STUDY OF
ILLUMINATION DESIGN AND LIGHTING SURVEY
OF THE
ALUMNI MEMORIAL AUDITORIUM
OF THE
UNIVERSITY OF TENNESSEE

BY

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P R E F A C E

Artificial illumination was inaugurated among the oldest peoples of whom we have records, yet the art has reached its culmination only in the present century. The wood fire was probably the first illuminant employed by primitive man and little better illumination is used today among some of the uncivilized people in the isolated portions of the world. History emphasizes the fact that it is the nature of civilized man to improve his environment and consequently the passing of the centuries has witnessed the introduction of the animal oil and wick lamps, the candle, and in the last century the kerosene, the gas and the incandescent lamps. Like most sciences the greatest acceleration of the illumination art has occurred during the latter part of the nineteenth and the early part of the twentieth centuries.

With the invention of the incandescent lamp by Edison in 1879 the modern illumination science may be said to have begun. Up to this time very little consideration had been given to the actual design of illumination systems. It is true, of course, that the gas lamp, with its high luminosity and other marked advantages over the other forms of illumin-

ants, had led to some improvement in the design of illumination systems. However, the uniformity of illumination, freedom from fire hazards, dependability, and other advantages of the incandescent lamp were so outstanding that the demand for this form of illuminant soon grew so insistent as to create a new industry, the commercial production of electrical energy. Since the chief source of income of these early electric companies was that derived from the sale of energy for incandescent lamps, it is not surprising that the companies should sponser investigations into illumination design by which the sale of electric power could be promoted. Research laboratories were established and investigations into illumination design made by a corps of competent engineers. Such organizations as the N. E. L. A., the I. E. S. and the illumination department of the General Electric Company were the direct offsprings of these early research laboratories.

Today the illumination art rests upon a rather secure footing. Time saving methods have been compiled by means of which the most complicated illumination problems can be solved approximately even by the novice. The properties of illuminants and luminaries have been investigated and the findings published to the engineering world.

"After the commercialization of the improved incandescent lamps, there issued a period of rapid development of luminaries, fixtures and other equipment for adapting the light for various uses. We appear now to have reached a point of comparative stability. The improvements of the past

year or so have been principally in the nature of refinements, involving no radical changes or new principles."

"As regards lighting practice, the advance consists of the more intensive use of light, a tendency toward better diffusion, and more artistic equipment and effects, especially with the use of light from neon tubes. New installations are showing a trend toward the recognized principles of good lighting, and many old installations have been revamped, as it was economically a good policy to do so. However, there is still a tremendous amount of educational work to be done to bring the average installation to the desired level and quality of illumination." [1]

It is proposed in this thesis to investigate a few important methods of illumination design and to apply these principles to the lighting system of the Memorial Auditorium of the University of Tennessee. The illumination system, installed in the auditorium, will be checked by commercial design methods and an actual illumination survey of the auditorium performed. Illumination terms will be used occasionally without proper explanation of their meaning and since the general public is not well informed upon the subject, the reader is referred to the accompanying glossary of illumination units and factors. Occasionally information will be used without due credit being given to the source but in general all data not of general information will be accredited to the proper authorities.

(1) Transactions of the NELA, Year Book, 1924.

GLOSSARY OF ILLUMINATION TERMS

CANDLEPOWER is the unit of intensity of a luminous source. It can be defined in general terms as the capacity of a source of light to act as an illuminant, or emitter of luminous flux in some particular direction, in terms of the internationally agreed unit, the candle.

MEAN SPHERICAL CANDLEPOWER is the average candle power in all directions in the space around a source.

LUMEN is the unit of luminous flux radiated and "equal to the flux emitted in unit solid angle by a uniform point source of one international candle."(2) A sphere 1 unit in radius with 1 standard candle at the center, will receive upon each square foot of surface area a light intensity of 1 lumen per sq. ft. of 1 ft. candle.

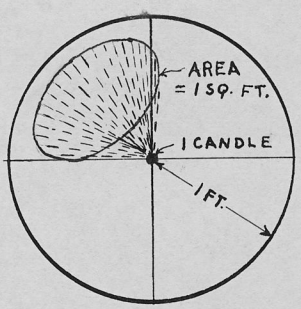


FIG. 1

ILLUMINATION is the surface density of flux received and is naturally quite independant of the nature of the surface.

FOOTCANDLE is the practical unit of illumination and is the illumination produced at a point on a surface, which at the point is normal to the direction in which a source, located at a distance of 1 ft., has an intensity of 1 candlepower.

LUX is also an unit of illumination and is equal to a luminous flux of 1 lumen per square meter.

BRIGHTNESS is a function of the flux emitted, whether the emission be a true self-emission, as the case of an incandescent body, or reflected-emission of an incandescent body, as in the case of a surface visible by reason of light received from some illuminant and reflected to the eye of the observer. The equation for brightness is $b_\theta = \frac{D\ I\ \theta}{D_s\ Cos\ \theta}$ where b_0 is the brightness in the direction 0 degrees from the normal to the area, D_s, and D I θ is the candlepower in that direction.

LAMBERT is the practical unit of brightness and is equal to a brightness of 1 n candles per sq. cm. of projected area. It is the average brightness of a surface emitting or reflecting one lumen per sq. cm.

GLARE is brightness within the field of vision of such a character as to cause discomfort, annoyance, and interference with vision or eye fatigue. It has some times been characterized as light out of place.

REFLECTION FACTOR is the ratio of the flux reflected by a body to the flux incident upon it.

COEFFICIENT OF UTILIZATION is the proportion of the generated light which reaches the plane of the work.

EQUILUX LINES are contours drawn through all stations of equal intensity on the working plane. Equilux lines correspond to isobaric lines on a weather map.

LUMINARES are reflectors, shades, or globes used to reflect or distribute light in cartain desired directions.

OUTLETS are merely locations of lamps and luminaries.

LIGHTING INSTALLATION OF THE AUDITORIUM

As a measure of economy the administration of the University of Tennessee combined the structures of an auditorium and a gymnasium in one edifice, completed in 1932 as a memorial to the alumni. The main assembly room of this building is used normally as an auditorium but on other occasions as a basket-ball court and dance floor. The lighting requirements of an auditorium and dance floor are practically identical but differ considerably from those of a basket-ball court. For an auditorium an average illumination of about 3 or 4 foot candles should be maintained, for a dance floor about 5 foot candles, and for a basket-ball court from 10 to 15 foot candles. The varying uses to which a part of the auditorium is subjected complicates the illumination design of the structure.

The auditorium is rectangular in shape and possesses balconys on three sides sloping at angles of thirty degrees. A picture of the auditorium can best be formed by a study of the accompanying photographs. Fig. 2 is a photograph of one side of the auditorium. The exposure was made at night with all lamps operating and gives an indica-

tion of the relative distribution of the artificial light. In the foreground of the photograph is the main floor of the auditorium. It will be noticed that there are black paint

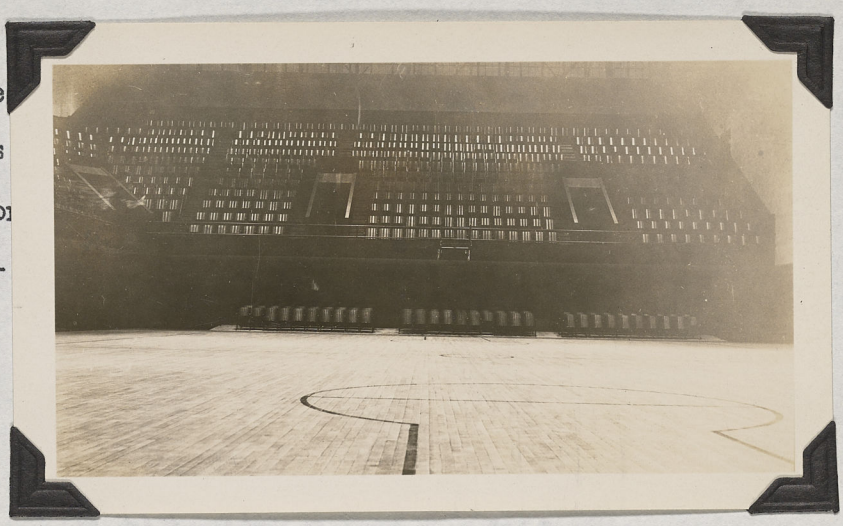


FIG. 2

markings upon the floor and a scaffold on the railing of the balcony. These markings, of course, constitute a part of the basket-ball court and the scaffold is provided for the support of the backboard (not shown in photograph). Normally seats, practically similar to those shown in and under the balconies, occupy the basket-ball court. Three exits are provided on the balcony.

Fig. 3 is also a photograph of one side of the auditorium. In this picture the daylight illumination,

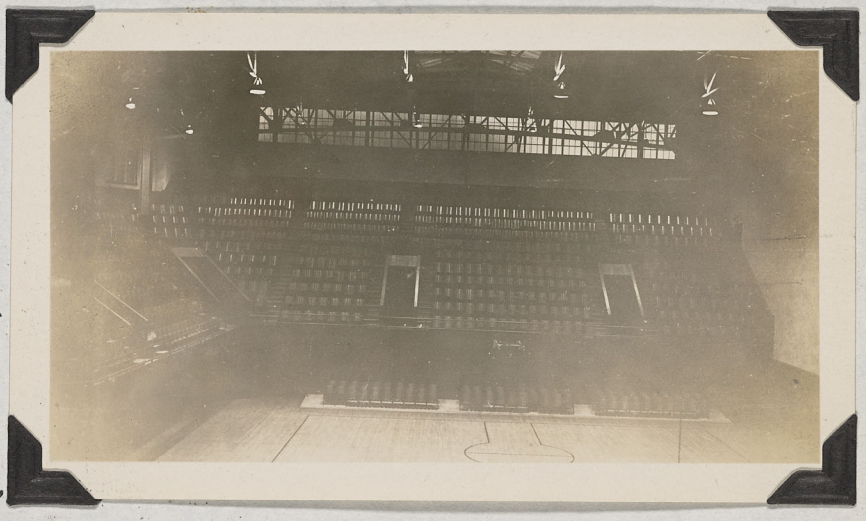


Fig. 3

consisting of skylight above the balconies can be seen.

These skylights present numerous difficulties in natural illumination. Although the skylights are made of frosted glass, they do not prevent the direct rays of the sunlight from passing thru and into the auditorium. During a large part of the day, therefore, a wide band of bright sunlight strikes some of the seats in the balcony and on the main floor. The sunlight shines directly into the faces of the audience and would be a source of acute discomfort, if the auditorium was used often during the day.

In Fig. 3 a part of the lighting layout of the auditorium can be seen. The direct lighting system is used in the auditorium. It will be noticed from a study of this photograph that there is a row of four large lamps above the main floor or basket-ball court. There are three rows of these lamps, spaced as shown in the plan view of the auditorium, Page 25a of the Appendix. The lamps used are 750 watts in capacity but the wiring and fixtures are designed in such a manner as to enable the size of the lamps to be increased to 1000 watts, if deemed necessary. It will be noticed that these lamps are not all mounted at the same height above the working plane. The actual height of the lamps above the basket-ball court are approximately 40 and 38 ft. respectively. Above the balcony are suspended twenty 200 watt lamps. These supplementary lamps are arranged in two rows at mounting heights of 18 and 12 ft., respectively, above the working plane. Referring to the plan view of the auditorium on Page 25-A of the Appendix, it will be noticed that the lamps

in the two rows, as seen from the stage, are staggered in such a manner as to distribute the illumination uniformly over the working plans. An examination of Fig. 2 and the plan view of the auditorium on Page 25-A of the Appendix will reveal the fact that 15 - 100 watt lamps are installed underneath the balconies. These lamps are mounted flush with the ceiling and are provided with glass domes. The stage is lighted by six 200 watt lamps, equipped with RIM dome reflectors, and staggered in a symmetrical pattern. All lamps used in the auditorium at present are manufactured by the Consolidated Electric Lamp Company.

The reflectors, employed with the 750 watt and 200 watt lamps above the main floor and balcony, were manufactured by the Curtis Electric Company, of Chicago, Illinois. The luminaires are termed "X-ray" silver glass mirror reflectors and possess characteristics as recorded in the following table:

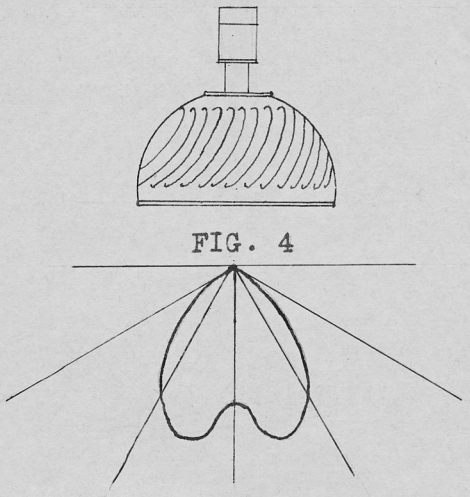


FIG. 4

CHARACTERISTICS

Relative Footcandle for a given lamp size:

O_n Horizontal = A + (excellent)

O_n Vertical = B (good)

Appearance of lighted room = B (good)

Direct glare = C + (very fair)

Reflected glare = D (unsatisfactory above polished surface)

Shadows = C (fair)

Maintenance = A (Excellent)

The reflectors for the 750 watt lamps were designed for an

installation of 1000 watts and are approximately 20" in diameter and 11" in depth. These reflectors are mounted at a height of approximately 7 ft. from the ceiling but, since the latter slopes from the center outward, the heights of the luminaires from the working plane are approximately 40 and 38 ft. respectively. The reflectors over the balcony are 12" in diameter and 9" in depth.

It will be noticed from a study of the flux distribution curve of these reflectors that the major portion of the light emitted by the lamp is directed downward. The maximum candle power is not secured directly downward, however, but at an angle of approximately 18 deg. with the nadir. The distribution of the light upon the working plane from one lamp will therefore appear as a dark circle directly under the lamp, a bright concentric circle, and then a circle gradually darkening radially outward from the center of the lamp. The actual distribution of the light from the reflector can be noted by an examination of Fig. 5 which is a photograph of the light received upon the basket-ball floor from one lamp. A distinct dark circle will be noted directly under the lumenaire, followed by a bright circle, and then by a dark circle gradually decreasing in

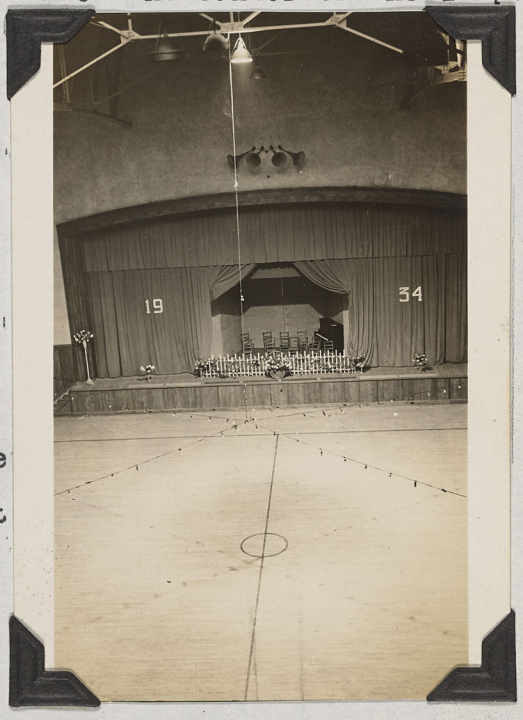


Fig 5

intensity as the distance from the lamp is increased. The reflectors provided with the installation are well adapted to the auditorium, since the majority of the light must be reflected downwards from a considerable height upon the working plane. A lumenaire which distributes the light at a maximum effective angle with the nadir of perhaps 70 deg. would be very unsuitable for this installation, since a large proportion of the light would be reflected upon the walls. The average reflection factor of the seats, walls, and floor is approximately 35 or 40 %. The major portion of the auditorium is painted with the same color scheme as the seats which have a reflection factor of 37 %. The reflection factors of the auditorium are as follows:

Walls of stage	65 per cent
Floor	38 per cent
Walls (10 ft. above floor to ceiling)	37 per cent
Seats	37 per cent
Concrete floor	44 per cent
Front Wall	50 per cent

ILLUMINATION DESIGN

The illumination of large rooms with high bays is a very complicated problem which must be solved by the designer before the wiring system, reflectors, and lamps are actually installed. It is not sufficient to merely locate a few outlets in positions convenient for wiring purposes and to then install reflectors and lamps without due regard for

the distribution of illumination that will thereby be secured upon the working plane. The type of illumination required upon the working plane will to a great extent determine the location of the outlets and the size of the lamps. For practically all installations a uniform illumination upon the working plane is desired and most of the present illumination systems are designed with this object in view. Occasionally localized lighting is desired upon a portion of the working plane and the lighting system that must therefore be provided differs considerably from that required for uniform distribution. An absolute uniform illumination is of course impossible but, like the Carnot cycle in the phermodynamic system, usually worth striving for.

In this portion of the thesis it is proposed to accomplish four purposes: (1) To evaluate the factors of illumination design encountered in the auditorium of the University of Tennessee. (2) To check a portion of the illumination system actually installed in the auditorium, (3) To endeavor to improve the illumination system by changing the spacing of the outlets in an effort to secure thereby a more uniform distribution of illumination, and (4) To determine whether the present illumination system can be made suitable for both an auditorium and a basket-ball court by dimming or extingishing certain lights. The present installation will be checked by two of the most important systems of illumination design in modern use: an adaptation of the point-to-point and the lumen methods. The calculations will be given in detail

wherever possible and the factors involved explained as rationally as possible. To determine a new spacing of outlets by which more uniform distribution of illumination can be secured upon the working plane, use will be made of a theory proposed by a member of the British Institute of Electrical Engineers. The study of illumination in the auditorium is considerably complicated by the fact that a portion of the auditorium is used for the dual purposes of a basket-ball court and an assembly room.

LIGHTING OF AUDITORIUMS

There is no such thing as a standard illumination design for auditoriums. Very few auditoriums are exactly similar in all architectural details or in lighting requirements. Some auditoriums are used for several purposes for which lighting requirements are different. In spite of the lack of uniformity among auditoriums, however, there are certain salient features applicable in general to most auditoriums.

It is of course assumed in any auditorium that there will be an audience facing the stage. Obviously, the lighting installation, therefore, should be satisfactory from the standpoint of the audience as well as the occupants of the stage. In practice it will occasionally be found that the lighting installation cannot be made satisfactory from the standpoint of both the audience and the stage; consequently in these instances the audience must be given primary consideration.

In general, brightness and glare should not be allow-

ed to occur in the field of vision of the audience. Eye fatigue is in great measure due primarily to glare and lumenaires and polished surfaces giving rise to glare should be avoided if possible. Since very few lumenaires of the direct type are satisfactory from the standpoint of glare above polished surfaces, this may mean in some instances the substitution of an indirect or semi-indirect system. The lamps should be well-shaded from the eyes. A low intensity of light upon the wall and ceiling of the auditorium is desirable and contrasts of light and shadow should be avoided. A uniform illumination of 3 or 4 footcandles is desirable in practically all auditoriums.

Since a higher illumination must necessarily be maintained upon the stage than in the auditorium, precautions should be taken to exclude glare from the auditorium lights as viewed by the occupants of the stage. Occasionally this may be impossible to affect without considerable increase in the cost of installation. The background of the stage should not possess a high reflection factor since when the auditorium is dimly lighted, the background will present a high contrast to the audience.

LIGHTING OF BASKET-BALL COURTS

The lighting of basket-ball courts is entirely distinct from that of an auditorium. A much higher intensity of illumination must be maintained on the basket-ball court in order that the eyes of the players may not be strained. The

following curve, Fig. 6 reproduced from "Illumination Design Data" of the General Electric Company, shows graphically the relation between illumination and the time required for perception. Basket-ball is a relatively fast game and the eyes of the players are subjected to considerable strain unless proper illumination is maintained. It is common practice to supply 15 foot candles upon basket-ball courts and a minimum of 10 foot candles.

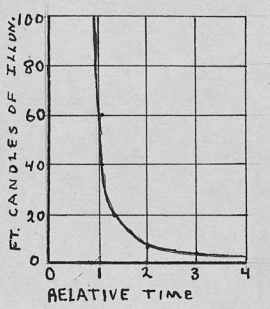


Fig. 6

Since the players' eyes are frequently directed toward the backboards, it is often advisable to supply a high level of illumination upon the latter. In order to avoid glare it is sometimes necessary to cover the backboards with a white matte paint.

In general all lamps should be shielded from the eyes of the players and as uniform an illumination maintained as possible. The general trend in design of basket-ball courts is toward higher levels of illumination and, consequently, no fear should be entertained of designing a basket-ball court with too high an intensity of light.

LOCATION OF OUTLETS

In the design of any illumination system the area and shape of the working plane will usually be known in advance. It becomes necessary therefore to determine the location and

number of outlets for a given installation. If the working plane is a square area, evidently for greatest uniformity $d = \frac{A}{M}$, if d is the distance between outlets, A the area of the working plane, and N the number of outlets. If, as is usually the case, the working plane is rectangular $d = \frac{A}{C\ N}$, where A is the area of the working plane, N the number of outlets, d the distance one way between lamps and C the distance to a lamp at right angles to the other direction. In the latter equation both, d, c, and N are unknown and, consequently, the value of two of the variables must be assumed and the equation solved for a suitable value of the remaining variable. The value of the spacing distances will depend in great measure not only upon the area to be illuminated and the number of outlets but also upon the mounting height. Since usually the mounting height will be fixed within rather narrow limits for a given installation, it is advisable to assume a convenient mounting height and then to determine the spacing ratio that must be selected in order to secure uniform lighting upon the working plane. It is apparent, therefore, that experience largely dictates the spacing distance and mounting height of a given installation. Numerous tests have been made to determine the maximum and minimum spacing distances for assumed mounting heights and these data, when available, are of considerable value to the illumination engineer.

An approximate value of the proper spacing distance can sometimes be secured from a study of the reflector. Usually

the type of reflector to be installed will be known in advance, the type selected, of course, being largely governed by the mounting height and illumination desired upon the working plane. Assuming, for instance, that the reflector used, possessed a distribution curve as shown in the following illustration, the spacing distances should be such as to make, E_1 the total illumination upon the working plane received from the two lumenaires, a horizontal line.

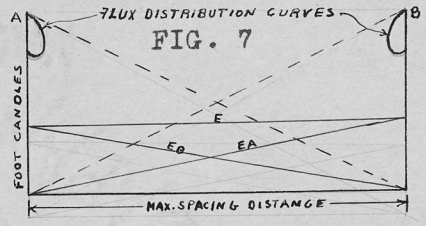


FIG. 7

E_a = illumination secured from lamp A

E_b = illumination secured from lamp B

E = total illumination due to both lamps

e = angle at which effective light is cut off by reflector.

Evidently this spacing distance would be the maximum at which the lumenaires could be placed and in actual commercial design the spacing would be much less. Shortening the spacing distance decreases the efficiency of the installation, although, perhaps, insuring a higher illumination upon the working plane.

For the installation over the working plane of the basketball court of the Memorial Auditorium of the University of Tennessee a silvered mirror glass reflector is used. The shape of the distribution curve of these reflectors is of such nature as to make e approximately 50 deg. The mounting height is approximately 40 feet. Consequently the maximum spacing distance should be 40 tan. 50 deg. = 48 feet approximately. The actual spacing distances selected for the installation were 32 and 18 feet and hence it is apparent that the design of the illumination system is not above the maximum spacing in ratio.

SIZE OF LAMPS

Having determined the area of the working plane, the spacing distance between outlets, the mounting height, and the number of lamps and reflectors, it is possible to determine the size of lamp required for the installation. Evidently, $W = \frac{A\,E}{K\,N}$, where W is the wattage of the lamps, A the area of the working plane in square feet, N the number of lamps, K the efficiency of the installation in lumens per watt, and E the illumination desired upon the working plane. The numerator, A E, in this equation is evidently the luminous flux received upon the working plane. In this equation the only two unknowns are K and W. W, the wattage of the lamps, is the value to be determined. The efficiency of the installation, K, according to Kunerth's "Textbook of Illumination," depends upon the following factors:

"(a) The type of lamp used.

(b) The type of lumenaire used.

(c) The cleanliness of bulbs and accessories.

(d) The reflection factor of the walls, ceiling, and furniture.

(e) The lighting system (direct, semi-direct, and indirect).

(f) The height and shape of the room and the location of the lamps. A great distance between lamps and working plane makes for a high efficiency of installation."

Obviously, the determination of the efficiency of the installation is not easy and in the hands of an inexperienced person may in fact be practically impossible. In the Auditorium of the University of Tennessee the average illumination up-

on the basket-ball court is approximately 10 ft. candles. Since the size of the court is 98 x 86 feet, the size of lamps 750 watts, and the number of lamps 12, evidently $K = \frac{A\,E}{W\,N}$. Therefore $K = \frac{86 \times 98 \times 10}{750 \times 12} = 94$ lumens per watt.

The determination of the lumens per watt reaching the working plane is almost wholly a matter of experience. The designer usually bases his calculations upon previous installations and installs equipment sufficient to produce a greater intensity of light upon the working plane than that calculated. In the lumen method of design much of the uncertainty of the above method is eliminated by tables of data which have been compiled for rooms of different shapes, mounting heights, lumenaires, and reflection factors. The lumen method is in fact based upon the foregoing principles but actual data instead of estimations are employed.

Since an estimation must be made in any event and since for all methods, except the lumen design system, these approximations are subject to considerable error, the size of lamps required can be computed by deciding upon the number of watts required per sq. ft. upon the working plane of the given installation. If the area in sq. ft. is then multiplied by the watts per sq. foot, the total wattage required for the installation will be obtained and thereby the size of lamps. This is in fact the method used by electricians in determining the size of lamps required for a given installation. From similar installations the electrician can estimate approx-

imately the watts per sq. ft. required and, therefore, the total wattage.

THE POINT-TO-POINT METHOD

Having by means of the foregoing principles determined the most practical spacing distance, the mounting height, and size and number of lamps and lumenaires the final step in illumination design is to calculate the amount of light actually reaching the working plane. In some respects this is the most important part of illumination design, since it serves as a positive check upon the accuracy of the system. In the lumen method the average illumination only is secured and no indication of the position or magnitude of the minimum and maximum illumination obtained. In the point-to-point method the location and number and size of lamps and lumenaires are determined in accordance with the above principles of illumination design, but the actual illumination reaching the working plane at various points is calculated. If the outlets have been located and the type of lumenaire and size of lamp selected, it is therefore possible by means of the point-to-point method to actually check the theoretical illumination upon the working plane at any selected point.

Stated briefly the point-to-point system of checking an illumination design is merely a method by which the components of the illumination from the light sources actually reaching arbitrarily chosen points on the working plane are calculated and added to give the total illumination. It is,

of course, common knowledge that the illumination reaching a plane from a light source is directly proportional to the intensity of the luminous source and inversely proportional to the square of the distance between the source and the plane or $E = \frac{1}{h^2}$, where E is the illumination or density of the luminous source in foot candles, 1 the intensity of the luminous source in candle power, and h the distance in feet between the light source and the point on the working plane. The above formula applies only to the special case where the working plane is normal to the beam of light. If the working plane is inclined at an angle to the beam of light, the intensity of luminosity is equal to the candle-power in the original direction multiplied by the cosine of the angle of incidence of the working plane and the light rays. If the light source be essentially a point, the rays will be emitted in all directions in space and hence the intensity of luminosity at points upon the working plane will be equal to the actual intensity in the given direction multiplied by the cosine of the angle of incidence.

The working plane in most instances is horizontal and it becomes necessary, therefore, to derive an equation by means of which the illumination upon a horizontal plane can be calculated. The following illustrations will indicate the methods by which the desired equation is derived.

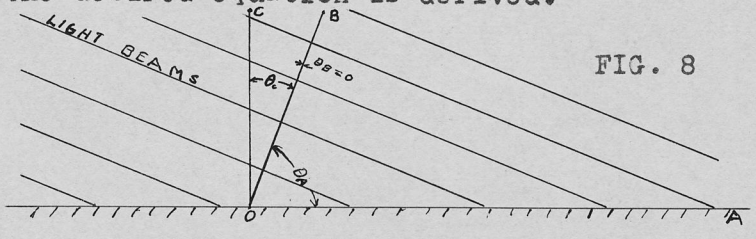


FIG. 8

Let OC, OB, OA = working plane at angles of e, e_2, and e_3 with the beam of light.

E = intensity of luminous flux in foot candles.

l = intensity of luminous source in candle power.

e = angle of incidence of working plane and beam of light.

Evidently, E is proportional to l cos e and consequently the intensity of illumination, E, increases as the angle of incidence, e, decreases.

If the light source is practically a point and the working plane horizontal, the conditions represented in the following illustration will exist.

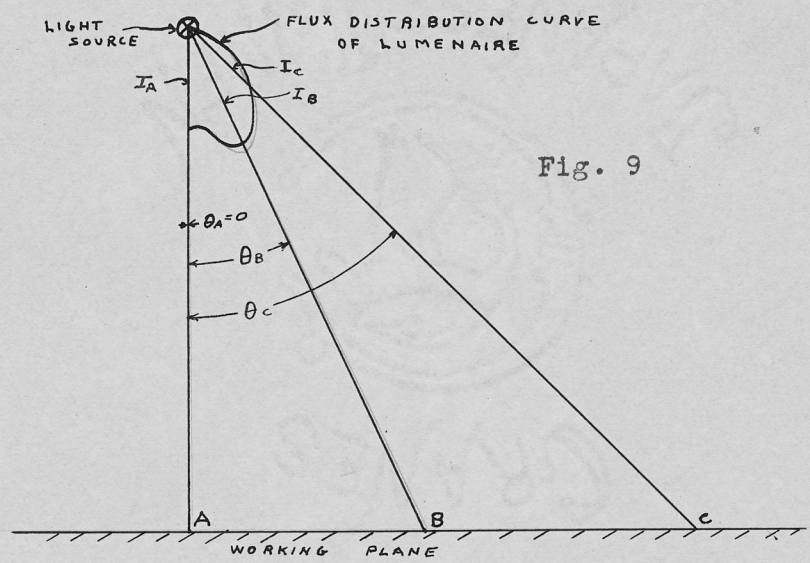


Fig. 9

Let lx = intensity of luminosity in candle power at an angle, e, with the perpendicular from the source, S, to the working plane.

E = intensity of luminous flux or the illumination in foot candles at the point, x, on the working plane, at a distance,

h_x from the source.

Evidently $E_x = \frac{lx \cos e}{h_x^2}$

But $h_x = \frac{h_o}{\cos e}$

Therefore $E = \frac{lx \cos e \cos^2 e}{h_o^2} = \frac{lx \cos^2 e}{h_o^2}$

For a horizontal working plane, therefore, the illumination at any point can be calculated directly from the equation $E = \frac{l \cos^3 e}{h_o^2}$

where E is the intensity of luminous flux or illumination in foot candles at a point upon the working plane.

l the intensity of luminosity of the source in the direction of the point on the working plane.

e the angle on incidence or angle between the beam and the working plane.

h the perpendicular distance between the light source and the working plane or the mounting height.

With these principles in mind it is not difficult to understand how the point-to-point method of determining the amount of illumination received upon a point on the working plane is applied to an installation. A drawing to scale of the working plane is first made and the position of the outlets marked. The final determination is then to obtain the illumination secured at a chosen point upon the plane from each of the lamps.

In order to actually use the equation $E = \frac{l \cos^3 e}{h_o^2}$

is necessary to determine the value of 1, the light intensity in the direction from the nadir e. The mounting height h_o, and the angle with the nadir will, of course, be constant and measurable, respectively. The amount of light intensity, 1, in candle power in any direction can be obtained directly from the flux distribution curve of the lumenaire. A flux distribution curve of a lumenaire or reflector shows graphically in polar coordinate form the intensity in candle power emitted by the reflector at different angles from the nadir. If the flux distribution curve of the reflector and lamp selected for the installation is available, it is, therefore, a relatively easy matter to determine the theoretical illumination received upon any portion of the working plane. In order to simplify the calculations it is convenient to determine the illumination upon the working plane secured at different distances on the horizontal plane from the projection thereon of one lamp. Having determined by means of the equation $E = \frac{1 \cos^3 e}{h_o^2}$ and the flux distribution curve of the lumenaire the illumination at various distances upon the working plane from the projection of one lamp, a curve can be plotted between foot candles of illumination and distance from the projection of the lamp to the point on the working plane. The illumination secured at any point upon the working plane from any lamp can then be determined by measuring the distance from the lumenaire to the selected point, and reading from the curve the illumination theoretically secured at the point. The sum of the component illuminations received at the point from all the lumenaires will then be ap-

proximately the total illumination at the point. By calculating in this manner the total illumination secured at various points on the working plane, the theoretical distribution of illumination upon the working plane can be determined and the minimum and maximum illumination noted.

The manufacturer of the lamps used in the Memorial Auditorium was written and asked to furnish the authors with a flux distribution curve of the lamps used. Unofrtunately the data compiled by the manufacturer was for a Benjamin Fluted Enamel Bowl Reflector, a very undesirable lumenaire for this installation. The flux distribution curve for this type of reflector is shown on Page 22A of the Appendix. It will be noted from a study of this flux distribution curve that the major portion of the light is directed downwards between an angle with the nadir of 70 degrees. Since the mounting height of the lumenaire in the Memorial Auditorium of the University of Tennessee is 40 feet, this form of distribution would obviously result in a very low installation efficiency, since a large portion of the light would be wasted upon the walls and ceiling. In accordance with the foregoing principles the illumination upon the working plane was calculated and found to be a maximum of 1.74 foot candles as contrasted with a maximum of 4.35 foot candles secured with the reflector actually used in the installation. The results of the calculations upon the Benjamin Fluted Enamel Bowl Reflector are as follows:

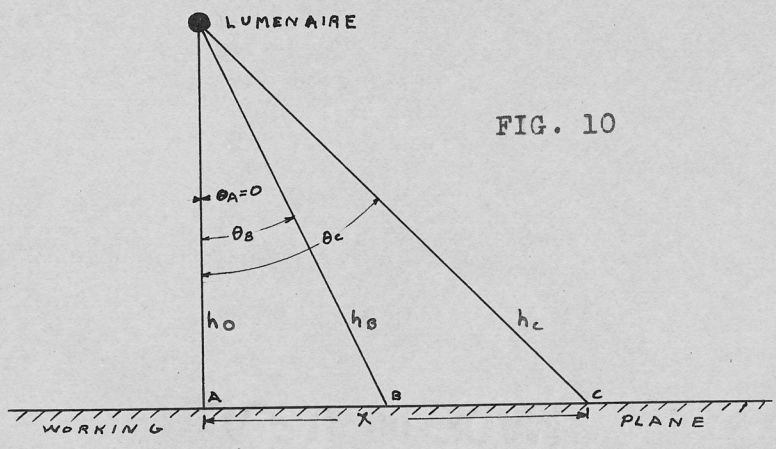


FIG. 10

$$E = \frac{l \cos^3 e}{h^2}$$

Values of l were given for 1000 watt lamp. For 750 watts

$$l = \frac{\text{lumens emitted by 750 watts}}{\text{Lumens emitted by 1000 watts}} \quad \text{x l for 1000 watts,}$$

$$l = \frac{14400}{20000} \quad \text{l for 1000 watts.}$$

h	x	e	cos e	Candle Power / 1000	Candle Power / 750	Ft. Candles
40	3.35	5	0.9962	3590	2585	1.74
40	10.30	15	0.9659	3610	2600	1.57
40	17.9	25	0.9063	3610	2600	1.31
40	27.0	35	0.8192	3780	2720	1.02
40	38.6	45	0.7071	3660	2635	0.64

Since the actual lumenaire, when tested, reflected a maximum amount of light sufficient to maintain an illumination of 4.35 foot candles upon the working plane, it is quite logical to expect that the total illumination received upon the

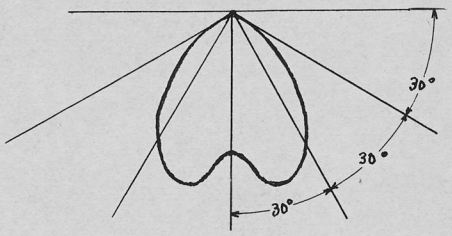
working plane from the reflectors of this type would be too small. Consequently, no further use of this distribution curve was made and it was decided instead to apply the point-to-point method to the actual reflector used in the installation.

The lumenaire actually installed in the auditorium was a Curtis Electric Company "Big Boy" silver, mirrored glass reflector. No distribution curve of this type of reflector was available and hence it was not possible to actually calculate, from the flux distribution curve, the total illumination that would be secured upon the working plane. In the actual design of the illumination system this lack of a flux distribution curve for the reflector would practically prohibit the use of the point-to-point method of checking the lighting system, since, of course, the calculations must be made before the system is installed. In this instance the lumenaires were already installed and hence the actual distribution of illumination upon the working plane could be determined by merely turning out all the lamps except one and reading with a foot-candle meter the illumination upon the working plane at various distances from the projection of the lamp upon the working plane. For the purpose of this investigation it was therefore sufficient to assume that this actual distribution curve of the illumination, as secured from tests upon one lamp, was the same as the value that would normally be calculated from the distribution curve of the lumenaire. Actually, of course, the two values would

differ, since the calculated values do not take into consideration the reflection factor of the walls, ceiling, floors, and furniture. The curve of distribution of illumination obtained from actual test is,therefore, more accurate than that obtained by the more orthodox method.

Fig. x Page 10-Aof the Appendix is the actual distribution upon the working plane of the light reflected from one of the lumenaires. It will be noted from a study of this curve that the illumination directly under the lamp was 2.3 foot candles and that at 12 feet from the center the illumination had increased gradually to 4.35 foot candles, while from 12 feet up to 45 feet the illumination gradually decreased to a negligible value at 45 feet. The form of the flux distribution curve of the reflector used in the auditroium was similar to the accompanying illustration, Fig. 11 From a study of this flux distribution curve evidently the maximum candle power is emitted at an angle with the nadir of approximately 18 degrees. Since the mounting height is 40 feet, evidently the distance from the center at which this intensity of luminous flux reaches the working plane is 40 x tan 18 deg. = 40 x 0.325 = 13 ft. Allowing for errors of measurement of the angle, it is evident that the flux distribution and actual illumination curves, when referred to the nadir of the lamp as an origin, check rather closely.

FIG. 11



The application of the point-to-point illumination system for calculating the amount of illumination reaching the working plane was easily made. The area to be illuminated was drawn to scale and the location of the outlets marked upon the drawing. This drawing is produced on Page 27A Fig. 19 of the Appendix. The drawing was then divided into rows A, B, C, D, E. F, G, F', E', D', C', B',A', and 1,2,3,4,5,6, 7, 8, 9, and the distance from the intersection of these rows to the lamps I, II, III, IV, V, VI, VII, VIII, IX, X, XI, XII, measured and recorded in a table. From the illumination distribution curve for a single lamp the illuminations corresponding to the distances from the various lamps to the intersections determined by merely adding the components due to each lamp. The data for one fourth of the working plane are recorded in Table I of the Appendix.

In order to determine the positions on the working plane at which illuminations of 1, 2, 3, 4, and other even foot-candles were secured, curves were platted between illumination in foot candles and distances from an arbitrarily chosen origin for the rows A, B, etc., and 1, 2, etc. These curves were reproduced on Pages 11,12A of the Appendix. On Page 11-A of the Appendix the curves show the distribution of illumination along the rows 1, 2, 3, etc., the distances being measured from Row A. On Page 12-A of the Appendix the curves show the distribution of illumination along rows A, B, etc., the distances being measured from Row 1. From these sets of curves it was possible to read the distances from the

origin along the rows at which an even illumination of 1, 2, 3, etc., foot candles was secured and the points located therefore on the drawing, Fig. 19 Page 27-a. A smooth curve connecting all the points on the drawing of equal illumination gave the theoretical equilux distribution that should have been secured upon the working plane. The data for the calculations are given on Pages 2-5-A... of the Appendix.

An examination of the equilux distribution lines, Page 27-A Fig. 19 of the Appendix, as calculated by the point-to-point method reveals at once the fact that the minimum illumination secured should be 4 foot candles and the maximum 14 foot candles. A comparison of this result with the actual equilux distribution lines indicates the fact that the variation in maximum and minimum illumination is not quite the same for both curves. The actual survey, to be described subsequently, showed that the minimum illumination was 6 foot candles and the maximum illumination 16 foot candles. However, it should be remembered that under actual conditions a portion of the total light is secured from 20 200 watt lamps suspended over the balcony of the auditorium and hence it is only natural to expect the actual illumination to be slightly greater than that calculated by the point-to-point method for the 12 750 watt lamps. The validity of the point-to-point method for calculating the light distribution upon the working plane of an installation is thus established, but the difficulty and labor re- by this system are apparent.

THE LUMEN METHOD

The general system of designing light installations and checking the results by the point-to-point method is cumbersome and very tedious and since mand of the factors involved must be estimated approximately, the results are subject to considerable error. Accordingly, various methods have been devised by means of which illumination systems can be designed, with sufficient accuracy, merely by reference to prepared charts and tables. Among these methods the lumen system is widely used at present.

The principles of the lumen method are identically the same as those of most illumination design systems. The mounting height, spacing distances, number of lamps, and size of lamps are determined by an application of the fundamental principles of illumination design but the results are recorded in tabular form and the actual design thus reduced to a study of data rather than calculations. The tedious calculations required by the point-to-point method of checking illumination design are entirely dispensed with and approximate results readily obtained. Unfortunately, however, the lumen method of determining the illumination received upon the working plane does not, like the point-to-point method, indicate at what point the minimum and maximum illumination will be secured.

The system is based upon a series of tests made upon rooms of different sizes, reflection factors, lamps, etc.,

and requires the use of tables compiled therefrom. In order to design an illumination system by the lumen method, the working plane is first drawn to scale and the maximum mounting height of the lumenaires measured and recorded. From a table compiled from a series of tests the permissible spacing ratio corresponding to the mounting height, is then read. Having determined the permissible spacing distance, the outlets are then located on the drawing as nearly symmetrical as possible without exceeding greatly the permissible spacing distance. It is good commercial practice to leave a maximum distance between outlets and walls of 1/2 the spacing ratio.

Having located the number and position of outlets, the next step in the lumen method is to determine the lamp size that must be installed. In order to effect this result use is made of three simple relationships:

(a) Area in sq. ft. per outlet = $\frac{\text{total floor area in sq. ft.}}{\text{number of outlets}}$

(b) Lamp lumens required per sq. ft. = $\frac{\text{Foot candles x DF}}{\text{Coefficient of Utilization}}$

(c) Lamp lumens req. per outlet = area in sq. ft. per outlet x lamp lumens required per sq. ft.

In these equations the only unknowns are the depreciation factor (DF) and coefficient of utilization. The foot candles are of course the desired average illumination upon the working plane. The depreciation factor is introduced to counteract the effect of aging of lamps and collection of dust upon the walls and lamps. From an elaborate series of tests the value of the depreciation factor for fairly clean conditions

has been found to be 1.3 and for dirty locations 1.5.

The coefficient of utilization is the proportion of the generated light from the lamps which reaches the plane of the work. Obviously this factor depends upon the size and shape of the room, the color of the walls, and the type of lumenaire, and its calculation is accordingly exceedingly difficult. Therefore, the determination of the coefficient of utilization for rooms of different shapes and sizes and colors has been the subject of considerable study by such organizations as the N. E. L. A. division of the G. E. Company. A room 10 ft. sq. by 10 ft. high forms the basis of these tests,and is classified as having a "room index" of I. From tests made with various reflectors in a room of this size the coefficients of utilization for walls, ceiling and furniture of different colors or reflection factors have been compiled and recorded in tables. In order to determine the coefficient of utilization, therefore, it is only necessary to measure the dimensions of the room and mounting height of the lamps, and the average reflection factor of the walls and furniture. The room index may then be read from a table and finally the coefficient of utilization from a table for the lumenaire under the column corresponding to the room index and reflection factor.

Having in this way determined the lamp lumens required per outlet, the watt rating of the lamp can then be read directly from a table which lists the lumen output secured from each size of tungsten lamp. The whole design of the in-

stallation can thus be affected mainly by the use of tables of data, and thus a great saving of time and labor effected. The illumination can be checked approximately by reading from another table the foot candles secured from the lumenaire and rated size of lamp when the coefficient of utilization is the specified value.

The lumen method method of illumination design was applied to the lighting installation of the Memorial Auditorium of the University of Tennessee. The detailed calculations and results of this investigation are shown on Page18,17-A of the Appendix. The data used for the calculations were furnished by the Illumination Department of the General Electric Company.

UNIFORM ILLUMINATION

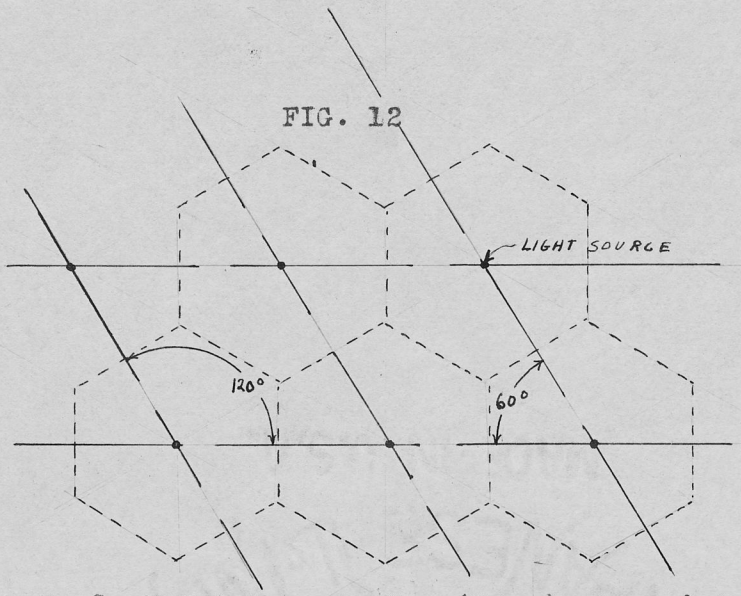
The question of uniformity in illumination is receiving more attention in modern installations than formerly. Artistically, of course, a uniform illumination is not desirable for some installations such as theaters, art galleries, and similar places where contrasts of light and shadow are employed extensively. With few exceptions, however, uniform illumination is desirable both from the standpoint of economy of light as well as physical influence on the visual organs.

It will be noticed from the discussion of the general or point-to-point and lumen illumination designs that for uniform illumination it was assumed that the lamps should be placed

over the centers of squares or rectangles. This is in fact the prevalent opinion upon the subject and practically all illumination engineers at present employ this scheme. However, it can be easily shown that this assumption is not strictly correct. Since a section of the distribution curve from a single lamp parallel to a horizontal working plane is essentially circular in shape, it would seem more logical to expect a more uniform illumination when the lamps are suspended over the centers of circular areas. Since, however, no area can be divided into circles without there being spaces left between, it would seem logical to expect the illumination to be most uniform when the area to be lighted is divided into equal areas, approximating most closely the shape of a circle, and the unit suspended over the center of the areas. It can be easily shown that the nearest geometrical approximation of a circle is a hexagon and therefore it would seem most logical to expect the greatest uniformity of illumination upon a working plane when the area is divided into hexagons and the lighting units suspended above the centers of the areas. A study of the accompanying illustration, Fig. 12 will prove that the outlets placed above the center of hexagons will lie at the corners of rhombuses having acute angles of 60 degrees.

From these considerations it would seem best for uniform illumination to divide the working plane into rhombuses having an acute angle of 60 deg. and to suspend the units at the corners of the rhombuses.

FIG. 12



H. R. S. McWhirter, B. Sc. (Eng.), Associate member of the British Institute of Electrical Engineers, published in the journal of the I. E. S., Vol. 68, 1930 an instructive article on "The Production of Uniform Illumination Over Large Areas." In this treatise the author announced the results of several tests made upon lumenaires suspended above the centers of various geometrical figures. The results of the tests proved conclusively that the most satisfactory ratio of the minimum to the average and the maximum to the average illumination of the working plane was secured when the units were suspended at the corners of rhombuses having an acute angle of 60 deg. Upon the basis of these tests the author suggested that illumination engineers substitute for the square a rhombus with a 60 degree angle.

As a study in uniformity of illumination it was decided to divide the working plane above the basket-ball court into rhombuses having an acute angle of 60 degrees and an

area equal to one twelfth of the working plane. Outlets were then suspended above the intersections of the rhombuses and located symmetrically on the drawing of the working plane. By an application of the point-to-point method the theoretical distribution of illumination due to this arrangement of outlets was determined. Fig. z Page13,14A secured as explained under the discussion of the point-to-point method, were employed in the calculations of the equilux lines shown in Fig. 20 Page 28-A.

A comparison of Fig. 20 Page28A with Fig.19 Page 27A will indicate at once that a more uniform distribution of illumination is secured when the outlets are arranged in the form of rhombuses with an acute angle of 60 deg. The maximum illumination secured by the arrangement of outlets in the form of rhombuses is less than when in the form of a rectangle but the distribution is much more uniform. There is not as great a tendency toward the formation of circles of high illumination beneath each lamp nor for that of circles of low illumination between lamps. However the improvement in uniformity is hardly great enough to have warranted the change in illumination design of the installation unless the initial cost of wiring of the two designs would have been approximately equal.

METHODS OF DECREASING ILLUMINATION FOR AUDITORIUM PURPOSES

Since a portion of the auditorium is used for the dual purpose of a basket-ball court and an auditorium, it was

necessary to install equipment capable of delivering upon the working plane the maximum illumination required. For a basket-ball court the illumination should never be less than 10 foot candles and for good practice should be approximately 15 foot candles. For an auditorium, on the other hand, the minimum illumination should be 2 foot candles and the recommended value 3 or 4 foot candles. It follows, therefore, that the illumination suitable for a basket-ball court is too great for an auditorium and conversely that the illumination suitable for an auditorium is too small for that required for a basket-ball court. Quite naturally, the installation in the auditorium was made adequate for the basket-ball court and no provision was made for the fact that this illumination is too great for the pruposes of the auditorium.

When all of the lamps above the basket-ball court are turned on the average illumination on the working plane is approximately 11 foot candles. An intensity of illumination of 11 foot candles is so great as to cause fatigue to the eyes of the audience. On numerous occasions the audiences have complained about this undesirable feature of the installation. On the occasion of Lawrence Tibbet's recital on April 19, 1933, the illumination proved discomforting to several members of the audience who expressed their depreciatory opinions upon the subject afterwards in the newspapers. It is proposed, therefore, in this portion of the thesis to investigate economical methods by means of which a lower intensity of light may be maintained over the basket-ball court

when the latter is being used as an auditorium.

Quite obviously the illumination can be decreased by extinguishing a few of the lamps. Since uniformity of illumination is desired, however, as well as a low intensity of light, it is necessary to determine which lights should be extinguished for this purpose. Fig. 21, Page29A of the Appendix represents a study made upon the portion of the auditorium used jointly as a basket-ball court and an assembly room. The data for this equilux distribution curves were obtained by the point-to-point method, as explained in the preceeding discussion. The curves required for this calculation are recorded on Pages 15,16*A Fig. x z of the Appendix.

In Fig. 21 Page 29A of the Appendix the lamps extinguished were II, III, V, VIII, X, XI. It will be noticed that this arrangement is staggered in such a manner as to permit the lamps not extinguished to be evenly distributed over the working plane and examination of the resultant equilux lines will reveal the fact that the illumination is fairly uniform and low in value. The maximum value of illumination with this arrangement of bright and dark lamps is 7 foot candles and the average illumination between 5 and 6 foot candles. Since with all the lights in operation the maximum illumination, as calculated by the point-to-point method, was 14 foot candles and the average about 10 to 11 foot candles, it is evident that the effect of extinguishing the lights mentioned is to decrease by one half the maximum and average illumination. Since it is good practice in auditorium de-

sign to provide an illumination upon the working plane of 4 to 5 foot candles, it is, therefore, evident that this arrangement of lights, while perhaps not reducing the intensity enough, is much more satisfactory for auditorium purposes than that produced when all the lamps are operating.

Another method that is probably more suitable for reducing the illumination level to that of an auditorium consists in decreasing the voltage applied to the lamps. On Pages 20-24-Aof the Appendix are recorded data secured from the Consolidated Electric Lamp Company. These data show the varation between applied voltage in % and lumen output in % of tungsten gas filled lamps. It will be noticed from a study of these data that the lumen output of a lamp varies as the 3.38 power of the voltage. Consequently a slight decrease in the voltage applied to the lamps will result in a correspondingly great decrease in lumen output. Since the illumination is approximately proportional to the lumen output of the lamp, it is, therefore, evident that a lower level of illumination upon the working plane can be secured by merely reducing the voltage applied to the lamps. The lamps are operated at an approximately constant voltage of 110, which is the rated value of the lamps. From the data on Page 23-A of the Appendix the per cent lumen output of the lamps for 100% voltage is, of course, 100%. Assuming that the average illumination upon the working plane is 10 ft. candles, it is evident that the per cent lumens required for 5 ft. candles would be:

$\frac{100}{10} = \frac{X}{5}$, or X = 50 % lumen output at rated voltage. From the table on Page 23-A of the Appendix the per cent voltage, corresponding to this lumen output, is 82.1 % and since the original voltage was 110, the new voltage would be 110 x 0.821 = 90 volts, approximately.

In order to reduce the illumination upon the basket-ball court to a value of 5 ft. candles it is therefore only necessary to reduce the voltage applied to the lamps to approximately 90. If a lower level of illumination is desired, this result may be secured by reducing the voltage to a value lower than 90. The reduction of voltage can be accomplished quite effectively by merely connecting an induction voltage regulator across the line supplying the lamps to be dimmed.

ILLUMINATION SURVEY

STANDARD CODE

The following rules and suggestions for illumination surveys are reproduced from the code book of the N.E.L.A. It is believed that these regulations represent the best commercial practice of today.

Illumination tests may be made for the following purposes: 1. To obtain a general idea of the intensities prevaling.

2. To compare the relative effectiveness of different lighting systems.

3. To determine the illumination qualities of different fixtures or lighting units.

For a rough determination all that is necessary for an illumination test is some type of "foot-candle meter." The meter can be placed at any desired point and a reading of intensity made in accordance with the rules accompanying the instrument. If a reasonably accurate and comparative test is to be conducted, it is necessary to use a portable photometer. The most satisfactory instrument upon the market at the present time is the Weston Foot-candle Meter which dispenses with the human element, entirely, and makes possible the direct determination of the illumination at any desired

point. The procedure of the test is to fix the test plate of the instrument in a horizontal position at the desired distance above the floor and read upon the scale, provided with the meter, the illumination at the selected point.

In conducting the illumination test the room is divided into sections of equal areas and readings of the illumination taken in the centers of each section. Duplicate readings are usually advisable in order to insure reliable results. The choice of stations will depend upon a number of factors. If the room is symmetrical, all four walls having practically the same characteristics, exploration of 1/4 of the room will be sufficient for the purpose, as indicated in Fig. 13 for there will be a corresponding reading in each of the remaining quarters of the room. On the other hand, if the room has one wall of comparatively high reflection power and the opposite wall has little or none due to a large number of windows, it will then be desirable to explore 1/2 of the room and in this case each of the stations will be duplicated in the other half. If a very large area, for example an industrial plant, is to be tested, a typical section may be explored. Having laid out the stations, the illumination at each station should be determined by means of a suitable instrument. A simple and arithmetical calculation will then give the average illumination of the area tested.

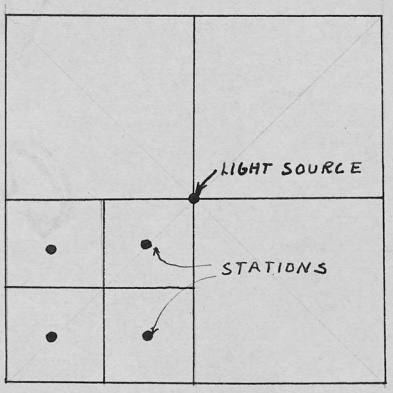


FIG. 13

In connection with an illumination test the following facts should be recorded:

1. Floor plan, showing test stations and lighting outlets.
2. Color of floor, walls and ceiling.
3. Height of ceiling and lamps.
4. Voltage.
5. Wattage and rated lumens of lamps.
6. Type of reflector or globe equipment, including trade name and dimensions.
7. Voltage of circuit.
8. Average illumination.
9. Maximum illumination.
10. Minimum illumination.
11. Total generated lumens.
12. Total effective lumens.
13. Coefficient of Utilization.

In the performance of the test the following precautions should be taken:

1. Do not allow the shadows of the observers to fall upon the test plate of the photometer.
2. Do not allow the current flowing or the voltage across the comparison lamp in the photometer (if this type is used) to vary from the calibrated values.
3. Maintain the test plate level on the horizontal plane.

In case the survey is to disclose the extent to which intensity of illumination varies from point to point in the

room, as well as the average for the room, more stations should be used.

After the actual readings for an illumination test have been taken, the final problem to be solved is the representation of the results. There are three methods in commercial use for recording the results of an illumination test:

1. Equilux lines.
2. Numerical values, tabulated on the designated stations.
3. Curves.

Equilux lines are obtained by connecting on the plan view stations of equal intensity. Curves are obtained by plotting the variation of intensity with distance across a section of the room.

WESTON FOOT CANDLE METER

The instrument used in the illumination survey of the auditorium was a Weston Illuminometer, Model No. 123, manufactured by the Weston Electrical Instrument Company. This meter, a very recent development in illuminometers, is far superior to the foot candle meters that have formerly been employed in illumination surveys. The old form of foot candle meter measured intensities by comparing a standard light source with the intensity to be measured. The comparison was made by eye and, therefore, subject to considerable error. The Weston Foot-Candle Meter, on the other hand, eliminates the human element entirely and makes possible the measurement of light intensities with a speed and accuracy entirely beyond the capacity of the older forms of illuminometers.

The active element of the Weston Illuminometer is the Photronic Photoelectric Cell, which consists essentially of a thin metal disk on which there is a film of material sensitive to light. The metal disk forms the positive terminal and a metal collector ring in contact with the light sensitive surface forms the negative terminal. In Fig. 14 is shown a photograph of the Weston Illuminometer or Foot Candle Meter. From a study of this photograph it will be seen that there are two of the cells included with the appa-

ratus. The cells are placed on a test plate which can be moved to any desired point. A long suspension cord connects the test plate with the rest of the instrument. The cells are connected in parallel to a microammeter. The deflections of the microammeter are, therefore, a direct indication of the amount of current flowing and, therefore, the intensity of the light striking upon the cells. By calibrating the scale of the microammeter the instrument can be made to read the illumination directly in foot candles. In order to measure large intensities of light with the instrument, it is only necessary to insert resistances in the circuit in order to limit the current flowing to a value measurable by the microammeter. In the Weston Illuminometer scales are thus provided for measuring maximum light intensities of 10, 50 and 250 foot candles.



FIG. 14

ILLUMINATION SURVEY OF AUDITORIUM

An illumination survey of the Memorial Auditorium of the University of Tennessee was made by means of a Weston Illuminometer. The survey was conducted in a somewhat dif-

ferent manner from the usual commercial test. It was desired to determine the actual distribution of illumination throughout the building. In order to accomplish this purpose the room was inspected and lines on the floor marked in convenient places. The approximate location along these lines at which even foot candles of illumination were obtained was determined. Enough measurements were made in this manner to determine the actual distribution of even foot candle lines throughout the building. Since the balconies were inclined at an angle with the zenith instead of being horizontal, it was necessary to record the actual illumination secured upon the working plane above the successive steps and to then interpolate for the even foot candle lines. A drawing was made to scale of the auditorium and the illumination at the various points tested marked upon the drawing. Equilux lines connecting all points of equal illumination were then drawn and an exact representation of the lighting distribution in the auditroium thus secured. Fig. 17,18 Page 25-26-A of the Appendix show the actual distribution of illumination on the main floor and in the balconies, respectively.

For the purposes of checking the illumination design of the auditorium by the point-to-point method a distribution curve of the illumination secured upon the working plane of the basket-ball court was obtained. In order to accomplish this purpose readings of illumination were taken from the center of the circle shown in Fig. 5 radially outward to a point where the amount of light falling upon the working

plane was negligible.

The installation was studied with a view towards determining the reflection factor, glare characteristics, and other details of the walls, celing and furniture. The reflection factor was determined by comparing the color of the walls or furniture with a color chart prepared by the General Electric Company. The chart consists of colored rectangles for which the reflection factors have been determined by an exact method. The approximate reflection factor of any surface can be determined by comparing the surface with the color chart and reading from the latter the reflection factor.

REMARKS UPON LIGHTING SYSTEM OF AUDITORIUM

The results of the investigation of the lighting system of the auditorium have revealed the following conditions, which may in some instances probably be improved as suggested.

1. Maximum illumination upon basket-ball court, 16 ft. candles. Minimum illumination upon basket-ball court, 4 ft. candles. This variation of from 4 to 16 ft. candles is large enough to be visible to the eye. This condition may cause eye fatigue.
2. Absolute inadequacy of the lights under the balcony. As will be seen by reference to Fig. 17 Page 25-A of the Appendix, the illumination under the balconies drops, due to the shadow cast by the railing, to less than 1 ft. candle. Near the wall underneath the balconies small dome lights are provided, but the illumination secured from these sources is inadequate and practically useless due to the fact that they are located back of the last row of seats, and also to the fact that their mounting height is so low as to limit their radius of usefullness.
3. The windows in the back of the stage are very undesirable, since the light transmitted by them causes a glaring surface to be presented to the audience in the day time. This objectional feature should never have been included

in the original design of the building.

4. The skylights provided for daylight illumination produce bright spots of direct sunlight upon a portion of the seats in the balconies and the main floor. The resulting glare caused by this condition is very objectionable from the standpoint of the occupants of the stage.

5. Actual average illumination upon the basket-ball court is 11 ft. candles. At present it is good commercial practice to provide an illumination of 15 and a minimum of 10 ft. candles for similar installations. The actual illumination provided for the basket-ball court is, therefore, adequate but by no means too great.

6. The illumination upon the balcony varies from below 1 ft. candle to 12 ft. candles. This variation of illumination is too great for an auditorium. The minimum illumination for an auditorium should be 2 ft. candles. It will be noticed from a study of Fig.15 that the lights in the back of the balcony cause very bright

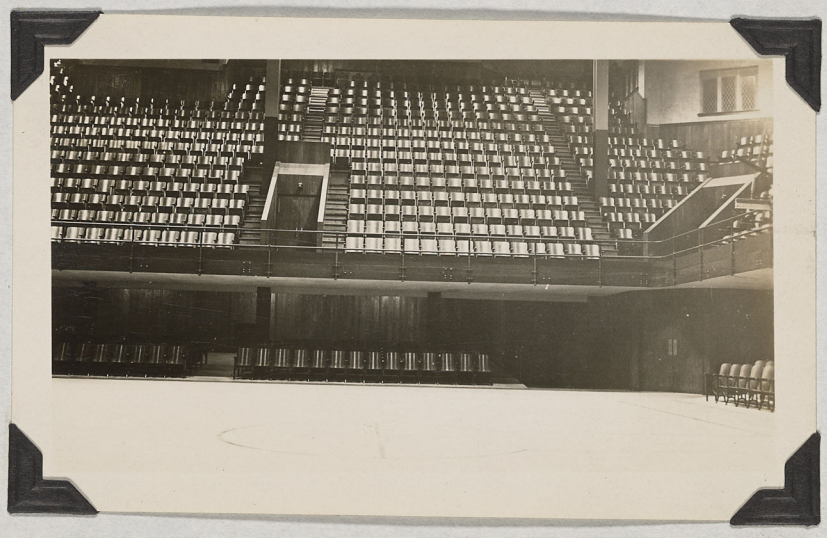


FIG. 15

spots, due chiefly to the low mounting height. More uniform distribution of light could have been obtained by employing twice as many lamps of half the wattage.

7. From the study of Fig. 15 it will be noticed that considerable glare is visible to the occupants of the stage. This glare is produced by the polished surfaces of the seats and little improvement can be affected without changing the type of luménaire.

8. By reference to Fig. 17 Page 25-A of the Appendix it will be noted that the illumination upon the basket-ball court is greater than that calculated by the point-to-point method. This condition is due, of course, to the fact that a portion of the light emitted by the lamps in the balcony is reflected to the basket-ball court. In the point-to-point method the illumination upon the basket-ball court was calculated upon the basis of the light emitted only by the 12 750 watt lamps above the working plane. The effect of the additional light received from the lamps above the balconies is to secure a more uniform distribution of illumination upon the basket-ball court.

9. If in the initial installation the lights above the working plane of the basket-ball court had been arranged in the form of rhombuses with an acute angle of 60 deg., a more uniform illumination would have been secured. The improvement would not have warranted an increased expenditure for wiring equipment, as explained in the

discussion on Page 37.

10. The lighting installation can be made more suitable for auditorium purposes by extinguishing lamps II, III, V, VII, X, XI, as shown in Fig. 21 Page 29-A and discussed on Page 39. The average illumination upon the basket-ball court would by this arrangement be decreased from 11, to 5 ft. candles. This illumination, while perhaps slightly greater than that recommended for commercial installations, would be satisfactory. The illumination could also, and probably more effectively, be decreased to a value suitable for an auditorium by reducing the voltage applied to the 750 watt lamps. If the voltage applied to these lamps was reduced from 110 to approximately 90, the average illumination upon the basket-ball court would be reduced from 11 to 5 ft. candles. This reduction of voltage could be affected by the installation of an induction voltage regulator as suggested in the discussion on Page 40.

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APPENDIX

ILLUMINATION SECURED UPON BASKETBALL COURT FROM 1 750 WATT LAMP

Luminaire: Curtis "Big Boy", X-Ray, Silver Glass Mirror Reflector.

Mounting height: 40 ft. above working plane.

D: distance from projection of Lumenaire upon working plane.

FC: Illumination in foot candles.

D	FC	D	FC	D	FC
0	2.3	20	1.9	35	0.43
5	2.4	21	1.7	36	0.42
7	2.8	22	1.6	37	0.30
7.5	3.0	23	1.5	38	0.28
9	3.5	24	1.3	39	0.28
10	4.1	25	1.3	40	0.20
11	4.3	26	1.2	41	0.18
12	4.4	27	1.1	42	0.18
13	4.2	28	1.0	43	0.18
14	3.7	29	0.85	44	0.17
15	3.2	30	0.73	45	0.12
16	2.9	31	0.73	46	0.10
17	2.5	32	0.58	47	0.08
18	2.3	33	0.56	48	0.08
19	2.1	34	0.50	49	0.04

DATA FOR FIG.

Component Illuminations Secured at Points upon Basketball Court from twelve 750 Watt Lamps.

Calculations made by point to point method.

Point	1-A		2-A		3-A		4-A		5-A	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	18	2.25	16	2.85	18.3	2.20	24	1.35	31.3	0.67
II	30.5	0.75	24	1.35	18.3	2.20	16	2.85	18.3	2.20
III	46.8	0.10	39.2	0.24	31.3	0.70	24	1.35	18.3	2.20
IV			56.3	0.02	47.7	0.08	39.5	0.23	31.3	0.67
V	49.5	0.04			49.6	0.04	52.2	0.02	55.8	0.02
VI	55.4	0.02			49.8	0.02	49.0	0.04	49.8	0.04
VII							52.2	0.02	49.8	0.04
VIII									56.0	0.02
TOTAL		3.16		4.46		5.28		5.87		5.86

Point	1-B		2-B		3-B		4-B		5-B	
I	11.5	4.35	8	3.10	12	4.35	19.6	1.97	28.2	0.94
II	27.2	1.03	19.6	1.97	12	4.35	8	3.10	12.1	4.35
III	44.8	0.15	36.8	0.33	28	1.95	19.6	1.97	11.8	4.35
IV			55.4	0.02	45.7	0.12	36.8	0.33	28.2	0.92
V	41.8	0.17	41.0	0.18	41.8	0.17	44.8	0.16	49.0	0.04
VI	48.6	0.08	44.7	0.15	49.1	0.04	41.0	0.18	41.8	0.17
VII			55.5	0.02	42.0	0.16	44.8	0.16	41.8	0.17
VIII							54.5	0.02	49.0	0.04
TOTAL		5.78		5.77		11.14		7.89		11.00

Point	1-C		2-C		3-C		4-C		5-C	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	8	3.10	0	2.3	9	3.50	18	2.25	27	1.05
II	28	0.95	18	2.25	9	3.50	0	2.30	9	3.50
III	41	0.17	36	0.37	27	1.05	18	2.25	9	3.50
IV	62	0.01	54	0.02	45	0.12	36	0.37	27	1.05
V	33.8	0.50	31.8	0.63	34.4	0.47	37.8	0.28	42.8	0.17
VI	42.0	0.18	37.6	0.30	34.4	0.47	33.3	0.54	34.3	0.47
VII	54.5	0.02	48.8	0.05	42.6	0.12	37.7	0.28	34.3	0.47
VIII					55.8	0.02				
TOTAL		4.93		5.92		9.25		8.27		10.38

Point	1-D		2-D		3-D		4-D		5-D	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	11.4	4.35	8	3.10	12	4.35	19.6	1.98	28.2	0.93
II	27.3	1.00	19.6	1.98	12	4.35	8	3.10	12.1	4.35
III	9	3.5	44.8	0.15	36.8	0.34	28	0.95	19.6	1.98
IV			54.5	0.01	45.7	0.15	36.8	0.34	28.2	0.85
V	18.7	2.10	24.8	1.27	26.6	1.10	30.8	0.71	36.8	0.34
VI	31.2	0.67	29.8	0.80	26.6	1.10	25	1.25	26.6	1.10
VII	47.3	0.08	43.8	0.15	36.8	0.34	30.7	0.71	26.6	1.10
VIII					51.6	0.02	43.8	0.16	36.8	0.34
TOTAL		8.35		7.65		12.36		10.21		13.36

Point	1-E		2-E		3-E		4-E		5-E	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	18	2.25	16	2.85	18.3	2.20	24	1.35	31.3	0.67
II	30.5	0.75	24	1.35	18.3	2.20	16	2.85	18.3	2.20
III	46.8	0.10	38.9	0.24	31.3	0.67	24	1.35	18.3	2.20
IV			56.3	0.01	47.7	0.08	39.5	0.23	31.6	0.67
V	18	2.25	16	2.85	18.3	2.20	24	1.35	31.3	0.67
VI	30.5	0.75	24	1.35	18.3	2.20	16	2.85	18.3	2.20
VII	46.8	0.10	39.2	0.24	31.3	0.67	24	1.13	18.3	2.20
VIII			56.3	0.01	47.7	0.08	39.5	0.23	31.3	0.67
TOTAL		6.20		8.90		10.30		11.46		11.48

Point	1-F		2-F		3-F		4-F		5-F	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	25.4	1.20	24	1.35	25.7	1.20	29.8	0.80	36.2	0.36
II	35.5	0.40	30.2	0.76	27.7	1.20	24.0	1.35	25.7	1.18
III	30.3	0.76	43.4	0.16	36.3	0.31	29.8	0.80	25.7	1.18
IV			59.7	0.01	51.0	0.02	43.4	0.16	36.3	0.36
V	12.1	4.34	8.8	3.47	12.8	4.25	20.1	1.88	28.5	0.95
VI	27.6	1.00	20.2	1.87	12.8	4.25	9	3.50	12.8	4.29
VII	44.7	0.17	37.0	0.32	27.4	0.92	20.1	1.88	12.8	4.29
VIII			54.6	0.01	23.8	1.38	37.0	0.32	28.4	0.95
IX	42.6	0.17	41.8	0.16	42.8	0.16	45.7	0.12	49.8	0.04
X	48.3	0.05	45.5	0.16	42.6	0.16	42.8	0.16	42.8	0.16
XI			55.2	0.01	49.8	0.04	45.7	0.12	42.8	0.16
TOTAL		7.34		8.28		13.89		11.3		14.26

Point	1-G		2-G		3-G		4-G		5-G	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	33.8	0.50	32.8	0.56	34.2	0.47	37.5	0.30	42.8	0.16
II	42.0	0.16	37.6	0.30	34.2	0.47	32.8	0.56	34.6	0.46
III	55.0	0.02	48.8	0.05	42.8	0.16	37.5	0.30	34.4	0.46
IV					55.8	0.01	48.0	0.05	42.4	0.16
V	9.0	3.50	00.0	2.30	9.0	3.50	18.0	2.25	27.0	1.09
VI	28.0	0.95	18.0	2.25	9.0	3.50	0.0	3.30	9.0	3.50
VII	44.0	0.16			27.0	1.05	18.0	2.25	9.0	3.50
VIII	62.0	0.01	54.0	0.38	45.0	0.12	36.0	0.37	27.0	1.09
IX	34.0	0.50	32.8	0.56	33.3	0.53	37.6	0.30	42.4	0.10
X	42.2	0.16	37.6	0.30	33.3	0.53	32.8	0.56	44.4	0.16
XI	55.2	0.01	48.8	0.05	42.6	0.16	37.6	0.30	44.8	0.16
XII					55.8	0.01	48.8	0.05	42.4	0.16
TOTAL		5.97		4.45		10.51		7.29		10.53

DATA FOR FIG.

Component Illumination Secured at Points upon Basketball court from twelve 750 watt lamps, spaced in the form of rhombuses with an acute angle of 60 degrees.

Calculations made by point to point method.

Point	1-A		2-A		3-A		4-A		5-A	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	37.7	0.30	15	3.24	6.9	2.77	5.7	2.50	13.7	3.88
II	48.2	0.15	40.2	0.20	31.3	0.66	22.6	1.53	13.7	3.88
III	28.3	0.91	26.7	1.18	28.0	0.91	30.3	0.75	37.2	0.30
IV	44.0	0.16	38.0	0.28	32.2	0.60	28.2	0.91	26.7	1.08
V					51.4	0.02	44.0	0.16	37.2	0.30
VI	55.5	0.01	51.2	0.02	49.6	0.04	49.2	0.04	50.6	0.02
VII					58.0	0.01	53.6	0.02	50.6	0.02
TOTAL		1.53		4.82		5.01		5.91		9.48

Point	1-B		2-B		3-B		4-B		5-B	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	22.5	1.53	14.8	3.25	6.5	2.66	5.2	2.43	13.2	4.08
II	48.0	0.05	40.2	0.18	31.2	0.67	22.4	1.54	13.5	4.00
III	20.8	1.78	18.8	2.08	20.3	1.85	25.0	1.25	32.0	0.62
IV	39.7	0.22	56.2	0.01	26.2	1.12	20.8	1.76	18.7	2.12
V			43.6	0.16	47.8	0.08	41.2	0.16	32.0	0.62
VI	46.7	0.10	57.0	0.01	41.4	0.18	46.5	0.10	43.0	0.15
VII	32.8	0.56			51.4	0.02				
VIII										
IX										
X										
TOTAL		4.24		5.69		6.58		7.24		11.74

Point	1-C		2-C		3-C		4-C		5-C	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	25.0	1.25	18.4	2.16	12.8	4.25	12.0	4.35	17.1	2.50
II	49.3	0.04	41.6	0.17	33.1	0.53	24.8	1.28	17.4	2.50
III	14.2	3.60	10.8	4.27	13.3	4.05	19.8	1.94	28.0	0.95
IV			29.3	0.84	21.0	1.75	14.2	3.63	10.8	4.27
V	39.8	0.22	55.0	0.02	45.3	0.15	36.8	0.34	28.1	0.95
VI	57.0	0.01	36.0	0.37	33.6	0.52	33.4	0.52	35.5	0.40
VII			51.8	0.02	45.3	0.15	39.8	0.22	35.5	0.40
VIII			55.5	0.01	56.0	0.01	58.0	0.01		
IX					58.0	0.01	56.0	0.01	55.4	0.01
TOTAL		5.12		7.86		11.42		12.31		11.98

Point	1-D		2-D		3-D		4-D		5-D	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	30.3	0.75	24.2	1.33	20.4	1.82	19.8	1.93	23.4	1.42
II	51.8	0.02	44.5	0.15	36.7	0.34	29.6	0.81	23.4	1.42
III	9.6	3.90	3.8	2.33	8.2	3.18	16.8	2.58	26.0	1.15
IV	35.0	0.43	27.3	1.03	18.3	2.20	9.6	3.90	2.7	2.30
V	61.0	0.01	53.0	0.02	44.0	0.15	35.2	0.42	26.2	1.12
VI	33.5	0.52	28.8	0.89	25.6	1.20	25.3	1.20	28.1	0.94
VII	54.0	0.01	47.1	0.08	38.9	0.22	33.1	0.52	28.0	0.94
VIII	48.8	0.05	47.3	0.08	48,1	0.05	50.2	0.02	47.3	0.08
IX	62.0	0.01	54.5	0.01	50.6	0.02	48.2	0.05	50.2	0.02
X							58.8	0.01	54.0	0.01
TOTAL		5.70		5.92		9.18		11.44		9.39

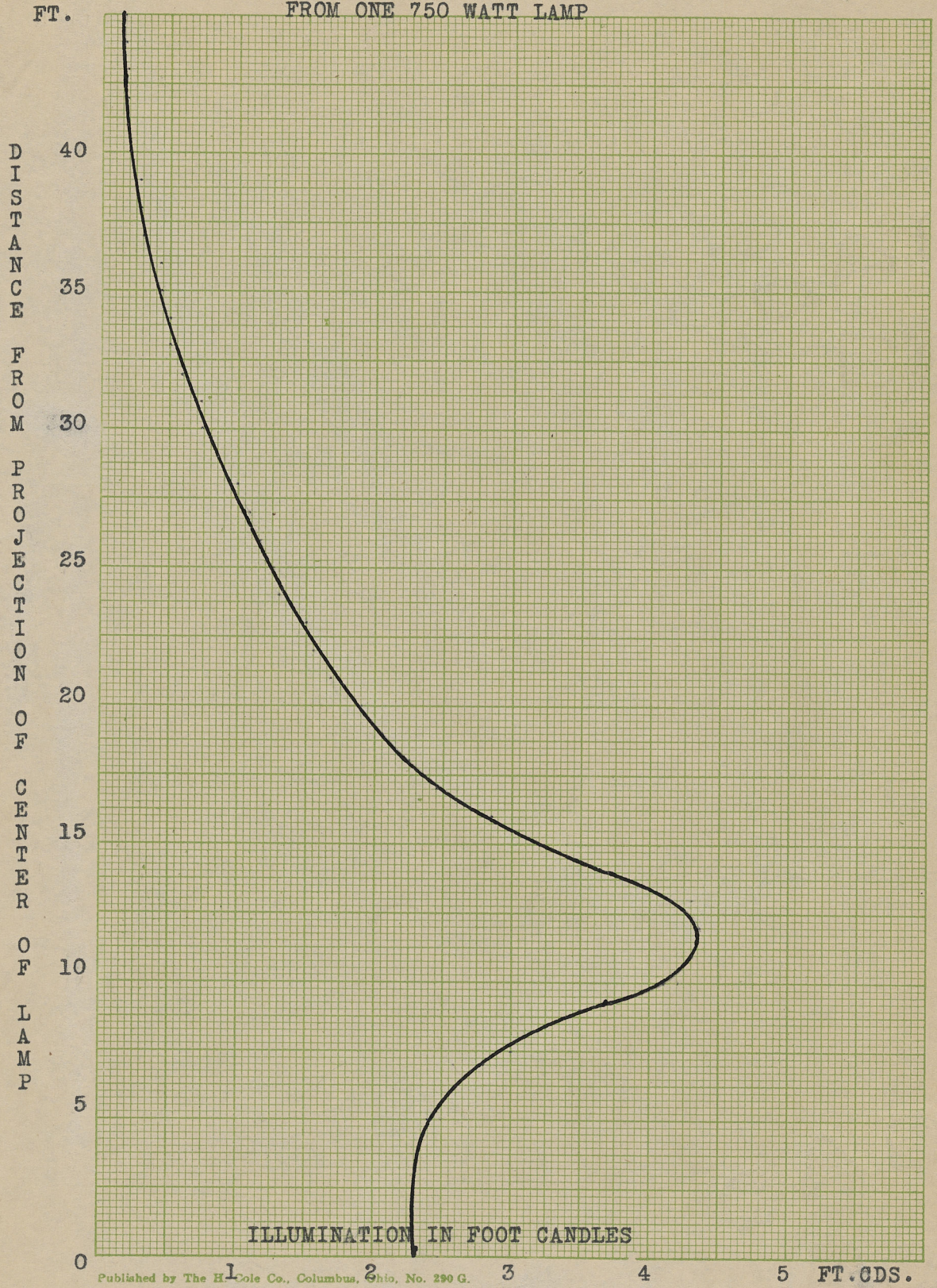
Point	1-E		2-E		3-E		4-E		5-E	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	35.4	0.40	31.0	0.70	28.2	0.93	27.8	0.97	30.5	0.73
II	55.3	0.01	48.6	0.05	41.5	0.20	35.4	0.40	30.5	0.73
III	10.6	4.23	5.5	2.47	12.0	4.35	17.5	2.38	26.5	1.10
IV	35.4	0.40	27.5	1.00	18.7	2.13	10.6	4.25	5.4	2.46
V	61.2	0.01	53.2	0.02	44.3	0.15	35.5	0.40	26.0	1.15
VI	28.0	0.95	22.3	1.54	17.8	2.32	17.4	2.38	21.3	1.70
VII	50.8	0.02	43.4	0.16	35.4	0.40	27.8	0.97	20.3	1.83
VIII	40.4	0.20	39.4	0.23	40.2	0.20	42.7	0.15	47.0	0.08
IX	52.6	0.02	47.7	0.08	42.9	0.16	40.3	0.20	39.2	0.24
X					58.0	0.01	52.8	0.02	47.1	0.08
XI									61.0	0.01
TOTAL		6.24		6.25		10.84		12.12		10.11

Point	1-F		2-F		3-F		4-F		5-F	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	41.8	0.15	38.3	0.26	35.8	0.39	35.6	0.40	37.7	0.28
II	59.6	0.01	53.4	0.02	47.2	0.08	41.8	0.17	37.7	0.28
III	16.1	2.80	13.3	4.05	15.4	3.03	21.4	1.68	29.2	0.84
IV	37.3	0.30	30.0	0.77	22.5	1.54	16.0	2.85	13.2	4.08
V	62.3	0.01	54.6	0.02	23.8	1.38	37.5	0.30	29.2	4.84
VI	24.0	1.35	16.8	2.55	10.5	4.23	9.8	4.05	15.8	2.95
VII	48.8	0.05	41.0	0.20	32.3	0.58	23.8	1.38	15.8	2.95
VIII	32.8	0.58	31.6	0.65	32.4	0.58	35.6	0.40	40.7	0.22
IX	47.0	0;08	41.4	0.20	36.2	0.36	32.7	0.57	31.4	0.65
X	41.4	0.20	35.0	0.43	58.0	0.01	55.5	0.01	54.2	0.01
XI	47.8	0.08	41.4	0.16			53.8	0.02	55.2	0.01
XII							58.0	0.02	55.2	0.01
TOTAL		5.33		8.73		12.18		11.92		13.31

Point	1-G		2-G		3-G		4-G		5-G	
Lamp#	D	FC	D	FC	D	FC	D	FC	D	FC
I	49.7	0.08	46.7	0.10	44.8	0.15	44.6	0.17	46.4	0.06
II			59.8	0.01	54.3	0.01	49.7	0.04	46.3	0.04
III	24.2	0.82	22.4	1.53	23.6	1.40	27.8	0.98	34.4	0.46
IV	41.5	0.20	35.0	0.43	28.7	0.88	24.2	1.33	22.4	1.54
V	m		57.5	0.01	48.9	0.04	41.6	0.20	34.4	0.46
VI	22.2	1.56	14.3	3.50	5.2	2.43	3.70	2.33	34.4	0.40
VII	48.0	0.05	39.9	0.22	29.0	0.85	22.0	1.60	22.4	1.54
VII	24.2	1.83	22.4	1.54	23.7	1.38	27.8	0.98	34.4	0.46
IX	41.4	0.20	35.0	0.43	57.4	0.01	24.2	1.33	46.4	0.04
X	65.8	0.01	57.4	0.01	49.3	0.04	41.6	0.17	46.4	0.04
XI	49.8	0.04	46.8	0.10	45.0	0.15	44.8	0.17	12.8	4.25
XII	65.4	0.01	60.0	0.01	54.5	0.01	49.8	0.04	12.8	4.25
TOTAL		4.80		7.89		8.22		9.34		13.52

FIG. 16

DISTRIBUTION OF LIGHT RECEIVED UPON BASKETBALL COURT
FROM ONE 750 WATT LAMP



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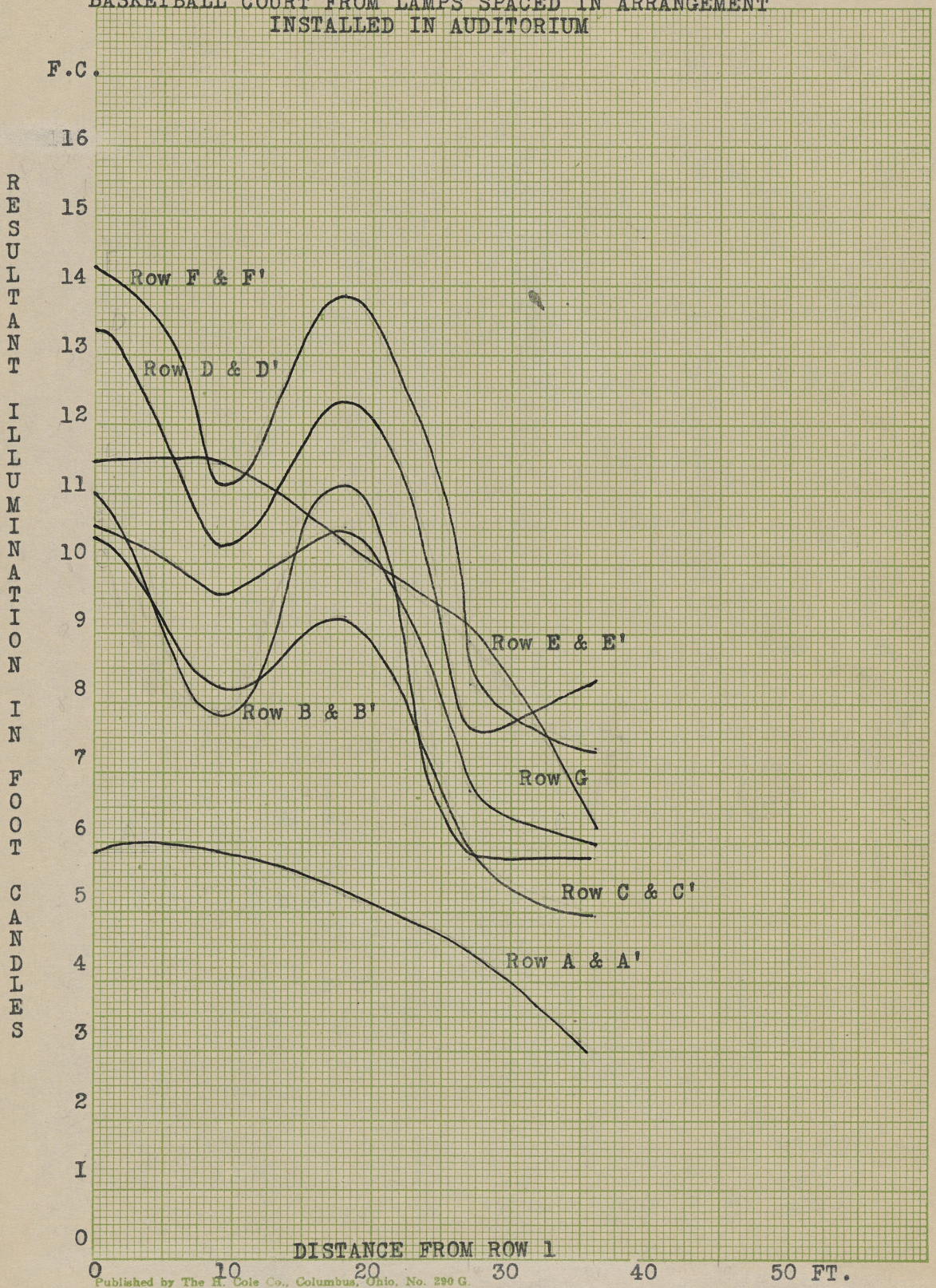
CURVES SHOWING RESULTANT ILLUMINATION AT POINTS ON BASKETBALL COURT FROM LAMPS SPACED IN ARRANGEMENT INSTALLED IN AUDITORIUM



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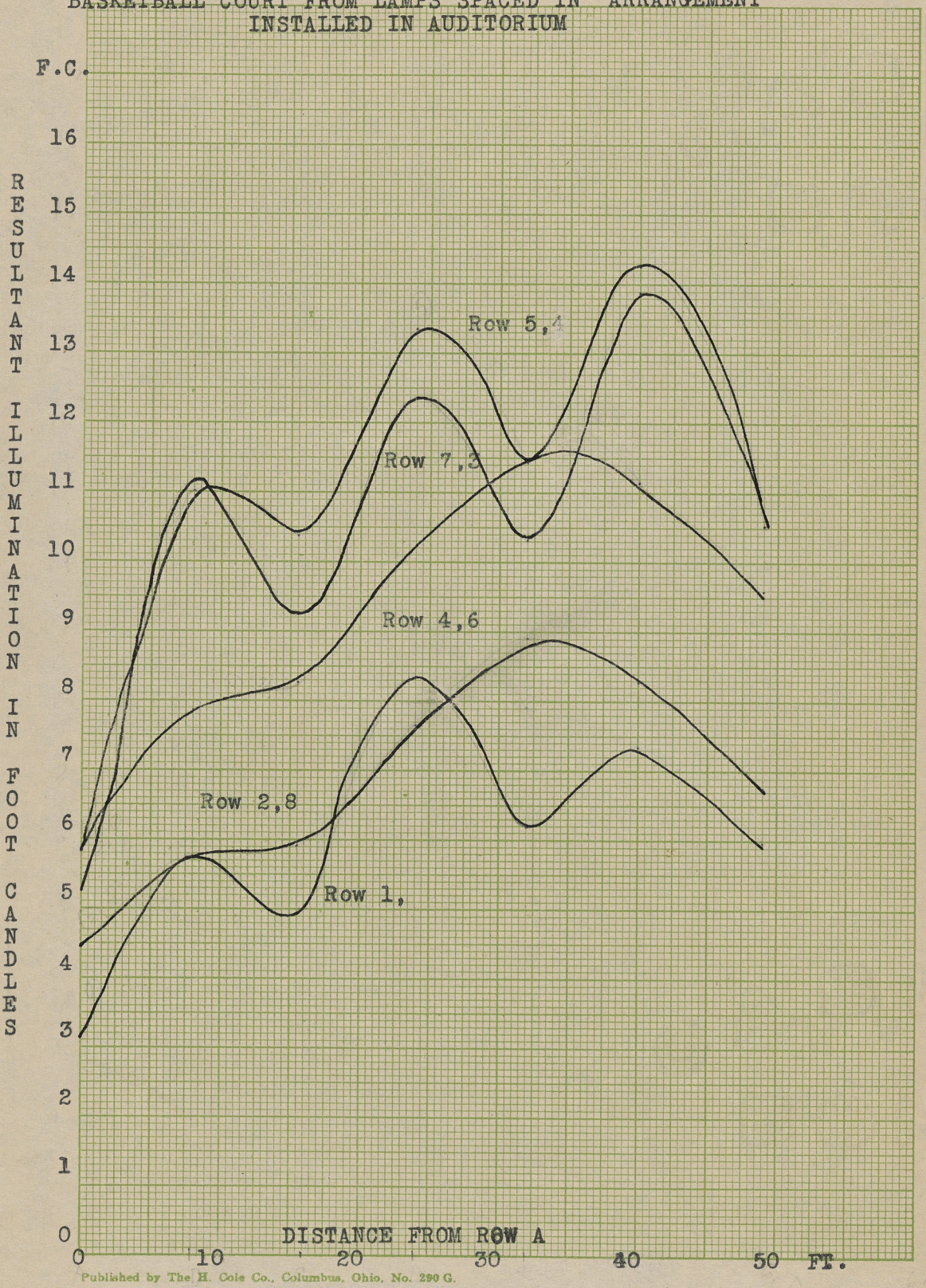

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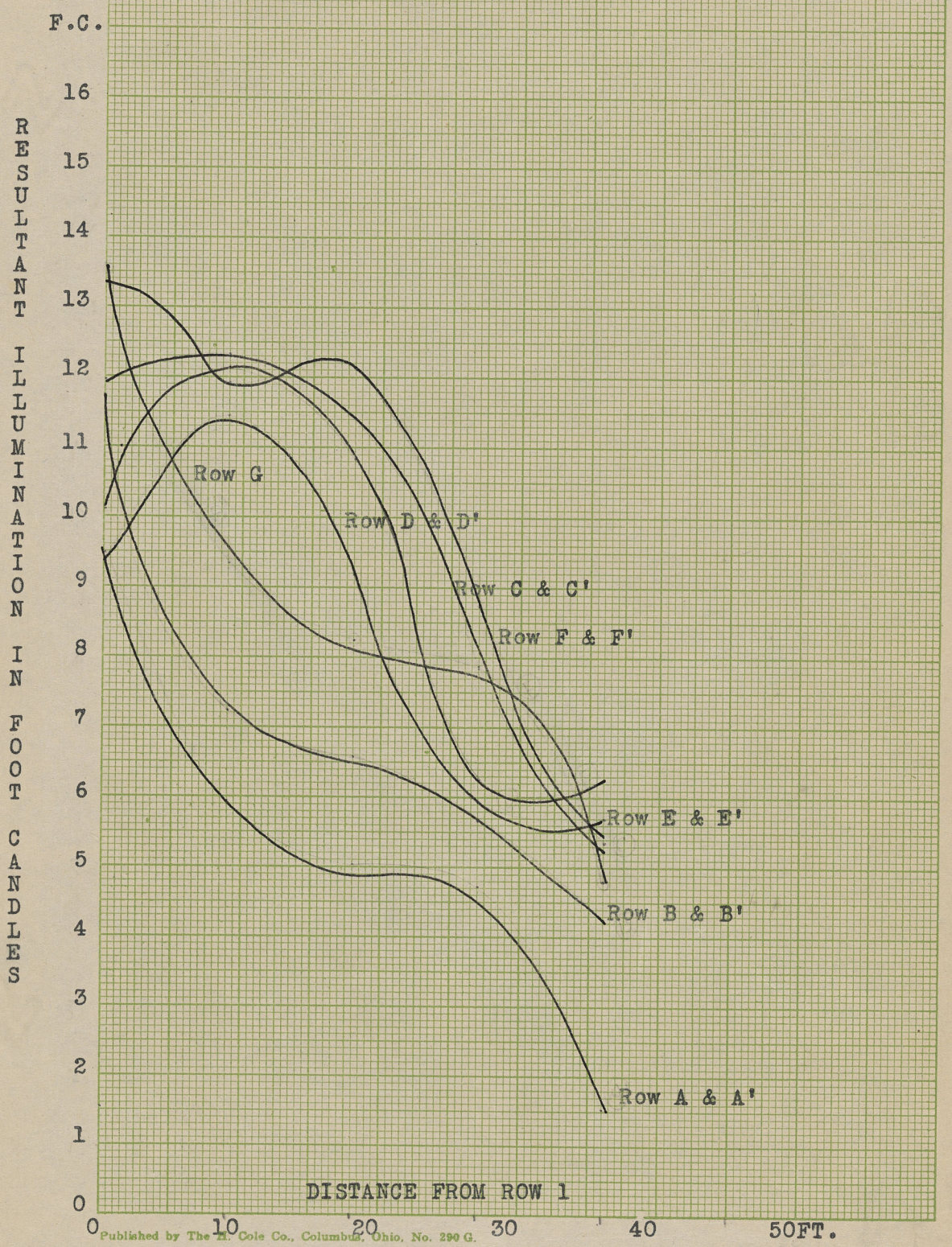
CURVES SHOWING RESULTANT ILLUMINATION SECURED ON BASKETBALL COURT FROM LAMPS SPACED IN ARRANGEMENT OF RHOMBUSES WITH AN ACUTE ANGLE OF 60 DEGREES



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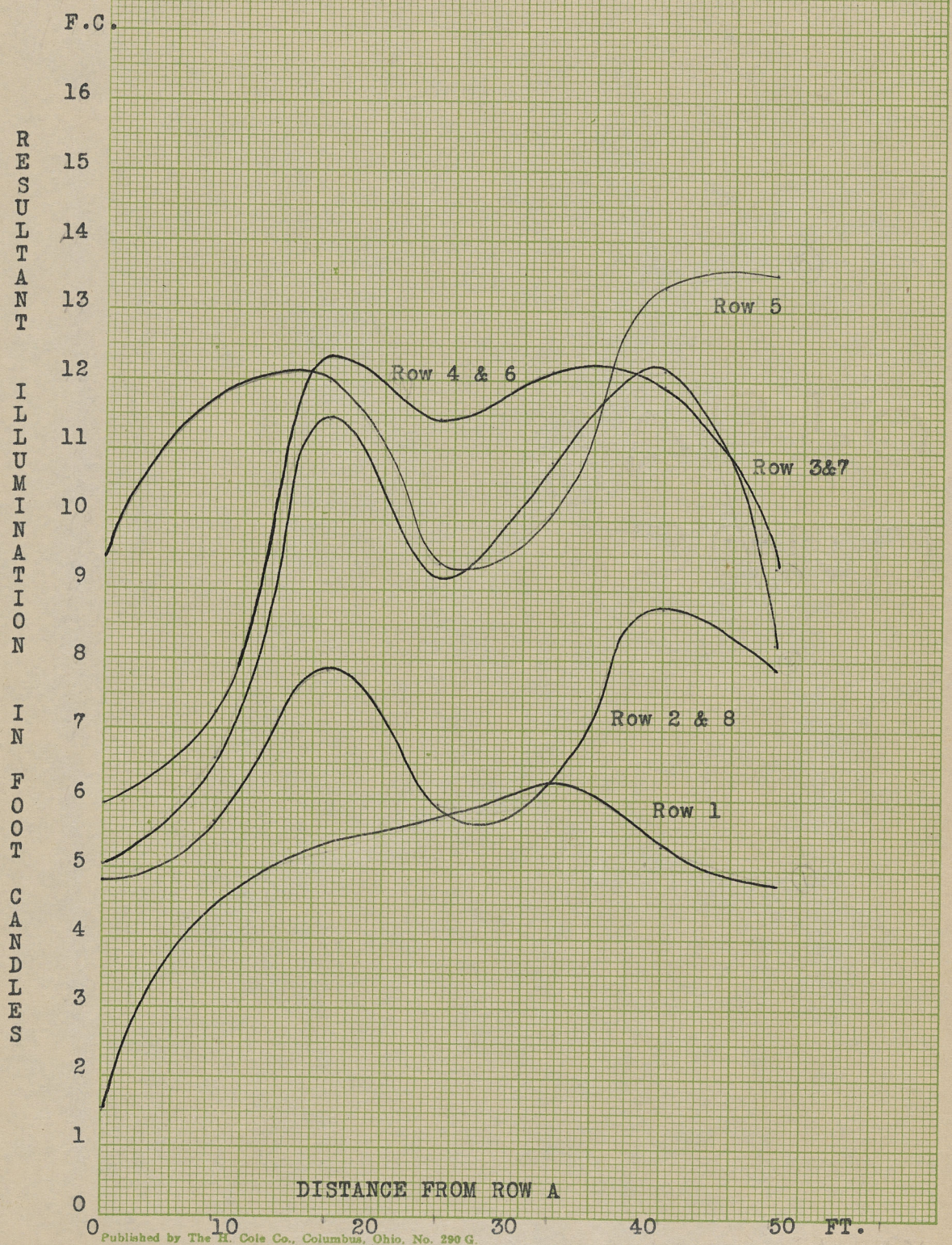

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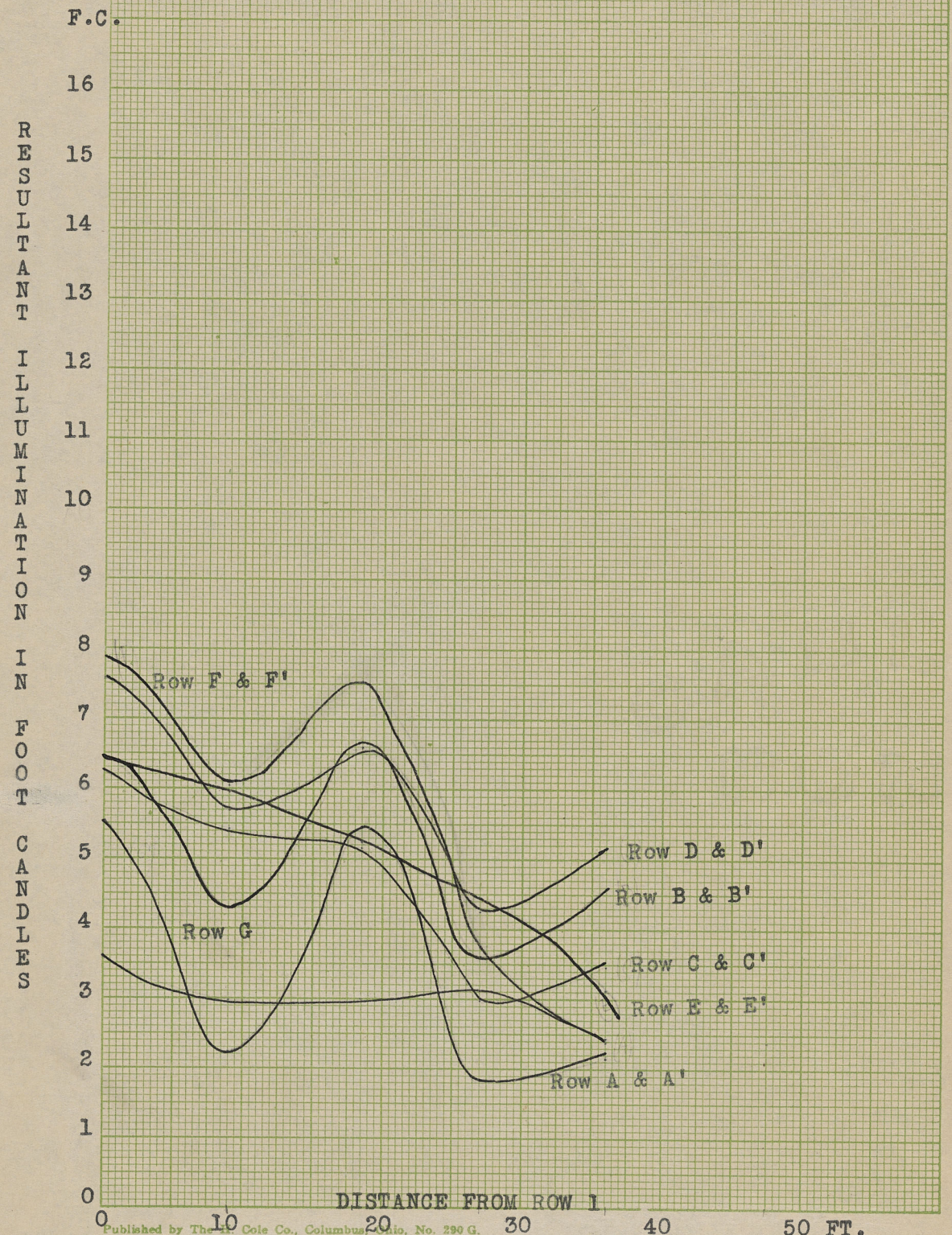
CURVES SHOWING RESULTANT ILLUMINATION AT POINTS ON BASKETBALL COURT FROM LAMPS SPACED IN ARRANGEMENT INSTALLED IN AUDITORIUM
SIX LAMPS EXTINGUISHED



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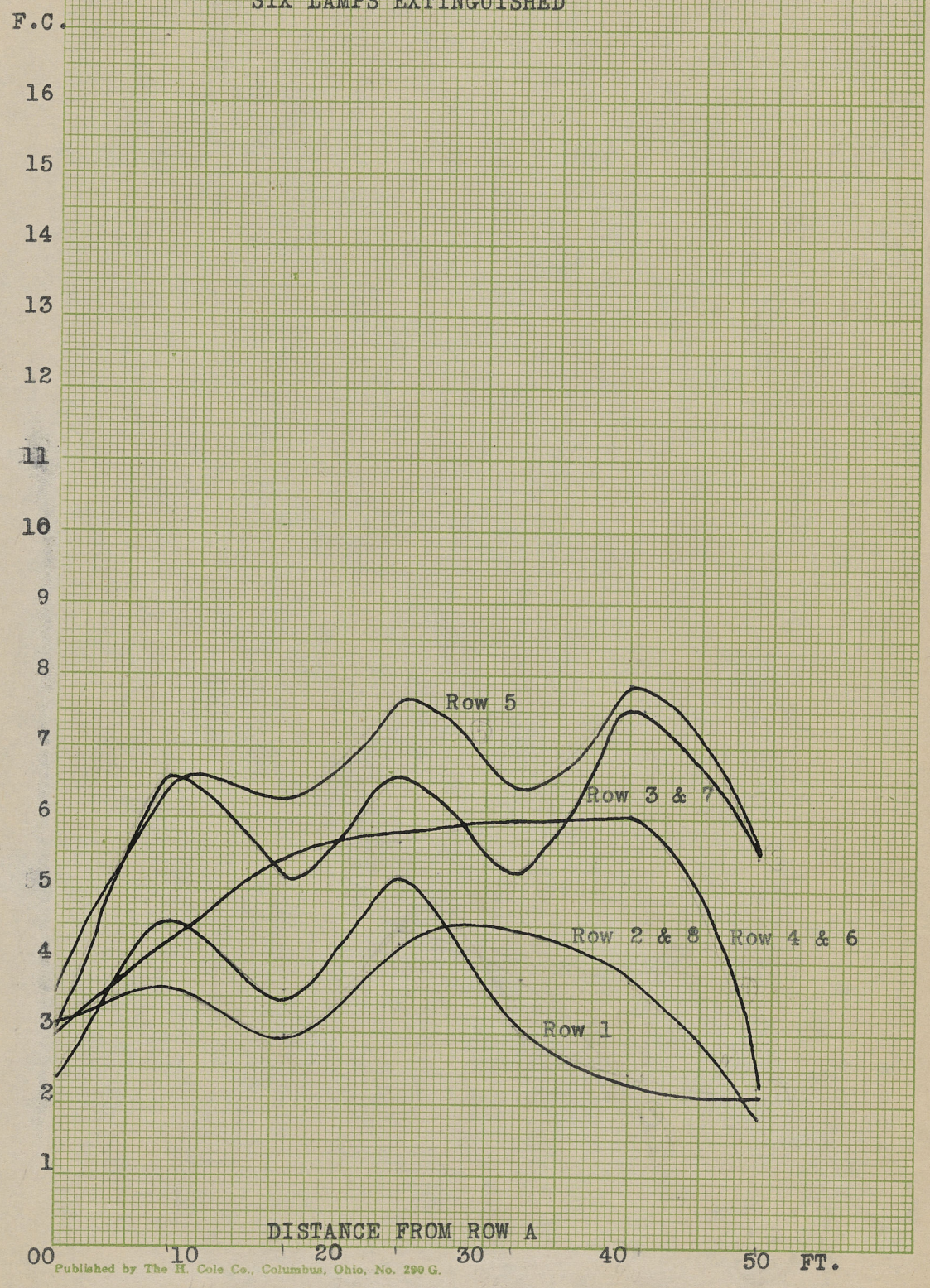

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TEST OF
LIGHTING SYSTEM OF MEMORIAL AUDITORIUM
BY THE
LUMEN METHOD OF ILLUMINATION DESIGN

Information Furnished by the General Electric Company.

Data Obtained from G.E."Illumination Design Handbook"

Data Given:

Ceiling height : 45 feet,Height in clear:40'

Floor Area: 86 x 98 feet

From tables for a height in the clear of 40 ft.,the spacing distance between outlets can be 25-30 or a maximun of 40'. For this installation the spacing distance was 32 and 18'. Similarly,the distance between outlets and walls can be 8-10 or a maximun of 16'. In respect to spacing distance,therefore,the design of the auditorium conforms to the recommendations of the lumen method.

Number of outlets: 12 (spaced symmetrically)

Area per outlet: 96 x 86 / 12 : 687 sq.ft. According to the table this value should be between 600-900 sq.ft.

Lamp lumens required per sq.ft. $\frac{\text{: foot candles x D.P.}}{\text{coefficient of utilization}}$

Where D.P.: depreciation factor

Lamp lumens required per outlet: area in sq.ft. per outlet x lamp lumens required per sq.foot

Assume illumination : 10 foot candles,the minimun that should be secured for a basketball court.

Assume Depreciation Factor: 1.3.an average value found by test to represent very approximately installations of

this nature.

To find coefficient of utilization:

From table the room index of the installation is 1.2

For mirrowed glass reflectors the reflection factor is 30 %,approximately

From table the coefficient of utilization corresponding to these values of room index and reflection factor is 0.58

Lamp lumens required per outlet: 697 x 10.0 x 1.3/0.58 : 15,600 lumens

From table of lamp sizes the lumen output of a 750 watt lamp is 14,400. Consequently,the lamp selected for this installation could,without serious error, be 750 watts in capacity. It will thus be seen that the installation should produce an average illumination upon the basket ball court of 10 foot candles ,provided 750 watt lamps are used. The actual illumination secured upon the basket ball court is 11 foot candles,but a portion of this light is secured from the lights suspended above the balconies.

TECHNICAL DATA

The following data were secured from the Consolidated Electric Lamp Company,an associated company of the General Electric Edison Company. These data pertain to the candle-power of 1000 watt "Champion " tungsten lamps,equipped with Benjamin Fluted Enamel Reflectors. Since these data are indorsed by the chief engineer of the company,they may be logically considered reliable.

CONSOLIDATED ELECTRIC LAMP CO.

LICENSED UNDER GENERAL ELECTRIC COMPANY'S INCANDESCENT LAMP PATENTS
INCORPORATED 1900



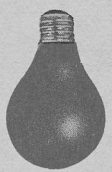




Champion
C.E.L. COMPANY
LAMPS
BULBS

LYNN
~~DANVERS~~
MASSACHUSETTS







JASPER MARSH
TREASURER

LONG DISTANCE PHONES
DANVERS 480-481-482
TELEGRAPHIC ORDERS
ACCEPTED COLLECT

"TWENTY-FOUR HOUR"
DELIVERY
SERVICE

April 22, 1933

Mr. Elmo M. Brewer
Blount Hall, Campus
University of Tennessee
Knoxville, Tennessee

My dear Mr. Brewer:

Enclosed you will find data and information pertaining to a 1000 Watt lamp and a Benjamin Fluted Enamel Bowl Reflector.

We have no ready data on a 750 Watt lamp but since the two lamps are almost identical the light distribution will be similar and the values of distribution will be proportional to the total luminous output of the two lamps, which, in the case of the 1000 Watt lamp, is approximately 20,000 lumens, and the 750 watt is approximately 14,400 lumens.

Champion Lamps use tungsten filament and the regular gas-filled types contain Argon gas.

We hope that this information will be of assistance to you.

Yours very truly,

CONSOLIDATED ELECTRIC LAMP COMPANY

E. H. Raddin

E. H. Raddin
Chief Engineer

EHR:MD
Encls.

CHAMPION LAMP WORKS

of

CONSOLIDATED ELECTRIC LAMP COMPANY

LYNN, MASS.

Engineering Dept.
Data Sheet

April 21, 1933

LUMINAIRE DISTRIBUTION

Mean Vertical

Mid Zone Angles	App. Candle Power at 10 feet	Mid Zone Angles	App. Candle Power at 10 feet
180 Zen.	---	90 Hov.	131
175	---	85	482
165	---	75	2740
155	---	65	3000
145	---	55	3370
135	---	45	3660
125	---	35	3780
115	---	25	3610
105	---	15	3610
95	---	5	3590
		0 Nadir	----

Light Flux Values

ZONE	LUMENS	
	Lamp	Luminaire
0-60°	4176	10688
0-90°	9935	13822
90-180°	10072	0
0-180°	20007	13822

ENGINEERING DEPARTMENT

Per G. A. Tamis

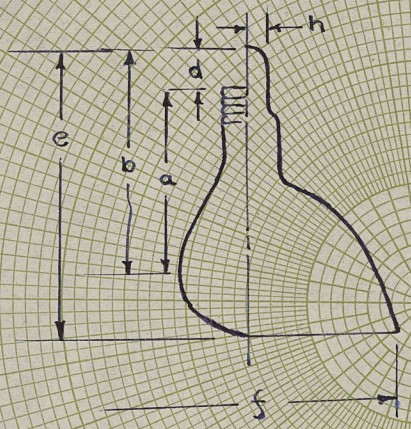
GAT:MD

KEUFFEL & ESSER CO., N. Y. NO. 343B.
POLAR CO-ORDINATE

CHAMPION LAMP WORKS

LYNN MASS

Lamp— 1000 watt 20,000 lumens
Bulb— PS52 clear
Filament— Sawtooth 110-120 volts
Reflector— Benjamin Fluted
Enamel Bowl Reflector
Procedure- Luminaire rotated



Dimensions of Luminaire

a	7 3/4	inches
b	9 1/2	"
c		
d	1 3/4	"
e	11 3/4	"
f	17	"
h	3	"

Consolidated Electric Lamp Company
Engineering Department
April 18 1933
Drawn by — G.A.T.

CHAMPION LAMP WORKS
of
CONSOLIDATED ELECTRIC LAMP COMPANY
LYNN, MASS.

Engineering Dept.
Data Sheet

April 22, 1933

VARIATION IN LUMENS AND AMPERES OF GAS FILLED LAMPS WITH VARIATION IN THE VOLTAGE APPLIED TO THE LAMP

Per cent Volts	Per cent Lumens	Per cent Amperes
80	45.4	88.7
84	54.3	91.0
88	64.2	93.3
90	69.5	94.5
92	75.1	95.6
94	80.9	96.7
96	87.0	97.8
97	90.2	98.4
98	93.4	98.9
99	96.6	99.9
100	100.0	100.0
101	103.4	100.5
102	106.5	101.1
103	110.5	101.6
104	114.1	102.2
106	121.5	103.2
108	129.2	104.3
110	137.2	105.4
112	145.4	106.4
116	162.5	108.5
120	181.0	110.5

From the above tables, lumens per watt may be determined.

These figures are of course approximate but within engineering limits. For more precise work:-

Let v and V represent volts
c and C " lumens
i and I " amperes

Then $\frac{i}{I} = \left(\frac{v}{V}\right)^{.541}$

$$\frac{c}{C} = \left(\frac{v}{V}\right)^{3.38} = \left(\frac{i}{I}\right)^{6.25}$$

FIG. IV Page 25 -A

Actual Distribution of Illumination
upon Main Floor of Auditorium

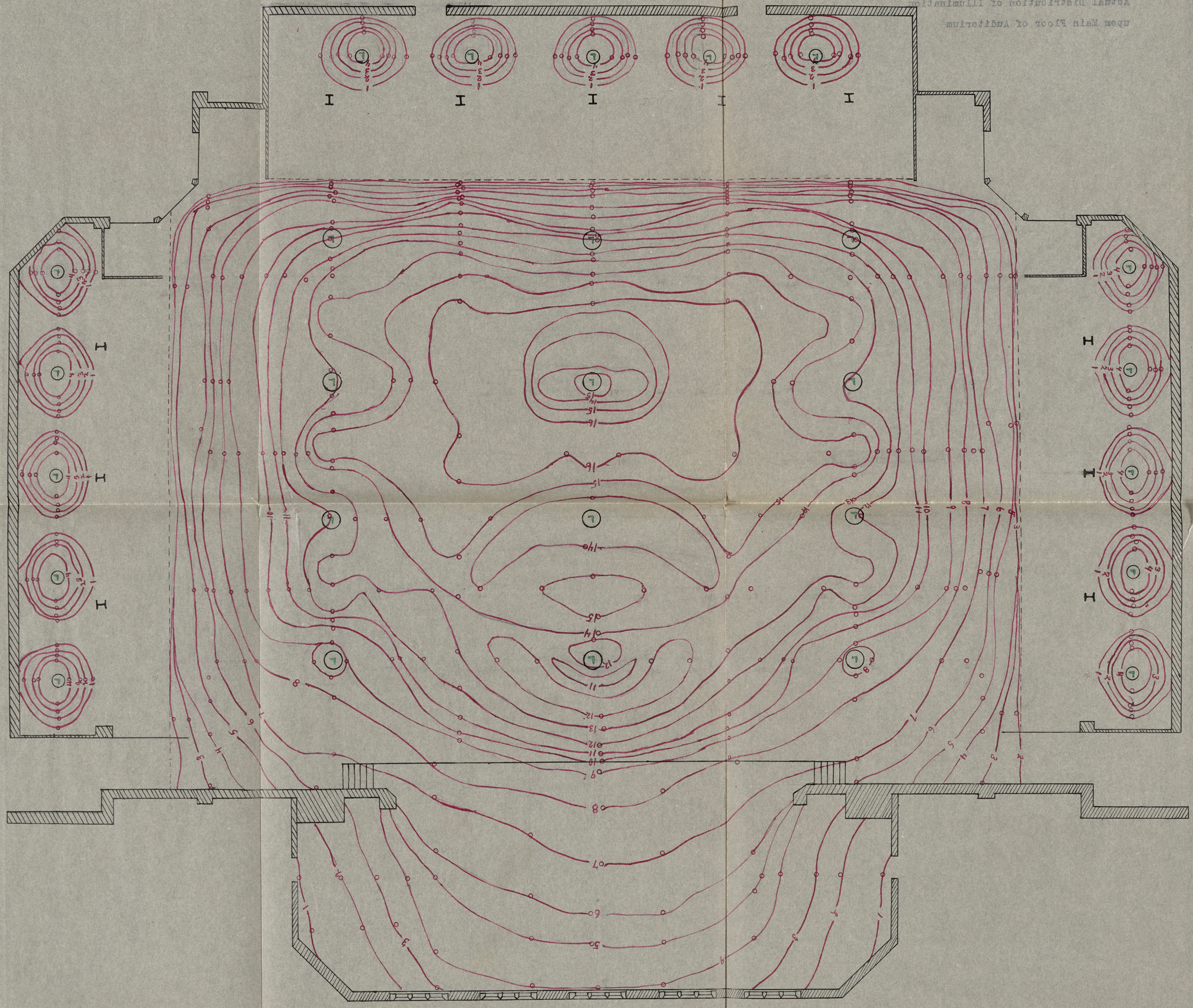


FIG. 18 Page 26-A

Actual Distribution of
Illumination upon
Balcony of Auditorium

FIG. 11. Face Stress Trajectories and Contours by the Point Method

Contours are in the Form of Ellipses as Indicated. Contour Lines Are Drawn to Illustrate Only the Trajectory Distribution

FIG. 50 Page 88 of
Isocentres' distribution
upon parasthesia Count'
a grouping according to
total potential method for
as carbonated pd and

FIG. 21, Page 29-A

Theoretical Distribution of
Illumination upon Basketball
Court, as calculated by the
Point to Point Method for
condition of Half of Lamps
operating.

Variation in L. and A. of Gas filled Lps.
With variation in voltage applied to lamp #2

The above formuli apply for small deviations from normal efficiency, but will also apply with reasonable accuracy through all short ranges of efficiency.

Respectfully submitted,

CONSOLIDATED ELECTRIC LAMP COMPANY

G. A. Tamis M.E.

G. A. Tamis
Engineering Department

GAT:MD

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrent its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name J. G. Tarbox

Title Professor of Electrical Engineering