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THIRD QUARTERLY REPORT

RESEARCH IN THE DEVELOPMENT OF AN IMPROVED MULTIPLIER PHOTOTUBE

Contract NASw-1576

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I. 0 ANALYSIS OF STANDARD ITTIL MULTIPLIER PHOTOTUBE DATA

The objectives of this data compilation and study were the determination, and comparison of ITTIL FW130 characteristic parameter values in analog (dc) and digital (single - electron pulse count) modes of information processing. A companion purpose was the reappraisal of tube specifications pertaining to these characteristics. The procedure followed was tabulation of available data on a large sample of FW130 tubes, with rejection of data on tubes for which only d-c data was available but retention of data whenever pulse-counting had been attempted even if performance had been unsatisfactory in the pulse mode.

The collected data appears as Table I. Cathode sensitivity was measured with the tube in a diode configuration; all other parameters were measured at the anode, with standard divider potentials. The d-c parameters (anode dark current, operating voltage, and equivalent noise input) were recorded for a constant anode responsivity of 2000 amperes per lumen. Other parameters were recorded for the designated operating voltage or responsivity at which data was available. Three dark current measurements appear in Table I and require explanation. The first and third are the usual dark current at 1800 volts and 2000 amperes per lumen respectively; the second, "@1800 volts K@D2", denotes a dark measurement made at 1800 volts with the cathode raised to the potential of the second dynode. This potential is positive with respect to the first dynode, and the dark current so measured is an indication of leakage across the stem and dynode thermionic emission.

Pulse count data had been determined at a common 1800 volts, but is readily compared to its d-c counterparts as the number of significant pulses is not generally voltage sensitive. Total pulses per second is the number above a small and undetermined bias level; this parameter is voltage sensitive and not very significant. The "80 to 90 percent C. Eff." pulses per second are those measured with a pulse-height bias level adjusted so that approximately 85 percent of the single electron pulses[1] are counted. The proper bias level is determined for each tube from its differential pulse height distribution with a light input. It is set at 60 percent of the peak. "Total pulses K@D2" should be analgous to the corresponding dark current. This information, however, is useful only qualitatively as it is measured at the undetermined bias level. The "peak to valley ratio" is of the light input differential pulse height spectrum. A criteria used requiring at least a peak-to-valley ratio 1.1:1.0 to set the 80 to 90 percent bias level provides assurance that the tube is operating properly.

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[1] The term "single electron" used herein refers to the triggering charge input to the first dynode. All countable output pulses contain many electrons, normally between 10^6 and 10^8.

For the purpose of a comparison between dark counts and dark current, an "observed single electron dark current", I_o, was defined at 1800 volts and extrapolated to 2000 amperes per lumen.

At 1800 volts:

$$I_{o\ 1800\ \text{volts}} = I_{\text{dark}\ 1800\ \text{volts}} - I_{\text{dark K@D2}}$$

At 2000 amperes per lumen:

$$I_{o\ 2000\ \text{a/l}} = I_{\text{dark}\ 2000\ \text{a/l}} \times I_{o\ 1800\ \text{volts}}\ I_{\text{dark}\ 1800\ \text{volts}}$$

The quantity $I_{o\ 2000\ \text{a/l}}$ is the dark current corrected for stem leakage and, perhaps, some multiplier contributions.

Next, a calculation was made of the dark pulse rate to which $I_{o\ 2000\ \text{a/l}}$ corresponds. Setting $I_{o\ 2000\ \text{a/l}}$ equal to I_o in the equation

$$N_o = I_o/e\ \mu_{dc}$$

where μ_{dc} is the d-c signal gain and

e is the charge of an electron

a production, N_o, was obtained of the number of single electron pulses per second which had occurred.

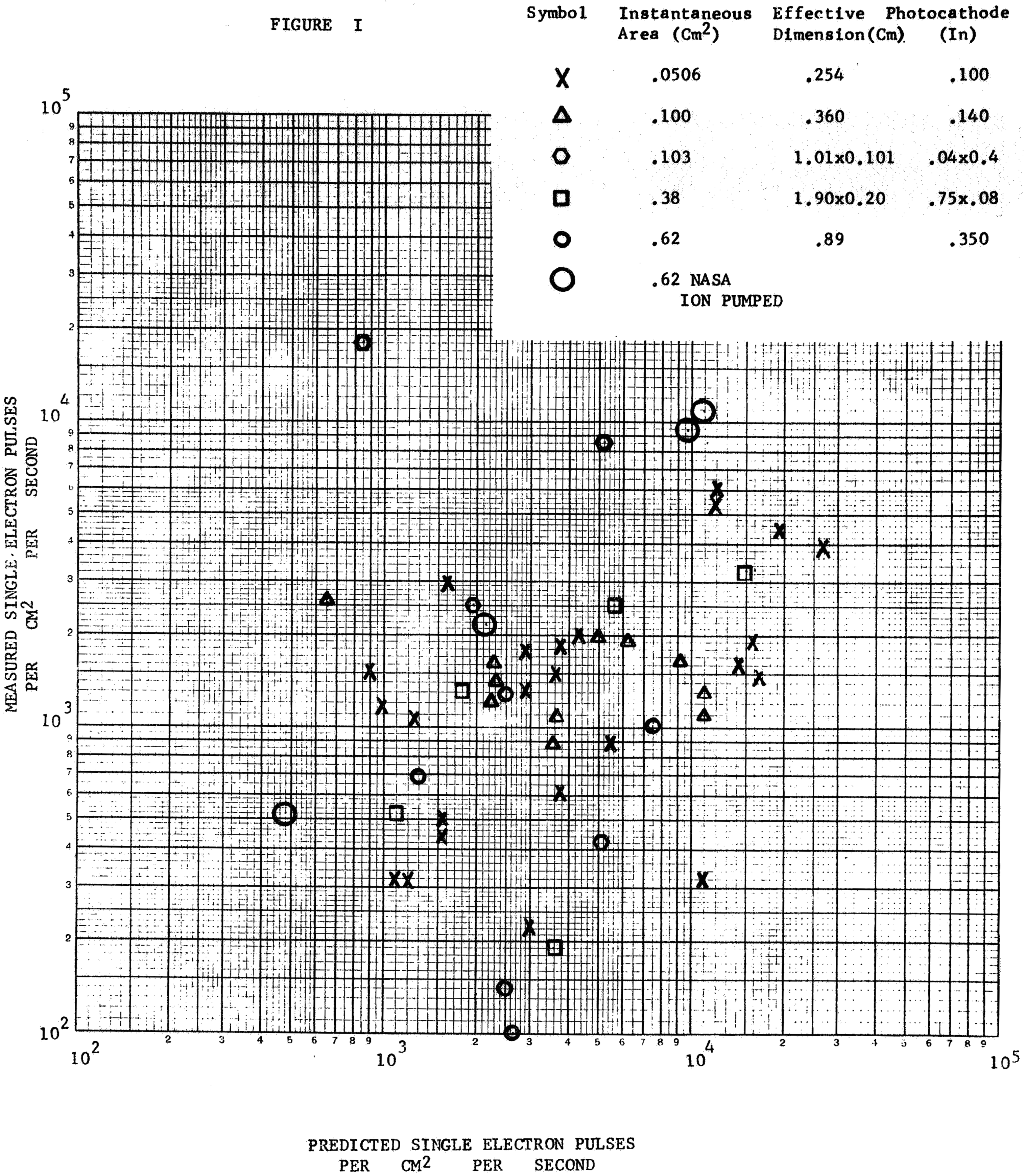
The measured (at 80 to 90 percent C. Eff. bias) anode pulses per second, N, and the predicted number, N_o, were normalized to the effective cathode area and plotted as the ordinate and absissa respectively in Figure 1. The counting efficiency, less than 100 percent, relates the expected values of N and N_o: $0.85 = N/N_o$.

A perfect correspondence between N and N_o would be observed in Figure 1 as all of the points lying on or near an "85 percent line."

1. The predicted dark pulse rate, calculated from d-c parameters, is (on the average) greater than the actual, observed dark pulse rate. (Conversely, the d-c dark current is greater than the equivalent current resulting from single electron pulses.) The average order of magnitude of this effect is a factor of two.

2. The ion-pumped tubes display a better absolute agreement between d-c predicted and the actual measured counting rates.

FIGURE I



Symbol	Instantaneous Area (Cm^2)	Effective Dimension(Cm)	Photocathode (In)
X	.0506	.254	.100
△	.100	.360	.140
⬡	.103	1.01x0.101	.04x0.4
□	.38	1.90x0.20	.75x.08
○	.62	.89	.350
◯	.62 NASA ION PUMPED		

3. Better agreement for the other tubes might have resulted if d-c and pulse count measurements had been made nearly simultaneously; the discrepancy due to red sensitivity changes of the cathode and differences of temperature would have been eliminated. In addition, the use of pulse-count-optimized first and second dynode potentials in d-c measurements (rather than "standard potentials") would also reduce error.

In general, the predicted dark count, based on d-c dark current measurements, is greater than the measured dark count. This was expected, and indicated that some anomalously large or small dark pulses are occurring. Large pulses due to cosmic rays[2] are to be expected, and small pulses due to such possibilities as dynode fluorescence, dynode bypassing, etc. are also to be expected. The contribution of these "spurious" dark pulses appears to be of approximately the same order of magnitude as the "true, single electron" dark counts.

It should be emphasized that dark leakage current (measured with the cathode at D2) has been subtracted from the dark current used to predict dark count in Figure 1. Examination of the data in Table I will allow a prediction of (greater) dark count if this dark leakage current is included.

The spread in the values of actual measured dark count (per unit area) in Figure 1 suggests one of two possibilities.

1. Comparatively large experimental measurement errors.
2. Comparatively large variations in cathode thermionic emission (including operating temperature changes).

Nevertheless it appears that the typical value of thermionic emission for S20 photocathodes, as formed in FW130 multiplier phototubes is:

$$1500\,^{+1500}_{-1100} \text{ electrons/cm}^2\text{/sec}$$

Our specification of maximum permissible dark count of 100 c/sec for a 0.1 inch IEPD S20 photocathode (FW130 tube) may therefore be compared with an expected most probable value of (1500)(0.05) = 75 electrons/second.

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[2] A. T. Young, Rev. of Sci. Inst. 37, 1472 (November 1966).

Table 1

IE PD Diameter: .254 cm (.100 in.) Area = .0506 cm^2

Tube Number	Cathode Sens. ua/l 2870^0K W	Operating Voltage @2000a/l	Dark Current (amps x 10^{-10})			Equivalent Noise Input lumen x 10^{-14}	Dark Pulses/Second			Peak-to-Valley Ratio	Noise Factor @200 a/l	Single Electron Pulses Per Cm^2	Per Second
			@1800V	K@D2 @1800V	@2000a/l		Total	@80-90% C. Eff.	K@D2*			Equivalent	Measured
1	160	1980	0.03		0.08	5.3	62	45		1.2			
2	115	1740	3		3	< 5.3	45	40		1.5			
3	175	1730	3	1.4	3	< 3.5	950			1.08			
4	147	1890	24	24	26	< 5.3	15000	31		1.3			
5	192	1700	1.7		1.7	< 5.3	96	31		1.2			
6	192	2050	0.1		1.1	6.3	105	83		1.3			
7	184	1710	10	1.3	4.6	4.2	8625			Exp.			
8	103	1860	2.4	1.1	3.1	4.2	81	59		1.2	1.07	99 x 10^1	117 x 10^1
9	120	1690	5.5		2.5	< 3.5	21	7		1.2			
10	144	1900	3.6	2.6	6.2	< 4.6	31	25		1.1		154	50
11	196	1820	2.8	0.4	2.8	< 3.5	262	67	2	1.4	1.95	291	133
12	214	1710	5	3.1	5	< 3.5					1.07		
13	200	1750	84	42	70	10.9	30000			Exp.			
14	195	1810	2.3	0.11	2.5	3.5	294	11	3	1.1	1.94	293	22
15	148	2060	1.1	64	3	3.5	111	53		1.6	1.7	125	105
16	137	1780	18	0.68	15	9.8	463	300		1.4		1200	594
17	149	1880	115	110	125	13.4	196	90	5	1.5	4.0		
18	158	1850	12	2.7	12	10.9	105	87	0	1.3	4.14	285	172
19	157	1780	220	210	210	4.6	154	98		2.2	1.35		
20	143	1980	2.2	1.1	6.4	5.3	143	44	0	1.1		546	87
21	245	1770	22	4.4	16	9.9	689	226	321	1.2	1.8	1940	447
22	170	1780	2.7	1.8	2.4	3.9	761		627	Exp.	1.52		
23	216	1710	10	3.3	4.1	5.3	219	93	96	1.5	2.56	375	184
24	135	1910	6.8	5.9	14	8.1	17000			Exp.	3.6		
25	180	1850	1.7	0.6	2.2	6.3	217	150	11	2.0	4.7	158	297
26	180	1670	22	13.5	8.4	4.9	1202	74	526	1.2	1.6	360	147
27	200	1570	60	2.2	9.4	7.0	248	16	72	1.4	3.7	1120	32
28	176	2080	1.3	0.67	3.3	7.04	385	23	127	1.4	4.6	166	45
29	140	2070	15	14.5	22	6.3	58	19	29	1.6	2.4		
30	140	1950	12	1.6	36	24	291	172	42	1.5	2.7	2700	388
31	179	1750	24	2.6	16	< 3.5	201	99	18	2.0	2.4	1660	194
32	123	1710	15	5	7.1	5.60	509	31	462	1.6	11.3	380	61
33	120	1960	8	7.0	12	6.0	74	16	66	2.0	2.6	111	32
34	195	1840	12	4.6	16	9.16	1344	282	90	1.5	3.1	1190	559
35	168	1850	40	38	52	8.1	300	38	118	1.2	1.6		
36	175	1960	7.5	2.6	20	13.0	153	82	42	1.9	2.3	1450	163
37	178	2430	0.16	0.05	1.2	< 3.5	184	77	3	1.2	1.45	88	152
38	145	1780	10	3.0	7.6	6.33	179	100	17	1.4	1.14	440	198
39	186	2020	4.2	0.05	14	13.4	240	169	10	1.4	3.7	1610	335
40	164	1770	4.4	3.2	4.4	4.57		16	28	1.7	2.9	122	32
41	171	1910	24	22	50	8.1	183	55	154	1.4	2.6		

Table 1 (Continued)

IEPD Diameter: 0.360 cm (0.140:n) Area = 0.100 cm^2

Tube Number	Cathode Sens. μa/l 2870°K W	Operating Voltage @2000a/l	Dark Current (amps x 10^{-10})			Equivalent Noise Input lumen x 10^{-14}	Dark Pulses/Second			Peak-to-Valley Ratio	Noise Factor @200 a/l	Single Electron Pulses Per Cm^2 Per Second	
			@1800V	K@D2 @1800V	@2000a/l		Total	@80-90% C. Eff.	K@D2*			Equivalent	Measured
1	202	1640	70	47	53	4.9	152	109		1.5		1100 x 10^1 ~~0.1100 x 10^1~~	109 x 10^1
2	129	1710	13	0.8	6.6	6.3	246	163		1.4	1.4	230	163
3	184	1760	3.6	2.1	2.9	< 2	444	263		1.1	1.46	64	263
4	165	1870	110	89	110	21	1460	132	1350	1.2	2.76	1080	132
5	181	1630	20	3	6.7	< 3.5	282	190	3	2.1	1.01		
6	140	2040	6.7	4.8	14	8.4	199	132	3	1.2	2.8	246	132
7	235	1840	3	1.3	5.5	7.1	212	124	42	1.5	2.4	230	124
8	145	1820	20	1.3	22	7.4	220	162	16	1.2	1.07	930	162
9	155	1720	50	35.	26	8.1	183	108	16	1.5		370	108
10	185	1970	4.2	1.3	11	8.6	329	88	230	1.4		355	88
11	144	1780	28	10	22	8.9	1231	196	1	1.7		635	196
12	165	1770	18	4.2	13	8.1	573	197	102	1.8		504	197
IEPD: 1.01 cm x 0.101 cm (0.04 in x 0.4 in) Area = 0.103 cm^2													
1	212	2090	47	46	56	3.5	141	103		1.7			
2	150	1610	20		5	4.9	142	117		1.2	2.0		
3	175	2080	34	39	52	5.9	67	51		1.09			
4	124	1870	40	30	54	5.5	150	43		1.16		514	42
5	158	1900	20	16	25	7.05	4035		25	Plat			
6	152	1900	23	22	27	5.0	259	202	28	1.3	7.1		
7	192	1860	44	41	49	6.0	317	260	10	1.17		194	252
8	144	1760	48	35	44	8.8	1126	895		1.87	1.51	524	868
9	134	1870	1.5	0.15	2.25	4.2	2287	1898		1.12		83	1840
IEPD: 1.90 cm x 0.202 cm (0.75 in x 0.08 in) Area = 0.386 cm^2													
1	190	1800	7.5	0.18	7.5	9.5	276	204		2.0	1.38	110	52
2	205	1800	93	71	93	9.2	2291	74	1689	1.4	2.18	360	19
3	185	1720	16	5.5	9	17.6	5851		4228	Exp.	9.7		
4	195	1730	85	3.7	100	15	1807	1262	25	2.0	2.27	1500	324
5	140	1690	34	2.1	17	9.9	926	512	93	1.3	1.32	180	131
6	178	1710	77	1.4	40	17.1	1360	971	1	2.1		560	250

Table 1 (Continued)

IEPD Diameter: 0.89 cm (0.350 in) Area = 0.62 cm^2

Tube Number	Cathode Sens. μa/l 2870°K W	Operating Voltage @2000a/l	Dark Current (amps x 10^{-10})			Equivalent Noise Input lumen x 10^{-14}	Dark Pulses/Second			Peak-to-Valley Ratio	Noise Factor @200 a/l	Single Electron Pulses Per Cm^2 Per Second	
			@1800V	K@D2 @1800V	@2000a/l		Total	@80-90% C. Eff.	K@D2*			Equivalent	Measured
1	170	1650	150	65	43	28	638			Plat.			
2	110	1600	68	41	18	6.1	670			Exp.			
3	100	1900	120		290	28.2	601			Exp.			
4	110	2260	0.2	0.1	23	12	290			Exp.			
5	98	1900	8.2	1.2	18	5.7	257			Plat.			
6	130	1750	14	11	7.8	< 3.5	893			Exp.			
7	155	1890	72	6.0	180	33	491	430		1.2		129 x 10^1	69 x 10^1
8	205	1770	32	1.5	25	12.4	917	793		1.4		250	127
9	175	2080	15		80	22	195	19		1.1		71	3
10	220	1850	70	0.9	94	17	4724			Plat.	2.46		
11	185	1850	80	16	110	23	9794			Exp.			
12	108	1900	27	24	50	18	2882			Exp.	1.75		
13	170	1800	53	0.42	53	18	471	40		1.2		266	6
14	160	1780	42	2.6	34	11	99	87		1.1		252	14
15	200	1800	75	0.6	75	18	827	648		1.2		740	104
Other IEPD													
1	215	1950	3.1	2.9	8	5.3	585	17		1.26		3540	1700
2	192	1640	48	4.6	18	10	1643	301		1.1		508	161
3	179	1760	33	1.9	24	10.5	201	159		1.9		2400	321
4	190	1860	24	2.2	33	9.5	957	774		Plat.			
5	211	1820	7.8	1.1	10	6.0	638			Exp.			
6	184	1920	7.3	6.8	8.3	< 3.5	80	33		1.4	6.5	38	38
7	158	1730	8	0.4	5	6.7	83	54	9	1.7		10300	2380
8	188		0.2	0.15	0.17		21	< 1	23	1.28		1980	< 800

Other IEPD

Tube Number	IEPD (CM)	IEPD AREA (CM^2)	IEPD (IN)
1	0.035 Diam.	0.001	0.014
2	0.76 x 0.24	0.193	0.3 x 0.1
3	0.071 x 0.71	0.0505	0.028 x 0.28
4	0.51 Diam.	0.202	0.20
5	0.51 Diam.	0.202	0.20
6	0.102 Diam.	0.081	0.04
7	0.0635 x 0.035	0.00225	0.025 x 0.014
8	0.0127 Diam.	0.000126	0.005

2.0 CORRELATION OF DARK CURRENT AND DARK COUNTING RATE

In the last report issued on this project[3], it was stated that the output of special tubes, built on this contract, would be increased. These tubes would be evaluated, both as to their d-c current and photon counting characteristics in order to see if these could be correlated and to determine if the design innovations used held promise for improved performance.

One approach to this goal involves the use of modified standard tube types. The tube type chosen for this work was the FW130. Two tubes of the group of four had 0.145 inch diameter apertures with 0.4 magnification image sections and the other two were constructed with 0.245 inch apertures and 0.7 magnification image sections, giving all four an IEPD of 350 mils. The FW130 photocathode is an S20 type. The only non-standard feature of these tubes was the use of a copper pumping tubulation connected to a one liter per second ion pump. This arrangement allowed evacuation to continue after a glass seal-off was made from the exhaust station. After removal from the exhaust station, the ion pump was started and allowed to operate until the pressure was of the order of 10^{-8} torr. At this time voltage was applied to the multiplier and the cathode illuminated to produce an anode current of 200 microamperes. Drawing current from a multiplier always raises the gas pressure so it was hoped that this aging technique would produce a tube with lower residual gas pressure due to dynode outgassing. Pumping was continued in this manner until a pressure of the order of 10^{-9} torr was produced as indicated by the ion pump current. At this point the tube and the ion pump were separated by pinching the copper tubulation.

Table 2 is a tabulation of the measured and calculated characteristics of these four tubes. The data presented was taken at a constant d-c gain of 5×10^6. Gain is obtained by dividing the anode responsivity by the cathode sensitivity. The applicable cathode sensitivity is the larger of the two numbers in that column and is the response of the cathode to luminous flux from a tungsten lamp operated at a color temperature of 2870 degrees K; the second, and smaller, sensitivity value will be discussed in connection with data to be presented later in this section.

It should be noted that the anode responsivity and the cathode sensitivity were the only two parameters that could not be measured directly in the pulse counting equipment. The same voltage divider was used in all measurements where a divider was required. Other changes of test equipment were avoided in order to eliminate possible error-producing variables.

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[3] Second Quarterly Report NASw-1576, Oct. 18, 1967.

Table 2

Tube Number	Cathode Sensitivity $\mu a/L$ *$2870^{0}K$ 2418 Filter	Anode Response Amperes/ Lumen	Divider Voltage	D. C. Gain (G) x 10^{6}	Single Electron Pulse Gain (μ) x 10^{6}	Dark Current x 10^{-10}		Dark Counts Per Second * Equivalent Dark Current x 10^{-10}			Calculated Dark Counts Per Second		Peak To Valley Ratio	ENI Lumens
						Total	Cath. at Dynode Two	Total	80 - 90% Counting Efficiency	Cath. at Dynode Two	Based On μ_{pc}	Based On μ_{dc}		
106701	*185 91	925	1790	5.0	4.22	36	0.11	*9753 67	*5900 40	*96 0.65	6000	4500	1.06	2.1
106702	*185 100	925	1760	5.0	3.48	1.9	0.16	* 500 7.8	* 330 1.8	*47 0.26	300	238	1.6	0.70
106703	*190 94	950	1970	5.0	4.96	52	7.2	*9839 78	*6250 49	*21 0.17	6540	6500	1.14	2.6
106704	*180 92	900	1880	5.0	5.62	12	0.16	*2010 18	*1330 12	*93 0.83	1330	1500	1.0	1.9

Two dark current measurements were taken, one with the cathode at its normal high negative potential and the other with the cathode at dynode two potential. In the latter case all emission from the cathode was suppressed leaving only leakage to the anode pin and dynode dark emission as the source of dark current. If the equivalent dark currents are calculated for the measured dark counts with the cathode biased to dynode two potential, it is seen that agreement to the same order of magnitude is found (except for tube No. 106703). Because of this close agreement, it would appear that the anode guard ring in these tubes is quite effective in preventing anode pin leakage current from appearing in the output.

The gain for these tubes could be measured in both the dc and the pulse counting modes. The actual operating voltages were established on the basis of the constant d-c gain μ_{dc} as mentioned earlier. The average gain (μ_{pc}) for the pulse counting mode was calculated for each tube by the relation

$$\mu_{pc} = \frac{Q}{e}$$

where $Q = C\bar{v}$, the product of C, the multiplier anode circuit capacity,

and $\bar{v}$ is the average pulse amplitude of the single electron output pulses (obtained by examination of the pulse amplitude distribution).

The gain figures obtained by these two dependent methods show fair agreement, though tube No. 106702 seems to differ rather widely even though a very good distribution was obtained, (as indicated by the good peak to valley ratio). Discrepancies between μ_{dc} and μ_{pc} would be more likely in the case of 106704 where the poor distribution would make it difficult to obtain the average pulse amplitude required for this calculation.

If the reverse calculation is performed, that is converting the measured dc dark current into its equivalent dark count, two sets of figures can be obtained by using both the dc gain (μ_{dc}) and single electron pulse gain (μ_{pc}). In all cases the number of dark counts calculated is lower than the actual measured value of total dark counts as previously defined. There is, however, a surprisingly close agreement between the calculated values and the actual number of dark counts at a counting efficiency of 80 to 90 percent. This fact may well be an indication that the dark counts removed by this calculated bias point are not true dark counts but rather preamplifier and external noise pickup which count in the early channels but which would not affect the d-c measurements because of their low amplitude.

The rather large number of dark counts remaining at 80 to 90 percent counting efficiency is almost certainly due to the high red sensitivity of the photocathode. This response is indicated by the smaller numbers in the cathode sensitivity column. They represent the response of the photocathode to 2870 degrees K luminous flux passed through a Corning 2418 glass filter, of half stock thickness, which transmits approximately 90 percent of all the standard lamp radiation above 650 nm, to which the photocathode is sensitive.

When cooled to -30 degrees C, two tubes showed dark counts of the order of 20 to 30 counts per second at 80 to 90 percent counting efficiency which would indicate that dynode emission as well as cathode emission may be reduced to very low levels. Temperature lower than -30 degrees C did not seem to produce lower dark counts although conclusive data is not available due to the inability of the cooler to maintain a given temperature long enough for the cathode to come to equilibrium. It is hoped that dark count versus temperature curves can be obtained at a later time with a thermoelectric cooler having an adjustable temperature control, thereby permitting the cathode temperature to stabilize. Typical curves for the dark count versus temperatures are shown in Figure 11.

3.0 TYPE F4003 MULTIPLIER PHOTOTUBES WITH REMOTELY PROCESSED CATHODES

Perhaps the most promising approach to producing an improved multiplier phototube is the processing of the photocathode before sealing it to the tube envelope. This results in a clean, cesium free tube interior and freedom from the problems associated with this contamination. Cesium of the multiplier may produce some contamination of the tube interior though this process allows more rapid removal of excess cesium than the standard process. It also provides an opportunity to form a group of cathodes, and select the best for the tube under construction.

While neither the technique nor the equipment for accomplishing this task were developed on this project, it seemed appropriate to adapt the process, developed at ITTIL, to a particular tube geometry which is suitable for astronomical detection purposes. The two major requirements are small tube diameter, 1 inch or less, and as large an effective photocathode, in that diameter, as possible.

The F4003, see Figure 2, is 1 inch in diameter, has a standard JEDEC 13-B, 13 pin stem and the possibility exists that a 0.5 inch diameter cathode, can be obtained while maintaining the unique features of the ITTIL multiplier phototube image section design. This later qualification will require the development of an image section with a magnification of 0.1, to be used in place of the present designs which have a magnification of 0.7 or 0.4.

Four tubes of this type have been built, the first of which was a leaker and was subsequently disassembled. The other three have been tested though one had a cathode of low sensitivity due to defective alkali metal generator. This tube functioned so poorly that test data was not obtainable.

Each tube has a fused silica entrance window on which the photocathode is formed. This type of faceplate gives UV response and minimizes sensitivity to high energy particle bombardment. The electron multiplier is a 16 stage device with a voltage divider between dynode three and twelve welded directly to the dynode tabs on the multiplier support plates.

The inclusion of a portion of the divider in the envelope allows the use of the standard 16 stage multiplier in a 1 inch blank with a 13 pin stem.

The photocathode of these tubes conforms closely to the S25 response shown in Figure 3.

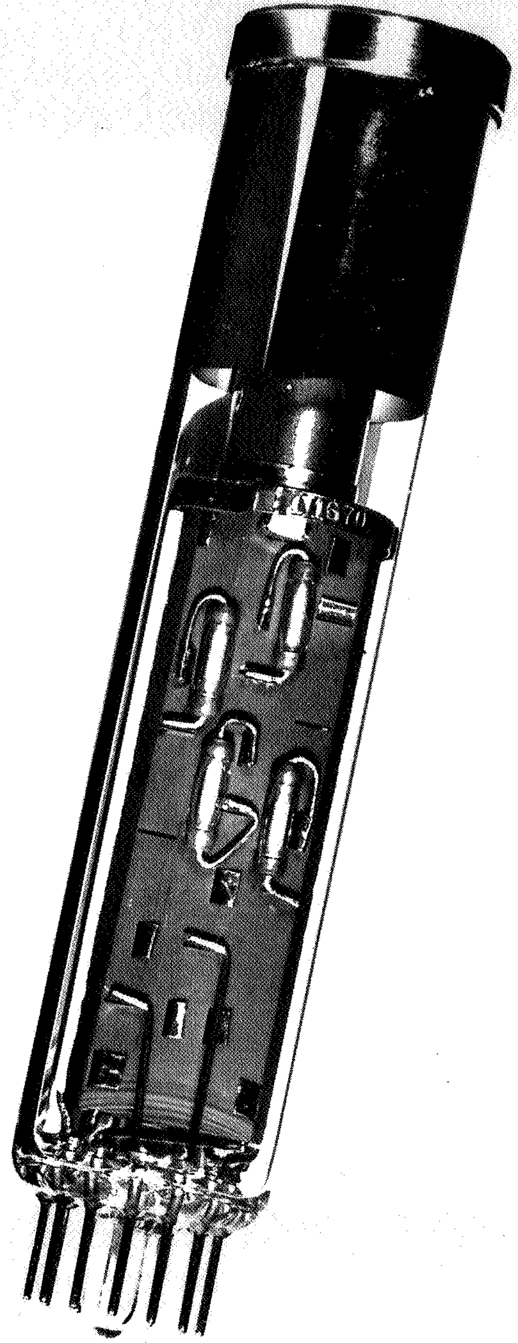

Figure 2 F4003 RP Multiplier Phototube

TYPICAL ABSOLUTE SPECTRAL RESPONSE CHARACTERISTICS

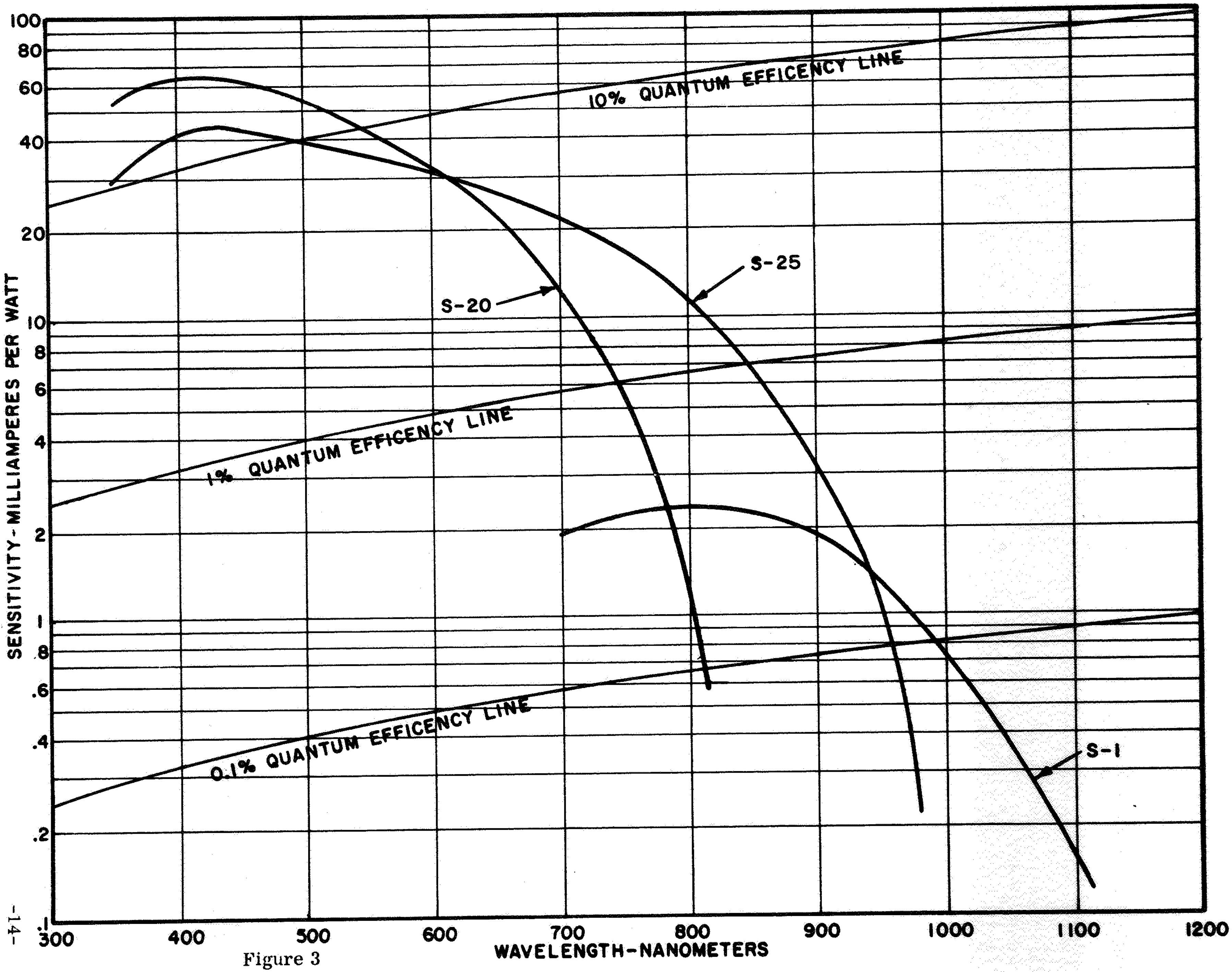

Figure 3

The obvious advantage of increased quantum efficiency of the S25 photocathode between 800 and 950 nanometers, with only minimal decrease in peak quantum efficiency, is accompanied by increased life at a given cathode current density, a higher peak output current without field distortion or defocusing, thermionic dark noise comparable to the S20 cathode and it is adaptable to multiple reflection optical trapping for further QE enhancement.

Figures 4, 5, and 6 are the spectral response curves for F4003RP 106702, 116701, and 116702 respectively. In Figure 3 the crosses indicate the effect of cooling to -30 degrees C. It is expected that even closer agreement with the typical S25 curve will be obtained when more samples of this type tube have been constructed and processing techniques have been refined. However there does exist a potential difficulty associated with the quartz faceplate. Quartz is known to be semi-permeable to helium and the leak rate ratio of quartz as compared to 7052 (borosilicate) glass is about 100 times.

A test program has been initiated in this laboratory to investigate the effect of helium diffusion on tubes in standard 7052 glass envelopes, stored in a helium atmosphere. However, it is not certain that significant results will be forthcoming during the course of this contract.

Several tubes with quartz envelopes, which have been on the shelf 2-1/2 years were tested to determine if their characteristics had deteriorated. No evidence could be found that they were in any way less sensitive or more noisy than they were when built. This would seem to indicate that helium diffusion should not impose serious limitations on the life of such tubes but quantitative data is not available now to substantiate such a conclusion.

Figures 7 and 8 are the d-c characteristics for tube numbers 106701 and 116702. Both tubes have similar gains, the dark current curves, however, have very dissimilar slopes indicating that the dark current for 106702 is primarily ohmic leakage which is not affected by the gain of the multiplier. Figures 9 and 10 are the pulse height distribution for the same two tubes; the upper curves are the signal plus dark count distributions and the lower curves are dark counts only. Both tubes have good peak to valley ratio of about 2.

The lower dark count for 106702 is due to its smaller effective photocathode area, which is approximately one tenth that of 116701.

Both of these tubes have been consigned to Lick Observatory, where they will be considered for use as cooled detectors in photon counting applications. Tubes previously built for this purpose and reported on an earlier[4] contract exhibited

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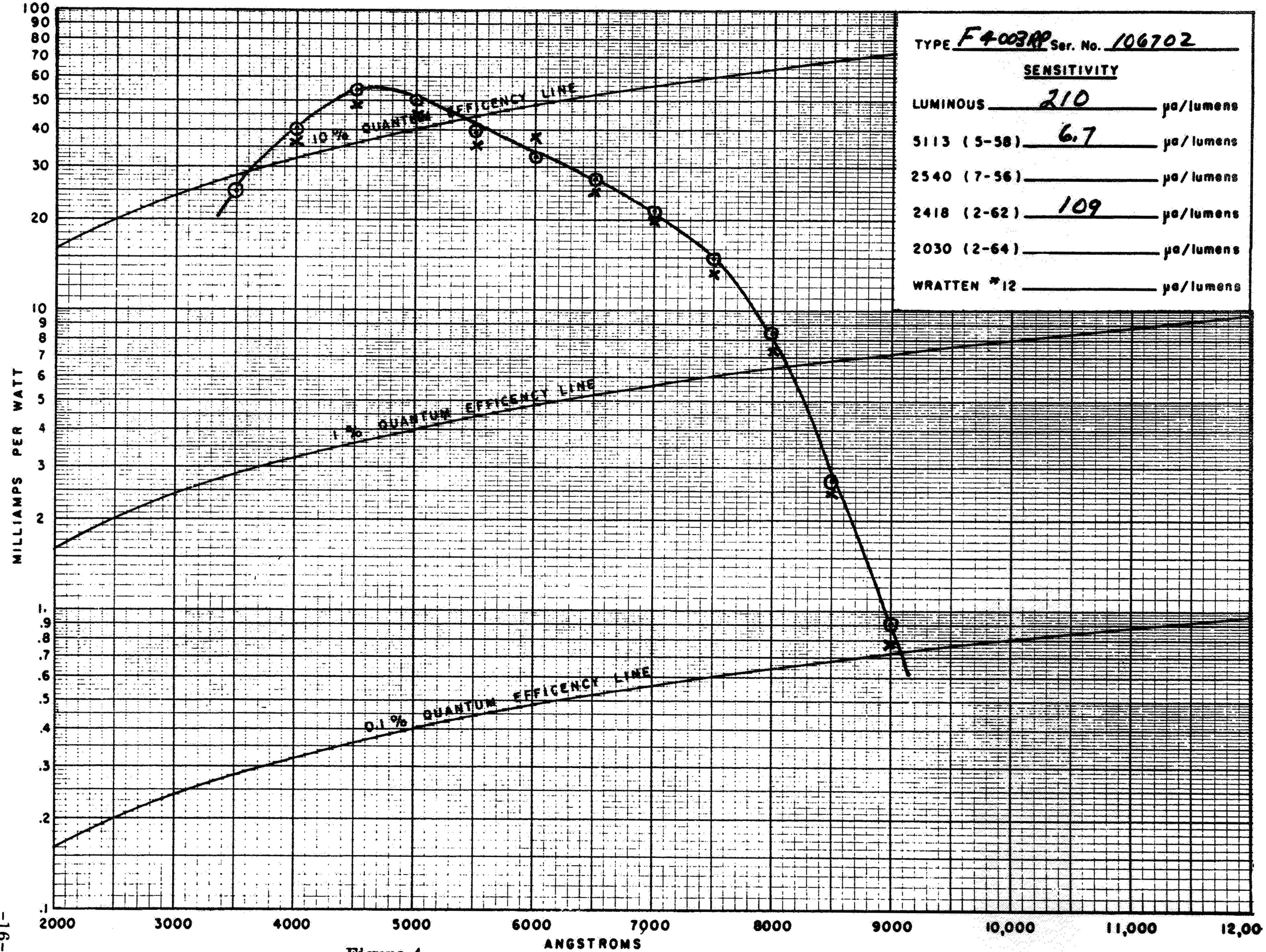
[4] Final Report - Research in the Development of an Improved Multiplier Phototube Contract NASw 1038, November 16, 1966.



TYPE F4003RP Ser. No. 106702

SENSITIVITY

LUMINOUS 210 μa/lumens
5113 (5-58) 6.7 μa/lumens
2540 (7-56) ______ μa/lumens
2418 (2-62) 109 μa/lumens
2030 (2-64) ______ μa/lumens
WRATTEN #12 ______ μa/lumens

Figure 4

ITTIL E-32a (6/66)

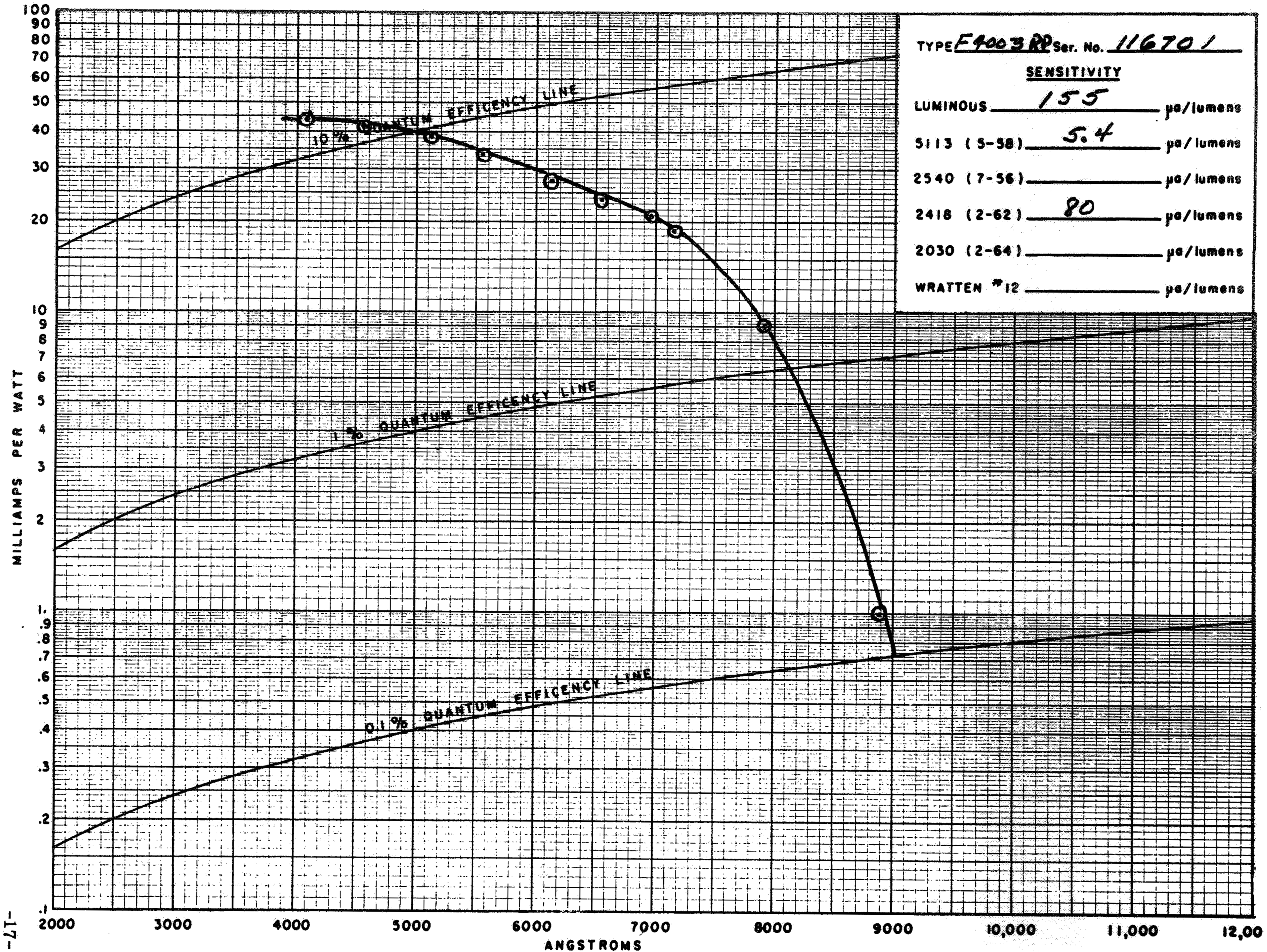
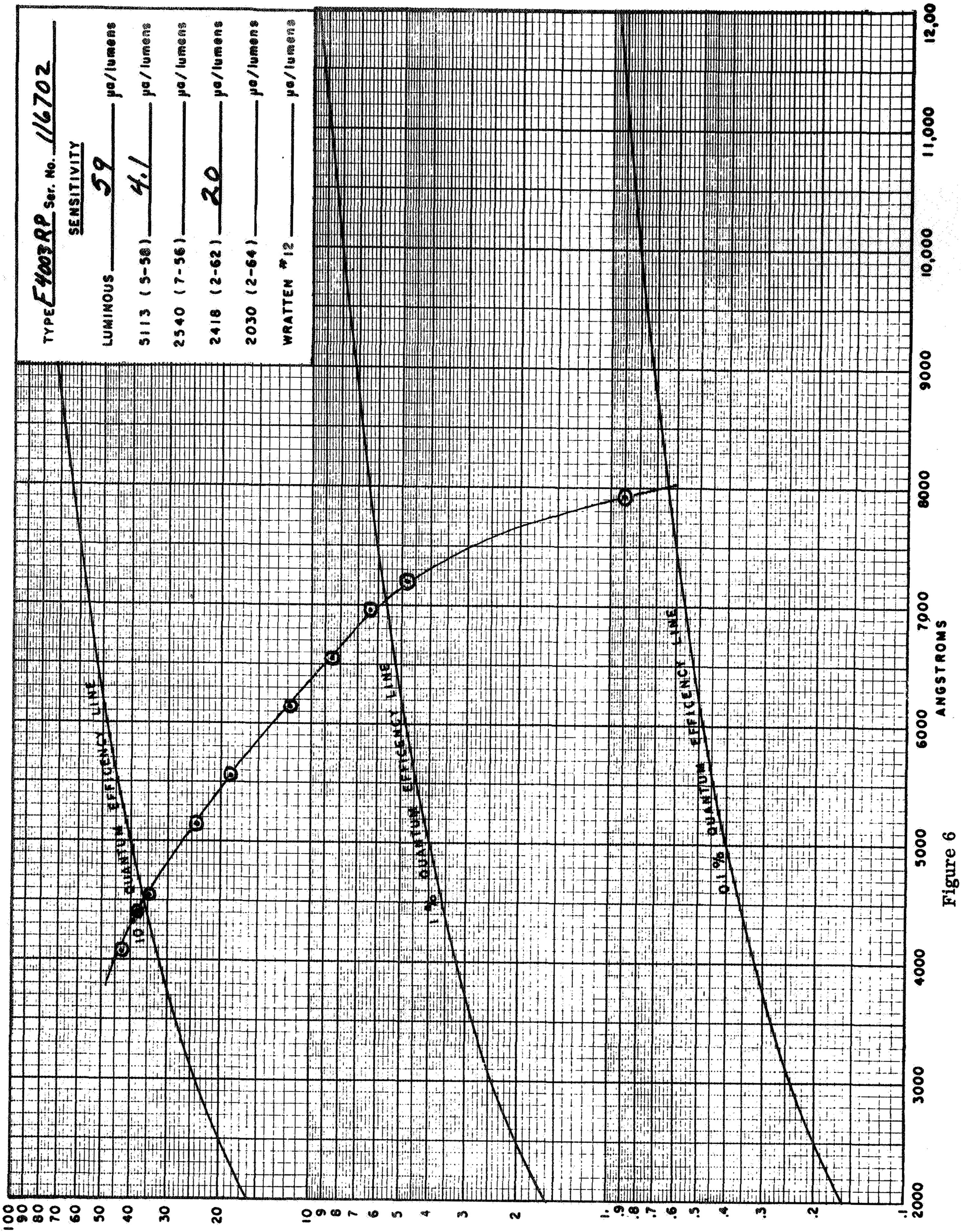

TYPE F4003RP Ser. No. 116701
SENSITIVITY
LUMINOUS 155 μa/lumens
5113 (5-58) 5.4 μa/lumens
2540 (7-56) μa/lumens
2418 (2-62) 80 μa/lumens
2030 (2-64) μa/lumens
WRATTEN #12 μa/lumens
10 % QUANTUM EFFICENCY LINE
1 % QUANTUM EFFICENCY LINE
0.1 % QUANTUM EFFICENCY LINE
MILLIAMPS PER WATT
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1.
.9
.8
.7
.6
.5
.4
.3
.2
.1
2000
3000
4000
5000
6000
7000
8000
9000
10,000
11,000
12,00
ANGSTROMS

Figure 5



TYPE F4003RP Ser. No. 116702

SENSITIVITY

LUMINOUS 59 μa/lumens

5113 (5-58) 4.1 μa/lumens

2540 (7-56) μa/lumens

2418 (2-62) 20 μa/lumens

2030 (2-64) μa/lumens

WRATTEN #12 μa/lumens

Figure 6

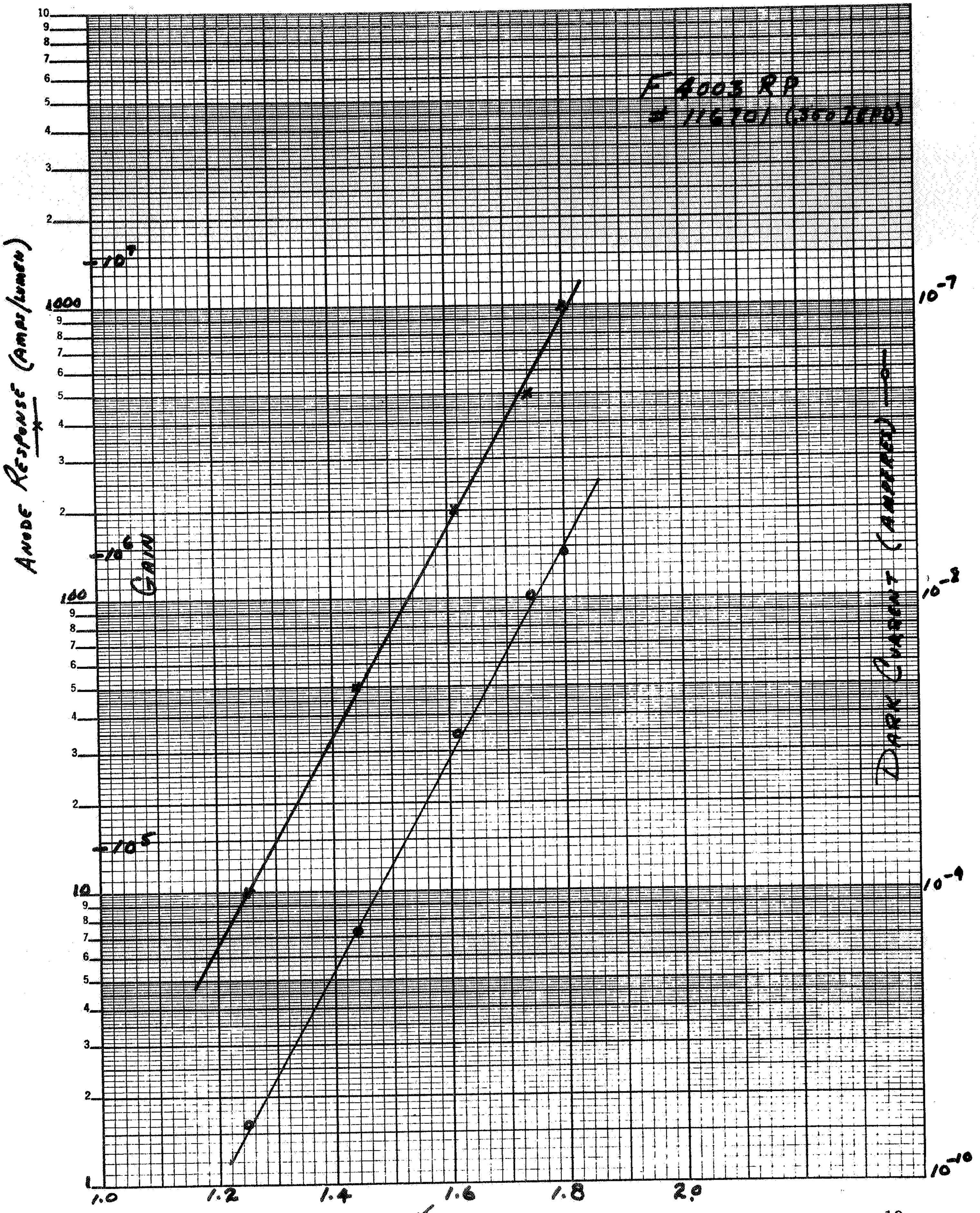

F 4003 RP
116701 (350 IEPD)
ANODE RESPONSE (AMPS/LUMEN) ×
GAIN
10^7
10^6
10^5
10
9
8
7
6
5
4
3
2
1000
100
10
1
DARK CURRENT (AMPERES) —○—
10^{-7}
10^{-8}
10^{-9}
10^{-10}
1.0
1.2
1.4
1.6
1.8
2.0
KILOVOLTS

Figure 7

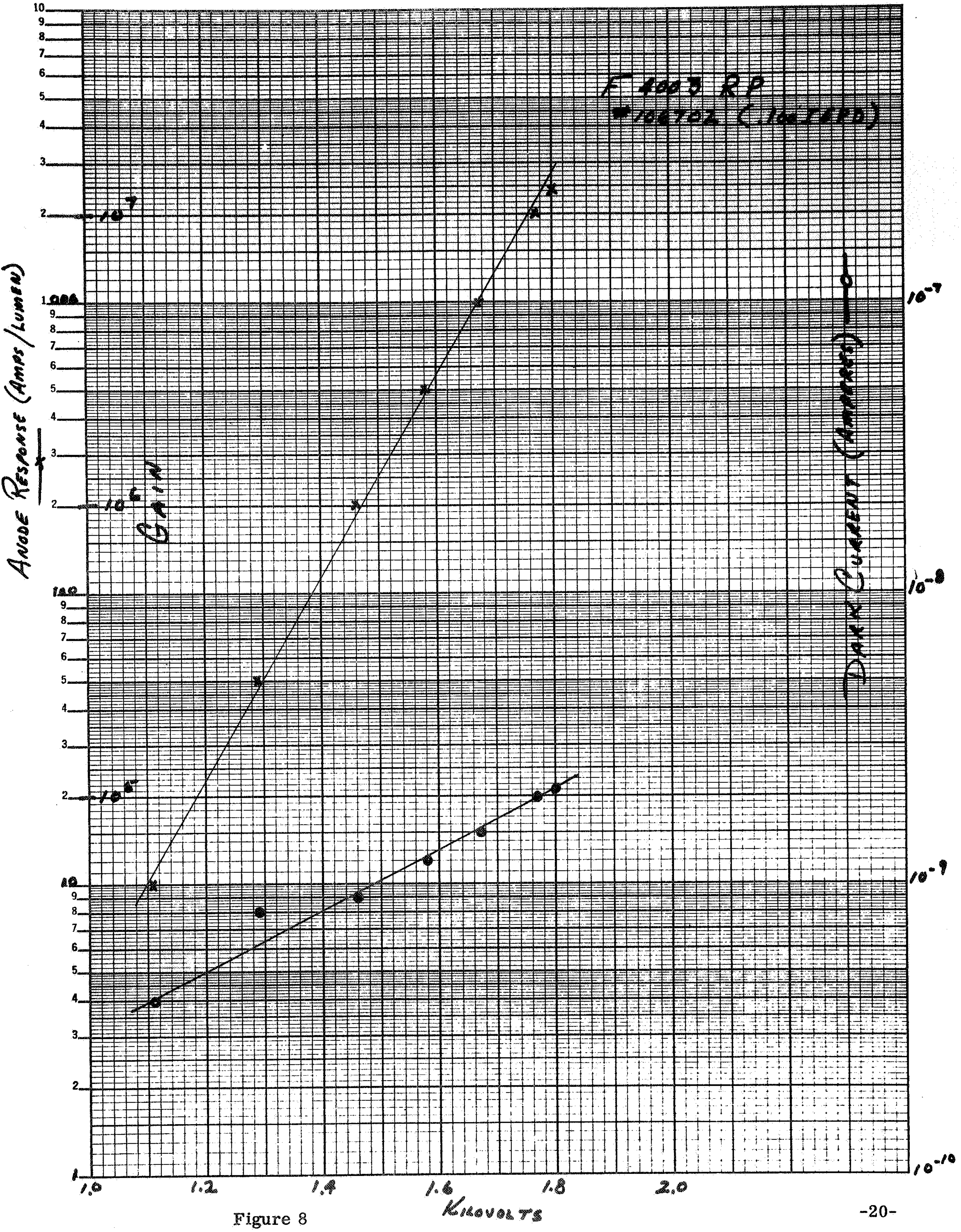

F 4003 RP
#106702 (.106 IEPD)
Anode Response (Amps/Lumen)
Gain
Dark Current (Amperes)
10^7
10^6
10^5
10^-7
10^-8
10^-9
10^-10
10
9
8
7
6
5
4
3
2
1,000
100
10
1
1.0
1.2
1.4
1.6
1.8
2.0
Kilovolts

Figure 8

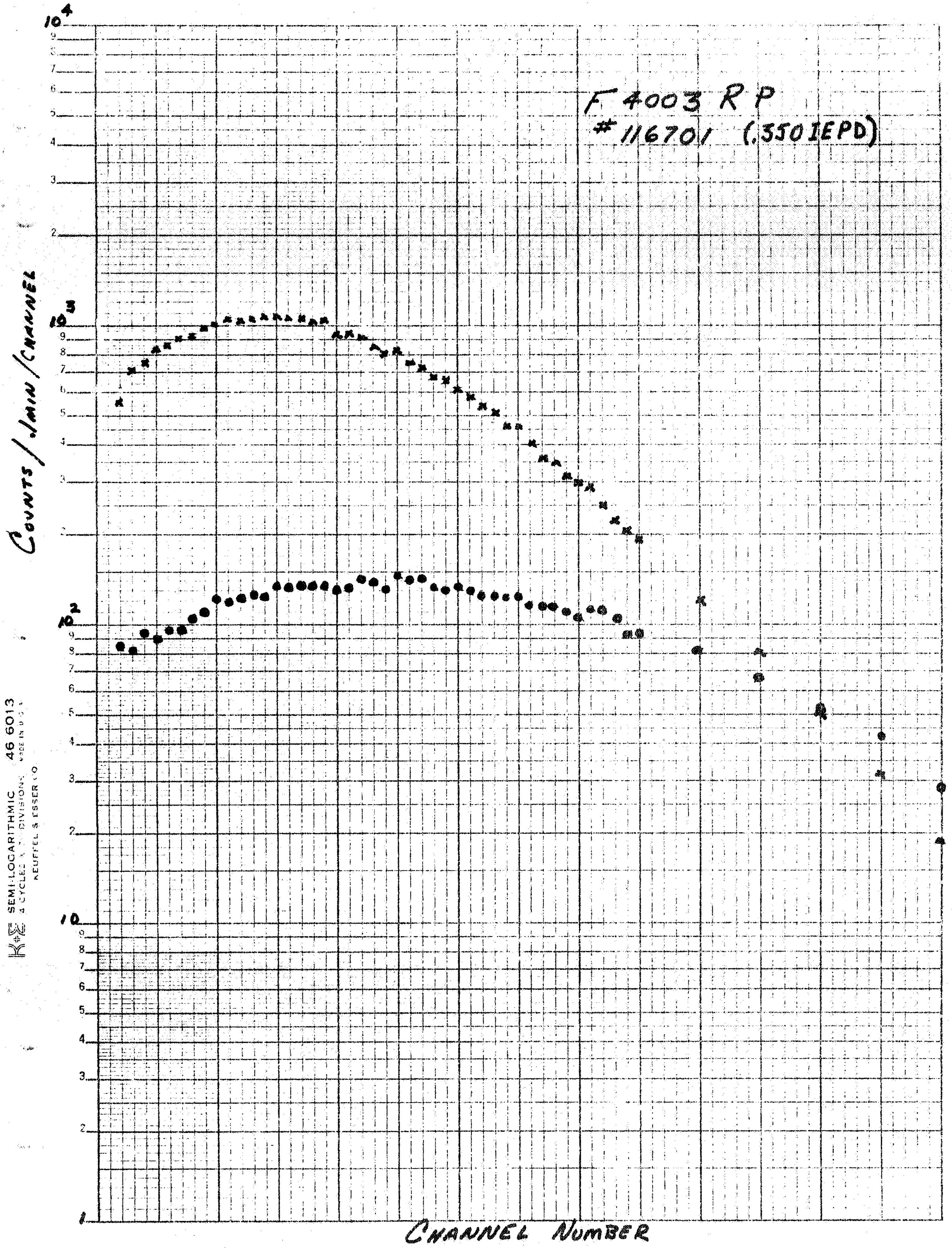

F 4003 R P
#116701 (.350 IEPD)
COUNTS / 1MIN / CHANNEL
CHANNEL NUMBER
10^4
10^3
10^2
10
1
9
8
7
6
5
4
3
2
K+E SEMI-LOGARITHMIC 46 6013
4 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

Figure 9

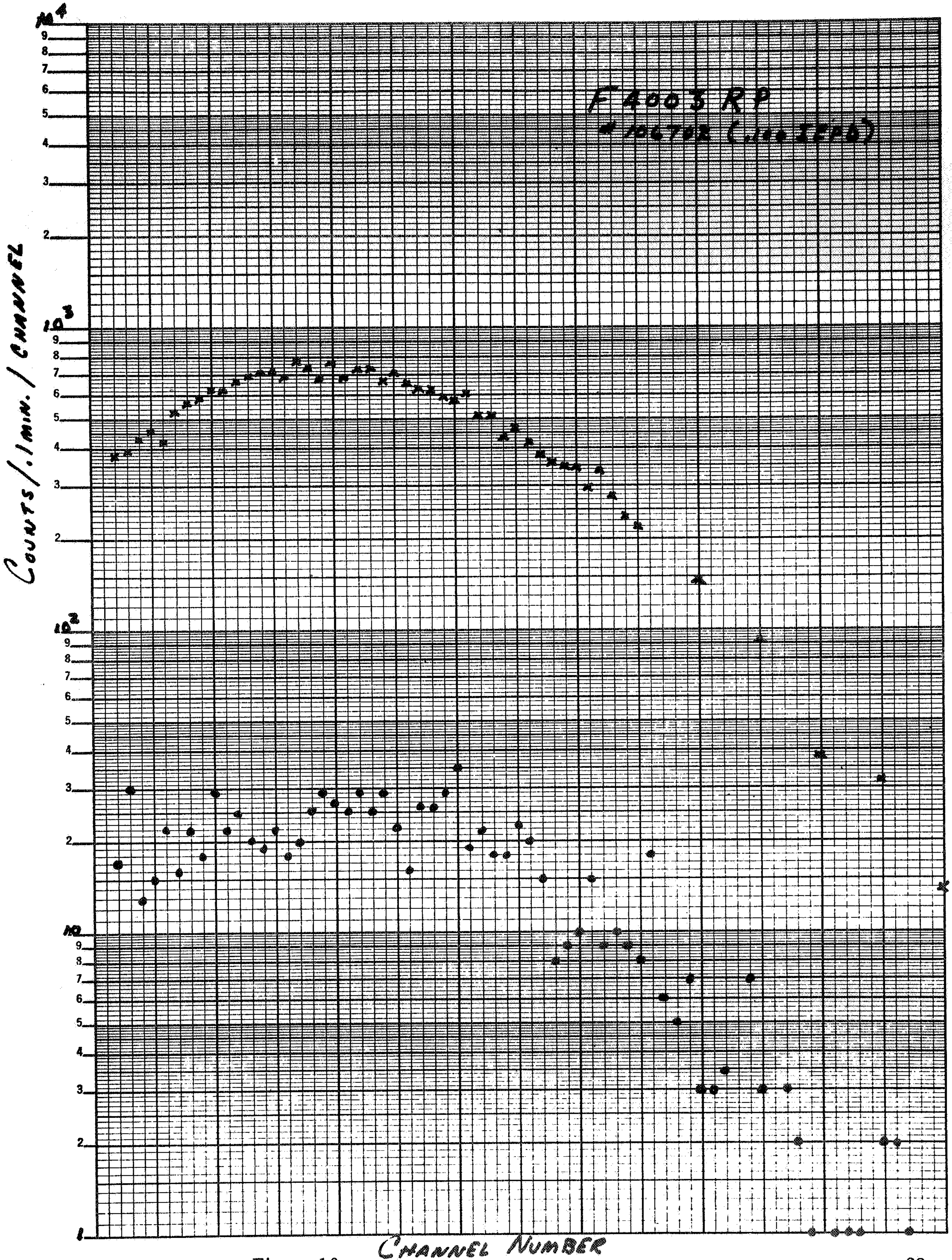
F 4003 RP
106702 (.180 IEPB)
COUNTS/.1MIN./CHANNEL
CHANNEL NUMBER
10^4
9
8
7
6
5
4
3
2
10^3
9
8
7
6
5
4
3
2
10^2
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
1

Figure 10

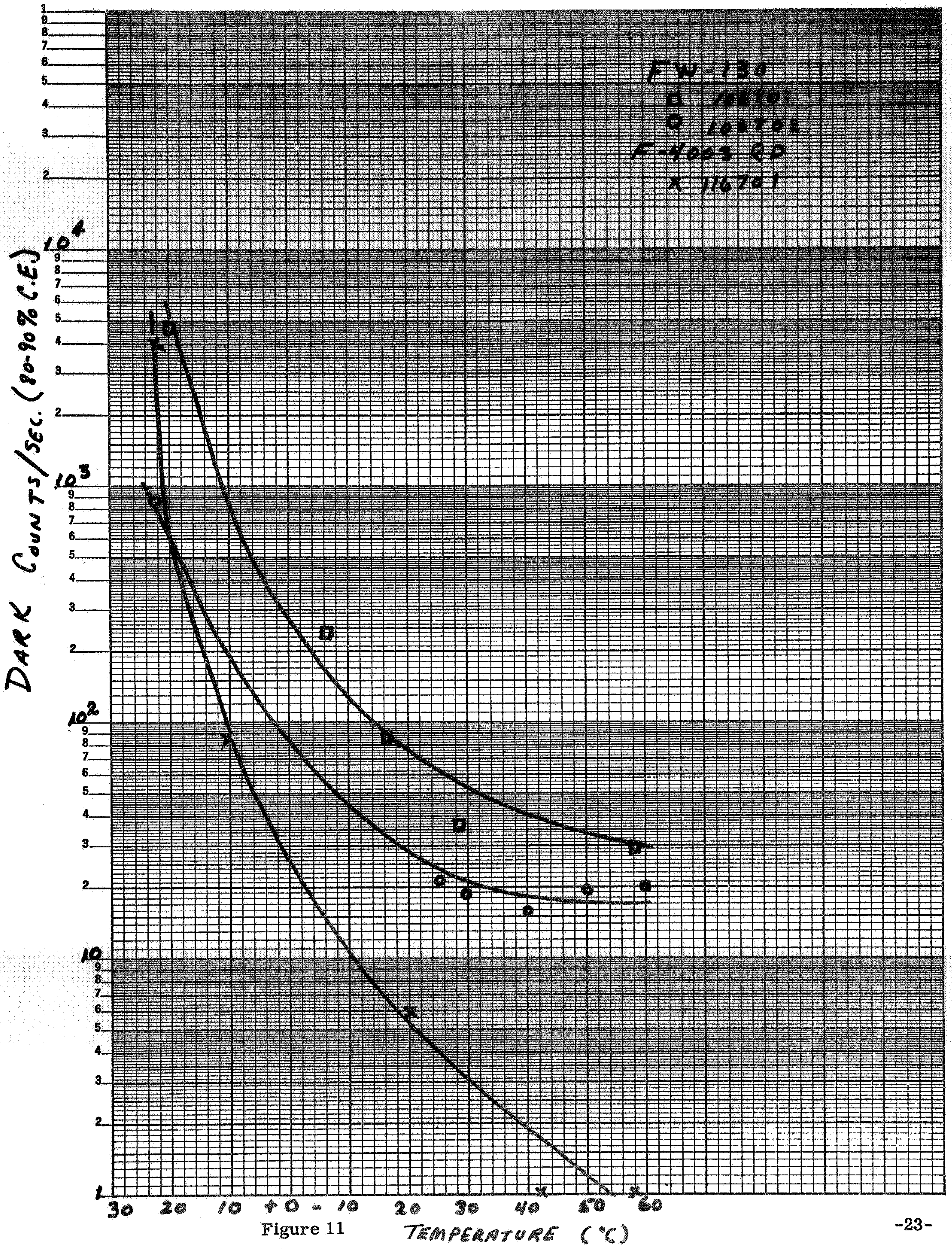

FW-130
□ 108701
○ 108702
F-4003 RD
× 116701
DARK COUNTS/SEC. (80-90% C.E.)
10^4
10^3
10^2
10
1
30
20
10
+0
-10
20
30
40
50
60
TEMPERATURE (°C)

Figure 11

occasional pulse of large amplitude which, in our equipment, appeared to be equal to many electrons. In the equipment at Lick Observatory, however, these pulses were resolved into their component single electron pulses because of the high resolution pulse processing circuits. This behavior is, objectionable especially at low counting rates. Though this difficulty does exist to a certain degree in all glass tubes, a large portion of this problem was found to result from the use of sapphire windows to extend the cathode response into the UV.

Tests showed that sapphire (ultra pure Al_2O_3) is an efficient scintillator,[4] which is easily activated by cosmic radiation and residual radioactivity in the tube itself and the local environment.

Preliminary test at Lick shows the first of these new tubes (0.100 inch IEPD) to be comparatively free of these multiple-electron pulses. The second tube (0.350 IEPD) is still being evaluated.

Cooled data was taken on only one of these tubes after the tube cooler was modified. Earlier data was unreliable due to poor temperature control and lack of thermal contact with the tube envelope. This condition will be remedied as mentioned earlier.

This new tube type lacks one desirable feature of the standard FW130 design in that the aperture electrode is now sealed into the glass envelope thereby interposing a light stop between the photocathode and the multiplier section of the tube. Whether or not this fact will detract from the operation of the tube is not yet known and any decision as to the advisibility of a design change in the F4003 RP to include this feature will depend on the results of further evaluation.

Future Plans

The limited success of the new tube design reported above is of sufficient importance that plans have been made to continue the construction of these tubes. As mentioned earlier, a tube with 0.1 magnification is needed and such a tube is presently being built and prepared for processing. Data on its performance will be presented in the next report.

Standard FW130 tube with ion pump will also be built to further evaluate the effect of lower residual gas pressure and to develop an aging process that might lead to lower noise.

Data will continue to be accumulated on our standard tube in an effort to correlate cathode size and dark count and dark current and to analyze, generally, their capabilities in sophisticated photon counting applications.