contracting as fast as uranium glass.
129	Zinc Oxide 31% Sodium Borate 61% Cobalt Oxide 8%	Oxy-Propane Burner Muffle Furnace	Fair	Fair	Good	860° C	Surface crazing only small strain lines.

TABLE XXIV. EFFECT OF VARYING WEIGHT OF MIXTURE PER SCREEN AREA

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Firing Temp.	Crazing	Mixture Weight	Remarks
130A	Cobalt Oxide 13% Sodium Borate 58% Zinc Oxide 29%	Oxy-Propane Burner Muffle Furnace	Poor	880° C	Fair	0.5 gram	This mass gives a film of about 0.5 mil thick, very poor dispersion.
130B	Cobalt Oxide 13% Sodium Borate 58% Zinc Oxide 29%	Oxy-Propane Burner Muffle Furnace	Fair	880° C	Poor	1.2 grams	Film thickness of 1.2 mils; flow was good, but contraction on cooling mismatched.
131A	Cobalt Oxide 14% Sodium Borate 57% Zinc Oxide 29%	Oxy-Propane Burner Muffle Furnace	Poor	880° C	Slight	0.5 gram	Flow very poor; surface had small craze marks.
131B	Cobalt Oxide 14% Sodium Borate 57% Zinc Oxide 29%	Oxy-Propane Burner Muffle Furnace	Fair	880° C	Poor	1.2 grams	Good dispersion, but heavy crazing beneath surface of glaze.
132A	Cobalt Oxide 15% Sodium Borate 57% Zinc Oxide 28%	Oxy-Propane Burner Muffle Furnace	Poor	880° C	Slight	0.5 gram	Not much change from 130 and 131; this mass may be too low.

TABLE XXIV. EFFECT OF VARYING WEIGHT OF MIXTURE PER SCREEN AREA (cont)

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Firing Temp.	Crazing	Mixture Weight	Remarks
132B	Cobalt Oxide 15% Sodium Borate 57% Zinc Oxide 28%	Oxy-Propane Burner Muffle Furnace	Fair	880° C	Poor	1.2 grams	Still good flow but very bad crazing on cooling.
133A	Cobalt Oxide 16% Sodium Borate 56% Zinc Oxide 28%	Oxy-Propane Burner Muffle Furnace	Poor	880° C	Fair	0.5g	Flow was very poor with many spots open.
133B	Cobalt Oxide 16% Sodium Borate 56% Zinc Oxide 28%	Oxy-Propane Burner Muffle Furnace	Fair	880° C	Poor	1.2g	Small thin running lines on surface; glaze fair.
134A	Cobalt Oxide 17% Sodium Borate 55% Zinc Oxide 28%	Oxy-Propane Burner Muffle Furnace	Poor	880° C	Fair	0.5g	Still poor dispersion.
134B	Cobalt Oxide 17% Sodium Borate 55% Zinc Oxide 28%	Oxy-Propane Burner Muffle Furnace	Fair	880° C	Fair	1.2g	Dispersion good when cool; the entire top surface lifted off; cobalt oxide contracting too fast.
135A	Cobalt Oxide 18% Sodium Borate 55% Zinc Oxide 27%	Oxy-Propane Burner Muffle Furnace	Poor	880° C	Fair	0.5g	Very poor flow because of thin film.

TABLE XXIV. EFFECT OF VARYING WEIGHT OF MIXTURE PER SCREEN AREA (cont)

Sample No.	Glass Formulation	Firing Method	Optical Clarity	Firing Temp.	Crazing	Mixture Weight	Remarks
135B	Cobalt Oxide 18% Sodium Borate 55% Zinc Oxide 27%	Oxy-Propane Burner Muffle Furnace	Fair	880°C	Fair	1.2g	This surface cobalt oxide film broke away in one piece after cooling again, contracting too fast.
136A	Cobalt Oxide 16-1/2% Sodium Borate 56% Zinc Oxide 27-1/2%	Oxy-Propane Burner Muffle Furnace	Fair	880°C	Poor	0.9g	Flow and glaze very good, but compression on cooling lifted off entire surface.
136B	Cobalt Oxide 16-1/2% Sodium Borate 56% Zinc Oxide 27-1/2%	Oxy-Propane Burner Muffle Furnace	Good	880°C	Fair	0.65g	Very good flow; very small lines of crazing.
137A	Cobalt Oxide 17-1/2% Sodium Borate 55-1/2% Zinc Oxide 27%	Oxy-Propane Burner Muffle Furnace	Good	880°C	Good	0.9g	No internal or surface crazing but a large pressure pattern shows between cobalt oxide and uranium glass.
137B	Cobalt Oxide 17-1/2% Sodium Borate 55-1/2% Zinc Oxide 27%	Oxy-Propane Burner Muffle Furnace	Good	880°C	Fair	0.7g	Edges have a small amount of crazing where they were overrun by cobalt oxide when in the liquid state.

TABLE XXV. EXPERIMENTS EMPLOYING SMALL PARTICLE SIZE FRITS AND HEAT TREATMENT OF CORNING NO. 3750 GLASS

Sample No.	Glass Formulation	Firing Method	Particle Size	Crazing	Optical Clarity	Flow or Wetting	Remarks
138	Cobalt Oxide 18% Sodium Borate 55% Zinc Oxide 27%	Oxy-Propane Burner Muffle Furnace	200 mesh	Very good	Good	Good	This piece is the best yet to date both in clarity and flow.
139	Cobalt Oxide 16% Sodium Borate 56% Zinc Oxide 28%	Oxy-Propane Burner Muffle Furnace	200 mesh	Good	Good	Good	Uranium glass was preheat treated to try and relieve internal stress.
140	Cobalt Oxide 15% Sodium Borate 57% Zinc Oxide 28%	Oxy-Propane Burner Muffle Furnace	300 mesh	Fair	Good	Good	Small amount of crazing as our percent of cobalt oxide drops.
141	Cobalt Oxide 20% Sodium Borate 54% Zinc Oxide 26%	Oxy-Propane Burner Muffle Furnace	300 mesh	Excellent	Good	Good	Best in all of our trys so far on 1 inch glass.

TABLE XXV. EXPERIMENTS EMPLOYING SMALL PARTICLE SIZE FRITS AND HEAT TREATMENT OF CORNING NO. 3750 GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Particles Size	Crazing	Optical Clarity	Flow or Wetting	Remarks
142	Cobalt Oxide 25% Sodium Borate 50% Zinc Oxide 25%	Oxy-Propane Burner Muffle Furnace	300 mesh	Fair	Good	Good	Surface crazing occurred as cobalt oxide percent was high.
143	Cobalt Oxide 25% Sodium Borate 50% Zinc Oxide 25%	Oxy-Propane Burner Muffle Furnace	300 mesh	Fair	Fair	Good	This coating was very heavy and the high required deformed the glass.
144	Cobalt Oxide 25% Sodium Borate 50% Zinc Oxide 25%	Oxy-Propane Burner Muffle Furnace	300 mesh	Fair	Fair	Fair	Coating was increased to 2 mils thick again, the glass deformed due to high heat.

TABLE XXVI. EXPANSION MATCHING OF U.V. FILTER TO NO. 3750 GLASS

Sample No.	Glass Formulation	Optical Clarity	Flow or Wetting	Firing Temp.	Adhesion	Firing Method	Remarks
145	Cobalt Oxide 5g Sodium Borate 10g Zinc Oxide 5g	Good	Good	820° C	Good	Oxy-Propane Burner Muffle Furnace	One gram was settled on surface. This gave an average of 0.7 mils thickness.
146	Cobalt Oxide 5g Sodium Borate 10g Zinc Oxide 5g	Fair	Good	820° C	Fair	Oxy-Propane Burner Muffle Furnace	Two grams were used here. Increased thickness crazed the cobalt oxide surface badly.
147	Cobalt Oxide 1.5g Sodium Borate 5.7g Zinc Oxide 2.8g	Good	Good	860° C	Good	Oxy-Propane Burner Muffle Furnace	This used a 2 inch x 2 inch piece of uranium glass on cooling. The glass pulled into a convex shape.
148	Cobalt Oxide 2g Sodium Borate 5.4g Zinc Oxide 2.6g	Fair	Good	860° C	Good	Oxy-Propane Burner Muffle Furnace	A 2 inch x 2 inch glass was used. Again this crazed badly and also pulled out of shape.

TABLE XXVII. PREPARATION OF U.V. SCREENS ON VYCOR SUBSTRATES

Sample No.	Manufacture	Phosphor No.	Substrate	Wavelength (Angstroms)	Screen Distribution (mg/cm^2)	Barium Acetate Solids (%)	Potassium Silicate Solids (%)
149	Sylvania Type No. 122	(P-20) green	Vycor glass	5600	5	0.03	0.42
150	Sylvania Type No. 147	(P-16)	Vycor glass	3850	5	0.03	0.42
151	Semi-Elements	Barium Silicate Lead	Vycor glass	3520	5	0.03	0.42
152	Semi-Elements	Calcium Silicate Lead No. 1	Vycor glass	3380	5	0.03	0.42
153	Semi-Elements	Calcium Silicate Lead No. 2	Vycor glass	3380	5	0.03	0.42
154	ITT Industrial Lab	H-3	Vycor glass	3000	5	0.03	0.42
155	ITT Industrial Lab	H-2	Vycor glass	≈3000	5	0.03	0.42

TABLE XXVII. PREPARATION OF U.V. SCREENS ON VYCOR SUBSTRATES (cont)

Sample No.	Manufacture	Phosphor No.	Substrate	Wavelength (Angstroms)	Screen Distribution (mg/cm^2)	Barium Acetate Solids (%)	Potassium Silicate Solids (%)
156	ITT Industrial Lab	H-4	Vycor glass	≈ 3000	5	0.03	0.42
157	ITT Industrial Lab	H-1	Vycor glass	≈ 3000	5	0.03	0.42
158	AAC U.V. Powder	7000	Vycor glass	≈ 3000	5	0.03	0.42
159	AAC U.V. Powder	7001	Vycor glass	≈ 3000	5	0.03	0.42

TABLE XXVIII. FABRICATIONS OF THIN U.V. FILTER BLANKS

Sample No.	Glass Formulation	Firing Method	Crucible Type	Blank Diameter	Blank Thickness	Temp. of Mold	Remarks
160	Sodium Borate 5.5g Zinc Oxide 2.7g Cobalt Oxide 1.8g	Oxy-Propane Burner	Iron	1-1/2 inches	200 mils	500°F	This piece broke up when cooled completely.
161	Sodium Borate 5.5g Zinc Oxide 2.7g Cobalt Oxide 1.8g	Oxy-Propane Burner	Iron	1-1/2 inches	40 mils	700°F	On cooling this piece also shattered.
162	Sodium Borate 5.5g Zinc Oxide 2.7g Cobalt Oxide 1.8g	Oxy-Propane Burner	Iron	1-1/2 inches	27 mils	700°F	This piece held its shape for a while on cooling, but was under stress, on handling it gave way.
163	Sodium Borate 5.0g Zinc Oxide 2.5g Cobalt Oxide 2.5g	Oxy-Propane Burner	Iron	1-1/2 inches	30 mils	1800°F	This piece was lapped down to 17 mils at which point it shattered.

TABLE XXIX. EXPANSION MATCHING OF U.V. FILTER TO A 2 X 2 INCH SECTION OF NO. 3750 FLUORESCENT GLASS

Sample No.	Glass Formulation	Firing Method	Flow or Wetting	Adhesion	Optical Clarity	Firing Temperature	Remarks
164	Sodium Borate 50% Zinc Oxide 30% Cobalt Oxide 20%	Oxy-Propane Burner Muffle Furnace	Good	Poor	Poor	1540°F	Interface crazed and surface was very spotty.
165	Sodium Borate 54% Zinc Oxide 26% Cobalt Oxide 20%	Oxy-Propane Burner Muffle Furnace	Good	Poor	Poor	1480°F	Very bad crazing throughout.
166	Sodium Borate 54% Zinc Oxide 26% Cobalt Oxide 20%	Oxy-Propane Burner Muffle Furnace	Fair	Poor	Poor	1520°F	Entire surface shattered on cooling.
167	Sodium Borate 54% Zinc Oxide 26% Cobalt Oxide 20%	Oxy-Propane Burner Muffle Furnace	Fair	Good	Fair	1420°F	On cooling the surface lifted off, taking some uranium glass with it.
168	Sodium Borate 60% Zinc Oxide 20% Cobalt Oxide 20%	Oxy-Propane Burner Muffle Furnace	Good	Good	Fair	1560°F	A checkerboard pattern formed on the surface from mismatch.

TABLE XXIX. EXPANSION MATCHING OF U.V. FILTER TO A 2 X 2 INCH SECTION OF NO. 3750 FLUORESCENT GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Flow or Wetting	Adhesion	Optical Clarity	Firing Temper-ature	Remarks
169	Sodium Borate 60% Zinc Oxide 20% Cobalt Oxide 20%	Oxy-Propane Burner Muffle Furnace	Fair	Poor	Fair	1560°F	To No. 168 mix was added. A 1/2 g of uranium glass 300 mesh. This fractured at the interface.
170	Sodium Borate 50% Zinc Oxide 25% Cobalt Oxide 25%	Oxy-Propane Burner Muffle Furnace	Fair	Poor	Poor	1580°F	Both surface and interface crazed.
171	Sodium Borate 48% Zinc Oxide 22% Cobalt Oxide 30%	Oxy-Propane Burner Muffle Furnace	Fair	Fair	Fair	1580°F	Surface was good, but small craze lines at interface.
172	Sodium Borate 44% Zinc Oxide 22% Cobalt Oxide 34%	Oxy-Propane Burner Muffle Furnace	Good	Fair	Good	1580°F	Surface was good with very small pressure marks at interface.

TABLE XXX. EXPANSION MATCHING OF U.V. FILTER TO NO. 3750 GLASS

Sample No.	Glass Formulation	Firing Method	Frit Size	Cycling Temperature	Cycling Time	Optical Clarity	Remarks
173	Cobalt Oxide 34% Sodium Borate 48% Zinc Oxide 18%	Muffle Furnace	300 mesh	870°C	2 hrs.	Fair	Frit settled onto uranium glass substrate, fired, and then cooled slowly. Cobalt oxide did not totally dissolve.
174	Cobalt Oxide 33% Sodium Borate 47% Zinc Oxide 20%	Muffle Furnace	300 mesh	875°C	2 hrs.	Good	Very fine surface craze lines. Subtrate approx. 2 inches x 4 inches. Settled, fired, and cooled slowly.
175	Cobalt Oxide 33% Sodium Borate 46% Zinc Oxide 21%	Muffle Furnace	300 mesh	875°C	2 hrs.	Poor	Settled, fired, and cooled slowly, crazed at interface.
176	Cobalt Oxide 32% Sodium Borate 47% Zinc Oxide 21%	Muffle Furnace	300 mesh	875°C	2 hrs.	Poor	Settled, fired, and cooled slowly, crazed at interface.

TABLE XXX. EXPANSION MATCHING OF U.V. FILTER TO NO. 3750 GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Frit Size	Cycling Temperature	Cycling Time	Optical Clarity	Remarks
177	Cobalt Oxide 35% Sodium Borate 41% Zinc Oxide 24%	Muffle Furnace	300 mesh	875°C	2 hrs.	Poor	Mix did not flow properly. Too much cobalt oxide or not enough heat.
178	Cobalt Oxide 34% Sodium Borate 42% Zinc Oxide 24%	Muffle Furnace	300 mesh	870°C	2 hrs.	Excellent	Settled, fired, and cooled. Cooling rate 250° per hour. Good flow and no crazing.
179	Cobalt Oxide 33% Sodium Borate 48% Zinc Oxide 19%	Muffle Furnace	300 mesh	870°C	2 hrs.	Poor	Some cooling rate as above, crazed badly.
180	Cobalt Oxide 33% Sodium Borate 43.8% Zinc Oxide 23.2%	Muffle Furnace	300 mesh	875°C	2 hrs.	Poor	Crazed at interface.
181	Cobalt Oxide 34% Sodium Borate 42% Zinc Oxide 24%	Muffle Furnace	300 mesh	875°C	2 hrs.	Poor	Same mix as sample No. 178 exhibited, crazing at interface and surface.

TABLE XXX. EXPANSION MATCHING OF U.V. FILTER TO NO. 3750 GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Frit Size	Cycling Temperature	Cycling Time	Optical Clarity	Remarks
182	Cobalt Oxide 35% Sodium Borate 41% Zinc Oxide 24%	Muffle Furnace	300 mesh	875°C	2 hrs.	Poor	Crazed badly.
183	Cobalt Oxide 36% Sodium Borate 41% Zinc Oxide 23%	Muffle Furnace	300 mesh	880°C 640°C	10 min. 10 min.	Poor	Crazed at interface. Temperature cycled. Good dispersion.
184	Cobalt Oxide 37% Sodium Borate 41% Zinc Oxide 22%	Muffle Furnace	400 mesh	880°C 640°C	10 min. 10 min.	Poor	Very bad crazing. Temperature cycled.
185	Cobalt Oxide 36% Sodium Borate 41% Zinc Oxide 23%	Muffle Furnace	300 mesh	880°C 640°C	2 hrs. 10 min.	Poor	Temperature cycled, very bad crazing.
186	Cobalt Oxide 36% Sodium Borate 40% Zinc Oxide 24%	Muffle Furnace	300 mesh	885°C 585°C	30 min. 10 min.	Good	Three-inch diameter substrate. Thin filter layer, no crazing. A second layer was added to increase the density and the glass crazed.

TABLE XXX. EXPANSION MATCHING OF U.V. FILTER TO NO. 3750 GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Frit Size	Cycling Temperature	Cycling Time	Optical Clarity	Remarks
187	Cobalt Oxide 34% Sodium Borate 42% Zinc Oxide 24%	Muffle Furnace	300 mesh	885°C 530°C	30 min. 10 min.	Fair	Same mix as sample No. 178. Exhibited crazing about one hour after removal from furnace.
188	Cobalt Oxide 34% Sodium Borate 42% Zinc Oxide 24%	Muffle Furnace	300 mesh	885°C 530°C	30 min. 10 min.	Poor	Same mix as sample No. 178, crazed on cooling.
189	Cobalt Oxide 34% Sodium Borate 43% Zinc Oxide 23%	Muffle Furnace	300 mesh	885°C 530°C	1 hr. 10 min.	Poor	Interface and surface crazed badly.
190	Cobalt Oxide 34% Sodium Borate 44% Zinc Oxide 22%	Muffle Furnace	300 mesh	885°C 530°C	1 hr. 10 min.	Very good	Two very small craze marks at interface.
191	Cobalt Oxide 34% Sodium Borate 42% Zinc Oxide 24%	Muffle Furnace	300 mesh	880°C 480°C	1 hr. 20 min.	Fair	Temperature cycled, cooled overnight. Exhibited six small craze marks.

TABLE XXX. EXPANSION MATCHING OF U.V. FILTER TO NO. 3750 GLASS (cont)

Sample No.	Glass Formulation	Firing Method	Frit Size	Cycling Temperature	Cycling Time	Optical Clarity	Remarks
192	Cobalt Oxide 34% Sodium Borate 42% Zinc Oxide 24%	Muffle Furnace	300 mesh	885°C 490°C	1 hr. 10 min.	Poor	Same mix as sample No. 178, very bad crazing.
193	Cobalt Oxide 34% Sodium Borate 44% Zinc Oxide 22%	Muffle Furnace	300 mesh	885°C 490°C	1 hr. 10 min.	Fair	Same mix as sample No. 190. Temperature cycled and cooled slowly. Crazed on one side of glass.
194	Cobalt Oxide 34% Sodium Borate 45% Zinc Oxide 21%	Muffle Furnace	300 mesh	890°C 500°C	1 hr. 10 min.	Poor	Temperature cycled and cooled slowly. Crazed badly.

APPENDIX VII

5-INCH MILITARY AND INDUSTRIAL CATHODE RAY TUBE

The cathode ray tube can be used in a typical application as an information display under high ambient light. It provides high brightness with less than 0.010 line width.

The basic characteristics using the HSC faceplate are:

- 5-inch flat face
- 40° magnetic deflection
- aluminized
- magnetic focus

See Figure 34 and refer to Table XXXI for general characteristics.

TABLE XXXI. 5-INCH MILITARY AND INDUSTRIAL CATHODE RAY TUBE, GENERAL CHARACTERISTICS

ELECTRICAL	
Cathode	Coated unipotential
Heater:	
Voltage	6.3 volts
Current	0.6 ampere
Direct Interelectrode Capacitances:	
Grid 1 to all other Electrodes	9 pf
Grid 2 to all other Electrodes	7 pf
Cathode to all other Electrodes	7 pf
Focusing Method	Magnetic
Deflection	40° Magnetic

TABLE XXXI. 5-INCH MILITARY AND INDUSTRIAL CATHODE RAY TUBE, GENERAL CHARACTERISTICS (cont)

OPTICAL	
Screen Phosphor	Sylvania 2071
Faceplate:	
Configuration	Flat
Glass	Special composite filter
Transmission	50%
Spectral Reflection	<0.5%
MECHANICAL	
Mounting Position	Any
Net Weight	1.75 lb.
Bulb	J40L1A
ABSOLUTE MAXIMUM RATINGS	
Anode 2 Voltage (Note 1)	25,000 max. volts
Grid 2 Voltage	600 max. volts
Grid 1 Voltage:	
Negative Bias Value	180 max. volts
Positive Bias Value	0 max. volts
Positive Peak Value	0 max. volts
Peak Heater-Cathode Voltage:	
Heater Negative with respect to Cathode:	
During Warm-up period of 15 sec. max.	410 max. volts
After equipment warm up	180 max. volts
Heater Positive with respect to Cathode	180 max. volts
LIMITING CIRCUIT VALUES	
Grid 1 Circuit Resistance	1.5 max. megohms
Grid 2 Circuit Resistance	0.5 approx megohm
TYPICAL OPERATION AND PERFORMANCE	
Anode 2 Voltage (Note 1)	20,000 volts
Grid 2 Voltage	500 volts
Grid 1 Spot Cutoff Voltage	-40 to -70 volts
Min. Light Output with Special Faceplate (Note 2)	10 Ft. L.

TABLE XXXI. 5-INCH MILITARY AND INDUSTRIAL CATHODE RAY TUBE, GENERAL CHARACTERISTICS (cont)

TYPICAL OPERATION AND PERFORMANCE (cont)	
Max. Line Width with ultraviolet phosphors	0.010 inch
Spot Position (Note 4)	10 mm

NOTES

1. Operation with voltage in excess of 16 KV may require shielding to limit radiation of very soft X-rays.

2. Light output is measured with Eb2 = 20,000 V. and Ib_2 = 500 microamperes on a 3-inch x 4-inch raster with 15750 x 60 cps scan rate.

3. Line width is measured by the shrinking raster method with a current of 500 microamperes. Line width with other phosphors may vary slightly. Dynamic focus modulation is necessary to maintain optimum resolution over entire face. Close control of supply regulation and ripple is necessary to ensure optimum focus.

4. With the tube shielded against external magnetic fields, the undeflected focused spot lies within a circle of 10 mm radius concentric with the faceplate.

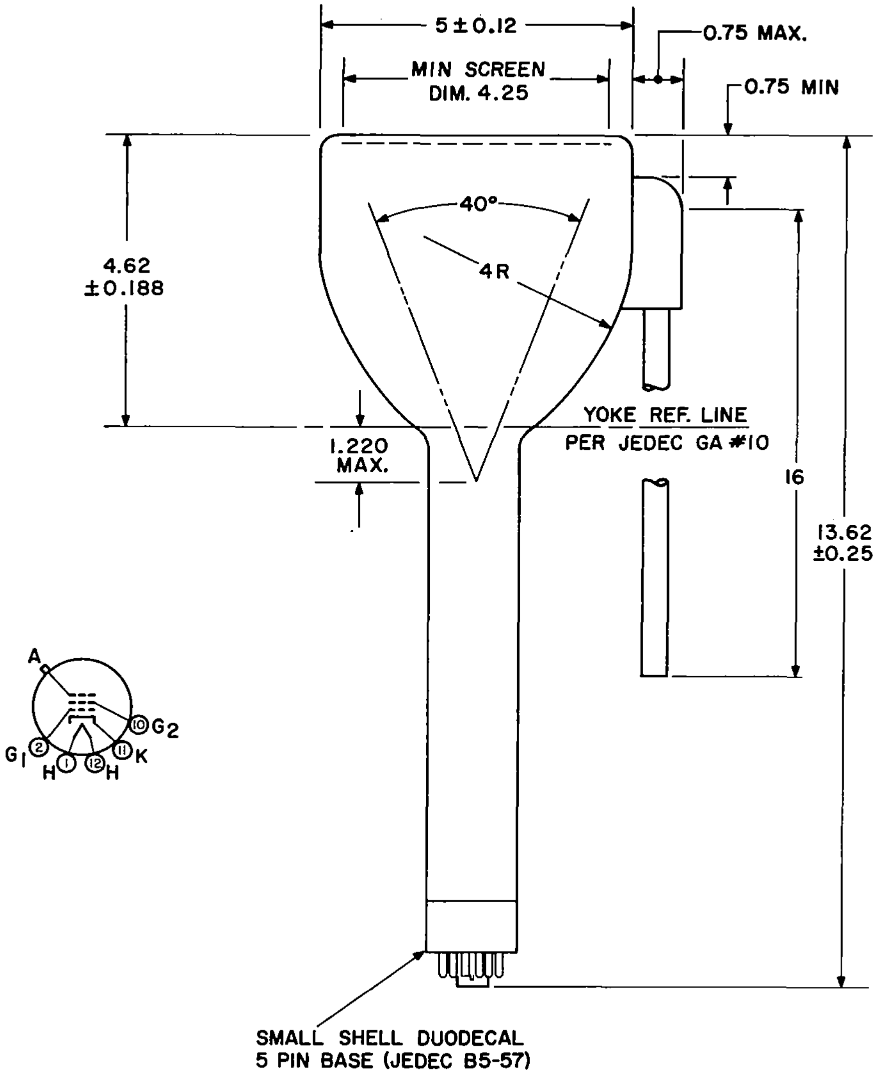

Figure 34. 5-Inch Military and Industrial Cathode Ray Tube Bulb, Type J40L1A

APPENDIX VIII

TECHNIQUE OF CASTING U.V. FILTER BLANKS

A series of experiments were initiated to perfect a technique of casting thin U.V. filter blanks. A cast iron mold preheated to 800°C and a stamping die heated to the same temperature combined to produce a uniform U.V. filter blank that could then be fused to the fluorescent glass substrate. By heating a zinc oxide, sodium borate, cobalt oxide mixture to a molten state (2100°C) in a cast iron crucible and pouring the molten glass into a preheated mold and then stamping with a heated die resulted in a 30 mil thick U.V. filter blank.

APPENDIX IX

NEW TECHNOLOGY

- Since the thickness of the U.V. pass band filter determines the amount of degradation in resolution, which is due to the degree of spreading of light between the ultraviolet emitter and the fluorescent converting layer, it becomes an essential factor for consideration in the fabrication of the faceplate. The specific constituents and the actual procedures employed in obtaining this thin film layer of less than 0.5 millimeters are described in Appendix IV.

- During the later part of this program, Hartman Systems Co. realized that a yellow color filter glass manufactured by Corning Glass Works was highly fluorescent. In addition, it possessed the same thermal expansion characteristics as the bulb which is a Corning No. 0120 glass. As a result of this finding the new fluorescent glass was sealed to both a 3 inch and a 5 inch funnel using Pyroceram frit as a seal. Observations under a polariscope showed near zero stress conditions in both cases after sealing. The yellow color filter which has proved compatible with the bulb glass is a Corning No. 3718 glass which has a coefficient of expansion of 96 x 10^{-7}/° C.

As the above data was not available until the end of this program, it was not possible to continue the evaluation and fabricate a tube under the contract. However, it is anticipated that this effort will continue in the near future, under company sponsorship.

APPENDIX X

FILTER FABRICATION PROCEDURE USING CORNING NO. 3718 FLUORESCENT GLASS

The following procedures are necessary for filter fabrication:

- U.V. glass lamination procedure
- Sealing
- Phosphor type and screening information
- Lacquering and aluminizing data
- Passive filter
- Anti-reflection coating

1. U.V. GLASS LAMINATION PROCEDURE

Refer to Appendix IV, paragraph 1; the procedure is the same.

2. SEALING(14)

Solder sealing glasses are commercially available with expansion coefficients between 40 and 120 x 10^{-7}/° C. This range permits matching most CRT bulb parts for rapid thermal processing. How close a match is needed depends on the geometry of the parts and the nature of the processing. In general, if the expansion coefficient is within $\pm 2 \times 10^{-7}$/° C of the theoretically best value, it should be very acceptable.

a. PREPARATION OF SUSPENSION

The finely divided powdered glass is prepared as a suspension using a low viscosity vehicle consisting of a nitrocellulose solution dissolved in amyl acetate. The powdered glass and liquid is weighed out in a ratio of 13:1 by weight. In this step, the vehicle should be added to the powdered glass and the combination mixed with a spatula until thorough mixing has occurred.

Containers storing the powdered glass must be kept tightly closed. Leaving the glass open to the air for prolonged periods may result in a change in its suspension characteristics. The vehicle must also be kept tightly closed since evaporation of the solvent will also affect suspension and sealing properties. The frit vehicle mixture has a finite shelf life and if it is stored for too long a period, a rubber-like set may result which is difficult to break.

b. PREPARATION OF THE SURFACE

Because contaminants on the seal area can cause weak or even leaky seals, it is essential that the parts be clean prior to application of the glass frit. The surface of both parts may be cleaned by gently scrubbing with acetone, xylene, isopropanol or other suitable solvent. All grease, oil fingerprints, and other organic or inorganic material must be eliminated or it may contribute to seal failure.

c. APPLICATION OF FRIT

Frit may be applied to a sealing area by hand, using a stainless steel spatula. The type of application and the amount of spreading desired determine the weight ratio of glass to vehicle. A ratio of 13:1 is usually found to be satisfactory. Lower rates show a tendency to spread out too far on the seal area.

When applied using a spatula, a smooth flat and uniform bead is formed around the peripheral edge of one of the surfaces to be joined. The bead should be slightly narrower than the seal edge. If frit drips over the seal edge onto the sides of the glass, it should be removed with a spatula.

d. SEAL STRUCTURE

The strength and thermal durability of a solder glass seal varies with the seal contour.

Various types of seals obtained with a flat plate and a ring section are shown in Figure 35. Part (a) of Figure 35 is undesirable because of a re-entrant angle caused by frit with little flow but with pressure applied in the sealing cycle is shown in part (b) of Figure 35. This type of seal can be utilized but is not the best. Part (c) of Figure 35 illustrates the most desirable type of seal where the solder glass has flowed and filletted well.

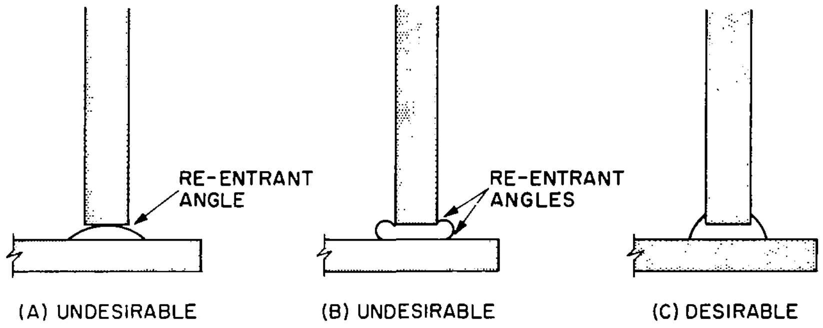

Figure 35. Ring Seals on Flat Plates

It may be necessary to apply external loading to the parts during sealing to produce frit flow between the mating surfaces and avoid a heavy or thick seal line. The average thickness of frit between the two mating surfaces, with proper pressure and flow, is between 0.005 to 0.010 inch.

e. SUSPENSION SCHEDULES

To prevent foaming and darkening of the frit during firing, the amyl acetate should be thoroughly evaporated from the suspension after application to the funnel. Drying is readily accomplished in air at room temperature or exposure to heat lamps directed onto the frit. Sometimes the one hour air drying is followed by a 10 to 15 minute infrared bake; the proper cycle is determined for a particular bulb type and process.

When the seal is fired according to prescribed schedules, a crystallization in the material occurs. During this process the solder glass melts while maintaining a sufficiently low viscosity long enough to allow the excess glass to readily flow out of the interface. This wets the surfaces to be joined and the mutual interaction forms a good bond with good fillet geometry.

The heating and cooling rates to and from the sealing temperature must be determined for a particular frit-bulb combination. Initially, it is best to start at very low heating and cooling rates and gradually determine the maximum rates. Heating rates less than 2° C/min. are not recommended because of the possibility of devitrification setting in before a good seal is obtained. It is very important that all parts of a joint be at the same temperature when the glass devitrifies. The rate of cooling will depend on the size and geometry of the bulb parts being sealed as well as the expansion match between the frit and material being sealed. In general, the optimum cooling rate can be somewhere between 1° and 6° C/min.

3. PHOSPHOR TYPE

The screen employed would be a Sylvania type P-16 Calcium magnesium silicate: Cerium ultraviolet phosphor. The U.V. phosphor has a peak emission of 385 millimicrons and is readily available as a standard type phosphor.

4. CRT SCREENING INFORMATION

Refer to Appendix IV, paragraph 3; the procedure is the same.

5. LACQUERING AND ALUMINIZING DATA

Refer to Appendix IV, paragraph 4; the procedure is the same.

6. PASSIVE FILTER

Refer to Appendix IV, paragraph 6; the procedure is the same.

7. ANTI-REFLECTION COATING

Refer to Appendix IV, paragraph 8; the procedure is the same.

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