IMPROVEMENT OF S-1 PHOTOCATHODE

SHELF LIFE STABILITY

Final Report

MASTER

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March, 1977

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4/22 1977 By *WML*

Prepared For

THE U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Under Contract No. EY-76-02-2822.*000
Formerly E(11-1) - 2822

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ABSTRACT

The purpose of this program was to stabilize sensitivity of S-1 photocathodes in C73435AG high speed image converters. Variations in bulb pre- and post-heating and in aging were investigated using partial tube assemblies consisting of the cathode bulb half of the standard tube. Successful processing of stable S-1 photocathodes in partial tubes led to adapting the schedules to complete tube assemblies. Five tubes processed on this contract yielded high but unstable photocathode sensitivity. Continued testing of tubes being made to fill customer orders shows that control of tube heating and cooling, together with careful control of evaporated cesium, can yield stable S-1 photocathodes. Additional experimentation is required to optimize a schedule yielding consistently stable photocathodes.

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TABLE OF CONTENTS

	<u>Page</u>
Statement of Problem	1
Background	1
Approach to Problem	5
Results	8
Discussion of Results	11
Conclusions	15
Recommendations	16
Literature Cited	17
Illustrations, 1 - 6	18
Tables, I - VIII	24

ILLUSTRATIONS

Figure 1	Outline Drawing - Original C73435AG
Figure 2	Outline Drawing - Redesigned C73435AG
Figure 3	Cathode Faceplate Assembly
Figure 4	Tubulated Cathode Envelope Assembly
Figure 5	Complete Cathode Envelope Assembly
Figure 6	Complete Anode Header Assembly

TABLES

Table I	Partial Tube Stability Data - Preheated Bulb
Table II	Partial Tube Stability Data - Preheated and Aged
Table III	Partial Tube Stability Data - Varying Preheat
Table IV	Partial Tube Stability Data - Long Preheat
Table V	Complete Tube Preheat Conditions
Table VI	Complete Tube Stability Data
Table VII	Complete Tube Electrical Data
Table VIII	Complete Tube (Noncontract) Stability Data

IMPROVEMENT OF S-1 PHOTOCATHODE SHELF LIFE STABILITY

STATEMENT OF PROBLEM

The decrease in S-1 (Ag-O-Cs) semi-transparent photocathode sensitivity during shelf life has been a continuing problem in image intensifier technology.^{1,2,3} Sensitivity of the photocathodes of most tubes decreases during shelf life at ambient temperatures. The effect is most rapid near the long wavelength threshold. Experience for tube type C73435AG has indicated that more than 50% of the photocathodes exhibiting high spectral response at 1060 nanometers slump to less than 25% of the original measurement within six months. The work for this contract was directed to improving the shelf life stability on type C73435AG.

BACKGROUND

The S-1 (silver-oxygen-caesium) photocathode was the first of the modern composite photocathodes to be discovered and produced in commercial quantities.^{4,5} It is still manufactured in essentially the same manner developed in the early 1930's, having undergone relatively little performance or manufacturing improvement over the years.⁶

The S-1 photocathode has relatively low quantum efficiency (typically, 1.5% at 0.35 micron and 0.5% at 0.80 micron) and therefore, has been overshadowed successively by interest in the S-11 (antimony, cesium), S-20 (antimony, potassium, sodium, cesium) and III-V compound photocathodes.

In spite of large expenditures on research and development, the S-20 has no usable response beyond 1.0 micron, and III-V photocathodes, while continuing to hold promise for the future, are still not available commercially in image intensifiers.

Interest in the semi-transparent Ag-O-Cs photocathode revived for several reasons:

1. The YAG-neodymium laser being used to study basic physical processes emits energy at about 1060 nanometers, well within the useful range of the S-1 photocathode.
2. The average electron emission energy of the S-1 is about 0.9 volt, the lowest of all practical photocathodes. This low energy contributes to very short time resolution in high speed streak tubes with S-1 photocathodes.
3. The S-1 photocathode can be made highly conductive, 300 ohms/square or better, thereby making possible its use with short, high intensity light pulses, while minimizing image defocusing caused by I^2R losses in the cathode.

4. Many pieces of optical equipment using S-1 photocathode image tubes are still in use by domestic and foreign military organizations.
5. Astronomers and others investigating the Doppler shift of spectral emission lines make use of the infrared response of the S-1 photocathode.
6. The iodine laser emits energy at 1315 nanometers, within the useful range of "long wavelength threshold" S-1 photocathodes.

The investigation of Kansky, et al³ into Ag-O-Cs photocathode instability concluded that cesium migrating slowly as a vapor to the vacuum interface of the photocathode is responsible for the slump in photocathode sensitivity. The observed phenomena reported were these:

1. Ability to restore lost sensitivity by a short heat treatment of the photocathode.
2. Continued sensitivity decrease at the same rate as observed before the heat treatment.
3. Slump of infrared sensitivity at a faster rate than that of white light sensitivity.
4. Ability to stop the sensitivity decrease by storing tubes at low temperatures.

Kansky et al concluded as follows:

"The stated measurements are leading to the following conclusions. The relatively short time synthesis of the cathode, usual in

technology, is far from satisfying equilibrium conditions in which the chemical potential of cesium u_c should be constant in the entire tube. Besides, the synthesis demands repeated heatings of the tube. At these, the temperature of the parts of the tube, whose thermal contact with the envelope is poor, does not follow the temperature of the surroundings and the envelope. The mentioned temperature differences accelerate the condensation of cesium on the cooler surfaces. Therefore, the synthesis being accomplished, it happens that the cesium vapor pressure over some inner surface is higher than over the photocathode. Herewith the condensation of residual cesium on the photocathode can begin."

"All these troubles can be avoided if the amount of residual cesium in the sealed-off tube is kept minimal. An efficient cesium getter would be a useful help."

Extensive testing of C73435AG's at RCA, prior to the beginning of the contract, revealed these S-1 photocathode characteristics:

1. Sensitivity of photocathodes which have slumped can be restored to approximately original levels by careful heat treatment of each photocathode.
2. Sensitivity then resumes slumping at approximately the original rate.
3. Infrared sensitivity slumps faster than white light sensitivity.
4. Sensitivity decrease is arrested by low temperature storage of tubes.

Obviously, the photocathode slump is exactly the same as that observed and reported by Kansky et al.

APPROACH TO PROBLEM

The usual method of fabricating a semi-transparent silver-oxygen-cesium photocathode⁶ requires evaporation of a thin layer of metallic silver on the vacuum side of the cathode faceplate, a procedure usually controlled by monitoring faceplate transmission. The silver layer is oxidized by introducing gaseous oxygen into the tube and setting up a glow discharge at the faceplate. The tube, including the cathode, is heated to 160°C. Cesium is carefully introduced while cathode thermionic emission is being monitored. When thermionic emission reaches a peak and begins to drop, cesium introduction is stopped. The tube is maintained at 160°C while thermionic emission climbs to a second peak, higher than the first. When the second peak is reached, the tube is rapidly cooled to room temperature.

The cesium vapor pressure problem caused by temperature differences of internal tube parts could easily be overcome by holding the tube at 160°C long enough to allow all parts to stabilize at that temperature. However, because normal silver oxide (Ag_2O) has a considerable dissociation pressure at temperatures above 100°C, such a long heating period destroys the silver oxide surface before the photocathode can be activated with cesium.

Work on this contract, then, concentrated on evaluating process variations designed to minimize condensation of excess cesium in the image tube during photocathode processing.

RCA type C73435AG is a gated type, electrostatic-focus image tube with electrostatic-deflection capability designed specifically for use as a high-speed light shutter. The tube has an S-1 photocathode on Corning Code No. 7056 glass input faceplate and a P-11 output screen on Galileo Electro-Optics (formerly Bendix) D-14 Ema-clad fiber optics. The tube uses two separate bulb assemblies of differing design joined together by inert gas welding of abutting flanges.

In order to heat parts of the tube without heating the photocathode, special heaters were designed and fabricated for cathode bulb, anode bulb, and phosphor screen. Temperatures were monitored using appropriately placed thermocouples.

Until the time of this contract, the exhaust tubulation used on all C73435 family types consisted of 1/4-inch O.D. glass tubing fused to the bulb glass adjacent to the cathode faceplate flange. The need to assemble and disassemble bulb heaters as a part of the photocathode processing on this contract made the continued use of glass tubing very risky, with a high probability of breakage. Therefore, the cathode bulb was redesigned to incorporate a 1/4-inch

O.D. copper tubing brazed to the flange at the opposite end of the cathode bulb. This change further necessitated the relocation of the cesium generators within the bulb assembly (treated further in Recommendations). The redesigned cathode bulb assembly proved much more rugged than the standard design, with no losses attributed to breakage. Figure 1 shows the original configuration of the C73435AG; Figure 2 shows the redesigned version incorporating the copper tubulation.

In the interest of cost effectiveness, process variations were investigated by using partial tubes consisting of:

- a) standard cathode faceplate assembly,
- b) mounted cathode bulb assembly containing all standard parts except grid wires, and
- c) a specially designed header to close off the anode end of the bulb assembly and hold the anode aperture and silver beads in a location identical to that in the complete tube assembly.

Details of the partial tube assemblies are shown in Figures 3 through 6.

Twenty-two (22) partial tubes with photocathodes having initially high sensitivity were made and evaluated for shelf life stability. Results from the partial tubes were used in making five operable C73435AG tubes.

Each partial and complete tube assembly was processed with an ion pump (8 liter per second rated capacity) attached to permit thorough tube outgassing after removal from the processing system.

RESULTS

Four partial tubes were exhaust baked, and photocathodes were processed in a standard manner, with these exceptions:

1. Cathode bulb heater raised bulb temperature to about 190°C before the oven was lowered to start photocathode heating and processing.
2. Bulb temperature reached about 240°C during photocathode processing because bulb heater was left on.
3. When oven was raised after second thermionic emission rise, cathode bulb heater was removed to promote uniform cooling of partial tube.
4. Partial tube was pumped for a day after removal from processing system.

The initial and shelf life sensitivity results are summarized in Table I.

Three partial tubes were processed like those above, but with this exception: Partial tube was high voltage aged during afterpumping (item 4 above); 15 kilovolts at one microampere photocurrent for two hours.

Photoemission measured at 1.06 micron dropped between 7% and 61% as a result of the aging operation. When treated with a standard rejuvenation schedule, photoemission returned to original, pre-aging values. Sensitivity results are summarized in Table II.

Shelf life stability data on the partial tube assemblies above indicated no apparent benefit from high voltage aging. Also, while stability was greatly improved compared to standard product, differences within groups indicated that uncontrolled variations in processing were the major remaining cause of photocathode instability. Accordingly, two partial tubes were run, employing widely differing bulb heating procedures.

The bulb heater of partial tube 7-6-6-3 was "on," preheating the bulb and internal parts to 160°C for 90 minutes before photocathode cesiation. After standard cesiation, during which time bulb temperature rose to 240°C, the oven was raised to cool the photocathode. The bulb heater was turned off, but left on the bulb for one hour, thus allowing the bulb to cool slowly.

The bulb heater of partial tube 7-6-6-4 was turned on at the same time that the oven was lowered for photocathode processing. During cesiation, the bulb temperature rose to 210°C. The heater was turned "off" but left on the tube for a ten-minute period after the oven was raised. Sensitivity data for these assemblies are summarized in Table III.

A series of partial tubes was made using a bulb preheat of 160°C to 180°C for 60 minutes (time at temperature). Bulb heater power was turned off four minutes after lowering the processing oven over the assembly and the photocathode was cesiated in the usual manner. Bulb temperature reached 180° to 200°C during cathode processing. When the oven was raised after photocathode processing, the bulb heater was left in position for about two minutes before removal from the partial tube. Sensitivity results are given in Table IV.

Based upon the predominantly stable photocathodes of the partial tubes made as reported above, five complete C73435AG's were processed using essentially the same schedule as above. Of course, the complete tube required the use of anode bulb heater and phosphor screen heater. The preheat times were 60 minutes for each tube; the preheat temperatures are recorded in Table V. Although bulb heaters were removed soon after raising the processing oven, the screen heater was left in position and allowed to cool slowly so as to avoid stripped frit seals. Table VI shows the shelf life stability data measured on the five tubes. Table VII summarizes the electrical test data on the tubes. Note that gain varies directly as a function of infrared sensitivity for each tube.

Results on the five tube assemblies, though disappointing, were not particularly surprising, because:

1. Nine partial tubes were processed before variables were

sufficiently under control to stabilize shelf life. The addition of the anode section was more influential on stability characteristics than expected; more than the short experimental effort permitted by five operable tubes could accommodate.

2. RCA's original proposal for this program included a total of seventy-five tube starts in place of the five actually funded.

Results on the five tubes above compared with the partial tube assemblies reported on Table IV prompted further process investigation, using tubes built subsequent to this program to fill customized tube orders. Variations in cathode bulb, anode bulb and phosphor screen temperature are represented in the stability data presented in Table VIII.

DISCUSSION OF RESULTS

Comparison of the data in Tables I and II shows no significant difference in photocathode stability due to high voltage aging during afterpumping. The spread of the data for both groups of tubes shows the influence of an uncontrolled variable on photocathode stability.

Careful consideration of the conclusions above suggested the need for a longer "soak" time before photocathode activation to overcome the thermal lag of internal tube parts caused by poor thermal

conduction from outside the partial tube. Study of the data presented in Table III showed the likelihood that the longer "soak" appreciably improved stability.

Results reported in Table IV for partial tubes with a one hour bulb preheat at 160° to 180°C show that careful temperature control is necessary to attain photocathode stability. Note, however, that numbers 9-14-6-7, 9-14-6-8 and 9-24-6-11 degraded severely over the hold period. 9-14-6-8 and 9-24-6-11 were two of only three tubes processed by a production exhaust operator. Both were subjected to excessive cesium during cathode activation. All other partial and complete tubes were processed by the project engineer. The reason for the slump of 9-14-6-7 is not so clear as the other two, but it, too, received somewhat more cesium than the stable photocathodes. The fact that all three photocathodes returned to approximately original levels when heated for a short period of time, then slumped again at about the original rate, verifies that excessive cesium migrating to the photocathode was the cause of the sensitivity slump.

The good performance of the last group of partial tubes (7 stable, 3 fairly stable, 3 unstable [2 with definite overcesiation]) led to the use of a similar processing schedule for complete tubes. However, stability of the five complete tubes was disappointing, with only one tube (10-26-6-6) exceeding the working minimum, 0.10 milliamperes per watt at 1060 nanometer irradiation, after the ninety

day hold period. The cathodes of these tubes were not reheated during the ninety day hold period.

After the five complete tubes were made in partial fulfillment of contract requirements, additional tubes were made to fill customer orders. The cathode of one of these tubes, 11-9-6-2, which showed severe cathode slump, was reheated for a short period of time. The cathode recovered sensitivity, but subsequently slumped at about the same rate as before. Other tubes, 11-12-6-3, 11-16-6-6 and 12-8-6-1, had cathodes resilvered to reduce resistivity and improve short pulse characteristics. Resilvering showed the same effect as simple reheating, causing cathode sensitivity to recover to about initial levels. However, all cathodes then slumped at about the original rate. Hence, it is clear that excessive cesium is still the cause of the stability problem.

Very carefully controlled tube preheating, though greatly improving the stability of cathodes made in partial tubes, is not the complete answer to stable photocathodes. Materials and parts processing procedures used for complete tubes are essentially the same as those used for partial tubes, although configurations are different. Major differences between partial and complete tubes from a photocathode processing standpoint are these:

- a. degree of thermal isolation of internal structure (anode and deflection plate assembly compared with focus grid assembly).
- b. surface area of internal structure.

- c. volume of tube envelope.
- d. presence of aluminized phosphor screen.

Vacuum pumping capacity of the processing system is more than adequate to handle total C73435AG volume, therefore item (c) will not be considered further. Likewise, because the aluminized screen shows no sign of interaction with cesium, item (d) will not be further explored at this time.

The complete anode assembly is a conical structure over 13 centimeters long, joined to the anode bulb by four welds at the screen end of the tube and electrically connected by four thin straps to buttons located in quadrature around the anode bulb. Thus, the structure, especially the deflection plates within the cone, is thermally isolated more completely than any other assembly within the tube, and may not be reaching equilibrium temperature during photocathode activation.

Much effort has been spent on attaining uniform internal temperatures during photocathode activation. However, when the oven is raised and the tube allowed to cool, the bulb wall is likely to cool more rapidly than the internal metal structures, thereby serving to condense cesium vapor and later serve as the cesium source responsible for slumping photocathodes. The phenomenon would be more pronounced for complete tubes than for partial tubes because of the distance from effective heat sources such as the transite block supporting the tube during processing.

Because cooling and its relationship to item (b) had not been thoroughly explored, three tubes (12-14-6-2, 12-14-6-3 and 12-20-6-4) were processed as described above, but with specially controlled cooling after photocathode activation. The data set forth in Table VIII, shows that stable, high sensitivity, S-1 photocathodes can be made in C73435AG tubes.

CONCLUSIONS

Activation of stable S-1 photocathodes is a precise task requiring careful control of photocathode cesiation. Preheating tube parts to processing temperature before heating and activating the photocathode overcomes the stability problem in partial tubes. However, this process does not achieve the desired stability when transferred to type C73435AG. Continued investigation of various preheat temperatures while processing tubes to fill customer orders showed cathode instability to be insensitive to preheat temperature so long as at least equal to photocathode substrate temperature. Data on three tubes shows that control of tube cooling as well as preheating can yield stable S-1 photocathodes in the C73435AG configuration. Additional tube starts are necessary to optimize a schedule leading to total stability.

RECOMMENDATIONS

Although only three C73435AG's demonstrate adequate photocathode stability, they are the only three tubes processed using controlled cooling. Because of the high probability of future success, it is recommended that further effort on photocathode stability be combined with spatial and time resolution improvements on C73435AG.

Proposed resolution improvements including greatly increased photocathode field strength, an einzel lens in place of the present grid No. 2, spherical image surface on output fiber optic and coarse- or fine-mesh grid structure are treated in more detail in the proposal entitled "Improved Performance of Ultrafast Streak Converter" dated September 24, 1976.

The location of cesium channels adjacent to the focus grid structure causes cathode non-uniformities normal to the channels. It is recommended that on future programs the channels be relocated further from the cathode to improve uniformity of cesium coverage.

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FIGURE 1: Outline Drawing - Original C73435AG

FIGURE 2: Outline Drawing - Redesigned C73435AG

FIGURE 3: Cathode Faceplate Assembly

FIGURE 4: Tubulated Cathode Envelope Assembly

FIGURE 5: Complete Cathode Envelope Assembly

FIGURE 6: Complete Anode Header Assembly

TABLE I

PARTIAL TUBE STABILITY DATA - PREHEATED BULB

<u>Partial Assembly Number</u>	<u>Time Days</u>	<u>White (Note 1) μa/l</u>	<u>IR (Note 2) μa/l</u>	<u>1.06 μ ma/w</u>	<u>1.315 μ μa/w</u>
6-10-6-2	0	33.0	4.6	.58	1.7
	2	32.0	4.5	.53	1.4
	8	33.0	4.4	.49	1.1
	16	31.5	4.2	.47	1.0
	23	32.2	4.2	.45	0.9
	40	31.8	4.0	.39	0.8
	47	31.0	3.8	.35	0.7
	76	30.0	3.5	.30	0.6
	98	31.5	3.4	.30	0.6
6-15-6-3	0	29.0	4.2	.58	2.9
	6	29.2	4.2	.58	2.3
	14	29.5	4.2	.58	2.1
	21	29.0	4.0	.58	2.1
	38	28.5	3.9	.52	1.8
	45	29.5	4.0	.52	1.7
	74	29.0	3.6	.47	1.4
	96	30.0	3.8	.46	1.2
6-15-6-4	0	34.0	4.9	.58	1.1
	6	34.0	4.4	.42	0.8
	14	34.5	4.4	.42	0.9
	21	33.0	4.1	.38	0.7
	38	32.5	3.9	.32	0.7
	45	32.0	3.6	.26	0.6
	74	31.5	3.4	.24	0.5
	96	33.0	3.3	.19	0.5
6-17-6-6	0	28.5	4.5	.68	4.6
	2	29.0	4.5	.68	4.1
	8	28.5	4.4	.68	3.7
	16	29.0	4.5	.69	3.5
	23	29.0	4.5	.71	3.7
	40	29.0	4.5	.69	3.5
	47	27.5	4.3	.68	3.6
	76	26.7	4.2	.66	3.6
	98	28.5	4.5	.71	4.2

Note 1 - 2854°K lamp.

Note 2 - 2854°K lamp filtered through CS5-58 filter.

TABLE II

PARTIAL TUBE STABILITY DATA - PREHEATED AND AGED

<u>Partial Assembly Number</u>	<u>Time Days</u>	<u>White (Note 1) $\mu\text{a/l}$</u>	<u>IR (Note 2) $\mu\text{a/l}$</u>	<u>1.06 μ ma/w</u>	<u>1.315 μ $\mu\text{a/w}$</u>
6-25-6-7	0	29.5	4.3	.59	1.7
	17	29.7	3.8	.44	0.9
	24	29.0	3.6	.37	0.7
	31	29.0	3.4	.32	0.7
	61	27.0	2.6	.17	0.4
	91	27.8	2.4	.12	0.2
7-2-6-1	0	29.5	3.9	.49	1.2
	17	29.0	3.6	.40	0.9
	24	29.0	3.6	.39	0.8
	31	28.7	3.5	.37	0.7
	61	28.0	3.2	.30	0.6
	91	29.0	3.0	.25	0.6
7-2-6-2	0	32.0	5.4	.84	4.6
	2	33.5	5.4	.84	5.1
	21	32.0	5.1	.79	3.8
	28	32.0	5.2	.78	3.5
	35	31.0	5.0	.74	3.5
	65	31.0	4.9	.73	3.1
	95	32.0	5.0	.73	2.8

Note 1 - 2854°K lamp.

Note 2 - 2854°K lamp filtered through CS5-58 filter.

TABLE III

PARTIAL TUBE STABILITY DATA - VARYING PREHEAT

<u>Partial Assembly Number</u>	<u>Time Days</u>	<u>White (Note 1) $\mu\text{a/l}$</u>	<u>IR (Note 2) $\mu\text{a/l}$</u>	<u>1.06 μ ma/w</u>	<u>1.315 μ $\mu\text{a/w}$</u>
7-6-6-3	0	25.6	3.8	.51	1.7
	3	26.6	3.8	.54	1.7
	10	26.5	3.8	.53	1.7
	17	26.0	3.7	.50	1.5
	25	25.2	3.6	.48	1.4
	32	26.0	3.6	.47	1.4
	39	25.5	3.5	.47	1.2
	46	26.5	3.5	.45	1.1
	60	26.0	3.4	.44	1.1
	90	27.0	3.5	.42	1.1
7-6-6-4	0	29.0	4.2	.58	1.1
	3	30.0	4.1	.54	1.4
	10	27.5	3.7	.45	1.1
	17	27.3	3.5	.41	1.0
	25	26.7	3.4	.39	0.9
	32	27.5	3.4	.37	0.9
	39	26.5	3.2	.35	0.8
	46	26.5	3.2	.34	0.7
	60	26.8	3.1	.31	0.7
	90	27.5	3.1	.28	0.5

Note 1 - 2854^{OK} lamp.

Note 2 - 2854^{OK} lamp filtered through CS5-58 filter.

TABLE IV

PARTIAL TUBE STABILITY DATA - LONG PREHEAT

Partial Assembly Number	Time Days	White (Note 1) $\mu\text{a/l}$	IR (Note 2) $\mu\text{a/l}$	1.06 μ ma/w	1.315 μ $\mu\text{a/w}$
8-17-6-2	0	28.0	4.3	.64	2.5
	5	29.0	4.4	.64	2.3
	12	30.0	4.4	.64	2.1
	19	30.0	4.4	.64	2.1
	26	30.0	4.4	.63	2.1
	34	30.5	4.5	.64	2.3
	40	30.0	4.4	.63	2.1
	64	31.0	4.5	.64	2.0
	68	31.5	4.6	.63	2.1
	90	30.5	4.6	.64	2.0
8-19-6-3	0	33.0	5.3	.83	4.6
	9	34.0	5.4	.84	4.5
	15	33.0	5.1	.78	3.7
	22	34.0	5.3	.81	3.8
	30	33.0	5.1	.77	3.5
	60	33.0	5.1	.76	3.5
	90	32.0	4.9	.72	2.8
8-30-6-5	0	23.4	4.1	.68	4.6
	4	24.5	4.2	.69	4.6
	12	25.0	4.2	.69	4.6
	19	25.5	4.3	.71	4.9
	25	24.5	4.2	.69	4.5
	32	25.5	4.3	.70	4.6
	61	26.0	4.4	.71	4.1
	90	25.5	4.2	.66	3.7
8-30-6-6	0	29.0	4.7	.71	3.5
	4	30.0	4.8	.72	3.1
	12	30.0	4.8	.76	3.8
	19	31.0	5.0	.77	3.9
	25	30.0	4.8	.74	3.7
	32	30.0	4.9	.74	3.5
	61	31.0	4.8	.72	2.8
	90	30.0	4.6	.67	2.3

Note 1 - 2854°K lamp.

Note 2 - 2854°K lamp filtered through CS5-58 filter.

TABLE IV (continued)

PARTIAL TUBE STABILITY DATA - LONG PREHEAT

<u>Partial Assembly Number</u>	<u>Time Days</u>	<u>White (Note 1) $\mu\text{a/l}$</u>	<u>IR (Note 2) $\mu\text{a/l}$</u>	<u>1.06 μ ma/w</u>	<u>1.315 μ $\mu\text{a/w}$</u>
9-8-6-1	0	29.5	5.0	.01	5.6
	9	30.0	5.2	.84	6.4
	15	29.5	5.2	.83	5.8
	22	29.5	5.2	.84	5.8
	30	29.0	5.0	.79	5.2
	60	29.5	5.0	.80	4.6
	80	29.0	5.0	.78	4.4
	90	29.5	4.8	.76	4.0
9-9-6-3	0	25.5	4.4	.67	3.7
	6	26.0	4.4	.70	4.0
	12	27.0	4.5	.70	3.9
	19	26.5	4.3	.67	3.5
	26	25.5	4.2	.66	3.4
	33	26.0	4.3	.68	3.2
	60	26.0	4.2	.64	2.8
	90	25.7	4.0	.61	2.3
9-9-6-4	0	29.0	4.7	.71	3.5
	6	29.5	4.6	.71	3.5
	12	30.0	4.6	.71	3.1
	19	29.0	4.5	.69	2.8
	26	29.0	4.6	.67	2.8
	33	29.0	4.5	.65	2.4
	60	29.0	4.2	.59	2.1
	90	29.0	3.9	.50	1.4

Note 1 - 2854°K lamp.

Note 2 - 2854°K lamp filtered through CS5-58 filter.

TABLE IV (continued)

PARTIAL TUBE STABILITY DATA - LONG PREHEAT

<u>Partial Assembly Number</u>	<u>Time Days</u>	<u>White (Note 1) $\mu\text{a/l}$</u>	<u>IR (Note 2) $\mu\text{a/l}$</u>	<u>1.06 μ ma/w</u>	<u>1.315 μ $\mu\text{a/w}$</u>
9-14-6-5	0	30.0	4.9	.76	4.0
	6	30.0	4.8	.73	3.5
	13	29.0	4.6	.71	2.8
	20	29.0	4.6	.67	2.5
	27	29.0	4.6	.66	2.3
	30	29.0	4.5	.65	2.3
	62	28.5	4.0	.53	1.6
	90	28.5	3.8	.47	1.2
9-14-6-7	0	31.5	4.6	.69	3.0
	6	31.5	4.6	.64	2.3
	13	31.0	4.4	.59	2.0
	20	30.5	4.2	.53	1.5
	27	30.5	4.0	.48	1.4
	30	30.0	4.0	.45	1.4
	62	29.0	3.0	.25	0.7
	78	28.0	2.7	.18	nm
	78	36.0	4.6	.61	nm
	reheat				
	82	34.0	4.0	.46	nm
	90	34.0	3.7	.36	1.0
9-14-6-8	0	32.0	4.6	.61	2.3
	7	28.0	4.2	.54	1.2
	14	29.5	3.8	.41	0.9
	21	29.0	3.3	.30	0.6
	28	28.0	2.9	.20	0.3
	32	27.8	2.6	.15	0.4
	60	23.5	1.5	.04	0.3
	76	22.0	1.3	.03	nm
	76	31.0	4.8	.71	nm
	reheat				
	89	29.5	3.6	.37	0.8

Note 1 - 2854°K lamp.

Note 2 - 2854°K lamp filtered through CS5-58 filter.

TABLE IV (continued)

PARTIAL TUBE STABILITY DATA - LONG PREHEAT

<u>Partial Assembly Number</u>	<u>Time Days</u>	<u>White (Note 1) $\mu\text{a/l}$</u>	<u>IR (Note 2) $\mu\text{a/l}$</u>	<u>1.06 μ ma/w</u>	<u>1.315 μ $\mu\text{a/w}$</u>
9-24-6-9	0	29.0	5.1	.79	7.0
	7	29.0	5.0	.83	7.0
	14	29.5	5.1	.84	7.0
	21	29.0	5.2	.85	6.9
	28	29.0	5.1	.84	6.7
	32	28.5	5.2	.84	6.7
	60	29.0	5.1	.84	5.8
	89	29.5	5.2	.85	5.8
9-24-6-10	0	25.5	4.8	.74	9.3
	7	26.0	4.8	.78	9.0
	14	25.6	4.7	.79	8.7
	21	26.0	4.8	.79	8.7
	28	26.0	4.8	.78	8.5
	32	26.5	4.8	.79	8.1
	60	26.0	4.7	.79	7.0
	89	26.5	4.7	.78	5.8
9-24-6-11	0	31.0	4.8	.68	2.3
	7	30.0	4.4	.58	1.6
	14	29.5	4.0	.52	1.3
	21	29.5	3.9	.47	1.2
	28	29.0	3.6	.40	0.9
	32	29.0	3.4	.37	0.9
	60	27.0	2.8	.22	0.5
	76	27.0	2.6	.17	nm
	76	32.5	5.0	.76	nm
	reheat				
	89	30.5	4.6	.64	2.1

Note 1 - 2854°K lamp.

Note 2 - 2854°K lamp filtered through CS5-58 filter.

TABLE V

COMPLETE TUBE PREHEAT CONDITIONS

	<u>Cathode Bulb</u> <u>(Degrees C)</u>	<u>Anode Bulb</u> <u>(Degrees C)</u>	<u>Output Screen</u> <u>(Degrees C)</u>
10-6-6-2	185	190	170
10-22-6-5	190	190	190
10-26-6-6	170	170	185
10-29-6-7	170	180	170
10-29-6-8	175	200	200

TABLE VI

COMPLETE TUBE STABILITY DATA

<u>Tube Number</u>	<u>Time Days</u>	<u>White (Note 1) μa/l</u>	<u>IR (Note 2) μa/l</u>	<u>1.06 μ ma/w</u>	<u>1.315 μ μa/w</u>
10-6-6-2	0	32.0	5.4	.78	4.1
	1	32.0	5.4	.84	4.0
	6	32.0	5.2	.78	2.9
	8	32.0	5.2	.77	2.9
	16	32.0	5.0	.73	2.3
	22	32.0	5.0	.67	1.9
	29	30.5	4.4	.56	1.4
	36	30.5	4.2	.49	1.1
	42	30.0	4.0	.44	0.9
	57	29.0	3.1	.25	0.6
	64	28.5	3.0	.22	0.4
	90	26.5	2.3	.09	0.6
10-22-6-5	0	40.0	6.2	.88	3.5
	6	37.5	5.5	.75	1.8
	13	37.5	5.3	.69	1.6
	20	37.5	5.1	.63	1.5
	26	37.5	5.0	.58	1.4
	41	36.0	4.3	.41	0.8
	48	35.0	4.0	.37	0.6
	60	33.0	3.5	.26	0.6
	90	32.0	3.2	.06	0.4

Note 1 - 2854°K lamp.

Note 2 - 2854°K lamp filtered through CS5-58 filter.

TABLE VI (continued)

COMPLETE TUBE STABILITY DATA

<u>Tube Number</u>	<u>Time Days</u>	<u>White (Note 1) $\mu\text{a/l}$</u>	<u>IR (Note 2) $\mu\text{a/l}$</u>	<u>1.06 μ ma/w</u>	<u>1.315 μ $\mu\text{a/w}$</u>
10-26-6-6	0	36.0	5.7	.88	3.5
	7	37.5	5.7	.85	2.9
	14	38.0	5.7	.84	2.8
	20	38.0	4.7	.81	2.6
	35	37.5	5.2	.69	1.6
	42	38.0	5.1	.63	1.6
	60	35.5	4.5	.47	0.9
	89	34.0	3.8	.30	0.6
10-29-6-7	0	36.0	5.1	.61	1.1
	3	36.0	4.8	.56	1.2
	10	35.5	4.2	.42	1.1
	16	34.5	3.9	.33	0.7
	31	31.5	2.9	.18	0.4
	38	30.5	2.6	.14	0.5
	60	29.0	2.2	.10	0.3
	95	28.5	1.7	.06	0.3
10-29-6-8	0	29.0	4.7	.74	3.2
	8	32.0	5.0	.73	2.3
	23	30.0	4.0	.42	0.8
	30	30.0	3.4	.28	0.6
	62	26.0	1.9	.06	0.2
	90	25.0	1.6	.05	0.4

Note 1 - 2854°K lamp.

Note 2 - 2854°K lamp filtered through CS5-58 filter.

TABLE

	<u>G₂ Voltage (volts)</u>	<u>G₁ Voltage (volts)</u>	<u>Center Reso- lution (lp/mm)</u>	<u>Edge Reso- lution (lp/mm)</u>	<u>Center Magni- fication</u>	<u>Edge Magni- fication</u>	<u>Distor- tion(%)</u>	<u>Align- ment</u>	<u>Image Sta- bility</u>	<u>Break- down</u>	<u>Grid Align- ment</u>
10-6-6-2	1790	180	28.5	20.0	.758	.769	1.45	Pass	Pass	Pass	Pass
10-22-6-5	1750	160	25.4	20.0	.761	.768	0.92	Pass	Pass	Pass	Pass
10-26-6-6	1750	172	28.5	22.6	.770	.773	0.39	Pass	Pass	Pass	Pass
10-29-6-7	1790	180	28.5	22.6	.750	.765	1.98	Pass	Pass	Pass	Pass
10-29-6-8	1820	193	28.5	20.0	.742	.745	0.40	Pass	Pass	Pass	Pass

	<u>Ion Spot</u>	<u>Uni- formity</u>	<u>Defl. Factor (volts/ inch)</u>	<u>Defl. Plate Break- down</u>	<u>G₁ Cutoff (volts)</u>	<u>Cathode & Screen Quality</u>	<u>Defl. Align- ment</u>	<u>Grid Wire Dis- tortion</u>	<u>500ns Res. Center (lp/mm)</u>	<u>50ns. Res. Center (lp/mm)</u>
10-6-6-2	Pass	Pass	1100	Pass	-60	Pass	Pass	Pass	22	13
10-22-6-5	Pass	Pass	1200	Pass	-60	Pass	Pass	Fail	18	14
10-22-6-6	Pass	Pass	1160	Pass	-60	Pass	Pass	Fail	20	13
10-29-6-7	Pass	Pass	1160	Pass	-68	Pass	Pass	Fail	20	13
10-29-6-8	Pass	Pass	1200	Pass	-64	Pass	Pass	Pass	20	14

	<u>500ns. Res. Defl. (lp/mm)</u>	<u>50ns. Res. Defl. (lp/mm)</u>	<u>Radiant Power Gain</u>	<u>Equiv. Back. Input (w/cm²)</u>	<u>Sens. 2854°K (μa/l)</u>	<u>Sens. 5-58 Filter (μa/l)</u>	<u>Sens. 1.06 micron (ma/w)</u>	<u>Sens. 1.315 micron (μa/l)</u>
10-6-6-2	14	9	4.5	5.2X10 ⁻¹⁰	30.0	4.9	.74	2.9
10-22-6-5	13	10	6.1	3.5X10 ⁻¹⁰	36.0	5.7	.86	2.9
10-26-6-6	14	10	5.1	3.6X10 ⁻¹⁰	32.0	5.3	.83	3.0
10-29-6-7	11	9	5.4	4.3X10 ⁻¹⁰	34.0	5.4	.86	3.7
10-29-6-8	14	13	5.0	6.6X10 ⁻¹⁰	29.0	5.0	.83	5.2

TABLE VIII

COMPLETE TUBE (NONCONTRACT) STABILITY DATA

<u>Tube Number</u>	<u>Time Days</u>	<u>White (Note 1) $\mu\text{a/l}$</u>	<u>IR (Note 2) $\mu\text{a/l}$</u>	<u>1.06 μ ma/w</u>	<u>1.315 μ $\mu\text{a/w}$</u>
11-8-6-1	0	30.0	5.0	.71	3.0
	3	35.5	5.7	.81	2.9
	7	32.0	5.3	.75	2.9
	12	34.0	5.4	.77	2.3
	21	34.0	5.2	.73	1.7
	25	34.0	5.1	.69	1.6
	33	34.0	4.8	.61	1.3
	56 (cust.)			.32	
	94 (cust.)			.13	
11-9-6-2	0	28.5	4.8	.71	3.5
	5	30.0	4.5	.61	1.5
	14	29.0	3.3	.30	0.6
	18	29.0	3.1	.25	0.5
	25	25.5	2.2	.13	0.2
	26 reheat	30.0	5.1	.83	3.5
	32	29.5	4.5	.66	1.7
	39	29.0	3.8	.42	1.0
	46	27.0	2.8	.20	0.2
	53	27.5	2.5	.13	0.5
	63	25.8	1.8	.07	0.4
11-12-6-3	0	32.0	5.2	.79	2.7
	7	33.0	5.0	.73	2.0
	14	32.0	4.8	.66	1.8
	21	32.0	4.6	.55	1.2
	28	31.0	4.0	.44	0.9
	35	20.5	0.6	nm	nm
	37 reheat	30.0	4.6	.62	1.2
	44	29.5	3.4	.28	0.5
	51	27.8	2.6	.12	0.4

Note 1 - 2854°K lamp.

Note 2 - 2854°K lamp filtered through CS5-58 filter.

TABLE VIII (continued)

COMPLETE TUBE (NONCONTRACT) STABILITY DATA

<u>Tube Number</u>	<u>Time Days</u>	<u>White (Note 1) μa/l</u>	<u>IR (Note 2) μa/l</u>	<u>1.06 μ ma/w</u>	<u>1.315 μ μa/w</u>
11-12-6-4	0	29.0	4.2	.66	2.2
	7	29.0	4.0	.55	1.3
	14	29.0	3.7	.42	0.9
	21	29.0	3.0	.25	0.6
	28	27.0	2.5	.14	0.4
	35	27.0	2.1	.10	0.5
	45	25.7	1.8	.06	0.4
11-16-6-5	0	30.0	4.8	.68	2.9
	8	31.0	4.5	.63	1.7
	15	30.5	4.0	.50	1.7
	22	30.0	3.6	.38	0.9
	29	29.5	3.0	.28	0.6
	36	29.5	2.8	.19	0.5
	46	29.0	2.2	.10	0.4
11-16-6-6	0	30.0	4.3	.64	1.8
	2	33.0	4.8	.71	2.3
	16	32.0	4.3	.57	1.6
	22	31.5	4.2	.52	1.3
	25 resil.	32.5	4.7	.67	1.7
	31 resil.	32.5	4.8	.67	1.6
	38	33.5	4.6	.62	1.7
	45	32.5	4.4	.54	1.2
	50	32.0	4.4	.56	1.4
	60	31.0	4.2	.52	1.4
	67	31.0	4.2	.50	1.2
	81 (cust.)			.34	

Note 1 - 2854°K lamp.

Note 2 - 2854°K lamp filtered through CS5-58 filter.

TABLE VIII (continued)

COMPLETE TUBE (NONCONTRACT) STABILITY DATA

<u>Tube Number</u>	<u>Time Days</u>	<u>White (Note 1) μa/l</u>	<u>IR (Note 2) μa/l</u>	<u>1.06 μ ma/w</u>	<u>1.315 μ μa/w</u>
12-8-6-1	0	20.5	4.3	.74	2.9
	14	25.5	4.4	.60	1.5
	20	28.0	4.2	.49	1.1
	23 resil.	32.0	5.5	.91	4.2
	29 resil.	30.0	5.4	.93	5.2
	36	30.5	5.4	.88	4.2
	42	30.5	5.2	.76	3.1
	47	31.0	5.1	.76	2.6
	57	30.0	4.5	.61	1.7
	64	30.0	4.1	.49	1.2
	78 (cust.)			.18	
12-14-6-2	0	19.0	3.4	.52	2.3
	6	21.5	3.7	.59	2.0
	12	23.5	3.8	.59	2.1
	15 resil.	28.0	4.1	.64	2.4
	28	28.0	4.3	.63	2.1
	35	28.5	4.1	.58	1.4
	84	27.5	4.0	.51	1.2
12-14-6-3	0	26.0	4.1	.61	2.9
	6	26.5	4.1	.62	1.8
	12	27.0	4.0	.58	1.6
	19	27.0	3.9	.57	1.9
	28	26.8	4.1	.69	3.0
	29	26.5	4.1	.66	2.9
	40 (cust.)			.51	
12-20-6-4	1	29.0	4.7	.64	2.3
	5	32.0	4.8	.66	1.8
	6	32.0	4.8	.66	1.7
	9	34.0	4.9	.68	1.7
	9 resil.	32.0	5.2	.83	3.5
	15 resil.	32.5	5.4	.84	3.5
	22	32.5	5.2	.78	2.6
	29	32.0	5.0	.72	2.0
	44	32.0	4.8	.67	2.0
	72	32.0	4.8	.64	1.7

Note 1 - 2854°K lamp.

Note 2 - 2854°K lamp filtered through CS5-58 filter.