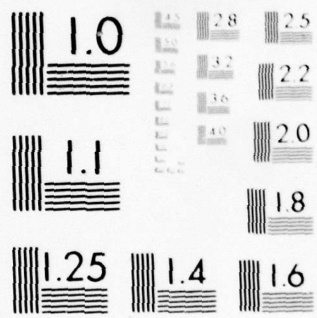
AD-A053 960 ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT COMM--ETC F/G 10/2
SOLAR CELL POWER FOR FIELD INSTRUMENTATION AT WHITE SANDS MISSI--ETC(U)
JAN 78 J W BOND, D H RECKART, W B MILWAY

UNCLASSIFIED MERADCOM-2229 NL

1 OF 1
AD
A053960

END
DATE
FILMED
6-78
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

Report 2229

SOLAR CELL POWER FOR FIELD INSTRUMENTATION AT WHITE SANDS MISSILE RANGE

by
John W. Bond, Jr.
Darwin H. Reckart, Jr.
and
William B. Milway

January 1978

Approved for public release; distribution unlimited.

U.S. ARMY MOBILITY EQUIPMENT
RESEARCH AND DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: 2229 (14) MERADCOM-2229 — 2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): SOLAR CELL POWER FOR FIELD INSTRUMENTATION AT WHITE SANDS MISSILE RANGE	5. TYPE OF REPORT & PERIOD COVERED: Final rept.
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): John W. Bond, Jr., Darwin H. Reckart, Jr., William B. Milway	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Energy Systems Project Office, DRDME-ES, U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia 22060	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 1U765702D623
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia 22060	12. REPORT DATE: Jan[redacted]78
	13. NUMBER OF PAGES: 57 (12) 49 p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Instrumentation Directorate, U.S. Army Test and Evaluation Command, Aberdeen Proving Ground, Maryland	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

PE 65702 A AS623

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Photovoltaic Systems
REMOTE Power Supplies
Solar Cells
Battery Systems
Field Instrumentation
Instrumentation Systems

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The initial phase of an Instrumentation Development Project to explore and document what solar power can do for remote field instrumentation systems is described. The work scope consisted of selection, design, construction, test, and delivery of a solar cell power system for White Sands Missile Range. A Drone Formation Control System Interrogator was selected; a power supply was built and installed in the San Andres Mountain Range at WSMR in late August 1977.

403 269

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

The work described in this report was authorized and funded by the U.S. Army Test and Evaluation Command (TECOM) under terms of Procurement/Work Directive EF-12-0003 (PRON K1-T-70021-01-K1-EF) to MERADCOM dated 17 December 1976. The work supports Department of the Army Project 1U765702D623.

Dr. John W. Bond, Jr., MERADCOM, was principal investigator for the effort. Design and construction of the equipment were performed at MERADCOM under the direction of Mr. Darwin Reckart, Electrical Engineer. This effort is related to the Military Applications of Photovoltaic Systems program.

TECOM guidance was provided by Mr. William Milway, Instrumentation Directorate. Mr. William Rice, Chief of the Drone Formation Control System, was primarily responsible for engineering efforts at the White Sands Missile Range (WSMR) under the Direction of Mr. James Scott. Mr. Larry Moore of the Army Atmospheric Sciences Laboratory (ASL) at WSMR made most of the solar radiation measurements.

CONTENTS

Section	Title	Page
	PREFACE	iii
	ILLUSTRATIONS	v
	METRIC CONVERSION FACTORS	vi
I	INTRODUCTION AND SUMMARY	1
II	THE DRONE FORMATION CONTROL SYSTEM, DFCS	2
III	INSOLATION AND ENVIRONMENT	3
IV	DESCRIPTION OF THE SCPS	6
V	FUTURE WORK FOR THE DFCS/SCPS	19
	APPENDICES	
	A. Program Plan	21
	B. SCPS Component Specifications	25
	C. Cinetheodolites and Telescopes	29
	D. Solar Cell Power for Other WSMR Applications	38
	E. Operating and Maintenance Instructions for the DFCS/SCPS	39

ILLUSTRATIONS

Figure	Title	Page
1	Map of WSMR Showing Goat Mountain and Army-II Sites	4
2	Block Diagram of the SCPS	7
3	Solar Panel	8
4	Interconnection Diagram	10
5	Power System Schematic	11
6	SCPS During Checkout at MERADCOM	12
7	Solar Cell System Installed on Top of Goat Mountain	13
8	Lift-off of Chinook 47 (CH-47) Helicopter with Instrumentation Building	14
9	CH-47 Landing the Instrumentation Building on Goat Mountain	15
10	CH-47 Landing One of the Storage Batteries on Goat Mountain	16
11	Assembling and Installing the Solar Cell Array on Goat Mountain	17
12	The SCPS Completed and Installed on Goat Mountain	18
B1	Exposed View of the Inverter	27
C1	Energy Balance as a Function of Load for a Typical Diesel Engine	35

METRIC CONVERSION FACTORS

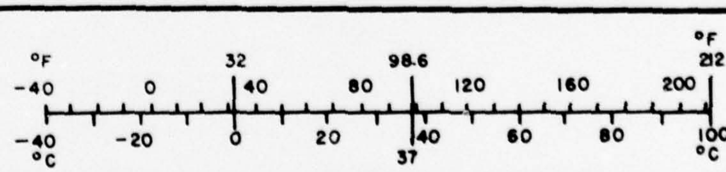
Approximate Conversions to Metric Measures

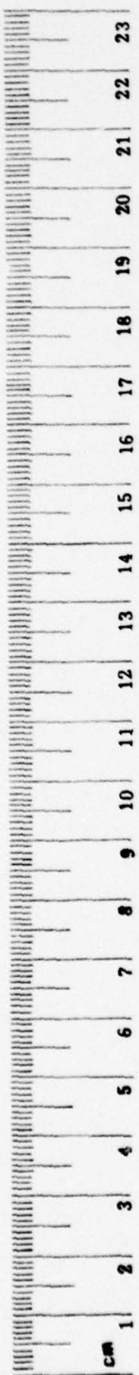
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric tons	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	L
pt	pints	0.47	liters	L
qt	quarts	0.95	liters	L
gal	gallons	3.8	liters	L
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in = 2.54 cm (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10 000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric tons (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
L	liters	2.1	pints	pt
L	liters	1.06	quarts	qt
L	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F





SOLAR CELL POWER FOR FIELD INSTRUMENTATION AT WHITE SANDS MISSILE RANGE

I. INTRODUCTION AND SUMMARY

The U.S. Army Test and Evaluation Command (TECOM) operates several large test ranges in remote areas of the West for weapons testing. These test ranges are heavily instrumented with telemetry, radar, optical devices, and electronic ranging systems. Many instrumentation sites are at inaccessible locations which do not have power or other improvements. Operation of instrumentation at such locations is difficult and expensive.

Improving the efficiency of TECOM operation through utilization of new or unique instrumentation technology is a goal of the TECOM Instrumentation Development Program, Project D623. One area that is of high interest in the program is finding ways to more efficiently provide power at such remote instrumentation sites. Solar power appears to offer high potential for accomplishing this. Solar power reference stations for a Range Measurement System have previously been acquired under D623 sponsorship at Yuma Proving Ground and have been successful.

The effort described in this report is the initial phase of an Instrumentation Development Project to carefully explore and document the pros and cons of what solar power can do for TECOM instrumentation. A representative instrumentation type and a location were chosen, and a solar cell power system was designed and installed by MERADCOM. This system will be carefully monitored, and subsequent reports will document the results. In addition, other instruments and locations will be selected for similar experimental applications of solar power.

The work scope (shown in the Program Plan, Appendix A) essentially consisted of the selection of an appropriate solar cell power application at White Sands Missile Range (WSMR) and subsequent design, construction, test, and delivery of a suitable solar cell power system to WSMR. With the cooperation of WSMR personnel, a Drone Formation Control System Interrogator (DFCS/I)[1] was selected from several candidate applications.

In addition, a cinetheodolite was selected for further design analysis. A design review was held at TECOM headquarters on 24 February 1977.

---

[1] Also referred to as the DFCS Distance Measuring Equipment (DFCS/DME).

The basic DFCS and the Interrogator (DFCS/I) are described in Section II. The DFCS/I requires 750 watts electric (We) power at 115 Vac for a maximum of 6 hours during any 24-hour period. The Solar Cell Power System (SCPS) consists of a solar cell array rated at 1.6 kilowatts peak (kWp), a 1.5-kWe inverter, a 1500-ampere-hour (Ah) battery, and miscellaneous electrical components and cables. This is believed to be the first terrestrial solar cell system in the United States to provide alternating current power (exclusive of the ERDA/DOD demonstration program).

The SCPS was installed at the top of Goat Mountain in the San Andres Mountain Range at WSMR in late August 1977. It was installed and will be serviced by helicopter. The environment is described in Section III, and the SCPS is described in Section IV (with component specifications in Appendix B).

Because of the isolated location and because of the desire for performance and reliability information, environment (including insolation) and system operation should be closely monitored (Section V).

Potential SCPS application to a cinetheodolite and other instrumentation at WSMR are discussed in Appendices C and D. Operation and maintenance instructions comprise Appendix E.

II. THE DRONE FORMATION CONTROL SYSTEM (DFCS)[2]

The DFCS was conceived in 1974 when it became apparent that a means of controlling multiple targets flying in formation would be required for missile testing.

The DFCS is self-contained with its own tracking and control equipment, telemetry link, and display consoles. It is the largest project to date in the Army's improvement and modernization program for range instrumentation and the only system of its kind.

During demonstration and acceptance tests conducted during late 1976 the DFCS showed its ability to control formations of two, three, and four BQM-34 Firebee drones and a formation of two PQM-102 (F-102) drone aircraft.

In future tests, the DFCS will control formations of four Firebees and two F-102's simultaneously. While tracking and controlling up to six of these targets, the system also has a capability to track up to four other drones.

The DFCS combines telemetry, radar, and distance-measuring equipment with an IBM computer. Control consoles and the computer are located in the Drone Control

[2] Excerpted from The Army Research and Development Magazine, March-April, 1977.

Center while a number of subsystems are located at various vantage points around the range.

Airborne drone units and interrogator stations located at the Drone Control Center and four other range sites form a data-link subsystem. The fixed interrogator stations, which are not manned during operation, are located at elevations ranging from 4,290 to 8,958 feet. A mobile interrogator station also is available for use wherever it is needed.

Flying at altitudes ranging from 600 feet above ground to 26,000 feet above sea level, drones can be controlled automatically by the computer or manually through the control consoles. Video screens allow operators to monitor flight paths of the drones at all times.

The fixed interrogator subsystem being powered by the SCPS is located at 6638 feet on top of Goat Mountain. It was emplaced and tested in August-September 1977. Requirements for this unit are:

Prime Instrument Power – 750 watts, 115 Vac (± 10%), 60 Hz, single-phase. The system may be required to operate at any time during a 24-hour day. Maximum requirement will be approximately 6 hours during any 24-hours (i.e., a minimum of 18 hours between operations). In addition, a continuous remote turn on/turn off receiver supply must be provided. This requirement is 11 to 12 Vdc, 250 mA.

Desired Optional Power – 750 watts, 115 Vac (± 10%), 60 Hz, single-phase. This power would be used for test equipment for on-site maintenance. Use would be intermittent, primarily daytime, and would be 2 hours every 3 months.

Location – The interrogator subsystem was initially located at the Army-II site just north of the Small Missile Range. However, it has since been installed on the top of Goat Mountain (Figure 1).

III. INSOLATION AND ENVIRONMENT

At the time this program was started, insolation data for WSMR were not available. The Goat Mountain site is at 6638 feet elevation in the San Andres Mountain Range approximately 20 miles northwest of Headquarters. The nearest station for which insolation data are available is El Paso, Texas, about 60 miles south of Headquarters. El Paso is at a much lower altitude than the Goat Mountain site and is located on the Rio Grande River. The next nearest station is Socorro, New Mexico, 100 miles north of Headquarters and located in a different mountain range than the San Andres.

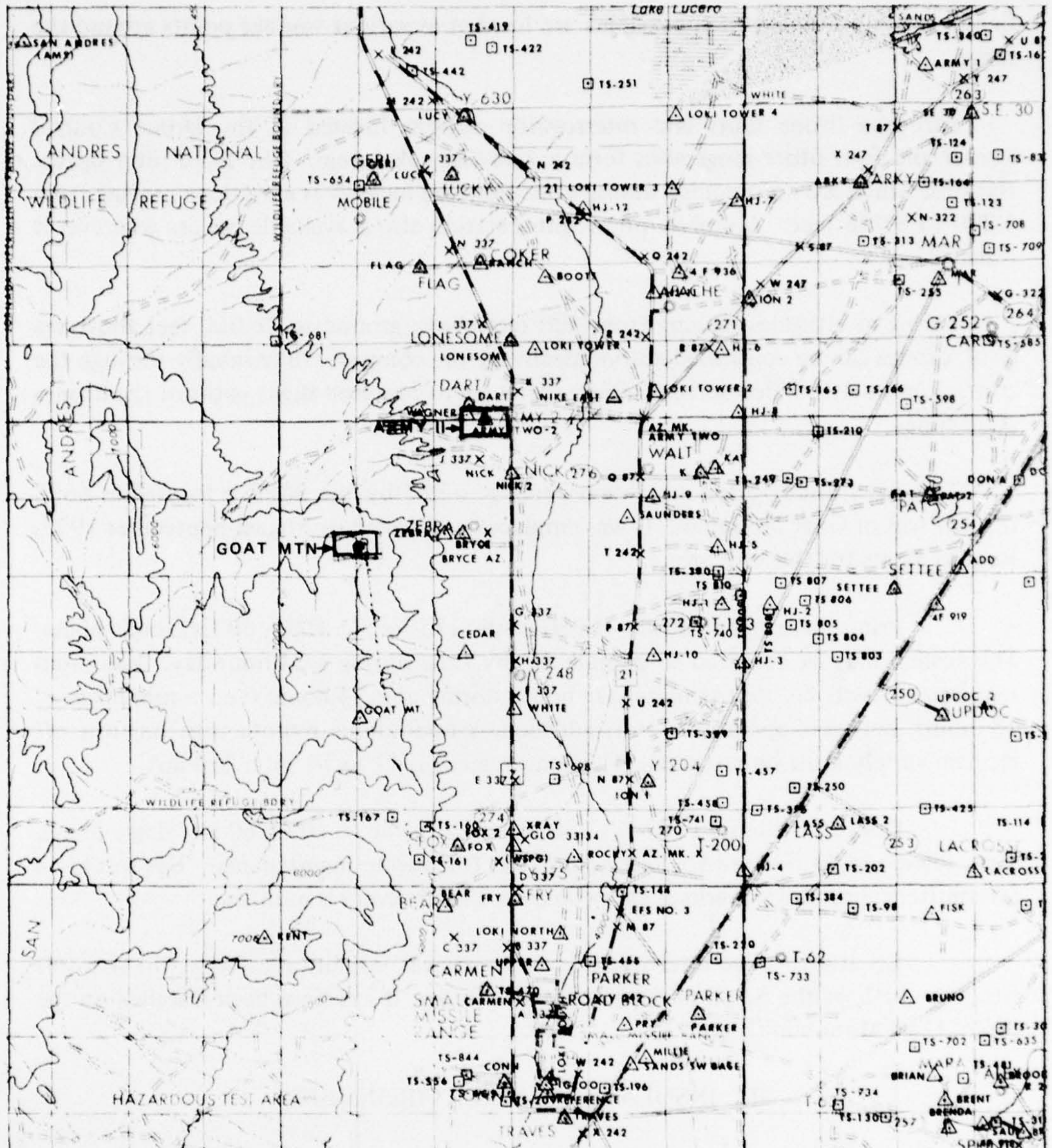


Figure 1. Map of WSMR showing Goat Mountain and Army-II sites.

Coincidentally, cursory examination of insolation data at Socorro and El Paso indicates that the stations are quite similar even though Socorro is 2 degrees latitude north of El Paso. If Socorro and El Paso were at the same elevation and general environmental conditions were similar, statistics suggest that Socorro insolation should be 10 percent less than El Paso insolation.

The Army Atmospheric Sciences Laboratory (ASL) located at WSMR started making insolation measurements at the WSMR Army-II site in December 1976. The Army-II site is located on the valley floor at WSMR at an elevation of about 4000 feet. As one would expect, the data are very similar to those for El Paso and Socorro. Accordingly, the El Paso/Socorro insolation data were used to design the SCPS. However, because of the recognized uncertainties, safety factors were included in the array size and in the storage capacity. The system was sized for 500 langleys/day with 6 days of energy storage.

The high peaks in the southern part of the WSMR, such as Goat Mountain, are characterized by sudden intense cloudiness and thunderstorms. Since the thunderstorms are of relatively short duration and the effective cloud layer is probably thin, it is probable that insolation will not be significantly affected, i.e., the Socorro, El Paso, Army-II insolation measurements should represent the Goat Mountain insolation.

There are several other items of particular importance at the Goat Mountain site. The site is high with exceptionally steep slopes suggesting extreme gust loading problems. Under these conditions, severe gust loading can occur within a few minutes or even tens of seconds. (This time factor is important because of the problem of environmental monitoring.) The site is also subject to severe thunderstorms with high lightning incidence. Direct strikes can be alleviated by lightning rods (tower) and adequate electric grounding. However, the far field from lightning (up to 10 miles distance) can couple into large conductors (such as the SCPS) and possibly cause damage to subsystem components.

Goat Mountain is located inside of the San Andres National Game Refuge. The game refuge includes wild horses, deer, and a herd of 25 wild mountain sheep. The sheep are of concern because of their proclivity to jump on almost anything that stands up. Accordingly, the panels have been placed on 12-foot-high metallic stilts. Cables are used to anchor the panels for protection against wind loading.

Two lightning rods (towers) about 40 feet high have been erected to protect against direct lightning strikes. One rod serves the solar cell array and the other rod serves the DFCS/I. A common electric ground, a 6-foot-square aluminum pan about 3 inches deep, is filled with a brine solution. Since the animals like salt, numerous salt blocks are distributed at lower parts of the mountain. It is hoped that this will keep the animals from licking the salt in the electric ground.

Another problem results because the animals like to chew the cabling used for such remote power systems. This problem is alleviated by placing all of the cables inside plastic (PVA) pipe.

IV. DESCRIPTION OF THE SCPS

a. **Requirements.**

(1) The Solar Cell Power Supply provides electrical power for operation of the following combined loads:

(a) Main – 750 watts, 115 Vac, 60 Hz single-phase, with a duty cycle of 6 hours operation per 24-hour interval.

(b) Standby – 4 watts, 12 Vdc, continuous operation.

(c) Auxiliary – 750 watts, 115 Vac, 60 Hz single-phase, with a duty cycle of 2 hours operation per 3-month interval.

(2) The system is designed to operate under the following environmental conditions:

(a) El Paso, Texas, and Socorro, New Mexico, insolation.

(b) Gust loads of 170 mph and temperatures as low as -5° F.

(3) The system is transportable by helicopter. Single components do not weigh more than 2000 pounds or have dimensions greater than 10 feet long, 5 feet wide, and 5 feet high.

b. **System Description.**

(1) Engineering Design. A block diagram of the system is shown in Figure 2. The major components are the solar array, battery, and inverter.

(a) The solar array consists of 20 series strings of modules paralleled together to produce a peak generating capacity of 1600 watts. The array is divided into five panels with each panel containing four series strings. Each panel is designed to be individually mounted 2 feet above the ground and to withstand gust loads of 170 mph.[3] Figure 3 shows the details of a single panel. For ease in handling and transporting by helicopter, each panel consists of two frames (each 4 feet by 7 feet) which

[3] The height above ground was extended to 12 feet to avoid problems with wild sheep.

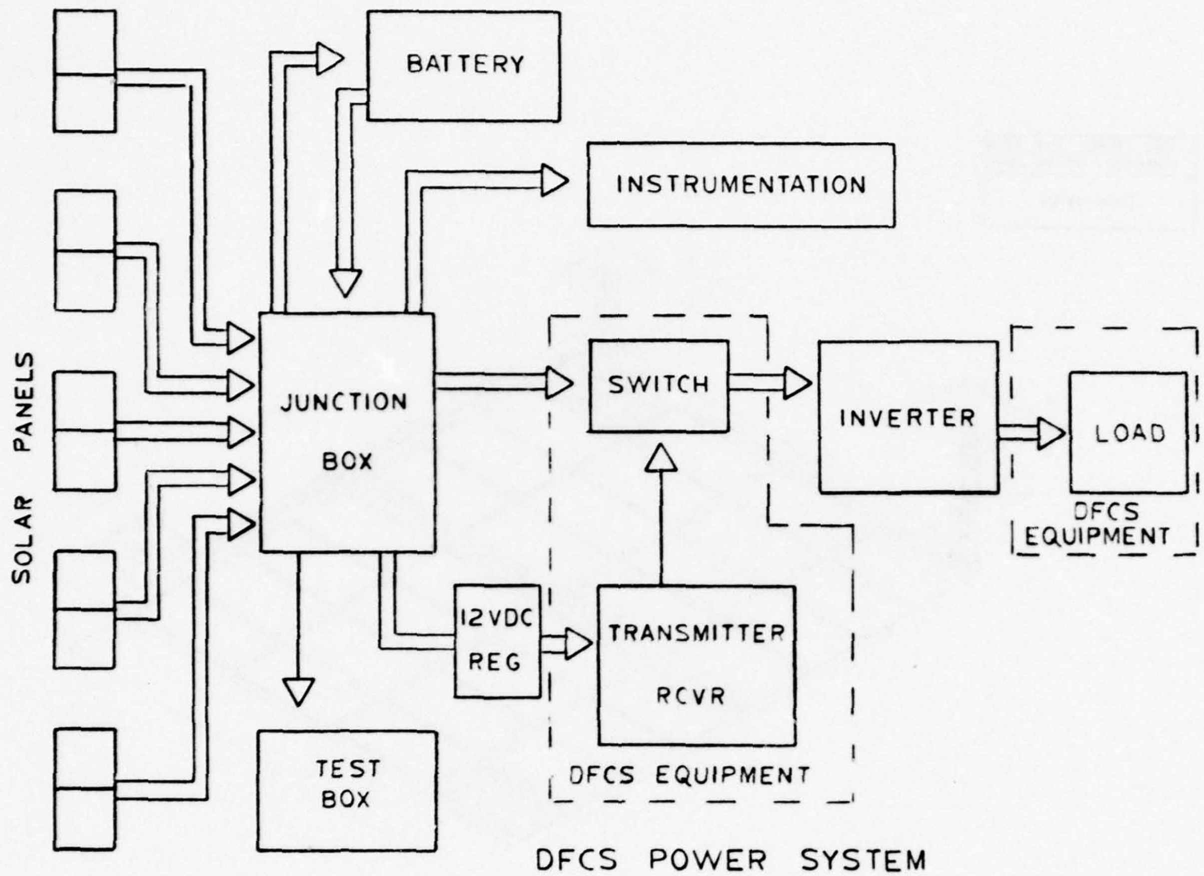


Figure 2. Block diagram of the SCPS.

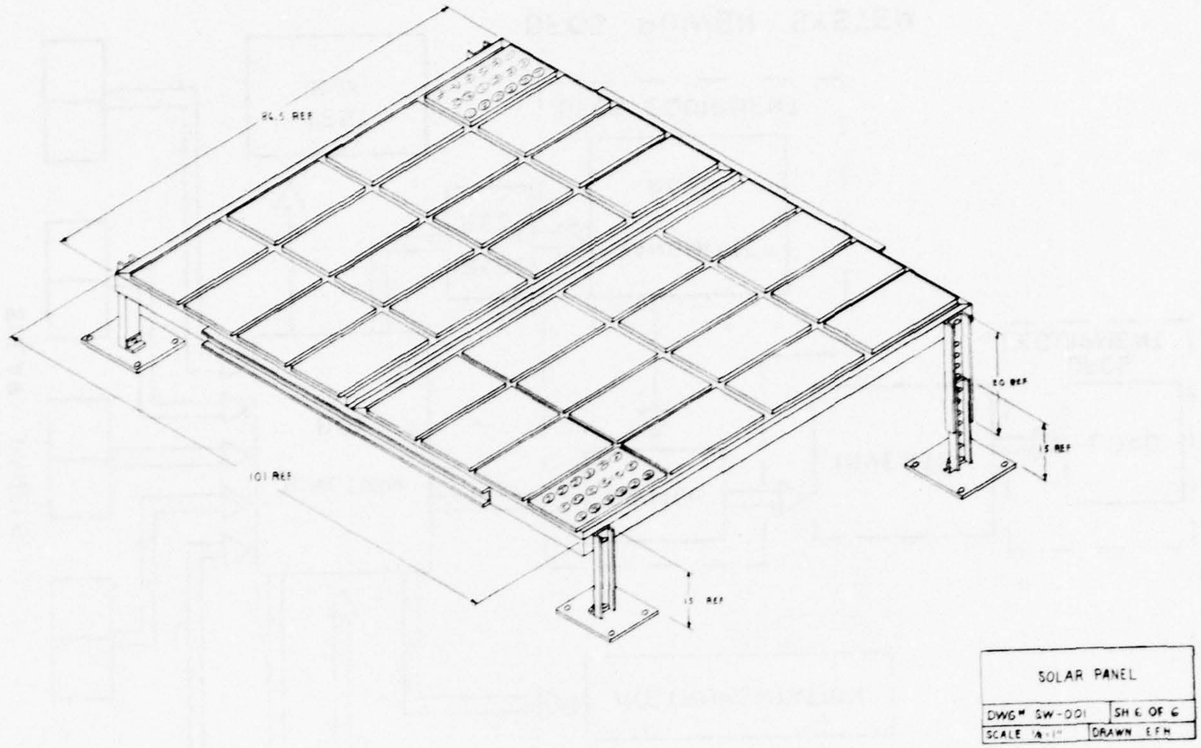


Figure 3. Solar panel.

are bolted together on site.

(b) Storage consists of four, 24-volt, lead-acid batteries connected in a series – parallel arrangement to provide a total storage capacity of 1500 ampere-hours at 48 volts. Each of the four batteries weighs 1600 pounds. To equalize battery temperature, the batteries are installed in an insulated compartment on the north side of the building which houses the DFCS equipment.

(c) The inverter provides up to 1500 watts single-phase power at 115 Vac, 60 Hz, to operate the main and auxiliary loads. The inverter is activated by a remotely controlled switch.

(d) A regulator provides 5 watts dc power at 12 volts for the standby receiver.

(e) The interconnection diagram is shown in Figure 4.

(f) The Power System Schematic is shown in Figure 5. The panel selector enables an I-V curve to be quickly run for each of the solar cell panels.

(2) Instrumentation and Test Plan. Previous test plans for the Army-II and Goat Mountain Sites were changed because of range requirements. The SCPS was installed directly on Goat Mountain without going to Army-II. It was installed and successfully tested during the week of 29 August 1977. Changes made are discussed in Section III. Briefly, they are as follows:

(a) The solar cell panels were raised on stilts to (approximately) 12 feet above ground level to avoid damage by the sheep.

(b) Cabling was encased in PVA piping to avoid chewing by the sheep and other animals.

(c) A lightning rod (tower) was provided to protect the solar cell panels from damage due to a direct strike by lightning.

(d) An electric ground was provided.

Photographs of some of the separate components of the SCPS during checkout at Fort Belvoir are shown in Figure 6. Photographs of the SCPS installed on Goat Mountain are shown in Figures 7 through 12.

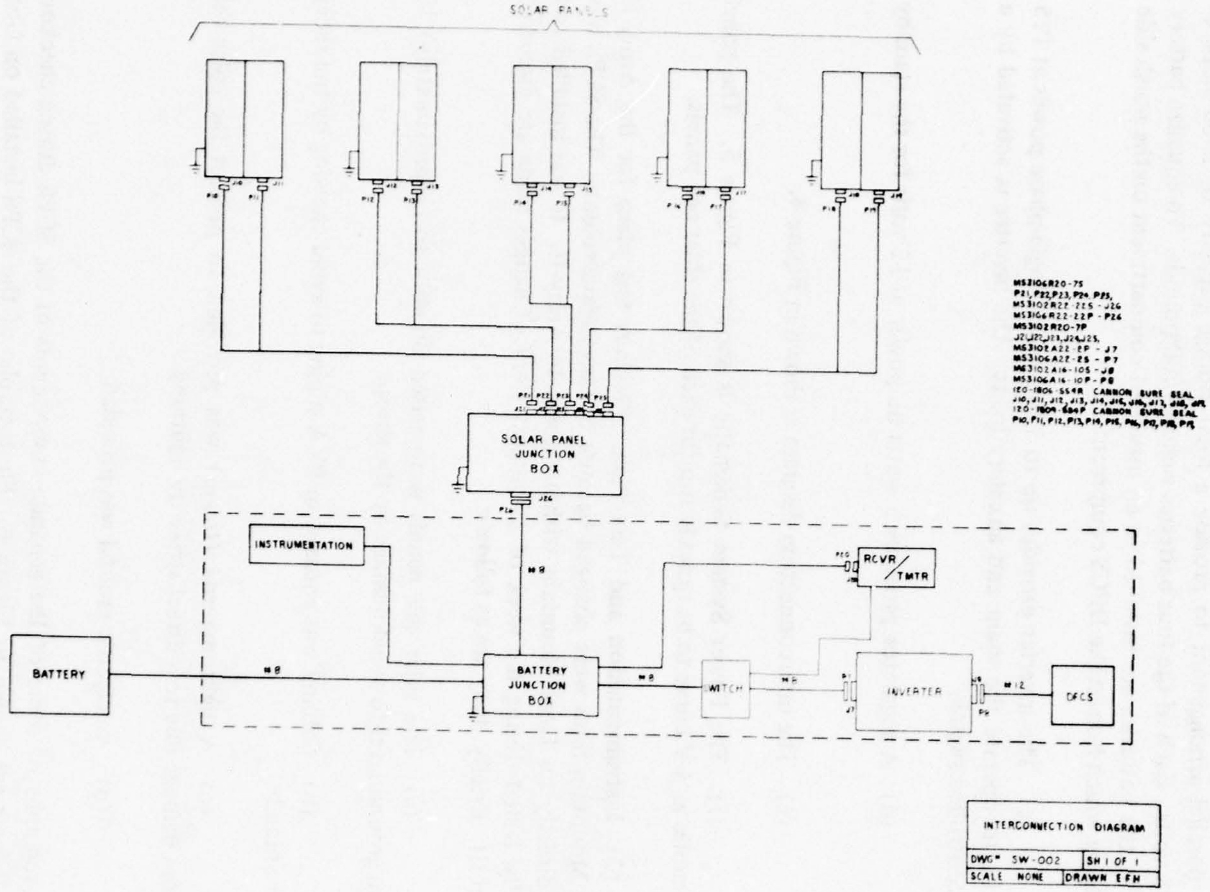


Figure 4. Interconnection diagram.

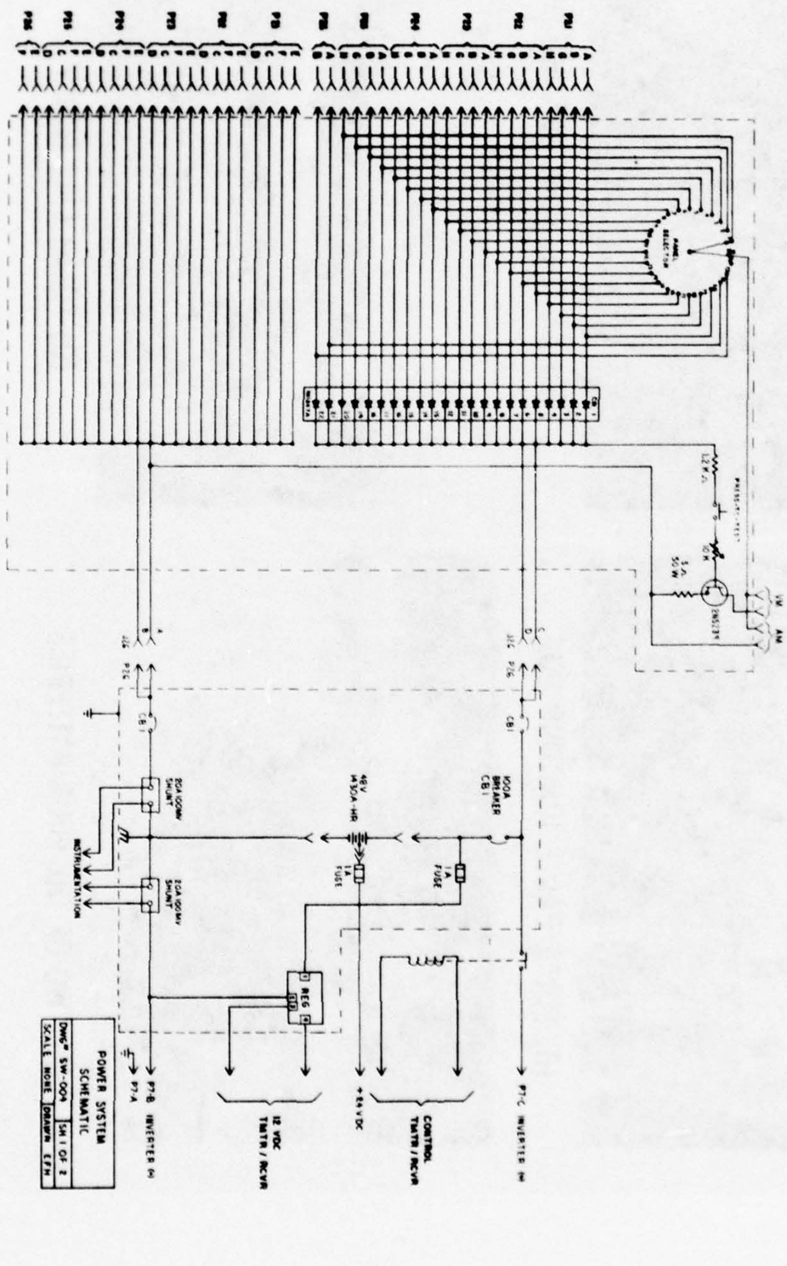
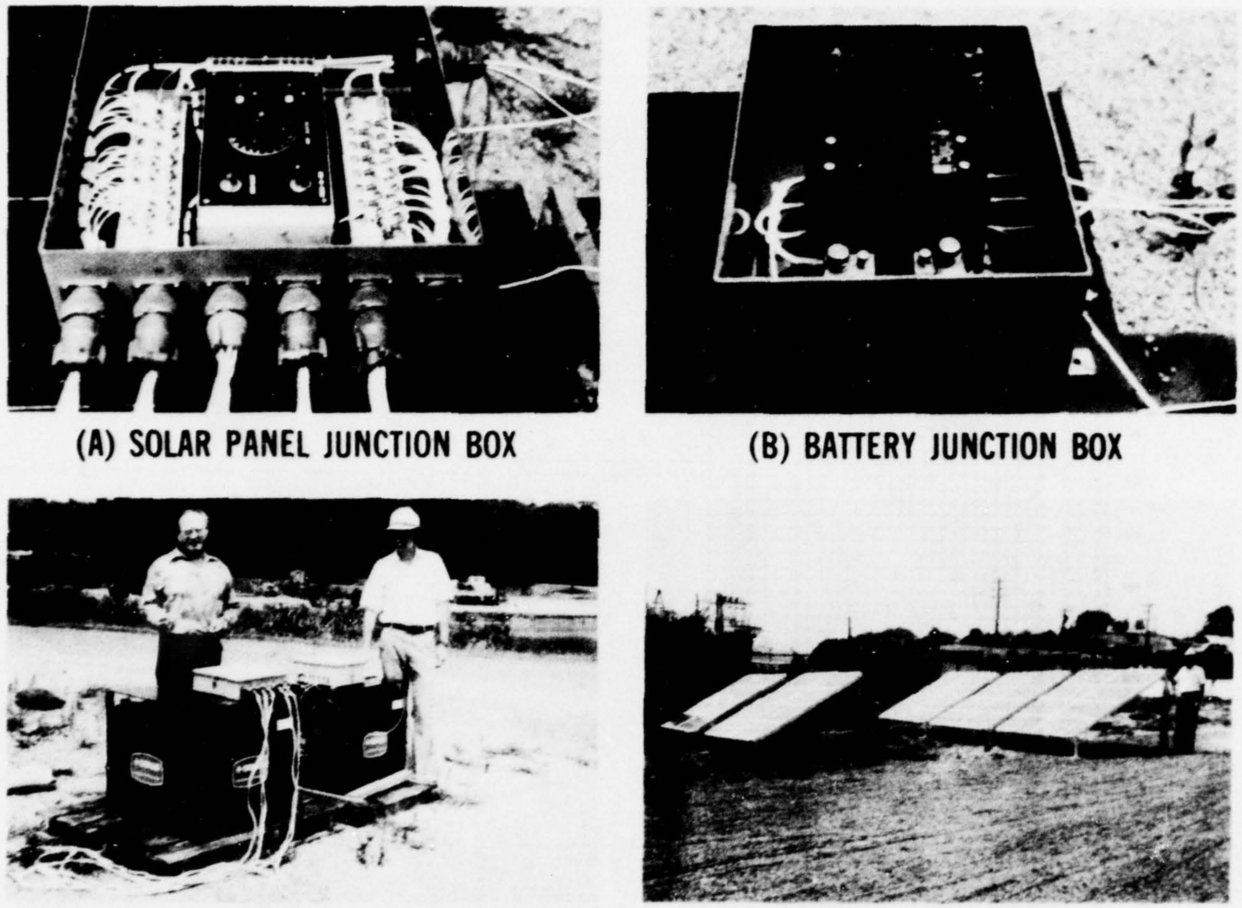


Figure 5. Power system schematic.



(A) SOLAR PANEL JUNCTION BOX

(B) BATTERY JUNCTION BOX

(C) TWO OF THE FOUR BATTERIES

(D) SOLAR CELL ARRAY

Figure 6. SCPS during checkout at MERADCOM.

Figure 7. Solar Cell Power System Installed on Top of Goat Mountain. The small tower antenna next to the white building is the transmitting antenna for the DFCS/I. The white building contains the inverter, batteries, and antenna electronics. The tall (40-ft) tower next to the building is for protection of the electronic systems against direct lightning strikes. At the base of this tower is a large pan filled with brine solution which serves as an electric ground. The other tower is to protect the solar cell panels against direct lightning strikes. The large cable from the solar cell array to the building is sheathed in PVC for protection against animals.

Figure 8. Lift-off of Chinook 47 (CH-47) Helicopter with Instrumentation Building.

Figure 9. CH-47 landing the Instrumentation Building on Goat Mountain.

Figure 10. CH-47 landing one of the storage batteries on Goat Mountain. The large box on the left contains the solar cell panels.

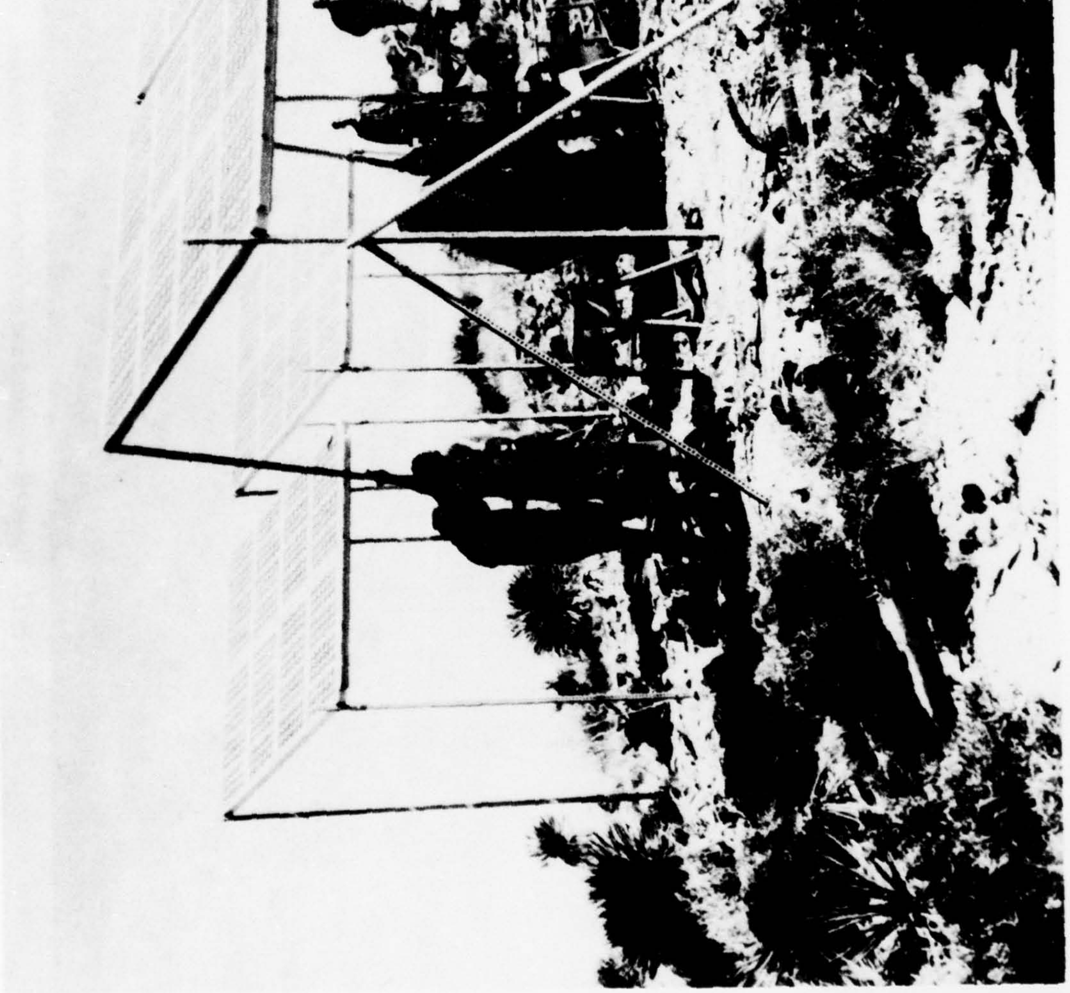


Figure 11. Assembling and installing the solar cell array on Goat Mountain.

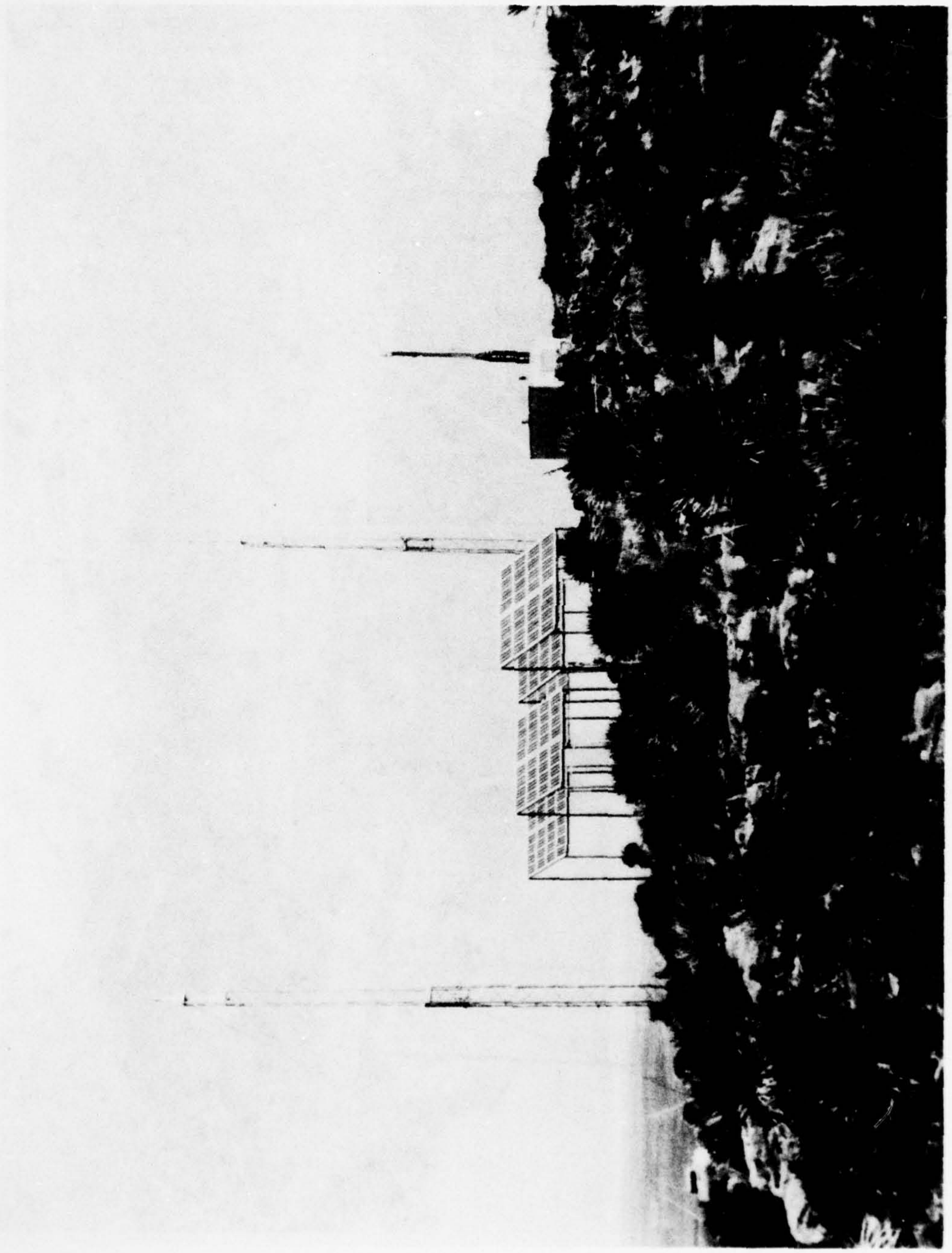


Figure 12. The SCPS completed and installed on Goat Mountain.

V. FUTURE WORK FOR THE DFCS/SCPS

This is the first DOD alternating current SCPS application; and it is also believed to be the first ac/SCPS, commercial or government, to operate successfully exclusive of the ERDA/DOD demonstration program. Accordingly, there is no previous experience upon which to gauge system's performance.

Furthermore, the system is remote, unattended, and subject to severe environmental conditions. Systems such as this have a high potential for extensive DOD (and commercial) usage.

Because of these reasons, careful and thorough performance and environmental monitoring is essential.

In Figure 5, current shunts on each side of the battery junction box are shown. These shunts enable output and input data for the batteries to be obtained. These measurements provide a good monitor for system's performance. The solar panel junction box selector (Figures 5 and 6) enables current-voltage measurements to be made on each of the 20 array circuits.

Final plans for monitoring the system have not yet been made. However, the following performance measurements should be taken:

- Output characteristics (I, V) of the solar cell panels
- Input and output current for the batteries
- Battery voltage
- Inverter output voltage

The following environmental measurements should also be taken:

- Daily average insolation
- Wind speed and direction
- Dew point
- Ambient temperature
- Solar cell temperature
- Lightning frequency and field strength (or equivalent)
- Precipitation

All of the performance data should be recorded. All of the environmental data except dew point and precipitation should also be recorded.

In cooperation and agreement with TECOM and WSMR, a plan for monitoring performance and environmental parameters will be prepared. In preparing this plan, economics will be carefully considered, and only those parameters deemed essential to gauge system's performance will be measured. This plan will be presented to TECOM in early FY78.

APPENDIX A

PROGRAM PLAN

SOLAR CELL POWER SUPPLY FOR SELECTED INSTRUMENTATION

SYSTEM AT WHITE SANDS MISSILE RANGE

Prepared by
U.S. Army Mobility Equipment Research and Development Command

September 1976

I. INTRODUCTION.

This plan describes the objectives, technical approach, estimated cost, and schedule for providing a solar photovoltaic (solar cell) power supply for an instrumentation site at White Sands Missile Range, NM. The work proposed will be performed by MERADCOM working under the guidance of the Instrumentation Directorate, U.S. Army Test and Evaluation Command (TECOM).

II. OBJECTIVES.

The primary objective of the work proposed is to demonstrate feasibility of solar cell power (from technical, logistic, and cost standpoints) for the selected application and, by inference, other Army test and evaluation instrumentation applications. While feasibility of solar cell power systems has been proven in a number of small, remote, d.c. applications in both DOD and the private sector, the WSMR application to be selected for this project will be carefully chosen so that the results will have widespread applicability to a broad class of Army field instrumentation. Emphasis will be placed on adequate instrumentation of the power system itself so that performance and reliability data needed for future applications can be obtained.

The secondary objective is to provide early applications data to TECOM which will be of value in planning near-term RDT&E programs for instrumentation systems.

III. APPROACH.

MERADCOM will design, fabricate, test, and deliver one Solar Cell Power System (SCPS) for application to a selected instrumentation system at WSMR. The SCPS will be capable of continuously meeting the electrical power requirements of the selected application under all environmental conditions expected to be encountered at WSMR.

The SCPS will consist of a photovoltaic array, battery subsystem, power conditioning, instrumentation, structural equipment, and power cables. Site-related equipment such as lightning protection, animal protection, and site preparation (if required) will not be provided, but MERADCOM will advise on such matters.

It is anticipated that the work will require the following tasks:

1. Identify Appropriate Applications.

In cooperation with WSMR and TECOM personnel, electrically powered instrumentation equipment at WSMR will be surveyed. Appropriate candidate systems for solar cell power will then be identified. As the first part of this task, a selection criteria will be prepared.

2. Select Application.

One recommended application, plus one or more alternatives, will be discussed with TECOM personnel for approval prior to proceeding to the next task. Detailed electrical and environmental requirements will be determined for these applications.

3. Design.

Design activities will include not only the electrical power system hardware but also instrumentation, design of a test program, and procurement specifications for the array modules and batteries. Consulting services by MIT's Lincoln Laboratory and the Jet Propulsion Laboratory (JPL), both involved in the National (ERDA) program, will be obtained at no cost to the program. A design review will be held at the conclusion of this task.

4. **Procurement and Fabrication.**

The SCPS will be constructed primarily in-house at MERADCOM. The array modules will be procured by solicitation from manufacturers of devices qualified as part of the ERDA program.

5. **Pre-delivery Test.**

The SCPS will be subjected to tests primarily at MERADCOM to insure satisfactory operation prior to deployment at WSMR. Sample photovoltaic modules will be tested at JPL. High- and low-temperature system tests will be performed at MERADCOM facilities.

6. **Delivery.**

The SCPS will be delivered f.o.b. WSMR upon completion of the tests described above. MERADCOM personnel will assist in installation of the system and will remain at WSMR until verification of performance is completed.

7. **Reporting.**

A technical report will be prepared and delivered to TECOM which will document the entire effort including test plans, initial test results, and operating and maintenance instructions.

8. **Post-delivery Support.**

While not an integral part of the proposed program, MERADCOM will continue to interact with TECOM on collecting and interpreting data from the SCPS after deployment. Troubleshooting services will also be furnished for an indefinite period.

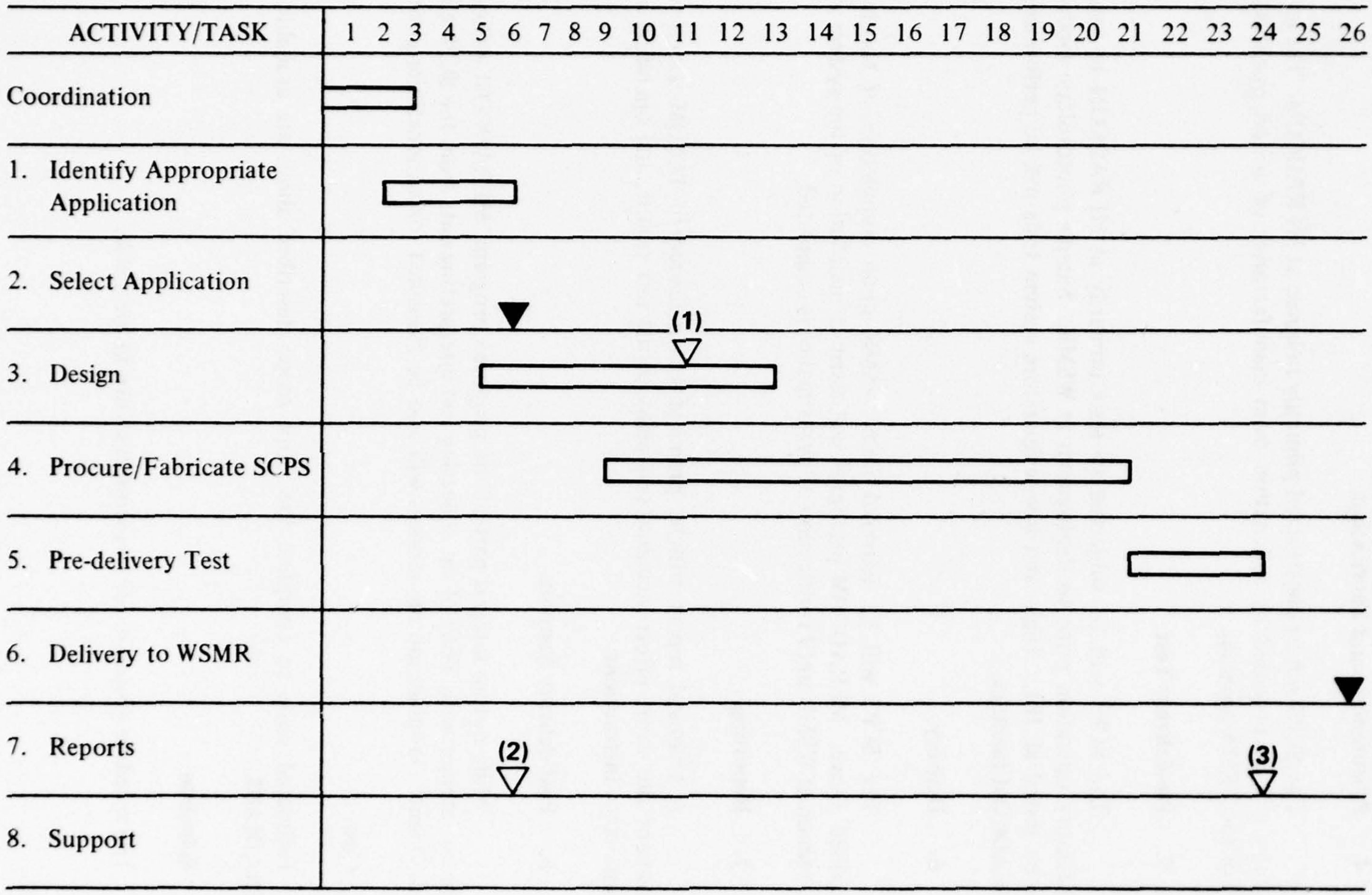
IV. Cost.

Estimated costs to complete the work scope described above are available at MERADCOM.

V. Schedule.

The schedule proposed for this work is shown in the Table.

PROPOSED SCHEDULE:
SOLAR CELL POWER SYSTEM FOR WSMR APPLICATION
(Weeks After Authorization)



(1) Design review; APG or MERADCOM.
(2) Application selection report.
(3) Final Report.

APPENDIX B

SCPS COMPONENT SPECIFICATIONS

The Solar Cell Power System (SCPS) for the Drone Formation Control System Interrogator consists of the solar cell (photovoltaic) array, battery, inverter, junction/test box, circuit breaker box, cables, and miscellaneous hardware. The purpose of this appendix is to document the detailed description of these components as an aid to system operation, maintenance, troubleshooting, and repair.

Array – The array is comprised of 160 solar cell modules contained in ten panel frames (16 modules per frame). Pairs of frames are bolted together on site so that the array contains five, separate, identical sections. Components and materials are:

Solar Cell Modules:

Manufacturer: Solarex Corporation
1335 Piccard Drive
Rockville, Md 20805

Model: 785 (Silicon solar cells, 18 cells in series, transparent silicon rubber encapsulant. Qualified under Jet Propulsion Laboratory Specification: 5-342, Rev B, Dec 76.)

Module Electrical Connectors: Deutsch Pin #800-20/32-1 and heat shrinkable tubing connect the module "pigtail" leads. Interpanel connectors are ITT Canon "Sure-Seal."

Module Mechanical Fasteners: The modules (and cable clamps) are secured with #6-32 x ½" machine screws, nuts, and washers.

Framework: Structural aluminum (6061-T6), anodized after fabrication.

Batteries – Four traction-type (lift-truck) lead-acid batteries are used:

Manufacturer: Gould, Industrial Battery Division.

Model: 65-X-23; 12 cells.

Rating: 715 amp-hours @ 6 hour rate; 24 volts.

Specific Gravity: 1.285.

Dimensions: 27-5/8 x 26 x 24 inches.

Weight: 1776 lb.

Solar Junction/Test Box – The solar junction/test box parallels the twenty series strings from the array, provides blocking diodes to prevent battery discharge at night, and contains a variable dummy loading circuit and selector switch used for measuring the performance of each series string (Figures 4 and 5):

Box: 5052 aluminum sheet (custom made).

Bus Bars: Silver plated copper, 2 each, 8 x 3 x ½ inches.

Diodes: 20 each, 1N1347A.

Dummy Loading Circuit: (See Figure 5).

Battery Junction Box – The battery junction box contains the master circuit breaker, shunts for current measurement, and the power supply (regulator) for the 12 Vdc load:

Box: 5052 aluminum sheet (custom made).

Circuit Breaker: 3-pole, 100-amp rating.

Regulator Circuit: (See Figure 4).

Shunts: 20-amp – 100 mV.

Cables – Cables are made from 16 gauge wire conforming to MIL-W-5086 and AN type connectors as shown in Figure 4.

Inverter – The inverter changes the dc voltage from the battery into a regulated 120-V, 60-Hz voltage. Figure B1 shows an exposed view of this inverter:

Manufacturer: Delta Electronic Control Corporation.

Model: 61098.

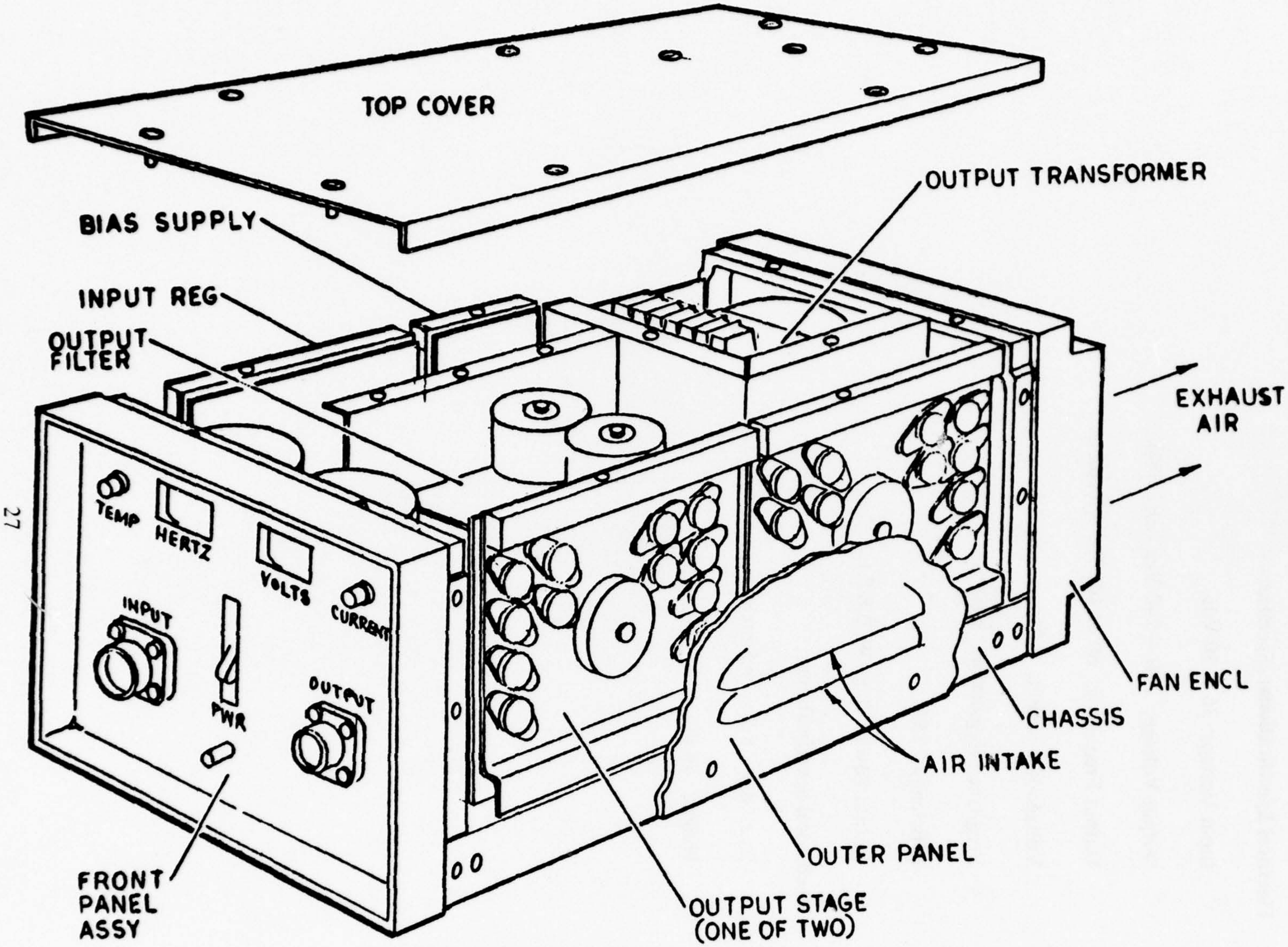


Figure B1. Exposed view of the Inverter.

Electrical Specifications:

Input Voltage: 36 – 60 Vdc.

Output Voltage: 120 – 240 Vac, selectable.

Output Frequency: 60 or 400 Hz, selectable.

Voltage Regulation: ± 2%.

Frequency Regulation: ± 0.5%.

Efficiency: 85%.

Output Power: 1.5 kW, 0.8 P.F.

Mechanical Specifications:

Size: 8.5 x 8.5 x 19.5 inches.

Weight: 54 lb.

APPENDIX C

CINETHEODOLITES AND TELESCOPES AT WSMR

The total number of prepared cinetheodolite sites is 150.[1] Of these, 63 do not have access to firm power. Of these latter, 58 use 60-kWe generators, 2 use 45-kWe generators, and 3 use 30-kWe generators. Of the 60-kWe generators, 52 are on optical prime mover platforms.

There are 238 telescope sites; 127 of these do not have access to firm power; 123 of these use 60-kWe generators, 2 use 45-kWe generators, and 2 use 30-kWe generators.

Those systems using generator power are listed in Table C1. (Reference C-1). In the first column, Site Designator, G, stands for cinetheodolite and T for telescope. Column three shows the round-trip mileage from HQ to the site. The generator capacity is shown in the fourth column. Note that most of the mobile systems use 60-kWe generator sets.

Table C1. Cinetheodolites and Telescopes at WSMR

Site Designator	Permanent or Mobile	Round-Trip Mileage	Generator Capacity (kWe)
G-66	Permanent	33	60
G-73	Permanent	58	30
G-164	Permanent	21	30
G-232	Permanent	38	60
G-234	Permanent	22	30
G-235	Permanent	62	60
G-236	Permanent	20	45
G-297	Permanent	58	60
G-298	Permanent	50	60
G-299	Permanent	52	60
G-62	Mobile	42	60*
G-63	Mobile	32	60*
G-89	Mobile	16	60*
G-228	Mobile	32	45
G-190	Mobile	48	60*
G-191	Mobile	70	60*

* Powered by optical prime mover.

[1] There are 25 mobile cinetheodolites – 8 Contraves, and 17 Askanias.

Table C1. Cinetheodolites and Telescopes at WSMR (Continued)

Site Designator	Permanent or Mobile	Round-Trip Mileage	Generator Capacity (kWe)
G-192	Mobile	62	60*
G-193	Mobile	44	60*
G-194	Mobile	36	60*
G-195	Mobile	18	60*
G-204	Mobile	10	60*
G-209	Mobile	58	60*
G-210	Mobile	44	60*
G-216	Mobile	80	60*
G-217	Mobile	96	60*
G-218	Mobile	102	60*
G-255	Mobile	82	60*
G-230	Mobile	48	60*
G-231	Mobile	38	60*
G-242	Mobile	78	60*
G-243	Mobile	80	60*
G-244	Mobile	80	60*
G-245	Mobile	58	60*
G-246	Mobile	62	60*
G-248	Mobile	28	60*
G-258	Mobile	98	60*
G-259	Mobile	–	60* Green River
G-260	Mobile	–	60* Green River
G-261	Mobile	–	60* Green River
G-262	Mobile	72	60*
G-263	Mobile	100	60*
G-265	Mobile	26	60*
G-267	Mobile	50	60*
G-272	Mobile	40	60*
G-277	Mobile	52	60*
G-278	Mobile	52	60*
G-279	Mobile	52	60*
G-280	Mobile	52	60*
G-281	Mobile	52	60*
G-282	Mobile	52	60*
G-292	Mobile	14	60*
G-293	Mobile	98	60*
G-294	Mobile	50	60*
G-302	Mobile	–	60*
G-313	Mobile	–	60*
G-314	Mobile	–	60*
G-315	Mobile	–	60*
G-316	Mobile	–	60*
G-318	Mobile	–	60*
G-319	Mobile	–	60*

* Powered by optical prime mover.

Table C1. Cinetheodolites and Telescopes at WSMR (Continued)

Site Designator	Permanent or Mobile	Round-Trip Mileage	Generator Capacity (kWe)
G-320	Mobile	–	60*
G-322	Mobile	–	60*
G-323	Mobile	–	60*
T-44	Permanent	58	60
T-169	Permanent	50	60
T-165	Mobile	66	60
T-164	Mobile	48	60
T-241	Mobile	38	30
T-246	Mobile	20	45
T-431	Mobile	62	60
T-489	Mobile	22	30
T-490	Mobile	32	45
T-494	Mobile	52	60
T-693	Mobile	58	60
T-193	Mobile	38	60
T-200	Mobile	28	60
T-255	Mobile	46	60
T-256	Mobile	20	60
T-264	Mobile	17	60
T-265	Mobile	70	60
T-287	Mobile	48	60
T-288	Mobile	70	60
T-289	Mobile	78	60
T-290	Mobile	48	60
T-291	Mobile	34	60
T-292	Mobile	22	60
T-318	Mobile	20	60
T-379	Mobile	30	60
T-411	Mobile	–	60
T-414	Mobile	40	60
T-421	Mobile	38	60
T-429	Mobile	62	60
T-437	Mobile	100	60
T-435	Mobile	38	60
T-448	Mobile	8	60
T-452	Mobile	32	60
T-454	Mobile	27	60
T-469	Mobile	88	60
T-470	Mobile	72	60
T-478	Mobile	102	60
T-488	Mobile	44	60
T-491	Mobile	30	60
T-492	Mobile	30	60
T-495	Mobile	56	60

* Powered by optical prime mover.

Table C1. Cinetheodolites and Telescopes at WSMR (Continued)

Site Designator	Permanent or Mobile	Round-Trip Mileage	Generator Capacity (kWe)	
T-496	Mobile	80	60	
T-497	Mobile	48	60	
T-499	Mobile	18	60	
T-505	Mobile	35	60	
T-506	Mobile	64	60	
T-507	Mobile	34	60	
T-526	Mobile	80	60	
T-549	Mobile	72	60	
T-550	Mobile	–	60	Green River
T-551	Mobile	–	60	Green River
T-552	Mobile	–	60	Green River
T-553	Mobile	33	60	
T-554	Mobile	36	60	
T-561	Mobile	20	60	
T-562	Mobile	20	60	
T-563	Mobile	20	60	
T-566	Mobile	22	60	
T-573	Mobile	50	60	
T-575	Mobile	50	60	
T-577	Mobile	16	60	
T-587	Mobile	58	60	
T-593	Mobile	4	60	
T-596	Mobile	42	60	
T-600	Mobile	54	60	
T-610	Mobile	50	60	
T-615	Mobile	52	60	
T-619	Mobile	52	60	
T-622	Mobile	22	60	
T-623	Mobile	22	60	
T-624	Mobile	22	60	
T-625	Mobile	22	60	
T-659	Mobile	58	60	
T-660	Mobile	80	60	
T-661	Mobile	80	60	
T-662	Mobile	78	60	
T-663	Mobile	30	60	
T-664	Mobile	46	60	
T-665	Mobile	28	60	
T-666	Mobile	30	60	
T-667	Mobile	14	60	
T-668	Mobile	–	60	
T-669	Mobile	26	60	
T-670	Mobile	24	60	
T-671	Mobile	30	60	
T-672	Mobile	22	60	

Table C1. Cinetheodolites and Telescopes at WSMR (Continued)

Site Designator	Permanent or Mobile	Round-Trip Mileage	Generator Capacity (kWe)
T-675	Mobile	24	60
T-677	Mobile	48	60
T-679	Mobile	68	60
T-681	Mobile	–	60
T-682	Mobile	8	60
T-683	Mobile	22	60
T-685	Mobile	38	60
T-686	Mobile	28	60
T-687	Mobile	–	60
T-688	Mobile	98	60
T-626	Mobile	70	60
T-627	Mobile	54	60
T-628	Mobile	94	60
T-629	Mobile	92	60
T-630	Mobile	74	60
T-631	Mobile	74	60
T-632	Mobile	74	60
T-633	Mobile	46	60
T-635	Mobile	58	60
T-637	Mobile	28	60
T-638	Mobile	10	60
T-639	Mobile	18	60
T-641	Mobile	58	60
T-642	Mobile	72	60
T-643	Mobile	72	60
T-644	Mobile	72	60
T-647	Mobile	44	60
T-648	Mobile	12	60
T-649	Mobile	22	60
T-650	Mobile	24	60
T-651	Mobile	26	60
T-652	Mobile	50	60
T-653	Mobile	50	60
T-654	Mobile	50	60
T-656	Mobile	30	60
T-657	Mobile	28	60
T-658	Mobile	30	60
T-689	Mobile	–	60
T-695	Mobile	16	60
T-697	Mobile	90	60
T-702	Mobile	32	60

It is seen from Table C1 that the average generator capacity is near 60 kWe.

These systems are used during daylight hours. Hence, storage would be minimal for solar cell power applications.

The average usage for the WSMR system's cinetheodolite is one day per week; during that day the load profile is 2 hours at 3 kWe and ½-hour at 7 kWe. However, there are numerous sites that may be in use 4-5 consecutive days, but only infrequently.

Present power for the mobile cinetheodolites is provided by the 60 kWe generators which are hauled on trailers or optical prime movers. If an operation lasts more than a few days, storage for the fuel must be provided or else a fuel truck must be on call. Note that operational efficiency of the generators is less than 5% (Figure C1, Reference C2).

On-site maintenance and repairs of the fuel generators are generally done by the electronic technician who must also operate the cinetheodolite system. However, a depot maintenance and overhaul crew is required since the MTBF for generator sets averages only a few hundred hours. Cost analysis of this would be difficult without more detailed information. An example, that could be considerably in error, is offered as a strawman. The initial costs for generator sets are assumed to be negligible since the generators are already there. However, the cost to the government for new or additional generators would not be negligible. Fuel costs are assumed to be \$500/year (\$0.50/gallon).[2] On-site O&M, off-site repairs, and overhaul are assumed to be \$1000/year. Hauling diesel generator and fuel to sites is estimated at \$10,000/year. Cost for fuel spills and other environmental problems could be fairly high but is listed as unknown. Limitations of fuel generator usage in wild life refuges, national parks, and other environmentalist areas are also listed as unknown.

The initial cost of the SCPS, assuming ERDA prediction for the cost of solar cell modules and assuming procurement in the spring of 1978, is estimated at \$8 to \$15 per Wp. This is based on estimates of \$5 to \$10 per Wp for the solar cell panels, \$2 per Wp for storage and power conditioning, and \$1 to \$3 per Wp for structure and installation. (Note: This latter cost could be less if the power truck, to be discussed later, were used.) It is assumed that O&M and other costs are negligible, except for haulage. It is clear that operations costs are negligible but maintenance is somewhat of an unknown factor as explained in Sections III and V. Of particular importance are the batteries and the inverter. This is because neither of these items has been tested or used under the prescribed conditions. There should be no trouble with the batteries because they will be under trickle-charge conditions and should not be subject to deep discharge. There is much more uncertainty about the inverter.

[2] All costs given are in 1977 dollars.

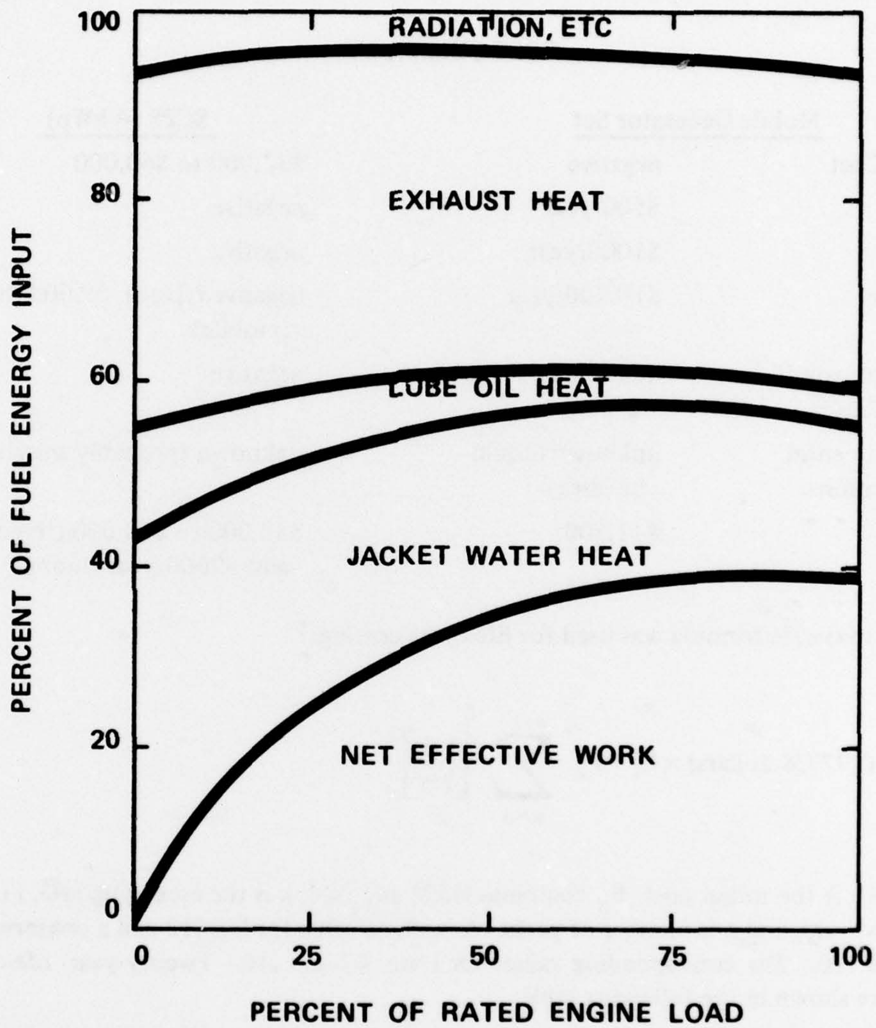


Figure C1. Energy Balance as a Function of Load for a Typical Diesel Engine.

If the SCPS were fixed in place, haulage would be negligible. However, if the power truck were used, haulage would be slightly less than for the generator sets (because fuel haulage would be unnecessary). An estimate is $9000 per year. The cost of the haulage truck is not included because it is assumed that a presently available truck could be used.

COST SUMMARY

	Mobile Generator Set	SCPS (4 kWp)
Initial Cost	negative	$32,000 to $60,000
Fuel	$500/year	negative
O&M	$1000/year	negative
Haulage	$10,000/year	negative (fixed), $9,000/year (mobile)
Environmental Problems	unknown	negative
Environmental Limitations	unknown (could be large)	unknown (probably small)
Total	$11,500	$32,000 to $60,000 (fixed) add $9000/year (mobile)

An approximate formula was used for life-cycle costing:[3]

$$P/V\ (1977/8\ \text{dollars}) = C_i + F_o \sum_{n=o}^{n-1} \left[\frac{1+k}{1+i}\right]^n$$

where C_i is the initial cost, F_o combines O&M and fuel, k is the escalating rate, i is the discount rate, and n is number of years. A realistic value for k is .12 and a conservative value is .10. The corresponding values for i are .07 and .10. Twenty-year, life-cycle costs are shown in the following table:

20-Year, Life Cycle Costs (in thousands of 1977 dollars)

	Mobile Generator Set	Fixed SCPS	Mobile SCPS
k = .12/i = .07	368	32–60	320–348
k = .10/i = .10	230	32–60	212–240

[3] Private communication from Prof Katzmann, Harvard University, 1977.

As seen in the table, the fixed SCPS's are far more cost-effective than the mobile systems. In fact, five to ten fixed systems would cost no more than a single, mobile system. Thus, if a cinetheodolite site were used only once a week it would be cost-effective to use a fixed SCPS. Before conclusions can be reached on the mobile systems, more detailed cost analysis is necessary. For example, the $9,000/year assumed for operating the mobile SCPS truck is probably too high.

The mobile SCPS will be studied in a contract to be let by JPL about January. It is presently conceived as being a five-ton flatbed truck (or, possibly, a van or trailer) that would carry 5 to 20 kWp of lightweight solar cell panels and 1900 ampere hours of traction storage batteries. The panels would be foldable and designed so that the truck driver or the cinetheodolite operator could easily erect the system within a few minutes.

The power characteristics of the telescopes are as follows:

Variable Tracking Mount (VTM): 208 V, 3ϕ

(1) When the cameras are turned on, there is a power surge of 49 kWe for 10 seconds.

(2) When the cameras are running, they use 30 kWe for 30 seconds.

(3) Everything is on but the cameras up to 3 hours/day at 10 kWe.

(4) Manned, but not operational, up to 6 hours/day at 5 kWe.

More information is needed before an efficient SCPS can be designed for the telescope systems. However, the power truck described above could easily handle the load.

Note: The numbers used above for escalation and discount rates are based on discussions with economists from the Massachusetts Institute of Technology, the California Institute of Technology, and Harvard University. Nevertheless, there are considerable uncertainties in the values used and in the methodology. This is particularly so for new systems, such as solar cell power systems for which there is no previous experience. A program is underway to clarify this situation; preliminary results should be available by November 1977.

References:

C1 Private Communication, James C. Scott, WSMR, 16 Dec 76.

C2 Ames Technology Evaluation – Internal Combustion Engines, Section 1A, C. L. Segaser, Jan 77.

APPENDIX D

SOLAR CELL POWER FOR OTHER WSMR APPLICATIONS

1. AME CALIBRATION UNIT

This is a small unit, two of which are located on the top of mountain peaks, requiring monthly helicopter service. Present power is by rechargeable batteries. One 24-V solar cell panel and one 12-V solar cell panel have been provided to WSMR. They will be used to maintain an adequate charge on the existing batteries, thereby extending the unattended operational capability to an indefinite period (6 months minimum).

2. SOTIM UNITS

Two each smaller panels (12 V) have been provided for acoustic arrays (SOTIM) which are used to locate missile impact by recording resultant pressure waves.

3. A 15-watt solar cell panel has been provided to ASL for experiment and testing.

APPENDIX E

OPERATING AND MAINTENANCE INSTRUCTIONS FOR DFCS/SCPS

A. Operating Instructions

1. The system is made operable by closing the 100-ampere circuit breaker in the battery junction box and the circuit breaker on the front panel of the inverter. The circuit breaker connects the solar array to the battery bus and energizes the contacts of the remote-control relay. The inverter circuit breaker protects the inverter and must be in the ON position for remote control.

2. The inverter has provisions for output voltage adjustment. By rotating the VOLTAGE ADJUSTMENT CONTROL on the front panel, the voltage can be adjusted from 111 to 130 volts.

B. Special Operating Instructions

A variable load and test points for testing individual series strings of the array have been provided in the solar junction box. To perform any of the following tests on the solar array, the 100-ampere circuit breaker *must* be in the OFF position:

1. **Open-Circuit Voltage.**

(a) Select the series string to be tested by rotating the panel selector to the string number desired (positions No. 21 and 22 are not used).

(b) Measure the open-circuit voltage at the VM test points with a VOM.

NOTE: Under normal sunlight, the open-circuit voltage of each string will be between 55 to 80 volts (temperature dependent).

2. **I-V Curve** – Current vs voltage curves are useful for monitoring performance of solar cell modules, especially as a historical record for long-term degradation. However, these curves are normally measured under standard conditions of sunlight and temperature. For this field application, only gross indications of performance will be possible without extensive calibrated instrumentation. Therefore, it is recommended that the following measurements be made only on clear days, over a short time interval near the solar noon, and that ambient temperature (and the time and date) be noted.

Open-circuit voltage varies inversely with temperature and maximum (short-circuit) current varies directly with incident solar radiation. Recommended procedure is as follows:

(a) Connect an ammeter with at least a 2-ampere range to the AM test points and a voltmeter to the VM test points.

(b) Select the desired series string by using the panel selector switch.

(c) Hold the press-to-test switch in the UP position. Turn the LOAD adjust control until maximum current is reached. Release the switch and record data.

NOTE: Under bright sunlight, the maximum current per string should be between 1.0 and 1.5 amperes.

(d) Measure other data points by rotating the LOAD adjust control and then holding the press-to-test switch in the UP position to read the current and voltage.

(e) Repeat step (d) until sufficient data points are obtained to construct an I-V curve.

C. Maintenance

1. **Solar Array** – The solar array requires very little maintenance. In fact, a periodic visual inspection is sufficient unless the output of the array is severely degraded by a noticeable accumulation of dust or debris on any of the panels. To detect a slow degradation of the array, I-V curves of each series string should be taken periodically. Recommended interval is 2 months.

2. **Batteries**

(a) The type of battery used contains extra electrolyte to avoid frequent additions of water; however, the electrolyte level should never be allowed to drop below the separation protector. When water is needed, follow directions given in the Gould *Instruction, Maintenance and Service Manual* for motive power batteries. (A copy has been furnished to WSMR.)

(b) Due to the slow rates of charging and discharging, the batteries may need a periodic equalization charging of the cells. The frequency and procedures for equalizing the batteries will be determined by WSMR and MERADCOM personnel as a follow-on effort under the program.

(c) Perform other maintenance checks as outlined in the Gould manual.

D. **Troubleshooting** – In the event of faulty system operation, the following check-list should be consulted:

Probable Cause	Remedy
1. No AC Voltage	
(a) Inverter Circuit Breaker Tripped*	Close Circuit Breaker.
(b) Battery Discharged*	Consult Battery Service Manual; Check solar output; open inverter circuit breaker and recheck after 8 hours of sunlight; check blocking diodes.
(c) Remote Control Relay Inoperable	Check 12 Vdc power supply; check remote-control relay fuse;* check radio links; replace relay.
(d) Inverter Inoperable	Replace inverter; repair.
2. AC Voltage Oscillations	
(a) Low Battery Voltage	See 1 (b) above.
(b) Inverter Defective	Replace Inverter; repair.
3. No (or Insufficient) Solar Output	
(a) Failed Solar Cell Modules (or) (b) Broken Electrical Connections in array or cables (or) (c) Current leakage to ground	Scan open-circuit voltage and maximum current for each string; visually inspect modules in low-performance string(s); replace faulty modules; repair broken connections or broken insulation.

* May be indicative of other faults.

DISTRIBUTION FOR MERADCOM REPORT 2229

No. Copies	Addressee
	Department of Defense
1	Director, Technical Information Defense Advanced Research Projects Agency 1400 Wilson Blvd Arlington, VA 22209
2	Dr. Walter C. Christensen OASD (MRA&L) EES Room 1D760, The Pentagon Washington, DC 20301
12	Defense Documentation Center Cameron Station Alexandria, VA 22314
2	Director of Defense Research and Engineering ATTN: Office, Assistant Director for Test Resources Room 3D116, The Pentagon Washington, DC 20301
1	Commander Defense Communications Agency ATTN: Mr. Worthington Reston, VA 22090
	Department of the Army
1	Commander US Army Material Development and Readiness Command ATTN: COL James F. Bleaker 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander US Army Materiel Development and Readiness Command Office of Lab & Dev Command Mgt ATTN: DRCLDC 5001 Eisenhower Ave Alexandria, VA 22333
1	Commander, HQ TRADOC ATTN: ATEN-ME Fort Monroe, VA 23651
1	HQDA (DAMA-AOA-M) Washington, DC 20310
1	HQDA (DAEN-RDL) Washington, DC 20314
1	HQDA (DAEN-MCE-D) Washington, DC 20314
1	Commander US Army Missile Research and Development Command ATTN: DRSMI-RR Redstone Arsenal, AL 35809
1	Chief, Engineer Division DCSLOG ATTN: AFKC-LG-E HQ Sixth US Army Presidio of San Francisco, CA 94129
1	Director Army Materials and Mechanics Research Center ATTN: DRXMR-STL Technical Library Watertown, MA 02172
1	US Army Ballistic Research Labs Technical Library DRXBR-LB (Bldg 305) Aberdeen Proving Ground, MD 21005
1	Technical Library Chemical Systems Laboratory Aberdeen Proving Ground, MD 21010
1	Commander US Army Aberdeen Proving Ground ATTN: STEAP-MT-U (GE Branch) Aberdeen Proving Ground, MD 21005
1	Director US Army Materiel Systems Analysis Agency ATTN: DRXSY-CM Aberdeen Proving Ground, MD 21005
1	Commander US Army Test and Evaluation Com ATTN: DRSTE-SG-H Aberdeen Proving Ground, MD 21005

No. Copies	Addressee
4	Commander US Army Test and Evaluation Command ATTN: DRSTE-RU (Mr. Milway) Aberdeen Proving Ground, MD 21005
1	Director US Army Engineer Waterways Experiment Station ATTN: Chief, Library Branch Technical Infor Ctr Vicksburg, MS 39180
1	Commander Picatinny Arsenal ATTN: SARPA-TS-S No. 59 Dover, NJ 07801
1	Commander US Army Troop Support and Aviation Materiel Readiness Com ATTN: DRSTS-KTE 4300 Goodfellow Blvd St Louis, MO 63120
2	Director Petrol & Fld Svc Dept US Army Quartermaster School Fort Lee, VA 23801
1	Commander US Army Electronics Research and Development Command ATTN: DRSEL-GG-TD Fort Monmouth, NJ 07703
1	President US Army Aviation Test Board ATTN: STEBG-PO Fort Rucker, AL 36360
1	US Army Aviation School Library P.O. Drawer 0 Fort Rucker, AL 36360
1	HQ, 193D Infantry Brigade (CZ) Directorate of Facilities Engineering Fort Amador, Canal Zone
1	Commander Special Forces Detachment (Airborne), Europe APO New York 09050
1	HQ, USAREUR & Seventh Army DCSENGR, ATTN: AEAEN-MO ATTN: Mil Ops Div APO New York 09403
2	Engineer Representative US Army Standardization Group, UK Box 65, FPO New York 09510
1	Commander Rock Island Arsenal ATTN: SARRI-LPL Rock Island, IL 61201
3	HQ, DA, ODCSLOG Directorate for Transportation and Services Army Energy Office Room 1D570 Washington, DC 20310
1	Plastics Technical Evaluation Ctr Picatinny Arsenal, Bldg 176 ATTN: A. M. Anzalone SARPA-FR-M-D Dover, NJ 07801
1	Commander Frankford Arsenal ATTN: Library, K2400, Bl 51-2 Philadelphia, PA 19137
1	Learning Resources Center US Army Engineer School Bldg 270 Fort Belvoir, VA 22060
1	President US Army Airborne, Communications and Electronics ATTN: STEBF-ABTD Fort Bragg, NC 28307
1	Commander Combat Development Experimentation Command ATTN: DCSI Fort Ord, CA 93941
1	President US Army Armor and Engineer Board ATTN: ATZK-AE-TD-E Fort Knox, KY 40121

No. Copies	Addressee
1	Commander 2nd Engineer Group ATTN: S4 APO San Francisco 96301
1	Commander and Director USAFESA ATTN: FESA-RTD Fort Belvoir, VA 22060
1	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL (Tech Lib) White Sands Missile Range, NM 88002
1	Commander US Army White Sands Missile Range ATTN: STEWS-ID White Sands Missile Range, NM 88002
4	Commander US Army White Sands Missile Range ATTN: STEWS-NR-D (Mr. James Scott) White Sands Missile Range, NM 88002
14	Secretariat Range Commanders Council ATTN: STEWS-SA-R (Mr. Robert O'Leary) White Sands Missile Range, NM 88002
2	Commander US Army Yuma Proving Ground ATTN: STEYP-MTS STEYP-MMI Yuma, AZ 85364
1	Commander US Army Tropic Test Center ATTN: STETC-TD-T APO NY 09827
1	Commander US Army Communications Com Fort Huachuca, AZ 85613

No. Copies	Addressee
1	Commander US Army Communications Com ATTN: CC-OPS-PD (Mr. William Abolt) Fort Huachuca, AZ 85613
2	Commander US Army Electronics Command Atmospheric Sciences Lab ATTN: COL W. E. Rawlinson White Sands Missile Range, NM 88002
1	Commander US Army Communications Systems Agency Squier Hall Fort Monmouth, NJ 07703
1	Commander US Army Missile Research and Development Command ATTN: Mr. Will Lewis Redstone Arsenal, AL 35809
1	Commander US Army NATICK Research and Development Command ATTN: Mr. Albert Carletti Natick, MA 01760
1	Commander US Army Electronic Proving Ground ATTN: STEEP-MT-I Fort Huachuca, AZ 85613
1	Commander Construction Engineering Research Laboratory Champaign, IL 61820
1	Commander Joint Tactical Communications Office Fort Monmouth, NJ 07703
1	Commander US Army Engineer Division Middle East (Rear) Box 2250 Winchester, VA 22601

No. Copies	Addressee
1	Research and Development Ofc Office, Chief of Engineers DAEN-RD Forrestal Building, Room 5G026 Washington, DC 20314
1	Commander US Army Combat Developments Experimentation Command ATTN: ATEC-IN-EP (Maj Brown) Fort Ord, CA 93941
1	Commander US Army Electronics Command ATTN: Mr. David Linden Chief, Power Sources Tech Area Fort Monmouth, NJ 07703
1	Commander US Army Aberdeen Proving Ground ATTN: STEAP-MT-G Aberdeen Proving Ground, MD 21005
1	Commander US Army Cold Regions Test Ctr ATTN: STECR-TD APO Seattle 98733
2	Commander US Army Dugway Proving Ground ATTN: STEDP-PO Dugway, UT 84022
2	Commander US Army TRADOC ATTN: ATCD-TC-T Ft Monroe, VA 23651
1	HQDA (DAMA-PPM-P) (LTC Toftoy) Washington, DC 20314
	MERADCOM
1	Commander, DRDME-Z Technical Director, DRDME-ZT Assoc Tech Dir/R&D, DRDME-ZN Assoc Tech Dir/Engrg & Acq, DRDME-ZE Spec Asst/Matl Asmt, DRDME-ZG Spec Asst/Tech Asmt, DRDME-ZK CIRCULATE
1	Chief, Ctrmine Lab, DRDME-N Chief, Engy & Wtr Res Lab, DRDME-G Chief, Cam & Topo Lab, DRDME-R Chief, Mar & Br Lab, DRDME-M Chief, Mech & Constr Eqpt Lab, DRDME-H Chief, Ctr Intrus Lab, DRDME-X Chief, Matl Tech Lab, DRDME-V Director, Product A&T Directorate, DRDME-T CIRCULATE
2	Elec Pwr Lab, DRDME-E
20	Energy Systems Project Ofc, DRDME-ES
10	Elec Equip Div, DRDME-EA
3	Tech Reports Ofc, DRDME-WP
3	Security Ofc, DRDME-S
2	Tech Library, DRDME-WC
1	Plans, Programs & Ops Ofc, DRDME-U
1	Pub Affairs Ofc, DRDME-I
1	Ofc of Chief Counsel, DRDME-L
	Department of the Navy
1	Director, Physics Program (421) Office of Naval Research Arlington, VA 22217
1	Commandant Marine Corps Code RD Quantico, VA 22134
1	Director Naval Research Laboratory ATTN: Code 2627 Washington, DC 20375
1	Commander, Naval Facilities Engineering Command Department of the Navy ATTN: Code 032-A 200 Stovall St Alexandria, VA 22332
1	Commander US Navy Civil Engineering Lab, NCBC ATTN: Mr. C. E. Parker Port Hueneme, CA 93043

No. Copies	Addressee
1	Officer-in-Charge (Code L31) Civil Engineering Laboratory Naval Construction Battalion Ctr Port Hueneme, CA 93043
1	Commander Naval Weapons Center ATTN: Mr. Richard Fulmer, Code 32404 China Lake, CA 93555
1	Naval Training Equipment Center ATTN: Technical Library Orlando, FL 32813
1	Chief of Naval Material The Navy Energy & Natural Resources Research & Development Office ATTN: MAT-03Z (Mr. Peter Ritzcovan) Crystal Plaza, Bldg 6, Room 606 Washington, DC 20360
	Department of the Air Force
1	HQ USAF/RDPS (Mr. Allan Eaffy) Washington, DC 20330
1	Mr. William J. Engle Chief, Utilities Branch HQ USAF/PREEU Washington, DC 20332
1	AFSC/INJ Andrews AFB, MD 20334
2	Commander HQ AF Electronic Systems Div ATTN: ESD/DE Hanscom AFB, MA 01731
1	AFCEC/XR/21 Tyndall AFB, FL 32401
1	HQ USAF/PREES ATTN: Mr. Edwin B. Mixon Bolling AFB-Bldg 626 Washington, DC 20332
1	AFAPL/SFL Wright-Patterson AFB, OH 45433
1	Commander Eglin AFB, FL 32542

No. Copies	Addressee
1	Commander Armament Development and Test Center ATTN: SD2 Eglin AFB, FL 32542
1	Commander AF Aero Propulsion Lab ATTN: AFAPL/POE-2 (Mr. Joseph Wise) Wright Patterson AFB, OH 45433
1	Commander Air Force Systems Com ATTN: AFSC/SDEC Andrews AFB, MD 20331
1	Commander Tactical Fighter Weapons Ctr ATTN: Range Group Las Vegas, NV 89191
1	Commander AF Strategic Air Command ATTN: HQSAC/DEME Offutt AFB, NB 68113
1	HQ USAF ATTN: LGY, The Pentagon Washington, DC
2	Commander HQ Aerospace Defense Com ATTN: DEE Peterson Air Force Base, CO 80914
1	Commander Rome Air Development Center Rome, NY 13440
1	Commander US Readiness Command MacDill AFB, FL 33608
1	Commander HQ Tactical Air Command/ DCXE Langly AFB, VA 23665
2	Commander HQ Air Force Flight Test Ctr (AFSC) ATTN: AFFTC/DOESD Edwards AFB, CA 93523

No. Copies	Addressee
1	Commander Air Force Civil Engineer Ctr ATTN: AFCEC/DE/21 Tyndall AFB, FL 32403
1	Commander HQ AF Space and Missile Test Ctr Vandenberg AFB, CA 93437
	Others
1	Mr. Gary Johnson Motorola Semiconductor Products, Inc. 5005 East McDowell Rd Phoenix, AZ 85008
2	Mr. Marvin Pope Manager, Solar Photovoltaic Field Tests and Applications Project MIT Lincoln Laboratory Lexington, MA 02173
2	Dr. Donald Schueler Division 5719 Sandia Laboratories Albuquerque, NM 87115
2	Mr. Samuel J. Taylor US Dept of Energy Room 3517, Federal Bldg 12th and Pennsylvania Ave, NW Washington, DC 20461
2	Mr. Roger Palmer NASA Lewis Research Ctr MS 302-1 21000 Brookpark Road Cleveland, OH 44135
3	Mr. Paul D. Maycock Assistant Director for Photovoltaics Div of Solar Technology US Dept of Energy Washington, DC 20545
1	Mr. Robert Gehrke System Planning Corporation Suite 1500 1500 Wilson Blvd Arlington, VA 22209
1	Mr. Robert Forney Program Manager, LSSA Jet Propulsion Laboratory California Institute of Technology 4800 Oak Grove Drive Pasadena, CA 91103

No. Copies	Addressee
1	Mr. Joseph Galian General Dynamics Electronics Division P.O. Box 81127 San Diego, CA 92138
1	Mr. Gary Hutchinson Spectrolab 12500 Gladstone Ave Sylmar, CA 91342
1	Mr. Paul Caruso Solar Power Corporation 23 North Avenue Wakefield, MA 01880
1	Mr. Joseph Lindmayer Solarex Corporation 1335 Piccard Drive Rockville, MD 20850
1	Mr. Irwin Rubin Sensor Technology, Inc. 21012 Lassen Street Chatsworth, CA 91311
1	Mr. Robert Terry BDM Corporation 7915 Jones Branch Drive McLean, VA 22101
1	Mr. J. W. Yerkes ARCO Solar 9701 Lurline Street Chatsworth, CA 91311
1	Professor Raymond R. Fox School of Engineering and Applied Science The George Washington Univ Washington, DC 20052
2	Dr. Mason Watson The Aerospace Corporation P.O. Box 92957 Los Angeles, CA 90009
3	Mr. Robert Sanders Motorola Government Electronics Div 8201 East McDowell Rd Scottsdale, AZ 85252