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RUGGEDIZED ELECTRONOGRAPHIC TUBE DEVELOPMENT

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Scott Nevin

ITT Electro-Optical Products Division
3700 East Pontiac Street
Fort Wayne, Indiana 46803

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GODDARD SPACE FLIGHT CENTER
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Preface

Electronographic tubes known as Spectracons are permanently sealed detectors whose signal electrons exit through a thin mica window and penetrate a photographic recording emulsion. Currently available tubes are of glass ring and glass envelope construction, suitable primarily for laboratory use. Their photocathode response is limited to the visible spectrum because graded seals of ultraviolet transmissive materials, such as magnesium fluoride, to the glass envelope is a difficult technology.

It is the object of this project to build a ruggedized version of the Spectracon having good ultraviolet sensitivity and, if possible, a large effective image area.

While the program is uncompleted for financial reasons, the design and sub-assemblies fabricated appear to meet well the requirements, and the chances of building successful operating Spectracons having the desired characteristics seem very good. Consequently, it is recommended that the work be completed in the near future.

Introduction

The Spectracon is a magnetically focused electronographic tube whose 40 kilovolt electrons exit a 4 µm thick mica window. Tubes described in the literature perform very well, but have severe limitations that restrict their use. Among the limitations are:

- No far ultraviolet sensitivity
- Not rugged enough for rocket launch
- No option for permanent magnet focusing.

Using technology developed for Generation II image tubes and magnetically focused image tubes, these limitations can be overcome.

Spectracon Design

The performance and mechanical requirements of this Spectracon design are shown in Table 1. These characteristics are compatible with the application of the tube.

The design proposed originally is shown in Figure 1. Note that the tube body is made of metallized ceramics with the accelerating electrodes brazed to it, not hung within it. This is a key feature of the ruggedization of the Spectracon. Although the 4 μm thick mica window is delicate, it is of low mass and if correctly supported it can easily withstand the forces of rocket launch. It is the Spectracon body and electrodes, the large mass items, that must be designed against shock and vibration damage.

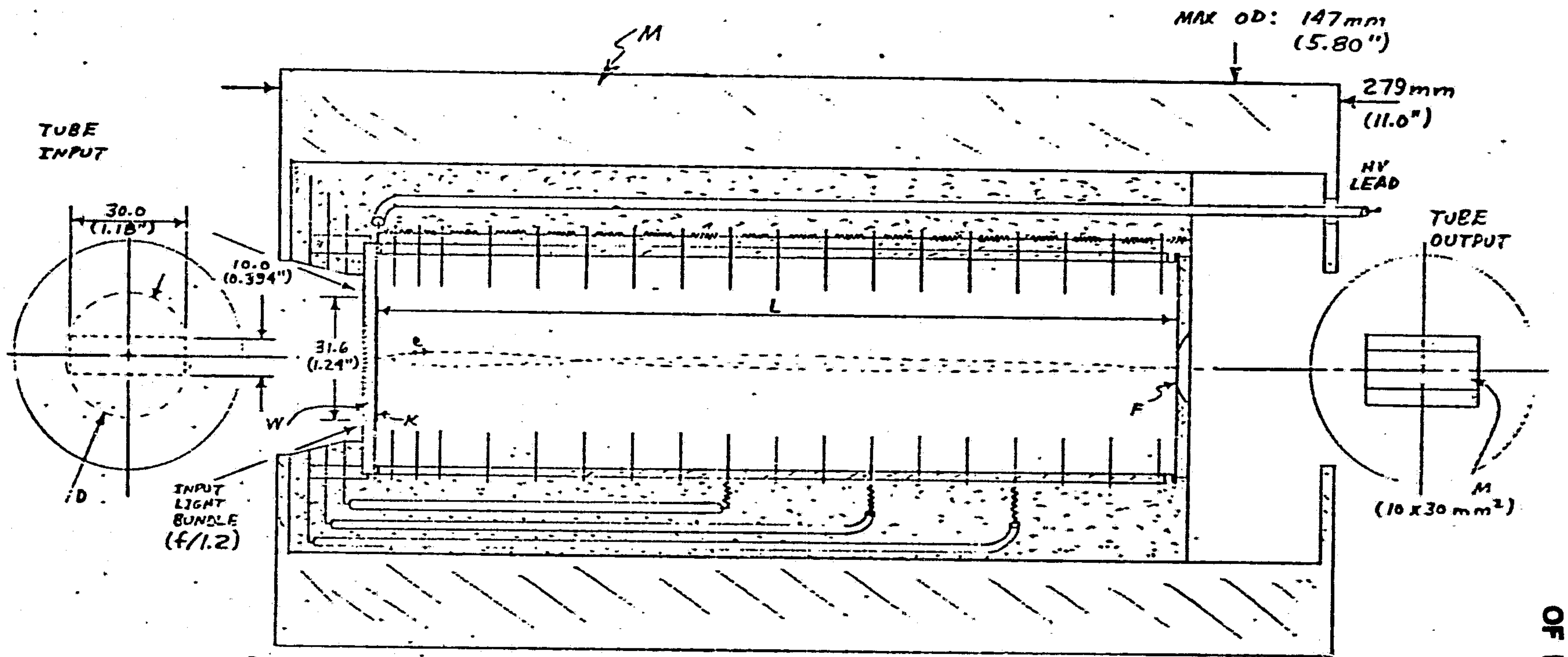
The photocathode is deposited on an ultraviolet transmitting magnesium fluoride faceplate in a remote process vacuum system. This permits any desired photocathode, such as bialkali, CsI, or multialkali, and results in uniform sensitivity over the whole active photocathode area. The faceplate, after photocathode processing, is sealed to the ceramic-and-metal tube body by a indium-bismuth solder seal. This seal tolerates the mismatch of the window and body expansion coefficients. It has been used on many tubes, including the International Ultraviolet Explorer image diode.

Encapsulation is done with the same potting compounds used for 45 kilovolt Generation I image tube assemblies.

The permanent magnet could be an exotic self-shielding design of the Raytheon type, but within the volume allotted, a stack of ring magnets, as used on the ITT F4089 magnetic focus image tube, can be placed and the magnetic field trimmed to provide Spectracon performance meeting Table 1. For the present, such a simple permanent magnet is proposed. See the Appendix.

TABLE 1 - SPECTRACON SPECIFICATIONS

PARAMETER	SPECIFICATION
PHOTOCATHODE RESPONSE	Bi-Alkali
WINDOW	MgF_2
PHOTOCATHODE SENSITIVITY	15% q.e.
DARK CURRENT (AT 15 °C, AFTER 0.5 h STABILIZATION)	MAXIMUM 1000 ELECTRONS/cm^2/sec TYPCIAL 100→200 ELECTRONS/cm^2/sec
PHOTOCATHODE UNIFORMITY	LESS THAN 10% OVER CENTRAL 15 mm by 3 mm AREA
MAXIMUM PHOTOCURRENT	1 μA/cm^2
PHOTOCATHODE OPERATING POTENTIAL	-40 kV
OUTPUT END	GROUNDED
CURRENT THROUGH POTENTIAL DIVIDER	30 μA approx.
EFFECTIVE IMAGE AREA	30 mm x 10 mm
DISTANCE OF PHOTOCATHODE SURFACE FROM INPUT WINDOW	4 mm max
ELECTRON OPTICAL MAGNIFICATION	UNITY
LIMITING RESOLUTION (3% MODULATION)	MINIMUM 80 lp/mm: TYPICAL 100→200 lp/mm
IMAGE ROTATION	<1°
IMAGE S-DISTORTION (AT 7.5 mm RADIUS)	<40 μm
IMAGE DRIFT (AFTER 1 h STABILIZATION OF TEMPERATURE AND HIGH VOLTAGE)	<20 μm/h
DIMENSIONS (S-4726156)	
TUBE LENGTH	238 mm (9.37")
TUBE OUTSIDE DIAMETER	102 mm (4.00")
PHOTOCATHODE SETBACK	25.4 mm (1.00")
PACKAGE LENGTH	279 mm (11.0")
PACKAGE OUTSIDE DIAMETER	147 mm (5.80")



SYMBOLS:
D CATHODE DIAMETER
M MAGNET
W INPUT WINDOW
K CATHODE
F MICA FILM WINDOW
L CATHODE/MICA WINDOW SPACING

25mm
(1.0")

2-LOOP FOCUS PARAMETERS:
$B = 20.0$ mT
$L = 212$ mm (8.35")
$V_a = 40.0$ kV

F9-163 SPECTRACON

S4726156

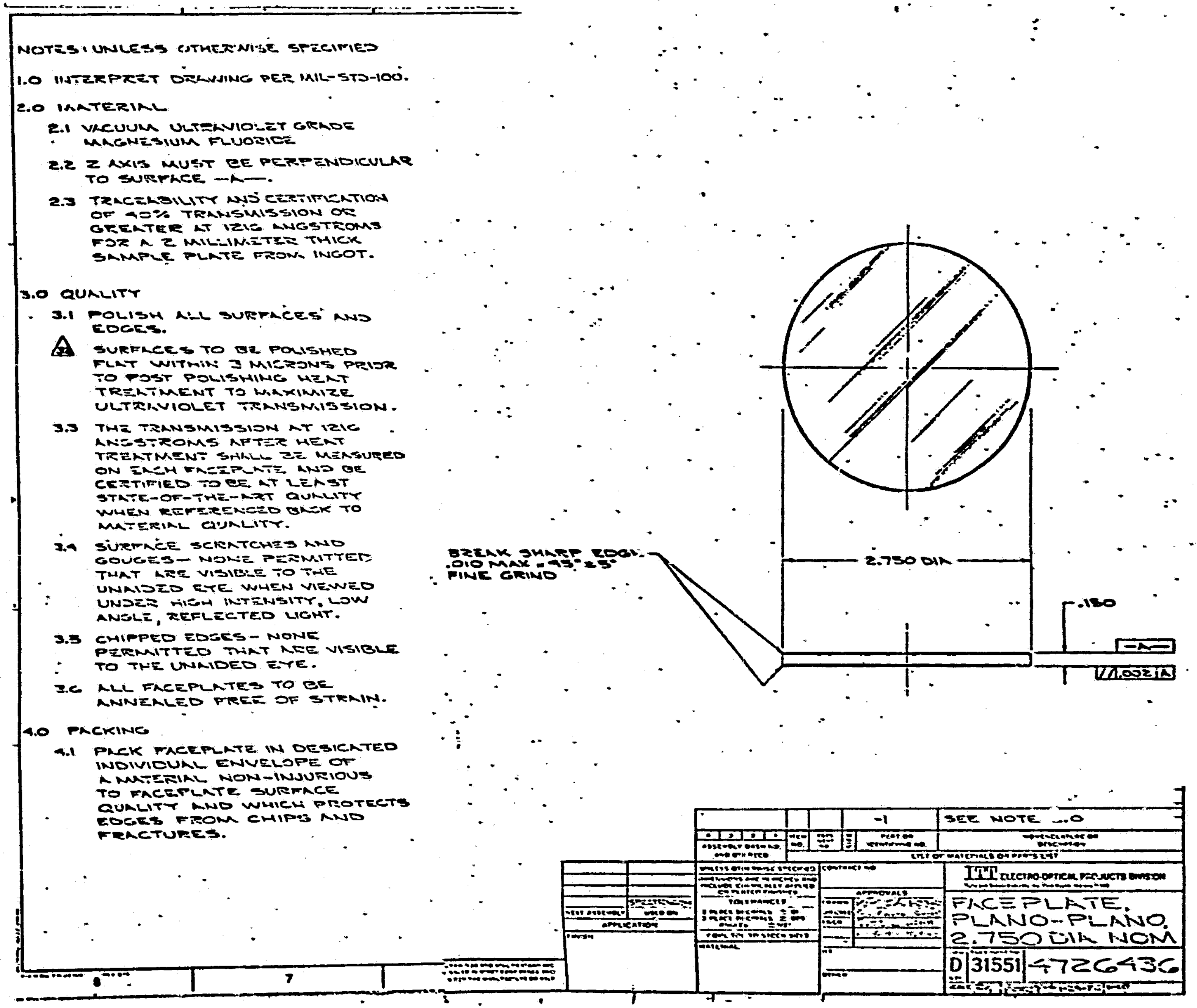
Figure 1

A requirement is for the magnesium fluoride window to have a maximum thickness of 4 μm. The I.U.E. image diode had a 2.54 mm thick magnesium fluoride window. Scaling laws would make the Spectracon's larger (70 mm versus I.U.E.'s 60 mm) faceplate 3.5 mm thick to have no more stress or deflection. A thickness of 3.81 mm was selected, Figure 2.

Before the input window's outside diameter was selected the design of the Spectracon's body ceramics was reviewed. The published Spectracon literature notes that McMullan, Powell, and Curtis[1] had instability problems when they increased the gaps between their electrodes from 10 mm to 20 mm. They attribute the instability to the charging of insulators exposed to the electron beam.

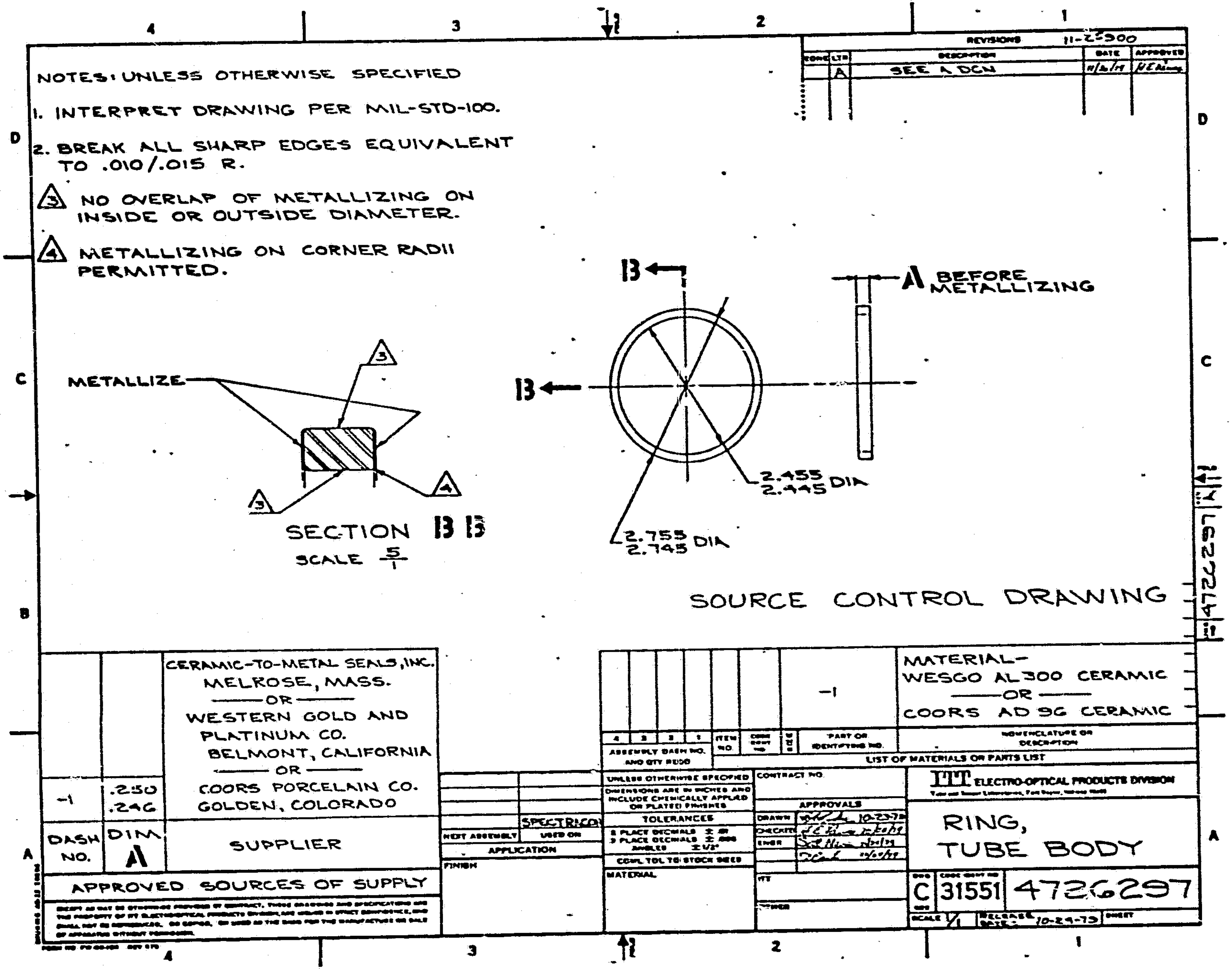
The narrow ceramic width of Figure 1 was increased to 3.81 mm to obtain a sufficiently wide metallized surface. Because the Spectracon assembly has a limited (maximum) outside diameter and needs potting and leads for 40 kilovolt operation, the ceramic ring width was attained by making the ring inside diameter smaller than originally planned. To prevent charging of the ceramic surfaces, each ring was made only 6.3 mm high, Figure 3.

To accompany the ceramic drawing, a 16-page specification (ITT VT 10000) was written to ensure metallizing of the ceramics that would provide leak tight envelope assemblies. The concern here can be explained as follows. A Spectracon body is comprised of over thirty brazed ceramic rings. To have 9 of 10 body assemblies leak tight means that each metallized ring must be perfectly brazed 99.67% of the time (299 good in 300 attempts).



MAGNESIUM FLUORIDE WINDOW

Figure 2



CERAMIC RING

Figure 3

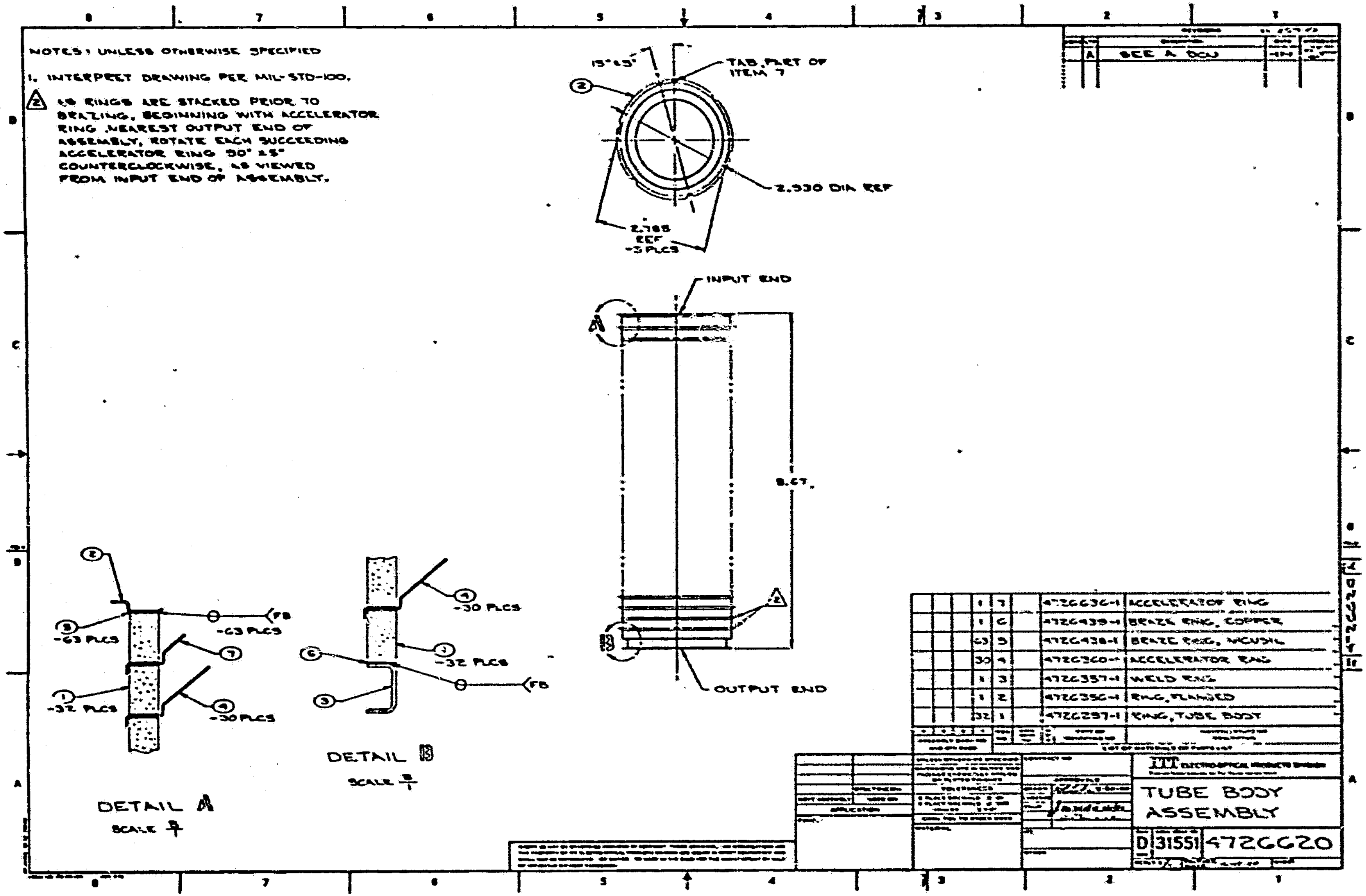
Our previous experience with brazed metallized ceramics had not been good, so we were careful not only about the specification but also about the vendor. Sample parts were to be tested before delivery was accepted. Several companies "no bid" our request for quote, and Ceramic-To-Metal Seals, Inc. was selected to supply the metallized ceramics.

The Spectracon tuby body, Figure 4, required a copper ring at its input end to which the magnesium fluoride window would eventually be sealed, and a U-shaped weld ring at its output end to accommodate the mica window assembly. Each of these electrodes were scaled from existing designs.

The accelerator rings were designed next. Conventional Spectracons have simple disk shaped accelerator electrodes. Cone shaped electrodes, Figure 5, are more stable in shape. This might be a problem during shock for flat disk electrodes, particularly since copper is dead soft after the braze operation.

The accelerators are lipped in a manner to make the ceramic and ring stack self-aligning when it is initially assembled at room temperature. Due to the difference in expansion between the copper and ceramic, alignment rods are also necessary for the braze fixture.

In using the accelerators, one has a choice regarding their orientation; they may point toward the photocathode or toward the mica exit window. Each orientation has advantages and disadvantages. With the cone-like accelerators pointed toward the mica window, the electron beam is shielded from the ceramic wall, except adjacent to the photocathode. But it is near the photocathode that the photoelectrons are most easily influenced by the electrostatic field. Hence, the orientation chosen for the accelerators is to direct them toward the photocathode, as Figure 4 shows.



SPECTRACON BODY ASSEMBLY

Figure 4

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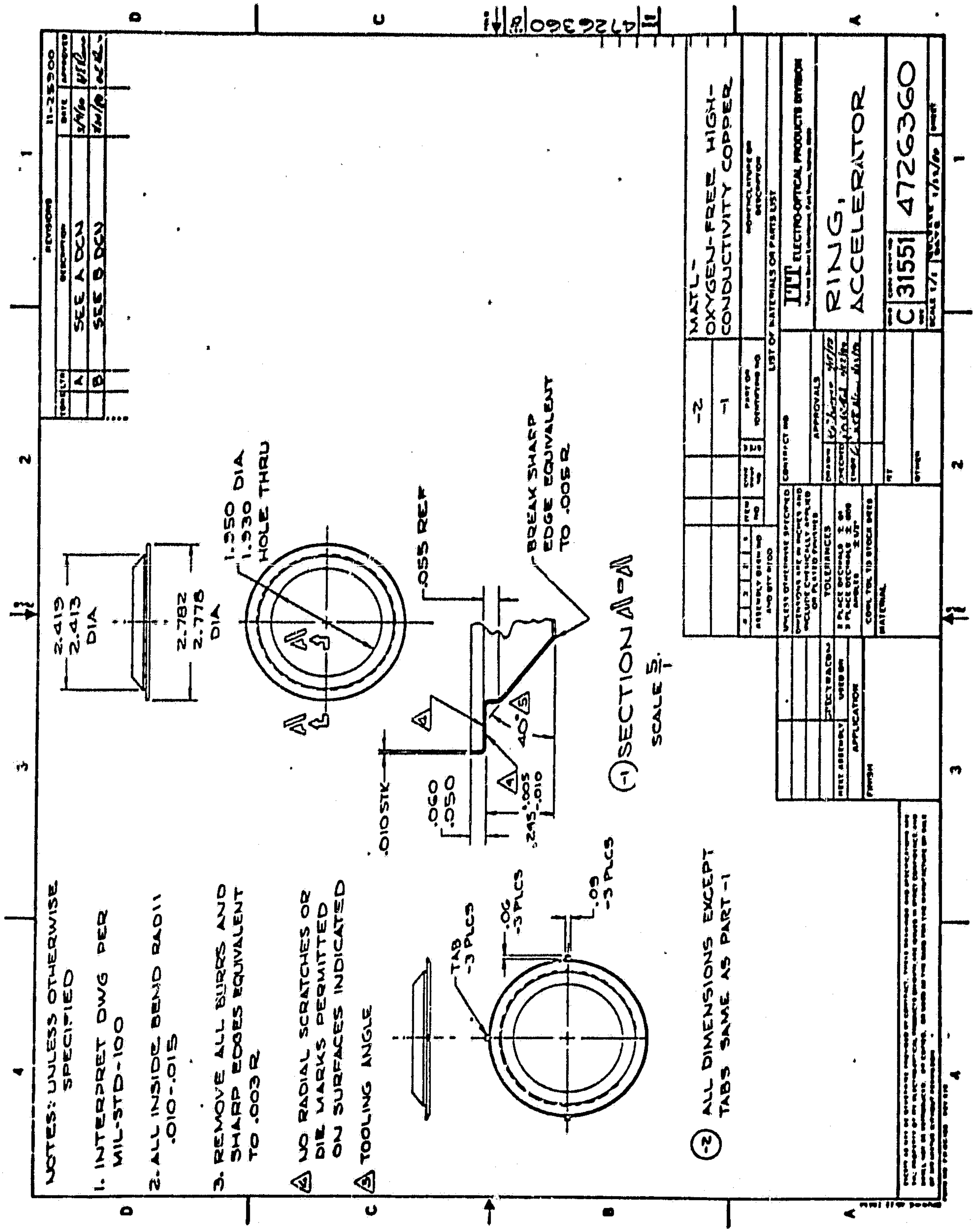

ACCELERATOR ELECTRODE

Figure 5

The voltage on the accelerator nearest the photocathode can be adjusted to minimize spiral distortion of the output image. This is done, to the specification of Table 1, in the ITT F4089 magnetic image tube wherein the same accelerator ring orientation is used. This adjustment is more necessary in the non-uniform field of permanent magnets than in the field of good solenoids.

Despite having made a choice of accelerator orientation, freedom from wall charging and the capability of long-term image position stability must be demonstrated in the operating tube.

The mica exit window is specified in Table 1 as 4 μm thick, see also Figure 6. The sealing of similar Lenard windows is described in the literature from at least 1942. A 1969 article[2] by J. D. McGee and D. McMullan specifically addresses the Spectracon window and suggests sealing the mica to a curved surface that approximates the curvature of the mica due to atmospheric pressure. This curved sealing surface tends to reduce stresses at the edge of the window. The article also notes that leak-free seals are easily obtained. But five years later, the same group reported[1] that mica window seals were indeed a problem--photocathode stability is very sensitive to small leaks.

The radius of curvature according to reference 2, equation 2 therein, ideally would be 32 mm, but mechanical constraints lead us to use a 50 mm radius, Figure 7.

The conventional Muscovite mica (thermal expansion coefficient of 9 to 12 x 10^{-6} per ^{o}C) window seal is made to Sylvania No. 4 metal (9 x 10^{-6} per ^{o}C) with Corning No. 7570 glass frit.

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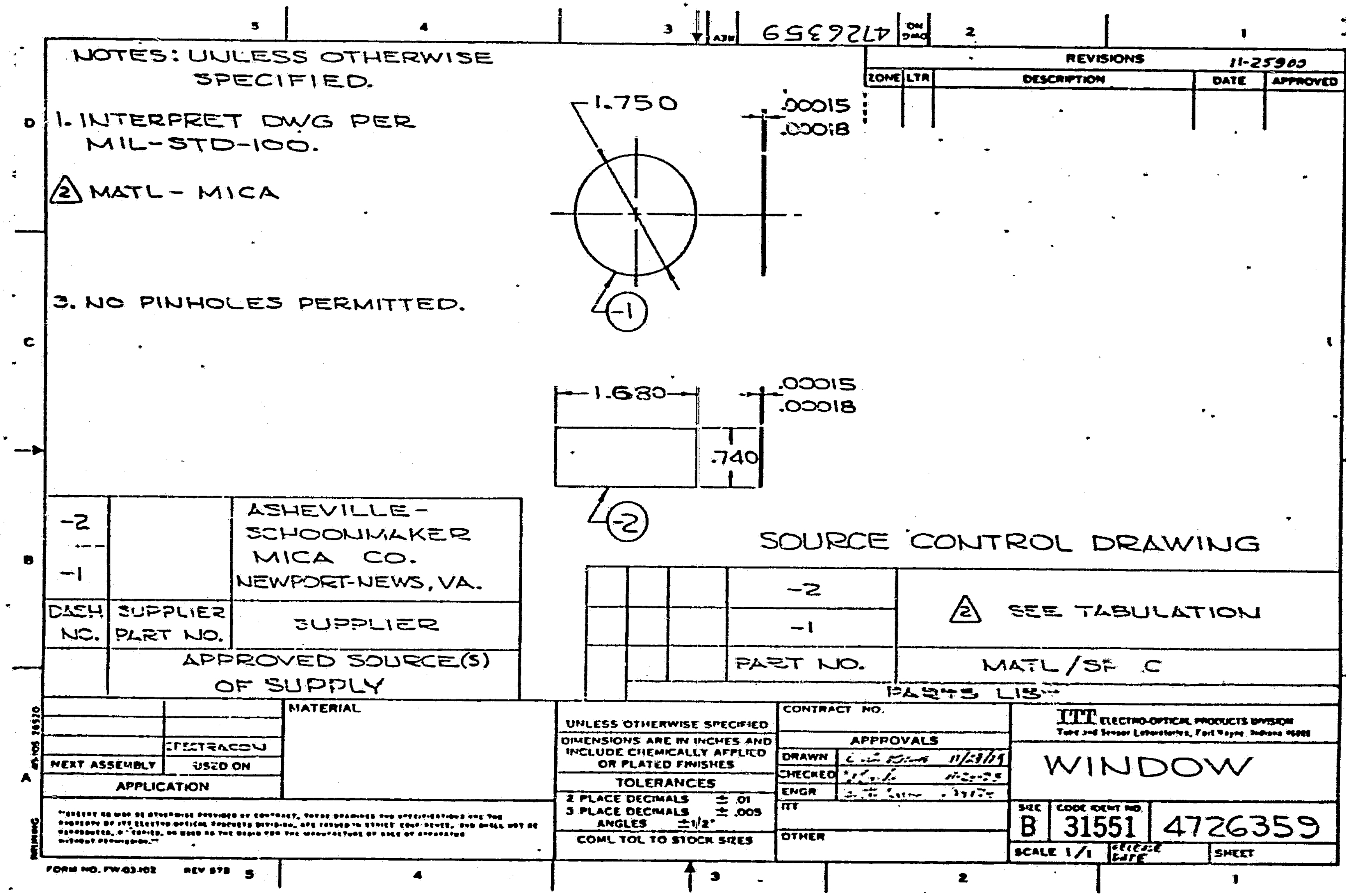
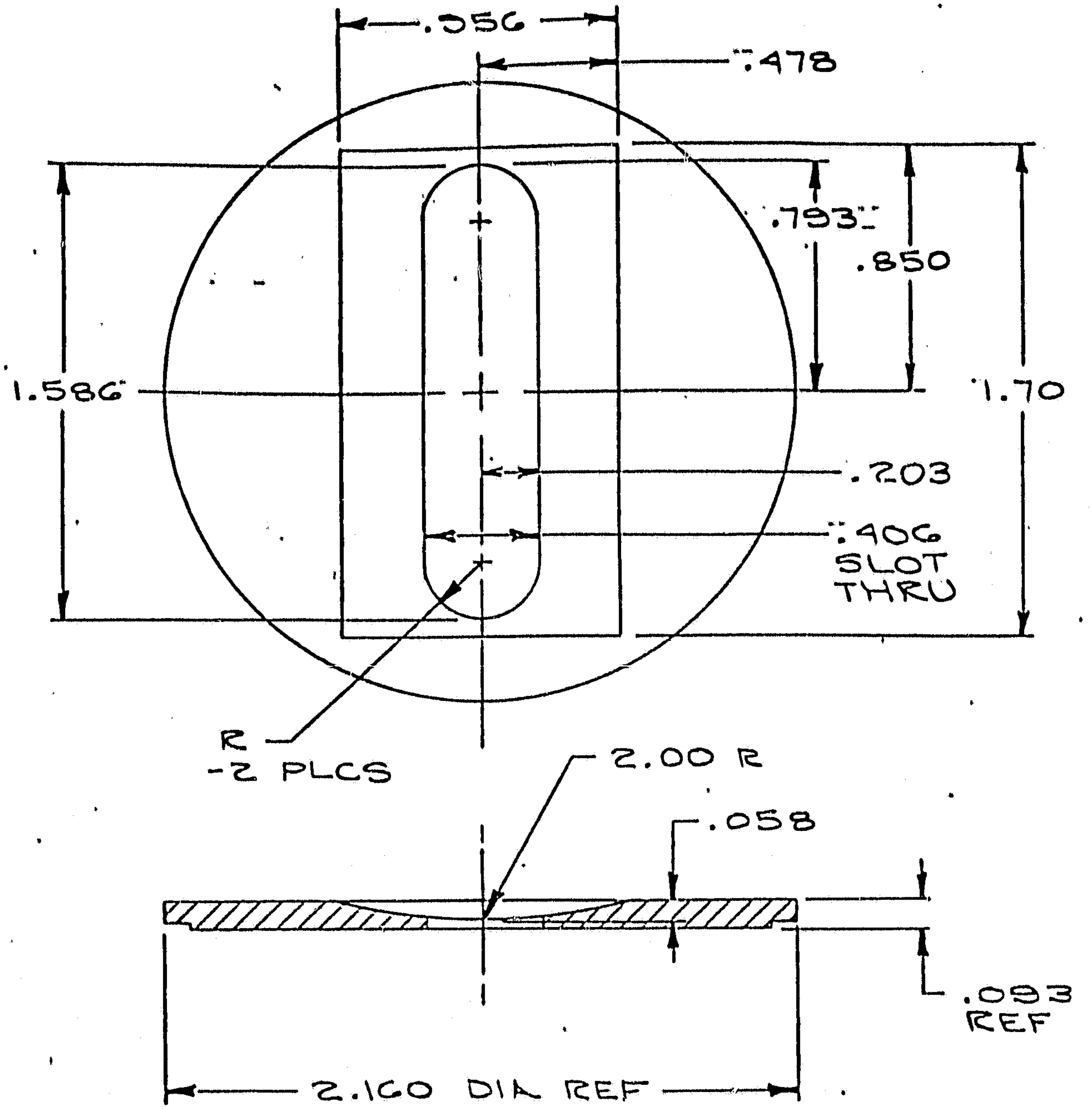


MICA EXIT WINDOW

Figure 6



SCALE 2/1

ALTER FROM S4726652-1
MATL REF - TITANIUM T-55A

PLATE, SUPPORT
MICA WINDOW

S4726940

Figure 7

Another combination, with which we have had some experience is titanium (actually Ti-55A) and Corning No. 7570 Pyroceram frit. Because the glass sealing steel alloys (Sylvania No. 4, Carpenter No. 426, etc.) are difficult to buy in small quantities, and because a relatively thick plate, see Figure 7, is desired, we elected to use titanium (expansion coefficient of 8.5×10^{-6} per ^{o}C) and Pyroceram.

The outside weld ring (4726357) at the exit end of the Spectracon body, Figure 4, mates with a weld ring (4726358) in which the titanium support plate is mounted. The two weld rings are heliarced together as one of the last steps of tube assembly. Mounting the titanium support plate to the inside weld ring (made of Carpenter No. 49 steel) presents somewhat of a problem. Titanium doesn't easily braze to steel; but it can be brazed if the steel is nickel plated.

Other than specifying the needed braze washers, this completed the design of the Spectracon tube itself. For the resistive divider to be potted around the tube, the resistors used for ITT's F4089 magnetic focus image tube were selected.

For the tube's 45 kilovolt operation, GE-118 primer and DC-170 encapsulant as used on Generation I image tube assemblies, that also operate at 45 kilovolts, were selected. High voltage cables made by Rowe, Inc., can be accommodated within the package dimensions.

Fixtures were designed for brazing, welding, masking, evaporation, leak check, processing, etc.

Tube Building

After the design effort, orders were placed for parts, materials, and fixtures.

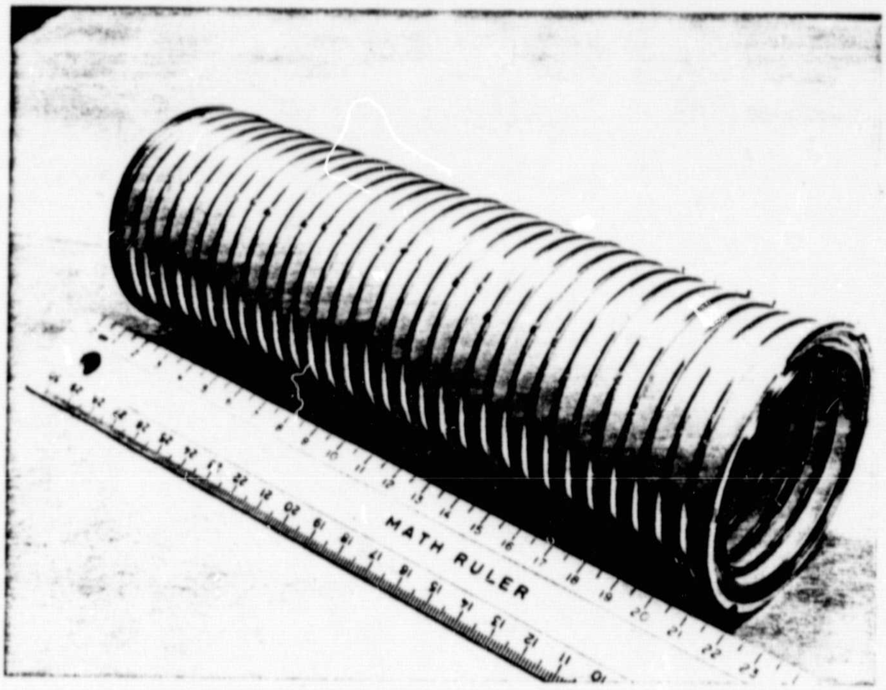
Mica, in 9 μm, 6 μm, and 4 μm thicknesses was obtained from Asheville-Schoonmaker Mica Company. The thicker pieces were to the desired shapes, Figure 6, but the 4 μm thickness was available only in sheets of varying outlines.

It turned out that titanium stock suitable for the mica support plate was as elusive to obtain as the Sylvania No. 4 metal we decided not to use, but a source was finally found. Tests to develop a fritting and firing schedule went ahead with the thicker mica pieces and thin titanium sheet stock. Eventually wrinkle-free and vacuum-tight windows, sealed with Corning Pyroceram No. 7570 frit, were obtained. Certified good windows using the 4 μm thick mica were not quite achieved during the project, but probably could be made now.

A major effort was being sure that the metallized ceramic rings were satisfactory. They were 100% visually inspected when received and sample braze seals made. Some were sent back for re-work; most were eventually deemed acceptable. Thus, the quality of the supplied metallized ceramics was pretty good. Stacks of a few rings were brazed, found to be leak tight, and after microscopic examination of the brazed joints the ceramics were deemed acceptable.

One full size Spectracon stack was brazed and appears to be leak tight, Figure 8. Because of past ceramic envelope problems, this was considered a major accomplishment.

Unfortunately, tube parts and the many fixtures needed to do the work right resulted in more cost than had been anticipated, so work had to be stopped.



BRAZED, LEAK TIGHT
SPECTRACON BODY

Figure 8

Status

Presently all parts and materials are on hand to build a Spectracon. One major subassembly, a ceramic body, has been brazed together, and it is leak tight. The individual metallized ceramics on hand should provide more good bodies.

The 4 μm thick mica window does require some refinement of sealing technique to be trustworthy, but it is thought that the problem is just that, refinement.

We were not successful, during the few trials made, at obtaining good braze seals between the titanium window support plate and the mating weld ring. Recently we have been working on another contract with an electron beam welding vendor who leads us to believe that the titanium could easily be welded by this technique.

We have no particular concern about photocathode processing or sealing the magnesium fluoride faceplate, but are curious about the possibility of charging at the ceramic wall. Since the cone-shaped electrodes could be re-oriented fairly easily, a test tube with phosphor output to evaluate the present design seems like a good experiment prior to building the full scale Spectracon.

In summary, a good design for a rugged Spectracon has been brought along through the sub-assembly stage. With or without a few verification experiments, a Spectracon is ready to be built.

Appendix

Magnet Design

The equation for focus of an electron beam in a magnetic field is

$$L = (1.06E\text{-}05)N(V)^{\frac{1}{2}} B^{-1}$$

where N is the number of loops
V is the anode voltage
B is the magnetic field, in Teslas
L is the beam length, in mm

For two loops of focus of a 40 kV beam traveling 212 mm, the magnetic field needed for focus is 20 mT. This can be generated by a very expensive Raytheon magnet, or by inexpensive Alnico rings. Using eight rings (a double FW313 four-ring focus magnet, Figure A-1) will provide a permanent magnet assembly that can be adjusted to 20 mT.

Table A-1 shows the magnet's characteristics and that of the Raytheon assembly, too.

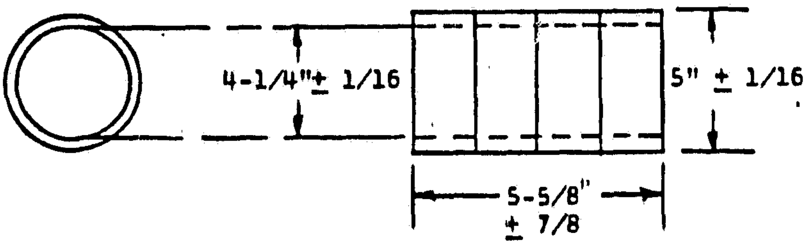
FW-313, FW-314
IMAGE TUBE FOCUS MAGNETS

FW-313 4 ring focus magnet

Axial field strength : 500 ± 100 gauss

Applicable tube types : Image Tubes : FW-116, FW-132, FW-167
Image Intensifiers : FW-113, FW-117, FW-159
Storage Image Tubes : FW-231, FW-232

Dimensions:



FW-314 6 ring focus magnet

Axial field strength : 500 ± 100 gauss

Applicable tube types : Image Intensifiers : FW-152, FW-153, FW-154, FW-155

Dimensions:

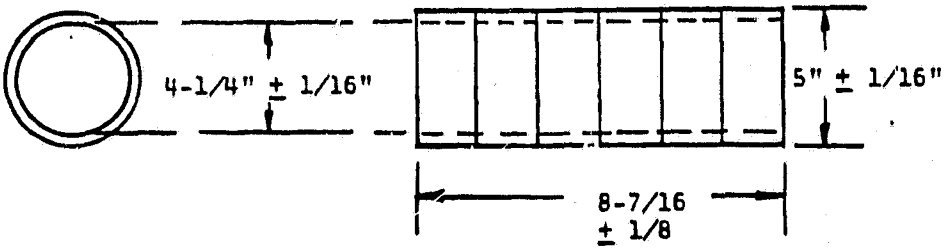


Figure A-1

MAGNET SPECIFICATIONS

Table A-1

	RAYTHEON MAGNET	ITT MAGNET
OUTSIDE DIAMETER	149 MM (5.86")	140 MM (5.50")
INSIDE DIAMETER	102 MM (4.00")	108 MM (4.25")
INPUT APERTURE	50.8 MM (2.00")	108 MM (4.25")
OUTPUT APERTURE	50.8 MM (2.00")	108 MM (4.25")
FIELD WITHIN 212 MM (8.35") ACTIVE LENGTH	20.0 ± 0.2 mT (200 ± 2G)	20.0 ± 2.0 mT (200 ± 20G)
FRONT-END OVERHANG (MAGNET-TO-CATHODE), MAXIMUM	25.4 MM (1.00")	38.1 MM (1.50")
SHIELD	YES	NO

REFERENCES

1. D. McMullen, J. R. Powell, and N. A. Curtis, Advances in Electronics and Electron Physics, Volume 40B, 1976, p 627-640.

2. J. D. McGee and D. McMullan, Journal of Scientific Instruments, Series 2, Volume 2, 1969, p 36-40.