# FINAL REPORT

PART I OF TWO PARTS

# ILLUMINATION IN GROUP SHELTERS



Prepared by
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## ABSTRACT

The effects of low levels of illumination on visual acuity and on performance of simple tasks were studied in an effort to evaluate group shelter illumination requirements. The purely objective determination of a minimum level was negative. The characteristics of various illumination sources are compared. Based on test results and evaluation of the illumination sources, designs and costs for standardized shelter lighting packages are presented.

# FOREWORD

This report is based on literature searches and original investigation into acceptable illumination levels for group shelters, evaluation of illumination sources, and on the design of standardized lighting packages for such shelters. The material was prepared by Sanders and Thomas, Incorporated, Pottstown, Pennsylvania under contract number OCD-OS-62-80 for the Department of Defense, Office of Civil Defense.

Acknowledgment is made to Dr. J. A. Vernon, of the Princeton University, Department of Psychology, for his assistance and guidance concerning the development and interpretation of the acuity tests and to Mr. Henry Brown, of the Office of Civil Defense, for his helpful suggestions.

## SUMMARY


### ILLUMINATION IN GROUP SHELTERS

*REQUIREMENT:*

To evaluate all alternative means of providing group shelter illumination on a cost-effectiveness basis and to recommend standardized lighting packages for 50, 500, and 2000 man shelters.

*PROCEDURE:*

Investigation was conducted to determine an acceptable level of illumination as a predication of the evaluation of sources and cost of such illumination. Selected levels of illumination were determined by the present experimenters in pretest trials as being within a range which would seem to produce a significant difference over normal or usual illumination levels, i.e., 10-foot candles. Vision tests were run at the selected levels and, based on these results and other non-experimental data, level of illumination was recommended and acceptable sources of illumination were determined and standardized light packages designed.

*FINDINGS:*

1. On a short term basis, i.e., a few hours, low levels of illumination in the range of one foot-candle down to one-quarter foot-candle could be used for shelter lighting without jeopardizing simple existence requirements.

2. Incandescent and fluorescent lamps are acceptable sources of illumination for all shelter sizes with fluorescent having a general cost advantage in the 500 space and 2000 space sizes.

3. The propane gas lantern is an acceptable source of illumination for the 50-space shelter with adequate ventilation; for the larger shelters the cost was excessive. It is an especially economical source when electricity is required for illumination only.

4. Achromatic light sources are subjectively more satisfactory than those predominant in only a few chroma.

5. It is possible to illuminate shelters with natural (sun) light under certain conditions. (See Part II of this report.)

6. Tasks that are essentially motor-performance are not greatly influenced in the short term by the amount of illumination.

# CONTENTS

Page

## LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION

The requirements of the project were to evaluate all alternative means of providing group shelter illumination on a cost-effectiveness basis and to recommend standardized lighting packages for such shelters of 50, 500, and 2000 space capacity. Three areas of investigation were followed. One, the amount of illumination required in a shelter; two, various sources of illumination; and three, the cost of illumination and the consequent design of acceptable lighting packages.

## A. AMOUNT OF ILLUMINATION

An important parameter is the quantity of light necessary for satisfactory shelter lighting. Only by determining this quantity could a proper recommendation, based on cost-effectiveness, be given with any real assurance since cost and effectiveness differ with varying levels of light and light sources. Though much literature (see bibliography) was applicable in many respects to the problem of low level illumination, no specific effort, as far as could be determined, had ever been directed at this particular question of interest. Written contacts with three foreign governments (Great Britain, Germany, and Sweden) concerning their shelter lighting requirements, did not provide information useful to this report.

Work has been done by various investigators concerning vision at levels of night road illumination with respect to fields of view, adaptation recovery, reflectance of surfaces, and other related night driving problems. Also, much research has been conducted by others on threshold levels of vision, speed of response, dark adaptation, and other parameters that essentially are concerned with the eye. However, these efforts did not appear suitable as specific determinants for solving the problem of minimum shelter lighting, even though they were contributive to this study (1).*

A question might be —what level of illumination represents a point where most individuals have much less visual acuity than is necessary to perform the simple tasks which may be required in a shelter? If it could be established that visual acuity breaks down at some definite level, then it could be said that the next higher increment of light was the lowest desirable level, and it could be recommended that this be the minimum lighting level for shelters. Further, this then would become the point at which cost-effectiveness may be determined, though because of the large variance in shelter sizes to be considered, this would not necessarily make one system of lighting universally recommended.

## B. SOURCE OF ILLUMINATION

A problem parallel to that of the level of illumination is the characteristics of sources of such illumination. There are many sources of illumination that have efficacies greater than the incandescent lamp or the fluorescent tube, but may have qualities that preclude their use as sources of shelter lighting. What are the energy requirements for the various illuminants? Are these illuminants available in desired light outputs? Which source will provide satisfactory illumination for an extended period without frequent servicing?

A satisfactory illumination source, therefore, must satisfy many conditions with regard to shelter inhabitants.

## C. COST AND DESIGN OF LIGHTING PACKAGES

Once the level of illumination had been established and a satisfactory selection of sources made, then the various sources must be weighed on a cost-effectiveness basis and be suitable for inclusion in a standardized lighting package.

Tests such as the following were made for each combination: were the selected sources readily available; what was the cost per unit of illumination; if portable, would this kind of illumination be simple to install for unskilled persons in what may be a disorganized situation? How does the cost vary with the level of illumination? Will the lighting system be suitable for all shelter sizes? If the illuminant is a result of combustion, would the fuel store for long periods of time? Will heat of combustion be a problem?

The examination of these problems was meant to provide sufficient information to (1) determine the most effective source of illumination from a cost standpoint, and (2) to design a standardized lighting package with due consideration for the attending parameters.

* Indicative titles of material referred to above.

"Better Visibility for Civilian Night Driving"

"Road Safety: Some Visual Aspects"

"Uniform Reflective Sign, Pavement and Delineation Treatments for Night Traffic Guidance"

"Studies on Dark Adaptation. IV. Preexposure Tolerance of the Dark Adapted Peripheral Retina"

"Design of Reflectorized Motor Vehicle License Plates"

"Dark Adaptation as a Function of Age and Tinted Windshield Glass"

"The Association Between Retinal Sensitivity and the Glare Problem"

# CHAPTER 2

## VISION TESTING FOR LOW LEVELS OF ILLUMINATION

### A. TESTING PROGRAM

#### 1. Selection of Illumination Source.

Tests were conducted in a windowless room, 19½ feet by 13 feet. The room was mechanically ventilated at all times during the tests.

• Several types of incandescent lamps were tested to determine what appeared to be the most effective source for the desired amount of illumination. Frosted, soft white and clear 120 volt incandescent lamps were tried in wattages from 7½ to 100. Several types of miniature incandescent lamps were also tested such as PR 6, PR 7, and 502 (flashlight); 1073 and 1141 (automotive); and 47 and 44 (instrument) with voltages ranging from 2.47 to 12.8 and amperages from .15 to 2.0. (Type of current whether AC or DC is not critical to the operation of any incandescent lamp.) Control of output was by means of 3.5 amp variac and measurement by means of a Weston No. 614 calibrated lightmeter.

When reduced voltage was applied, incandescent lamps gave light of a red hue. This red hue is both objectively and subjectively duller in that the Purkinje effect* is gradual throughout the visual spectrum. Blue spectrum begins to affect the majority of retinal response about the upper mesopic range but contributes to vision in ranges above this (2). Thus for low levels of illumination, the more blue in the illumination source, the more bright the light appears due to the additional excitation of the rods.

An effort was made to establish illumination levels with smaller lamps in order to utilize higher filament temperatures which did not produce this objectionable red hue. The experimenters found that at the one foot-candle level the higher filament temperatures produced a subjectively *brighter* and *more pleasant* light because the higher temperature included more blue spectra.

Miniature lamps between six and 12 volts have the most efficiency and though smaller voltage lamps were tried (see above), the voltage levels for the required amount of light were so high that lamp life would be exceedingly short. (Life of incandescent lamps normally varies inversely as the twelfth power of the voltage, while light output varies directly only as the 3.6 power.) (3) Also many of the smaller lamps have normal expected life of from 15 to 30 hours, deemed too short by the experimenters; hence a lamp of reasonably long life at rated voltage with sufficient output for the levels desired in the test room was required. Consideration was also given to the possibility of using such a lamp for shelter lighting. The required voltage output of the standard 115-120 volt emergency power plant could be controlled by means of an inexpensive transformer.

On the above basis, a No. 1073 single contact bayonet base lamp was chosen for the tests. This lamp has a rated life of approximately 250 hours at 12.8 volts and draws 2.0 amperes (4).

#### 2. Establishment of Illumination Levels.

Illumination levels were established by using four No. 1073 lamps and turning them off

* Purkinje Effect – The shift from cone to rod (night) vision wherein maximum sensitivity of response is shifted approximately 50 millimicrons of wave length toward the blue spectrum. See IES Handbook, pages 2-5, 2-6.

singly in a predetermined sequence which was not varied. Voltage input to the branch circuits for whatever number of lamps were lit was maintained constant. This was done in order to maintain as near constant filament temperature as possible and thus to have the same degree of *whiteness* to the light. As each lamp was turned off, the variac setting was adjusted to maintain the constant voltage reading and a check of the lightmeter was made to confirm the illumination level. Control of the various levels was thus achieved by (1) starting with four lamps, closely arranged on a board, all lighted, then turning them off one at a time in a predetermined sequence and (2) changing the variac setting to maintain a constant potential across each lamp. Care was taken that the turnoff sequence was so arranged as to not have any turned off lamp shade the working area.

In order to establish illumination levels at which subjects would be tested, the experimenters, using the stimuli to be used on the subjects, found that there was little apparent change in their overall performance from the 45 foot-candle room lighting down to the one foot-candle level. One foot-candle appeared to be the level where general visual acuity started to fall off. (Subsequently, actual check of the subjects at two foot-candles showed no significant difference from 45 foot-candle illumination. At 45 foot-candles there were no errors in white Landolt rings (see page 5) and at two foot-candles there was less than one per cent error.) It was also noted by the experimenters that color discernment of both bright and pastel colors could be made at two foot-candle level. Hence, it was decided to start testing at one foot-candle and reduce in one-quarter foot-candle increments down to one-quarter foot-candle.* The one-quarter foot-candle increment was the smallest increment that could be determined with the desired accuracy by means of the available equipment.

All illumination levels were determined as the amount of light on the working surface regardless of the nature of the task.

### 3. Recording Technique.

In the course of determining light levels the procedures for administration of the acuity and performance tests were worked out and a standardized form for recording results was devised. See Appendix, Figure 12.

The subjects were not informed as to the level of illumination for any given test and the various levels were utilized in both random and systematic order. It was felt that systematically increasing or decreasing levels might in some way unduly influence the results, whereas scrambling the order would render the subject more naive. As it turned out, this was an unnecessary precaution. Analysis of the effects of each method did not reveal any discernable differences.

## B. COMPOSITION OF SUBJECT GROUP.

### 1. Characteristics.

Volunteer subjects consisted of 42 employees of Sanders and Thomas, Incorporated, and represented the engineering, drafting, and secretarial staffs. Subjects were selected at random with the exception of visual correction, on which point the subject group consisted of 50 per cent who were emmetropic.

Some characteristics of the subject group were:

There were 33 males and nine females.

The males averaged 34.6 years; females 29.4 years.

The eldest subject was 64 years; the youngest 19 years.

The median age was 30.5 years.

The average age of subjects was 33.7 years.

It was anticipated that with this subject group, the composition would not be misrepresentative of the adults in a shelter group.

* Examples of low foot-candle levels commonly encountered are moonlight, .02 FC; motion picture theater auditorium, 0.2 FC (when picture is being shown); drive-in theater parking area, 0.5 FC (during intermission); average well-lighted business street, 2.5 FC.

2. **Indoctrination.**

The subject group was prepared for testing by means of a note explaining the purpose of the test and emphasizing that performance was not competitive. They were informed that the test program was intended to show only differences that may occur as a result of lowered illumination levels. A copy of this message is in the Appendix, page A-6.

3. **Processing Through Test Program.**

Acuity testing both at the 45 foot-candle and the low levels of illumination was done on an individual basis, though because of adaptation consideration, frequently there were others in the test room. The needle threading, nut, washer and bolt assembly, and reading tests, however, were done in randomly selected sub-groups of six. Sequence of testing within the groups as well as time of day of presentation was randomized.

## C. ACUITY TEST RESULTS.

The following are the results of the various tests. A description of the procedure and equipment for the tests from which the results below were obtained begins on page A-11.

1. **Illiterate E's.**

There was a statistically significant change* beyond the probability of chance between 45 and one foot-candle. Between one and 3/4 foot-candle there was no significant change, and between 3/4 and 1/2 the significance was just beyond the limits of chance. A significant change occurred between 1/2 and 1/4 foot-candle. This pattern is roughly followed in tests reviewed below. See Figure 13, Table A.

2. **Random Digits.**

Although at a lower level of acuity, the results for the random digit tests as to the number of those changing and the significance followed the pattern for Illiterate E's. See Figure 13, Table A.

3. **Landolt Rings.**

a. Five Minute Visual Angle, Achromatic and Chromatic.

The five minute visual angle test is a conventional standard in acuity work and hence it was adopted at the beginning of the present investigation. It failed to produce any errors for any of the acuity tests, regardless of color, at the 45 foot-candle level, or in a total of 2866 responses. Thus, the five minute visual angle pattern was discontinued in favor of two minute visual angle.

b. Two Minute Visual Angle.

(1) Achromatic.

Although only 14.9 per cent of the subjects had a change in response in the interval from 45 foot-candles to one foot-candle, the change was consistent enough to be significant. A further significant change did not occur until the comparison between 1/2 and 1/4 foot-candle was made when 47.6 per cent of the subjects changed. Between one foot-candle and 3/4 foot-candle 16.7 per cent changed and between 3/4 and 1/2 foot-candle 28.6 per cent changed. Though the number of response errors increased as the amount of light decreased, there were sufficient changes in the opposite direction (apparent *increased* acuity) to make the results not statistically reliable between one and 3/4 and 1/2 foot-candle.

(2) Chromatic.

The same random series of positions as used for the achromatic rings was also used for the chromatic rings. The series were in fact conducted concurrently, that is, chromatic followed achromatic for all subjects and in the same sequence of colors, vis – red, green, and blue. However, no random series was repeated for any one subject. Chromatic results, as expected, showed considerably more acuity change than achromatic. This was mostly due to the fact that

*As determined by the nonparametric technique by Wilcoxon for paired replicates. See Appendix, page A-7.

contrast levels were very much less in chromatic than for achromatic (1/16 by Blackwell's formula (see derivation of contrast levels in Appendix, page A-16). Also, there was the possibility of contamination from chromatic obtuseness (insensitivity to color), the incidence of which was unknown in the subject group. There was significant change in acuity for all colors between 45 foot-candle and one foot-candle. The per cents of those changing were 69.0 for red, 54.8 for blue, and 50.0 for green. Acuity did not change significantly for red and green between one and 3/4 foot-candles, but did change significantly for blue at these illuminations. Comparison of the two lowest levels showed that the number of errors increased sufficiently to provide significant change.

**4. Parallel Bars.**

a. Five Minute Visual Angle, Achromatic and Chromatic.

The same result occurred with parallel bars as was explained above for Landolt rings. Response to this size was so prompt and without error that both achromatic and chromatic five minute angle tests were not conducted at the lower levels. This decision is further borne out by the results for achromatic two minute visual angle tests discussed below.

b. Two Minute Visual Angle.

(1) Achromatic.

There was no significant difference between illumination levels for achromatic two minute visual angle until the 1/4 foot-candle level was reached. From the 45 foot-candle level to the one foot-candle level 11.9 per cent of the subjects changed, 19.1 per cent from the one to 3/4 foot-candle levels, and 26.2 per cent from the 3/4 to 1/2 foot-candle levels. Thirty-five and eight-tenths per cent changed from the 1/2 to 1/4 foot-candle levels, but this change was significant only to a probability equal to 0.2.

(2) Chromatic.

The results of the chromatic parallel bar tests followed the pattern of Landolt rings tests for the number of subjects changing between 45 foot-candles and one foot-candle, all colors showing a change and having a significance. (See Figure 13, Table A.) There was a noticeably greater ability on the part of the subjects to detect the horizontal (expecially) and vertical positions of the bars as against the diagonals at low levels of illumination. To a lesser degree, the same effect was noted for Landolt Rings. This concurs with the findings of Weymouth (7).

**5. Color Discrimination.**

In general, the ability to identify colors was not impaired by reducing the illumination. There was a slight and statistically nonsignificant trend toward misidentification of the lighter colors.

## D. PERFORMANCE TEST RESULTS.

**1. Howard-Dohlman Depth Perception.**

Results show that with each decrease in illumination there was a statistically significant change in performance. The consistency of the above results indicates that a decrease in the level of illumination seriously affects depth perception. This is in agreement with the findings of O. W. Richards with regard to night driving (10). See Figure 13, Table B, and Figure 20, Curve, in Appendix.

**2. Needle Threading Test.**

Needle threading showed a significant decrease from the 45 foot-candle level to the one foot-candle level. At lower levels there was no statistical significance. Though this test appeared to have an important degree of visual involvement, the mechanical portion was dominant enough to prevent lowered illumination levels from adversely affecting results. See Table B, Figure 13.

**3. Bolt, Washer, and Nut Assembly.**

There was no significant change in performance between any of the levels tested.

### 4. Newsprint Reading.

A significant difference did not appear until the level of 1/4 foot-candle was reached even though 74 per cent of the subjects changed both from one to 3/4 and from 3/4 to 1/2 foot-candles. From 1/2 to 1/4 foot-candles 83 per cent changed with a probability greater than .01. For a short period, at least, ability to read seems highly persistent. Longer period (more than a few minutes) persistency would require further testing. See Figure 13.

## E. DISCUSSION.

The above tests indicate there was no level within the test range at which visual ability decreased markedly over the next higher level. But there were statistically significant differences in acuity in all but one test between the 45 foot-candle level and the one foot-candle level. When they occurred, significant differences between the various low levels in the direction of reduced visual ability did not appear universally until the 1/4 foot-candle level. An exception to the above was the test requiring relatively little visual involvement which did not produce a statistically significant difference at any of the low levels tested when compared with the 45 foot-candle level.

The inference may be drawn that for the short term, nominal shelter tasks such as food preparation, reading or sewing may also be performed at these levels even though such levels are from six per cent to less than one per cent of currently recommended levels for such activities (e.g. recommended casual reading level is 30 foot-candles. One-quarter foot-candle is 0.83 per cent of this level). (11) It may also be inferred that simple, familiar tasks high in motor performance such as the minimum dressing and undressing for sleeping could be performed at levels much less than those of the tests.

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## CHAPTER 3

# ILLUMINATION SOURCES

The illumination sources investigated covered 15 possibilities and fall into three categories, combustion, electric, and natural. The source in this case is the actual light-producing element and must be distinguished from the energy producing element such as a battery or engine-generator, though some combinations are usually thought of as an integral unit such as a flashlight. Evaluation of energy sources is beyond the scope of this report. Consideration was given to the energy sources only insofar as they are readily available and are compatible with the recommended illumination sources. In addition, a source of illumination by means of radioactive gas was briefly considered.

## A. COMBUSTION.

The various combustion sources of illumination investigated require oxygen for operation and are exothermic.

### 1. Open Flame Sources.

Ordinary wax candles, calcium carbide lamps and kerosene lanterns are three common sources of flame illumination. In addition to using oxygen, the production of light is quite low for the flame-type ranging from 10 to 100 lumens. Normally these sources are also short-lived without attention. They are essentially open-flame sources and represent a hazard.

### 2. Gasoline Lantern.

The single mantle gasoline lantern produces approximately 360 lumens but requires mechanical pressurization of a highly volatile fuel and does not lend itself to an integrated system. The fuel, gasoline, may not be stored for more than 18 months and remain useable.

### 3. Liquid Petroleum (Propane) Gas Lantern.

Liquid petroleum gas lanterns, however, may be used to advantage as a source of illumination, at least in the small (50-space) group shelters. In the 500- and 2000-space shelters, this source may be at a cost disadvantage since the lighting element is understandably more expensive than an incandescent lamp, for example.

A single L-P gas mantle produces 530 lumens, (1) and because combustion is complete, little, if any carbon monoxide or other undesirable by-products other than heat are produced (2). The light is nearly white and should require little attention once lit. Mantle life should approximate 500 hours (3), and if replacement is necessary it is a simple procedure. A single propane lantern will consume approximately .32 cu. ft. of air per minute and will add .013 cu. ft. of water vapor and .04 cu. ft. of $CO_2$ per minute to the shelter air. (4) The air requirement is less than two per cent additional to the 3 cu. ft. per minute recommended by Fallout Shelter Surveys: Guide to Architects and Engineers at the maximum (2 foot-candle) level of illumination considered in this report. (One lantern per 63 sq. ft., see page 25, Lighting Distribution.) But the $CO_2$ addition is equivalent to a 10 per cent additional ventilation requirement based on a maximum two percent concentration of $CO_2$ and 3 CFM per person rate of air exchange. This is exclusive of the important point of heat output. (For a further discussion of this aspect, see Appendix, page A-27.)

An as-purchased gas mantle lantern may be satisfactorily connected to a standard L-P storage tank, or a specific design as shown in Figure 1 may be used. An underwriter-approved hose connection also is available that permits connection of an ordinary lantern to a large supply source (e.g., 100 lb tank). The propane gas lantern may have two advantages, (1) where the cost of an electrical energy source must be considered specifically for lighting, and (2) if electrical energy is required for other reasons, the power source could be fueled by propane. Most small gasoline engines are readily convertible to propane.

## B. ELECTRICAL.

Many electrical illuminants were examined and discarded for not meeting one or more of the report parameters. Standard flashlights, for example, using "D" cells have a cell life of 400 to 600 minutes for intermittent use and less than half that in continuous use. Further, shelf life under average storage conditions is from one to two years (5).

### 1. Mercury Lamps.

Mercury-vapor, quartz-iodine, sodium-thallium (mercury) lamps were investigated as possible sources of shelter illumination. All three lamps have high efficacies but are not commonly available in units of lumen output which would best serve shelter needs, and are relatively expensive. These lamps, having a pressurized section, must be handled with great care (6). The electrical requirements are such as to not lend themselves to simple inexpensive light packages.

### 2. Electro-Luminescent Panels.

Electro-luminescent panels were also considered briefly but this source though relatively heat-free and maintenance-free produces only limited illumination with efficacies less than incandescent lamps (7). It is also quite expensive.

### 3. Incandescent Lamps.

The incandescent lamp is one of the two most desirable sources of illumination for group shelters. These lamps, of course, lack the hazards of combustion devices, have desirable chromatic qualities and require simple arrangements for installation. Average life of a lamp is greater by about a factor of two than the maximum anticipated (336 hours) length of shelter stay. The electrical energy requirement for the incandescent lamp is also compatible with nominal power sources. Incandescent lamps operate at slight discrepancies of rated voltage without serious effect, and type of current, A.C. or D.C., is not critical. Incandescent lamps are available in a wide range of sizes, all with common screw bases, making the amount and/or arrangement of illumination within a shelter quite flexible. The simplicity of wiring and the general familiarity with this source are additional advantages (8).

### 4. Fluorescent Lamps.

The fluorescent lamp is also a desirable source of illumination for shelters. It has in general the same advantages of incandescent lamps over the other electrical sources as to color of light, lamp life, and energy source requirements. The light source is less glaring than incandescent in that the light emitting surface covers much more area than the incandescent filament. The efficacy of fluorescent lamps is greater than incandescent lamps, over normal usage ranges, i.e., 40-100 watt incandescent and 15-40 watt fluorescent. Thus, the power requirement for the same level of illumination would be considerably less (9).

### 5. Emergency Auxiliary Light Unit.

A so-called auxiliary lighting unit is available that will supply light equivalent to a large flashlight. It is designed for six volt dry cell operation and thus is not suitable as a primary source of shelter lighting but could be useful for initial temporary lighting. See page A-3 in Appendix.

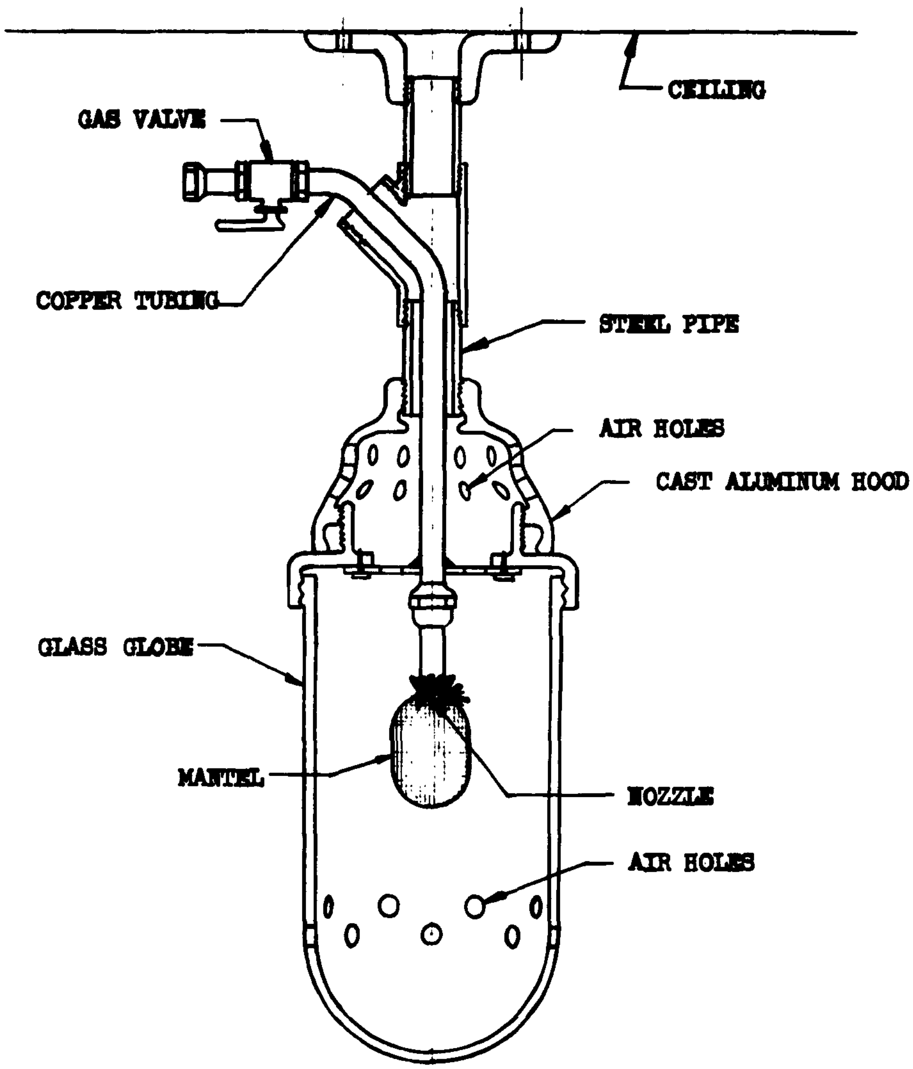



Figure No. 1. Example of a Propane Lamp Unit for Group Shelters

## C. NATURAL.

The possibility of using natural light to augment shelter illumination without the danger of fallout was considered, both as a means of reducing the overall power requirement, especially fuel, and of possible beneficial psychological effects on shelter inhabitants. Three possibilities were considered,* laminated glass blocks, fiber optics, and a light admitting device.

### 1. Laminated Glass Plate.

Plates of glass laminated together to form solid blocks eight inches square and up to three feet long are available for inclusion as part of the ceiling or external shelter wall. This solid mass of glass has good attenuation qualities (the same mass density as granite) (10) but transmission losses are approximately 30 per cent of admitted light in a three-foot length. Average daylight illumination on a clear day is about 1,000 lumens, excluding direct sunlight. Thus the eight by eight inch square would produce only 138 lumens from a three foot length. This approximates a 15 watt incandescent lamp, but this illumination would be essentially directed in a narrow beam.

### 2. Fiber Optic Cable.

* Fiber optic cable was considered from the standpoint that this light pipe is flexible and could be used around corners or through an existing window well without disturbing the attenuation capabilities of the shelter. The cable can be made to resolve images and the possibility of providing both light to the shelter and a means of outside observation had merit. Light losses are about three per cent per foot. However, such a cable is prohibitively expensive in that a four foot length with a five by five millimeter viewing surface costs over $1,000.00 at present day prices.

### 3. Light Admitting Device.

An inexpensive periscope-like device of relatively large viewing surface could serve as a light admitting device as well as providing a means of viewing the external situation but without disturbing shelter attenuation.

The use of such a device may be restricted to shelter configurations that would permit easy and simple installation and one which would permit exposure of the external opening to the sun for at least a greater part of the day. Shelters in areas with surrounding tall buildings or trees would not be suitable for installation of such a device as a sunlight admitting instrument, though a simplified version (less collecting mirror) may still be advisable for external viewing.

The device would consist of a periscope-like structure with a rather large reflecting area with, say, a one foot square viewing surface and two additional mirrors, also one foot square, external to the basic unit. One of these would be outside the shelter but adjustable 180 degrees horizontally and 90 degrees vertically from within the shelter. This would provide a means of collecting sunlight and directing it into the device. It would also provide a reasonable view up to 30 degrees from the shelter wall in addition to the direct view, assuming a typical basement shelter where building height would preclude the external opening from being in the roof. The second mirror would be fixed within the shelter at a distance from the viewing surface consistent with reasonable light distribution and to allow sufficient room for direct viewing by shelterees. This mirror would direct the collected sunlight to a diffusing surface on the ceiling of the shelter.

Assuming a minimum reflectance for the mirrors of 80 per cent and maximum absorption of the external window of 80 per cent, 33 per cent of available sunlight should be directed on the diffusing surface. (No glass would be used on the internal end of the device.) Such surfaces can have a reflectance of 90 per cent or more, thus the directed light onto shelter surfaces should be 30 per cent of the strength of available sunlight on the collecting mirror. Solar illumination in the United States varies on the average from 4000 to 8000 lumens winter to summer (11), so the device in question could provide, with a one square foot mirror area, 1200 to 2400 lumens in the shelter depending upon the season. With best grade mirrors (90 per cent reflectance) this level would be raised to a range of 2100 to 4200 lumens. Doubling the reflecting areas would of course double the available lumens.

If the external collecting mirror were exactly the same size as the viewing area of the device, (one foot-square) frequent adjustment of the collecting mirror would be necessary to maintain this mirror at its maximum capability. However, by doubling the width of this mirror, adjustment would be reduced to approximately once per hour if the collecting mirror were three feet from the periscope, based on 18 degrees per hour solar traverse.

The accompanying sketch, Figure 2, shows the general arrangement of the type of device described above. A more detailed description of a constructed prototype of this device may be found in Part II of this report.

## D. RADIOACTIVE-GAS LAMP.

A recent patent discusses a light source which involved the activation of phosphors by means of Krypton -85 gas which has high beta but low gamma emission. The design is such as to make the lamp radiation-safe and to last approximately 10 years without attention, but emission of light is so small (.02 of a lumen per square inch of emitting surface) as to make it unsuitable.

## E. DISCUSSION.

The propane gas lantern, the incandescent and fluorescent electric lamps are all acceptable sources of illumination for a group shelter and fall within the established parameters. The other sources investigated all had one or more qualities that made them unsuitable as sources of shelter illumination. The light admitting device being a special case will not be analyzed here.

The three acceptable sources will be analyzed in the following section to determine which of these are most suitable for the various shelter sizes.

## F. REFERENCES.


1. United States Testing Company, Inc. Report No. E-10432, October 5, 1954
2. Otto Bernz Company, Inc. letter M. E. Webster, August 21, 1962
3. Welsbach Mantle Data (1914) United Gas Institute Library Philadelphia, Pa.
4. Mechanical Engineers Handbook, L. S. Marks Fifth Edition, 1951, PP 340 – 343
5. Electrical Engineers Handbook, Pender & Del Mar Fourth Edition, 1953, Pg 7-04
6. IES Lighting Handbook, Third Edition, Illuminating Engineering Society, 1962, Pg 8-37
7. IES Lighting Handbook, Pg 1-22
8. IES Lighting Handbook, PP 8-1 to 8-17
9. IES Lighting Handbook, PP 8-46 to 8-64
10. Mechanical Engineers Handbook, L. S. Marks Fifth Edition, 1951, PP 522 – 523
11. IES Lighting Handbook, Pg 7-5
12. IES Lighting Handbook, PP 5-3 to 5-5

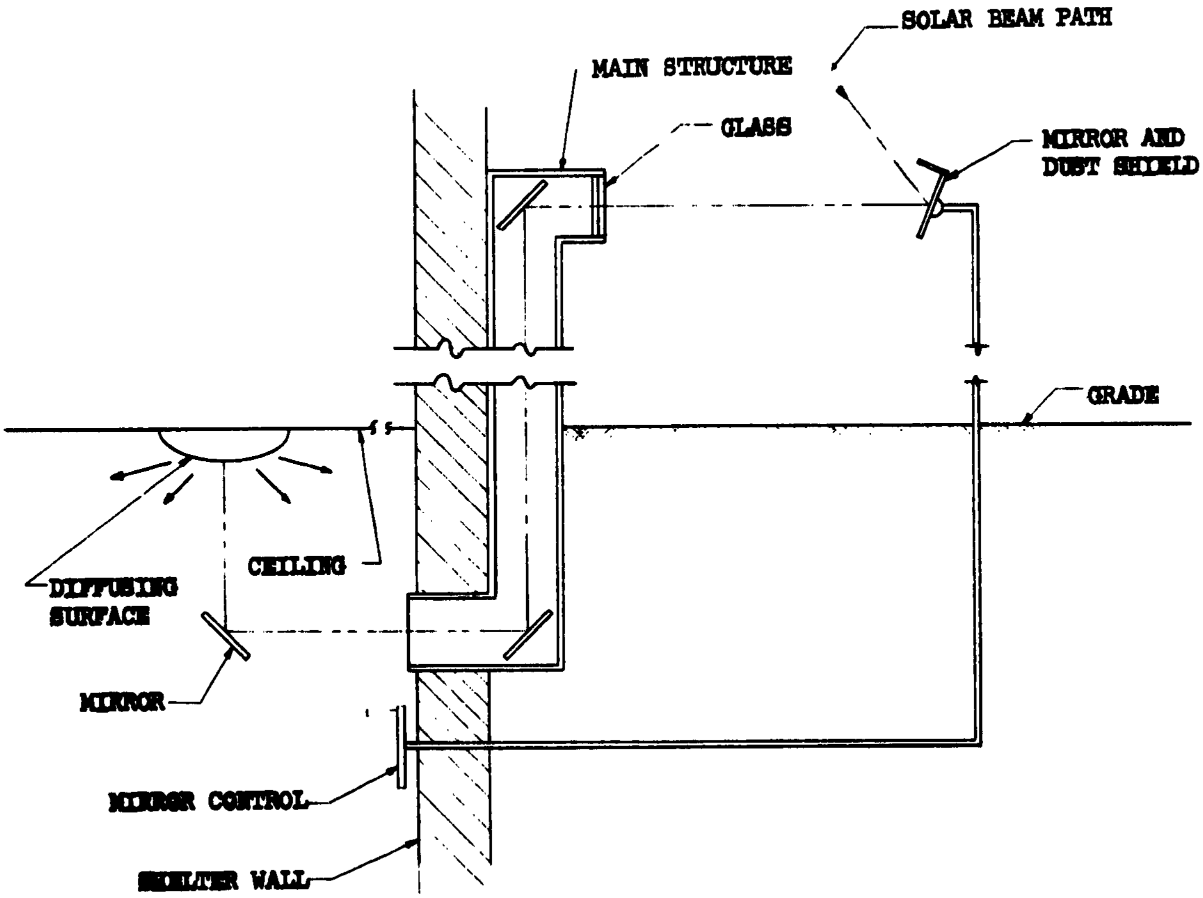



Figure No. 2. Light-Admitting Device

## CHAPTER 4

# STANDARDIZED PACKAGE DESIGN

## A. FACILITIES AND COST CRITERIA.

The determination of package design included the following criteria:

1. Illumination Level
2. Ready Availability of Material
3. Simplicity of Installation
4. Flexibility of Application
5. Unit Cost per Foot-Candle
6. Energy Source

Though the energy source is extraneous to the lighting package, under certain conditions shown in the analysis, this consideration can be the critical determinant of the cost-effectiveness of a system for the small shelter.

The first four criteria above have been discussed in earlier portions of this report and the systems discussed here will be ones which meet those requirements. The principal element for discussion will be the unit costs and where applicable, the energy source with respect to cost.

The levels of illumination analyzed for cost will be the two foot-candle level used in Preliminary Systems and Components Catalogue (April 1962) and the levels used in the acuity test, i.e., one, 3/4, 1/2, and 1/4.

Lamp sizes used in the analysis were chosen as best meeting criterion number two above, as well as providing a reasonable distribution of illumination. The No. 1073 lamp used in the acuity test was rejected mainly on the basis of the large number of lamps necessary to provide the proper level of illumination without any cost advantage.

### 1. Cost Bases.

The bases of the various costs are as follows:

a. PSCC costs were used whenever applicable.

b. Six hundred watts maximum per switch.

c. Cable allowed was 13 feet per fixture — incandescent or fluorescent, with a 20 foot minimum.

d. Connectors were allowed on the basis of 2½ per fixture.

e. Fluorescent tubes are T-12 Standard Cool White.

f. Fluorescent wattages include 10 watt ballast for 40 W and 5 watt ballast for 20 W and 15 W lamps for purpose of determining number of switches.

g. Fluorescent installation costs based on the Estimator's Electrical Man Hour Manual — Gulf Publishing Company, Houston, Texas (1959).

h. Propane lantern costs are estimated based on local retail prices.

i. Piping capacity (for propane gas distribution) and installed cost from Building Construction Cost Data, Robert Snow Means Company, Duxbury, Massachusetts (1962).

j. Piping allowance was 10 feet plus 10 feet per lantern.

k. Hardware allowance — Electrical 1.00

per fixture (with a 5.00 minimum) propane, 3.00 per lantern.

l. Electrical Energy Source Complete Costs – PSCC 1962.

m. Propane Energy Source Complete Costs for 100 gallons or less – R. C. Equipment Company, Philadelphia, Pennsylvania. (Above ground.)

n. Propane fuel tank installation costs for over 100 gallons based on PSCC costs for similar size gasoline tank, plus regulating equipment costs from R. C. Equipment Company, Philadelphia, Pennsylvania. (Under ground.)

o. Shelter area assumed rectangular of reasonable proportions.

p. Items costs for 50 space shelter rounded to nearest half dollar and to nearest dollar for 500 and 2000 space shelters.

2. **Illumination Bases.**

The calculations of the illumination levels for the three shelter sizes were based on the following:

a. Ten square feet per person.

b. Foot-candle values are total lumens divided by total square feet using PSCC Code 4010 as the criterion for the two foot-candle level. This is the *average* level in the shelter.

c. Electric lumen outputs are from IES Handbook, Third Edition, 1962.

d. Propane lantern lumens from U. S. Testing Laboratory Report for Otto Bernz Company, 1954. Values in this report which compared lantern lumens with 60 W and 100 W incandescent lamps, gave values for these lamps approximately 18 per cent higher than those in the IES Handbook for initial lumens. Consequently, the lumen output of the lantern was lowered by 18 per cent.

e. The number of fixtures designated for each level was based on the lumen requirements with no consideration given to "good lighting practice."

f. Energy source requirements for propane assumed continuous burning of lanterns for 14 days.

See Figure 21 in Appendix for calculations of number of lamps or lanterns required for the various illumination levels and shelter sizes.

## B. FIXED LIGHTING SYSTEMS – COST-EFFECTIVENESS.

1. **50 Space Shelter.**

a. Electrical.

With considerations for the lighting package only, the 100 watt incandescent system is the least cost, or equal, (to fluorescent or propane) at any level though only one lamp is required for the one foot-candle level. Package costs increase as the lumen output of the individual lamps, either fluorescent or incandescent, become smaller, but a more satisfactory lighting arrangement is had by increasing the number of lighting units to reduce sharp shadows and provide better average illumination. At 3/4 foot-candle level, for example, four 40 W incandescent lamps are required as against two 60 W incandescent or one 15 W fluorescent. However, the four 40 W lamp system costs $65.00; the two 60 W, $43.00; and the one 15 W fluorescent, $49.00.

b. Propane.

The cost of the propane system is quite high at all levels, being $120.00 at the 3/4 foot-candle level. However, if an electrical energy source is required for shelter lighting, the cost of a minimum capacity fixed unit from PSCC when added to the lighting system cost makes the electric light about four times as expensive as propane for the 3/4 foot-candle level. Considering a portable generator only, the cost of a propane system is approximately equivalent to electric at the two and one foot-candle levels. At 3/4 foot-candle and below propane is cheaper. See Figure 6, page 21.

Propane lanterns at 2000 Btu per hour

versus 3.40 Btu per watt per hour for electrical systems, give off much more heat which increases minimal ventilation requirements. See page A-27 in Appendix.

c. Curves.

Figure 3, page 18, illustrates the costs of lighting package only for incandescent, fluorescent and propane for all light levels considered in this report. Curves that stop above the 1/4 foot-candle level indicate that this is the minimum level with one fixture. Curves that bypass a level indicate that there is no whole number of fixtures approximating that foot-candle level.

**2. 500 Space Shelter.**

a. Propane.

Propane was investigated as a possibility for this size shelter. However, total system cost becomes economical only at the 1/4 foot-candle level and only when the cost of an energy source is considered for the electrical systems. Since it is understood that there will be electrical requirements in shelters of this size for reasons other than lighting, the electrical energy source was assumed fixed rather than portable. On this basis and assuming the entire cost of the electrical system chargeable to electric lighting, propane becomes marginal at 1/2 foot-candle level and appears economical at 1/4 foot-candle level. However, it does not seem appropriate to charge the entire cost of the electrical energy source to lighting and, thus, a propane light source for this size shelter appears uneconomical and will not be considered. See Figure 7.

b. Electrical.

The same relative cost proportions hold true for this shelter size for electrical systems as for the 50 space shelter, except that the 40 W fluorescent system is now least expensive, rather than the 100 watt incandescent. See Figure 4.

This is due to the larger incremental cost for fluorescent fixtures so that in a very small system with the number of other components being nearly equal, fluorescent lighting is at a disadvantage.

**3. 2000 Space Shelter.**

Costs for the 2000 space shelter are in the same proportions as for the 500 space shelter. All costs are approximately four times those of the smaller size. A brief analysis of propane light for this size shelter indicates an even greater disparity of cost than for the 500 space shelter. See Figure 5 and 8.

## C. PORTABLE LIGHTING SYSTEM.

Portable lighting systems, though less desirable than a fixed system which is essentially "ready to go", may be a source of lighting for shelter areas which for various reasons the installation of a lighting system was not feasible prior to occupancy. These systems are easily packaged, will store indefinitely, take up a small space, and are simple to install.

**1. 50 Space Shelter.**

The portable lighting system presented for the 50 space shelter is essentially the same as that presented in Code 6200 of PSCC with two exceptions. Rather than using a guarded lamp with switch, a simple pin socket with an unguarded lamp is used. This is in keeping with the bare lamps used in fixed systems. A second change is in using Number 16 two-wire cord rather than Number 14 3-wire. The system as presented is based on two foot-candle level for the 50 space shelter, but may be used with any of the sizes of incandescent lamps used in the analysis.

The system is simple enough to be installed with a few instructions given to unskilled persons under emergency conditions. A further advantage is that the only tool necessary would be a pocket knife. See Figure 9.

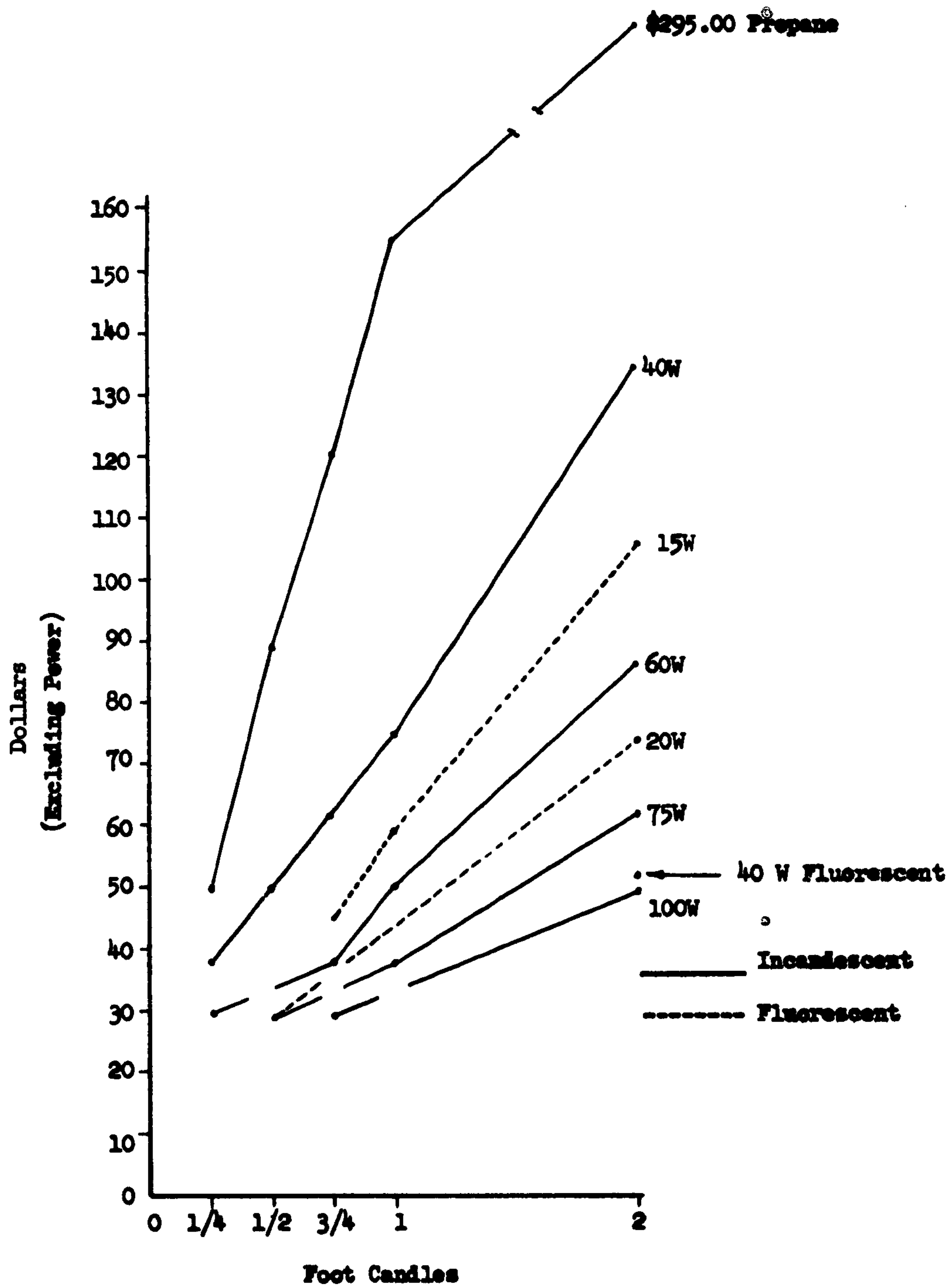



Figure No. 3. 50 Space Shelter

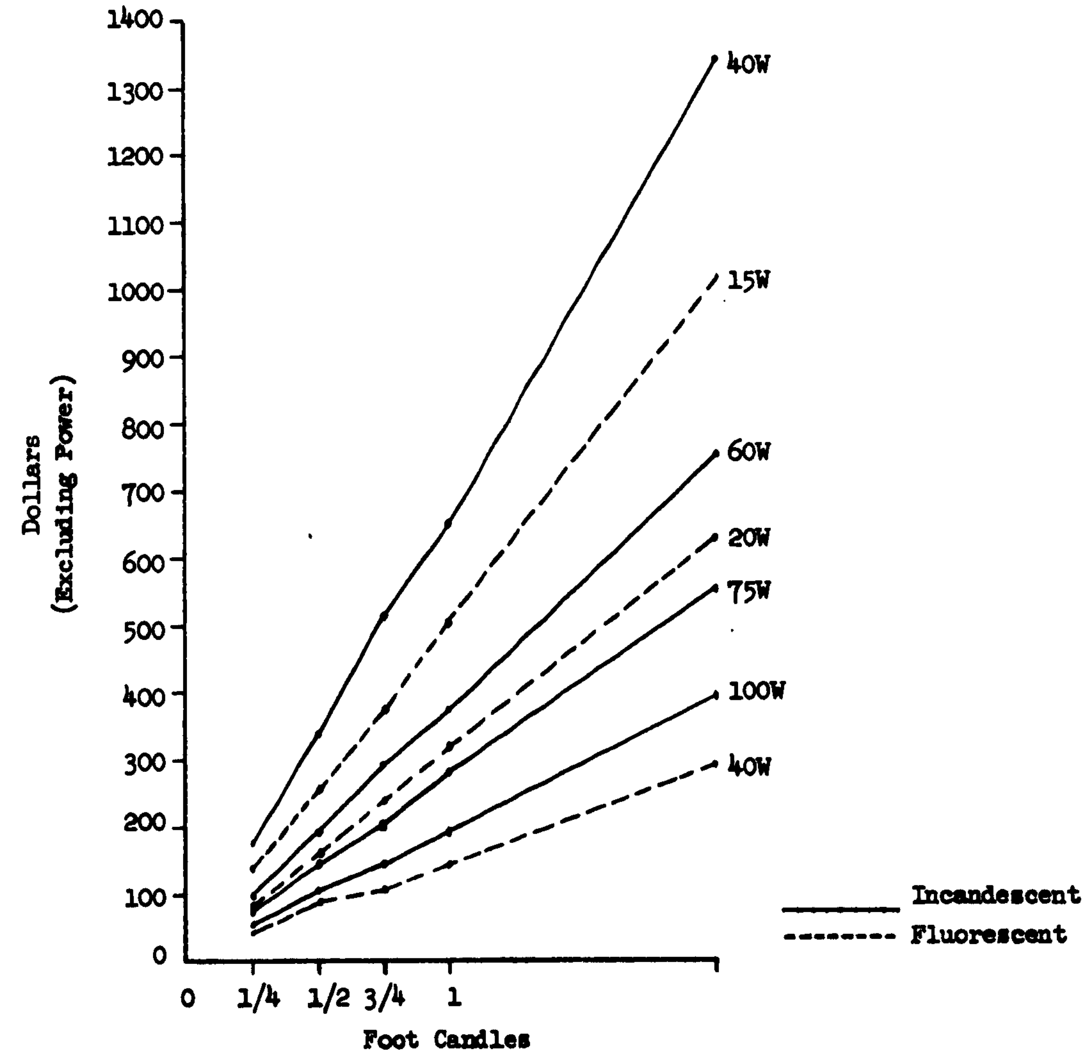



Figure No. 4. 500 Space Shelter

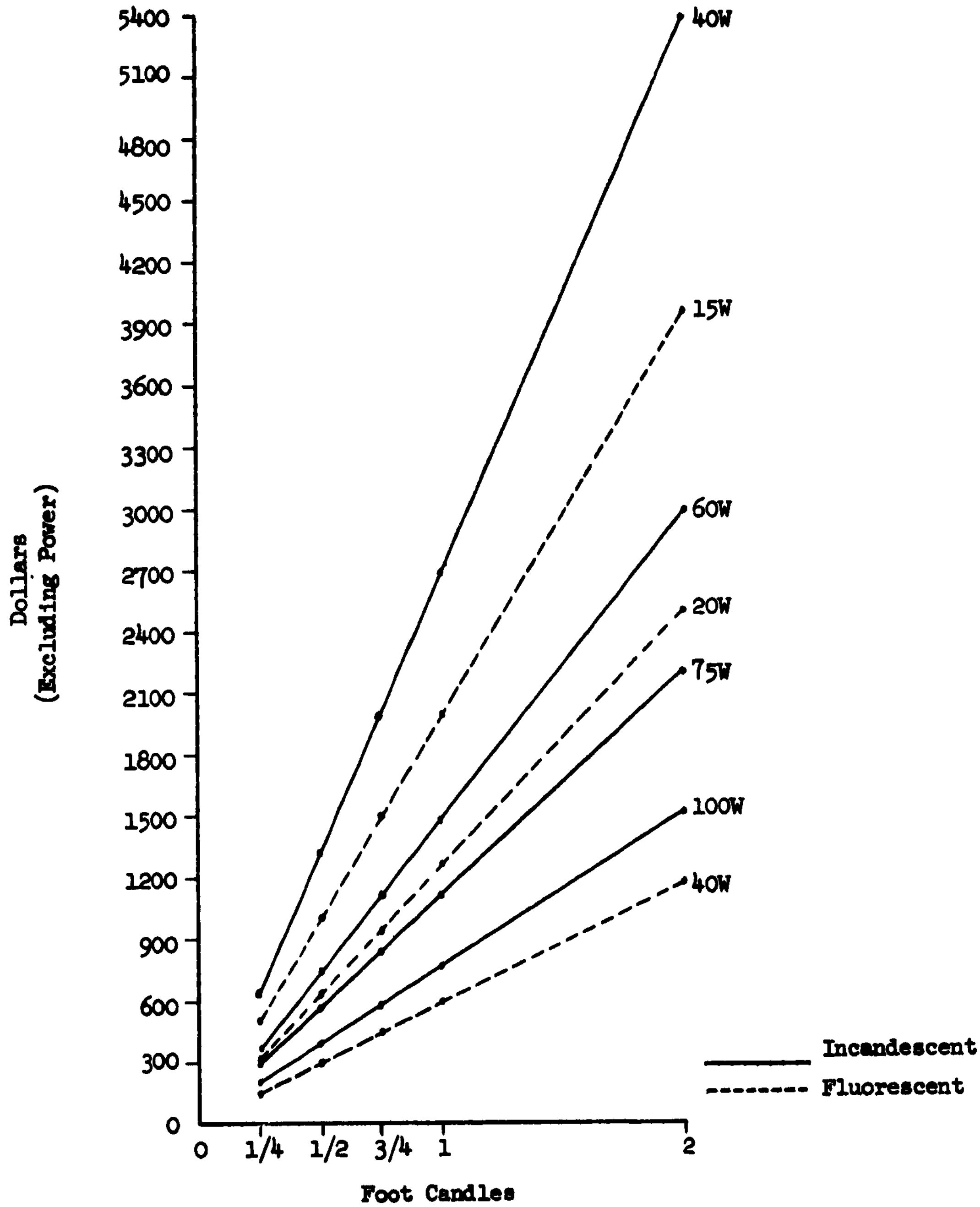



Figure No. 5. 2000 Space Shelter

| | Description | Unit | Unit Cost | 100W | TWO FOOT CANDLES Incandescent 75W | 60W | 40W | Flucrescent 40W | 20W | 15W | Pro-pane | TWO FOOT CA[illegible] Incandescent [illegible]5W | 60W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Box 4" Octagon Ceiling | Ea | $ 3.00 | $ 9.00 | $ 12.00 | $ 18.00 | $ 30.00 | $ | $ | $ | $ | [illegible]2.00 | $ 18.00 |
| 2. | Box 4" Square Wall | Ea | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | | 3.00 | 3.00 |
| 3. | Cover 4" Square Switch & Rec. | Ea | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | | 1.00 | 1.00 |
| 4. | Incandescent Lamp Medium Screw | Ea | .50 | 1.50 | 2.00 | 3.00 | 5.00 | | | | | 2.00 | 3.00 |
| 5. | Flucrescent (T-12) | Ea | 2.00 | | | | | 4.00 | 8.00 | 12.00 | | | |
| 6. | Propane Lantern | Ea | 16.00 | | | | | | | | 128.[illegible] | | |
| 7. | Receptacle Dup. Grounding | Ea | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | | 2.50 | 2.50 |
| 8. | Receptacle - Ceiling | Ea | 2.50 | 7.50 | 10.00 | 15.00 | 25.00 | | | | | [illegible]0.00 | 15.00 |
| 9. | Fixture - Flucrescent | Ea | * | | | | | 22.00 | 28.00 | 42.00 | | | |
| 10. | Switch | Ea | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | | 2.50 | 2.50 |
| 11. | Cable 13'/light | LF | .35 | 13.50 | 18.00 | 27.50 | 45.50 | 9.00 | 18.00 | 27.50 | | [illegible]8.00 | 27.50 |
| 12. | Connectors, Cable (2-1/2) | Ea | .50 | 4.00 | 5.00 | 7.50 | 12.50 | 3.00 | 5.00 | 7.50 | | 5.00 | 7.50 |
| 13. | Pipe 10' + 10'/light | LF | 1.50 | | | | | | | | 135.[illegible] | | |
| 14. | Connectors, Pipe | Ea | 1.00 | | | | | | | | 8.[illegible] | | |
| 15. | Hardware | LS | | 6.00 | 6.00 | 7.00 | 8.00 | 5.00 | 6.00 | 8.00 | 24.[illegible] | 6.00 | 7.00 |
| 16. | SUB-TOTAL | | | 50.00 | 62.00 | 87.00 | 135.00 | 52.00 | 74.00 | 106.00 | 295.[illegible] | [illegible]2.00 | 87.00 |
| 17. | Energy Source Complete (Less Fuel) | | | 741.00 | 741.00 | 741.00 | 741.00 | 741.00 | 741.00 | 741.00 | 175.[illegible] | [illegible]1.00 | 741.00 |
| 18. | TOTAL COST | | | $791.00 | $803.00 | $828.00 | $876.00 | $793.00 | $815.00 | $847.00 | $470.[illegible] | [illegible]3.00 | $828.00 |

| | Description | Unit | Unit Cost | 100W | 1/2 FOOT CANDLE Incandescent 75W | 60W | 40W | Flucrescent 40W | 20W | 15W | Pro-pane | 1/2 FOOT CA[illegible] Incandescent [illegible]5W | 60W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Box 4" Octagon Ceiling | Ea | $ 3.00 | | $ 3.00 | $ 6.00 | $ 9.00 | | $ | | $ | 3.00 | $ 6.00 |
| 2. | Box 4" Square Wall | Ea | 3.00 | | 3.00 | 3.00 | 3.00 | | 3.00 | | | 3.00 | 3.00 |
| 3. | Cover 4" Square Switch & Rec. | Ea | 1.00 | | 1.00 | 1.00 | 1.00 | | 1.00 | | | 1.00 | 1.00 |
| 4. | Incandescent Lamp Medium Screw | Ea | .50 | | .50 | 1.00 | 1.50 | | | | | .50 | 1.00 |
| 5. | Flucrescent (T-12) | Ea | 2.00 | | | | | | 2.00 | | | | |
| 6. | Propane Lantern | Ea | 16.00 | | | | | | | | 32.[illegible] | | |
| 7. | Receptacle Dup. Grounding | Ea | 2.50 | | 2.50 | 2.50 | 2.50 | | | | | 2.50 | 2.50 |
| 8. | Receptacle - Ceiling | Ea | 2.50 | | 2.50 | 5.00 | 7.50 | | | | | 2.50 | 5.00 |
| 9. | Fixture - Flucrescent | Ea | * | | | | | | 7.00 | | | | |
| 10. | Switch | Ea | 2.50 | | 2.50 | 2.50 | 2.50 | | 2.50 | | | 2.50 | 2.50 |
| 11. | Cable 13'/light | LF | .35 | | 7.00 | 9.00 | 13.50 | | 7.00 | | | 7.00 | 9.00 |
| 12. | Connectors, Cable(2-1/2) | Ea | .50 | | 2.50 | 3.00 | 4.00 | | 2.00 | | | 2.50 | 3.00 |
| 13. | Pipe 10' + 10'/light | LF | 1.50 | | | | | | | | 45.[illegible] | | |
| 14. | Connectors, Pipe | Ea | 1.00 | | | | | | | | 2.[illegible] | | |
| 15. | Hardware | LS | | | 5.00 | 5.00 | 6.00 | | 5.00 | | 9.[illegible] | 5.00 | 5.00 |
| 16. | SUB-TOTAL | | | | 29.50 | 38.00 | 50.50 | | 29.50 | | 88.[illegible] | [illegible]9.50 | 38.00 |
| 17. | Energy Source Complete (Less Fuel) | | | | 741.00 | 741.00 | 741.00 | | 741.00 | | 79.[illegible] | [illegible]1.00 | 741.00 |
| 18. | TOTAL COST | | | | $770.50 | $779.00 | $791.50 | | $770.50 | | $167.[illegible] | [illegible]0.50 | $779.00 |

FIGURE NO. 6

50 SPACE SHELTER

COST COMPARISON

**TWO FOOT CANDLES**

| candescent W | 60W | 40W | Fluorescent 40W | 20W | 15W | Propane |
|---|---|---|---|---|---|---|
| .00 | $ 18.00 | $ 30.00 | $ | $ | $ | $ |
| .00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | |
| .00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | |
| .00 | 3.00 | 5.00 | | | | |
| | | | 4.00 | 8.00 | 12.00 | |
| | | | | | | 128.00 |
| .50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | |
| .00 | 15.00 | 25.00 | | | | |
| | | | 22.00 | 28.00 | 42.00 | |
| .50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | |
| .00 | 27.50 | 45.50 | 9.00 | 18.00 | 27.50 | |
| .00 | 7.50 | 12.50 | 3.00 | 5.00 | 7.50 | |
| | | | | | | 135.00 |
| | | | | | | 8.00 |
| .00 | 7.00 | 8.00 | 5.00 | 6.00 | 8.00 | 24.00 |
| .00 | 87.00 | 135.00 | 52.00 | 74.00 | 106.00 | 295.00 |
| .00 | 741.00 | 741.00 | 741.00 | 741.00 | 741.00 | 175.00 |
| .00 | $828.00 | $876.00 | $793.00 | $815.00 | $847.00 | $470.00 |

**ONE FOOT CANDLE**

| Incandescent 100W | 75W | 60W | 40W | Fluorescent 40W | 20W | 15W | Propane |
|---|---|---|---|---|---|---|---|
| $ | $ 6.00 | $ 9.00 | $ 15.00 | $ | $ | $ | $ |
| | 3.00 | 3.00 | 3.00 | | 3.00 | 3.00 | |
| | 1.00 | 1.00 | 1.00 | | 1.00 | 1.00 | |
| | 1.00 | 1.50 | 2.50 | | | | |
| | | | | | 4.00 | 6.00 | |
| | | | | | | | 64.00 |
| | 2.50 | 2.50 | 2.50 | | 2.50 | 2.50 | |
| | 5.00 | 7.50 | 12.50 | | | | |
| | | | | | 14.00 | 21.00 | |
| | 2.50 | 2.50 | 2.50 | | 2.50 | 2.50 | |
| | 9.00 | 13.50 | 23.00 | | 9.00 | 13.50 | |
| | 3.00 | 4.00 | 6.00 | | 3.00 | 4.00 | |
| | | | | | | | 75.00 |
| | | | | | | | 4.00 |
| | 5.00 | 6.00 | 7.00 | | 5.00 | 6.00 | 12.00 |
| | 38.00 | 50.50 | 75.00 | | 44.00 | 59.50 | 155.00 |
| | 741.00 | 741.00 | 741.00 | | 741.00 | 741.00 | 127.00 |
| | $779.00 | $791.50 | $816.00 | | $785.00 | $800.50 | $382.00 |

**3/**

| Incandesc 100W | 75W | 6 |
|---|---|---|
| $ 3.00 | $ | $ |
| 3.00 | | |
| 1.00 | | |
| .50 | | |
| | | |
| | | |
| 2.50 | | |
| 2.50 | | |
| | | |
| 2.50 | | |
| 7.00 | | |
| 2.50 | | |
| | | |
| | | |
| 5.00 | | |
| 29.50 | | 3 |
| 741.00 | | 74 |
| $770.50 | | $77 |

**1/2 FOOT CANDLE**

| candescent W | 60W | 40W | Fluorescent 40W | 20W | 15W | Propane |
|---|---|---|---|---|---|---|
| .00 | $ 6.00 | $ 9.00 | | $ | | $ |
| .00 | 3.00 | 3.00 | | 3.00 | | |
| .00 | 1.00 | 1.00 | | 1.00 | | |
| .50 | 1.00 | 1.50 | | | | |
| | | | | 2.00 | | |
| | | | | | | 32.00 |
| .50 | 2.50 | 2.50 | | | | |
| .50 | 5.00 | 7.50 | | | | |
| | | | | 7.00 | | |
| .50 | 2.50 | 2.50 | | 2.50 | | |
| .00 | 9.00 | 13.50 | | 7.00 | | |
| .50 | 3.00 | 4.00 | | 2.00 | | |
| | | | | | | 45.00 |
| | | | | | | 2.00 |
| .00 | 5.00 | 6.00 | | 5.00 | | 9.00 |
| .50 | 38.00 | 50.50 | | 29.50 | | 88.00 |
| .00 | 741.00 | 741.00 | | 741.00 | | 79.00 |
| .50 | $779.00 | $791.50 | | $770.50 | | $167.00 |

**1/4 FOOT CANDLE**

| Incandescent 100W | 75W | 60W | 40W | Fluorescent 40W | 20W | 15W | Propane |
|---|---|---|---|---|---|---|---|
| | | $ 3.00 | $ 6.00 | | | | $ |
| | | 3.00 | 3.00 | | | | |
| | | 1.00 | 1.00 | | | | |
| | | .50 | 1.00 | | | | |
| | | | | | | | 16.00 |
| | | 2.50 | 2.50 | | | | |
| | | 2.50 | 5.00 | | | | |
| | | 2.50 | 2:50 | | | | |
| | | 7.00 | 9.00 | | | | |
| | | 2.50 | 3.00 | | | | |
| | | | | | | | 30.00 |
| | | | | | | | 1.00 |
| | | 5.00 | 5.00 | | | | 3.00 |
| | | 29.50 | 38.00 | | | | 50.00 |
| | | 741.00 | 741.00 | | | | 79.00 |
| | | $770.50 | $779.00 | | | | $129.00 |

* NOTE - Fluoresce

•

Electric energ
generator for t
excess capacity
0/1500 W size p
manufacturers m

Figure

2

PACE SHELTER

COMPARISON

### ONE FOOT CANDLE

| Incandescent 100W | 75W | 60W | 40W | Fluorescent 40W | 20W | 15W | Propane |
|---|---|---|---|---|---|---|---|
| $ | $ 6.00 | $ 9.00 | $ 15.00 | $ | $ | $ | $ |
| | 3.00 | 3.00 | 3.00 | | 3.00 | 3.00 | |
| | 1.00 | 1.00 | 1.00 | | 1.00 | 1.00 | |
| | 1.00 | 1.50 | 2.50 | | | | |
| | | | | | 4.00 | 6.00 | |
| | | | | | | | 64.00 |
| | 2.50 | 2.50 | 2.50 | | 2.50 | 2.50 | |
| | 5.00 | 7.50 | 12.50 | | | | |
| | | | | | 14.00 | 21.00 | |
| | 2.50 | 2.50 | 2.50 | | 2.50 | 2.50 | |
| | 9.00 | 13.50 | 23.00 | | 9.00 | 13.50 | |
| | 3.00 | 4.00 | 6.00 | | 3.00 | 4.00 | |
| | | | | | | | 75.00 |
| | | | | | | | 4.00 |
| | 5.00 | 6.00 | 7.00 | | 5.00 | 6.00 | 12.00 |
| | 38.00 | 50.50 | 75.00 | | 44.00 | 59.50 | 155.00 |
| | 741.00 | 741.00 | 741.00 | | 741.00 | 741.00 | 127.00 |
| | $779.00 | $791.50 | $816.00 | | $785.00 | $800.50 | $382.00 |

### 3/4 FOOT CANDLE

| Incandescent 100W | 75W | 60W | 40W | Fluorescent 40W | 20W | 15W | Propane |
|---|---|---|---|---|---|---|---|
| $ 3.00 | $ | $ 6.00 | $ 12.00 | $ | $ | $ | $ |
| 3.00 | | 3.00 | 3.00 | | | 3.00 | |
| 1.00 | | 1.00 | 1.00 | | | 1.00 | |
| .50 | | 1.00 | 2.00 | | | | |
| | | | | | | 4.00 | |
| | | | | | | | 48.00 |
| 2.50 | | 2.50 | 2.50 | | | 2.50 | |
| 2.50 | | 5.00 | 10.00 | | | | |
| | | | | | | 14.00 | |
| 2.50 | | 2.50 | 2.50 | | | 2.50 | |
| 7.00 | | 9.00 | 18.00 | | | 9.00 | |
| 2.50 | | 3.00 | 5.00 | | | 3.00 | |
| | | | | | | | 60.00 |
| | | | | | | | 3.00 |
| 5.00 | | 5.00 | 6.00 | | | 5.00 | 9.00 |
| 29.50 | | 38.00 | 62.00 | | | 45.00 | 120.00 |
| 741.00 | | 741.00 | 741.00 | | | 741.00 | 79.00 |
| $770.50 | | $779.00 | $803.00 | | | $786.00 | $199.00 |

### 1/4 FOOT CANDLE

| Incandescent 100W | 75W | 60W | 40W | Fluorescent 40W | 20W | 15W | Propane |
|---|---|---|---|---|---|---|---|
| | | $ 3.00 | $ 6.00 | | | | $ |
| | | 3.00 | 3.00 | | | | |
| | | 1.00 | 1.00 | | | | |
| | | .50 | 1.00 | | | | |
| | | | | | | | 16.00 |
| | | 2.50 | 2.50 | | | | |
| | | 2.50 | 5.00 | | | | |
| | | 2.50 | 2.50 | | | | |
| | | 7.00 | 9.00 | | | | |
| | | 2.50 | 3.00 | | | | |
| | | | | | | | 30.00 |
| | | | | | | | 1.00 |
| | | 5.00 | 5.00 | | | | 3.00 |
| | | 29.50 | 38.00 | | | | 50.00 |
| | | 741.00 | 741.00 | | | | 79.00 |
| | | $770.50 | $779.00 | | | | $129.00 |

* NOTE - Fluorescent fixture (installed) - 40 watt, $11.00
- 20-15 watt, $7.00

Electric energy source complete substitutes the Code 6301 generator for the generator in Code 5100. This is greater excess capacity (1500 W vs 1000 W) but greater demand 0/1500 W size provides cheaper unit selling price by manufacturers making both sizes.

Figure 6. Cost Comparison - 50 Space Shelter

| | Description | Unit | Unit Cost | TWO FOOT CANDLES | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Incandescent | | | | Fluorescent | | | Pr pe |
| | | | | 100W | 75W | 60W | 40W | 40W | 20W | 15W | |
| 1. | Box 4" Octagon Ceiling | Ea | $300 | $ 81 | $ 120 | $ 165 | $ 300 | $ | $ | $ | |
| 2. | Box 4" Square Wall | Ea | 300 | 15 | 15 | 18 | 21 | 6 | 6 | 9 | |
| 3. | Cover 4" Square Switch & Rec. | Ea | 100 | 5 | 5 | 6 | 7 | 2 | 2 | 3 | |
| 4. | Incandescent Lamp Medium Screw | Ea | .50 | 14 | 20 | 28 | 50 | | | | |
| 5. | Fluorescent Lamp (T-12) | Ea | 200 | | | | | 28 | 78 | 126 | |
| 6. | Propane Lantern | Ea | 1600 | | | | | | | | |
| 7. | Receptacle Dup. Grounding | Ea | 250 | 13 | 13 | 15 | 18 | 5 | 5 | 8 | |
| 8. | Receptacle - Ceiling | Ea | 250 | 68 | 100 | 138 | 250 | | | | |
| 9. | Fixture - Fluorescent | Ea | * | | | | | 154 | 273 | 441 | |
| 10. | Switch | Ea | 250 | 13 | 13 | 15 | 18 | 5 | 5 | 8 | |
| 11. | Cable (13'/light) | LF | .35 | 123 | 182 | 250 | 455 | 64 | 177 | 287 | |
| 12. | Connectors, Cable (2-1/2) | Ea | .50 | 35 | 50 | 69 | 125 | 18 | 50 | 79 | |
| 13. | Pipe 10' + 10'/light | LF | 150 | | | | | | | | |
| 14. | Connectors, Pipe | Ea | 100 | | | | | | | | |
| 15. | Hardware | LS | | 27 | 40 | 55 | 100 | 14 | 39 | 63 | |
| 16. | SUB-TOTAL | | | 394 | 558 | 759 | 1344 | 296 | 635 | 1024 | |
| 17. | Energy Source Complete (Less Fuel) | | | 1197 | 1197 | 1197 | 1535 | 841 | 841 | 1032 | |
| 18. | TOTAL COST | | | $1591 | $1755 | $1956 | $2879 | $1137 | $1476 | $2056 | |

| | Description | Unit | Unit Cost | 1/2 FOOT CANDLE | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Incandescent | | | | Fluorescent | | | Pr pe |
| | | | | 100W | 75W | 60W | 40W | 40W | 20W | 15W | |
| 1. | Box 4" Octagon Ceiling | Ea | $300 | $ 21 | $ 30 | $ 42 | $ 75 | $ | $ | $ | |
| 2. | Box 4" Square Wall | Ea | 300 | 6 | 6 | 6 | 6 | 3 | 3 | 3 | |
| 3. | Cover 4" Square Switch & Rec. | Ea | 100 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | |
| 4. | Incandescent Lamp Medium Screw | Ea | .50 | 4 | 5 | 7 | 13 | | | | |
| 5. | Fluorescent Lamp (T-12) | Ea | 200 | | | | | 8 | 20 | 32 | |
| 6. | Propane Lantern | Ea | 1600 | | | | | | | | |
| 7. | Receptacle Dup. Grounding | Ea | 250 | 5 | 5 | 5 | 5 | 3 | 3 | 3 | |
| 8. | Receptacle - Ceiling | Ea | 250 | 18 | 25 | 35 | 63 | | | | |
| 9. | Fixture - Fluorescent | Ea | * | | | | | 44 | 70 | 112 | |
| 10. | Switch | Ea | 250 | 5 | 5 | 5 | 5 | 3 | 3 | 3 | |
| 11. | Cable (13'/light) | LF | .35 | 32 | 46 | 64 | 114 | 18 | 46 | 73 | |
| 12. | Connectors, Cable (2-1/2) | Ea | .50 | 9 | 13 | 18 | 31 | 5 | 13 | 20 | |
| 13. | Pipe 10' + 10'/light | LF | 150 | | | | | | | | |
| 14. | Connectors, Pipe | Ea | 100 | | | | | | | | |
| 15. | Hardware | LS | | 7 | 10 | 14 | 25 | 5 | 10 | 16 | |
| 16. | SUB-TOTAL | | | 109 | 147 | 198 | 339 | 90 | 169 | 263 | |
| 17. | Energy Source Complete (Less Fuel) | | | 841 | 841 | 841 | 841 | 841 | 841 | 841 | |
| 18. | TOTAL COST | | | $950 | $988 | $1039 | $1180 | $931 | $1011 | $1104 | |

FIGURE NO. 7

## 500 SPACE SHELTER

## COST COMPARISON

### TWO FOOT CANDLES

| Incandescent 75W | 60W | 40W | Fluorescent 40W | 20W | 15W | Pro-pane |
|---|---|---|---|---|---|---|
| $ 120 | $ 165 | $ 300 | $ | $ | $ | |
| 15 | 18 | 21 | 6 | 6 | 9 | |
| 5 | 6 | 7 | 2 | 2 | 3 | |
| 20 | 28 | 50 | | | | |
| | | | 28 | 78 | 126 | |
| 13 | 15 | 18 | 5 | 5 | 8 | |
| 100 | 138 | 250 | | | | |
| | | | 154 | 273 | 441 | |
| 13 | 15 | 18 | 5 | 5 | 8 | |
| 182 | 250 | 455 | 64 | 177 | 287 | |
| 50 | 69 | 125 | 18 | 50 | 79 | |
| 40 | 55 | 100 | 14 | 39 | 63 | |
| 558 | 759 | 1344 | 296 | 635 | 1024 | |
| 1197 | 1197 | 1535 | 841 | 841 | 1032 | |
| $1755 | $1956 | $2879 | $1137 | $1476 | $2056 | |

### ONE FOOT CANDLE

| Incandescent 100W | 75W | 60W | 40W | Fluorescent 40W | 20W | 15W | Pro-pane |
|---|---|---|---|---|---|---|---|
| $ 39 | $ 60 | $ 81 | $ 150 | $ | $ | $ | |
| 9 | 9 | 9 | 12 | 3 | 3 | 6 | |
| 3 | 3 | 3 | 4 | 1 | 1 | 2 | |
| 7 | 10 | 14 | 25 | | | | |
| | | | | 14 | 40 | 62 | |
| 8 | 8 | 8 | 10 | 3 | 3 | 5 | |
| 33 | 50 | 68 | 125 | | | | |
| | | | | 77 | 140 | 217 | |
| 8 | 8 | 8 | 10 | 3 | 3 | 5 | |
| 59 | 91 | 123 | 228 | 32 | 91 | 141 | |
| 16 | 25 | 35 | 38 | 9 | 25 | 39 | |
| 13 | 20 | 27 | 50 | 7 | 20 | 31 | |
| 195 | 284 | 376 | 652 | 149 | 326 | 508 | |
| 1032 | 1032 | 1032 | 1032 | 841 | 841 | 841 | |
| $1227 | $1316 | $1408 | $1684 | $990 | $1167 | $1349 | |

| Incand 100W | 75W |
|---|---|
| $ 30 | $ 45 |
| 6 | 6 |
| 2 | 2 |
| 5 | 5 |
| 5 | 5 |
| 25 | 38 |
| 5 | 5 |
| 46 | 68 |
| 13 | 19 |
| 10 | 15 |
| 147 | 208 |
| 841 | 1032 |
| $988 | $1240 |

### 1/2 FOOT CANDLE

| Incandescent 75W | 60W | 40W | Fluorescent 40W | 20W | 15W | Pro-pane |
|---|---|---|---|---|---|---|
| $ 30 | $ 42 | $ 75 | $ | $ | $ | |
| 6 | 6 | 6 | 3 | 3 | 3 | |
| 2 | 2 | 2 | 1 | 1 | 1 | |
| 5 | 7 | 13 | | | | |
| | | | 8 | 20 | 32 | |
| 5 | 5 | 5 | 3 | 3 | 3 | |
| 25 | 35 | 63 | | | | |
| | | | 44 | 70 | 112 | |
| 5 | 5 | 5 | 3 | 3 | 3 | |
| 46 | 64 | 114 | 18 | 46 | 73 | |
| 13 | 18 | 31 | 5 | 13 | 20 | |
| 10 | 14 | 25 | 5 | 10 | 16 | |
| 147 | 198 | 339 | 90 | 169 | 263 | |
| 841 | 841 | 841 | 841 | 841 | 841 | |
| $988 | $1039 | $1180 | $931 | $1011 | $1104 | |

### 1/4 FOOT CANDLE

| Incandescent 100W | 75W | 60W | 40W | Fluorescent 40W | 20W | 15W | Pro-pane |
|---|---|---|---|---|---|---|---|
| $ 9 | $ 15 | $ 21 | $ 39 | $ | $ | $ | |
| 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 2 | 3 | 3 | 3 | | | | |
| | | | | 4 | 10 | 16 | |
| 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 8 | 13 | 18 | 33 | | | | |
| | | | | 22 | 35 | 56 | |
| 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 14 | 23 | 32 | 59 | 9 | 23 | 36 | |
| 4 | 6 | 9 | 16 | 3 | 6 | 12 | |
| 5 | 5 | 7 | 13 | 5 | 5 | 8 | |
| 52 | 75 | 100 | 173 | 53 | 89 | 138 | |
| 841 | 841 | 841 | 841 | 841 | 841 | 841 | |
| $893 | $916 | $941 | $1014 | $894 | $930 | $979 | |

* NOTE - Fluore

Figure

2

CE SHELTER

OMPARISON

| | ONE FOOT CANDLE | | | | | | |
|---|---|---|---|---|---|---|---|
| | Incandescent | | | Fluorescent | | | Pro- |
| 0W | 75W | 60W | 40W | 40W | 20W | 15W | pane |
| 39 | $ 60 | $ 81 | $ 150 | $ | $ | $ | |
| 9 | 9 | 9 | 12 | 3 | 3 | 6 | |
| 3 | 3 | 3 | 4 | 1 | 1 | 2 | |
| 7 | 10 | 14 | 25 | | | | |
| | | | | 14 | 40 | 62 | |
| 8 | 8 | 8 | 10 | 3 | 3 | 5 | |
| 33 | 50 | 68 | 125 | | | | |
| | | | | 77 | 140 | 217 | |
| 8 | 8 | 8 | 10 | 3 | 3 | 5 | |
| 59 | 91 | 123 | 228 | 32 | 91 | 141 | |
| 16 | 25 | 35 | 38 | 9 | 25 | 39 | |
| 13 | 20 | 27 | 50 | 7 | 20 | 31 | |
| 195 | 284 | 376 | 652 | 149 | 326 | 508 | |
| 032 | 1032 | 1032 | 1032 | 841 | 841 | 841 | |
| 27 | $1316 | $1408 | $1684 | $990 | $1167 | $1349 | |

| 3/4 FOOT CANDLE | | | | | | | |
|---|---|---|---|---|---|---|---|
| Incandescent | | | | Fluorescent | | | Pro- |
| 100W | 75W | 60W | 40W | 40W | 20W | 15W | pane |
| $ 30 | $ 45 | $ 63 | $ 114 | $ | $ | $ | |
| 6 | 6 | 9 | 9 | 3 | 3 | 3 | |
| 2 | 2 | 3 | 3 | 1 | 1 | 1 | |
| 5 | 5 | 11 | 19 | | | | |
| | | | | 10 | 30 | 46 | |
| 5 | 5 | 8 | 8 | 3 | 3 | 3 | |
| 25 | 38 | 53 | 95 | | | | |
| | | | | 55 | 105 | 161 | |
| 5 | 5 | 8 | 8 | 3 | 3 | 3 | |
| 46 | 68 | 96 | 173 | 23 | 68 | 105 | |
| 13 | 19 | 26 | 48 | 6 | 19 | 29 | |
| 10 | 15 | 21 | 38 | 5 | 15 | 23 | |
| 147 | 208 | 298 | 515 | 109 | 247 | 374 | |
| 841 | 1032 | 1032 | 1032 | 841 | 841 | 841 | |
| $988 | $1240 | $1330 | $1547 | $950 | $1088 | $1215 | |

| | 1/4 FOOT CANDLE | | | | | | |
|---|---|---|---|---|---|---|---|
| | Incandescent | | | Fluorescent | | | Pro- |
| 0W | 75W | 60W | 40W | 40W | 20W | 15W | pane |
| 9 | $ 15 | $ 21 | $ 39 | $ | $ | $ | |
| 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 2 | 3 | 3 | 3 | | | | |
| | | | | 4 | 10 | 16 | |
| 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 8 | 13 | 18 | 33 | | | | |
| | | | | 22 | 35 | 56 | |
| 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| 14 | 23 | 32 | 59 | 9 | 23 | 36 | |
| 4 | 6 | 9 | 16 | 3 | 6 | 12 | |
| 5 | 5 | 7 | 13 | 5 | 5 | 8 | |
| 52 | 75 | 100 | 173 | 53 | 89 | 138 | |
| 841 | 841 | 841 | 841 | 841 | 841 | 841 | |
| 893 | $916 | $941 | $1014 | $894 | $930 | $979 | |

* NOTE - Fluorescent fixture cost (installed) - 40 watt, $11.00
- 20 - 15 watt, $7.00

Figure 7. Cost Comparison - 500 Space Shelter



3

| | Description | Unit | Unit Cost | TWO FOOT CANDLES<br>Incandescent<br>100W | 75W | 60W | 40W | Fluorescent<br>40W | 20W | 15W | Propane |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Box 4" Octagon Ceiling | Ea | $300 | $ 321 | $ 480 | $ 657 | $ 1206 | $ | $ | $ | |
| 2. | Box 4" Square Wall | Ea | 300 | 54 | 60 | 66 | 81 | 15 | 21 | 27 | |
| 3. | Cover 4" Square Switch & Rec. | Ea | 100 | 18 | 20 | 22 | 27 | 5 | 7 | 9 | |
| 4. | Incandescent Lamp Medium Screw | Ea | .50 | 54 | 80 | 110 | 201 | | | | |
| 5. | Fluorescent Lamp (T-12) | Ea | 200 | | | | | 116 | 314 | 500 | |
| 6. | Propane Lantern | Ea | 1600 | | | | | | | | |
| 7. | Receptacle Dup. Grounding | Ea | 250 | 45 | 50 | 55 | 68 | 13 | 18 | 23 | |
| 8. | Receptacle Ceiling | Ea | 250 | 268 | 400 | 548 | 1005 | | | | |
| 9. | Fixture - Fluorescent | Ea | * | | | | | 638 | 1099 | 1750 | |
| 10. | Switch | Ea | 250 | 45 | 50 | 55 | 68 | 13 | 18 | 23 | |
| 11. | Cable 13'/Light | LF | .35 | 487 | 728 | 996 | 1829 | 264 | 714 | 1138 | |
| 12. | Connectors, Cable (2-1/2) | Ea | .50 | 134 | 200 | 274 | 503 | 73 | 196 | 313 | |
| 13. | Pipe 10' + 10'/light | LF | 150 | | | | | | | | |
| 14. | Connectors, Pipe | Ea | 100 | | | | | | | | |
| 15. | Hardware | LS | | 107 | 160 | 219 | 402 | 58 | 157 | 250 | |
| 16. | SUB-TOTAL | | | 1533 | 2228 | 3002 | 5390 | 1195 | 2544 | 4033 | |
| 17. | Energy Source Complete (Less Fuel) | | | 3660 | 3660 | 3660 | 5346 | 1197 | 1535 | 1535 | |
| 18. | TOTAL COST | | | $5193 | $5888 | $6662 | $10736 | $2392 | $4079 | $5568 | |

| | Description | Unit | Unit Cost | 1/2 FOOT CANDLE<br>Incandescent<br>100W | 75W | 60W | 40W | Fluorescent<br>40W | 20W | 15W | Propane |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Box 4" Octagon Ceiling | Ea | $300 | $ 81 | $ 120 | $ 165 | $ 300 | $ | $ | $ | |
| 2. | Box 4" Square Wall | Ea | 300 | 15 | 15 | 18 | 21 | 6 | 6 | 9 | |
| 3. | Cover 4" Square Switch & Rec. | Ea | 100 | 5 | 5 | 6 | 7 | 2 | 2 | 3 | |
| 4. | Incandescent Lamp Medium Screw | Ea | .50 | 14 | 20 | 28 | 50 | | | | |
| 5. | Fluorescent Lamp (T-12) | Ea | 200 | | | | | 28 | 78 | 126 | |
| 6. | Propane Lantern | Ea | 1600 | | | | | | | | |
| 7. | Receptacle Dup. Grounding | Ea | 250 | 13 | 13 | 15 | 18 | 5 | 5 | 8 | |
| 8. | Receptacle Ceiling | Ea | 250 | 68 | 100 | 138 | 250 | | | | |
| 9. | Fixture - Fluorescent | Ea | * | | | | | 154 | 273 | 441 | |
| 10. | Switch | Ea | 250 | 13 | 13 | 15 | 18 | 5 | 5 | 8 | |
| 11. | Cable 13'/Light | LF | .35 | 123 | 182 | 250 | 455 | 64 | 177 | 287 | |
| 12. | Connectors, Cable (2-1/2) | Ea | .50 | 34 | 50 | 69 | 125 | 18 | 49 | 79 | |
| 13. | Pipe 10' + 10'/light | LF | 150 | | | | | | | | |
| 14. | Connectors, Pipe | Ea | 100 | | | | | | | | |
| 15. | Hardware | LS | | 27 | 40 | 55 | 100 | 14 | 39 | 63 | |
| 16. | SUB-TOTAL | | | 393 | 558 | 759 | 1344 | 289 | 634 | 1004 | |
| 17. | Energy Source Complete (Less Fuel) | | | 1197 | 1197 | 1197 | 1535 | 841 | 841 | 1032 | |
| 18. | TOTAL COST | | | $1590 | $1755 | $1956 | $2879 | $1130 | $1475 | $2036 | |

FIGURE NO. 8

## 2000 SPACE SHELTER

## COST COMPARISON

FOOT CANDLES

| | Incandescent | Fluorescent | | | Propane |
|---|---|---|---|---|---|
| | 40W | 40W | 20W | 15W | |
| | $ 1206 | $ | $ | $ | |
| | 81 | 15 | 21 | 27 | |
| | 27 | 5 | 7 | 9 | |
| | 201 | | | | |
| | | 116 | 314 | 500 | |
| | 68 | 13 | 18 | 23 | |
| | 1005 | | | | |
| | | 638 | 1099 | 1750 | |
| | 68 | 13 | 18 | 23 | |
| | 1829 | 264 | 714 | 1138 | |
| | 503 | 73 | 196 | 313 | |
| | 402 | 58 | 157 | 250 | |
| | 5390 | 1195 | 2544 | 4033 | |
| | 5346 | 1197 | 1535 | 1535 | |
| | $10736 | $2392 | $4079 | $5568 | |

ONE FOOT CANDLE

| Incandescent | | | | Fluorescent | | | Propane |
|---|---|---|---|---|---|---|---|
| 100W | 75W | 60W | 40W | 40W | 20W | 15W | |
| $ 159 | $ 240 | $ 327 | $ 603 | $ | $ | $ | |
| 27 | 30 | 33 | 42 | 9 | 12 | 15 | |
| 9 | 10 | 11 | 14 | 3 | 4 | 5 | |
| 27 | 40 | 55 | 101 | | | | |
| | | | | 58 | 158 | 250 | |
| 23 | 25 | 28 | 35 | 8 | 10 | 13 | |
| 133 | 200 | 273 | 503 | | | | |
| | | | | 319 | 553 | 876 | |
| 23 | 25 | 28 | 35 | 8 | 10 | 13 | |
| 241 | 364 | 496 | 915 | 132 | 359 | 569 | |
| 66 | 120 | 136 | 251 | 36 | 99 | 156 | |
| 53 | 80 | 109 | 201 | 29 | 79 | 125 | |
| 761 | 1134 | 1496 | 2700 | 602 | 1284 | 2022 | |
| 2311 | 2311 | 2311 | 2837 | 1032 | 1032 | 1197 | |
| $3072 | $3445 | $3807 | $5537 | $1634 | $2316 | $3219 | |

3/4 FOOT

| Incandescent | | | |
|---|---|---|---|
| 100W | 75W | 60W | |
| $ 120 | $ 180 | $ 246 | $ |
| 21 | 24 | 27 | |
| 7 | 8 | 9 | |
| 20 | 30 | 41 | |
| | | | |
| 18 | 20 | 23 | |
| 100 | 150 | 205 | |
| | | | |
| 18 | 20 | 23 | |
| 182 | 273 | 373 | |
| 50 | 75 | 103 | |
| 40 | 60 | 82 | |
| 576 | 840 | 1132 | |
| 1535 | 1535 | 1535 | |
| $2111 | $2375 | $2667 | $ |

FOOT CANDLE

| | Incandescent | Fluorescent | | | Propane |
|---|---|---|---|---|---|
| | 40W | 40W | 20W | 15W | |
| | $ 300 | $ | $ | $ | |
| | 21 | 6 | 6 | 9 | |
| | 7 | 2 | 2 | 3 | |
| | 50 | | | | |
| | | 28 | 78 | 126 | |
| | 18 | 5 | 5 | 8 | |
| | 250 | | | | |
| | | 154 | 273 | 441 | |
| | 18 | 5 | 5 | 8 | |
| | 455 | 64 | 177 | 287 | |
| | 125 | 18 | 49 | 79 | |
| | 100 | 14 | 39 | 63 | |
| | 1344 | 289 | 634 | 1004 | |
| | 1535 | 841 | 841 | 1032 | |
| | $2879 | $1130 | $1475 | $2036 | |

1/4 FOOT CANDLE

| Incandescent | | | | Fluorescent | | | Propane |
|---|---|---|---|---|---|---|---|
| 100W | 75W | 60W | 40W | 40W | 20W | 15W | |
| $ 39 | $ 60 | $ 78 | $ 150 | $ | $ | $ | |
| 9 | 9 | 9 | 12 | 3 | 3 | 6 | |
| 3 | 3 | 3 | 4 | 1 | 1 | 2 | |
| 7 | 10 | 13 | 25 | | | | |
| | | | | 14 | 40 | 62 | |
| 8 | 8 | 8 | 10 | 3 | 3 | 5 | |
| 33 | 50 | 66 | 75 | | | | |
| | | | | 77 | 140 | 217 | |
| 8 | 8 | 8 | 10 | 3 | 3 | 5 | |
| 59 | 91 | 118 | 228 | 32 | 91 | 141 | |
| 16 | 25 | 33 | 63 | 9 | 25 | 39 | |
| 13 | 20 | 26 | 50 | 7 | 20 | 31 | |
| 195 | 284 | 362 | 627 | 149 | 326 | 503 | |
| 1032 | 1032 | 1032 | 1032 | 841 | 841 | 841 | |
| $1227 | $1316 | $1394 | $1659 | $990 | $1167 | $1344 | |

* NOTE - Fluorescent fixtu

Figure 8. Cost Co

2

SPACE SHELTER

T COMPARISON

**ONE FOOT CANDLE**

| Incandescent 100W | 75W | 60W | 40W | Fluorescent 40W | 20W | 15W | Propane |
|---|---|---|---|---|---|---|---|
| $ 159 | $ 240 | $ 327 | $ 603 | $ | $ | $ | |
| 27 | 30 | 33 | 42 | 9 | 12 | 15 | |
| 9 | 10 | 11 | 14 | 3 | 4 | 5 | |
| 27 | 40 | 55 | 101 | | | | |
| | | | | 58 | 158 | 250 | |
| 23 | 25 | 28 | 35 | 8 | 10 | 13 | |
| 133 | 200 | 273 | 503 | | | | |
| | | | | 319 | 553 | 876 | |
| 23 | 25 | 28 | 35 | 8 | 10 | 13 | |
| 241 | 364 | 496 | 915 | 132 | 359 | 569 | |
| 66 | 120 | 136 | 251 | 36 | 99 | 156 | |
| 53 | 80 | 109 | 201 | 29 | 79 | 125 | |
| 761 | 1134 | 1496 | 2700 | 602 | 1284 | 2022 | |
| 2311 | 2311 | 2311 | 2837 | 1032 | 1032 | 1197 | |
| $3072 | $3445 | $3807 | $5537 | $1634 | $2316 | $3219 | |

**3/4 FOOT CANDLE**

| Incandescent 100W | 75W | 60W | 40W | Fluorescent 40W | 20W | 15W | Propane |
|---|---|---|---|---|---|---|---|
| $ 120 | $ 180 | $ 246 | $ 453 | $ | $ | $ | |
| 21 | 24 | 27 | 33 | 6 | 9 | 12 | |
| 7 | 8 | 9 | 11 | 2 | 3 | 4 | |
| 20 | 30 | 41 | 76 | | | | |
| | | | | 44 | 118 | 186 | |
| 18 | 20 | 23 | 28 | 5 | 8 | 10 | |
| 100 | 150 | 205 | 378 | | | | |
| | | | | 242 | 413 | 658 | |
| 18 | 20 | 23 | 28 | 5 | 8 | 10 | |
| 182 | 273 | 373 | 687 | 100 | 268 | 428 | |
| 50 | 75 | 103 | 189 | 28 | 74 | 118 | |
| 40 | 60 | 82 | 151 | 22 | 59 | 94 | |
| 576 | 840 | 1132 | 2034 | 454 | 960 | 1520 | |
| 1535 | 1535 | 1535 | 2311 | 1032 | 1032 | 1032 | |
| $2111 | $2375 | $2667 | $4344 | $1486 | $1992 | $2552 | |

**1/4 FOOT CANDLE**

| Incandescent 100W | 75W | 60W | 40W | Fluorescent 40W | 20W | 15W | Propane |
|---|---|---|---|---|---|---|---|
| $ 39 | $ 60 | $ 78 | $ 150 | $ | $ | $ | |
| 9 | 9 | 9 | 12 | 3 | 3 | 6 | |
| 3 | 3 | 3 | 4 | 1 | 1 | 2 | |
| 7 | 10 | 13 | 25 | | | | |
| | | | | 14 | 40 | 62 | |
| 8 | 8 | 8 | 10 | 3 | 3 | 5 | |
| 33 | 50 | 66 | 75 | | | | |
| | | | | 77 | 140 | 217 | |
| 8 | 8 | 8 | 10 | 3 | 3 | 5 | |
| 59 | 91 | 118 | 228 | 32 | 91 | 141 | |
| 16 | 25 | 33 | 63 | 9 | 25 | 39 | |
| 13 | 20 | 26 | 50 | 7 | 20 | 31 | |
| 195 | 284 | 362 | 627 | 149 | 326 | 503 | |
| 1032 | 1032 | 1032 | 1032 | 841 | 841 | 841 | |
| $1227 | $1316 | $1394 | $1659 | $990 | $1167 | $1344 | |

* **NOTE - Fluorescent fixture cost (installed) - 40 watt, $11.00**
**- 20 - 15 watt, $7.00**

Figure 8. Cost Comparison - 2000 Space Shelter



3

Figure 9. Portable Lighting System

Lighting, Portable, 4 Lamp, 60 Foot Cord - Complete System $17.40
Two Foot-Candle Level, 50 Space Shelter

| DESCRIPTION | UNIT | QUANTITY | UNIT COST | TOTAL |
|---|---|---|---|---|
| Cord #16/2 Type Spt | L.F. | 60 | $ .10 | $ 6.00 |
| Body, Cord Connector, 15 A, 125V, 3 Wire | Each | 1 | 1.00 | 1.00 |
| Cap, Cord Connector, 15 A, 125V, 3 Wire | Each | 1 | .50 | .50 |
| Socket Pin Med. Scr. Base | Each | 4 | .35 | 1.40 |
| Lamp 40W, 120 V, Med. Scr. | Each | 4 | .25 | 1.00 |
| Hardware, Pkg. Assorted Hooks | Each | 1 | 1.50 | 1.50 |
| Assembling and Packaging | L.S. | | | 6.00 |

2. **500 Space and 2000 Space Shelters.**

Since required lumen values are much greater for these sizes of shelters, maximum utilization shall be made of the wire capacity to reduce the number of strings of lamps necessary to provide the various levels of illumination.

National Electric Code for Number 16 wire, thermoplastic cover, allows an 8 ampere load. At 120 volts this is 960 watts. However, as a safety margin 6 amperes will be considered a nominal maximum so that strings of lamps will be based on 720 watts. Using the same incandescent lamp wattages on which fixed lighting system lumen data were determined gives the following table:

| Lamp Wattage | Number of Lamps | Total Watts per String |
|---|---|---|
| 100 | 7 | 700 |
| 75 | 10 | 750 |
| 60 | 12 | 720 |
| 40 | 18 | 720 |

Cost of wire for portable units is based on 20 foot lead in plus 10 feet per lamp. All other component unit prices are as used for 50 space system on Figure 9. Under this system fuse cabinets are deemed a necessary safety installation and have been included as part of the costs. Costs for fuse cabinets are quoted installed.

The following tables show the approximate costs of an all-portable lighting system using 100 watt lamps.

500 Space Shelter

| Foot Candle | Strings | Cost | Fuse Cabinet | Total |
|---|---|---|---|---|
| 2 | 4 | $90.80 | $17.00 | $107.80 |
| 1 | 2 | 45.40 | 13.00 | 58.40 |
| 3/4 | 2 | 45.40 | 13.00 | 58.40 |
| 1/2 | 1 | 22.70 | 13.00 | 35.70 |
| 1/4 | 1 | 22.70 | 13.00 | 35.70 |

2000 Space Shelter

| Foot Candle | Strings | Cost | Fuse Cabinet | Total |
|---|---|---|---|---|
| 2 | 15 | $340.50 | $120.00 | $460.50 |
| 1 | 8 | 181.60 | 40.00 | 221.60 |
| 3/4 | 6 | 136.20 | 29.00 | 165.20 |
| 1/2 | 4 | 90.80 | 17.00 | 107.80 |
| 1/4 | 2 | 45.40 | 13.00 | 58.40 |

Other sizes of lamps would represent relatively minor variations in cost, the most expensive string being the 40 watt at $40.30 each and the two foot-candle level for the 2000 space shelter amounting to $724.50.

A minimum prerequisite for the use of a portable system is the installation of fuse cabinets where the utilization of strings of lamps represents the method of supplying illumination. Consideration must also be given to the probability that initial confusion is likely to be very great in large shelters and the placing of such strings of light would be quite difficult and time consuming. For small groups where very few strings are all that will ultimately be required the placing of one string could suffice for an initial period until such time as a semblance of organization had been achieved. At that time the additional strings could be placed advantageously.

In shelters where fixed lighting has been installed with a very low foot-candle level, one or more strings of this type may be useful in providing additional light in critical areas. See "Lighting for Specific Activities", page A-25 in Appendix.

## D. LIGHTING DISTRIBUTION.

1. **Areas.**

Note again that the foot-candle values are based strictly on lumen output and floor area. Therefore, fixture spacing varies quite widely. An example of the various distributions in the

500 space shelter, *for the two foot-candle level* per fixture is as follows:

| Incandescent | Fluorescent |
|---|---|
| 100 watt – 185 sq. ft. | 40 watt – 357 sq. ft. |
| 75 watt – 125 sq. ft. | 20 watt – 128 sq. ft. |
| 60 watt – 90 sq. ft. | 15 watt – 79 sq. ft. |
| 40 watt – 50 sq. ft. | |

The areas above will vary as an inverse proportion of the foot-candle level. Propane lantern distribution, where used, is 63 square feet per lantern.

2. **Foot-Candle Values.**

At a point directly under the fixture, 30 inches off the floor (the normal working plane), and assuming the fixture (lamp) being mounted eight feet from the floor, the following foot-candle values can be expected:

| Incandescent | | Fluorescent | | Propane* |
|---|---|---|---|---|
| Lamp | F.C. | Lamp | F.C. | F.C. |
| 100 W | 4.24 | 40 W | 5.84 | 1.39 |
| 75 W | 2.84 | 20 W | 2.40 | |
| 60 W | 2.08 | 15 W | 1.85 | |
| 40 W | 1.13 | | | |

Incandescent and propane values were determined by the Inverse Square Law; fluorescent values by means of a Toroidal Distribution Formula. Since interreflections were ignored, the values in an actual installation may be somewhat higher.

## E. USE OF REFLECTORS AND PAINT.

Consideration was given to the use of reflectors on the lamps to improve the light level, however, the slight advantage gained by reflectors was offset by the overall cost. Great improvement in the light level can be expected if dark dull surfaces in a shelter, particularly ceilings, are painted white. The increased reflectance of such surfaces can more than double the average level of illumination in areas where the ceiling height to room-width or -length ratio is near unity. Such painting can appreciably increase the illumination level in rooms with ratios as high as 1:10. (12)

*For a single mantle lantern with a bulb-shape as in Figure 1, page 11.

## F. UNIT POWER REQUIREMENTS.

The following table represents the power requirements in terms of watts per ten square feet (or per person) for the 500 space shelter. The other shelter sizes are in the same range.

| | Incandescent | | | | Fluorescent | | |
|---|---|---|---|---|---|---|---|
| F.C. | 100W | 75W | 60W | 40W | 40W | 20W | 15W |
| 2 | 5.40 | 6.00 | 6.60 | 8.00 | 1.40 | 1.95 | 2.51 |
| 1 | 2.60 | 3.00 | 3.24 | 4.00 | .70 | 1.00 | 1.2 |
| 3/4 | 2.00 | 2.25 | 2.51 | 3.04 | .50 | .75 | .92 |
| 1/2 | 1.40 | 1.50 | 1.76 | 2.00 | .40 | .50 | .64 |
| 1/4 | .60 | .75 | .84 | 1.04 | .20 | .25 | .32 |

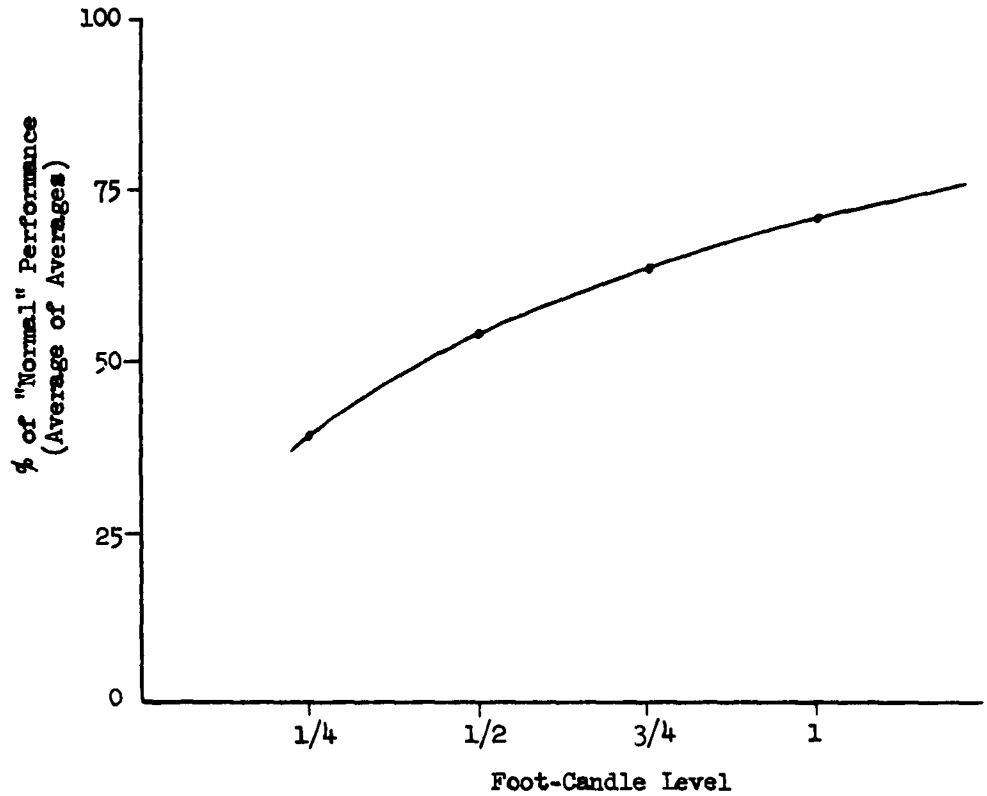
## G. HUMAN PERFORMANCE VERSUS ILLUMINATION LEVEL AND COST.

1. **Performance versus Illumination Level.**

An approximate idea of what may be expected from shelter inhabitants due to various illumination levels may be seen from the curve, Figure 10, page 30. This curve was developed from averaging raw averages of all the vision tests, Figure 16, page A-15, in Appendix. This is in effect, a cumulative curve of those presented in the Appendix, Figures 17, 18, 19, 20 on pages A-19, A-20, A-21, and A-22, which represent the raw average values of the individual tests. The "performance" percentages are arrived at by assuming the results obtained at the 45 foot-candle level as "normal", and decreased acuity or fewer correct responses as the percentage of "normal." Newsprint reading was excluded since no trial was made at the 45 foot-candle level.

2. **Performance versus Illumination Cost per Person.**

The curve, Figure 11, page 31, equates the average cost of incandescent lighting on a per person basis versus the performance




Note: The assumption is made that results at 45 foot-candle were "normal." Newsprint reading has been excluded as no test was made at the 45 foot-candle level.

Figure 10. Average Performance Curve for all Vision Tests

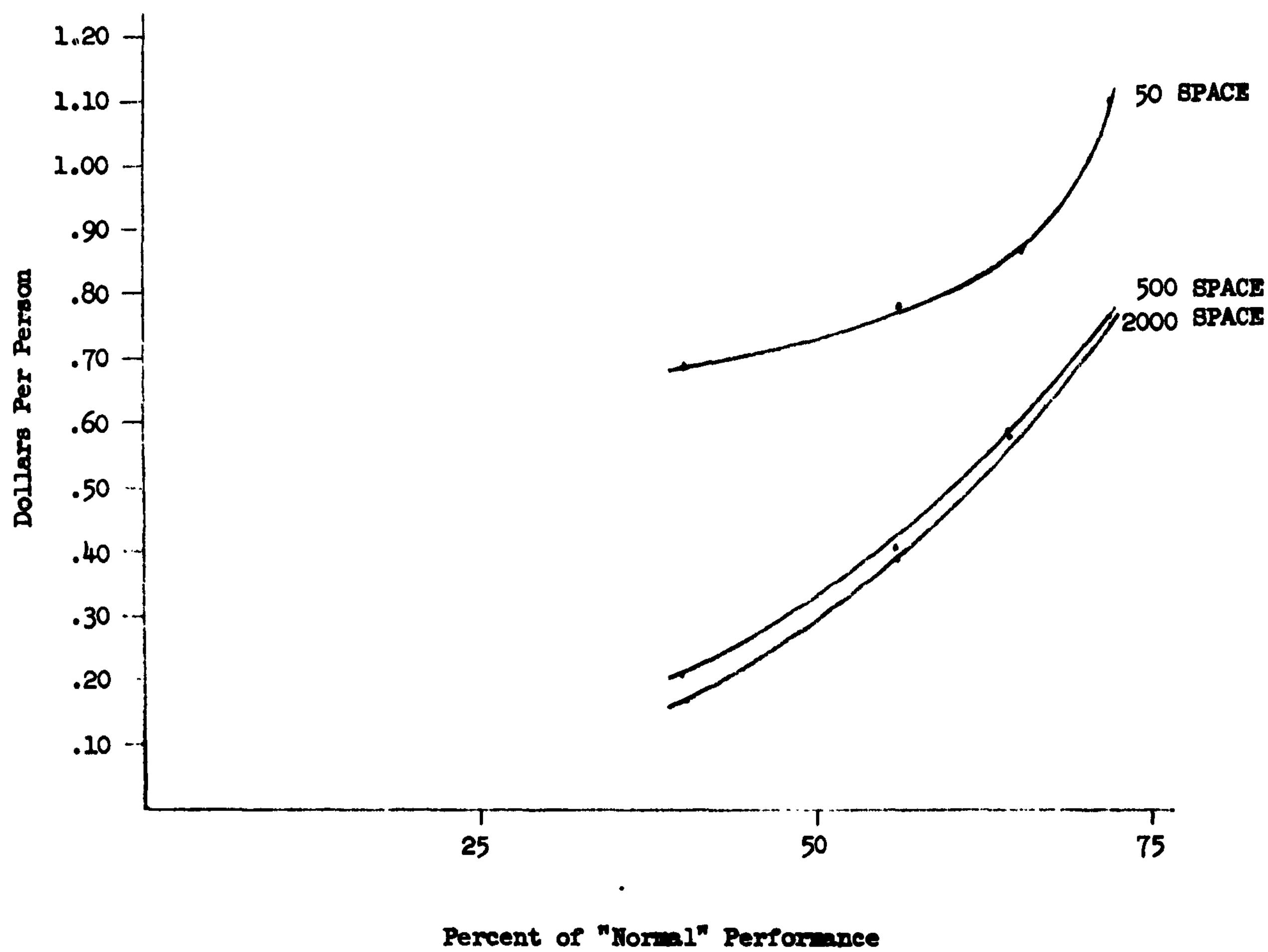



Figure No. 11. Illumination Cost Versus Performance percentage. Incandescent lighting was used as an indicative example, the other systems following similar curves. This curve is based on an assumed overall illumination level; however, it must not be assumed that the vision tests, on which the performance percentages are based, are necessarily representative of acuity requirements for most shelter inhabitants.

## CHAPTER 5

## RECOMMENDATIONS

1. On a short term basis at least, (i.e., a few hours) low levels of illumination in the range of one to 1/4 foot-candles could be used for shelter lighting without jeopardizing simple existence requirements.

2. Further testing should be done in a more realistic situation to determine long-term effects of low levels of illumination.

3. Fluorescent lighting is the most acceptable illumination source for larger shelters from the cost-effectiveness standpoint. Fluorescent lighting is also advisable in that energy requirements are approximately one-third of those for incandescent lighting.

4. Consideration should be given to arrangement of lighting other than on an equal distribution basis, particularly in the larger shelters. Though all of the lighting packages presented will satisfy Recommendation No. 1, it may be desirable to make specific lighting arrangements insofar as possible. That is, whenever shelter configurations lend themselves to preplanning the arrangement of facilities such as kitchen, administrative area, sleeping area, etc., the lighting fixtures be arranged so as to provide higher concentrations in kitchen and administrative areas and lower concentrations in sleeping areas. One or more portable units would also supply this need. See "Lighting for Specific Activities", page A-25, in Appendix.

5. Providing for special lighting needs in the larger shelters could be implemented by maintaining the fixed portion of shelter lighting at minimum levels and providing an appropriate number of the portable systems presented in this Report.

6. Propane should be considered for the 50 space size shelter where an electrical energy source is not otherwise provided.

7. The light-admitting device should be developed for test purposes and cost analysis. (This will be accomplished in Part II of this Report.)

8. Some means should be provided to insure immediate temporary illumination of any value during initial occupancy of the shelter. See Initial Shelter Occupancy, page A-3 in Appendix.

APPENDIX

## INITIAL SHELTER OCCUPANCY

Since it can be expected that some time will be consumed in putting the shelter lighting system in working order, (e.g., starting the motor-generator) some means of providing immediate temporary light should be provided. In situations where normal power sources are still operative and the shelter has lighting connected to this power, the problem is much less serious if it is safe to assume that the normal power source will be available a sufficient time to get the shelter power system operable. It would not seem prudent to rely on this, however.

Neither would it seem prudent to rely on shelter occupants bringing flashlights, candles, or other handy illumination sources. If shelter occupancy were to occur at night this is a possibility, but may be forgotten if occupancy is required during daylight. Thorough indoctrination or ample warning time with concurrent instructions would of course improve this situation greatly.

Three possibilities for providing the initial temporary lighting can be suggested. All of these have indefinite shelf life, take up little room, are inexpensive, and would meet the need.

One is a bicycle-type generator which could be mounted on a bicycle wheel equipped with hand or foot cranks plus a bicycle headlight with a length of electric cord.

The second is a dry-charged automobile battery along with the activating fluid and an appropriate lamp and cord. The auxiliary light unit described on page 10 would be suitable. This unit comes equipped with a 15 foot cord and switch. Four lamp types are recommended giving various light intensities and also varying drain on the battery. The automobile battery, having many more ampere hours of life than a normal dry cell of equal voltage, will provide as many as several hundred hours of life on one charge. The lowest intensity lamp will allow 240 hours of continuous use with the best grade six volt dry cell. However, the terminals as presently provided would have to be redesigned to make them readily attachable to automobile battery terminals. Lamp life will be much more of a problem than battery life for this use, since average life of the recommended lamp is from 10 to 60 hours depending upon intensity. With a sufficient supply of lamps this source of illumination may be used for some other purpose once the initial need is over. That is, it could be used as, say, a toilet light, storage area light, or for some other purpose where a small amount of illumination is all that is necessary.

The third and least desirable would be a supply of ordinary wax candles and matches. This is the least expensive but is undesirable from both the fire hazard standpoint and the low level of illumination provided.

The possibility of automobile batteries being removed from automobiles in the vicinity of the shelter as a power source for the initial lighting need was considered. This possibility was rejected for the following points, listed without rank.

1. Automobile batteries weigh generally 40 to 50 pounds.
2. Terminals are frequently difficult to remove and especially so for unskilled persons.
3. Persons unfamiliar with the automobile may not know how to raise the hood and/or locate the battery.
4. The removal of a battery in the dark can be especially difficult.
5. It would seem doubtful that, in a situation serious enough to demand shelter occupancy, early arrivals could be persuaded to leave the shelter to search for batteries.
6. Unfamiliar or hurried handling of a battery can spill a relatively strong acid on the person or clothing.
7. Voltages may be six or 12 and suitable lamps are not interchangeable.

Whatever system is used, it seems imperative that several persons be familiarized with the location and operation of shelter equipment so that at least one person is present who can put the various systems into operation.

NAME ______________________ APPENDIX DATE ______________

## VISUAL ACUITY TEST
(45 Foot Candle Illumination)

| | | | | | |
|---|---|---|---|---|---|
| ILLITERATE "E's" (One error max) | 20 - 30 | 20 - 20 | 20 - 15 | 20 - 10 | |
| RANDOM DIGITS (One error max) | 20 - 30 | 20 - 20 | 20 - 15 | 20 - 12 | 20 - 10 |
| DEPTH PERCEPTION TRIAL | 1 | 2 | 3 | 4 | 5 |
| (MM Error) | 6 | 7 | 8 | 9 | 10 |

| | WHITE | | RED | | GREEN | | BLUE | |
|---|---|---|---|---|---|---|---|---|
| LANDOLT RINGS (5 and 2 Minute Angles) | 5' | 2' | 5' | 2' | 5' | 2' | 5' | 2' |
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| PARALLEL BARS (5 and 2 Minute Angles) | 5' | 2' | 5' | 2' | 5' | 2' | 5' | 2' |
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

## PERFORMANCE TEST

| | ILLUMINATION LEVEL | | | |
|---|---|---|---|---|
| | 1 F.C. | 3/4 F.C. | 1/2 F.C. | 1/4 F.C. |
| NEEDLE THREADING (Times) | | | | |
| NUT, WASHER, BOLT ASSEMBLY (Times) | | | | |
| NEWSPRINT READING (Lines) | | | | |
| DEPTH PERCEPTION (Avg error-5 tries) | mm | mm | mm | mm |
| ILLITERATE "E's" (One error max) | 20- | 20- | 20- | 20- |
| RANDOM DIGITS (One error max) | 20- | 20- | 20- | 20- |

| | P | L | P | L | P | L | P | L |
|---|---|---|---|---|---|---|---|---|
| PARALLEL BARS & LANDOLT RINGS (2' Angle - 4 Positions) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

| | -A- | | -B- | | -C- | | -D- | |
|---|---|---|---|---|---|---|---|---|
| RIBBON IDENTIFICATION | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| WH BK GY RD BL | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 |
| GN Y LR DR LB | 5 | 6 | 5 | 6 | 5 | 6 | 5 | 6 |
| DB LG DG LY DY | 7 | 8 | 7 | 8 | 7 | 8 | 7 | 8 |

**Figure 12. Recording Sheet**

September 26, 1962

**SUBJECT: FALLOUT SHELTER LIGHTING TEST**

We are planning on using approximately forty volunteers to participate in some minimal lighting tests as part of a project to determine minimum acceptable levels for fallout shelter lighting. For those of you who may be participants, this note is to serve as a briefing as to what to expect and the criteria of the test.

First, we are not interested in the results of any one individual as far as these tests are concerned. You will all become a part of the statistics. No one will do well, nor will anyone do poorly. The first part of the test will be a general eye test to determine the average visual acuity level of the test group, so that it may be compared with a national average. We hope the test group will not greatly differ from the national average so that the performance test to follow can be properly evaluated.

The performance test will consist of various simple tasks to be performed at various levels of low illumination. Again it is emphasized that individual efforts in performing these tasks is of no interest per se, but we shall be interested in any variance of performance that may occur as a result of varying the light level.

Morell C Smith

Morell Smith
Project Engineer

## NONPARAMETRIC TECHNIQUE

An approximate method which is useful in interpreting results of experiments. This is specifically a Rank Method in which there is substituted for the actual experimental data, serial numbers 1-2-3 corresponding to the magnitude of the experimental figures. This method does not require the assumption of normality of data which underlies such procedures as the analysis of variance. The results of this method showof two treatments being compared, whether or not the differences noted are due to experimental error or of chance fluctuations. If the probabilities obtained are rather small (less than .05 corresponding to odds of 19-1) then it is usual to conclude the treatments really differ from each other. If the probability is greater than .05 then it is usual to conclude that the treatments do not differ or proof of difference may only be demonstrated by further experimental work. This is the type of reasoning commonly used in determining the significance of differences obtained in experiments.

An example of the usage of this method is illustrated below using the differences found in Acuity Levels between the one-half foot-candle level and the one-quarter foot-candle level. The numbers, either plus or minus, represent the number of Acuity Levels that a subject changed, as from 20/20 to 20/40 would be 2 (by-passing the 20/30 level). Number one indicates a one level change whether it be from 20/20 to 20/30 or 20/15 to 20/20. Signs are arbitrarily chosen with the opposite sign meaning a change in the opposite direction. (In this case one subject indicated an *increase* in acuity as the illumination level went down.)

| ½ to ¼ Foot-Candle | Highest Rank Total | Lowest Rank Total |
|---|---|---|
| +1 | + 4.0 | |
| +2 | +11.0 | |
| +1 | + 4.0 | |
| +2 | +11.0 | |
| +2 | +11.0 | |
| +1 | + 4.0 | |
| +1 | + 4.0 | |
| +1 | + 4.0 | |
| +2 | +11.0 | |
| +1 | + 4.0 | |
| +2 | +11.0 | |
| +2 | +11.0 | |
| −2 | | −11.0 |
| +1 | + 4.0 | |
| (14) | +94.0 | −11.0 |

Fourteen subjects had a change in acuity between the two levels. (33.3%) The remainder of the subjects (28) had no change in acuity. There are seven subjects who changed one level. The rank number is at the midpoint of seven or 4.0. Also, seven subjects changed two levels of acuity. The rank number is 11.0 which is midway between eight and 14. The smallest rank total according to sign is -11.0. Ranking tables show that for 14 replicates the probability of *chance occurrence* of getting a rank total equal to 13 or less is 0.01 (odds of 99-1). Since 11.0 is smaller, the probability is also 0.01. If the smaller rank total had been higher than 21, the change would not have been significant.

•

Figure 13. Significance of Changes

TABLE A. ACUITY MEASURES

| Foot Candle Levels | 45 FC vs 1 | | 1 vs 3/4 | | 3/4 vs 1/2 | | 1/2 vs 1/4 | |
|---|---|---|---|---|---|---|---|---|
| | No.Ch. | Sig. | No.Ch. | Sig. | No.Ch. | Sig. | No.Ch. | Sig. |
| Ill. E's | 76.2% | .01 | 19% | N.S. | 28.6% | .05 | 33.49 | .01 |
| Rand. Digits | 78.5% | .01 | 11.9% | N.S. | 26.2% | .05 | 40.5% | .01 |
| Landolt Circle 2' | | | | | | | | |
| White | 14.3% | .02 | 16.7% | N.S. | 28.6% | N.S. | 47.6% | .01 |
| Red | 69.0% | .01 | 59.5% | N.S. | 42.8% | .01 | 38% | .01 |
| Green | 50.0% | .01 | 47.6% | N.S. | 54.8% | .01 | 50% | .01 |
| Blue | 54.8% | .01 | 40.4% | .05 | 59.5% | .01 | 42.8% | .01 |
| Parallel Bars 2' | | | | | | | | |
| White | 11.9% | N.S. | 19.1% | N.S. | 26.2% | N.S. | 35.8% | .02 |
| Red | 59.5% | .01 | 42.8% | .05 | 35.8% | N.S. | 45.2% | .01 |
| Green | 62.0% | .01 | 50.0% | .05 | 54.8% | N.S. | 54.8% | .01 |
| Blue | 47.6% | .01 | 35.8% | N.S. | 38.0% | .02 | 59.5% | .01 |

TABLE B. PERFORMANCE MEASURES

| Foot Candle Levels | 45 FC vs 1 | | 1 vs 3/4 | | 3/4 vs 1/2 | | 1/2 vs 1/4 | |
|---|---|---|---|---|---|---|---|---|
| | No.Ch. | Sig. | No.Ch. | Sig. | No.Ch. | Sig. | No.Ch. | Sig. |
| Depth Perception | 93% | .01 | 74% | .05 | 71.5% | .01 | 54.8% | .01 |
| Needle Threading | 74% | .01 | 88% | N.S. | 91.0% | N.S. | 88.0% | N.S. |
| Assembly Task | 69% | N.S. | 54.8% | N.S. | 62.0% | N.S. | 78.5% | N.S. |
| Reading Print | --- | | 74.0% | N.S. | 74.0% | N.S. | 83.0% | .01 |

N.S. - Not Significant
No.Ch. - Number Changing
Sig. - Significance better than chance

# TEST PROCEDURES

## A. ACUITY TESTS.

### 1. Adaptation.

As the low levels of illumination were used, an adaptation time of five to six minutes was required when changing from 45 foot-candles to one foot-candle and when reducing from one foot-candle to any lower level. When a reduction was made to 1/4 foot-candle from 45 foot-candle approximately eight to 10 minutes was required. Army night vision tests indicate that at 1/4 moonlight (.005 foot-candle) ten minutes was ample time for adaptation, thus, it was felt that the test subjects were in all cases fully adapted when the tests were run (5).

### 2. Illiterate E's.

A standard Snellen-type chart of so-called illiterate E's was used. The chart is designed for use at a distance of 20 feet. By arranging to read the chart along a major diagonal of the 19½ foot room, a 20 foot reading distance could be achieved. The 20 feet was carefully measured from the eye position of a seated subject to the chart and at the same height. The acuity measures of which the chart was capable ranged from 20/200 to 20/10. The most important ranges for this study were 20/40, 20/30, 20/20, 20/15, and 20/10. See figure 14.

The subject was instructed to read the chart as far toward the small range as possible. There was no time limit on how long he required to read the most difficult line. One error in reading was allowed, but if more than one error occurred the subject's acuity was recorded as the next less acute range. Subjects were at no time informed as to how they performed.

Since repeated tests were run in the same range on this chart, readings by the subject were alternated right to left and left to right, as well as inverted, to preclude memorization.

### 3. Random Digits.

The procedure for testing visual acuity using the Random Digit Chart was the same as that for Illiterate E's. See Figure 14.

The question of why the lower acuity level on digits was resolved when a check of the Digit chart showed that though the line width for the digits was the same as for the Illiterate E's in corresponding acuity levels, the minor dimension of digits such as six, five, two, and nine was only .54′ visual angle for the 20-20 line as against a minor dimension of 8′ visual angle for the corresponding E's. This discrepancy, though giving a set of results indicating less visual acuity for the Random Digits, is of relative unimportance in that the acuity difference between levels of illumination for a given chart is significant rather than the levels themselves from chart to chart. As can be seen by a comparison between the results of Illiterate E's versus Random Digits, these acuity differences were of the same order. See Figure 17.

**4. Landolt Rings, Five-Minute and Two-Minute Visual Angle, Achromatic and Chromatic.**

As a further test of visual acuity under various levels of illumination, Landolt rings were prepared in sizes subtending both five-minute and two-minute visual angles. Both achromatic and chromatic rings were prepared. Achromatic was a white ring on a black background. Chromatics were red, green, and blue on a grey background providing a much lower contrast than the achromatic. The effect of contrast will be discussed further on page A-16.

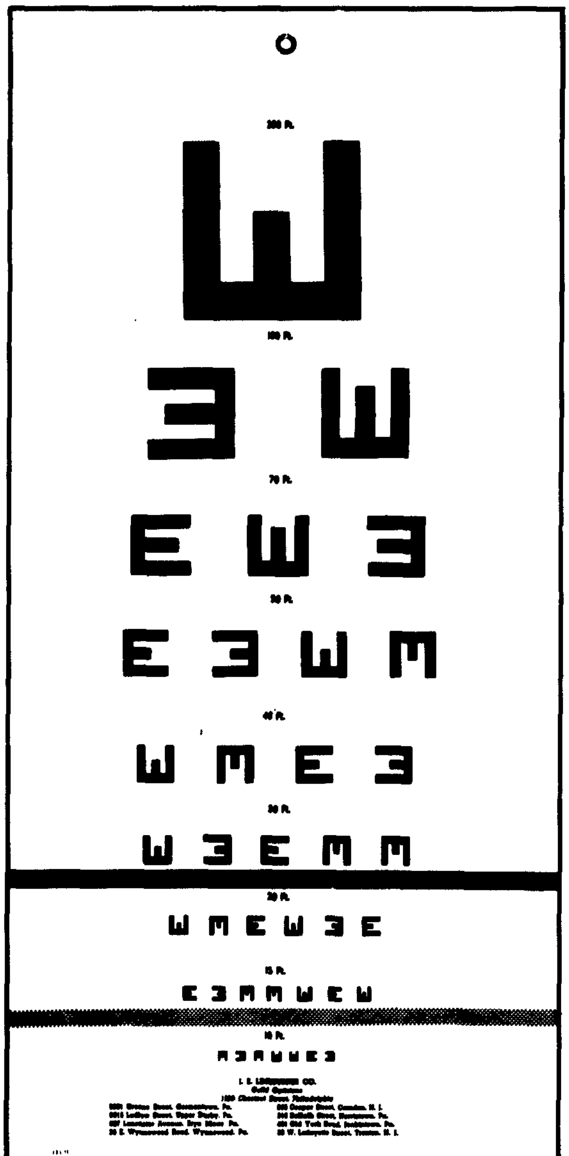
Standard conformation of rings, wherein the line width is equal to the gap and outside diameter is five times the line width, was used (6). (Page 7) Gap widths were five millimeters and two millimeters which at a distance of 11 feet 4 inches subtended visual angles of five minutes and two minutes, respectively. The rings were mounted on a circular background subtending a visual angle of 1° 42′.

Holes were punched in the periphery of the circular background at 45° increments so that the circle could be hung (and the gap placed) in any one of eight positions. A small hook provided the means of placement and identification. It was centered on a cardboard square which had digits placed clockwise around the edge corresponding to the 45° increments, numbered from one to eight. The peripheral numbers were large enough and intense enough so that they could be read easily from 11 feet 4 inches at 1/4 footcandles. The subject was to identify the position of the gap by identifying the number which it faced. See Figure 15.

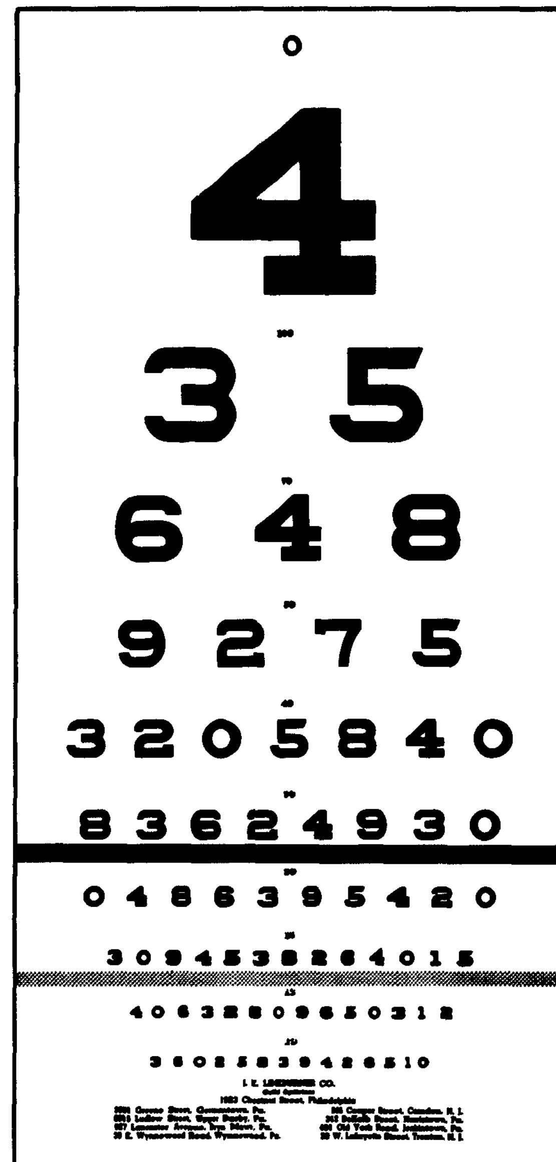
Several sets of six random digits were used to determine the sequence of gap placement. Two vexierversuch* were included in the sequence. The vexierversuche was a gapless ring on the back of the background circle, of the same size and color as the gapped ring. Vexierversuch were used with the subjects' knowledge to help maximize attention and minimize guessing. The position of the circle on the hook was masked each time a change of position was made.

Difference in response was indicated by noting the number of errors made by the subject in calling out the positions of the gap at one illumination level as against the next level. Subject was allowed five seconds to make his response.

*Vexierversuch – Fake tests to preclude subject guessing.

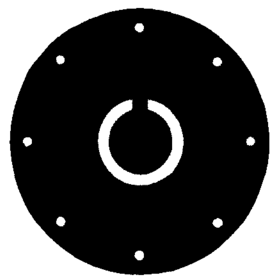


Illiterate E's

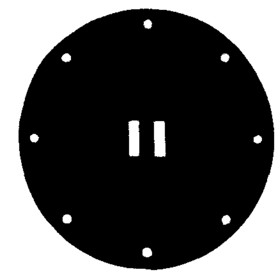



Random Digits

Figure 14. Snellen-Type Charts

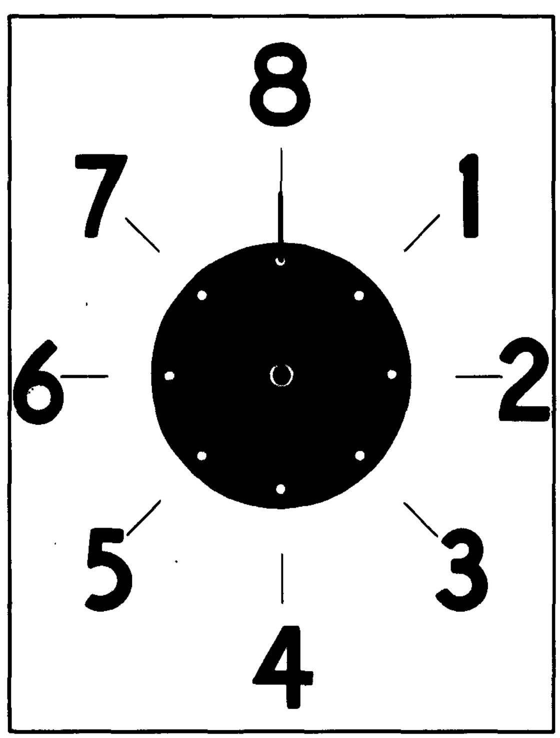


Landolt Ring

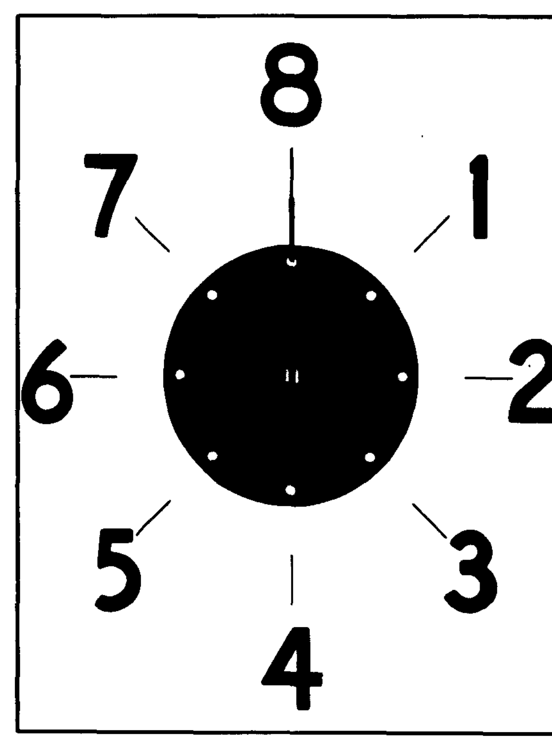


Parallel Bars

Five Minute Visual Angle




Landolt Ring




Parallel Bars

Presentation Arrangement Showing Two Minute Visual Angle

(Size Relationship between Five Minute and Two Minute Visual Angles is actual.)

Figure 15. Visual Angle Charts

Figure 16. Low Level Illumination Test
Summary of Raw Averages

| ILLUMINATION - Foot Candles | 45 | 1 | 3/4 | 1/2 | 1/4 |
|---|---|---|---|---|---|
| **ACUITY TEST** | | | | | |
| Illiterate "E's" (Acuity Level) | 20/14.4 | 20/19.4 | 20/19.8 | 20/21.2 | 20/23.5 |
| Random Digits (Acuity Level) | 20/18.0 | 20/26.4 | 20/26.6 | 20/28.5 | 20/33.1 |
| White Landolt Ring, Black Background - 2' Angle | 2 | 13 | 18 | 25 | 46 |
| Red Landolt Ring, Grey Background - 2' Angle | 1 | 56 | 66 | 100 | 136 |
| Red Landolt Ring, Grey Background - 2' Angle | 8 | 82 | 90 | 123 | 159 |
| Green Landolt Ring, Grey Background - 2' Angle | 9 | 63 | 79 | 105 | 147 |

The above figures (for rings) represent the number of visual errors made by 42 subjects in a total of 252 trials for each color and each illumination level.

| | | | | | |
|---|---|---|---|---|---|
| White Parallel Bars, Black Background - 2' Angle | 1 | 7 | 15 | 24 | 43 |
| Blue Parallel Bars, Grey Background - 2' Angle | 1 | 51 | 58 | 79 | 132 |
| Red Parallel Bars, Grey Background - 2' Angle | 1 | 73 | 94 | 109 | 160 |
| Green Parallel Bars, Grey Background - 2' Angle | 2 | 62 | 89 | 91 | 144 |

The above (for bars) are from a total of 168 trials for each color and each level.

| | | | | | |
|---|---|---|---|---|---|
| **PERFORMANCE TEST** | | | | | |
| Needle Threading (Times) | 13.0 | 8.1 | 7.3 | 7.0 | 7.0 |
| Nut, Washer, Bolt Assembly (Times) | 7.95 | 7.88 | 7.76 | 7.86 | 7.67 |
| Newsprint Reading (Lines) | -- | 88.5 | 87.5 | 84.4 | 79.1 |
| Depth Perception (MM Error) | 21 | 32 | 47 | 103 | 169 |

5. **Parallel Bars.**

The last acuity test was a test using parallel bars. The same achromatic and chromatic construction was used for parallel bars as for the Landolt rings. The bars consisted of two parallel strips of length equal to three times their width and the gap between equal to the width (6). (Page 7 ) The sum of dimensions thus formed a square. The width of the bars was the controlling dimension which was made to subtend visual angles of five minutes and two minutes for the 11 feet 4 inch distance as used for Landolt rings. See figure 15.

The vexierversuche consisted of a solid square of the same dimension as parallel bar configuration and was mounted on the reverse side of the mounting circle as for Landolt rings.

6. **Color Discrimination.**

This test was to determine to what extent color discrimination suffered at the lower illumination levels employed. The test consisted of identification of eight ribbons of different colors: red, white, pink, green, black, light blue, yellow, and light green. In a pretest trial it was found that color discrimination was not impaired at the two foot-candle level, thus the tests were conducted only at the lower levels.

Each subject received a different randomized series of ribbons. The subjects' responses were self-recorded in a sequence which was later checked against the actual presentation.

## B. CONTRAST AND REFLECTIVITY.

Contrast levels were determined for the achromatic and chromatic tests by means of a color corrected Weston lightmeter. An 8½ by 11 sheet of paper of the color to be measured was placed flat on a table at a fixed position with regard for the light source which in this case was approximately 80 foot-candles of diffused, soft white fluorescent light. Using Blackwell's contrast formula $C = \frac{B_T - B_B}{B_B}$, wherein $B_T$ represented reflectivity of the Landolt ring or parallel bars (target) and $B_B$ the reflectivity of the background, contrast levels were found to be as follows: (8)

| | |
|---|---|
| Achromatic (white on black) | 9.0 |
| Chromatic | |
| Red on Grey | .550 |
| Green on Grey | .425 |
| Blue on Grey | .675 |

Though the contrast levels of the chromatics were approximately 1/18 of the achromatic, the number of errors in calling out the positions of the gap or bars did not approach this difference. Some subjects indicated a lack of sensitivity to one or more colors by being unable to identify any position at the lower levels, but this did not greatly influence the results.

## C. PERFORMANCE TESTS.

### 1. Howard-Dohlman Depth Perception.

The Howard-Dohlman depth perception test requires the subject to align two posts in such a manner that for perfect alignment both posts are equidistant from the subject. One post is stationary, the other being movable on a track. The subject can manipulate the movable post from a distance (in this test 10½ feet) by means of cords which permit both forward and backward motion. Observation is possible only of the midportion of the posts by requiring the subject to view the posts through a window of restricted size which is part of the apparatus, (9) (page 7). The background is also a part of the apparatus and the entire unit, including the posts is painted dull black presenting a very low contrast value.

After the experimenter had misaligned the posts in random fashion with the cords resting on the floor, the subject was required to align the posts. This was done ten times at the 45 foot-candle level and five times at each subsequent level. The five additional trials at the 45 foot-candle level were allowed in order to minimize the effects of practice.

### 2. Needle Threading Test.

This test was designed to measure the effect of lowered illumination upon a task which consisted of both visual ability and motor performance, but with a relatively high degree of the visual aspect.

Each subject was required to thread a needle with black thread as many times as possible in a one minute period. To preclude the difficulty of threading due to frayed ends, both ends of the thread were sealed with clear glue. All subjects worked against a background of white bond paper 8½ by 11. The threading procedure consisted of threading the needle, pulling the 12 inch length completely through the eye and repeating.

Initially, each subject was given a free period to practice and determine his technique.

### 3. Bolt, Washer, and Nut Assembly.

This test consisted of the assembly of a 5/8 inch long by 3/16 inch diameter stove bolt to a square nut with a lock washer between. The assembly was done on an 8½ by 11 inch sheet of white bond paper. The test was for a one minute period. It was recognized that this test would be high in motor performance and low in visual involvement to a degree something like the opposite proportion to needle threading. As might be expected from the needle threading results, the motor performance completely dominated visual effort.

4. **Newsprint Reading.**

The test consisted of having the subjects read silently from passages of a lengthy newspaper article which consisted of highly legal jargon. Newsprint was chosen as being reasonably difficult and the article of legal jargon was used because the experimenters found that of many types of articles read in pretest trials, reading different passages of this particular article, which presented throughout the same lack of knowledge of subject matter, gave the most consistent reading speeds. Further, since no subject had legal training, the article would be read with disinterest (the article was from a several weeks' old newspaper) and with little understanding. Thus, it was felt the principal variable would be the amount of illumination and this would show up as a speed variation. The test was run for two minutes and to preclude the competitive aspect and to prevent any subject from knowing how much he had read, subjects were asked to point to the line they had reached at the time limitation, and this in turn was translated into words read through a control copy of the passage.

Since each passage to be read was different for each level of illumination and since all subjects were literate, the element of practice was assumed to be nonexistent. No determination of reading speed was made at the 45 foot-candle level.

## D. CRITIQUE.

A review of the procedures suggests improvements that could be made in performing such a program in the future. These are as follows:

1. Changes in the levels of illumination be made as constant proportions rather than as linear values as was done in the current procedure.
2. The percentage of vexierversuch be reduced to minimize the effect of subject guessing.
3. Utilize performance tests with a higher proportion of visual ability inasmuch as motor performance so heavily overrides the visual aspect.
4. Improve control of the reading test by having subjects read aloud, monitored by an experimenter.

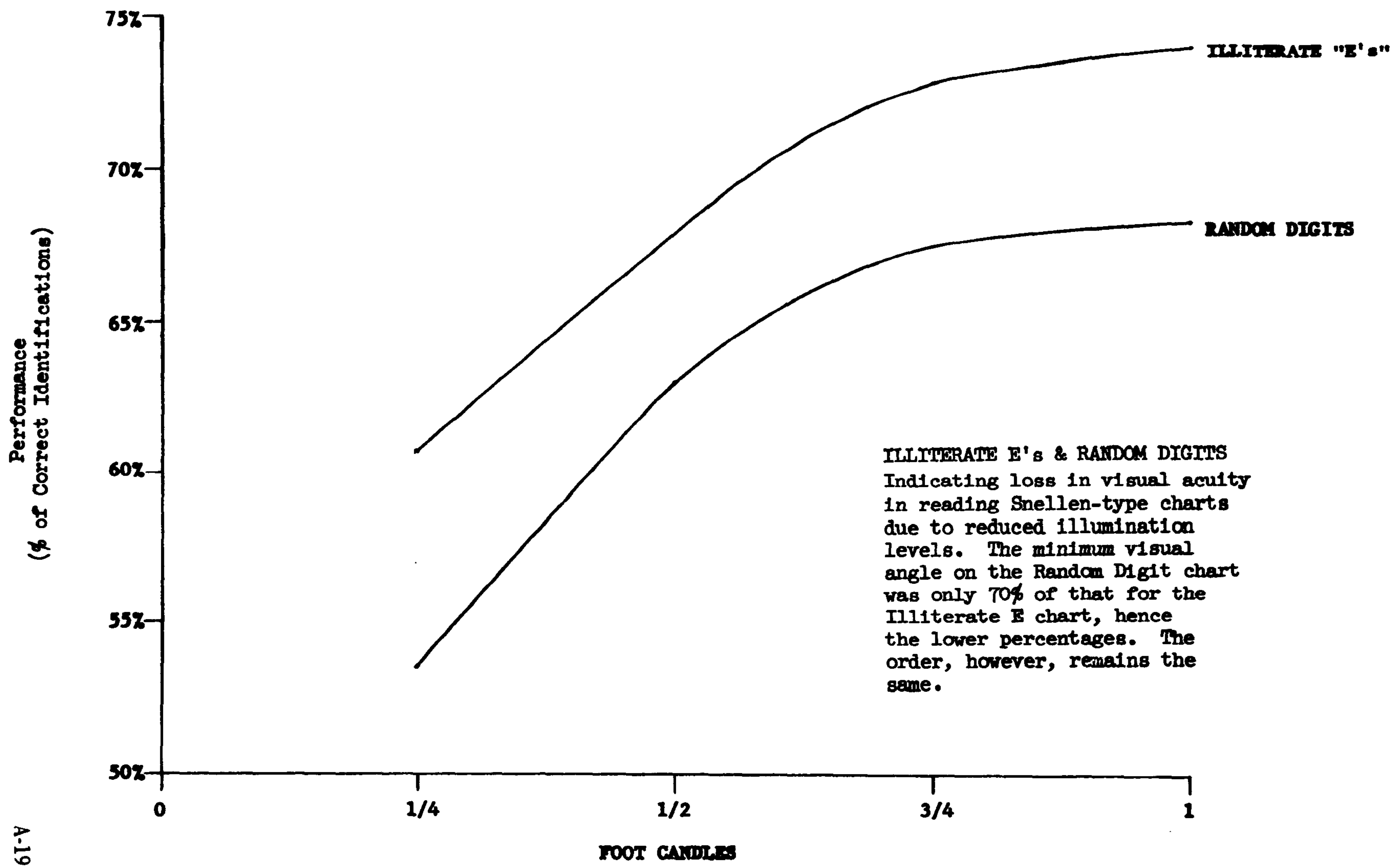



Figure 17. Illiterate E's and Random Digits

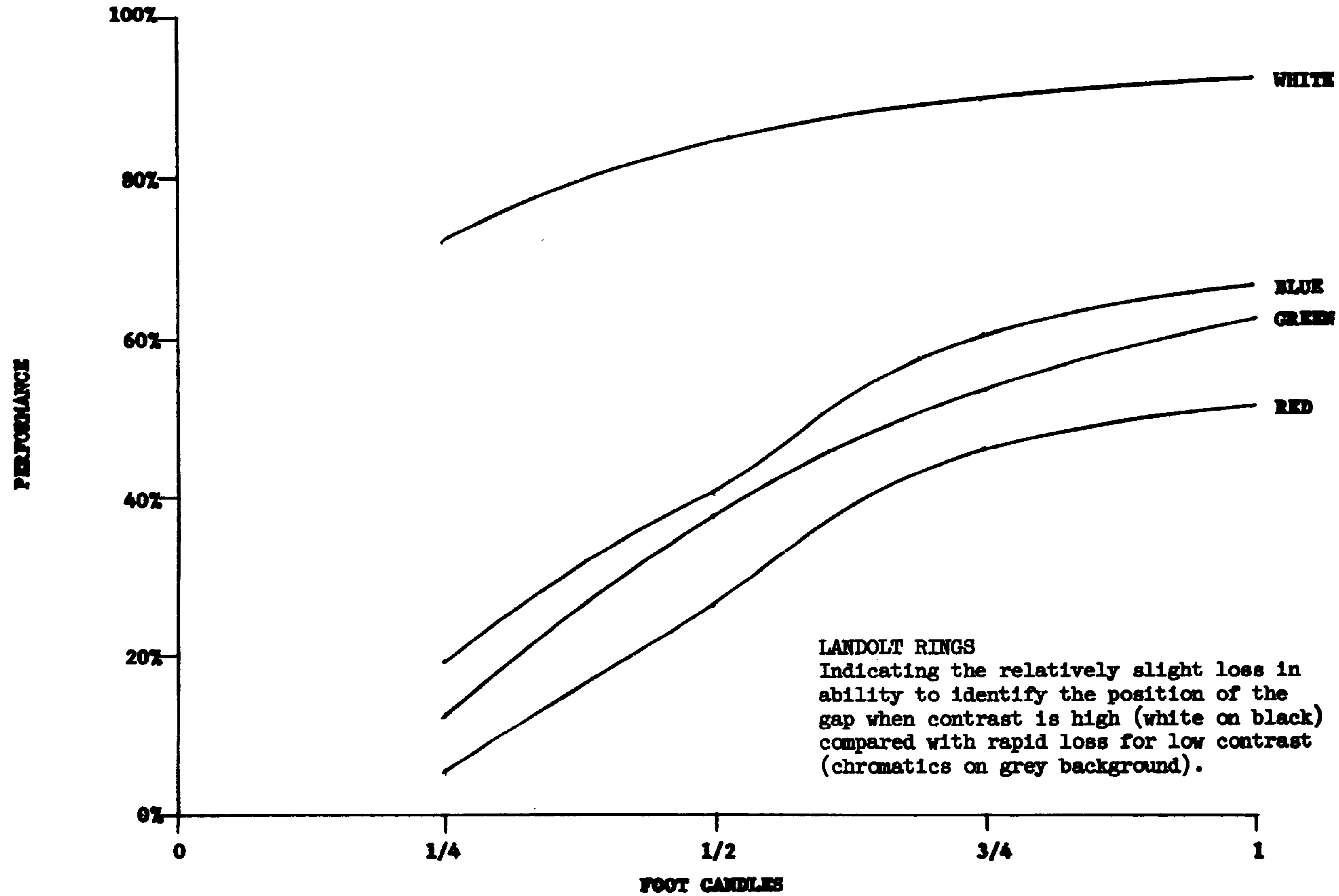



Figure 18. Landolt Rings

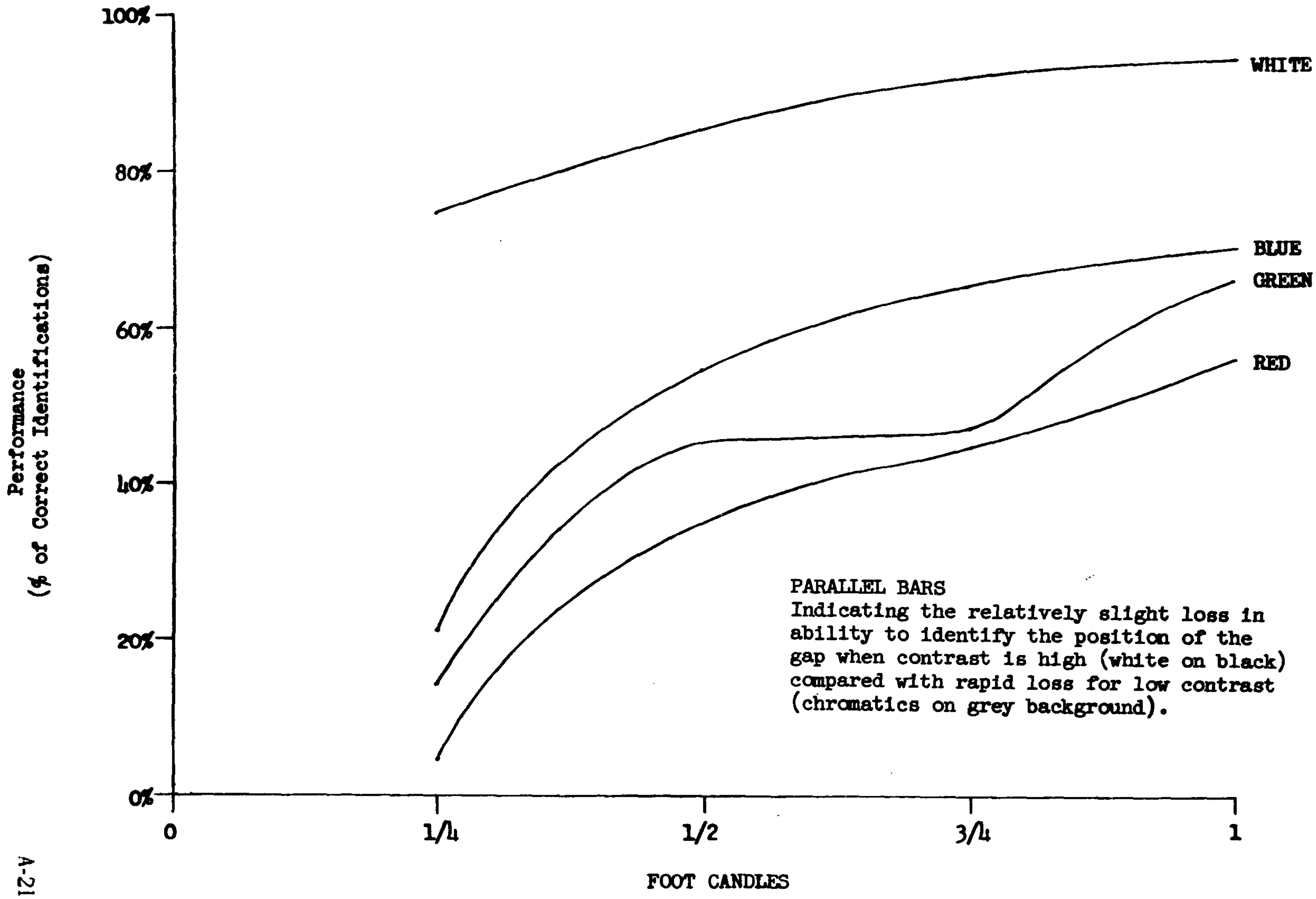



Figure 19. Parallel Bars

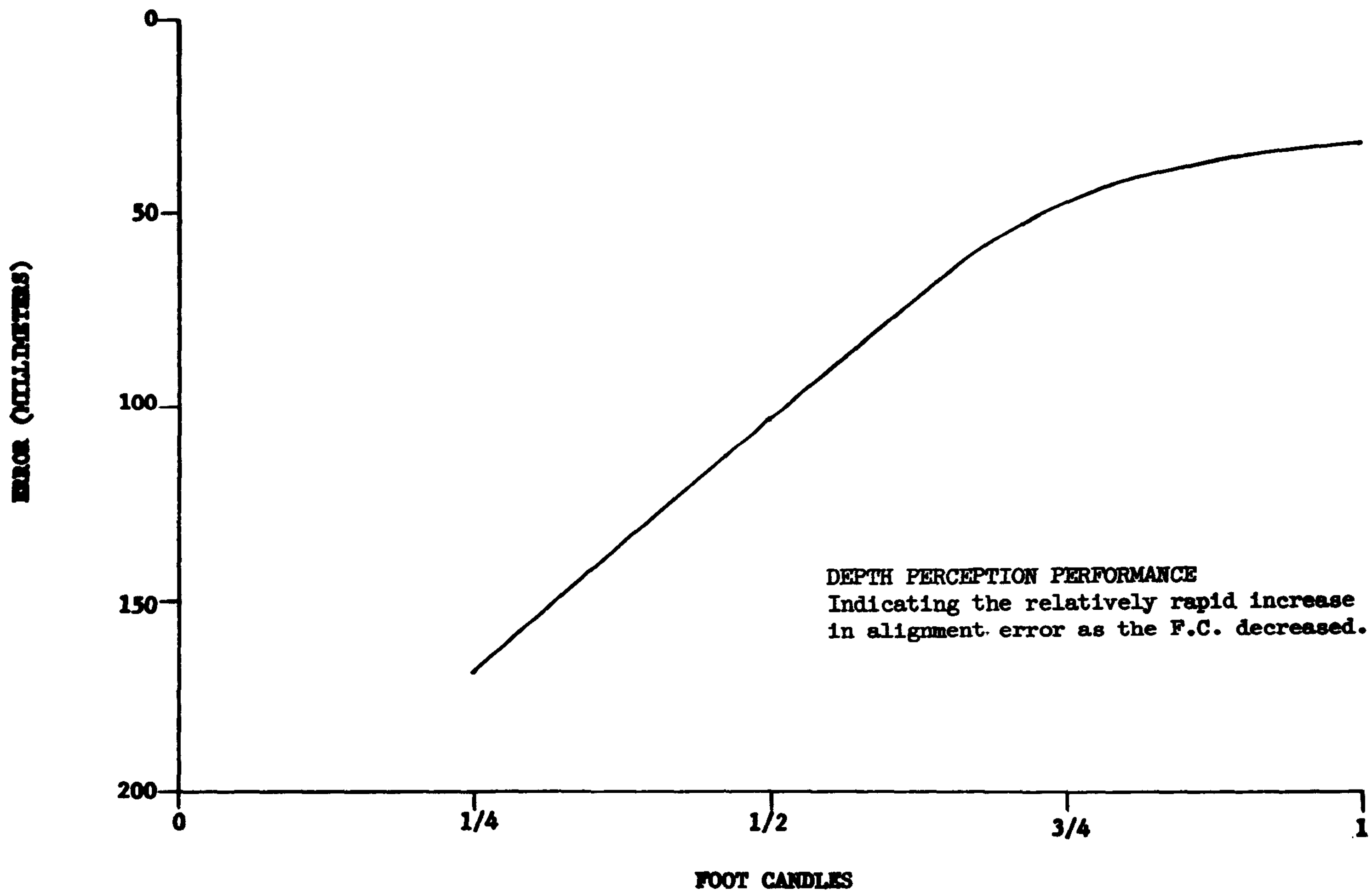



Figure 20. Depth Perception

**Figure 21. Calculation of Lamp Requirements Using Code 4010 Criteria for 2 Foot-Candle Level (Sh 1 of 2)**

4 - 75 W Incandescent Lamps = 4 x 1080 Avg Lumens = 4320 Lumens total for 50 space (500 sq. ft.) Shelter

2160 Lumens = 1 Foot-Candle    1620 Lumens = 3/4 Foot-Candle
1080 Lumens = 1/2 Foot-Candle    540 Lumens = 1/4 Foot-Candle

Lamp Values - Average Lumens

100 W Incandescent = 1615 Lumens    75 W = 1080
60 W = 790    40 W = 430

40 W Fluorescent = 3000 Lumens    20 W = 1100    15 W = 690 Lumens

INCANDESCENT

| F.C. | Lamp Size | 50-Space No. | 50-Space Lumens | 50-Space Watts | 500-Space No. | 500-Space Lumens | 500-Space Watts | 2000-Space No. | 2000-Space Lumens | 2000-Space Watts |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 100 | 3 | +4845 | 300 | 27 | 43605 | 2700 | 107 | 172805 | 10700 |
| 2 | 75 | 4 | 4320 | 300 | 40 | 43200 | 3000 | 160 | 172800 | 12000 |
| 2 | 60 | 6 | 4740 | 360 | 55 | 43450 | 3300 | 219 | 173010 | 13140 |
| 2 | 40 | 10 | 4300 | 400 | 100 | 43000 | 4000 | 402 | 172860 | 16080 |
| 1 | 100 | - | - | - | 13 | 20995 | 1300 | 53 | 85595 | 5300 |
| 1 | 75 | 2 | 2160 | 150 | 20 | 21600 | 1500 | 80 | 86400 | 6000 |
| 1 | 60 | 3 | 2370 | 180 | 27 | 21330 | 1620 | 109 | 86110 | 6540 |
| 1 | 40 | 5 | 2150 | 200 | 50 | 21500 | 2000 | 201 | 86430 | 8020 |
| 3/4 | 100 | 1 | 1615 | 100 | 10 | 16150 | 1000 | 40 | 64600 | 4000 |
| 3/4 | 75 | - | - | - | 15 | 16200 | 1125 | 60 | 64800 | 4500 |
| 3/4 | 60 | 2 | 1580 | 120 | 21 | 16590 | 1260 | 82 | 64780 | 4920 |
| 3/4 | 40 | 4 | 1720 | 160 | 38 | 16340 | 1520 | 151 | 64930 | 6040 |
| 1/2 | 100 | - | - | - | 7 | 11305 | 700 | 27 | 43605 | 2700 |
| 1/2 | 75 | 1 | 1080 | 75 | 10 | 10800 | 750 | 40 | 43200 | 3000 |
| 1/2 | 60 | - | - | - | 14 | 11000 | 880 | 55 | 43450 | 3300 |
| 1/2 | 40 | 3 | 1290 | 120 | 25 | 10750 | 1000 | 100 | 43000 | 4000 |
| 1/4 | 100 | - | - | - | 3 | 4845 | 300 | 13 | 20995 | 1300 |
| 1/4 | 75 | - | - | - | 5 | 5400 | 375 | 20 | 21600 | 1500 |
| 1/4 | 60 | 1 | 790 | 60 | 7 | 5530 | 420 | 26 | 20540 | 1560 |
| 1/4 | 40 | 2 | 860 | 80 | 13 | 5590 | 520 | 50 | 21500 | 2000 |

## FLUORESCENT

| F.C. | Tube Size | 50-Space No. | 50-Space Lumens | 50-Space Watts* | 500-Space No. | 500-Space Lumens | 500-Space Watts* | 2000-Space No. | 2000-Space Lumens | 2000-Space Watts* |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 40 | 2 | +6000 | 100 | 14 | 42000 | 700 | 58 | 174000 | 2900 |
| 2 | 20 | 4 | 4400 | 100 | 39 | 42900 | 975 | 157 | 172700 | 3925 |
| 2 | 15 | 6 | 4140 | 120 | 63 | 43470 | 1260 | 250 | 172500 | 5000 |
| 2 | | | | | | | | | | |
| 1 | 40 | - | - | - | 7 | 21000 | 350 | 29 | 87000 | 1450 |
| 1 | 20 | 2 | 2200 | 50 | 20 | 22000 | 500 | 79 | 86900 | 1975 |
| 1 | 15 | 3 | 2070 | 60 | 31 | 21390 | 620 | 125 | 86250 | 2500 |
| 1 | | | | | | | | | | |
| 3/4 | 40 | - | - | - | 5 | 15000 | 250 | 22 | 66000 | 1100 |
| 3/4 | 20 | - | - | - | 15 | 16500 | 375 | 59 | 64900 | 1475 |
| 3/4 | 15 | 2 | 1380 | 60 | 23 | 15870 | 460 | 94 | 64860 | 1880 |
| 3/4 | | | | | | | | | | |
| 1/2 | 40 | - | - | - | 4 | 12000 | 200 | 14 | 42000 | 700 |
| 1/2 | 20 | 1 | 1100 | 25 | 10 | 11000 | 250 | 39 | 42900 | 975 |
| 1/2 | 15 | - | - | - | 16 | 11040 | 320 | 63 | 43470 | 1260 |
| 1/2 | | | | | | | | | | |
| 1/4 | 40 | - | - | - | 2 | 6000 | 100 | 7 | 21000 | 350 |
| 1/4 | 20 | - | - | - | 5 | 5500 | 125 | 20 | 22000 | 500 |
| 1/4 | 15 | - | - | - | 8 | 5520 | 160 | 31 | 21390 | 620 |
| 1/4 | | | | | | | | | | |

* - Including balance.

## PROPANE

| F.C. | 50-Space Fuel-lbs* | 50-Space No. of Lanterns | 50-Space Lumens | 500-Space Fuel-lbs* | 500-Space No. of Lanterns | 500-Space Lumens | 2000-Space Fuel-lbs* | 2000-Space No. of Lanterns | 2000-Space Lumens |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 228 | 8 | 4240 | 2337 | 82 | 43460 | 9291 | 326 | 172780 |
| 1 | 114 | 4 | 2120 | 1169 | 41 | 21780 | 4646 | 163 | 86390 |
| 3/4 | 86 | 3 | 1590 | 884 | 31 | 16430 | 3477 | 122 | 64660 |
| 1/2 | 57 | 2 | 1060 | 570 | 20 | 10600 | 2337 | 82 | 43460 |
| 1/4 | 29 | 1 | 530 | 285 | 10 | 5300 | 1169 | 41 | 21780 |

* Fuel requirement is for continuous burning for 14 days.

Figure 21. (Sh 2 of 2)

## LIGHTING FOR SPECIFIC ACTIVITIES

Inasmuch as some activities may be going on throughout a twenty-four hour period, some selectivity of lighting particularly in the 500 space and 2000 space shelters should be available. Kitchen lighting can be expected to be on earlier in the morning than general lighting for example. Night security lighting will also be necessary and toilet lighting can be expected to be on twenty-four hours per day for the entire shelter stay. Shelter studies with groups as small as 30 persons indicates the desirability of such arrangements. In the larger shelters there is a requirement for a sick bay. Lighting levels should also be adequate for housekeeping and reading. Reading has been found to be a major pastime in confining situations where other diversions are limited.

Assuming some prior planning and administrative controls for the operation of a shelter, the following represents possibilities of skills that may be available from a random selection of population based on data extracted from the U. S. Statistical Abstract for 1961. This is not to say that such skills will in fact occur in any shelter group, since the randomization is from the ideal situation. Shelter groups may be heavily representative of one or more of the skills listed, or of ones not considered, dependent upon the peculiarities of the local situation. In a 50 space shelter, all skills listed below would be small fractions of persons and, thus, the likelihood of any one of these occurring must be discounted. The same is true for birth and death possibilities.that follow. Consequently, figures are given only for 500 and 2000 space shelters.

Some Expected Distributions in Random
Samples of U. S. Population as of 1961

| | 500-Space | 2000-Space |
|---|---|---|
| Physicians | .65 | 2.60 |
| Dentists | .29 | 1.14 |
| Nurses | 1.34 | 5.36 |
| Printing Industry | 2.50 | 10.00 |
| Electrical Industry | 3.50 | 14.00 |
| Instrument Industry | .75 | 3.00 |
| Communication Industry | 2.00 | 8.00 |

The above is to indicate what skills may be present on the basis of manufacturing in the various industries. This is not to say that these persons would be skillful in the use, repair, and/or maintenance of related equipment in the shelter. On the other hand, many persons may have such skills as a hobby or as engineers which have not been considered in the industry figures given above. Printing was included in that the distribution of "news" media and other printed information may be considered a morale factor and thus such skill would be helpful. Physicians, dentists, and nurses were shown from the standpoint of whether or not other than bare medical essentials might be included. This would seem to indicate a negative requirement especially when coupled with the birth, death, and illness figures listed below. These were interpolated from the 1961 Abstract.

| For 14 Days | 500-Space | 2000-Space |
|---|---|---|
| Births | .45 | 1.80 |
| Deaths | .18 | .72 |
| Taken sick | 2.50 | 10.00 |
| Ill at any one time | 1.70 | 6.80 |

As can be seen from the above, there is less than one chance in two of a birth and less than one chance in five of a death in a 500 space shelter in 14 days. A sick bay should certainly be provided in both sizes of shelters since two persons on the average will be ill at all times in the 500 space shelter and seven persons in the 2000 space shelter. Included in the illness figures will be some portion of the birth and death figures since a large proportion of the births at least are hospital cases and the incidence of illness above is based on hospital admissions. The illness figures on the other hand are probably low since it is very likely that bed illness as represented by hospital admissions may represent no more than a majority of all such illnesses.

## PROPANE COMBUSTION

Using the high heat value figure from Marks' Handbook of 2480 Btu per cubic foot for propane, and the Otto Bernz Company figure of 2000 Btu-hr output for their propane lantern, the relationship gives a requirement of .8 cubic foot of gas per hour per lantern. Propane requires 23.87 cubic feet of air per cubic foot of gas for complete combustion, thus each lantern requires 19.2 cubic feet of air per hour or .32 cubic foot per minute. Water vapor is produced at the rate of four cubic feet for each cubic foot of propane consumed, or on the basis of .8 cubic foot of gas per hour, this is .013 cubic foot per minute per lantern. One cubic foot of propane also produces three cubic feet of $CO_2$ during combustion. At .8 cubic foot of propane per hour per lantern, this is 2.4 cubic feet per hour of $CO_2$ per lantern or .04 cubic foot per minute.

At the maximum (2 foot-candle) illumination level considered, 8 by .04 or .32 cubic foot per minute of $CO_2$ would be added to the shelter air of a 50 space shelter. Preferable concentrations of $CO_2$ are two per cent or less with a maximum of three per cent according to Fallout Shelter Surveys: Guide to Architects and Engineers, NP-10-2, Office of Civil and Defense Mobilization, May 1960. Using the two per cent figure and the minimum required mechanical ventilation figure of 3 CFM from the same manual, the allowable addition of $CO_2$ would be .06 cubic foot per minute per person. The eight lanterns in producing .32 cubic foot per minute thus are nearly equivalent to five persons or 10 per cent of the capacity of a 50 space shelter. A 10 per cent increase in the minimum ventilation requirement is indicated to control $CO_2$. At lesser illumination levels the necessary increase in ventilation to maintain the same $CO_2$ concentration would be proportionately smaller.

The requirement of air for combustion purposes is much less important in that at the same 2 foot-candle level, 8 by .32 or 2.56 cubic feet per minute is needed, or less than two per cent of the ventilation requirement.

Reference – Mechanical Engineering Handbook, L. S. Marks, Fifth Edition, 1951, pages 340 – 343.

**Heat Output –**

As noted above neither $CO_2$ nor air present much of an additional requirement on ventilation. However, the heat output is such as to present a considerably increased requirement on ventilation.

A sedentary adult gives off 400 Btu per hour. This can be as much as 3000 to 4000 Btu under heavy exertion.* Thus, depending on the current situation in the shelter, four propane lanterns as required for the two foot-candle level of illumination in the 50 space shelter, and giving off 8000 Btu per hour can represent 20 sedentary adults or two adults hard at work. This then is from a four per cent to a 40 per cent increase in heat output (depending on whether shelter occupants are at rest or at work) which may be expected as maximum variable conditions in a 50 space shelter fully occupied. Whether or not this imposes an unsatisfactory condition on planned ventilation equipment is not within the province of this report.

*Reference – Industrial Ventilation – A Manual of Recommended Practice, American Conference of Governmental Industrial Hygienists. 1958.