EVALUATION OF LOW PRESSURE SODIUM VAPOR ILLUMINATION

by

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Research Project 5-02-75-263
Report No. 1

October 1979

ABBREVIATIONS USED

MV	Mercury Vapor
HPS	High Pressure Sodium
LPS	Low Pressure Sodium
MH	Luminaire mounting height above roadway, feet
FC	Horizontal footcandles
MF	Maintenance factor - ratio of illumination on given area after a period of time to the initial illuminant on the same area. Equals LDD x LLD.
LDD	Luminaire Dirt Depreciation Factor, part of Maintenance Factor
LLD	Lamp Lumen Depreciation Factor
TTI	Texas Transportation Institute

ACKNOWLEDGEMENTS

The authors wish to thank the Texas Transportation Institute for supplying the test area and electrical facilities. Special thanks are given to the TTI personnel who spent many long hours at night taking photometric measurements.

Also, special thanks are given to the personnel of Materials and Tests Division who spent many hours at night taking photometric measurements.

ABSTRACT

Low Pressure Sodium (LPS) roadway illumination systems of 35, 55, 90, 135 and 180 watts were studied and compared to Mercury Vapor (MV) and High Pressure Sodium (HPS) roadway illumination systems.

Systems of 180 watt LPS, 400 watt HPS, and 1000 watt MV, and systems of 135 watt LPS, 250 watt HPS, and 400 watt MV are compared with respect to photometrics, visual acuity, disability veiling glare, and energy savings. Actual photometric data, including isolux curves are shown as measured on a simulated roadway.

I. SUBJECT: Evaluation of Low Pressure Sodium Illumination.

II. PURPOSE: The purpose of this study was to evaluate Low Pressure Sodium (LPS) as a roadway illumination system for new construction and replacement for existing Mercury Vapor (MV) and High Pressure Sodium (HPS) systems.

III. CONCLUSIONS: Systems of 180 watt LPS units exhibit better uniformity and visual acuity with less glare than 400 watt HPS or 1000 watt MV systems.

Systems of 135 watt LPS units exhibit equal or better uniformity and visual acuity with less glare than 250 watt HPS or 400 watt MV systems.

Under some designs the 90 watt LPS system should be considered as a substitute for the 250 watt HPS or 400 watt MV systems. Underpass lighting systems utilizing 55 watt LPS units should be considered as a substitute for the 150 watt HPS or 250 watt MV systems.

Significant energy savings will be realized through the use of LPS roadway illumination systems.

Color rendition of pavement markings and signing due to the monochromatic light of LPS will not be a significant factor to the motorist.

IV. RECOMMENDATIONS: It is recommended that the State Department of Highways and Public Transportation implement the findings of this study as outlined in Section VIII of this report.

V. PROCEDURE FOR COLLECTING DATA: All photometric data was taken at the Texas Transportation Institute (TTI) facilities near Bryan, Texas. The facilities are a concrete area with a grid pattern 12.5 feet by 15 feet.

Portable towers on trailers were used to support the luminaires. Mounting heights from 10 to 60 feet were obtainable.

Photometrics were run with either a G.E. SL 480 light meter by TTI personnel or with a Tektronix J-16 light meter by Materials and Tests Division personnel.

VI. DISCUSSION: In the 1950's the use of multi-lane freeway systems began to drastically accelerate. Multi-lane freeways and increased traffic density, particularly at night, focused on the use of fixed roadway lighting for motorist safety throughout the nation.

The Texas State Department of Highways and Public Transportation followed step and used "off-the-shelf" lighting units developed by the various lighting manufacturers.

By the late 1950's it was obvious that although the systems were designed the same, the unsatisfactory installations far outnumbered the few that were satisfactory. Many systems exhibited extreme glare, poor visual acuity, extreme nonuniformity, and in general undesirable results coupled with maintenance problems.

In 1959 research began on 400 watt MV systems at a mounting height of 30 feet. A survey of manufacturers' literature showed that all brands of MV luminaires exhibited essentially the same photometric characteristics (length and width of roadway enclosed within the 0.1 footcandle curve). Photometric and electrical measuring equipment was purchased. Luminaires and ballasts from all of the major and some minor manufacturers were secured. An outdoor test area was established by which photometric data could be gathered on a 10-foot grid pattern, 320 feet in length, and 120 feet in width. All units secured and numerous units supplied on projects were run through photometric and electrical tests.
Horizontal footcandles, ballast input and output volts, amps, and watts were determined. This data was compared to manufacturers' published literature. Electrical characteristics showed no alarming discrepancy. Photometric characteristics were completely foreign from published data. Out of six or seven manufacturers, three produced luminaires that exhibited photometric characteristics that were 80 percent as good as their literature indicated. The remainder produced luminaires that exhibited photometric characteristics about 50 percent as good as literature indicated.
Specifications were developed for photometric and ballast criteria around the better units. Design criteria were altered to reflect the specification criteria. This eliminated numerous maintenance problems and brought the levels of illumination up to an acceptable

level. Numerous rejections of ballasts and luminaires were encountered at first, but manufacturers gradually improved their quality to a point that the rate of rejection was within acceptable limits.

Visual acuity, uniformity, and glare were improved but were still not satisfactory, in our opinion, even though they met IES published design criteria.

Research was expanded to higher mounting heights and wattages in an effort to improve visual acuity and uniformity and to reduce glare. A study was initiated on an improved method for expressing uniformity as minimum to average, average to maximum, or minimum to maximum ratio of measured light on the roadway did not necessarily express true uniformity.

It was found that one could use a 400 watt MV unit on a 40-foot pole or 1000 watt MV unit on a 50-foot pole, depending on the roadway width to be illuminated, and stretch pole spacing out to 300 feet and achieve better illumination in the form of better uniformity and visual acuity with less glare. Also a method was developed to express uniformity as a function of point to point decreasing or increasing light intensities down the roadway. This method of expressing uniformity was easily reverted to photometric characteristics of individual lighting units. Thus, one could design around desired minimum and maximum illumination levels and uniformity, and then test lighting units to insure the criteria would be achieved on the roadway.

In the late 1960's and early 1970's efforts were concentrated on a more efficient system, the high pressure sodium (HPS). A minimum amount of research proved it was feasible to substitute the 250 watt HPS for the 400 watt MV, and the 400 watt HPS for the 1000 watt MV with no changes in the design of illumination systems. Two decided advantages were gained by going to HPS - better visual acuity and less energy consumption.

In 1974 a brief look was taken at low pressure sodium (LPS) to establish it's advantages and disadvantages. The advantages appeared greater than the disadvantages, so in 1975 serious research began on LPS. In general, the LPS units at the time did not incorporate the use of reflectors. The first round of tests at TTI facilities in Bryan, Texas, on 35, 55, 90, 135 and 180 watt LPS units at mounting heights ranging from 10 to 60 feet (depending on the wattage) gave disappointing results. Visual acuity due to the monochromatic light was improved over the MV and HPS systems at comparable illumination levels. The glare was greatly reduced due mainly to the larger light source. The pole spacing that could be achieved and still produce acceptable minimum light levels was disappointing.

One unit was tested with a reflector and it definitely indicated that improved photometrics could be accomplished by the use of a reflector. The existing reflector design was studied and it was found that the reflector was primarily designed to get more of the available light out of the unit, but not necessarily increase the length of illuminated roadway.

Reflector design was discussed with the manufacturers and initial steps to improve the design were carried out by the researchers "hand shaping" a reflector. Improvement was encountered and this encouraged the manufacturers to redesign the reflector in line with the researchers' recommendations.

Units were tested in various uptilt positions. It was found that optimum light utilization occurred at a 15 degree uptilt.

One of the researchers made a trip to the factory to discuss reflector design and redesign of the entire unit to eliminate as near as possible the use of tools in routine maintenance of lamp and ballast replacement. A new unit was developed with significantly improved maintenance features, but it took four reflector designs to achieve the photometric characteristics desired by the researchers.

Initial units exhibited favorable photometrics at pole spacings ranging from 240 to 250 feet at 50-foot mounting height for the 180 watt unit. The redesigned units allow pole spacings at 270 feet with minimum footcandle levels of 0.4 footcandles and 300 feet pole spacing at 0.2 minimum footcandles.

Four of the redesigned 180 watt units were obtained and placed on a simulated roadway utilizing median lighting, twin-mounted units at 50-foot mounting heights. Spacing was varied from 270 to 300 feet in 10-foot increments. At one end of the system, a High Mast (150 feet) HPS system was incorporated. At each pole spacing, test drives were made at speeds ranging from 30 to 70 miles per hour in an effort to evaluate visual acuity and disability veiling glare. Test drives were made with and without the HPS system energized.

Table 1 shows typical lamp and ballast data for LPS, HPS, and MV.

Lamp Wattage and Type	Rated Life Hours	Lumen Output Initial	9000 Hrs.	18,000 Hrs.	Input* Watts	Input Amps @ 480 Volts
55 LPS	18,000	8,000	8,000	8,000	83	0.19
90 LPS	18,000	13,500	13,500	13,500	131	0.30
135 LPS	18,000	22,500	22,500	22,500	197	0.46
180 LPS	18,000	33,000	33,000	33,000	247	0.57
100 HPS	24,000	8,800	8,700	7,744	123	0.28
150 HPS	24,000	15,000	14,850	13,200	184	0.43
250 HPS	24,000	27,500	27,225	24,200	296	0.685
310 HPS	24,000	37,000	37,555	33,855	375	0.87
400 HPS	24,000	50,000	52,000	46,500	478	1.11
250 MV	24,000	10,685	7,854	5,450	285	0.66
400 MV	24,000	20,067	15,711	12,325	449	1.04
1000 MV	24,000	54,286	42,184	31,802	1067	2.47

Table 1. Lamp and Ballast Data for MV, HPS, and LPS

*Ballast input watts for LPS is average of initial and end of lamp life watts. MV and HPS input watts are from actual tests of initial watts.

In the opinion of the researchers, disability veiling glare was reduced to the point that it was either insignificant or nonexistent. At 0.2 footcandles minimum for LPS, the visual acuity was considered satisfactory, and at 0.3 footcandles it was considered to be equal to HPS at 0.4 footcandles (See Figures 1 and 2). Figures 1 and 2 do not exhibit the true colors since they are color copies of actual photographs. However, actual visual acuity is depicted very close to actual observation. Figure 1 is LPS foreground and background with a maximum of 1.8 footcandles, minimum of 0.26 footcandles and 1.4 footcandles at the location of the automobiles. Figure 2 has a foreground of HPS and background of LPS. Figure 2 has a maximum measured 2.6 footcandles, a minimum of 0.26 footcandles, and 2.1 footcandles at the automobile location.

Color rendition with no light available other than the LPS leaves a little to be desired. Nonreflective pavement markings such as white and yellow jiggle bars or traffic buttons would achieve a slightly different color hue.

LPS lighting will have no appreciable effect on signing from the motorist view. Overhead signs are independently illuminated with MV and will therefore continue to exhibit the color effects achieved by the MV. Shoulder-mounted signs are reflectorized and the color to the motorist would be influenced only by the automobile headlight until the motorist is some 30 or 40 feet from the sign, at which point he is no longer interested in the sign. (The same would be

Figure 1
Low Pressure Sodium

Figure 2
High Pressure Sodium

true for reflectorized overhead signs that are not independently illuminated.)

VII. DISCUSSION OF RESULTS:

Iso-footcandle curves for the underpass lights and the re-designed 180 watt LPS in single-arm and twin-arm configurations were plotted (Appendix A). Curves for 135 watt LPS, extrapolated from the re-designed 180 watts, are included.

Appendix A also includes various curves for MV and HPS roadway luminaires. These curves were developed from previous data taken at TTI.

The rated life for MV and HPS lamps is 24,000 hours, while the rated life for LPS lamps is 18,000 hours. The MV and HPS lamps have a declining LLD curve, while the LPS maintains its lumen output at 100 percent throughout its life.

For this study, it is assumed that the MV and HPS lamps are group-replaced[1] at 18,000 hours, and LPS lamps are group-replaced at end of rated life, 18,000 hours. Photometric performance of the various lamps are compared at the mean life of 9,000 hours.

Based on the lumen outputs of the lamps at 9,000 hours (Table 1), the following comparisons are suggested:

MH	MV	HPS	LPS
50'	1000 watt	400 watt	180 watt
40'	400 watt	--	90 watt
40'	--	250 watt	135 watt
30'	400 watt	150 watt	90 watt
15' - 25' u/p	250 watt	100 watt	55 watt

Table 2. Comparison of MV, HPS, and LPS at various mounting heights.

For new construction, comparisons are made between MV, HPS and LPS luminaires. Established design criteria[2], in part, specify "a minimum initial intensity" of 0.4 horizontal footcandles on all main lanes and direct connections" using HPS luminaires. Design criteria recommend, for median-mounted lighting, twin-arm 400 watt HPS luminaires at 50' MH spaced 300 feet. Appendix B-1 shows resulting footcandles for this configuration at 9,000 hours. (All curves in Appendix B were graphically plotted from Appendix A data.) An alternate to this construction, twin-arm 180 watt LPS luminaires at 50' MH and 255' spacing, is shown at B-2. This arrangement provides comparable footcandles at mid-span. Curve B-3, twin-arm 180 watt LPS at 50' MH and 270' spacing provides the required 0.4 footcandle minimum at mid-span out to 60' from center line.

Curves for twin-arm 250 watt HPS at 40' MH and 225' spacing are shown at B-4. This design has been used for 4- and 6-lane, narrow median expressways. The twin-arm 135 watt LPS at 40' MH and 225' spacing, Curve B-5, provides comparable footcandles.

Some existing roadway lighting in the State consists of house-side mounted single luminaire 400 watt MV at 30' MH, spaced at approximately 180' (Curve B-6). The 135 watt LPS at 30' MH (Curve B-7) is an adequate replacement for the 400 watt MV at 180' spacing.

Additional existing lighting consists of twin-arm 1000 watt MV at 50' MH and 250' to 300' spacing. The twin-arm 180 watt LPS at 50' MH is an adequate replacement for the 1000 watt MV at spacings of 270' or less, and in some instances up to 300' (Curve B-3).

One obvious advantage of LPS lamps is in energy and operating cost savings.

Table 3 shows pole spacing, lamps per mile, annual KWH, and energy costs per year for illumination systems designed on MV, HPS, and LPS. Figures are based on 4,000 hours operation per year and $0.04 per KWH energy costs.

Light Source/MH	Pole Spacing	Lamps per mi.	Annual KWH	Energy Costs
2-1000 MV/50'	300'	35.2	150,234	$6009.34
2-400 HPS/50'	300'	35.2	67,302	2692.10
2-180 LPS/50'	300'	35.2	34,778	1391.10
2-1000 MV/50'	270'	39.1	166,879	6675.15
2-400 HPS/50'	270'	39.1	74,759	2990.37
2-180 LPS/50'	270'	39.1	38,631	1545.23
2-400 MV/40'	225'	46.9	84,232	3369.30
2-250 HPS/40'	225'	46.9	55,530	2221.18
2-135 LPS/40'	225	46.9	36,957	1478.29
1-400 MV/30'	180'	58.7	105,425	4217.01
1-135 LPS/30'	180'	58.7	46,256	1850.22

Table 3. Energy cost per mile per year for MV, HPS, and LPS.

Another inherent advantage is related to the 100 percent lumen maintenance during the life of the LPS lamp. The MV lighting in the State is not on a group-replacement program; lamps are spot-replaced as they burn out. Therefore, those MV lamps that have a longer than normal life continue to use the same power at a much-depreciated lumen output, resulting in poor lighting. This does not happen with LPS lamps, since they maintain rated lumen output to end of life.

VIII. RECOMMENDATIONS:

A. For energy considerations, the following systems are recommended for new constructions:

1. For 8- and 10-lane expressways, twin-arm median-mounted 180 watt LPS at 50' MH spaced 270' to 300'.

2. For 4- and 6-lane expressways, twin-arm median-mounted 135 watt LPS at 40' MH spaced 225'.

3. For safety lighting, the 135 watt LPS at 40' MH is recommended. At ramps, spacing should be 200' - 225'.

4. For underpass lighting, 55 watt LPS.

B. For replacement of existing systems, the following is recommended:

1. For house-side mounted single-arm 400 watt MV, replace with 135 watt LPS or 90 watt LPS depending on pole spacing and mounting height.

2. For median-mounted twin-arm 400 watt MV, replace with 180 watt LPS or 90 watt LPS depending on pole spacing and mounting height.

C. To gain cost figures for invested cost versus operating cost comparison, it is recommended that, as soon as feasible, one continuous lighting project and one safety lighting project be let to contract. Further study of economic factors should be made following these projects.

D. Recommend that structural analysis be made to determine if LPS systems require more expensive support structures than HPS and MV systems.

E. Recommend that those Districts involved in the initial LPS systems monitor the systems and provide information on experience data (i.e., early lamp/ballast failure rate, etc.).

F. It is further recommended that LPS systems be evaluated for high mast (100 foot mounting height or greater) illumination systems.

Footnotes:

1. See Research Report UDOT-MR-77-6 "400-Watt High Pressure Sodium Vapor Lighting Test." This report indicates that rated life of some HPS lamps is questionable.

2. See Highway Design Division Operations and Procedures Manual, Appendix Section B-100.

APPENDIX A

APPENDIX A

ISO-FOOTCANDLE CURVES

A-1 2 - 180 Watt LPS at 50' MH

A-2 1 - 180 Watt LPS at 50' MH

A-3 2 - 135 Watt LPS at 40' MH

A-4 1 - 135 Watt LPS at 40' MH

A-5 1 - 135 Watt LPS at 30' MH

A-6 55 Watt Underpass Luminaire - 15' MH

A-7 55 Watt Underpass Luminaire - 20' MH

A-8 55 Watt Underpass Luminaire - 25' MH

A-9 2 - 400 Watt HPS at 50' MH

A-10 1 - 400 Watt HPS at 50' MH

A-11 2 - 250 Watt HPS at 40' MH

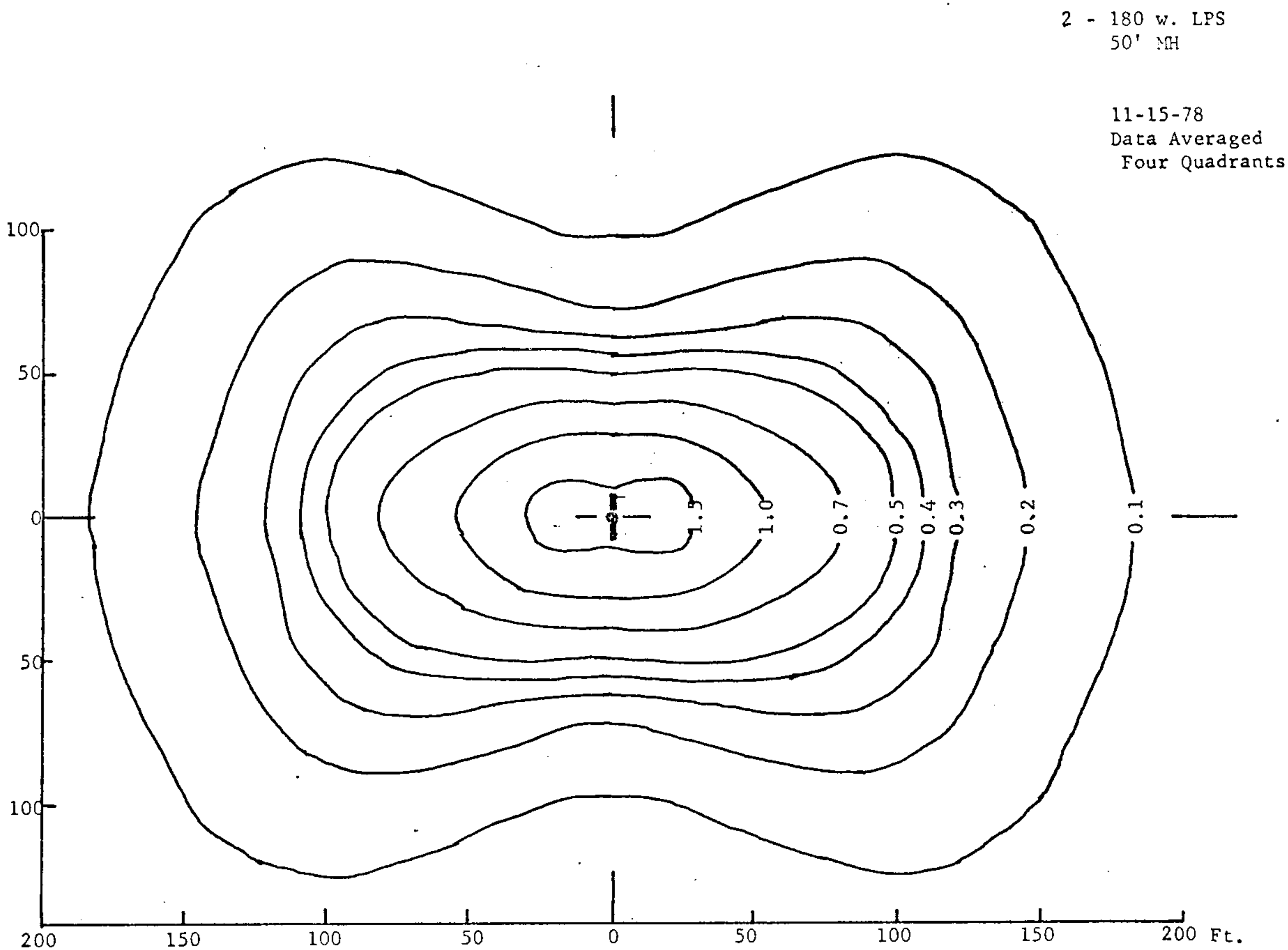
A-12 1- 250 Watt HPS at 40' MH

A-13 2 - 1000 Watt MV at 50' MH

A-14 1 - 1000 Watt MV at 50' MH

A-15 1 - 400 Watt MV at 40' MH

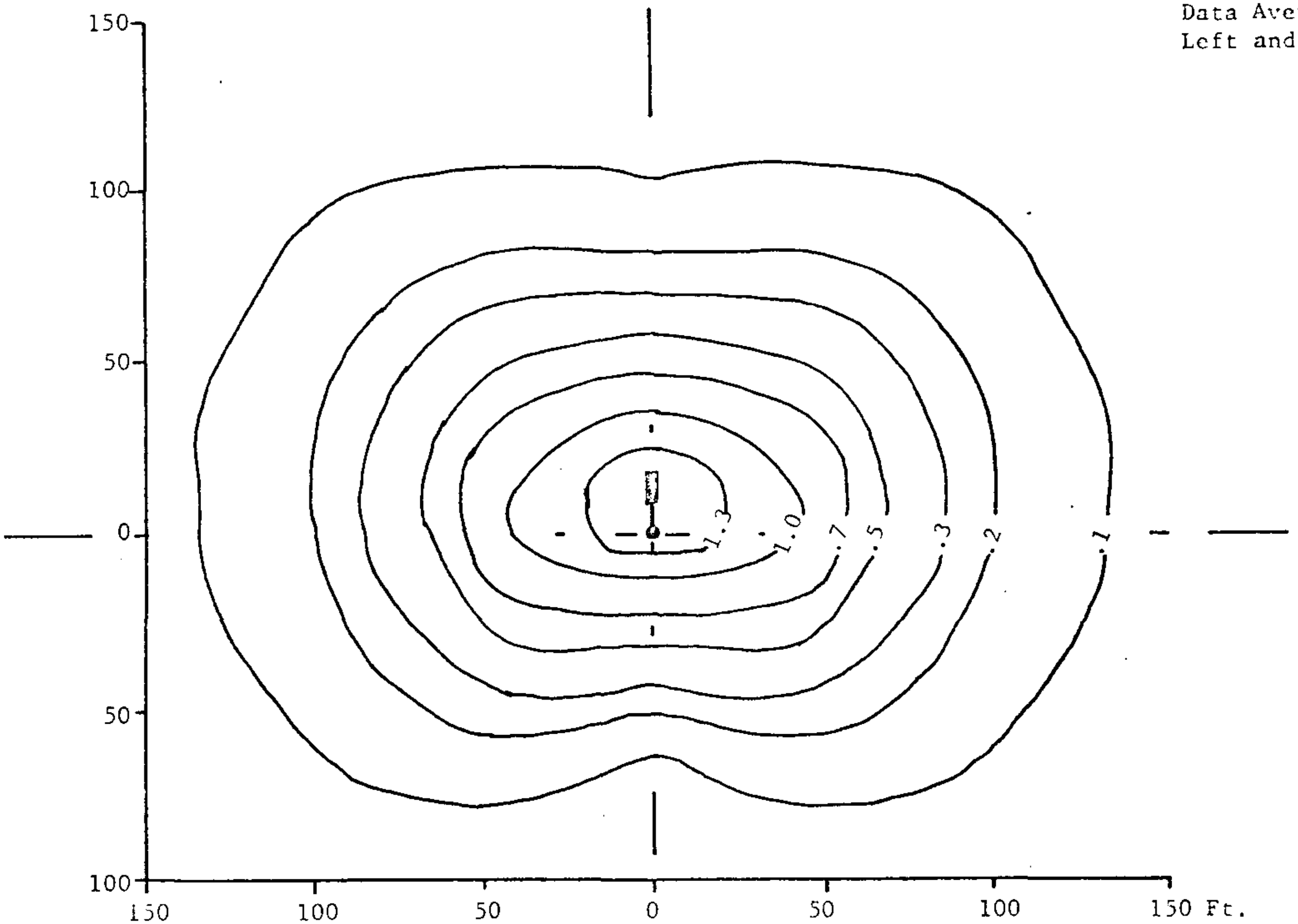
A-16 1 - 400 Watt MV at 30' MH



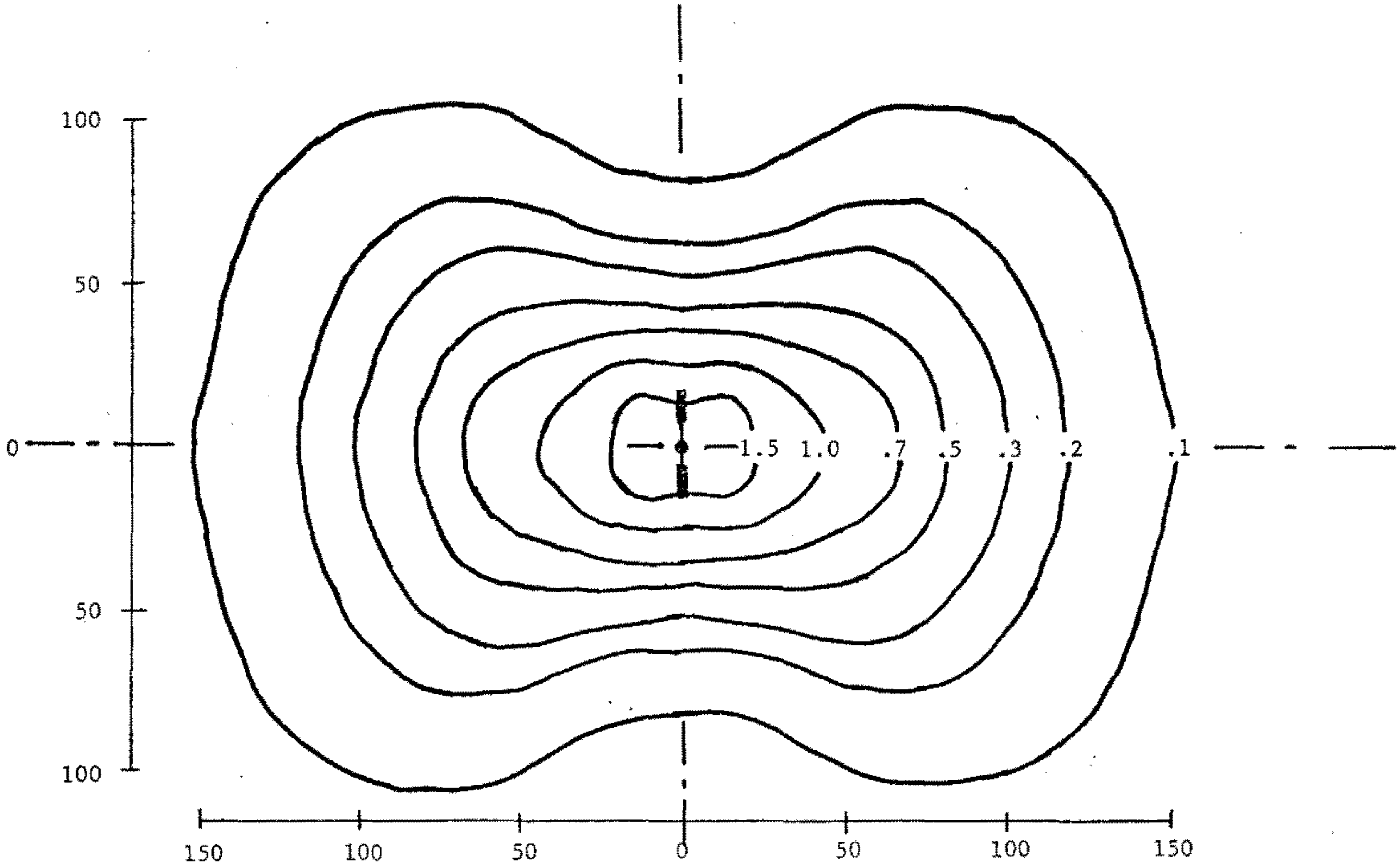
2 - 180 w. LPS
50' MH
11-15-78
Data Averaged
Four Quadrants
100
50
0
50
100
1.5
1.0
0.7
0.5
0.4
0.3
0.2
0.1
200
150
100
50
0
50
100
150
200 Ft.

1 - 180 watt LPS
50' MH

5-18-78
Data Averaged
Left and Right



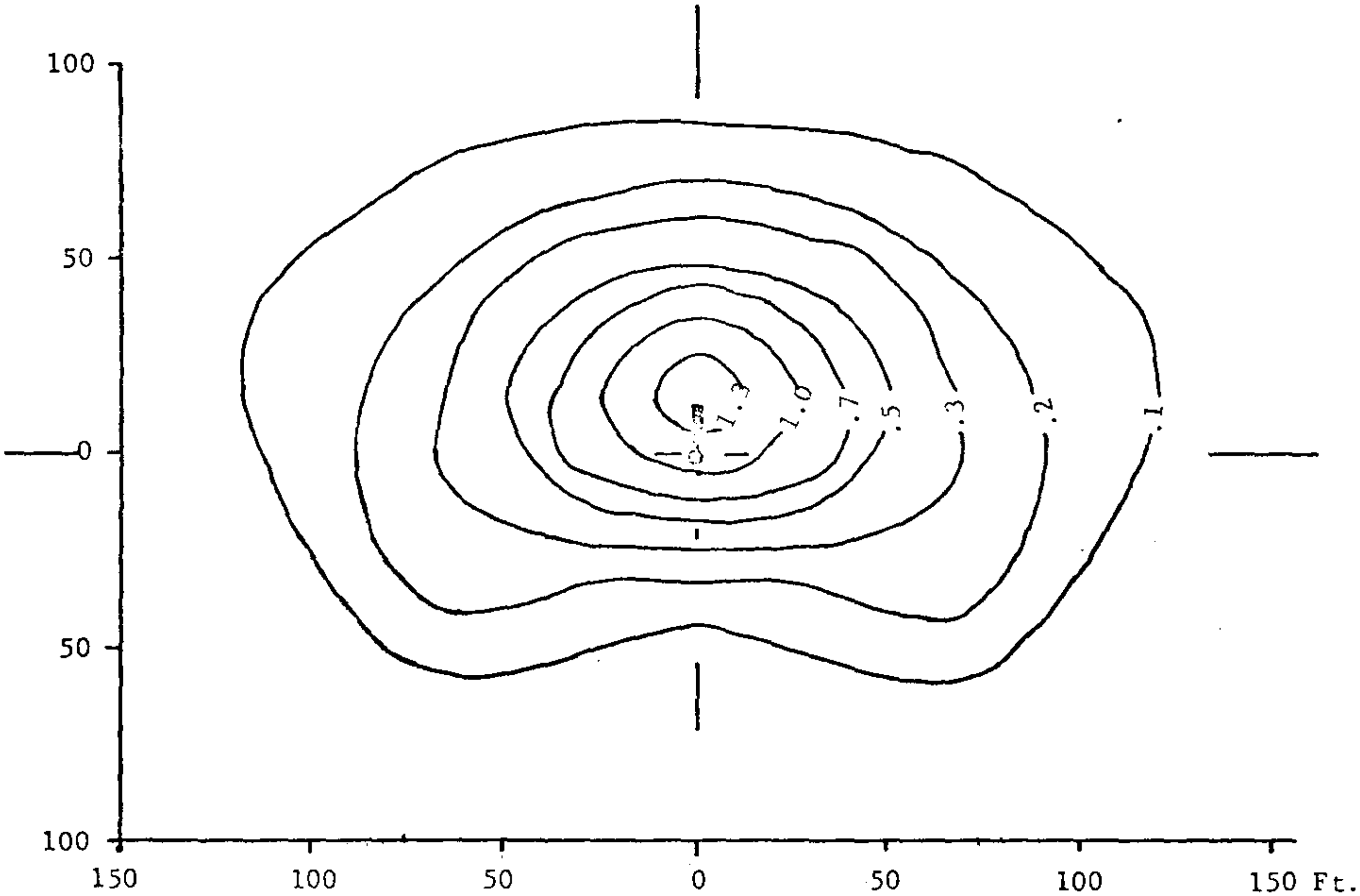
2 - 135 WATT LPS
40' MH

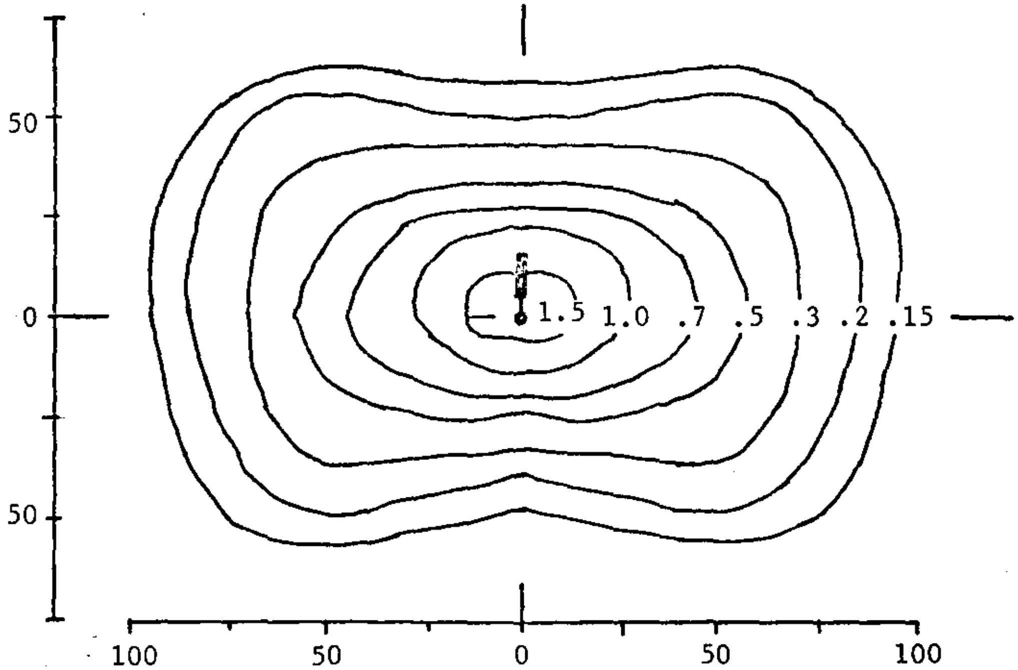


Scale: 1" = 50'

1 - 135 watt LPS
40' MH

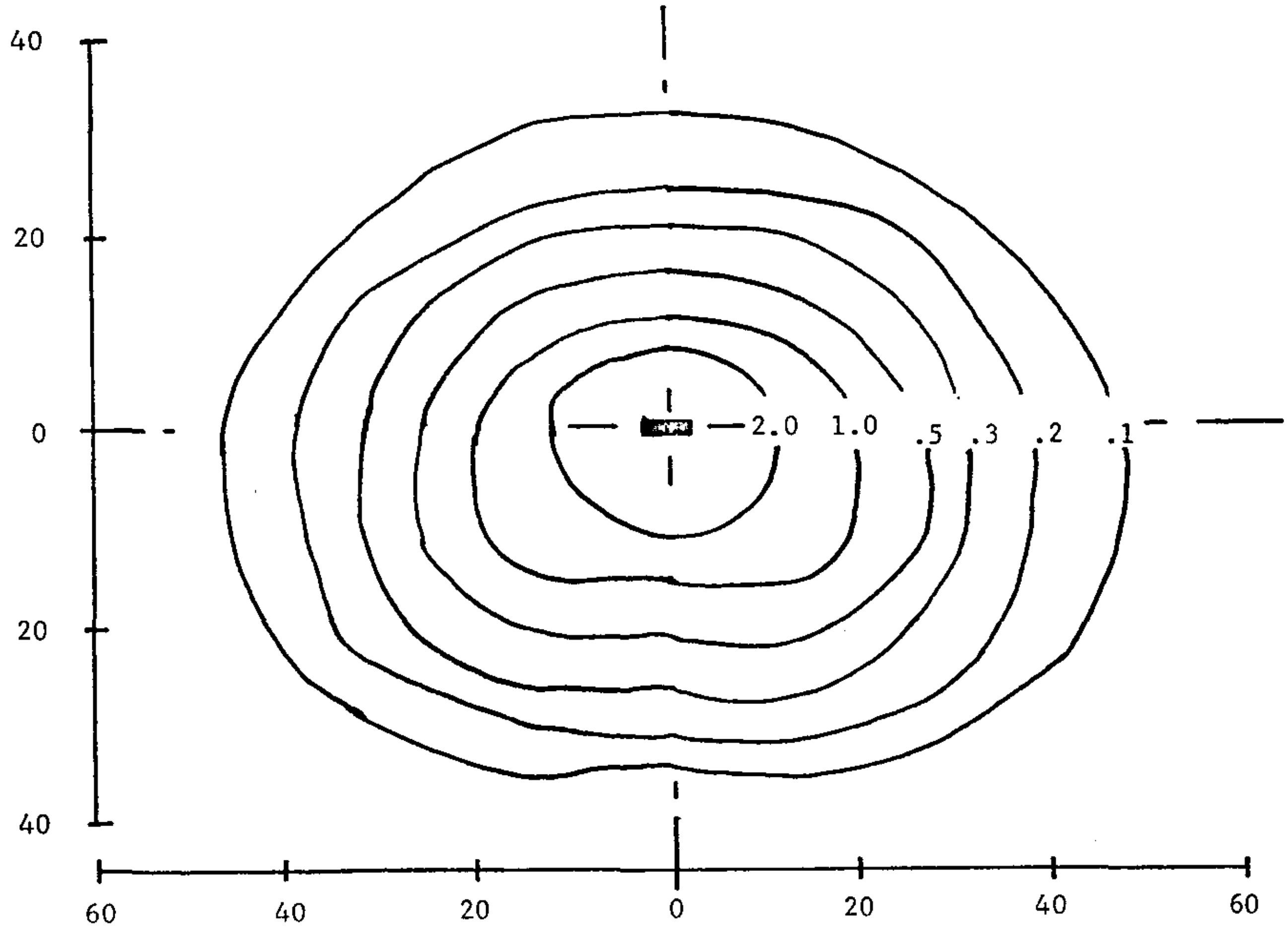
1-24-79
Data Averaged
Left and Right





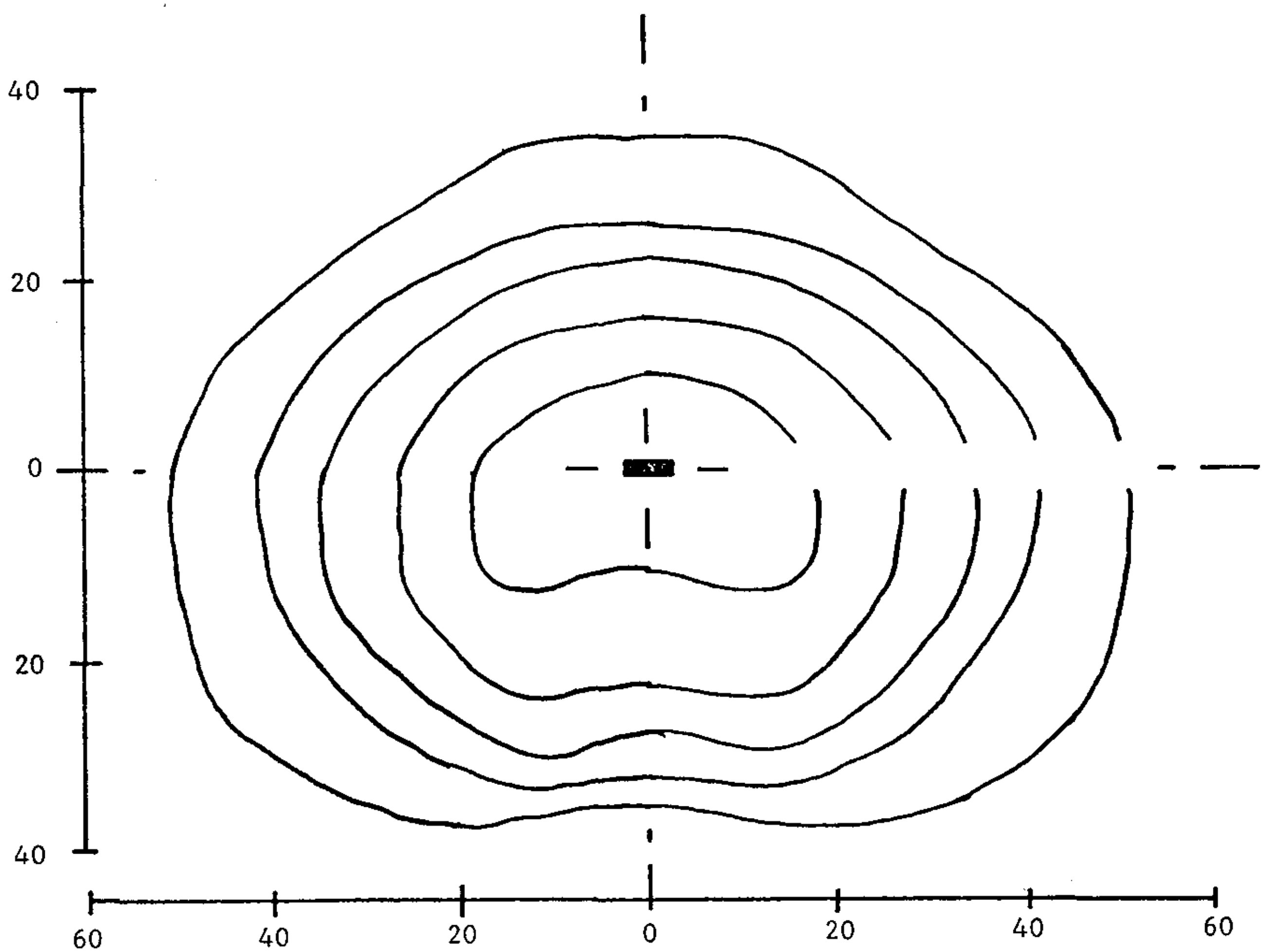
ISO-FOOTCANDLES
1 - 135 Watt LPS
30' MH

Scale: 1" = 50'



1 - 55 WATT LPS
UNDERPASS LUMINAIRE
15' MH

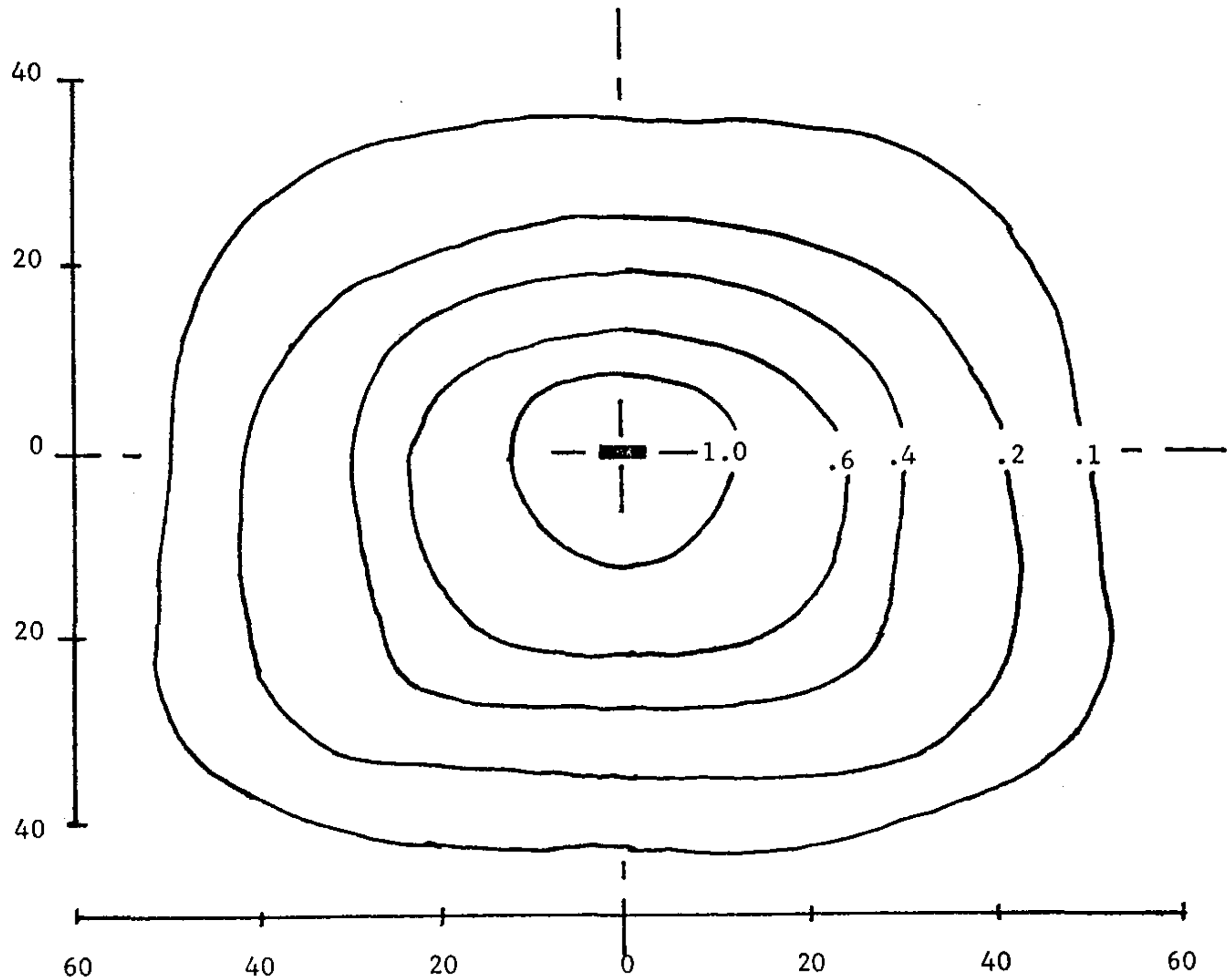
Scale: 1" - 20'



1 - 55 WATT LPS
UNDERPASS LUMINAIRE

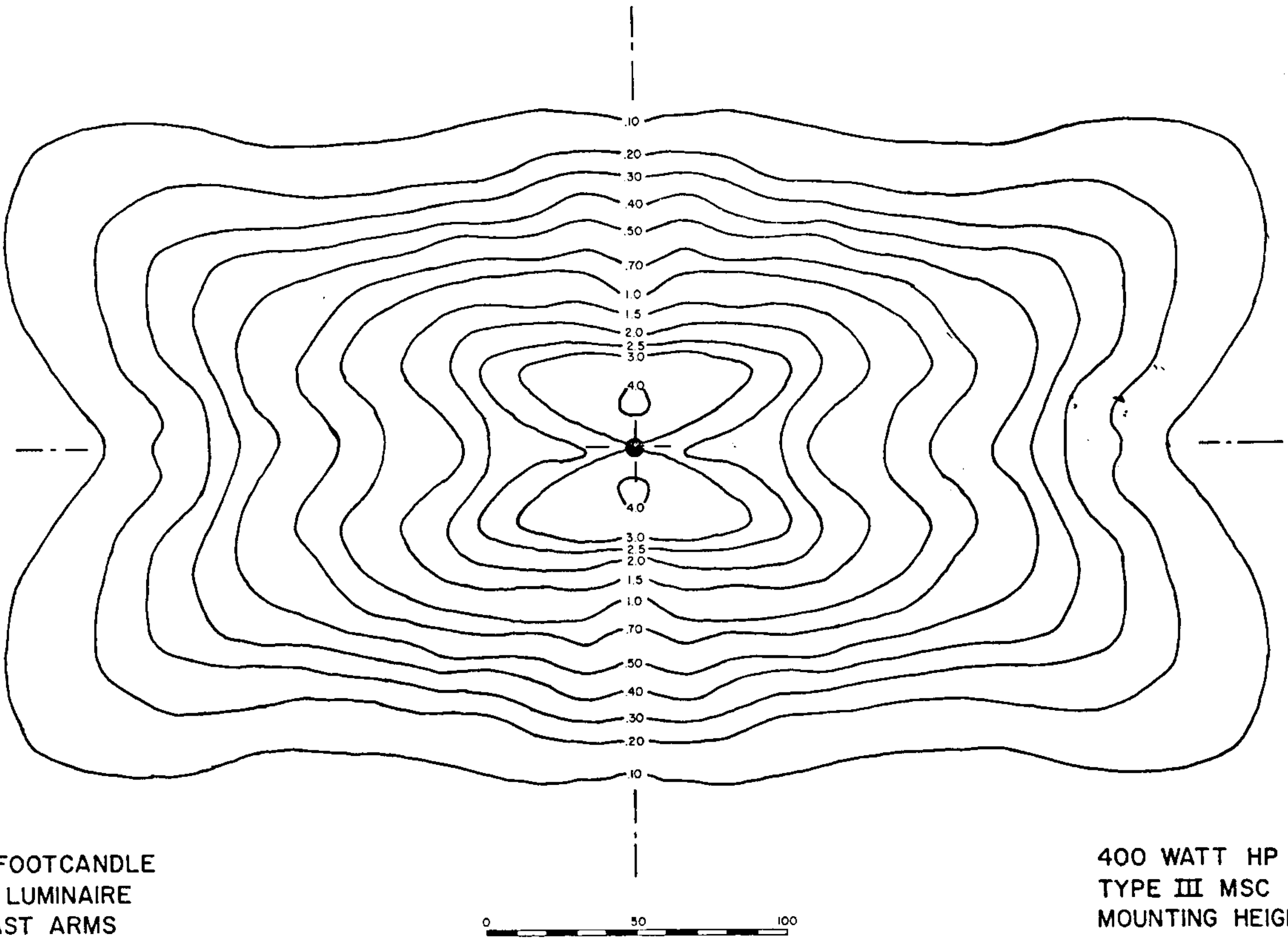
20' MH

Scale: 1" - 20'



1 - 55 WATT LPS
UNDERPASS LUMINAIRE
25' MH

Scale: 1" = 20'



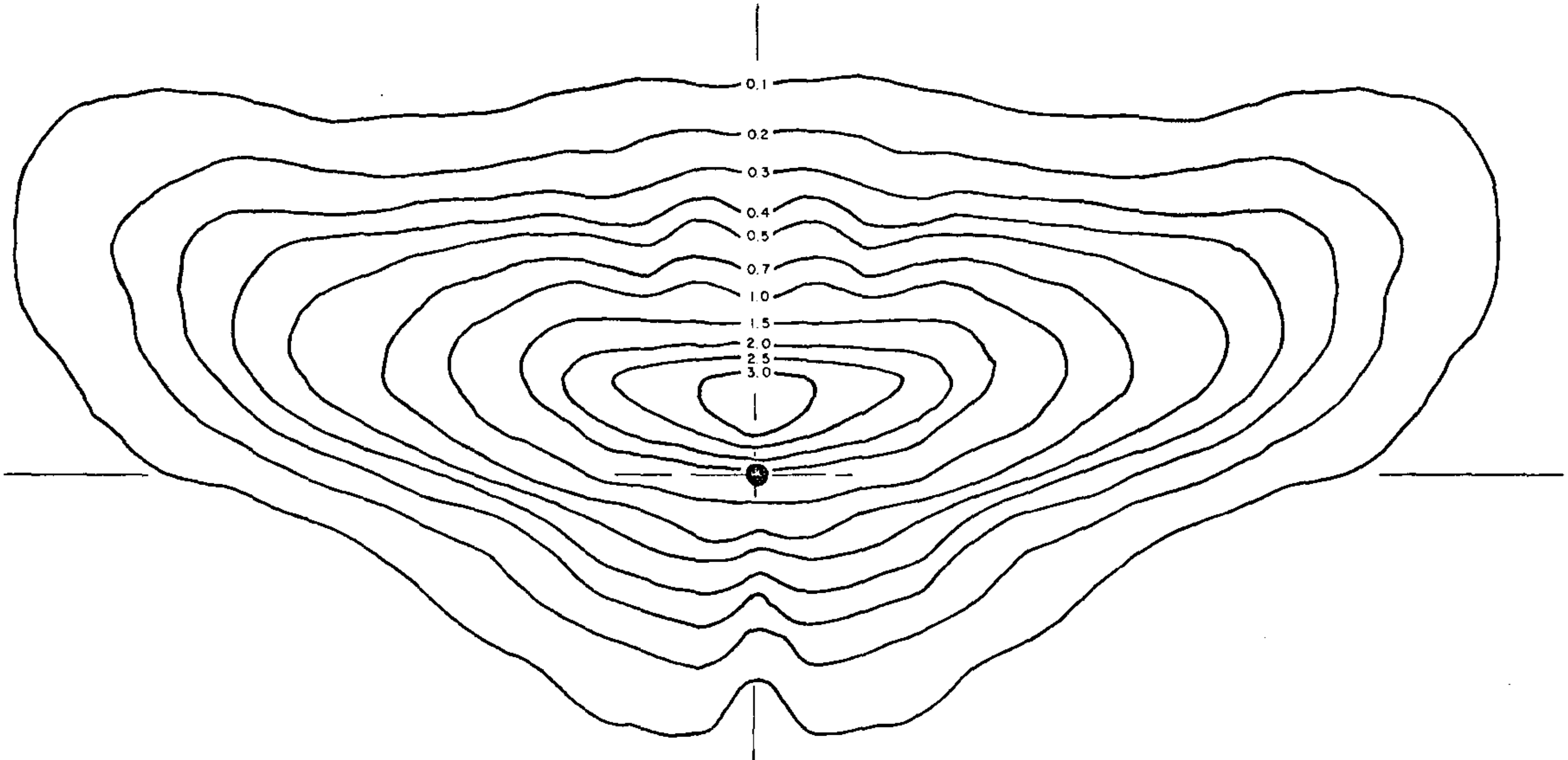
ISO - FOOTCANDLE
TWIN LUMINAIRE
8' MAST ARMS

0 50 100

SCALE : 1" = 50'
JUNE 1975

400 WATT HP SODIUM
TYPE III MSC
MOUNTING HEIGHT : 50'

INITIAL FOOTCANDLES



SO - FOOTCANDLE
SINGLE LUMINAIRE
3' MAST ARMS

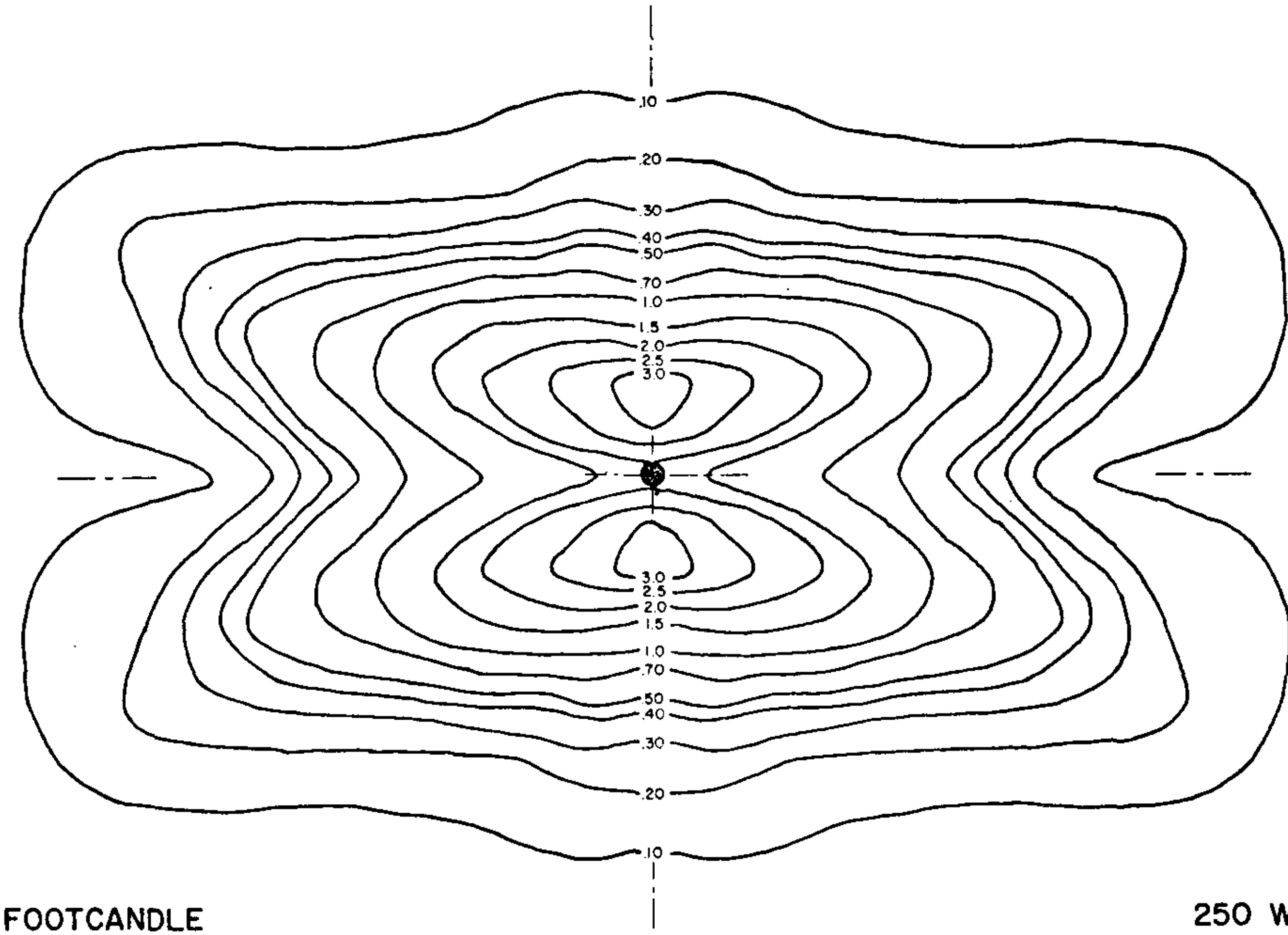
0 50 100

SCALE : 1" = 50'

JUNE 1975

400 WATT HP SODIUM
TYPE III MSC
MOUNTING HEIGHT: 50'

INITIAL FOOTCANDLES



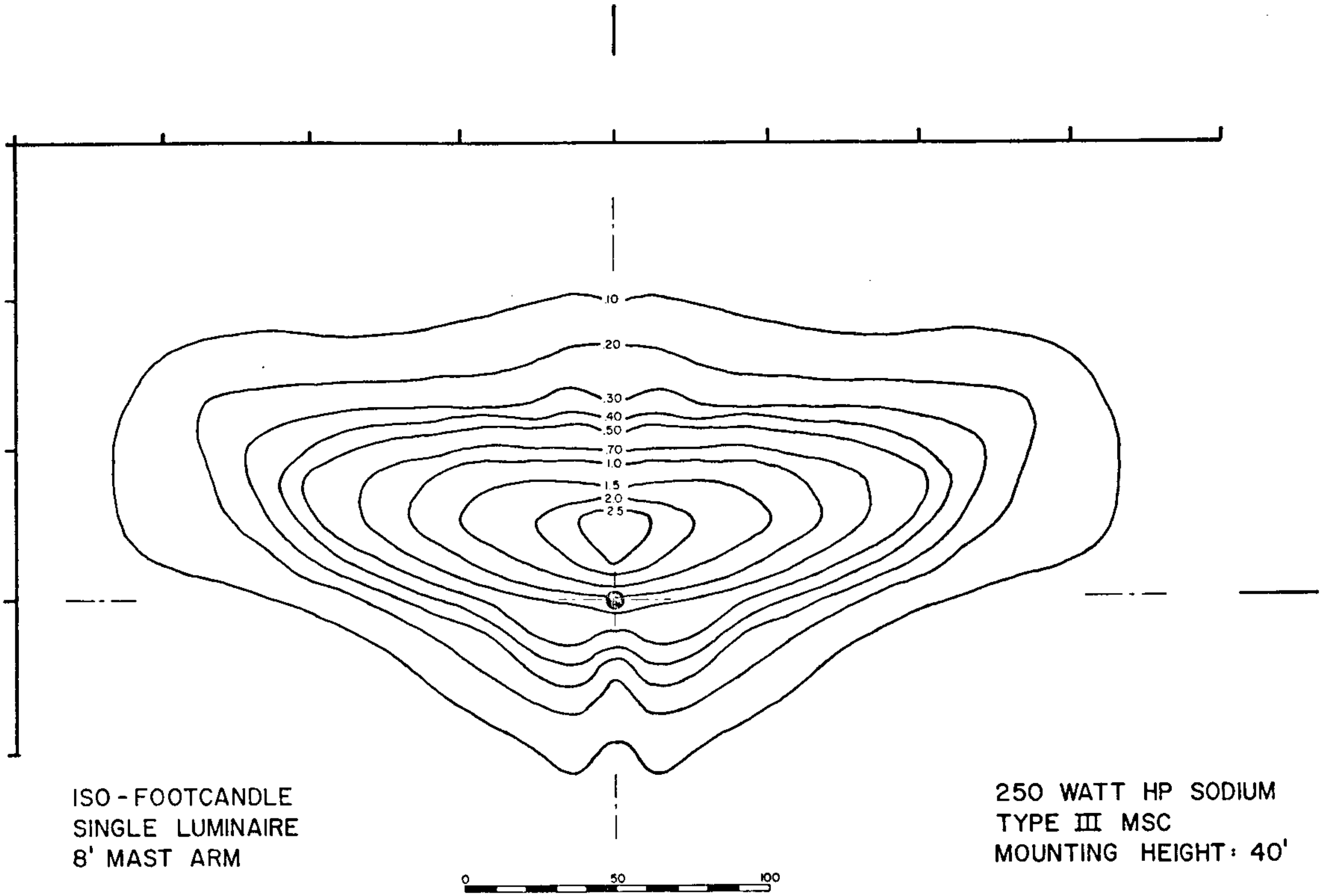
ISO - FOOTCANDLE
TWIN LUMINAIRE
8' MAST ARMS

250 WATT HP SODIUM
TYPE III MSC
MOUNTING HEIGHT : 40'

0 50 100

SCALE : 1" = 50'
JUNE 1975

INITIAL FOOTCANDLES

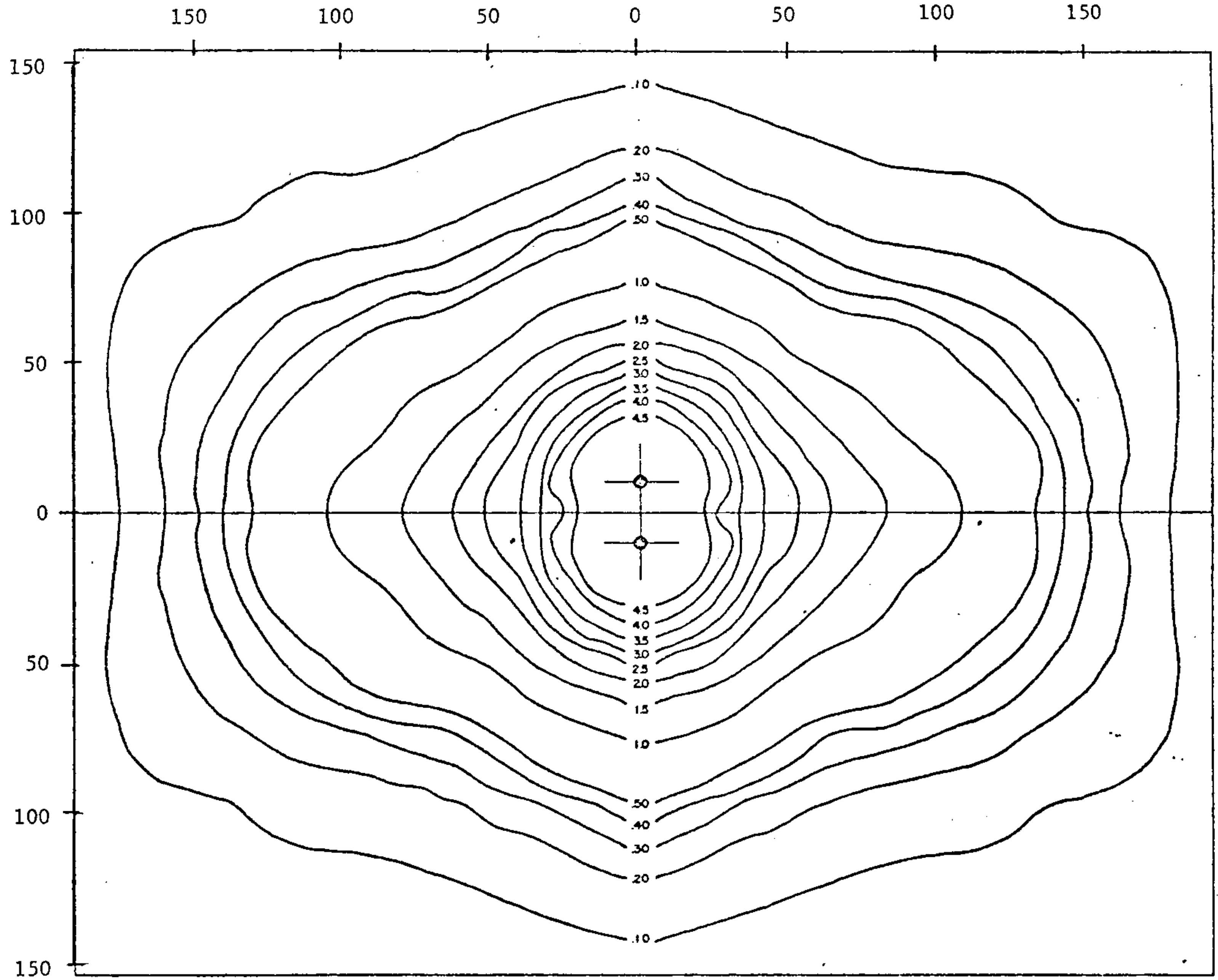


ISO - FOOTCANDLE
SINGLE LUMINAIRE
8' MAST ARM

250 WATT HP SODIUM
TYPE III MSC
MOUNTING HEIGHT: 40'

SCALE: 1" = 50'
JUNE 1975

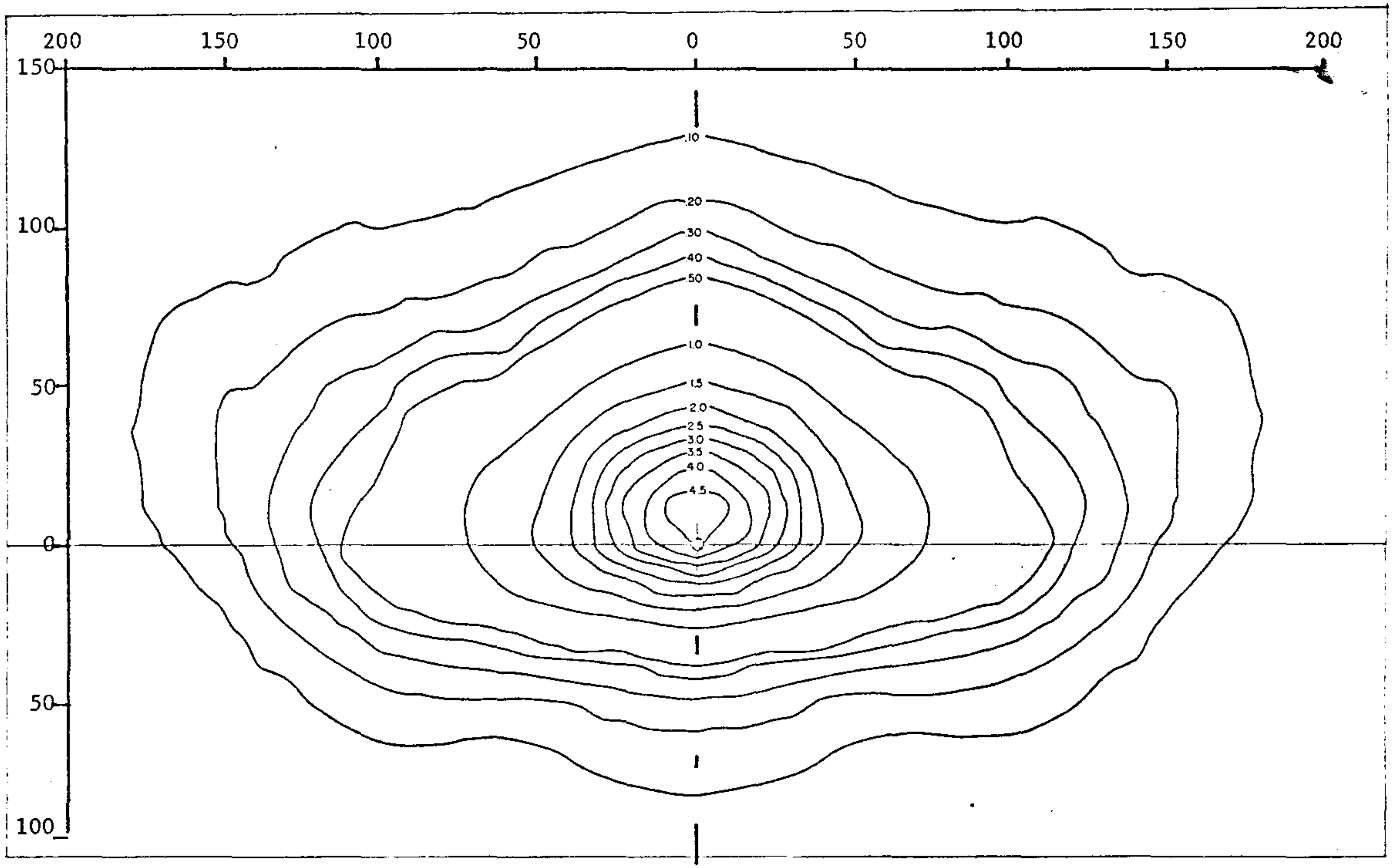
INITIAL FOOTCANDLES



ISO-FOOTCANDLE CURVE

2 - 1000 WATT MERCURY VAPOR
INITIAL FOOTCANDLES
For FC at 9000 Hours
Multiply by 0.78

LUMINAIRE : 1000 WATT, TYPE III
MOUNTING HEIGHT : 50'
SCALE : 1" = 50'

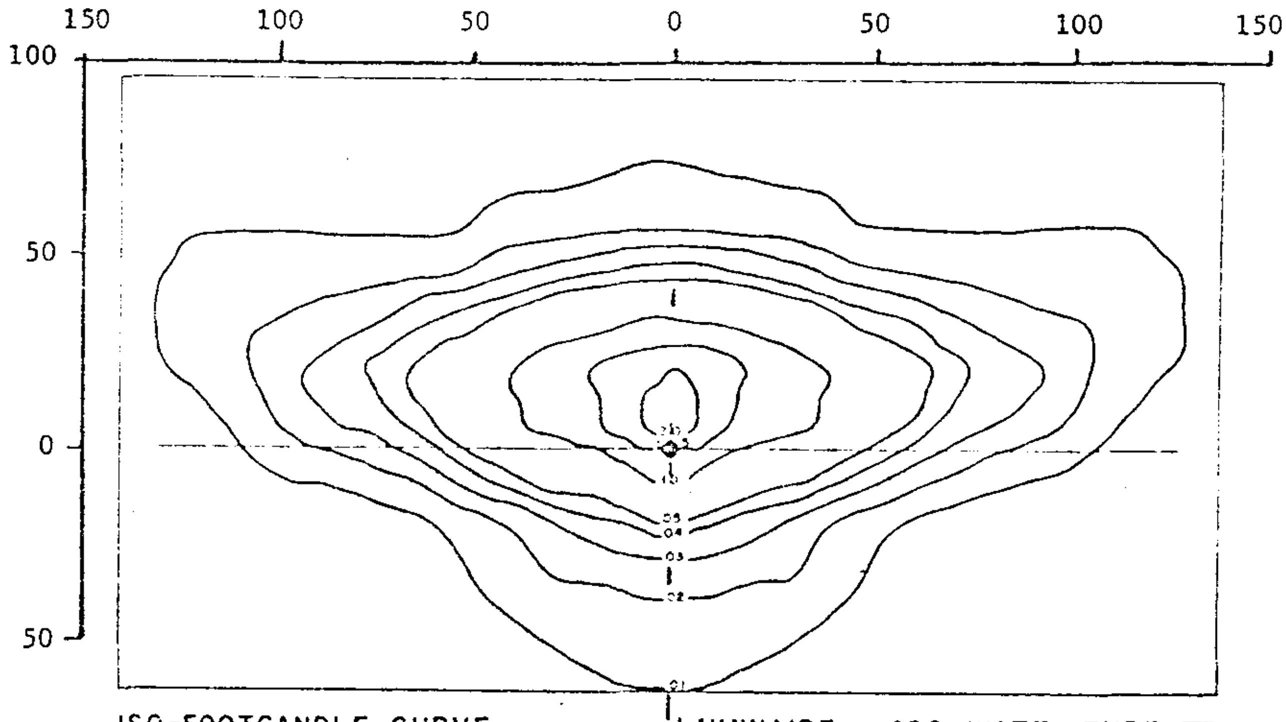


ISO-FOOTCANDLE CURVE
SINGLE LUMINAIRE

LUMINAIRE: 1000 WATT, TYPE III.
MOUNTING HEIGHT: 50'

SCALE: 1"=50'

1 - 1000 WATT MERCURY VAPOR
INITIAL FOOTCANDLES
For FC at 9000 Hours
Multiply by 0.78



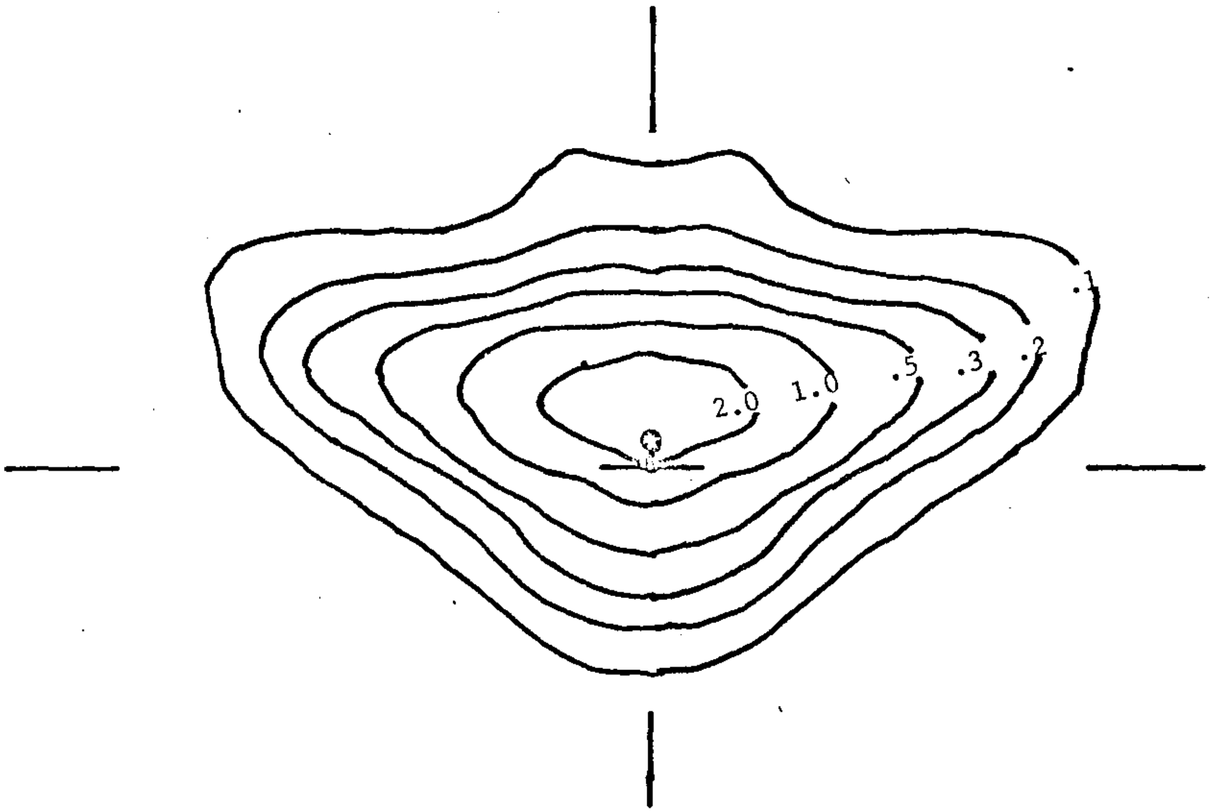
ISO-FOOTCANDLE CURVE
SINGLE LUMINAIRE.

LUMINAIRE: 400 WATT, TYPE III
MOUNTING HEIGHT: 40'

SCALE: 1"=50'

1 - 400 WATT MERCURY VAPOR

INITIAL FOOTCANDLES
For FC at 9000 Hours
Multiply by 0.78



ISO-FOOTCANDLES

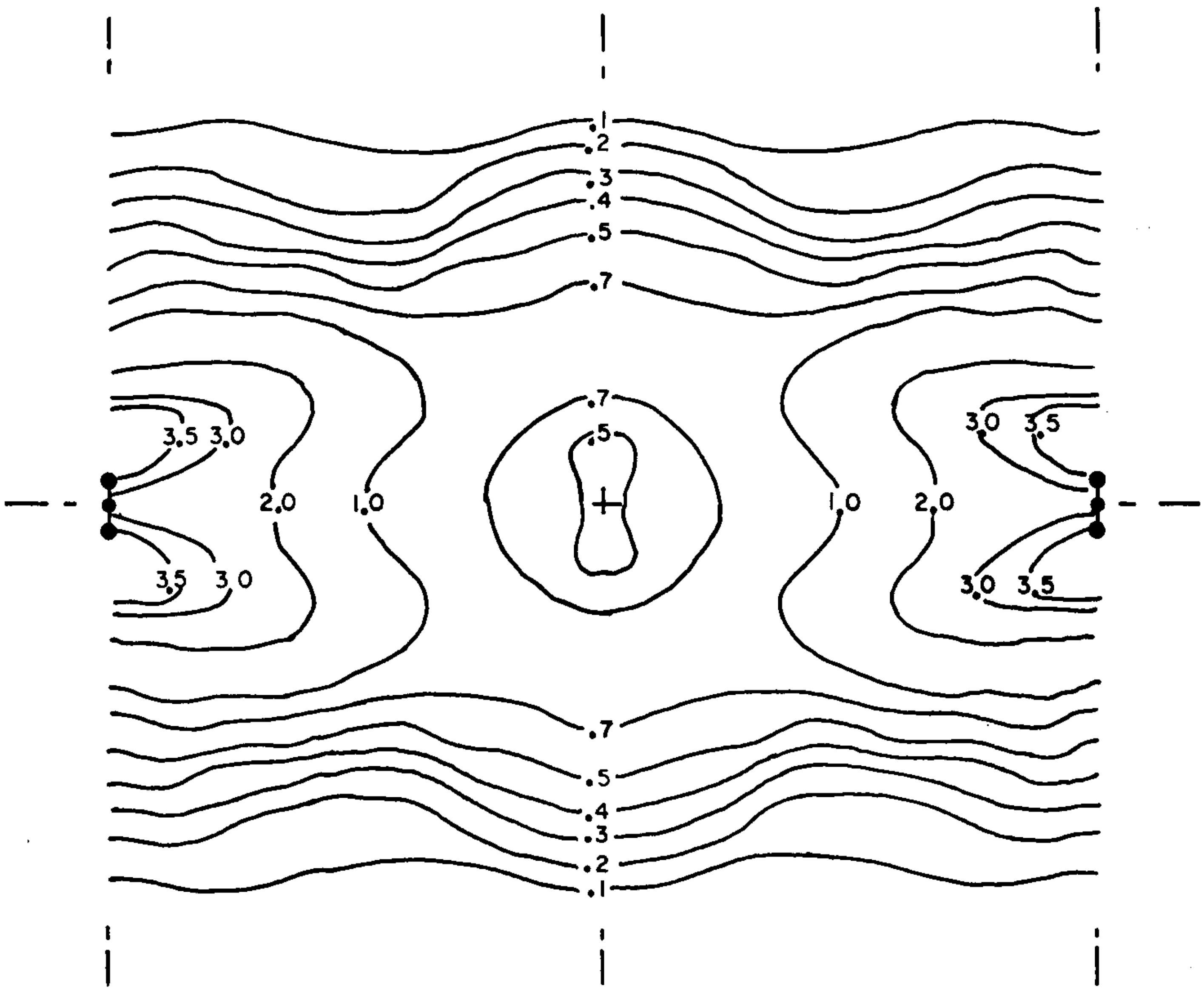
1 - 400 WATT MV
30' MH
Initial Footcandles
For FC at 9000 Hours
Multiply by 0.78

Scale: 1' = 50'

APPENDIX B

APPENDIX B

ISO-FOOTCANDLE CURVES

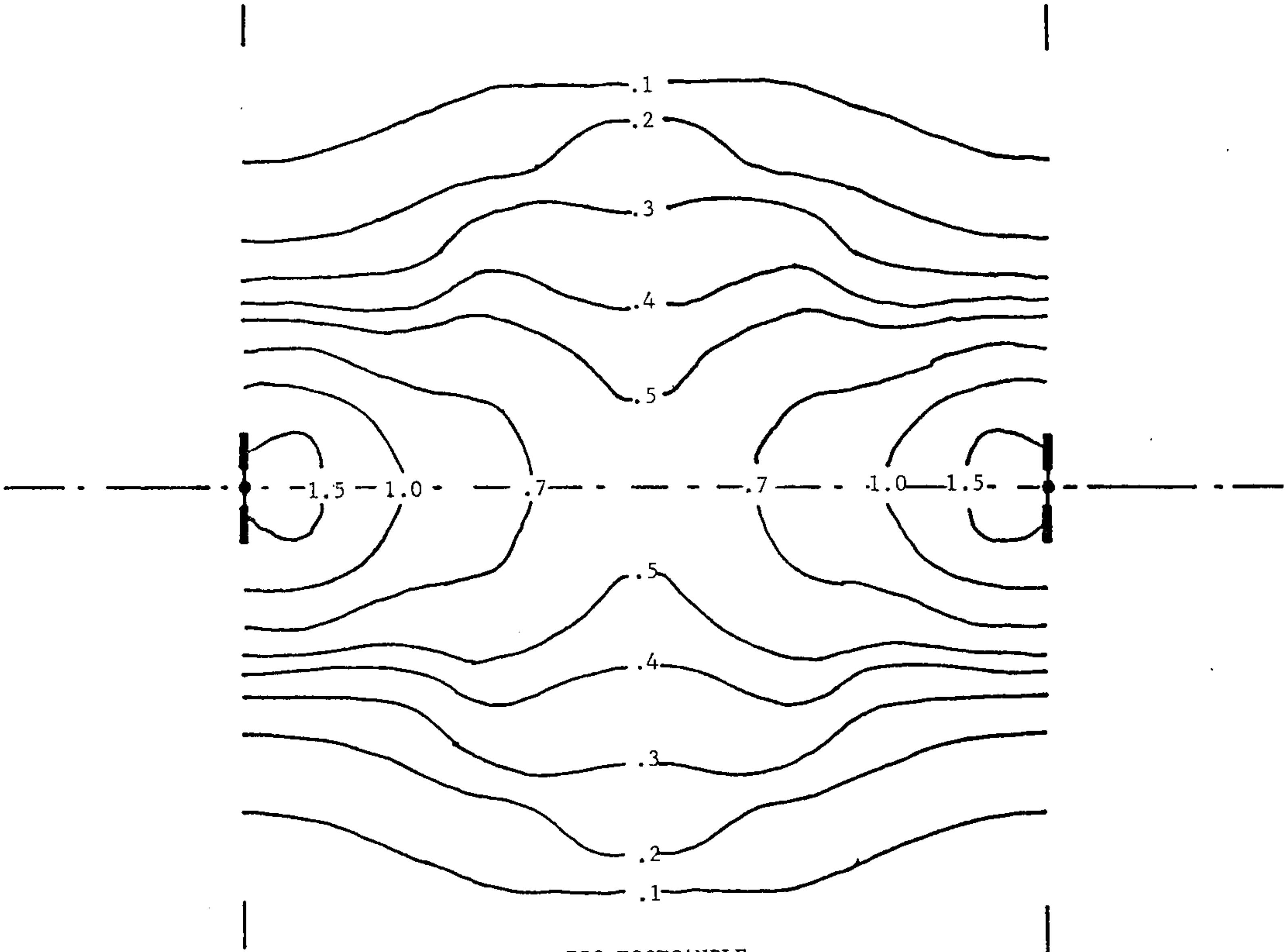


ISO-FOOTCANDLES

400 WATT HPS TWIN LUMINAIRE

50' MH 300' Spacing

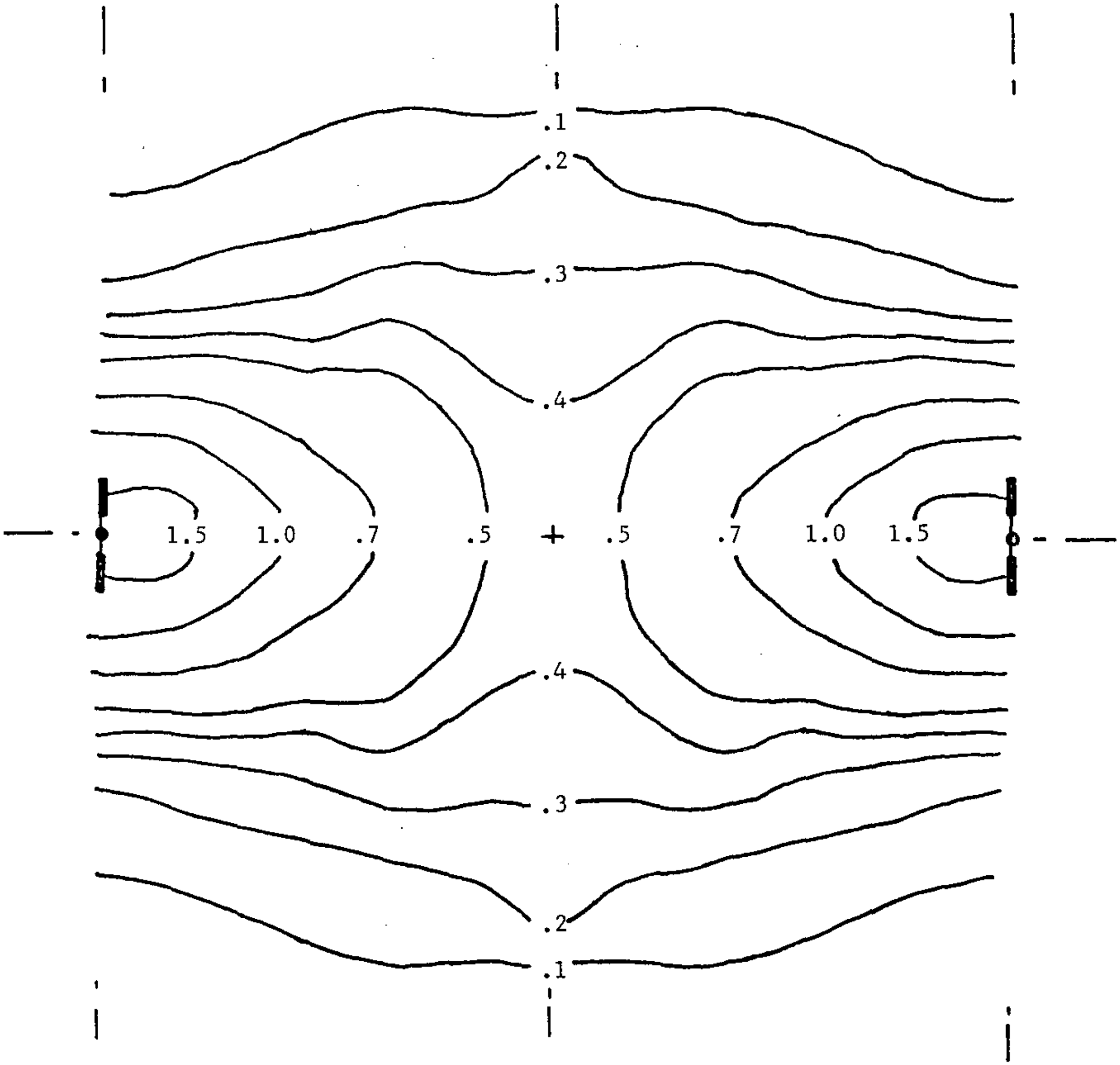
Scale: 1" = 50'



ISO-FOOTCANDLE

180 WATT LPS　　TWIN LUMINAIRE
50' MH　　255' Spacing

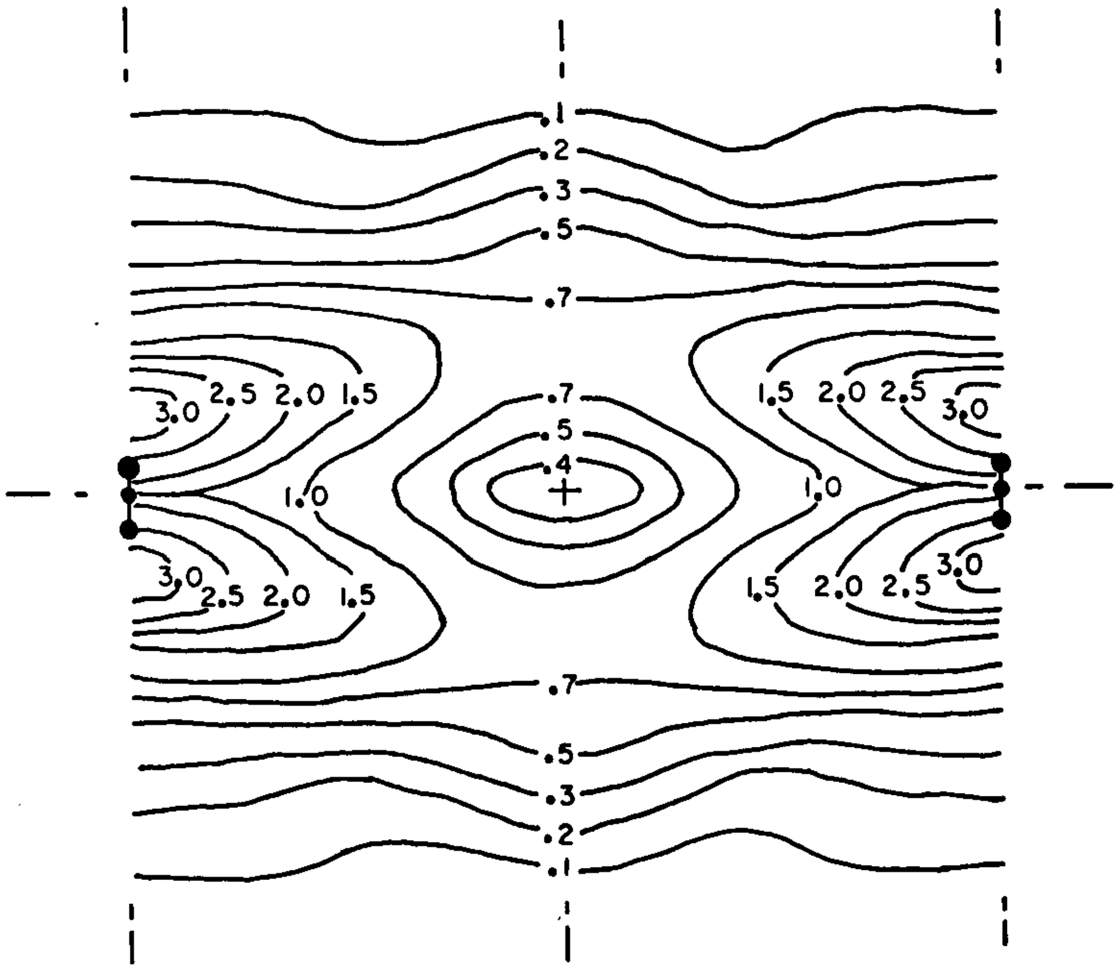
Scale: 1" = 50'



ISO-FOOTCANDLE

180 WATT LPS TWIN LUMINAIRE

50' MH 270' Spacing Scale: 1" = 50'

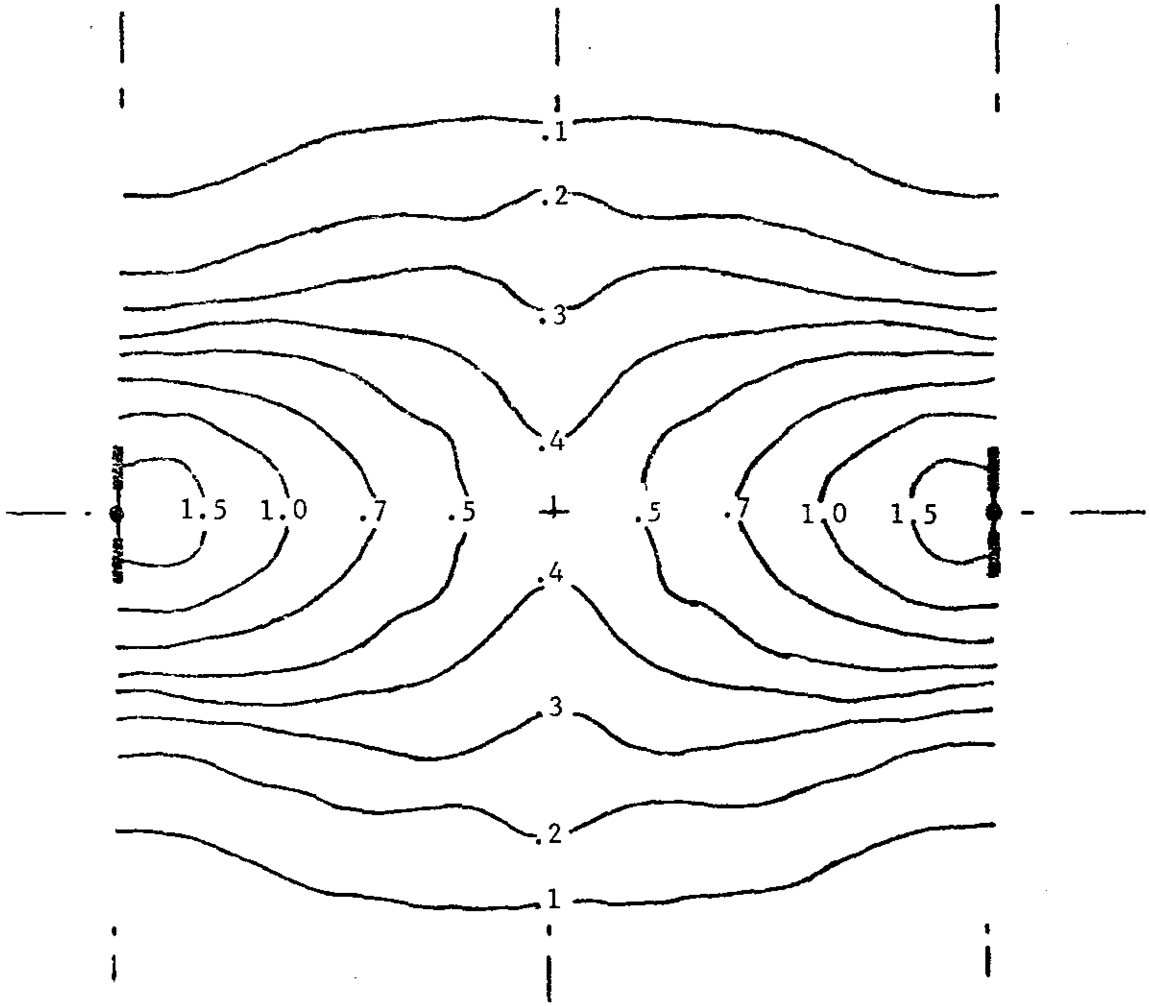


ISO-FOOTCANDLES

250 WATT HPS TWIN LUMINAIRE

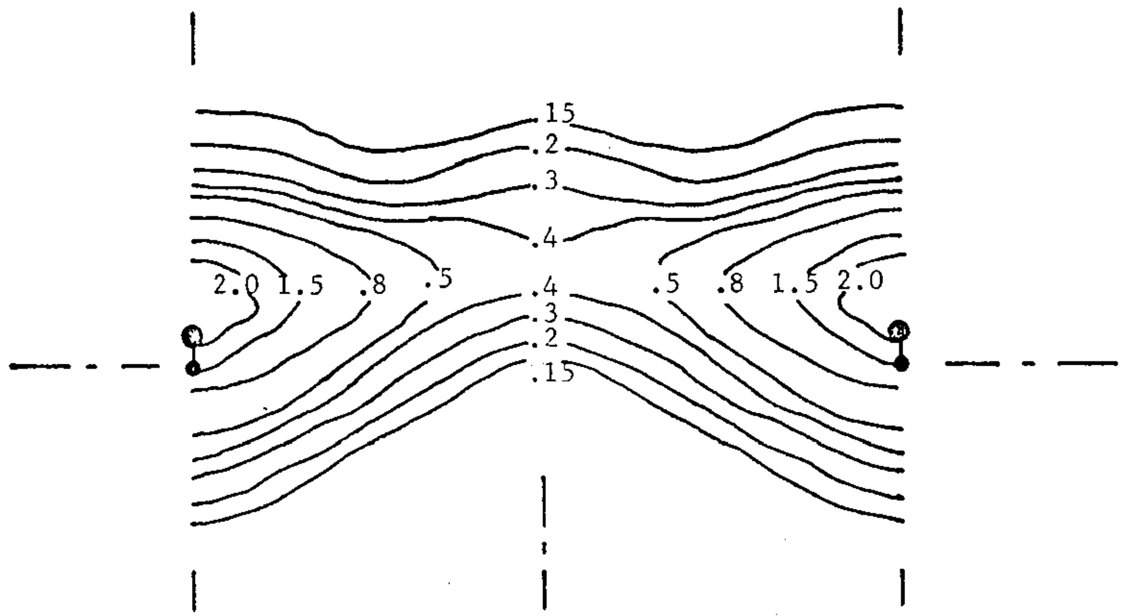
40' MH 225' Spacing

Scale: 1" = 50'



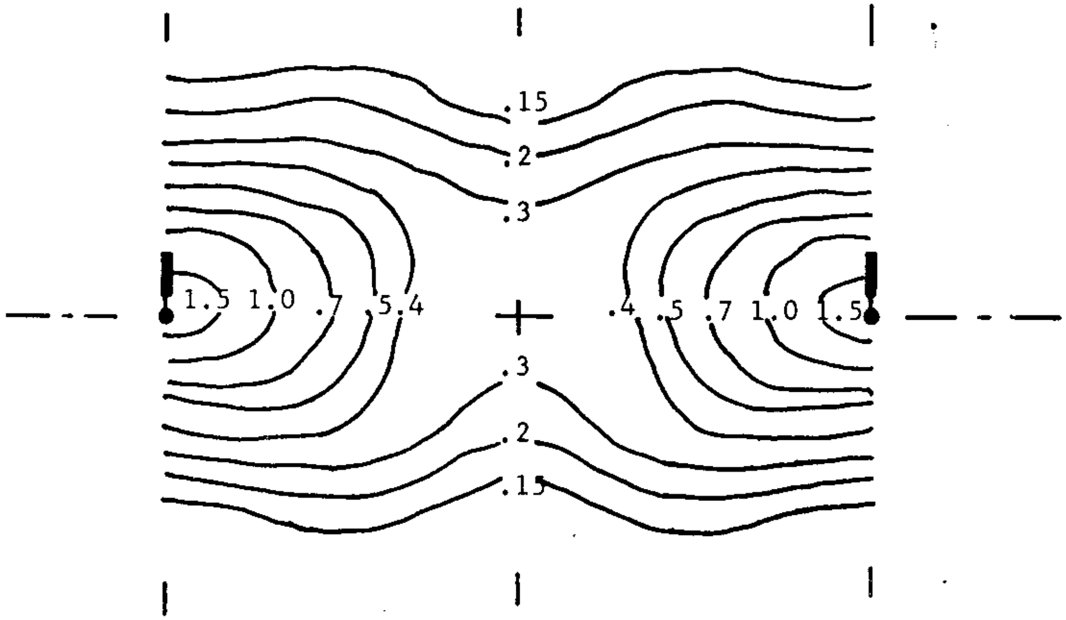
ISO-FOOTCANDLE
135 WATT LPS TWIN LUMINAIRE
40' MH 225' Spacing

Scale: 1" = 50'



ISO-FOOTCANDLES
at 9000 Hours
400 Watt MV Single Arm
30' MH
180-Foot Spacing

Scale: 1" = 50'



ISO-FOOTCANDLES
135 Watt LPS   Single Luminaire
30' MH   180-Foot Spacing

Scale: 1" = 50'

APPENDIX C

STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

SPECIAL SPECIFICATION

LOW PRESSURE SODIUM VAPOR LIGHTING ASSEMBLIES

I. General

All materials shall be new and unused, and shall be of the latest design. Materials and equipment shall comply with the applicable provisions of the National Electrical Code and National Electrical Manufacturers Association standards. Faulty fabrication or poor workmanship in any material or equipment will be considered justification for rejection.

II. Luminaires

A. The luminaire housing shall be cast or drawn from a nonferrous alloy or from Acrylonitrile Butadiene Styrene (ABS) polymer that has been coated with a minimum of 0.005 inch of an acrylic aluminum coating, and shall be free of cracks and excessive porosity. All nuts, screws, clips, washers, and attaching hardware shall be made of stainless steel or shall be electro-zinc-plated, minimum thickness of 0.002 inch, with olive drab or yellow chromate conversion coating. All threaded surfaces used in the housing shall be lubricated with a silicone grease.

B. The slipfitter shall securely clamp the luminaire to the mast arm. A positive means of vertical adjustment shall be incorporated either internally or externally that will permit adjustment of the luminaire to any uptilt position between the level position and fifteen degrees above horizontal.

C. The luminaire shall be equipped with resilient gaskets that provide and maintain a positive seal against weather and other contaminants for either the optic assembly or the entire luminaire.

D. The luminaire shall be designed to permit ready removal of the refractor or lens from the luminaire but shall provide a positive means of preventing an unintentional separation.

E. The latch or latches shall provide a positive means of maintaining closure of the luminaire.

F. The optic assembly shall be provided with a specular reflector having sufficient strength to prevent being distorted during routine operations.

G. The optic assembly shall be provided with a means of supporting the lamp near the end opposite the socket, to protect the arc tube from vibration damage.

H. The refractor or lens shall be crystal clear, and shall be constructed of either high impact-resistant plastic or high impact-resistant tempered glass. It may either have completely smooth surfaces or be equipped with refracting prisms.

I. Routine servicing shall require the use of no more than one hand tool.

J. The weight and projected surface area of the lighting assemblies, complete with lamp and ballast, shall not exceed the limits listed in the table below.

Wattage	Weight	Projected Area
180	56 lbs.	3.75 sq. ft.
135	50 lbs.	3.0 sq. ft.
90	43 lbs.	3.0 sq. ft.
55	31 lbs.	2.0 sq. ft.

III. Photometrics

A. The 55-watt luminaire, when mounted 20 feet above the midpoint of either long side of a rectangular area measuring 75 feet by 25 feet, shall provide a measured minimum intensity of 0.1 footcandle and a maximum intensity of 3.0 footcandles at any point on the surface of the area. The intensity shall decrease at a rate not to exceed 0.5 footcandles in any five-foot interval along any side of the previously defined rectangle.

The uniformity factor "F" shall be not less than 2.5 when calculated from the equation:

$$F = \frac{L \text{ (I min.)}}{\text{I max.}}$$

Where: F = The Uniformity Factor

L = 75

I min. = Minimum measured intensity within the rectangle.

I max. = Maximum measured intensity within the rectangle.

B. The 90-watt luminaire, when mounted 30 feet above the midpoint of either long side of a rectangular area measuring 140 feet by 40 feet and tilted 15 degrees above horizontal, shall provide a measured minimum intensity of 0.1 footcandle at any point on the surface of the area. Intensities along a line parallel to and 20 feet in from the long side of the previously defined rectangle above which the luminaire is mounted shall decrease at a rate not to exceed 0.25 footcandle in any 10-foot interval along the aforementioned line from 10 to 70 feet on both sides of the luminaire.

The uniformity factor "F" shall be not less than 5.0 when calculated from the equation:

$$F = \frac{L\ (I\ min.)}{I\ max.}$$

Where: F = The Uniformity Factor

L = 140

I min. = Minimum measured intensity within the rectangle.

I max. = Maximum measured intensity within the rectangle.

C. The 135-watt luminaire, when mounted 40 feet above the midpoint of either long side of a rectangular area measuring 180 feet by 50 feet and tilted 15 degrees above horizontal, shall provide a measured minimum intensity of 0.1 footcandle at any point on the surface of the area. Intensities along a line parallel to and 20 feet in from the long side of the previously defined rectangle above which the luminaire is mounted shall decrease at a rate not to exceed 0.25 footcandle in any 10-foot interval along the aforementioned line from 10 to 70 feet on both sides of the luminaire.

The uniformity factor "F" shall be not less than 6.0 when calculated from the equation:

$$F = \frac{L\ (I\ min.)}{I\ max.}$$

Where: F = The Uniformity Factor

L = 180

I min. = Minimum measured intensity within the rectangle.

I max. = Maximum measured intensity within the rectangle.

D. The 180-watt luminaire, when mounted 50 feet above the midpoint of either long side of a rectangular area measuring 220 feet by 70 feet and tilted 15 degrees above horizontal, shall provide a measured minimum intensity of 0.1 footcandle at any point on the surface of the area. Intensities along a line parallel to and 30 feet in from the long side of the previously defined rectangle above which the luminaire is mounted shall decrease at a rate not to exceed 0.3 footcandle in any 10-foot interval along the aforementioned line from 10 to 70 feet on both sides of the luminaire.

The uniformity factor "F" shall be not less than 7.0 when calculated from the equation:

$$F = \frac{L\ (I\ \text{min.})}{I\ \text{max.}}$$

Where: F = The Uniformity Factor

L = 220

I min. = Minimum measured intensity within the rectangle.

I max. = Maximum measured intensity within the rectangle.

E. The luminaires shall meet the photometric requirements of paragraphs III.A through D when energized at 10 volts less than the rated line voltage.

IV. Ballasts

A. The ballast shall be located in the luminaire and shall be a constant wattage type designed to operate low pressure sodium lamps.

B. The input wattage to the ballast shall not exceed 145 percent of the nominal lamp rating during fluctuations of the primary voltage up to plus 8 volts or minus 12 volts.

C. The power factor of any ballast when tested at the circuit voltage indicated in the plans shall be not less than 90 percent.

D. Luminaires or ballasts shall permanently and clearly indicate the manufacturer's name, lamp type, catalog number, voltage rating, and connection diagram.

V. Lamps

A. Low pressure sodium vapor lamps shall have a rated average life of 18,000 hours.

B. Lamps shall be capable of normal operation when mounted in any position between level and 20 degrees above horizontal (base down).

VI. Testing

A. Ballasts and luminaires will be tested using a lamp furnished for the same project.

B. Luminaires, ballasts, and lamps will be sampled and tested in accordance with the State Department of Highways and Public Transportation Manual of Testing Procedures.

C. The Department will bear the cost of testing all materials meeting the requirements of this specification. The Contractor will bear the cost of testing all materials failing to meet the requirements. The cost for testing failing materials will be deducted from amounts due the Contractor on Monthly and Final Estimates.

D. All fixtures will be inspected and evaluated after they have been installed, adjusted, and energized, to determine final acceptance of the units.

VII. Construction Methods

The installation of low pressure sodium vapor lighting assemblies shall be carried out in accordance with the details shown in the plans. Upon completion of the work, each assembly shall present a neat and workmanlike finished appearance.

VIII. Measurement

The lighting assemblies will be measured as each unit installed, complete in place.

IX. Payment

Work performed and materials furnished as prescribed in this specification, measured as provided under "Measurement," will be paid for at the unit price bid for each Low Pressure Sodium Vapor Lighting Assembly, which payment shall be full compensation for furnishing, installing, and testing all assemblies complete with lamp; all conductors between foundation and luminaires; hardware and internal connections; and for furnishing all labor, tools, equipment, and incidentals necessary to provide the lighting complete in place.