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SAFETY ANALYSIS REPORT NATURAL BRIDGES NATIONAL MONUMENT 100-kW PV POWER SYSTEM

September 1981

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Prepared for
THE U.S. DEPARTMENT OF ENERGY
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ABSTRACT

The 100-kWp solar photovoltaic power system at Natural Bridges National Monument is a unique electrical power-generation system. Safety was a paramount concern in the design of the system. This report analyzes the potential hazards that exist, both in the environment and the facility, and then provides an insight into the protection and safety systems that exist at the site.

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Safety Analysis Report
Natural Bridges National Monument
100-kW PV Power System

1.0 INTRODUCTION

1.1 Scope

The purpose of this Safety Analysis Report (SAR) is to identify the potential hazards that exist at the photovoltaic (PV) power system installed at Natural Bridges National Monument (NBNM) Utah. Methods of hazard elimination or control are specified, together with an assessment of risk where appropriate or possible. Methods used to minimize risks to the health and safety of the public and working personnel at NBNM are identified, as well as an assessment of how adequately property and the environment are protected.

The objectives of this SAR are to systematically identify the potential hazards that exist at NBNM, to analyze the potential impacts of these hazards and to identify the reasonable measures taken to eliminate, control, or mitigate them.

The following information is provided to accomplish the purpose and objectives of this SAR:

- Description of the site
- Description of the PV system and its operation
- Where appropriate, the design criteria required for systems, components, and structures
- Identification of potential hazards
- Identification of potential accidents, including those resulting from natural phenomena
- Physical design features and administrative controls provided for the prevention and mitigation of potential accidents

- Where possible or appropriate, the probability of occurrence and predicted consequences of possible accidents, expressed in quantitative terms
- Normal and emergency operating procedures
- Operational limitations.

1.2 Summary of Facility and Operators

MIT Lincoln Laboratory (MIT LL) under the sponsorship of the U. S. Department of Energy (DOE) and in collaboration with the National Park Service (NPS) has managed the design, fabrication, installation, and testing of a 100-kW-peak PV power system for NBNM in southeastern Utah. This system became operational in May 1980. It converts sunlight into DC electrical power, supplies AC power to the NBNM site through an inverter, and has on-site electrical storage in a large battery bank. Typically, the site demand runs from 10 to 40 kW. In addition, certain critical PV system AC loads are supplied from an uninterruptable power source (UPS) inverter. Since there is no electric utility service for NBNM, nor is one planned, a diesel-powered generator serves as a backup for the PV system during periods of reduced solar energy.

As shown on Fig. 1-1, the PV system layout is composed of a solar array field connected to equipment installed in the PV building by means of a 1000-foot underground power cable. The equipment layout within the PV building is shown in Fig. 1-2. The diesel-powered generators, housed in a separate building adjacent to the PV

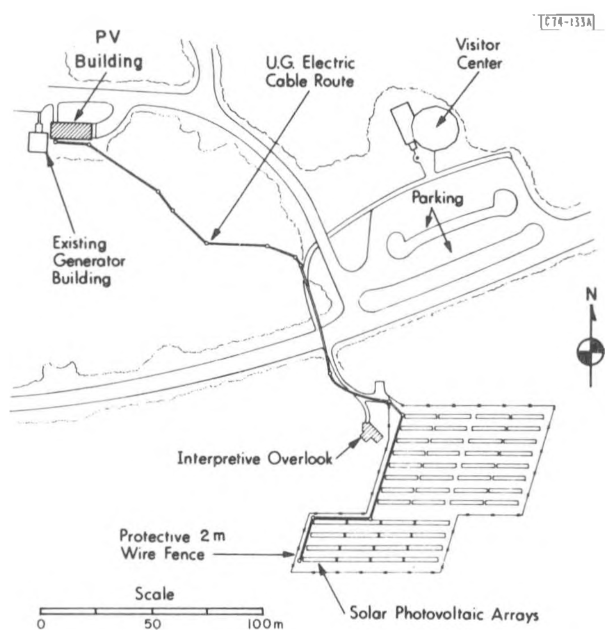

Fig. 1-1. PV system layout.

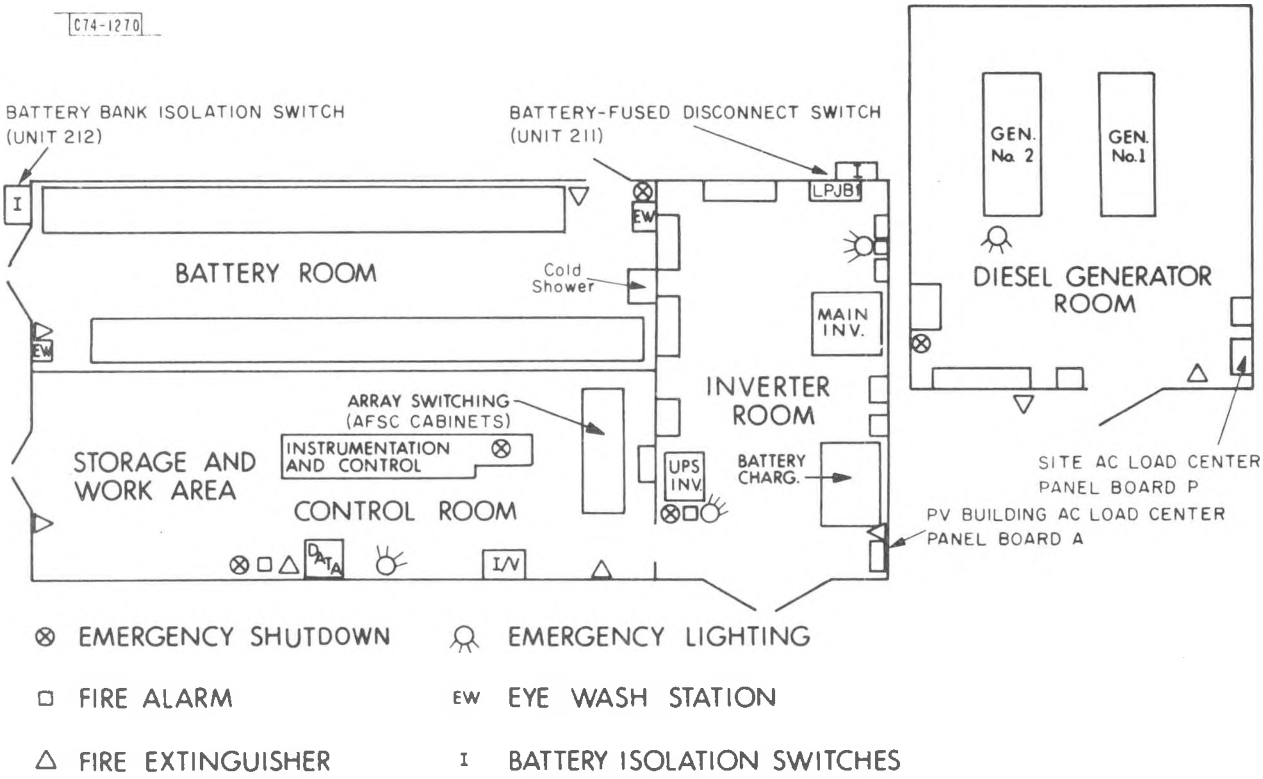

Fig. 1-2. NBNM PV building.

building, were used prior to the installation of the PV power system; they had provided the only power available to NBNM.

Refer to Chapter 3, "Site Description," and Chapter 4, "Facility and Operations Description," for more detailed information.

2.0 SUMMARY

2.1 Potential Hazards

Potential hazards can be attributed to natural causes, operational causes, and extrinsic causes.

Environmental analysis revealed little probability of hazards due to natural causes. Floods and landslides are not expected to have a significant impact. The area devoted to the PV system is remote from the small streams which traverse lower ground. The gently sloping soil is not likely to generate a landslide. Specifications for construction included such factors as anticipated snow and wind loads, frost depth, and seismic activities.

The principal hazards associated with the operations of the system are electrical shock, electrical arcs, and bodily injury. Other hazards (Table 4-1) include acid burns, explosion, lightning strikes, fire, and glare. It should be emphasized that these hazards are speculative since no history of such hazards has been reported since the site became operational in May 1980. These potential hazards were considered during the design of the PV system.

Extrinsic causes are not directly related to the operation of the PV system. They include such factors as traffic control and visitor safety. NPS regulations govern this aspect of the hazard analysis.

2.2 Summary, Safety Analysis

The design of the NBNM PV system was completed with safety as a paramount feature. Any potential hazard was guarded against by a combination of redundant warning devices, protective devices, and construction practices. For example, the potentially most dangerous condition would be a hydrogen gas explosion in the battery room. To prevent this from happening, three hydrogen gas detectors connected to alarms were placed within the battery room, which was sealed to prevent gas seepage into any adjacent rooms. A ventilation system was installed to introduce outside air to dilute any hydrogen gas present and to vent the air to the outside. In addition, sealed vent caps were installed on the batteries to prevent the escape of hydrogen into the battery room. Finally, if an explosion did somehow occur, the south wall of the battery room was designed to blow out more easily than the interior wall, thus protecting lives and equipment in the control room. This attention to detail was carried out throughout the entire design of the PV system.

3.0 SITE DESCRIPTION

3.1 Site Location

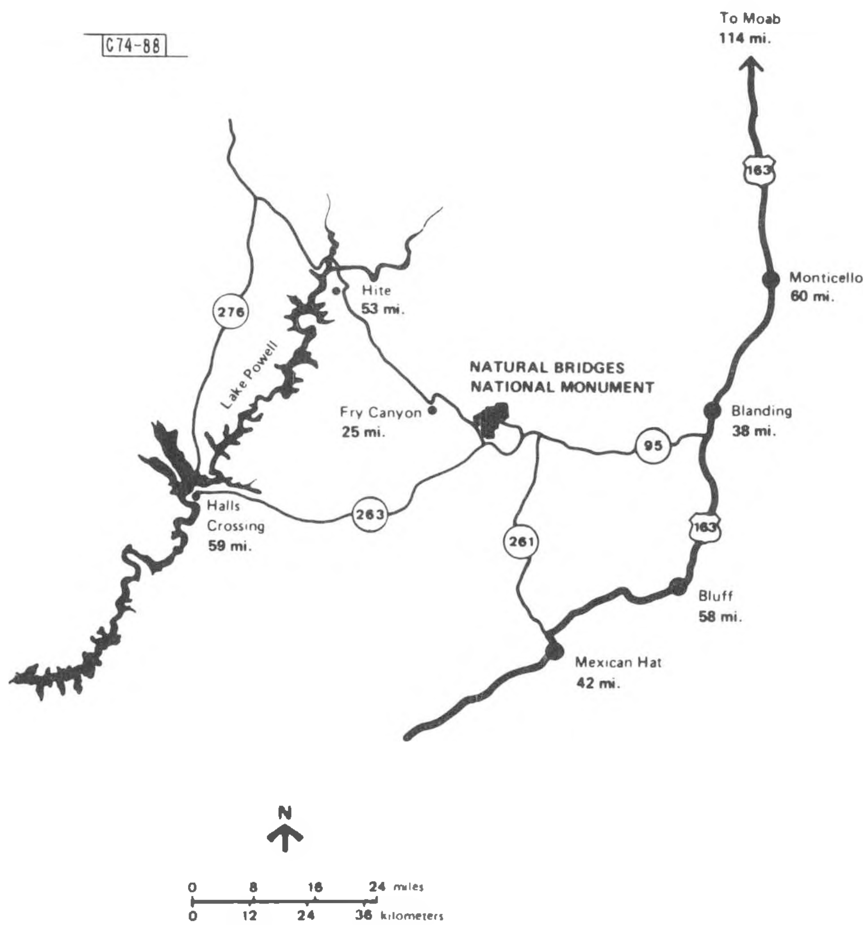

Fig. 3-1. Distances from Natural Bridges National Monument.

As shown on Fig. 3-1, NBNM is located 38 road miles west of Blanding, Utah, which is the location of the nearest public utility. The site is approximately 55 road miles east of Lake Powell and has an elevation of 6500 feet.

Three magnificant sandstone bridges are located at NBNM. Carved by the occasionally violent scouring action of desert streams, the bridges bear mute testimony to nature's power to reshape the land. In 1908, President Theodore Roosevelt proclaimed the area as a national monument. In 1980, approximately 80,000 visitors visited NBNM.

3.2 Environmental Factors

3.2.1 Geology and Topography

NBNM is situated within the Colorado plateau, which embraces most of the eastern half of the state. The surrounding countryside contains deeply incised canyons, natural bridges and arches, and towers and turrets of every description. The geology of NBNM is composed of a cross-bedded sandstone known as cedar mesa sandstone which lies close to the surface.

3.2.2 Climatology and Meteorology

In general, the climate is temperate with occasional severe wind, rain, and snowstorms. Tornadoes are almost unknown. Weather information from 1965 to 1975 is shown in Table 3-1.

Table 3-1

NBNM Weather Information

Month	Average Precipitation (inches)	Average Snowfall (inches)	Temperatures			
			Highest Recorded	Average Maximum	Average Minimum	Lowest Recorded
January	0.73	8.77	60	40.70	16.45	-11
February	1.00	9.07	64	45.87	21.56	0
March	1.06	8.49	73	52.13	26.81	5
April	0.71	4.41	78	60.44	31.18	6
May	0.54	0.68	92	74.39	40.64	18
June	0.75	—	101	84.44	51.17	35
July	1.93	—	103	90.71	59.13	48
August	1.73	—	99	86.34	56.48	40
September	0.89	—	92	77.33	48.48	30
October	1.71	1.18	83	64.76	38.40	6
November	1.72	5.50	69	49.92	27.92	-2
December	1.53	17.91	58	36.85	17.11	-7
Yearly average	14.30	56.01				

3.2.3 Demography

Human population at NBNM, except for visitors is very sparse, and limited to a small group of NPS personnel who protect and maintain the area on a year-round basis.

3.2.4 Vegetation

The vegetation at the site is that which normally prospers in high-altitude, fertile, nonalkaline soil. The soil depth varies from 0 to 30 inches.

3.2.5 Animal Life

There are numerous animals of varying size and type which are common to this area of Utah. The most common are mule, deer, hawks, and rattlesnakes to name a few.

3.2.6 Air Quality

The air quality, which is normally good, has been improved by the installation of the PV system. Previously, electric power was provided by two diesel generators which emitted exhaust products into the atmosphere. The diesel generators are now seldom used except as a backup power source when solar insolation is poor over a protracted period.

3.2.7 Noise and Vibration

Ambient noise levels due to the operation of the diesel generators have been curtailed since the installation of the PV system.

3.2.8 Earthquake Probability

Earthquake probability is moderate. The seismic risk zone for NBNM is 2, as determined by American National Standard Building Code (ANSI A58.1-1972) requirements for "Minimum Design Loads in Buildings and Other Structures."

3.2.9 Floods and Landslide Probability

Floods and landslides are not expected to have a significant impact. The area devoted to the PV system is remote from the small streams which traverse lower ground. The gently sloping soil is not likely to generate a landslide.

4.0 FACILITY AND OPERATIONS DESCRIPTIONS

4.1 General Facility Description

The principal components of the 100-kW-peak PV power system for NBNM, together with their potentially hazardous areas are identified in Table 4-1.

Table 4-1
NBNM PV Power System
Principal Components and Hazards

Hazard Areas	Hazard Types							
	Electrical Shock	Electrical Arcs	Bodily Injury	Acid Burns	Explosion	Lightning Strikes	Fire	Glare
Solar PV array	X	X	X			X		X
Buried power cable	X	X						
PV building battery room	X	X	X	X	X		X	
PV building control room	X	X	X				X	
PV building inverter room	X	X	X				X	
Generator building	X	X	X		X		X	

4.2 Operations Description

The PV power system is organized as shown in Fig. 4-1. Power from the array field subsystem is fed through a 1000-foot underground cable to power conditioning equipment housed in the PV building. An adjacent building contains the diesel-powered generator which serves as backup to the PV system. Under normal operation, the site AC power is supplied by a 40-kVA main inverter which draws DC power from lead-acid batteries. The momentary overload capability of the inverter supports motor-starting

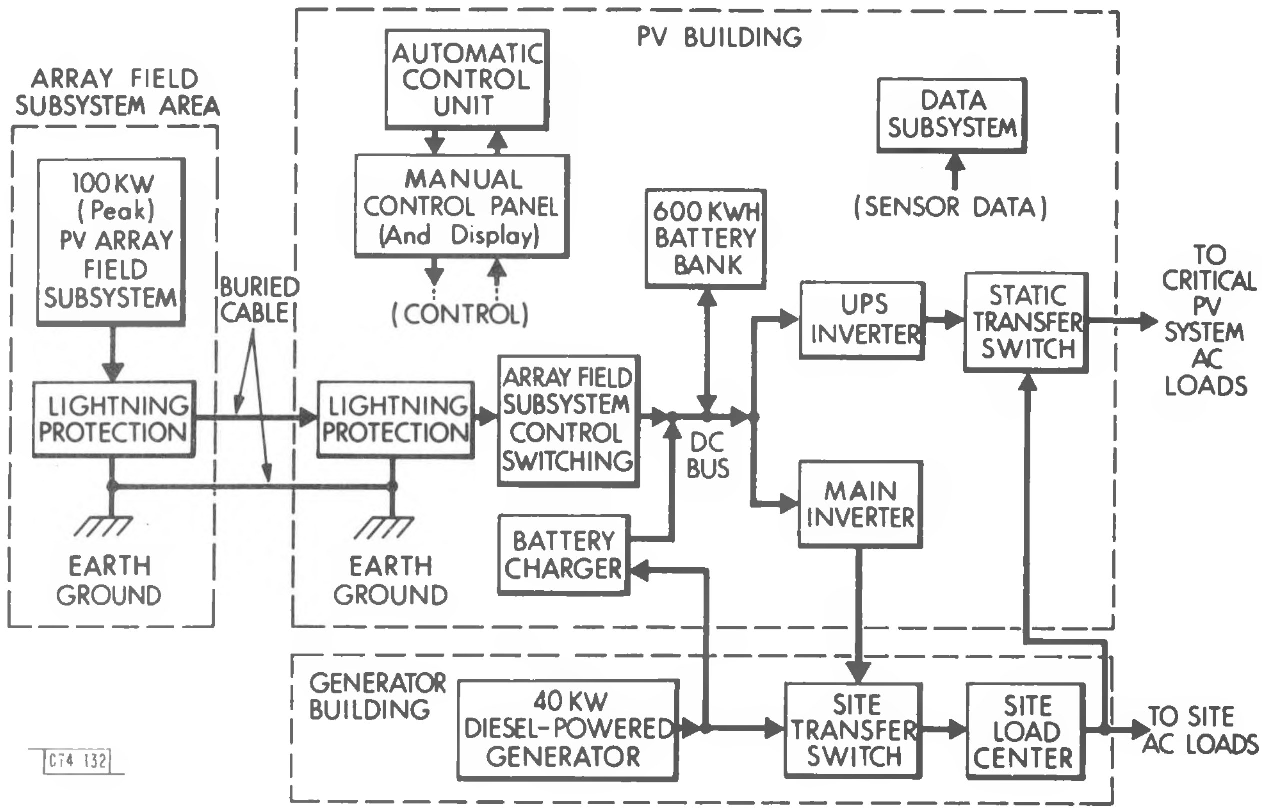

Fig. 4-1. Simplified PV power system.

transients. The hazards associated with the equipment located in areas are provided in Table 4-1.

The solar energy from the PV array field is used to recharge the batteries during daylight hours. When weather patterns prevent the collection of adequate solar energy from the array field, the diesel will be used to charge the batteries through a battery charger. Hourly simulations have indicated that the diesel will supply less than 15 percent of the annual energy consumption. Conservation measures may reduce this figure considerably.

The normal operating mode for the PV system makes use of an Automatic Control Unit (ACU) which activates the elements of the system through a Manual Control Panel (MCP). Charge control for the battery is accomplished by shedding one or more of the 48 array subfields when the battery reaches full charge. A periodic battery equalization cycle is automatically scheduled by the ACU and accomplished by running the diesel to power the battery charger.

Certain critical AC loads, such as the control subsystem (ACU and MCP), the data subsystem, and the alarm subsystem is powered by a small (5-kva) UPS inverter. A static transfer switch switches the critical loads to site power if the UPS inverter should fail.

Energy storage for the PV system is provided by a bank of lead-acid batteries with a usable storage capacity of 600 kWh. This capacity was chosen based on hourly simulations by considering the displacement of fossil fuel (diesel oil).

It is expected that the usable capacity of 600 kWh will correspond to a maximum allowable battery drawdown of 80 percent of total capacity. The routine drawdown beyond this point, which corresponds to a state of charge (SOC) of 20 percent, will be avoided so as to not adversely affect the battery life.

If the battery SOC should fall to 20 percent the ACU will implement an operational mode which goes as follows. The ACU will initiate the process of automatically starting the diesel and bringing it under load. In the simplest case, the generator output power is fed through the battery charger to recharge the batteries while the site AC power continues to be supplied by the main inverter.

In the event that the diesel fails to start, the ACU will initiate an alarm and continue to monitor the battery SOC. If the SOC reaches 17 percent, the ACU will shut down the main inverter thereby dropping the site. Following the main inverter shutdown, the only load on the battery will be through the UPS inverter which powers the critical AC loads. As a consequence of the small demand (less than 1 kW), the battery SOC might be expected to drop no faster than 1 percent every six to seven hours.

Allowing an additional 2-percent drop before final shutdown, that is to a battery SOC of 15 percent, leaves a minimum of 12 hours for remedial action to either start the diesel, or place the alternate diesel-powered generator in service. If for any reason a backup diesel cannot be brought on-line, at 15-percent SOC, the ACU will initiate a shutdown of the UPS inverter, and thus itself, leaving the system nonoperational.

The array field subsystem (AFS) is located on a 1.4-acre plot and consists of 48 array subfields arranged in 12 rows. The layout was chosen to take advantage of a 6-percent southward slope and to follow the natural terrain.

A total of 266,028 silicon solar cells in 4716 glass-covered PV modules from three manufacturers converts sunlight to DC electric power. The modules are Motorola (Block III*), Spectrolab (Block II), and Arco Solar (Block III). Each of the 48 array subfields produces just over 2 kW at the bus voltage of 220 VDC on a clear day.

When maintenance operations are required, any subfield may be removed from the line and a test set employed for diagnostic testing at the branch circuit (string) or subcircuit level. In addition, test wiring and connectors are provided for each of the two parallel branch subcircuits in the array subfield so that test sets may be used to perform tests down to the smallest electrical units (4 Motorola modules, 5 Spectrolab modules, or 5 Arco Solar modules).

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* These so-called "Block numbers" refer to DOE-sponsored developments of PV modules via the Jet Propulsion Laboratory's Low-Cost Solar Array Project. These procurements began in 1975, and at the time of this writing (December 1980) steps are under wat to initiate the Block V procurement round. Each successive procurement is intended to result in modules which offer better performance and lower manufacturing cost (given high-volume production capacity); and the attainment of the DOE PV Program's module cost goal of 0.70$/watt in FY-86.

The DC power from the 48 subfields in the array field is transmitted approximately 1000 feet through an underground cable to the PV building (Fig. 1-2). The building provides 1440 square feet of floor space divided into four rooms. As a consequence of the requirement that the PV power system provide all of the energy needs of the building, no LP gas will be used, and a number of energy-conserving features have been designed into the structure. These include six inches of insulation in the walls, double-glazed windows with additional storm windows, and insulated sashes which may be closed in the winter.

The battery subsystem is housed in a room which is sealed from the remainder of the building to prevent the transfer of the potentially explosive hydrogen gas, which is evolved from the batteries during overcharge. A solid concrete interior wall divides the battery room from the other rooms.

A conflict exists in the winter between the need to maintain the battery room, and thus the batteries, at a level of no less than 2°C to prevent a loss of battery capacity, and the need to bring in fresh outside air to vent the hydrogen gas during charging operations. This conflict has been resolved by the use of batteries that evolve minimal hydrogen gas due to the use of lead-calcium plates and hydrogen recombiners. Thus, a minimum amount of cold outside air used for hydrogen venting is needed and has a negligible effect on battery temperature. This air is drawn into the building on the south wall and is usually well warmed on a sunny winter day.

Although lightning in the NBNM area usually strikes the surrounding peaks, the PV system is protected by an extensive lightning protection subsystem provided by the NPS. In the array field area, a network of ground cables and air terminals (lightning rods) provides protection against direct strikes. In addition, all power and signal lines in the underground cable are equipped with spark gaps or surge arrestors tied to the ground network to reduce induced effects resulting from either direct or nearby strikes.

Six air terminals are located along each of the 12 rows in the array field. The potential problem of shadows cast by the air terminals is handled by using thin rods. The rods are sized so that the umbra of the shadow never reaches more than halfway to the modules in the next row.

4.3 Design Criteria

The design criteria established for the PV system are provided in the following document: "An RFI for System Work for the 100-kW-Peak Photovoltaic Power System for Natural Bridges National Monument," M.I.T. Lincoln Laboratory, 15 June 1978.

This document provides the complete specifications required by prospective subcontractors to bid on the work, including the construction of the PV building, and the layout and erection of the solar PV arrays.

The environmental design loads and criteria recommended by NPS were as follows:

Snow load:	25 psf	
Wind load:	Effective velocity pressure for ordinary buildings and structures	18 psf
	Effective velocity pressure for parts and portions of buildings and structures	27 psf
	Effective velocity pressure for tributary areas between 200 and 1000 sq. ft is given by the formula: $$P_v = \frac{(1000 - A)9}{800} + 18$$ where A is the area of wind loading	
Earthquake:	Seismic zone 2	
Frost depth:	18 in.	

5.0 PROTECTION AND SAFETY SYSTEMS

5.1 Safety Systems

5.1.1 Detection

A portion of the Manual Control Panel (MCP) located in the control room is devoted to alarms (Fig. 5-1). The alarms are split into two divisions: the major alarms and the minor alarms. Each division contains 18 total single alarms. Various types of sensors provide inputs to these alarms. These alarms are controlled by two switches for each section, a silence and a reset switch. In the event of an alarm, the horn will sound and the lights behind the two switches, "silence" and "reset," will flash indicating an alarm has occurred. The horns for the two major alarm systems are distinguishable from each other by their own characteristic audio quality. When an alarm is set, the electromechanical indicators for each individual alarm channel will turn from a yellow to a red condition, indicating alarm. When the alarm condition is cleared, the indicators can be reset by pushing the "reset" button. This will return the indicator from the red back to the yellow condition. If, however, the alarm condition is not cleared and the reset button is pressed, the horn and flashing lights will reset themselves and the silence button will once again have to be depressed to disarm the flashing lights and horn.

Major alarms are due to conditions which merit immediate attention. These conditions directly affect the performance of the entire PV system. If an alarm condition in this area should arise, the condition itself must be immediately alleviated to prevent further damage or failure to the system. Minor alarm systems, however, have a lower status and no immediate attention is necessary. These conditions should be attended to, but system performance or immediate system shutdown is not probable. When

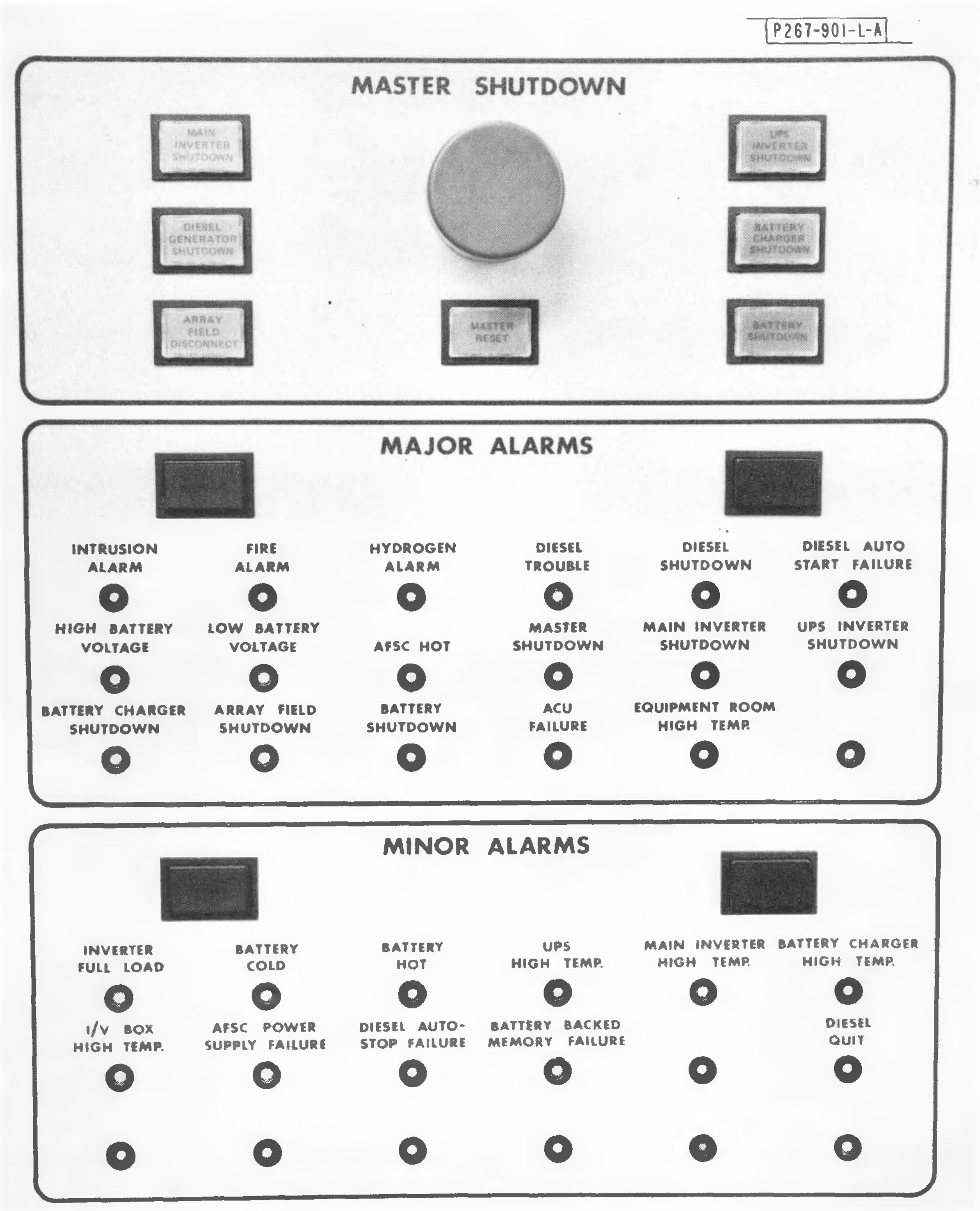

Fig. 5-1. Shutdown and alarm functions, manual control panel.

any alarm condition presents itself in either major or minor alarm areas, the particular alarm card should be referenced for that alarm in the alarm index cards. These cards should be kept near the control panel. On each of these cards is a complete description of what to do in case any particular alarm is activated, what to record, and how to alleviate the alarm condition.

The major safety alarms are Fire Alarm, Hydrogen Battery Hot Alarm, UPS High Temperature Alarm, Main Inverter (Battery Room) (I/V Box) High Temperature Alarms.

The master shutdown area contains six shutdown switches, the "master shutdown" switch, and the "master reset" switch. The six independent shutdown switches will shut down any single major piece of equipment that is indicated in the graphic on the MCP diagram. These are the "main inverter shutdown," "diesel generator shutdown," "array field disconnect," "UPS inverter shutdown," "battery charger shutdown," and "battery shutdown" switches.

When the "main inverter" shutdown switch is depressed, the main inverter will be disconnected from the system. This disconnection is also true for the "diesel shutdown," "UPS inverter shutdown," "battery charger shutdown," and the array field disconnect switches. However, when the "battery shutdown" switch is depressed, it will disconnect the main inverter, the array field disconnect, and the UPS inverter simultaneously. This is because all these components are connected to the battery. When the battery is disconnected these components must also be disconnected simultaneously. The master shutdown, when depressed, activates all six shutdown switches simultaneously and will completely disable the entire PV system. Redundant emergency shutdown switches are located in the generator building, inverter room, control room, and the battery room. When a shutdown condition has been corrected and there is no other shutdown active, the master reset switch is depressed to clear all six shutdown conditions simultaneously.

In addition, to completely isolate the battery system, there are two disconnect switches located outside each battery room exit door. If the battery fusable disconnect switch located on the southwest corner is placed to its OFF position, the battery system is disconnected from the inverter room. If the battery isolation switch located on the southeast corner is placed to its OFF position, the two battery banks are isolated from each other.

5.1.2 Prevention

Hydrogen Venting. Hydrogen is emitted by the battery system as a normal counterpart to charging and equalizing procedures. It is not possible to eliminate this potentially explosive hazard, so design constraints implement its control. A hydrogen venting system has been installed to provide ventilation to disperse battery gases and to maintain a minimum temperature at 35°F in the battery room so that battery storage capacity will not be affected adversely in winter. Outside air is drawn through a louver on the south wall and is usually warmed by the sun even on a cold winter day. The air is passed to the outside by redundant exhaust fans. This provides for the dilution of hydrogen gas to a safe level of no more than one-half of the lower explosive limit (4% by volume) for any combination of the following design conditions:

- air temperature from -30° to +120°F
- relative humidity from 0 to 100%
- battery SOC from 0 to 100%
- altitude of 6500 ft
- battery charging currents up to 500-A total.

Battery Room Sealing. Special emphasis was placed on the sealing of the battery room from the remainder of the PV building to prevent the interchange of hydrogen between rooms.

Hydrogen Recombiners and Vent Caps. To prevent the escape of hydrogen into the battery room, hydrogen recombiners are used as well as sealed vent caps.

Insulating Covers. Insulating covers installed on the batteries prevent the electrical shorting of any battery terminal to another terminal or to ground when tools or other maintenance items are used within the battery room. This protective device prevents the casual visitor from making contact with any electrically active, and potentially hazardous, terminals.

Gas Sensors. Two hydrogen gas sensors provide local audible and visual alarms as well as a contact closure for display on the MCP (Fig. 5-1). They start the fans at 1-percent hydrogen and sound an alarm if the concentration rises to 2-percent hydrogen.

Safety Codes. All equipment designs comply with the requirements of the National Fire Code (NFC), National Electric Code (NEC), and the Uniform Building Code (UBC). All electrical items installed in the battery room are certified for use in a Class 1, Division 2 location in a Group C or Group D atmosphere.

Electrical Hazards. To prevent accidental electrical shock or electrical arcing, insulating covers have been placed over exposed terminals, junction boxes and disconnects have been enclosed, and warning signs have been posted or placed where appropriate. Metal cabinets enclosing electrical equipment have been furnished with locks to prevent casual entry. Interlocks have not been provided because of the need to service the equipment while it is operating. Wire runs have been separated according to whether they carry power or control signals in order to perform servicing safely.

Fire Protection. Because of its isolation, fire protection at NBNM is of paramount concern. Its implementation is made according to specific fire directives promulgated by NPS and by the following stipulations:

- Location of several dry chemical and carbon dioxide extinguishers as indicated in Fig. 3, "Safety Procedures for the 100-kW Solar Photovoltaic System at Natural Bridges National Monument" manual.

- No smoking permitted within the PV building.
- Diesel generators must be provided with spark arrestors approved by the NPS.

Lightning Strikes. An extensive lightning protection system provided by the NPS prevents lightning strikes from damaging or harming personnel. In the PV array field, a network of ground cables and air terminals (lightning rods) provides protection against direct strikes. Refer to Paragraph 4.1 for additional information.

Rigging. To prevent bodily injury, heavy equipment (such as batteries and array panels) should be moved or transported by means of the forklift provided, or other mechanical aids. Care must be exercised in the use of these mechanical aids to prevent injury.

Safety Procedures. The following document is required instructional material for all personnel working at the PV power system:

"Safety Procedures for the 100-kW Solar Photovoltaic System at Natural Bridges National Monument," DOE/ET/20279-108, M.I.T. Lincoln Laboratory. This document serves to enumerate the methods and techniques necessary to perform normal site operation in a safe manner and to make field personnel more safety conscious as well. It is included in this document as Appendix A.

3.1.3 Mitigation

The systems that suppress or confine the effects of accidents are:

Battery Room. The south wall of the PV building is of frangible frame construction and contains four double windows which also serve as explosion apertures. Battery racks are designed to withstand seismic risk zone 2 activity as well as spilled battery acid. Two self-contained eye-wash stations and a safety shower have been installed to mitigate the effects of battery acid.

First Aid Procedures. In the event of injury, knowledge of first aid procedures, including cardiopulmonary resuscitation (CPR) is essential. Appendix A contains information on this subject, as does information published by and available to NPS personnel.

5.2 Environmental Protection Systems

A summary of the design features and systems which reduce the facility's impact on the surrounding environment is included below:

Acoustic Noise Level. To prevent aural fatigue, the acoustic noise level provided by the equipment does not exceed either Occupational Safety and Health Association (OSHA) specifications or that level generally recognized as being achievable by competent modern design. It should be noted that prior to the installation of the PV system, the noise of the diesel generator permeated a wide area around the generator building including the visitor center and the residential area. This noise has now been largely eliminated due to only the occasional use of the diesel generators.

Air Quality. The present air quality at NBNM has been improved by the installation of the PV system and the great reduction in the exhaust products emitted by the diesel generators.

Glare. Because of the remoteness of array location and its direction with respect to access roads; glare to passersby will be negligible.

Impact on Human, Plant, and Animal Life. An environmental assessment for the proposed PV electrical system was prepared in May 1-77. The recommendation was that "after reviewing the proposal and environmental impacts expected, it is not considered to be a major Federal action that will significantly affect the quality of the human environment and is not highly controversial; therefore an environmental impact statement is not required and will not be prepared."

6.0 SAFETY ANALYSIS

6.1 General

Safety analysis must accomplish the following objectives:

- Demonstrate compliance with applicable guides, codes, and standards.
- Ensure that all proposed individual efforts and operations within a facility are bounded by the analysis.
- Demonstrate that all identifiable hazards have been analyzed and that inputs to the analysis accurately reflect the design features and operations proposed.
- Demonstrate reasonable assurance that the operation can be conducted in a manner that will preclude undue risks to the health and safety of the public and employees, and adequately protect property and the environment.

The first objective has been met by MIT LL and NPS specifying guides, codes, and standards that apply to safety, and then checking that these procedures have been carried out and are maintained.

The second objective has been met by MIT LL and NPS providing leadership and guidance in the erection of the buildings and array field and the installation of equipment and cabling according to specifications.

The third objective has been met by the presentations included in Chapters 3 through 5 of this report.

The fourth objective has been met through an approved environmental assessment (Paragraph 5.1) and by the fact that the PV system at NBNM has not been the cause of any accident since its inception in May 1980.

6.2 Safety Analysis

A hazards analysis with appropriate safety design criteria may be found in Appendix A, "Safety Procedures for the 100-kW Solar Photovoltaic System at Natural Bridges National Monument."

6.3 Normal and Off-Normal Operation

The design of the PV system provides the normal operation described in Paragraph 4.2. Depending upon which components are affected, off-normal operation due to failure of equipment may or may not cause interruption of power.

Appendix A

Safety Procedures for the 100-kW Solar Photovoltaic System at Natural Bridges National Monument

ABSTRACT

The 100-kWp solar photovoltaic power system at Natural Bridges National Monument is a unique electrical power-generation system and special safety guidelines have been developed to govern its operation. General safety requirements have been set forth to safeguard newcomers to the PV system at Natural Bridges National Monument. Procedures to be used in event of emergency, including a recommended shutdown procedure, are included together with specific safety hazards inherent in the array field, battery room, control room, and inverter room. It is the intention of this book to inform guides for visitors, operators, and maintenance personnel of the nature of these safety hazards and to detail means of effectively dealing with them.

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LIST OF ILLUSTRATIONS

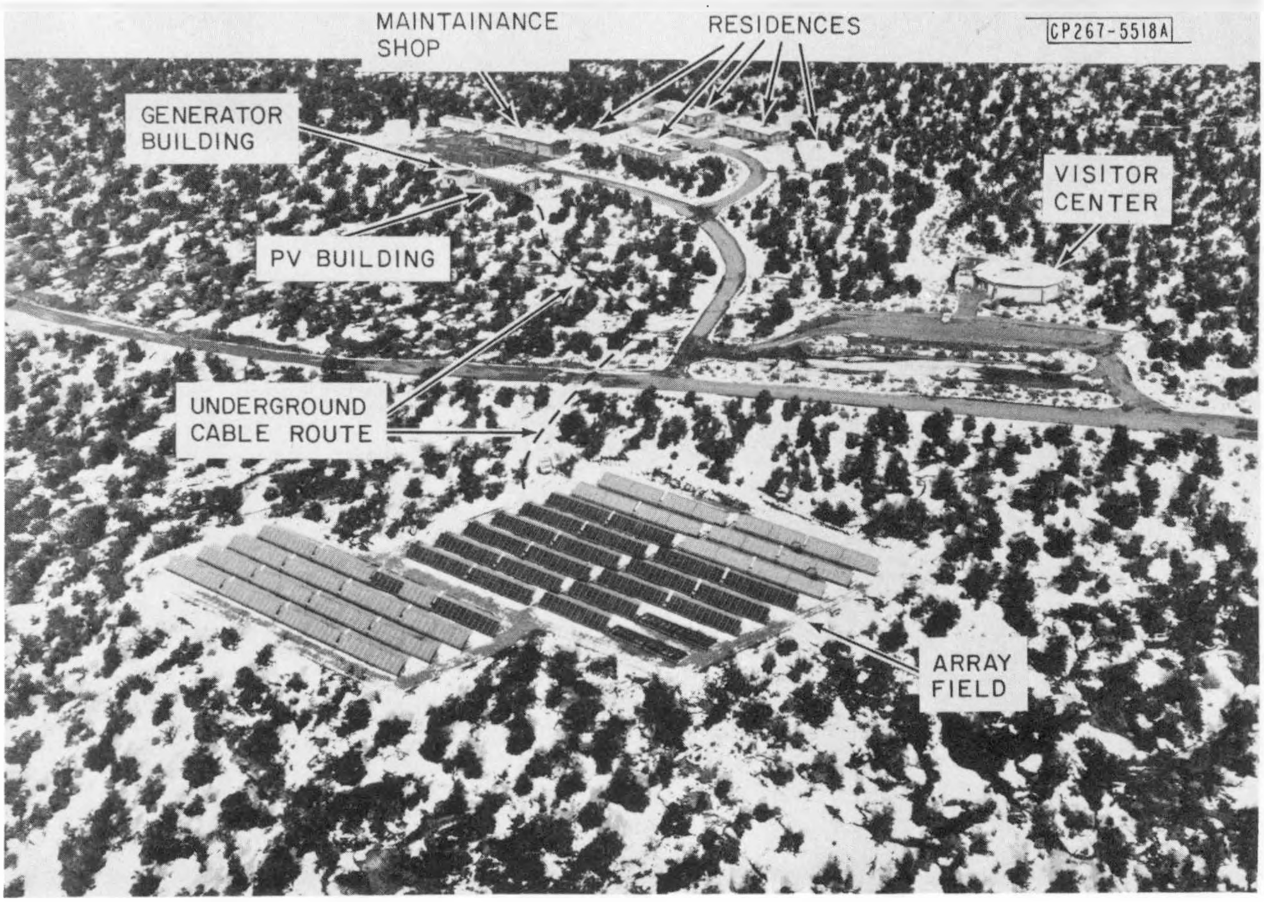

Fig. 1. Aerial view of site.

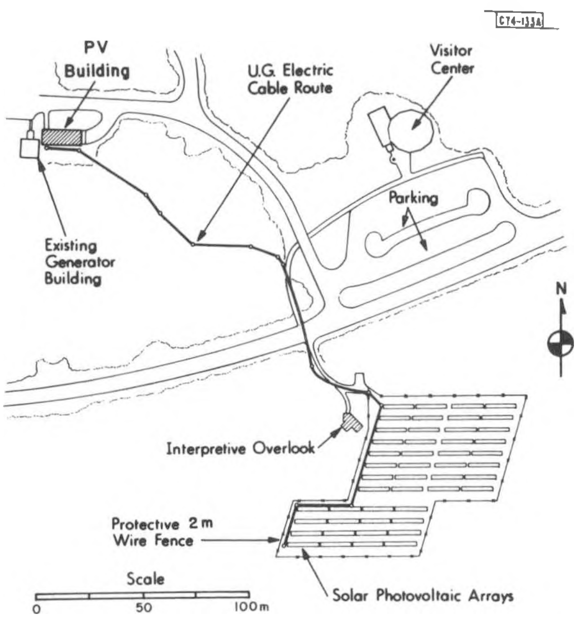

Fig. 2. Site plan.

SAFETY PROCEDURES FOR THE 100-kWp SOLAR PHOTOVOLTAIC SYSTEM AT NATURAL BRIDGES NATIONAL MONUMENT

1.0 BACKGROUND

MIT Lincoln Laboratory (MIT LL), under the sponsorship of the Department of Energy and in partnership with the National Park Service of the Department of the Interior, has designed and installed a 100-kW-peak photovoltaic (PV) power system at the Natural Bridges National Monument (NBNM) in southeastern Utah (Figs. 1, 2). This system converts sunlight to DC electrical power, stores all or part of the accumulated energy in a large battery storage facility, and supplies AC power to various loads at the NBNM site through a 50-kVA main inverter. The site electrical demand usually varies between 10 and 20 kW. In addition, certain critical PV system AC loads are supplied from an uninterruptible power source (UPS) inverter if main power is interrupted. Since there is no electrical utility service at NBNM, a diesel-powered generator serves as a backup for the PV system during periods of reduced solar energy (Refs. 1,2).

The choice (Refs. 3,4) of NBNM for the location of a PV power system was based on such factors as its remoteness from a public utility grid, the size of its annual electrical consumption, the diversity of its loads, and its accessibility to visitors. The PV system supplies power to all local loads, such as lighting, appliances, shop tools, and refrigerators.

Because of the remoteness of the site and the potential hazards that exist, specific safety guidelines have been developed. For example, in the array field, it will be necessary to inspect some of the PV modules, remove some modules from arrays for more detailed analysis in the laboratory, make measurements that locate electrically defective modules, wash and clean the modules, and perform various other module-related maintenance and testing operations during daylight hours. These operations are all potentially hazardous. This book details the correct methods of performing these tasks, both generally and specifically, and warns of any especially hazardous operations. All operators and maintenance personnel should understand the nature of the hazards involved as well as the recommended procedures for dealing with them.

Since lead-acid batteries are used to provide energy storage for the power system, special safety guidelines for the testing and handling of batteries are included. Finally, attention is focused on the power-conditioning equipment and its safe operation and maintenance.

2.0 GENERAL SAFETY REQUIREMENTS

WARNING

All operating and maintenance personnel should understand that lethal voltages exist in the array field, power conditioning equipment, storage batteries and cabling of the NBNM PV System. Read and understand this chapter prior to operating and maintaining the NBNM PV System.

2.1 Safeguarding Oneself and Others

Do not rely on other people for your own protection. Report to your supervisor any obvious equipment defects, as well as accidentally energized objects, such as conduits.

If your duties do not require you to handle energized equipment, keep away from such equipment.

If you do work on or near energized equipment, consider how you do your job, taking into account your safety as well as that of other employees on the job site.

Avoid working in areas where objects and materials may be dropped by persons working overhead. If this cannot be avoided, wear a hard hat for protection.

If you are in doubt as to the safe performance of any work assigned to you — *Stop!* Request specific instructions from your supervisor.

2.2 Lockout Procedures

Before you start work on the PV system, *it is your responsibility* to make a personal inspection to assure yourself and the person working with you that it is de-energized. Opening a switch is not enough! To ensure that all appropriate systems are isolated, it is necessary for all possible sources of power to be investigated and de-energized.

To isolate a system and guarantee that it remains de-energized, all appropriate disconnecting switches must be locked open and tagged with the name of the individual responsible. These locks and tags must be removed after the job is completed by the person who placed them on the switches, except when the switches are in view.

Before anyone begins work on a de-energized circuit or system it must be checked out with a reliable voltage tester or other appropriate device to verify that it is "dead". *Do not work on energized equipment unless you have been trained to do so.*

2.3 Working Alone Policy

If it is necessary to work on or about energized equipment, do not work by yourself, but only under the direct supervision of an experienced and qualified person. It should be emphasized that it is not good practice to work alone, regardless of experience. The only exception to this paragraph would be in the case of reading meters, inspection visits, and routine attending of the data system.

2.4 Clearance from Live Parts

Maintain safe working distances around energized equipment at all times. When repairing equipment and live parts operating at 600 volts or less, a minimum distance of 30 inches should be maintained between you and any other equipment or walls. Do not trap yourself. *Do not wear metal objects,* such as rings, metal wrist bands, watches, key chains, or zippered material around exposed conducting material.

2.5 Making Connections

Always make connections *from the load to the source.* Make disconnections first at the source and work toward the load.

The one hand rule should always be used: *use one hand to make electrical connections while keeping your other hand either at your side or in your pocket.* The intent of this rule is to reduce the chance of providing a shock path across the chest from one hand to the other. Rigidly observe the one hand rule when opening switches, removing leads, pulling plug leads from apparatus such as terminal or distribution boards, measuring voltages, replacing fuses, or when testing circuits where any voltage may be present.

2.6 Energizing Equipment

After making repairs or alterations, never close a circuit until all personnel are clear of equipment to be energized and circuit breakers. *Do not close any switch until you are certain that it is safe to energize the circuit and all of the equipment on it.* Prior to energizing equipment, all locks and tags should be removed by the person who installed them.

Before using equipment, test for adequate insulation resistance and ground connections. Always close and open circuits with apparatus suitable for the circuits involved.

2.7 Handling Capacitors

Before working on capacitors, disconnect them from the energized source, wait for built-in bleeder resistors to discharge the capacitors, test for any voltage, short circuit them, and ground them. In addition, short circuit any ground or any line to which the capacitors are connected. Do not depend on their internal resistance to discharge capacitors.

2.8 Site Visitors

When a guide is accompanying uninstructed employees or visitors near equipment, it is his/her responsibility to safeguard the people in his/her care and see that safety rules are observed. It is good practice to ensure that cabinets with exposed voltages are closed and locked before escorting visitors near equipment.

2.9 Area Protection

Before doing any work that may endanger the public, warning signs and/or traffic control devices, should be put in place. If further protection is needed, suitable barrier guards should be erected. If the work is particularly hazardous, a person should be stationed to warn traffic away while the hazard exists.

If the work exposes energized or moving parts that are normally protected, display danger signs and erect suitable guards to warn other personnel in the area.

Keep all access doors to the PV building and the gate to the array field closed at all times; these entrances should be locked when the systems are unattended.

3.0 EMERGENCY SHUTDOWN PROCEDURES

3.1 PV System Operation

In the event of a fire or an accident, power to and from the PV system must be cut off immediately. *This is accomplished by depressing any one of the red EMERGENCY SHUTDOWN pushbuttons.* These pushbuttons are located in the diesel generator building, inverter room, control room, battery room, or on the control console (Fig. 3). Everyone should know where each pushbutton is located.

One should use judgement before depressing the EMERGENCY SHUTDOWN pushbutton. Only do it, if, in your judgement, a real emergency exists. The reason is that the loss of power will cause the following problems:

a. Lights will extinguish, which may create an inconvenience at night.

b. Water pumps, safety showers and eyewash stations will not operate.

c. Radio equipment and the intercom system will lose power.

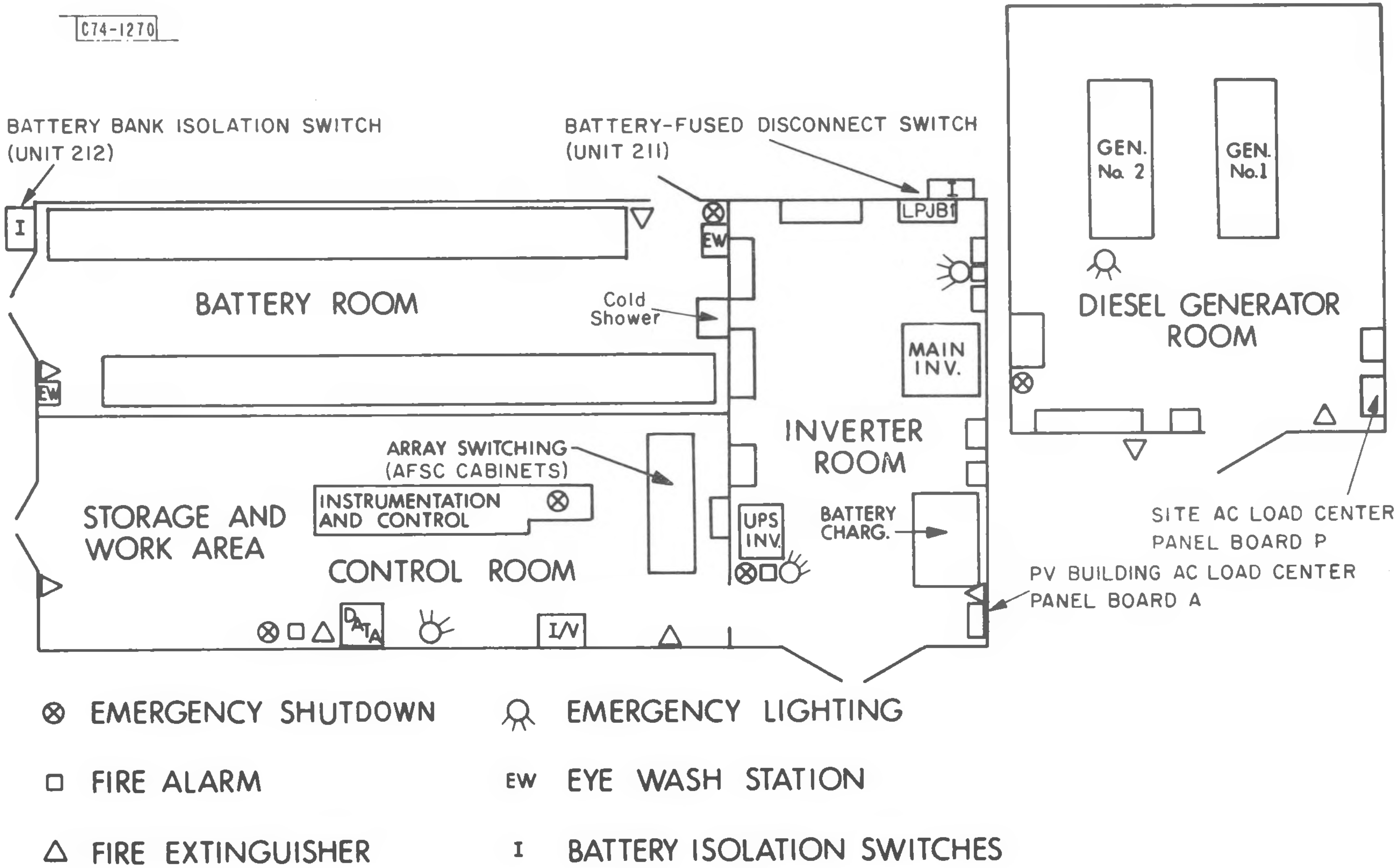

Fig. 3. PV building layout showing safety features.

Power to other buildings can be shut off selectively at the site load center (Panel P) in the generator building. If the PV system is not affected, this is a preferred course of action.

3.2 Diesel Generator Operation

Depressing any of the red EMERGENCY SHUTDOWN pushbuttons will cut off power throughout the system *if the diesel generator was in the automatic control mode at the time the pushbutton was depressed* (refer to the Operations Manual). If the diesel generator was in the manual control mode at the time the pushbutton was depressed, the diesel generator must be manually shut down as described in the Operations Manual. Control power will still be present in the PV building until the diesel generator is shut down, because the AC control power normally supplied by the UPS is automatically transferred to the diesel generator when the EMERGENCY SHUTDOWN pushbutton is depressed.

4.0 EMERGENCY POWER ISOLATION PROCEDURES

After the EMERGENCY SHUTDOWN pushbutton has been depressed, it will be necessary to isolate power sources within the system. Follow the procedures outlined below:

4.1 Battery Isolation Requirements

To completely isolate the battery storage facility, the two disconnect switches located outside each battery room exit door must be placed to their OFF positions. Specifically:

a. Place the battery fusable disconnect switch (Unit 211, Fig. 4) located on the southwest corner to OFF. This disconnects the battery room from the inverter room.

b. Place the battery isolation switch (Unit 212, Fig. 4) located on the southeast corner to OFF. This isolates the two battery banks from each other.

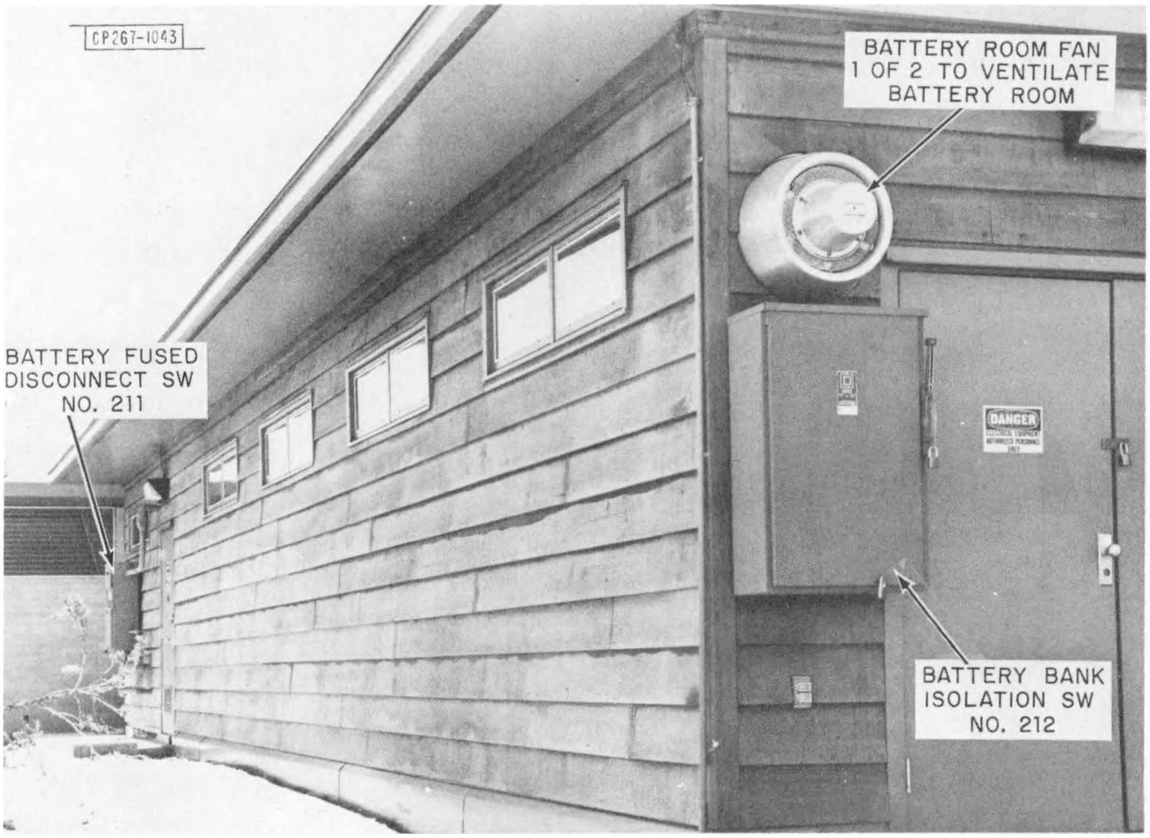

Fig. 4. Battery room, south exterior wall.

4.2 Array Field Isolation Requirements

After the EMERGENCY SHUTDOWN pushbutton has been depressed, PV power from the array will still be present in the lightning protection junction box (LPJB), Unit 224, and the array field subsystem control (AFSC) cabinets, Units 221, 221A, 221B, located in the PV building. This is because the system was designed without a main array field disconnect switch. To remove array power from the LPJB1 (Unit 224) and AFSC proceed as follows:

a. In each of the 48 array subfield junction boxes (ASJB) (Fig. 5), located as shown in Fig. 6, place DISCONNECT switch S2 to OFF.

b. Lock and tag each of the ASJB boxes. Refer to Paragraph 2.2. (In a fire emergency, the relocking of cabinets can be done later. Two people can shut down the array very quickly.)

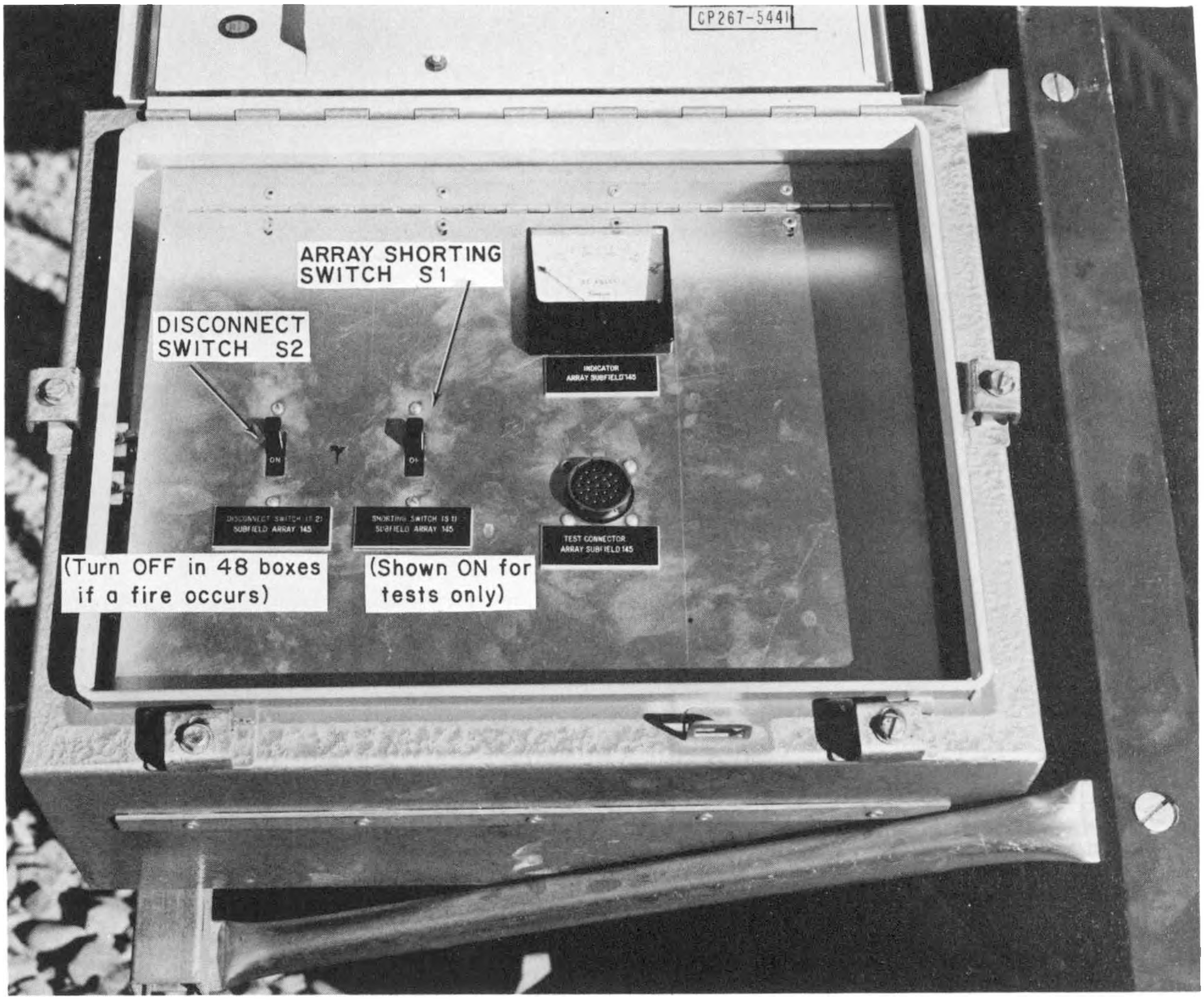

Fig. 5. Array subfield junction box (ASJB).

WARNING

It is essential to follow the procedures provided in Paragraph 4.2 before attempting to extinguish fire in the LPJB or AFSC cabinets. Use either dry chemical or CO_2 fire extinguisher. Never use water on electrical fires.

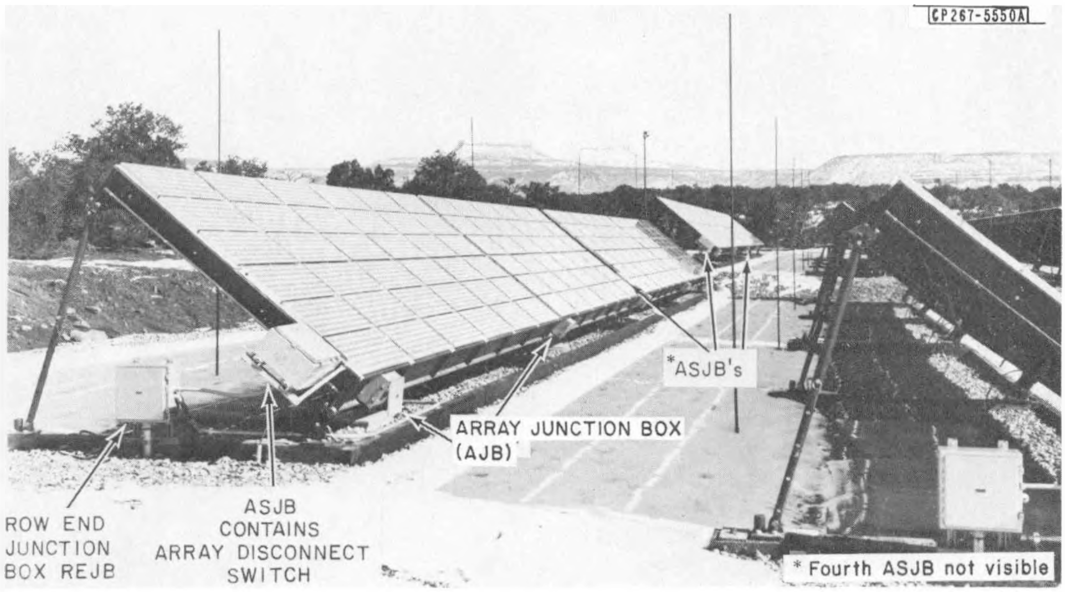

Fig. 6. Location of ASJB and AJB boxes.

NOTE

The LPJB 1 and AFSC cabinets are painted red to indicate that unswitched (and lethal) power is present.

4.3 Diesel Generator Isolation Requirements

Refer to Paragraph 3.2. If under manual control, the diesel generator is shut down by placing the yellow knob on the diesel control panel to OFF. The diesel control panel is located on the north wall of the generator building. Refer to NPS instructions for shutting down diesel generator No. 2 (portable generator).

4.4 PV Building Power and PV System Control Power Isolation Instructions

PV building power is cut off at the site load center in Panel P in the generator building, or at Panel A in the PV building. When the EMERGENCY SHUTDOWN pushbutton switch is depressed, the PV system control power, normally supplied by the UPS inverter, will then be supplied by the diesel generator. This control power will be present unless cut off at the site load center in Panel P in the generator building or at Panel A in the PV building.

When working on the control system, prompt power shutdown is available by placing breakers 30 and 32 in Panel A (Unit 270) of the PV building to OFF. This action will permit only the UPS inverter to provide power to the control system loads. The EMERGENCY SHUTDOWN pushbutton switch can be depressed to cut off power to the UPS inverter. Refer to the Operations Manual for further technical explanation.

5.0 EMERGENCY MEASURES

5.1 Electrical Shock

Free the person involved from the live circuit. If a person is "frozen" to a live electrical contact, shut off the current if possible. If this cannot be done, use dry wooden boards, poles or sticks, a belt, a piece of dry rope, an article of clothing, or any *nonconducting* material of sufficient length to pull the body away from the contact. Act quickly and remember to protect yourself by using rubber gloves which have been tested beforehand for electrical serviceability.

Administer cardiopulmonary resuscitation (CPR) when there is no breathing and/or pulse present in a victim. *It is recommended that all residents of remote sites, such as NBNM, be provided with CPR training.*

Each person should be familiar with the locations of the EMERGENCY SHUTDOWN pushbutton switches (Paragraph 3.1) and the methods available for summoning help. Two-way portable radios can save valuable time in an emergency if they are monitored and maintained properly. Their use at both ends of a radio circuit ensures communications irregardless of a power interruption.

Any shock received, no matter how slight, should be reported immediately to your supervisor or other appropriate authority. In addition, any popping or sparking associated with equipment operation should be reported together with any other observations that might indicate potentially hazardous conditions.

5.2 Acid Burns

An emergency shower, located at the west end of the battery room (Fig. 7), is used to rinse acid from the body. Two emergency eyewash stations located at each end of the battery room may be used to treat acid or electrolyte burns as follows:

a. The eyes should be washed out immediately with large amounts of water, repeating this operation several times to make certain that all traces of acid have been removed.

b. Wash the eye lids thoroughly by pressing downward below the eye for the lower lid and elevating the upper lid and applying water under the lids.

NOTE

An emergency power shutdown will remove power from the pumps in the emergency shower and emergency eyewash stations. One-gallon jugs of distilled water are available for acid treatment under these conditions.

Remove acid-splattered clothing promptly. Acid should be rinsed promptly from the skin with copious quantities of water, and then apply bicarbonate of soda pastes or solutions.

5.3 Thermal Burns

Thermal burns should be treated with cold water until the pain subsides; do not use grease, tannic acids, or other ointments on severe or extensive burns. Cover the burned body area loosely with a clean cloth or bandage and then seek medical attention.

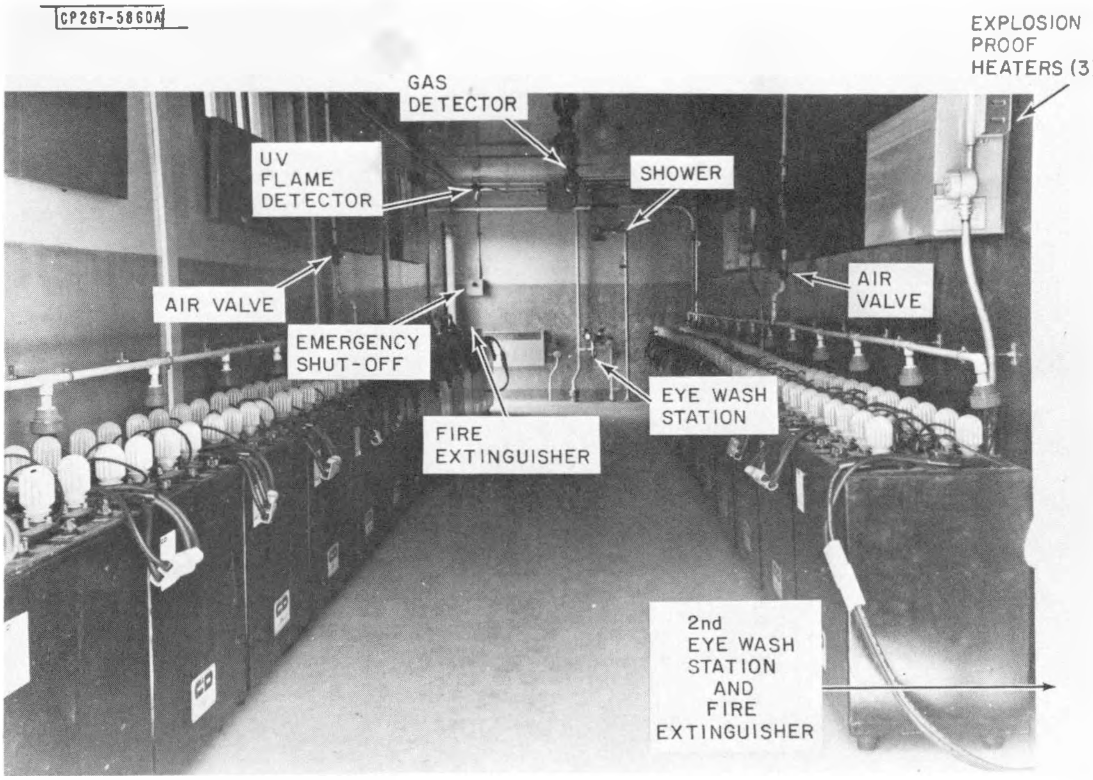

Fig. 7. Battery room.

5.4 Electrical Burns

Burns resulting from high-voltage electrical arcs are similar to those produced by high-intensity heat sources. The true electrical burn is often characterized by a pinkish mark on the skin surface. These burns may penetrate deeply and require a considerable time to heal. Burns produced by electricity usually heal without infection. Treatment is the same as for thermal burns (Paragraph 5.3).

5.5 Bodily Injury

It is best not to move an injured person before a physician or experienced ambulance crew arrives, unless there is real danger of his receiving further injury by being left at the accident site. Control bleeding, maintain breathing, and splint all suspected fractured bones before moving. Administer CPR when there is no breathing and/or pulse present in a victim.

If a victim must be pulled to safety, protect the head and move the victim head first or feet first, but never sideways.

If a victim must be lifted to safety (before a check for injuries can be made) be sure that every part of the body is kept in a straight line and not bent.

5.6 Evacuation

Seriously injured persons may need to be evacuated to the nearest hospital as quickly as possible. Refer to NPS procedures for MEDEVAC instructions.

5.7 Fire Fighting

In case of a major fire in the PV building, power to and from the PV system should be cut off immediately by following the procedures outlined in Paragraph 3.0.

NOTE

Unless there is good reason, do not walk along the exterior south wall of the battery room. This is a blow-out wall, and in the event of an explosion this wall would be pushed out by the force of the explosion.

When fighting a fire that is not located in the AFSC cabinets or in the LPJB box, fight the fire first, then disconnect the array field (Paragraph 4.2a)

The recommended procedure for fighting a fire in the NBNM PV building is as follows:

a. Depress nearest red EMERGENCY SHUTDOWN pushbutton switch.

b. Open battery fused disconnect switch, Unit 211, as shown on Fig. 4.

c. Open battery isolation switch, Unit 212, as shown on Fig. 4.

d. Cut off the PV building power at the site load center in the generator building (panelboard P, Fig. 3).

e. In each of the 48 ASJB boxes, Fig. 5, located as shown in Fig. 6, place DISCONNECT switch S2 to OFF.

f. Fight the fire with suitable fire extinguishers or materials.

NOTE

Portable CO_2 and dry chemical fire extinguishers are provided throughout the PV building and on the outside wall of the diesel generator building near the exit door (Fig. 3). Use the CO_2 fire extinguisher for electrical fires and the dry chemical fire extinguisher for flammable liquids. The CO_2 fire extinguisher will cause less mess because it leaves no residue. In extremity, after cutting off power, fight the fire with water (except for petroleum-based fires).

Shutdown of the electrical power in event of a fire should be balanced with the need for continued radio, telephone communications and lights. If the PV power system is contributing to the fire, it should be shut down. The generator can then be used for site power after a very short warmup.

6.0 ARRAY FIELD SAFETY

WARNING

Be careful when digging near the cable trench which runs from the array to the PV building (Fig. 2). This cable trench does not take a direct line-of-sight path. Careful digging with a small hand shovel to locate the cable marker tapes and the cables is essential (Fig. 8). Severe electrical shock would result if the cable insulation were removed and contact made with the exposed cable. Best practice would be to avoid making any excavations near the cable trench, unless there is a need to repair or replace the cable.

6.1 Potential Hazards

6.1.1 Electrical Shock

If the PV module terminals are touched, the person touching them will receive an electrical shock. The ARCO modules have terminals which are accessible from the front (Fig. 9). The Motorola and Spectrolab modules are no less lethal; however, their terminals are protected by a screen on the rear of the modules. Workers and visitors should not touch these module terminals.

6.1.2 Electrical Arcs

Do not remove modules without properly grounding each module or sub-frame. To avoid electrical arcs, modules must be removed by short-circuiting

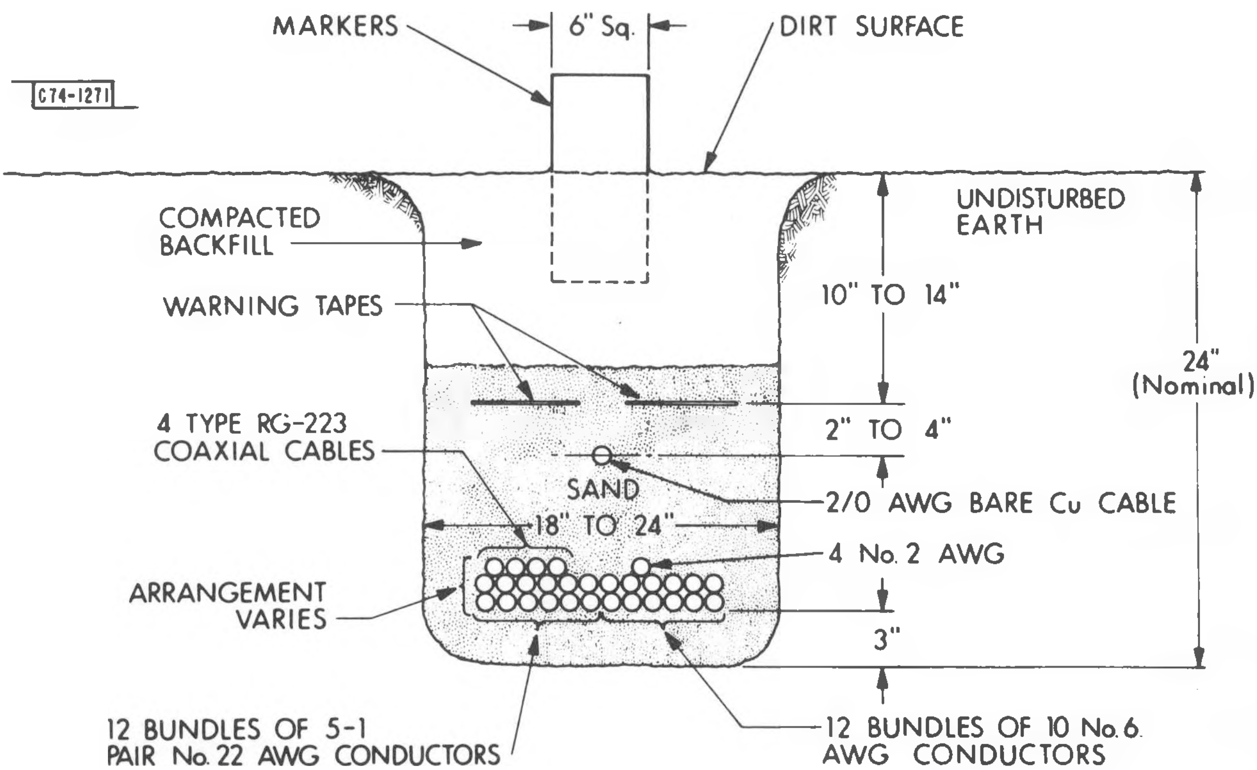

Fig. 8. Cable trench.

the subarray upon which the module is attached. Each side of the module to be removed must be grounded, or arcing will occur when removing leads from an active circuit.

6.1.3 Bodily Injury

To lower array frames, if necessary, use proper equipment. To prevent bodily injury, ensure that everyone is at a safe distance from a frame before attempting to change its angle. Care and attention must also be given when removing a module or subarray from an array frame. Each module or subarray must be properly supported (as outlined in the Maintenance Manual) before removal is attempted.

Many safety features have been incorporated into the design of the array to prevent bodily injury and equipment damage, such as:

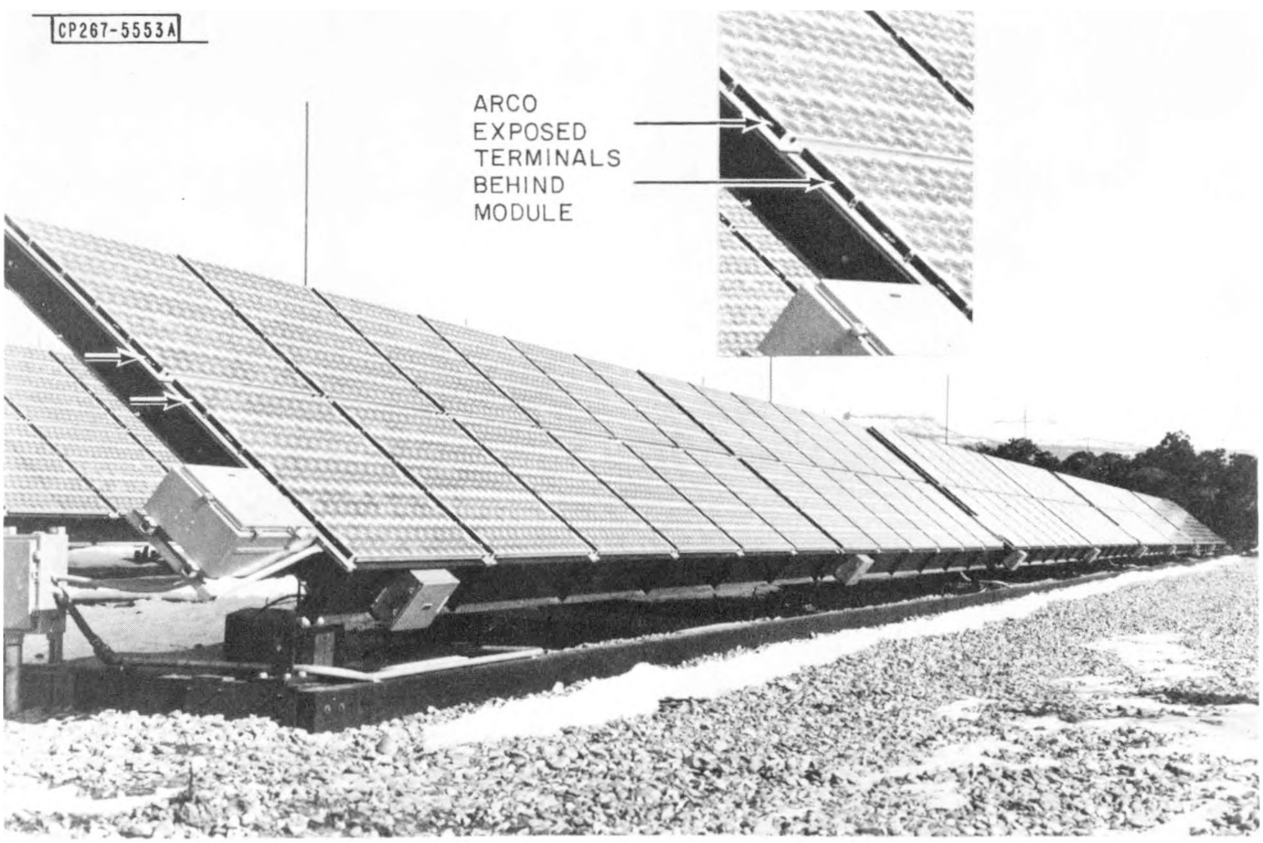

Fig. 9. ARCO array field.

a. Lightning protection

b. Surge elimination

c. Lockable gate and junction boxes

d. Fencing

e. Protective screening on the rear of the modules

f. Grounding of all metallic parts.

6.2 Array Maintenance

6.2.1 Module Inspection

To inspect the array field, follow the procedure provided in the Maintenance Manual. Be especially careful if the module cover glass is broken, since the high-voltage connections may be touched. Avoid cuts from broken glass. Be alert for damaged wires. Be careful not to bump your head while working under the array frames; wear a hard hat when working there.

6.2.2 Module Removal

NOTE

Refer to the Maintenance Manual before removing a subarray or module.

A defective module cannot be removed without removing the subarray, of which it is a part. Each subarray, measuring 4 by 4 feet, contains a different number of modules, depending on the manufacturer:

a. Motorola four modules per subarray

b. ARCO five modules per subarray

c. Spectrolab three modules per subarray

To remove the intended subarray, proceed as follows:

a. Isolate the desired subfield (that contains a defective subarray) by placing DISCONNECT switch, S2, located in the ASJB box (Fig. 5) to OFF. This cuts the power from that particular subarray to the PV building.

b. Short-circuit the negative line to its positive line by placing SHORTING switch S1, located in the ASJB box (Fig. 5) to ON.

c. Unfasten the tie-down hardware located on the bottom and top of the subarray to be removed.

CAUTION

While performing this operation, support the subarray by using 2 X 4 wooden members.

d. Lift the outside edge of the defective subarray and ground the subarrays to both sides of it. This is done by attaching a ground lead from the frame to one of the module terminals, as described in the Maintenance Manual.

e. Unplug the connectors that are attached to the defective subarray.

f. Remove the defective subarray.

CAUTION

Two people are required to remove a subarray because of its 70-pound weight.

Once a subarray has been removed from a subfield, the defective module can be replaced. After module replacement, reverse the procedure provided above to reinstall the subarray and return the subfield to service.

6.2.3 Washing

The array field must be made electrically safe before the front surface of the array can be washed. This is done by placing DISCONNECT switch S2 to OFF and placing SHORTING switch S1 to ON in the ASJB box (Fig. 5). One or two subfields at a time can be switched as washing progresses so that the power system can remain in operation. Unless full power is needed, the power from a few subfields will not be needed during the time washing is performed.

7.0 BATTERY ROOM SAFETY

7.1 Potential Hazards

7.1.1 Electrical Shock

Since electrical shock happens when the body becomes part of an energized electrical path and energy is transferred between parts of the body, or through the body to a ground, care must be taken at all times to keep a safe distance from the batteries unless one is trained to perform maintenance duties. The battery room provides a large DC power source with voltages between 200 and 300 VDC with very high current. Switches are provided to break the electrical circuit to the batteries if isolation is necessary (Fig. 4).

7.1.2 Electrical Arcs

Care must be taken to avoid creating electrical arcs by closing switches or circuit breakers too slowly, since electrical arcs can burn the body and damage the eyes. Never disconnect or connect a battery while a circuit is active. Always disconnect the battery system before doing any modifications or repairs by switching off the fused disconnect switch located on the exterior southwest corner and the isolation switch on the exterior southeast corner (Fig. 4) of the PV building.

7.1.3 Explosion

All lead-acid batteries produce hydrogen during equalization and at the end of daily charging, and during normal periods of prolonged sunny weather. These large batteries tend to produce larger amounts of hydrogen than smaller batteries, so extreme care has been taken in the design of the battery system to eliminate the chance of a hydrogen explosion.

The lead-calcium alloy battery plates used in these batteries inherently produce much less gas during charging than lead-antimony battery plates. In addition, the cells are sealed so that any gas produced must exit through the hydrogen recombiner bulbs on the top of each cell. These recombiners catalytically recombine the hydrogen and oxygen into water for return to the cell.

Hydrogen gas, lighter than air, will rise to the ceiling and seek escape through cracks or other openings in the roof.

Realistically, the only way a hydrogen explosion could take place is if the batteries were improperly charged, all of the safety devices were rendered inoperative, and an open flame or arc was introduced into the battery room. This is highly unlikely. When air contains 4% by volume of hydrogen it becomes explosive. To prevent this, two hydrogen detectors are set to activate an exhaust fan when the hydrogen level reaches 1% by volume, and then sound an alarm (with an indication on the control panel) when the hydrogen level reaches 2% by volume.

The battery room has been constructed with explosion-proof fixtures and the following safety features:

a. Two hydrogen detectors

b. UV flame flicker detector (fire detector)

c. Explosion-proof inner wall constructed of reinforced concrete

d. Exhaust fans to reduce hydrogen concentration by air exchanging

e. Blow-out panels in south wall of PV building

f. No sources of electric sparks.

It is best to stay out of the battery room unless your duties require your presence there. *Smoking is never permitted in the battery room.*

7.1.4 Acid Burns

Refer to Paragraph 5.2.

7.1.5 Bodily Injury

Do not attempt to move a battery without using the pallet jack provided, and do not attempt to climb on a battery to reach another object. When removing a battery with the pallet jack, be careful not to run over a person's foot or cause any other injury. The battery modules each weigh approximately 2400 pounds.

7.1.6 Fire Fighting

Take care when fighting a fire in the battery room because the potential exists for a hydrogen explosion. Refer to Paragraph 5.7 for procedures to be followed in fighting a fire.

7.1.7 Evacuation

Seriously injured persons may need to be evacuated to the nearest hospital as quickly as possible. Refer to NPS procedures for MEDEVAC instructions.

7.2 Battery Maintenance Protective Equipment

The following protective equipment is available and should be used by personnel who maintain batteries:

a. Goggles or face shields

b. Acid-resistant gloves

c. Protective aprons (with sleeves) or disposable laboratory coats

d. Shoe covers or rubber boots

e. Eyewash stations and shower (Fig. 10)

f. Bicarbonate of soda (or an equivalent neutralizing agent) for acid spills. One pound will be available in the battery room, and a further supply will be kept in storage.

g. Insulated tools for use with batteries

h. A nonmetallic or insulated flashlight

i. Distilled water kept in one-gallon jugs for use if the shower and eyewash stations are inoperative.

7.3 Battery Maintenance Safety Precautions

The following precautions should be followed when working in the battery room:

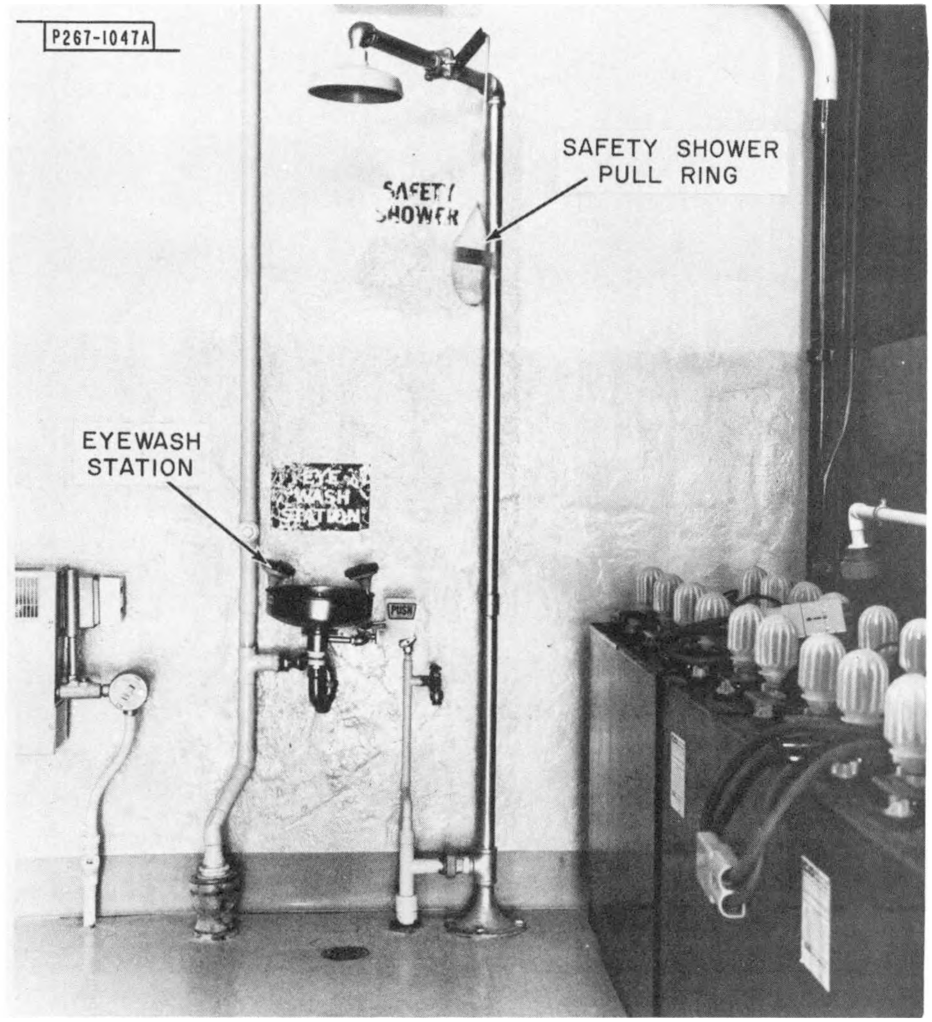

Fig. 10. Eyewash station and shower.

a. Always wear proper protective equipment (Paragraph 7.2) when performing battery maintenance. *Whenever you enter the battery room you should always wear goggles or a face shield* (Fig. 11)

b. Absolutely no smoking or open flames are permitted

c. Never work alone in the battery room

d. Make sure that the fan is working

e. Keep battery room aisles clear

f. Make periodic inspections of the protective equipment and keep it in good repair

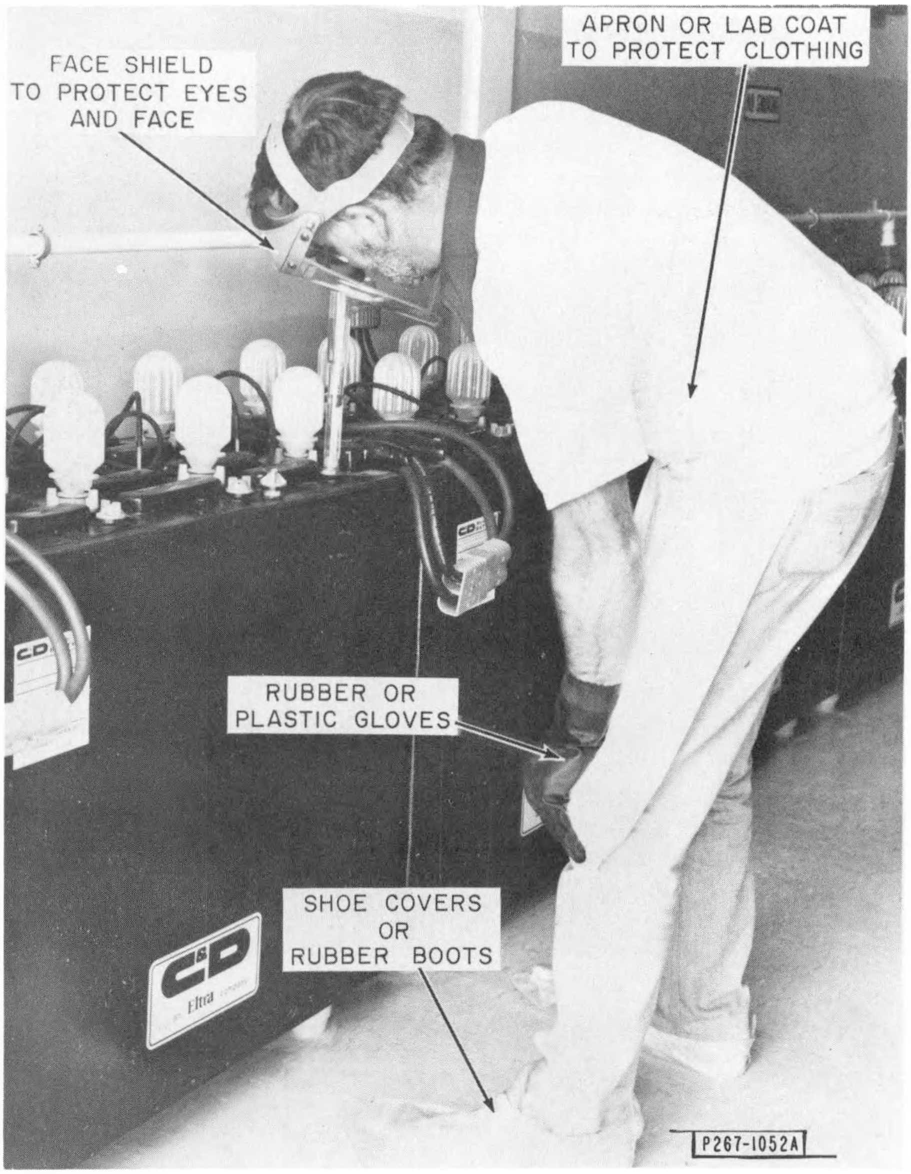

Fig. 11. Battery maintenance protective equipment.

g. "NO SMOKING" and "DANGER-HIGH VOLTAGE" signs must be displayed inside, and "NO UNAUTHORIZED PERSONNEL" signs must be posted at both entrances to the battery room

h. Guides should instruct visitors never to touch the batteries to prevent accidental shock and possible acid burns

i. Never walk on the batteries or use them for a work surface

j. If working above the batteries, use a suitable ladder or scaffold and cover the batteries to protect them from falling objects

k. When cleaning a battery module, be careful not to touch the lead terminals (normally covered with black plastic caps). When cleaning, keep one hand behind your back or in your pocket and use the other for cleaning. *Do not come in contact with any liquid which may be on top of the battery modules; this may be electrolyte which conducts electricity and can cause a lethal shock.*

l. Avoid dropping or placing metal tools (such as wrenches) on top of a battery module, because severe arcing may result. Use tools with insulated handles or wrap metal tools with electrical tape to minimize risk of accident

m. Be careful washing the battery room floor because the wet floor increases the danger of electrical shock. Avoid hitting the sides of the battery modules when using the power floor scrubber. Only use enough water for the task.

n. Shut down the battery subsystem (Paragraph 4.1) when washing the batteries with a hose. Do not place any bottles or floor washing aids on top of the battery modules.

NOTE

The battery room floor may be splattered with acid after measurement of specific gravity. Since the batteries will be off line, this would be a good time to schedule floor washing.

7.4 Battery Module Removal

The pallet jack (Fig. 12), located in the battery room, is used to remove a battery module from the battery room. Pallet jack operators must make certain that the PV power system has been separated from the battery room (Paragraph 4.1) before removing the battery module. Refer to the instructions in the Maintenance Manual.

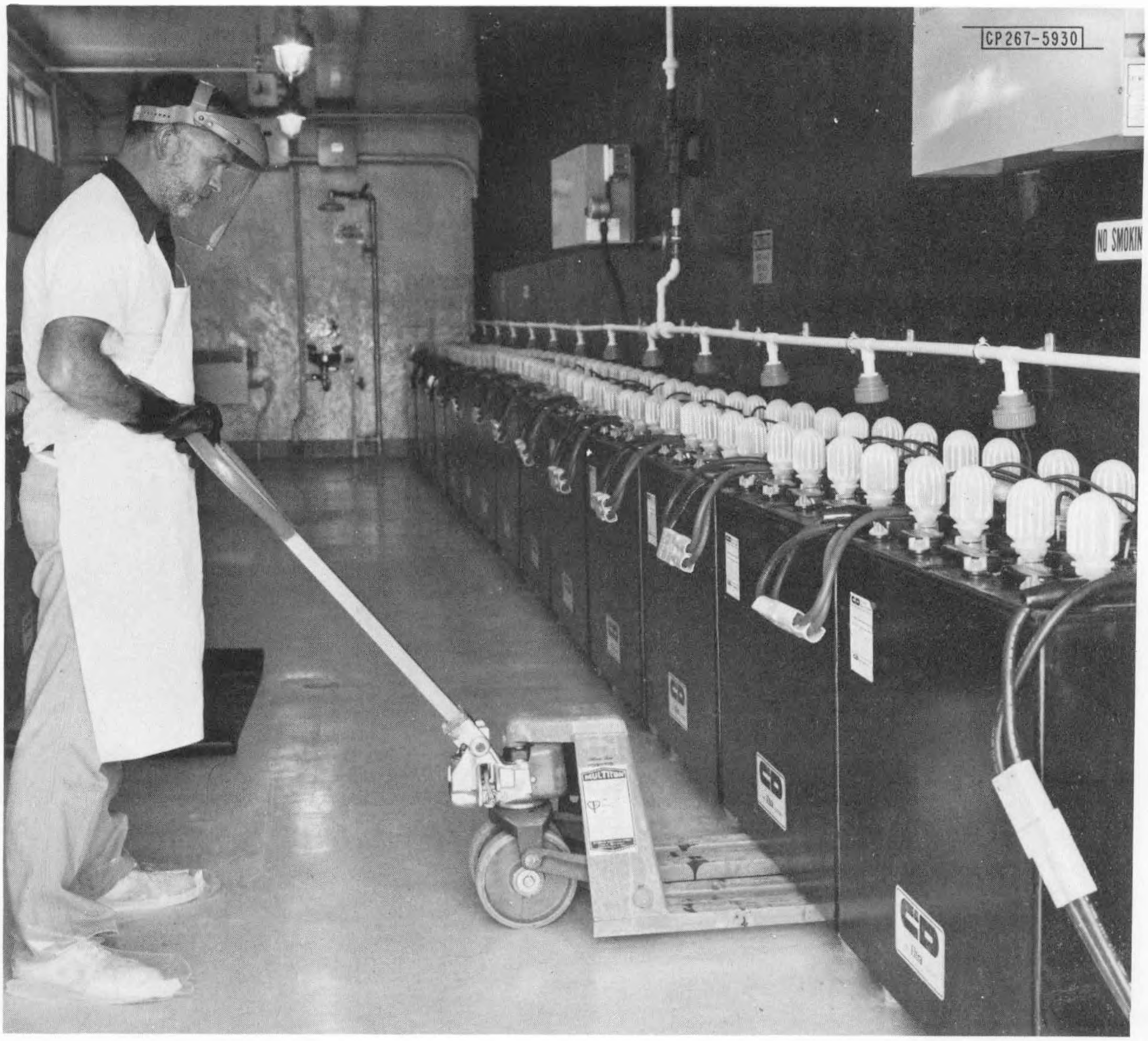

Fig. 12. Battery removal.

WARNING

Do not connect the leads of a battery module together! Wrap and tape the connectors with paper or cloth to ensure that they cannot be interconnected. If the leads were connected together, a huge short-circuit current would flow and extensive damage would result, such as fire and explosion.

Disconnect the positive and negative leads to the battery. Be careful when moving a loaded pallet jack. Move slowly to avoid damaging the sides of other batteries. *At least two people are required to ensure that the battery module can be moved and stopped safely.* Do not lift a battery module higher than necessary.

8.0 CONTROL ROOM SAFETY

8.1 Potential Hazards

8.1.1 Electrical Shock

The potential for an electrical shock exists inside all the electrical equipment located within the control room. The control room contains two cabinets where high-voltage DC power (250-300 VDC) is available: the AFSC switching cabinet and the I/V load box. Other cabinets in this room contain 120 VAC and lower DC voltages.

To aid in servicing, cabinet doors in the control room are not provided with safety interlocks, but they are provided with locks. Unless maintenance is required these cabinet doors should always be locked shut, with the keys kept by trained personnel in the key cabinet (Unit 265A) in the PV building.

Do not touch any electrical or electronic equipment unless authorized. If equipment must be repaired, first make a personal inspection to assure that it is de-energized.

8.1.2 Electrical Arcs

Since arcing usually happens when high-energy circuits are broken, care must be taken that power is cut off to the AFSC cabinets before replacing one of the 48 AFSC modules. Reduced array output is present early and late in the day, and these are the best times to replace an AFSC module. If possible, avoid changing modules in the middle of the day, but if it is necessary, place DISCONNECT switch S2 in the corresponding ASJB box to OFF (Fig. 5). Refer to the appropriate instructions in the Maintenance Manual.

8.1.3 Fire Fighting

Fires can have electrical causes, for example, overloaded circuits can cause fires by overheating. Circuits should not be overloaded by using improperly sized extension cords. Poor contact between plugs and receptacles can also cause arcing, leading to a serious fire hazard. Make sure that contacts are secure. Should a fire start, it can be more readily extinguished if there is no burnable matter in its path. For this reason the control room (and the storage area) should be kept free of flammable debris.

8.1.4 Bodily Injury

Power supplies, oscilloscopes, chassis and other heavy materials should be lifted in such a way as to prevent back injuries. To prevent tripping, cables should be routed in cable ways or overhead.

8.2 Alarm Indicators

The system alarm panel is located on the left side of the main control console (Unit 240) (Figs. 13 and 14). At present, there are 17 major alarm "eyeballs" and 11 minor alarm "eyeballs". Those related to safety are:

Major Alarms: FIRE ALARM; HYDROGEN ALARM; AFSC HOT ALARM

Minor Alarms: BATTERY HOT ALARM; UPS HIGH TEMPERATURE ALARM; MAIN INVERTER HIGH TEMPERATURE ALARM; BATTERY ROOM HIGH TEMPERATURE ALARM; I/V BOX HIGH TEMPERATURE ALARM.

If any alarm has been enabled, check the equipment associated with that alarm, taking all proper precautions.

In addition, a PV building alarm panel, (Unit 236), located on the west wall of the control room (Fig. 15) contains two gas alarms (Units 237A and 237B) to warn of excess hydrogen in the battery room, as well as fire and thermal alarms from the battery room, control room and inverter room.

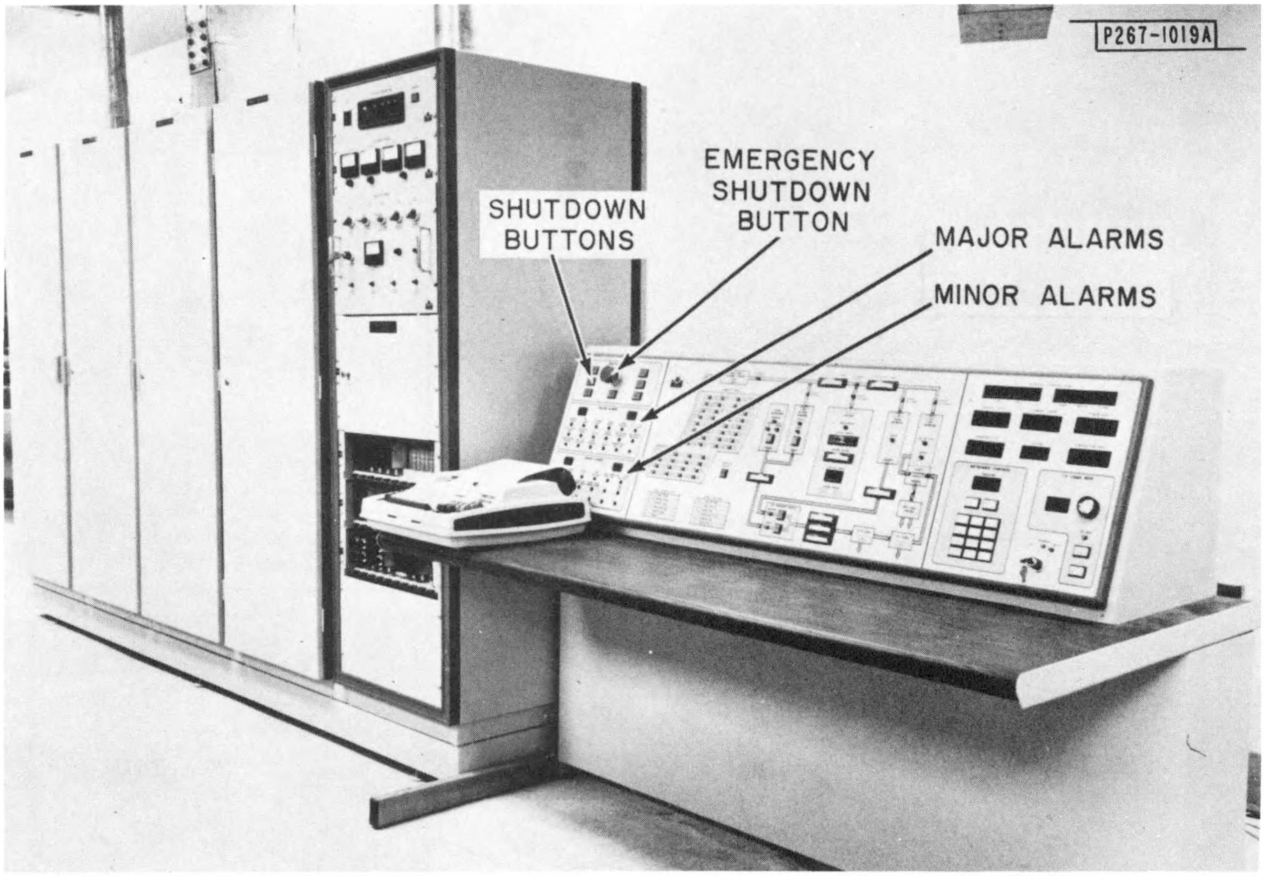

Fig. 13. Control console.

8.3 Control Room Maintenance

Be careful when operating or maintaining electrical equipment, for your safety as well as the safety of others.

Servicing may be done from the front or back of each equipment rack. Be neat. Do not use spaces behind and under consoles or power supplies for storage.

All equipment located within the control room, with the exception of the AFSC cabinets, can easily be de-energized for service. Refer to Paragraph 4.2 for instructions for removing power from the AFSC cabinets.

If it is necessary to obtain voltage indications while the equipment racks are energized, use the one-hand technique described in Paragraph 2.5, wear insulated and tested rubber gloves, and stand on an insulated rubber mat.

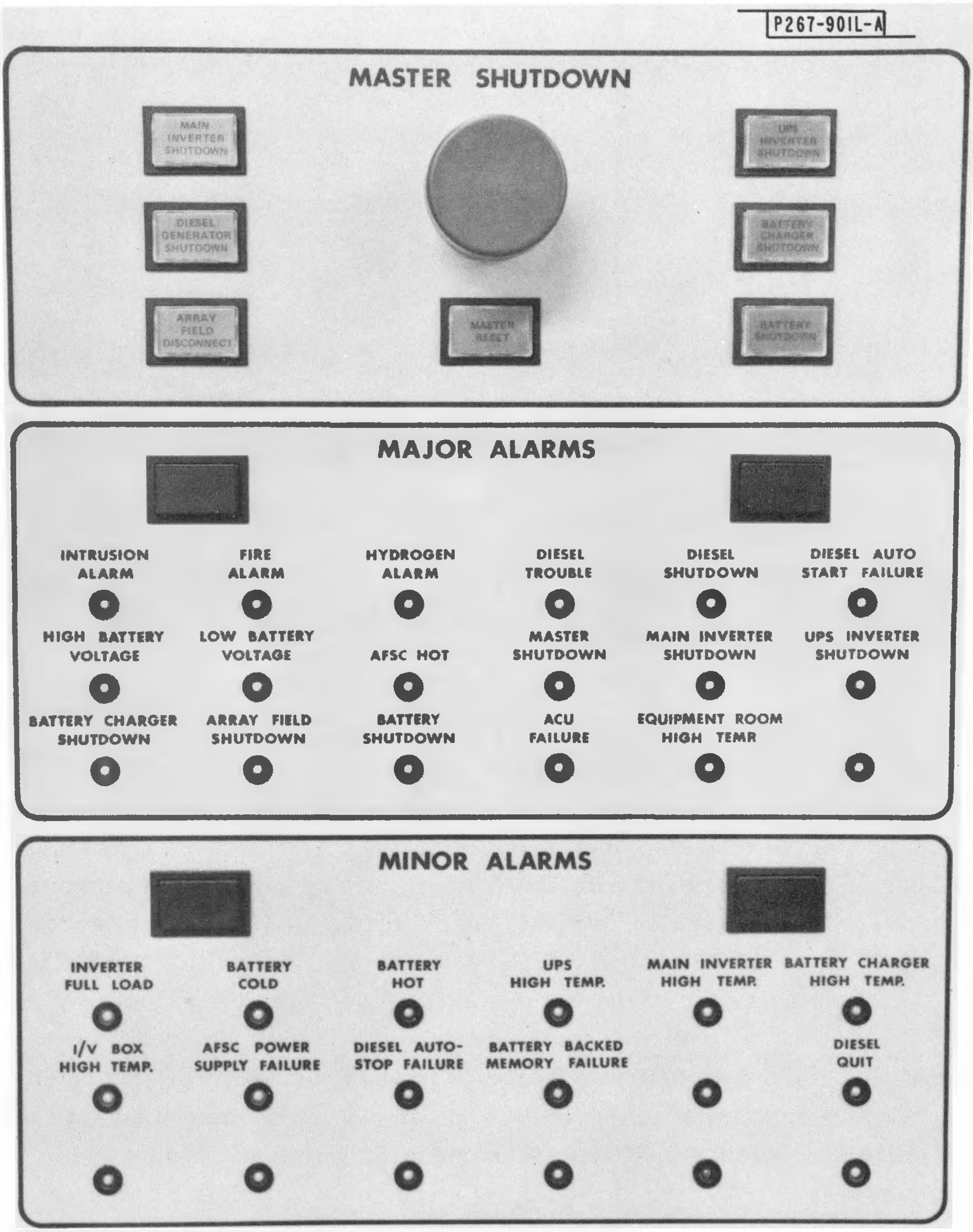

Fig. 14. Console alarm panel close-up.

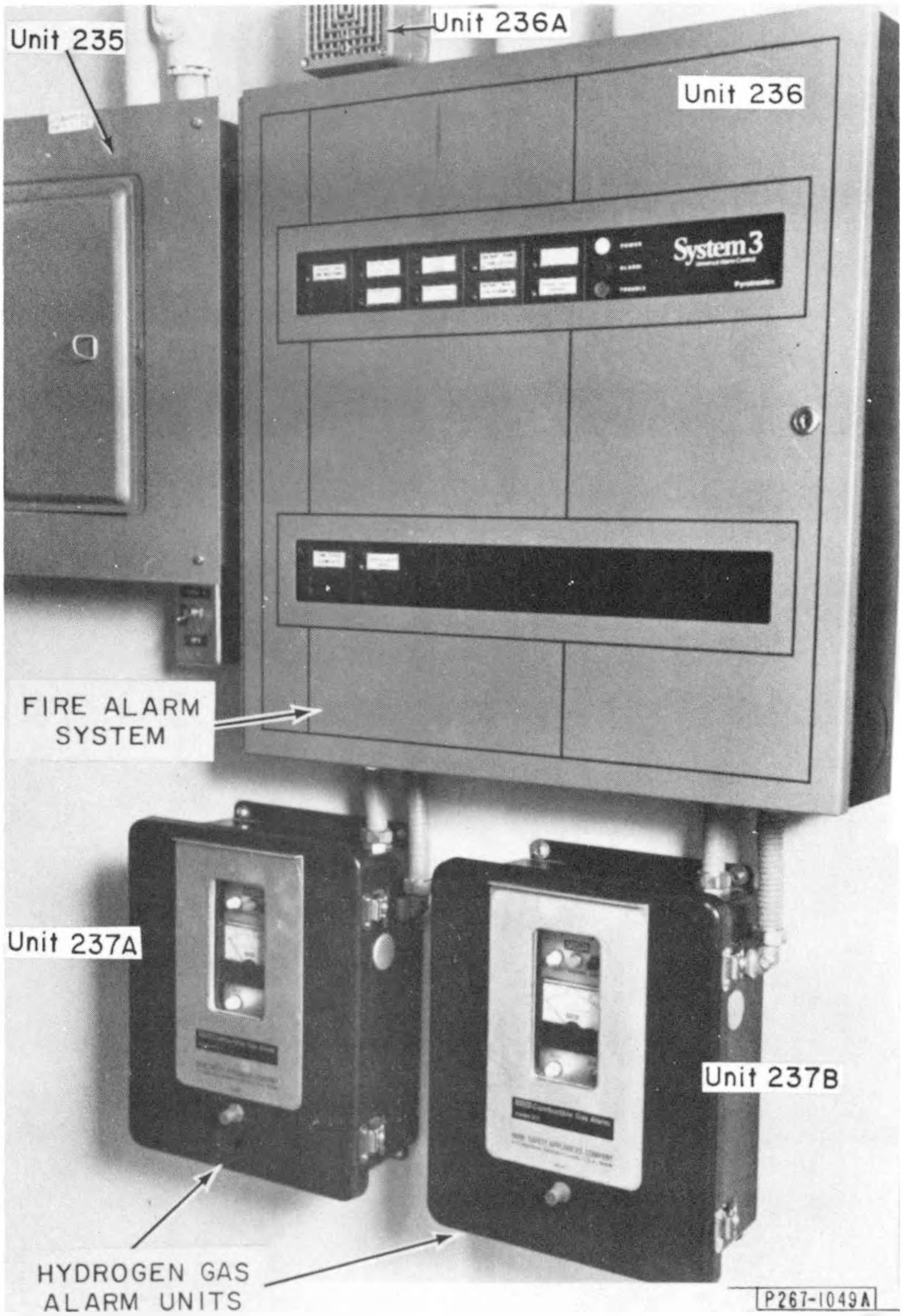

Fig. 15. PV building alarm system.

9.0 INVERTER ROOM SAFETY

9.1 Potential Hazards

9.1.1 Electrical Shock

The potential for electrical shock exists in all the equipment located within the inverter room. Located within this room are the main inverter and a UPS inverter along with a battery charger. Accompanying this equipment are AC and DC disconnects and circuit breakers (Figs. 16 and 17). AC and DC voltages in excess of 240 volts are present in this equipment and in the disconnects.

Before repairing any equipment it is your responsibility to make a personal inspection to assure yourself that it is de-energized. *Opening a switch is not*

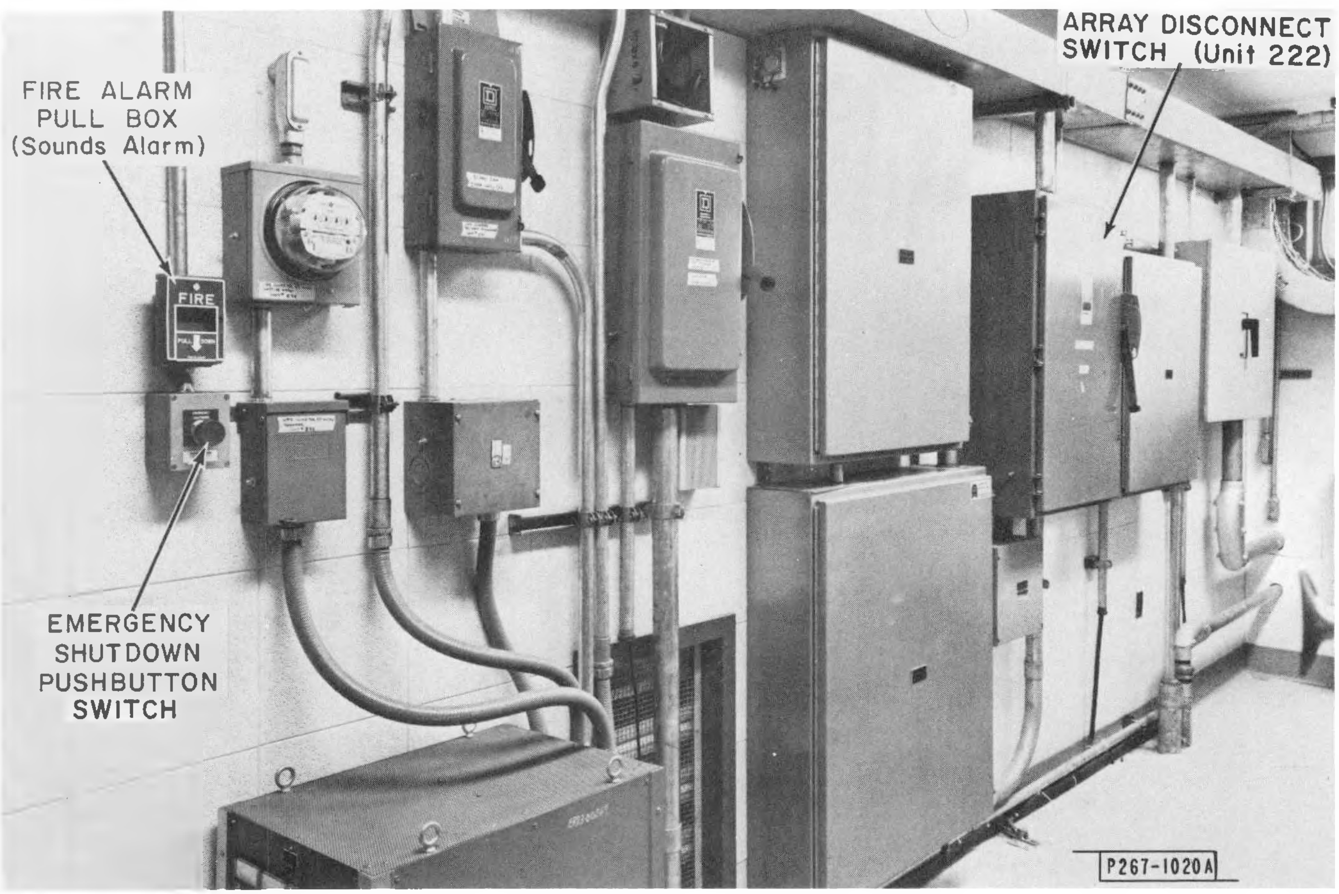

Fig. 16. Inverter room, east wall.

enough! To ensure that all appropriate systems are isolated, it is necessary that all possible sources of power be investigated and de-energized. Before working on any power-conditioning equipment which include capacitors, disconnect them from the energized source, allow time for normal discharge by bleeder resistors and then test them by shorting and grounding. Refer to Paragraph 2.7. Test circuits with a voltage sensor such as a voltmeter before your touch!

9.1.2 Electrical Arcs

Since burns from arcs can be severe, never close a switch slowly or hesitantly, as arcing may result. Arcing happens when breaking high-energy

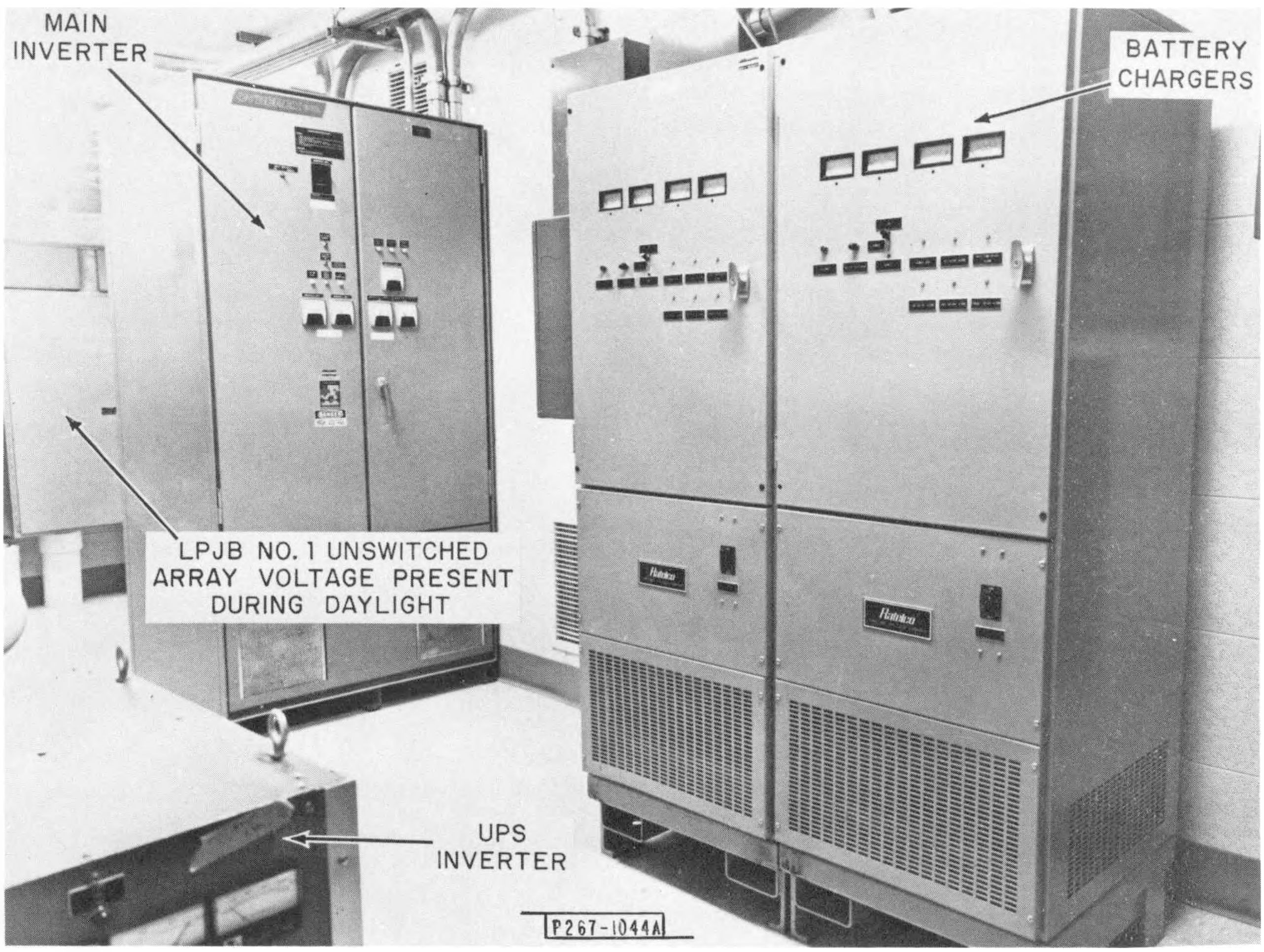

Fig. 17. Inverter room, west wall.

circuits, which are present in this room. Caution must be taken to properly de-energize equipment before attempting repair. *While this system has been carefully designed, it is always best to stand to the side and look away when opening or closing high-power switches.*

9.1.3 Fire Fighting

The potential exists for a fire in the power-conditioning equipment should any component become shorted. This equipment has many built-in safety features to protect it. If by chance a fire should start, the grounded metal enclosures should prevent damage to other equipment. Refer to Paragraph 5.7.

If the array field is struck by lightning, it is remotely possible for the lightning surge arrestors to catch fire. The lightning surge arrestors are located in the LPJB 1 box (Fig. 17) located on the south wall. It will be necessary to shut down PV power to fight the fire, as described in Paragraph 3.0.

9.1.4 Bodily Injury

Refer to Paragraph 5.5.

9.1.5 Evacuation

Refer to Paragraph 5.6.

9.2 Inverter Room Maintenance

When maintaining the electrical equipment in the inverter room, it is necessary to take safety precautions for oneself and for those providing assistance. Do not attempt any repairs unless you are a technician trained in servicing high-power equipment. All power equipment located within the inverter room can be easily de-energized for service. Refer to Paragraph 2.7 before handling capacitors.

Care must be taken when servicing the LPJB 1 box (Fig. 17), which contains the lightning surge arrestors. Before servicing, cut off array power by following the instructions provided in Paragraph 4.2. Then place the array disconnect switch Unit 222, located on the east wall of the inverter room to OFF. Refer to the procedures provided in the Maintenance Manual for checking and replacement of fuses.

Replacing the fuse inside the main inverter (and other maintenance in the inverter) should be done with the main inverter DC disconnect switch (Unit 202) placed to OFF, locked, and tagged by the person doing the work. The AC disconnect switch is Unit 204. The same is true when servicing the UPS inverter and the battery charger. Refer to Paragraph 2.2.

The battery charger must be isolated from the AC power provided by the generator as well as from the DC power available on the battery bus. Place the AC and DC disconnect switches to OFF before servicing this unit. The DC disconnect switch is Unit 217 and the AC disconnect switch is Unit 215.

The UPS inverter also has three power feeds. Place the following switches to their OFF positions:

DC disconnect (Unit 232)

No. 32 50-A AC (Unit 270) Panel A

No. 30 20-A AC (Unit 270) Panel A

A bypass switch can be used to supply power to the control system.

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APPENDIX
Definition of Terms

Array

An array is a mechanically integrated assembly of modules together with interconnects, junction box, conduit, heat-transfer elements, and support structure (frame for this project) but exclusive of foundations. An array forms a DC power-producing unit. For this project, an array is 8 × 24 ft and contains 12 panels. The array produces approximately 1-kW peak and is a branch subcircuit.

Array Field (AF)

The AF is the aggregate of all array subfields, associated electrical auxiliaries, and support foundations. In this document, when AF is used in a contractual context, the support foundations (structual work or members below the top of the NPS provided foundation elements) shall be excluded from the definition. The AF incorporates 48 array subfields for a total power of approximately 100 kW.

Array Junction Box (AJB)

An AJB is an electrical junction box located at the west end of the easterly array in an ASF which provides for power connection of the easterly array to the ASJB and provides the required apparatus for testing of the easterly array (branch circuit) at the subarray level.

Array Subfield (ASF)

An array subfield (ASF) is, for the purposes of this project, the combination of two arrays into an 8 × 48 ft electrical unit. An ASF produces approximately 2-kW peak at the required DC bus voltage and is a branch circuit.

Array Subfield Junction Box (ASJB)

An ASJB is an electrical junction box located at the west end of a 48-ft array subfield. The ASJB incorporates provision for power summing of the two arrays in the ASF, testing of both arrays at the array level, and testing of the westerly array at the subarray (branch circuit) level. The ASJB also includes the necessary isolation diodes, current shunts, switches, lightning protection devices, and other required components.

Branch Circuit

A branch circuit is the electrical interconnection of solar modules in an array subfield. For this project, a branch circuit (array subfield) will include two branch subcircuits (arrays).

Frame

A frame is the support structure in which subframes are mounted. The frame used for this project has nominal dimensions of 8 × 24 ft and will accommodate 12 subframes. The frame incorporates appendages for attachment to a foundation and for the adjustment of the zenith angle. When combined with panels, a frame becomes an array.

Panel

A panel is the electrical and mechanical integration of an appropriate number of solar modules in a subframe including the intermodule power wiring, a module shunting diode, the intersubarray power wiring with companion connectors, module test wiring with companion connectors and the required assembly hardware. For our purposes a panel is 4-ft square; twelve panels fit into an 8 × 24 ft frame to make an array.

Photovoltaic (PV)

The photovoltaic (PV) effect involves the direct conversion of light energy (in this case sunlight) to electric potential by photon ionization at the junction of a semiconductor.

Photovoltaic System

An installed aggregate of solar array subfields and other subsystems transmitting power to a given application. A system may include the following subsystems; (a) array fields, (b) power conditioning and control, (c) storage, (d) backup, (e) thermal, if required, (f) land security system and building,

(g) on-site conduit/wiring, (h) instrumentation, and (i) maintenance and repair equipment.

Row-End Junction Box (REJB)

A REJB is an electrical junction box located at the west end of a row of four ASFs. It includes the functions of an ASJB except that it has additional provisions for the power summation of all the ASFs in the row and for the interconnection with the underground cable connecting the row with the PV building.

Solar Cell

The solar cell is a semiconductor which presents a relatively large junction area to incident sunlight. The solar cells used for this project are of silicon type and have a diameter of approximately 8 cm. The solar cell is the basic photovoltaic conversion device.

Solar Module

A solar module is the electric interconnection and physical integration of a significant number of solar cells into a complete environmentally compatible assembly. The solar module, in addition to the solar cells and their interconnects, includes a supporting framework for the solar cells, an embedment to minimize thermal and environmental protection to the solar cell surfaces. The module incorporates terminals for external electrical connection as well as a means for mounting in higher assemblies. Three different glass-covered module types with metal framework are used on this project.

Subframe

A subframe is the supporting structure in which solar modules are mounted. The subframe used for this project has standardized dimensions of 4 ft × 4 ft and will accommodate all three solar module types. When combined with solar modules, diodes, hardware, wiring, and connectors, a subframe becomes a panel.

Underground Cable

The underground cable is a buried cable providing for power and signal interconnection of the AF with other components of the photovoltaic system, which are housed in the PV building.