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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

A STUDY OF PHOTOMETRIC AND LIFE TESTS ON INCANDESCENT TRAFFIC SIGNAL LAMPS

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September 28, 1956

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State of California
Department of Public Works
Division of Highways
Materials and Research Department

September 28, 1956

Lab. Order No. 6002

Mr. R. H. Wilson
Assistant State Highway Engineer
Sacramento, California

Dear Sir:

Submitted for your consideration is:

A STUDY OF PHOTOMETRIC AND LIFE TESTS

ON INCANDESCENT TRAFFIC SIGNAL LAMPS

Tests made by . . . . . Structural Materials Section

Under general direction of . . . . . J. L. Beaton

Supervised by . . . . . J. E. Barton

Report prepared by . . . . . Max Pausch

Very truly yours,

F. N. Hveem
Materials & Research Engineer

MP:mw
cc: GGMcGinness
FEBaxter
GMWebb
EWithycombe
MHarris

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I. INTRODUCTION

A proposal to undertake a traffic lamp study was approved at the Service and Supply board meeting on May 11, 1951. The purpose of this study originally initiated by Mr. Milton Harris was to develop a testing program and specifications to control the quality of lamps to be purchased by the state for use in signal installations. Testing under controlled conditions was considered to be the only means of determining comparable life and lumen service efficiencies among the various brands and also to furnish information which would permit an effective set of specifications to be prepared. The following is quoted from the minutes of this meeting:

> "The Division of Highways purchases lamps in the amount of $25,000 annually.....Lamps are purchased primarily on price consideration. Labor costs in changing lamps are extremely high, especially on outdoor lamps for traffic signals and highway lighting. Outdoor lamps are changed regularly regardless of whether or not the lamps are worn out, and, in spite of the practice, numerous lamps are burned out before their normal life expectancy. The cost of changing an individual lamp amounts to as much as $30.00.
>
> "There are 1845 signal installations in the State Highway System which increase at the rate of 114 installations per year. The number of signal lamps required is approximately 55,000 whose maximum life is nine months and generally will not last their full life. The total cost of maintaining traffic signals in the Highway System amounts to $600,000 per year of which a sizeable portion is for maintaining and replacing lamps .....
>
> "Commercial laboratories are primarily concerned with lamp manufacturers and will not release their data and findings to us. The University of California has a partial set-up for testing lamps but do not want to be obligated to the extent of testing our lamps."

The actual assignment of this project to the Materials and Research Department was by letter dated July 26, 1951, from Wilson to McCoy. Approved by Mr. McCoy on July 26, 1951.

Detailed plans for the photometric sphere were executed in 1952, and most of the orders for the requisite equipment were placed in the latter part of 1951 and early in 1952. Prolonged delays in receiving the equipment due to slowness of the suppliers together with design changes in the arrangement for the lamp aging racks forced by our limited laboratory space prevented assembling the component parts until January 1954. Initial tests were performed at that time using the new photometering apparatus. Final completion of a test program was further delayed by construction

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activities following the laboratory fire of March 1954, but by May 1954 the lamp testing equipment was completed and arranged so that in addition to the testing of the traffic lamps, other types such as Mercury vapor or incandescent lamps which may be used in highway service could also be tested.

Preliminary findings and field experience caused the Maintenance Department to suggest (May 1954 memorandum) that traffic signal lights should meet the following specifications:

a. 67 watt

b. 130 volts

c. 6000 hours life

d. 600 lumens initial light output

e. Not more than 20% drop in lumen output during the total specified life of the lamp.

As a consequence of this recommendation all traffic signal lamps tested have been of the 67 watt, 130 volt series. Ten brand types in batches of twenty to fifty lamps each have been examined under closely controlled conditions for lumen decay and lamp mortality rates. Practically all brands were found seriously deficient in their rated life expectancy when operated at the above prescribed standard voltage. A large variation in lumen decline has been noted. However, none of the brands investigated dropped materially below the 480 lumen end-point recommended by Maintenance.

The lamp test program included the following phases:

(1) Aging the lamps in a light test rack at 130 volts.

(2) Taking periodic light output measurements of these lamps.

(3) Tabulating data, making graphs, and analyzing the results.

(4) Writing a recommended specification, based on the Maintenance Department's recommendations and the results of the lamp tests.

The following pages give the theory and procedure involved. Exhibits which are grouped in the Appendix include:

Exhibit I	Recommended specifications.
Exhibit II	Diagram of Sphere Photometer and Associated Instruments.
Exhibit III	Curve of Lumens vs. Age Showing Decline.
Exhibit IV	Mortality Rate of Traffic Lamps.

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Exhibit V	Curve of Light Output vs. Voltage.
Exhibit VI	Curve of Theoretical Life vs. Voltage.
Exhibit VII	Curve of Lumens vs. Age (Accelerated Tests).
Exhibit VIII	Mortality Rate from Accelerated Tests.
Exhibit IX	Table of Light Output vs. Voltage for Exhibit V.
Exhibit X	Summarized Data of Lumen Decline with Age.
Exhibit XI	Table of Lumen Decline from Accelerated Aging.

A discussion of the results and the application of this information as employed in writing the specifications appears under "Summary and Recommendations".

The results indicated that lamps which would conform substantially to the general requirements recommended by the Maintenance Department are commercially available.

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II. THEORY AND PROCEDURE

In general the equipment (Exhibit II) and procedure used conforms to the recommendations of the Illuminating Engineering Society in their "Guides to Testing Procedures" dated November 1950.

The lamps were aged on life test racks with the voltage regulated to 130 volts. At intervals throughout the life of the lamps the bulbs were removed from the racks and tested individually in an Ulbricht spherical integrating photometer to determine the light output. These tests were made first after an initial seasoning, then at 1/4 rated life, 1/2 rated life, 3/4 rated life, and at rated life. Data and graphs of the photometric results as well as the mortality curves may be found in the Appendix (Exhibits III and IV). Nineteen lamps were photometered at reduced voltage and these results also appear in the Appendix (Exhibit V). In addition a curve showing the theoretical lamp life versus voltage is included (Exhibit VI). The last named curve illustrates the necessity for carefully regulating the voltage of the life test racks. During the tests voltage regulators maintained the voltage within 0.25% of the rated value. A continuous record of the applied voltage was maintained by recording voltmeters.

A schematic sketch of the apparatus used to make the photometric measurements on the lamps is given as Exhibit II in the Appendix. The photometer is a 60" hollow sphere whose interior surface is painted with a special white paint giving an efficient diffused reflecting surface. With the light source set at the center of the sphere and a shield arranged to block any direct rays from the lamp which would fall on the photocell, the photocell receives only reflected light from the sphere wall. This reflected light is proportional to the total light output of the source. For this purpose six calibrated traffic lamps were purchased from the Electrical Testing Laboratories for use as primary reference standards. Other lamps were calibrated and used as everyday working standards for rating all lamps which were on test. The lumens of flux from the unknown lamps under test were then established by multiplying the lumens of the standard lamp by the ratio of photocell readings of any unknown lamp to the standard lamp.

The manufacturers rated life (rated life is the point where 50% of the lamps fail when operating at rated voltage) of the lamps tested varied from 3000 to 7000 hours. Brands A, B, and C were 3000 hour lamps, brand D was rated at 5000 hours, and brands E, F, G, J, and K were 6000 hour lamps. Brand H is reported to have a 6500-7500 life expectancy. Exhibits III and IV show that reasonably long life can be obtained, (several makes are not as long lived as rated) and that prolonged use entails a sacrifice in efficiency. In essence the 3000 hour lamps generally give a greater light output than the 5000 and 6000 hour lamps. It will be noted that all long life lamps meet the proposed specifications for 600 lumens initial output, and that only two brands fell below the 480 lumens minimum which is the 20% maximum drop off point after 5000 hours burning time, suggested by the Maintenance Department.

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Lamp life can be materially extended by operating the 130 volt lamps below their rated voltage. This obviously results in a lower light output. As an example, a 130 volt lamp burned at 120 volts will last about 2.8 times as long as is possible when operating at its rated voltage, but there is a corresponding reduction in light output amounting to approximately 25%. The curves in Exhibits V and VI summarize effects from varying the voltage. Both the experimentally determined and theoretical values are recorded therein. The tabulations in Exhibits IX and X are included to substantiate the findings shown in Exhibits III and V.

Six to ten months are required to conduct life tests on the long life lamps when they are aged at their rated voltage. Therefore, it would obviously be advantageous to accelerate the aging by increasing the operating voltage on the lamps as long as such procedure produces relevant values. In November 1955 such a procedure was initiated. Two brands have been aged at 140 volts and two at 160 volts. The lumen decline with age and the mortality rates of these lamps are graphically depicted in Exhibits VII and VIII. The lamps were photometered at 130 volts, and in the graphs the values were plotted against the hours of life corresponding to normal 130 volt operation. This theoretical life was calculated from the empirical formula given in the I.E.S. Lighting Handbook, Second Edition, pages 8-14, which, when adapted to our case, reads as follows:

$$\frac{\text{life}_1}{\text{life}_2} = \left(\frac{130 \text{ volts}}{\text{Volts}_1}\right)^{13.1}$$

in which "life_1" is the actual lamp life obtained from operating at voltage "Volts_1" and "life_2" is the calculated lamp life corresponding to 130 volt operation. From this it can be computed that 414 hours at 160 volts corresponds to 6000 hours at 130 volts. The results of the two tests conducted at 160 volts substantially corroborate these values.

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III. SUMMARY AND DISCUSSION

The following tabulation summarizes the results of the above tests:

Lamp Brand	Number of Lamps Tested	Life (Hours) Mfg's. rated	Life (Hours) Actual*	Intensity Initial	Intensity Rated Life **
A	25	3000	2125	763	535
A1	30	3000		827	
B	48	3000	2450	786	595
C	24	3000	2900	757	580
C1	28	3000		757	
D	25	5000	4500	680	477
E	21	6000	5150	715	529
F	25	6000	10000	630	475
F1	25	6000 over	7000	604	
G	25	6000	5275	670	525
H	30	7000 over	8000	615	480

* Taken from Exhibit IV.

** Taken from Exhibit III.

Of the longer lifed lamps brands E, F, G, and H showed the least decline in light intensity. F and H are the only brands showing a good 6000 hour life.

Attention is called to Federal specification W-L-101e which states that samples containing 20 to 24 lamps each should have an allowable percentage variation not exceeding 12% from the specified rated life. Brands E, F, G, and H meet this specification.

The Maintenance Department reports that an appreciable number of lamps have failed during the first few hours of operation.

Should this difficulty continue, consideration should be given to the practical aspects of obtaining lamps seasoned 10 hours at 135 volts, or for Service and Supply to do this seasoning before installation of the lamps.

Further study can be performed when more experience is gained with lamps purchased according to the proposed specifications.

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IV. RECOMMENDATION

It is recommended that the specifications titled, "Proposed Specification for Traffic Signal Lamps", (included as Exhibit I in the Appendix of this report) be used for all future purchase orders of signal lamps for the Division of Highways.

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V. BIBLIOGRAPHY

1. Minutes of Service and Supply Board Meeting for May 11, 1951.

2. Federal Specification for Lamps; electric, incandescent, large, tungsten-filament: W-L-101e.

3. Engineering Bulletin - Incandescent Lamps -- Sylvania Electric. 0-89.

4. Photometry - by M. H. Gabriel, C. F. Koenig, E. S. Steeb, Jr., Standardizing Department, Lamp Division, General Electric Co.

5. I. E. S. Lighting Handbook, Second Edition, 1952, published by the Illuminating Engineering Society.

6. Memorandum to Mr. F. N. Hveem from Mr. G. G. McGinness dated May 28, 1954.

7. Memorandum to Mr. G. T. McCoy from Mr. Richard H. Wilson dated July 26, 1951.

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July 25, 1956

Exhibit I

PROPOSED SPECIFICATION FOR TRAFFIC SIGNAL LAMPS

Traffic signal lamps which comply with the below description, physical inspection test, initial rating test, and accelerated life performance test will be accepted for use. The normal and accelerated life performance tests will be performed concurrent with use. If the lamps fail to meet the requirements of the normal life performance test, then the bidder shall not be provided another opportunity to bid until his lamps have been prequalified.

Lamp Description:

Approximate watts:	67 watt
Bulb type:	A 21
Base:	medium screw
Rated voltage:	130 volts
Minimum rated life:	6000 hours
Burning position:	horizontal

Bid Samples:

Each bid shall be accompanied by 48 lamps offered for compliance with this specification. All lamps will be retained by the State.

PHYSICAL INSPECTION TEST

Lamp selection and test quantity.--The number of lamps to be selected by the inspector for physical inspection shall be not less than 5 percent (minimum 20 lamps) of the lot, taken at random and proportionately from the individual packages of the lot. Lamps thus selected for inspection are known as "the inspection-test lamps".

Rejection for major physical defects.--Major physical defects are those which render lamps inoperative or which would cause them to give unquestionably poor service. A lot may be rejected without further test if 1 percent or more of the inspection-test lamps have major physical defects. Individual lamps having major physical defects may be rejected and eliminated from an accepted lot, and shall be replaced by the manufacturer without additional charge.

INITIAL RATING TEST

Lamp selection and test quantity.--The number of lamps selected for rating shall be not less than 5 percent (minimum 20 lamps) of the lot, taken at random and proportionately from the individual packages of the lot. The lamps may be the same as those selected for physical inspection and are known as "the rating-test lamps." The rating test lamps will be seasoned for at least 15 hours at 130 volts before the initial rating test is made of the lumen output.

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Rejection for low lumen rating.--Rating-test lamps will be operated at 130 volts. A lot of lamps shall be rejected if 1 percent or more of the rating-test lamps fall below 600 lumens.

NORMAL LIFE-PERFORMANCE TEST

Lamp selection and test quantities.--The lamps for the life-performance test shall be selected from the rating-test lamps at the ratio of not less than 4 from the first 1000 lamps of any lot and at least 1 lamp from each 500 lamps (or part thereof) by which the lot exceeds 1000 lamps. The life-test lamps shall be representative of the rating-test lamps.

Life-test lamps to be counted as part of quantity delivered.--The life-test lamps selected by the inspector will be destroyed in the course of the life test. Lamps destroyed in life tests will be counted as a part of the quantity of lamps delivered by the contractor to the State of California.

Position of burning.--Lamps will be burned in a horizontal position.

Voltage regulation.--Accurate recording meter records will be obtained throughout the tests to show the variation of the circuit. The voltage will not exceed one-quarter of 1 percent variation from 130 volts.

Lamp life.--The life of a lamp is the length of time (in hours) to burn out.

Failure to meet life requirements.--Any lot of lamps shall be considered as failing if more than 5 percent of the life-test lamps burn out before 3000 hours or if more than 50 percent burn out before 6000 hours.

Determination of lumens maintenance.--Life-test lamps will be measured at 130 volts for lumen output after an interval of 4000 hours.

Failure to meet lumens maintenance requirement.--Any lot of lamps shall be considered as failing if more than 10% of the lamps tested fall below 500 lumens at the 4000 hour interval.

ACCELERATED LIFE PERFORMANCE TEST

At the option of the laboratory an accelerated life-performance test shall be run by increasing the operating voltage to 160 volts. The lamp life expected from 130 volt operation will be obtained by multiplying the accelerated life by 6000/414. The lumens maintenance will be determined after aging 276 hours. All photometering will be done at 130 volts.

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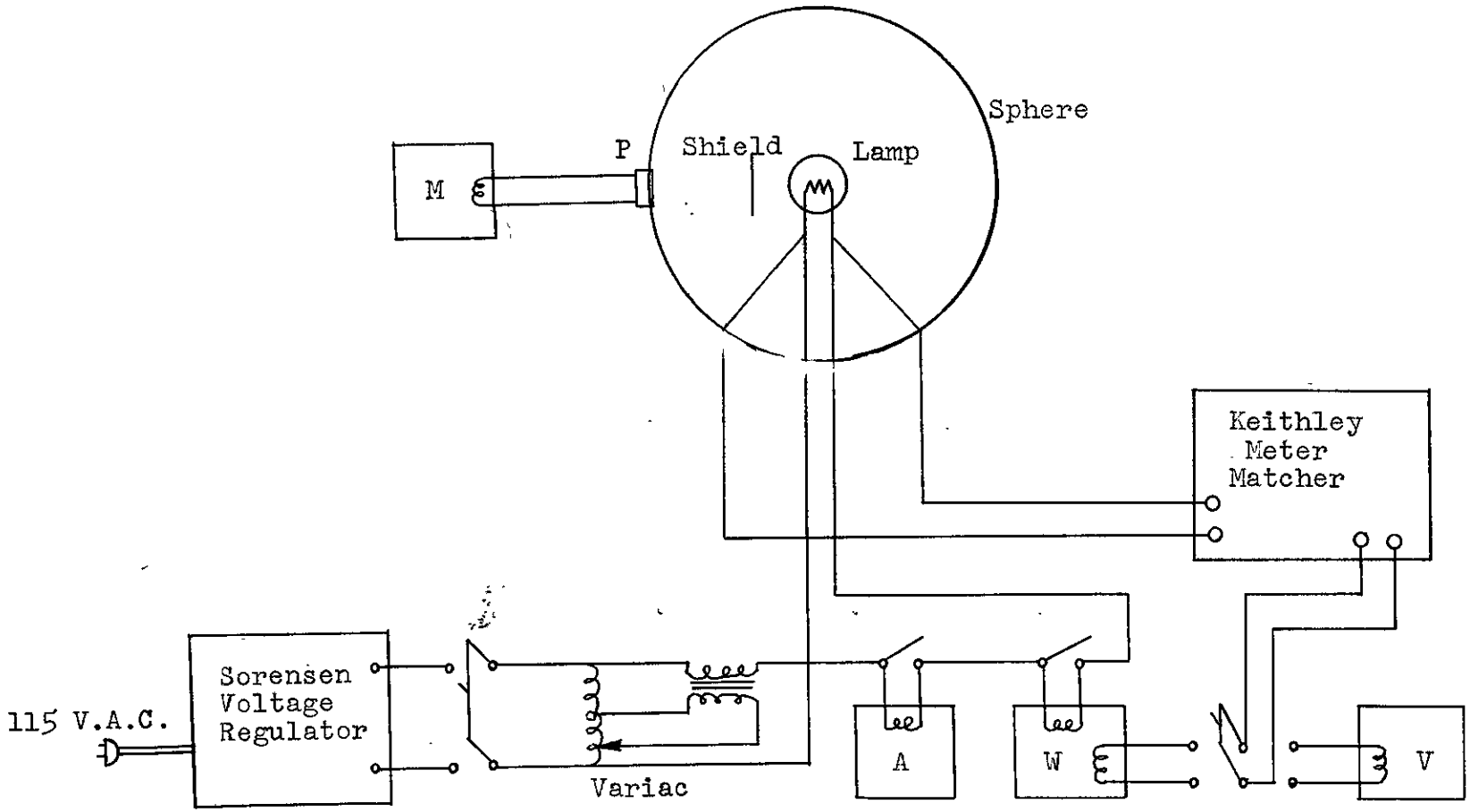
SPHERE PHOTOMETER AND ASSOCIATED INSTRUMENTS



Identification

M - G. E. Microammeter DP-9
P - Weston Photronic Cell No. 594-RR-OV
A - G. E. Type PL-2 Laboratory Standard Ammeter
W - G. E. Type PL-2 Laboratory Standard Wattmeter
V - G. E. Type PL-2 Laboratory Standard Voltmeter

Exhibit II

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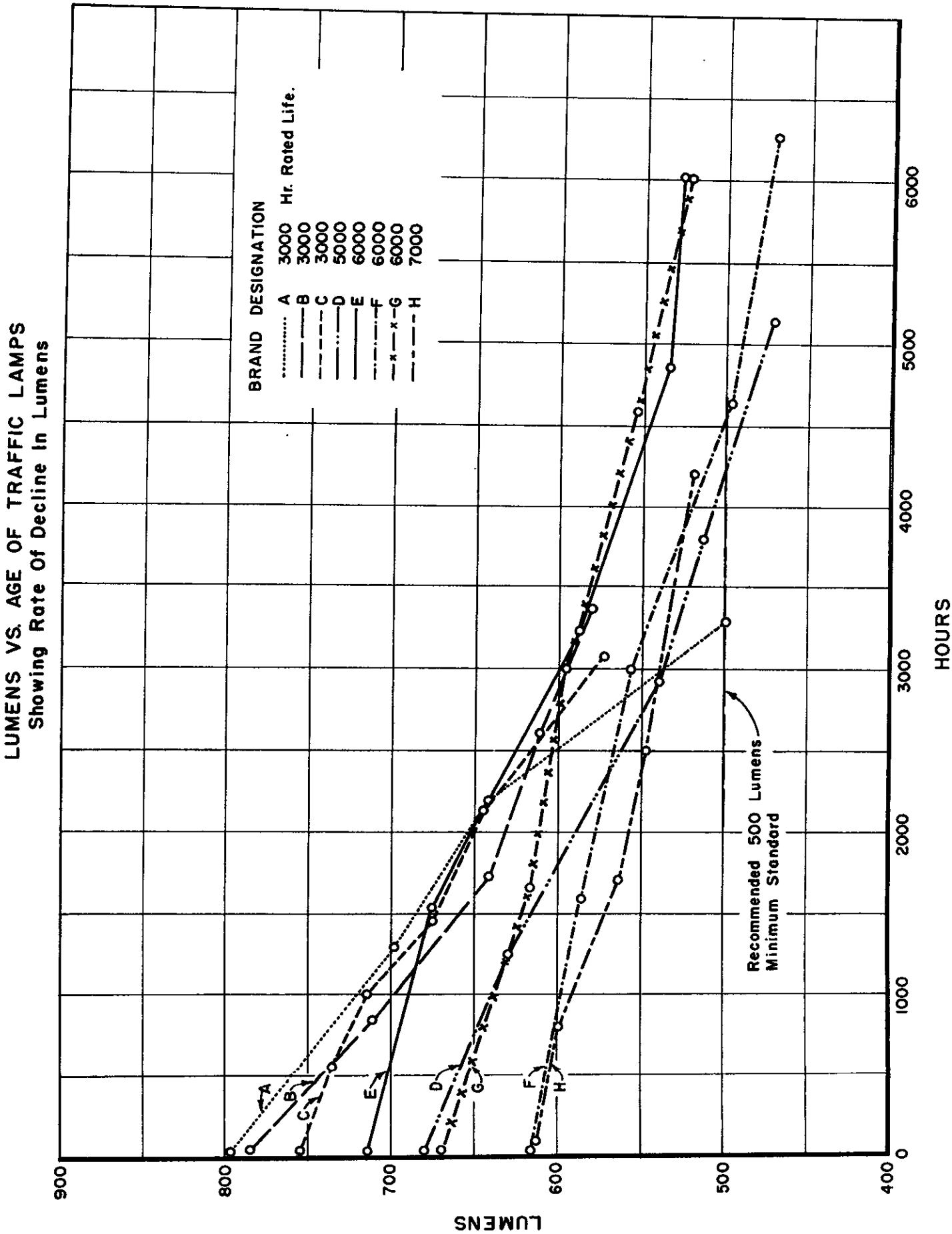
Exhibit III



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MORTALITY RATE OF TRAFFIC LAMPS

SHOWING ACTUAL LIFE FOUND FOR VARIOUS REPRESENTATIVE SAMPLES

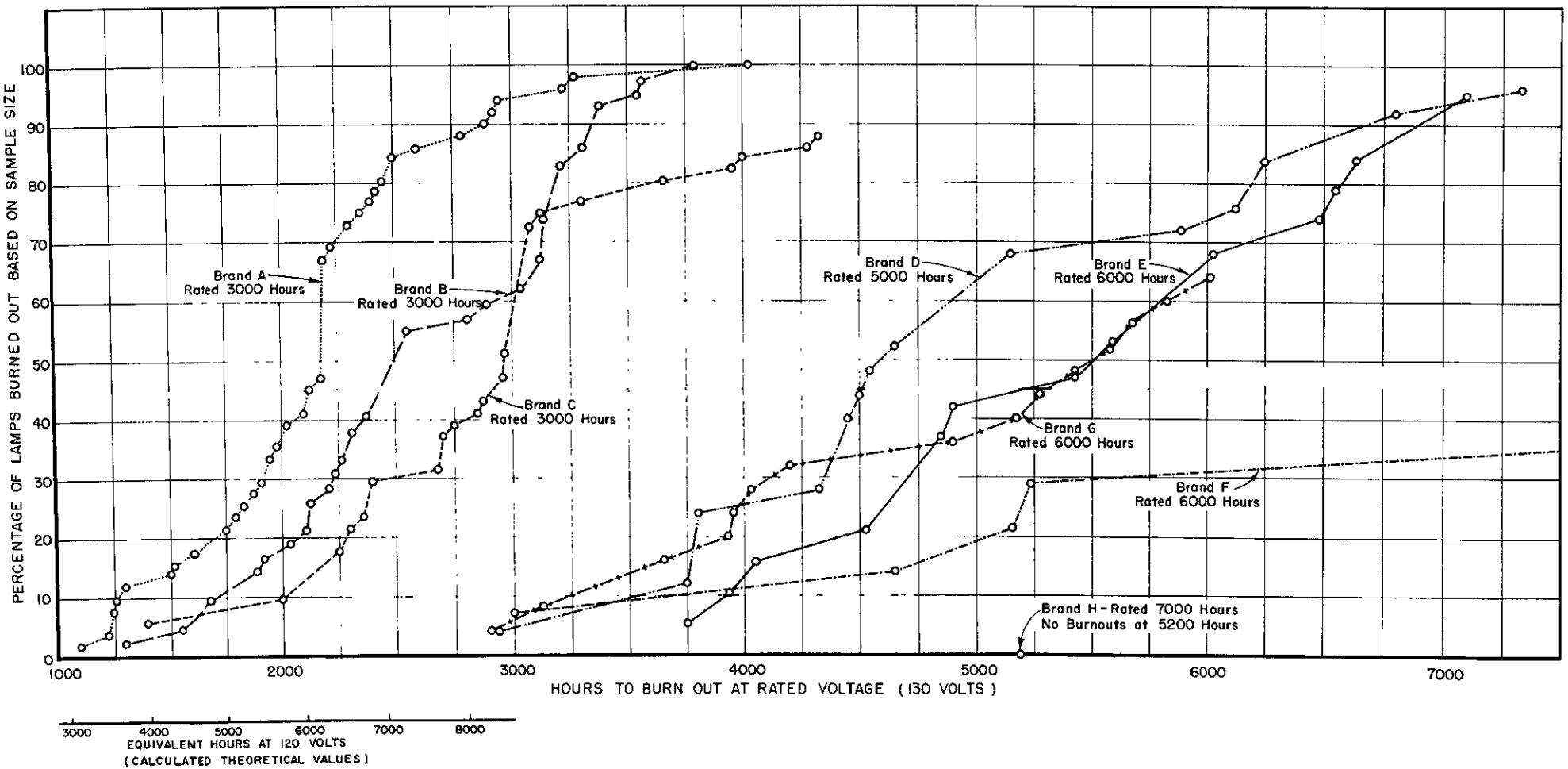

Exhibit IV

Exhibit V

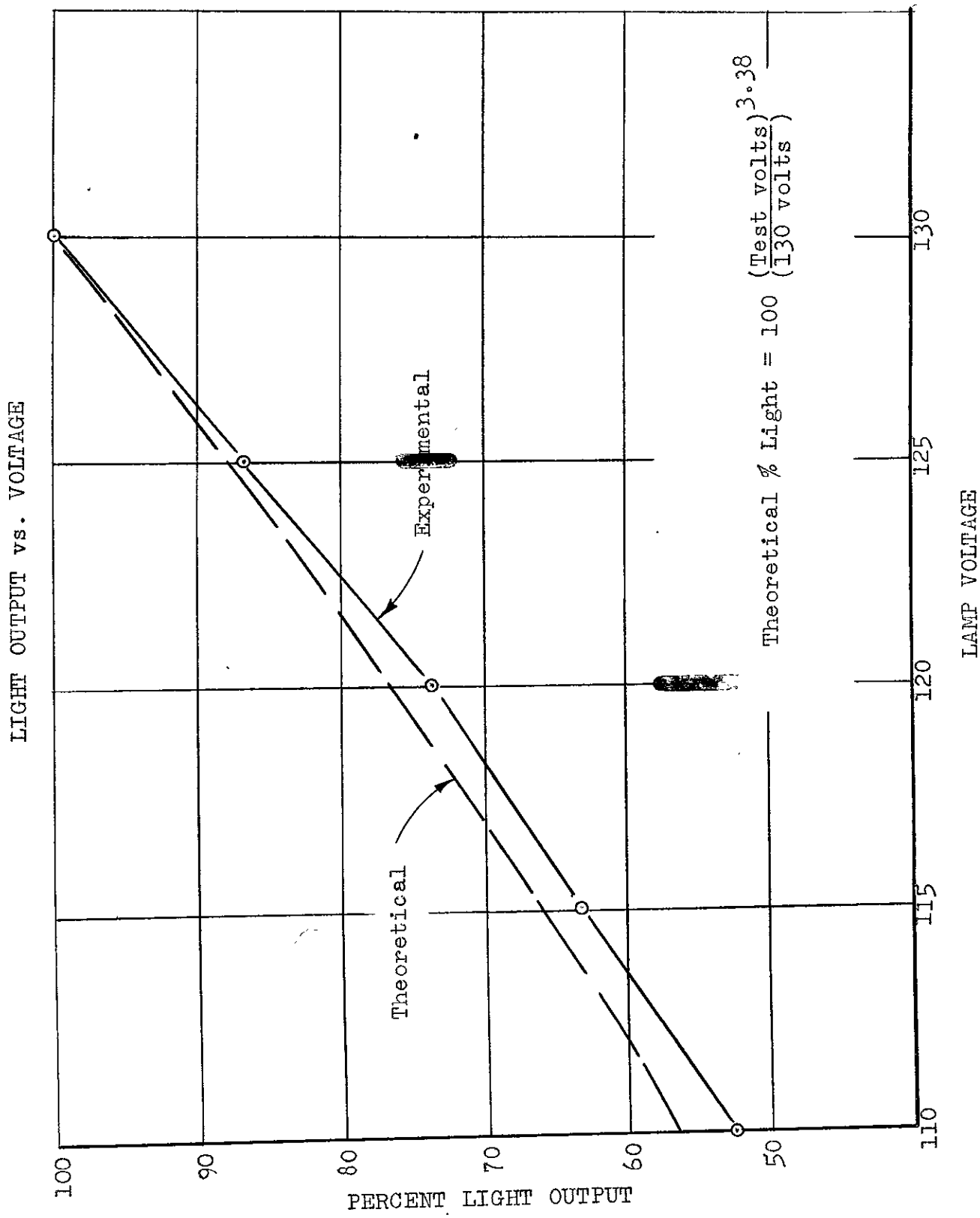

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Exhibit VI

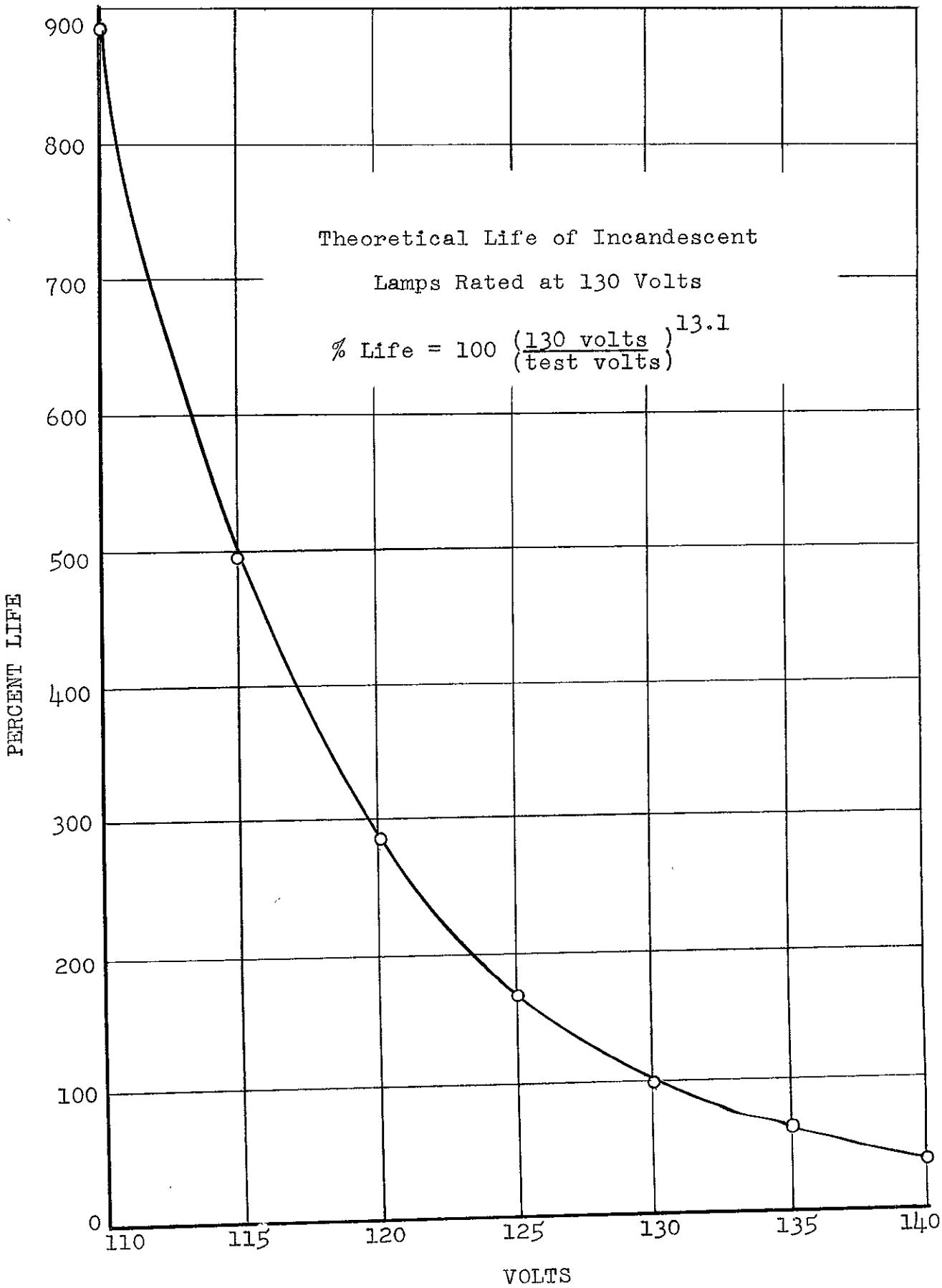

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Exhibit VII

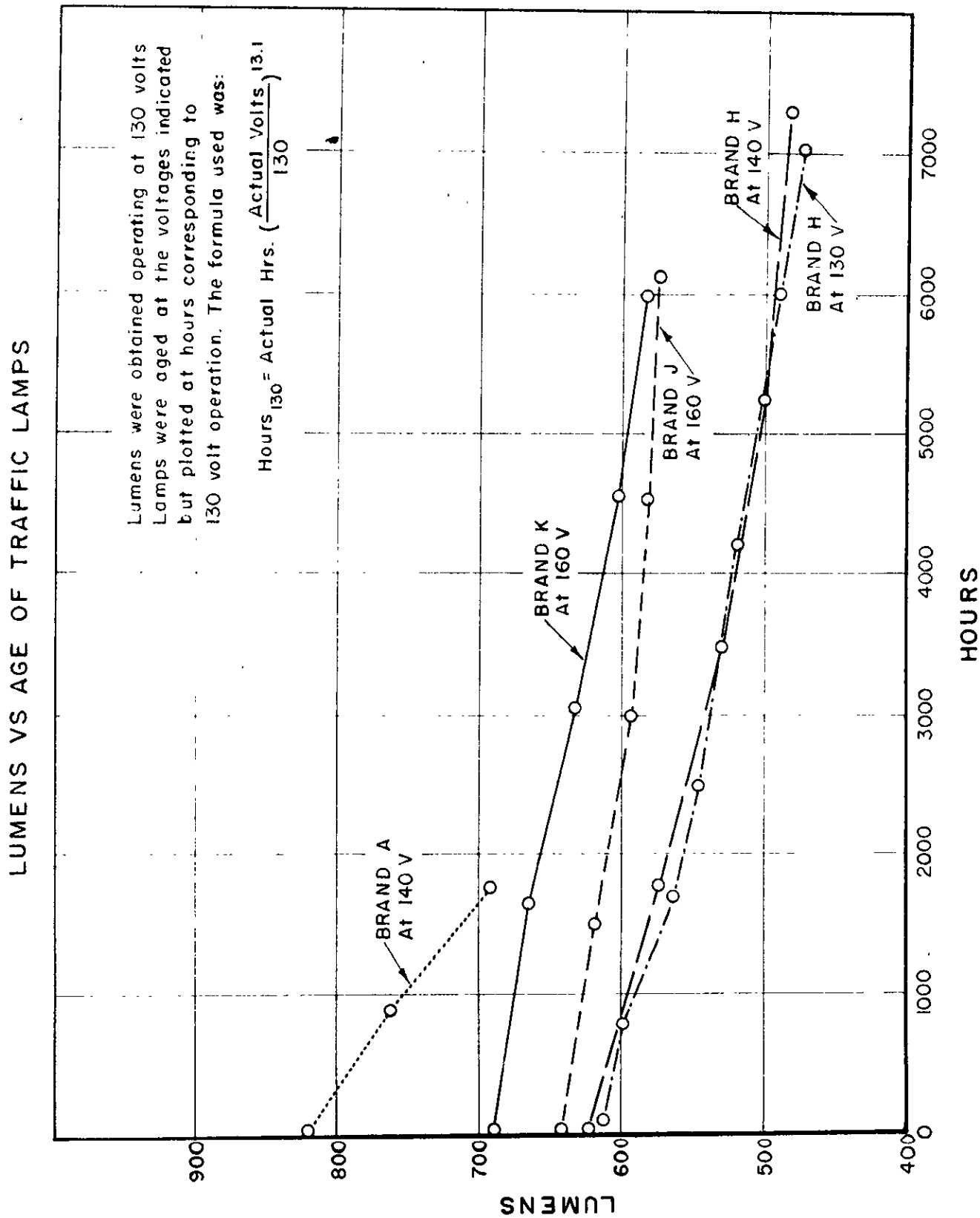

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Exhibit VIII

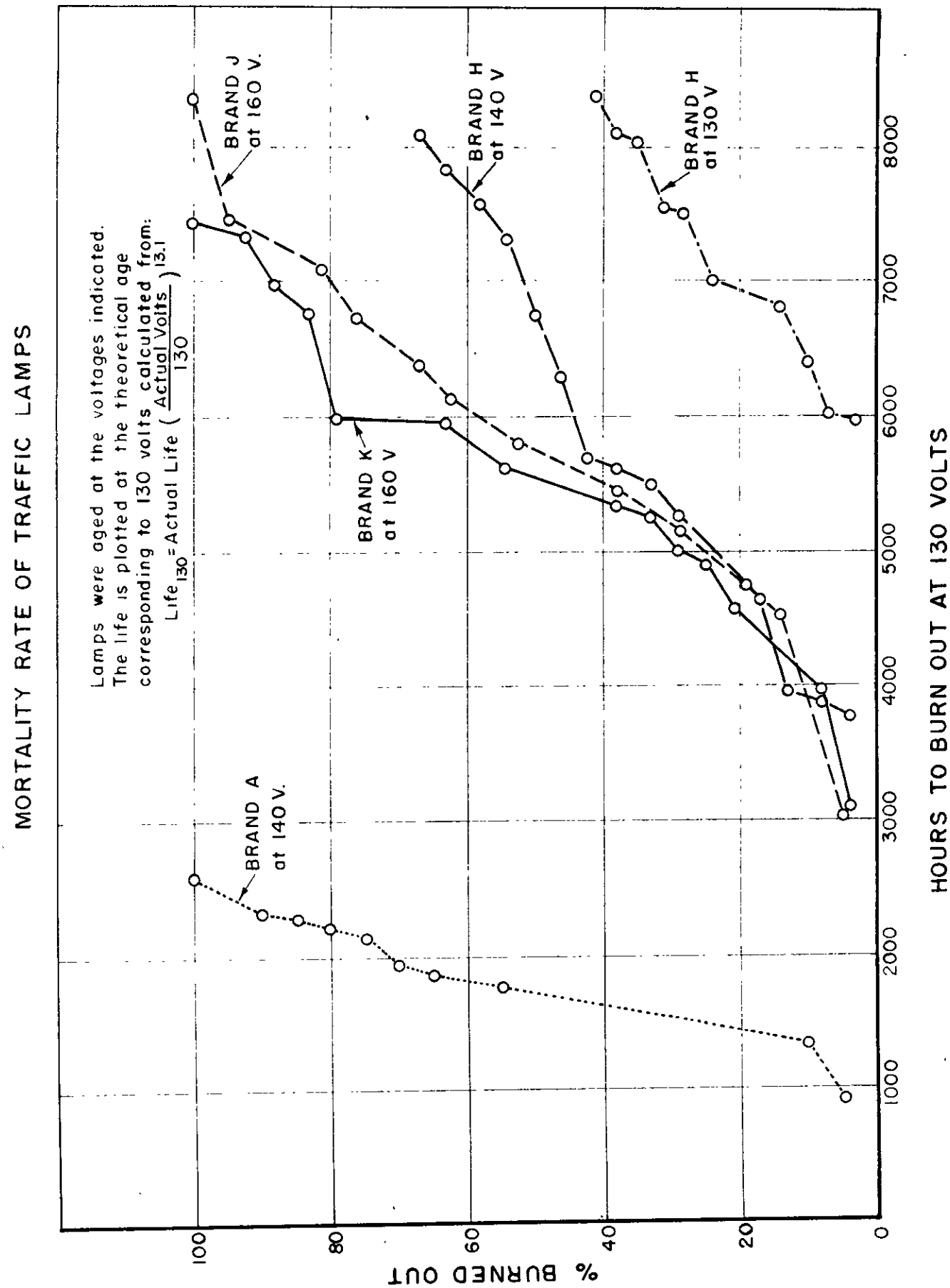

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Exhibit IX

PERCENT LIGHT OUTPUT IN LUMENS OF 19 LAMPS OPERATED AT VARIOUS VOLTAGES

Luminous Flux at 130 V = 100%

Lamp No.	Hours in Operation	110	115	120	125	130
C 25	1392	54	64	74	87	100
C 26	1392	54	64	74	87	100
A 33	1327	54	64	74	87	100
A 34	1327	54	64	74	87	100
E 10	4707	52	63	74	86	100
E 11	4707	52	63	74	86	100
B 37	1818	54	64	74	87	100
B 38	1818	54	64	74	87	100
F 70	1705	52	63	74	87	100
F 87	1705	52	63	73	86	100
F 100	1705	52	63	73	86	100
F 26	6264	51	62	73	86	100
F 36	6264	52	63	73	87	100
F 50	6264	51	62	73	86	100
G 1	1666	52	63	73	86	100
G 2	1666	53	64	74	87	100
F 21	100	52	63	73	86	100
E 12	4855	52	63	74	86	100
E 13	4855	52	63	74	87	100
	Average	52.6	63.3	73.6	86.5	100
	Theoretical*	56.8	66.0	76.4	87.6	100

* Calculated from: $\% \text{ Light} = 100 \left(\frac{\text{Test Volts}}{130 \text{ Volts}}\right)^{3.38}$

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Exhibit X

LUMEN DECLINE WITH AGE

Brand Designation	Age In Hours	Maximum Lumens	Minimum Lumens	Average Lumens
A	23	804	734	763
	1259	716	683	698
	3279	573	434	500
A_1	28	860	787	827
	1327	732	681	699
	2184	654	625	640
B	48	890	751	786
	840	758	680	711
	1722	720	619	643
	2604	645	579	610
	3360	608	557	581
C	23	776	734	755
	546	749	716	736
	1000	728	700	715
	1504	717	684	700
	2004	696	646	668
C_1	25	780	740	757
	1392	670	639	652
	2228	642	605	620
	3072	588	560	573
D	23	711	644	680
	1259	653	604	630
	2938	574	508	540
	3804	546	490	514
	5143	484	462	472
E	23	737	684	715
	1500	704	649	675
	3225	623	562	586
	4855	585	517	536
	6030	596	502	529
F	24	648	621	630
	1570	618	586	606
	2981	597	575	583
	4637	512	490	498
	6264	481	461	471
F_1	16	635	579	604
	1610	582	547	567
	3010	554	502	530
	4541	520	470	505
	6033	504	474	489

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Brand Designation	Age In Hours	Maximum Lumens	Minimum Lumens	Average Lumens
G	35	724	624	670
	1666	686	574	617
	2994	671	551	595
	4593	593	527	555
	6012	545	512	525
H	94	666	562	615
	790	669	539	601
	1691	611	528	564
	2499	596	506	548
	4200	560	494	520
	6010	520	462	491
	7018	502	450	473

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LUMEN DECLINE FROM ACCELERATED AGING
LAMPS PHOTOMETERED AT 130 VOLTS

Brand Designation	Age In Hours	Age Corres. to 130 V.	Maximum Lumens	Minimum Lumens	Average Lumens
H	18	47	685	544	624
Aged at 140 V.	681	1780	603	526	574
	1336	3490	560	502	531
	2007	5240	536	477	500
	2793	7290	510	457	482
A	18	47	879	783	821
Aged at 140 V.	345	900	801	740	762
	676	1770	722	668	692
J	1	16	728	578	642
Aged at 160 V.	104	1510	685	557	619
	208	3010	682	536	594
	311	4520	682	538	580
	423	6130	676	531	577
K	2	23	710	664	690
Aged at 160 V.	115	1670	694	646	667
	211	3060	652	617	631
	315	4570	620	590	602
	413	5990	587	575	581

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