MASTER

THE ENGINEERING AND ECONOMICS OF LIGHTING FOR CLOSED CIRCUIT TELEVISION (CCTV) SECURITY ALARM ASSESSMENT*

by

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ABSTRACT

This study examines the economics and applicability of low and high pressure sodium sources in both streetlight and floodlight luminaires for CCTV illumination of high-security areas. In addition the signal outputs of several popular CCTV camera tube types operated in the presence of common lighting sources are calculated. These calculations take into consideration the spectral response of the camera tubes and the spectral output of the light sources. The results are presented in terms of "dollars per unit camera signal strength" and also "camera signal strength per connected watt of electrical load."

I. INTRODUCTION

General:

The potential threat of terrorists or other malcontents to steal valuable material from, or sabotage, public or privately owned facilities has brought about an increased interest in physical security. To improve physical security, greater emphasis is being placed on the type of security equipment used. The use of security equipment for military applications alone is expected to increase from the fiscal 1979 year amount of $118 million per year to over $300 million per year by 1983.(1)

An essential function of every high-security system is the early detection and assessment of any unauthorized activity. As it is used in this report, assessment is defined as the means of determination of the cause of an alarm. The state of the art in sensor technology is presently not sufficiently advanced to allow adequate assessment without visual inspection. This inspection can be done with roving patrols, guards located in guard towers, quick response guards, or closed-circuit television (CCTV). Because of the costs associated with the use of guards for continuous coverage, the use of CCTV has become widespread. Since the costs of electrical energy required to provide lighting for CCTV is also rising and the nation is becoming more energy conservation minded, it is expedient to choose the most cost-effective forms of producing the lighting for CCTV.

This paper deals, in part, with the design of CCTV lighting systems. Topics addressed include: design considerations, economic analysis, comparison of expected illumination performance with actual performance as measured from existing systems. A discussion of the factors that contribute to the deviation in actual from designed performance is also included.

Another major portion of this paper is concerned with the spectral match of several popular CCTV camera tube types with various common lighting sources. The results of this portion allow performance comparison of various camera tube type/illumination source combinations with respect to efficiency and economics.

Lighting Systems Design:

For good video rendition, the scene covered by CCTV must be lighted so as to provide (1) adequate intensity for the cameras being used and (2) uniform illumination over the field-of-view to prevent scene highlights from causing camera bloom as well as prevent loss of detail in the dark areas of the scene. In addition, it is economically desirable to have a good spectral match between the cameras and the light source, enabling high efficiency operation to be achieved.

Given illumination intensity and uniformity specifications that must be met (for a particular CCTV system), it is important to meet these specifications in the most economical manner. Acknowledging the current popularity that sodium vapor sources enjoy in CCTV illumination, a portion of this study was undertaken to find the most economical high pressure sodium (HPS) and low pressure sodium (LPS) lighting systems that meet the specifications given in the next section. The specifications have proven workable (though not optimized) for several installations which were equipped with silicon diode array and Newvicon camera tubes.

CCTV/Light Source Interaction:

Another portion of this study is devoted to characterizing the interaction of several popular CCTV lighting sources with various CCTV camera tubes to determine which combinations produce the highest camera signal strength per lumen of lamp output (micro-amperes/lumen) and per watt of total electrical load (micro-amperes/watt).

II. SPECIFICATIONS

Lighting System Design:

CCTV lighting was designed for a perimeter security system. Figure 1 shows the geometry of a segment of the perimeter lighting system. The area was to be lighted from one side only. Pole spacing was to be as large as possible and still meet the other requirements of the specifications. Because of possible interaction with a sensor system, mounting heights were limited to 0.8 (25.2+d) feet or 0.8 (8+d) metres, where d = setback.

Separate low and high pressure sodium lighting systems were to be designed for setbacks from zero to 25 ft. (7.62 m) in five foot (1.52 m) increments.

The illumination specifications were as follows:

- A minimum level of 1.0 footcandle (10.76 lux) in a horizontal plane 6 in. (0.15 m) above the ground was required at any point over the area and at any time throughout the relamping and maintenance schedule.

- The uniformity throughout the area was requied to be 3:1 (average to minimum) and 6:1 (maximum to minimum).

A luminaire dirt depreciation (LDD) factor of 0.8 was assumed.

The above items constitute the specifications that the lighting systems had to meet. Hereafter in this paper, they will be refered to collectively as the Specification.

This portion of the study consisted of a comparison of both high pressure and low pressure sodium sources in both flood-light and roadway luminaire configurations. The least expensive system in terms of footcandles per dollar was determined by comparing the costs of each designed system that met the Specification.

CCTV/Light Source Interaction:

The following light sources were studied to determine the maximum signal strength when used in conjunction with certain CCTV camera tubes:

(a) low pressure sodium
(b) high pressure sodium
(c) metal halide
(d) mercury
(e) tungsten halogen

Each of the above sources are to be considered to be used with each of the following CCTV camera tubes:

(a) silicon diode array vidicon (low blooming)
(b) Newvicon
(c) standard vidicon (sulphide)
(d) silicon intensified target (SIT)
(e) intensified silicon intensified target (ISIT)

III. GENERAL CONSIDERATIONS

Lighting Systems Design:

Introduction -- Several manufacturers of roadway and flood-lighting equipment, each employing high pressure and low pressure sodium lamps, were invited to submit data to be considered for the functional specification design portions of this project. These data were used in a trial and error fashion to determine maximum spacings possible that would meet the design criteria within the mounting height limitation imposed for each of the setbacks.

All luminaires for which photometrics and other data were received were considered for application in this study. Tables I and II show features of the 180-watt LPS and 400-watt HPS luminaries for which sufficient data were made available for consideration.

Lamp lumen maintenance and mortality data used in the illumination calculations and economic analyses were taken from manufacturer's published data.

In each of these cases a somewhat arbitrary spacing S shown in Figure 1 was used initially in a computer program that calculates footcandles point-by-point throughout the area. The results were compared with the criteria contained in the Specification. If these criteria were met, the spacing was increased an increment of 10 feet (3.05 m) and the results were again compared to the Specification. This step was repeated again and again until the criteria were not met.

Then, the luminaire orientations (aiming) were modified until the criteria were met. Again, the spacing was increased until criteria were not met. This process continued until it was demonstrated that no further re-aiming could compensate for the increase of spacing. At that point the previously used greatest spacing(s) was adopted along with the successful aiming as an "optimum" result in terms of maximum spacing feasible to achieve the criteria within the other constraints imposed by the Specification.

This point-by-point footcandle computer program was also used to predict the values that would be generated by two actual installations, one each of HPS and LPS sources.

Economic Analyses -- Table III shows a special economic analysis computer program that was created to assist in evaluating the various lighting systems that met the functional specifications. Only two systems (#8 and #14) are shown here for illustrative purposes even though all 17 systems shown in Tables V and VI (under "RESULTS") were compared. For each system, a computer analysis was run for the case of energy costing 1¢, 2¢, 3¢, 4¢, 6¢, and 10¢ per kwh.

The two systems illustrated in Table III were for the case of 1¢/kwh (see Item #45) and setbacks of 5 feet (1.52 m) each using two luminaires per pole at mounting heights of 25 feet (8.62 m). See Tables V and VI. Note that the key items which indicate overall costs are Items No. 38, 68, and 69. Some of the other key input items used in these analyses are listed in Table IV.

Existing Installations -- Existing HPS and LPS installations were set up on the computer and point-by-point illumination values were predicted before actual measurements were made. Since both of these installations are relatively new, lamp lumen depreciation (LLD) and LDD factors of 1.00 and 0.90 were assumed.

CCTV/Light Source Interaction:

The CCTV camera signal strength was determined by obtaining the product of the spectral energy sensitivity of each of the TV camera tubes with the spectral energy distribution of each of the lamps contained in Section II.

Figures 2 through 6 show the spectral energy sensitivity of each of the five TV camera tubes covered in this study. Figure 7 shows the spectral energy distribution of a 180-watt low pressure sodium (LPS) lamp. Spectral distribution data for the other sources considered are not included here in the interest of saving space but are readily available from the respective lamp manufacturers. Actually, two different manufacturers' data were used for a clear 400-watt metal halide lamp. Both were included in this study since it is generally agreed that significant visual differences exist.

Some readers may be concerned tht the vidicon data shown in Figures 3 and 4 do not match. They represent performance of different manufacturers. Actually, they are very similar since they both peak at about the same wavelength and the absolute maximum responses can be made to be exactly equal by adjusting the operating gun voltage. The one shown in Figure 4 was the one used in all calculations.

IV. RESULTS

Lighting Systems Design:

Design Considerations -- Tables V and VI show the floodlighting and streetlighting systems, respectively, that meet the Specification and were used in the economic analyses. The reader will note that luminaries E, A, H, and D (from Tables I and II) were used and B, C, F, an G were not chosen. The reasons were that where choices occurred, either a particular photometric distribution could not be made to meet the specifications regardless of aiming or did not perform as well as the one that was chosen. It is further emphasized here that although the word "optimized" is used in this study it should not be interpreted as the ultimate in performance. Obviously, there could very well exist other luminaires that were not brought to the authors' attention that could possibly perform better, or for that matter, new and/or special designs could yet be offered that could significantly out-perform the best discovered in this limited study. An "optimized" system is considered here to be the design which meets the Specification most economically.

An attempt was made to design lighting systems utilizing these chosen two streetlights and two floodlights, one each operating a 400-watt HPS and a 180-watt LPS lamp. In each of the four cases, lighting systems were checked out with the setbacks varying from zero to 25 feet (7.62 m) in increments of 5 feet (1.52 m), keeping the mounting height within the specified limits and the pole spacing as large as the other constraints would allow.

Note that 17 configurations are shown in Tables V and VI, however, one (no. 9) could not be made to meet the Specification regardless of aiming. This one configuration was retained in the tabulation for comparison purposes. Other configurations that could not be made to meet the Specification are also shown but data columns and the system reference numbers are left blank.

The economic analyses resulted in Systems 8 and 14 being chosen as the least expensive LPS and HPS systems, respectively. Figures 8 and 9 show computer point-by-point calculations for these "optimized" systems. The uniformity and illumination parameters included in Tables V and VI are taken from computer point-by-point calculations similar to those shown in Figures 8 and 9.

Economic Analyses -- Table VII summarizes the results of the economic analyses for all 17 systems. These relative numbers should be compared with each other only in horizontal lines (same power cost ¢/kwh). They are not comparable in the vertical columns under each lighting system.

Systems 8 and 14 demonstrate a high relative performance with respect to initial investment and operating cost per footcandle as exhibited by Table VII. Based on this information as well as other factors, systems No. 8 and 14 were chosen as the basic "optimized" lighting systems utilizing LPS and HPS lamps respectively. The bar chart summary (Figure 10) shows that on a cost per average maintained footcandles basis.

System 1¢/kwh	Lamp	Initial Investment (Item 39)	Annual Owning & Operating Cost (Item 67)
8	LPS	$5283	$1015.41
14	HPS	4270	924.52
Difference		$1013	+$ 90.89

These numbers would imply that the HPS system is to be preferred over the LPS system but the reader is reminded that this comparison is based on power costing 1¢/kwh. As power costs increase, the LPS system tends to be preferred. For example, a comparison of the same numbers from the 2¢/kwh and 4¢/kwh economic analyses yields:

2¢/kwh	Lamp	(Item 39)	Cost (Item 67)
8	LPS	$5283	$1097.82
14	HPS	4270	1111.20
Difference		$1013	- $13.38

4¢/kwh	Lamp	(Item 39)	Cost (Item 67)
8	LPS	$5283	$1262.63
14	HPS	4270	1484.57
Difference		$1013	-$221.94

From this we see that at 1¢/kwh the HPS system is $90.89 per year less expensive to own and operate. However, when the power rates are boosted to 2¢ and 4¢/kwh the LPS system is $13.38 and $221.94, respectively less expensive to own an operate annually. This consideration will tend to offset the relatively higher initial system cost of the LPS system ($5283-$4270=$1013).

From the above considerations is is concluded that the "optimized" systems are systems No. 8 and 14.

Existing Installations -- A comparison between the design predictions and actual field measurements are shown in Table VIII. System errors that could contribute to the difference between predicted and actual performance are treated below.

System Error: The actual performance of an installed lighting system usually deviates from the designed performance because of the reasons discussed in this subsection. This deviation will hereafter be referred to as system error. To compensate for system error, thus ensuring required performance, systems are usually overdesigned. Reduction of the uncertainty between design and actual performance would result in economic savings (both in installation and operating costs) by reducing the amount of overdesign necessary to achieve required system performance. In this subsection, (1) major sources of system error are noted, (2) the sources are ranked as to frequency of occurrence, and (3) recommendations to reduce system error are made.

System error can result from a multiplicity of reasons. Some of these are shown below:

1. Published photometric performance may not typify actual luminaire because:

a. degree of inherent accuracy of the photometric laboratory generating the data.
b. actual lamp may not generate rated lumens even when rated wattage is consumed by lamp.
c. lamps used may not have "center-rated" physical and therefore "optical" properties when used within a specific optic; this results in an asymmetrical light distribution and/or lowered efficiency.
d. optical components have ± assembly tolerances, i.e., position of lamp socket relative to reflector and/or refractor.
e. optical components have manufacturing tolerances such as finish, dimensions, curvature, etc.
f. ballast does not deliver rated wattage even when rated volage is applied.

2. Field variances from design assumptions could include actual:

   a. pole location and spacing
   b. mounting height
   c. aiming points
   d. applied voltage
   e. change of orientation of luminaire with time due to such things as wind vibrations, pole shifting, mounting structure bending under gravity load, improper mounting adapter orientation, physical interferences between adjacent floodlights.

3. Apparent system error may exist because of field measurement errors such as:

   a. measurement apparatus not calibrated, color corrected and/or cosine corrected
   b. inaccurate placement, orientation and/or leveling of illumination meter
   c. careless operator techniques such as allowing either direct or reflected stray light to pollute the measurements or to permit partial shadowing of the photo receptor
   d. transmissivity of atmosphere less than 100% because of humidity, smoke, and/or other pollutants
   e. luminaires are not clean and/or lamps may be extra-ordinarily aged.

The "Ranking of Causes of System Error" shown in Table IX represents a subjective appraisal as to the frequency that the item indicated is the real cause of error. Actually, system error will result if any one of the listed causes are in effect and the significance will of course depend on the magnitude of the differential from the norm.

Item 3a (inaccurate measurement apparatus) could increase to a much higher rank of importance in cases where the photoreceptor is inadequately "color corrected." Errors of 12% or greater could be introduced. Therefore, the authors recommend that whenever instrumentation is required to read values that may be of a critical (no or no-go) nature, the photoreceptor should be certified to be accurate ±5% for that specific light source.

Recommendations to reduce system error include:

1. Require luminaires to be tested from samples randomly chosen from finished stock rather than selected specimens.
2. Test a group of three samples instead of just one.
3. All manufacturers should publish the same information in the same format.
4. Testing procedures should be standardized, industry wide.
5. Only use instrumentation that is certified to be accurate ±5% for the particular light source being measured.

CCTV/Light Source Interaction:

The spectral energy generated by each of the lamps in each 10 nanometer increment was multiplied by the spectral response of each of the TV camera tubes in the corresponding increments to produce total camera tube signal output. The total signal strength in micro-amperes per lumen of each tube-lamp combination was characterized by summing the products resulting from the above multiplication. These calculations are summarized in Table X in terms of both signal strength per lumen and signal strength per connected electrical watt. The following lamp efficiencies were used for the generation of the lower portion of Table X.

Lamp Type	Efficiency Lumens/Watt
LPS	157
HPS	112.5
Metal Halide	90
Mercury	52.5
Tungsten Halogen	21.5

The earlier economic analysis considerations were based on footcandles which are in turn based on the response of the human eye. From the study summarized in this section, we see that there are different relative signal strengths realizable from various CCTV camera tube and light source combinations.

Figure 11 is a reproduction of Figure 10 but based on cost per unit CCTV signal strength (here a unit of CCTV camera signal strength is 1036 micro-amperes) instead of cost per footcandle when using the Silicon Diode Vidicon tube. The base of 1.00 was maintained for the HPS system annual cost with simply a multiplier of 1.167 (, data obtained from Table X) applied to all LPS annual costs. None of the initial costs are affected.

Obviously, similar bar charts could be developed for the other CCTV tube and light source combinations for various energy and owning costs.

It should be noted that the absolute signal strengths contained herein are based on performances of the camera tubes with no lens attenuation. The reported signal strengths should be reduced by the transmission factor of the lens used with each specific light source.

V. CONCLUSIONS

It appears feasible to achieve the CCTV lighting performance specified within this paper with either HPS or LPS lamps operating as floodlights. Also an HPS streelighting configuration performs adequately. However, and LPS streetlighting configuration has the wrong distribution to meet the Specification.

The most economical system in terms of dollars/fc appears to utilize high pressure sodium lamps, assuming current power costs, but will begin to favor LPS lamps as power costs increase.

Computer analyses can be used to predict end results of a lighting installation but there are many reasons which will cause field measurements to result in significantly different values than that predicted even when reasonable care is exercised.

The economics of an overall lighting system tend to favor HPS over LPS lamps in terms of "dollars/unit camera signal strength." However, if the dollar is no consideration there appears to be an advantage in using LPS instead of HPS lamps in terms of "camera signal strength/connected watt of electrical load."

VI. REFERENCE

1. International Military Intrusion Detection Market, Report No. 505, Frost and Sullivan, Inc., New York, New York, 1977.

VII. ACKNOWLEDGEMENTS

Sincere appreciation is extended to all of the lamp, lighting equipment, and closed circuit TV camera tube manufacturers for their interest and assistance in supplying the basic data essential for this project. Special thanks are extended to Mr. George Robinson of RCA who was especially helpful with information, comments, and advice. Thanks are also given to Mr. James F. Chapek and James D. Williams, both of Sandia Laboratories, for many helpful discussions.

Further thanks are also due Mr. George Robinson who informed the authors that the information for the Newvicon tube has changed since Figure 3 was constructed. Unfortunately, this information arrived too late to be included in the manuscript. However, the changes are of such a nature that the relative positions of the Newvicon tube would not be different from those shown in Table X, although the absolute values would be slightly modified. It is apparent that these studies should be updated as existing equipment is modified and new equipment is made available.

FIGURES

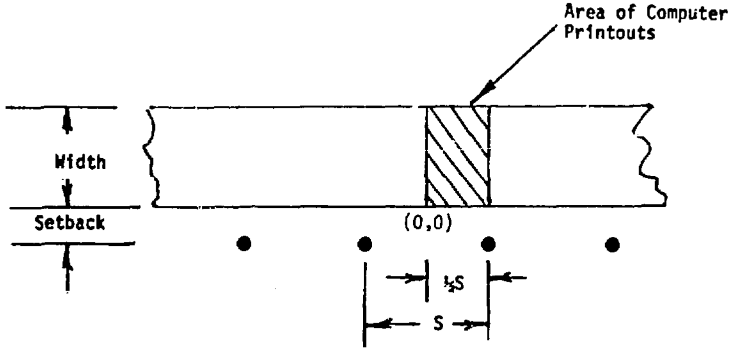


Fig. 1

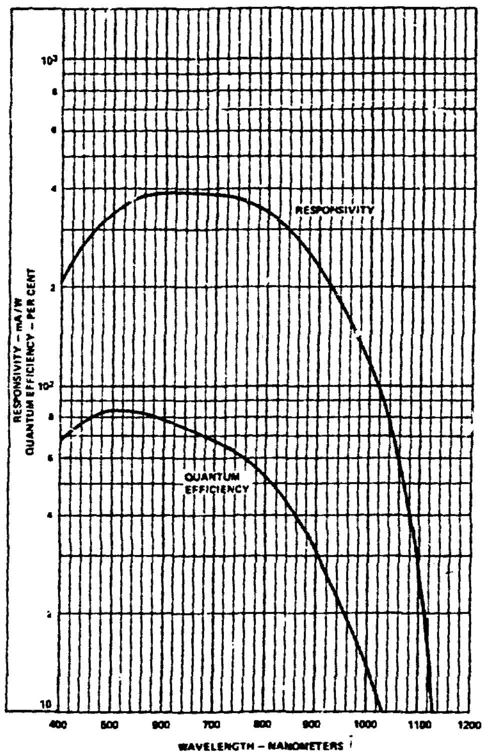
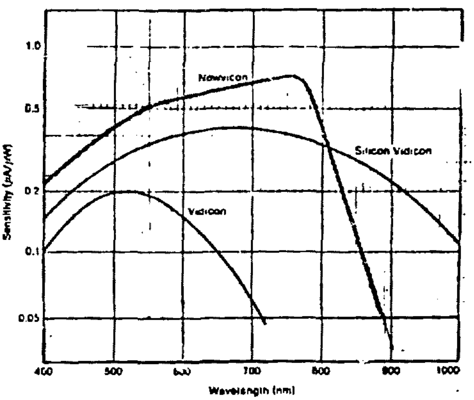
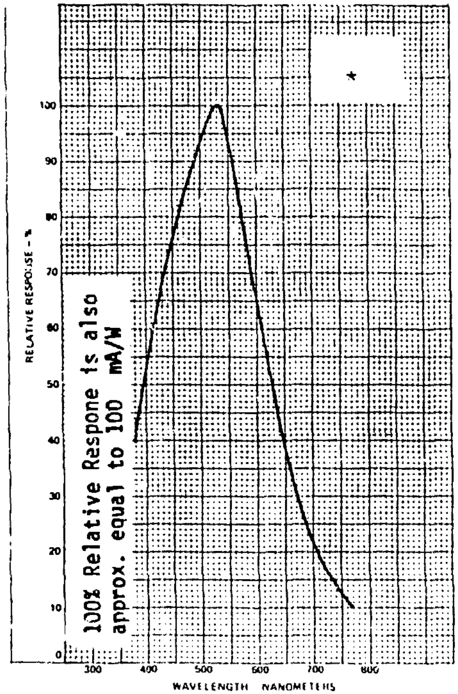

RESPONSIVITY
QUANTUM EFFICIENCY
RESPONSIVITY – mA/W
QUANTUM EFFICIENCY – PER CENT
WAVELENGTH – NANOMETERS
400
500
600
700
800
900
1000
1100
1200
10³
8
6
4
2
10²
8
6
4
2
10

Fig 2



Spectral response curve of NEWVICON, in comparison with silicon vidicon and vidicon.

Fig. 3



* CAUTIONARY NOTE!

The reader is cautioned that the "VIDICON" has a non-linear "gamma function" which will create distorted and misleading results when attempts are made to compare integrations of spectral response and lamp energy distributions with other combinations. But nevertheless, this comparison is made in this study for purposes of completeness. Conclusions should be drawn with proper caution.

Fig. 4

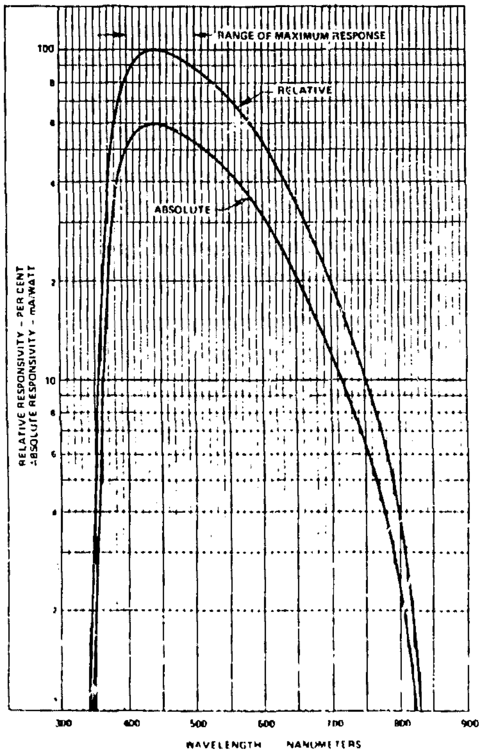

RANGE OF MAXIMUM RESPONSE
RELATIVE
ABSOLUTE
RELATIVE RESPONSIVITY - PER CENT
ABSOLUTE RESPONSIVITY - mA/WATT
100
10
300
400
500
600
700
800
900
WAVELENGTH NANOMETERS

Fig. 5

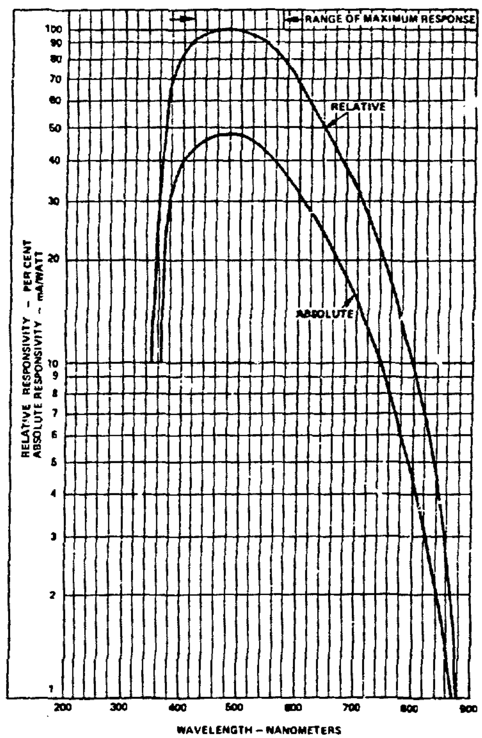

RANGE OF MAXIMUM RESPONSE
RELATIVE
ABSOLUTE
RELATIVE RESPONSIVITY – PER CENT
ABSOLUTE RESPONSIVITY – mA/WATT
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
200
300
400
500
600
700
800
900
WAVELENGTH – NANOMETERS

Fig. 6

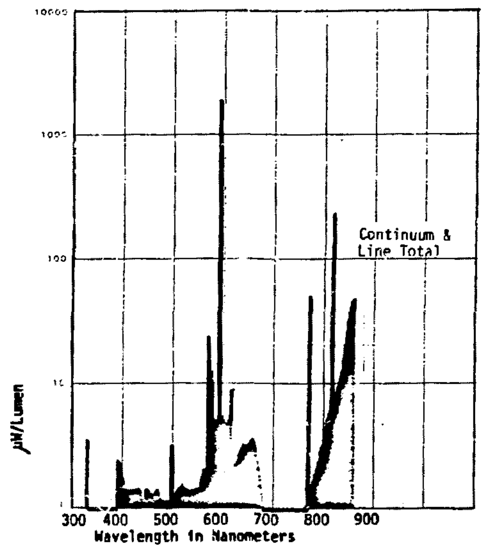

10000
1000
100
10
1
μW/Lumen
Continuum &
Line Total
300
400
500
600
700
800
900
Wavelength in Nanometers

Fig 7

MAINTAINED HORIZ FC 6" ABOVE GRADE.
400W HPS, INITIAL LUMENS = 50000, LLF = .568 (.8 LDD X .71 LLD).
SETBACK = 5', MH = 25', TILT = 47 DEG, SPACING= 80'. 2 UNITS PER POLE.

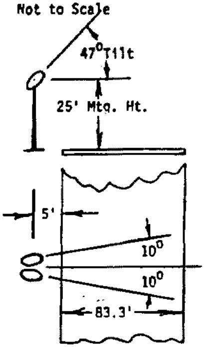
Horizontal Index in Feet (X 0.305=meters)

Vertical Index in Feet (X 0.305 = meters)	.00	5.71	11.43	17.14	22.86	28.57	34.29	40.00
83.30	1.00	1.00	1.01	1.02	1.02	1.02	1.03	1.03
77.35	1.12	1.13	1.15	1.17	1.18	1.17	1.18	1.19
71.40	1.28	1.29	1.32	1.34	1.36	1.35	1.37	1.38
65.45	1.47	1.48	1.52	1.54	1.57	1.56	1.59	1.63
59.50	1.69	1.70	1.74	1.79	1.80	1.83	1.86	1.92
53.55	1.93	1.96	1.99	2.06	2.09	2.15	2.20	2.26
47.60	2.18	2.22	2.28	2.34	2.45	2.55	2.63	2.67
41.65	2.47	2.49	2.58	2.69	2.84	3.02	3.18	3.23
35.70	2.77	2.77	2.86	3.02	3.27	3.50	3.74	3.93
29.75	3.02	3.04	3.15	3.32	3.59	3.95	4.26	4.38
23.80	3.11	3.23	3.51	3.61	3.74	4.03	4.44	4.50
17.85	3.31	3.37	3.52	3.65	3.64	3.67	3.91	4.11
11.90	3.18	3.29	3.31	3.42	3.45	3.42	3.63	3.65
5.95	2.66	2.69	2.83	3.33	3.77	3.92	4.40	4.76
.00	1.89	2.05	2.41	3.15	4.02	4.30	5.10	5.92

AVERAGE=	2.598	AVG/MIN=	2.61
MAXIMUM=	5.916	MAX/AVG=	2.28
MINIMUM=	.996	MAX/MIN=	5.94

Multiply all fc values by 10.76 to convert to lux.

Not to Scale



Typical Luminaire Orientations; Poles are 80' apart

See Figure I for Area of Computer Printout

Fig 8

MAINTAINED HORIZ FC 6" ABOVE GRADE.
PHOTO # 2179. 33000 INITIAL LUMENS, LLF = .84 (=.8 LD) X 1.05 (LD)
SETBACK = 5', MH = 25', SPACING = 90'. 2 UNITS PER POLE.

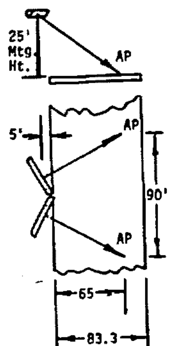
Horizontal Index in Feet (X 0.305 = meters)

Vertical Index in Feet (X 0.305 = meters)	.00	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00
83.30	1.12	1.12	1.12	1.14	1.16	1.18	1.20	1.21	1.21	1.21
77.35	1.25	1.25	1.26	1.29	1.32	1.35	1.37	1.39	1.39	1.39
71.40	1.38	1.40	1.43	1.47	1.50	1.54	1.57	1.60	1.61	1.61
65.45	1.53	1.57	1.61	1.65	1.70	1.76	1.80	1.85	1.87	1.87
59.50	1.75	1.77	1.82	1.87	1.93	2.01	2.09	2.14	2.17	2.17
53.55	1.98	1.99	2.04	2.12	2.21	2.30	2.39	2.46	2.51	2.52
47.60	2.20	2.23	2.32	2.40	2.49	2.61	2.74	2.82	2.90	2.91
41.65	2.45	2.47	2.55	2.69	2.79	2.93	3.12	3.24	3.32	3.32
35.70	2.66	2.69	2.77	2.92	3.11	3.27	3.46	3.64	3.82	3.88
29.75	2.79	2.84	2.96	3.13	3.34	3.54	3.86	4.18	4.35	4.38
23.80	2.87	2.91	3.01	3.20	3.52	3.94	4.35	4.66	4.90	4.98
17.85	2.77	2.81	2.92	3.18	3.56	4.08	4.66	5.24	5.55	5.46
11.90	2.48	2.54	2.73	2.97	3.32	3.78	4.43	5.16	6.07	6.57
5.95	2.16	2.20	2.31	2.55	2.90	3.27	3.85	4.49	5.53	5.98
.00	1.70	1.75	1.85	2.01	2.32	2.82	3.30	3.45	2.99	2.05

AVERAGE=	2.664	AVG/MIN=	2.39
MAXIMUM=	6.571	MAX/AVG=	2.47
MINIMUM=	1.116	MAX/MIN=	5.89

Multiply all fc values by 10.76 to convert to lux.

Not to Scale



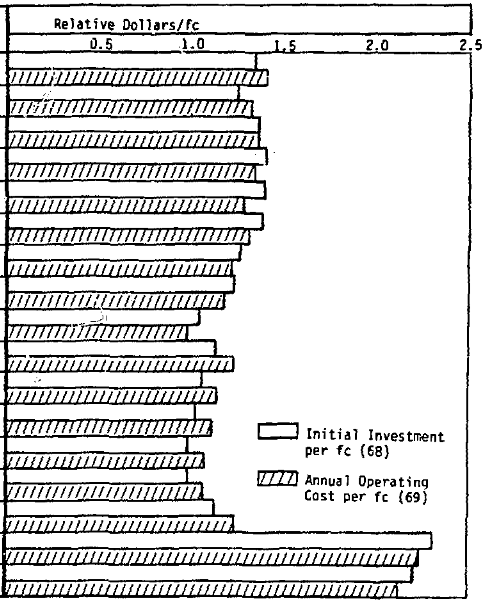
Typical Luminaire Aiming Points (AP) Poles are 90'Apart

See Figure 1 for Area of Computer Printout

Fig 9

COSTS PER 1000 Ft. Modular Length of Area per FOOTCANDLE

System	No.	Init.Invest. Per fc (39)	Ann.Oper. Cost/fc (67)
HPS Flood	1	$5721	$1200
	2	5339	1133
	3	5878	1175
LPS Flood	4	6041	1156
	5	5767	1100
	6	5965	1129
	7	5425	1036
	8	5283	1015
	9*	4470	850
HPS Street	10	4956	1061
	11	4585	995
	12	4392	963
	13	4268	935
	14	4270	925
	15	4865	1074
LPS Street	16	9896	1918
	17	945[illegible]	1821

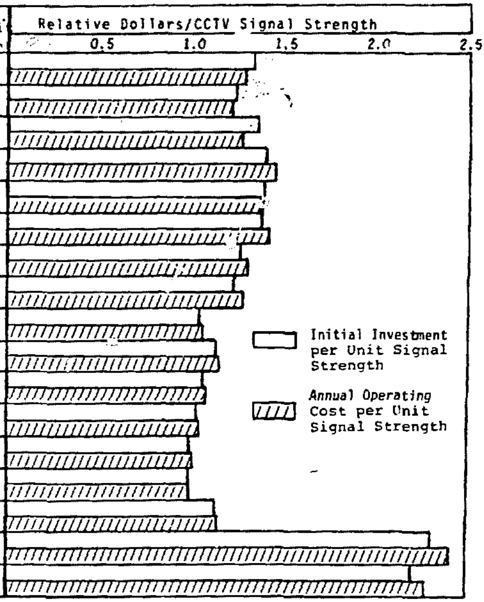


*System #9 does not meet the Specification but was used as base = 1.0 for Item 69

Fig. 10

COSTS PER 1000 Ft. Modular Length of Area per CCTV Tube Signal Strength
For Silicon Diode Vidicon

System No.		Initial Inv. Per Unit Signal Strength	Annual Op. Cost/Unit Signal Strength
HPS Flood	1	$5721	$1200
	2	5339	1133
	3	5878	1175
LPS Flood	4	6041	1349
	5	5767	1284
	6	5965	1317
	7	5425	1209
	8	5283	1185
	9	4470	992
HPS Street	10	4956	1061
	11	4585	995
	12	4392	963
	13	4268	935
	14	4270	925
	15	4865	1074
LPS Street	16	9896	2238
	17	9498	2125



*System #9 does not meet the Specification.

System #14 used as base = 1.00 for both items 68 and 69.

Fig 11

TABLES

TABLE I

180W LPS Luminaires (Wattage Input = 247)

ITEM	Manufacturers			
	"A"	"B"	"C"	"D"
Luminaire Type	Floodlight	Streetlight	Floodlight	Streetlight
Housing	Fabricated	Fabricated	Fabricated	Fabricated
Reflector	Removable	Removable	Removable	Removable
Outside Dim. (inches)	6¼x13x52	7¼x16x51¼	9x14x48	9½x7½x58
Max. Projected Area (sq.ft.)	4.8	2.5	4.7	3.0
Weight (lbs)	51	45	71	48
Enclosure	Polycar-bonate	Acrylic	Acrylic	Acrylic
Gasket	Silicone	Wool	Neoprene cell foam	Neoprene cell foam
Photometrics	ERL 2179	ITL 17218	LRL 979-3A	LRL-377-4D
Total Eff.	.658	.798	N/A	N/A
Total Beam	.617	.774	N/A	N/A
Total Down	N/A	.787	0.49	0.66
Deg. Spread (HxV)	145.5x108.2	152.7x166.1	N/A	N/A
Aiming Adjustment	Universal	Fixed hori-zontal $\pm 20^0$	5 fixed angles	fixed hori-zontal $\pm 20^0$
Lamp List $	68.00	68.00	68.00	68.00
Lamp Net $	44.00	44.00	44.00	44.00
List Price $	489.00	450.00	489.00	375.00
Net Price $	336.00	337.00	336.00	258.00

N/A = Not applicable or not available

TABLE II
400W HPS Luminaires (Wattage Input = 485)

ITEM	Manufacturers			
	"E"	"F"	"G"	"H"
Luminaire Type	Floodlight	Floodlight	Floodlight	Streetlight
Housing	*Cast	Cast	Fabricated	Cast
Reflector	Removable	Removable	Removable	Removable
Outside Dim (inches)	10x10x15½	9x18x22½	8-7/8x 22-1/8x26½	N/A
Max.projected area(sq.ft.)	1.8	2.8	2.72	1.2
Weight (lbs)	49(shipping)	55	62	50
Enclosure	Tempered Glass	Tempered Glass	Tempered Glass	Tempered Glass
Gasket	Rubber	Charcoal Filter	Rubber	Silicone
Photometric	ITL20922	35-176382	45543	35-175816
Total Eff.	.616	N/A	N/A	.779
Total Beam	.385	.47	.463	N/A
Total Down	N/A	N/A	N/A	.732
Deg. Spread (H X V)	109x54.4	112 X 86	134.6x94.5	N/A
Aiming Adjustment	Universal	Universal	Universal	Universal
Lamp List $	60	60	60	60
Lamp Net $	39	39	39	39
List Price $	306.67	333.00	560.00	219.00
Net Price $	230.00	250.00	420.00	165.00

TABLE III
ECONOMIC ANALYSIS FOR OUTDOOR LIGHTING SYSTEMS
INDEPENDENT TESTING LABORATORIES, INC. BOULDER, CO.

	THIS STUDY ASSUMES A MODULAR SECTION OF AREA 83.3 X 1000 FT	SYSTEM ID	B FLOOD 5 SB LPS 2/POLE	14 STREET 5 SB HPS 2/POLE
	KEY SHEET			
	EQUIPMENT INFORMATION			
1.	PHOTOMETRIC DAT	INPUT	ERL 2179	175816
2.	LUMINAIRE CAT. NO.	INPUT	SFL 33685	C7S-2457
3.	BALLAST CAT. NO.	INPUT	INTEGRAL	INTEGRAL
4.	POLE CAT. NO.	INPUT	25 MTG HT	25 MTG HT
5.	LAMP CAT. NO.	INPUT	SOI—180	HPS--400
	ILLUMINATION CALCULATIONS			
6.	SPACING OF POLES	INPUT	90.	80.
7.	UTILIZATION FACTOR	INPUT	.369	.304
8.	LIGHT LOSS FACTOR	INPUT	.840	.568
9.	AVERAGE ILLUMINATION	INPUT	2.664	2.598
	INITIAL EQUIPMENT INVESTMENT			
10.	NUMBER OF LUMINAIRES	INPUT	22.2	25.0
11.	COST PER LUMINAIRE	INPUT	336.00	165.00
12.	TOTAL COST LUMINAIRES	#10 X #11	7465.92	4125.00
13.	QUANTITY OF BALLAST	INPUT	.0	.0
14.	COST PER BALLAST	INPUT	.00	.00
15.	TOTAL COST BALLAST	#13 X #14	.00	.00
16.	QUANTITY OF POLES	INPUT	11.1	12.5
17.	COST PER POLE (MISC.)	INPUT	68.00	68.00
18.	TOTAL COST POLES	#16 X #17	755.48	850.00
19.	COST PER FOUNDATION	INPUT	.00	.00
20.	TOTAL COST POLES AND FOUNDATIONS	#16 X (#17 + #19)	755.48	850.00
21.	NO. LAMPS/LUMINAIRE	INPUT	1.	1.
22.	TOTAL NO. OF LAMPS	#10 X #21	22.22	25.00
23.	COST PER LAMP	INPUT	44.00	39.00
24.	TOTAL COST LAMPS	#22 X #23	977.68	975.00
25.	TRANSFORMERS, WIRE, MISC. CONTROL, ETC.	INPUT $25 X #41/1000	137.00	303.00
26.	TOTAL EQUIPMENT COST LESS LAMPS	#12 + #15 + #20 + #25	8158.40	5278.00
27.	TOTAL EQUIPMENT COST WITH LAMPS	#24 + #26	9336.08	6253.00
28.	STORAGE AND HANDLING	INPUT DEC. %	.15	.15
29.	INITIAL EQUIPMENT INVESTMENT	#27 + (#27 X #28)	10735.49	7190.95
30.	RELATIVE INVESTMENT	#29/(LOWEST #29)	1.55	1.04
	INITIAL INSTALLATION LABOR ESTIMATES			
31.	POLE INSTALLATION	INPUT	108.00	105.00
32.	LUMINAIRE INSTALLATION	INPUT	90.00	90.00
33.	BALLAST INSTALLATION	INPUT	.00	.00
34.	NET LABOR, LUMINAIRES, POLES, BALLASTS	#16 X #31 X #10 X 32 + #13 X #33	3199.68	3600.00
35.	TRANSFORMERS, WIRE, MISC. CONTROL ETC.	INPUT $25 X #41/1000	137.00	303.00
36.	INITIAL LABOR COST	#34 + #35	3336.68	3903.00
37.	INITIAL COST, LABOR EQUIPMENT	#29 + #35	14073.17	11093.95
38.	RELATIVE INVESTMENT	#37/(LOWEST #37)	1.45	1.14
39.	INITIAL $/FC	#37/#9	5267.72	4270.19
	ANNUAL COSTS			
40.	WATTS PER LUMINAIRE	INPUT	247.	485.
41.	SYSTEM TOTAL WATTS	#10 X #40	5486.	12125.
42.	HOURS OF OPERATION YEAR	INPUT	4000.	4000.
43.	SYSTEM ENERGY KWH/YR	#41 X #42/1000	21953.	48500.
44.	DEMAND CHARGE PER YEAR	INPUT	.00	.00
45.	COST PER KWH	INPUT	.01	.01
46.	ENERGY COSTS PER YEAR	#43 X #45 + #44	219.53	485.00
47.	LAMP LIFE (HOURS)	INPUT	18000.	24000.
48.	NO. OF LAMPS EACH YEAR	#10 X #21 X #42/#47	4.938	4.167
49.	COST OF LAMPS EACH YEAR	#23 X #48	217.26	162.50
50.	COST ENERGY, LAMPS/YEAR	#46 + #49	436.80	647.50
	ANNUAL MAINTENANCE LABOR AND MATERIALS			
51.	COST OF LABOR $/MAN-HR	INPUT	15.00	15.00
52.	RELAMPING TIME EACH	INPUT	.50	.30
53.	NO. RELAMPINGS PER LUMINAIRES/YEAR	#42/#47	.222	.167
54.	RELAMPING LABOR ONLY	#53 X #52 X #10 X #51	37.03	18.75
55.	CLEANING TIME/UNIT	INPUT	.50	.30
56.	NO. OF CLEANINGS/YR	INPUT	.22	.17
57.	SYSTEM CLEANING COSTS LABOR ONLY	#10 X #51 X #55 X #56	36.66	18.74
58.	PAINTING TIME/POLE	INPUT	.00	.00
59.	NO. PAINTING/POLE/YEAR	INPUT	.00	.00
60.	LABOR COST PAINTING/YEAR	#16 X #51 X #58 X #59	.00	.00
61.	PARTS, PAINT, ETC.	1% OF #26	83.58	52.78
62.	MAINTENANCE COST LESS LAMPS	#54 + #57 + #60 + #61	157.28	90.32
63.	TOTAL COSTS LAMPS, ENERGY, MAINTENANCE	#62 + #50	594.08	737.82
	ANNUAL FIXED COSTS			
64.	FIXED OWNING COSTS	INPUT DEC. %	.15	.15
65.	TOTAL FIXED COSTS	#37 X #64	2110.98	1664.09
66.	TOTAL OPERATING COSTS	#63 + #65	2705.05	2401.91
67.	COST PER FOOTCANDLE	#66/#9	1015.41	924.52
	RELATIVE COST OF LIGHT			
68.	RELATIVE INVESTMENT/FC	#39/(LOWEST #39)	1.24	1.00
69.	RELATIVE OPERATING COSTS FOOTCANDLE	#67/(LOWEST #67)	1.19	1.09

Table IV

Key Input Data Used for the Economic Analyses

Item	HPS	LPS	Item No.
Rated Life (Hours) also group Relamping Period	24000	18000	47
Lamp Lumen Depreciation Factor (LLD)	0.71	1.05	
Luminaire Dirt Depreciation Factor (LDD)	0.8	0.8	
Light Loss Factor (LLD) x (LDD)	0.568	0.84	8
Lamp Watts	400	180	
Ballast Input Watts	485*	247	41
% Ballast Losses	21.25	37.2	

*Regulator (Constant wattage type)

Table V <u>Floodlight Systems That Meet The Specifications</u>

Luminaire: E
Lamp: 400W HPS
Lumen Rating: 50000
Luminaire Dirt Factor: 0.80 (LDD)
Lamp Lumen Depreciation Factor: 0.71 (LLD)
Light Loss Factor: (LDD) X (LLD) = 0.568
Photometric Data: ITL 20922

LIGHT SYSTEM Economic Analysis	Pole Setback Feet (Meters)	Mounting Height Feet (Meters)	Number Units Per Pole	Pole Spacing Feet (Meters)	Max/Min Ratio	Average/Min Ratio	Minimum fc (lux)	Average fc (lux)
1	25 (7.62)	41 (12.5)	4	200 (61)	4.61	1.71	1.039 (11.2)	1.778 (19.1)
2	20 (6.10)	37 (11.3)	4	200 (61)	5.94	1.73	1.054 (11.3)	1.822 (19.6)
3	15 (4.57)	33 (10.1)	2	110 (33.5)	4.97	1.87	1.014 (10.9)	1.900 (20.5)
	10 (3.05)	29 (8.84)						
	5 (1.52)	25 (7.62)						
	0 (0)	21 (6.40)						

Luminaire: A
Lamp: 180W LPS
Lumen Rating: 33000
Luminaire Dirt Factor: 0.80 (LDD)
Lamp Lumen Deptreciation Factor: 1.05 (LLD)
Light Loss Factor: (LDD) X (LLD) = 0.84
Photometric Data: ERL 2179

4	25 (7.62)	41 (12.5)	4	170 (51.8)	5.56	2.34	1.087 (11.7)	2.542 (27.4)
5	20 (6.10)	37 (11.3)	3	150 (45.7)	5.7	2.32	0.941 (10.1)	2.299 (24.7)
6	15 (4.57)	33 (10.1)	2	100 (30.5)	4.32	2.17	1.070 (11.5)	2.138 (25.0)
7	10 (3.05)	29 (8.84)	2	100 (30.5)	5.41	2.35	1.03 (11.1)	2.419 (26.0)
8	5 (1.52)	25 (7.62)	2	90 (27.4)	5.89	2.39	1.116 (12.0)	2.664 (28.7)
9*	0 (0)	21 (6.40)	1	50 (15.2)	26.89*	12.89*	.233* (2.51)	3.004 (32.33)

*Does Not Meet Specification

Table VI   Streetlighting Systems That Meet The Specifications

Luminaire: H
Lamp: 400W HPS
Lumen Rating: 50000
Luminaire Dirt Factor: 0.80 (LDD)
Lamp Lumen Depreciation Factor: 0.71 (LLD)
Light Loss Factor: (LDD) X (LLD) = 0.568
Photometric Data: 35-175816

LIGHT SYSTEM Economic Analysis	Pole Setback Feet (Meters)	Mounting Height Feet (Meters)	Number Units Per Pole	Pole Spacing Feet (Meters)	Max/Min Ratio	Average/Min Ratio	Minimum fc (lux)	Average fc (lux)
10	25 (7.62)	41 (12.5)	4	170 (51.8)	5.19	2.23	0.986 (10.6)	2.201 (23.7)
11	20 (6.10)	37 (11.3)	4	170 (51.8)	5.75	2.28	0.994 (10.7)	2.265 (24.4)
12	15 (4.57)	33 (10.1)	4	160 (48.8)	5.65	2.38	1.02 (11.0)	2.426 (26.1)
13	10 (3.05)	29 (8.84)	3	120 (36.6)	5.67	2.49	1.005 (10.8)	2.506 (27.0)
14	5 (1.52)	25 (7.62)	2	80 (24.4)	5.94	2.61	0.996 (10.7)	2.598 (28.0)
15	0 (0)	21 (6.40)	2	60 (18.3)	5.69	2.851	1.182 (12.7)	2.851 (30.7)

Luminaire: D
Lamp: 180W LPS
Lumen Rating: 33000
Luminaire Dirt Factor: 0.80 (LDD)
Lamp Lumen Depreciation Factor: 1.05 (LLD)
Light Loss Factor: (LDD) X (LLD) = 0.84
Photometric Data: LRL377-4D

16	25 (7.62)	41 (12.5)	3*	76 (22.9)	5.25	2.31	1.037 (11.2)	2.399 (25.8)
17	20 (6.10)	37 (11.3)	2	52 (15.8)	5.61	2.53	1.013 (10.9)	2.561 (27.6)
	15 (4.57)	33 (10.1)						
	10 (3.05)	29 (8.84)						
	5 (1.52)	25 (7.62)						
	0 (0)	21 (6.40)						

*Unit rotated so lamp is parallel to area. Does not meet the Specification if lamp is left perpendicular to area.

TABLE VII

SUMMARY OF ECONOMIC ANALYSES

ITEM	Power @ ¢/kwh	LIGHTING SYSTEM: HPS Flood 1	2	3	LPS Flood 4	5	6	7	8	9	HPS Streetlight 10	11	12	13	14	15	LPS Street 16	17
Relative Initial Investment (Item 38)	1-10	1.05	1.0	1.15	1.58	1.36	1.42	1.35	1.45	1.38	1.12	1.07	1.10	1.10	1.14	1.43	2.44	2.50
Relative Initial Investment/fc (Item 68)	1-10	1.34	1.25	1.38	1.41	1.40	1.39	1.27	1.24	1.05	1.16	1.07	1.03	1.00	1.00	1.14	2.32	2.22
Relative Operating Cost/fc (Item 69)	1	1.41	1.33	1.38	1.36	1.29	1.33	1.22	1.19	1.00	1.25	1.17	1.13	1.10	1.09	1.26	2.26	2.14
	2	1.55	1.47	1.49	1.36	1.29	1.33	1.22	1.20	1.00	1.38	1.31	1.27	1.23	1.21	1.42	2.27	2.15
	3	1.67	1.59	1.57	1.36	1.30	1.32	1.22	1.20	1.00	1.50	1.42	1.39	1.35	1.3[illegible]	1.56	2.28	2.16
	4	1.77	1.69	1.65	1.37	1.30	1.32	1.22	1.21	1.00	1.61	1.53	1.49	1.45	1.42	1.68	2.30	2.16
	6	1.94	1.86	1.78	1.37	1.30	1.32	1.23	1.21	1.00	1.78	1.70	1.66	1.61	1.58	1.87	2.32	2.17
	10	2.19	2.11	1.97	1.37	1.30	1.31	1.23	1.22	1.00	2.03	1.95	1.92	1.86	1.81	2.16	2.34	2.19

*Does not meet the specification

TABLE VIII

Comparison of Design Predictions and Measurements

Light Source Lamp Lumens	400 HPS 50000		180 LPS 33000	
No. per pole	2		2	
Age of Installation	15½ months		4 months	
Photometric Data	ITL 20922		ITL 17218	
Modular Area	160 X 75		80 X 70	
Aiming	70° apart, 65° up		10° up-tilt	
LDD (dirt)	.90		.90	
LLD (lumens)	1.00		1.00	
Voltage Applied (measured)	460		122.7	
Rated Ballast Voltage	N/A		N/A	
	Design	Measured	Design	Measured
Pole Setback	25	28		
Mtg Ht	25	27'9"	40*	N/A
Pole Spacing	160	160	80	78'9" (average)
No. Points	221	63	135	40
Footcandles Average	1.70	1.33	1.957	1.38
Maximum	3.15	2.27	4.165	2.96
Minimum	1.20	0.72*	0.584*	.42*
Ratio Max/Min	2.63	3.15	7.13*	7.05*

N/A Not Available
*Does Not Meet the Specification

System Errors

SYSTEM	HPS LAMPS			LPS LAMPS		
Item	Design	Measured	% Error	Design	Measured	% Error
Max/Min	2.63	3.15	19.8	7.13	7.05	1.1
Average	1.70	1.33	21.8	1.957	1.38	41.8

TABLE IX Ranking of Causes of System Error

Ranking In Order of Importance		System Error	
		Average Illumination	Uniformity Max/Min Ratio
VERY	1	1a	1a
	2	3c	2c
	3	2d	2a
	4	1b	2b
	5	1f	2e
MODERATE	6	3d	3b
	7	3a	3c
	8	1c	1c
	9	1d	1d
	10	1e	1e
SLIGHT	11	2c	3e
	12	2a	3a
	13	2b	1b
	14	2e	1f
	15	3c	3d
	16	3b	2d

TABLE X Signal Strength

TV Camera Tube	Lamps					
	LPS 180	HPS 400	Tung. Halog. 500	Clear Merc. 400	"B" Met. Halide 400	"A" Met. Halide 400
	Signal Strength in micro-amperes per lumen					
Silicon Diode Vidicon	888	1036	4203	988	1368	1093
Newvicon	1269	1526	4783	1334	1715	1559
Standard Vidicon (Sulphide)*	140	163	278	210	245	241
SIT	108106	132852	247815	218148	240336	236321
ISIT	3977196	4895802	9775590	6600840	7854792	7715304
TV Camera Tube	Signal Strength in amperes/watt of electrical power (a product of above signal strengths and lamp efficiencies in lumens per watt)					
Silicon Diode Vidicon	.139	.117	.0904	.0519	.123	.098
Newvicon	.203	.172	.103	.070	.1[illegible]4	.140
Standard Vidicon (Sulphide)*	.022	.0183	.00598	.0110	.022	.0217
SIT	17.0	14.9	5.33	11.5	21.6	21.3
ISIT	624.	551.	210.	347.	707.	694.

*Refer to cautionary note associated with Figure 4