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MASTER

UCID- 18516

PHOTOCATHODE FATIGUE OF L-24 PM HEAD
DUE TO HIGH INTENSITY LIGHT PULSES

K. F. BAILEY

January 8, 1980

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LER 454-7
February 26, 1963

1.0 INTRODUCTION

1.1 Problem

Does the sensitivity of a nuclear detector, which utilizes photo-multipliers, change because of exposing the multiplier phototubes to the high intensity light pulses used during dry run? This report is to exhibit the effects of light saturation fatigue, and its causes.

1.2 Procedure

Six L-24 photomultiplier (PM) heads were tested for fatigue due to saturating light pulses. The Co⁶⁰ gamma calibration was monitored continuously for 12 hours or more, for each head, throughout the test.

1.3 Results

Test results are that generally less than 5% change in sensitivity occurs because of pulse light saturation of FM detector heads for the L-24 detector. Furthermore, the sensitivity and dark current may become unstable or erratic on some detectors. This condition may be determined in the laboratory for most detector heads.

1.4 Conclusion

No change in field dry run procedures are warranted by results of this report. Further evaluation tests are suggested to enhance our knowledge of nuclear detectors.

2.0 APPARATUS

- 2.1 Figure 1 is a diagram of the apparatus and hook-up used for the fatigue measurements.
- 2.2 The Co⁶⁰ sources used were 0.328 and 150 curies as of 7/17/62. The source doors were motor-operated off a timer which opened for about 14.5 minutes and closed for 1 minute intervals. A xenon flash lamp can be pulsed while the source door is closed. A collimator was not used except as noted.
- 2.3 Two L-24 detectors were used for mounting the photomultiplier (PM) and photodiode (PD) heads.

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a) EXPERIMENTAL BLOCK DIAGRAM.

b) EXPERIMENTAL DETECTOR ARRANGEMENT ON CART.

FIGURE 1. a) BLOCK DIAGRAM OF APPARATUS ARRANGEMENT.
b) L-24 DETECTOR ARRANGEMENT ON CART.

DIST. CODE	DRAWING NO. IER 454-7	ELECTRONICS ENGINEERING DEPT. LAWRENCE RADIATION LABORATORY UNIVERSITY OF CALIFORNIA LIVERMORE, CALIFORNIA	UNLESS OTHERWISE SPECIFIED: CAPACITORS 500 MADC.	
			RESISTORS CARBON ± 5%, C > 1 = MF C < 1 = UF.	
TITLE	FILING REFERENCE PHOTOGRAPHY DIVISION OF L-24 FM HEAD DUE TO HIGH INTENSITY LIGHT PULSES	ORIGINAL: K.F. Bailey DATE: 2-26-63	APPROVED	CHANGES
			DATE	CHANGES

2.3.1 One L-24 has a fluor only with one FM head. This is used for gamma only fatigue measurement to speed up data acquisition. This is L-24A.

2.3.2 One L-24 has a fluor, FX-8 xenon flash lamp, FM and PD head. This is used to record Co⁶⁰ gamma fatigue and Co⁶⁰ gamma plus high intensity light fatigue. This is L-24B.

2.4 Signal cables are 50-nanosecond RG8/U to electrometers and/or scope.

2.5 The recording instrumentation is as follows:

2.5.1 Electrometers are both Keithley Model 610R. An F-6 diode is placed on the input of one electrometer to protect it when the xenon lamp flashes. The electrometers then drive the recorders.

2.5.2 The recorders are a Brown Model SY 153X and Easterline Angus Model AW.

2.5.3 A Tektronix 519 scope is used to measure and record the FM pulse generated by the xenon lamp. A Tektronix 545A scope is used to measure and record the PD pulse as above.

2.5.4 John Fluke high voltage power supplies were used.

3.0 PROCEDURE

3.1 Place FM in dark and power at -2KV for at least 4 hours prior to test.

3.2 Install FM on L-24 and test gamma sensitivity. The gamma current should be 10 times dark current minimum.

3.3 Test effect of PD on FM by placing black paper between PD and FM.

3.4 When the above has been completed satisfactorily, run Co⁶⁰ gamma fatigue cycle for 12 hours minimum.

3.5 The detector is then placed in the dark and powered at -2KV until the original gamma sensitivity is recovered.

3.6 The Co⁶⁰ gamma plus xenon lamp fatigue is then run. The Co⁶⁰ is on for about 14.5 minutes and then closes for one minute. During the one-minute closure, the cable is moved from the electrometer to the 519 scope. Forty seconds after the Co⁶⁰ shutter is closed, the xenon lamp is fired, saturating the FM head. Photographs are recorded and labeled on both scopes for the first and last 5 light pulses of a run.

3.7 One FM detector was run with a 4-inch collimator.

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			RESISTORS $\pm$ CARBON $\pm$ 5% C > 1 = PF C < 1 = μ F.	
TITLE PHOTOCATHODE FATIGUE OF L-24 PM HEAD DUE TO HIGH INTENSITY LIGHT PULSES	CALLING REFERENCE PHOTOMULTIPLIER	ORIGINATOR K.F. Bailey	DATE	2-26-63
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4.0 RESULTS

- 4.1 The recorded data for Co⁶⁰ gamma fatigue alone are shown in Figures 2 thru 8 (page 14 to 20).
- 4.2 The recorded data for Co⁶⁰ gamma plus light fatigue are shown in Figures 9 thru 14 (page 21 to 26).
- 4.3 The normalized data for Co⁶⁰ gamma fatigue minus dark current are shown in Figures 15 thru 21 (page 27 to 33).
- 4.4 The normalized data for Co⁶⁰ gamma plus light fatigue minus dark current are shown in Figures 22 thru 27 (page 34 to 39).
- 4.5 The normalized light only fatigue (4.4 minus 4.3) are shown in Figures 28 thru 33 (page 40 to 45).
- 4.6 Photographs of the PM light saturation are shown in Figures 34 thru 39 (page 46 to 51).
- 4.7 Rise time, time to 50%, overshoot, saturation amplitude, and relative light pulse amplitude (PD output) are shown in Table I.
- 4.8 The six PM heads tested are listed in Table II.
- 4.9 Table III lists sensitivities for start and finish as read on the electrometer.

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TITLE PHOTOCATHODE FATIGUE OF L-24 PM HEAD DUE TO HIGH INTENSITY LIGHT PULSES			0 C Levis APPROVED ORIGINATOR DATE 2-26-65	

TABLE I. Dynamic Fatigue Evaluation of Rise Time, Time to 50%, Overshoot, Saturation Amplitude, and Relative Light Pulse Amplitude (PD Output).

DT-2-005 - Start

Photo #	Time	10-90% Rise Time (ns)	Time to 50% (ns)	% Overshoot	Saturation Amplitude (volts)	Light Pulse Amplitude (volts)
1-A	1:40 p.m.	12.2	10.4	-	111.5	300
2-A	1:55 p.m.	8.2	9.5	-	114.5	295
3-A	2:10 p.m.	9.7	11.6	-	115.5	300
4-A	2:25 p.m.	11.2	11.5	-	113.5	270
5-A	2:40 p.m.	9.5	12.3	-	113.5	270

DT-2-005 - Finish

1-B	-	9.2	10.7	-	111.5	290
2-B	-	5.5	8.5	3	111.5	280
3-B	-	8.9	9.9	3	111.5	290
4-B	-	6.0	9.6	-	113.5	280
5-B	-	7.8	9.6	-	112.5	310

DT-2-021 - Start

1-A	1:30 p.m.	5.4	8.0	-	87.8	310
2-A	1:45 p.m.	7.4	9.2	-	87.8	290
3-A	2:00 p.m.	7.6	9.2	1	89.8	290
4-A	2:15 p.m.	8.3	9.0	2	88.8	295
5-A	2:30 p.m.	5.6	6.4	3	86.9	305

DT-2-021 - Finish

1-B	-	5.5	9.1	1	86.9	240
2-B	-	8.3	10.4	3	85.9	230
3-B	-	7.7	9.7	3	85.9	240
4-B	-	5.0	8.5	2	85.6	225
5-B	-	8.9	10.8	3	85.9	260

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	FILING REFERENCE PHOTOMULTIPLIER		APPROVED	DRAWN	DATE	CHANGES		
TITLE PHOTOCATHODE FATIGUE OF L-24 PM HEAD DUE TO HIGH INTENSITY LIGHT PULSES			CHANGE					

Photo #	Time	Rise Time (ns)	Time to 50% (ns)	Overshoot %	Saturation Amplitude (volts)	Light Pulse Amplitude (volts)
<u>DL-1-019 - Start</u>						
1-A	2:45 p.m.	7.6	7.2	-	72.1	300
2-A	3:00 p.m.	6.4	6.7	-	70.1	340
3-A	3:25 p.m.	4.6	6.6	-	70.1	305
4-A	3:30 p.m.	4.2	6.8	-	69.1	310
5-A	3:45 p.m.	4.9	6.9	-	71.1	310
<u>DL-1-019 - Finish</u>						
1-B	-	4.5	7.0	1	71.1	310
2-B	-	4.3	6.7	-	70.1	300
3-B	-	4.3	6.8	-	71.1	310
4-B	-	4.2	6.9	-	71.1	320
5-B	-	4.2	6.8	-	70.1	315
<u>P-2 (LRL) - Start</u>						
1-A	3:00 p.m.	12.3	5.9	-	51.3	No Photo
2-A	3:15 p.m.	15.0	6.0	-	51.3	290
3-A	3:30 p.m.	11.4	6.2	-	49.4	290
4-A	3:45 p.m.	10.5	5.7	-	49.4	290
5-A	4:00 p.m.	11.9	6.2	-	51.3	295
<u>P-2 (LRL) - Finish</u>						
1-B	-	11.1	6.6	-	51.3	280
2-B	-	10.9	6.2	-	48.4	280
3-B	-	12.5	6.5	-	50.3	280
4-B	-	13.2	6.2	-	50.3	305
5-B	-	13.0	6.0	-	51.3	290

Pr. 7 of 52

D 1	C.	APPROVED	DATE	CHANGES	DRAWN	DATE	APPROVED	CHANGE	TITLE	DRAWING NO.	ELECTRONICS ENGINEERING DEPT. LAWRENCE RADIATION LABORATORY UNIVERSITY OF CALIFORNIA LIVERMORE, CALIFORNIA	PHOTOGRAPHIC FATIGUE OF L-24 FM HEAD DUE TO HIGH INTENSITY LIGHT PULSES
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TABLE II. FM Heads Tested With Type Tubes and Voltage Under Test.

	Head #	FM Tubes	Voltage	Remarks
A	DT-2-005	3-2059	-2.6 KV	Co ⁶⁰ only recorded on L-24A, Co ⁶⁰ + light recorded on L-24B.
A	DT-2-021	3-2059	-2.1 KV	Co ⁶⁰ only recorded on L-24A, Co ⁶⁰ + light recorded on L-24B.
B	P-1 (LRL)	3-2059	-2.65 KV	Co ⁶⁰ only and Co ⁶⁰ + light re- corded on L-24B.
A	P-3 (LRL)	3-1P21	-1.8 KV	Co ⁶⁰ only recorded on L-24A, Co ⁶⁰ + light recorded on L-24B.
B	DT-1-019	2-6328 & 1-7117	-1.95 KV	Co ⁶⁰ only and Co ⁶⁰ + light re- corded on L-24B.
A	P-2 (LRL)	3-7117	-2.0 KV	Co ⁶⁰ only recorded on L-24A, Co ⁶⁰ + light recorded on L-24B.

TABLE III. Start and Finish Sensitivities for FM Heads as Read on the Electrometer.

Head #	Sensitivity (I _s) Co ⁶⁰ only		Sensitivity I _s Co ⁶⁰ + Light		Remarks
	Start	Finish	Start	Finish	
	(ua)	(ua)	(ua)	(ua)	
DT-2-005	2.08 A	-	1.21 B	1.13	This head was checked in L-24A before run in L-24B with I _s =1.42 ua.
DT-2-021	1.23 A	-	1.07 B	-	This head was checked in L-24A before run in L-24B with I _s =1.07 ua.
P-1	5.57 B	-	4.1 B	3.75	
P-3	5.7 A	4.92	4.39 B	4.2	This head was checked in L-24A prior to sec- ond run with I _s =5.58 ua. The second run was stopped short after 4 1/2 hrs. The I _s =4.95 at the start of that run in L-24B. 17-3/4 hrs. later the third run was started with the value I _s as shown.
DT-1-019	1.68 B	1.43	1.63 B	1.48	
P-2	1.24 A	1.30	1.26 B	1.26	This head was checked in L-24A before run in L-24B with I _s =1.65 ua.
With 4" Collimator					
DT-1-019	0.83	-	0.73		

Pg. 8 of 51

DIST. CODE	DRAWING NO. LER 454-7	ELECTRONICS ENGINEERING DEPT. LAWRENCE RADIATION LABORATORY UNIVERSITY OF CALIFORNIA LIVERMORE, CALIFORNIA	UNLESS OTHERWISE SPECIFIED: CAPACITORS 500 MDC.	
			RESISTORS - CARBON, A = 5%, C > 1% IF C < 1% = 1%.	
TITLE PHOTOCATHODE FATIGUE OF L-24 PM HEAD DUE TO HIGH INTENSITY LIGHT PULSES	FILMS REFERENCE PHOTOMULTIPLIER	ORIGINATOR K.F. Bailey	APPROVED	CHANGES
			DATE 2-26-63	

5.0 DISCUSSION

5.1 Raw data of Co^{60} only (Figures 2 thru 8) reveal the following information.

5.1.1 Photomultiplier gamma sensitivity decreases when left in a steady-state field. The greatest change can be expected within the first 150 minutes. Furthermore, the rate of decreasing sensitivity is greatest at the time of initial exposure and can be expected to stabilize after a few hours.

5.1.2 The increase of P-2 (Figure 7) is not typical.

5.1.3 DT-2-005 exhibited the greatest decrease in sensitivity.

5.1.4 The dark current appears to follow the sensitivity in all cases.

5.1.5 All of the data seems to be relatively consistent except P-2.

5.2 Raw data of Co^{60} plus light pulse (Figures 9 thru 14) reveal the following.

5.2.1 P-2 became very unstable with both sensitivity and dark current increasing as exhibited in Figure 14. Most of the instability is attributed to the dark current which is illustrated by Figure 27 where dark current has been subtracted.

5.2.2 Comparing Co^{60} plus light to Co^{60} only, it is quite evident that a greater decrease in sensitivity occurred with Co^{60} only. Any one of the following, or combination of the following, could cause the above effect.

5.2.2.1 The PM sensitivity is increased by light saturation. This has been noticed by others.¹

5.2.2.2 The Co^{60} fatigue has become stable due to previous run.

5.2.2.3 There was insufficient time allowed for the recovery of previous run.

5.2.2.3.1 Table IV gives time between first (Co^{60} only), second (Co^{60} plus light), and third (Co^{60} only with 4" collimator) runs.

5.2.3 The dark current behavior appears to be reasonable except P-2. Light saturation of PM heads, while monitoring dark current, may offer a means of detecting unstable detectors.

5.2.4 All data appears to be relatively consistent except P-2.

¹Private discussions.

DRIVING NO. **454-7**

FILE NO. **454-7**

PHOTO MULTIPLIER

TITLE **PHOTOCATHODE FAULTS OF L-24 PM HEAD DUE TO HIGH INTENSITY LIGHT PULSES**

DESIGNED BY **W. F. Bailey**

DATE **2-20-63**

APPROVED **W. F. Bailey**

DATE **2-20-63**

UNLESS OTHERWISE SPECIFIED: CAPACITORS 500 WDC.

RESISTORS = CARBON, $\pm 5\%$, C > 1 = 9F, C < 1 = μF .

R = OHMS, L = μH , SYMBOLS = ASA

CHANGE APPROVED _____

DATE _____

DRAWN _____

DATE _____

TABLE IV. Time Between Data Runs.

Head #	Time Between 1st & 2nd Runs (Hours)	Time Between 2nd & 3rd Runs (Hours)	Remarks
DT-2-005	84	-	
DT-2-021	12	-	
P-1	62	-	
P-3	-	-	150 hrs. after 1st. run. 2nd run was started, at 4 1/2 hrs. later, timing sys- tem failed. 17-3/4 hrs. after failure, the test was started over.
DT-1-019	126	219	
P-2	52	-	

5.3 Normalized Data

- 5.3.1 The dark current was subtracted from the sensitivity in all cases before normalizing.
- 5.3.2 The initial gamma sensitivity of each run was taken as 100 in all cases.
- 5.3.3 The percent Co^{60} only, Co^{60} plus light, and Co^{60} plus light minus Co^{60} only, are listed in columns A, B, and C, respectively in Table V.

TABLE V. Total Percent Change of Co^{60} Only, Co^{60} Plus Light, and Co^{60} Plus Light Minus Co^{60} Only for PM Heads.

PM Head #	A	B	C
	% Change Co^{60} Only	% Change Co^{60} Plus Light	% Difference Co^{60} Plus Light & Co^{60} Only
DT-2-005	38.5	7.0	32.5
DT-2-021	13.8	2.5	12.5
P-1	30.0	7.0	25.0
P-3	15.0	4.2	11.3
DT-1-019	11.3	6.7	4.4
P-2	6.0	23.0	-
DT-1-019*	14.5	-	-

* With 4-inch Collimator.

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			RESISTORS R = OHMS L = INCHES C = CAPACITORS	CARRYING C > 1 = PF C < 1 = MF	SYMBOLS - ASA	CHANGES
TITLE PHOTOGRAPHIC RESPONSE OF L-24A PM HEAD DUE TO HIGH INTENSITY LIGHT PULSES		APPROVED K.F. Bailey		DATE 2-26-63		

5.3.4 Each detector is analyzed as follows:

- 5.3.4.1 DT-2-005 exhibits the greatest percent change in Co^{60} only. Table III lists a starting $I_S = 2.08 \text{ ua}$ in L-24A and $I_S = 1.42 \text{ ua}$ in L-24A just prior to Co^{60} plus light run. This is a percent difference in initial sensitivities of 31.7, which compares favorably to the value 32.5 listed in column C of Table V. The value listed in column C could therefore be attributed to 5.2.2.3.
- 5.3.4.2 DT-2-019 had a starting $I_S = 1.23 \text{ ua}$ in L-24A and $I_S = 1.07 \text{ ua}$ in L-24A just prior to Co^{60} plus light run. This is a percent difference in initial sensitivities of 13.0 which again compares favorably to the value 12.5 listed in column C of Table V. The value listed in column C could again be attributed to 5.2.2.3.
- 5.3.4.3 F-1 had a starting $I_S = 5.57 \text{ ua}$ in L-24B and $I_S = 4.1 \text{ ua}$ in L-24B at the start of Co^{60} plus light run. This is a percent difference in initial sensitivities of 20 which compares with the value 25 listed in column C of Table V. Most of the value listed in column C could be attributed to 5.2.2.3.
- 5.3.4.4 F-3 had a starting $I_S = 5.7 \text{ ua}$ in L-24A and $I_S = 5.58 \text{ ua}$ in L-24A prior to Co^{60} plus light run. Unfortunately, after 4 hours in L-24B, (Co^{60} plus light test) the experiment was interrupted and stopped due to failure of timing and safety equipment. The test was started over after 17-3/4 hours. However, the I_S in L-24A was not recorded at this point. The percent difference in initial sensitivities between Co^{60} only and first run of Co^{60} plus light is 2.1%. The value 11.3% listed in column C of Table V is reasonable considering only 17-3/4 hours elapsed between runs 2 and 3.
- 5.3.4.5 DT-1-019 had a starting $I_S = 1.68 \text{ ua}$ in L-24B and $I_S = 1.63 \text{ ua}$ in L-24B at the start of Co^{60} plus light run. This is a percent difference in initial sensitivities of 2.97 which compares with the value 4.4 listed in column C of Table V.

After 219 hours, a third run was made on DT-1-019 with a 4-inch collimator and Co^{60} only. This data is shown in Figures 8 and 21. The data listed in column A of Table V shows that a percent change of 14.5 and 11.3 occurred for 4" collimator and no collimation, respectively. It is interesting that a 3.2% greater change in sensitivity occurred for the collimated case.

Pa. 26-4 53

DIST. CODE	DRAWING NO. LER 154-7 PHOTO MULTIPLIER	ELECTRONICS ENGINEERING DEPT. LAWRENCE BERKELEY LABORATORY UNIVERSITY OF CALIFORNIA LIVERMORE, CALIFORNIA	UNLESS OTHERWISE SPECIFIED: CAPACITORS 500 WVO. C.	
			RESISTORS = CARBON W 1 5%, C > 1 = P F C < 1 = MF. R = OHMS. I = μ H. SYMBOLS - ASA	
TITLE PHOTO MULTIPLIER FATIGUE OF L-24 FM HEAD DUE TO HIGH INTENSITY LIGHT PULSES	DATE 2-26-63	ORIGINATOR F. F. Bailey	APPROVED	CHANGES
			DATE	CHANGES

A logical comparison of data at this point would seem to rule out Co^{60} fatigue becoming stable, as previously suggested in 5.2.2.2. About 3% of the 4.4% can be accounted for by insufficient time allowed for the recovery of previous run. This leaves about 1.4% that might be attributed to FM sensitivity increased by light saturation. The above data is suggested only and not known to be the gospel.

5.3.4.6 P-2 will not be considered because of its erratic behavior.

5.4 Perusal of the dynamic fatigue data in Table I and Figures 34 thru 39 seem to reveal nothing at first. However, if one takes the average saturation amplitude for the start and finish of each run, the interesting data of Table VI results.

5.4.1 TABLE VI. Average Start and Finish Saturation Amplitude and Percent Decrease.

FM Head #	Average Saturation Amplitude		
	Start (Volts)	Finish (Volts)	% Decrease
DT-2-005	113.7	112.1	1.408
DT-2-021	88.2	86.0	2.5
P-1	126.1	124.2	1.505
P-3	42.4	40.7	4.05
DT-1-019	70.5	70.7	0.184 (% Increase)
P-2	50.7	50.3	0.79

5.4.2 The data of Table VI shows that in general, the saturation amplitude decreases under condition of light saturation plus Co^{60} . The data does not indicate which environment causes the decrease. A test with light saturation alone would be illuminating at this point.

6.0 SUMMARY

6.1 The fatiguing effects of light saturating a FM detector head are found to be as follows:

6.1.1 There is a small increase in DC gamma sensitivity, perhaps a few percent are due to light fatigue.

6.1.2 The dark current may increase or become very unstable due to light fatigue.

DIST. CODE	DRAWING NO. LER 454-7	FILING REFERENCE PHOTOMULTIPLIER	ELECTRONICS ENGINEERING DEPT. LAWRENCE RADIATION LABORATORY UNIVERSITY OF CALIFORNIA LIVERMORE, CALIFORNIA	UNLESS OTHERWISE SPECIFIED: CAPACITORS 500 WVDC. RESISTORS - CARBON 1/2 W. C > 1 = PF C < 1 = MF. R = OHMS. L = μ H. SYMBOLS - ASA	APPROVED	DATE	CHANGES	P. Lewis C. Lewis APP'D ORIGIN K.F. Bailey DATE 2-26-63
								TITLE PHOTO-CATHODE FATIGUE OF 1-24 IN. HEAD DUE TO HIGH INTENSITY LIGHT PULSES

- 6.1.3 The sensitivity may become very unstable due to light fatigue.
- 6.1.4 There may be no detectable fatigue.
- 6.1.5 The light saturation amplitude may decrease a few percent.
- 6.2 There are no changes in field dry run procedures necessary as a result of this evaluation. The data presented in this report indicates a very small change in sensitivity due to light saturation.
- 6.3 The results of this report indicate that further testing and evaluation is required in the following areas to enhance our knowledge of nuclear detectors.
- 6.3.1 Cause and effect of Co^{60} gamma fatigue which seems to follow a folding mechanism.
- 6.3.2 Monitor dark current while light pulse saturating PM head to uncover unstable detectors.
- 6.3.3 Evaluate a PD head under same test conditions as this report describes. This should separate the cause of Co^{60} gamma fatigue between photocathode or dynode.
- 6.3.4 An evaluation which has long been passed over is DC to pulsed correlation with respect to both amplitude and time. The DC calibration has been extrapolated as much as eight decades with respect to both. This evaluation is not necessarily indicated by results of this test, but certainly worth mention.

Kenneth F. Bailey

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Electronics Engineering Dept.

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208°

DC FATIGUE - CO⁶⁰ ONLY

LER 454-7

DC FATIGUE - CO⁶⁰ ONLY

LER 454-7

DC FATIGUE - CO⁶⁰ ONLY

LER 454-7

DC FATIGUE-CO⁶⁰ ONLY

LER 464-7

DC FATIGUE - CO⁶ ONLY

LER 454-7

DC FATIGUE - CO⁶⁰ ONLY

LRR 454-7

DC FATIGUE - CO⁶⁰ + 4" COLLIMATOR

DC FATIGUE - CO⁶⁰ + LIGHT

LER 454-7

DC FATIGUE - CO^{60} + LIGHT

LAB 454-7

Pg. 22 of 51

DC FATIGUE - CO⁶⁰ + LIGHT

LER. 454-7

DC FATIGUE - CO⁶⁰ + LIGHT

DC FATIGUE - CO⁶⁰ + LIGHT

LER 454-7

DC FATIGUE - CO⁶⁰ + LIGHT

DC FATIGUE - CO⁶⁰ ONLY

DC FATIGUE - CO⁶⁰ ONLY

DC FATIGUE - CO⁶⁰ ONLY

DC FATIGUE - CO⁶⁰ ONLY

DC FATIGUE - CO⁶⁰ ONLY

LER 454-7

DC FATIGUE - CO⁶⁰ ONLY

LRR-454-7

DC FATIGUE - CO⁶⁰ + 4" COLLIMATOR

LER 464-7

DC FATIGUE - CO⁶⁰ + LIGHT

LER 454-7

DC FATIGUE - CO⁶⁰ + LIGHT

LER 454-7

DC FATIGUE - CO⁶⁰ + LIGHT

LER 454-7

DC FATIGUE - CO⁶⁰ + LIGHT

LER 454-7

DC FATIGUE - CO⁶⁰ + LIGHT

LER 454-7

DC FATIGUE - CO⁶⁰ + LIGHT

LER 454-7

DC FATIGUE - LIGHT ONLY

LER 464-7

DC FATIGUE - LIGHT ONLY

DER 454-7

DC FATIGUE - LIGHT ONLY

LER 454-7

DC FATIGUE - LIGHT ONLY

LER 464-7

DC FATIGUE - LIGHT ONLY

LER 454-3

DC FATIGUE - LIGHT ONLY

LER 454-7

Photo #1-A

Photo #1-B

Photo #2-A

Photo #2-B

Photo #3-A

Photo #3-B

Photo #4-A

Photo #4-B

Photo #5-A

Photo #5-B

a)

b)

Figure 34. DT- 2-005 PM Light Saturation Pulses for a) Start-Up of run and b) End of Run.

Photo #1-A

Photo #1-B

Photo #2-A

Photo #2-B

Photo #3-A

Photo #3-B

Photo #4-A

Photo #4-B

Photo #5-A

Photo #5-B

a)

b)

Figure 35. DT-2-021. FM Light Saturation Pulses for a) Start of Run and b) End of Run.

Photo #1-A

Photo #1-B

Photo #2-A

Photo #2-B

Photo #3-A

Photo #3-B

Photo #4-A

Photo #4-B

Photo #5-A

Photo #5-B

a)

b)

Figure 30 - P-1. HM Light Saturation Pulses for a) Start of Run and b) End of Run.

Photo #1-A

Photo #1-B

Photo #2-A

Photo #2-B

Photo #3-A

Photo #3-B

Photo #4-A

Photo #4-B

Photo #5-A

Photo #5-B

a)

b)

Figure 37. P-3. FM Light Saturation Pulses for a) Start of Run and b) End of Run.

Photo #1-A

Photo #1-B

Photo #2-A

Photo #2-B

Photo #3-A

Photo #3-B

Photo #4-A

Photo #4-B

Photo #5-A
a) Photo #5-B
b)

Figure 38. DT-1-019 PM Light Saturation Pulses for a) Start of Run and b) End of Run.

Photo #1-A

Photo #1-B

Photo #2-A

Photo #2-B

Photo #3-A

Photo #3-B

Photo #4-A

Photo #4-B

Photo #5-A

Photo #5-B

a)

b)

Figure 39. P-2 FM Light Saturation Pulses for a) Start of Run, and b) End of Run.