AN EXPERIMENTAL DESIGN OF A STAGE LIGHTING SYSTEM USING LOW VOLTAGE SEALED-BEAM LAMPS

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AN EXPERIMENTAL DESIGN OF A STAGE LIGHTING SYSTEM USING LOW VOLTAGE SEALED-BEAM LAMPS

By

Donald Louis Murray

A THESIS

Submitted to the College of Communication Arts of Michigan
State University of Agriculture and Applied Science
in partial fulfillment of the requirements
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BIOGRAPHY

Donald Louis Murray was born in Kenosha, Wisconsin, and received his elementary and secondary education in the public schools of that city. After graduation from high school, he attended the University of Wisconsin in Madison, Wisconsin, where he received a Bachelor of Science degree with a major in Speech and minors in English, Natural Science, and Education.

For a period of two years following graduation from the University of Wisconsin, Mr. Murray was the Speech and Dramatics Director at Decorah High School, Decorah, Iowa. His responsibilities included the teaching of Senior Speech and English Literature, the production of three-act and one-act plays, and the direction of a complete forensic and debate program.

During the past year, Mr. Murray has been a graduate assistant in technical theatre for the Michigan State University Department of Speech. In this capacity, he has participated in many phases of theatrical production, including lighting, directing, scenery construction and painting, make-up and acting.

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ABSTRACT

This thesis presents a proposed design and an analysis of a stage lighting system using PAR 36, twenty-eight volt sealed-beam lamps. The problem of the utilization of three particular models of the PAR 36 lamp to light a small stage area is treated in (1) an introductory analysis of conventional lighting practices and previous experimental research in the area of low-budget stage lighting; (2) the testing of PAR 36 twenty-eight volt sealed-beam lamps number 4502, 4505, and 4589, and an analysis of their characteristics comparative to the 500-watt Fresnel spotlight; (3) the design and construction of a suitable lamp housing and mounting; (4) the design of a control and distribution system; and (5) a summary and evaluation of the proposed low-voltage stage lighting system.

Chapter I discusses current lighting practices and the need for a method for lighting the stage which is economical, lightweight, compact and simple.

Chapter II, divided into three parts, presents in Part One the characteristics of the PAR 36, twenty-eight volt sealed-beam lamp determined in experiments conducted with three models of this lamp. Part Two treats the design and construction of a lamp housing which would permit the adaptation of the sealed-beam lamp to use for theatrical lighting. In Part Three, the development of a suggested control

and distribution system is analyzed in relation to the requirements of low-voltage operation and the demands of stage lighting.

Chapter III summarizes the potentialities of the PAR 36 twenty-eight volt sealed-beam lamp as a basic light source for a small stage area, and evaluates the low-voltage stage lighting system in terms of its assets and limitations. Conclusions regarding the usefulness of a low-voltage system in lighting the stage are drawn and recommendations for employment of the proposed system are presented.

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CHAPTER I

INTRODUCTION

The problem. Since the advent of modern stage lighting the stage technician has been concerned with the designing of apparatus to overcome limitations of equipment already in use and the development of new and workable plans for the improvement of existing equipment. Most of the stage lighting equipment in current use in professional, community, university, college, and secondary school theatres is expensive, weighty, cumbersome, and requires fairly heavy-duty electric service for satisfactory operating results. Theatrical organizations operating on a small stage or a low budget, or both, often find that commercially available lighting equipment is unobtainable or unsatisfactory. Groups producing in the popular arena or flexible style of theatrical presentation sometimes find conventional lighting equipment limited for their particular use by reason of expense, size and weight, and light output characteristics. These often necessitate a certain amount of adaptation which results in a loss of efficiency.

Particularly affected are those groups which tour their productions or find it necessary for one reason or another to produce in locations not designed or equipped for theatrical use. The development, therefore, of a system for lighting the stage that is economical, lightweight, compact, and simple would be highly advantageous where considerations of cost, portability and flexibility are of primary importance.

Background and justification of the study. Authorities in the field of stage lighting have offered numerous suggestions and recommendations regarding what they consider to be the minimum lighting equipment required for the small stage. An example of this type of recommendation is presented by Stanley McCandless in what he terms "a typical up-to-date layout, with the minimum equipment required even if only one play a year is presented."[1] Mr. McCandless' suggestions include six six-inch lens ellipsoidal-reflector spotlights mounted in front of the proscenium and six 500 watt Fresnel lens spotlights hung inside the proscenium as acting area lights. Additional illumination for the acting area is to be provided by two borderlight sections, each with sixteen 100 watt lamps, and three sections of disappearing footlights. Special accent instruments such as four four-and-one-half inch lens ellipsoidal spotlights, two sections of 200-to-300 watt borderlights and a 1000-to-2000 watt follow-spotlight are also suggested by Mr. McCandless. Completing this proposed system are a 250-to-750 watt beam projector for sunlight and moonlight effects, and a 2000 watt sciopticon to project moving patterns and natural effects such as snow, rain, fire and clouds. Since Mr. McCandless is concerned with a permanently-installed lighting system, such additional items as connection strips, wall-mounted receptacles, floor pockets and outlet boxes are also part of the initial installation. For light control a wall-mounted auto-transformer switchboard with a patch panel and

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[1] Stanley McCandless, "Lighting the Small School Stage," Architectural Record, May, 1955, pp. 230, 233, 235.

twenty-four 1000 watt and three 6000 watt circuit dimmers is recommended. On the basis of the prevailing market prices of Century lighting equipment, this proposed system for lighting the small school stage would cost approximately $11,000, not including installation.[2]

This figure of course could be greatly lowered by the use of less expensive conventional apparatus. For example, applying the minimum requirements recommended by Mr. McCandless, a more economical lighting system for the small stage might include six 1000-to-2000 watt plano-convex lens spotlights, six 500 watt Capcolities, a Capital type S. E. borderlight containing forty 100 watt lamps, and two sections of portable footlights. For special accenting purposes, four 250-to-400 watt baby plano-convex spotlights, four sections of 200 watt Grand striplights, and a 1500-to-2000 watt plano-convex follow spotlight could be used. Ideally the addition of an effect machine and a sciopticon would be highly advantageous. However, such instruments could be rented or borrowed for specific occasions when required and would not necessarily be a part of the standard equipment of the school or theatre with a limited lighting budget. The various instruments, instead of being permanently wired, could be connected with a series of flexible stage cables, permitting not only a reduced initial cost but also use in other locations away from the theatre. Completing this low-budget conventional lighting system could be a combination of portable control boards such as those manufactured by The Superior Electric Company and The

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[2] Ibid. Additional information on prices and equipment taken from a printed insert supplied by Century Lighting Incorporated, New York, New York, 1955.

Arielite-Davis Company. Probably such switchboards would necessitate the sacrifice of some degree of dimmer control obtainable with the twenty-seven dimmer installation recommended by Mr. McCandless. However, in addition to greatly reduced cost, there would be certain advantages which could not be realized with a permanently-mounted switchboard. A portable control-board system would permit the location of the control station at various points on the stage or possibly even in the auditorium. Furthermore, the complete system could be moved to another location for touring, for an arena production, or other special event where lighting might be required. This suggested lighting system, utilizing portable boards and less expensive conventional lighting equipment, on the basis of Capitol Lighting Company[3] and the Grand Stage Lighting Company[4] catalogues, would cost approximately $3,500 to $4,500. Although this figure is considerably less than the original $11,000 estimate, even such a less expensive stage lighting system using conventional apparatus is beyond the means of many non-professional producing groups.

Other suggested stage lighting layouts can be referred to in order better to ascertain the experts' opinions. Mr. Theodore Fuchs' recommendations for essential apparatus necessary to light a small stage with a proscenium opening from twenty-four to thirty feet, include

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[3] Capitol Stage Lighting Apparatus, No. 25, Perfection Lighting Company, Incorporated, New York, New York.

[4] Controlled Light by Grand, Grand Stage Lighting Company, Chicago, Illinois, 1955.

six 500 watt ellipsoidal spotlights, two 1000 watt spotlights, twenty 500 watt Fresnel spotlights, two 1000 watt and six 500 watt wide-beam floodlamps, a unit section of footlights, three unit sections of borderlights, a cyclorama borderlight tray, four three-foot and one six-foot section of striplights, a twenty-four circuit auto-transformer dimmer unit and plugging panel and five floor pocket receptacles.[5] Mr. Fuchs' essential lighting layout for the small stage, in number and type of units resembles the previously mentioned plan proposed by Mr. McCandless and, therefore, would be approximately in the same price range, beyond the budget of many non-professional theatrical organizations.

The most inexpensive small-stage lighting system using conventional apparatus to come to the attention of the writer is that proposed by Century Lighting Company. This includes four 500 watt Lekolites, two five-foot sections of disappearing footlights, four 250-to-750 watt and one 1000-to-1500 watt Fresnelites, one borderlight unit, and two floor pockets. Total cost is $1,509.60.[6] This figure does not include any type of dimmer unit, the addition of which would raise the total cost considerably. Although this minimum-budget system seems more within the financial range of many non-professional producing groups, the disadvantages of a lack of portability and, more importantly, flexibility limit the usefulness of a system of this nature.

Despite the fact that a stage lighting system using conventional apparatus may not necessarily be prohibitive in price if a limited

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[5] Theodore Fuchs, Suggested Layouts of Stage Lighting Equipment for Typical Large, Medium-sized and Small Non-commercial Stages, Northwestern University Theatre, Evanston, Illinois, 1949, pp. 9-11.

[6] Century Stage Lighting Facilities for the School and Community Theatre, Century Lighting Incorporated, 1953, p. 7.

layout is chosen, many non-professional theatrical organizations are not adequately equipped. This fact is revealed in several studies conducted by people who have been actively engaged in drama programs in secondary schools. A survey conducted by Mr. Jed Davis in the high schools of Minnesota suggests the type and amount of equipment generally found on high school stages.[7] Mr. Davis reports that two-thirds of the high schools surveyed had no dimmers, eighty per-cent had fewer than three spotlights, three-fourths had some borderlights, and almost one hundred per-cent had footlights. Special-effect equipment was non-existent in all of the high schools surveyed. A study by Miss Eleanor Chase of the stage facilities and equipment in various small high schools in Michigan revealed that, of the thirteen schools surveyed, only two owned more than one spotlight and four had no conventional lighting equipment whatsoever.[8] The administrators or boards of many high schools, then, apparently either cannot afford or are unwilling to purchase modern lighting equipment, and the drama program consequently must struggle along with make-shift and generally inadequate lighting apparatus.

Many college, university, and community theatres across the country apparently are better equipped than the average high school. However, they normally have lighting systems that are permanently

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[7] Jed H. Davis, "A Critical Survey of the Stage Lighting Equipment in the High Schools of Minnesota," Master of Arts Thesis, University of Minnesota, 1949.

[8] Eleanor Sarah Chase, "A Budget Plan for the Purchase of Stage Scenery and Lighting Equipment for the Small High School," Master of Arts Thesis, Michigan State College, 1944, p. 13.

installed, making them totally unavailable or impracticable for production use in any place other than the theatre or auditorium in which they are installed. This fact serves to eliminate or greatly reduce the possibility of touring productions to other locations or of presenting plays in the popular arena style unless a certain amount of duplicate equipment is available. Much conventional equipment is too bulky or heavy to be efficiently transportable, and in many cases such switchboards as are available are permanently mounted. Furthermore much equipment suitable for use in large theatres is not adaptable to use on a small stage or in the arena due to its size and weight, its design for long-range throws, and its comparatively high wattage which necessitates an extraordinarily large power supply.

The inadequacies of stage lighting systems across the country in school and community theatres, then, stem first from the expense of the equipment, when the minimum requirements for a small stage often exceed a limited budget, and secondly from the very nature of conventional equipment.

The purpose. The purpose of this study is to suggest a low-cost stage lighting system utilizing low-voltage sealed-beam lamps that will satisfy many normal lighting situations encountered in forms of theatrical presentation ranging from arena to conventional or proscenium. The proposed system would include twenty-four low-voltage sealed-beam lamps, operating on eight circuits of three lamps each, lamp housings suitable for the mounting of the lamps in various positions, a step-down filament transformer to reduce standard 110/120 volt electricity to the operating voltage of the sealed-beam lamps, a dimmer control-board composed of nine auto-transformers, and cable and wire connections necessary for the flexible use of this system. The resulting lighting system, embodying characteristics that would make it easily transportable, would allow greater freedom in mobility, operation, and storage than possible with conventional equipment.

Procedure. This study is an investigation of the use of a particular type of low-voltage sealed-beam lamp in a stage lighting system to evaluate its possible advantages to theatrical groups desiring a flexible, compact, efficient and inexpensive method for lighting the stage. The procedure followed is divided into three parts. First, three distinctly different models of the PAR 36 lamp, manufactured by General Electric for use as automotive spot-lamps and aviation signal-lamps, are tested at distances of five, ten, and twenty feet to determine the maximum candlepower, beam pattern and spread, and lumen output. Then, the characteristics of the sealed-beam lamp having been established to determine its adaptability to stage lighting, the second part of this study treats the designing and construction of a suitable lamp housing for the PAR 36 lamp that would protect the lamp, permit the unit to be mounted in many positions and aiming directions, allow for use of colored gelatin media, permit ready access to the lamp while the unit is mounted, and be small and inexpensive. The third part of this study covers the development of a control and distribution system that will operate twenty-four low-voltage sealed-beam lamps in eight circuits of three lamps each. Experimentation for determining suitable equipment necessary to reduce standard voltage to the operating voltage of the lamp is reviewed. The next step treats the selection and utilization of suitable commercially manufactured apparatus necessary to complete the control unit. Finally the determination of proper cable to be used in the distribution system is discussed.

Limitations of previous studies. Within recent years other investigators have suggested methods of lighting the stage utilizing a variety of lamp types that deviate from standard theatre equipment. The use of self-contained reflector-filament lamps in some instances and low-voltage incandescent filament lamps in others has been explored. In many non-commercial theatres in this country the use of PAR 38 projector and R-40 reflector lamps has been common practice, particularly on small stages. Acceptable home-made cylinder lamp housings have been developed for the R-40 lamp in the replacement or supplementation of conventional equipment.[9] Additionally, various types of R-40 and PAR 38 housings intended for or adaptable to stage use are commercially available.

The PAR 38 lamp is manufactured for 150 watts, while the R-40 is available in sizes of 150, 300, and 500 watts.[10] While these lamp units are popular for low-budget operation, they are larger in overall dimensions and somewhat heavier than the PAR 36 low-voltage sealed-beam lamps, and necessitate a larger and bulkier housing for practical and

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[9] David W. Weiss, "Lighting On a Small Budget," Players Magazine, XXIX, December 1952, pp. 62-65.

[10] "Projector and Reflector Lamps," Application and Design Data, LS-152, Lamp Division, General Electric, July, 1953.

efficient operation on the stage. A further disadvantage is their characteristic of considerable uncontrolled spill. The PAR 38 and R-40 lamps use 110/120 volts of alternating current, requiring fairly large and expensive control units and larger cable than would be necessary in low-voltage lighting. The R-series standard voltage lamp, when compared with the low-voltage sealed-beam unit, is considerably more fragile and consequently would not withstand the rigors of touring theatre as well.

Other reflector lamps such as the R-30, rated at seventy-five watts, and the R-52 rated at 500- and 750-watts,[11] are of either too low or too high a light output to be of great value for use on small and medium-sized stages. These lamps also are restricted to use with 110/120 volt current. Several additional models of the standard-voltage projector lamp are also available. The PAR 46 at 200-watts and the PAR 56 at 300-watts[12] are efficient and sturdy units, but because of their size and the fact they need 110/120 volts of electricity they possess certain disadvantages as compared to their low-voltage counterparts. To summarize the material discussed the following table is presented:

LAMP	WATTS	VOLTS	MAX. BEAM FOOTCANDLES	MAX. LENGTH INCH.
PAR 38	150	110/120	116	5 5/16
PAR 46	200	110/120	87,000	4
PAR 56	300	110/120	200,000	5
R-30	75	110/120	20	5 3/16
R-40	150	110/120	68	6 1/2
	300	110/120	145	7 1/4
	500	110/120	230	7 1/4
R-52	500	110/120	*	11 3/4
	750	110/120	*	11 3/4

*Test data not available.

[11] *Ibid.*

[12] *Ibid.*

The Arielite Manufacturing Company markets a low-voltage lamp unit that utilizes a PAR 46 lamp operating at a design voltage of 6.4 volts.[13] The lamp unit has a built-in transformer to step-down the line voltage across the filament from 110/120 volts to 6.4 volts and is commonly referred to in theatrical parlance as the "grain of wheat lamp." This Arielite APS-30 Pin Spot throws an intense beam of light, which cannot be adjusted in size, over a small area from a considerable distance. Thus its use for stage lighting is limited to small-area, high-accent spotting. Since the transformer is mounted within the lamp housing, the total unit is relatively large and weighty and therefore offers certain disadvantages for various uses, especially in touring theatre.

Other research has been conducted using low-voltage filament lamps.[14] The lamps used were of low voltage and high wattage resulting in the need for a considerably larger amount of current than conventional lighting units. Whenever high amperage is found in a circuit, the size, weight, and expense of cable and control equipment are increased in such proportions as to nullify the advantages of the small size of the lamp. Use of the PAR 36 twenty-eight volt sealed-beam lamp in a stage lighting system seems to indicate potentialities for greater flexibility, compactness, simplicity, economy, and efficiency than other suggestions which have come to the attention of the writer.

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[13] A.I.A. No. 31-F-25, Bulletin 602, Arielite Manufacturing Company, Salt Lake City, Utah.

[14] Frederick Bentham, Stage Lighting, London, 1950, pp. 25-26.

Organization of the study. The following chapter presents in Part One an analysis of the characteristics of the twenty-eight volt, PAR 36 sealed-beam lamp. Part Two treats the design and construction of a lamp housing, and Part Three considers the control and distribution system. Chapter III presents a summary and evaluation. An Appendix includes lamp performance tables, graphs, scale drawings, and a wire connection drawing of the proposed equipment.

CHAPTER II

A LOW-VOLTAGE STAGE LIGHTING SYSTEM

A system for lighting the stage is generally composed of three basic elements: (1) the lamp which generates the light, (2) the housing which holds the lamp and makes it possible for the lamp to be mounted in various positions and aimed in a wide variety of directions, and (3) the control and distribution system that regulates and delivers the current to the lamp units. This chapter presents an analysis of the proposed low-voltage stage lighting system in respect to these three main divisions.

Part One: Characteristics of the PAR 36 Twenty-eight Volt Sealed-beam Lamp

The use of low-voltage sealed-beam lamps offers a wide range of possibilities for theatrical lighting. The lamp is a highly efficient, ruggedly constructed and precise optical instrument.

> The aluminized reflector of the all-glass lamp does not tarnish. There can be no deterioration by moisture or dust and dirt particles since these cannot enter the hermetically sealed, one piece lamp. The very large volume and relatively low wattage minimize the effect of blackening always prominent in smaller bulbs.
>
> As a result depreciation in light output of the G-E Sealed Beam Headlamp is practically non existent.[15]

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[15] Miniature Lamp Catalogue, Lamp Division, General Electric, Litho. in U. S. A., 3-412-6, Nela Park, Cleveland, Ohio, p. 13.

Several manufacturers of electrical lamps produce four series of the sealed-beam PAR projector lamp operating on low voltage ranges including 6, 12, 24, 26, and 28 volts. The model numbers from the smallest size to the largest are the PAR 36, PAR 46, PAR 56, and the PAR 64.[16] The lamps are ellipsoidal in shape, with an overall length of from two and five-sixteenths inches for the PAR 36 to six and one-half inches for the PAR 64. They are fitted with screw terminal-posts and are of a smaller overall length than other lamps of comparable light output.[17] A wide range of light output is characteristic of these lamps. Maximum spherical candlepower from 400 to 570,000 candles is available in different models.[18] At any one voltage a considerable number of intensities can be obtained, making possible a versatile combination of lamps for stage lighting purposes. Different models produce a variety of beam patterns, including ellipsoidal, rectangular and inverted-keystone patterns.[19] This variety indicates the possibility of using different models of the same voltage to insure complete area coverage and allow for special accents of light where needed. Another possible advantage would be the avoidance of unnecessary light and shadows upon the scenery. The use of low voltage, instead of 110/120 standard voltage, permits a decrease in cable size and correspondingly smaller and less

[16] Engineering Data on PAR Lamps, General Electric, Nela Park, Cleveland, Ohio, June, 1955.

[17] Miniature Lamp Catalogue, pp. 16, 21, 23.

[18] Engineering Data on PAR Lamps.

[19] Ibid.

expensive dimmers to be used to control the same or larger amounts of light.

The twenty-eight volt sealed-beam was chosen as the lamp best suited for stage lighting purposes because (1) a variety of beam patterns and intensities is available, and (2) low-voltage sealed-beam lamps adequate to produce sufficient light for theatrical purposes should be rated at a minimum of approximately thirty-five watts. Lower wattages would not have a high enough light output to compare adequately with conventional lighting apparatus. If wattage remains constant, a smaller operating voltage requires a higher amperage of current to operate a particular lamp. Therefore, an important consideration in the choice of a lamp is the current required. A six-volt lamp rated at thirty-five watts needs 5.83 amperes of current, and a twelve-volt lamp at the same wattage requires only 2.73 amperes. Twenty-eight volt sealed-beam lamps are available only at a minimum of fifty watts, well above the minimum wattage necessary to compare favorably with conventional short range lighting equipment. Therefore, a twenty-eight volt lamp uses 1.785 amperes of current, a relatively small amount when compared with 5.83 amperes for the six-volt lamp and 2.73 amperes for the twelve-volt lamp. A lighting circuit that uses large amounts of current, or high amperage, needs heavy cable and large voltage-transforming and control equipment to meet the requirements of the National Electric Code and to satisfy the flexible operational requirements engendered by use in the theatre.

The PAR 36 sealed-beam was the model decided upon to achieve as small and compact a lamp unit as possible. In comparison with the other available models, the PAR 36 is considerably smaller in diameter, four and one-half inches, in contrast to the five and three-quarters inch measurement of the next size, the PAR 46 sealed-beam. The full-size drawing of the PAR 36 lamp in Appendix A contains additional physical dimensions of this lamp.

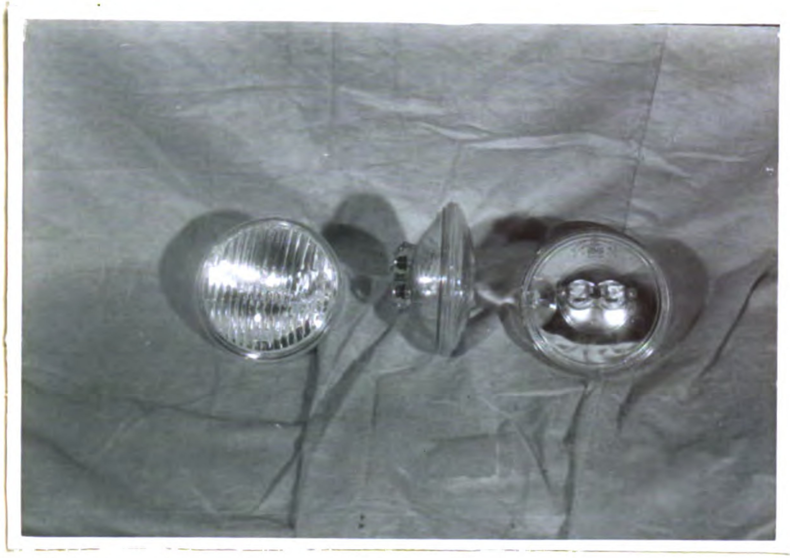
For experimental purposes three varieties of the PAR 36 sealed-beam lamp, rated at twenty-eight volts and fifty watts, were chosen. Each lamp has distinctive characteristics which set it apart from the others and make possible comparisons of operating results. The General Electric catalogue numbers of the three test lamps are 4502, 4505, and 4589.

Lamp number 4502 has an approximate initial candlepower rating of 10,000 candles and a beam spread of forty degrees horizontally and seven degrees vertically. Lamp number 4505 has an approximate initial output of 40,000 candles and a beam spread of eleven degrees horizontally and six degrees vertically. A maximum initial rating of 5,500 candles and an inverted-keystone beam pattern are characteristic of the last lamp, number 4589. Plate I shows three views of each lamp with which this study is concerned.

For testing purposes a canvas screen measuring five feet square was constructed, and on it were drawn fourteen concentric circles spaced two inches apart. Eight lines radiating from the center divided the circles into eight segments of 45 degrees each. These lines were

PLATE I

PAR 36 Twenty-eight Volt Sealed-Beam Lamps



#4502

#4505

#4589

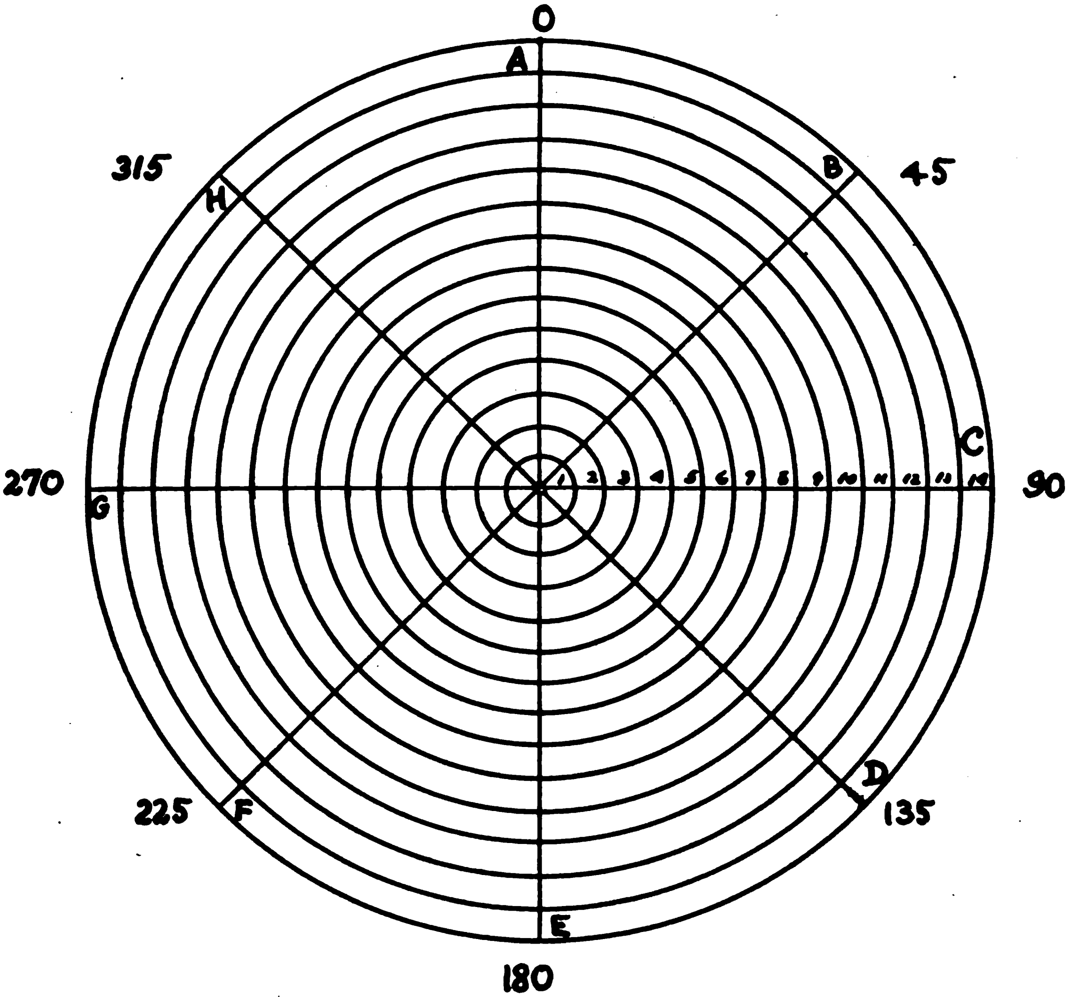
lettered clockwise from A to H. The circles were numbered 1 through 14 from the center as illustrated in Plate II.

Each sealed-beam lamp was connected to the output side of a model V-20 Variac auto-transformer and mounted in a wooden frame. The lamp was then set at distances of five feet, ten feet and twenty feet from the center of the canvas screen for each series of tests so that the axis of the light-beam in each case struck the screen in the center of Ring 1. The V-20 Variac auto-transformer was used to regulate the input voltage to the lamp in order to maintain a constant voltage flow of twenty-eight volts. To insure an accurate operating voltage, a Burlington A. C. Volt Meter, model 31A, was used throughout the test series. Eight readings in footcandles were taken at the intersections of the 45 degree radiant lines and at each circular ring with a General Electric Exposure Meter, Type DW-68, and then recorded on a test sheet. In order to determine the area in square feet of each concentric circular ring on the test screen, the term π (3.1416) was multiplied by the difference between the square of the radii of the two circles forming each ring, and the product was divided by 144. The formula for this calculation is $\frac{\pi(R^2-r^2)}{144}$. The circular areas are indicated in Plate III.

On the test sheet the readings in each ring were added and then averaged; the resulting average was then multiplied by the circular area in square feet. The result was the lumen illumination in the area. The lumens in all rings were added to give the total lumen output of the lamp at the particular test distance. The test sheets are included in Appendix A.

PLATE II

Lamp Test Screen



Scale: 1" = 1'0"

PLATE III

Screen Areas

RING	OUTSIDE DIA.	AREA IN SQ. FT.
1	4"	.08726
2	8"	.2618
3	1'-0"	.4235
4	1'-4"	.6108
5	1'-8"	.7854
6	2'-0"	.9599
7	2'-4"	1.1275
8	2'-8"	1.3090
9	3'-0"	1.4842
10	3'-4"	1.6573
11	3'-8"	1.8326
12	4'-0"	2.0071
13	4'-4"	2.1816
14	4'-8"	2.3555

As a result of these tests the following characteristics of each of the sealed-beam lamps were determined. Graphs of these results for each lamp at a test distance of five feet, showing footcandle and iso-candle distribution, are included in Appendix A. At a test distance of five feet from lens to screen, the PAR 36 lamp number 4502 produced 406.04 lumens with a maximum beam footcandle output of 260. The beam spread was twelve degrees vertically and fifty degrees horizontally. The beam pattern measured one foot on the vertical axis and five feet on the horizontal axis. At a test distance of ten feet the results were 336.54 total lumens, a maximum of 85 footcandles output at the center of the beam, a beam spread of forty-five degrees horizontally and sixteen degrees vertically, and an ellipsoidal beam pattern measuring eight and one-half feet horizontally and three feet, four inches vertically. At the final test distance of twenty feet, lamp number 4502 produced a total of 122.90 lumens with a maximum beam footcandle output of 22.5. The beam spread horizontally was thirty-eight degrees with six degrees vertically measuring fourteen feet by two and one-half feet respectively. In summary, lamp number 4502, rated at a maximum candle-power of 10,000, produced a long narrow ellipsoidal beam pattern in intensities from 406.4 lumens for a test distance of five feet to 122.90 lumens at twenty feet.

Sealed-beam lamp number 4505, at a test distance of five feet produced a total of 135.6 lumens with a maximum beam footcandle output of 1000. A rectangular beam pattern spreading eight degrees on the vertical plane and ten degrees on the horizontal plane was recorded.

The rectangular pattern measured eight inches vertically by ten inches horizontally at this test distance. The results of the ten-foot test indicated a lumen output of 185.06 with a maximum beam footcandle output of 300. The rectangular beam pattern had a characteristic spread of twelve degrees horizontally and four degrees vertically which measured two feet by one foot. At the twenty-foot test distance the total lumen output of number 4505 was 176.64 lumens, with a maximum beam concentration of 54 footcandles. The concentrated rectangular beam pattern measured five feet horizontally and two feet vertically, spreading fourteen degrees by four degrees. The rectangular beam pattern of this lamp produced a highly concentrated area of light that was markedly brighter than the surrounding area also included.

Lamp number 4589 at the initial test distance of five feet produced a total of 900.5 lumens with a maximum beam footcandle output of 150. The beam pattern of this lamp was an inverted keystone, as indicated on the isocandle graph, Plate XX in Appendix A. A beam spread of thirty-six degrees vertically and twenty-six degrees horizontally, measuring two feet by two feet at the widest points, was recorded. The results of the second test series at a distance of ten feet showed the total lumen output to be 197.77 lumens. The inverted-keystone beam pattern spread thirty-three degrees vertically and thirty-one degrees horizontally. At a distance of ten feet the beam pattern measured three feet by two feet and eight inches. Lamp number 4589, at the final test distance of twenty feet, produced a total of 51.24 lumens with a maximum central concentration of four footcandles. The beam spread at this distance was twenty-nine degrees horizontally by twenty-five degrees vertically to an output of one footcandle. The inverted-keystone beam pattern measured six and one-half feet vertically by eight feet and three inches horizontally.

Summarizing the test results, lamp number 4505 producing a rectangular beam pattern was found to have the highest light output of the three models tested. The highly concentrated pattern of this lamp seems to indicate its usefulness as a special accent lamp. The beam patterns, ellipsoidal and inverted-keystone, of lamps number 4502 and 4589 respectively, lacking a strong intensity and producing a softer-edged lighted area than number 4505, appear to be better suited for lighting larger areas uniformly. Since the three models tested are sufficiently different in light output characteristics, results of test data indicate that they could be used in varying combinations to light a small stage area.

In a study conducted by G. Edward Hearn at the State University of Iowa, various Fresnel spotlights were tested in a manner similar to the procedure followed in this study.[20] Since the 500-watt Fresnel-lens spotlight is a familiar and commonly used instrument for theatrical lighting, the low-voltage sealed-beam lamps tested in this study were compared with the 500-watt Fresnel on the base of maximum beam candlepower, lumen output, beam spread in degrees, and beam pattern. The six-inch Kopp Fresnel lens, with a focal length of three and seven-

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[20] G. Edward Hearn, "An Experimental Study of the Efficiencies and Adaptability of Fresnel Lenses," Master of Arts Thesis, State University of Iowa, 1940.

sixteenths inches and set at medium focus, was selected as the particular setting most comparable to the characteristics of the low-voltage sealed-beam lamp. Test data sheets prepared from the experiments conducted by Mr. Hearn and listed in Appendix A of this study show that the total lumen output of the Fresnel unit was 2,439 lumens at a distance of five feet. The beam spread was approximately seventy degrees on both axes, indicating a circular beam pattern measuring six feet, eight inches in diameter. The maximum beam candlepower at this distance was 460 footcandles. At a test distance of nine feet and eight inches, roughly comparable to the ten-foot distance used in this study, the 500-watt Fresnel unit produced a total of 1,572.4 lumens with a maximum beam concentration of 482 footcandles. The beam spread was approximately one hundred degrees and measured eight feet in diameter. A comparative tabulation of the operational characteristics of the PAR 36 sealed-beam lamps and the 500-watt Kopp Fresnel unit is shown in Plate IV.

Using the results of the low-voltage sealed-beam tests and those of the Fresnel, the following comparative conclusions may be drawn. In maximum beam intensity, sealed-beam lamp number 4505 is approximately equal to the 500-watt Fresnel at a distance of ten feet, and approximately twice as bright at the five-foot test distance. The remaining two sealed-beam lamps, numbers 4502 and 4589, are of considerably less maximum footcandle intensity than the Fresnel unit. Four different beam patterns are evident including an ellipsoidal shape for sealed-beam number 4502, a rectangular shape for number 4505, an inverted-keystone for number 4589, and a circular pattern for the Fresnel unit. Since a

PLATE IV

Light output Characteristics
PAR 36 Twenty-eight Volt Sealed-beams
500-watt Fresnel Spotlight
Five Foot Distance

LAMPS	LUMENS	MAX. BEAM Ft.C	BEAM SPREAD (degrees)	beam PATTERN	BEAM SPREAD (feet)
4502	406.04	260	12 Vert. 50 Hor.	Ellipsoidal	1'-0" Vert. 5'-0" Hor.
4505	136.6	1000	8 Vert. 10 Hor.	Rectangu-lar	8" Vert. 10" Hor.
4589	900.5	150	36 Vert. 26 Hor.	Inverted-keystone	2'-0" Vert. 2'-0" Hor.
500 watt Fresnel	2439.0	460	70 Vert. 70 Hor.	Circular	6'-8" Vert. 6'-8" Hor.

test screen composed of concentric circles was used, and total lumen output by this method is based upon the average footcandle illumination multiplied by the area in square feet, the sealed-beam lamps with characteristics of non-circular patterns apparently do not produce as high a lumen output over the same area as a lamp unit with a circular pattern. However, this is only an apparent disadvantage because the pattern of the former covers less area than the latter. The tests conducted show that, in regard to total lumen output, lamp number 4502 is one-fifth as intense as the 500-watt Fresnel, lamps number 4505 and 4589 one-seventh as intense. Although the lumen output test data suggest that the sealed-beam lamps tested are considerably less powerful than the 500-watt Fresnel, the test also shows that sealed-beam number 4505, for example, has a greater intensity of light at the center of the pattern, approximately three times that of the Fresnel at five feet. The remaining two models, numbers 4502 and 4589, have a maximum center intensity in the beam pattern of, respectively, approximately one-half and one-third that of the 500-watt Fresnel.

The disparity that appears to exist as a result of a lumen output comparison actually is not a true indicator of the respective light output values of the sealed-beam lamps and the 500-watt Fresnel. An additional examination of the footcandles found in the beam pattern area of the three sealed-beam lamps compared with the approximate coverage of the same area by the 500-watt Fresnel gives added support to the conclusion that the sealed-beam lamps, in particular number 4505, will light an area, although smaller in size, brightly enough to compare favorably with the Fresnel. To illustrate, at a distance of five feet the total footcandles in the rectangular area pattern of sealed-beam number 4505 was approximately 5,500 compared with a brightness of approximately 9,500 footcandles for the Fresnel. Models number 4502 and 4589 produced approximately 3,000 and 2,000 footcandles in that order. This data more accurately indicates that a sealed-beam lamp such as number 4505 is not one-seventh as intense, but produces over one-half the total brightness of the larger and more expensive Fresnel lamp unit. Lamps number 4502 and 4589 are considerably less bright than the Fresnel, according to the results obtained. However, the type of area coverage characteristic of these lamps suggests their usefulness in stage lighting despite their lack of favorable comparative brightness.

The areas of illumination covered by the sealed-beam lamps to one footcandle, by comparison, are considerably smaller than the 500-watt Fresnel unit. This would seem to indicate that if each low-voltage lamp were used separately as the only model for stage illumination, approximately eight number 4505 lamps, two number 4502 lamps, or three number 4589 lamps would be required in order to light the same area lighted by one 500-watt Fresnel lamp unit at a distance of ten feet. However, stage lighting instruments are generally mounted at projection distances of not less than twenty feet. Therefore a comparison between data compiled by the Century Lighting Company for the 500-watt Fresnelite[21] at medium focus and test results of this study may be made. At a

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[21] Lighting By Century, Century Lighting Incorporated, New York, revised, June, 1952, p. 500.

distance of twenty feet the diameter of the area lighted by the Fresnelite at medium focus is fifteen and two-tenths feet. The three sealed-beam lamps tested at the same distance cover areas measuring fourteen feet by two and one-half feet, five feet by two feet, and six and one-half feet by eight and one-quarter feet, for lamps 4502, 4505, and 4589 respectively. To cover the same area as the Fresnelite then, four 4502 sealed-beam lamps, four 4589 lamps, or six 4505 sealed-beams would be needed. It is recommended, however, on the basis of the ease by which the three sealed-beam lamps can be exchanged in the same housing, that for use on a small or medium sized stage various combinations of the three sealed-beam lamps be employed. The number and variety would depend upon the size of the area and the lighting demands of the production. For example, either sealed-beam models 4502 or 4589 might be employed for general area lighting. Number 4502 is particularly advantageous in this case because of the wide horizontal spread as compared with a relatively narrow vertical spread. This would permit complete coverage of a long rectangular stage area with no necessity for matting out unwanted light and thus reducing the efficiency of the unit. Without such matting the circular pattern of the Fresnel tends to produce spill light which, on a conventional stage, falls on the upstage wall behind the lighted area or on the apron in front of it. In arena staging where short light-throws are common and light spill from conventional equipment is a difficult problem to cope with, the use of such sealed-beam units as numbers 4502, with a long narrow beam pattern, and 4589 with a small vertical and longer horizontal spread, would be a substantial aid in meeting these conditions. Lamp number 4505, with a relatively small rectangular pattern, could be used for special accent purposes to complete the lighting coverage of a small or medium-sized stage.

Two experiments were conducted to determine more specifically (1) the area covered by each of the sealed-beam lamps mounted so as to approximate normal stage use, and (2) the maximum stage area covered by a combination of twenty-four sealed-beam lamps comprising the proposed low-voltage stage lighting system. Each sealed-beam lamp was mounted at a height of twenty feet and aimed for a projection distance of eighteen feet making an angle of about forty-five degrees from horizontal. The lighted area was measured horizontally and vertically to five footcandles, and footcandle readings were taken to determine the maximum intensity. The results of the first test revealed the following characteristics:

LAMP	MOUNTING HEIGHT	PROJECTION DISTANCE	LIGHTED AREA *	MAXIMUM FOOTCANDLES
4502	20'	18'	10' Vert. 6' Hor.	25
4505	20'	18'	4½' Vert. 4½' Hor.	65
4505	20'	30'	6½' Vert. 10½' Hor.	25
4589	20'	18'	6½' Vert. 7½' Hor.	7
4589	10'	10'	3' Vert. 3' Hor.	20

* To 5 footcandles.

Since the light intensity desirable on a stage is an extremely variable factor, an intensity of twenty-five footcandles was felt by the investigator to be normally satisfactory for general stage illumination. Therefore, the maximum mounting height for lamp 4502 is twenty feet with a maximum projection distance of eighteen feet. Lamp number 4505 has a maximum mounting height of twenty feet and a maximum projection distance of thirty feet. This lamp at a mounting height of twenty feet and a projection distance of eighteen feet delivers a maximum of sixty-five footcandles and appears to be suitable for accent lighting. Lamp number 4589 at a mounting height and projection distance of over ten feet will not produce satisfactory illumination for stage lighting purposes. Thus, the use of this lamp, considering a mounting of over ten feet to be customary, is not recommended for theatrical lighting except where a very low level of light is required.

For the second test, combinations of lamps number 4502 and 4505 were aimed at a flat vertical surface eighteen feet from the base of the twenty-foot mounting tower. The intensity was read in footcandles, and the lighted area measured to five footcandles. This experiment was designed to reveal the size stage the twenty-four sealed beam lamps in the low-voltage stage lighting system could light satisfactorily. The results indicated that a proscenium stage measuring thirty feet wide and eighteen feet deep could be lighted from a mounting height of twenty feet so as to achieve a general illumination of twenty-five footcandles by sixteen number 4502 lamps, and accent spotting of sixty-five footcandles by eight number 4505 sealed-beam lamps. Further, an arena stage measuring twenty-four feet by twenty-two feet could be lighted from a mounting height of twenty feet with a general illumination of twenty-five footcandles by fifteen number 4502 lamps, and accent spotting of sixty-five footcandles by nine 4505 sealed-beam lamps. Proscenium stage areas larger than thirty feet by eighteen feet or arena stages larger than twenty-four feet by twenty-two feet would not be lighted satisfactorily by the stage lighting system proposed in this study. In all fairness to the proposed system it should be noted that certain dramatic productions require unusual, low-intensity, or localized lighting effects that could be achieved with the low-voltage lighting system in larger or irregular-shaped proscenium or arena stage areas.

In summary, then, the twenty-eight volt sealed-beam lamp was selected for testing because of its low wattage combined with high efficiency, its small size, its low cost, and the variety of available models. When compared to a 500-watt Fresnel spotlight, it revealed a considerably smaller output of lumens but a near-comparable degree of brightness in the area covered by the beam pattern of one model, 4505, and a lower illumination factor in the remaining two models. Sealed-beam lamps number 4502 and 4505 produced sufficient light to be used for stage lighting purposes at mounting heights up to twenty feet, while lamp number 4589 lacked adequate light output at mounting heights above ten feet to be satisfactory for use in a low-voltage stage lighting system. The variety of beam patterns and light output characteristics produced by the two sealed-beam lamps indicates diversification in their use for lighting a proscenium area up to a thirty feet by eighteen feet maximum and an arena area up to a maximum of twenty-four feet by twenty-two feet from a maximum mounting height of twenty feet. Special lighting demands of certain productions may possibly make these lamps suitable for larger stage areas that are unusually shaped, require a low-intensity, or need highly localized lighting. However, desirable coverage is extremely variable and difficult to ascertain with any degree of positiveness. The lighting of an arena stage by means of sealed-beam lamps with more precise control of coverage suggests the possibility of reducing undesirable spill and shadows while providing a smoothly blended area of light.

Part Two: A Lamp Housing

A necessary step in utilizing the sealed-beam lamp for stage lighting purposes is the development of a simple and efficient housing which provides a means of mounting the lamp in a variety of positions. To insure a degree of safety for the lamp, the housing should be constructed substantially enough that it will withstand handling and such impacts as are common in stage or touring usage. The housing should permit ease and variety in mounting, ready access to the lamp unit for replacement of the lamp, a means of using colored gelatin, and flexibility in aiming horizontally and vertically. Finally, it should be relatively light in weight, compact and inexpensive.

The lamp housing developed for this study, as illustrated in Plate V, is designed as a small cylinder unit with two circular concentric louvers, a strap-metal mounting yoke, and a circular, hinged

PLATE V

PAR 36 Sealed-beam Lamp Housing

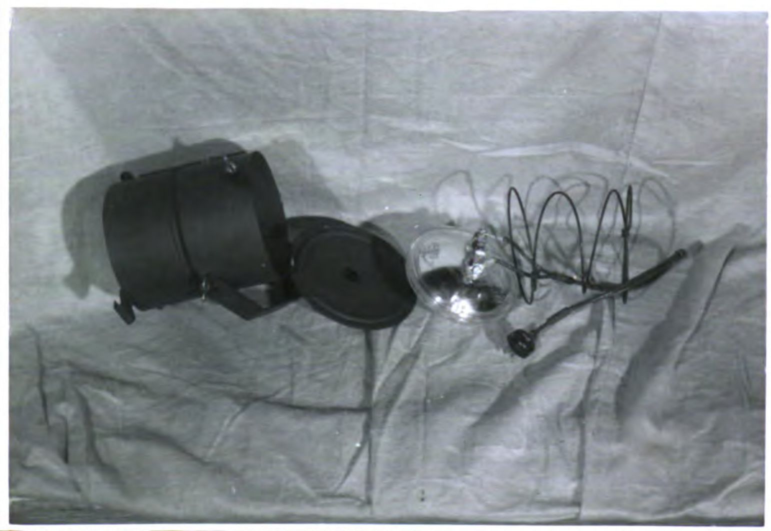
Front-Angle View

Side-Angle View

Rear-Angle View

PLATE V

PAR 36 Sealed-beam Lamp Housing
(continued)



Exploded View

Component-Parts View

rear-entrance door. The cylindrical shape approximates that of the sealed-beam unit and affords a compact and tightly fitting encasement for the lamp. Two concentric circular louvers are placed inside the cylinder near the front opening in order to minimize side spill by eliminating all but the central beam of light insofar as possible. The sealed-beam unit is positioned approximately in the center of the cylinder against a retaining circular bead pressed inward from the housing. There it is held securely in place, regardless of the position of the housing, by a large coiled spring which is forced against the rear of the lamp by the rear-entrance door when this door is closed. The power cable of two-conductor number eighteen wire is connected to the screw terminals of the sealed-beam lamp by means of small Y-shaped terminal lugs to allow for positive contact and easy lamp replacement. The cable extends from the cylinder through a small circular opening in the rear door of the housing to a length of one and one-half feet and is intended to be connected to the line cable by means of a miniature twist-lock plug. The mounting yoke is secured to the cylinder by a pair of adjustable wing-nuts permitting a vertical aiming arc when mounted of one hundred and eighty degrees. At the base of the mounting yoke is a small beam-clamp that makes it possible for the lamp housing to be attached to a pipe or wooden batten so that the unit may be rotated horizontally through an arc of three hundred and sixty degrees. By virtue of a set-screw where the mounting clamp is fastened to the yoke, the lamp housing may be securely locked in position or left free for focusing. With a mounting yoke and clamp arrangement of this type, a variety of horizontal and vertical aiming directions can be obtained, thus allowing sufficient coverage of the stage area from numerous mounting positions.

The rear-entrance door is hinged to the bottom of the cylinder and swings downward in an arc of one hundred and seventy degrees. The door is held securely closed by means of a metal catch which is mounted perpendicularly to the door and tightened against the top of the cylinder by an adjustable wing-nut. The opening and closing of the rear door can be accomplished rapidly and easily while the unit is mounted in position, permitting an easy change of the lamp unit that will not disturb the focus. Three gelatin clips are permanently attached to the cylinder at the bottom and the sides of the front opening. A gelatin frame can be slid readily into position and firmly anchored against the cylinder by these clips, thus avoiding any spill of uncolored light at the sides.[22]

The cylinder unit and component parts of the lamp housing are constructed of galvanized sheet metal and finished with a dull black paint. The housing weighs one pound and nine ounces without the sealed-beam lamp and the mounting clamp, and the material cost was approximately one dollar and twenty-five cents. The sheet metal construction offers rigidity and strength without excessive weight, size, or expense.

A lamp housing of this design for the PAR 36 twenty-eight volt lamp enhances the efficiency of the sealed-beam unit by confining the light rays in a concentrated pattern of light, and provides a method of

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[22] See Appendix B for scale drawing.

mounting the lamp in a number of positions, either on pipe towers or wooden battens, so as to allow multi-directional aiming of the lamp. When the complete lamp unit is removed from its mounting position, the sealed-beam lamp remains secure in its place, making its removal unnecessary for storage or transportation purposes. The complete lamp-housing and sealed-beam are of a size sufficiently smaller than most conventional lighting apparatus used on a small stage or for touring productions that the quantity of units necessary to light a production can be transported in considerably less space. With a total price of approximately four dollars and fifty cents for the combined lamp housing and sealed-beam lamp, several of these units could be purchased for the price commonly paid for a single standard stage lighting unit.

An obvious disadvantage is that such a housing as suggested here is not available commercially. However, it can be easily, quickly, and economically fabricated in a normally equipped metal-working shop, such as found in many schools as part of the vocational education program. In the event such shop facilities are not available, a set of housings could certainly be custom-made by a commercial metal-working firm at a cost well below that for conventional lighting apparatus.

Part III: The Control and Distribution System

Perhaps the most important single element in a stage lighting system, aside from the light source used, is the means by which the light output is controlled. Stage lighting today, in addition to providing selective illumination, has come to mean the utilization of light to enhance the mood and atmosphere of a theatrical presentation and to illuminate the actors three-dimensionally. In so doing, stage lighting aids the remaining elements of the *mise en scène* in the creation of a visual representation that is designed to play upon the emotions and intellect of the audience. A system for lighting the stage, therefore, must incorporate adequate light control that will permit obvious or subtle changes in intensity, over one or several acting areas, to be made with ease. This control unit should provide sufficient flexibility to meet the demands of a wide variety of plays. In particular circumstances where a small stage is used or the production travels from place to place, it is important that the control system be both lightweight and compact.

The control and distribution system developed in this study incorporates a step-down filament transformer with a series of Variac autotransformers, the whole making a compact, flexible, and efficient unit. The completed lighting system is designed to include a maximum of twenty-four twenty-eight volt sealed-beam lamps. They are controlled in eight individual circuits each including three lamps, with one master control capable of operating all twenty-four lamps.

The twenty-eight volt sealed-beam lamp rated at fifty watts, according to Ohm's law, $E = \frac{R}{I}$, uses 1.785 amperes of current. Most incandescent lamp units for stage purposes operate on a parallel circuit, one in which the lamps are connected across the two main current lines rather than in line with the main source of power. To operate lamps connected in parallel the voltage necessary for the operation of one lamp can be used for any number of lamps, while the amperes of current necessary for one lamp must be doubled with the addition of another lamp in the parallel circuit. To calculate the amount of current necessary for a parallel circuit, therefore, the number of lamps in the circuit is multiplied by the load in amperes of one lamp.[23] The system developed in this study, composed of eight circuits of three lamps on each circuit, will draw 5.355 amperes per circuit or a total of 42.840 amperes for the whole system.

A prerequisite to the use of a low-voltage lighting system is the reduction of standard electric current to the required voltage necessary to operate the particular lamp. The electricity available in most places where a play might be performed is generally 110/120 volts of fifty/sixty cycle alternating current, commonly referred to as standard electric current. Since the sealed-beam lamps used in this proposed system are designed to be operated on twenty-eight volts, the common standard voltage must be stepped-down to twenty-eight volts while a maximum of 42.840 amperes of current is permitted to flow to the lamps. For this operation the use of some type of transformer capable of reducing standard voltage to twenty-eight volts is required. Two methods of doing this are possible.

A variable auto-transformer can be connected to the line supply, the indicator dial set at twenty-eight volts, and the low-voltage line attached to the secondary or output terminals of the auto-transformer.

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[23] Samuel Selden and Hunton D. Sellman, Stage Scenery and Lighting, F. S. Crofts and Company, New York, 1947, pp. 238-239.

The use of a variable auto-transformer, at a fixed voltage, however, invalidates the purpose of the flexible range feature of the auto-transformer and over a period of time will cause uneven wear and rapid depreciation resulting in malfunctioning of the equipment. Since the current necessary for the total system is 42.840 amperes, a suitable transformer of this type would weigh approximately eighty pounds and cost one hundred and twenty-four dollars.[24] The weight and expense are of course significant factors where cost and portability are important. Then, too, after sufficient use the accuracy of the indicator dial in registering the correct voltage would be doubtful. Further, the possibility of the dial's being accidentally moved, causing an incorrect voltage flow, further indicates that this method of voltage reduction is not practical for stage use.

The second and far superior method of voltage reduction utilizes a step-down filament transformer in conjunction with an auto-transformer. The use of the variable auto-transformer and the step-down filament transformer to reduce the standard electric current is accomplished by connecting the input terminals of the auto-transformer to the standard current line supply, the secondary output terminals to the primary input terminals of the filament transformer, and the secondary output, or low-voltage, terminals of the filament transformer to the load, in this case the low-voltage sealed-beam lamps. The use of a step-down filament transformer between the variable auto-transformer and the load permits an increased current capacity of the auto-transformer in the

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[24] Variac, Bulletin N, General Radio Company, Cambridge, Mass., 1955.

ratio of line voltage to operating range, which means a smaller variable transformer can be used to furnish the required amount of current than when a variable transformer is used separately. Also finer adjustments in regulating the output voltage to the load are possible since the range from zero to full output voltage is spread over the whole auto-transformer scale.[25] The filament transformer and the auto-transformer must be of the same volt-ampere (V.A.)[26] rating in order to achieve the correct voltage reduction and utilize the increase in current capacity factor.

In this proposed system, drawing 42.840 amperes of current, the volt-ampere rating at twenty-eight volts is 1119.52 V. A. A filament transformer that would reduce the primary voltage of 110/120 volts to twenty-eight volts at the secondary, and have a current capacity of 42.840 amperes, is necessary for the operation. The suggested transformer could be rated at 1000 volt-amperes with a primary of one hundred and fifteen volts and a secondary of twenty-eight volts. This would result in a slight overload of the transformer since the total volt-amperes used would be 1119.52, but for periods of operation that would generally not exceed three hours, followed by a cooling-off period of approximately the same time or longer, no damage would be done to the equipment. The use of a filament transformer with a secondary output of twenty-eight volts would be one possible method. However, such a

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[25] M-10 Variac, Operating Instructions, General Radio Company, Cambridge, Mass., p. 4.

[26] Wiring Materials Power Apparatus, General Electric Supply Corporation, The Jaqua Company, Grand Rapids, 1951, p. 1029.

transformer is not available commercially as a standard item and has to be custom-made at considerable expense. Further, as will be discussed later, such a unit will not compensate for a loss in voltage from resistance in transmission cable. Delivery on this type would probably take from four to ten weeks, a disadvantage that might handicap the assemblage of a low-voltage sealed-beam lighting system.

In view of the problem of availability of a twenty-eight volt secondary filament transformer, the investigator recommends the use of a thirty-two volt secondary filament transformer manufactured by General Electric Company as Model number 9T51Y6195 and rated at 1500 volt-amperes with a primary of 120/240 volts and a secondary of 16/32 volts.[27] This standard transformer is manufactured by General Electric at the Speciality Transformer Division in Fort Wayne, Indiana, and can be obtained on order. It is used commercially in lighting or power circuits where low-voltage lamps and power tools operated from standard voltage circuits in such locations as mines, steel plants, meat packing plants and in damp locations to prevent injury in case of accidental grounding of the circuit through the operator's body. This thirty-two volt filament transformer weighs approximately thirty pounds and retails for eighty-two dollars and fifty cents. However, educational institutions and perhaps other groups can secure a sizeable discount on the purchase of this transformer, generally in the neighborhood of fifty-five percent.

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[27] General Electric Supply Corporation Handbook, 52/20, Cleveland, Ohio, p. 2.

Although the sealed-beam lamps used in this proposed lighting system are designed to operate on twenty-eight volts of electric current, the thirty-two volt filament transformer can be used. The four primary lead wires are connected in parallel and the four secondary lead wires are connected in series. This will result in an input voltage rating of one hundred and twenty volts and an output voltage of thirty-two volts. The variable auto-transformer to which the filament transformer is connected regulates the input voltage to the filament transformer. By experimentation conducted with a Burlington A. C. Volt Meter connected to the primary lead wires of the filament transformer, and careful regulation of the calibrated dial of the auto-transformer, it was determined that the maximum output range of one hundred and fifteen volts on the zero to one hundred and fifteen volt dial of the auto-transformer would result in an output voltage of thirty-one volts. In order partially to compensate for a loss of a maximum of four volts, or a fourteen percent voltage drop due to line resistance,[28] an output voltage to the lamps of thirty-one volts is used instead of the design voltage of twenty-eight volts. Since the full range of the auto-transformer dial is utilized the wide range potential of this instrument remains as a valuable asset.

The auto-transformer used in conjunction with the filament transformer is a Variac, model V-10, rated at from 1000 to 1500 volt-amperes, with a one hundred and fifteen volt primary and a zero to one hundred

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[28] Voltage drop explanation and calculations referred to in detail later in this section.

and fifteen volt secondary. The V-10 weighs eleven and three-quarters pounds and costs thirty-three dollars.[29] Although the V-10 has a maximum current rating of only thirteen amperes and the system in which its use is proposed will draw 42.840 amperes, the use of the V-10 Variac in parallel with the thirty-two volt filament transformer will permit a maximum draw of 48.10 amperes. This figure is determined on the basis of the previously mentioned advantage of the combined use of a filament transformer and an auto-transformer of the same volt-ampere rating connected in parallel. The calculations are as follows:

1. Ratio of line voltage to output voltage.

   115 volts : 31 volts = 3.70 : 1

2. Increase of current capacity of auto-transformer in a ratio of line voltage to output voltage multiplied by the maximum rated current capacity.

   13 amperes x 3.70 = 48.10 amperes

Since the combination of the Variac auto-transformer and the filament transformer connected in parallel as described has the potential for 48.10 amperes of current to flow through the apparatus to the load, and the load will only use a maximum of 42.840 amperes of current, a safety factor of 5.26 amperes reduces the possibility of an electrical failure.

The control of the eight individual circuits, each drawing 5.355 amperes at twenty-eight volts, is accomplished by the use of eight small auto-transformers. The unit chosen for this purpose is the Variac model M-5, a 350 to 12,000 cycle auto-transformer that can be used for fifty/sixty cycle operation at reduced voltages up to sixty volts.[30] The

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[29] Variac, Bulletin N, pp. 8, 16.

[30] Ibid., p. 14.

M-5 is rated at 860 volt-amperes with a maximum current of seven and one-half amperes, weighs three and one-quarter pounds, and costs twenty-two dollars and fifty cents.[31] Thus it provides a light-weight and relatively inexpensive dimmer unit capable of handling the load of 5.355 amperes necessary to power each circuit, with an adequate safety margin. The M-5 Variac is the smallest and least expensive auto-transformer unit available for the generation of a maximum of seven and one-half amperes of current. Eight M-5 Variacs, one for each circuit, make it possible to control from one to three sealed-beam units on each circuit and a total of twenty-four units in the complete system.

The 5.26 amperes underload would permit the addition of a ninth M-5 Variac dimmer, if desired, to feed a circuit of three more lamps. This would result in a slight overload of approximately 0.1 amperes on the filament transformer when all circuits were operated at full intensity. Such an addition would permit more light but would demand greater caution in operation.

The two control units for the low-voltage stage lighting system are individually encased to provide easy portability and maximum protection for the apparatus. The filament transformer as purchased is compactly encased and measures four and seven-eights by five and seven-sixteenths and twelve and one-eighth inches and weighs approximately thirty pounds.[32] The V-10 and the eight M-5 Variacs can be mounted in three rows of three behind the front panel of a number sixteen galvanized sheet metal case measuring twenty-two and seventeen thirty-seconds

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[31] Ibid.

[32] See Appendix C for scale drawings.

inches high, by eighteen and twenty-five thirty-seconds inches long, by five inches wide, weighing approximately fifty pounds.[33] Each Variac has a separate toggle switch, Dialco pilot light assembly, and "slow blow" (thermal delay) fuse mounted below the auto-transformer. At the bottom of the front panel are output connection receptacles for twist-lock plugs, one for each dimmer. On the left side-panel is an additional connection receptacle for the line voltage input to the V-10 Variac. This connection is the source of power for the system, and wiring connections inside the control unit bring this power to the input primary terminals of the V-10. Permanent connection lines to and from the filament transformer are located on the front and rear panels of the control case.[34] The Variac control unit and the filament transformer unit can be equipped with side-mounted collapsible handles for carrying.

The suggested switchboard system, providing eight complete circuits and a master dimmer, offers a wider range of control than any comparable unit on the market today. It also is somewhat smaller in size and proportionally lighter in weight than such well-known units as the Powerstat 6-100[35] and the Davis portable-switchboard[36] when it is considered that these two switchboards have only six dimmers as compared to nine in this proposed low-voltage control system.

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[33] See Appendix C for scale drawings.

[34] See Appendix C for wire connection diagram.

[35] Packaged Powerstat Light Diming Equipment, Bulletin D 651 P, The Superior Electric Company, Bristol, Conn., pp. 5, 12.

[36] Davis Portable Switchboard Dimmer, Model TL-67, Ariel Davis Manufacturing Company, Provo, Utah, 1951.

The distribution system necessary for low-voltage lighting deviates from conventional wiring practices to some degree. Under the regulations established by the National Electric Code in 1951, incandescent lamps that operate on voltages below 110/120 volts are considered to be low-voltage. Lamps operating on thirty or less volts are classified as miniature lamps. The wiring requirements are not as rigid for a low-voltage operation, making it possible to use smaller wire and less insulation. The cable necessary to distribute the electricity in this proposed system is an important consideration. The proper size for any electrical circuit is determined in a reasonably accurate manner by the following formula based on Ohm's law:[37]

$$\frac{\text{Length of run in Ft. x amperes x 21.5}}{\text{volts lost}} = \text{Circular Mils}$$

The resultant in Circular Mils is applied to a table which indicates the carrying capacities of insulated wires and cables.[38] In residential and business wiring systems, the accepted practice is to allow a maximum loss in volts, or voltage drop, of only two per-cent of the rated value.[39] The light output is considerably affected by substantial variations from design voltage. It is possible, however, in this low-voltage system to allow for a greater drop than two per-cent without seriously reducing the total light output of the lamp. For example, sealed-beam

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[37] Wiring Material Power Apparatus, p. 1035.

[38] Ibid., p. 1034.

[39] IES Lighting Handbook, Illuminating Engineers Society, 1947, p. A-7.

lamp number 4505 produces approximately 5,500 footcandles at a distance of five feet. The lumen output of this lamp at the same distance was 135.6 lumens. It has been shown in Part One of this Chapter that lamp number 4505 compares favorably with one of the common theatrical lamps, the 500-watt Fresnel. Therefore, a voltage drop resulting in a slight decrease in light output will not seriously handicap the performance of this sealed-beam lamp. It should be noted, however, that with the use of a thirty-two volt filament transformer regulated to produce thirty-one volts, as indicated earlier in this part of Chapter II, voltage drop is not a problem because the initial increased voltage compensates for the majority of the voltage lost. The use of number sixteen two-conductor, rubber insulated wire is recommended since this size (approximately one-quarter inch in diameter including insulation, with an individual wire area of 2,583 Circular Mils)[40] is considerably lighter and more flexible than standard stage cable using two conductor number fourteen wire. By using the Circular Mils formula the following voltage loss is found.

$$\frac{\text{90 ft. x 5.355 amperes x 21.5}}{\text{volts lost}} = \text{2,583 Circular Mils}$$

$$\frac{10361.925}{\text{Volts lost}} = 2{,}583$$

Volts lost = 4.01

If the lamps were to operate with an output voltage of twenty-eight volts

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[40] Calvin C. Bishop, Electrical Drafting and Design, pp. 193, 195.

from the filament transformer, the loss of 4.01 volts, or a 14 per-cent voltage drop, the actual voltage to the lamps would be approximately 24 volts. In order to determine more accurately the volts lost with a run of ninety feet of number sixteen, two-conductor cable, a ninety foot length of this size cable was connected to the secondary of a variable transformer, the dial set at twenty-eight volts. A load of three lamps and a Burlington A. C. Volt Meter were attached to the ninety-foot end of the cable and a reading was taken at this point. The resulting voltage drop was 4.0 volts. With a test drop of 4.0 volts the resulting loss in light output, if the lamps were operating from a filament transformer with an output voltage of twenty-eight volts, can be calculated from this formula:

$$\frac{\text{Lumens}}{\text{LUMENS}} = \left(\frac{\text{Volts}}{\text{VOLTS}}\right)^{3.51}$$ [41]

Sealed-beam lamp number 4502 would lose forty-two per-cent of the light output and operate at 236.3 lumens of light output, number 4505 would also lose forty-two per-cent of the light output as would lamp number 4589, while the former would operate at 78.9 lumens and the latter at 524.2 lumens of light output. This can be seen to be an extremely high loss in light output and therefore an impractical operating situation.

Two important considerations should be noted here. First, only occasionally does the length of run reach ninety feet on the small or medium-sized stage, the figure being used to represent a maximum length

[41] IES Lighting Handbook, pp. 6-10, 6-11.

to determine the greatest possible voltage drop that could occur. In most cases, when a run of approximately ninety feet is used, this length will be common only to two or three circuits at the most, with the remaining circuits operating with a shorter run and consequently less voltage drop. Secondly, since a thirty-two volt filament transformer is recommended for this system and it is operated, as described in Part Two of this Chapter, to permit only thirty-one volts to be drawn, the maximum voltage drop has been compensated for excepting one volt. On a ninety foot cable run the sealed-beam lamps will burn at twenty-seven volts, one volt less than the design voltage. Consequently a decrease of twelve per-cent instead of forty-two per-cent in lumen output will be noted. To calculate this decrease the formula for lumen variation previously cited is used. Lamp number 4502, according to this formula will produce 357.4 lumens, lamp number 4505 119.3 lumens, and lamp number 4589 792.4 lumens. It can be seen that a twelve percent decrease in light output is not sufficient to handicap the performance of the lamps operated on a cable run of ninety feet with an output voltage of thirty-one volts. However, since only some of the lamps will operate at a distance of ninety feet, those lamps operating with a shorter run, and consequently less than the maximum voltage drop, will burn at a voltage higher than the design voltage of twenty-eight volts. For example lamps operating with a forty foot cable, representing a minimum run, would have a voltage drop of approximately 1.8 volts, figured from the Circular Mils formula cited previously. The voltage delivered to these lamps at the end of a forty foot run would be 29.2

volts. In order to determine the lumen output of each sealed-beam lamp at an over-voltage of 1.8 volts the lumen formula

$$\frac{\text{Lumens}}{\text{LUMENS}} = \left(\frac{\text{Volts}}{\text{VOLTS}}\right)^{3.51}$$

used previously is applied. Those lamps operating with a run of forty feet will increase sixteen per-cent in lumen output and decrease forty-three per-cent in lamp life if operated at full intensity. Lamp number 4502 will produce 529.5 lumens, lamp number 4505 176.8 lumens, and lamp number 4589 1174 lumens. Each model will have an approximate average life of two hundred and twenty-seven hours instead of four hundred hours as when operated at design voltage, determined by a corollary of the lumen formula

$$\frac{\text{Life}}{\text{LIFE}} = \left(\frac{\text{VOLTS}}{\text{Volts}}\right)^{13.5}$$

When a stage lighting system of this nature is used the length of the cable run for each circuit will vary depending upon the size and characteristics of the stage and the lighting demands of the production. This variation in the use of the system makes it virtually impossible to determine the exact voltage at which the lamps in any circuit will burn. However, in most cases, the cable runs will be between forty and ninety feet, for stage areas not larger than thirty feet by eighteen feet on a proscenium stage and twenty-four feet by twenty-two feet on an arena stage, so that the lamps will operate without excessive variance from their design voltage and perform relatively closely to the indicated characteristics in this study.

Number sixteen two-conductor wire can be used throughout the system except for two connections: (1) the main power cable from the line outlet to the Variac control board, and (2) the supply line from the Variac control unit to the filament transformer unit and back to the control board. By using a voltage-drop table[42] and allowing an estimated run of thirty feet, the wire size is determined to be two-conductor number fourteen wire for a one-and-a-half per-cent voltage drop. Since the voltage over this cable is one hundred and fifteen volts instead of the thirty-one volts characteristic of the load line, the ampere rating is correspondingly less according to Ohm's law. The load in amperes drawn on the standard voltage line can be calculated by comparing the factors involved in establishing the volt-ampere rating previously referred to, as follows:

$$42.840 \text{ amperes} \times 31 \text{ volts} = 1328.04 \quad ^{43}$$
$$x \text{ amperes} \times 115 \text{ volts} = 1328.04$$
$$\therefore 11.54 \text{ amperes} \times 115 \text{ volts} = 1328.04$$

With a current draw of 11.54 amperes at one hundred and fifteen volts the low-voltage system can use number fourteen wire for all one-hundred-and fifteen volt lines and can draw from any standard voltage outlet that is fused at fifteen or more amperes. This amperage capacity is a

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[42] Calvin C. Bishop, p. 227.

[43] Volt-ampere rating different than previously stated for twenty-eight volt output do to change in output voltage to compensate for voltage drop with a thirty-two volt transformer.

common minimum in circuits throughout the country, making it possible to operate this low-voltage stage lighting system in practically any conceivable place where standard alternating current is available.

The proposed control and distribution system discussed in this part suggests a sufficiently compact and flexible method for the regulation and control of the low-voltage sealed-beam lamp. The use of a thirty-two volt filament transformer in conjunction with a Variac model V-10 auto-transformer permits twenty-four sealed-beam lamps to be regulated from bright to fully out. Individual Variacs model M-5, operating three lamps on eight circuits, provide a flexible means for dimming small groups of lamps in many combinations. The use of number sixteen two-conductor stage cable, being smaller in size and lighter in weight than conventional stage cable, enables the lighting system to be set-up and transported without great quantities of heavy cable. The size of the control unit should permit relatively easy transportation of the lighting system. The complete control system will cost approximately three hundred dollars,[44] a figure lower than conventional control equipment of the same capacity.

The complete stage lighting system discussed in this chapter, utilizing twenty-four low-voltage sealed-beam lamps mounted individually in a small and compact housing and controlled in eight circuits of three lamps each by eight M-5 Variacs and one master V-10 Variac in combination with a thirty-two volt filament transformer, appears to offer a flexible means for lighting a small stage area. The twenty-eight

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[44] See Appendix C for Estimated Lighting System Cost Sheet.

volt sealed-beam lamps, available in several intensities and beam patterns, when mounted in a lamp housing of the design suggested in this study, could illuminate a small stage area without the need for matting out unwanted light, a practice common to conventional apparatus with short throws. This would be an especially valuable asset in arena lighting. Also, the sealed-beam lamps compare adequately with the 500-watt Fresnel spotlight in light output to permit their use in lighting small areas with intensities not a great deal less than the Fresnel. Furthermore, the unit is inexpensive, easily obtained, or in the case of the lamp housing, simply made, and small by conventional lighting standards, permitting ease in transportation and storage.

The control unit, which offers a flexible means for regulating the amount of light, is compact and less expensive than comparable conventional dimming units. The complete Variac control board is not available commercially as a unit and would have to be either assembled in a metal-working shop or custom made by a metal-working firm. However, all of the component parts are available on the commercial market, so that only the case in which the auto-transformers are mounted would have to be specially built.

The use of low-voltage current permits the utilization of smaller control units, smaller and less expensive lamps and housings, and lighter-weight, more flexible stage cable. The complete low-voltage stage lighting system would cost approximately five hundred and thirty-six dollars,[45] making it possible for theatrical organizations which

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[45] See Appendix C for Estimated Lighting System Cost Sheet.

are not able to afford the more costly conventional systems to equip themselves with an adequate means of lighting the small or medium-sized stage.

CHAPTER III

SUMMARY AND EVALUATION

Summary. This study has proposed a system for lighting the stage using low-voltage sealed-beam lamps. The PAR 36 twenty-eight volt sealed-beam lamp was selected as the type of lamp unit best suited for stage lighting purposes because of its small size, wide range of intensities, beam patterns and spreads, and relatively low amperage in comparison to other low-voltage lamps. Three models, number 4502, 4505, and 4589 were tested to determine the maximum candlepower, beam pattern and spread, and lumen output at distances of five, ten, and twenty feet. In a comparative analysis with the 500-watt Fresnel spotlight at medium focus, the twenty-eight volt sealed-beam lamps were shown to have smaller, non-circular beam patterns that covered an area from one-fifth to one-seventh that of the Fresnel at the same test distances. The sealed-beams produced from approximately sixty per-cent to approximately twenty per-cent of the light output of the Fresnel spotlight at a distance of five feet. Tests revealed that lamp number 4589 at mounting heights and projection distances over ten feet does not produce enough light to be used successfully for lighting a stage except at a very low intensity level. For stage lighting purposes the sealed-beam lamps indicated potentials for providing specific area coverage relatively free from the bothersome spill common to conventional short-throw apparatus such as the 500-watt Fresnel. Experimentation indicated that a general illumination level of twenty-five footcandles and accent spotting of sixty-five footcandles from a maximum mounting height of twenty feet can be obtained with a combination of lamps number 4502 and 4505. Twenty-four such lamps can provide adequate coverage for a proscenium stage up to thirty feet wide and eighteen feet deep and an arena stage with maximum measurements of twenty-four feet by twenty-two feet.

A lamp housing which would firmly encase the sealed-beam lamp was designed and constructed. The housing, cylindrical in nature and constructed of sheet metal, was fitted with gelatin-slide clips, concentric louvers, a rear-access door, coil retaining spring, strap mounting yoke, and adjustable beam clamp so that the sealed-beam bulb would be protected from damage, the unit would have provisions for application of colored gelatin, be free as far as possible from spill light, allow rapid and easy replacement of the bulb, and be capable of being mounted in a wide variety of positions and aiming directions. The combined lamp housing and bulb unit is small and compact, measuring approximately four and five-eights inches in diameter by approximately eight inches in length. The housing, not available commercially, can be constructed simply at a slight cost with ordinary metal-working equipment.

Control of the twenty-four twenty-eight volt sealed-beam lamps is accomplished by two separate but connected units. A Model 9T51Y6195 filament transformer with a primary input voltage of one hundred and twenty/two hundred and forty volts and a secondary output voltage of sixteen/thirty-two volts comprises the first unit which is connected by number fourteen two-conductor cable to the secondary of a V-10 Variac auto-transformer, the master control dimmer in the second unit, the switchboard. The primary leads of the filament transformer are connected in parallel to achieve a one hundred and twenty volt input, and the secondary leads are connected in series to result in a thirty-two volt output. Rotation of the dial of the one hundred and fifteen volt output V-10 Variac results in an output voltage from the secondary of the filament transformer to the lamps of thirty-one volts. The excess of three volts over the sealed-beam operating voltage of twenty-eight volts partially compensates for an approximate four-volt drop due to resistance in the maximum run of ninety feet of number sixteen two-conductor cable that carries the electricity to each circuit of three lamps. The second unit, the switchboard, also includes eight M-5 Variac auto-transformers, each controlling the light output of three lamps from full bright to completely out. The proposed switchboard also includes thermal delay fuses, toggle switches and pilot light assemblies for each circuit along with receptables for miniature and standard twist-lock plugs. The separate control units weigh approximately thirty and fifty pounds resulting in a total weight of eighty pounds. Total cost of the complete control set-up is approximately three hundred dollars.

Evaluation. A stage lighting system such as the one proposed in this study utilizing a low-voltage sealed-beam lamp has some distinctive characteristics that constitute both advantages and disadvantages in comparison with conventional lighting apparatus for use on a small stage, an arena stage, or by theatrical groups that tour or desire easily portable equipment.

The complete lamp unit is approximately one-fifth as expensive as a 500-watt Fresnel spotlight without lamp. It is considerably smaller, about one-third the size, and approximately one-eighth as heavy. The sealed-beam unit could not be substituted for the Fresnel unit-for-unit because the sealed-beam does not produce as much light. Where, for example, fifteen 500-watt Fresnels are used approximately twenty-four twenty-eight volt sealed-beams would be required to produce comparable illumination. However, the lack of equal intensity and the consequent need for more low-voltage units than Fresnels would still allow for easier portability since the sealed-beam unit is considerably smaller and lighter. Thus a relatively large number of these units would be needed to equal or surpass the bulk and weight of a few 500-watt Fresnels.

The sealed-beam lamp provides a variety of beam patterns, of which the three major types, ellipsoidal, rectangular, and inverted keystone, were considered in this study. Thus they may be used in various combinations so as to light a small stage area uniformly and without excessive amounts of spill. However, lamp number 4589 from a mounting height of over ten feet will not produce enough light to warrant its use in normal stage lighting. Twenty-four lamps number 4502 and 4505, at a maximum mounting height of twenty feet and a maximum projection distance of eighteen feet, will provide an illumination level of twenty-five footcandles and accent spotting of sixty-five footcandles over an area measuring thirty feet wide and eighteen feet deep for a proscenium stage, and twenty-four feet by twenty-two feet for an arena stage. If the twenty-four sealed-beam lamps in this system are used at mounting heights of more than twenty feet and projection distances greater than eighteen feet, it would not be possible to maintain a minimum illumination level of twenty-five footcandles over the stage areas indicated. At mounting heights of less than twenty feet and shorter projection distances the lighted areas of both sealed-beam 4502 and 4505 decrease in size while the illumination level increases. Therefore, when used on smaller stages, either proscenium or arena, higher light levels would be realized, but a decrease in area coverage would necessitate the use of at least the same number of lamps used on the larger stage.

A distinct limitation is the fact that the sealed-beam lamp is prefocused. Thus the three possible methods for enlarging or decreasing the size of the lighted area are: (1) the lamp can be moved either closer or farther away from the area to be lighted, (2) the model used for a particular area may be replaced by another model with different beam spread characteristics, and (3) certain models, the 4502 for example, can be rotated in the housing to change the beam pattern from long on the horizontal axis to long on the vertical axis. However, the time consumed in executing such adjustments and the limitations of possible variations may provide a handicap in the use of the sealed-beam lamp for a variety of productions. The Fresnel spotlight, on the other hand, is focusable and therefore considerably more flexible than the sealed-beam lamp. The choice of beam patterns of the sealed-beam suggests possible advantages in arena theatre where short light throws are common and spill light a disturbing handicap in conventional short-throw equipment.

The use of the sealed-beam lamps tested in this study is limited in another important respect for the lighting of some productions. Since the beam patterns of number 4502, 4505, and 4589 are non-circular and relatively concentrated, satisfactory lighting of a wide area such as a sky-drop or background cyclorama would be difficult if not impossible. If lamps number 4589 and 4505 were used to light a sky-drop, a smoothly blended coverage of light would be practically unobtainable due to the intense light-center concentration characteristics of these two lamps. The lack of satisfactory backdrop lighting apparatus would mean that some additional lighting equipment would have to be used in conjunction with the low-voltage system. This addition would considerably offset the flexibility and reduce the portability of the low-voltage lighting system. It is possible, however, that other twenty-eight volt sealed-beam lamps which would adequately light a sky-drop or similar surface might be found or become available in the future.

The housing of this sealed-beam lamp, since it is not available commercially, would have to be custom-made. The cost, therefore, might be somewhat increased. However, the twenty-four housings necessary for this system could probably be made for approximately eighty dollars. The biggest individual item in this estimate would be labor costs, as the material cost would probably not greatly exceed one dollar per unit.

Obviously, if these housings could be made in such a way as to avoid the cost of labor, the expense would be reduced considerably. Functionally a lamp housing of this design combines features of more expensive units with low cost, compactness, and durability.

The control unit of this low-voltage stage lighting system incorporates a type of lighting control that is functional and comparatively inexpensive. Auto-transformers are manufactured by many of the major electrical companies. The Variac auto-transformer manufactured by General Radio Corporations was chosen because of two factors: (1) the availability of a small high frequency model that can operate successfully on low voltage and is smaller and lighter than comparable fifty/sixty cycle Variacs, and (2) a wider selection of fifty/sixty cycle Variacs rated in small amperage increases from two amperes to well over one hundred amperes is available. The use of an auto-transformer for circuit dimming permits one lamp, or in the case of this particular system, up to three lamps for the M-5 Variac and twenty-four lamps for the V-10 Variac, to be dimmed rapidly or slowly or set for a period of time at any stage of brightness. The dimming achieved with a Variac is smooth, uninterrupted by jumps or lags in the operation. The use of a combination of a filament transformer and an auto-transformer encased separately in this system avoids some of the transformer bulk that is necessary to reduce line voltage, but increases the potential amperage capacity.

A thirty-two volt filament transformer used as the voltage step-down instrument, because of its availability as a standard item, is highly recommended. If the procedure explained in Chapter II, Part Three, of establishing the desired input and output voltage of the filament transformer and regulating the voltage to the input side of the filament transformer, is followed, an output voltage that will compensate for all but one volt of the maximum voltage drop in the line at a distance of ninety feet will be realized. The lamps, depending upon the length of run, would burn from twelve per-cent below to fifteen per-cent above the design voltage. Therefore, the lamps operating at the maximum distance from the elctric supply would lose a small percentage of light output while those close to the supply would gain somewhat in light output. These figures are the probable maximum and minimum factors that would be encountered if this lighting system were used on a proscenium stage thirty feet by eighteen feet and an arena stage twenty-four feet by twenty-two feet. The use of this proposed system on stages smaller than these would mean shorter cable runs. However, since the actual cable distance for a stage area or particular dramatic production is widely variable, it is practically impossible to determine the exact voltage drop. It seems likely that for the majority of the stages where this system might be satisfactorily employed, the cable distances would not be less than forty feet nor more than ninety feet for any one circuit. Then, in this case, the voltage drop would be between 1.8 volts and four volts, and the resulting gain or loss in light output would not be sufficiently great to handicap the system's application.

The combined control unit weighs more than the sixty-six pound

6,000-watt Davis Dimmer or the seventy pounds of the Powerstat 6-1000 portable switchboard. However, the low-voltage control system has eight circuits plus a master control capable of dimming a maximum of twenty-four lamps, while the two portable control boards with which it is compared have only six circuits, lack a master control, and can dim only twelve 500-watt lighting units. With the advantage of three additional circuits, the weight disparity of approximately twelve to sixteen pounds becomes less significant. Further the control unit for the low-voltage system is actually two separate units weighing approximately thirty and fifty pounds respectively. Since the individual units are lighter in weight than either of the two conventional switchboards mentioned, the low-voltage control units can be transported more easily. The advantage of low weight and bulk realized by this low-voltage stage lighting system is not confined to the control unit alone, but is found throughout the complete system since the lamp housing and the sealed-beam lamp are considerably smaller and lighter in weight than comparable conventional apparatus. The high proportional advantage in weight of the lamp housing and the very slight weight disadvantage of the total control system combine to result in a considerable saving in total equipment weight, making the low-voltage lighting system far easier to transport and store than conventional equipment.

In respect to size, the proposed low-voltage switchboard and filament transformer displace approximately 2,500 cubic inches, similar to the Powerstat 6-1000, and approximately 400 cubic inches more than the 2,160 cubic inch displacement of the Davis Dimmer. However, the low-voltage control system offers an advantage over these two conventional switchboards because it contains two additional dimmers and provides electrical master control.

The Powerstat 6-1000 portable switchboard retails for four hundred and twenty-five dollars, and the Davis Dimmer for seven hundred and fifty dollars. The control units proposed in this study can be purchased for approximately three hundred and twenty-seven dollars, a figure considerably less than the two popular commercial switchboards. One apparent disadvantage of the low-voltage control unit however, is that it is not manufactured as a complete switchboard. The thirty-two volt filament transformer, the V-10 Variac, the eight M-5 Variacs, and the accessory controls would have to be purchased separately and mounted in a cabinet such as the sheet-metal one suggested in this study. For the amateur not familiar with metal-working this task may be extremely difficult. However, if such is the case, a metal-working firm could custom-build the case, and a competent electrician could wire the control board. This would of course somewhat increase the total cost of the switchboard, the exact amount depending upon local conditions.

To distribute the electricity, number sixteen two-conductor rubber-covered cable is recommended for use in the load circuits. A cable of this size is smaller in diameter and more flexible than the cable currently used with conventional lighting systems. The use of number sixteen two-conductor cable results in a voltage drop ranging from a maximum of four volts to a probable minimum of 1.8 volts. With the use of a filament transformer capable of producing enough voltage to allow for a substantial compensation of the voltage drop, a saving in cable size can be made at the expense of a small amount of electricity.

One of the greatest advantages of this low-voltage stage lighting system is the fact that it may be powered from any standard voltage outlet fused at fifteen or more amperes. This type of outlet is available in almost any place where electricity is used. Standard voltage conventional lighting systems generally draw far more than fifteen amperes of current, or operate on 220/240 volts of electricity, neither of which is readily available in places other than a stage where a play might be produced or controlled lighting needed. A low-voltage stage lighting system is therefore far more versatile from this standpoint than conventional systems for lighting the stage.

In conclusion, certain advantages and disadvantages are apparent in the low-voltage stage lighting system. This proposed lighting system seems best suited for use on arena stages twenty-four feet by twenty-two feet or smaller because the output characteristics of the sealed-beam lamps could be utilized more advantageously at short-throw distances where a restricted area coverage is desired. However, if a proscenium stage is not larger than thirty feet by eighteen feet and does not require backdrop lighting, this low-voltage system could be used successfully. Stage areas larger than these dimensions or those on which broad background or sky-drop lighting is desired could not make satisfactory use of this system unless more circuits were provided.

The low-voltage lighting system proposed in this study is cheaper and more compact than comparable systems. It is more versatile from the standpoint that it can be used from any standard electrical outlet fused at fifteen amperes or more, and this system is considerably lighter in weight. However, because some of the equipment has to be custom-made the low-voltage lighting system may be difficult to assemble and probably would require more effort and time to procure than conventional systems. Further, the low-voltage system is not as flexible in operation as conventional systems since the light source is not easily focusable and backdrop or sky-drop lighting is not possible. For these reasons the low-voltage sealed-beam stage lighting system does not fill the requirements for all stage lighting situations and could not fully replace conventional apparatus. However, it does provide a means for lighting a small stage adequately for many theatrical productions at a cost that would bring a system of controlled area lighting within the means of some production groups operating on a limited budget. This system would also offer touring theatrical groups, or those groups which do not have an established place for production, a means of avoiding some of the difficulties and expense involved in transporting and storing conventional lighting equipment, while providing them with a basic lighting system that could be successfully used for many theatrical productions. Probably a final evaluation of the merits and limitations of the system could be made only after continued experimentation under a variety of production conditions.

A study of the use of low-voltage sealed-beam lamps for stage lighting purposes reveals points of consideration that deserve further study. The utilization of other models of the low-voltage sealed-beam lamp for uniform lighting coverage of wide areas such as backdrops or sky-drops, some means of making more readily available the lamp housing and switchboard case, and a method by which some type of lens might be used to permit the lamp unit to be focused more readily are areas of study worthy of further investigation and research. Continual experimentation with newly developed sealed-beam lamp models as they become available may lead to improvements in this proposed system that could make it even more valuable to production groups desiring a method for lighting the stage that overcomes some of the limitations of conventional lighting systems.

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APPENDIX A

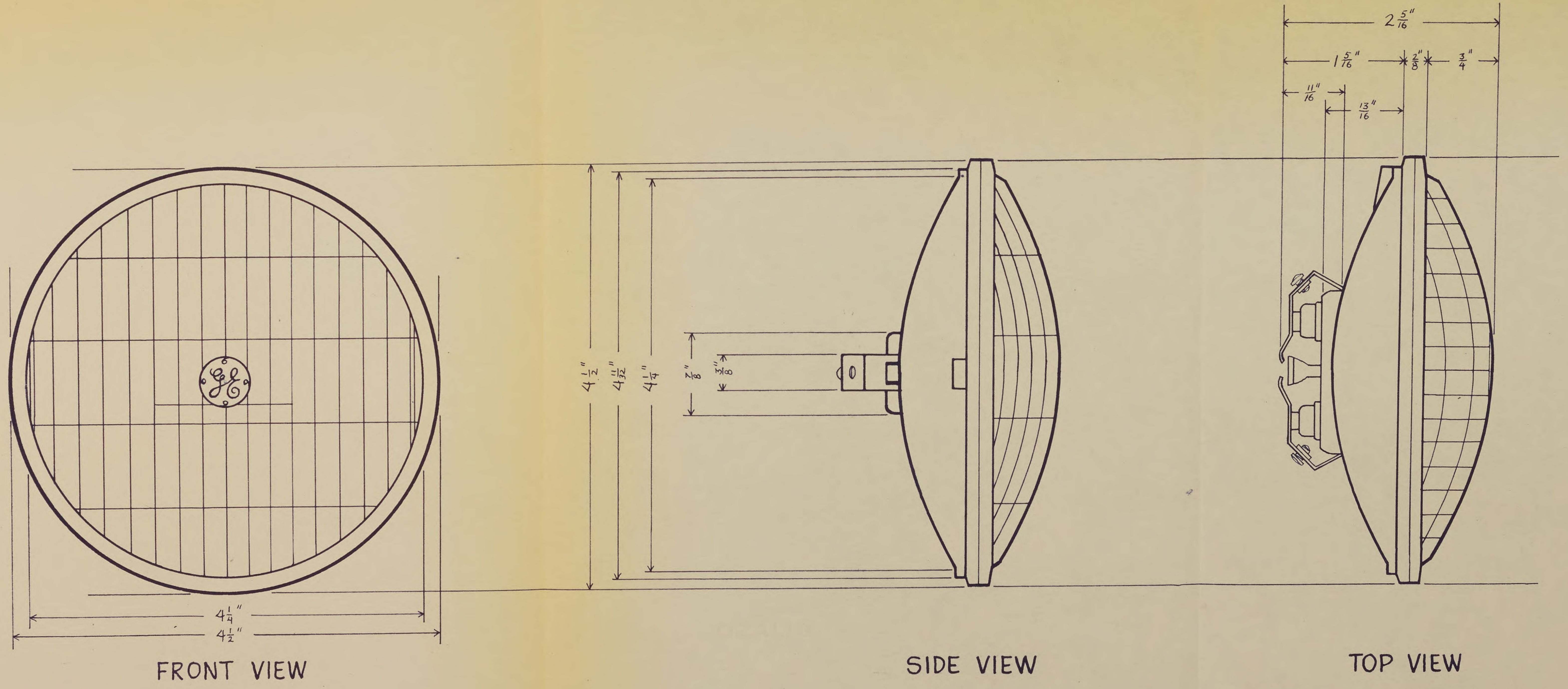


PLATE VI • SEALED BEAM LAMP UNIT

LAMP TYPE - PAR 36
VOLTAGE -28
MANUFACTURER - GENERAL ELECTRIC CORP.
DRAWN BY: Donald L. Murray
DATE: MAY 9, 1956 • SCALE: EXACT SIZE

SEALED-BEAM TEST DATA

Lamp #4502

Lens to Screen - 5'-0"

AREA	A	B	C	D	E	F	G	H	TOTAL *	AV. *	LUMENS IN AREA
1	200	250	240	190	150	155	235	250	1670	209	18.24
2	60	130	225	95	55	80	225	135	1005	126	32.99
3	20	45	220	45	20	35	220	48	653	82	34.73
4	12	25	200	20	14.5	21	210	30	533	67	40.92
5	9.5	13.5	175	16	10	11.5	180	13	429	54	42.41
6	7.5	10	150	10.5	7.5	8	145	10	349	44	42.24
7	6.5	7.5	120	7.5	6	5.5	125	8	286	36	40.59
8	6	6	90	6	5	5	90	5	213	28	36.65
9	5.5	5	60	5	4	4.25	70	4	158	20	29.68
10	5	4.5	45	4	3	3	45	4	114	14	23.20
11	4.5	4	42	3.25	3	2.25	43	4	106	13	23.82
12	4	3.5	24	2	3	1.5	26	3.5	68	9	18.06
13	3.5	3	14	1.25	3	1.25	16	3	45	6	13.09
14	3	2.75	8	1	2.5	1	8	2.5	29	4	9.42
* To nearest whole number										TOTAL	406.04

PLATE VII

SEALED-BEAM TEST DATA

Lamp #4505

Lens to Screen - 5'-0"

AREA	A	B	C	D	E	F	G	H	TOTAL *	AV. *	LUMENS IN AREA
1	160	215	550	800	650	720	680	240	4015	502	34.81
2	25	35	235	260	80	180	320	45	1180	148	38.75
3	11	15	70	40	20	31	110	23	320	40	16.94
4	7.5	8	15	11	8	12.5	24	11	97	12	7.33
5	5	4.5	8	11	4	5	7	6.5	51	6	4.71
6	4	4	4.5	5	4	5	4.5	5.5	37	5	4.80
7	3.5	3.5	3.5	4	3.5	4.5	3.5	4	30	4	4.51
8	3	3	2.5	3	2.5	3	2.5	3	23	4	5.24
9	2.5	2.5	2	2	2	3	2	2.5	19	2	2.97
10	2.5	2.5	1.5	2	1.5	2	1.5	2	16	2	3.32
11	2	2	1.5	2	1.5	2	1	2	14	2	3.67
12	2	2	1	2	1	2	1	1.5	13	2	4.01
13	2	2	1	1.5	1	1	1	1	11	1	2.18
14	1.5	2	1	1	1	1	1	1	10	1	2.36
* To nearest whole number										TOTAL	135.60

PLATE VIII

SEALED-BEAM TEST DATA

Lamp #4589

Lens to Screen - 5'-0"

AREA	A	B	C	D	E	F	G	H	TOTAL *	AV. *	LUMENS IN AREA
1	125	115	90	95	80	85	85	108	783	98	8.55
2	142	130	90	90	95	95	95	125	862	108	28.27
3	160	120	95	95	100	95	97	133	895	112	47.43
4	170	143	92	101	101	95	95	135	932	117	71.46
5	185	155	90	106	106	105	90	142	979	121	95.03
6	195	160	80	105	100	105	85	150	980	123	118.07
7	190	165	75	105	85	105	87	155	967	121	136.43
8	177	170	72	101	82	100	72	155	929	116	151.84
9	100	170	60	80	55	80	50	110	705	88	130.61
10	32	45	15	50	16	57	19	50	284	36	59.66
11	8	22	8	23	7	20	11	27	116	14	25.66
12	1.5	10	2	12	2	11	3	13	55	7	14.05
13	1.5	4	1	5	1.5	7	2	6	28	4	8.73
14	1.5	2	1	2	1	3	1	3	15	2	4.71
* To nearest whole number										TOTAL	900.50

PLATE IX

SEALED-BEAM TEST DATA

Lamp #4502

Lens to Screen - 10'-0"

AREA	A	B	C	D	E	F	G	H	TOTAL *	AV. *	LUMENS IN AREA
1	85	85	85	75	75	75	85	85	650	81	7.07
2	42	63	82	58	45	58	82	61	491	61	15.97
3	19	34	80	41	29	42	80	33	358	45	19.06
4	10	20	80	30	18	30	80	20	288	36	21.99
5	14	5	80	21	11	22	80	12.5	245	31	24.35
6	4.5	8	80	15	7.5	15.5	80	7.5	218	27	25.92
7	3	5	80	9	5	9.5	80	4	196	24	27.06
8	2.5	3.5	80	7	5	6	80	2.5	187	23	30.11
9	2	3	68	5	4.5	4.5	72	1.5	161	20	29.68
10	1.5	2	64	4	2	3.5	61	1	139	17	28.17
11	1	1.5	60	2.5	2	3.5	54	1	126	16	29.32
12	1	1	48	2.5	3	4	49	1	111	14	28.10
13	1	1	48	1.5	1.5	2	40	1	96	12	26.18
14	1	1	42	.5	1	2	32	1	81	10	23.56
										TOTAL	336.54

2'-2" to 1 Ft. C. on Hor. Axis

* To nearest whole number

PLATE X

SEALED-BEAM TEST DATA

Lamp #4505

Lens to Screen 10'-0"

AREA	A	B	C	D	E	F	G	H	TOTAL *	AV. *	LUMENS IN AREA
1	200	220	250	250	200	220	210	190	1740	218	19.02
2	100	150	210	190	200	150	150	120	1270	159	41.63
3	36	90	160	110	120	65	100	80	761	95	40.23
4	13	52	120	57	12	36	72	32	394	49	29.93
5	7	18	85	22	5	14	35	13.5	200	25	19.64
6	4.5	8	48	6	2.5	5.5	14	6	96	12	11.52
7	2.5	4.5	25	4	1.5	3	6	4	51	7	7.89
8	1	3	13	1.5	1	1.5	3	3	27	3	3.93
9	1	1.5	6.5	1	1	1.5	1.5	1	15	2	2.97
10	1	1	3	.5	1	1.5	1	1	10	2	3.32
11	.5	1.5	.5	.5	.75	1	1	.5	6	1	1.83
12	.25	.25	.5	.25	.5	1	.5	.5	4	1	2.01
13	.25	.25	.25	.25	.25	.5	.25	.25	2	.25	.55
14	.25	.25	.25	.25	.25	.25	.25	.25	2	.25	.59
* To nearest whole number										TOTAL	185.06

PLATE XI

SEALED-BEAM TEST DATA

Lamp #4589

Lens to Screen - 10'-0"

AREA	A	B	C	D	E	F	G	H	TOTAL *	AV. *	LUMENS IN AREA
1	16	15	13	13	11.5	12	12	14	107	12	1.05
2	19.5	18	13.5	13.5	12	12.5	12.5	16	118	12	3.14
3	23	17.5	13	13.5	13.5	13	12	18.5	124	15	6.35
4	26.5	20	12	14	14	13	11.5	19.5	131	16	9.77
5	32	22	12	14	14	11	14	21	140	18	14.14
6	40	24	11	14	13	14	10.5	22.5	149	19	18.24
7	39.5	25	10.5	14	11.5	14	10	24.5	149	19	21.42
8	30	28	10	13	10.5	12.5	8.5	24.5	137	17	22.25
9	19	28.5	9.5	11.5	9.5	11	7	21	117	15	22.26
10	10.5	26.5	8	10	9.5	10.5	6	15	96	12	19.89
11	7	21	7.5	8.5	9.5	11	4	10	79	10	18.33
12	5.5	15.5	5.5	8	10	9.5	3.5	5.5	63	8	16.06
13	4.5	10	5	7.5	10	9	2	3	51	6	13.09
14	3.5	5.5	3.5	8	10	8.5	1.5	1.5	42	5	11.78
* To nearest whole number										TOTAL	197.77

PLATE XII

SEALED-BEAM TEST DATA

Lamp #4502

Lens to Screen - 20'-0"

AREA	A	B	C	D	E	F	G	H	TOTAL *	AV. *	LUMENS IN AREA
1	16.5	19	20	22	19	20	20	15	152	19	1.66
2	11	15	20	22	15	18	20	10	131	16	4.19
3	7	11	20	20	11.5	15	20	7	112	14	5.93
4	5	7.5	20	17.5	9	12	20	7	98	12	7.33
5	3	5	20	14.5	6.5	10	20	5	84	11	8.64
6	1.5	4	20	11	5	7	20	3.5	81	10	9.60
7	1	3	20	9.5	4	5.5	20	2.5	66	8	9.02
8	.5	1.5	20	6	3	5	19.5	1.5	66	8	10.47
9	.5	1	20	5	1.5	4.5	18	1	52	7	10.39
10	.5	1	20	4	1	4	17.5	.5	49	6	9.94
11	.5	1	20	4	1	3	17	.5	47	6	11.00
12	.5	.5	19.5	3	1	2.5	16	.5	44	6	12.04
13	.5	.5	19.5	2	.5	1.5	15.5	.5	41	5	10.91
14	.5	.5	19	1	.5	1	15	.5	38	5	11.78
				2'-6" to 1 Ft.C. on Hor. Axis							
*	To nearest whole number									TOTAL	122.90

PLATE XIII

SEALED-BEAM TEST DATA

Lamp #4505

Lens to Screen - 20'-0"

AREA	A	B	C	D	E	F	G	H	TOTAL *	AV. *	LUMENS IN AREA
1	54	50	49	49	52	54	54	52	414	52	4.54
2	50	46	44	46	51	55.5	56	46	395	49	12.83
3	40	40	38	42	45	54.5	55	41	356	44	18.63
4	32	32	34	35	36.5	48	53.5	32	303	38	23.21
5	22	24	30	28	28	41	50	26	249	31	24.35
6	12	17	25	22	18	32.5	45	20	192	24	18.85
7	5	13	20	15	7.5	23	40	12	136	17	19.17
8	3	9	15	10	4	15	35	9	100	13	17.02
9	1	5	10	5	1.5	9.5	28	5	65	8	11.87
10	.5	3	7	2.5	1	5	23	2.5	45	6	9.94
11	.5	1.5	5	1	.5	3	12	1	25	3	5.50
12	.5	.5	3	.5	.5	1	10	1	18	2	4.01
13	.5	.5	2	.5	.5	1	8	.5	14	2	4.36
14	.5	.5	1	.5	.5	.5	5	.5	9	1	2.36
* To nearest whole number										TOTAL	176.64

PLATE XIV

SEALED-BEAM TEST DATA

Lamp #4589

Lens to Screen - 20'-0"

AREA	A	B	C	D	E	F	G	H	TOTAL *	AV. *	LUMENS IN AREA
1	3	3.5	3	3.5	3	3	3	2.5	25	3	.25
2	3	3.5	3	3.5	3	3	2	2	23	3	.79
3	3	3.5	3	3.5	3	3	2	2	23	3	1.27
4	3.5	3.5	3	3.5	3	3	2.5	2	24	3	1.83
5	3	3	3	3.5	3.5	3	2.5	3	25	3	2.36
6	3.5	2.5	3	3.5	3.5	3.5	2.5	3.5	26	3	2.88
7	4	3	3	3.5	3.5	3.5	2.5	3.5	27	3	3.38
8	4	3	3	3.5	3.5	3.5	2.5	3.5	27	3	3.93
9	4.5	3	3	3.5	3	3.5	2.5	4	27	3	4.45
10	5	3.5	2	3.5	3	3.5	2.5	4	27	3	4.97
11	5	3	1.5	3.5	2.5	3.5	2.5	4.5	26	3	5.50
12	5	3	1.5	3	2	4	2.5	4.5	26	3	6.02
13	5.5	3	1.5	2	1.5	3.5	2.5	5	25	3	6.54
14	7	3	1	1.5	1.5	3.5	2.5	5	26	3	7.07
										TOTAL	51.24

2'-8" to 1 Ft.C. on Hor. Axis
1'-0" to 1 Ft.C. on Vert. Axis

* To nearest whole number

PLATE XV

500-WATT FRESNEL TEST DATA[1]

Kopp 6" Lens - Focal Length 3 7/16"

Medium Focus - Lens to Screen 5'-0"

AREA	A	B	C	D	E	F	G	H	TOTAL	AV.	LUMENS IN AREA
1	454	450	450	452	459	458	453	442	3618	452	39.4
2	425	426	436	439	460	457	449	448	3540	443	115.8
3	418	402	411	422	445	443	420	415	3376	422	178.7
4	371	364	379	403	420	423	399	394	3153	393	240
5	329	324	330	362	370	400	363	355	2833	354	278
6	282	284	301	319	340	360	325	303	2514	314	301.4
7	232	222	250	280	308	302	275	238	2107	263	296.5
8	180	175	190	219	246	229	209	176	1624	203	265.7
9	133	121	124	148	180	161	159	129	1155	145	239.3
10	84	71	69	74	114	108	107	83	710	89	147.5
11	73	38	35	45	63	66	60	52	432	54	99
12	30	20	17	33	38	44	41	37	255	32	64.2
13	18	12	13	24	25	28	20	19	159	20	43.6
14	11	8	9	19	18	16	13	15	109	14	31.8
15	5	7	8	13	14	12	9	12	80	10	25.3
16	5	6	6	9	11	9	7	11	64	8	21.6
17	4	4	5	7	7	7	5	8	50	6	17.3
18	4	4	4	5	7	5	4	5	38	5	15.5
19	3	3	3	4	5	4	3	5	30	4	11.2
20	3	2	2	3	3	3	2	4	22	3	7.2
									TOTAL		2439.0

[1] Figures from, G.Edward Hearn, "An Experimental Study of the Efficiencies and Adaptability of Fresnel Lenses", (an unpublished Master's Thesis, State University of Iowa, 1940), p. 39.

PLATE XVI

500-WATT FRESNEL TEST DATA[1]

Kopp 6" Lens - Focal Length 3 7/16"

Flood Focus - Lens to Screen 9'-8"

AREA	A	B	C	D	E	F	G	H	TOTAL	AV.	LUMENS IN AREA
1	471	480	482	475	472	464	468	470	3782	473	41.3
2	448	430	410	421	448	475	460	449	3541	443	115.8
3	400	355	320	335	395	440	437	412	3094	387	163.9
4	340	265	239	263	317	395	392	270	2581	323	197
5	260	170	155	218	262	315	333	312	2025	253	198.7
6	200	119	110	176	211	222	260	244	1542	193	185.3
7	141	68	68	133	161	141	195	158	1065	133	150
8	89	44	44	80	112	82	120	92	663	83	108.6
9	60	30	26	52	73	56	70	60	427	54	79.3
10	40	21	17	35	50	38	46	42	289	36	59.7
11	26	14	13	22	35	28	24	36	198	25	45.8
12	17	10	9	18	24	19	23	20	140	18	35.1
13	13	8	7	14	17	15	17	15	106	13	28.4
14	10	6	6	12	13	12	12	11	82	10	23.5
15	7	5	5	11	10	10	9	9	66	8	20.2
16	6	4	4	10	8	8	7	7	54	7	18.9
17	5	4	4	9	7	7	6	6	48	6	17.9
18	4	4	3	8	7	6	5	6	42	5	15.3
19	4	3	3	7	6	5	5	5	38	5	16
20	3	3	3	6	5	5	4	4	33	4	13.6
21	2	2	3	5	5	3	3	4	26	3	12.4
22	2	2	2	4	4	3	3	4	24	3	11.2
23	2	2	2	3	3	3	3	4	22	3	11.7
24	2	1	2	3	3	2	2	3	18	2	8.2
									TOTAL		1572.4

1 *Op. cit.*, p. 40.

PLATE XVII

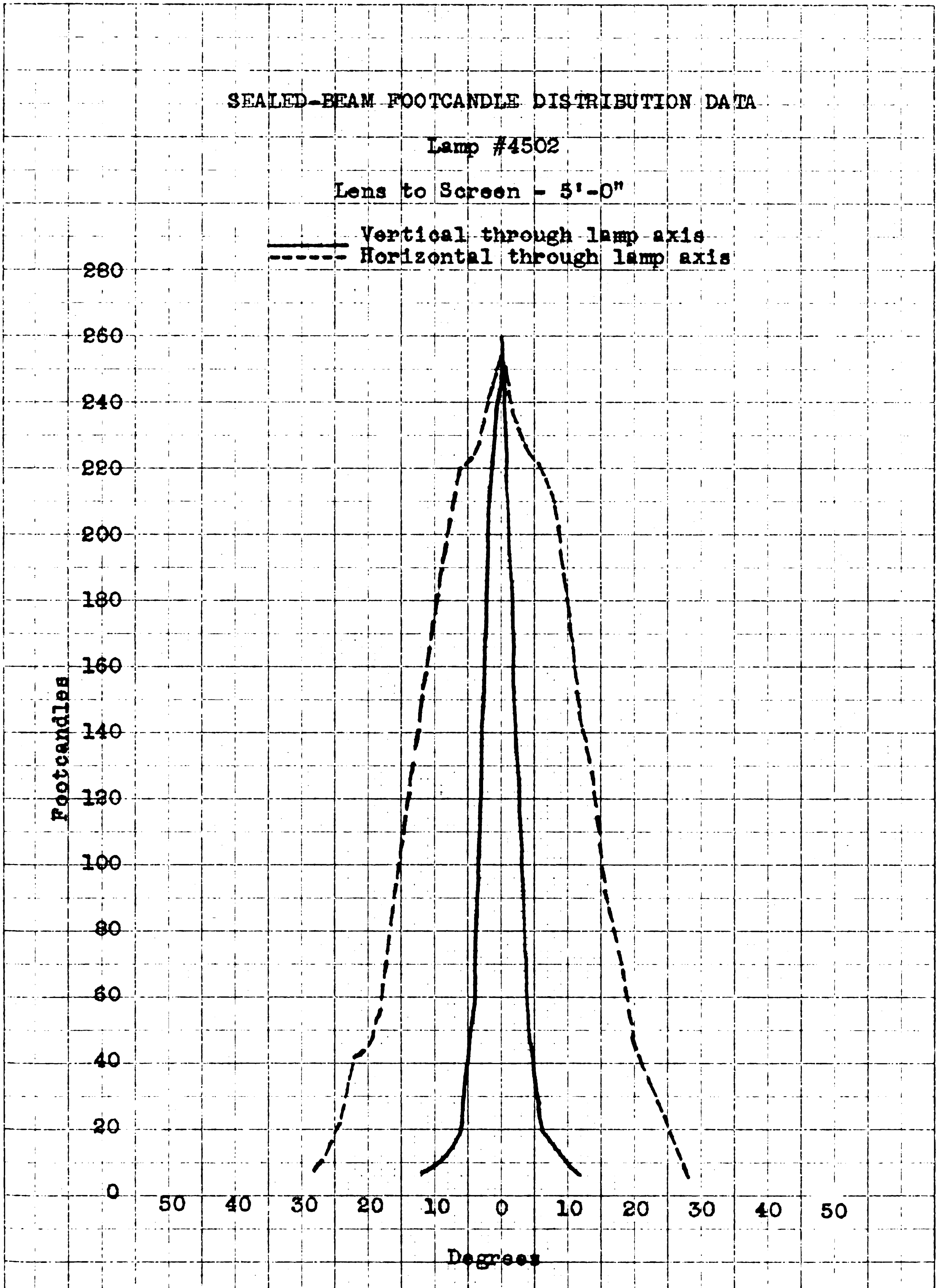

SEALED-BEAM FOOTCANDLE DISTRIBUTION DATA
Lamp #4502
Lens to Screen - 5'-0"
Vertical through lamp axis
Horizontal through lamp axis
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
Footcandles
50
40
30
20
10
0
10
20
30
40
50
Degrees

PLATE XVIII

SEALED-BEAM FOOTCANDLE DISTRIBUTION DATA

Lamp #4505

Lens to Screen - 5'-0"

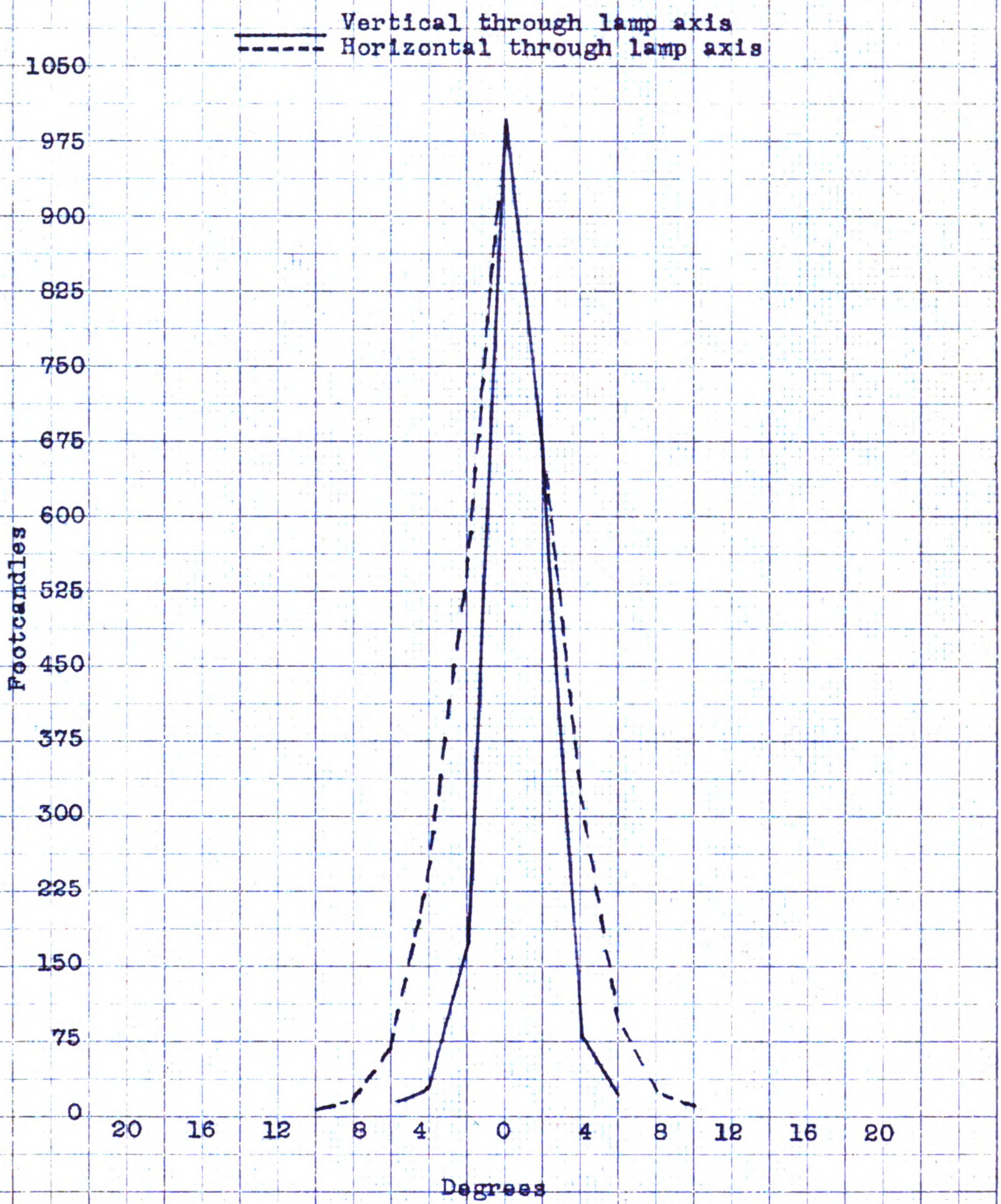


PLATE XIX

SEALED-BEAM FOOTCANDLE DISTRIBUTION DATA

Lamp #4589

Lens to Screen - 5'-0"

——— Vertical through lamp axis
- - - - - Horizontal through lamp axis

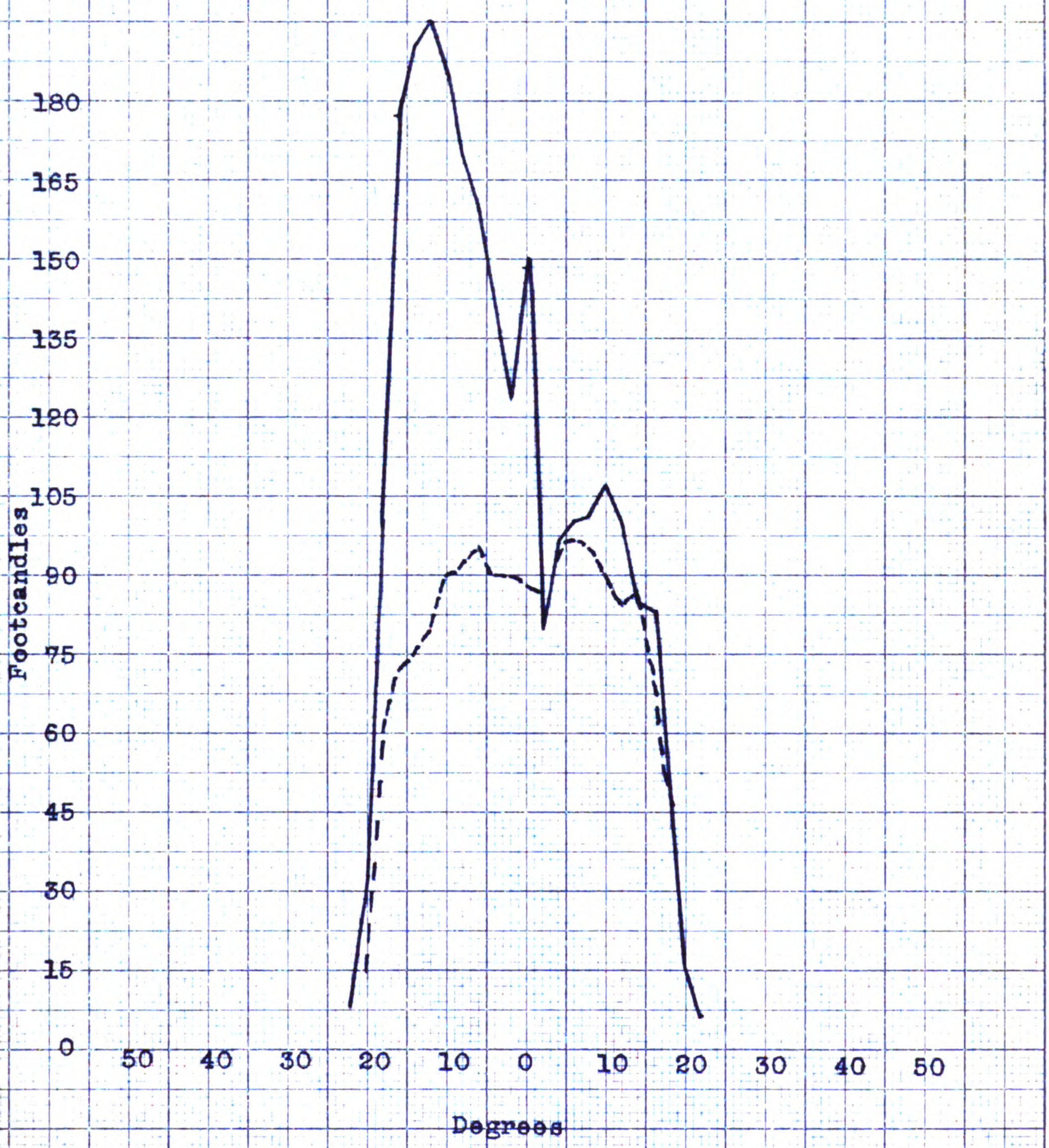


PLATE XX

SEALED-BEAM ISOCANDLE DISTRIBUTION DATA

Lamp #4502

Lens to Screen - 10'-0"

Rings Measure Footcandles

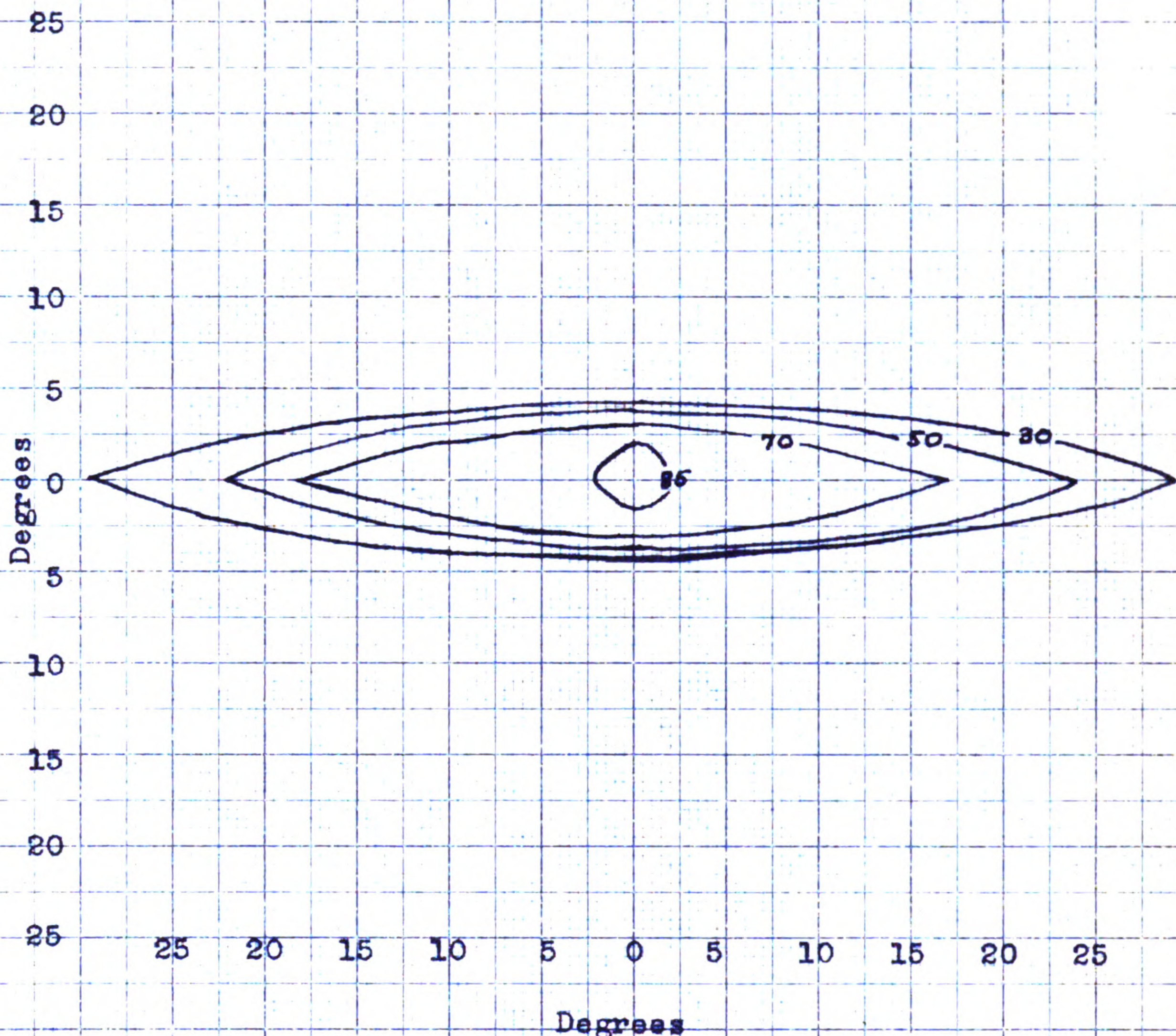


PLATE XXI

SEALED-BEAM ISOCANDLE DISTRIBUTION DATA

Lamp #4505

Lens to Screen - 10'-0"

Rings Measure Footcandles

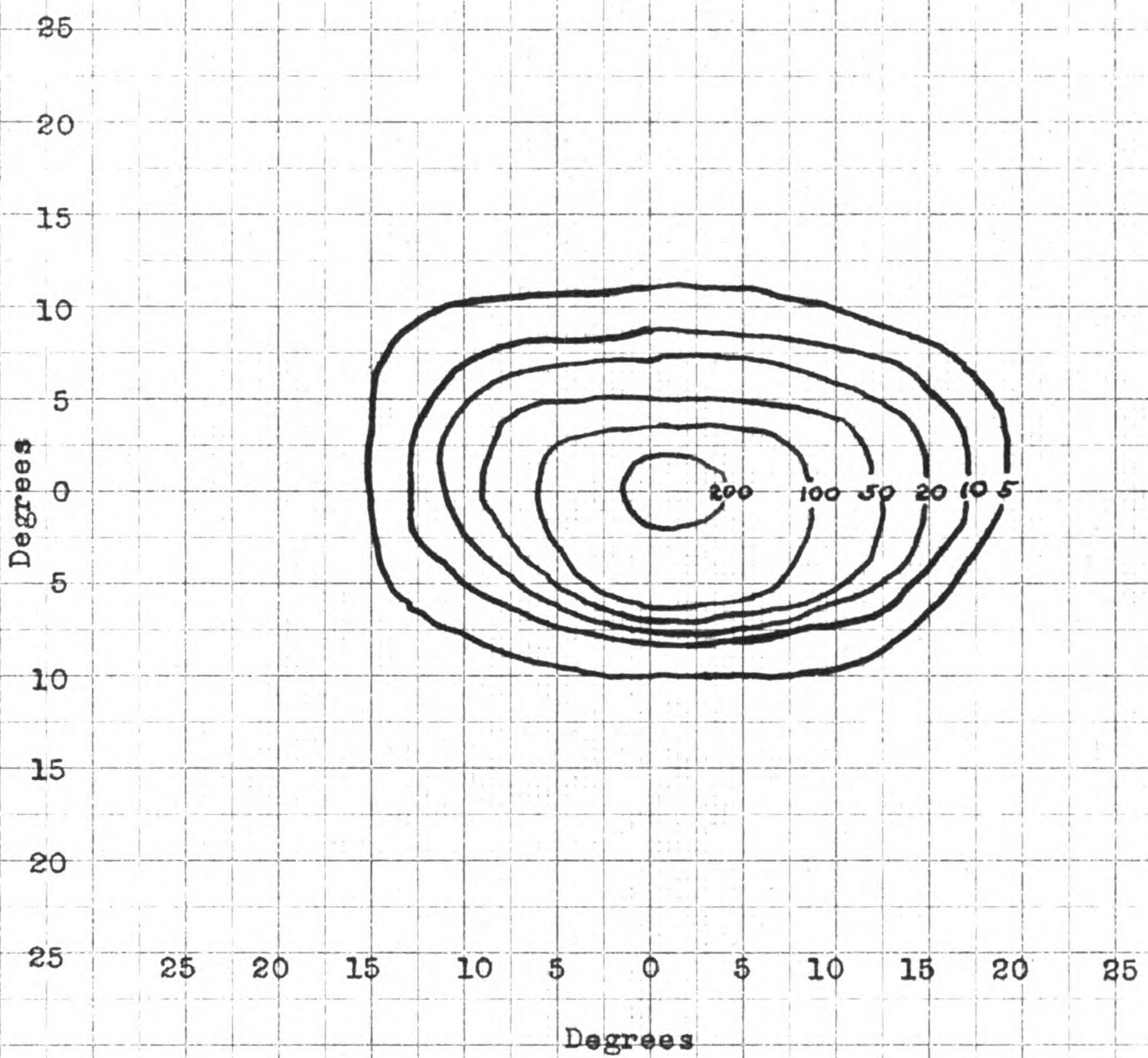


PLATE XXII

SEALED-BEAM ISOCANDLE DISTRIBUTION DATA

Lamp #4589

Lens to Screen - 10'-0"

Rings Measure Footcandles

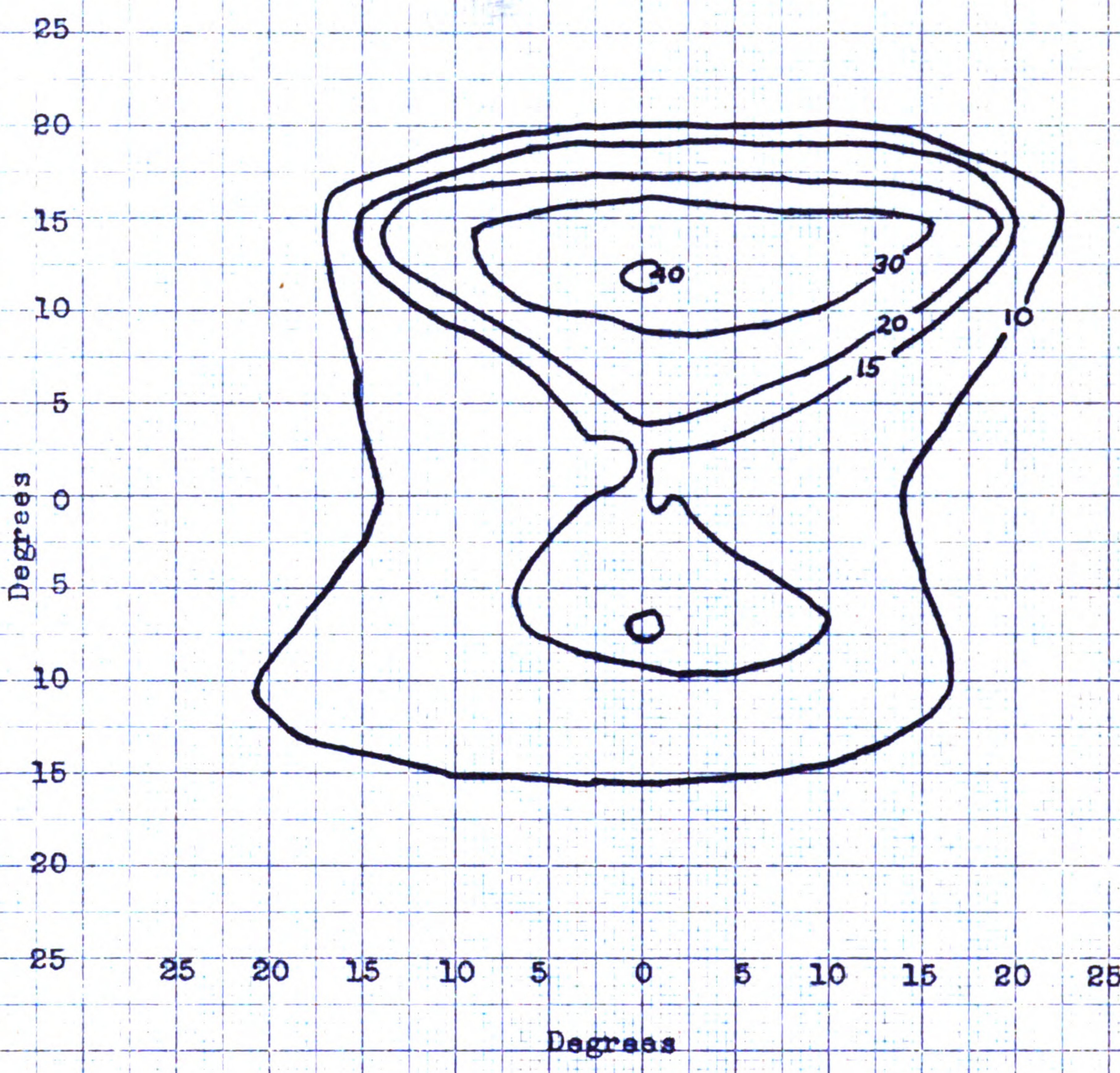


PLATE XXIII

APPENDIX B

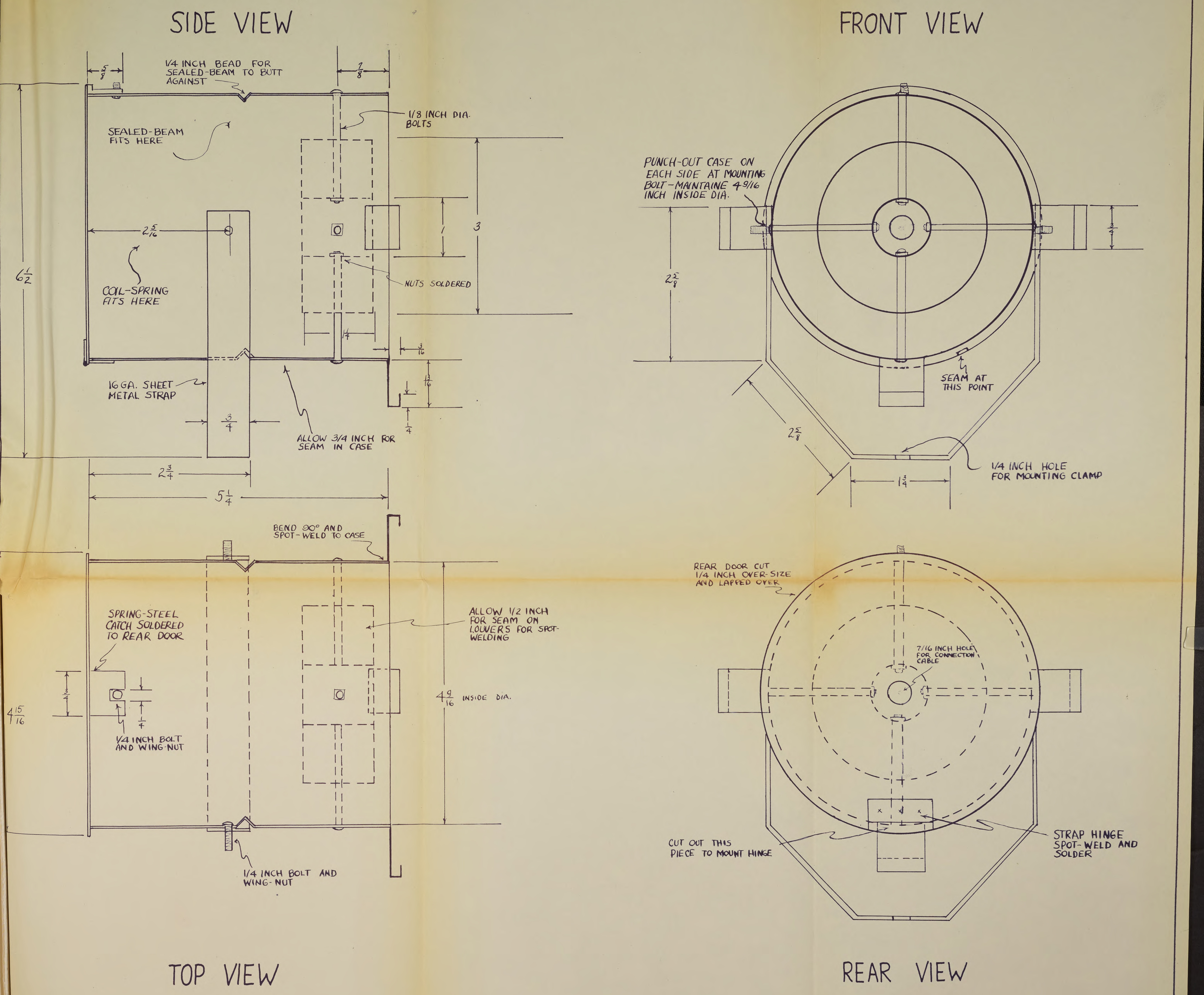


PLATE XXIV - LAMP HOUSING

CONSTRUCTED OF # 22 GA. SHEET METAL
FINSHED IN DULL FLAT BLACK
WEIGHT: ONE POUND NINE OUNCES
MATERIAL COST: APPROX. $1.25

ACTUAL SIZE

DATE: MAY 9, 1956 DRAWN BY Dm

APPENDIX C

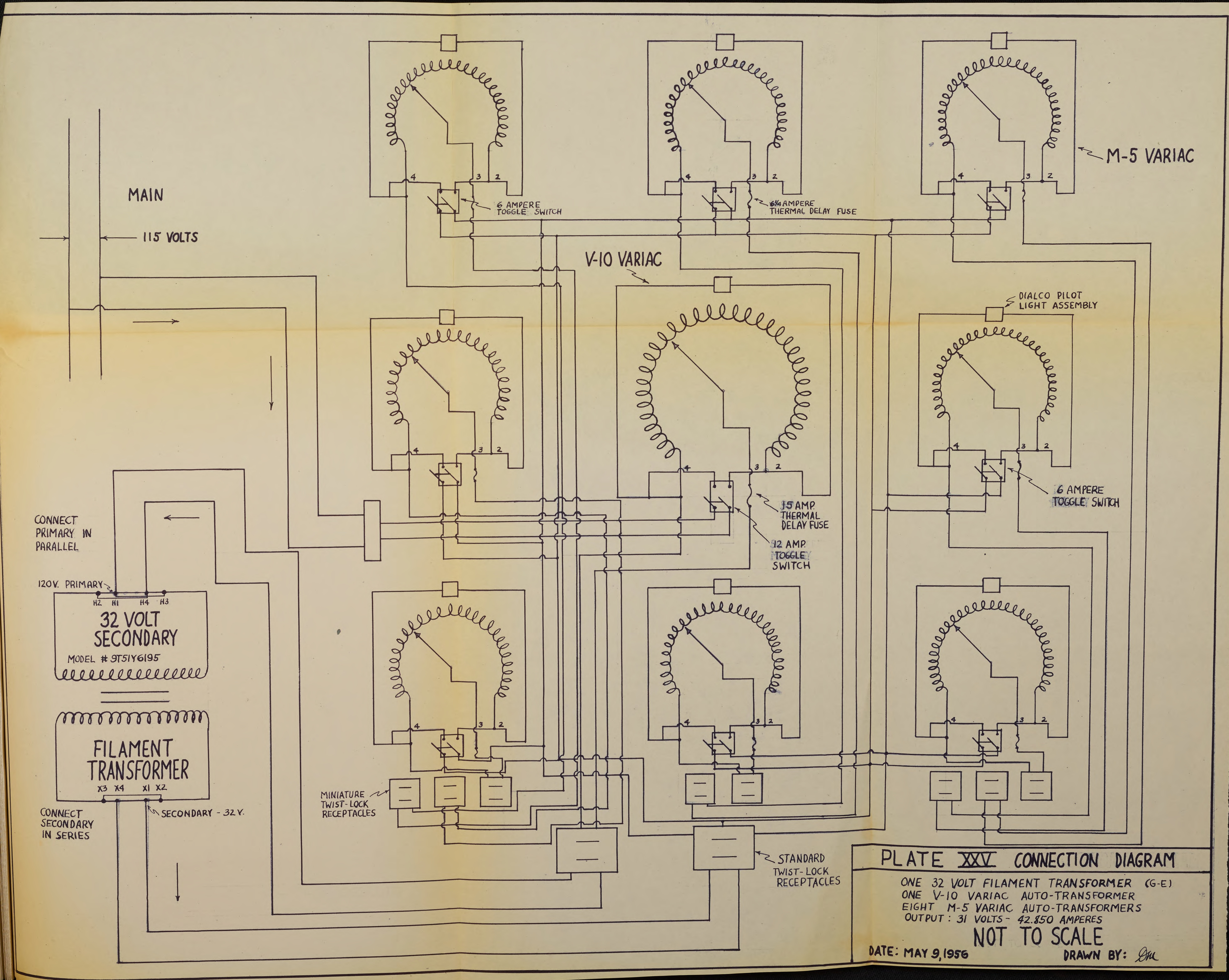
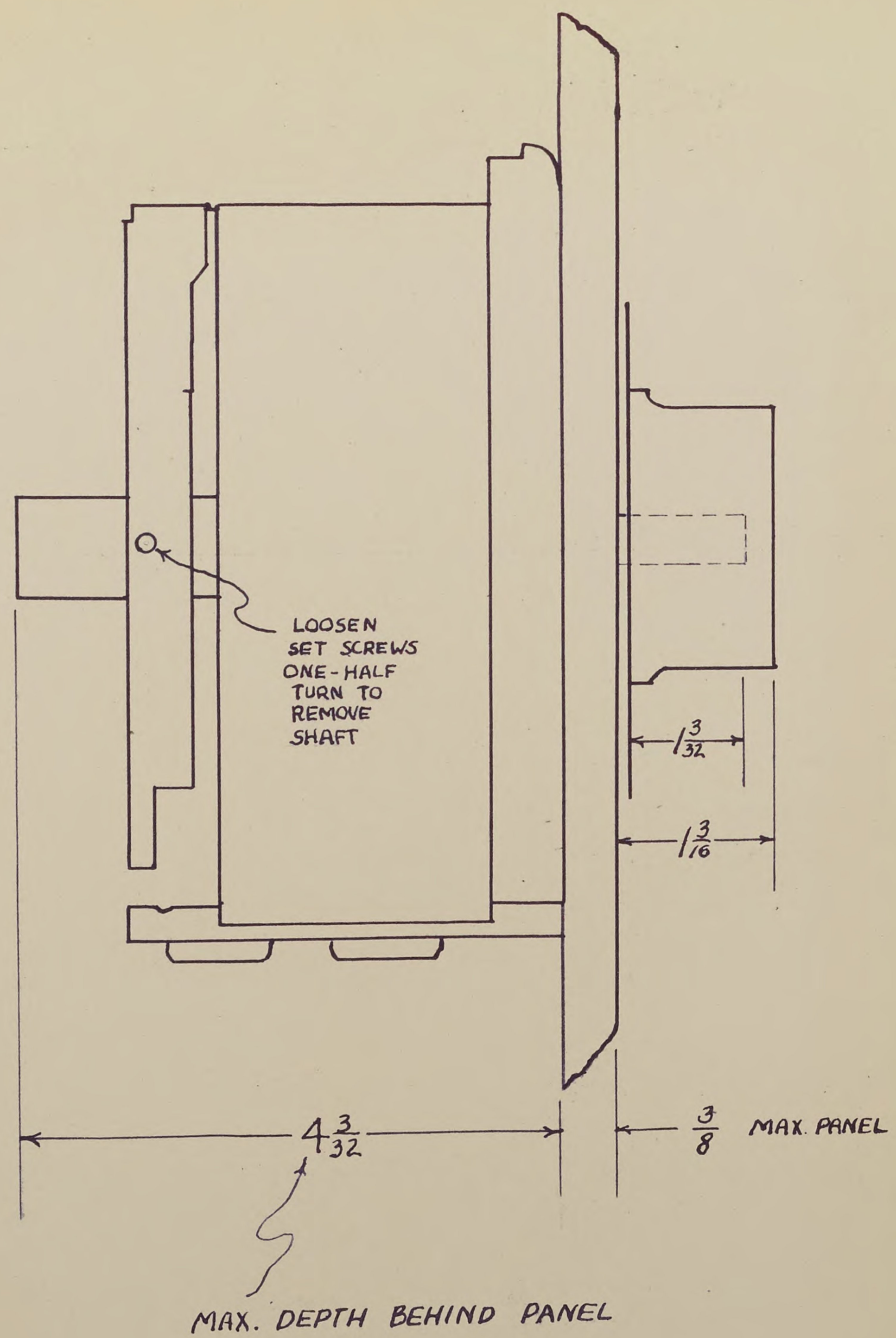


PLATE XXV CONNECTION DIAGRAM

ONE 32 VOLT FILAMENT TRANSFORMER (G-E)
ONE V-10 VARIAC AUTO-TRANSFORMER
EIGHT M-5 VARIAC AUTO-TRANSFORMERS
OUTPUT: 31 VOLTS - 42.850 AMPERES

NOT TO SCALE

DATE: MAY 9, 1956 DRAWN BY: [illegible]



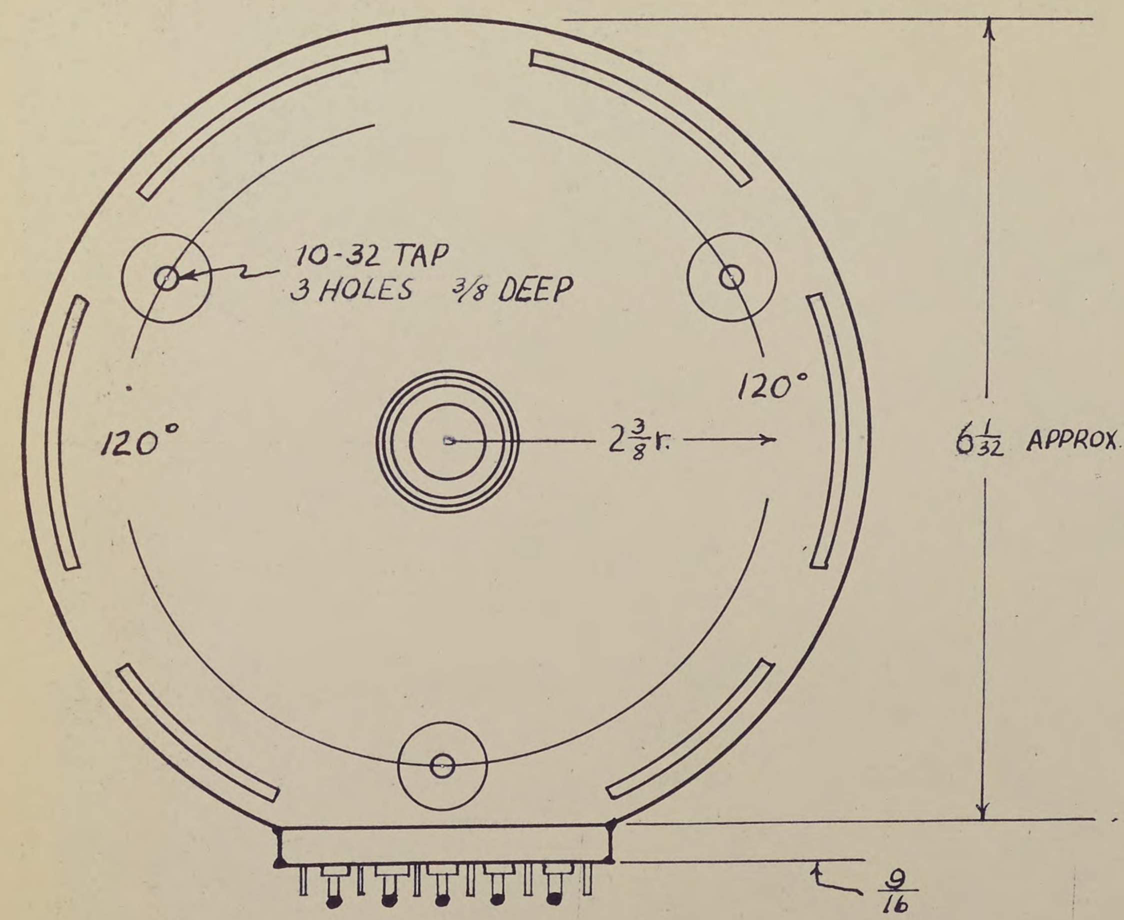


PLATE XXVI · V-10 VARIAC

INPUT VOLTAGE - 115	WEIGHT 11¼ POUNDS
OUTPUT VOLTAGE - 0-115	PRICE $33.00
MAXIMUM CURRENT - 13A.	DRAWN BY: DM.
LINE FREQUENCY - 50-60 c.	
DATE: MAY 9, 1956	SCALE: ¾" = 0'-1"

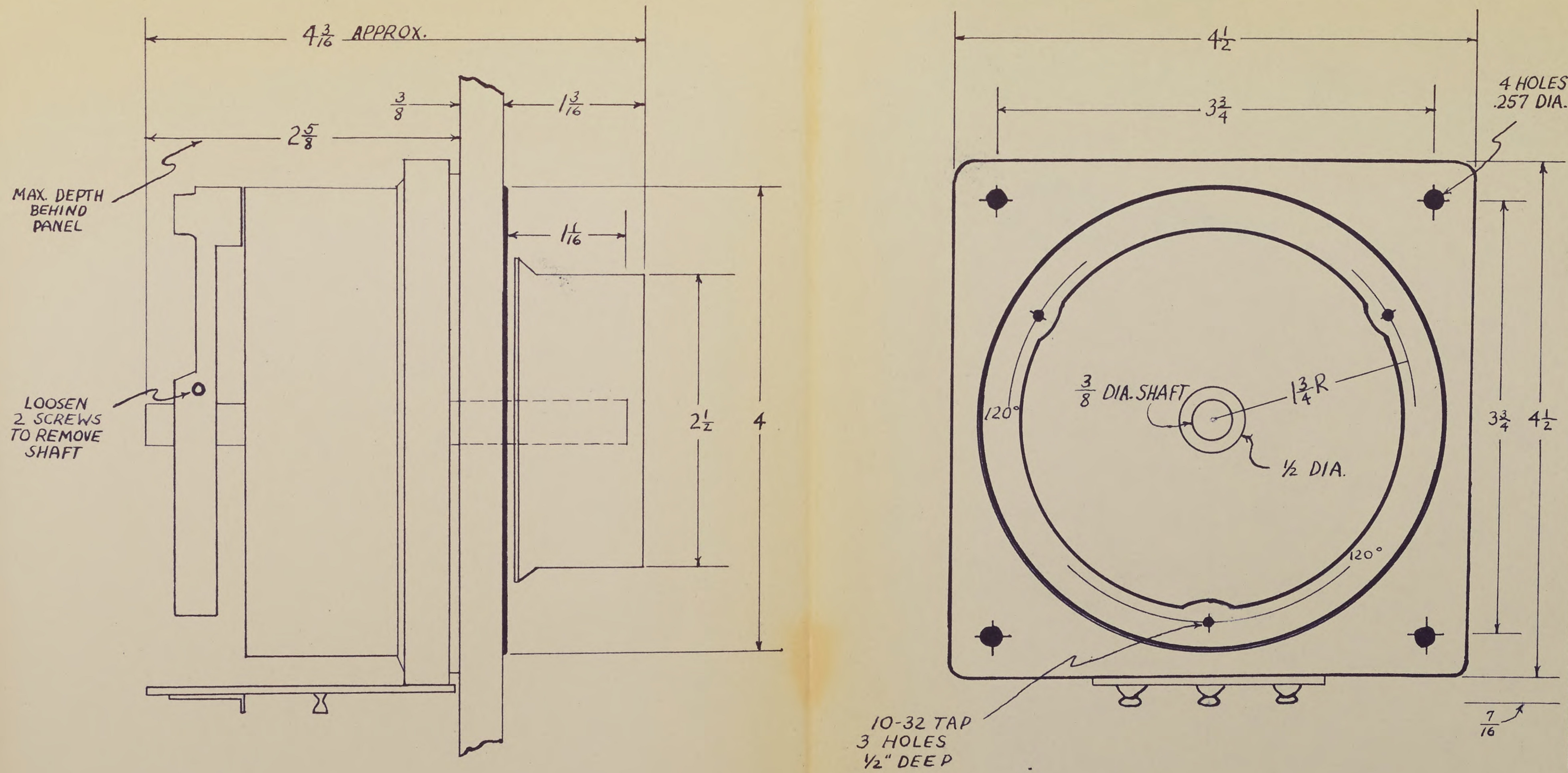


PLATE XXVII · M-5 VARIAC

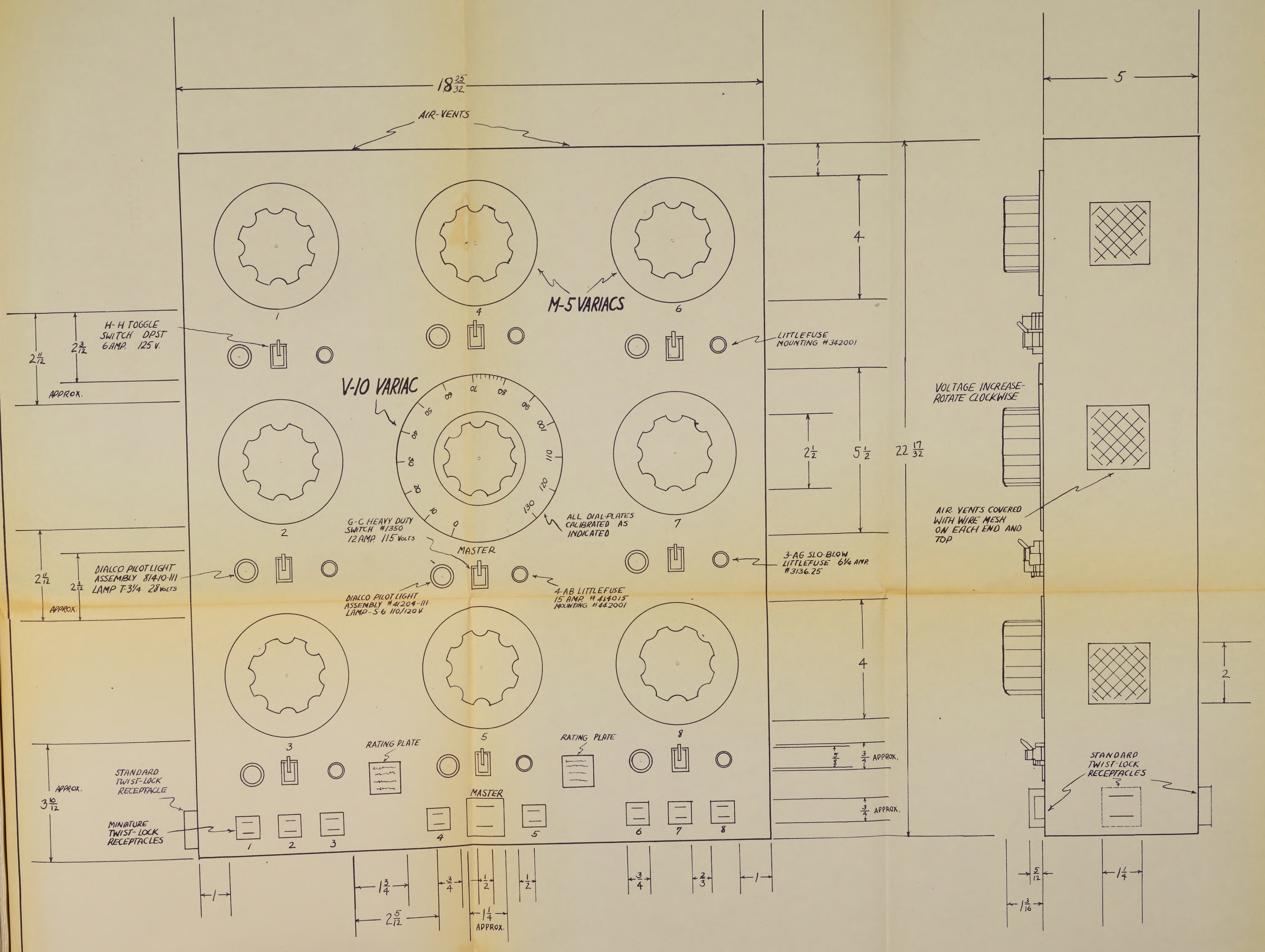
INPUT VOLTAGE - 115 WEIGHT 3¼ POUNDS

OUTPUT VOLTAGE - 0-115 PRICE $22.50

MAXIMUM CURRENT - 7.5 A. DRAWN BY: D.M.

LINE FREQUENCY - 350-1200 c.

DATE: MAY 9, 1956 SCALE: ACTUAL SIZE

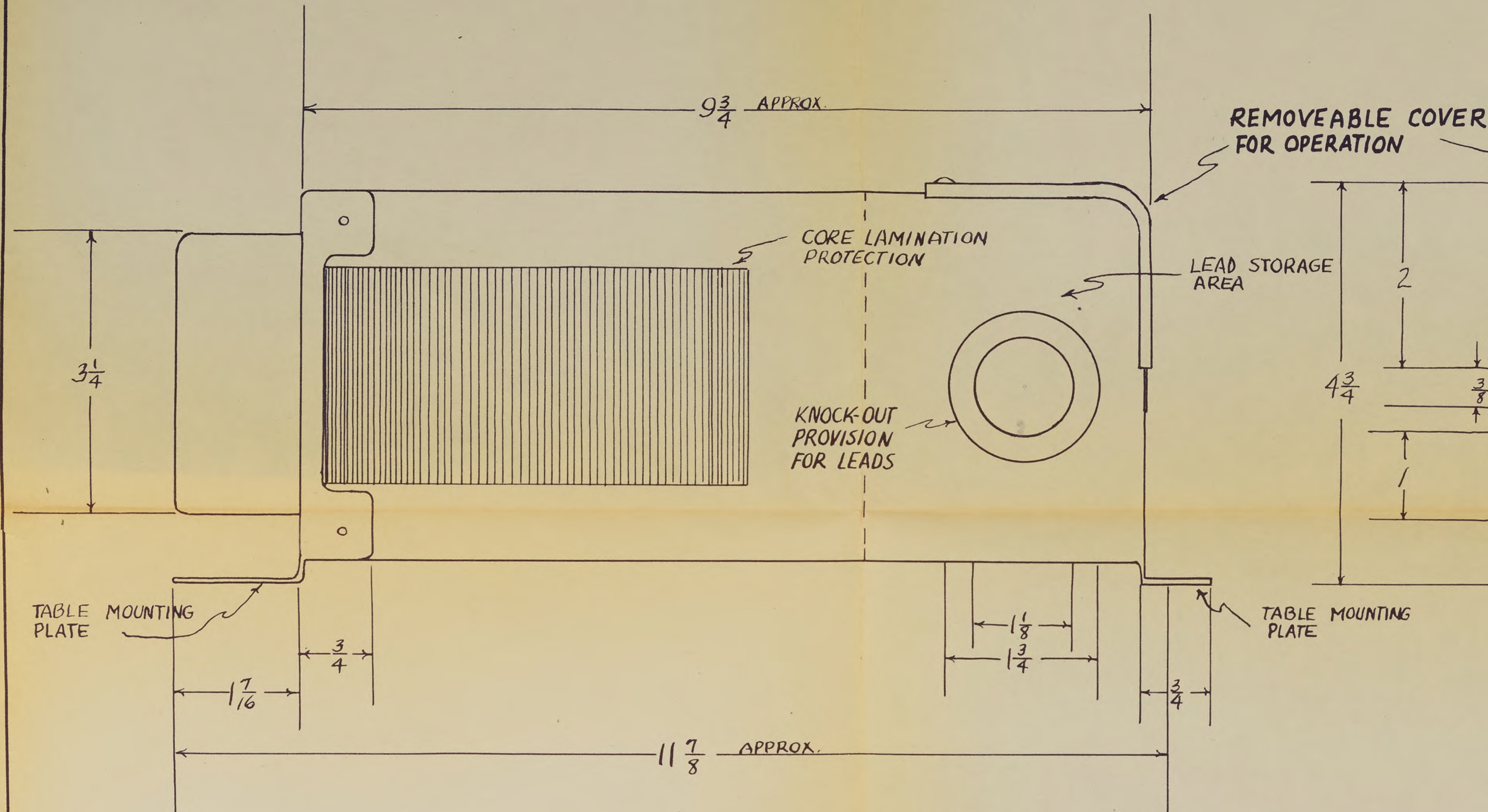


CONSTRUCTION AND ASSEMBLY

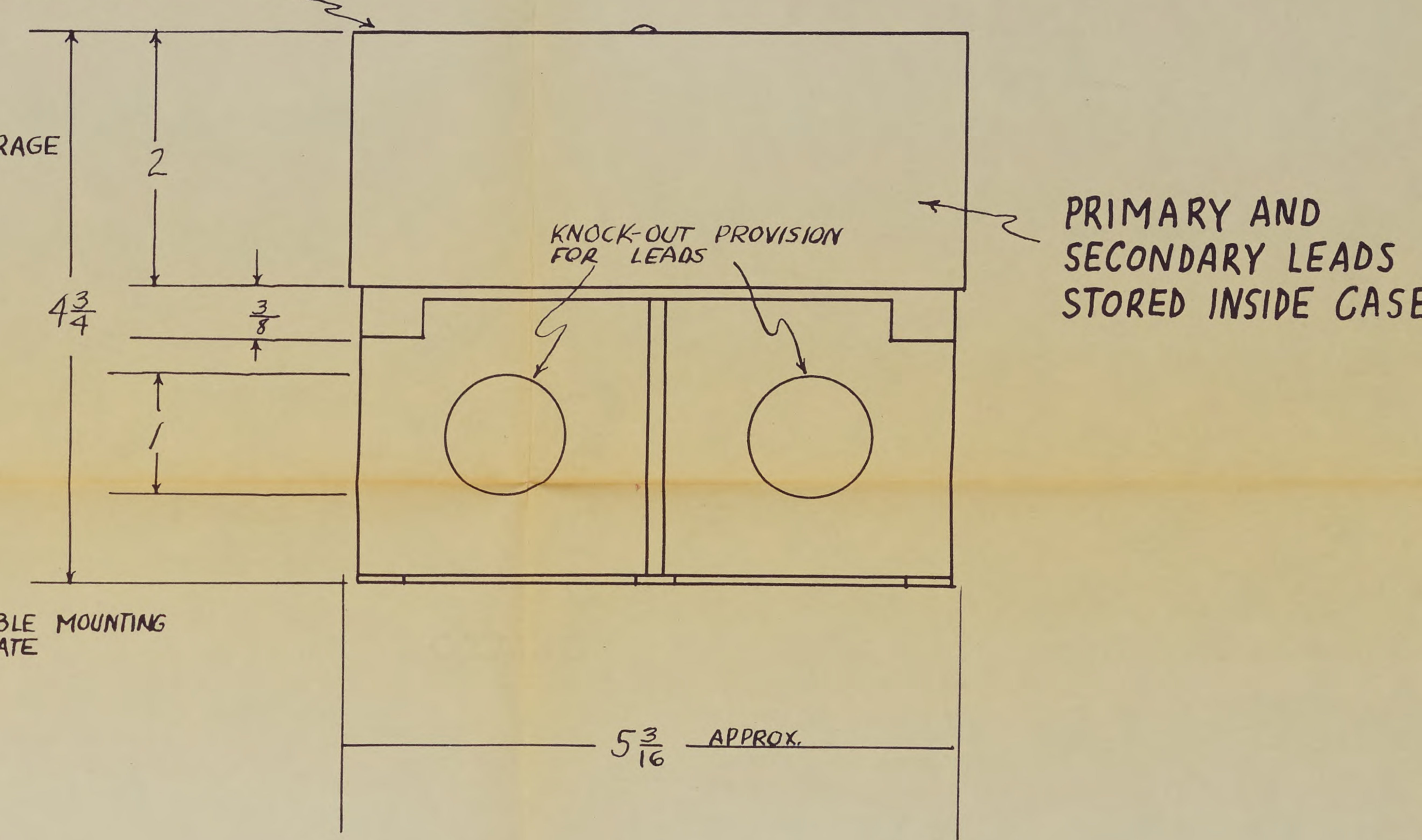
USE #16 GALVANIZED SHEET METAL (USE INSIDE IRON SUPPORTS IF NECESSARY)
MOUNT VARIACS SO KNOB NOT DIAL ROTATES
REAR PANEL MUST BE REMOVEABLE FOR MAINTAINCE
ALL VARIACS NUMBERED OR NAMED AS INDICATED
LABEL RECEPTACLES AS INDICATED
CARRYING HANDLES OPTIONALLY SIDE MOUNTED (NOT INDICATED)
RATING PLATES MUST CLEARLY INDICATE CONTROL CHARACTERISTICS

PLATE XXVIII - CONTROL BOARD

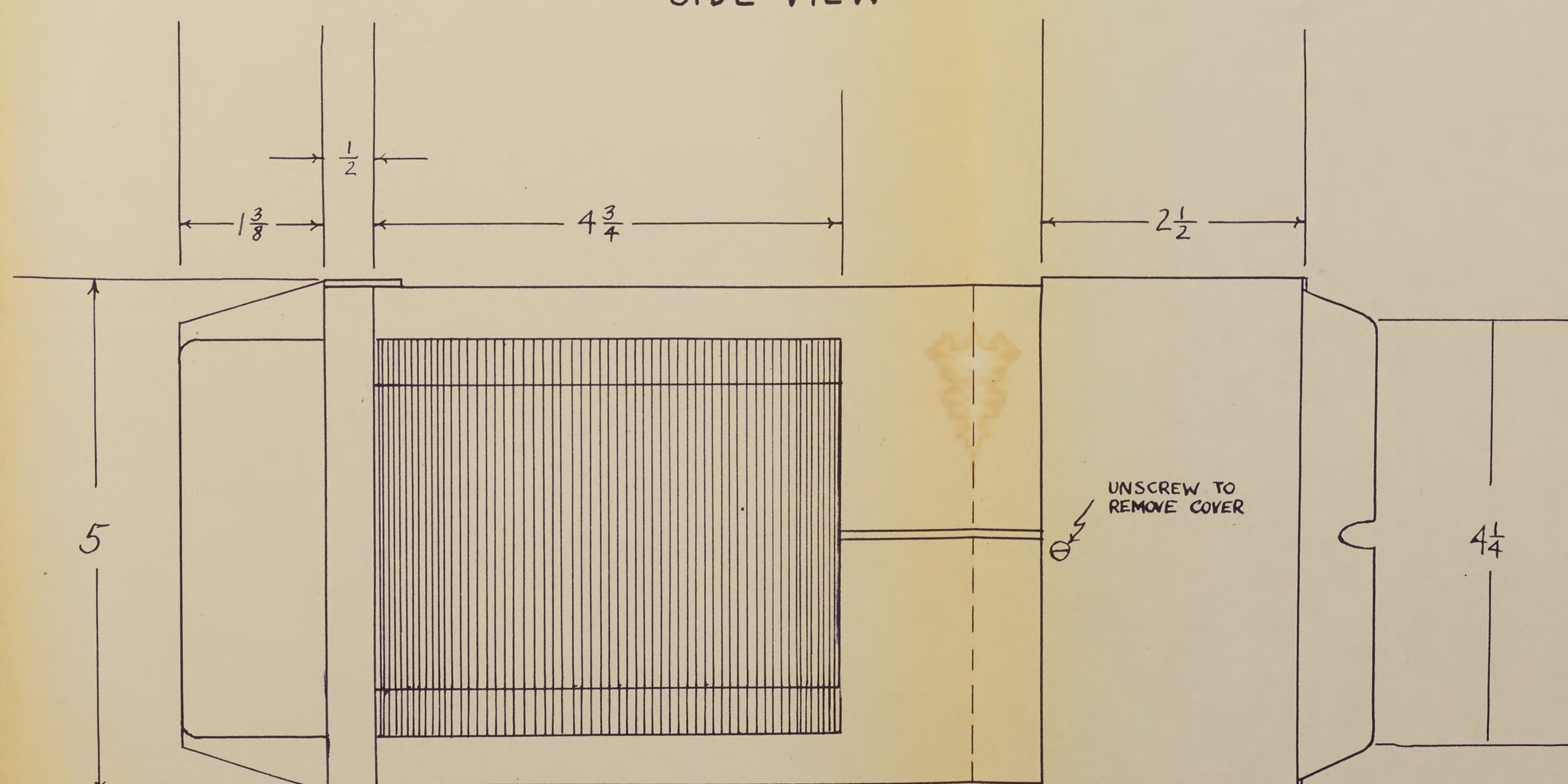
ONE V-10 VARIAC AUTO-TRANSFORMER
EIGHT M-5 VARIAC AUTO-TRANSFORMERS
ONE DIALCO PILOT ASSEMBLY # 41204-111
ONE G-C HEAVY DUTY SWITCH # 1350
ONE 4-AB LITTELFUSE #414015
EIGHT DIALCO PILOT ASSEMBLY # 81410-111
EIGHT H+H TOGGLE SWITCHES DPST 6 AMP. 125 V.
EIGHT 3-AG SLO-BLO LITTELFUSES # 3136.25
INPUT VOLTAGE - 115/31 OUTPUT - 31 MAX. AMPS. 42.850
DATE: MAY 9, 1956 SCALE: 1/2" - 0'-1" DRAWN BY: [illegible]



SIDE VIEW



CONNECTION END VIEW



- CONNECT 5 INCH PRIMARY LEADS IN PARALLEL
- CONNECT 5 INCH SECONDARY LEADS IN SERIES
- ALL LEADS EMERGE FROM CONNECTION END
- FOR STORAGE OR TRANSPORTATION LEADS ARE ENCLOSED IN CASE AND COVER REPLACED
- COIL AND CORE FULLY ENCLOSED BY HEAVY GAUGE METAL CASE

TOP VIEW

PLATE XXIX - 32 VOLT FILAMENT TRANS.

GENERAL ELECTRIC MODEL #9T51Y6195
PRIMARY: 120/240 v. SECONDARY: 16/32 v.
CYCLE: 50/60 K.V.A.: 1.5
80°C. TEMPERATURE RISE
WEIGHT: 30 POUNDS APPROXIMATELY
PRIMARY: 4 LEAD WIRES SECONDARY: 4 LEAD WIRES
DATE: MAY 9, 1956 SCALE: 3/4" = 0'-1"
DRAWN BY: [signature]

ESTIMATED COST SHEET

LOW-VOLTAGE SEALED-BEAM STAGE LIGHTING SYSTEM

Control Unit

1	Model 9T51Y6195 Filament transformer....	38.40
1	V-10 Variac auto-transformer...........	33.00
8	M-5 Variac auto-transformers @ $22.50...	180.00
1	Metal case............................	35.00
	Misc. (insludes switches, pilot assemblies fuses, wire, etc.........................	20.00
	TOTAL	$306.40

Sealed-Beam Lamp Unit

24	Sealed-beam Lamps @ $2.25................	55.00
24	Lamp housings @ $3.50...................	84.00
	TOTAL	$139.00

Distribution Cable

500 Ft.	Stage cable (rubber insulation) $14.00 per 100 ft....................	70.00
	Misc. (includes connection plugs and receptacles)........................	20.00
	TOTAL	$90.00
	GRAND TOTAL	$535.40

PLATE XXX