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THE DEVELOPMENT OF A TECHNIQUE FOR THE PHYSICAL MEASUREMENT OF RESIDENTIAL STREET LIGHTING

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The quality of residential street lighting systems may be judged along several dimensions by those who wish to evaluate the adequacy with which they meet citizens' needs.[1] The most salient and frequently used evaluative dimension, however, is the amount of light emitted by the system in the form of photometric intensity. Measures of this output are generally thought to be measures of what is commonly referred to as the "brightness" of streetlighting, and it is brightness which the Illuminating Engineering Society uses to establish standards for municipal lighting.[2]

Accordingly, the Workshop's Measures team selected photometric intensity as the dimension of residential street lighting for which a detailed physical measurement would be developed. This report recounts that development and presents a description of the instrument used and the methodology employed. The appendix to this report is designed to serve as a handbook for those wishing to utilize the measurement procedure in other studies.

[1]For a discussion of the multi-mode approach used in this research, see Report Number 1 in this series.

[2]See The Illuminating Engineering Society, American National Standard Practice for Roadway Lighting, New York, IES, 1972.

Background of the Method of Measurement

Several available photo meters were considered as possible measuring instruments before selecting the meter described in the Appendix, the Model FC-200-TV/B SPECTRA Illumination Meter Manufactured by Photo Research Corporation. This model was chosen because it was 1) well suited to the range of light commonly encountered on residential streets, 2) highly sensitive to variations in light intensity, 3) convenient to use in the field, and 4) it reacted to photometric intensity in much the same way as the human eye.

The first two of these characteristics provided the capacity for precise, detailed measurement of lighting conditions while the third feature helped insure the practical value of any methodology developed for use of the light meter by municipal officials, citizens' groups, or others interested in evaluating output accurately but inexpensively. The fourth characteristic increased the precision of the analogy between the physical measurement and measurements taken in the form of citizens' perceptions, thus facilitating valid comparisons.

Where to Measure

Having selected an instrument for measuring brightness, we turned to the task of developing a method for its use in the field. Streetlighting falls over a large area and measurements could be taken at virtually any number of points in almost any arrangement. Knowledge of the fact that we were seeking a measure which was analogous to the phenomena referred to by citizens when they spoke of brightness guided our selection of a series of points for measurement.

Citizens observe street lighting in the street as drivers and on the sidewalk as pedestrians. In order to determine which of these locations citizens were most likely to use as a point of reference in judging the overall brightness of street lighting, questions as to which area (the street or sidewalk) respondents considered the most important target for lighting were included on early pretests of survey research instruments. However, respondents were approximately evenly divided in their judgments, with a slightly larger number choosing the sidewalk area as the more important location for good lighting.

Unable to make a decision on the basis of citizen responses, Workshop team members began taking a series of measurements at various locations along several streets with different lighting characteristics. These measurements were designed to provide information on the behavior of light meter readings taken at different locations so that a choice among them could be made on technical grounds.

The selection of a strategy for taking even these preliminary measurements involved some important decisions, however. Among them was the decision about <u>where</u> to measure. Streetlighting is a continuous phenomena, but the light meter records only the light falling on the surface of its photo cell. The best measurement possible with the light meter, therefore, would be a series of readings representing the illumination on separate points along a street, not a truly continuous measure.

The most accurate measure of the lighting on a street would be one in which the points of measurement were as close together as possible.

As the distance between points of measurement increases, information is lost and the accuracy of the image of the lighting actually on the block which is conveyed by the measurements declines. This loss of information, however, has to be weighed against the time and effort costs of taking more numerous measurements. Only if readings can be completed within reasonable time and effort constraints will the information they yield be worth the effort of acquiring them.

After experimentation and some study of the physics of luminescent bodies, the Workshop's team choose to take the initial measurements at ten-foot intervals. This was believed to be a large enough distance to allow completion of a block face in a reasonable time, but also a small enough interval to allow valid inferences about the behavior of the light levels between the actual points of measurement. We anticipated that the results of the first round of measurements would provide emperical grounds for a choice about the interval which could be used in the final method.

Another aspect of the problem of where to measure is the question of what effect different types and spacings of lights would have on the readings. It was entirely possible that different methods would be required for accurate measurement on different types of streets.

Well-lighted streets with complex placement of municipal and nonmunicipal lights might exhibit sufficient variation in lighting to justify the use of a measurement method different from that suited to a dimly lit residential street with a simple placement pattern of municipal lights and a few non-municipal lights. Similarly, the effects of different light sources (incandescent, mercury vapor, neon, etc.) on the readings obtained was in doubt before the first round of measurement.

In order to obtain the data necessary to resolve these questions, the Workshop team elected to take a series of readings on several blocks representing different types of streets which might be frequently encountered. These included 1) sparsely lit residential areas, 2) moderately well-lighted residential areas, and 3) brightly lighted commerical areas. In each area, blocks with different types of light sources were selected.

The final aspect of the problem of where to measure is that of which series of points along a block is best used as the location for readings. As noted above, the locations which are suggested by use patterns are in the street and along the side of the street in the sidewalk area. Whether walking or driving, however, citizens do not generally restrict their view of streetlighting to that which falls on line with their movement.

They are likely to gain an impression of the "overall" lighting level on the block being traversed from light stimuli from a variety of points. Accordingly, a third line of measurement between the street and sidewalk on the curb line seemed as justifiable as either of those suggested by use pattern. We realized that any line of measurement selected would be arbitrary and would not fully reflect the perceptions of citizens. A central purpose of the study, however, was to discover what relationship existed between systematically taken physical measurements and reports of citizens' perceptions.

Following the reasoning outlined above, a series of readings were taken at ten-foot intervals on a) the curb or on the line where a curb would be if constructed,[3] b) five feet from the curb line into the street, and c) five feet from the curb line into the sidewalk area. The readings were subsequently plotted in a series of graphs like those presented as Tables 1 through 6 of this report. The graphings all revealed patterns similar to those in the tables in that readings on the street, curb, and sidewalk all tended to rise and fall together, indicating that variations in lighting were roughly parallel along the three lines. The team concluded, therefore, that readings taken along any one of the three lines would be adequate to give an accurate profile of the general lighting pattern on the block. This finding allowed us to rely on a single series of measurements, saving time both in field operations and data analysis.

The question of which of the three reading lines to use remained. The team selected the curb line series for several reasons. First, this line was easily identified and did not require measuring lateral distances from some reference point as did the other two. This saves time. Secondly, given the approximately equal division of citizens in the pretest over whether the street or sidewalk was a more crucial area to light, the curb line seemed a point which did not automatically bias readings against the perceptions of either group.

[3]This was defined as the line of contact between the street or shoulder surfacing and the abutting ground.

EXAMPLE OF A WELL-LIGHTED AREA

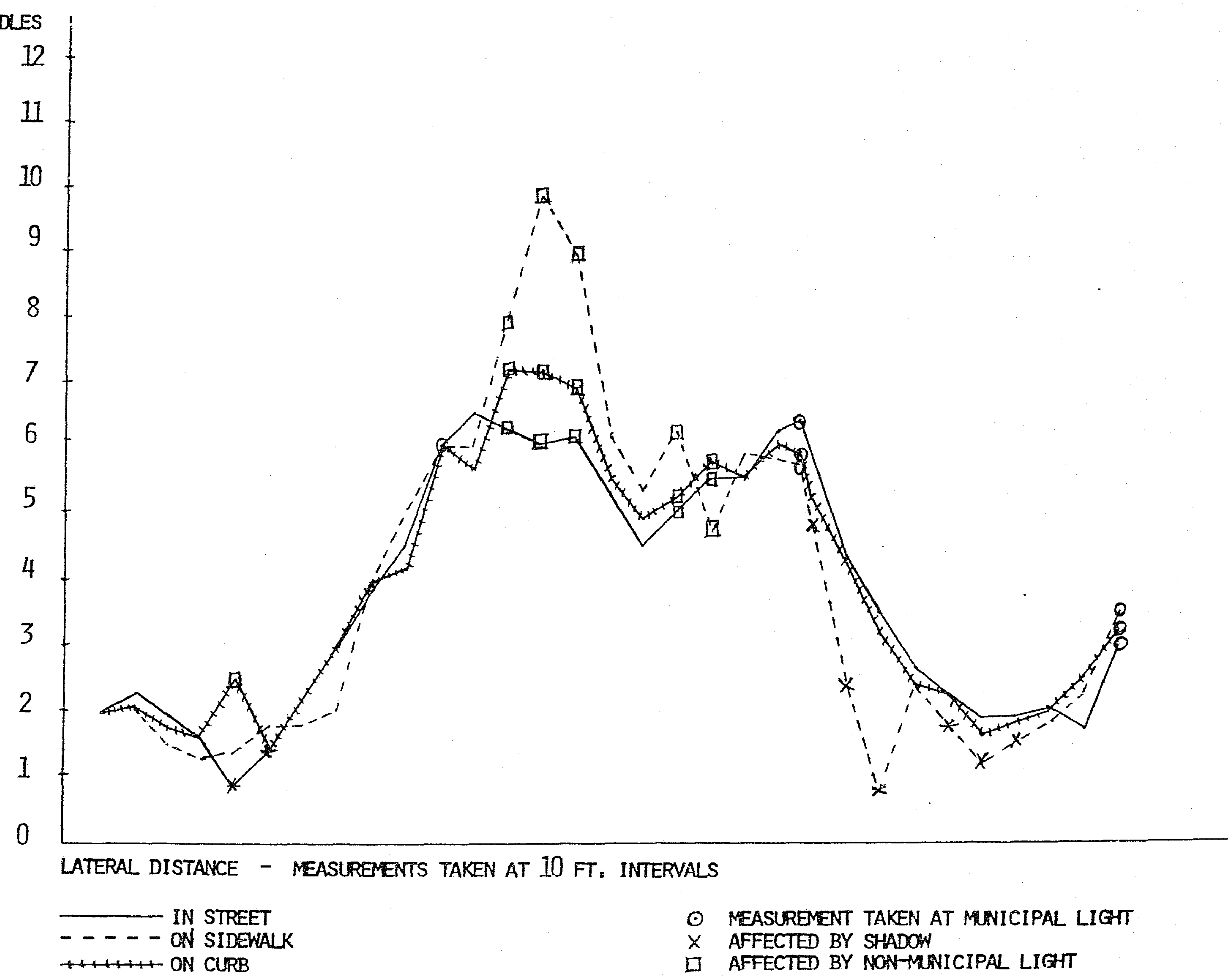


FIGURE 2

EXAMPLE OF A WELL-LIGHTED AREA

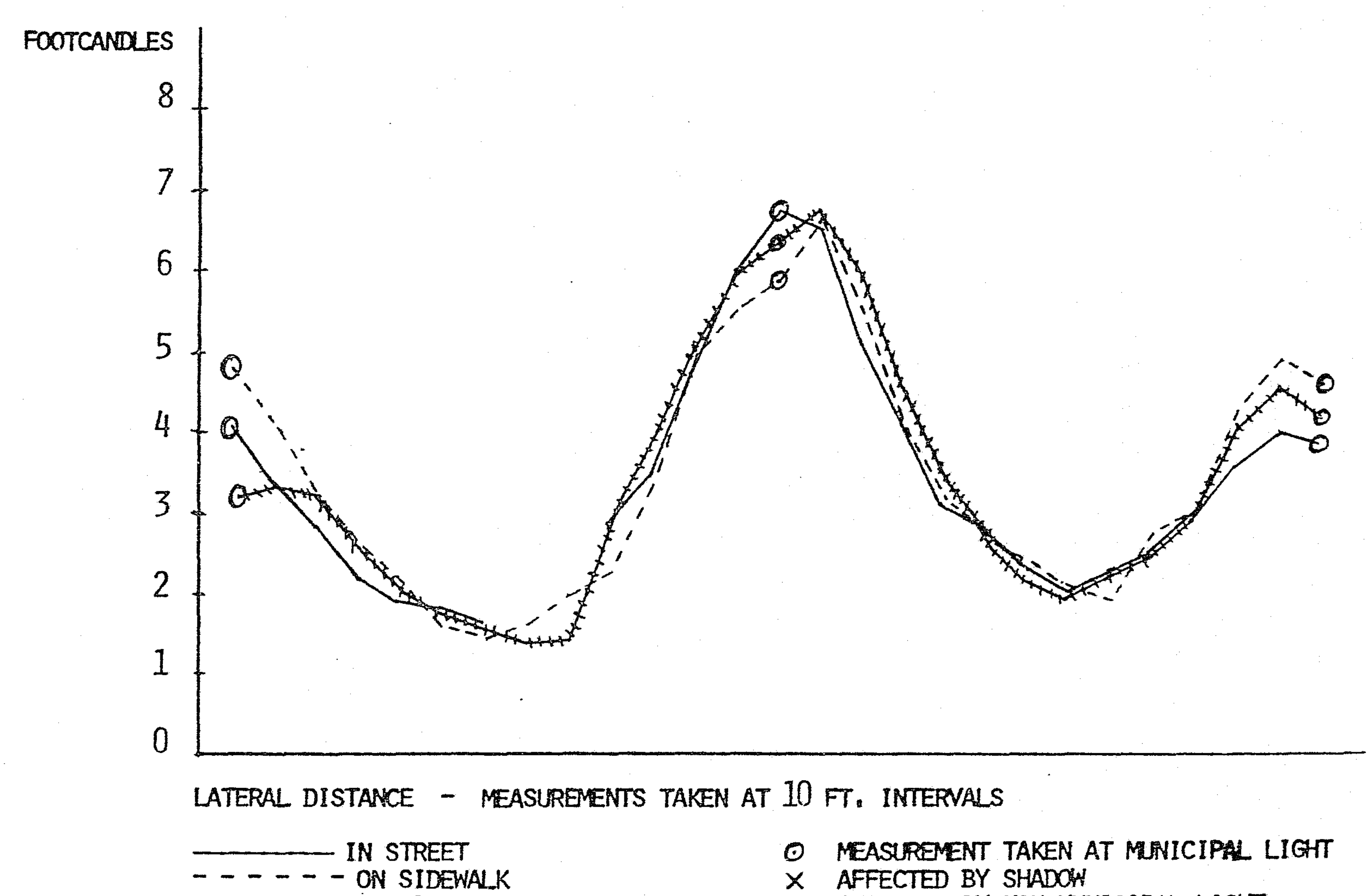


FIGURE 1

EXAMPLE OF A MODERATELY WELL-LIGHTED AREA

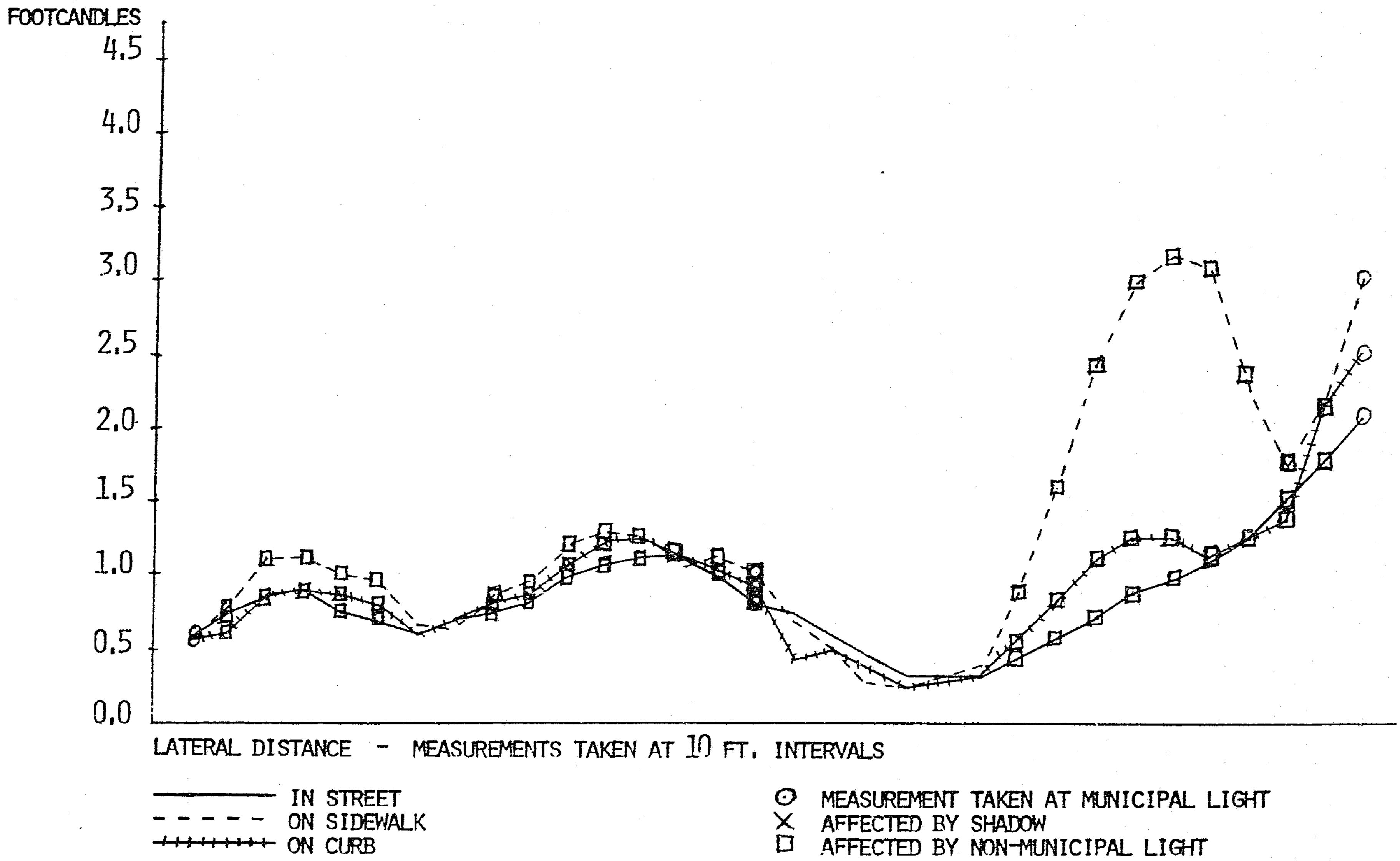


FIGURE 4

EXAMPLE OF A MODERATELY WELL-LIGHTED AREA

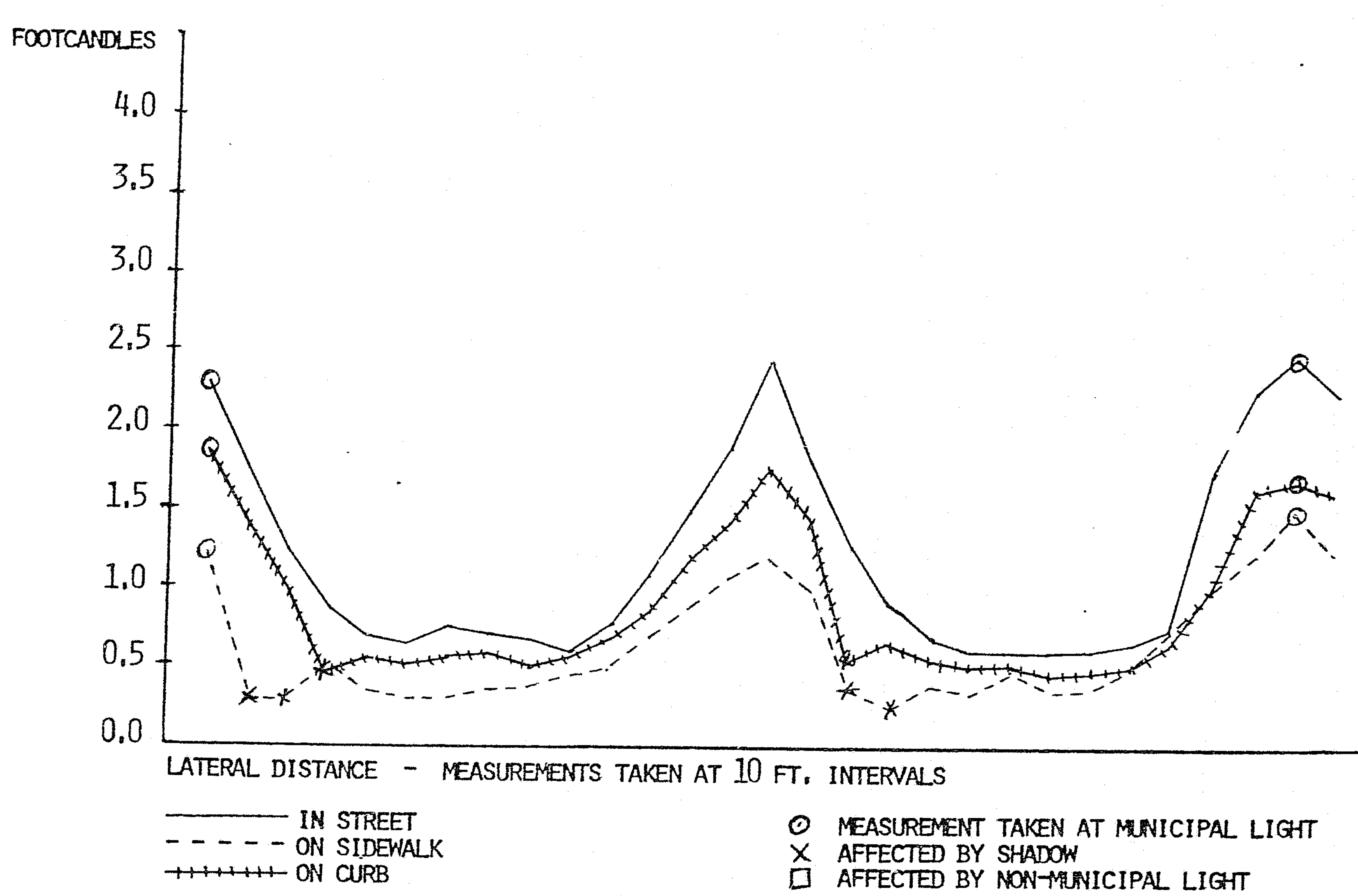


FIGURE 3

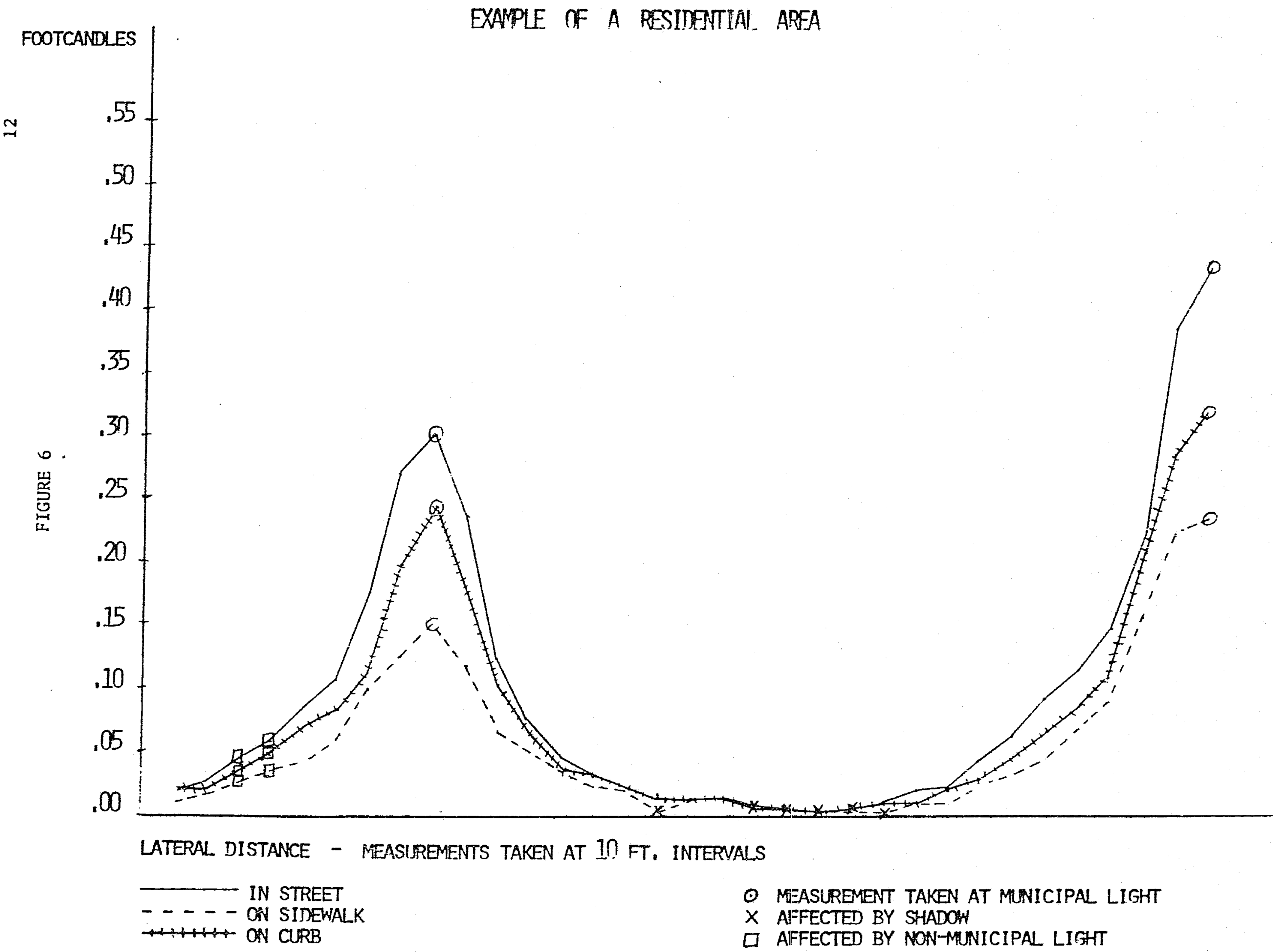


FIGURE 6

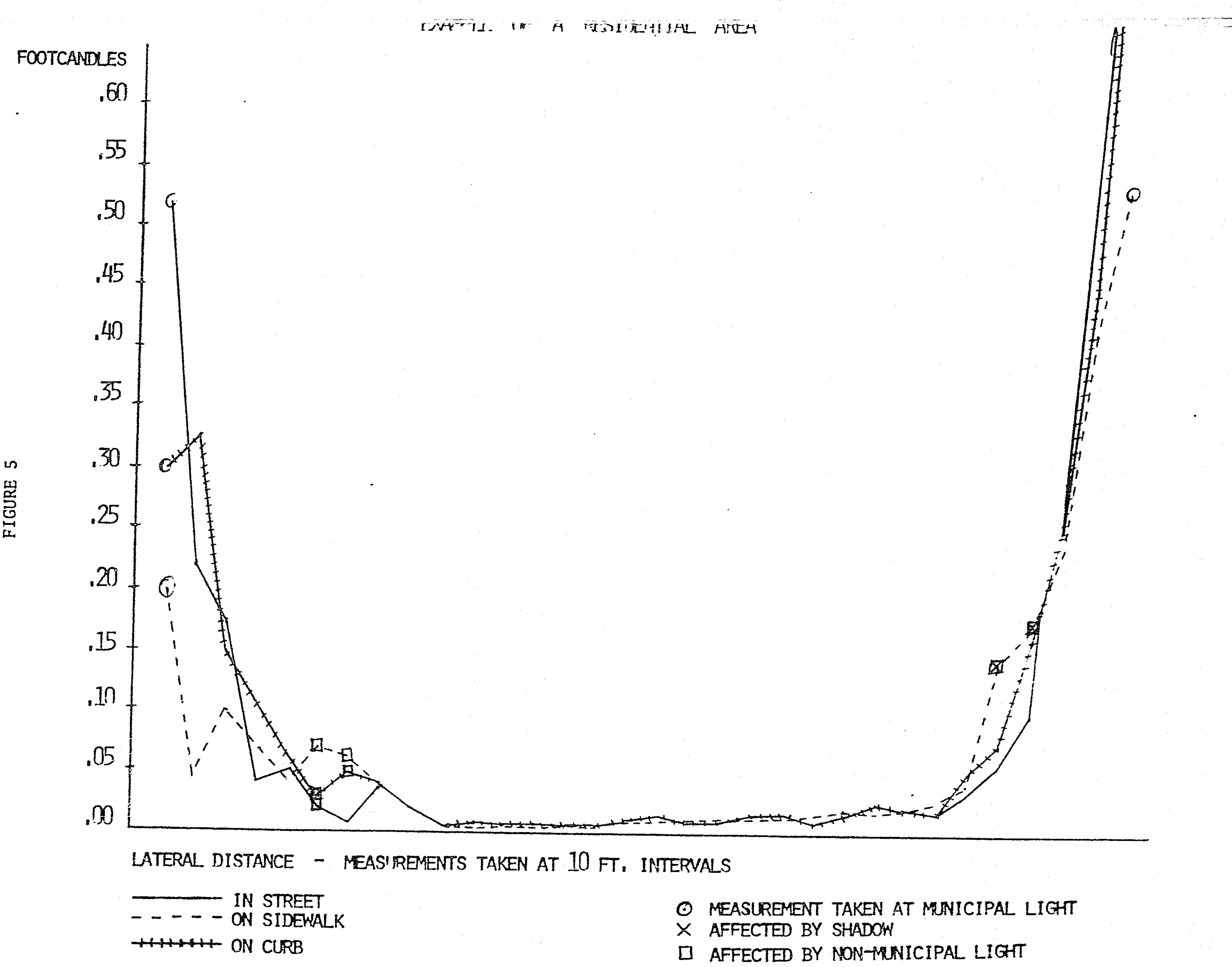


FIGURE 5

In addition, the first round of measurements revealed that the readings obtained with the method selected did not behave differently on streets with different types of light sources or different patterns of placement. The same method was suitable for all types of streets frequently encountered in municipal settings in that it yielded consistent block profiles under widely divergent lighting conditions.

When to Measure

A separate problem from that of where to take measurements was when to take them. One aspect of this question is the matter of what hour of the night to take readings. Of course, it was necessary to measure under conditions of full darkness rather than during the hours of dusk or dawn. However, it was possible that the headlights of passing traffic might interfere with the process of taking readings to such a degree that the time selected for measurement would have to be one which coincided with minimum traffic use of the streets.

The first round of measurements demonstrated that automobile headlights could, under certain conditions, interfere with readings. It is, therefore, advisable to take readings at times when traffic flow is at its lowest ebb if the blocks to be measured are subject to heavy use. If the blocks where readings are to be taken are characterized by low levels of traffic, however, the time selected for taking readings need not be determined by the use patterns of the streets. Even on these streets, however, it will be necessary to suspend measuring while cars pass if there is any chance that their lights will interfere with the readings. This may slow the process

of measurement but should not inordinately extend it on low-use streets.

A matter of even greater significance than the influence of passing cars is the question of what effect variation in the natural light on a given night might have on the readings. If the light of the moon on clear nights added substantially to the level of the readings obtained, it might be necessary to take measurements only on nights with heavy cloud covers or darker moon phases.

In order to determine the effects of moonlight on the photometric readings, Workshop team members took readings of the light level on the surface of open fields uninfluenced by artifical light on clear nights with different moon phases. These readings showed that a full moon consistantly yielded a reading of .007 footcandles in the latitude of Bloomington in the month of September.[4] This amount falls to near zero on heavily overcast nights and on nights of very low moonlight due to the moon's phase.

While the light cast by the moon will influence readings any time the moon's light falls on the photo cell, the maximum value of this influence (.007 footcandles) is quite small relative to illumination cast by artificial light sources. Moreover, the places where moonlight could represent a significant proportion of the total variation recorded are those streets where illumination is exceptionally low due to the absence or spacing of lights or to the interference

[4]One might expect slightly higher readings from a full moon in latitudes nearer the equator or in high altitudes.

of heavy foliage. These blocks are likely to be grouped together in any analysis of the results of measurements in that they fall far below code lighting levels, and since it is inadvisable to base a detailed analysis of results on lighting variations smaller than .01 footcandles due to the reliability constraints inherent in the method of measurement.[5]

In light of these facts, the Measures team reasoned that it would be possible to ignore the effects of lunar light in selecting a time for taking readings.[6] To test the accuracy of this judgment, readings in the first round of measurement were taken on nights with widely different natural light conditions. Graphs of sample readings taken on nights with different moon phases are presented in Tables 7 and 8. The results suggested that there was no consistant variation of reading patterns by natural light conditions which was of any significance in the type of interpretations which were reasonably to be made from the data. Accordingly, the team elected to disregard natural light conditions in selecting times for measurement.[7]

[5]These constraints stem from the fact that it is probably impossible to reproduce the finest variations in readings on different nights due to such influences as fluctuation in electrical current, changes in cloud cover, and human error in reading the meter's scale.

[6]Stelar light, of course, is insignificant for these purposes.

[7]One possible alternative strategy for those who wish to use the methodology developed in this study but who are, for some reason, interested in even the fine variation possibly caused by natural light, is to correct for natural lighting conditions. This could be done by taking a reading of the natural light level uninfluenced by artificial light before measuring light levels on each block. The footcandle value of natural light could then be subtracted from all readings where natural light fell on the photo cell.

FIGURE 7

COMPARISON OF CURB READINGS TAKEN ON DARK* AND MOONLIGHT+ NIGHTS

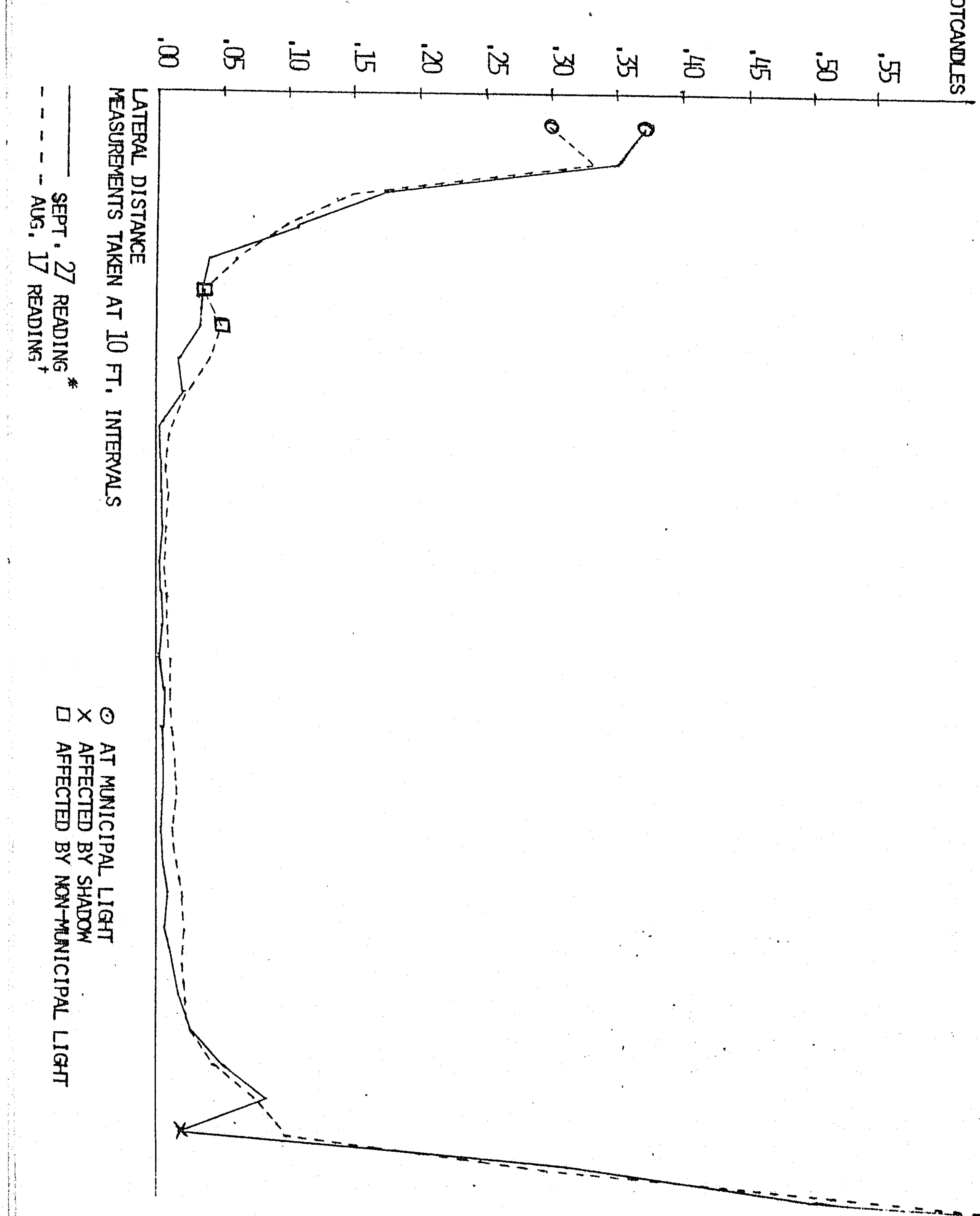
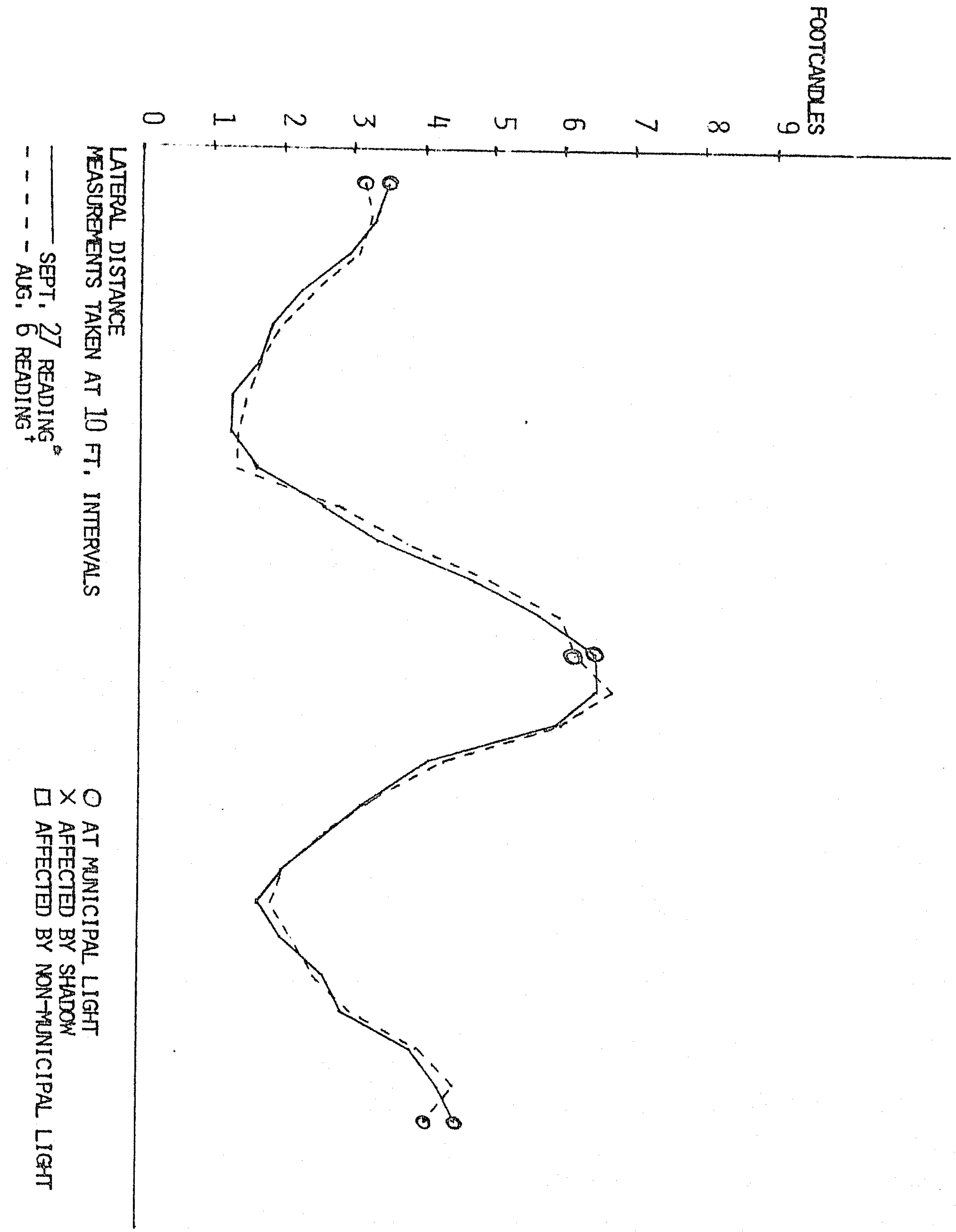


FIGURE 8



COMPARISON OF CURB READINGS TAKEN ON DARK* AND MOONLIGHT+ NIGHTS

Another aspect of the problem of when to measure is the question of what time of year to measure. The season of measurement has an influence on results to the extent that variation in the density of foliage affects the amount of illumination reaching the street's surface. There will be a substantial difference between readings taken during seasons when trees and shrubs are in leaf and those taken during seasons when they are barren <u>if</u> there are large numbers of trees overhanging the streets where measurements are taken. Because these differences will be constant across streets measured in the same season, however, the only important consideration is that all readings be completed during a single season so that the extent of foliage does not change significantly during the course of readings.

While measurement is possible in wet and winter months, it is advisable to take them in dry and warmer months if possible. This is because it is virtually impossible to take accurate readings in the rain and because the light-reflecting qualities of snow have a profound

This alternative is <u>not</u> advisable for several reasons. First, there are likely to be substantial problems in locating an area where natural light readings can be taken that is geographically proximate to the blocks where readings are to be taken. If a substantial distance separates the two areas, differences in localized atmospheric conditions may invalidate the logic of subtracting a natural light value from all blockface readings. Secondly, even if the problem of geographical proximity could be solved, it would be valid to subtract natural light values from blockface readings only when natural light fell on the photo cell. This makes it necessary for field operatives to make frequent judgments as to whether foliage or other obstacles block the moon's light from the photo cell. These judgments represent one more opportunity for human error to influence the validity and reliability of the readings. In short, the time and reliability costs of efforts at correcting for the influence of natural light levels seem to far outweigh the possible contribution of such a correction to the amount of useful information obtained from measurement.

influence on the light meter's readings.

In summary, then, we found that it was possible to develop a consistent, relatively economical methodology for physical measurement of residential streetlighting, a methodology which then allows careful comparison of lighting service provided on different blockfaces in residential neighborhoods. The details of the of measurement developed by the Measures team are presented in the Appendix. We hope that this method will prove helpful to persons wishing to replicate this type of study. It should also be of some use to municipal lighting officials concerned with the problem of output measurement and monitoring.

APPENDIX

HANDBOOK FOR THE USE OF A PHOTOMETER IN OBTAINING MEASURES OF RESIDENTIAL STREET LIGHTING

One of the physical outputs of municipal expenditures on street lighting is the amount of illumination which falls on the surface of the streets and sidewalks of blocks with municipal lighting. If a physical measurement of these illumination levels can be obtained in an efficient manner, these measures can be used in making comparisons of the relative quality of services delivered to different neighborhoods, and the actual levels of lighting provided relative to those desired by citizens, as well as other comparisons which might be of policy relevance.

This handbook describes the method developed for the measurement of street lighting levels as part of a study sponsored by the National Science Foundation and conducted by the Workshop in Political Theory and Policy Analysis of the Department of Political Science at Indiana University.

The Light Meter

The instrument used for this study is a Model FC-200-TV/B SPECTRA Illumination Meter manufactured by Photo Research Corp. of Burbank, California. It is a compact, lightweight directreadout meter which has a highly ledgible dial easily visible under conditions of poor illumination.

The scale is calibrated in "footcandles",[1] the most commonly used measurement unit in streetlighting engineering. Figure I is a diagrammatic representation of meter used.

The meter features cosine and color corrections in its measurement readouts.[2] Together, these corrections insure that the meter will respond to light in much the same manner as the human eye and will give a reading which reflects what a human observer might perceive when confronted with the same lighting.

While this particular meter proved quite well suited to the purpose of obtaining measures of streetlighting, the methodology described below could be used with other meters having similar characteristics. The only modification made in the Photo Research meter for use in the study was the addition of a base for the photo cell (see Figure II). This base was a metal plate designed to hold the photo cell securely so

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[1]A footcandle is equal to the illumination falling on a surface one foot from a one-candlepower light source.

[2]The amount of illumination cast on a surface by a beam of light is a function of both the intensity of the beam and the angle at which it strikes the surface. As a beam of light is tilted so that it strikes a surface at an angle, the area illuminated by the beam increases. Since the amount of light in the beam remains constant, the illumination on any point in that area decreases. The meter reading of a cosine-corrected instrument represents the true illumination on the light sensor regardless of the angle from which the light comes.

The different characteristics of different colors of light (light from different types of source) cause uncorrected photo cells of the type used in the FC-200-TV/B to react differently to light than does the human eye. With a color correction, the cell responds to light in much the same way as the human eye and meter readings reflect on those ranges and aspects of light perceived by the human eye.

that the cell could be placed flat upon the ground. This was done to ensure that the reading taken would be of the light that falls on the same plane as the "natural" surface.

<u>Procedures for Use of Light Meter</u>

The following instructions pertain to the operation of the VC-200-TV/B in the field. While the instructions in this section are, therefore, specific to use of the particular meter used in this study, the procedures described in the next section of the manual may be utilized with any similar meter.

Understanding of the instructions may be facilitated by reference to the diagrammatic sketch of the FC-200-TV/B provided in Figure I.

1) Test the batteries. Set "ON-OFF" switch to "BT" and check the reading on the meters dial. The reading should be at or above the red reference line marked "BT". If it is not, replace the batteries.

2) Check calibration. Set "ON-OFF" switch to "ON" position. Turn range dial to reach range (300 through .1 footcandles base). The reading should be at precisely zero for each range. If it is not, rotate the "coarse" or "fine" adjustment dials to obtain a reading of zero on the meter face. After adjusting, leave range dial set on 300 footcandle range.

3) Attach sensor head firmly to aluminum plate using thumbscrews provided. Plug sensor head cable into "PC" socket on meter and tighten socket screws.

4) Place sensor head and aluminum plate on the surface where illumination is to be measured.

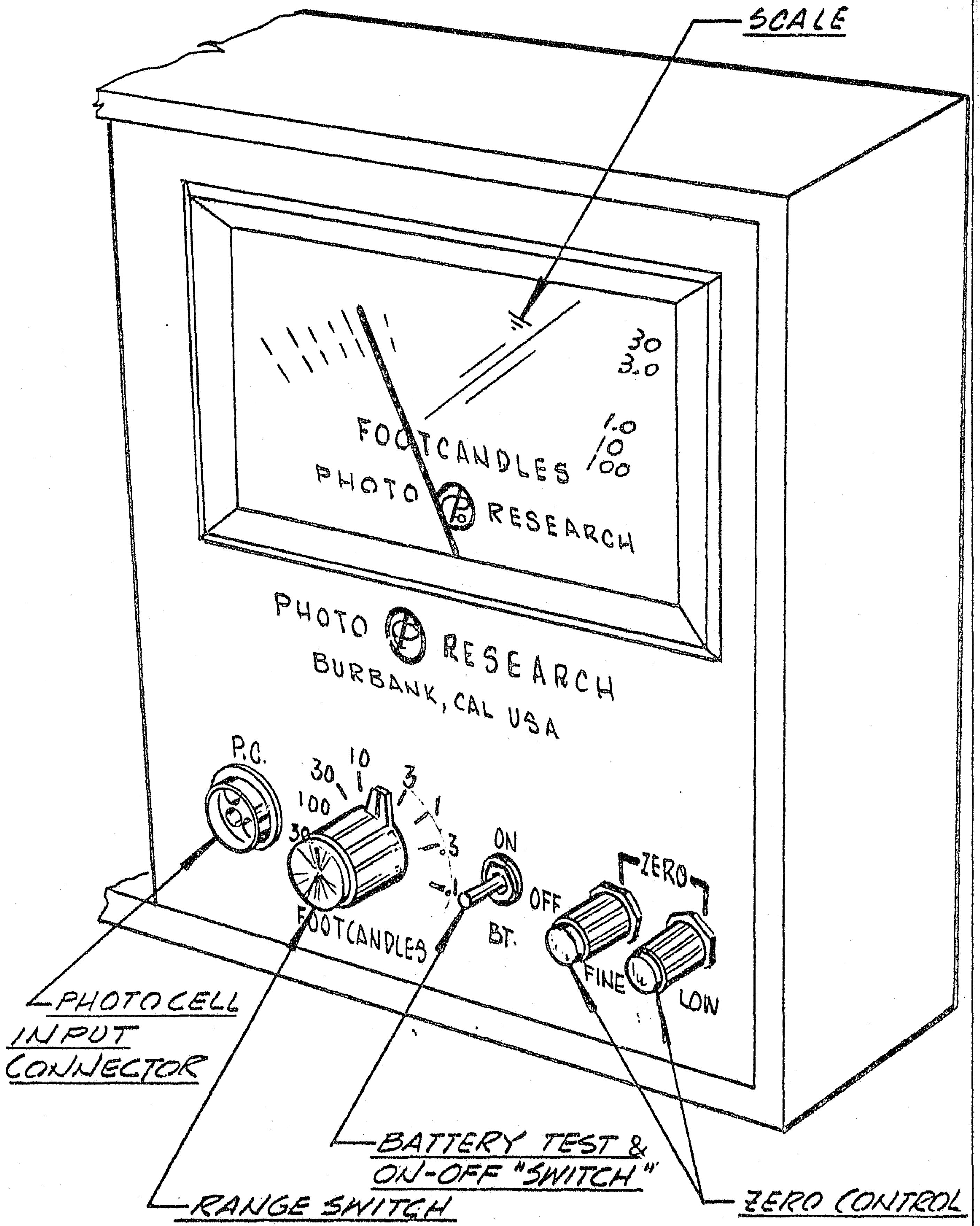

FIG. 1
FC-200TV-B CONTROL PANEL

5) Turn range dial to successively lower ranges until a setting is reached where deflection on the meter face is more than one quarter of the full scale (until, for example, a reading of .25 or greater is obtained on the 1.0 scale or a reading of 2.5 or greater is obtained on the 10.0 scale). The meter will then be ready for making measurements in lighting conditions similar to those where the preceding adjustments were made. Changes in the intensity of illumination, however, may make it necessary to repeat step 5 in order to get accurate readings.

6) Read illumination in footcandles from the dial on the meter's face. If the range is set on "1.0", "10", or "100", read the measure directly from the appropriate line on the lower portion of the dial face. For the "0.0" scale, read on the "1.0" scale but divide each reading by ten before recording. If the range is set on "3" or "30", read directly from the appropriate upper scale. For the "300" scale, read from the "30" scale and multiply each reading by ten before recording.

7) After taking all readings, loosen the socket screws on the sensor head cable and unplug the cable from the "PC" socket. Remove sensor head from the aluminum plate and store it in the space provided beside the meter's face.

8) Test batteries as in step 1 above, and set the "ON-OFF" switch to "OFF".

Field Measurement Procedures

The following instructions are designed for a team of two persons taking streetlighting measures, and will yield a "profile" of the lighting on a single line of points along a blockface when followed in the field. The only equipment required is 1) an illumination meter similar to the FC-200-TV/B, 2) a clipboard with appropriate recording forms, 3) a small flashlight or penlight to facilitate recording readings under conditions of darkness (an illuminated clipboard is especially useful if available), and 4) a spring-loaded tape measure.

1) Designate a blockface for measurement and select one end of the block as a point of origin. For consistency and ease of interpretation, a criteria should be established for selecting the point of origin for each block. One may, for example, want to begin at the end of the block with lower house or lot numbers and work toward the end with larger numbers.

2) Find the point at which lines drawn along the curb of the blockface to be measured and the curb of the interesecting street would meet to form a 90° angle (point A in Figure III felow). If there are no actual curbs on either or both the street where measures are to be taken and the intersecting street, locate the point of intersection of an imaginary line drawn along the area where a curb would be if constructed, that is, at the line of contact between the street surfacing and adjoining ground or sidewalk.

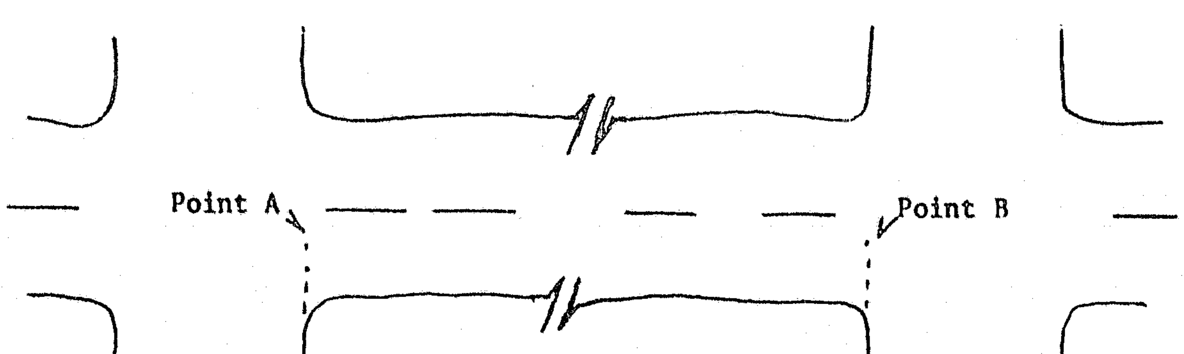

Figure I

3) With one team member , preferably the one who will be carrying the light meter and calling out readings, holding one end of a long (50 to 100 foot), spring-loaded tape measure of the type used by carpenters and surveyors, the second member of the team should feed out the tape along the top of the curb or on the border of the street surfacing and abutting ground where a curb would be if present.

4) When the second member of the team returns to the point or origin, leaving the tape stretched out, the first team member will place the head of the photo cell on that point and take a reading of the illumination following the instructions in Steps 4 through 6 in the preceding section of this report, and will call out that reading to the second team member who will record it according to Step 5 below. Both members of the team must take care that their shadows not fall on the sensor head when readings are being taken!

5) Record the meter reading on a form like that shown in Appendix 2, noting any interferences which might cause the reading to deviate from its "true" value. Examples of such interferences would include the shadow of a low shrub or a parked car which fell on the spot where the reading was taken and reduced its value, or the beam of a non-municipal light (like a porch light) which happened to fall on the spot and raise the value of the illumination reading. If it is necessary for the recording member of the team to use a flashlight to see the clipboard, every precaution should be taken to prevent the beam from that light from falling on the sensor head when readings are being taken!

6) Both team members move along the tape, stoping at 10 foot intervals to take readings as they move. In each case readings are

taken and recorded as described in Steps 4 and 5 above (except, of course, that the point of measurement changes).

7) As readings are being taken the second or recording member of the team should be making notes of the addresses of houses fronting on the blockface and of their distance from the point of origin. This distance is determined by noting the reading at the point on the tape which falls directly in front of the center of the front door of the house, or, if there is no door facing the street and the house is still considered to front that street, by noting the reading on the tape at the point which is opposite the center of the house.

8) Once the end of the tape is reached, the first member of the team should stand at the terminal point while the second member pulls the tape along, stretching it out over its full length again. The first member should halt the tape's end at the point where the last measurement was taken and resume readings at 10 foot intervals once the second member has returned to the head of the tape.

9) Meter readings should rise near lights and fall as one moves away from the lights creating a wave-like graph. If there are large distances between streetlights and no intervening nonmunicipal lights, the lumination of the street lamps may not overlap and dark areas will appear on the blockfaces.

Where no artificial light covers an area the value of meter readings may be relatively constant over a considerable interval. At these times, considerable time can be saved in the measurement procedure if one does as follows.

When a reading of .05 footcandles or less is obtained at a point <u>not</u> influenced by a temporary or small shadow, and the adjoining area appears equally dark for some distance, the team should move along the tape <u>without taking readings</u> until they reach a point on a 10-foot interval where they feel illumination has increased above the .05 footcandle level. Here they should take a reading. If the reading is substantially greater than .05 they should retreat to previous 10-foot intervals, taking and recording readings until they reach or drop below the .05 level for reasons other than an interference. Then they should move back to the point where readings were initially resumed after skipping space and proceed down the block with measurements.

If the value of the reading at the point where recording is resumed initially is less than or equal of .05, the team should simply proceed with readings at 10-foot intervals from that point until the end of the block is reached or another dark area is encountered.

A value of .05 is then assigned to all points falling between the termination and resumption of readings. This procedure costs very little in the way of information since variations in illumination under the .05 footcandle level are hardly perceptable under street conditions. It can, however, save a great deal of time on streets with widely separated light standards.

10) On reaching the end of a block, a terminal readings should be taken at the 10-foot interval nearest the intersection of imaginary lines drawn along the curb lines of the perpendicular streets (point B in Figure III).

END