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FINAL REPORT
THE DEVELOPMENT OF STERILIZABLE IMAGE DISSECTOR TUBES

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1. INTRODUCTION

The purpose of this program was to develop and fabricate sterilizable electrostatic, wide angle, 1 1/2 inch diameter, image dissectors with a bi-alkali photocathodes.

The early part of the program was directed toward the development of bi-alkali photocathode processing techniques adaptable for use in sterilizable image dissectors. The photocathode development work was conducted using 2" diameter photomultiplier tubes with ten multiplication stages. In order to arrive at a bi-alkali photocathode activation process yielding most stable photocathodes the photomultiplier tubes were subjected to thermal sterilization. The effect of the sterilization process on the photocathode and the electron multiplier was evaluated. In the course of this work an activation schedule was developed, resulting in bi-alkali photocathodes with sensitivities of up to 65 microamperes per lumen.

This activation schedule was then used for exhaust processing of 15 sterilizable image dissector tubes, ten of which were subjected to gas and dry heat sterilization. During the sterilization and subsequent testing of image dissectors it became apparent that the major problem area in making sterilizable image dissector tubes was the photocathode stability. In general, the overall photocathode sensitivity of the tubes after six thermal cycles ranged between 4 and 29 microamperes/lumen, however the uniformity was poor. Very promising results were achieved with one tube No. M-1319 demonstrating the feasibility of making high sensitivity, sterilizable photocathodes. The photocathode sensitivity of this tube was 47 microamperes/lumen after thermal sterilization and the response uniformity of the cathode was 83%. The less successful results with other tubes suggest a need for further work on processes similar to that used on tube No. M-1319.

2. THE 2" PHOTOMULTIPLIER

2.1 The Bi-Alkali Photocathode Development

The bi-alkali photocathode development was conducted using 2" diameter photomultiplier tubes with ten multiplication stages. The availability of parts and ease of construction made the photomultiplier tube an economical vehicle for the bi-alkali photocathode work. Throughout the program 66 photomultiplier tubes were built of which 59 were processed. In order to develop the most promising technique for bi-alkali photocathode formation, recordings of time, pressure, temperature, alkali generator currents and photoresponse were made during the cathode activation process. The first five tubes in the program were processed with varying values of generator currents and oven temperatures to establish a basic activation schedule. In this schedule potassium and antimony were deposited simultaneously followed by deposition of sodium. An additional variation introduced to this schedule was photocathode preformation which was accomplished by deposition of small amounts of Sb, K and Na until photoresponse was observed. After the tube was subjected to an additional bake of 18 hours the photocathode was formed. The initial activation process or its variations, was used on eight more tubes resulting in photocathodes with sensitivities below 20 microamperes per lumen. Since the success with this activation schedule was limited and the procedure very time consuming a second approach without preformation was tried. This approach in which potassium is released before any deposition of antimony, was found to be inadequate since it was highly dependent on the skill of the operator. Based on the observations made, a simplified processing schedule was devised. This schedule consisted of initial deposition of a small amount of Sb followed by alternate additions of K and Sb until peak response was reached before the deposition of Na. The cycle was then repeated and the activation ended with deposition of small amounts of Sb and K for final peak in sensitivity. This schedule, besides yielding photocathodes of relatively high sensitivity proved to be highly repeatable. The possibility of overloading the photosurface with an excess of any one element, which is always present when using the co-evaporation method, was also reduced. This is so because the change in photoresponse is recorded for each cathode forming element separately thus showing the effect of a single element on the photoresponse. In addition, the initial deposition of Sb followed by evaporation of K resulted in faster indication of photoresponse than that observed with the coevaporation method.

Table 1A shows the sensitivities of 8 tubes obtained with the initial coevaporation method. The sensitivities of tubes activated according to the revised simplified process are shown in Table 1B. The tables also show the response to 2870°K source

TABLE 1

PHOTOCATHODE RESPONSE DATA

TABLE 1A BI-ALKALI PHOTOCATHODES

Tube No.	Photoresponse uA/L			Relative Photoresponse*	
	White	Blue	Red	Blue	Red
10	14	2.2	.7	2.94	1
11	1	-	-		
12	11	.9	.09	10	1
13	19.4	3.3	1.6	2.0	1
14	11	1.1	.1	10	1
15	16	2.5	.88	2.9	1
16	1	-	-		
17	1.2	-	-		

TABLE 1B BI-ALKALI PHOTOCATHODES

18	40	4	1	4	1
19	1	-	-		
20	23.5	3.75	.85	4.35	1
21	34	5.	2	2.45	1
22	44	5	2	2.5	1

TABLE 1C TYPICAL S11 PHOTOCATHODES

1	58	4.1	2	2.1	1
2	75	10	2	6.3	1
3	66	5.4	1.6	3.4	1
4	58	5	1.25	4.1	1

* 2870 K source with Corning red filter No. 2418) half stock thickness
Corning blue filter No. 5113)

with a Corning 5113 blue filter and a Corning 2418 red filter (half stock thickness) between the photocathode and the luminous source. Comparative responses of typical S-11 photocathodes are shown in Table 1C. The data in Tables 1A, 1B and 1C indicate that the higher sensitivity bi-alkali photocathodes had a greater red response than those with lower sensitivities. The relative blue to red response of the high sensitivity bi-alkali photocathodes was somewhat lower than that of S-11 photocathodes.

While striving for highest possible photoresponse which would remain stable after the tube is cooled prior to tip-off, it was found that a 40% to 50% drop in photoresponse during "post activation" bake resulted in good and stable photoresponse upon cooling of the tube. In every case the photoresponse increased above the peak obtained during activation. The extensive "post-activation" bake was adapted in the finalized simplified activation schedule. Table 2 shows the sensitivities of bi-alkali photocathodes obtained with the activation schedule employing the extended "post activation" bake. The results of the same schedule with only partial "post activation" bake are shown in Table 3.

The advantageous effect of the longer post activation bake on photocathode sensitivity is evident upon comparing the values of Tables 2 and 3. The average sensitivity for cathodes listed in Table 2 is 50.6 microamperes/lumen as compared to 35.6 microamperes/lumen

TABLE 2

Bi-Alkali Photocathode

(Performance Prior to Thermal Sterilization)

	Photoresponse			Relative Photoresponse	
Tube No.	uA/L*	Blue**	Red***	Blue	Red
M-1235	40	5.2	1.1	4.7	1
M-1236	36	5	.8	6	1
M-1237	50	6.2	1.65	3.7	1
M-1238	50	5.8	1.3	4.4	1
M-1239	50	6.2	1.25	4.9	1
M-1240	65	7.5	3.0	2.1	1
M-1243	65	7.5	3.0	2.1	1
M-1244	50	6.	2.1	2.8	1
M-1245	50	5.8	2.	2.9	1

* 2870°K Tungsten source.

** 2870°K Tungsten source with Corning 5113 filter.

*** 2870°K Tungsten source with Corning 2418 filter.

TABLE 3

BI-ALKALI PHOTOCATHODES

(Performance Prior to Thermal Sterilization Cycles)

TUBE NO.	PHOTORESPONSE			RELATIVE PHOTORESPONSE	
	* uA/L.	± Blue	+ Red	Blue	Red
M-1221	45	5.0	2.0	2.5	1
M-1222	20	2.5	0.54	2.16	1
M-1223	24	3.3	1.0	3.3	1
M-1224	21	3.1	0.62	5.0	1
M-1225	30	5.0	1.0	5.0	1
	37	5.8	2.0	2.9	1
M-1228	41	5.8	1.2	4.8	1
M-1229	36	5.0	1.2	4.2	1
M-1230	41	5.0	1.4	3.6	1
M-1231	40	5.0	1.0	5.0	1
M-1232	45	5.8	1.8	3.2	1
M-1233	48	5.8	1.8	3.2	1
M-1234	35	4.1	2.3	1.8	1

* 2870°K Tungsten Source

± 2870°K Tungsten Source with Corning 5113 Filter.

\+ 2870°K Tungsten Source with Corning 2418 Filter (Half Stock Thickness) for those of Table 3. The ratios of maximum to minimum sensitivity were as follows:

Table 2 $\frac{65}{36} = 1.8$ Table 3 $\frac{48}{21} = 2.3$

The relative response of tubes listed in both tables to 2870°K light source with blue and red filters was similar.

2.2 Thermal Sterilization

Since the final product of this program was a sterilizable image dissector with a bi-alkali photocathode, the experimental photomultipliers were subjected to 6,36 hour, 145°C thermal sterilization cycles.

In order to evaluate the methods of bi-alkali cathode formation under development, the first 19 tubes to undergo thermal cycling were divided into 3 groups as follows:

Group I - photocathodes formed by initial coevaporation method.

Group II - photocathode formed by the simplified method.

Group III - photocathode formed by the simplified method with extended post activation bake.

Thermal cycling of the photomultiplier tubes was performed in an air oven with controls capable of holding the temperature at 145 ± 2°C. The temperature was recorded during each thermal cycle. The photocathode sensitivity and gain of all tubes was measured prior to and after each thermal cycle.

2.2.1 Photocathode Sensitivity

The variations in photocathode sensitivity of tubes, in each group, versus the number of thermal cycles are shown in Figures 1, 2 and 3. The decrease in photoresponse of tubes in Group I (Figure 1) was gradual throughout thermal cycling with large variations between tubes. The variations in photocathode sensitivity of tubes in Groups II and III were similar i.e. the major fall in sensitivity took place during the first cycle. Subsequent cycles resulted in small reduction in sensitivity. This behavior can be attributed to the stabilizing effect of the more controllable activation technique and the post activation bake. The gradual extension of the post activation bake contributed to the improved photocathode sensitivity and to smaller variations in sensitivity between tubes during cycling.

The results of continuous improvements in the bi-alkali cathode activation process are shown in Figure 4. The sensitivities of these four bi-alkali cathodes ranged from 25 to 35 microamperes/lumen after completion of six thermal cycles.

2.2.2 Multiplier Gain

The continuous improvement in the stability of multiplier gain is evident from Figures 5 (Group I), 6 (Group II) and 7 (Group III). As shown in Fig. 5 the gain of tubes in Group I was unstable during the major portion of thermal cycling. The effect of the

FIGURE 1

EFFECT OF 145°C THERMAL CYCLING ON PHOTOCATHODE RESPONSE

GROUP I

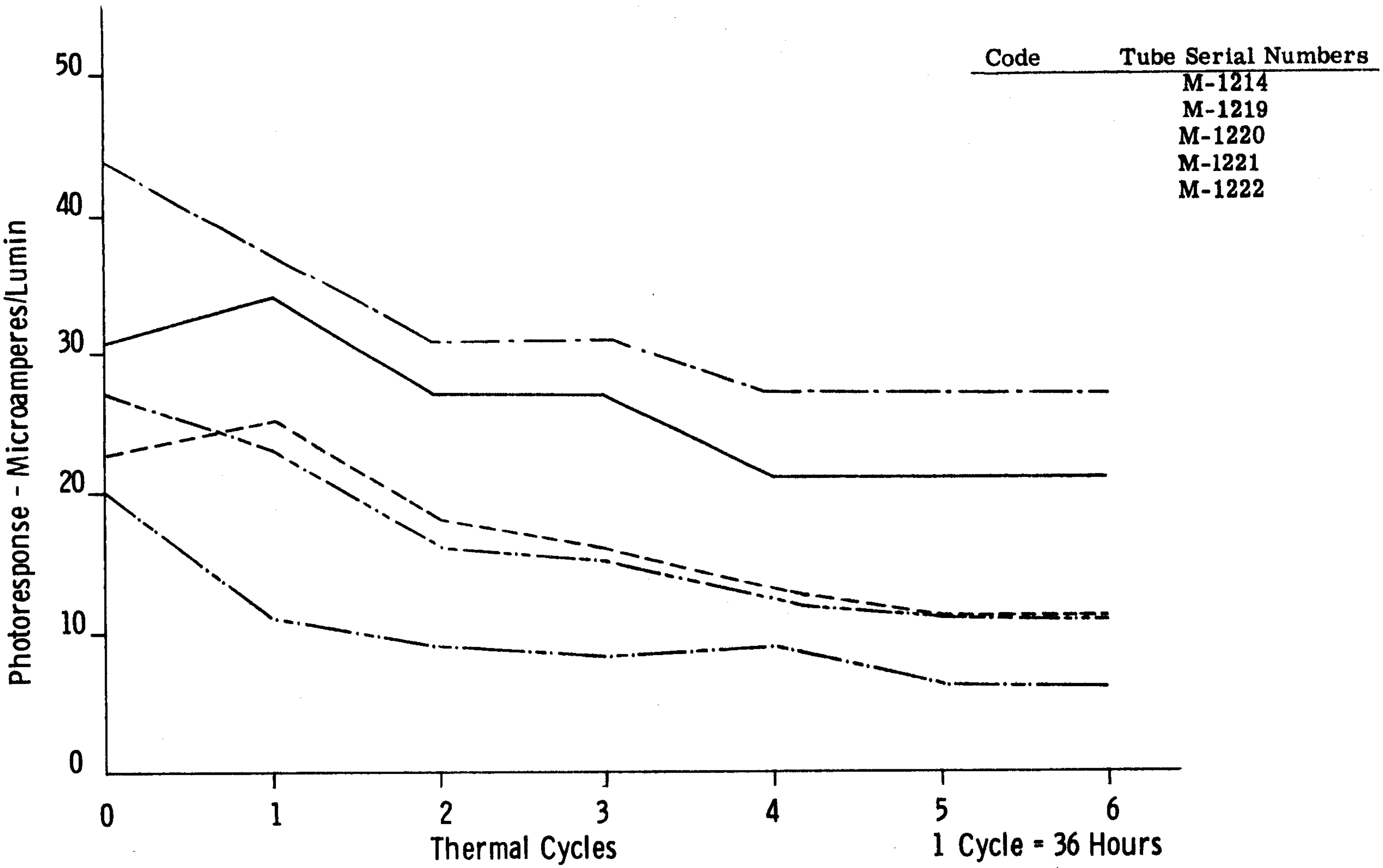


FIGURE 2

EFFECT OF 145^{o}C THERMAL CYCLING ON PHOTOCATHODE RESPONSE

GROUP II

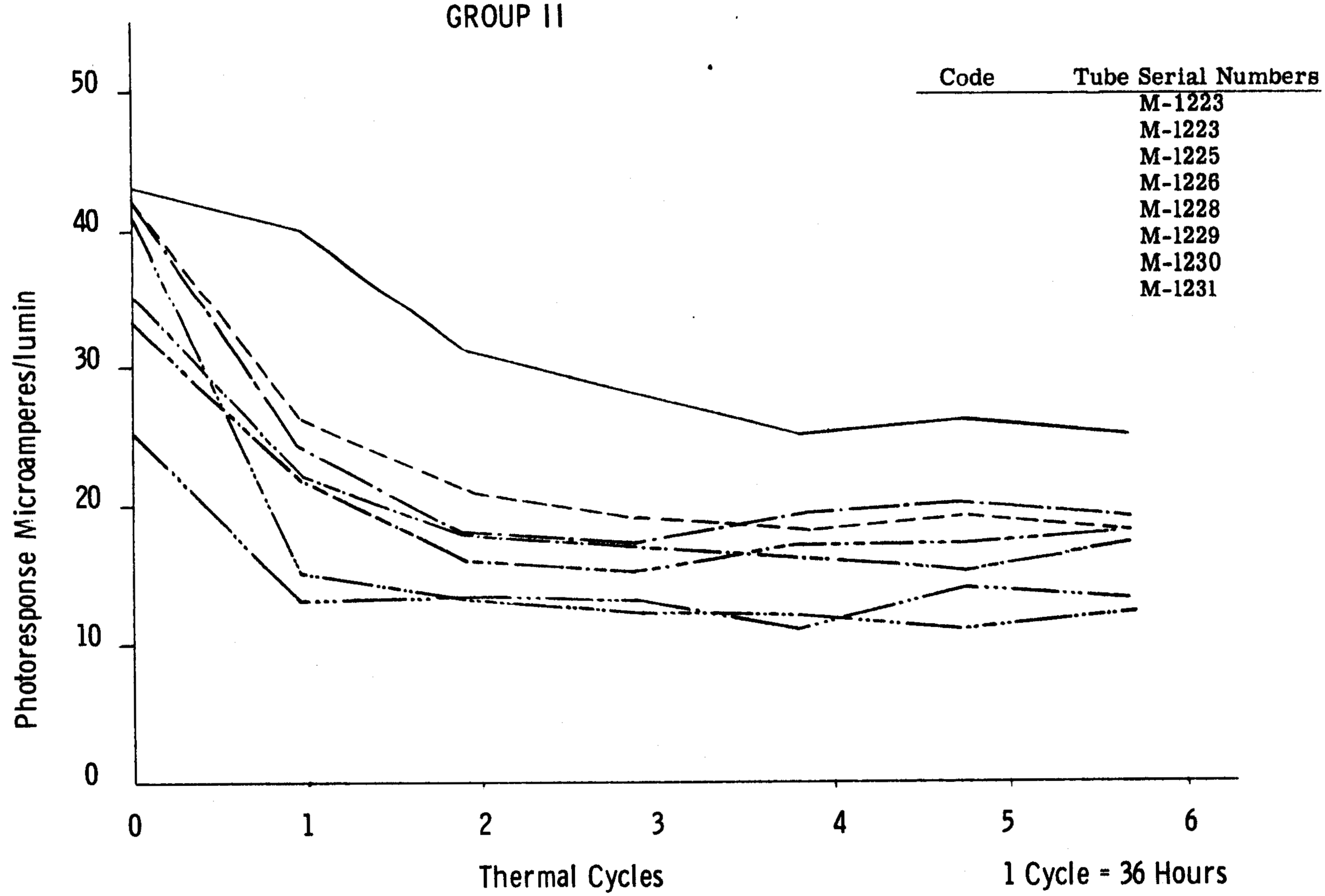


FIGURE 3

EFFECT OF 145°C THERMAL CYCLING ON PHOTOCATHODE RESPONSE

GROUP III

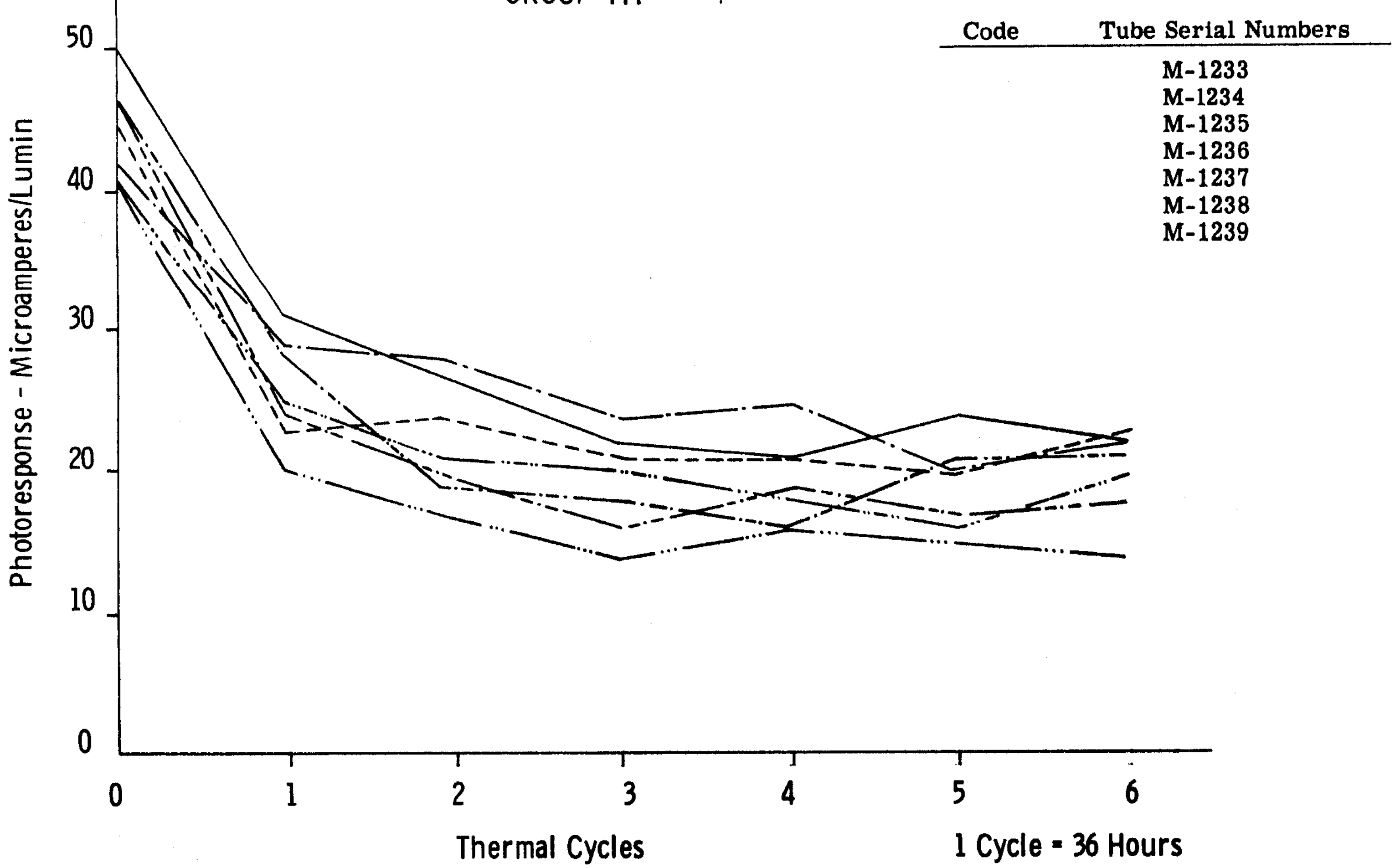


FIGURE 4

EFFECT OF THERMAL CYCLING ON PHOTOCATHODE RESPONSE

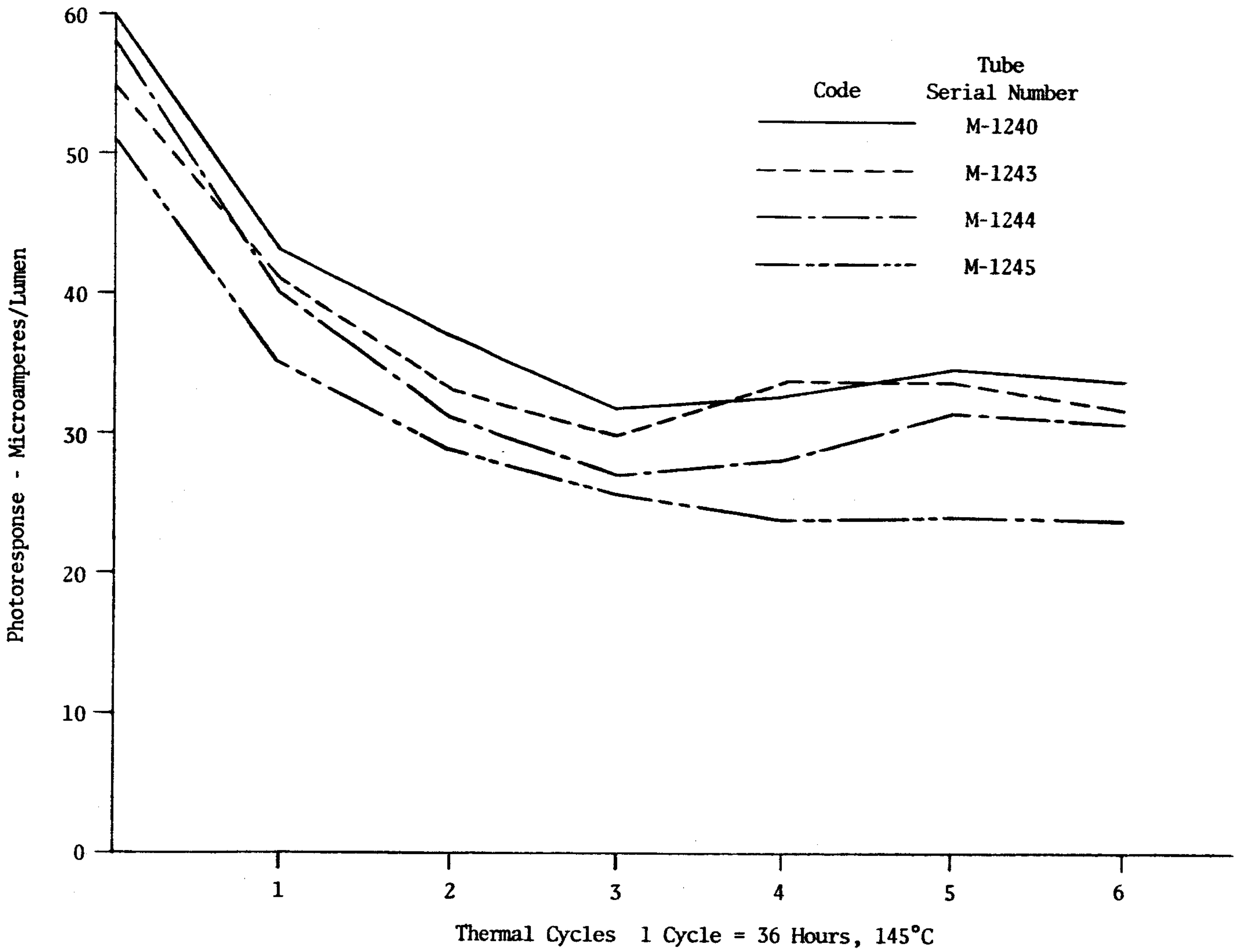


FIGURE 5

EFFECT OF 145°C THERMAL CYCLING ON MULTIPLIER GAIN

GROUP I

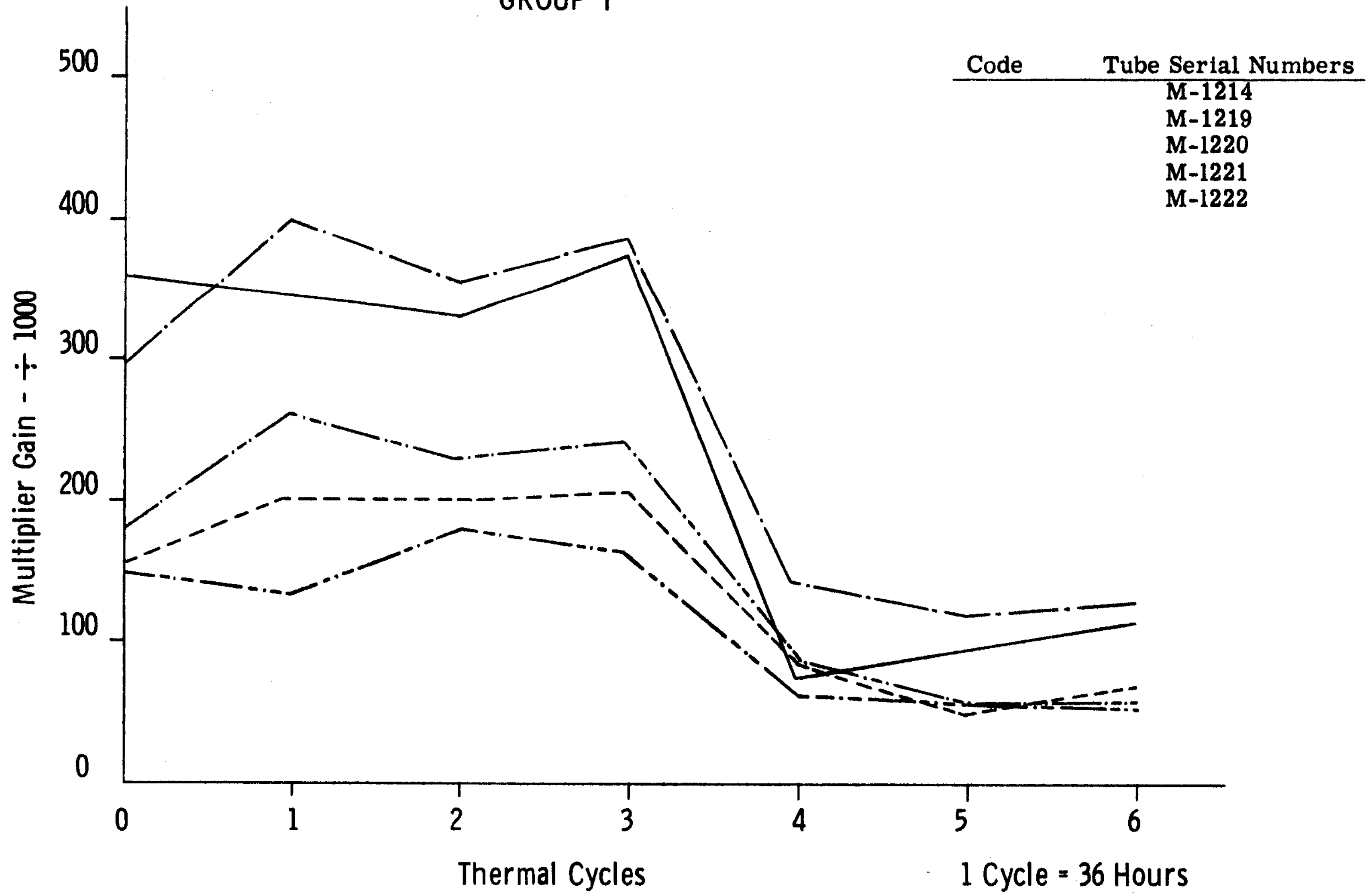


FIGURE 6

EFFECT OF 145°C THERMAL CYCLING ON MULTIPLIER GAIN

GROUP II

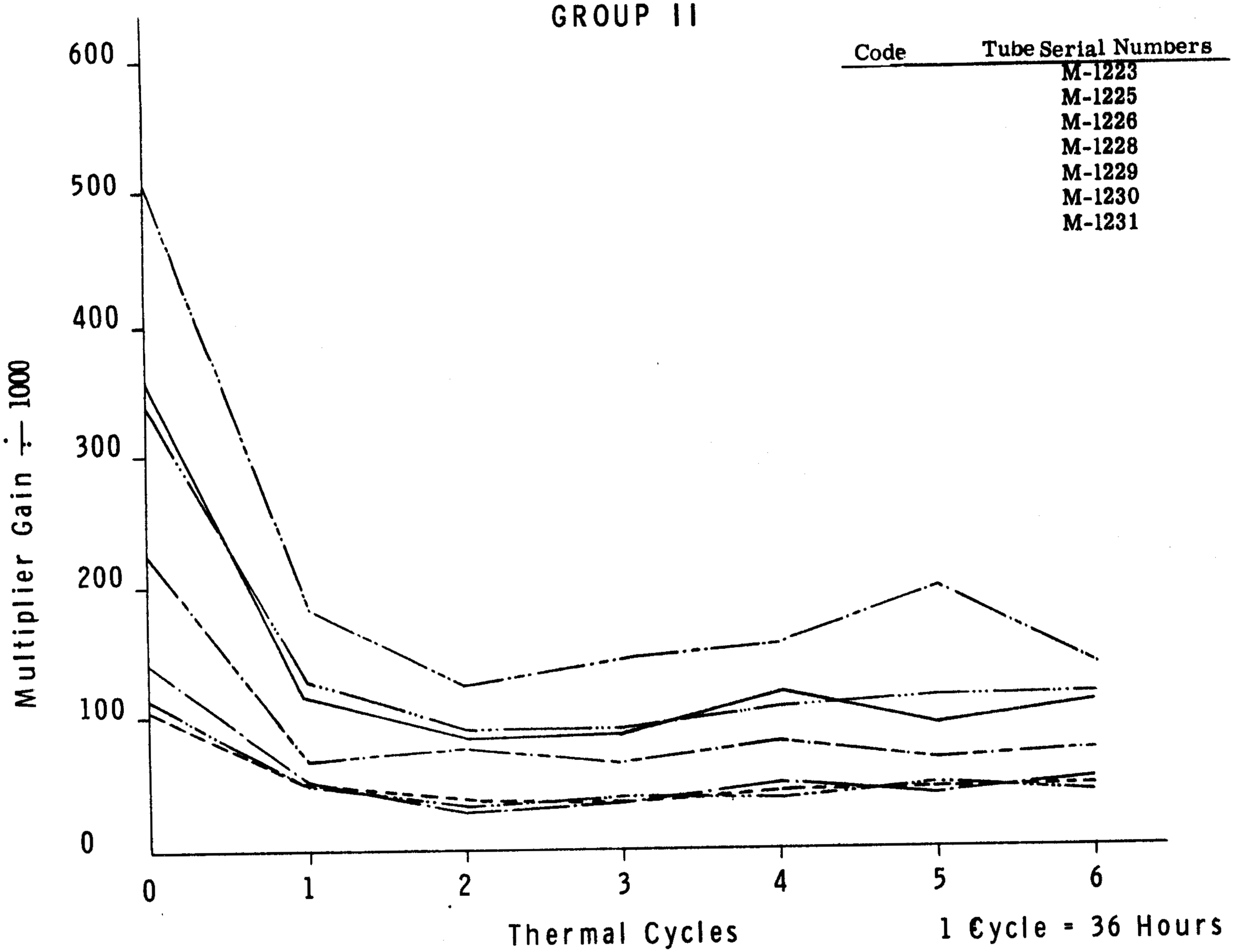
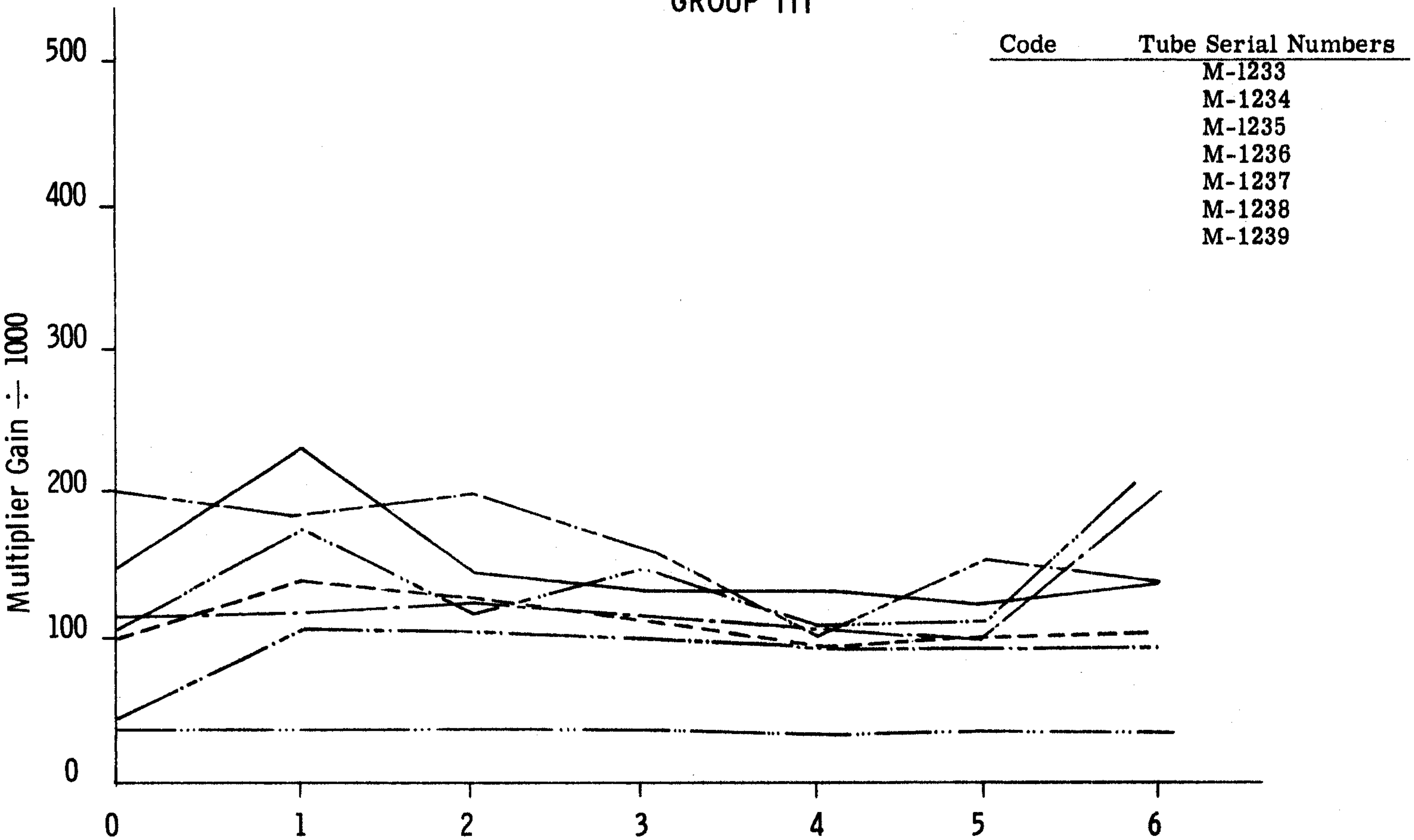


FIGURE 7

EFFECT OF 145°C THERMAL CYCLING ON MULTIPLIER GAIN

GROUP III



simplified activation schedule and the gradual extension of "post activation" bake can be seen in Figures 6 and 7. In Figure 6 the initially high gain of tubes in Group II decreased rapidly during the first thermal cycle while the gain of tubes in Group III (Figure 7) remained relatively stable from the first cycle on due primarily to the extended "post activation" bake. Further improvement in gain stability of the bi-alkali photomultiplier tubes is evidenced by Figure 8 where only minimal fluctuations in gain occurred.

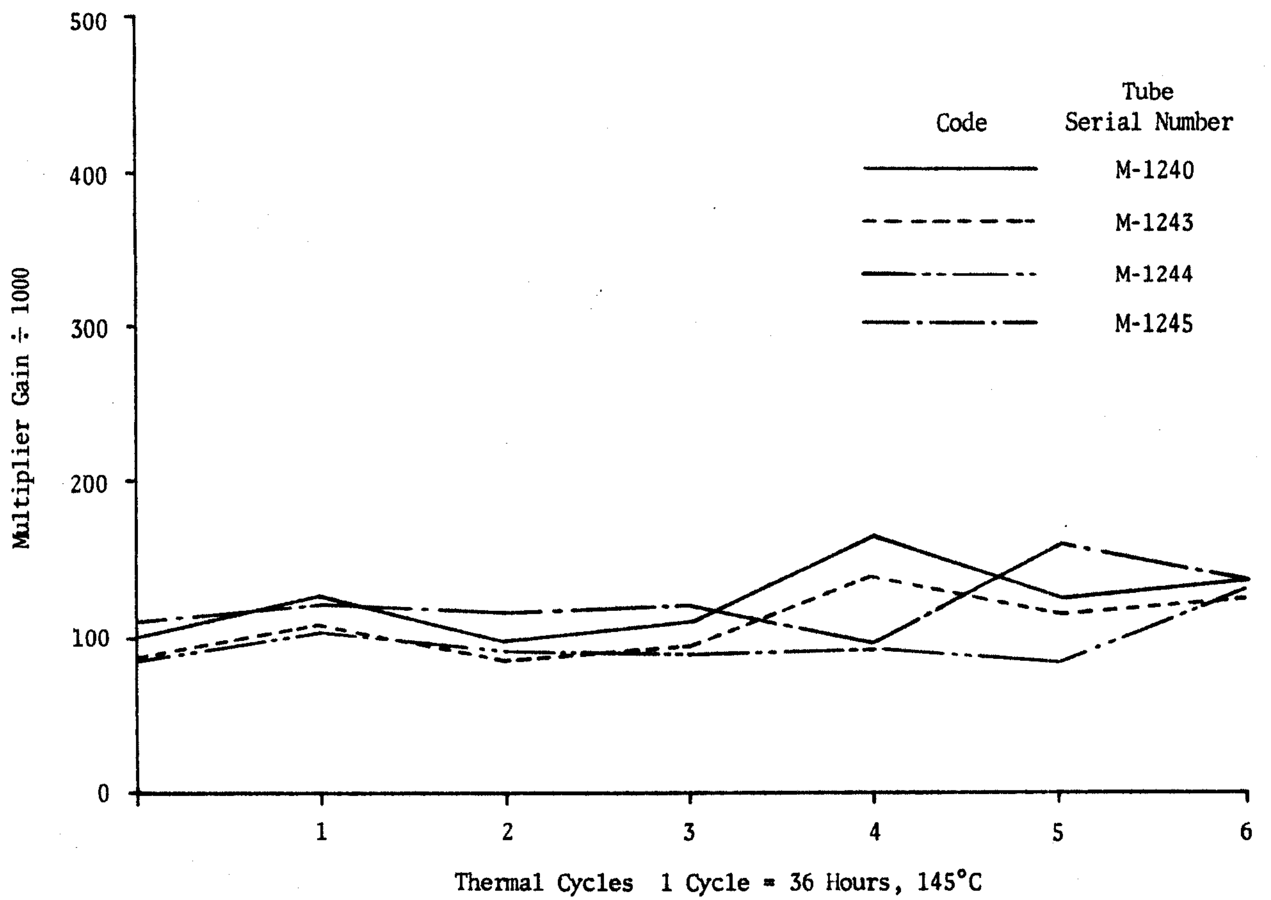
2.2.3 Spectral Response Characteristics

Limited spectral response measurements of the bi-alkali photocathodes were made during this phase of the program. Late delivery of the spectrophotometric equipment hampered the evaluation of spectral characteristics early in the program. The acquisition of a monochromator later in the program resulted in reasonably accurate evaluation of the spectral characteristics of bi-alkali photocathodes. Spectral response curves of a typical bi-alkali photocathode are shown in Figure 9. Since a suitable thermopile was not available at the time of measurements the values for the curves were computed as follows:

Using the monochromator output the spectral response of a 60 microamperes/lumen S11, photocathode was measured. Correction factors were derived with a published curve and these factors

FIGURE 8

EFFECT OF THERMAL CYCLING ON MULTIPLIER GAIN



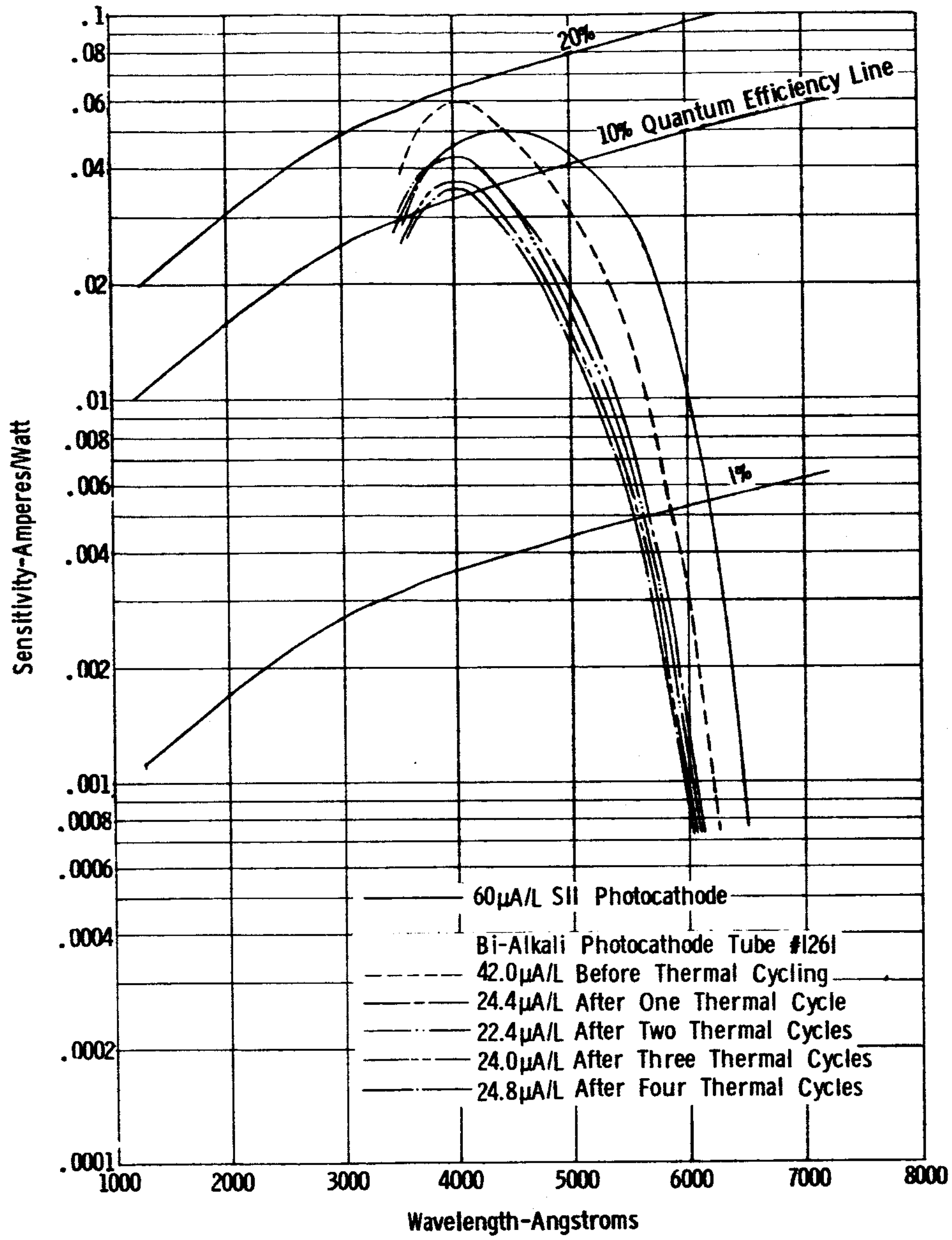


FIGURE 9

PHOTOCATHODE RESPONSE CURVES

were used in calculating the bi-alkali response curves. According to the curves the peak response of a bi-alkali photocathode occurred at 4000 Angstroms and its position was not affected by thermal sterilization. Thermal sterilization, however, caused an overall decrease in photocathode sensitivity.

3. THE BI-ALKALI IMAGE DISSECTOR

3.1 Image Dissector Fabrication

Fifteen image dissectors incorporating the design improvements resulting from work undertaken under JPL Contract No. 950508 were assembled during this program. The design improvements included the integrated anode/deflection cone, the new focus electrode and the modified faceplate mounting. During the program quality assurance was performed as an engineering function and the necessary standards,required to perform this work, were maintained. This approach was followed in order to minimize the difficulties which can occur in the transferring of the developmental processes into a program requiring the rigorous quality assurance procedures associated with flight hardware.

3.2 Exhaust and Test Results

All fifteen tubes were exhausted and processed according to specified procedures. In order to minimize the residual gas pressure each tube was exhausted with an auxiliary ion pump which was sealed off after post exhaust aging. The formation of the bi-alkali photocathodes was performed according to the simplified schedule with extended "post activation" bake developed in the 2" photomultipliers. Although the same schedule was used it was necessary to adapt it to the geometry of the image dissector.

This involved changes in alkali elements deposition rates, generator outgassing rates, and post activation bake.

Out of 15 completed tubes 3 were rejected due to the following reasons:

Tube No. M1284	low photoresponse (7 microamperes/lumen)
Tube No. M1298	became gassy after tip off due to undetected leak. All tubes are checked for leaks prior to exhaust, however, the sensitivity (10^{-12}c.c/sec) of modern instruments does not permit the location of smaller leaks which can easily cause the failure of a tube over a short period of time.
Tube No. M1308	an excess of antimony due to an uncontrolled evaporation

The remaining 12 image dissector tubes had an average initial photocathode sensitivity of 41 microamperes/lumen. The values ranged from 25 microamperes/lumen to 56 microamperes/lumen. The initial photomultiplier gains at 125 volts/stage ranged from 1.2×10^6 to 9.5×10^6 with an average gain of 5.4×10^6. Ten image dissectors were designated for ethylene oxide and thermal sterilization cycling. The tubes with their corresponding aperture sizes are listed below.

Tube No.	Aperture Size
M1296	.005" x .137"
M1297	.0035" dia. round
M1299	.026" x .144"
M1306	.026" x .144"
M1307	.0035" dia. round
M1309	.005" x 137"
M1310	.0035" dia. round
M1312	.0035" dia. round
M1319	.0035" dia. round

3.2.1 Deflection Plate and Aperture Alignment

In all tubes employing rectangular apertures the alignment was within 1° comparing favorably with the 5° called for in JPL Spec. GMO-50391-DSN.

3.2.2 Electromechanical Null Accuracy

The geometric center of the electron aperture with reference to the outside window ring of the photocathode was measured in 7 tubes. In 6 out of 7 tubes the center of the electron aperture was within the specified .030". The tube which did not meet the specification had an excentricity of .054". Considering the accuracy of equipment used in making the measurements it is believed that the values obtained should be considered as approximations only.

3.2.3 The Electronic Spot Size

The electronic spot size measurements were made according to the following method. With the image section potential of 700 volts and the focus electrode voltage adjusted for maximum resolution at the center of the photocathode a small circular spot of light (.001" diameter) was focused on the photocathode and moved along the horizontal, vertical and diagonal diameters of the photocathode up to .4 inches away from the tube axis. Because of the plano-concave shape of the faceplate the spot was refocused optically at every point on the photocathode where spot measurements were made. At each of these points the spot was moved across the aperture until the anode output decreased to 20% of its maximum value. The distance between the 20% amplitude points less the effective aperture width or length, depending whether the spot was moved vertically or horizontally, was taken as the spot diameter. The measurements were made for both vertical and horizontal diameters in order to determine the shape of the spot. According to the measurements the spot remained circular in shape at up to 0.4 inches from the center of the photocathode. The curves of Figure 10 show the variations in electronic spot size as functions of displacement from center of the photocathode. The electronic spot size in the center of the tube was .0025 - .003 inches in diameter. This is somewhat smaller than the minimum spot size observed in similar tubes with S-11 (see curve) type photocathodes. Some improvement was expected since the higher work function of the bi-alkali photocathode results in a reduction in the energy spread of the emitted photoelectrons and therefore a reduction in the effect of the chromatic aberration of the imaging system.

The rapid increase of the electronic spot size at points greater than 0.3 inches from the tube axis is attributed to multiple reflections between the curved cathode surface and the flat outer surface of the faceplate and to electronic distortion of the electron beam originating at the peripheral areas of the photocathode.

3.2.4 Deflection Sensitivity and Linearity

The deflection sensitivity in all tubes was greater than the specified

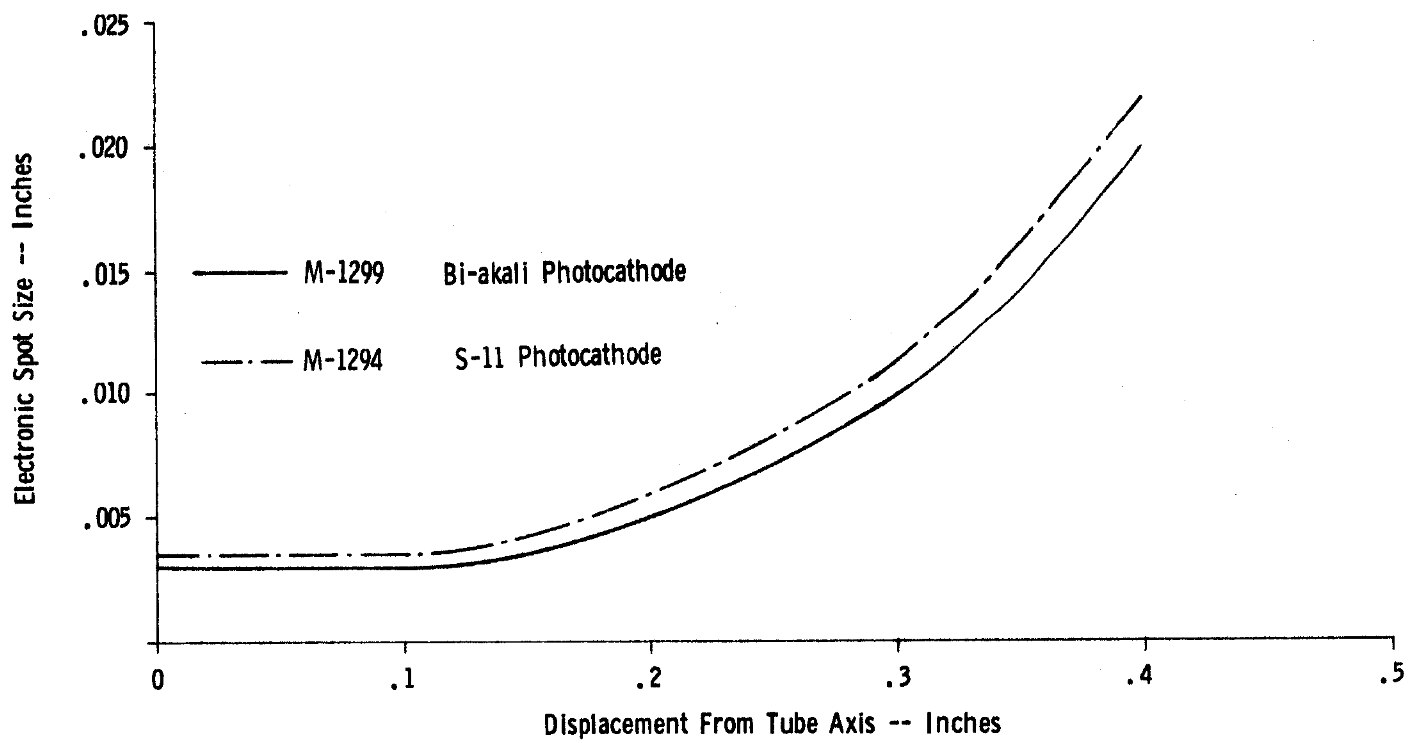


FIGURE 10
TYPICAL ELECTRONIC SPOT SIZE VS DISPLACEMENT AT PHOTOCATHODE

0.0016 inch per volt with an accelerating potential of 700 volts. The average deflection sensitivity was 0.00185 inch per volt per 700 volts of accelerating potential. The linearity of deflection plate voltage with respect to the position of the electronic spot was within 1% in all tubes.

3.2.5 Photocathode Fatigue

Photocathode fatigue tests were performed on 9 image dissectors with bi-alkali photocathodes. The test consisted of exposing the photocathode to 2500 ft-C, 2870°K, uniform illumination, for 60 seconds. The image section potential during exposure was 700 volts. The photocathode sensitivity was measured just before the test and one hour after exposure. The results of these measurements are listed in Table 4.

3.2.6 Drift Measurements

Using the new drift tester 4 tubes were subjected to the short term deflection stability test of up to 18 hours duration. There was no drift detected in any of the four tubes tested.

3.3 Ethylene Oxide Sterilization Cycling

Ten image dissector tubes with bi-alkali photocathodes, were subjected to six, 24 hour ethylene oxide sterilization cycles. The ethylene oxide sterilization was performed at the American Sterilizer Company

TABLE 4

PHOTOCATHODE FATIGUE TEST RESULTS

Tube No.	Photocathode Signal Current in Microamperes			Photocathode Dark Current in Microamperes	
	Before Exp.	1 Hr. after Exp.	Ratio $\frac{max}{min}$	Before Exp.	1 Hr. after Exp.
M1296	.032	.028	1.14	zero	zero
M1297	.0275	.027	1.02	zero	zero
M1299	.15	.145	1.03	.018	.018
M1307	.0665	.066	1.008	zero	zero
M1309	.0630	.054	1.16	zero	zero
M1310	.165	.165	zero	zero	zero
M1311	.0308	.025	1.2	zero	zero
M1312	.11	.105	1.045	zero	zero
M1319	.38	.375	1.014	zero	zero

Laboratories, in Erie, Pennsylvania. The tubes, each with attached thermocouple, were placed in loosely covered stainless steel trays. The trays were then placed inside the sterilization chamber. The temperature of each tube, the humidity and the ethylene oxide concentration in the chamber were recorded during each of the six, 24 hour, sterilization cycles.

The conditions in the sterilization chamber during cycling were as follows:

Temperature	$50°C \pm 2°$
Humidity	$35\% \pm 5\%$
Ethylene Oxide concentration	450 mg/liter $^{+50}_{-0}$ mg/liter

The leakages between tube elements were measured before and after each sterilization cycle and more extensive testing was performed after completion of all six sterilization cycles. The results of tests performed before and after sterilization are listed in Table 5. According to the results the photocathode sensitivity of four tubes was not affected by sterilization cycling. A decrease in photocathode sensitivity, of 5% to 10% was observed in four tubes. The remaining two tubes No.'s M1297 and M1296 had their photocathode sensitivities lowered by 13% and 24% respectively.

The decrease in photocathode uniformity varied between 0 and 10% except for tube No. M1296 which was the first tube with a bi-alkali photocathode made under this program. The photocathode uniformity of this tube decreased from 83% to 12%. The gain and dark current

TABLE 5

TUBE TEST DATA (Before and after sterilization)

Tube #	P.C. Sensitivity uAmps/Lumen		P.C. Response Uniformity %		Gain at 125 V/ST		Anode I Dark at 125 V/ST Amps		Overall Response Uniformity %		Dynode Uniformity %	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
<u>M1296</u>	56	42.5	83	12	$8.7x10^{6}$	$3.1x10^{6}$	$6.7x10^{-8}$	$2x10^{-8}$				
<u>M1297</u>	50	45.5	85	79	$9.5x10^{6}$	$5.5x10^{7}$	$2.7x10^{-9}$	$4x10^{-9}$				
<u>M1299</u>	55	51	91	83	$2.5x10^{6}$	$1.6x10^{6}$	$8.3x10^{-8}$	$5x10^{-8}$	66	71	79	80*
<u>M1306</u>	46	41	85	80	$1.2x10^{6}$	$4.9x10^{7}$	$4x10^{-7}$	$2.6x10^{-7}$	58	4	83	80*
<u>M1311</u>	36	32.5	79.5	79	$7.0x10^{6}$	$7.3x10^{6}$	$4x10^{-8}$	$3.6x10^{-8}$				
M1307	25	25	35	34	$2x10^{4}$	$2.26x10^{4}$	$1.9x10^{-9}$	$2x10^{-9}$				
M1309	35	35.5	42.4	46	$2.4x10^{6}$	$2.1x10^{7}$	$1.5x10^{-8}$	$1.2x10^{-8}$				
<u>M1310</u>	43.5	43.4	89	80	$1.25x10^{7}$	$1.27x10^{7}$	$1.1x10^{-8}$	$2.5x10^{-9}$				
M1312	38.5	38.5	74	78	$8.4x10^{5}$	$8.7x10^{5}$	$3.5x10^{-9}$	$1.8x10^{-9}$				
<u>M1319</u>	30	28.5	81	82.5	$6.47x10^{6}$	$8.0x10^{6}$	$3.9x10^{-9}$	$2.1x10^{-9}$				

The underlined numbers indicate tubes which met the JPL Specifications before sterilization.

* Measured as per JPL Spec. No. 31163A - Paragraph 4.1.5.

improved slightly in most tubes and the interelectrode resistances of the tubes were not affected by the sterilization cycling.

As expected the ethylene oxide sterilization did not effect the spectral characteristics of the bi-alkali photocathodes. Figures 11 through 13 show relative spectral response curves measured before and after sterilization.

Apart from Tube M1296, the changes recorded in tube performance are of a magnitude which might normally be expected during initial shelf life aging.

3.4 Thermal Sterilization

Following the ethylene oxide sterilization the same 10 image dissector tubes were subjected to six 92 hour 135°C thermal cycles. During the thermal cycling the faceplate temperature of each tube was continuously monitored with thermocouples and a multichannel chart recorder. Tests of major parameters, were performed prior to and after each consecutive cycle.

3.5 The Effect of Thermal Sterilization on Tube Characteristics

3.5.1 Photocathode Sensitivity

As shown in Figure 14 the photocathode sensitivity of 9 tubes decreased during the thermal cycling. The factor by which the sensitivity decreased varied, the smallest being 1.5 and the

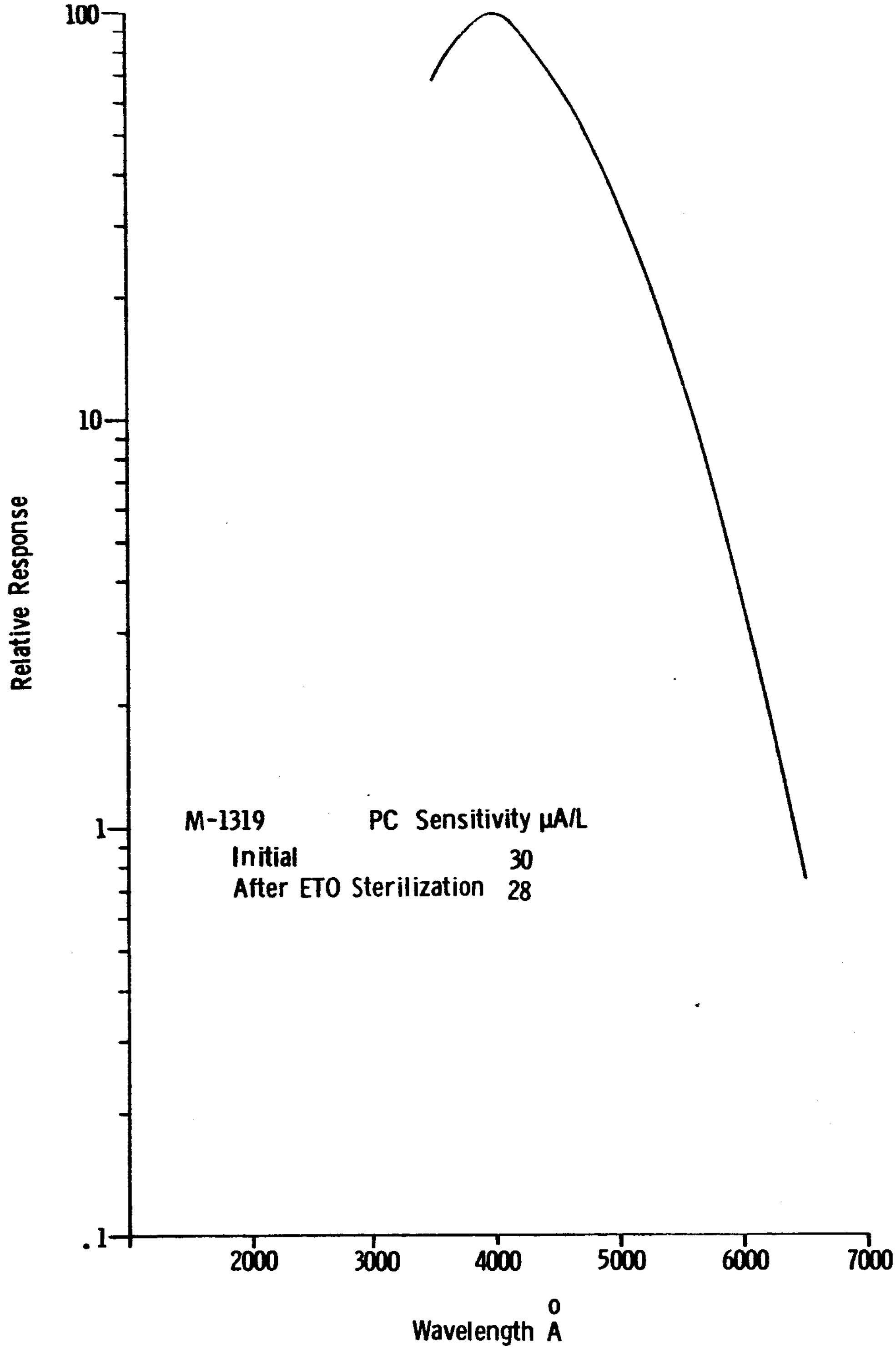


FIGURE 11
PHOTOCATHODE SPECTRAL RESPONSE CURVES

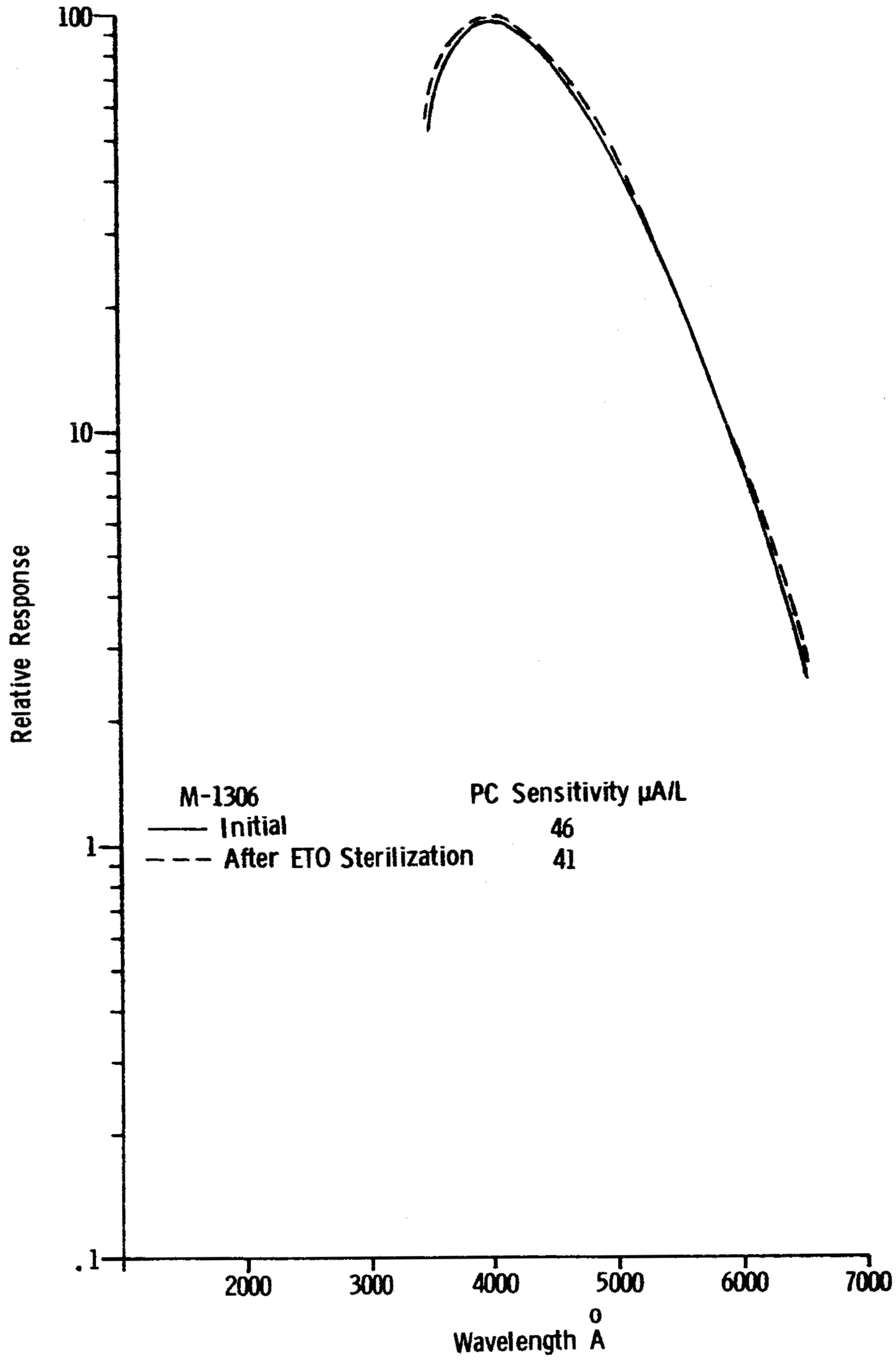


FIGURE 12
PHOTOCATHODE SPECTRAL RESPONSE CURVES

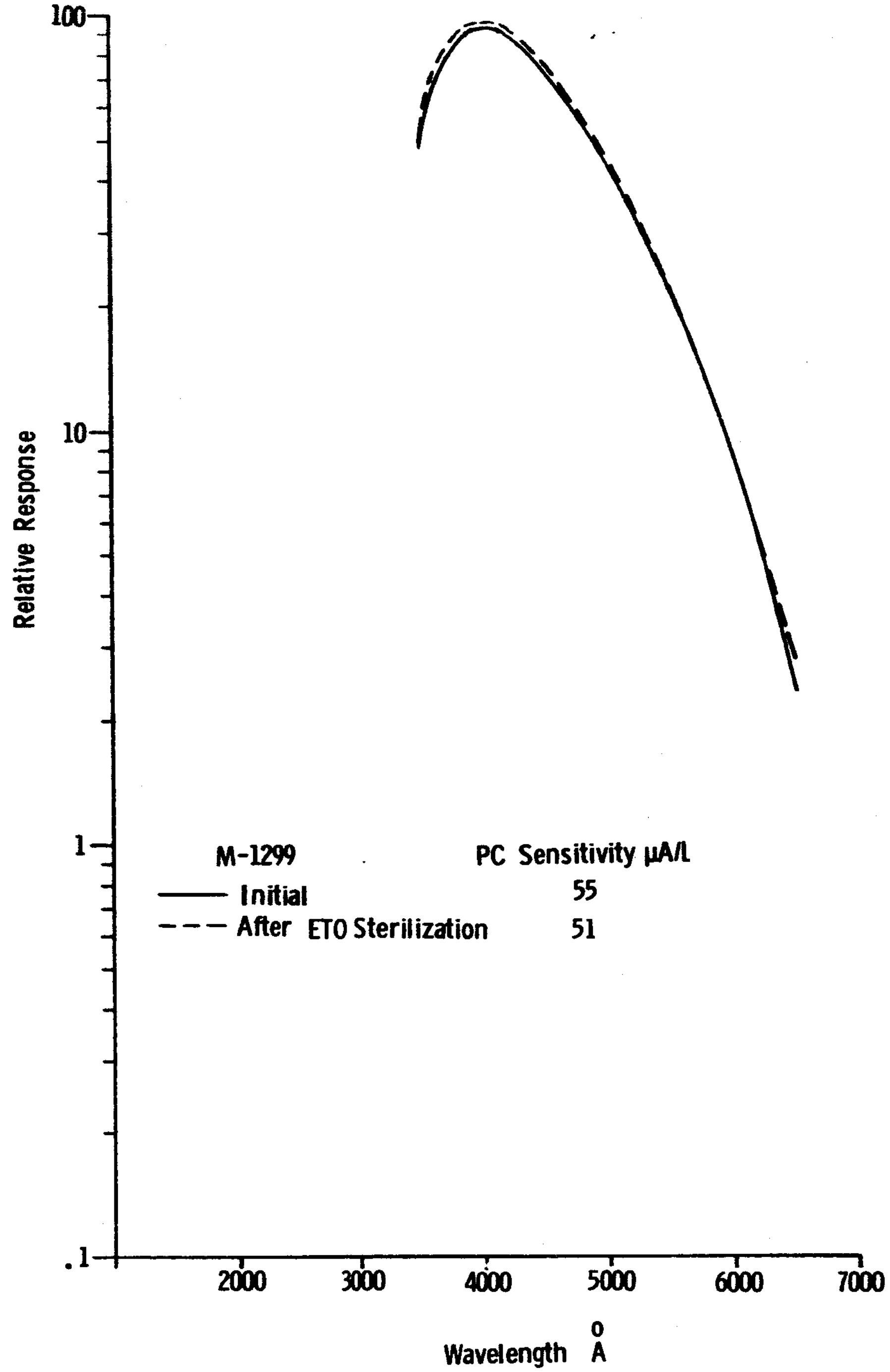


FIGURE 13
PHOTOCATHODE SPECTRAL RESPONSE CURVES

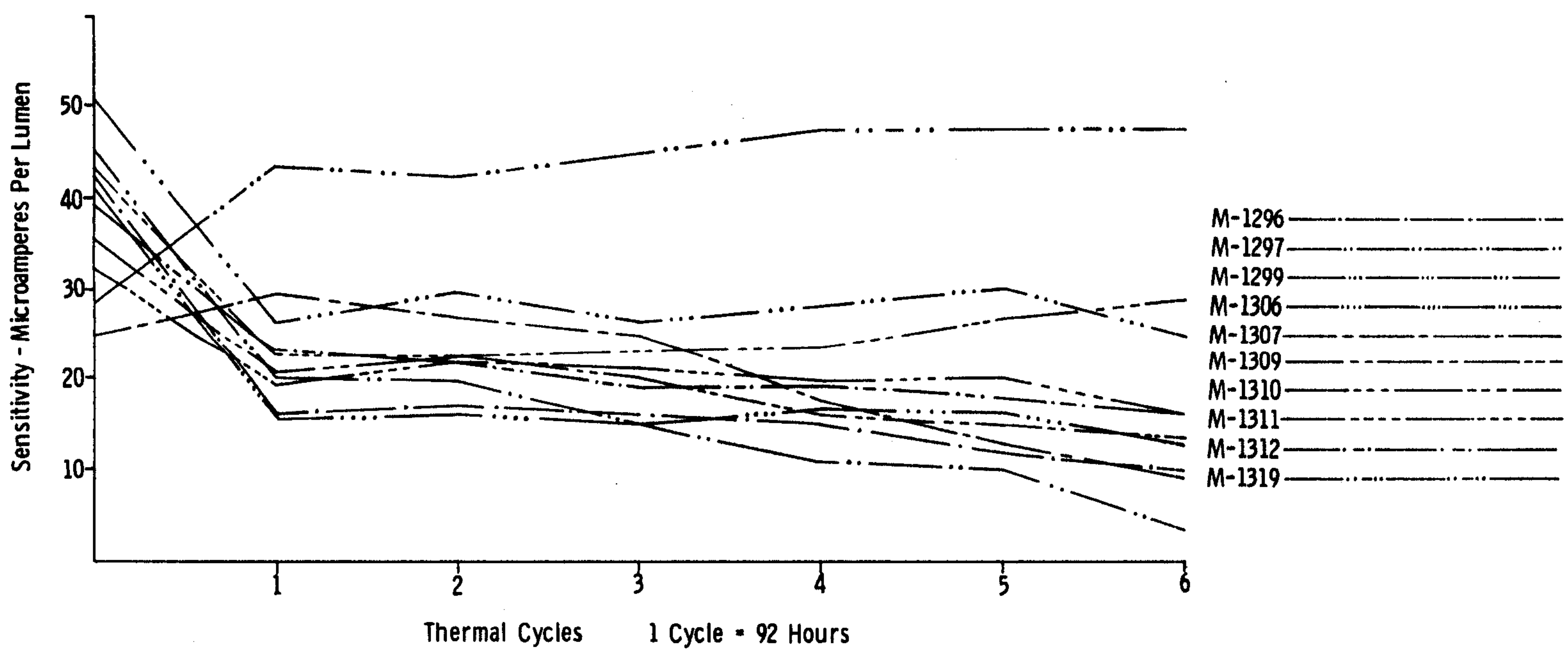


FIGURE 14
EFFECT OF 135° C THERMAL CYCLING ON PHOTOCATHODE SENSITIVITY

largest 13. Excluding the tube with the factor of 13, the photocathode sensitivity of 8 tubes decreased by an average factor of 2.6. The largest decrease in photocathode sensitivity was caused by the first thermal cycle. The photocathode sensitivity of Tube No. M1319 increased from 28.5 to 43.5 microamperes per lumen after the first thermal cycle, reached 47.4 microamperes per lumen after the fourth cycle and thereafter remained at this value.

Tube M1319 is evidently an exception and worthwhile considering since this tube was subjected, somewhat by chance, to a different processing schedule. During the early stages of the activation process an excess of antimony and potassium was deposited on the photo surface. Because of this the tube was subjected to a further high temperature bake and then reprocessed using the regular activation procedure.

The activation was not abandoned when the excess of antimony was deposited since we had found in earlier work with multi-alkali photocathodes, that the deposition of cathode material and the subsequent high temperature bake prior to activation resulted in an improvement of photocathode sensitivity. This approach was discontinued when later development work resulted in further increases of sensitivity.

The general decrease in photocathode sensitivity caused by thermal cycling, was expected since similar photocathode behavior had been observed, earlier, in the program when bi-alkali photomultipliers were being subjected to 36 hours, 145°C thermal cycles.

3.5.2 Photocathode Response Uniformity

The effect of thermal cycling on photocathode response uniformity is shown in Figure 15. As in the case of cathode sensitivity, Tube #M1319 behaved exceptionally well. This, however, does not apply to other tubes, which show large variations in photocathode response uniformity. The major changes occurred during the first and second thermal cycles.

The net results of completed thermal cycling was a decrease of photocathode uniformity in 6 tubes and an increase in 3 tubes. The cathode response uniformity of Tube #M1319 remained constant.

3.5.3 Dynode Uniformity

The dynode uniformity of image dissectors remained relatively constant throughout the thermal cycling with only small fluctuations occurring during each cycle. Figure 16 shows dynode uniformity variations versus the number of thermal cycles.

3.5.4. Electron Multiplier Gain and Anode Dark Current

Figure 17 shows that a significant reduction in the spread of gain

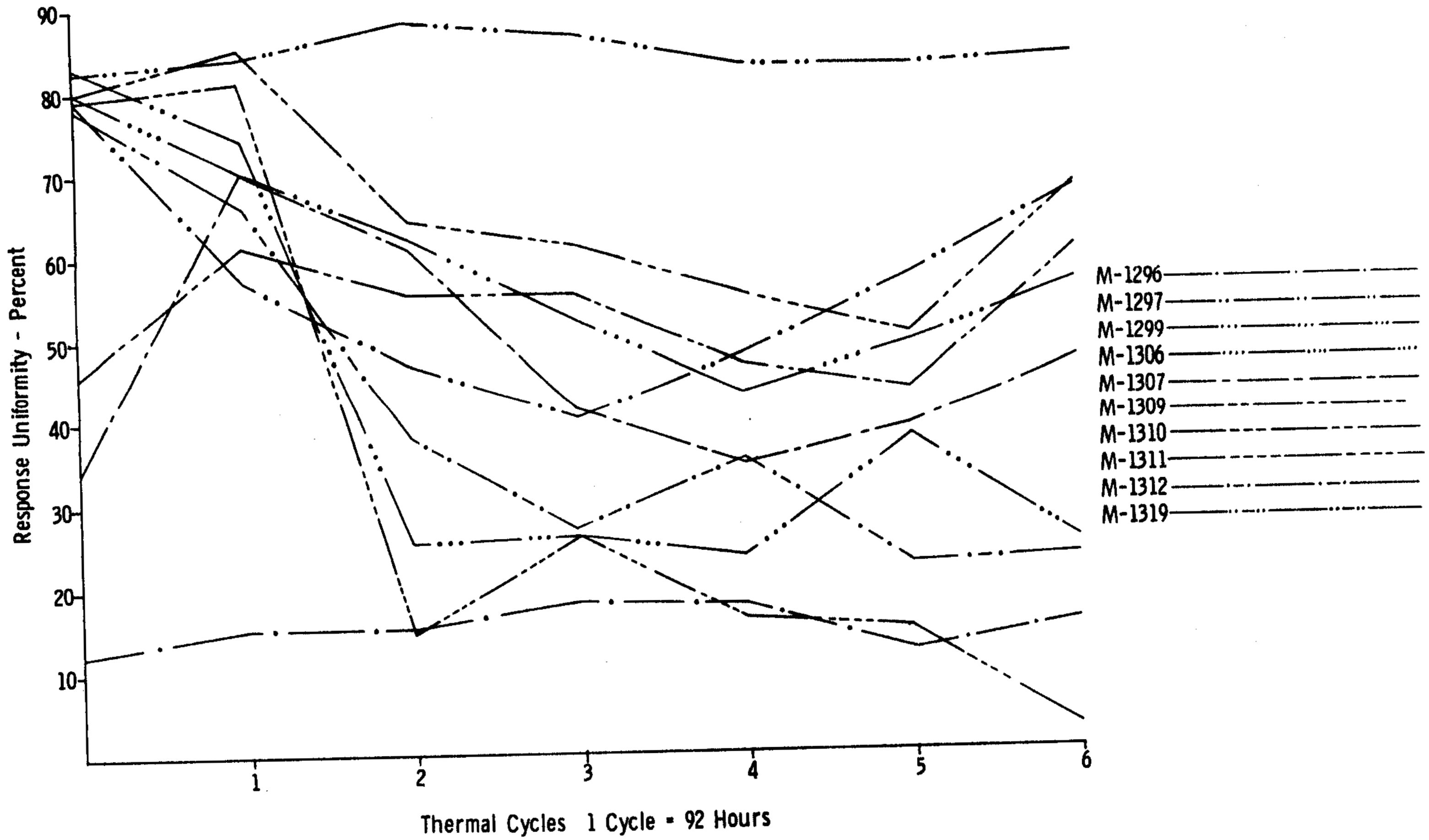


FIGURE 15

EFFECT OF 135°C THERMAL CYCLING ON PHOTOCATHODE RESPONSE UNIFORMITY

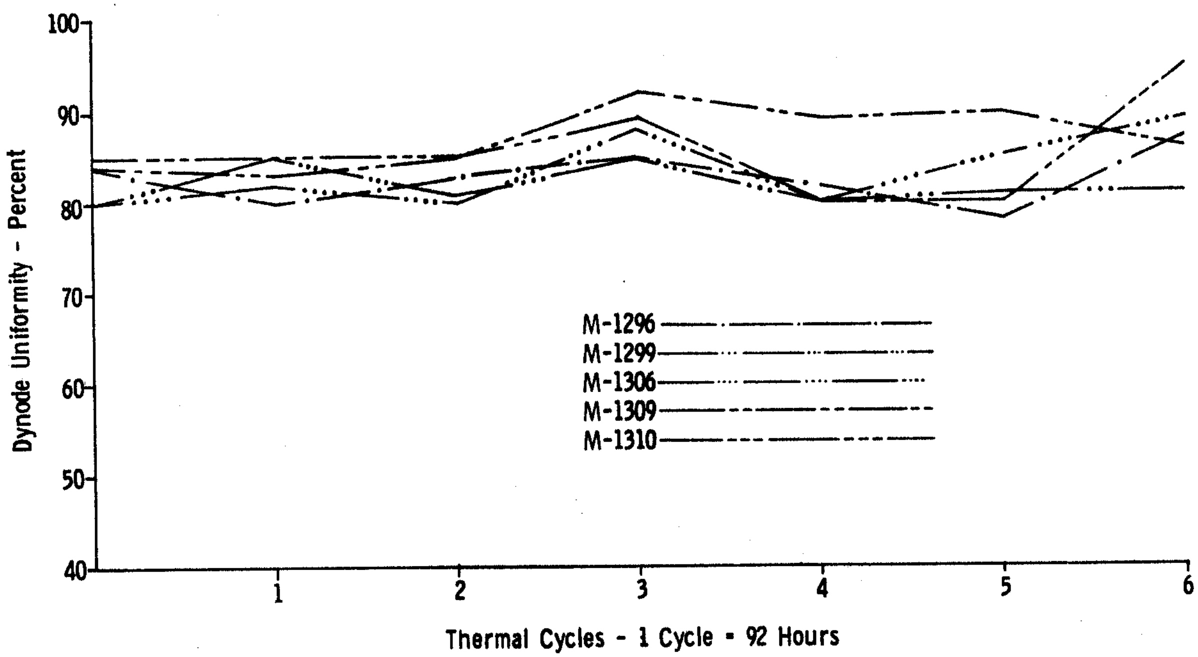


FIGURE 16

EFFECT OF 135° C THERMAL CYCLING ON DYNODE UNIFORMITY

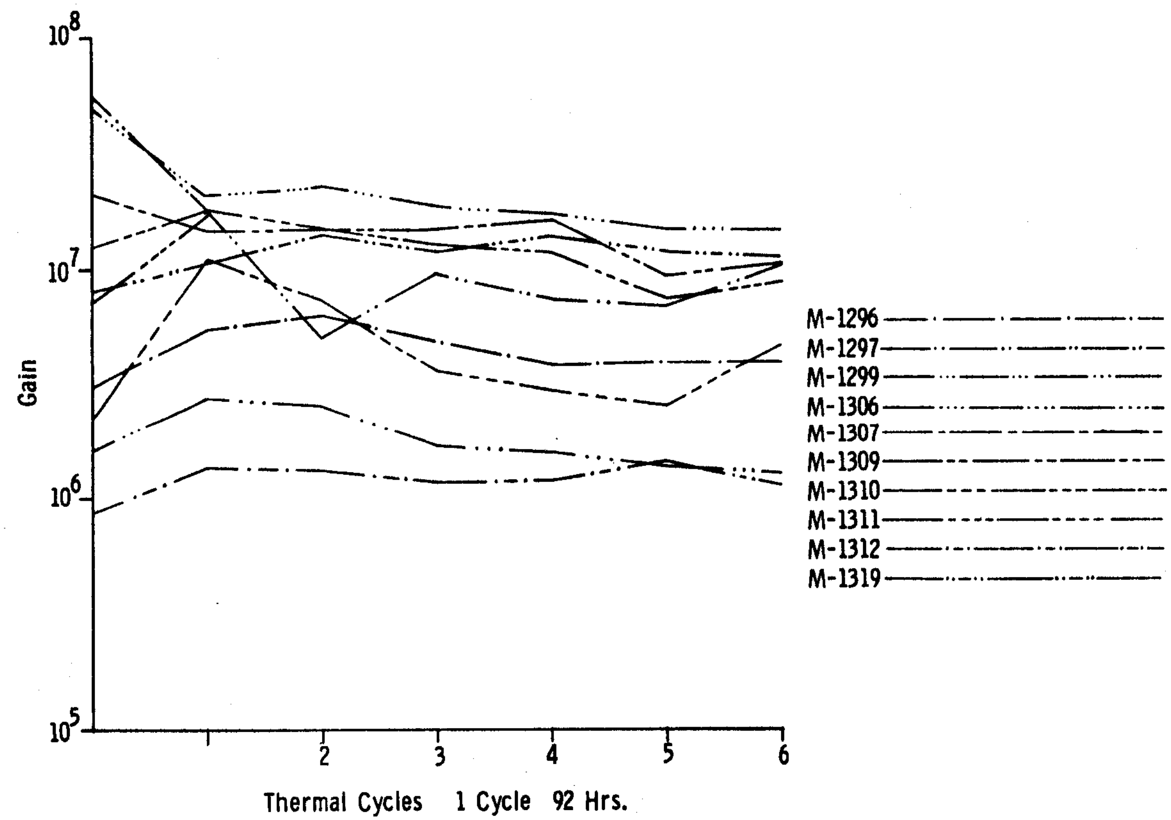


FIGURE 17
EFFECT OF 135° C THERMAL CYCLING ON GAIN AT 125 VOLTS/STAGE

occurred during the thermal cycling. The gain of the tubes changed during cycling, on average, by a factor of 2 with the major change occurring during the first cycle. The effect of thermal cycling on anode dark current is shown in Figure 18. As in the case of gain, a reduction in spread of dark current values occurred during thermal cycling. The final values of anode dark current of all tubes varied from 2.2×10^{-9} to 7.1×10^{-9} amperes while the initial values before thermal cycling ranged from 2.6×10^{-7} to 1.8×10^{-9} amperes.

3.5.5. <u>Overall Response Uniformity</u>

Two different methods were employed to measure the overall response uniformity of the tubes. Tube No's M1299 and M1306 with large (.030 x $.160^{6}$) apertures had their response uniformity measured according to Paragraph 3.4.5 of JPL Specification GMO-50391 DSN. The overall response uniformity of four tubes with .0035" diameter apertures was measured according to the method described below.

With the photocathode uniformly illuminated the electronic spot is scanned horizontally across the photocathode. The resulting line scan is then moved slowly in the vertical direction covering the entire photocathode and the amplitude of signal output is monitored with an oscilloscope.

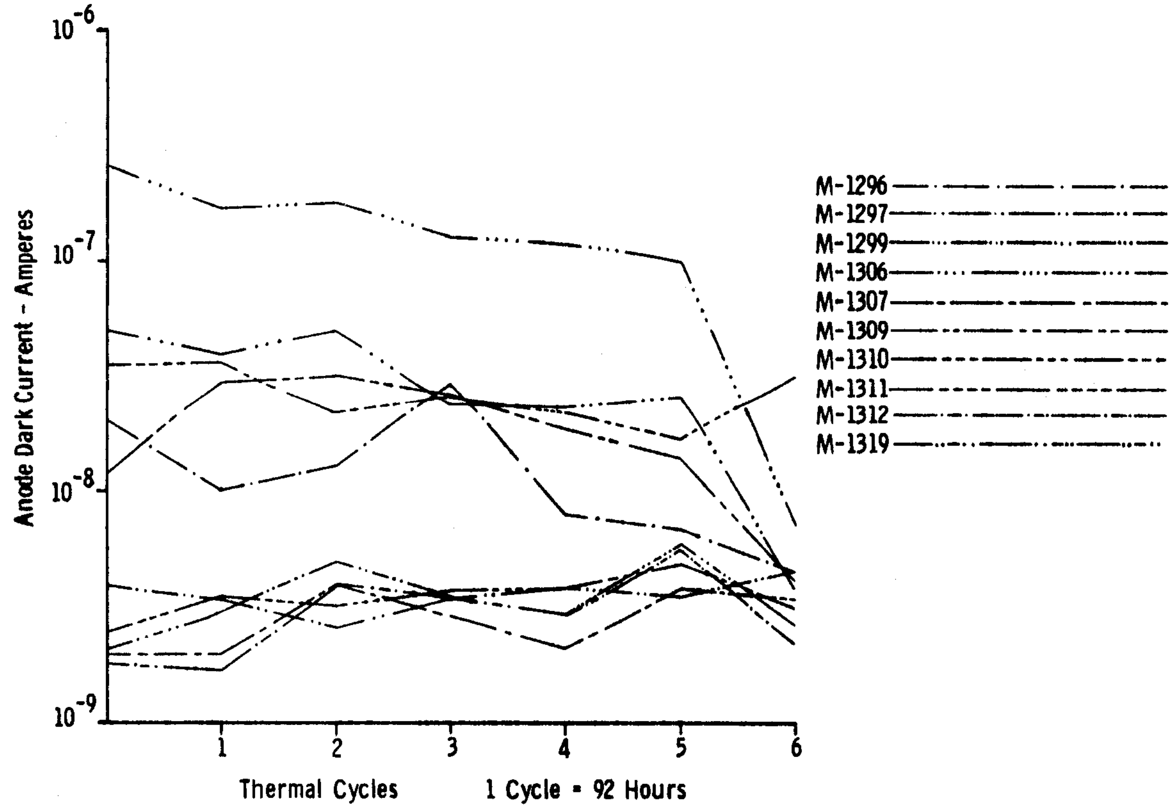


FIGURE 18

EFFECT OF THERMAL CYCLING ON ANODE DARK CURRENT AT 125 VOLTS/STAGE

According to Figure 19 the response uniformity deteriorated in all the tubes tested, including Tube No. M1319 although the rate of uniformity decrease in this tube was smallest. The data demonstrates that the fall in overall response uniformity was due almost entirely to the fall in cathode uniformity.

3.5.6 Spectral Response Characteristics

Figures 20, 21 and 22 show spectral response characteristics of image dissectors with bi-alkali photocathodes measured initially and after 1 and 6 thermal cycles. According to the curves, the spectral response of image dissector bi-alkali photocathodes was only slightly affected by thermal cycling.

The peak spectral response in Figure 20 shifted from 4000 Å to 4300 Å during the first thermal cycle and remained at this value after the last cycle. Much smaller shift in peak response (4000 to 4100K) occurred with the curve of Figure 21.

The photocathode of Tube No. M1319 behaved somewhat differently as seen in Figure 22. Here, the response increased slightly in the longer wavelength region beginning at 4900 angstroms. The peak response however remained at about 4000 angstroms throughout thermal cycling.

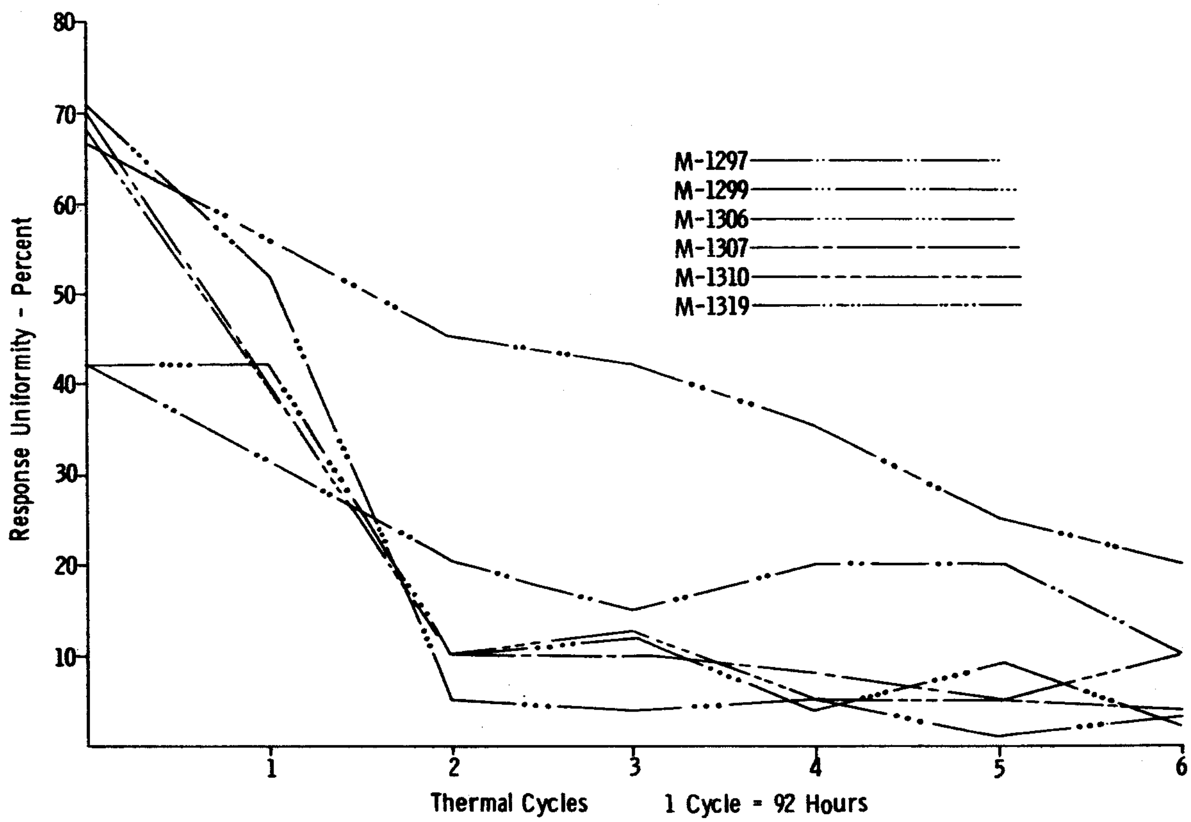


FIGURE 19

EFFECT OF 135° C THERMAL CYCLING ON OVERALL RESPONSE UNIFORMITY

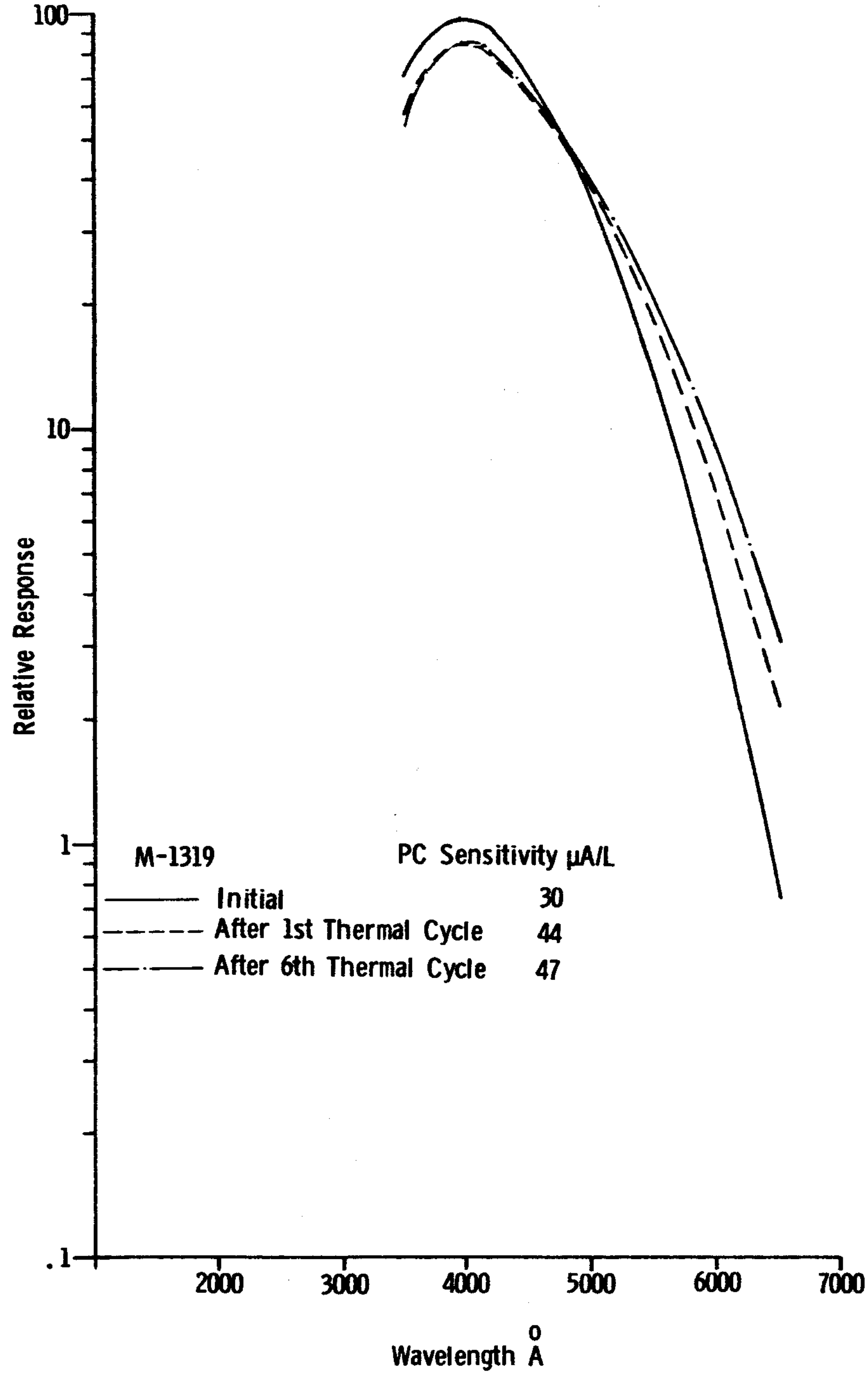
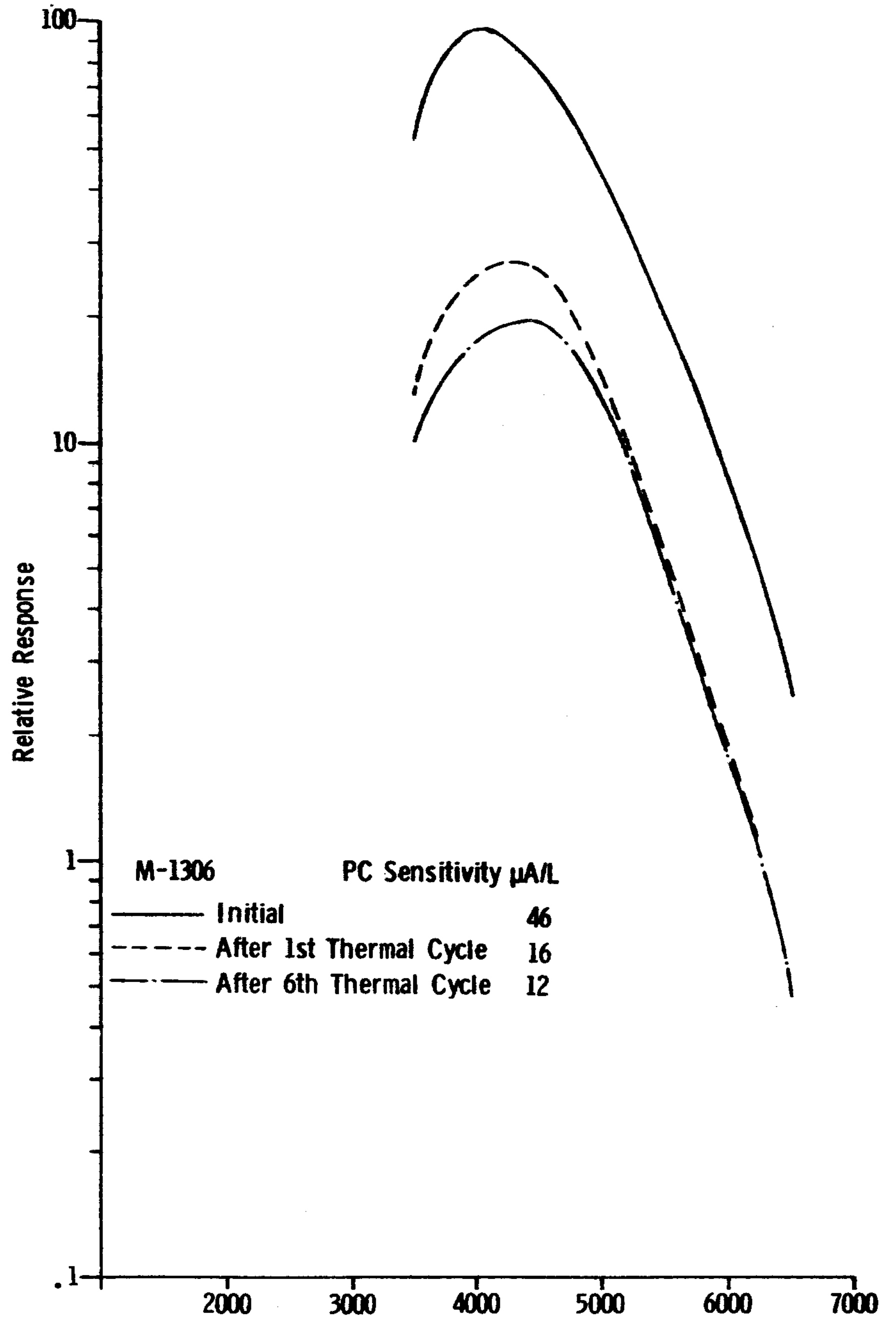


FIGURE 20

PHOTOCATHODE SPECTRAL RESPONSE CURVES



Wavelength Å

FIGURE 21
PHOTOCATHODE SPECTRAL RESPONSE CURVES

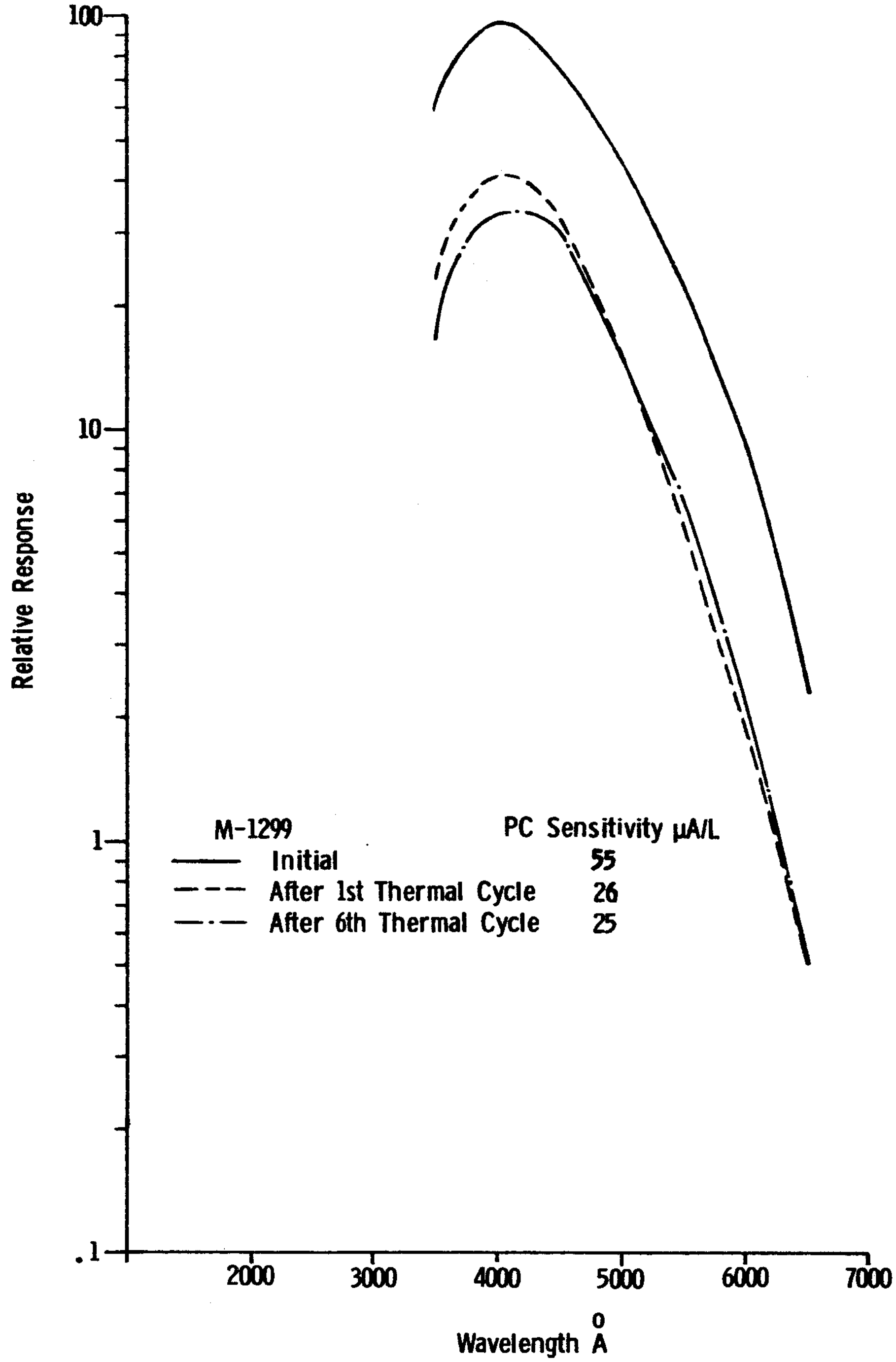


FIGURE 22
PHOTOCATHODE SPECTRAL RESPONSE CURVES

The above spectral response measurements were made with a thermopile calibrated monochromator.

3.5.7 Multiplier and Deflection Plate Leakage

The interelectrode leakages of image dissectors were not affected by dry heat sterilization cycling.

4. CONCLUSIONS

A bi-alkali cathode formation process, yielding cathodes of consistently high sensitivity, was developed. This process was successfully adapted to the exhaust processing of image dissectors. The sensitivity of bi-alkali cathodes was comparable to that of S-11 cathodes. The performance characteristics, of image dissectors with bi-alkali photocathodes, were evaluated and found to be equal to or better than those of dissectors with S-11 cathodes.

It was found that thermal sterilization cycling adversely affected the sensitivity and response uniformity of the bi-alkali photocathodes. These in turn caused deterioration of the overall response uniformity in image dissectors. The effect of sterilization cycling on all other tube characteristics was negligible.

The feasibility of making high sensitivity thermally sterilizable image dissectors was demonstrated by the exceptional performance of Tube M1319. In this tube the cathode substrate was exposed to excess of antimony and potassium followed by high temperature bake prior to formation of the photocathode. It is hypothesized that this pre-formation procedure pre-conditioned or pacified the substrate surface and this limited the diffusion and combination of the cathode forming elements into or with the substrate during subsequent processing and thermal cycling. In view of the promising results obtained with

Tube M1319 it is recommended that further effort be directed at developing and evaluating processes similar to that used in the manufacture of this tube.