Report No. FAA/RD 78-144
(18) (19)

LEVEL II (12)

(6)

EVALUATION OF THRESHOLD AND PRETHRESHOLD LIGHTS FOR MEDIUM INTENSITY APPROACH LIGHTING SYSTEMS

(10) GUY S. BROWN

(14) FAA-NA-78-44

(11) DEC[illegible]78

(12) 46p.

(9) FINAL REPORT. Mar 77 - Jul 78

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-78-144		

4. Title and Subtitle	5. Report Date
EVALUATION OF THRESHOLD AND PRETHRESHOLD LIGHTS FOR MEDIUM INTENSITY APPROACH LIGHTING SYSTEMS	December 1978
	6. Performing Organization Code
7. Author(s) Guy S. Brown	8. Performing Organization Report No. FAA-NA-78-44
9. Performing Organization Name and Address Federal Aviation Administration National Aviation Facilities Experimental Center Atlantic City, New Jersey	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. 071-412-550
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590	13. Type of Report and Period Covered Final March 1977 - July 1978
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report describes the evaluation of runway threshold lights for use with medium intensity approach lights with runway alignment indicator (strobe) lights (MALSR) systems. Three different lamps and fixtures were selected for final evaluation. Based on flight tests and photometric measurements, it was concluded that 300-watt, 300PAR56/NSP lamps would provide the improved visual guidance and conspicuity of the threshold necessary for operations in visibility conditions as low as Category I, 2,400 feet runway visual range (RVR). The green threshold lights spaced 10 feet apart with the outer lights inline with the runway edge lights will conform to ALSF-1 and ICAO criteria for Category I operations.

A supplementary test was conducted to evaluate proposed configurations of red wing bar lights in the prethreshold area to augment the threshold lights for improved visual guidance. The test results concluded that, with the bold and distinctive threshold, red prethreshold wing bar lights did not provide appreciable improvement in guidance under the test conditions.

17. Key Words	18. Distribution Statement
Visual Aids Runway Lighting Threshold Lighting Airport Lighting	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	17	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

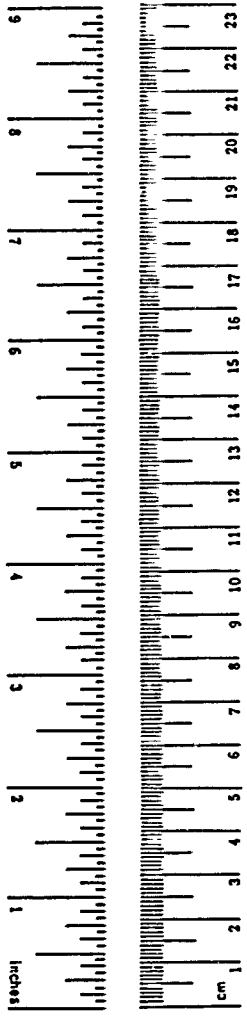
240 550

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

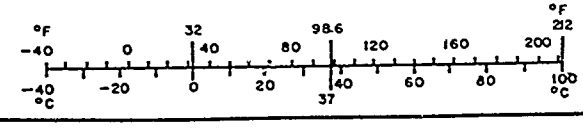


TABLE OF CONTENTS

	Page
INTRODUCTION	1
Purpose	1
Background	1
Test Requirements And Configurations	3
DISCUSSION	3
General	3
Photometric Measurements	7
Threshold Light Tests	7
Prethreshold Red Wing Bar Light Tests	10
RESULTS	11
Threshold Lights	11
Prethreshold Red Wing Bar Lights	12
CONCLUSIONS AND RECOMMENDATIONS	13
REFERENCE	14
APPENDICES	
A - Review of Equipment and Installation Options for MALS, MALSF, and MALSR Threshold Lights	
B - Isocandela Curves	
C - Photometric Data for MALSR Threshold Test Lamps	

LIST OF ILLUSTRATIONS

Figure		Page
1.	ALSF-1 Configuration	2
2.	MALSR Configuration with Threshold Lights	4
3.	MALSR Configuration with Threshold Lights and Red Wing Bar Test Lights (100 ft from threshold)	5
4.	MALSR Configuration with Threshold Lights and Red Wing Bar Test Lights (200 ft from threshold)	6

INTRODUCTION

PURPOSE.

The purpose of this report was to test and evaluate selected runway threshold lights for use with medium intensity approach light and runway alignment indicator (strobe) light (MALSR) systems. From this evaluation a recommendation for a lighting standard could be made in order to provide improved visual guidance in visibility conditions as low as Category I, 2,400 feet (ft) runway visual range (RVR).

Also, as a supplemental test, selected wing bar lights were tested and evaluated in the prethreshold area in order to determine if they added improved visual guidance.

BACKGROUND.

It is widely agreed, and an accepted practice for Category I and II operations, that the runway threshold must be lighted with a conspicuous row of green threshold lights that are reasonably well balanced in intensity ratio with the approach and runway lights to provide the pilot with adequate visual guidance.

Medium intensity MALSR-type systems have been installed in the approach zone to runways that were not previously equipped with approach lights. These systems do not include threshold lights as part of the medium intensity approach lighting system but rely on the airport system of green threshold lights, usually four on each side of the threshold, that are powered by, and are part of, the airport runway edge lighting system.

The inadequacy of runway threshold lights used for nonprecision and Category I precision approach operations, including those with MALSR installations, has long been a source of complaint from user organizations: air carrier, general aviation, and military. It is recognized that the MALSR systems should provide a similar degree of guidance as that required of the ALSF-1, Category I threshold light specifications. With the ALSF-1, this was accomplished by requiring 500-watt (W) PAR56 low-profile, elevated lights with green filters.

It has been proposed that a configuration of red wing bar lights in the prethreshold area, together with suitable threshold lights may be desirable for use with MALSR systems to provide adequate visual guidance for operations in Category I, 2,400 ft RVR, conditions. Red prethreshold wing bar lights have been used with ALSF-1 systems which are approved for Category I operations for a number of years (figure 1). They consist of two light bars with five red-filtered lights in each bar located on either side of the extended runway centerline and 100 ft short of the runway threshold.

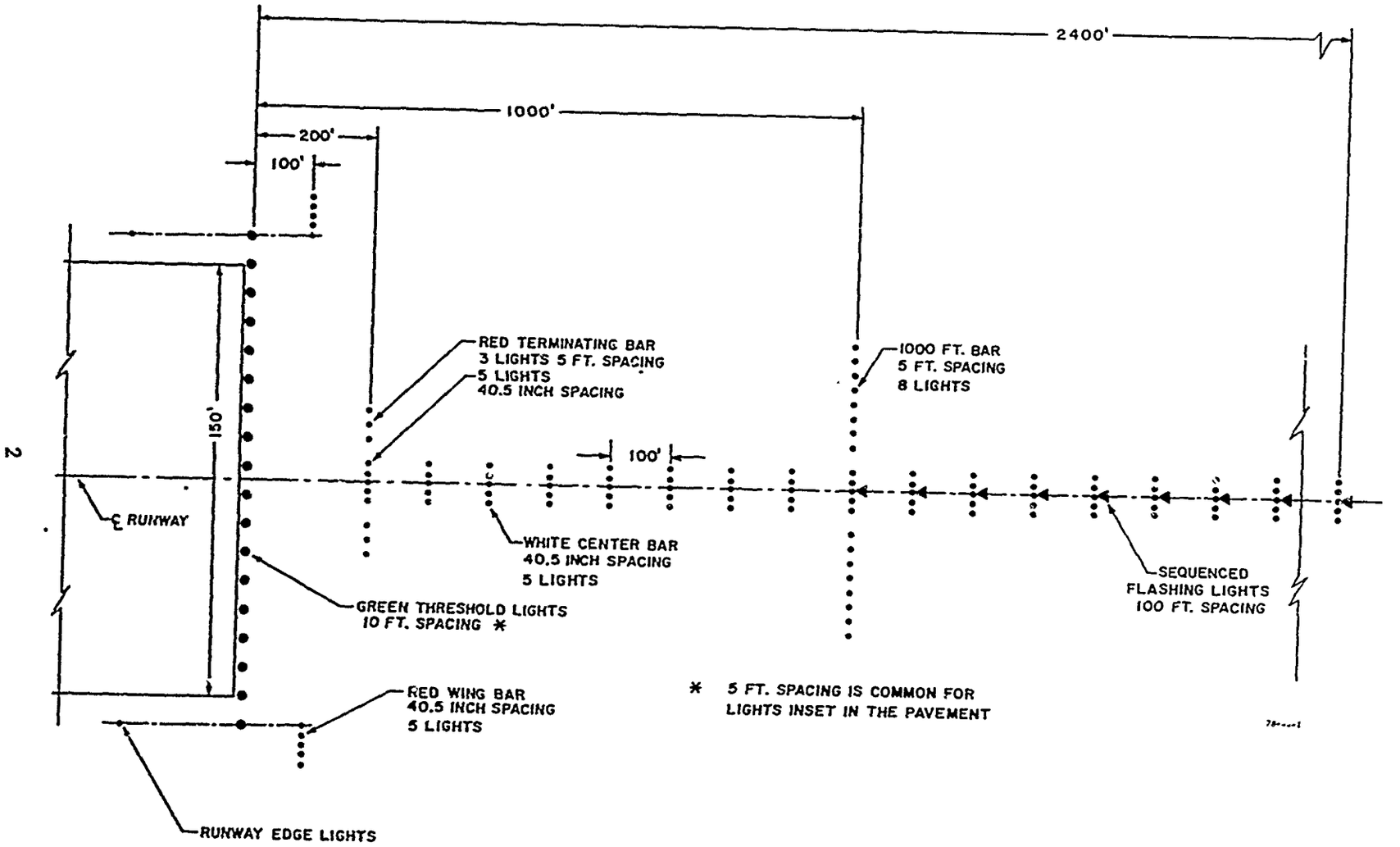


FIGURE 1. ALSF-1 CONFIGURATION

TEST REQUIREMENTS AND CONFIGURATIONS

A spacing of 10 ft between threshold lights, with the overall width confined to the width of the runway edge lights, was proposed as a requirement by the Systems Research and Development Service (SRDS) in coordination with the other sponsoring services. The spacing and overall width was considered adequate for MALSR installations to be used for Category I operating conditions. This configuration conforms with the current standard for ALSF-1 threshold lights (reference 1)used for Category 1 operations and was recommended for those ALSF-1 systems approved for Category II conditions (reference 2). Using the 10-foot spacing between lights, the number of threshold lights is determined by runway width and location of the runway edge lights. The edge lights are commonly located 10 ft beyond the pavement with the outer threshold lights inline with the edge lights. For a full system, this requires 18 threshold lights for a common runway width of 150 ft (figure 2). If the present eight threshold lights associated with the airport runway edge lighting system are determined to be adequate, MALSR threshold lights could be added to fill-in the center gap between the airport threshold lights. This would require 10 added lights for a 150-foot-wide runway.

The configurations of prethreshold red wing bar lights recommended for test were: (1) both five or three lights in each bar located 100 ft from the threshold with the inboard lights inline with the runway edge lights (figure 3), and (2) both five or three lights in each bar located 200 ft from the threshold with the outboard lights in each bar inline with the runway edge lights (figure 4). After reviewing previous practices and criteria of red filtered wing bar lights, it was concluded that in order to provide an appropriate balance of intensity, the same type of lamps should be used as those with the green-filtered threshold lights. The width of each prethreshold wing bar was 13.5 ft, (40.5-inch spacing), the same as that used with the ALSF-1 systems.

The ratio of intensity between the proposed prethreshold wing bar and/or threshold lights and the approach and runway edge lights should comply with ICAO Category I minimum requirements specified in ICAO Document, Annex 14. The balance in brightness of these lights will be acceptable to the user for operations in visibility conditions ranging from VFR to Category I, 2,400 ft RVR.

DISCUSSION

GENERAL.

This final report incorporates two National Aviation Facilities Experimental Center (NAFEC) Technical Letter Reports. The first phase of this project culminated in a report entitled, "Review of Equipment and Installation Options for MALS, MALSF, and MALSR Threshold Lights," (reference 3) which is included in this report as appendix A.

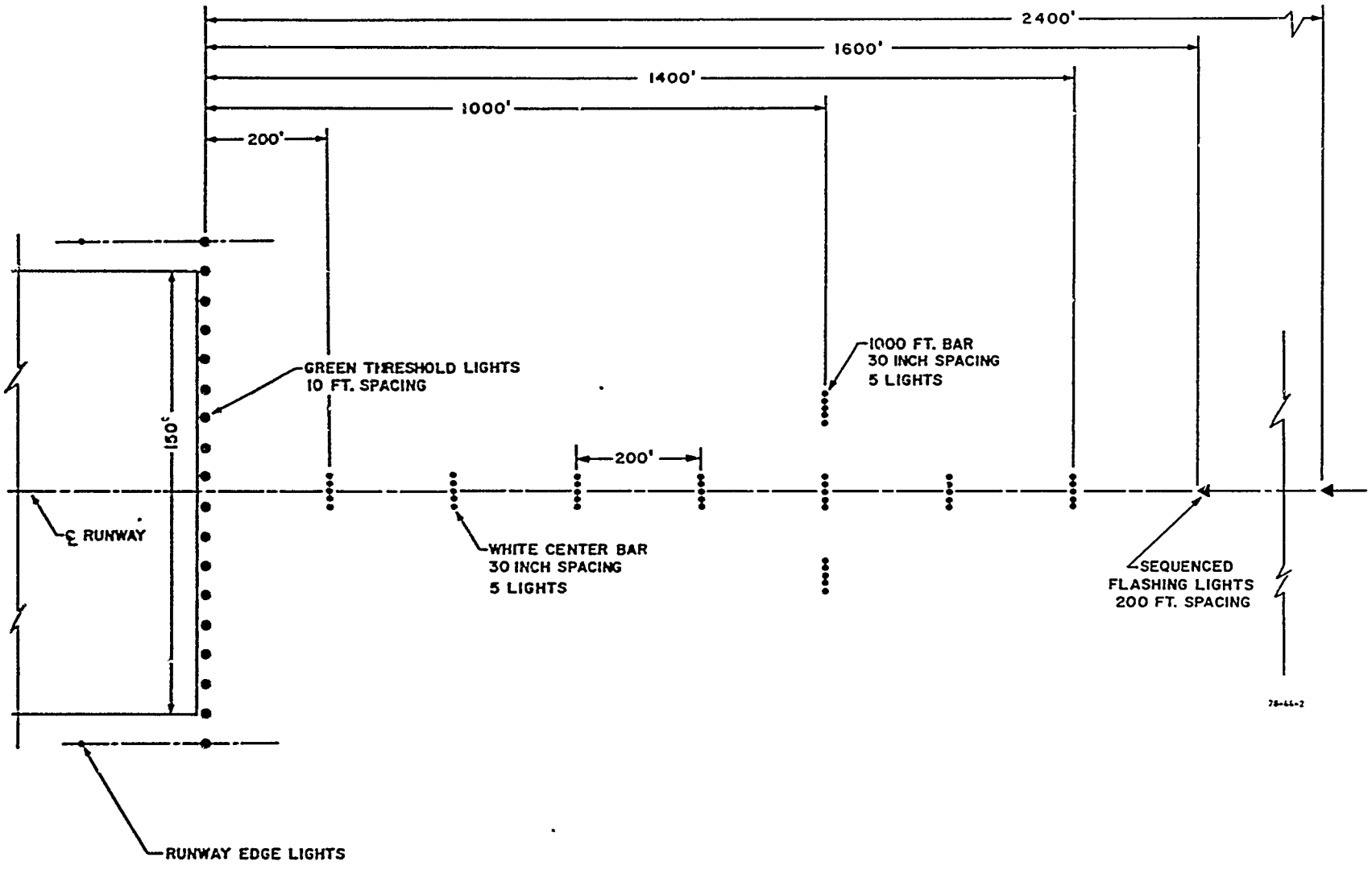


FIGURE 2. MALSR CONFIGURATION WITH THRESHOLD LIGHTS

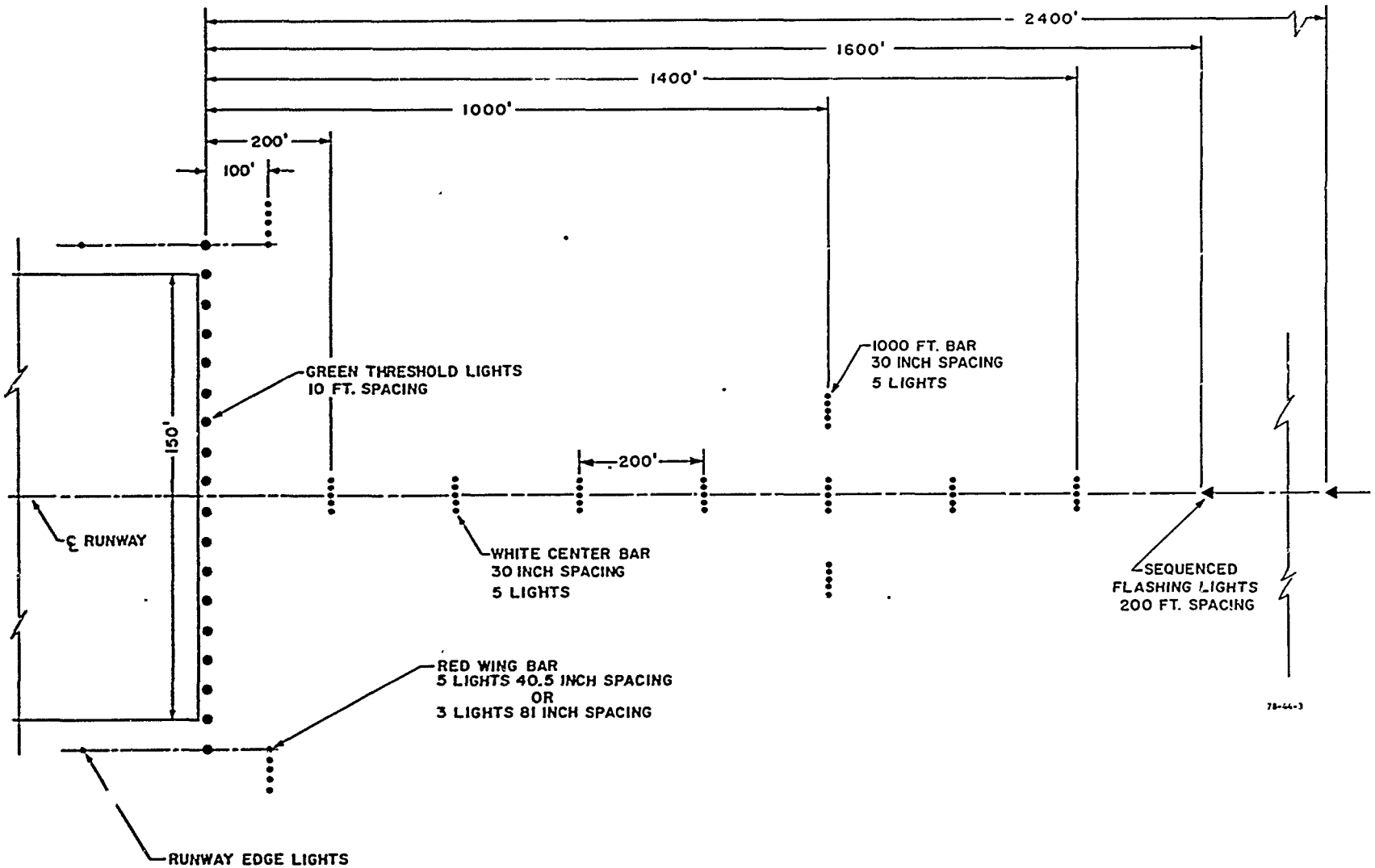


FIGURE 3. MALSR CONFIGURATION WITH THRESHOLD LIGHTS AND RED WING BAR TEST LIGHTS (100 FT FROM THRESHOLD)

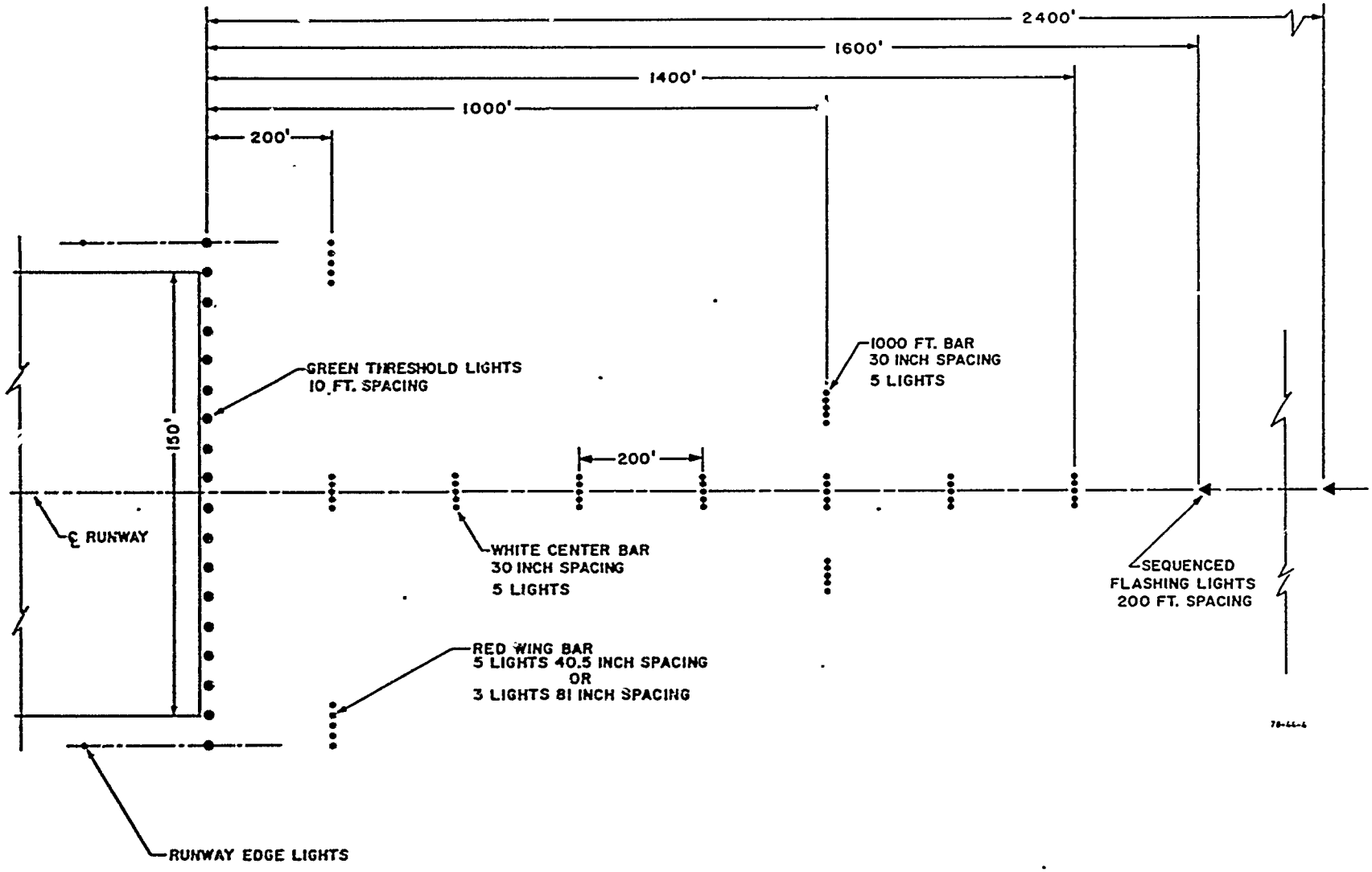


FIGURE 4. MALSR CONFIGURATION WITH THRESHOLD LIGHTS AND RED WING BAR TEST LIGHTS (200 FT FROM THRESHOLD)

The second report, "Test and Evaluation of MALSR Threshold Lights," (reference 4) was incorporated into this final report and expanded to included additional flight testing of the threshold light systems with and without red wing bar lights in the prethreshold area.

Following the first phase, four commercially available lamps together with appropriate lampholders and green filters were selected by representatives of the sponsoring services for test and evaluation. The selected lamps are listed in table 1 together with intensity and other lamp data. Also included, for comparative purposes, are data on other lamps.

Flight tests of the threshold lights were conducted in two phases. The initial flight tests included evaluation of lamps and systems subsequently selected for final testing. Following selection of the most promising threshold lights, the configurations of red wing bar lights in the prethreshold area were evaluated as a supplemental test. The threshold lights selected for final test were paired with different combinations of red wing bar lights for flight testing. This testing was more abbreviated than that conducted with the threshold lights.

PHOTOMETRIC MEASUREMENTS.

Photometric measurements were made on samples of each type lamp, with the exception of the L-862. The isocandela curves shown in appendix B were plotted from tabular data of representative lamps found in appendix C. Additional data on the various lamps are included in tables 1 and A-1.

THRESHOLD LIGHT TESTS.

The selected threshold lights were installed on runway 4 at NAFEC for flight test and evaluation since it is equipped with a MALSR system and L-819 high intensity runway lights (HIRL).

THRESHOLD TEST LIGHTS AND INSTALLATION. The fixtures selected for the L-862- and PAR56-type test lamps were designed to meet Federal Aviation Administration (FAA) specifications for threshold lights. The L-862 green filter was enclosed in a standard L-862 light assembly. The PAR56 lamps were mounted in the low-profile-type FAA-E-982 holder and a green filter, 8 3/8 inches in diameter (Kopp Glass Inc. AP 3510), was fastened to the exterior of the lampholder with standard filter clips.

A commercially available lampholder, Stonoco Model V4400 (cast aluminum with 1/2-inch male mounting arm) was selected for use with PAR38 lamps. The 360 degree (°) shield protects the lamp and provided for the use of standard 2-inch filter clips (slightly modified) to mount a 6 1/2-inch green filter (Kopp Glass Inc. No. AP3650). An alternative PAR38 lampholder, proposed by Multi-Electric, would utilize the standard PAR56 FAA specification FAA-E-982D lampholder modified with a faceplate and a screw base socket to accommodate the PAR38 lamp.

TABLE 1. LAMP AND INTENSITY DATA

Type Lamp	Volts/ Amps	Watts	Design Life (hours)	Initial PBCP (a) (clear)	Beamspread to 10% PBCP Hor.°	Ver.°	Beamspread to 50% PBCP Hor.°	Ver.°
*L-862 HIRL Threshold	6.6A	200	500	26,000	19	10	10	6
*Q250PAR38SP	120	250	3000	25,000	24	24	13	13
*300PAR56/NSP	125-130	300	2000	50,000(b)	20	15	12	9
*399PAR56	115	399	100	30,000	52	22	38	13
150 PAR38/SP MALS, clear	12	150	2000	10,000	30	30	15	15
Q20A/PAR56 ALS, clear	20A	300	500	27,000	50	20	39	12
Q20A/PAR56/1 ALSF Threshold	20A	500	500	48,000	50	25	40	12
L-862 HIRL R/W Edge	6.6A	100	500	13,000	19	9	13	7
L-819 HIRL Edge & Threshold	6.6A	210	500	25,000	8	8	5	4

(a) Peak Beam Candle Power (PBCP) or Candelas
(b) Operated at 120 volts

* MALSR Threshold Test Lights

The three different-type fixtures were temporarily installed across the threshold of runway 4 with each fixture spaced 10 ft apart (figure 3). Provisions were made for selection of the appropriate intensity step settings as specified in FAA Handbook 7110.65.

THRESHOLD LIGHT TEST CONFIGURATIONS. The test lamps were configured to provide two types of systems: (1) a full or complete system for each of the three types of lamps tested which extend across the threshold with all lamps and fixtures of the same type, and (2) added lights using either PAR56 or PAR38 120-volt (V) lamps to fill-in the center section between four L-862, 6.6-ampere (A) lights on each side of the runway threshold. The L-862 threshold lights would be part of the runway lighting system provided by the airport.

FLIGHT TESTS OF THRESHOLD LIGHTS. Initial flight tests were conducted under visual flight rules (VFR) conditions during dusk and darkness and in 1- to 1 1/4-mile visibility with moderate snow in daytime conditions. Twelve NAFEC pilots participated in the evaluation. All were test pilots highly experienced in evaluation of airport lighting for visual guidance. All lamp combinations were evaluated during the initial flight tests to aid in selection of the most promising for final testing.

Based on the results of the initial flight tests and other factors, it was concluded that full systems of either L-862 or 399W PAR56 lamps should not be considered for final evaluation. While the L-862 lights across the threshold were adequate in VFR conditions, they were judged to be quite dim in comparison with the MALS and runway edge lights in the reduced visibility test conditions. Also, the brightness was noticeably reduced when the aircraft was slightly to the left or right of the extended runway centerline due to the narrow beam. Costs of the lights, installation, maintenance, and power requirements were also considered and are discussed in appendix A.

The 399-W PAR56 lamps were initially considered because of the wide horizontal beam spread and the peak intensity when compared with other lamps used for ALSF-1 and ALSF-2 threshold lights. Even though the rated life of this lamp was very low, it was proposed that the filament could be redesigned to increase the life if this wider beam were required. The flight tests indicated that while the wide beam provided improved threshold brightness when on base leg for a circling approach and when well offset from the extended runway centerline, it was not required from a standpoint of normal deviations that could be expected for a successful ILS approach. In an additional test, 300-W PAR56 lamps were installed on the right half of the threshold with 399-W PAR56 lamps on the left in order to directly compare brightness and beam widths. During VFR conditions and in the reduced visibility with snow, very few pilots could detect any noticeable difference in brightness between the lamps. The pilots judged these threshold lamps to be bright but not excessive. The 300-W lamp, which has a higher intensity, should, however, provide some increased range in lower visibility, Category I conditions. Since the 300-W PAR56 as well as the 250-W PAR38 lamps provided adequate beamwidth when compared with that of the MALSR and runway edge lights, it was concluded that the higher powered 399-W lamp should not be considered for final evaluation.

Following the initial tests, System Research and Development Service (SRDS), in coordination with the other sponsoring services, selected the remaining lamps and system configurations for final test and evaluation. The lamps selected were the following:

1. 250-W PAR38 lamps as a full system across the threshold,

2. 300-W PAR56 lamps as full system,

3. Four 200-W L-862 threshold lights outboard on each side of the threshold with 250-W PAR38 lamps to fill-in the center section, and

4. Four 200-W L-862 threshold lights outboard on each side of the threshold with 300-W PAR56 lamps to fill-in the center section.

The final tests were conducted in VFR conditions during dusk, darkness, daytime, and in 1.5-mile visibility with light rain and fog in daylight. Low ceilings associated with the weather systems during the test period and the lack of precision approach ILS guidance for approaches below 400 ft to runway 4 precluded evaluation in lower visibility conditions.

Since the initial flight tests of the threshold lights included evaluation of lamps and systems subsequently selected for final testing, and since lower visibility conditions were not obtained during the test period, the test results for all phases of testing have been combined.

PRETHRESHOLD RED WING BAR LIGHT TESTS.

The configurations of red wing bar lights selected for test were installed in the prethreshold area of runway 4 at NAFEC (figures 3 and 4) for flight test and evaluation in combination with the threshold test light configurations.

RED WING BAR TEST LIGHTS AND INSTALLATION. The most promising candidates as threshold lights were also selected for use as red wing bar test lights. Those selected were the 250-W PAR38 lamp with the experimental PAR38 lampholder and the 300-W PAR56 lamp with the standard PAR56 lampholder. Both types of lamp and fixture combinations were temporarily installed to provide bars of red lights 13.5 ft wide. These lights were powered independently of the threshold lights and were configured to provide each type of light with either three or five lights in each bar. This provided the capability of selecting the threshold light configurations independently or paired with either of the two types of wing bar lights.

WING BAR LIGHT TEST CONFIGURATIONS. The wing bar lights, with either three or five lights in each bar, were paired with the same type, PAR38 or PAR56, threshold lights for testing. The threshold light configurations, as previously described, included full systems of each PAR-type as well as L-862 lights across the threshold. The wing bar lights were first installed 100 ft short of the runway threshold with the inboard lights inline with the

runway edge lights (figure 3) as required for the ALSF-1. Following the flight testing at this position, the wing bars lights were relocated to a position 200 ft short of the threshold with the outboard lights inline with the runway edge lights (figure 4).

FLIGHT TESTS OF RED WING BARS WITH THRESHOLD TEST LIGHTS. Two consecutive approaches were made in a random order during each flight session with either three or five lights in each wing bar paired with each of the threshold light configurations previously described, and also with threshold lights without wing bar lights. The flight tests were conducted in VFR conditions during dusk and darkness and in day fog conditions with 1 to 1.5 miles visibility. Twelve pilots judged the visual guidance provided by the wing bar lights when used in combination with the threshold test light configurations and the threshold lights without red wing bars.

RESULTS

THRESHOLD LIGHTS.

When four L-862 lamps were used outboard with either the PAR38 or PAR56 lights in the center section of the threshold, the L-862's were judged to be weak. Numerous comments were received from the pilots such as:

1. "Outboard lights aren't noticeable until close-in on final approach--quite weak.

2. Didn't care for the two-tone green threshold lights, outboard lights too weak for the rest of the system.

3. Dim outboard (lights)--need lights all across (the threshold) for low visibility.

4. The bright lights in the center with lower intensity outboard give the impression of a hump or crown in the runway; prefer a balanced threshold.

5. Don't buy low intensity outboard lights.

6. The solid line (same type of lights) gave better roll guidance."

From the flight tests the L-862 lights appear to have a narrower beam than that observed with both the PAR38 and PAR56 lamps. This is noticeable when slightly offset from the centerline and beyond 0.5 mile from the runway threshold. The lights become considerably brighter within 0.5 mile and when aligned with the centerline of a 3° glidepath. In addition to pilot judgement of the L-862 lights, other factors previously mentioned should be considered when proposing them for use as part of a MALSR threshold light system. These factors are discussed along with various options in appendix A.

It was the consensus of the majority of the subject pilots that a full system of the same type of lights across the threshold was preferred for low-visibility operations over the system of different types of lights. There was no strong preference for the full system of 300-W PAR56 lamps over a full system of 250-W PAR38 lamps. In the reduced visibility conditions, however, the PAR38 lights with green filters were reported less bright than the MALSR clear approach lights and the runway edge lights; but, this was never a strong complaint from the subject pilots. The balance in brightness for the full systems of PAR-type lights was always judged to be good when compared with MALS and runway edge lights. These threshold lights were judged to be bright but not excessively bright for VFR operations.

Other factors indicate several advantages for use of the 300-W PAR56 lamp. This lamp provides a higher intensity in the peak and near the center of the beam than the 250-W PAR38 lamp, while maintaining horizontal and vertical beam spreads. These beam spreads are comparable to the MALSR 150-W PAR38 lamps and both L-819 and L-862 runway edge lights. The horizontal beam-spread is slightly wider above 10,000 candelas (cd) than the 250-W PAR38 lamp. This intensity will, of course, be reduced by green filters to about 17 to 20 percent of the 10,000-cd clear value. The reduced intensity values of the 300-W PAR38 lamps are similar to those of the white approach lights 150-W PAR38. The data are shown in table 1 and the isocandela curves in appendix B.

The PAR56 lamp, designed for 125-130 V operation, provides added benefits when operated at 120 V. The extremely good 2,000-hour design life feature will be extended to even a greater length. Also, the intensity will approximate that specified for lamps used in the ALSF-1 threshold, terminating, and wing bars for Category I operations. In 2,400 ft RVR Category I conditions, the intensity will provide a calculated visual range that is comparable to that of the current ALSF-1 threshold lights. The calculated curves of target light intensity versus visual range are shown in figure A-1.

PAR56 lamps are commercially available, and the filters and fixtures are FAA-approved stock items. These lights may also be operated in the MALSR system by simply increasing the power capacity of the supply transformer with an increase in the current-carrying capacity of the feeder cables, or by using an additional feeder cable which may be more practical.

PRETHRESHOLD RED WING BAR LIGHTS.

The red wing bar lights, used in combination with the threshold lights, did not provide an improvement in visual guidance under the test conditions. The wing bars with five red lights in each bar were judged to be "not needed" by a significant majority of the pilots when installed with a bold threshold as provided by either the 250-W PAR38 or 300-W PAR56 threshold lights. They did not provide an improvement in guidance when installed at either location.

Two pilots noted that the bars with five lights each located 100 ft from the threshold and extending outboard of the runway edge lights provided added cues and roll guidance. However, when installed 200 ft from the threshold and extended inboard from the threshold lights, another pilot commented that, if used, he would prefer them to extend outboard of the threshold lights to provide more roll guidance.

The wing bar lights with only three red lights in each bar were judged to be inadequate at both locations by a near majority of the subject pilots. Several pilots commented that the bars with three lights were not well defined and could be confused with red obstruction lights. Also there was concern that these red wing bar lights, especially the three-light bars outboard of the runway edge light line, may be mistaken for Visual Approach Slope Indicator (VASI) lights. For this reason it was suggested that, if these lights are used, they should be located inboard of the line of runway edge lights.

These test results for the threshold with and without red wing bar lights appear to be in agreement with an evaluation to improve ALSF-1 threshold and prethreshold lighting for Category II operations (reference 2). In this evaluation it was found that: "Strengthening the threshold guidance signal was determined to be the single most important improvement" and "improvement of maintenance for the approach light system and the runway lighting is mandatory." The latter is considered a critical requirement in order to maintain a reasonable balance of brightness between individual lights as well as between the different-type lights.

CONCLUSIONS AND RECOMMENDATIONS

Based on the test results the following is concluded:

1. The system to be used for the threshold lighting should consist of 300-W 300 PAR56/NSP, 120-V (rated 125-130) lights with FAA-E-982D lampholders and standard green filters spaced 10 ft apart extending completely across the active threshold from edge light to edge light.

2. Having improved the visual guidance and conspicuity of the green threshold lights, the red wing bar lights did not appear to be necessary. However, if the prethreshold lights are to be installed, the five-light bars should be the same type fixtures and lamps as used for the threshold lights, but with red filters.

REFERENCES

1. Revised Approach Lighting Criteria, Department of Transportation, Federal Aviation Administration, Order 6850.9, Para. 5d, April 9, 1975.

2. Brown, Guy S., Test and Evaluation of Modifications to ALSF-1 Threshold and Prethreshold Lighting to Improve Visual Guidance for Category II Operations, National Aviation Facilities Experimental Center, Technical Letter Report NA-77-47-LR, September 1977.

3. Brown, Guy S., Review of Equipment and Installation Options for MALS, and MALSR Threshold Lights, NA-77-35LR, July 1977.

4. Brown, Guy S., Test and Evaluation of MALSR Threshold Lights, NA-78-35LR, June 1978.

APPENDIX A

REVIEW OF EQUIPMENT AND INSTALLATION OPTIONS FOR MALS, MALSF, AND MALSR THRESHOLD LIGHTS

INTRODUCTION

PURPOSE

The purpose of this review is to aid in making a selection of lamps, fixtures, and power source arrangements for test and evaluation of threshold lights to be used with MALSR for 2400-foot RVR, Category I, conditions and for MALS and MALSF installations where additional threshold lighting may be required. The content of this report summarizes information on commercially available equipment, possible ways of connecting into the present lighting systems, and the extent of additional power that will be required to supply the improved threshold lights. Approximate costs of procuring and installing representative examples of the improved lights are also summarized.

BACKGROUND

It is widely agreed and an accepted practice for Category I and II operations, that the runway threshold must be lighted with a conspicuous row of green threshold lights that are reasonably balanced in intensity ratio with the approach and runway lights to provide the pilot with adequate visual guidance. Where high intensity ALSF-I and ALSF-II approach light systems are installed for Category I and Category II operations a full row of green threshold lights is included as part of the approach light system and is powered from the approach light power source.

Medium intensity MALS-type systems have been installed in the approach zone to runways that were not previously equipped with approach lights. These systems do not include threshold lights as part of the MALS, but rely on the airport system of green threshold lights, usually four on each side of the threshold, that are powered by and are part of the airport runway lighting system.

The inadequacy of threshold lights for Category I operations has long been a source of complaint from user organizations: air carrier, general aviation, and military. It is recognized that the MALSR systems should be brought up to a similar degree of guidance as called for by ALSF-I,Category I systems that were recently upgraded. With ALSF-1, this was accomplished by increasing the intensity of the PAR-56 lamp wattage from 300 to 500 watts while using standard low-profile, above-ground, threshold lighting fixtures. Hence, this program has been established to test and evaluate threshold lights for new MALSR installations as well as for retrofitting existing systems with improved threshold lighting. With suitable improvements in threshold guidance, new and retrofit MALSR systems should comply with ICAO, Category I minimum requirements, providing proper intensity ratios are attained among the approach, threshold, and runway edge lights.

Since there are many available ways of accomplishing this improvement in threshold lighting, a selection must be made of the most promising methods and equipments for test and determination of a standard. It is hoped that the data and discussion contained herein will permit selection of those candidates.

REQUIREMENTS

The number of lights required is determined by runway width and the standard (ALSF-1 and ICAO) spacing of 10 feet, with the outer lights inline with the runway edge lights located 10 feet beyond the pavement. This gives a requirement for 18 threshold lights for the common runway width of 150 feet for a full system. If the present eight threshold lights associated with the airport runway edge lighting system are used, and MALS threshold lights are added to fill-in the center gap between the airport threshold lights, 10 added lights would be required for the common runway width.

INTENSITY

To aid in estimation of the absolute intensity requirements and the intensity requirements for suitable balance in the total lighting system, figure I portrays graphically the relationship of light intensity in candela (cd) and the visual situations represented by homogeneous atmospheres that produce RVR measures of 2400, 2600, and 2800 feet. The equation from which these graphed data were prepared is as follows:

$$I = \frac{E_t \left(\frac{VR}{5280} \right)^2}{\left(t_b \right)^{VR/b}}$$

In the calculation, I is the required target light intensity in candelas. E_t represents the daytime visual illuminance threshold of 1000-mile candles (1000 lumens per square mile). VR is the visual range that is required, or the desired distance for visual recognition of the subject target light. The term t_b represents atmospheric transmittance per transmissometer baseline distance, b, to support an RVR at runway edge light step 5 (10,000 cd). Values of t_b are 0.668 for RVR of 2400 feet, 0.699 for RVR of 2600 feet, and 0.727 for RVR of 2800 feet. The baseline distance, b, is selected as 250 feet. It should be noted that the 10,000 cd value is obtained as being representative of the inservice intensity in the direction from which it would be viewed by the pilot during a flare and landing. Although peak intensities of high intensity runway edge lights, L-819/862, are higher, it is common United States and ICAO practice to base step 5 RVR computations on a 10,000 cd standard. Reference: Douglas, C. A. and Booker, R. L., "Visual Range: Concepts, Instrumental Determination and Aviation Applications," National Bureau of Standards.

The stated requirement (RD&E Form 9550) for sufficient candlepower for the green threshold lights to be visible at least 2800 feet in 2400 foot RVR atmospheric conditions would require an effective intensity of approximately 26,000 cd, as shown in figure 1. Also, as shown in figure 1, approximately 10,000 cd is required for a visual range of 2400 feet, while about 7,500 cd. is required for a visual range of about 2300 in 2400 foot RVR conditions.

The ALSF-I and II, PAR-56 green threshold lights, used for Category I and II operations, provide about 9,000 cd. in green. This is considered to be a reasonable balance in intensity when operating with high intensity ALS white approach light bars and High Intensity Runway Lights (HIRL). Therefore, the PAR-56 threshold lights probably provide an intensity that could be considered as maximum for use with the medium intensity PAR-38, MALS lights.

LAMPS, LAMP DATA, FILTERS, AND LAMP HOLDERS

Commercially available 120 volt and 6.6 amp constant-current lamps were reviewed. Those lamps which have potential application as threshold lights for MALSR systems are listed in table 1 and are identified with an asterisk. The remaining lamps in the table are used for airport lighting, as indicated, and are listed for comparative purposes. Lamp

DAYLIGHT CONDITIONS

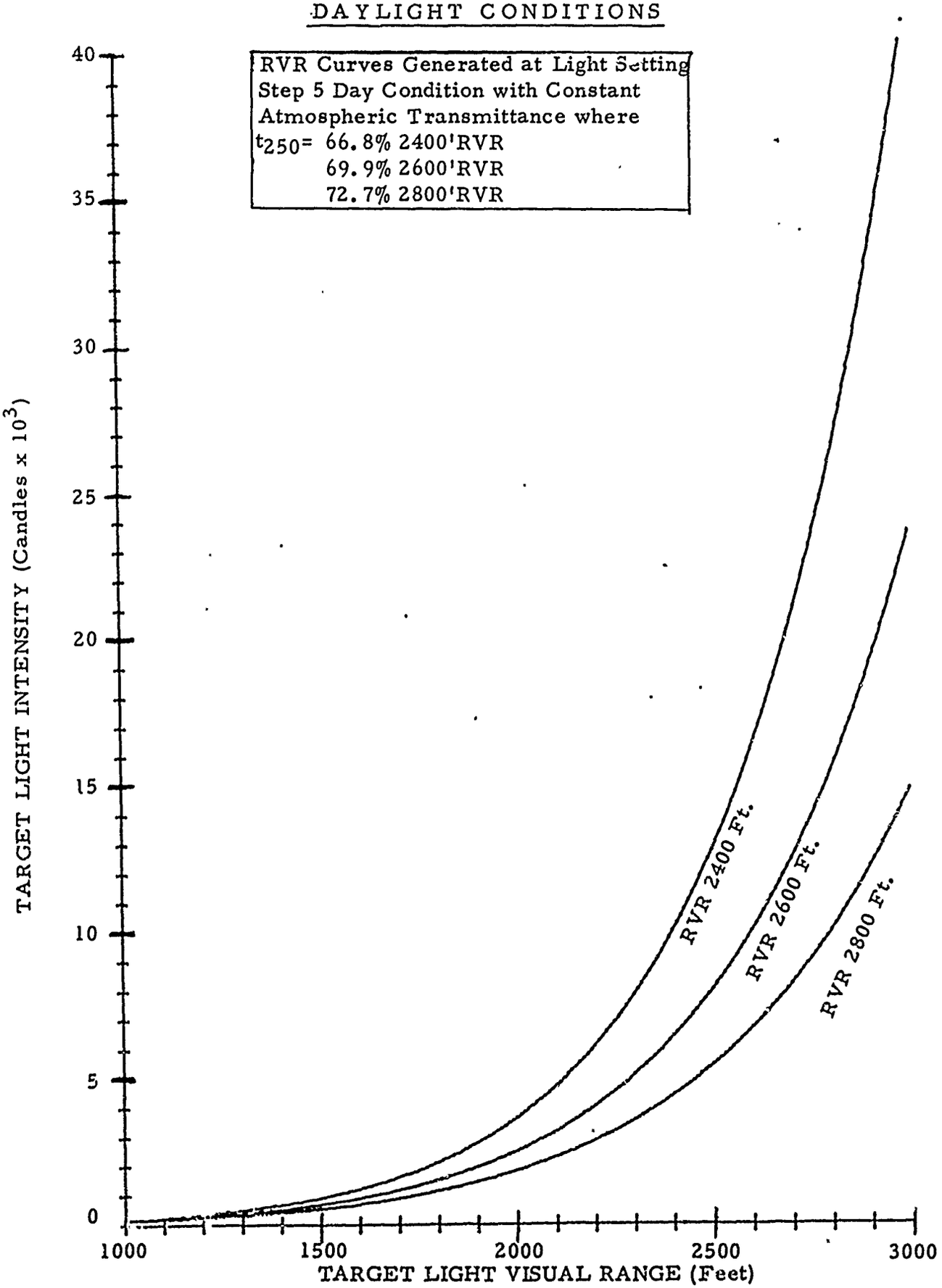


FIGURE 1. TARGET LIGHT INTENSITY VERSUS VISUAL RANGE

TABLE A-1. LAMP AND INTENSITY DATA (REVISED 9/22/77)

	Type Lamp	Volts/ Amps	Watts	Design Life (hours)	Initial PBCP(a) (clear)	Beamspread to 10% PBCP Hor.°	Beamspread to 10% PBCP Ver.°	Beamspread to 50% PBCP Hor.°	Beamspread to 50% PBCP Ver.°	Initial PBCP(b) (green)	Visual Range(c) w/green filter (2400RVR-day)
1.	150PAR38/SP	120	150	2000	10,000(d)	30	30	15	15	1,700	1,750
2.	*Q250PAR38SP	120	250	3000	25,000	24	24	12	12	4,250	2,050
3.	*200PAR46/3NSP	120	200	2000	31,000(d)	23	17	N/A	N/A	5,270	2,150
4.	**300PAR36/2NSP	12)	300	2000	47,000(d)	20	15	N/A	N/A	7,990	2,300
5.	**300PAR56/2SP	120	300	2000	70,000(d)	20	15	N/A	N/A	11,900	2,450
6.	*Q500PAR56NSP	120	500	4000	96,000(d)	32	15	N/A	N/A	16,320	2,600
7.	Q20A/PAR56 ALS, clear	20A	300	500	27,000	50	20	39	12	4,590	2,100
8.	Q20A/PAR56/1 ALS w/filters	20A	500	500	48,000	50	25	40	12	8,160	2,300
9.	L-862 HIRL R/W Edge	6.6A	100	500	13,000	11	7	13	7	2,210	1,875
10.	*L-862 HIRL Threshold	6.6A	200	500	26,000(e)	19(e)	9(e)	13(e)	7(e)	4.420	2.075
11.	*L-819 HIRL Edge & Threshold	6.6A	210	500	25,000	5	4	8	8	4,250	2,050
12.	L-802 HIRL Edge & Threshold	6.6A	45	1000	1,000	3	2	6	7	170	1,200
13.	***300PAR56/NSP	125-130	300	2000	50,000(f)	20	15	12	9	8,500	2,340
14.	***399PAR	115	399	100	30,000	52	22	38	13	5,100	2,130

* Candidate lamps for test
** Delete, excessive heat
*** Add candidate lamps
N/A Not Available

(a) Peak Beam Candle Power (PBCP) or Candelas.
(b) Green filter ratio 0.17 x clear value.
(c) From figure 1 in feet.
(d) Approximate initial mean candlepower in central 5° cone.
(e) Sepco data, 3/28/77
(f) Operated at 120V.

intensity and other data are also included under headings that are self-explanatory. Manufacturers data on the horizontal and vertical beamspread to 50 percent peak beam candle power are not available for the commercial (nonairport) lamps. Hence, photometric measurements with horizontal and vertical distribution curves will be made at NAFEC on samples of those lights selected for test and evaluation.

Data on the initial peak beam candle power in green were calculated using a green filter ratio of 0.17 x the clear value. Other filters have a ratio of 0.20, while paint-type coatings, such as the SEPcoated filters, will have higher light transmission. The coating-type filter has been developed primarily for application to lenses used with runway edge and taxiway lights. Use of coatings of this type applied directly to the face of the lamp has not yet been fully evaluated for compliance with aviation chromaticity and light transmission specifications. Durability, considering the heat generated on the face of the lamp and the environmental conditions to be encountered operationally over a period of time, may present problems that would have to be evaluated for the particular type lamp. Further development may be required.

Dichroic color filters, such as used in the manufacture of PAR-38 color lamps for general commercial purposes, do not meet the aviation color specifications. It is reported that numerous attempts to use this technique over the past 25 years have failed to produce a satisfactory lamp for aviation use. Reports indicate that possibly a development contract with optical specialists, such as Bausch & Lomb, who contract with lamp manufacturers for dichroic filters, could produce colors in the desired spectrum. Another alternative is the use of colored face plates to replace the clear face when the lamp is manufactured, such as has been used for PAR-36 lamps in special military applications. This procedure is reported to be extremely costly. Therefore, considering development time and cost, it is doubtful that either coated or dichroic filters can be considered, at this time, for MALS threshold lights. Standard glass filters (Kopp) in aviation green are available in three sizes, 4 27/32-inch, 6-inch, and 8-inch diameters, which can be adapted to the lampholder in the conventional manner.

Lampholders are commercially available for all size lamps either in aluminum or cast metal with deep shields or hoods to protect base and neck of the lamp. With the exception of standard PAR-56 lampholders manufactured to FAA specifications, other commercial units require a method of aiming and tests of ability to withstand wind and jet blasts.

POWER FOR MALS THRESHOLD LIGHTS

There are two possible sources for power to the MALS threshold lights: (1) from the FAA 120/240 volt MALS power source, or (2) from the airport constant-current runway lighting system. A choice between these may be influenced by several factors, such as the decision whether to supplement the present eight airport lights with 10 additional lights or to install a new full-width threshold made up of 18 lights. Also, in some older systems, the present eight airport threshold lights are not spaced at the currently required 10 foot intervals, and some are medium intensity which will require replacement. Other considerations are the capacity of the airport regulator, reimbursement agreements with the airport for power, and maintenance of the threshold system.

When installing a new MALS system with integrated threshold lights, a full-width threshold system powered from the MALS 120/240 volt source would require additional trenching and cable to extend the power from Stations 2 and 4 plus the width of the runway for a total length of approximately 600 feet. Also, a larger 15 kw transformer would have to be used instead of the 10 kw unit for lamps in the 200 to 300 watt range, or a 20 kw unit for 500 watt lamps. The additional capacity could also be used to power a VASI or other future needs. Use of 6.6 amp series lights, such as the L-862, would in addition to the above trenching and cable, require stepdown transformers for each of the lights powered by 120/240 volts. These and other power requirements are listed in table 2.

When retrofitting an existing MALS system with a full-width threshold, it would ordinarily be necessary to add trenching and cable from the power source near Station 10, an average distance of about 1400 feet. This is because most systems do not have appropriate size cable for the additional power requirements. The 10 kw transformer commonly used for the approach lights has an excess capacity of about 2.75 kw. An additional 2.5 kw transformer would be adequate for lamps up to 250 watts. (See table 2 for other combinations of lamps and numbers of lights.)

Added lights to fill-in the gap between the threshold lights provided by the airport would require, for a new installation, the same trenching and cable (600 feet) to the threshold as described for a full system of lights. The additional capacity of the MALS 10 kw transformer could be utilized for 10 lamps up to 250 watts with 150 foot wide runways. (See Table 2.) Higher wattage lamps for either 150 or 200 foot wide runways would require 15 kw transformers. As previously mentioned, the use

of 6.6 amp constant-current lights, such as the L-862, to fill-in the gap would require step-down transformers for each of the lights powered from 120/240 volts. Retrofit of existing systems to provide additional lights to fill-in between the airport's threshold lights would require the same trenching and cable (1400 feet) as described for a new installation with a full-threshold system. The MALS 10 kw transformer would accommodate 10 additional lights up to 250 watts for runways 150 ft wide. An additional 2.5 or 5 kw transformer would be required for higher wattage lights and/or for runways 200 feet wide. With either a full system or added lights, an interlock system would be required to insure that the threshold, approach, and runway lights operate on the same step or intensity setting.

Use of power from the airport constant-current runway lighting system would require the same number of lights (18) described using power from the 120/240V MALS for full-threshold lighting or the alternative of added lights (10) to fill-in the gap between the existing eight threshold lights. An agreement would be necessary between the FAA and the airport to reimburse the airport for power used for the MALS threshold lights. Similarly, an agreement on installation and maintenance costs would be necessary.

TABLE A-2. POWER REQUIREMENTS

	10 Lights[a]		18 Lights[b]	
Lamp Wattage	Threshold Only	Threshold +MALS[c]	Threshold Only	Threshold +MALS[c]
200	2.0Kw.	9.25	3.6	10.85
250	2.5	9.75	4.5	11.75
300	3.0	10.25	5.4	12.65
500	5.0	12.25	9.0	16.25

(a) Ten added lights to fill-in between the airport threshold lights for runways 150 feet wide.

(b) Eighteen light systems, for runways 150 feet wide, complete and independent of the airport's runway lighting system.

(c) Total power required for both threshold and approach lights not including line loss, about 5 percent or less.

NOTE: The standard MALS without threshold lights uses 7.25 kw from the 10 kw transformer commonly installed.

Since the 10 lights located between the four lights on each side of the threshold would be required only when the MALS was in use, it would be necessary to provide a switching control that would deactivate this center section of lights during good weather when only the runway edge and eight threshold lights are required. This would require a switching or shorting circuit from the 120/240 V MALS to control by relay operation of these threshold lights only when the MALS was in use. Trenching and cable would be required from Station 2 (200 feet from the threshold) to provide power for the shorting relay. An additional interlock system would be required to insure that all threshold and edge lights powered from the runway circuit, as well as the MALS, operate on the same step or intensity setting.

Full threshold lighting or added lights to fill-in the gap between the airport threshold lights for both new and retrofit installations would require power as previously described and shown in table 2. To determine the power available from the airport runway system for threshold lighting, each airport would have to be surveyed to determine the capacity of the regulators and the cable installed. Inquiries indicate that few airports would have the excess capacity to power the threshold lights. The cost of replacing an airport regulator or adding an appropriate size, together with costs of trenching and cable, if required, would have to be investigated for each installation.

COSTS

Due to the variety of situations that will be encountered in making the new and retrofit installations, as discussed in previous paragraphs, and the several alternative methods that may be considered for accomplishing the improvement of threshold lights, it does not seem appropriate at this time to estimate specific costs for typical installations. Approximate costs to procure and install typical components can be stated; however, and illustrative examples covering lamps, filter transformers, cable, trenching, (table 3) and installation are summarized in table 3.

SUMMARY

This report has presented data on the requirements for MALSR threshold lights, candidate lamps and fixtures, power requirements, and estimated costs. It is anticipated that this data will be helpful in decisions as to the units to be tested and the system connections to be considered. Following selection of the lamps and fixtures, photometric tests, and evaluation flight tests will be conducted at NAFEC, as requested in the subject project assignment.

TABLE A-3. APPROXIMATE COST (IN DOLLARS) (REVISED 1978)

LIGHTS

Type	Lamp	Filter, green	Lamp Holder	Low Profile Mounting(1)	Mounting Stake	Total
L-862, 200w	9.90				8.00	62.00(2)
Q250PAR38/SP	5.63(3)	5.00(4)	14.93	10.00	8.00	38.50
200PAR46/3NSP	2.90	5.00	15.00	10.00	8.00	40.90
300PAR56/NSP	6.30	6.00	14.00	10.00	8.00	44.30
399PAR	7.27	6.00	14.00	10.00	8.00	45.27
Q500 PAR56/NSP	9.63	6.00	14.00	10.00	8.00	47.63

(1) Includes frangible coupling, wiring, etc.
(2) Plus cost of isolation or stepdown transformer for each light.
(3) Commercial quote, quantity 10 or more (not available Federal Stock) Quote on other lamps are Federal Stock prices.
(4) 4 - 27/32" or 6" glass

TRANSFORMERS

6.6A	Isolation	$ 60.00	120/240V	5kw	$ 350.00
120/30V	Stepdown	90.00	120/240V	10kw	425.00
240/30.3V	Stepdown	58.00	120/240V	15kw	550.00
120/240V	2 1/2kw.	275.00	120/240V.	20kw	625.00

INSTALLATION

Fixtures: Stake Mounted, $50.00/light; Pavement Mounted, $100.00/light.

Trenching and cable (No. 8) complete including backfill: $2.00/foot.

REGULATORS

Depending on capacity: $2,000 to $6,000.

The proposed test site is Runway 4 at NAFEC. This runway, 150 feet wide and 6100 feet long, is equipped with L-819 High Intensity Runway Edge Lights and a MALSR, Medium Intensity Approach Light System with Runway Alignment Indicator Lights.

APPENDIX B

ISOCANDELA CURVES

LAMP TYPE	WATTS	VOLTS/AMPS	PAGE
L-862	200	6.6A	B-1
Q250PAR38/SP	250	120V	B-2
300PAR56/NSP	300	125-130V	B-3
399PAR	399	115V	B-4
Q20A/PAR56	300	20A	B-5

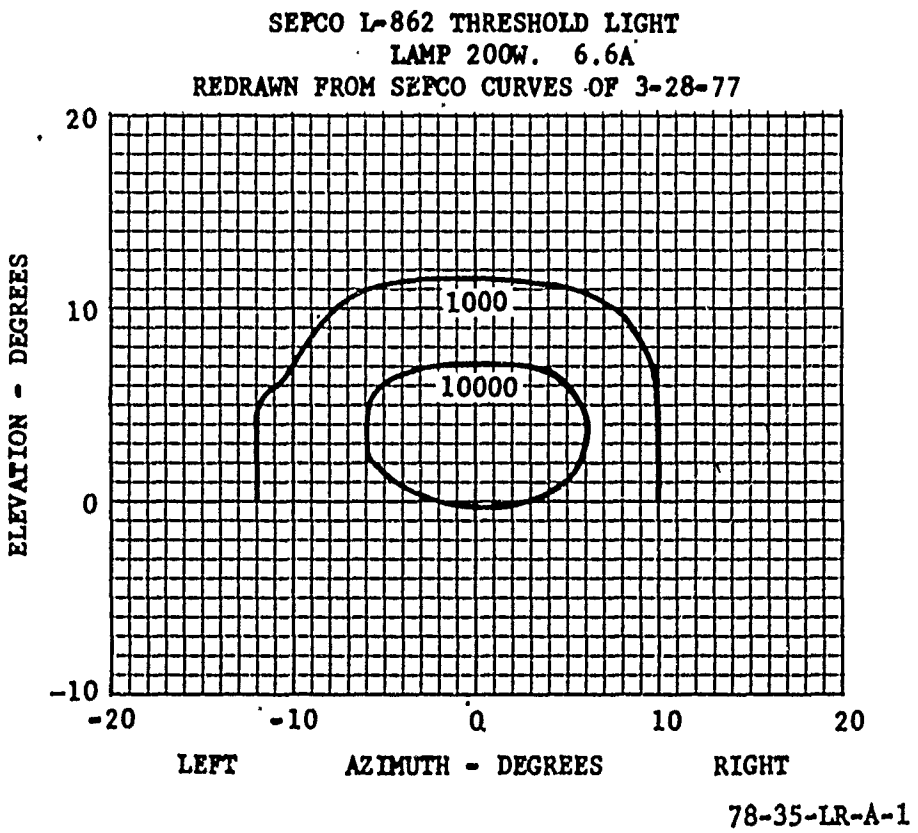


FIGURE B-1. ISOCANDELA CURVES INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES

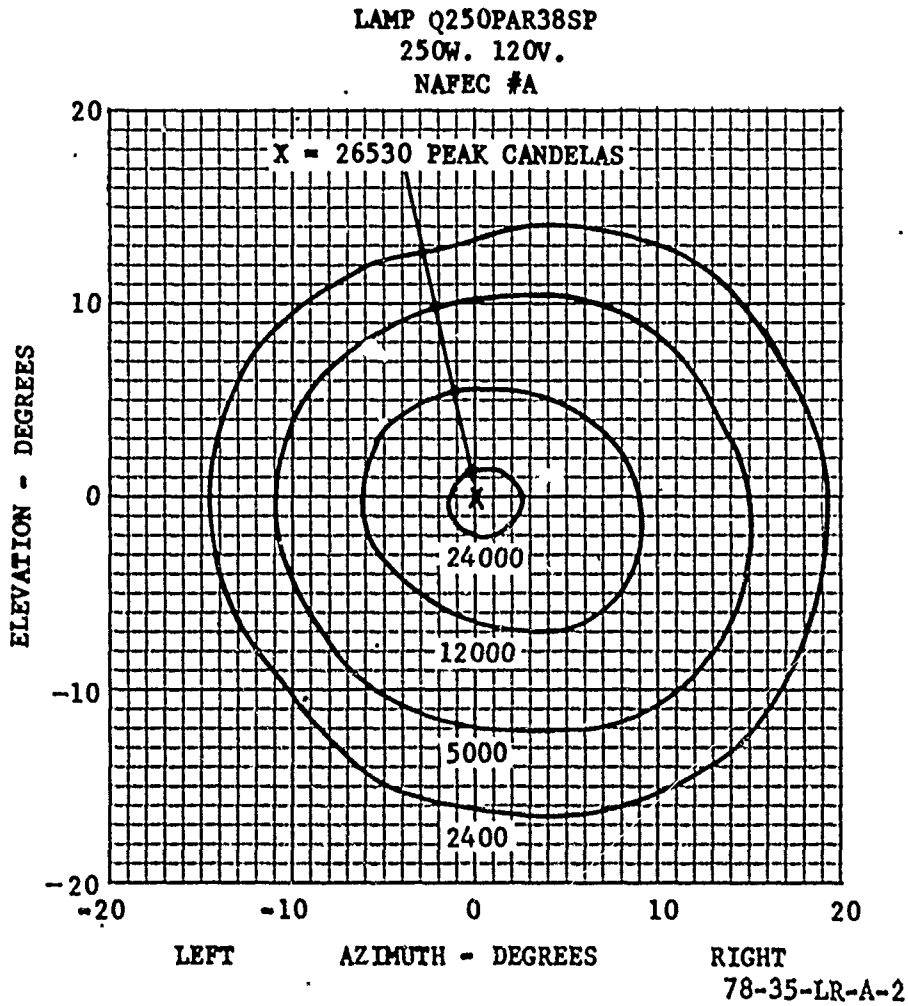


FIGURE B-2. ISOCANDELA CURVES INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES

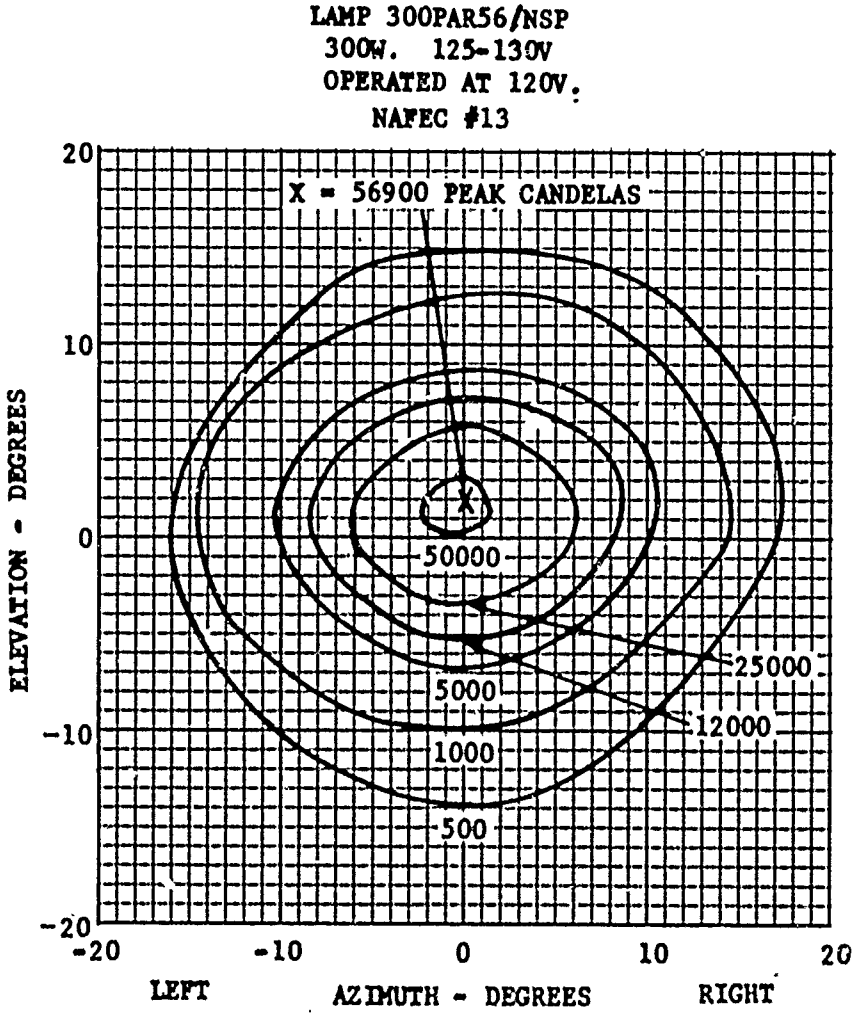


FIGURE B-3. ISOCANDELA CURVES INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES

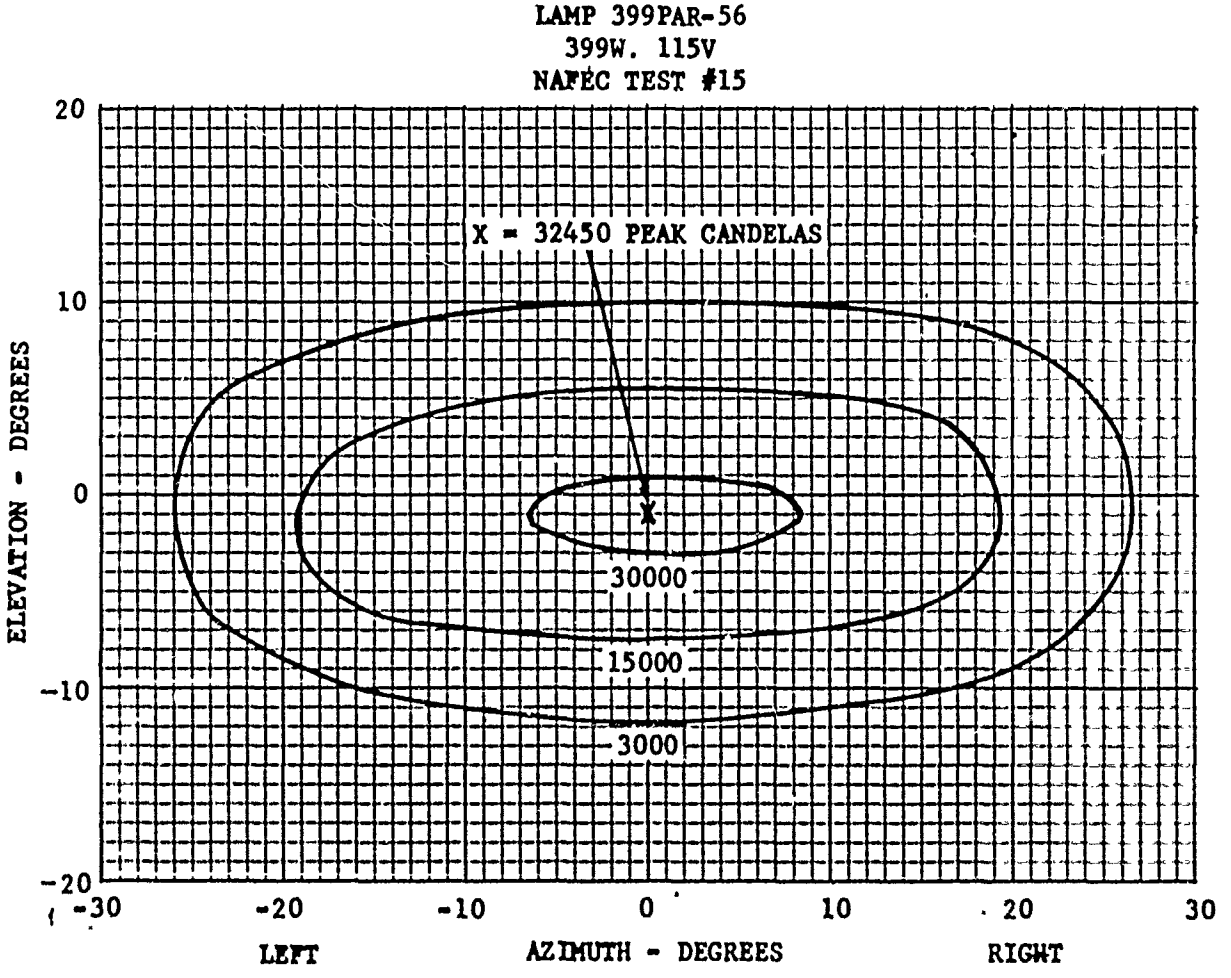


FIGURE B-4. ISOCANDELA CURVES INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES

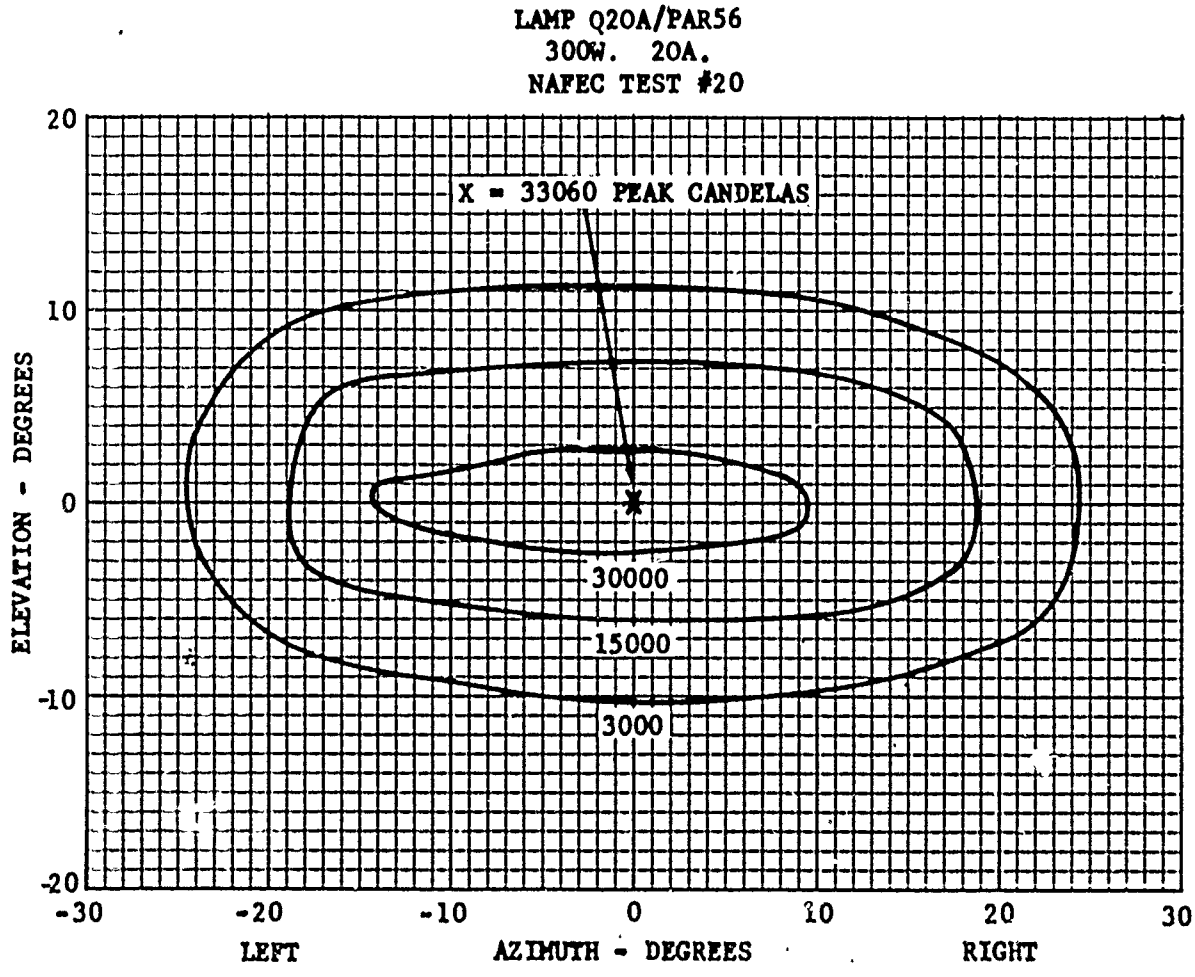


FIGURE B-5. ISOCANDELA CURVES INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES

APPENDIX C

PHOTOMETRIC DATA FOR MALSR THRESHOLD TEST LAMPS

NAFEC TEST LAMP NO.	TYPE LAMP	WATTS	VOLTS/AMPS	PAGE
"A"	Q250PAR38/SP	250	120	C-1
"B"	Q250PAR38/SP	250	120	C-2
13	300PAR56/NSP	300	125-130	C-3
14	300PAR56/NSP	300	125-130	C-4
15	399PAR56	399	115	C-5
15	399PAR56	399	115	C-6
16	399PAR56	399	115	C-7
19	Q20A/PAR56	300	20A	C-8
20	Q20A/PAR56	300	20A	C-9

AZIMUTH	ELEVATION -1.0	.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0
-15.0	2150	2130	2080	2080	1960	1870	1780	1690	1550	1440	1310	1190	1080	990	910
-14.0	2580	2620	2570	2460	2380	2250	2130	1960	1820	1670	1520	1360	1210	1080	980
-13.0	3250	3170	3090	3020	2930	2670	2500	2350	2170	1920	1730	1540	1350	1190	1050
-12.0	3920	3940	3840	3650	3490	3260	3030	2750	2500	2250	2010	1770	1550	1320	1170
-11.0	4880	4750	4600	4490	4280	3880	3570	3290	2970	2580	2270	1990	1720	1480	1300
-10.0	5840	5890	5670	5500	5090	4740	4330	3840	3420	3020	2630	2260	1940	1660	1420
-9.0	7120	7170	6960	6560	6210	5720	5200	4600	4060	3540	2990	2540	2160	1850	1570
-8.0	8590	8470	8440	7940	7470	6700	6050	5450	4780	4020	3410	2880	2420	2040	1700
-7.0	10080	10270	9970	9600	8990	8010	7200	6240	5420	4620	3890	3250	2660	2200	1840
-6.0	12100	12370	12030	11550	10470	9490	8420	7240	6190	5210	4270	3540	2910	2380	1930
-5.0	14550	14460	14440	13420	12370	11080	9510	8190	6800	5660	4640	3810	3090	2510	2030
-4.0	16910	17330	16740	15810	14070	12440	10560	8950	7420	6080	4950	4020	3230	2590	2090
-3.0	19550	19970	19630	17900	16020	13710	11650	9590	7870	6400	5160	4180	3360	2710	2160
-2.0	22550	23030	21950	19830	17530	14980	12380	10190	8240	6640	5350	4330	3470	2800	2240
-1.0	24730	25160	23930	21660	18820	15770	13010	10540	8540	6880	5550	4470	3620	2920	2350
.0	26140	26530	25180	22550	19470	16270	13390	10820	8740	7080	5730	4640	3790	3070	2490
1.0	26050	26430	25020	22520	19430	16330	13490	10950	8890	7250	5930	4830	3960	3230	2630
2.0	24810	24920	23840	21510	18890	16000	13370	11030	9090	7480	6130	5070	4150	3380	2770
3.0	22680	22490	21660	19820	17780	15250	13030	10950	9150	7630	6350	5250	4350	3560	2900
4.0	20750	20370	19290	18120	16290	14430	12430	10630	9040	7650	6410	5340	4430	3640	2970
5.0	18680	18160	17450	16220	14910	13180	11720	10070	8710	7500	6310	5300	4410	3610	2950
6.0	17120	16510	15550	14690	13400	12120	10740	9450	8260	7220	6110	5140	4320	3540	2890
7.0	15450	14790	14060	13110	12180	10880	9860	8780	7740	6760	5790	4960	4170	3450	2800
8.0	13920	13360	12430	11530	10750	9820	8840	7970	7130	6330	5470	4730	3980	3310	2700
9.0	12170	11640	10790	10190	9310	8590	7800	7120	6570	5830	5130	4420	3740	3110	2570
10.0	10510	10010	9460	8720	8180	7640	6990	6420	5890	5360	4700	4100	3520	2940	2410
11.0	9180	8750	8100	7460	7040	6620	6130	5710	5250	4800	4260	3740	3210	2710	2270
12.0	7820	7470	7090	6580	6100	5740	5440	5040	4670	4370	3870	3410	2950	2460	2090
13.0	6690	6400	6120	5730	5420	5110	4760	4510	4190	3860	3420	3090	2630	2250	1870
14.0	5870	5640	5310	5110	4770	4470	4240	3980	3650	3430	3040	2700	2340	1980	1700
15.0	5020	4870	4690	4470	4170	3900	3660	3430	3200	2930	2610	2370	2060	1770	1530
16.0	4380	4180	4050	3840	3650	3420	3200	2920	2700	2530	2260	2010	1800	1560	1360
17.0	3660	3590	3510	3330	3000	2880	2700	2520	2330	2110	1940	1730	1540	1360	1180
18.0	3090	3060	2910	2770	2630	2450	2290	2140	1990	1860	1660	1500	1320	1190	1070
19.0	2530	2490	2450	2340	2150	2060	1890	1770	1660	1550	1390	1260	1160	1040	960

AZIMUTH	ELEVATION -16.0	-15.0	-14.0	-13.0	-12.0	-11.0	-10.0	-9.0	-8.0	-7.0	-6.0	-5.0	-4.0	-3.0	-2.0
-15.0	700	780	830	920	1020	1130	1260	1400	1530	1660	1790	1900	2030	2060	2100
-14.0	750	830	910	1030	1160	1300	1470	1660	1830	1980	2140	2290	2400	2520	2520
-13.0	810	910	1010	1140	1320	1480	1670	1920	2130	2380	2580	2780	2960	3050	3160
-12.0	880	1010	1130	1330	1480	1740	1980	2280	2550	2790	3070	3340	3530	3660	3800
-11.0	980	1150	1310	1500	1750	2000	2290	2660	2990	3310	3750	3960	4350	4530	4710
-10.0	1100	1320	1520	1750	2040	2350	2730	3160	3580	3990	4430	4830	5140	5520	5780
-9.0	1260	1490	1720	2030	2370	2690	3170	3600	4190	4700	5260	5750	6140	6490	6830
-8.0	1400	1700	1990	2300	2680	3090	3630	4110	4700	5420	6100	6720	7260	7730	8230
-7.0	1600	1940	2270	2630	3060	3500	4030	4630	5300	6020	6850	7630	8350	9220	9860
-6.0	1810	2170	2520	2970	3390	3860	4520	5100	5910	6730	7740	8720	9740	10870	11760
-5.0	1990	2420	2810	3270	3818	4340	4940	5670	6480	7500	8700	9940	11280	12480	13670
-4.0	2200	2670	3050	3580	4120	4760	5360	6190	7130	8190	9570	11080	12720	14590	15810
-3.0	2330	2840	3290	3810	4410	5060	5780	6660	7690	9010	10590	12480	14570	16560	18540
-2.0	2430	2960	3440	4000	4660	5340	6180	7090	8330	9700	11460	13570	16070	18520	20890
-1.0	2480	3020	3510	4130	4840	5688	6470	7560	8850	10380	12290	14560	17290	20330	23090
.0	2510	3060	3558	4200	4920	5720	6700	7940	9380	11080	13130	15450	18230	21320	24160
1.0	2550	3090	3600	4250	4990	5810	6840	8170	9750	11600	13730	15990	18590	21450	24310
2.0	2500	3130	3630	4300	5030	5900	6980	8360	10010	11890	14040	16180	18550	21000	23330
3.0	2640	3180	3680	4330	5070	5950	7040	8440	10170	12090	14190	16280	18290	20110	21920
4.0	2700	3250	3750	4380	5110	5980	7090	8510	10210	12110	14150	16090	17830	19250	20210
5.0	2740	3300	3790	4410	5110	5960	7040	8450	10100	11930	13840	15640	17180	18100	18830
6.0	2720	3280	3770	4370	5040	5860	6930	8260	9810	11440	13200	14950	16090	16920	17190
7.0	2650	3220	3680	4260	4920	5690	6710	7910	9300	10810	12230	13740	14670	15390	15770
8.0	2550	3080	3540	4110	4780	5510	6460	7530	8750	9940	11210	12330	13290	13910	14283
9.0	2420	2880	3360	3930	4560	5300	6110	6990	7980	9060	10090	11030	11840	12120	12460
10.0	2250	2710	3130	3690	4300	4980	5650	6380	7190	8030	8850	9580	10220	10660	10740
11.0	2060	2490	2900	3410	4020	4580	5210	5860	6510	7070	7870	8460	8758	9100	9180
12.0	1880	2270	2640	3130	3640	4140	4700	5230	5750	6190	6830	7290	7640	7930	8000
13.0	1720	2050	2360	2800	3230	3740	4150	4590	5040	5520	5920	6260	6550	6790	6830
14.0	1520	1830	2120	2460	2890	3260	3690	4080	4470	4770	5110	5500	5590	5750	5820
15.0	1350	1590	1850	2180	2500	2820	3190	3550	3870	4200	4470	4700	4870	5020	5070
16.0	1210	1420	1640	1880	2150	2470	2730	3020	3370	3570	3780	4070	4110	4250	4320
17.0	1060	1250	1420	1640	1870	2090	2360	2610	2830	3050	3230	3370	3520	3640	3700
18.0	950	1100	1240	1390	1620	1790	1970	2220	2400	2520	2730	2850	2980	3080	3120
19.0	850	960	1070	1210	1360	1510	1680	1830	1980	2120	2230	2320	2420	2500	2540

C-1. INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES—NAFEC TEST LAMP A(Q250PAR38SP, 250W, 120V)

AZIMUTH	ELEVATION -17.0	-16.0	-15.0	-14.0	-13.0	-12.0	-11.0	-10.0	-9.0	-8.0	-7.0	-6.0	-5.0	-4.0	-3.0	-2.0	-1.0
-15.0	950	1020	1130	1280	1420	1650	1840	2050	2230	2440	2530	2550	2550	2460	2460	2370	2430
-14.0	1020	1120	1280	1490	1730	1980	2250	2510	2830	3000	3130	3140	3130	3130	2990	3000	2970
-13.0	1110	1260	1460	1730	2050	2390	2810	3170	3470	3670	3820	3960	3810	3800	3650	3650	3630
-12.0	1220	1420	1660	2010	2420	2850	3360	3810	4190	4410	4610	4770	4750	4600	4430	4420	4380
-11.0	1370	1590	1930	2310	2810	3410	3930	4480	4960	5430	5660	5700	5710	5560	5330	5480	5410
-10.0	1490	1810	2200	2710	3300	3910	4620	5290	5890	6350	6700	7000	6850	6950	6700	6600	6480
-9.0	1630	2010	2520	3070	3720	4420	5220	6000	6720	7300	7830	8300	8500	8400	8420	8000	7810
-8.0	1810	2240	2770	3460	4210	5000	5790	6650	7500	8400	9150	9660	10060	10400	10170	10020	9670
-7.0	1950	2440	3030	3770	4600	5460	6420	7380	8390	9340	10320	11340	12070	12280	12480	12010	11600
-6.0	2100	2640	3290	4100	4970	5910	6880	7940	9060	10200	11410	12730	13730	14170	14500	14500	14140
-5.0	2210	2780	3480	4300	5190	6180	7230	8430	9790	11140	12600	13990	15240	16270	16860	16700	16560
-4.0	2310	2920	3630	4450	5350	6370	7490	8770	10200	11730	13370	15140	16650	17750	18660	18920	19100
-3.0	2410	3020	3740	4550	5470	6500	7650	8950	10470	12140	13870	15740	17440	18860	20180	21100	21820
-2.0	2460	3090	3820	4650	5550	6560	7700	9030	10560	12230	14020	15930	17790	19590	21430	23290	24410
-1.0	2470	3100	3820	4640	5540	6540	7670	8950	10440	12060	13810	15760	17730	19860	22100	24600	26570
.0	2430	3060	3770	4590	5460	6440	7470	8710	10130	11700	13390	15150	17170	19570	22130	24980	27200
1.0	2350	2960	3630	4430	5310	6200	7220	8390	9730	11200	12670	14480	16470	18860	21450	24150	26520
2.0	2250	2800	3480	4240	5060	5930	6910	7990	9220	10500	11910	13620	15450	17510	20020	22400	24140
3.0	2110	2630	3250	4000	4770	5600	6470	7480	8620	9830	11100	12420	13990	15960	17750	19970	21310
4.0	1940	2410	2990	3660	4340	5150	6040	6980	8020	8970	10040	11310	12630	13920	15570	16820	17760
5.0	1790	2190	2720	3310	3970	4730	5580	6430	7230	8180	9110	10000	11240	12210	13060	14180	14830
6.0	1630	1990	2400	2980	3590	4290	4980	5720	6540	7370	8180	8890	9660	10580	11100	11820	12160
7.0	1470	1770	2150	2610	3150	3760	4450	5120	5850	6470	7110	7830	8430	8860	9370	9520	9610
8.0	1330	1570	1910	2320	2770	3290	3910	4520	5150	5670	6210	6810	7280	7550	7870	7860	7840
9.0	1220	1410	1640	1980	2416	2850	3300	3800	4330	4860	5310	5650	6010	6320	6320	6210	6340
10.0	1100	1230	1460	1720	2010	2360	2790	3220	3660	3990	4340	4750	5000	5040	5180	5050	5140
11.0	1010	1120	1280	1490	1720	2000	2330	2680	2950	3300	3580	3760	3940	4100	4030	4050	3980
12.0	940	1030	1120	1270	1440	1640	1880	2130	2330	2590	2790	3040	3170	3170	3120	3120	3180
13.0	900	940	1030	1120	1250	1400	1560	1720	1940	2070	2230	2340	2420	2420	2480	2490	2430

AZIMUTH	ELEVATION .0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0
-15.0	2410	2490	2490	2380	2250	2050	1850	1640	1440	1270	1140	1020	920	850	800
-14.0	3050	3020	3010	2890	2730	2480	2250	1960	1780	1530	1330	1160	1030	930	870
-13.0	3700	3640	3600	3530	3250	2970	2680	2430	2110	1820	1550	1350	1150	1060	960
-12.0	4460	4330	4260	4150	3820	3600	3160	2860	2480	2120	1830	1560	1350	1190	1070
-11.0	5310	5280	5140	4830	4570	4170	3780	3340	2870	2520	2140	1840	1550	1330	1180
-10.0	6300	6200	5980	5740	5280	4810	4360	3920	3380	2910	2470	2100	1790	1530	1310
-9.0	7720	7480	7120	6610	6070	5610	4950	4453	3880	3350	2920	2410	2040	1720	1460
-8.0	9210	8850	8340	7700	7120	6420	5780	5050	4390	3870	3300	2780	2290	1950	1610
-7.0	11310	10500	9830	9280	8290	7360	6570	5850	5060	4350	3680	3080	2580	2130	1780
-6.0	13460	12910	12060	10950	9920	8680	7640	6600	5740	4890	4210	3430	2810	2320	1930
-5.0	16430	15390	14420	13010	11680	10050	8670	7350	6340	5340	4470	3710	3030	2520	2060
-4.0	19280	18780	17170	15870	13640	11510	9750	8170	6930	5780	4800	3970	3270	2690	2200
-3.0	22380	21930	20560	18330	15550	13170	10830	9080	7480	6210	5180	4210	3450	2810	2300
-2.0	25330	24860	23180	20470	17240	14470	11790	9730	7930	6550	5380	4430	3590	2920	2380
-1.0	27470	27010	25080	22030	18610	15320	12510	10200	8260	6790	5550	4540	3670	2990	2420
.0	28400	27920	25810	22700	19030	15620	12690	10360	8330	6800	5570	4550	3660	2990	2430
1.0	27510	27010	24920	22040	18440	15240	12430	10110	8140	6620	5420	4450	3590	2930	2400
2.0	25300	24860	22940	20430	17190	14388	11710	9570	7750	6340	5220	4270	3460	2850	2330
3.0	21790	21360	20290	17820	15440	13110	10750	8710	7140	5960	4930	4010	3300	2730	2230
4.0	18560	18140	16860	15350	13180	11370	9420	7880	6570	5420	4490	3750	3090	2550	2110
5.0	14930	14610	14080	12950	11250	9870	8280	7050	5800	4900	4109	3430	2820	2390	2010
6.0	12150	11930	11190	10430	9480	8220	7170	6050	5130	4370	3690	3100	2590	2220	1890
7.0	9860	9680	9110	8570	7630	6885	6120	5220	4469	3840	3180	2720	2320	2020	1740
8.0	8000	7820	7370	7010	6290	5720	5150	4420	3830	3250	2800	2430	2100	1850	1610
9.0	6260	6100	5970	5510	5160	4720	4120	3690	3150	2790	2450	2100	1880	1680	1480
10.0	5030	4930	4660	4460	4050	3730	3400	2980	2650	2310	2060	1850	1640	1490	1340
11.0	3900	3830	3750	3470	3270	3040	2710	2470	2160	1870	1790	1600	1460	1329	1200
12.0	3120	3060	2910	2800	2560	2400	2170	2000	1790	1640	1520	1410	1280	1180	1090
13.0	2380	2350	2320	2170	2070	1960	1790	1680	1510	1430	1310	1230	1140	1050	990

C-2. INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES—NAFEC TEST LAMP B(Q250PAR38SP, 250 W, 120 V)

AZIMUTH	EVALUATION -7.0	-6.0	-5.0	-4.0	-3.0	-2.0	-1.0	.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
-11.0	650	790	1000	1360	1860	2220	2700	3250	3160	3030	2740	2180	1770	1290	970	730	580
-10.0	760	1010	1380	2020	2800	3750	4730	5410	5710	5150	4580	3570	2760	2000	1410	990	720
-9.0	900	1320	1900	2910	4240	5690	7320	8530	9080	8700	7650	5860	4330	2880	2040	1310	930
-8.0	1090	1720	2650	4100	6190	8610	11190	13160	14080	12910	11200	8480	6190	4170	2760	1720	1170
-7.0	1340	2230	3620	5670	8460	11920	15600	18340	19560	18530	15360	11920	8340	5590	3630	2280	1590
-6.0	1630	2880	4690	7640	11300	16040	20970	24550	25900	24260	19590	15450	10840	7280	4720	2930	1990
-5.0	2030	3630	6110	9900	14710	21030	27330	31820	33160	30770	25270	19600	13920	9450	6140	3770	2240
-4.0	2440	4570	7670	12650	18900	26370	33910	39290	40720	37730	31330	24580	17710	12150	7880	4810	2780
-3.0	2930	5610	9560	15460	22560	31020	39130	45060	47080	44530	36760	30360	22190	15590	9810	5910	3430
-2.0	3380	6610	11220	17850	25370	34000	41790	48020	51530	50740	43700	36420	27400	18300	11750	6920	3920
-1.0	3750	7400	12460	19330	26990	34920	42110	48970	54270	55350	50520	40960	30740	20850	13270	7705	4250
.0	3880	7670	12840	19720	27070	34520	41630	49320	55650	56900	51830	41930	31570	21480	13[illegible]0	7970	4395
1.0	3780	7350	12.10	18920	26040	33530	40720	48020	53860	53790	47950	38940	29270	20410	13[illegible]9	7810	4320
2.0	3520	6630	11240	17440	24210	31360	38240	44680	48840	47520	42150	33460	25760	18010	11995	7200	4050
3.0	2980	5610	9630	15340	21540	28390	35030	41140	44080	41930	36580	28820	21820	15690	10620	6480	3700
4.0	2430	4540	7750	12600	18290	24840	31210	36890	39130	36720	31940	25110	19360	13700	9360	5740	3360
5.0	1950	3470	6000	9840	14600	20880	25830	30130	32870	31250	27720	22480	17080	12060	8160	5000	2950
6.0	1530	2580	4390	7140	10840	15720	19440	23120	25960	25530	23430	19120	14990	10430	7040	4260	2520
7.0	1170	1880	3050	5070	7320	10540	13860	17340	19560	19950	19020	15820	12370	8770	5800	3470	2090
8.0	900	1370	2140	3460	5060	7260	9650	12350	14210	14830	14500	12210	9490	6870	4520	2720	1630
9.0	730	1030	1520	2380	3520	5030	6660	8080	9720	10320	9780	8740	6830	4790	3230	1990	1270
10.0	620	800	1120	1630	2400	3450	4480	5340	6440	6700	6360	5750	4540	3260	2280	1480	1000
11.0	520	640	820	1150	1610	2210	2800	3380	3780	3870	3900	3330	2710	2050	1530	1100	790

AZIMUTH	EVALUATION -40.0	-35.0	-30.0	-25.0	-20.0	-15.0	-10.0	-5.0	.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0
-45.0	410	320	280	250	250	250	220	220	220	230	270	280	280	300	330	320	330
-40.0	330	300	270	280	280	270	240	230	220	230	260	280	270	300	310	340	320
-35.0	310	300	290	280	270	270	250	240	230	230	290	280	280	310	290	330	330
-30.0	290	320	290	300	280	280	270	280	270	260	280	280	280	290	300	310	330
-25.0	300	330	300	290	300	300	290	300	300	330	310	300	300	290	300	290	320
-20.0	310	310	300	310	330	330	340	360	370	340	330	320	320	290	290	300	320
-15.0	320	320	310	320	350	370	390	460	550	480	370	340	330	310	300	300	310
-10.0	320	330	330	340	360	390	500	1310	5530	2820	510	340	330	310	300	300	310
-5.0	320	340	340	350	370	450	660	5770	31410	14210	1290	410	330	340	300	280	300
.0	320	340	330	350	370	440	810	12940	49410	32360	2400	410	330	320	300	300	300
5.0	300	320	310	310	370	420	650	6160	32100	17600	1740	370	330	300	300	300	280
10.0	300	300	300	310	330	380	460	1170	5730	4640	760	340	300	310	300	300	300
15.0	310	280	300	290	310	350	370	400	640	670	390	300	300	300	280	300	300
20.0	290	280	280	290	310	320	320	310	340	300	300	270	280	290	290	290	300
25.0	290	290	290	280	290	290	290	280	270	260	250	260	270	270	290	300	300
30.0	300	300	290	290	280	280	260	240	240	230	230	250	240	270	290	290	290
35.0	330	310	290	300	290	260	250	220	230	220	220	230	250	280	280	280	290
40.0	330	300	290	290	290	260	250	220	200	220	220	220	260	270	280	290	310
45.0	330	310	310	270	290	250	260	220	200	210	230	220	220	250	270	300	340

C-3. INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES--NAFEC TEST 13 (300 W PAR56/NSP, 125-130 V, OPERATED AT 120 V)

AZIMUTH	EVALUATION -8.0	-7.0	-6.0	-5.0	-4.0	-3.0	-2.0	-1.0	.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0
-11.0	740	970	1350	1870	2460	3130	3650	3990	4000	3640	3090	2510	1950	1500	1170	920	760
-10.0	920	1280	2000	2780	4030	5390	6260	6890	6880	6150	5040	3910	2850	2070	1490	1100	870
-9.0	1160	1780	2890	4190	6050	8220	10390	11120	11120	9820	8180	5940	4120	2860	1920	1320	980
-8.0	1490	2420	3920	5980	8710	11750	14810	16600	16660	14690	11650	8680	5930	3850	2540	1620	1110
-7.0	1820	3040	4990	7690	11320	15550	20000	22670	22960	20390	16250	12130	8280	5470	3300	2030	1290
-6.0	2160	3670	6100	9450	14030	19470	24790	28460	29160	26210	21220	16000	10970	7080	4320	2620	1570
-5.0	2490	4320	7230	11220	16860	23120	30050	34790	35800	32530	26740	20480	14280	9250	5770	3330	1930
-4.0	2790	4930	8460	13200	19840	27490	35490	41160	42530	39640	32580	25530	18330	11940	7270	4150	2330
-3.0	3070	5660	9860	15360	22990	31960	40520	46840	48790	45610	39070	30940	21880	14600	8700	5010	2770
-2.0	3360	6280	11090	17330	25840	34580	43570	50150	53670	52430	45670	35780	25520	16800	10110	5750	3100
-1.0	3530	6720	11880	18580	27300	36170	45080	53180	58860	58190	50600	39680	27860	18480	11140	6250	3360
.0	3630	6890	12100	18810	27520	36620	46000	54740	60930	60060	52010	40440	28600	18940	11530	6510	3450
1.0	3500	6620	11630	18080	26550	35290	44070	51450	56840	55070	47680	37540	26980	18210	11220	6330	3360
2.0	3330	6130	10530	16460	24230	32060	39220	44980	48870	46910	40720	32610	24160	16390	10220	5890	3140
3.0	3070	5510	9320	14350	21070	27940	34630	39900	42660	40280	34690	27800	20420	14160	8950	5170	2850
4.0	2800	4910	8100	12340	18240	24460	31140	36120	37720	35190	29640	23380	17100	11840	7540	4430	2480
5.0	2570	4360	7170	10690	15780	21720	27800	32040	32950	30150	24880	19410	14100	9730	6240	3680	2080
6.0	2300	3870	6180	9290	13820	18840	23840	27520	27320	24770	20270	16020	11560	7780	5000	3040	1760
7.0	2000	3330	5350	8020	11700	16200	20260	22600	22570	20360	16640	12820	9340	6300	4050	2430	1450
8.0	1710	2820	4470	6760	9810	13400	16380	18500	18260	16410	13420	10280	7290	4990	3140	1940	1200
9.0	1390	2240	3590	5310	7790	10460	12790	13950	13720	12350	10130	7770	5460	3700	2390	1510	980
10.0	1150	1750	2710	4030	5810	7580	9000	9670	9810	8550	7110	5460	3860	2650	1770	1180	810
11.0	890	1290	1970	2750	3830	4800	5700	6340	6140	5650	4540	3680	2650	1800	1260	880	690

C-4. INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES--- NAFEC TEST 14 (300 W PAR56/NSP, 125-130 V, OPERATED AT 120 V)

AZIMUTH	ELEVATION -12.0	-11.0	-10.0	-9.0	-8.0	-7.0	-6.0	-5.0	-4.0	-3.0	-2.0	-1.0
-26.0	750	790	890	1000	1210	1530	1830	2130	2410	2590	2720	2640
-24.0	790	900	1050	1370	1780	2270	3000	3560	4070	4360	4670	4570
-22.0	870	1070	1400	1990	2800	3730	4860	5770	6550	7120	7720	7510
-20.0	1020	1320	1870	2830	4180	6040	7530	8980	10740	11690	12090	12420
-18.0	1230	1610	2410	3840	5970	8430	11070	13760	15730	17110	18530	18290
-16.0	1460	2030	3120	4980	7710	10920	14440	17800	20390	22290	23750	23490
-14.0	1680	2450	3830	5950	9080	12740	17000	20520	23300	25550	26950	26680
-12.0	1890	2780	4380	6750	10080	13990	18480	22130	24940	27300	28470	28520
-10.0	2110	3140	4850	7380	10690	14700	19020	22440	25310	27430	28640	28890
-8.0	2340	3450	5310	7960	11410	15160	19120	22560	25440	27640	29020	29200
-6.0	2490	3730	5750	8500	11850	15550	19410	22980	26110	28640	29890	30250
-4.0	2680	3930	5970	8830	12200	15880	19770	23420	26760	29410	30730	31220
-2.0	2780	4070	6210	9090	12520	16230	20250	23950	27340	29970	31270	31920
.0	2810	4170	6310	9280	12740	16530	20650	24520	27820	30410	31840	32450
2.0	2790	4150	6300	9220	12740	16550	20630	24310	27600	30150	31720	32150
4.0	2670	3910	5950	8900	12370	16080	20110	23780	27020	29580	31170	31770
6.0	2550	3740	5690	8560	11950	15670	19640	23330	26630	29250	30760	31420
8.0	2430	3580	5490	8190	11520	15010	18900	22570	25670	28220	29780	30290
10.0	2270	3340	5190	7900	11130	14650	18510	22230	25110	27440	28840	29300
12.0	2070	3010	4680	7160	10410	14010	18160	21980	24800	26910	28380	28690
14.0	1800	2570	3990	6270	9380	12760	16620	20450	23380	25170	26790	27110
16.0	1550	2170	3350	5200	7980	11100	14460	17630	20420	21850	23350	23810
18.0	1320	1820	2710	4130	6250	8800	11570	13990	16280	17470	18650	18990
20.0	1140	1480	2100	3060	4500	6340	8060	10160	11330	12570	13310	13570
22.0	980	1200	1590	2210	3110	4280	5400	6500	7610	8070	8540	8600
24.0	870	990	1210	1540	2070	2780	3470	4140	4600	5140	5430	5460
26.0	850	880	1000	1160	1430	1810	2210	2600	2870	3170	3360	3400

AZIMUTH	ELEVATION .0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
-26.0	2740	2420	2340	2050	1780	1560	1360	1150	990	890	850
-24.0	4420	4130	3930	3430	2970	2490	2020	1600	1250	1030	910
-22.0	7470	6910	6490	5610	4760	3930	3140	2360	1790	1350	1030
-20.0	11930	11060	10340	8910	7520	6040	4650	3360	2430	1690	1270
-18.0	17730	17000	15220	13300	11560	9240	6670	4790	3180	2140	1490
-16.0	22740	20950	19280	16900	14160	11250	8380	5940	3920	2550	1720
-14.0	25870	24030	21820	18890	15790	12590	9460	6740	4480	2900	1890
-12.0	27590	25690	23070	19950	16550	13280	10100	7320	4940	3230	2090
-10.0	28010	26090	23600	20500	17170	13830	10630	7770	5370	3500	2310
-8.0	28510	26690	24280	21270	17790	14410	11150	8230	5750	3800	2510
-6.0	29670	27810	25390	22300	18860	15260	11800	8730	6150	4130	2740
-4.0	30600	28810	26460	23380	19770	16020	12390	9150	6420	4290	2850
-2.0	31380	29580	27200	24190	20470	16570	12810	9400	6620	4490	2980
.0	31800	29910	27560	24530	20810	16860	13060	9610	6780	4620	3080
2.0	31470	29750	27400	24390	20780	16960	13140	9730	6870	4680	3130
4.0	31200	29590	27210	24250	20550	16680	12890	9530	6710	4550	3070
6.0	30990	29250	26840	23800	20040	16250	12560	9300	6580	4510	3050
8.0	29850	28230	25880	22890	19450	15750	12190	8950	6390	4410	2960
10.0	28910	27240	24920	22070	18550	15170	11680	8550	6010	4150	2820
12.0	27990	26540	24300	21380	17940	14590	11150	8120	5720	3920	2640
14.0	26430	24840	22880	20060	16760	13650	10420	7480	5210	3540	2390
16.0	23280	21890	19980	17610	14870	12030	9200	6610	4530	3050	2080
18.0	18600	17500	15930	14140	12020	9820	7280	5370	3780	2580	1800
20.0	13230	12480	11520	10160	8700	7250	5440	4110	2910	2100	1520
22.0	8710	8410	7510	7010	6110	4960	3950	2930	2220	1670	1270
24.0	5220	5420	5170	4690	4110	3400	2720	2120	1670	1310	1080
26.0	3420	3380	3280	3030	2710	2380	1930	1620	1320	1110	1000

C-5. INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES--
NAFEC TEST 15 (399 W PAR56, 115 V)

AZIMUTH	EVALUATION -40.0	-35.0	-30.0	-25.0	-20.0	-15.0	-10.0	-5.0	.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0
-45.0	650	700	680	480	670	560	380	520	470	390	490	720	700	530	840	770	800
-40.0	700	860	780	610	810	710	540	700	710	560	760	970	970	630	1000	900	750
-35.0	740	940	830	700	970	830	640	870	860	710	740	1060	1120	730	990	980	710
-30.0	710	920	740	790	1030	880	740	1190	1220	930	830	1130	1170	710	930	1020	740
-25.0	750	870	630	720	920	720	950	2740	3290	1850	840	1120	1160	730	870	1090	770
-20.0	810	950	640	750	960	730	1870	901	11750	5810	1210	1120	1150	800	850	1130	770
-15.0	890	970	620	770	960	860	3360	19160	24320	11920	1760	1140	1200	840	810	1170	790
-10.0	910	940	610	770	990	990	4810	22480	27990	13890	2270	1180	1180	850	770	1150	810
-5.0	890	960	610	820	1010	1160	5820	23140	30090	15720	2800	1170	1230	880	790	1160	860
.0	850	950	620	790	1020	1250	6220	24460	31820	17070	3090	1220	1270	930	790	1170	880
5.0	900	980	640	810	1040	1210	5740	23490	31300	16720	3100	1230	1290	940	780	1170	900
10.0	920	1000	630	830	1020	1140	5080	22090	29030	15420	2880	1180	1300	930	790	1160	900
15.0	900	1030	630	780	970	1020	3580	19370	25440	13260	2300	1080	1280	910	800	1180	860
20.0	860	1020	670	750	890	940	2090	10100	13850	7520	1550	1040	1200	850	800	1130	840
25.0	770	1000	710	730	890	950	1090	3390	4350	3010	1040	1070	1200	810	800	1090	790
30.0	690	950	730	710	940	1020	820	1300	1690	1320	830	1150	1250	810	840	1100	750
35.0	650	990	800	700	970	990	680	910	1090	950	740	1090	1210	810	940	1100	720
40.0	700	990	830	630	830	870	560	670	820	780	640	980	1050	730	890	1010	710
45.0	710	860	750	510	640	650	460	530	630	530	490	770	800	580	790	810	710

C-6. INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES--NAFEC TEST 15 (LOWER) (399 W PAR 56, 115 V)

AZIMUTH	ELEVATION -11.0	-10.0	-9.0	-8.0	-7.0	-6.0	-5.0	-4.0	-3.0	-2.0	-1.0	.0
-26.0	760	790	840	940	1100	1330	1580	1800	1920	2040	2110	2120
-24.0	810	920	1080	1370	1770	2280	2800	3280	3480	3710	3840	3660
-22.0	940	1170	1530	2040	2940	3980	4920	5860	6380	6880	7100	6830
-20.0	1120	1530	2150	3050	4600	6320	7980	9170	10770	11820	12420	12150
-18.0	1320	1930	2920	4280	6620	9470	12500	14680	17190	18900	19930	19680
-16.0	1590	2430	3780	5640	8700	12530	16270	20030	23280	25510	26940	26700
-14.0	1860	2950	4650	7000	10200	14280	19030	23400	26620	29030	30440	30600
-12.0	2110	3380	5270	8030	11480	15760	20730	25290	28510	31010	32390	32490
-10.0	2340	3750	5950	8690	12290	16650	21350	25740	28960	31270	32540	32830
-8.0	2600	4150	6450	9410	13050	17180	21710	25900	29070	31630	33040	33450
-6.0	2810	4490	6990	10090	13820	17910	22380	26580	29910	32640	34410	34900
-4.0	2990	4790	7340	10530	14370	18510	23010	27230	30850	33730	35720	36150
-2.0	3160	5010	7700	10970	14900	19110	23620	27880	31400	34400	36430	36890
.0	3230	5190	7950	11350	15370	19590	24130	28470	32180	35090	36930	37520
2.0	3250	5210	8070	11480	15460	19670	24210	28410	32060	34990	36850	37320
4.0	3150	5020	7720	11160	15130	19420	24000	28280	31910	34650	36640	37010
6.0	3060	4910	7530	10840	14810	19030	23660	27940	31560	34470	36500	36900
8.0	2960	4730	7270	10480	14400	18600	22980	27230	30620	33390	34990	35480
10.0	2820	4500	7040	10280	14150	18450	22910	27220	30520	32780	34050	34520
12.0	2590	4130	6430	9620	13720	18080	22650	27160	30360	32670	33870	34100
14.0	2320	3690	5620	8520	12590	16890	21230	25520	28580	30860	32410	32440
16.0	2040	3210	4830	7330	10780	14830	18560	22650	24860	26990	28630	28830
18.0	1750	2630	3990	5850	8510	11830	15220	17320	20250	21500	22740	23010
20.0	1430	2020	2960	4230	5990	8220	10540	12210	13790	14490	15460	15720
22.0	1150	1530	2000	2830	3930	5270	6650	7560	8560	8940	9470	9110
24.0	970	1160	1370	1830	2460	3210	4050	4590	4860	5320	5570	5390
26.0	870	960	1060	1260	1540	1920	2340	2610	2930	3190	3160	3040

AZIMUTH	ELEVATION 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0
-26.0	2040	2000	1880	1590	1410	1240	1100	970	870	790	740
-24.0	3670	3560	3380	2880	2480	2090	1680	1360	1050	890	780
-22.0	6760	6410	5600	5010	4290	3570	2800	2030	1520	1180	910
-20.0	11940	11120	10190	8510	7190	5830	4430	3110	2200	1580	1130
-18.0	19300	17860	16340	13770	11490	9130	6730	4510	3010	2010	1320
-16.0	25950	23790	21560	18590	15530	12130	8970	6010	3780	2390	1540
-14.0	29730	27560	24770	21370	17770	13740	10120	6950	4440	2670	1680
-12.0	31360	29430	26510	22930	18950	14680	10920	7580	4950	3000	1850
-10.0	31870	29690	26900	23470	19590	15280	11480	8100	5370	3310	2030
-8.0	32630	30430	27550	24110	20190	15990	12010	8570	5680	3550	2200
-6.0	34360	32020	29070	25220	21100	16620	12550	9070	6110	3890	2350
-4.0	35260	32960	30080	26320	22230	17650	13310	9560	6400	4050	2470
-2.0	36130	33920	30910	27070	22830	18150	13750	9860	6590	4170	2560
.0	36620	34260	31120	27420	23270	18570	14020	10040	6660	4210	2610
2.0	36550	34310	31050	27260	23070	18510	14010	10110	6740	4240	2630
4.0	36070	33880	30700	26820	22520	17940	13530	9700	6500	4050	2520
6.0	36040	33610	30290	26270	21880	17240	12900	9200	6190	3890	2440
8.0	34540	32440	29320	25350	21120	16660	12390	8790	5970	3690	2330
10.0	33450	31360	28260	24420	20450	15900	11660	8210	5490	3370	2120
12.0	32870	30660	27620	23710	19500	14950	10760	7460	4950	3080	1910
14.0	30950	28800	25540	21980	17960	13890	9850	6670	4360	2800	1760
16.0	27290	25260	22610	19320	15540	12000	8620	5730	3710	2350	1550
18.0	21450	19830	17750	15160	12560	9380	6700	4540	3040	1940	1310
20.0	14500	13600	12280	10420	8800	6590	4820	3380	2280	1560	1110
22.0	8960	8590	7490	6730	5710	4300	3220	2320	1710	1230	950
24.0	5360	5250	4580	4180	3370	2720	2120	1630	1250	1010	870
26.0	3090	3070	2920	2510	2080	1730	1430	1200	1020	900	820

C-7. INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES—NAFEC TEST 16 (399 W PAR56, 115 V)

AZIMUTH	ELEVATION -11.0	-10.0	-9.0	-8.0	-7.0	-6.0	-5.0	-4.0	-3.0	-2.0	-1.0	.0
-26.0	600	620	610	680	780	900	1060	1230	1340	1350	1440	1530
-24.0	630	660	690	820	1030	1430	1820	2240	2670	2830	3070	2980
-22.0	720	790	900	1120	1630	2450	3410	4410	5370	5860	6420	6390
-20.0	830	960	1200	1670	2460	3800	5890	7890	9080	10590	10860	11850
-18.0	980	1190	1560	2300	3490	5870	8360	11360	13490	15970	17480	17660
-16.0	1110	1490	2070	3170	5000	7940	11170	14710	18110	21170	21950	22110
-14.0	1270	1710	2490	3820	5990	9360	13490	18210	22080	25190	26050	26490
-12.0	1410	1950	2900	4530	6790	10630	14980	20080	23920	26380	27080	26910
-10.0	1610	2280	3410	5230	7730	11820	16100	20640	23990	26000	26500	26200
-8.0	1750	2540	3800	5820	8680	12820	16720	20940	23990	25970	26550	26450
-6.0	1880	2750	4160	6390	9320	13470	17320	21400	24320	26010	26600	26570
-4.0	1960	2920	4460	6750	9810	13850	17670	21580	24330	26000	26620	26490
-2.0	1980	2980	4600	7000	10080	14020	17860	21770	24490	26050	26760	26790
.0	2020	3040	4610	7100	10240	14240	18070	21820	24490	26070	26860	26890
2.0	2130	3080	4670	7140	10290	14350	18280	21890	24400	26010	26570	26740
4.0	2110	3090	4610	6990	10100	14220	18150	21650	24100	25510	26080	26230
6.0	1970	2900	4390	6730	9670	13820	17810	21360	23730	25010	25500	25740
8.0	1840	2600	4050	6290	9230	13390	17460	21030	23270	24510	25070	25120
10.0	1640	2330	3550	5610	8540	12790	17080	20690	22870	23990	24360	24370
12.0	1440	2000	3020	4900	7570	11900	16330	20300	22450	23510	24050	24140
14.0	1340	1800	2690	4320	6830	10340	14240	17670	20350	21430	22290	22040
16.0	1150	1500	2110	3520	5450	8250	11070	14110	15700	17310	17600	18140
18.0	950	1150	1610	2460	3810	5860	7820	10010	11630	12420	13340	13330
20.0	830	940	1150	1720	2560	3860	5100	6430	6920	7890	8490	8290
22.0	710	760	870	1140	1540	2250	2870	3250	3790	4330	4680	4420
24.0	660	680	720	790	920	1250	1470	1690	1740	1860	1940	2040
26.0	640	640	640	660	750	940	1080	1130	1150	1180	1230	1240

AZIMUTH	ELEVATION 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0
-26.0	1520	1380	1320	1300	1240	1120	950	870	770	680	680
-24.0	2950	2860	2640	2360	2220	1970	1650	1260	1040	860	800
-22.0	6970	6190	5690	4970	4370	3680	2890	2170	1520	1180	970
-20.0	11780	10720	9990	9270	7930	6050	4570	3290	2270	1540	1160
-18.0	17380	15860	14700	13710	11090	8790	6530	4490	2950	1980	1390
-16.0	21790	20340	19620	17580	14770	12080	8720	5900	3880	2440	1620
-14.0	25700	24740	23360	21170	18260	14080	9890	6480	4320	2750	1830
-12.0	26460	25540	24190	22520	19720	15550	10940	7210	4670	2950	1980
-10.0	25630	24760	23470	21820	19310	15710	11540	7810	5090	3220	2130
-8.0	25950	24880	23500	21490	19060	15930	12030	8270	5420	3470	2260
-6.0	26220	25240	23740	21830	19500	16320	12470	8650	5680	3650	2360
-4.0	26310	25490	24050	22280	19890	16630	12890	8950	5910	3750	2400
-2.0	26400	25580	24210	22500	20020	16660	12850	8990	5920	3740	2410
.0	26570	25630	24210	22440	19810	16480	12710	8920	5810	3650	2380
2.0	26380	25440	24080	22110	19450	16050	12350	8570	5610	3540	2330
4.0	25930	25100	23770	21610	18770	15400	11680	8090	5290	3390	2220
6.0	25480	24660	23280	21160	18160	14740	11010	7500	4930	3120	2070
8.0	24820	23880	22700	20520	17600	14010	10220	6850	4420	2830	1860
10.0	24070	23240	22080	20020	17110	13310	9460	6240	3930	2520	1730
12.0	23670	22850	21340	19520	16660	12690	8610	5490	3350	2170	1560
14.0	21880	21000	19360	17440	14430	10910	7340	4440	2680	1820	1410
16.0	18210	17520	16090	14460	11780	9020	6150	3750	2250	1540	1220
18.0	13330	12640	11350	10190	8090	6290	4530	2740	1770	1250	1060
20.0	8290	7900	7070	6270	4920	3830	2620	1790	1180	970	910
22.0	4460	4320	3810	3370	2680	2070	1500	1150	910	820	800
24.0	2130	2180	1960	1780	1400	1110	940	840	740	720	710
26.0	1280	1340	1210	1090	920	800	750	670	660	650	650

C-8. INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES—NAFEC TEST 19 (Q20A/PAR56, 300 W, 20A)

AZIMUTH	ELEVATION -11.0	-10.0	-9.0	-8.0	-7.0	-6.0	-5.0	-4.0	-3.0	-2.0	-1.0	.0
-26.0	780	830	860	950	1070	1350	1600	1720	1840	1900	1970	2060
-24.0	830	860	930	1090	1370	1780	2180	2640	2870	3240	3400	3580
-22.0	920	1000	1110	1380	1840	2870	3960	4760	5750	6160	6660	7150
-20.0	1060	1200	1440	1860	2750	4210	6550	8380	9810	11510	12730	12690
-18.0	1190	1440	1790	2480	3910	6420	9510	12460	15800	17900	19700	20630
-16.0	1360	1700	2380	3500	5330	8670	12480	16500	20460	23360	25500	26500
-14.0	1490	1890	2670	4040	6450	10170	15080	20370	24970	28330	30250	30530
-12.0	1680	2140	3010	4570	7280	11060	16180	21700	25950	28960	30220	30460
-10.0	1850	2480	3490	5230	8250	12480	17620	22710	26480	29270	30670	30970
-8.0	2000	2720	3860	5890	9170	13500	18640	23530	27250	29990	31400	31900
-6.0	2060	2840	4250	6560	10030	14570	19710	24360	28060	30600	31940	32430
-4.0	2170	3020	4600	7010	10700	15480	20540	25000	28390	30830	32290	32700
-2.0	2230	3130	4770	7370	11010	15750	20900	25390	28630	31040	32500	33040
.0	2270	3200	4870	7630	11250	15890	21060	25410	28700	31080	32490	33060
2.0	2350	3280	4950	7700	11310	16010	21190	25570	28780	31090	32280	32800
4.0	2390	3310	5000	7690	11130	15940	21110	25430	28580	30640	31820	32200
6.0	2340	3170	4870	7450	10870	15610	20850	25230	28180	30140	31200	31640
8.0	2180	2930	4490	6970	10310	14940	20270	24590	27600	29320	30270	30600
10.0	2000	2640	3970	6290	9620	14410	20070	24270	26980	28810	29590	29720
12.0	1830	2430	3630	5810	9000	13640	19490	23870	26640	28350	29230	29420
14.0	1660	2190	3230	5130	7910	12100	16650	20730	23490	26150	26930	26990
16.0	1330	1740	2410	3950	6180	9480	13360	16640	19050	21260	22600	22790
18.0	1130	1350	1780	2800	4560	6870	9390	11540	13870	15370	16530	16720
20.0	1000	1150	1400	2020	3070	4800	6130	7820	8610	9510	10080	10900
22.0	910	990	1140	1350	1950	2810	3740	4290	5040	5600	5730	5740
24.0	860	900	940	1030	1290	1790	2080	2270	2510	2690	2590	2880
26.0	840	870	880	900	1110	1440	1660	1700	1740	1700	1700	1780

AZIMUTH	ELEVATION 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0
-26.0	2070	2020	1970	1920	1750	1520	1330	1190	1110	1040	1030
-24.0	3310	3190	3020	2860	2730	2400	1920	1650	1450	1250	1170
-22.0	7340	7270	6690	5990	5090	4290	3490	2550	1980	1570	1360
-20.0	13060	12720	11860	11180	9460	7280	5680	4100	2910	2010	1590
-18.0	20410	18740	17310	16140	13950	11390	8330	5830	3960	2630	1910
-16.0	25850	25000	23180	20590	17800	14390	10650	7210	4790	3230	2280
-14.0	29970	28750	26970	25190	22310	17150	11860	7910	5250	3580	2490
-12.0	29940	28490	27210	25960	23350	18740	13480	8710	5730	3840	2680
-10.0	30280	28760	27150	25620	23120	19210	14320	9820	6460	4200	2880
-8.0	31160	29510	27820	25980	23400	19960	15080	10570	6910	4480	3050
-6.0	31770	30510	28720	26580	24030	20400	15590	10980	7150	4670	3240
-4.0	32190	30880	29120	27170	24470	20800	16080	11440	7380	4790	3310
-2.0	32330	31030	29330	27530	24750	20820	16080	11390	7370	4670	3240
.0	32550	31100	29400	27600	24680	20640	16000	11400	7360	4680	3240
2.0	32270	30940	29330	27400	24480	20470	15850	11100	7170	4610	3180
4.0	31780	30500	28940	26560	23610	19530	14980	10520	6750	4370	3030
6.0	31080	30010	28450	26090	22880	18710	14010	9750	6290	4090	2830
8.0	30200	29000	27550	25140	21890	17750	13020	8770	5690	3710	2630
10.0	29250	27960	26580	24390	21170	16900	11980	7970	4980	3260	2400
12.0	28750	27240	25730	23880	20570	15940	11060	6850	4200	2870	2220
14.0	26250	24480	23040	21280	17780	13880	9500	5770	3510	2470	2040
16.0	21560	20600	19490	17230	14600	11390	7510	4710	2900	2150	1850
18.0	16440	15780	14150	12330	10800	7960	5340	3440	2290	1740	1550
20.0	10250	9950	9430	8210	6560	4680	3170	2320	1610	1430	1340
22.0	5940	5820	5080	4410	3700	2570	1860	1440	1280	1210	1190
24.0	2890	3210	2880	2330	1910	1420	1230	1120	1070	1070	1090
26.0	1820	1900	1800	1570	1390	1160	1060	1030	980	1020	1030

C-9. INTENSITY IN CANDELA VERSUS AZIMUTH AND ELEVATION ANGLES IN DEGREES—NAFEC TEST 20 (Q20A/PAR56, 300 W, 20 A)