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FEASIBILITY OF USING PHOTOVOLTAIC POWER SYSTEMS (PPS)
WITH HIGH PRESSURE..(U) NAVAL CIVIL ENGINEERING LAB
PORT HUENEME CA G WATSON JAN 84 NCEL-TN-1685

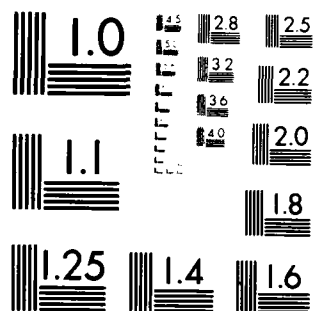
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TITLE: FEASIBILITY OF USING PHOTOVOLTAIC POWER
SYSTEMS (PPS) WITH HIGH PRESSURE SODIUM
(HPS) LAMPS FOR MAGAZINE ENTRY LIGHTING

AUTHOR: G. Watson

DATE: January 1984

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NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

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INTRODUCTION

The Department of Defense (DOD) has dictated new magazine security requirements that, among other considerations, call for entry lighting and intrusion detection systems (IDS), both of which require electrical power. As a result NCEL has undertaken efforts to develop and test photovoltaic power systems (PPS) to provide power for security lighting. Past tests of lighting systems have included an incandescent bulb with an in-line inverter, a 12-volt fluorescent bulb, and a 12-volt low pressure sodium lamp. During FY82 a 24- to 48-volt high pressure sodium (HPS) lamp was tested.

NCEL, in its effort to satisfy the DOD requirements, has addressed the development and proof of concept of using high efficiency lighting fixtures for security lighting using PPS as the power source. Since entry lighting is expected to be more energy intensive than IDS, a PPS developed to meet the lighting requirement can be easily sized to accept the additional load for an IDS without greatly increasing the size and cost of the PPS. Therefore, development of physical security/PPS systems have emphasized the lighting application.

The HPS lamp tested was housed in an explosion proof fixture designed for use in the mining industry. This fixture prevents the intrusion of explosive gases or dust particles into the vicinity of the bulb and circuits driving the bulb. Additionally, the fixture is stressed to contain fragments resulting from bulb failure. As this fixture is designed for use within mine shafts where explosive gas and dust dispersions are typical hazards, it is felt the fixture will provide more than adequate explosion protection when deployed outside magazines in the ambient environment.

PPS is a solar energy collection system that converts solar energy (photons) directly into electricity and makes this electrical power available, as needed, 24-hr/day. For DC loads, a typical PPS is composed of photovoltaic (PV) modules, batteries for electrical power storage, and voltage regulation. AC loads require the addition of power conditioning (inverter). PPS can reliably provide electrical power, but costs are high; an installed system properly designed for a 20-year life can cost up to \$25 for a watt of peak power.* However, the high costs can be justified for small, remotely located electrical power requirements where utility (grid) power is not available and the costs of supplying grid power approach or exceed that of PPS.

*Peak power refers to the maximum power output of the PV panels when fully illuminated by the sun.

BACKGROUND

As the threat of terrorist activities increased throughout the world and in the United States, concern arose that the conventional arms stored in DOD magazines (arms, ammunition, and explosives - A,A&E) would fall into the hands of terrorist groups. DOD redefined security criteria for A,A&E and prioritized physical security upgrades at magazines in the following order:

1. Hardening (new doors, locks, vent vans as required)
2. Fencing (chain link fences around magazines)
3. Intrusion detection systems - IDS
4. Entry lighting

The Naval Sea Systems Command (NAVSEA) allows about 300 magazines (out of a total of about 6,000 magazines in the Navy) to be upgraded each year. Magazines to be upgraded are prioritized according to the sensitivity of the ordinance stored in them. There are four general classes of A,A&E stored in magazines. The most sensitive ordinance is Category I, which includes shoulder-fired weapons designed to provide air defense for ground troops against fighter aircraft. All Category I magazines have been modified to meet the first and second upgrade requirements - hardening and fencing.

The remaining ordinance classifications include Category II - full automatic weapons; Category III - nonautomatic arms; and Category IV - shotguns, handguns, and other such weapons. These magazines will be upgraded as funds become available. There are about 900 magazines in Category II and probably about 4,800 magazines in Categories III and IV.

Typically, security upgrades cost about \$5,000 per magazine. Hardening and fencing are addressed first, and IDS and entry lighting are relegated to a secondary consideration because both require electrical power. Magazine complexes do not generally have utility grid power available for reasons of safety and access. Magazines are generally located in remote areas on land that does not have priority for other purposes, and also they are usually placed in areas where accidental explosions will not have major consequences. This constraint can place magazines miles from other facilities and the attendant grid powerlines. However, the absence of powerlines enhances safety as the danger from fire and explosion caused by electrical sparks and downed powerlines is removed. The Navy finds that the vast majority of magazines under its jurisdiction do not have access to the grid when it is necessary to equip magazines with security upgrades that require electrical power.

The cost of making grid power available to magazines can be prohibitive. Overhead lines would have to traverse several thousand feet to a few miles, in some cases over rough terrain, in order to reach the magazine complex. As a safety precaution the powerlines would have to be

trenched to the magazine over the last 50 feet.* It is difficult to project how much money would be required to supply grid power to magazines because the distance to be traversed, the type of terrain, and the number of magazines per complex can vary greatly. However, a ballpark estimate for overhead powerlines is about \$5/linear ft. The overhead lines will likely require primary wires sized for about 5 to 10 KVA. The trenched cable would cost about \$10 to \$15/linear ft for a 24-inch deep trench with concrete encased cable. Some transformers would be required costing roughly \$5,000 for each magazine complex where a step-down in voltage from 5,000 to 220 or 110 volts is required. So, the cost per magazine will be at least \$500 for trenched power cable plus the amortized cost of overhead lines and transformers. Also, an AC to DC power supply would be required for each IDS installed, which could cost an additional \$200/magazine.

Since the need for electrical power at magazines is for entry lights and IDS only, the required load is quite small. IDS will require just a few watts (less than 5 watts) and entry lights, even the most inefficient ones, will require about 100 watts. Thus, making grid power available at magazines calls for a high dollar cost to serve a relatively small load.

PROGRAM SUMMARY

The PPS array has twelve modules and eight batteries that can be easily wired in series and parallel combinations to provide DC power in increments of 12 volts. Power can be supplied to DC loads or to AC loads through use of an inverter. During the initial phases of the test program only AC lamps were evaluated. However, the need for an inverter in the powerline creates high inefficiencies (30 to 50% losses) in the over-all system. Therefore, efforts were undertaken to develop high efficiency lamps that could use DC directly available from the PPS and obviate the need for inverters.

During FY82, under contract to NCEL, ROSHOK of Boulder, Colo., developed a high pressure sodium (HPS) lamp with a ballast that could accept direct current over a range of voltages from 18 to 60 VDC. This allowed the lamp to be driven by PPS with nominal voltages of 24, 36, and 48 VDC, providing a great deal of flexibility in configuring the PPS for the lamp. ROSHOK delivered five lamps to NCEL. Tests showed that these lamps were compatible with PPS and provided enough light to meet NAVSEA physical security requirements for magazine entry lighting (0.2 foot-candles on vertical walks**). However, the lamps did experience failures due to problems with the electronic circuitry delivering power to the ballast and the HPS bulb. ROSHOK is continuing development of ballast circuits for HPS lamps. New designs will use 12 VDC power and will be available for test and evaluation in FY83-84.

*No overhead lines are allowed to be within 50 feet of the magazine to assure that no downed powerlines can fall across the magazine.

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DISCUSSION

Approach

Since the electrical load required by physical security upgrades at magazines is low, an optional power source to be considered is PPS. In this approach, PPS would be installed on each magazine, providing each unit with an independent power source. This adds desirable redundancy to the security of magazine compounds in that the entire complex is not dependent on one power source (grid power), which can be periodically interrupted. The IDS would probably be coupled with an RF link to monitor the system. The electrical power required by the IDS/RF link would be a few watts. Several options are available to provide entry lighting at the magazine door. Among the choices are incandescent, mercury vapor, fluorescent, and sodium lamps. In past experimental tests at NCEL (Ref 1 and 2), incandescent and fluorescent lamps have been shown to be compatible in operation with a PPS. However, incandescent lamps do not efficiently convert electrical power into light; and fluorescent lamps, although more efficient, have a troublesome temperature dependency that makes them difficult to activate and operate efficiently in cold weather. High pressure sodium lamps do not exhibit this temperature dependence and are among the most efficient lamps available. During FY82 efforts were made at NCEL to adapt the HPS lamp to operation with DC power available from PPS.

Practically all commercially available lamps are designed to operate off AC power with the exception of various fluorescent lamps made available for the recreational vehicle and boating industries. Operation of HPS with DC power requires a ballast design that can accept the DC current. Efforts were made to locate a vendor for an HPS lamp system that could accept DC power. Only one vendor was found that could respond to this requirement.

ROSHOK, of Boulder Colo., is a vendor for HPS lamps that can operate off primary batteries for use in the mining industry. These lamps usually operate at voltages higher than typically used in PPS. However, ROSHOK modified its ballast design to accept DC voltages from 24- to 48-volt PPS. During FY82 this lamp design was submitted to operational tests with a PPS at NCEL.

PPS Test Facility

Flexibility was designed into the PPS in order to easily evaluate the operation of a number of lamps at various system voltages. To this end, the PPS array has a variable tilt mechanism to adjust the seasonal collection efficiency as required by the load. The batteries and modules are connected to terminal strips inside a junction box (Figure 1), which allows the PPS to be rapidly reconfigured to any voltage level in nominal increments of 12 volts. Terminal strips for instrumentation and lamps are also included in the terminal box.

The photovoltaic modules as originally deployed for initial lamp tests are shown in Figure 2. During the Memorial Day weekend of 1982, five of the PV modules were broken, apparently by vandals throwing rocks from outside the woven wire fence around the NCEL compound. As a

precaution against further breakage, a chicken wire screen was erected over the PV modules as can be seen in Figure 3. The entire PPS/lamp test facility is shown in Figure 3. The structure to the rear of the PPS is a 4x8-foot sheet of 3/4-inch plywood with the top edge at 10 feet of elevation used to simulate a large magazine door. The lamp at the top of the structure is a ROSHOK HPS lamp. The two lamps on either side are low pressure sodium (LPS) lamps made by Bodine Engineering, Memphis, Tenn. The Bodine lamps were not submitted to quantified testing during FY82; operational lamp testing during FY82 only addressed the HPS lamp because the HPS system produce a broader color spectrum of light and, in general, have better conversion (electrical power to light) efficiencies through LPS systems. Also, LPS lamps have a troublesome temperature dependence that inhibit lamp performance at low temperatures making them less desirable in cold climates; so HPS systems have more potential for wide deployment in cold as well as warm climates.

HPS Lamp Characteristics

HPS lamps belong to the general classification known as electric-discharge lamps. In this type of lamp, light is produced by the passage of an electric current through a vapor or gas. The application of an electric potential ionizes the gas and permits current to flow between two electrodes located at opposite ends of the lamp. The electrons, which comprise the current stream or "arc discharge," are accelerated at tremendous speeds. When they collide with the atoms of the gas, or vapor, they temporarily alter the atomic structure. Light results from the energy given off as the disturbed atoms return to their normal state.

In HPS lamps, the gas utilized is vaporized sodium. The arc tube contains xenon as a starting gas and a small quantity of sodium-mercury amalgam, which is partially vaporized when the lamp attains operating temperature. The mercury acts as a buffer gas to raise the gas pressure and operating voltage of the lamp to a practical level. The original arc is struck through the ionization of this xenon gas. Once the arc strikes, the heat generated vaporizes the amalgam. The impact of the arc heats the emissive material which supplies electrons to maintain the arc.

The HPS lamps require starting voltages to ionize the neon gas and permit the arc to strike. The electrical field setup between two electrodes at either end of the bulb causes an emission of electrons which develop a local glow and ionize the starting gas.

The sodium gradually vaporizes and carries an increasing portion of the current. At the instant the arc strikes, the current is high and the voltage is low. Normal operating values are reached after a warmup period of several minutes, during which the current drops and the voltage rises until the arc attains a point of stabilization in vapor pressure.

Each ballast must be designed for the specific voltage, frequency, and lamp with which it will be used. An important advantage of HPS lamps is their ability to operate well over the range of input voltages for which the ballast was designed. Operation with input voltages above or below the ballast voltage range is not recommended. If the supply voltage is unusually low, the lamp may not start or may require a longer time to warm up. When the supply voltage is too high, excessive lamp wattage may result.

HPS lamps are constructed with two bulbs: an inner bulb or arc tube, which contains the arc, and an outer bulb which shields the arc tube from changes in temperature and in some cases acts as a filter to remove certain wavelengths of the arc radiation. The arc tube is made of quartz in most lamps and of hard glass in a few of the older types. Quartz permits a more concentrated source of higher efficiency.

HPS lamps radiate energy across the visible spectrum, and the light input produced is golden white in color with all frequencies visible to the human eye present. These lamps have efficacies of 60 to 140 lumens/W, depending on the size of the bulb. Increasing the sodium pressure increases the percentage of red radiation and thus improves color rendition.

ROSHOK HPS Lamp

The ROSHOK N-H035LE HPS Luminaire (Figures 4 and 5) with sun sensor inhibitor is designed to provide outdoor wall-wash illumination, using a low voltage DC power source. A switch selects either a high or low output light level.

A ROSHOK solid-state ballast system properly operates the 35-watt HPS. The ballast system performs all necessary functions to start the lamp, to match an acceptable wide voltage range input into the ballast to the lamp requirements, and to precisely control power for an ideal lamp/ballast characteristic as recommended by the lamp manufacturer for long life and proper operation. The solid-state ballast efficiently changes the low DC input voltage (18-55 VDC) into a high frequency output with precisely regulated power at the lamp.

All printed circuit boards are humisealed as protection against moisture and corrosion. The housing and controls are RTV-sealed to prevent moisture from entering. To ensure the integrity of the seals, only the front glass panels are opened for relamping. Two release levers are provided on the front panel for opening and closing.

The lamp meets the following specifications and operating characteristics:

Input

Safe limits	0 to +60 VDC
Operating range	+20 to +52 VDC
Lamp inhibits to standby	<18 VDC; >55 VDC
Standby current (max)	2mA @ 20 VDC; 4mA @ 40 VDC
Reverse polarity	Shorts input (20 ampere capacity)
Operating power	25-50 watts depending on input voltage and brightness switch selection; lowest power dissipation at largest input voltage.
Hookup	Red (+); black (-); and case ground.

Lamp System

Lamp	High Pressure Sodium, GE LU35/MED
Socket	Medium (MED) base
Housing	Modified Keene fixture Cat. No. CT-500 Series
Starting pulse	Approximately 1 sec, several pulses may be necessary to restrike
Weight	11 pounds
Dimensions	6 x 9 x 9 in.
Mounting	Any orientation

Controls (Rear mounted)

Brightness Toggle Switch

H

High power, 35-watt lamp output

L

Low power, 20-watt lamp output

Sun Sensor

Adjust sensitivity by moving metal clip.

Blockage of sun sensor turns lamp on sooner; off later. Put very dark tape over sun sensor if daylight operation is desired.

Ambient Environment

Sealed unit

Suitable for wet outdoor installation

Temperature

-40° to +55°C

The lamp was designed for easy, rapid installation as well as high efficiency operation attendant with the HPS bulb. ROSHOK designed a DC/DC power conditioning unit to drive a standard ROSHOK ballast. Both electrical components are integrally contained within the lamp enclosure. With this ballast design, the DC power available from the PPS is supplied directly to the lamp. An inverter need not be placed in the powerline as is required by other commercially available HPS lamps. The electrical installation merely involves connecting two power leads (Figures 4 and 5) with proper polarity. The lamp housing is mounted with a standard 3/4-inch electrical conduit which allows the lamp to rotate through 360 degrees about the azimuth plane and 180 degrees through the polar plane. A sun switch to turn the lamp on at dusk and off at dawn is indicated by the finger in Figure 5, and there is no need to hook up an external sun switch, making for a more convenient installation. Also seen in Figure 5 is a switch for high or low light intensity operation.

The lamp can operate at input voltages from 20 to 52 VDC. Operational tests were done at NCEL by driving the lamp with the PPS configured to a 24-VDC system. Sizing analyses showed that the lamp would need 200 AH at 24 VDC of battery storage and about 150 peak Watts of PV array to operate the lamp. The PPS was configured as shown in Figure 6 to meet this requirement. The Delco 1150 batteries provide 210 AH of storage, and the ARCO Solar ASI 16-1200 modules will provide 150 watts at peak sun. The batteries are protected from overcharge by an ARCO Solar universal charge controller (UCC).

The PPS was instrumented to monitor system performance. Current shunts were placed in the grounded leads, negative pole, on the battery charge circuit and the lamp load circuit to quantify the charge and load currents. Battery voltage was recorded, and insulation was monitored by a Rho Sigma PV pyranometer. The instrumentation setup is also shown in Figure 6.

Recorded data indicate the lamp current draw varied from 2.35 to 2.6 amperes from dusk to dawn. The battery voltage accordingly varied from 24 to 23.2 VDC. The corresponding power draw by the lamp was 56.4 to 60.3 watts. The power drain is higher than the expected 50-watt load for the ROSHOK lamp. The lamp has a General Electric 35-watt HPS bulb, and the power supply circuitry and ballast were expected to draw about 15 watts. Although the instrumentation setup draws some power at the current shunts (about 0.8 watts are dissipated by the shunt in the load line), it can be concluded that the lamp circuit and bulb present a load

of about 60 watts to the PPS. This would indicate that the PPS configured for a 50-watt load is somewhat undersized and will likely not be able to power the lamp through the longer nights of the winter season. To meet the 60-watt nighttime load, the PPS will be reconfigured in future tests to 10 PV modules and six batteries.

The lamp tested at NCEL has performed in an acceptable manner throughout the test period. The density of the luminous flux (illuminance) incident on the simulated door and emanating from the lamp was measured by a Weston footcandle meter model 614. Illuminance was measured on the vertical surface on which the lamp was mounted and on the ground immediately below the lamp. The spatial distribution in foot-candles (fc) is depicted in Figure 7 for the illuminance on the vertical surface (x-y plane) and on the ground (x-z plane). The lamp is hung over the door and is canted slightly back toward the door. The unit normal between the door and the face of the lamp is about 75 degrees. A relatively high illuminance (34 fc) was measured close to the lamp as this location is well within the directed beam of the lamp. The illuminance quickly falls to 3 fc at the midpoint of the door and diminishes to 1 fc at the 2-foot elevation. This occurs principally because cosine losses become significant at these lower elevations. The illuminance is higher on the x-z plane because the cosine losses are not nearly as pronounced in this plane. These data clearly show that greater illuminance can be attained if the lamp can be displaced away from the door along the positive z-axis and oriented to shine back onto the door as this will reduce cosine losses.

A nighttime photo taken with high speed black and white film of the illumination pattern given off by the lamp is shown in Figure 8. Although illuminance cannot be quantified from Figure 8, it does give an indication of the definition of light patterns available with the lamp.

NAVSEA specifications for physical security illumination calls for a minimum light level of 0.2 fc on vertical surfaces. Data in Figure 7 show that the ROSHOK HPS lamp meets this minimum requirement. However, the data were taken with a light meter that did not have sufficient sensitivity to define accurately the variation in illuminance across the door. NCEL has initiated procurement of a more sensitive light meter that can measure luminance (light reflected from the surface to be observed) with an accuracy of hundredths of foot-candles over a range from 0.01 to 20.00 fc. Further tests will better define the lumination of these lamps.

ROSHOK delivered five HPS lamps to NCEL in February 1982. One lamp has been operating continuously on PV power at NCEL from April to September 1982. However, the other four lamps have failed due primarily to a high current, field-effect transistor (FET) used in the DC/DC power supply which is designed to drive the ballast with DC power directly from the PPS. The FET tends to burn out if it is not protected from current flow at low voltages. The ballast will draw high currents at low voltages which in turn overheats the FET. Although the lamps will operate with this power supply configuration, ROSHOK has considered other circuits to adapt the HPS lamps to PPS. Second-generation DC circuits for the DC power supply are appropriate in further lamp procurements.

PPS Cost for Magazine Lighting

Photovoltaics can provide reliable power to remote high priority loads where the low maintenance attributes of PV are valuable. However, costs for PV are high. The costs of installed PPS to serve remote, stand-alone loads for which the Navy has contracted are today at about \$15 to \$25 per peak watt of PV power, depending primarily on the difficulty of the installation. Access to very remote sites (mountain tops, for instance) drive the cost up dramatically. Based on this criteria, the 200-peak-watt PPS recommended for the RUSHOK HPS lamp can be expected to cost about \$3,000, which is at the lower end of the cost range, because all magazines have road access and thus cannot be considered truly remote sites. Also, the cost of PV has dropped sharply in the last 5 years, and further drops are expected by industry and government officials. As the physical security upgrades at Navy magazines for A, A&E will apparently take place over the next several years, the cost of PPS for magazine entry lighting can be expected to become more competitive with conventional power.

It is difficult to make meaningful comparisons of the cost of PV-powered security lighting systems with grid-powered systems because the total cost of making grid power available to magazine sites depends to a large degree on the distance over which powerlines must be installed. However, the requirement that powerlines must be installed in trenches within 50 feet of magazines offers a starting point for estimating the cost for grid installation. As reported in the BACKGROUND section of this document, trenched powerlines will cost about \$500/magazine. If an IDS is installed at each magazine as well as lights, a DC power supply must be provided for each magazine. This would cost at least \$200/magazine. On the other hand, with PPS, the cost of DC power supplies is circumvented because PV power is DC itself. Added to costs for the trenched powerlines and IDS installation is the expense of installing overhead powerlines from the existing grid to the magazine site as well as transforming banks to make the high KVA grid power available to conventional lamps and DC power supplies for IDS. Overhead lines and the attendant transformers are an unknown but certainly are substantial cost items for all magazine complexes that are at considerable distances from the power grid. The total cost would be spread over the installation cost of all magazines in the complex (\$700 plus cost of overhead lines and the transformers). Total cost, including installation for the PPS, is \$3,000, as indicated earlier.

CONCLUSIONS AND RECOMMENDATIONS

HPS lamps are very efficient converters of electrical energy into light. Tests performed at NCEL have shown that it is feasible to operate HPS lamps with DC power available from PPS. Further testing of HPS lamps throughout all seasons is required to confirm sizing methodologies. More lengthy field tests of HPS lamps/PPS systems will offer additional support for durability of this lamp in the field.

The cost of PV has decreased in the past, and further price declines are expected, which makes use of PPS for magazine security more attractive in the future as the major portion of Navy physical security upgrades at A, A&E magazines is carried out.

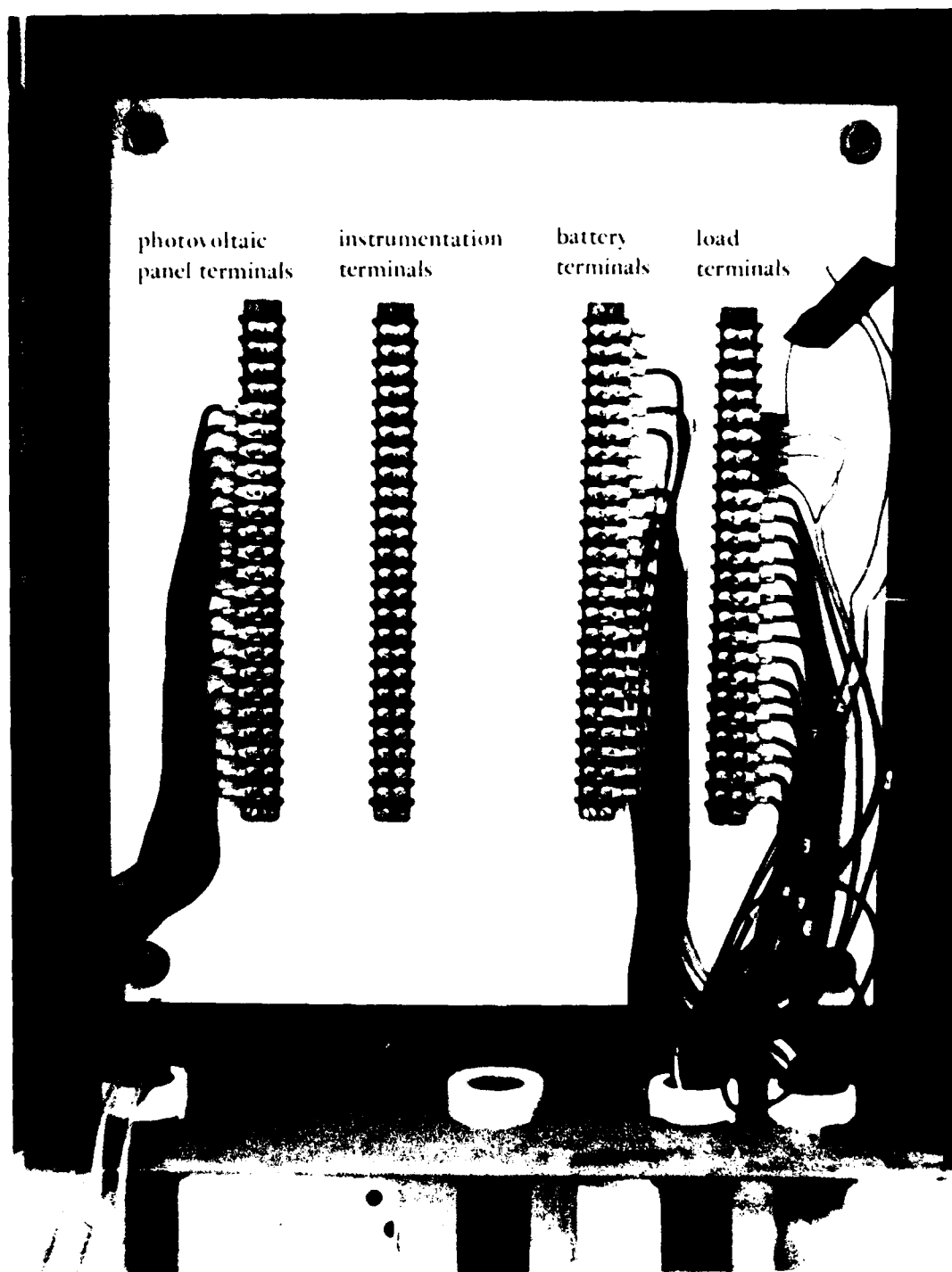


Figure 1. Terminal box for PPS/lamp test.

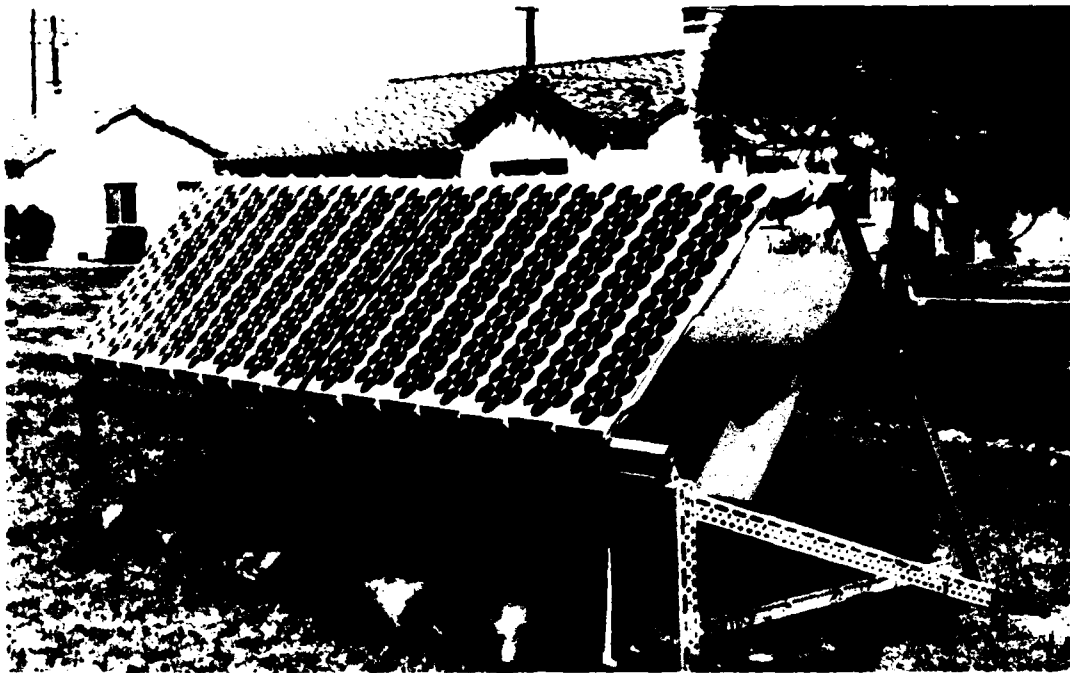


Figure 2. Photovoltaic array.

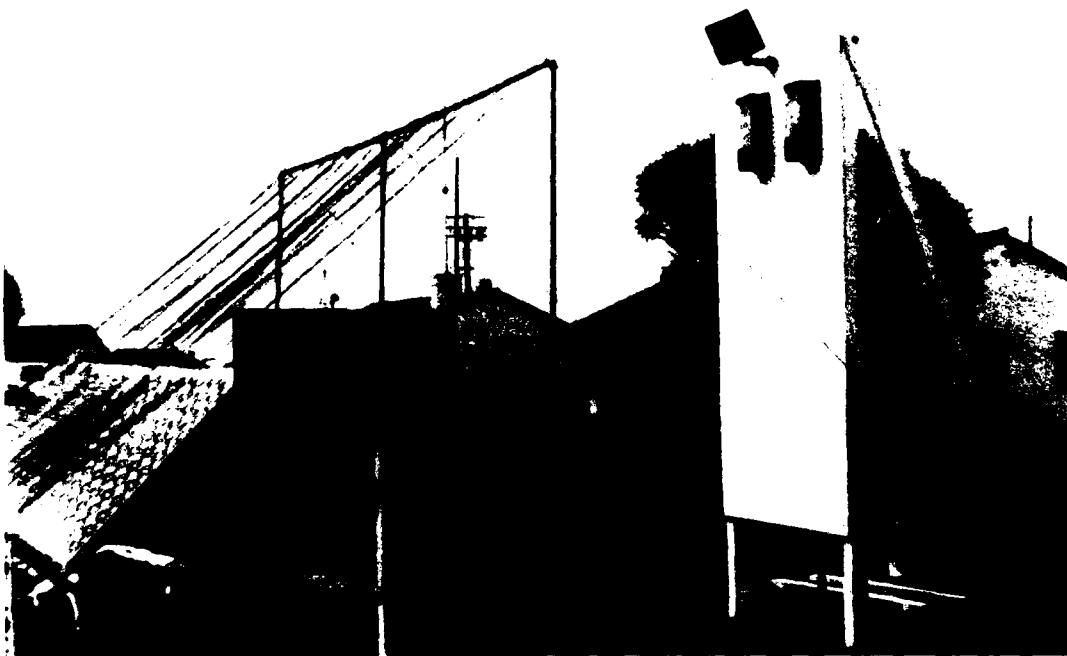


Figure 3. PPS with lamp test stand.



Figure 4. ROSHOK lamp with 35-watt HPS bulb.



Figure 5. ROSHOK HPS lamp controls.

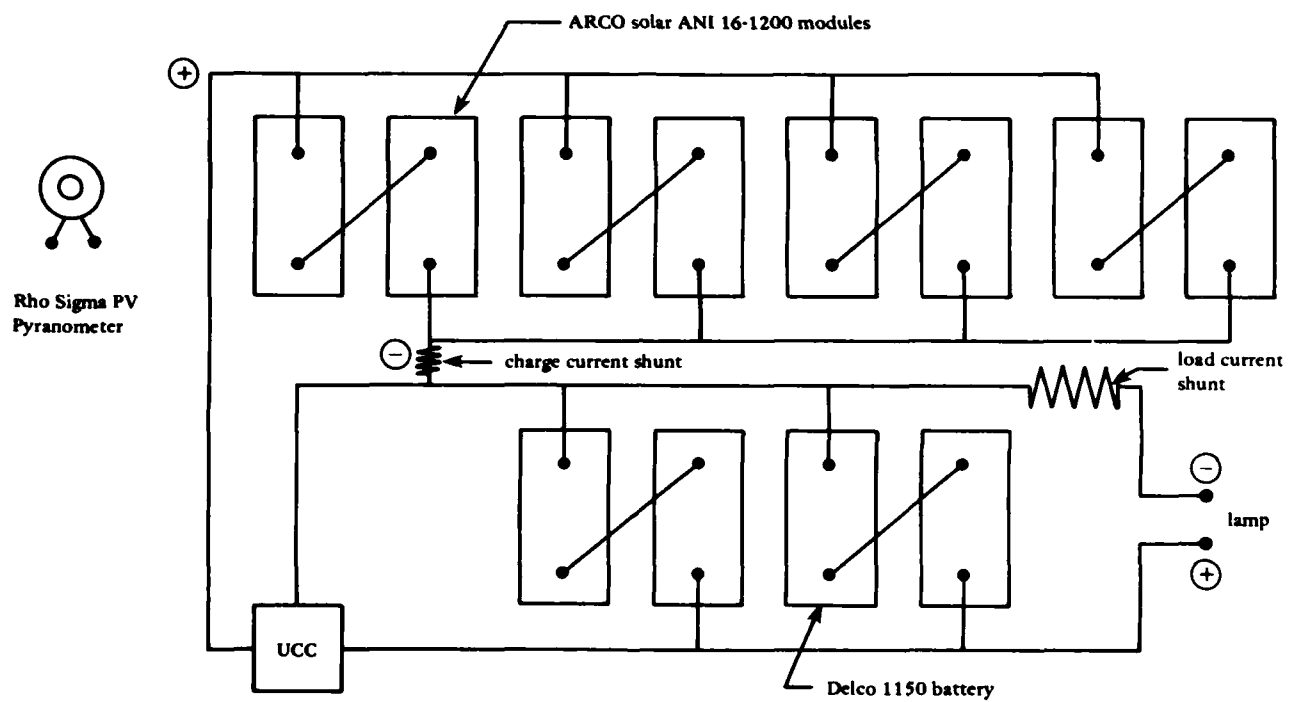


Figure 6. PPS 24 VDC configuration with instrumentation as indicated.

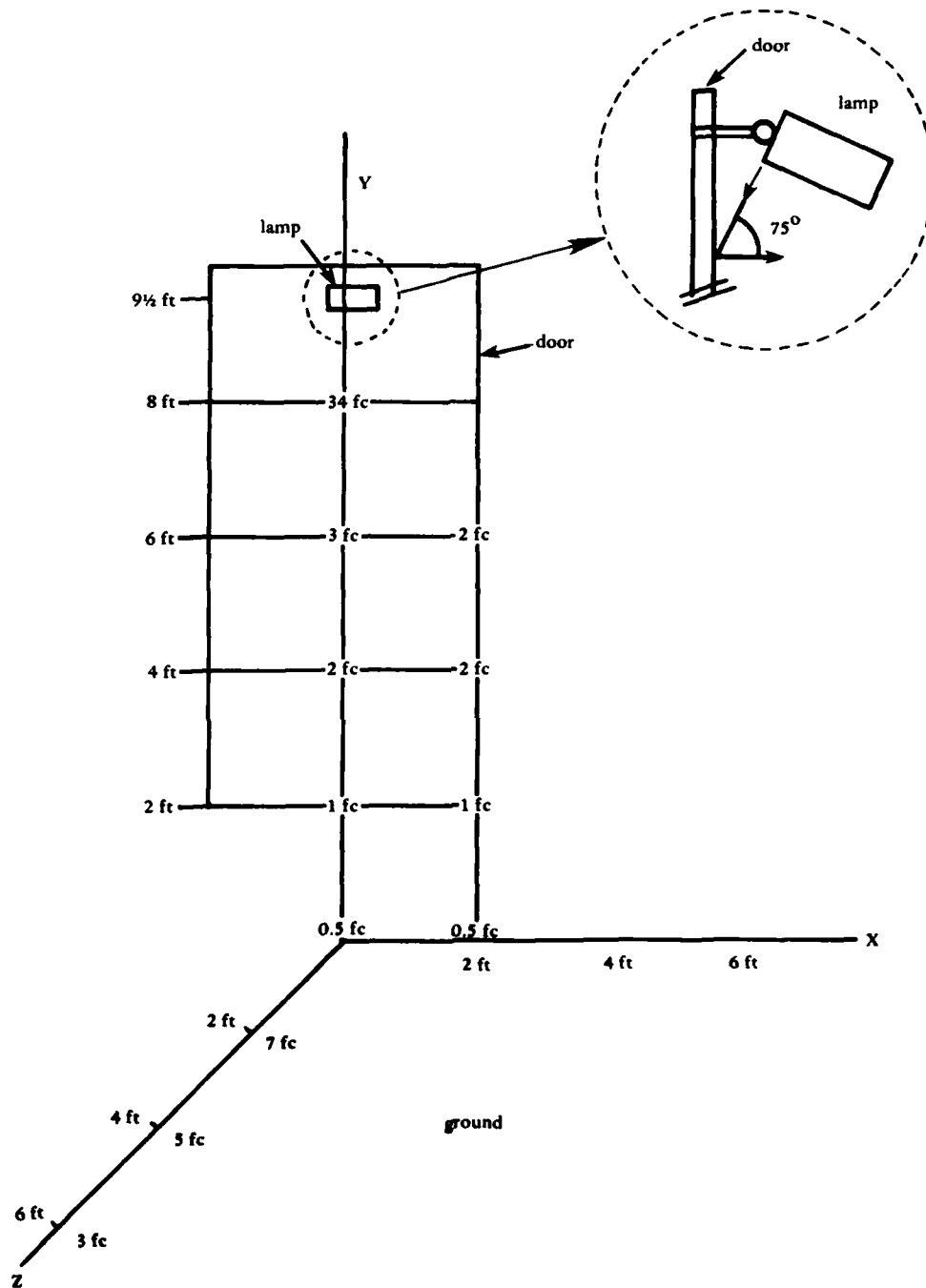


Figure 7. Measured illuminance distribution for HPS lamp.



Figure 8. Nighttime illumination with HPS lamp.

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