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SPACE TELESCOPE DIGICON TECHNOLOGY

FINAL STATUS REPORT

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Prepared For:

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SUMMARY

The objective of this program was to develop the technology for the HRS Space Telescope Digicon and construct a number of tubes conforming to the chosen configuration. As part of this project, a number of specific tasks were to be carried out to improve those design aspects known to be deficient or non-existent.

A total of ten starts were made and ten tubes went through to test. One tube was scheduled to be re-processed (making it the eleventh start) as part of this program to determine if the recovery procedures were adequate. The results on this tube are not yet available. Of the ten tubes three were CsI on LiF, six were CsTe on MgF_2 and one was KNaCsSb on SiO_2. All three face-plate crystals sealed successfully using indium as the sealant. In addition a number of test seals were made and two photocathode sample runs were made.

The tasks E-field, faceplate, anti-corona and electron optical analysis were actively pursued and the results integrated into the BASD HRS project. A number of problems in these areas remained, but the required effort to solve them became easier to estimate. Only in the anti-corona area did it appear as if an acceptable solution would be difficult to achieve. However, this work did have some impact on photocathode development for the LiF and was thus useful. It also stimulated a search for other alternatives such as front-end ion traps.

MANAGEMENT

The management of this project proceeded along the lines explained in the first Monthly Report. An extreme amount of control was required in order to bring emphasis on a number of critical path items. This management control served as a basis for the continuation of the HRS program into the Ball Aerospace Systems Division program which in turn will lead to flight hardware. The major area of program management system control was exerted in subcontracts, in particular, diode arrays and headers.

Internal management tasks required in-depth planning and continual changes dictated by vendor delivery and EVC manufacturing improvements. This resulted in a fluid program where decisions were made with overall program objectives as a goal. In some cases these decisions resulted in less than optimum quality Digicons in order to build up a larger data base.

PROGRAM PLAN

The program plan was developed for the purpose of developing Digicon technology. There were nine tasks: (1) Program Management, (2) E field, (3) Faceplate, (4) Anti Corona, (5) Sealing, (6) Setup tubes, (7) Prototypical tubes, (8) Documentation, and (9) Electron Optical Analysis. All these tasks were carried out at EVC, with the exception of the anti-corona work which was primarily performed by UCSD and Curtis Associates. UCSD also carried out a large portion of the faceplate work.

The program plan was continuously updated to meet the needs of UCSD and NASA and was eventually merged into the BASD program.

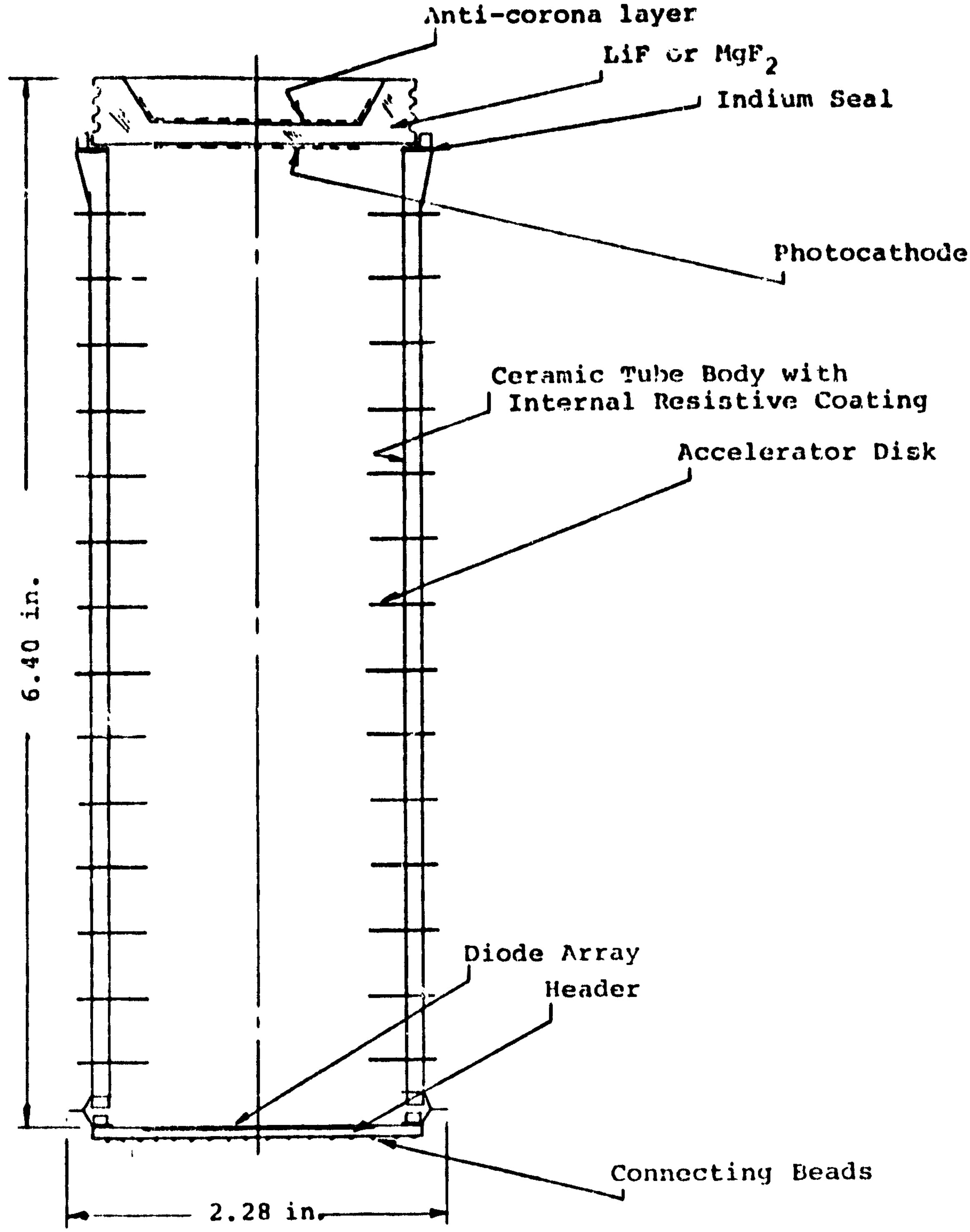
Two major changes were the inclusion of S20 photocathode on quartz full-up Digicons and the recovery of tube E5 accidentally damaged during customer testing.

DESIGN

The design of the 512 Digicon was based on that proposed to UCSD and completed on a previous contract. The configuration was changed to accommodate the special MgF_2 and LiF crystals used for the faceplate. This design, shown in Figure A, remained substantially unchanged through the program.

FIGURE A

512 DIGICON



The changes that did occur were in the header, where aluminum wirebond pads were substituted for the normal gold and in the diode array.

The history of the Digicon goes back to the late 1960s and the considerable groundwork laid in that intervening time resulted in the dimensions as shown. Table I delineates some of the requirements that needed to be satisfied and Figure A shows the results of the physical dimensions. Table II shows the relationships between the performance/design objectives and characteristics of the Digicon tube and the system elements. As can be seen, a systematic approach to the design was required and the information available to date has shown that the design is near-optimized from this viewpoint. The system approach viewpoint here covers customer end use requirements, available customer system compromises, the Digicon tube, the magnetic field system, Digicon tube processing, vendor capability and basic physical limitations. EVC's considerable experience with UCSD and others in the astronomy field has been the basis for the design which, it is expected, will become universally used.

RESULTS

E Field

The E-O analysis (see Appendix) showed that two areas of concern required work. The first was that the focus disks needed to be flat and the second that reasonably uniform wall coatings were required for the first rings.

The flatness of the focus disks in the tubes built were generally excellent. In some cases, handling caused dents to appear and it was decided to attempt to find a means of flattening. To this end a simple hand-operated tool was designed and built. The method of flattening is somewhat tedious but the results were acceptable.

The main task was to develop a rugged and uniform coating for the interior walls of the ceramic tubing. The initial results are shown in Figures B and C and as can be seen, two problems

TABLE I

TUBE BODY

Digicon Requirements	Tube Body Design Criteria (Constraints)
Physical Size Limit	Minimum Length and Diameter
Optical Area Maximized	Maximum Optical ID
High Voltage Holdoff - External	Minimum Tube Diameter to Maximize Potting Thickness
- Internal	Maximum Length to Reduce Electric Field Stress
Near-Perfect Electrostatic Field (which must remain stable under operating conditions)	Uniform High Resistance Wall Coating Across Each Ceramic Spacer. Coating to be Rugged to Withstand Cleaning, Firing, and Vacuum Processing. Note: Impact of Increasing ID of Accelerator Rings.
Stable Low Gas Pressure in Tube	Tube Body Must Remain Hermetic and Have Very Low Internal Outgassing After Processing
Alignment of Faceplate	Tube Body Must be of Precision Construction
Non-Magnetic	No Magnetic Components Allowed
Header to Faceplate Parallelism	Precision Ground Ceramics

TABLE II

SPECIFICATIONS/CHARACTERISTICS

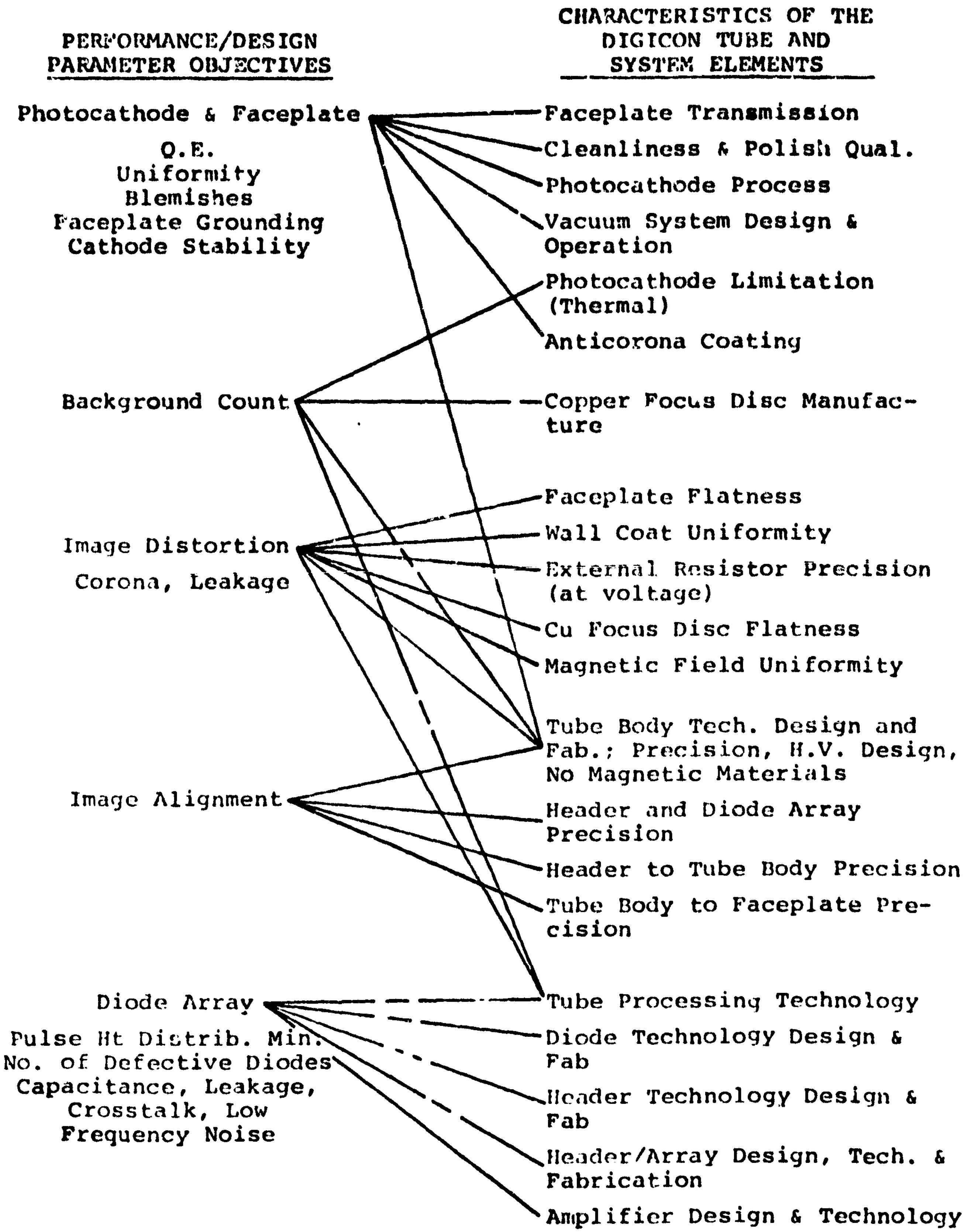
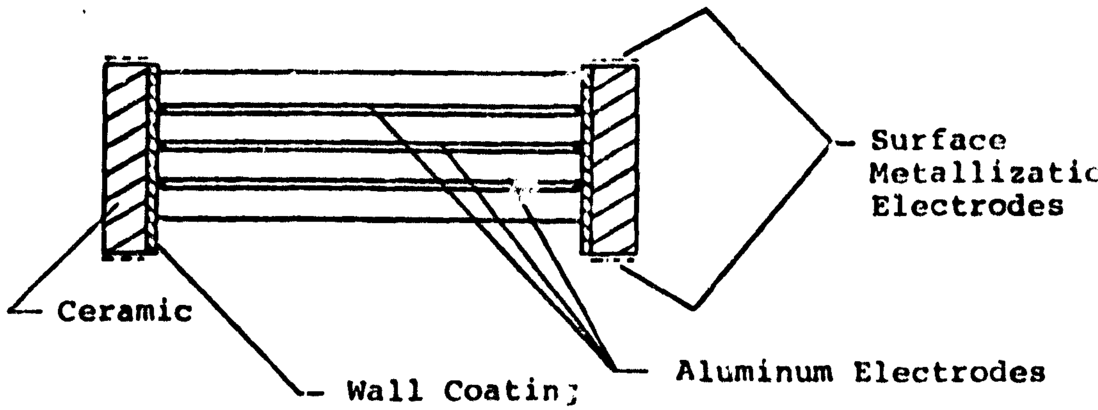


FIGURE B

SECTIONED CERAMIC RESISTANCE MEASUREMENTS



EVC Ceramic Ring No.	Current in 10^{-9}A at 2.5 kV Section				Comments
	1	2	3	4	
162-1 (1kV)	6,400	38,000	34,000	6,800	Too Thick
162-2 (1kV)	200	900	500	360	Too Thick
162-3	7.6	5.1	3.2	5.8	Improved
162-4	21	24	28	7.5	End Thin
162-5	.8	.9	.9	.9 to .5	Unstable
162-6	75	175	175	145	End Thin
162-A	1.4	5.1	5.1	4.1	End Thin
162-B	1.2	7.1	6.8	1.6	End Thin
162-C	.9	1.7	1.6	1.1	Improved

FIGURE C

CERAMIC WALL COATING RESISTANCE

Ceramic No.	Resistance at 2.5kV, $x10^{12}\Omega$
AJI	2.7
AJJ	.30
AJK	1.3
AJL	1.9
AJM	3.1
AJN	.7
AJO	.8
AJP	.17
AJQ	1.2
AJR	.58
AJS	.96
AJT	.17
AJU	.27
AJV	1.2
AJW	.32
AJX	.27
AKA	.13
AKB	.49
AKC	3.57
AKD	3.57
AKE	.8
AKF	1.6
AKG	4.1
AKH	.67
AKI	.29
AKJ	12.5

arose. The first was that each ceramic varied from the other showing poor consistency. The second was that the uniformity, as measured vertically down the inner wall, was inadequate. The objective had been to produce a surface with a uniformity approaching 30% and a resistance between 10^{10} and 10^{13} ohms. As can be seen, variations greater than this occurred.

A visit of EVC personnel to the vendor, Veler, Inc., resulted in an attempt by Veler to use a different application method. This entailed the use of a "tape" applied to the inside of the ceramic. The concept is that a precision tape could be produced that would meet the uniformity requirements. The method was tried but failure occurred due to insufficient experience and understanding of the factors affecting the adhesion of the tape to the inside of the ceramic cylinders. It was decided to abandon the method because of impact of the cost to develop the technique which, although used successfully on flat surfaces, did not appear to be transferrable to vertical curved surfaces without extensive development. The final decision then was to go back to the basic approach initially used but to refine the control. This method consisted of using a spray gun and hand-spraying the compound on the surface. Control was purely operator initiated and it was conceded that this was less than optimum. This development, however, did result in a correct value of the resistance being achieved and these coatings survived all the Digicon manufacturing processes. Due to the need for improved spray control, a machine was designed to apply the coating material in a rigidly controlled manner but using the same material and spray gun. Thus, no major change in the basic application method (nor the mixture) would be required. This machine was only finished in time for the HRS Flight tube program, and results are not in to date. From the standpoint of ruggedness and stability, the coatings sprayed on by hand appeared to be excellent and machine sprayed coatings should not be different.

Faceplate

The primary objectives in the faceplate design and manufacture were:

(a) Minimum thickness to maximize vacuum ultraviolet (VUV) transmission.

(b) High voltage resistance (dielectric strength) in order to accommodate 25 kV differential.

(c) Structural strength adequate to withstand atmospheric pressure.

(d) Optical quality, blemishes, scratch/dig and flatness.

(e) A long path length from the high voltage photocathode connection to the grounded anti-corona surface.

(f) In the case of LiF, maximizing the VUV transmission by "dry" handling procedures.

The design for the faceplate is as shown in Figure A. This design accomplishes the criteria of minimizing the thickness while maximizing the structural strength. For lithium fluoride with a yield point of 1500 psi the thickness is critical and calculations show a safety factor greater than 1.0 for a 3 mm thick 1.8 in. diameter faceplate unclamped. With the additional rigidity supplied by the 1 cm thick rim, this safety factor could increase to greater than 2.0. Magnesium fluoride has an unknown yield point, but its elastic constant is much greater than LiF and 3 mm thick faceplates of 2 in. diameter have been used at EVC with no noticeable structural problems. It is thus conceivable that the MgF_2 faceplates could have reduced thickness, but in order to maintain commonalty with the LiF it was decided that additional transmission was not worth the problems of trying to match tubes with different windows in the flight package. A 3 mm thickness was thus considered standard.

The high voltage resistance was not analyzed in this program since it was beyond scope. However, EVC had built tubes on an AFGL program from 1975 to 1977 where 3 mm MgF_2 and 2½ mm Al_2O_3 faceplates were subjected to 30 kV without failure. UCSD personnel found data relating to LiF where breakdown voltage was stated to be a factor of 30 greater than the planned 25 kV. Thus there appears to be ample margin. The fluorescent effects are unknown, but in the case of MgF_2 no detectable background was measured on the AFGL program.

With respect to optical quality, considerable work, not originally planned for, was required. UCSD assisted in this area in two ways. The first was to develop a method of machining the brittle crystalline materials of LiF and MgF_2 and a yield of approximately 30% occurred. The second was to contract with an optical polishing company, Western Miniature Optics, to finish the faceplates.

The results of this work were that some successful faceplates were produced but at a high cost. The 30% yield coupled with the difficulty of polishing the surface in the "pocket" became of concern for the flight tube program. The 30/10 scratch/dig (goal 20/10) of the HRS Flight tube specification appears to be possible and some faceplates were subjectively judged to meet this criteria. In the case of LiF it was observed that the machined surface had a tendency to cleave and this was attributed by the crystal manufacturer to have been caused by excessive machining pressure.

The requirement for a long path length from the high voltage photocathode connection to the grounded anti-corona surface was met by machining deep grooves in the faceplate edge. The handling procedures for LiF required that during and after polishing low humidity atmosphere is required. This was accomplished at EVC by carrying out the polishing under a tent purged with dry nitrogen. Some short exposure periods in normal atmosphere ~50-60% RH occurs when transferring the faceplate between processes. The LiF faceplate on tube E9 was exposed to an atmosphere of 50% for approximately 20 minutes between polishing and vacuum system pumpdown. The QE was acceptable, but it is not known what the effect on the QE of this short exposure was. The vacuum bakeout process should eliminate all but the extremely tightly bound water vapor. It is known from the QE curve of E9 that no large amount of damage to the transmission occurred, and short exposures are thus not serious.

These questions could not be addressed on this program, but clearly the basic handling techniques were adequate to meet most of the QE specifications (which includes the faceplate transmission).

Anti-Corona

EVC contributed some effort to this program in assisting UCSD and Curtis Associates. The first test carried out at EVC was to vacuum bake some samples and this showed that very thin films of metal do not survive this environment. Thereafter coatings were deposited on completed tubes using a holder which cooled the indium seal during the process. The results of this program are reported elsewhere.

Sealing

EVC has had previous experience in sealing MgF_2 and no problems were expected. However, no information was available on sealing of LiF other than the classic silver chloride technique. EVC developed the LiF "hot-indium" seal technique for this program and tested the method on three sample tube bodies—two with LiF and one with MgF_2. No failures in the indium seal or the header-to-tube body cold weld were observed in all the tube runs. As part of the sealing task two shorty tube bodies with photocathodes were produced. These showed that no fundamental processing problems would occur in this procedure.

As part of the sealing task a silver chloride seal design was required. This was shown in the Third Status Report and appeared to be feasible. The design accommodated the silver chloride seal, the EVC cold weld design and the flat electrical field requirement at the photocathode. This design is thus an alternate to the indium seal should the environmental conditions in space prohibit the latter.

Setup Tubes

The design of the HRS Digicon went through a number of minor modifications before the first tubes were built. It was decided early in the program that no aluminum to gold wire bond connections were allowable. This meant that the UDT diode arrays which, because they had aluminum pads, required aluminum wire. The header pads, therefore, needed to be aluminized. This required the development by UCSD and Curtis Associates of a method of applying aluminum to the A and B layers on the header. The setup tubes were used to test the results and wire bond quality was determined to be excellent. The initial tubes had approximately 50 connected diodes but the aluminization quality improved to the point where all 512 pads were usable in the prototypical tubes. This task proved successful near the end of the program and thus complete for use in Flight tubes, if required. The development of the 512 header was pursued as part of this program. Initially it appeared as if this area would be satisfactory but subsequent in-depth testing revealed several flaws. The first was shorting between some leads and the other was high capacitance. These problems could not be solved in this program, but the test results obtained pointed the way to the correct solution.

The setup tubes were constructed using known technology and available diode arrays and headers. Various minor deficiencies in parts quality occurred and these were cleared up as the program progressed. Improvements were observed in the pad aluminization, the tube body brazing, particularly handling procedures, and in the faceplate pocket flatness. Changes in the photocathode processing and setup fixtures were made with the purpose of improving the process control.

The tube bodies used for these and subsequent tubes were coated with material of resistance varying between 10^{10} and 10^{13} ohms. Generally 10^{11} ohms were observed and this was the goal.

No major problems occurred and all tubes were operable. Tube E5 was accidentally damaged when tested at GSFC and this tube will be used to develop a re-processing operation on the HRS program.

Prototypical Tubes

Header full-up aluminization was accomplished in time for the full-up prototypical tubes. Good quality tube bodies were received, although the uniformity of resistance problem had not been solved, as explained earlier, and adequate faceplates were obtained. The processing proceeded under good control and all tubes were successfully sealed. The CsI cathode on E9 was processed using a hydrogen lamp and the resultant QE was within specification down to 1216 Å. The CsTe cathode on E8 was not satisfactory and would normally have been aborted and restarted if schedule impact had not been the major concern.

The new design, Figure D, diode arrays were obtained for these tubes and indications were that the pulse height distributions, Figure E, were superior to the previous design, Figure F. This was a significant design improvement justifying the effort made. The reason for the improvement was redesigning of the masks so that no aluminum covered the sensitive area of the diodes. The "old" array design resulted in a pulse height distribution (PHD) where the valley was partially filled. This was due to electrons penetrating through the aluminum layer and generating single pulse signals of lower than normal gain due to energy loss in passing through the aluminum. This aluminum overcoating was covering the diodes at the edges and enough signal would be generated that the peak-to-valley reading would not be acceptable. In order to improve the PHD of a tube made with such a diode array it would be necessary to shield the incoming radiation on the outside of the tube faceplate such that only a narrow slit of electrons would strike the diodes in the area clear of the aluminum pads. This is not practical. The new design solved this problem, and the change was incorporated in the diode array design and specification.

The three full-up 512 prototypical tubes, E8: CsTe on MgF_2; E9: CsI on LiF; and E10: KNaCsSb on SiO_2 (S20 on quartz), represent the three main tube types to be used in the Space Telescope application. Preliminary tests on these tubes showed excellent operating characteristics with only the background count of E9 being a problem. The tube list, Figure G, shows the important characteristics that were tested. These tubes were tested unpotted which makes the dark count (background) somewhat suspect.

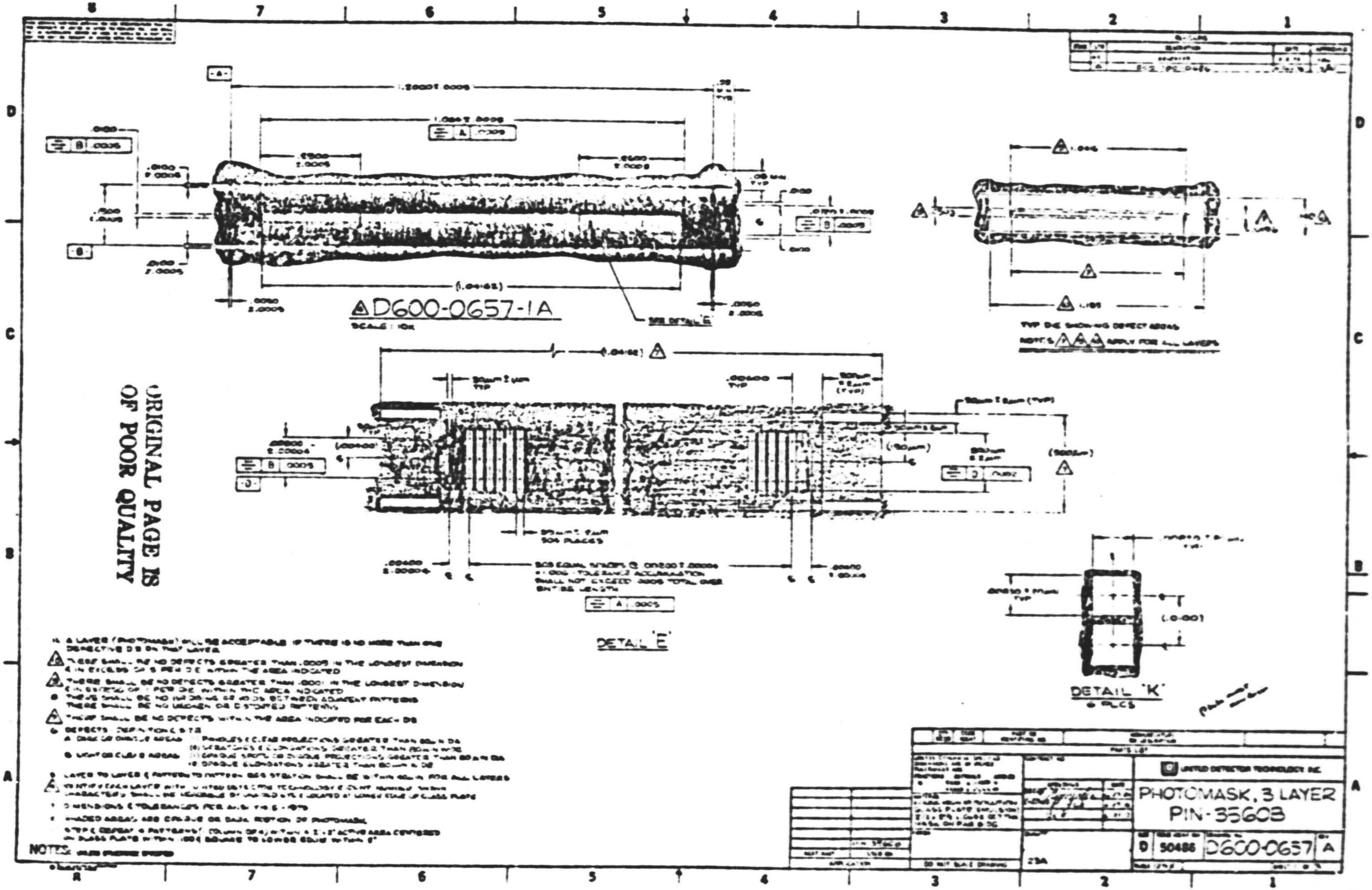

D600-0657-1A
DETAIL 'E'
DETAIL 'K'
PHOTOMASK, 3 LAYER
PIN-35603
D600-0657
NOTES:

FIGURE D

FIGURE E

SINGLE ELECTRON PULSE HEIGHT DISTRIBUTION

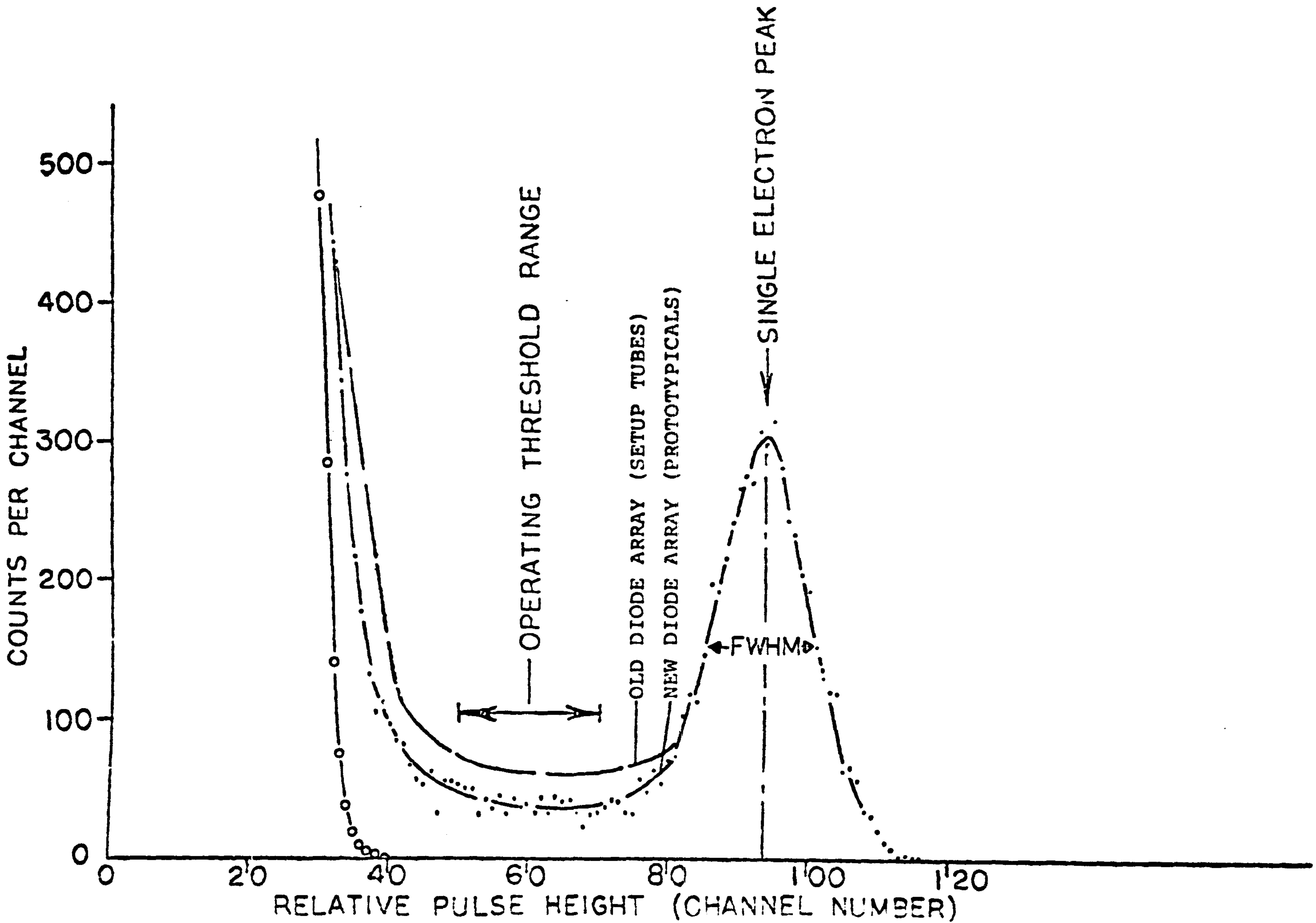
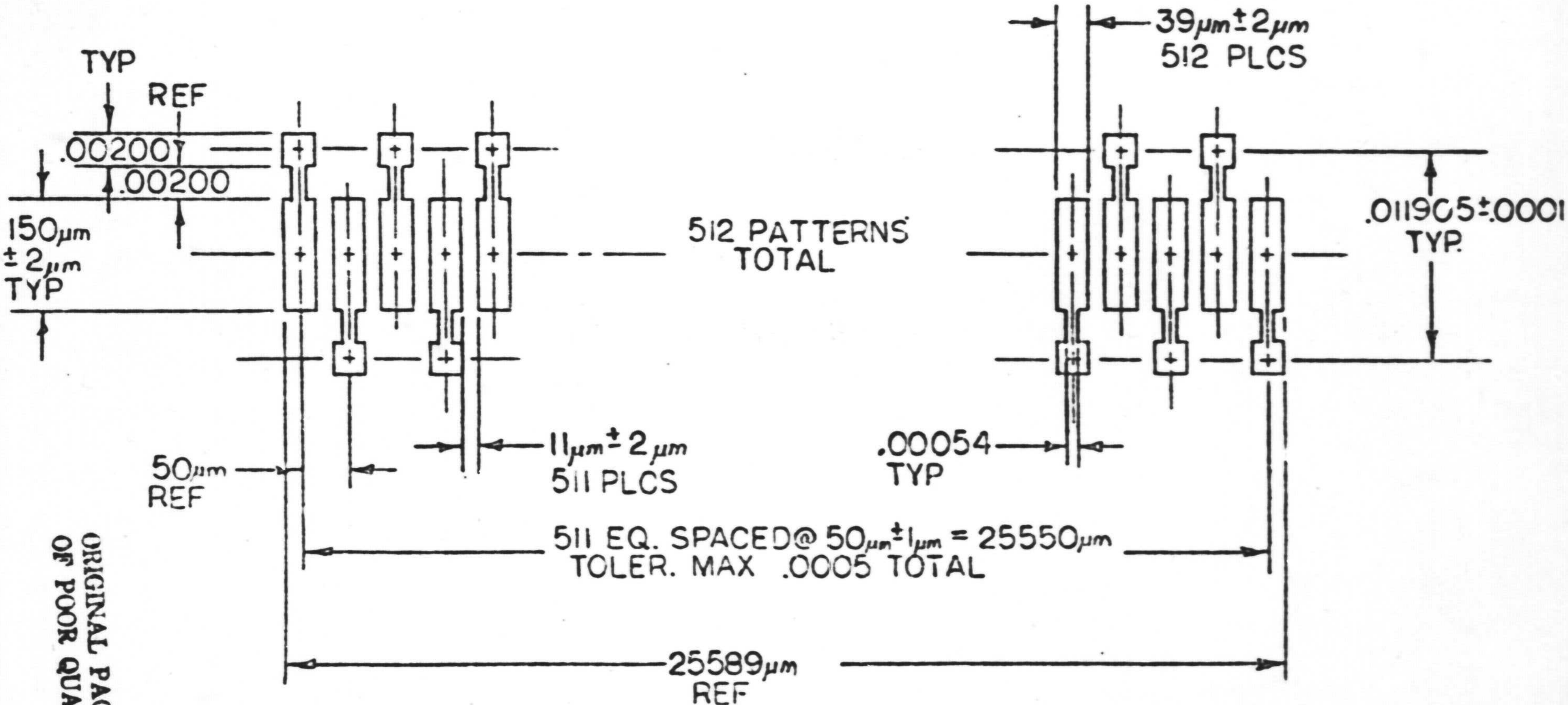


FIGURE F



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2. MATERIALS: IRON OXIDE PHOTOPLATE 2-1/2 X 2-1/2 X .064±.007.

NOTE: 1 TOLERANCES .XXXXX ±.00009.

	TITLE	SIZE	CODE IDENT.	DWG. NO.	REV.
ELECTRONIC VISION CO. A DIVISION OF SCIENCE APPLICATION 11526 Sorrento Valley Road, San Diego, Ca A DIVISION OF SCIENCE APPLICATIONS, INC.	U.D.T.I. PHOTOMASK 3 LAYER (REF DWG D100-1382)	A	54779	22-2-303	
		SCALE	10-24-78	SHEET 1 OF 1	

FIGURE G

HRS DIGICON (UNPOTTED) TEST SUMMARY

Tube No.	Faceplate	Cathode	Typical Diode Leakage (nA)	Tube Test Voltage (kV)	Dark Counts Per 100 Sec.	Peak QE % at 2 nm
E1	MgF_2	CsTe	0.6-15	22.4	36	nm --
E2	LiF	CsI	nm	22.4	6	16.5 1400
E3	LiF	CsI	0.2	23.0	6 <1	11.5 1400
E4	MgF_2	CsTe	0.14	24	4	5 2200
E5 (A)	MgF_2	CsTe	Broken After Shipment			5 2200
E5 (B)	MgF_2	CsTe	No Data as of This Writing			
E6	MgF_2	CsTe	0.1	23.0	30	8.3 2100 2600
E7	MgF_2	CsTe	0.14	23.0	5	15.5 1950 2450
E8	MgF_2	CsTe	≤0.05	23 23 25 28	1.3 1.5 3 6	nm
E9	LiF	CsI	≤0.05	24.0 24.0 28.0	12 35 129	15 1300
E10	SiO_2	KNaCsSb	<0.05	23.0	<1	30 2000

EVC, however, feels that the readings do indicate that the tubes in general will not meet the requirements of .01 c/s. The diode leakage currents were excellent on the three prototypicals and well within specification for all tubes except E1. The capacitance measurements (not shown here), however, were high for those diodes which were connected through long traces in the header. It was also observed that header ceramic material choice was important in minimizing amplifier noise. This discovery, which occurred at EVC as part of the follow-on BASD HRS program on testing, was significant in that for the first time a source of noise had been traced to material, rather than design or processing.

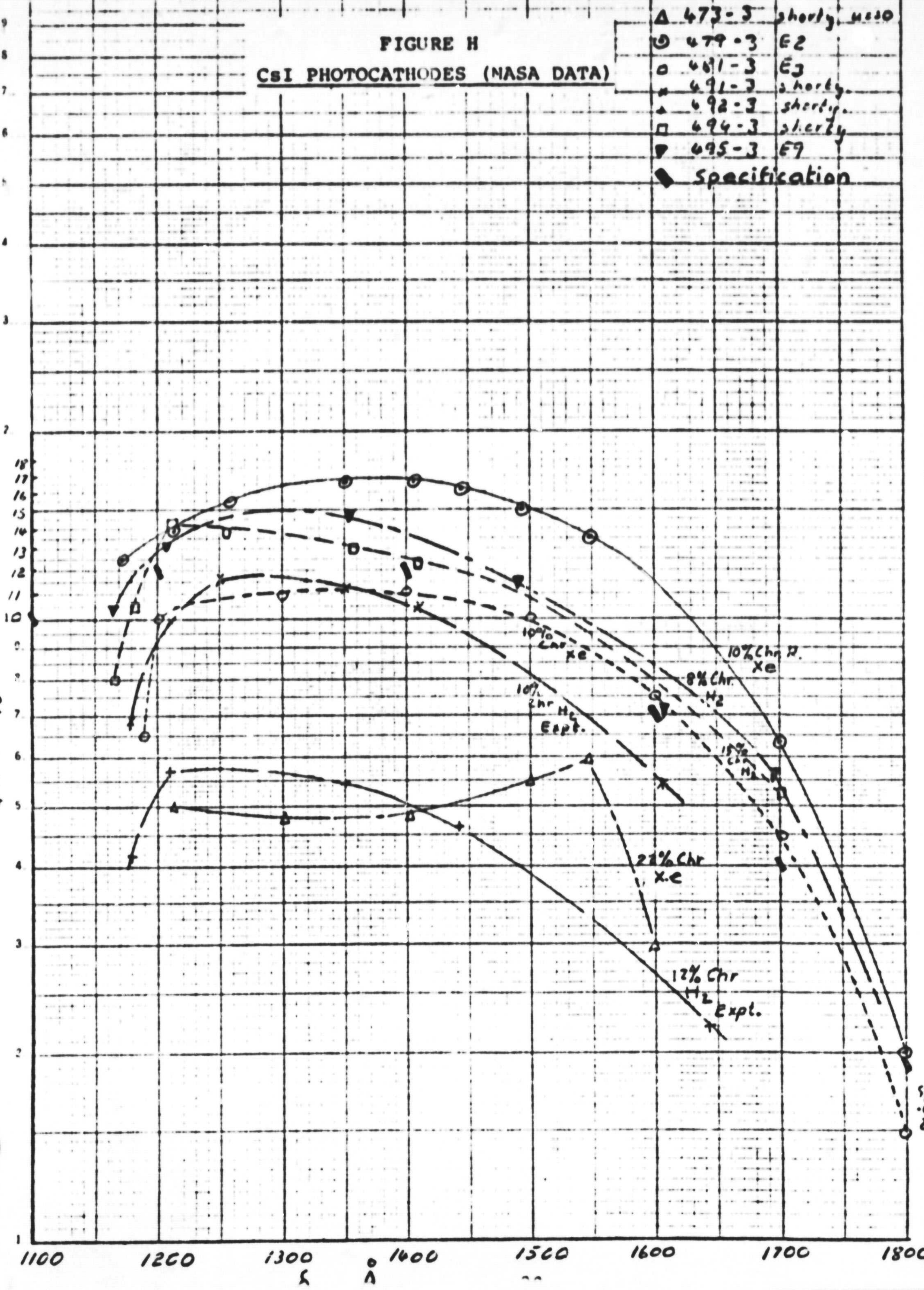
The quantum efficiency of all tubes, Figures H and I, showed that reasonable process control had been achieved. However, the curves showed that at less than 1216 Å the CsI cathodes were sharply below specification. This could have been due to measurement error (the NASA UV monochromator needed a major overhaul and readings below 1200 Å were suspect) or due to an absorbent or reflective surface layer with sharp cutoff characteristics. This still needs to be evaluated and tests on UV transmission of the faceplate metal undercoating will characterize the degree of cutoff.

In the case of CsI on LiF the biggest problem was thought to be cleanliness. The great affinity of LiF for water is seen as a fundamental problem. This was approached with the concept of using an abrasive cleaning operation with an anhydrous vehicle followed by a high temperature vacuum bake. It is believed that this approach worked well since the QE at 1216 Å (a main guide-point) was acceptable. There is a question, however, of the probability of some water molecules firmly bound in the surface which affects the growth of the CsI photocathode surface. Other cleanliness aspects have to do with purity of materials and general parts cleanliness.

In the case of CsTe on MgF_2, lower average values than expected are shown. Part of the reason was that experimentation was still in progress and schedule and parts constraints decreed that even if the cathode was low the tube had to be completed.

FIGURE H

CsI PHOTOCATHODES (NASA DATA)



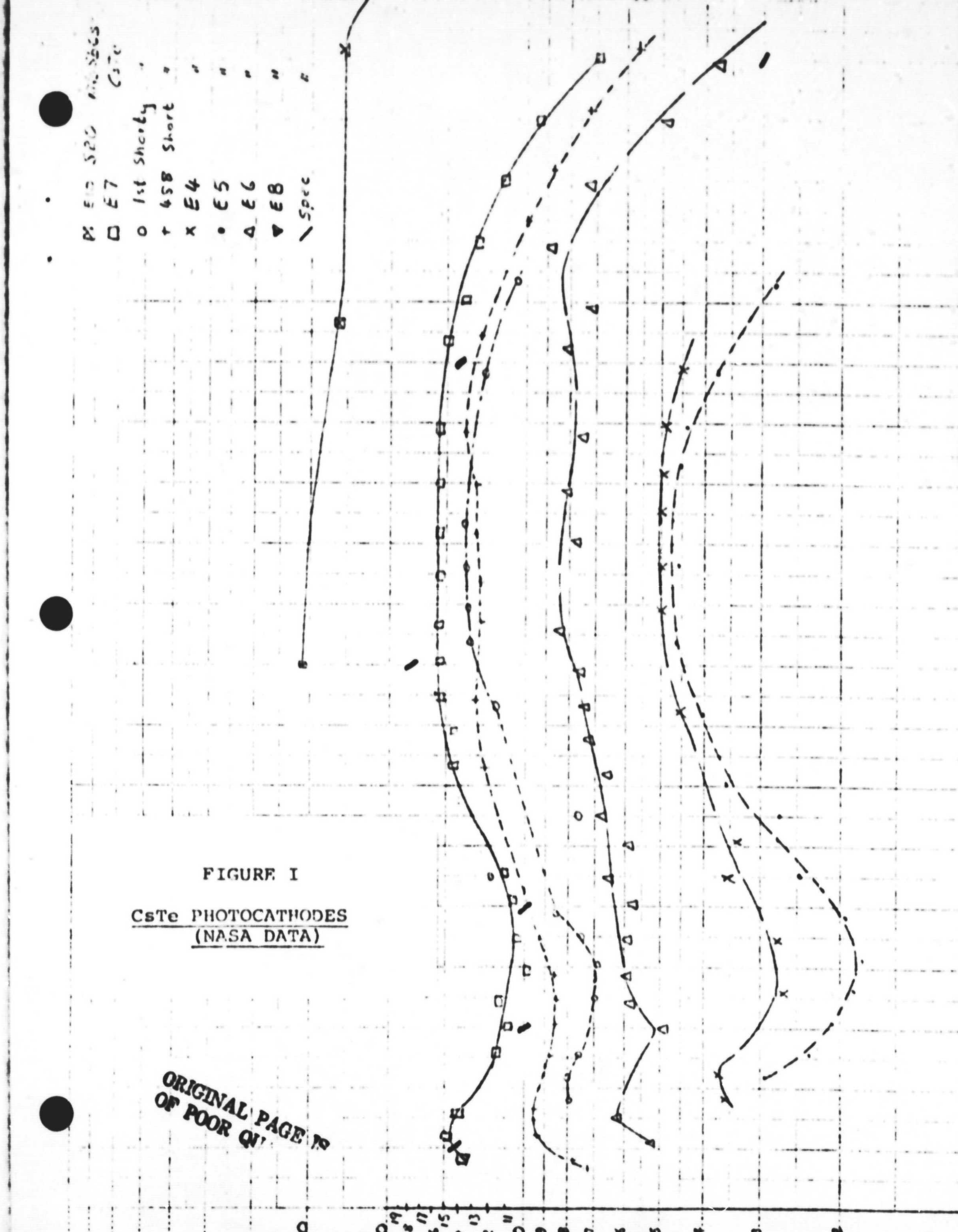


FIGURE I

CsTe PHOTOCATHODES
(NASA DATA)

No opportunity to place two faceplates in the processing chamber occurred. Nevertheless one tube, E7, showed a satisfactory value of 15.5% QE at 1950 Å. The classic difficulty with CsTe photocathodes is that in order to ensure a high degree of solar blindness it is necessary to under-process, that is, to limit the amount of free cesium deposited on the surface during processing. This has the general result of decreasing the peak quantum efficiency by a small amount, but it also decreases the visible light response by orders of magnitude. Thus, additional experimentation was required in order to achieve the desired result of high maximum QE in the UV and low minimum QE in the visible. EVC feels, however, that the process is well understood and that tube E7 is an indication that the technology is well advanced.

Remaining Problem Areas

With the exception of the anti-corona coating the remaining problems appear to be solvable. The following list covers the pertinent items.

(1) Anti-Corona Coating

The problem is that conductive coatings of virtually any kind severely attenuate VUV radiation. The problem becomes acute below 1400 Å. After extensive work (although budget limited), it appears that no simple solution is at hand. Some success was achieved and measurements did show that less than 20% loss in transmission is possible, but the resultant layers are too thin and fragile for the flight tube application. A "real world" difficulty is that when handled there is a high probability that the Digicon tube would be in an environment where the face becomes coated with dust or "oily" contaminants. Normally photodetector tubes are cleaned prior to installation and testing with optical quality materials. Thus, it can be expected that this would occur and thus destroy the anti-corona layer.

In the case of Digicons used in the visible spectrum, rugged anti-corona coatings are used and cleaning is not a problem. This is not available at present for the VUV.

It would appear, therefore, that other means of discharging the outside face of the tube will need to be applied. EVC has had experience with grid networks on MgF_2 and these worked well. However, on LiF it may be more difficult to generate a grid since photoetching techniques (water-based solvents) are required which would probably damage the surface. In both cases there would have to be an optical analysis made of the acceptable dimensions of this grid that would not produce optical errors.

(2) The Ceramic Inside Wall Coating

The results of the E-O Analysis study pointed out the need for uniformity of wall coating of less than 30%. That is, a 30% variation in the first ceramic would result in a degree of image distortion that could be detectable. The emphasis is thus on this first ceramic (where the photoelectrons have low velocity and are thus more subject to refraction) and the initial results as mentioned earlier were not encouraging. Nevertheless some tests showed that good uniformity is possible and that the method of application was probably the only factor.

Therefore, the action taken on the follow-on BASD HRS program has been to design, fabricate and test a machine that allows the application method to be tightly controlled. It is expected that since the wall coatings produced by hand-operated spraying were of high quality but somewhat non-uniform that we can expect a very high degree of uniformity with this machine. A cautionary note is that the coating thickness has a major effect on the conductivity. It was observed that the difference between two and three sprayed layers was orders of magnitude. Thus, the importance of mixture emission from the gun, adhesion to the surface and homogeneity all play a part.

(3) Header Capacitance

The EVC discovery that the base ceramic material normally used in header manufacture was causing pre-amplifier noise was of major significance to the whole Space Telescope program. In addition to this noise contribution, it was found that the inherent capacitance was higher than that of another ceramic material. The difference between these materials was the inclusion of a metallic substance in the first which produced a desirable black color. Desirable, that is, for a number of other users but obviously deleterious to low noise charge preamplifiers. The changeover to the inclusion-free (white) ceramic was thus imperative since both the capacitance and noise effects were unacceptable. No technical problems in this changeover are expected, although cost increases are expected.

The other problem area in the headers has been interlead shorting and this will be solved by both re-design and through the use of different methods of applying the tungsten traces.

(4) Photocathode

The program demonstrated that acceptable photocathodes could be produced over most of the required spectral range. The range below 1216 Å on CsI is of concern because the readings did show a drop off, but it is felt that measurement difficulties in this region make the data suspect. The prime area of concern is thus to first develop a method of measuring in this region and re-evaluating the tubes made to date. The monochromator used at NASA did not produce a signal large enough to ensure accuracy and EVC has taken an approach that is expected to improve this aspect.

The sensitivity of the CsI photocathode in the region 1050 Å to 1216 Å has been characterized by Space Telescope scientists to be of prime importance. EVC has started to concentrate its efforts in this region by a number of process changes. If the measurements shown in the curves, Figures H and I, are correct then further effort to improve quantum efficiency will be required.

It is known that unusual effects start to occur below 1200 Å when thin films are applied. Transmission, absorption reflection and refraction effects are considerable and the interrelationships are complex. It will be necessary to carry out a literature search in this field and then to experiment with various thicknesses to optimize the processes. The area of surface cleanliness will need to be investigated particularly with respect to the absorbtion of water molecules on the LiF surface. Although the test data on the faceplates do not show obvious effects of surface polish quality, it is assumed that less problems with smooth surfaces will be encountered. In particular smooth surfaces should enhance the CsI crystal properties and enable the metallic deposition to be regular and smooth. Efforts to produce high quality polished surfaces will need to be made irrespective of the optical (scratch/dig) requirements of the system.

EVC is convinced that higher QE's than that demonstrated to date can be obtained. The CsI deposition technique and process chamber quality contribute to the crystal purity and possibly to the structural uniformity.

In the case of CsTe, work will be required to improve the solar blind aspect while improving the peak QE. EVC considers this task to involve a number of test runs to enable operating personnel to develop experience with the variable process parameters. This experience will result in a higher degree of precision and should raise the maximum QE to the desired level of 18%. The undercoating work carried out on the CsI cathodes will also apply here.

ADDENDUM - FOS 512 DIGICON

UCSD requested EVC to build a 512 Digicon to conform as close as possible to the Faint Object Spectrograph requirements. The only significant difference was that since the FOS diode arrays were not available the HRS type were used. However, there are no differences between the operating parameters of these diodes and those for the FOS Digicons.

The basic difference between HRS and FOS Digicons is in the faceplate/photocathode area. The FOS tube EVC was requested to build was the S20 on SiO_2 (quartz) type. This entailed producing a sensitive S20 photoemitter on quartz and sealing the faceplate to the tube body. The EVC-developed indium seal enabled a transition from the MgF_2/LiF/glass-to-tube-body seal to a quartz-to-tube-body seal to be easily accomplished. Thus the only significant task required was to produce a sensitive S20.

EVC work on S20 photocathodes and personnel experience enabled a specific direction to be taken. There was a clear understanding that sensitivity in the ultraviolet was desirable. There was also a desire to obtain response ("red" response) beyond 700 nm. However, the FOS photocathode specification does not call for a "red" response cathode as far as the standard image tube nomenclature is concerned, but rather a high quality S20 (KNaCsSb) type. Furthermore, the concern for low background count predicated the need for a low thermal noise photoemitter. This was accomplished twice, first in a sealed-off shorty tube and secondly in the FOS 512 Digicon. In both cases the processes were carried out to a point where red response was starting to show signs of increasing. At this point processing was terminated. EVC feels that excellent control in this area has thus been demonstrated, and the background count rate of less than .01 cs^{-1} on the FOS tube is a major achievement. This translates to a thermal emission rate of approximately 10^{-17} amps cm^{-2}. S20 thermal emission levels are typically rated at 10^{-15} to 10^{-16} amp cm^{-2}. A peak QE of 31% at 2000 Å was measured at NASA.

Tests on the diode array showed, as expected, no deleterious changes in performance.

The tube will need more detailed testing in order to both determine that all performance parameters, e.g., all 512 diodes, are acceptable and to obtain some initial life test data. It is expected, however, that based on previous EVC experience that excellent performance for many years can be expected.

ADDITIONAL TASK - EXTERNAL RESISTOR STRING

The E-O analysis showed that the external resistors were required to be within 1% in order to establish a field that would cause minimum image distortion. EVC carried out two tasks. The first was to determine the effect of voltage on the resistance value. The second was to test all the resistors at the expected applied voltage and separate them into groups of specific values. Thus an available supply of precision resistors, within .1%, could be drawn on. The voltage value chosen was 400V per resistor. Figure J shows the effect of applied voltage on a specific resistor. Other resistors tested showed the same basic curves and should behave linearly with voltage.

The resistor string would thus be made up of resistors within 0.1% of each other over the length of the tube. Naturally, as with the wall coating, the first electrode resistors nearest the photocathode are the most important.

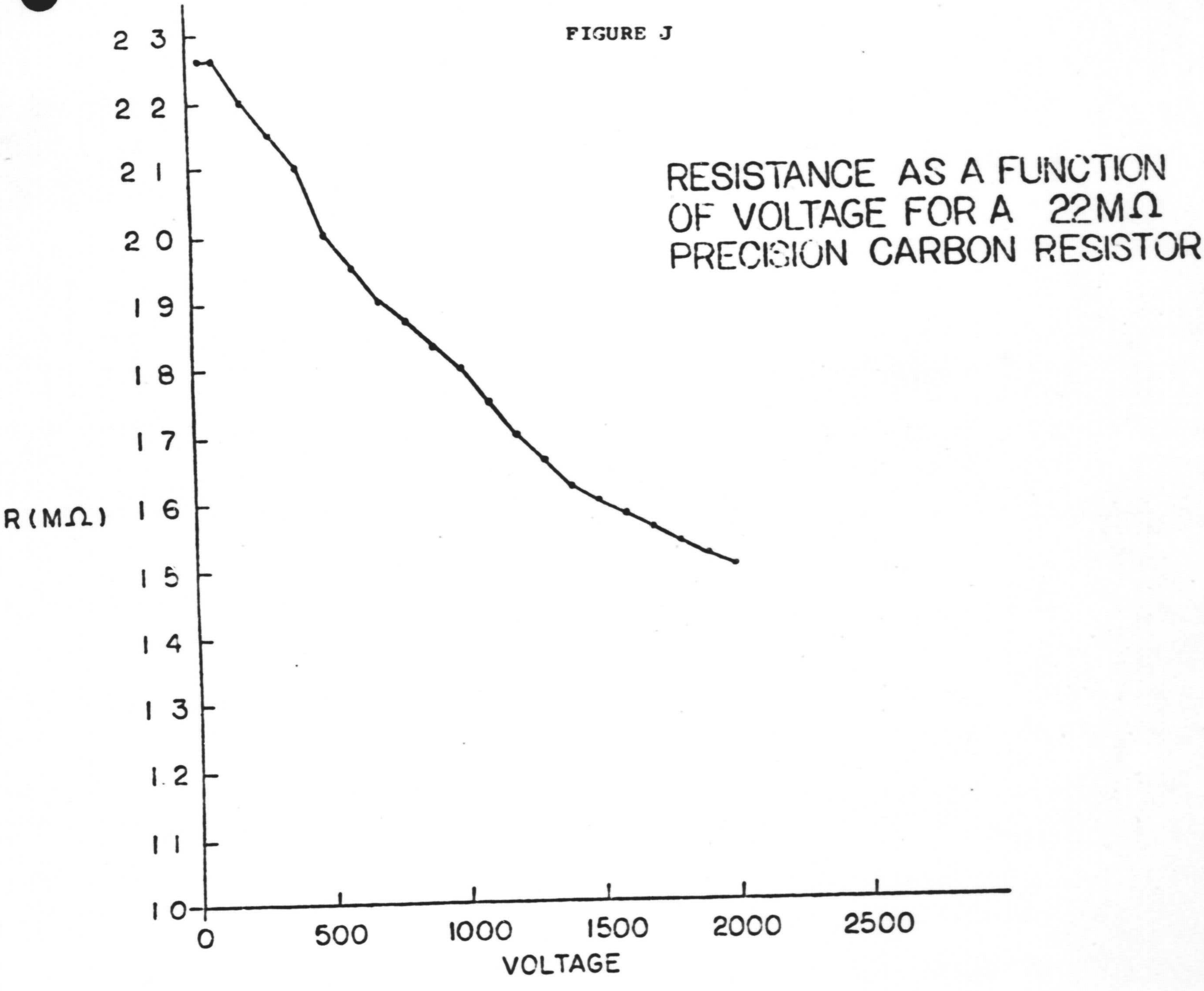
Attachment of the resistor string was carried out at EVC using epoxy at the sensitive photocathode area and solder at the other electrodes. EVC has encapsulated tubes to the configuration shown in Figure K. Tube E3 on this program was encapsulated in this manner and the results appeared to be satisfactory.

CONCLUSION

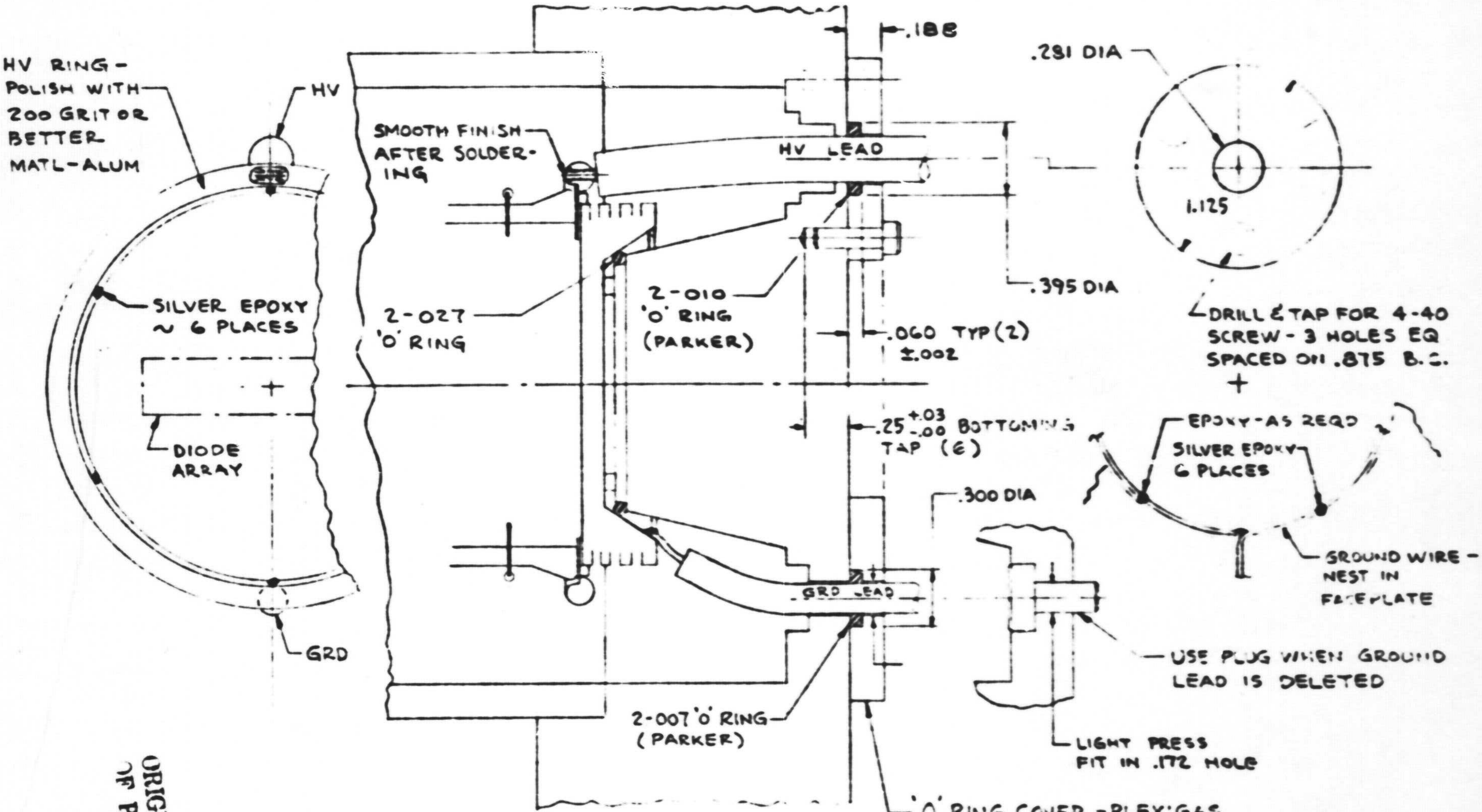
The objectives of this project were met. The initial set-up tube runs pin-pointed areas of concern and prototypical tubes demonstrated the capability of bridging the technology gap to the Space Telescope application. Two areas of concern that remain are solvable with known technology. These include header capacitance and faceplate cleanliness and polish quality. Areas of secondary importance are maximizing photocathode sensitivity, wall coating uniformity and header/diode array quality.

The areas of major concern are background count and anti-corona coating. The A-C coating could be eliminated through the use of ion-traps in the Digicon system but this is a system

FIGURE J



RESISTANCE AS A FUNCTION OF VOLTAGE FOR A 22MΩ PRECISION CARBON RESISTOR



DIGICON TUBE - POTTING MOLD - 2 x SIZE

FIGURE K

problem. To date the only practical tube solution appears to be some form of surface electrode on the faceplate that could be grounded.

The background count problem can be solved by working on the principal causes of field emission, building evaluation tubes and carrying out a thorough testing program.

The manufacture of the FOS Digicon demonstrated that a changeover to this tube type can be accomplished with minimal setup costs. No new technical problems are expected.

The program was thus successfully concluded as shown in Figure L, and as planned, flowed into the BASD Space Telescope HRS program with minimal programmatic changes.

FIGURE L

HRS/FOS DIGICON DEVELOPMENT PROGRAM SUMMARY

Tube	Faceplate	Photo Cathode	Array Type & No.	No. of Active Diodes	A/C Coating Date	Potting	Comments
Shorty 476-3	MgF_2	CsTe	None	--	--	--	Seal OK. Cathode process with Hg lamp, response at 1216 Å low.
Shorty 473-3	LiF	CsI	None	--	--	--	Seal OK. Heavy chrome—low response.
E1	MgF_2	CsTe	Old, #8	100+	Cracked Window	None	Seal OK. Cathode process standard.
E2	LiF	CsI	Old, #5	100+	WPd, 1-22-79	--	Seal OK. Best CsI Photocathode.
E3	LiF	CsI	Old, #3	100+	WPd, 11-25-78	BASD Urethane	Seal OK. Expt Cathode.
E4	MgF_2	CsTe	Old, #9	100+	WPd, 11-25-78	BASD Urethane	Seal OK. Expt Cathode.
E5	MgF_2	CsTe	Old, #10	100+	--	--	Seal OK but tube broken at customer.
E6	MgF_2	CsTe	Old, #11	100+	WPd, 1-16-79	--	Seal OK. Heavy chrome, below normal response.
E7	MgF_2	CsTe	Old, #12	100+	WPd, 1-18-79	BASD	Seal OK. Process standard. High response at 1216 Å.
E8	MgF_2	CsTe	New, #2	512(-)	--	BASD	Seal OK. Poor cathode, sealed due to schedule requirements.
E9	LiF	CsI	New, #6	512(-)	--	BASD	Seal OK. Cathode process standard. Good QE.

FIGURE L (CONTINUED)

HRS/FOS DIGICON DEVELOPMENT PROGRAM SUMMARY

Tube	Faceplate	Photo Cathode	Array Type & No.	No. of Active Diodes	A/C Coating Date	Potting	Comments
E10	SiO_2	KNaSbCs	New, #4	512(-)	--	--	Seal OK. Excellent QE at 2000 Å of 30%.
E11	SiO_2	KNaSbCs		Not complete as of report date			

FIGURE M

UCSD TUBE STATUS

S/N	Window	Potting	Diode Array	2/16/79 Location	Anti-Corona	Q.E. Peak	Application
E2	L		Old 20+	GSFC	X	16%	EVC—Background test.
E3	L	X Silicone	Old 20+	GSFC	X	11%	GSFC—General purpose testing.
E4	M	X	Old 20+	BASD	?	6%	EVC—Life test, then BASD—Temp. Cycle after noise characterization
E5	M/L			EVC		4%	EVC—Repair w. LiF window
E6	M	X	Old 20+	BASD	X	5%	GSFC—Radiation testing
E7	M		Old 100+	GSFC	X	15%	EVC—Noise investigation, then BASD—Potting
E8	M		New All	GSFC		11%	EVC—Noise invest. For a short time, then BASD—Potting
E9	L		New All	GSFC		15%	EVC—Noise invest. For a short time, then BASD—Potting
E1	M		Old 20+	UCSD		NM	EVC—For background test.
FOS	SiO_2 S20		New All	GSFC		30%	EVC—For background test, then UCSD, then GSFC
VIS	SiO_2 BiAlk	X Silicone	Old 20+	BASD		~20%	BASD—Set up work
SDC	LiF		Test 200				EVC—Life testing, array evalu tion
E10	SiO_2						UCSD—then GSFC

APPENDIX

Table 1

General Specifications

of the

Model of the Digicon Tube

Operating Volume: 15 cm long
1.75 cm radius

Magnetic Field: Axial B_z = 112.10 Gauss
Deflection B_x = 5.7785 Gauss
B_y = 1.8455 Gauss

Numerical Trajectory Integration:

.2 cm maximum displacement in one time step

.1μm maximum error per time step

.05 cm sample distance to get derivative of potential

1μm maximum distance from image plane for termination

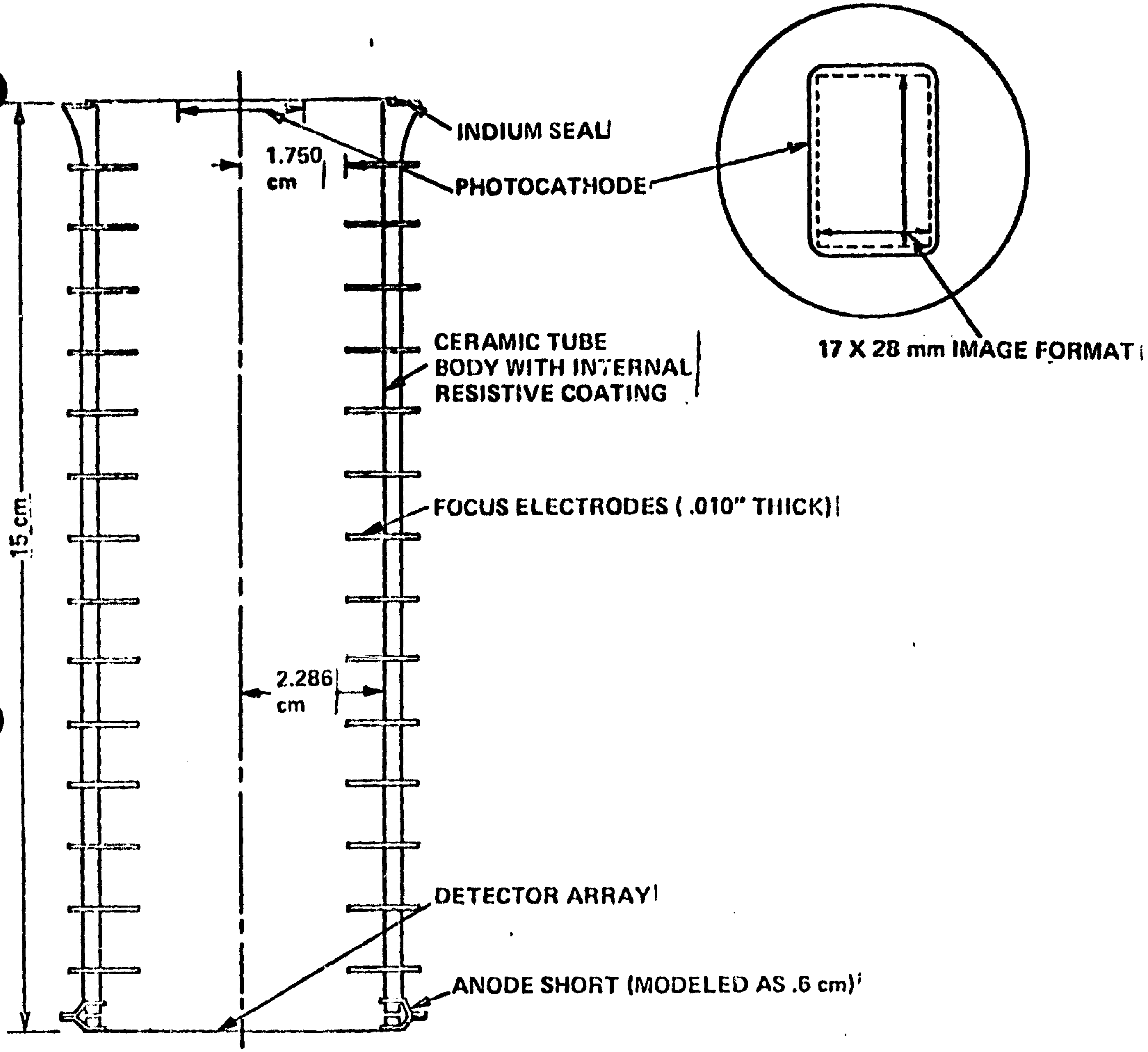


FIGURE 1. BASELINE DIGICON DESIGN MODELED IN THIS REPORT.

There are six different configurations considered here. They investigate the following:

- Distortion caused by the 10 mil indium seal
- Distortion caused by the shorted anode region (modeled as .6 cm, somewhat larger than in baseline design)
- Distortion caused by the finite thickness of the first two guard rings (the thickness of the others being judged unimportant)
- Distortion due to the first ring being at a potential 1% higher than the intended design
- Distortion due to the wall coating being 30% higher resistance at the first and last thirds (approximately) of the first centimeter than in the middle third
- Distortion due to a combination of the first three effects above

The last is a good representation of the baseline tube design.

Electron trajectories were calculated using the TRAJEC code for electrons with zero initial velocity. The results are presented in Tables 2 through 7 and Figures 2 through 8. The Tables give the problem specification by defining the potential at the inner tube radius along the entire boundary, (linear interpolation being used between the specified points) and they give the electron source and image transverse coordinates. Limitations in the accuracy of the potential due to finite zoning of the geometry indicate an accuracy of about $\pm$ 5μm absolute for the image position. (This is an estimate obtained by the most extreme changes in the coordinate as a function of arbitrary parameters in the trajectory integration. In this case, it is due mainly to an inaccuracy in the calculation of the derivative of the potential). The relative error, from one case to the next is much less than this. The figures show the error vectors: vectors pointing from the ideal image position to the true image position, magnified by various scale factors to enable each distortion to be viewable on the scale of the image plane.

The conclusion reached by observing the results is that the distortions in all the configurations are small. Notice in particular Figure 8 where two of the three distorting features included in the baseline design model are juxtaposed on the same scale (the third feature being negligibly small in comparison

The fortunate opposition of these two aberrations certainly contributes to the relatively small distortion of the final line image for the full baseline model.

The quantitative impact of the distortion on tube performance was not evaluated here.

Table 2a

Potential Specification at a Radius of 2.286 cm

for

Modeling 10 mil Indium Seal

Axial Position (cm)	Potential (Statvolts)
-1×10^{-7}	1×10^{-6}
.0255	1×10^{-6}
1.000001	5.555555
15.00001	83.3333333

Guard rings modeled as zero thickness.

Table 2b

Source and Image Positions

for

Model of Digicon with 10 mil Indium Seal

Source X	Source Y	Image X	Image Y
-0.8500	-1.4000	-0.0024	-1.4019
-0.8500	-1.2000	-0.0017	-1.2011
-0.8500	-1.0000	-0.0013	-1.0007
-0.8500	-0.8000	-0.0009	-0.8004
-0.8500	-0.6000	-0.0008	-0.6002
-0.8500	-0.4000	-0.0007	-0.4000
-0.8500	-0.2000	-0.0005	-0.1999
-0.8500	0.0000	-0.0005	0.0002
-0.8500	0.2000	-0.0004	0.2003
-0.8500	0.4000	-0.0004	0.4005
-0.8500	0.6000	0.0004	0.6007
-0.8500	0.8000	0.0004	0.8009
-0.8500	1.0000	-0.0004	1.0012
-0.8500	1.2000	-0.0004	1.2019
-0.8500	1.4000	-0.0005	1.4029

DISTORTION OF A LINE SOURCE OF ELECTRONS

AT THE IMAGE PLANE OF A DIGICON TUBE

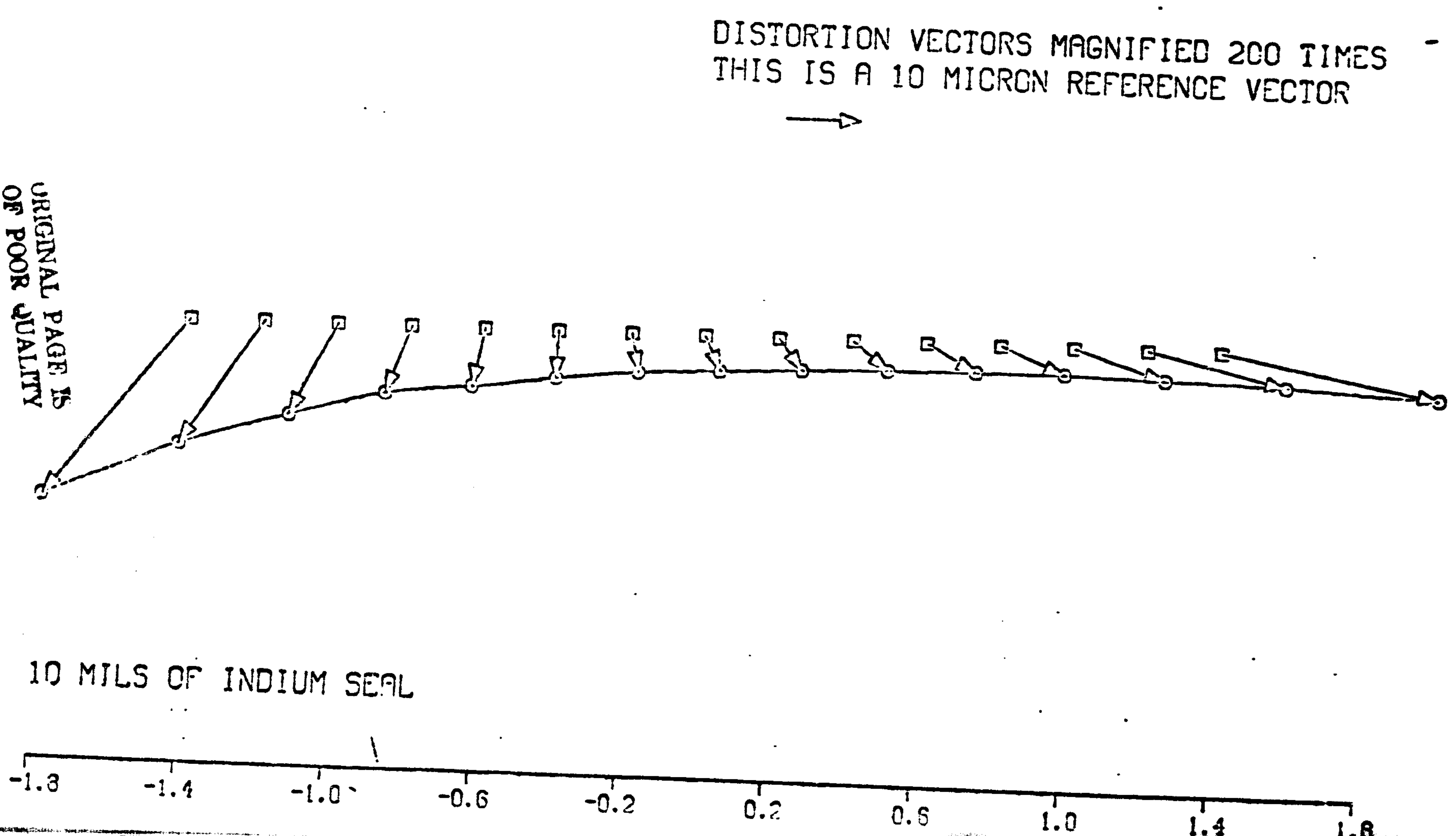


Table 3a

Potential Specification at a Radius of 2.286 cm

for

Modeling a .6 cm Short at Anode Region

Axial Position (cm)	Potential (Statvolts)
-1×10^{-7}	1×10^{7}
14.00001	77.777777
14.399999	83.3333333
15.00001	83.3333333

Guard rings modeled as zero thickness.

Table 3b

Source and Image Positions for Model

of

Digicon with .6 cm Short at Anode Region

Source		Image	
X	Y	X	Y
-0.8500	-1.4000	-0.0002	-1.3999
-0.8500	-1.2000	-0.0002	-1.1999
-0.8500	-1.0000	-0.0001	-1.0000
-0.8500	-0.8000	-0.0001	-0.8000
-0.8500	-0.6000	-0.0001	-0.6000
-0.8500	-0.4000	-0.0001	-0.4000
-0.8500	-0.2000	0.0000	-0.2000
-0.8500	0.0000	0.0000	0.0000
-0.8500	0.2000	0.0000	0.2000
-0.8500	0.4000	0.0001	0.4000
-0.8500	0.6000	0.0001	0.6000
-0.8500	0.8000	0.0001	0.8000
-0.8500	1.0000	0.0001	1.0000
-0.8500	1.2000	0.0002	1.1999
-0.8500	1.4000	0.0002	1.3999

DISTORTION OF A LINE SOURCE OF ELECTRONS

AT THE IMAGE PLANE OF A DIGICON TUBE

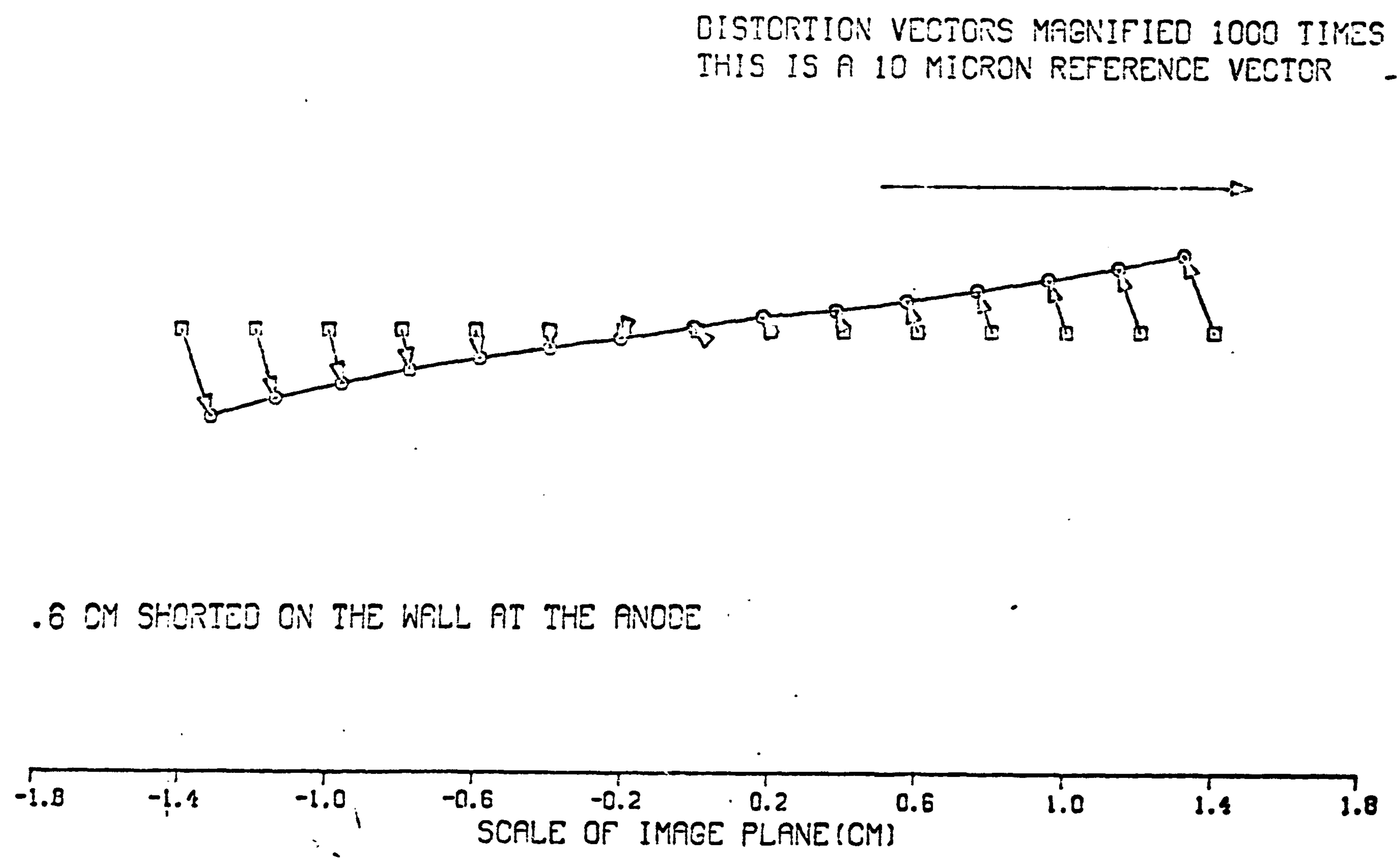


Table 4a

Potential Specification at a Radius of 2.286 cm

for

Modeling the First Two Guard Rings as 10 mils Thick

Axial Position (cm)	Potential (Statvolts)
-1×10^{-7}	1×10^{-6}
.986	5.555555
1.014	5.555555
1.986	11.1111111
2.014	11.1111111
3.	16.666666
15.00001	83.333333

Guard rings, except, first two, are modeled as zero thickness

Table 4b

Source and Image Positions for Model

of

Digicon with First Two Guard Rings 10 mil Thick

Source		Image	
X	Y	X	Y
-0.8500	-1.4000	0.0021	-1.3980
-0.8500	-1.2000	0.0017	-1.1987
-0.8500	-1.0000	0.0013	-0.9992
-0.8500	-0.8000	0.0009	-0.7995
-0.8500	-0.6000	0.0008	-0.5997
-0.8500	-0.4000	0.0007	-0.3999
-0.8500	-0.2000	0.0006	-0.2000
-0.8500	0.0000	0.0005	-0.0002
-0.8500	0.2000	0.0005	-0.1997
-0.8500	0.4000	0.0005	-0.3995
-0.8500	0.6000	0.0005	-0.5993
-0.8500	0.8000	0.0005	-0.7990
-0.8500	1.0000	0.0006	-0.9986
-0.8500	1.2000	0.0006	1.1979
-0.8500	1.4000	0.0007	1.3970

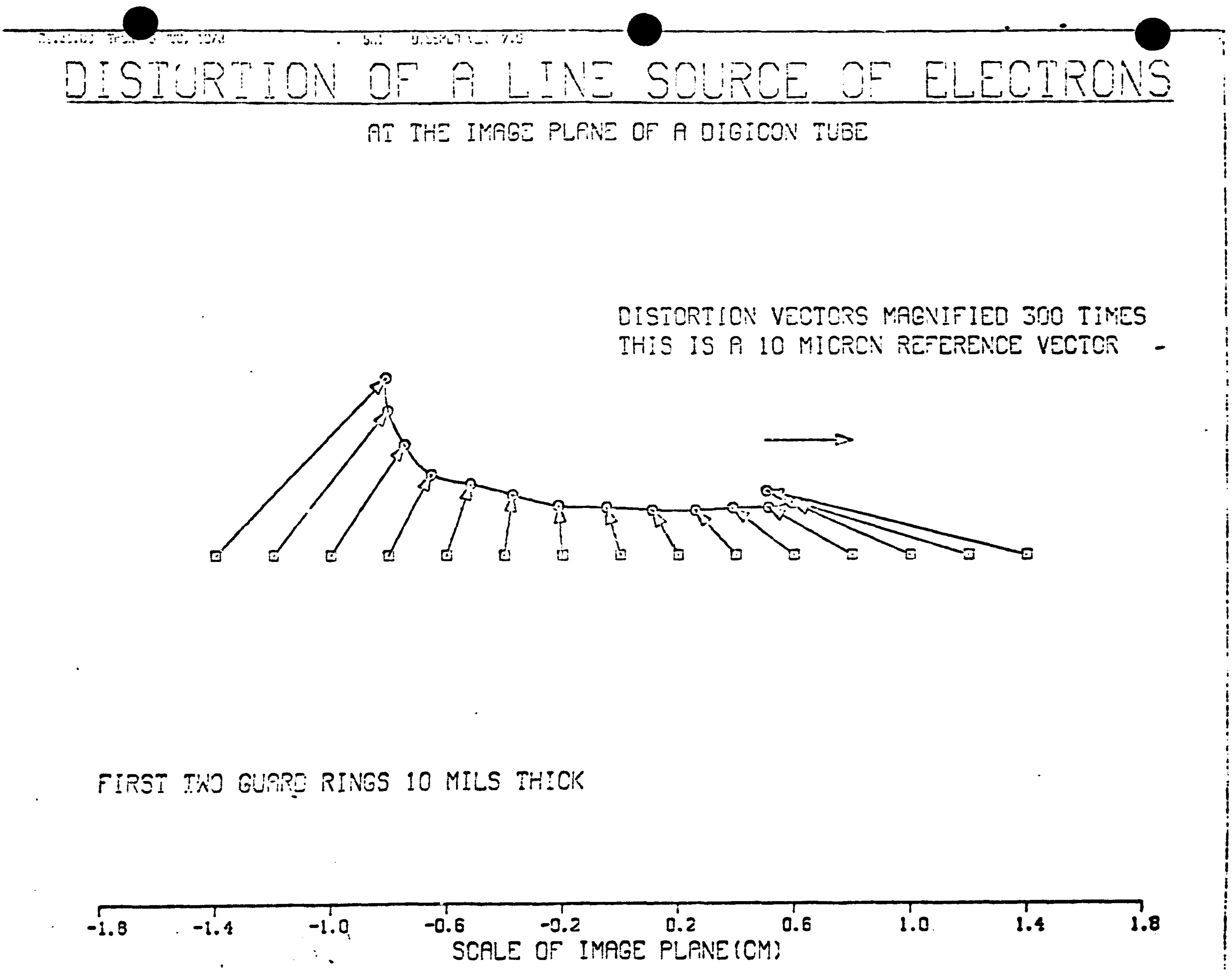

DISTORTION OF A LINE SOURCE OF ELECTRONS
AT THE IMAGE PLANE OF A DIGICON TUBE
DISTORTION VECTORS MAGNIFIED 300 TIMES
THIS IS A 10 MICRON REFERENCE VECTOR
FIRST TWO GUARD RINGS 10 MILS THICK
-1.8
-1.4
-1.0
-0.6
-0.2
0.2
0.6
1.0
1.4
1.8
SCALE OF IMAGE PLANE(CM)

Table 5a

Potential Specification at a Radius of 2.286 cm
for
Modeling the First Guard Ring at 1% too High a Potential

Axial Position (cm)	Potential (Statvolts)
-1×10^{-7}	1×10^{-6}
1.	5.611111
2.	11.11111
15.00001	83.333333

Guard rings modeled as zero thickness.

Table 5b

Source and Image Positions for Model of Digicon
with
First Guard Ring at 1% too High a Potential

Source X	Source Y	Image X	Image Y
-0.8500	-1.4000	0.0043	-1.3978
-0.8500	-1.2000	0.0037	-1.1985
-0.8500	-1.0000	0.0031	-0.9990
-0.8500	-0.8000	0.0026	-0.7995
-0.8500	-0.6000	0.0024	-0.5999
-0.8500	-0.4000	0.0020	-0.4002
-0.8500	-0.2000	0.0017	-0.2006
-0.8500	0.0000	0.0015	-0.0009
-0.8500	0.2000	0.0013	0.1987
-0.8500	0.4000	0.0010	0.3984
-0.8500	0.6000	0.0008	0.5980
-0.8500	0.8000	0.0007	0.7974
-0.8500	1.0000	0.0005	0.9970
-0.8500	1.2000	0.0002	1.1962
-0.8500	1.4000	-0.0001	1.3954

DISTORTION OF A LINE SOURCE OF ELECTRONS

AT THE IMAGE PLANE OF A DIGICON TUBE

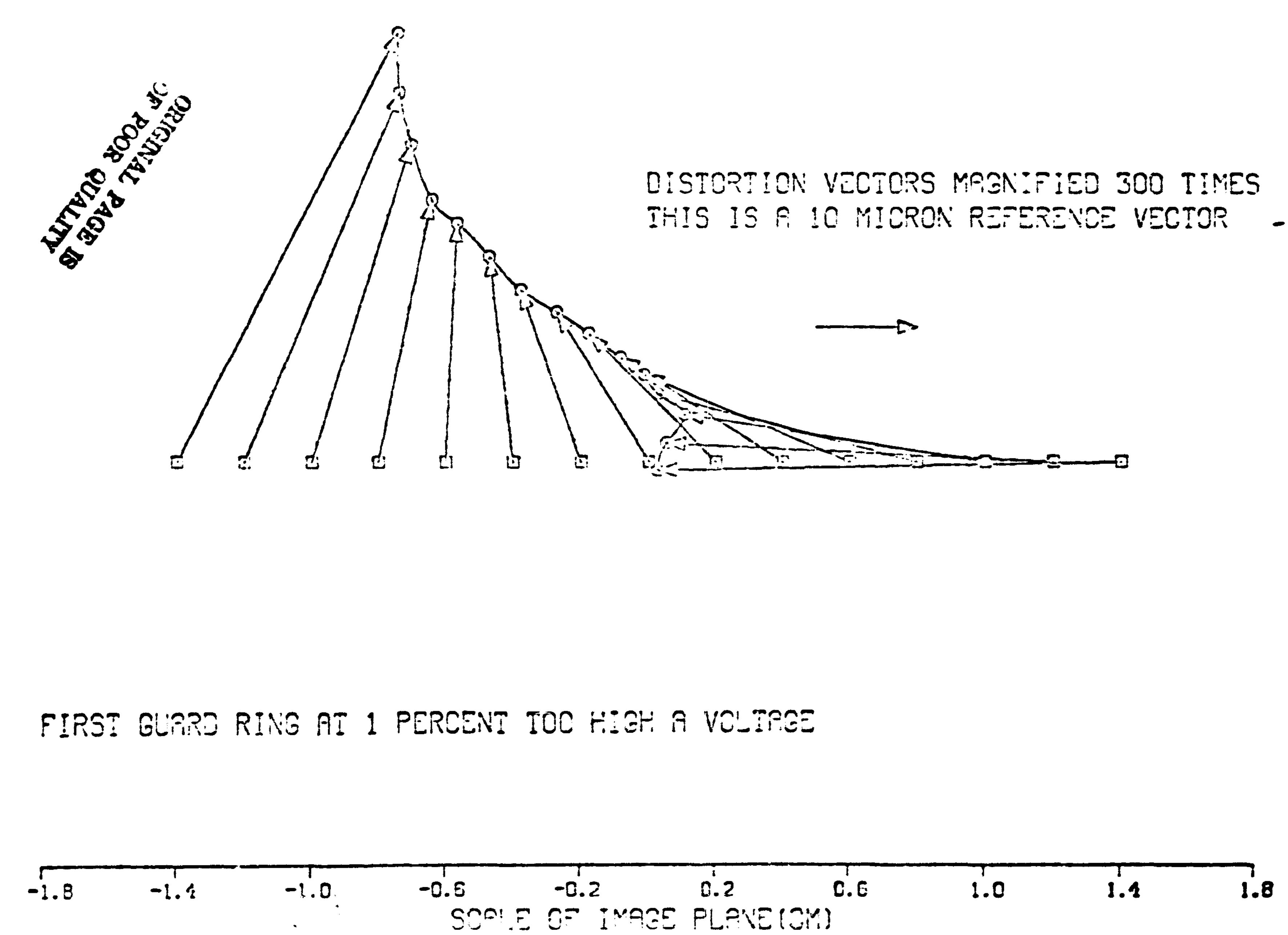


Table 6a

Potential Specification at a Radius of 2.286 cm for Modeling the Wall Coating as Being 30% High Resistance at First and Last Thirds of First Centimeter

Axial Position (cm)	Potential (Statvolts)
-1×10^{-7}	1×10^{-6}
.33333333	2.0061728
.666666667	3.5493827
1.	5.55555555
15.000001	83.3333333

Guard rings modeled as zero thickness.

Table 6b

Source and Image Positions for Model of Digicon with Wall Coating 30% High A Resistance at First and Last Thirds of First Centimeter

Source		Image	
X	Y	X	Y
-0.8500	-1.4000	0.0002	-1.3997
-0.8500	-1.2000	0.0000	-1.1999
-0.8500	-1.0000	-0.0000	-1.0000
-0.8500	-0.8000	-0.0000	-0.8000
-0.8500	-0.6000	-0.0000	-0.6000
-0.8500	-0.4000	-0.0000	-0.4000
-0.8500	-0.2000	-0.0000	-0.2000
-0.8500	0.0000	-0.0000	-0.0000
-0.8500	0.2000	-0.0000	0.2000
-0.8500	0.4000	-0.0000	0.4000
-0.8500	0.6000	-0.0000	0.6000
-0.8500	0.8000	0.0000	0.8000
-0.8500	1.0000	0.0000	1.0000
-0.8500	1.2000	0.0001	1.1999
-0.8500	1.4000	0.0001	1.3997

DISTORTION OF A LINE SOURCE OF ELECTRONS

AT THE IMAGE PLANE OF A DIGICON TUBE

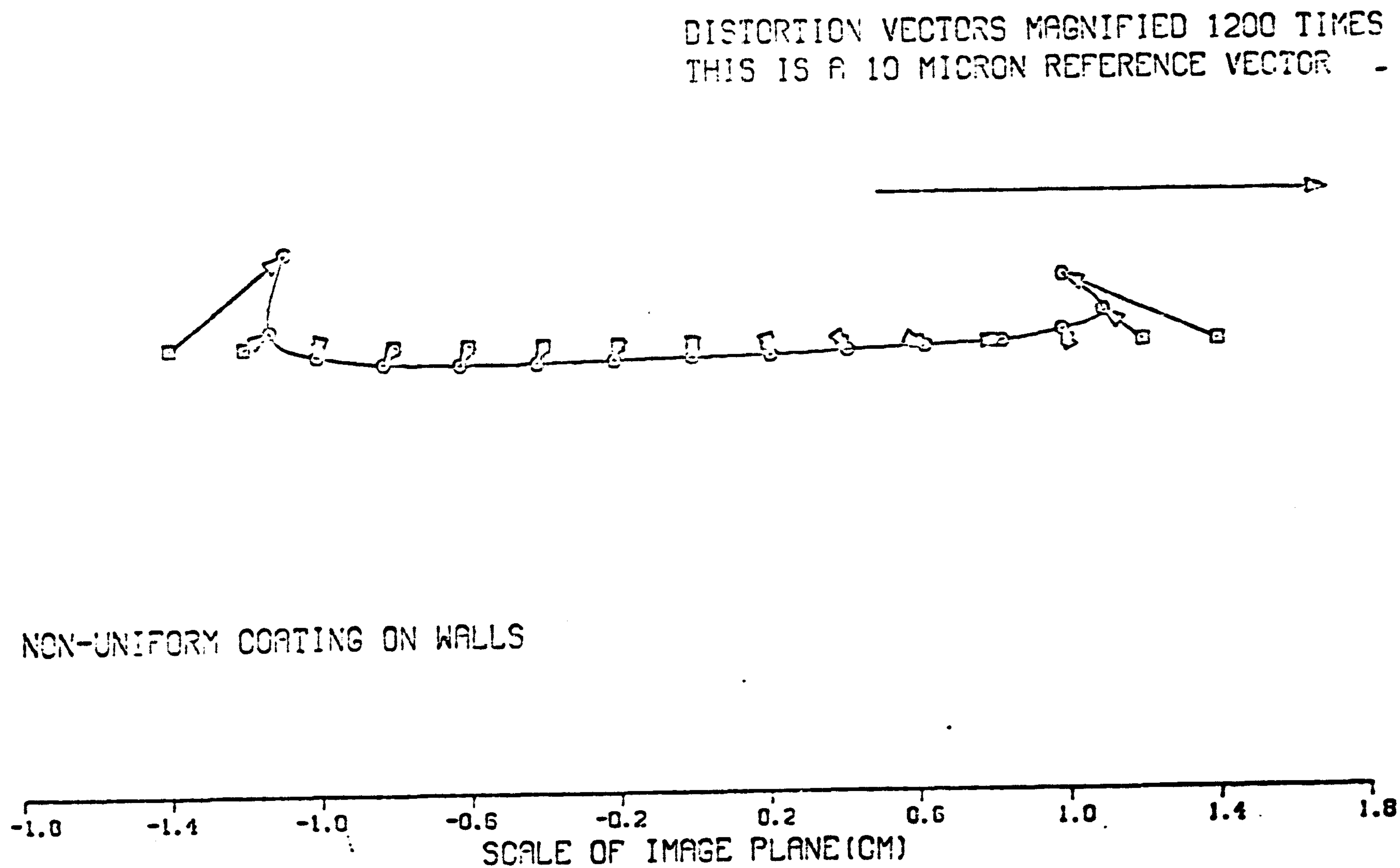


Table 7a

Potential Specification at a Radius of 2.286 cm for Modeling the Baseline Digicon Design (10 mil Indium Seal, First Two Guard Rings 10 mil Thick, .6 cm Short at Anode Region)

Axial Position (cm)	Potential (Statvolts)
-1×10^{-7}	1×10^{-6}
.0255	1×10^{-6}
.986	5.555555
1.014	5.555555
1.986	11.1111111
2.014	11.1111111
3.	16.666666
14.000001	77.777777
14.399999	83.333333
15.000001	83.3333333

First two guard rings modeled as 10 mil thick, remaining as zero thickness.

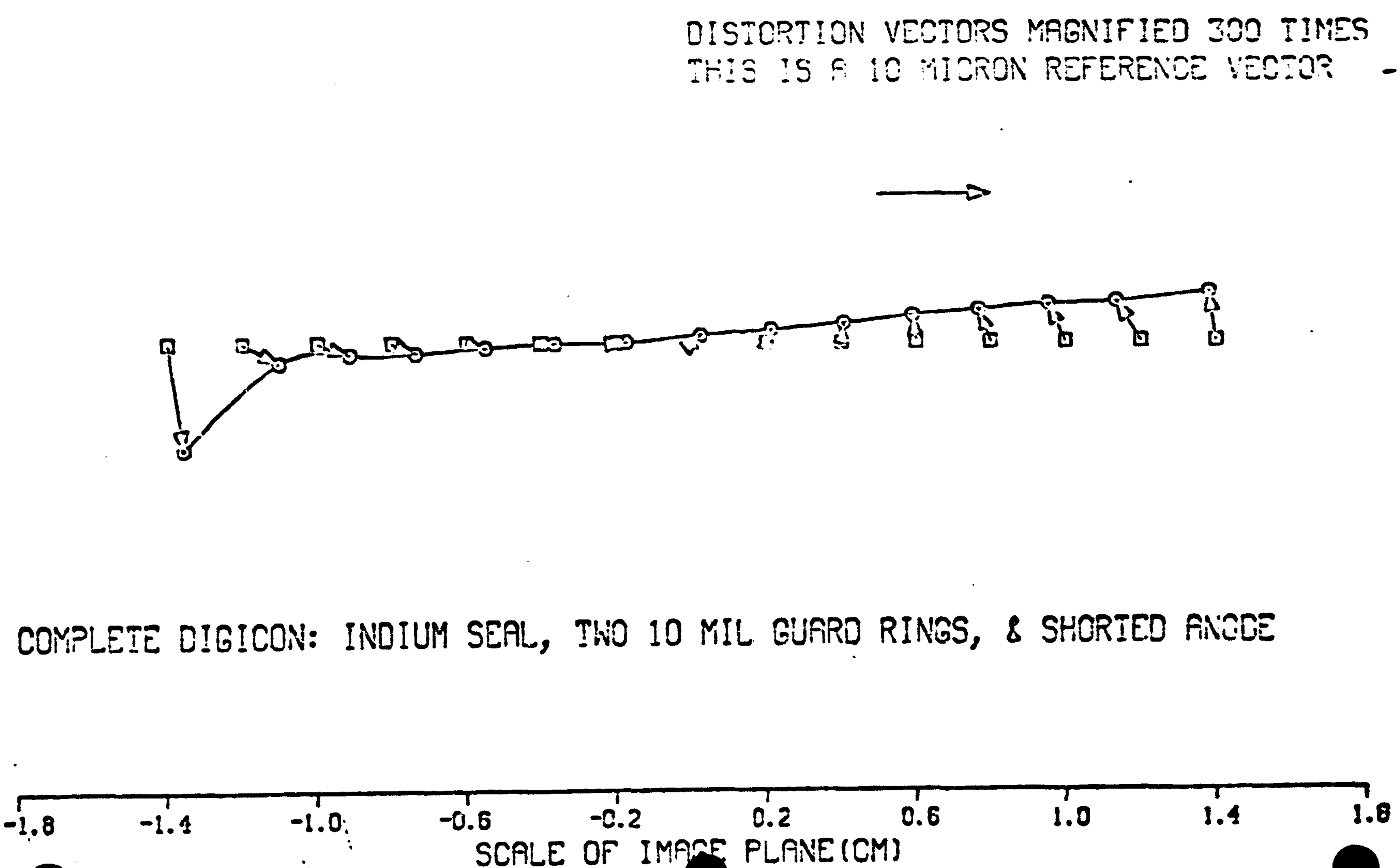
Table 7b

Source and Image Positions for Model of Baseline Digicon Design (10 mil Indium Seal, First Two Guard Rings 10 mil Thick, .6 cm Short at Anode Region)

Source		Image	
X	Y	X	Y
-0.8500	-1.4000	-0.0009	-1.3999
-0.8500	-1.2000	-0.0002	-1.1997
-0.8500	-1.0000	-0.0001	-0.9997
-0.8500	-0.8000	-0.0001	-0.7998
-0.8500	-0.6000	-0.0000	-0.5998
-0.8500	-0.4000	-0.0000	-0.3999
-0.8500	-0.2000	0.0000	0.1999
-0.8500	0.0000	0.0001	0.0001
-0.8500	0.2000	0.0001	0.2000
-0.8500	0.4000	0.0002	0.4000
-0.8500	0.6000	0.0002	0.6000
-0.8500	0.8000	0.0003	0.7999
-0.8500	1.0000	0.0003	0.9999
-0.8500	1.2000	0.0004	1.1998
-0.8500	1.4000	0.0004	1.3999

DISTORTION OF A LINE SOURCE OF ELECTRONS

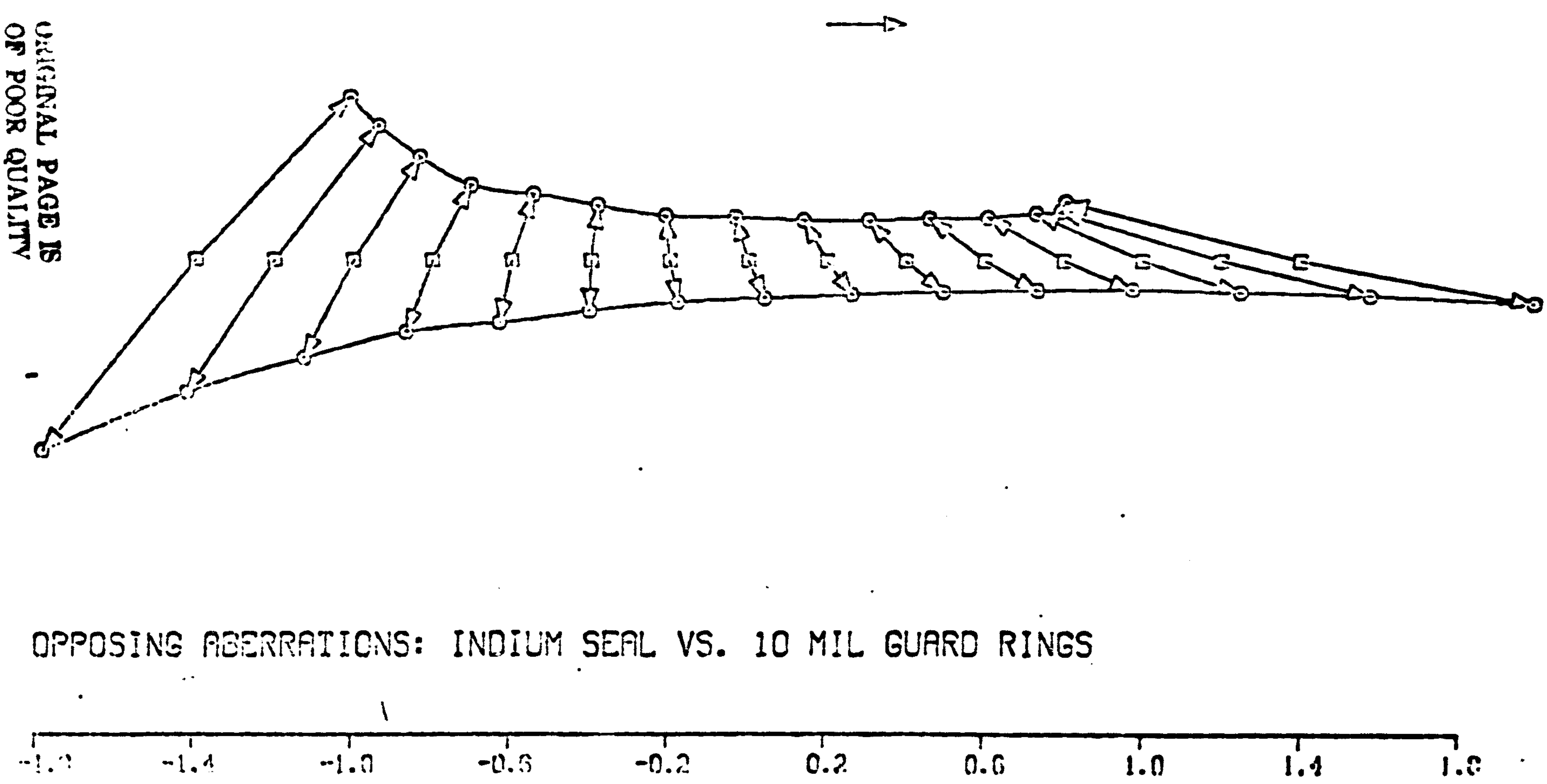
AT THE IMAGE PLANE OF A DIGICON TUBE



DISTORTION OF A LINE SOURCE OF ELECTRONS

AT THE IMAGE PLANE OF A DIGICON TUBE

DISTORTION VECTORS MAGNIFIED 200 TIMES-
THIS IS A 10 MICRON REFERENCE VECTOR



OPPOSING ABERRATIONS: INDIUM SEAL VS. 10 MIL GUARD RINGS

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OF POOR QUALITY

Appendix

Calculation of the Electric Potential

The potentials internal to the Digicon tube were calculated using a section of the ZAPADO code. The code was designed to handle rotationally symmetric objects with complex geometries and calculate the solution to Poisson's equation given specified potentials on the object and outside boundaries. The method used by the code is not sophisticated particularly when compared to the TRAJEC code used in the imaging calculations. The method was more than adequate, however, because the tube conforms to the cylindrical coordinate system used in the code. Furthermore, since the fields must be very close to uniform and axial to produce the desired effect, the fields and potentials also conform closely to the coordinate system. The conformation makes the method appropriate.

A description of the Chebyshev successive overrelaxation method is described by Potter (1973). The description given there is for equal spacing of the grid in cartesian coordinates, but the generalizations are fairly obvious (see the TRAJEC report). The method is iterative and the convergence obtained here is to about 4×10^{-7} (fractional deviation from totally converged potential at a point .5 cm from the photo cathode and 1.65 cm from the tube axis).

The potential is determined on a set of points defined by the intersection of two sets of lines (the axial and radial zoning, presented in table A1). Conductors are specified by a set of closed regions. Points in these regions are held at a constant, predetermined potential during the iteration process. In all the calculations, conducting disks 2.67 cm in radius were specified at axial positions of 0 cm and 15 cm. Annuli of 1.75 cm inner radius and 2.67 cm outer radius are placed every centimeter from 1 cm to 14 cm. These were of zero thickness except where the effect of finite ring thickness was modeled in which case the first ring extended axially from .9873 cm to 1.013 cm and the second ring from 1.987 cm to 2.013 cm making each one about 10 mil thick.

The finite zoning introduces an error in the field calculations and consequently in the electron trajectories. The TRAJEC code prints the error accumulated in the integration of the equations of motion. This is small (.1μm typically).

The rest of the error is due to the inaccuracies in the differentiation of the potential. By varying the distance (DELTXI in TRAJEC) over which the code samples the potential, an idea of the possible error due to error in the potential can be obtained and is estimated as less than $\pm$ 5μm in absolute electron position at the anode. The relative error, i.e. the error in the change in the distortion when going from one geometry or potential specification to another is probably less than .1μm if the same integration parameters are used in the TRAJEC computation.

Table A.1a

Axial Zoning (cm)

Input to ZAPADO for the Description of the Digicon Tube

-.0127	.906	1.50	4.25	10.3
0	.9111	1.70	4.50	10.7
.0127	.9288	1.85	4.75	11.0
.0254	.9365	1.9	5.0	11.3
.0381	.9492	1.95	5.25	11.7
.0508	.9619	1.975	5.5	12.0
.0635	.9746	1.987	5.75	12.3
.0762	.9873	2.0	6.0	12.7
.0889	1.0	2.013	6.25	13.0
.0994	1.013	2.025	6.5	13.25
.11	1.025	2.05	7.0	13.5
.14	1.038	2.1	7.25	13.75
.19	1.051	2.2	7.5	14.0
.29	1.064	2.35	7.75	14.2
.40	1.076	2.5	8.0	14.4
.50	1.089	2.7	8.3	14.6
.60	1.090	3.0	8.7	14.8
.71	1.11	3.25	9.0	15.0
.81	1.14	3.5	9.3	15.2
.86	1.19	3.75	9.7	15.4
.89	1.29	4.0	10.0	

Table A.1b

Radial Zoning (cm)

Input to ZAPADO for the Description of the Digicon Tube

0.	1.2	1.64	1.87
.1	1.3	1.65	1.93
.2	1.4	1.66	2.00
.3	1.45	1.67	2.1
.4	1.50	1.68	2.2
.5	1.55	1.69	2.286
.6	1.57	1.70	2.40
.7	1.59	1.715	2.5
.8	1.60	1.73	2.54
.9	1.61	1.75	2.667
1.0	1.62	1.78	2.78
1.1	1.63	1.82	2.9

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