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# Photovoltaic-Powered Vaccine Refrigerator - Freezer Systems Field Test Results

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# PHOTOVOLTAIC-POWERED VACCINE REFRIGERATOR - FREEZER

# SYSTEMS FIELD TEST RESULTS

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## SUMMARY

In 1979 the NASA Lewis Research Center, in cooperation with the U.S. Centers for Disease Control and the U.S. Department of Energy, began a project to develop and field test photovoltaic-powered refrigerator/freezers suitable for vaccine storage. Development contracts were awarded to Solar Power Corp. and Solavolt International. Three refrigerator/freezers were qualified; one by Solar Power Corp. and two by Solavolt. Follow-on contracts were awarded to Solar Power Corp. for 19 field test systems and to Solavolt for 10 field test systems. The U.S. Agency for International Development joined in the field tests systems effort. A total of 29 systems were installed in 24 countries between October 1981 and October 1984. This report includes an explanation of the project, systems descriptions, installation experiences, performance data for the 22 systems for which field test data was reported, an operational reliability summary, and recommendations relative to system designs and future use of such systems. Performance data indicates that the systems are highly reliable and are capable of maintaining proper vaccine storage temperatures in a wide range of climatological and user environments.

## INTRODUCTION

There are over three billion people in developing countries who suffer from a variety of infectious diseases. Because these diseases tend to flourish in populations existing at the poverty level, they are important indicators of a vast state of collective ill health. This collective disability has an adverse effect on agricultural and industrial development. It also results in high infant and child mortality making people reluctant to participate in attempts to control population growth.

Vaccination has been used extensively in developed countries over the last few decades for the prevention of such debilitating communicable diseases as poliomyelitis, smallpox, diphtheria, and measles. The disease prevention experiences gained in these countries are now being transferred on a gradually increasing scale to the developing world. However, the application of vaccination in developing countries has met with a number of economic, operational, and technological problems. One of the main problems is the need to provide refrigerated storage and transportation for vaccines, i.e., to establish and maintain the so-called "cold chain". The cold chain is a refrigerated transportation and storage system for distributing vaccines in the potent state from the manufacturer to the actual vaccination site. Vaccines exposed to elevated temperatures suffer a permanent loss of potency. To remain potent most vaccines must be maintained at temperatures between 0 to 8 °C. For the more sensitive polio and measles vaccines, a -20 °C temperature is recommended for extended storage.

The available technical solutions to the problem of providing a cold chain are mainly based on the presumption of a dependable supply of electric power which is frequently not the case in developing countries. Where electricity is not available, vaccines are stored (if at all) in kerosene-fueled refrigerators. These refrigerators suffer from a multitude of problems including high maintenance requirements, fuel availability and purity, high fuel costs, and lack of adequate temperature control. Vaccine transportation and storage in most developing countries is especially difficult because many of them have hot or tropical climates and because many of the refrigerators produced for use in developed countries are unsuitable for use in locations having high ambient temperatures.

Approximately 75 percent of the population that needs to be served by immunization programs is in areas not served by reliable refrigeration. Thus, the Centers for Disease Control of the U.S. Department of Health and Human Services and the World Health Organization consider the development of cost-effective photovoltaic-powered refrigerator/freezer systems for vaccine storage vital to the implementation of immunization programs in developing countries.

## BACKGROUND

In 1975, the NASA Lewis Research Center was assigned responsibility by the U.S. Energy Research and Development Administration (predecessor to the U.S. Department of Energy) for developing and field testing stand-alone photovoltaic power systems and developing related system technology. Several of the early field test systems included refrigerators, some of which were used for storage of medical supplies. Recognizing that photovoltaic (PV)-powered refrigerator/freezers (R/F's) represented a probable solution to the urgent need for vaccine storage in rural areas of developing countries, the U.S. Centers for Disease Control (CDC) requested in 1979 that NASA Lewis undertake a program to develop and field test PV-powered R/F systems for vaccine storage.

The program that ensued called for a two-phased approach. The first, or development phase, was to develop and qualify one or more PV-powered R/F systems. The second, or field test phase, was to place eight PV-powered R/F systems in remote (rural) health centers in six representative countries and to monitor their performance and operation for a period of one year.

The first phase began in February 1980 with a solicitation for competitive procurement for the development and qualification of PV-powered R/F systems. The design and performance specifications and the qualification test requirements were developed by NASA Lewis in consultation with the U.S. CDC and the World Health Organization (WHO) Expanded Programme on Immunization. These specifications and requirements contained elements relating to PV system design and performance based on U.S. standards and elements relating to R/F design and performance based on CDC and WHO inputs and American National Standards Institute performance measurement requirements.

Three contracts were subsequently awarded; one to the Solar Power Corporation (SPC) on February 19, 1981, another to Motorola (Solavolt International (SVI))[1] on March 19, 1981, and a third to ARCO Solar. Shortly after the award, ARCO Solar requested and received permission to withdraw from their contract because of problems with the R/F they had proposed. The Solar Power Corporation successfully qualified a PV-powered R/F system on June 26, 1981 using an Adler-Barbour R/F. Solavolt International successfully qualified two PV-powered R/F systems in January 1982, one using an R/F now manufactured by the Marvel Division of the Dayton Walther Corp., and another using a R/F manufactured by Polar Products. The result of this multiple award qualification effort was that three different types of R/F's were qualified. All three use the same compressor, but each uses a different approach to compartment cooling; i.e., Adler-Barbour uses a single evaporator in the freezer compartment, Marvel uses a eutectic (cold storage) cell in the freezer compartment, and Polar Products uses two completely separate refrigeration systems, one for the refrigerator compartment and one for the freezer compartment. Both Solar Power Corporation and Solavolt International were awarded follow-on contracts (January 19, 1982 and January 26, 1983, respectively) for the fabrication, test, and deployment of PV-powered vaccine storage R/F field test systems.

The scope of the second or field test phase was expanded almost three-fold when NASA Lewis proposed to the U.S. Agency for International Development (AID) that PV-powered R/F's for vaccine storage be included in the U.S. AID Development Support Program managed by NASA Lewis. The objective of that program is to determine the suitability of PV systems technology in terms of cost competitiveness and reliability for selected applications in rural areas of developing countries. AID emphasized the health care delivery application category since the relatively high cost of PV generated electricity can be more readily justified for those uses. The NASA Lewis strategy in implementing the AID projects was to award contracts for design and development of systems resulting in prototype systems and design packages.

Subsequent negotiations with AID missions raised the total number of CDC and AID PV-powered vaccine R/F field test systems to 29. Nineteen field test systems were procured from SPC and 10 systems were procured from SVI. The SVI qualification test systems have been installed at NASA Lewis where they are undergoing endurance testing. The SPC qualification test system was installed in India and one of the SPC production systems was installed at NASA Lewis for endurance testing. A complete listing of all NASA Lewis field test sites having vaccine R/F's is given in table I. That table also shows six additional R/F systems being used for vaccine storage and installed in larger PV system applications developed as part of other AID PV development programs. One such application is the clinic in the PV powered village of Hammam Biadha, Tunisia. The other five R/F systems are at PV powered clinic systems in South America and Africa.

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[1]On October 1, 1981, Motorola and Shell Oil Company combined their photovoltaic operations and formed a partnership named Solavolt International.

The field test plan calls for one year of operational support and performance monitoring and evaluation for all systems. Installation of the SPC systems evolved into a protracted affair with the first SPC system being installed in India in October 1981 and the last system being delayed (through no fault of the Solar Power Corporation) until October 1984. Eighteen of the 19 systems were installed by October 28, 1983. The nineteenth system (Liberia) was delayed due to numerous delays in completing the health center there. Installation of the SVI systems began on November 3, 1983 and was completed on June 26, 1984.

This report summarizes systems designs of both SPC and SVI systems, installation experiences, systems performance, reliability, operational experiences, and recommendations. Another report containing additional operational information for the SVI systems will be issued at the close of the evaluation period for those systems.

The photovoltaic powered vaccine refrigerator/freezer project began in 1979 and will continue through mid-1985 when all of the field tests will be completed. In the early 1980's, a general phase-out of the terrestrial photovoltaic activities at NASA Lewis was initiated. As a result of ensuing personnel changes, a fairly large number of people participated directly in this project. Although they are not listed as coauthors, they contributed measurably to the success of this project. They are: Lawrence A. Thaler who initially managed the project, managed the development phase contracts, and participated in the installation of the first Solar Power Corp. systems; John Toma who managed the Solar Power Corp. field test contract and the Solavolt field test contract through most of the installation phase, participated in many Solar Power Corp. and Solavolt systems installations, performed some of the early data analyses and reporting, and conducted most of the endurance tests at the NASA Lewis; Dr. Patricia O'Donnell who served as Project Manager for a short time; Ralph Thomas who installed and brought on line the endurance test systems at the NASA Lewis and who offered considerable assistance in solving field test systems instrumentation problems; and James E. Martz who participated in the installation of several of both Solar Power Corp. and Solavolt systems, provided considerable input into data analysis software formulation, assisted with data analysis, and reviewed this report.

## SYSTEM DESCRIPTION

A PV-powered vaccine R/F system consists of a 12-V PV array, a power cable from the array to the R/F, one or more voltage regulators, batteries, a refrigerator/freezer, and, in the case of these field test systems, instrumentation. The SPC and SVI systems differ slightly in regard to component selection and design philosophy. Each is described in detail below and in table II. All of the systems, however, were designed for fully automatic operation and minimum maintenance. Maintenance is limited to washing the PV modules as necessary and removing frost from the evaporator. Spare parts, tool kits, and user manuals were supplied to each system site.

### Solar Power Corp. Systems

The SPC systems used from 7 to 11 SPC LG12-351 33-W PV modules depending on system location (table I). The PV power systems were sized based on best available insolation data, 630-A-hr of battery capacity and R/F compressor

TABLE I. - NASA LEWIS PV-POWERED VACCINE REFRIGERATOR FIELD-TEST SUMMARY

| Latin America/Caribbean | Africa | Near East | Asia |
|---|---|---|---|
| (CDC) Peru<br>Pucara [a]248/[b]525<br>14 Oct. 82 SPC/AB | (CDC) Gambia<br>1. Kaur 320/630<br>2. Gunjur 320/630<br>27 Jan. 83 SPC/AB | | (CDC) Maldives<br>Kuluduffushi 284/630<br>6 May 82 SPC/AB |
| (CDC) Columbia<br>Bocas Del Palo 284/630<br>11 Sep. 82 SPC/AB | (CDC) Ivory Coast<br>1. Niofouin 355/630<br>2. Zaranou 355/630<br>5 Feb. 83 SPC/AB | | (CDC) India<br>Bhoorbaral 355/630<br>19 Oct. 81 SPC/AB |
| (AID) Dominican Republic<br>Las Tablas 284/[b]525<br>28 Aug. 82 SPC/AB | (AID) Ivory Coast<br>Menee 280/315<br>25 Feb. 84 SVI/PP | (AID) Jordan<br>Mowaqar 160/420<br>28 June 84 SVI/M | (AID) Indonesia<br>1. Cibung Bulang 320/630<br>2. Batujaya 320/630<br>16 Apr. 82 SPC/AB |
| (AID) Guatemala<br>Tierra Blanca 248/630<br>7 Oct. 82 SPC/AB | (AID) Burkina Faso<br>Orodara 200/315<br>21 Feb. 84 SVI/PP | (AID) Tunisia<br>1. Es-Smirat (Siliana) 240/315<br>2. Bir Amama 240/420<br>1. 3 Feb. 84 1. SVI/PP<br>2. 6 Feb. 84 2. SVI/M | (AID) Thailand<br>Tambon Tha Thong 200/420<br>2 Nov. 83 SVI/M |
| (AID) Honduras<br>Guaimaca 200/420<br>12 Jan. 84 SVI/M | (AID) Liberia<br>Suenn 390/630<br>12 Oct. 84 SPC/AB | (AID) Morocco<br>Bouaboute 355/[b]525<br>28 Oct. 83 SPC/AB | |
| (AID) Haiti<br>Anse-A-Veau 284/630<br>2 Sep. 82 SPC/AB | (AID) Zaire<br>Kionzo 355/[b]525<br>11 Feb. 83 SPC/AB | (AID) Tunisia[c]<br>Hammam Biadha --/630<br>Jan. 83 SPC/AB | |
| (AID) Guyana<br>Schepmoed 284/630<br>30 Sep. 82 SPC/AB | (AID) Zimbabwe<br>Chiota 284/630<br>15 Feb. 83 SPC/AB | | |
| (AID) Ecuador<br>Comuna Cobos 284/630<br>23 Sep. 82 SPC/AB | (AID) Mali<br>Ouelessebougou 200/315<br>14 FEb. 84 SVI/PP | | |
| (AID) St. Vincent & the Grenadines<br>1. New Sandy Bay 200/420<br>2. Canouan 160/315<br>1. 18 Jan. 84 1. SVI/M<br>2. 25 Jan. 84 2. SVI/PP | (AID) Kenya[c]<br>1. Kibwezi --/630<br>2. Ikutha --/630<br>10 May 83 SX/AB | | |
| (AID) Guyana[c]<br>Waramuri --/630<br>1 Feb. 83 SX/AB | (AID) Zimbabwe[c]<br>Chikwakwa --/630<br>31 May 83 SX/AB | | |
| (AID) Ecuador[c]<br>Pedro Vicente<br>Maldonado --/630<br>31 Mar. 83 SX/AB | | | |

LENGEND:

SPC = Solar Power Corp. AB = Adler-Barbour
SX = Solarex PP = Polar Products
SVI = Solavolt International M = Marvel

a = Array peak watts/battery ampere-hours
b = One battery damaged or lost in transit
c = R/F is part of larger clinic system

Modules: SPC: LG12-351, 35.5Wp; SVI: MSP43E40, 40Wp
Batteries: SPC: Delco 2000, 105A-hr; SVI: Delco 2000, 105A-hr

Systems on test at NASA Lewis:
2/22/83 SPC/AB 330/630
3/24/83 SVI/PP 400/315
2/22/83 M with LeRC PV array and array/voltage regulator 450/420

TABLE II. - REFRIGERATOR/FREEZER DESIGN CHARACTERISTICS

| Characteristic | Adler-Barbour | Marvel | Polar Products |
|---|---|---|---|
| Refrigerator compartment volume | 68.3 liters | 85 liters | 104 liters |
| Freezer compartment volume | 25.5 liters | 28.3 liters | 23 liters |
| Type of evaporator | Roll bonded aluminum, capillary fed evaporator | Eutectic cold cell | Expanded tube |
| Compressor manufacturer | Danfoss | Danfoss | Danfoss |
| Number of compressors | 1 | 1 | 2 |
| Number of evaporators | 1 | 1 | 2 |
| Cabinet material | Outer: Epoxy coated aluminum<br>Inner: One piece aluminum extrusion | Thermo-ABS reinforced plastic and fiberglass reinforced | Molded polyethylene |
| Type of insulation | Rigid expanded polyurethane | Foamed in-place polyurethane | Foamed in-place polyurethane |
| Type of thermostat | Mechanical | Mechanical | Refrigerator: Electronic<br>Freezer: Electronic |
| Number of thermostats | 1 | 1 | 2 |
| Method of refrigeration compartment temperature control | Thermostatically controlled air door | Thermostatically controlled air door | Thermostats with separate compressors each compartment |
| System voltage (nominal) | 12 V dc | 12 V dc | 12 V dc |
| Battery capacity (DELCO 2000) | 6 Batteries, 630 A-hr | 4 Batteries, 420 A-hr | 3 Batteries, 315 A-hr |
| Weight (without batteries) | 117.9 kg | 55 kg | 77 kg |
| Condenser | Finned copper | Finned copper | Finned copper |
| Minimum freezer compartment temperature at 43 °C | -25 °C | -7 °C | -25 °C |
| 24 hr A-hr consumption following insertion of 2 kg of 43 °C water (in cold packs) into freezer compartment[a] | 109 | 76 | 80 |
| Low voltage cutout | 10.8 V dc | 11.5 V dc | 11.5 V dc |
| Reconnect Voltage | 11.5 V dc | 13.5 V dc | 13.5 V dc |
| Fan cooled condenser | Yes | Yes | Yes |
| High freezer compartment temperature alarm | Yes | No | No |

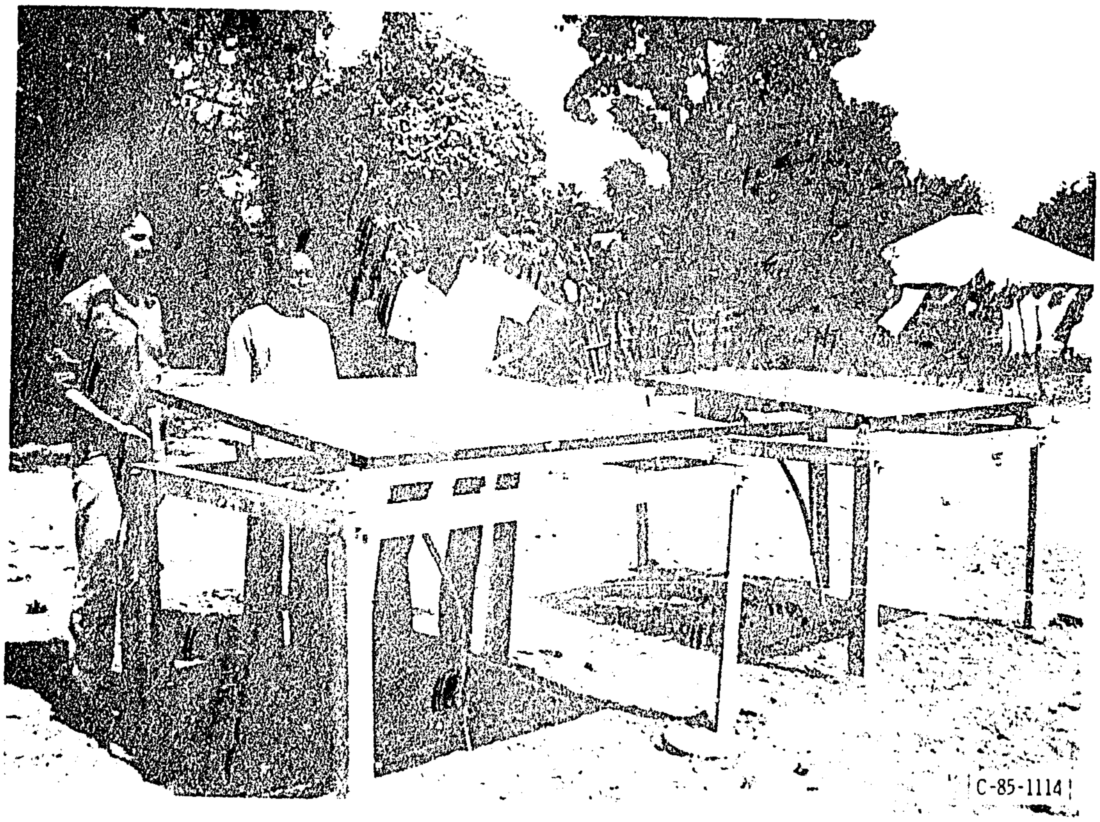
[a]Ambient temperature = 43 °C

energy requirements for the average ambient temperature at each location. The contract called for one spare module to be supplied with each system. SPC elected to mount and wire that module into the array at the time of installation creating an on-line spare. Thus every system initially had from 14 to 9 percent (respectively) increased array capability.

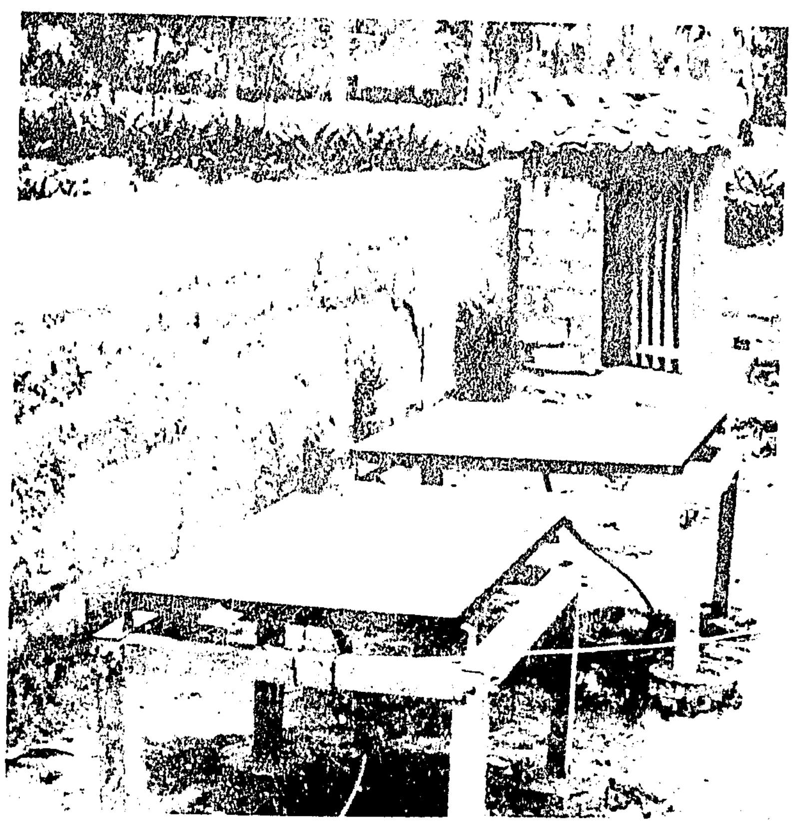
The array structure was designed to be assembled on-site and consists of specially fabricated precut and drilled galvanized angle metal members. The support structure was designed for ground mounting (figs. 1(a) to (c)) although a few arrays were installed on roofs (figs. 2(a) to (c)) and other raised structures (figs. 3 and 4). A 30-m length of two conductor No. 2 armored cable was supplied with each four module array panel of each system to bring array power to a junction box located near the R/F. A short cable carries power from the junction box to a twist-lock connector on the R/F cabinet. The number 2 conductors were required to minimize the voltage drop between the PV array and the R/F. Since the maximum power point of the SPC 36 cell module is ~15 V at 2.3 A in a 30 °C ambient temperature and since the batteries need to be charged at 15 V when in a 30 °C ambient, virtually no voltage drop could be accepted in the power cable. Hence the large diameter multiple cables.

The voltage regulator, batteries, compressor, controls, and instruments are all contained in or on the R/F cabinet except for the insolometer and the ambient temperature thermograph which are separate instruments. The voltage regulator, six Delco 2000 batteries each having a 105-A-hr capacity, the compressor and the compressor controller are all located in the bottom of the R/F cabinet (fig. 5(a)). Power system instrumentation is located on the side of the R/F cabinet and a temperature recorder and alarms (audible and visual) are located on the front of the R/F cabinet (fig. 5(b)). The voltage regulator is an SPC designed shunt type regulator which allows for measurement of total potential array output (versus consumed array output for a series or switching type regulator). Power system instrumentation is composed of a voltmeter, array and compressor current meters, array and compressor ampere-hour meters which are powered by 9-V dry cells, and a compressor run-time meter (fig. 5(c)). A spring wound 7-day circular chart temperature recorder is used to record refrigerator and freezer compartment temperatures. A separate (stand-alone) spring wound 7-day circular chart temperature recorder is used to record ambient temperature. Also, a separate stand-alone insolometer was supplied with each system. The insolometer consists of a Li-Cor silicon photovoltaic cell sensor and a battery powered Campbell-Scientific Integrator.

The SPC systems use an Adler-Barbour model DCM-12SM refrigerator/freezer which is characterized in table II and figures 16(a) and (b). The freezer temperature controller and freezer temperature indicator are located on the front of the R/F cabinet and can be field adjusted. In addition, an adjustable thermostatically controlled air door and adjustable air return ports in the refrigerator/freezer compartment separator wall permit refrigeration compartment temperature control. Audio and visual alarms indicating high freezer compartment temperature are also located on the front of the cabinet. The alarms are powered by a 6-V dry cell lantern battery.

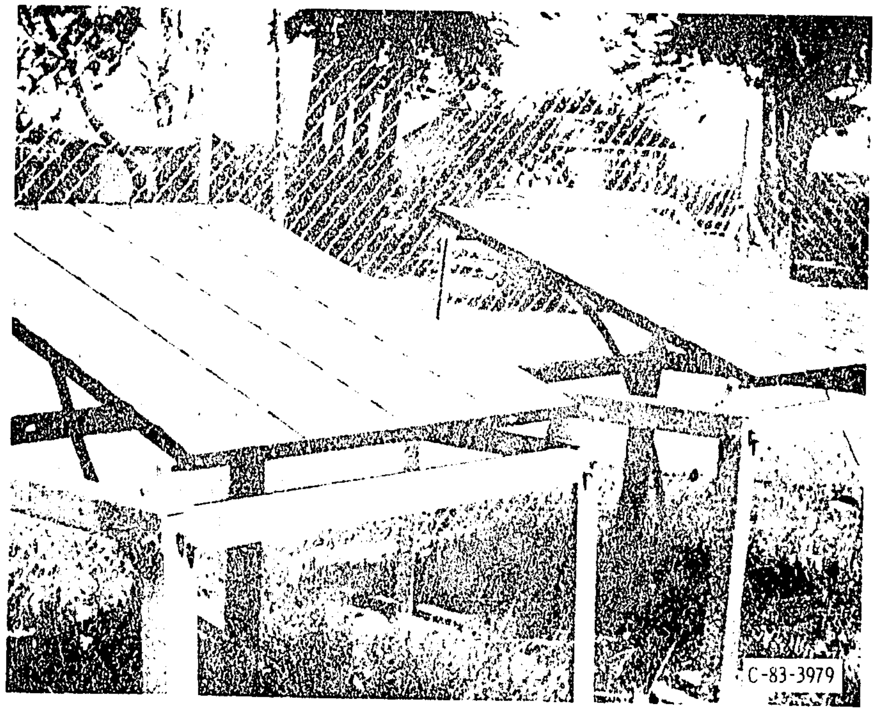



(a) Gambia.



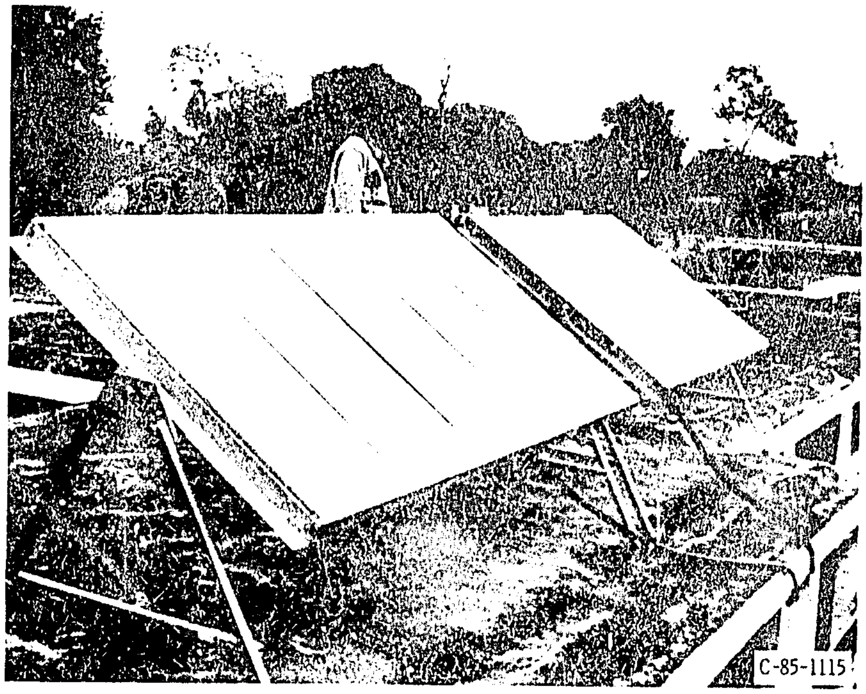
(b) Ecuador.

Figure 1. - Solar Power Corp. ground mounted PV array.

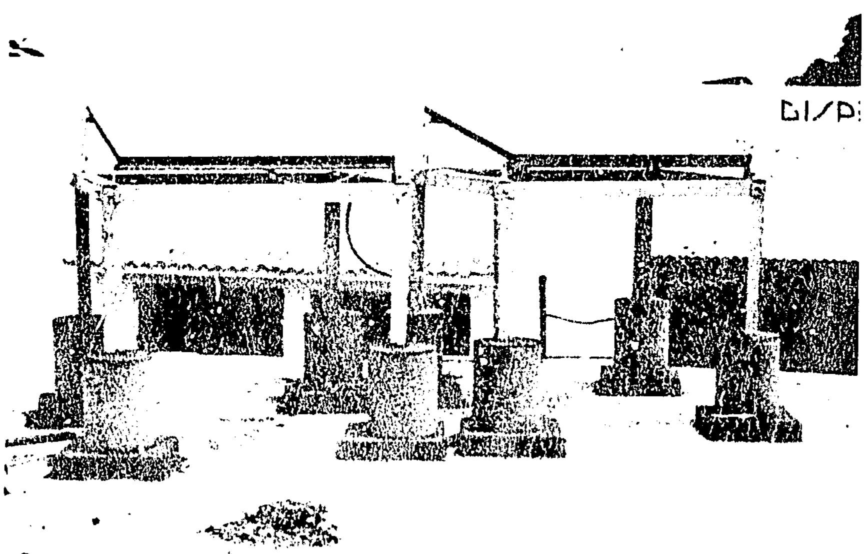



(c) Zimbabwe.

Figure 1. - Concluded.




(a) India.



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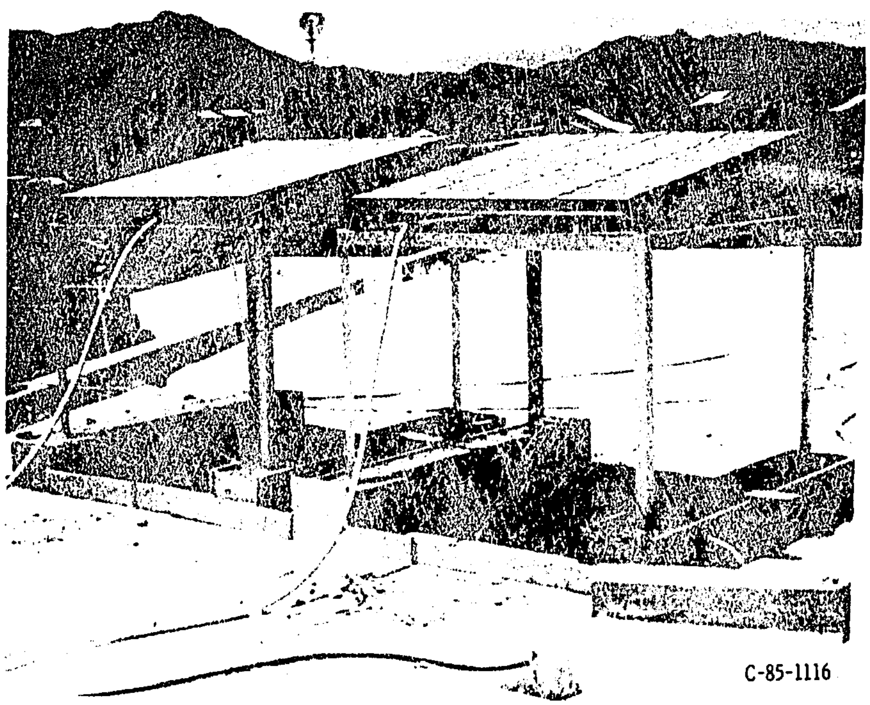
(b) Haiti.

Figure 2. - Solar Power Corp. roof mounted PV array.



(c) Dominican Republic.

Figure 2. - Concluded.

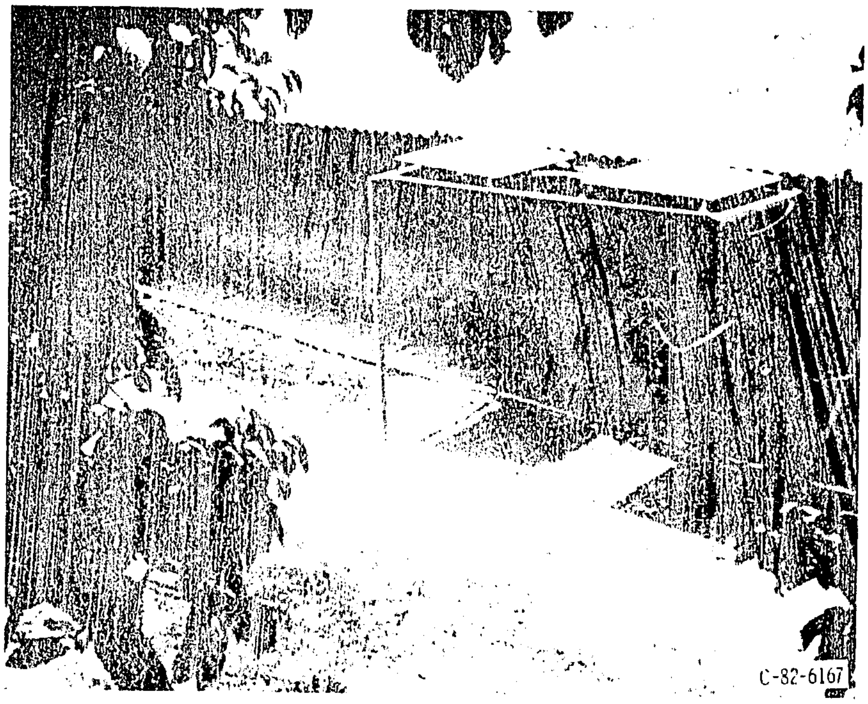



Figure 3. - Solar Power Corp. raised PV array - Columbia.

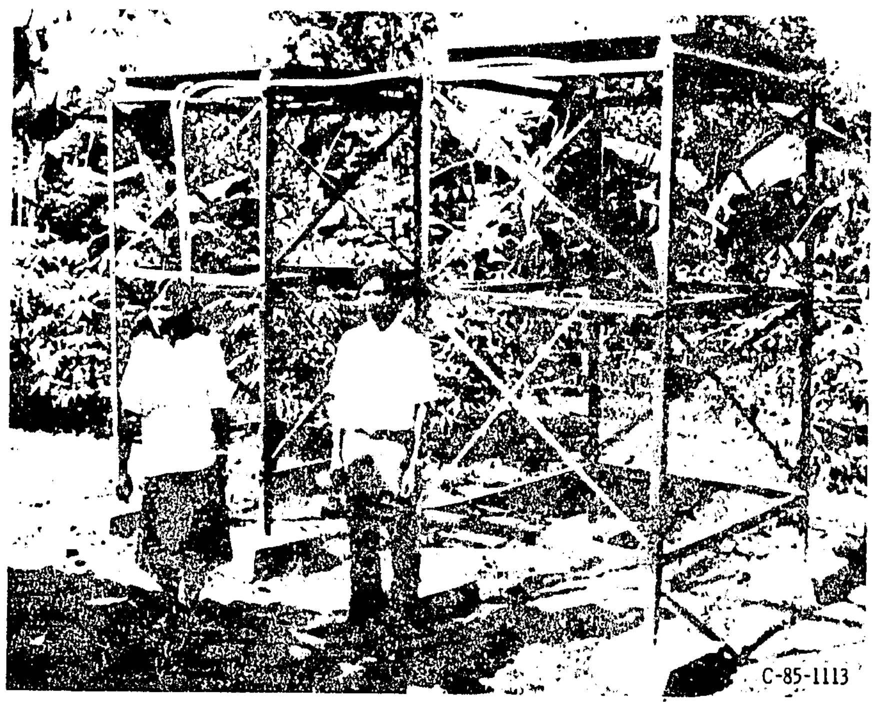
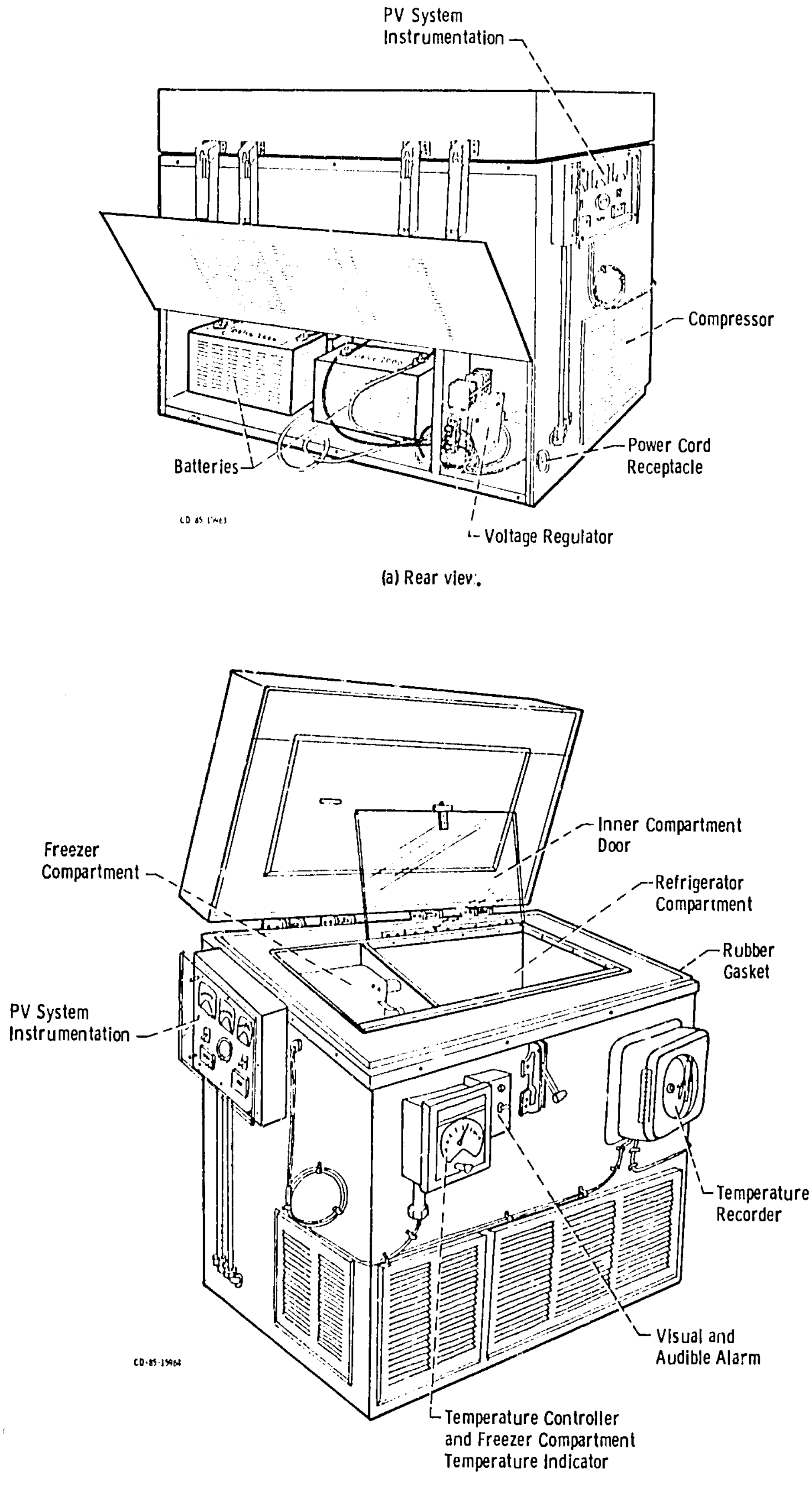



Figure 4. - Solar Power Corp. raised PV array - Indonesia.

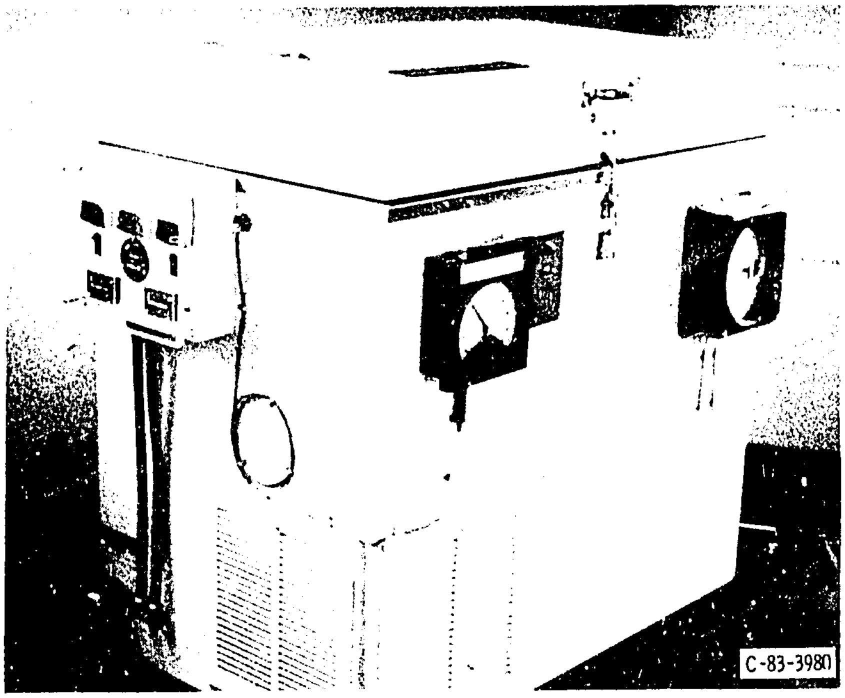



(a) Rear view.



(b) Front view.

Figure 5. - Solar Power Corp./Adler-Barbour PV powered vaccine refrigerator/freezer.




(c) Installed unit.

Figure 5. - Solar Power Corp./Adler-Barbour PV powered vaccine refrigerator/freezer.

Solavolt International Systems

The SVI systems use from four to seven SVI MSP43E40 40 W PV modules depending on the type of R/F and the system location (table I). These PV power systems were sized based on best available insolation data, R/F compressor energy requirements for the average ambient temperature at each location, and 315-A-hr of battery capacity for the Polar Products R/F and 420-A-hr battery capacity for the Marvel R/F. No spare modules were procured from SVI.

The SVI array structure was also designed to be assembled onsite and consists of sections of standard "Unistrut", channel and telescoping box sections. This array structure was also designed for ground mounting (fig. 6) although some arrays also were installed on roofs (figs. 7(a) to (d)). A single 30-m length of four conductor No. 8 direct burial cable was supplied with each array to bring array power to a terminal block on the back of the R/F. The large wire size was required here for essentially the same reason as for the SPC systems, to keep voltage losses to an absolute minimum, but also to divide the array into segments that generate 10 A or less to accommodate voltage regulator limitations.

The voltage regulators, batteries, compressor(s) (the Polar Products R/F has two compressors), controls, and PV system instruments are all contained in the bottoms of the R/F cabinets (figs. 8(a),(b) and 9). The insolometers, which are the same as those supplied with the SPC systems, are stand-alone instruments. The temperature recorder for the Polar Products R/F is also located on the bottom part of the R/F cabinet while the temperature recorder for the Marvel R/F is located on the front of the R/F cabinet (figs. 10 and 11).

SVI procured the 30-A rated switching type voltage regulators from Speciality Concepts, Inc. and used them in a derated capacity (10 A) based on previous experience with relays and contractors operated at or near the manufacturer's current rating. Solavolt now rates these regulators at 20 A and field experience suggests that this is a valid rating. The voltage regulator is a switching type which precludes measuring total potential array output.

Power system instrumentation on both types of R/F's is composed of a single switched meter which displays system voltage and array and compressor(s) current, an array ampere-hour meter, a load ampere-hour meter which records compressor(s) and instrumentation ampere-hours, and run-time meters (one in the Marvel and two in the Polar Products). All these instruments are powered from the R/F 12-V power system.

Each R/F also has a three channel 7-day circular chart spring wound temperature recorder. This instrument records freezer and refrigerator compartment temperatures and ambient temperature.

The SVI systems use refrigerator/freezers manufactured by the Marvel Division of Dayton-Walther Corp. and Polar Products both of which are characterized in table II and figures 16(a) and (b). The thermostatic controls for the freezer compartment in the Marvel and for both freezer and refrigerator compartment in the Polar Products are located in the cabinets under the R/F boxes, are factory set, and are not easily field adjustable.

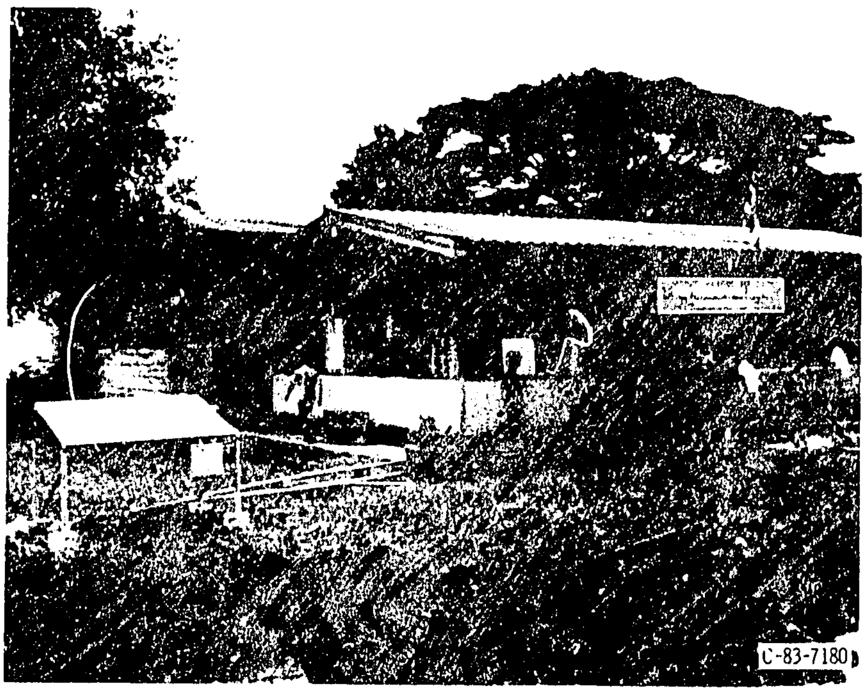
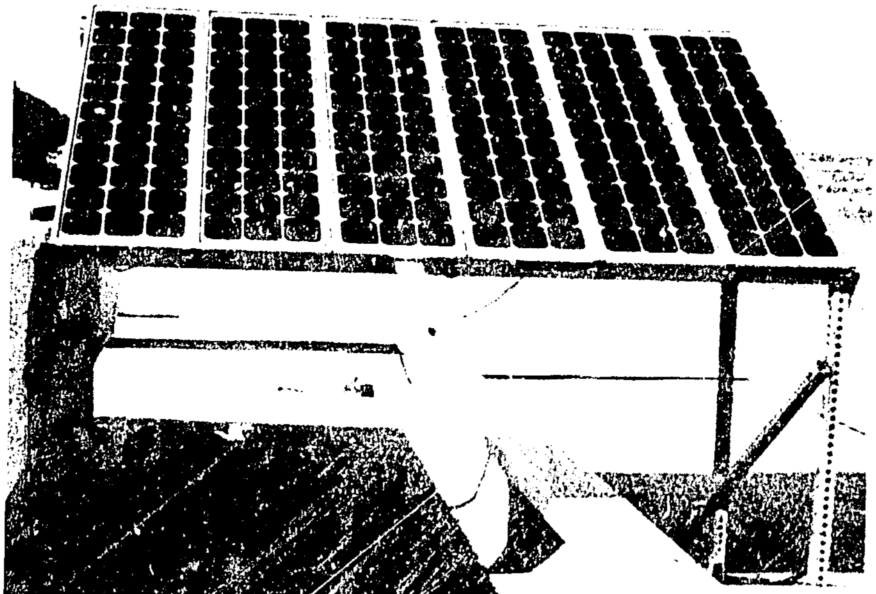



Figure 6. - Solavolt International ground mounted PV array - Thailand.



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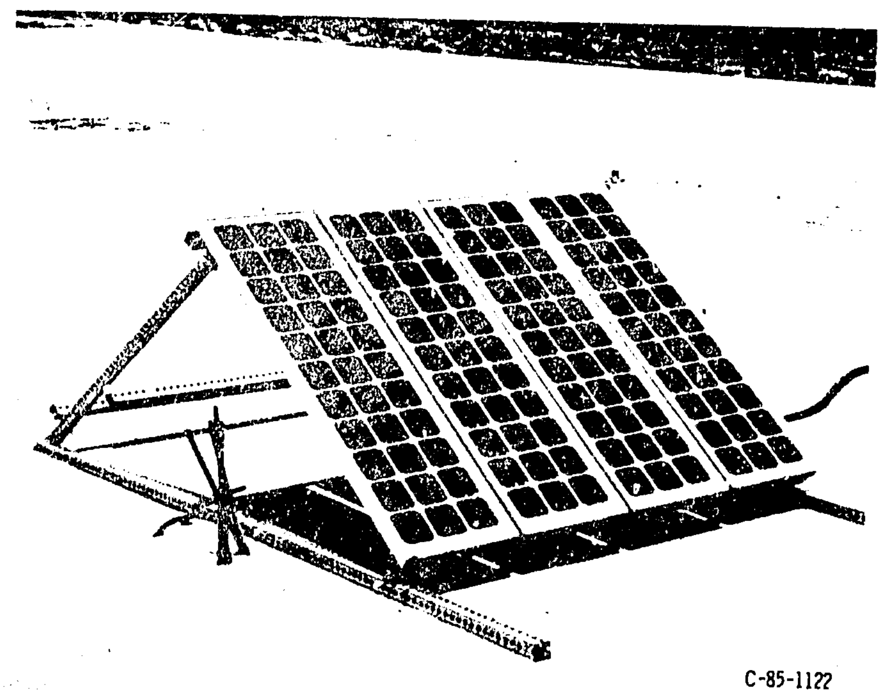
(a) Tunisia



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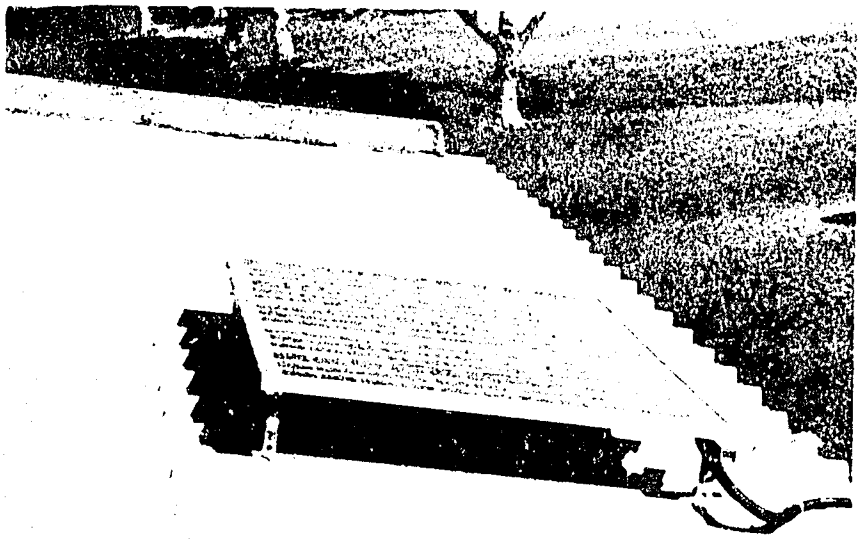
(b) Jordan.

Figure 7. - Solavolt International roof mounted PV array.



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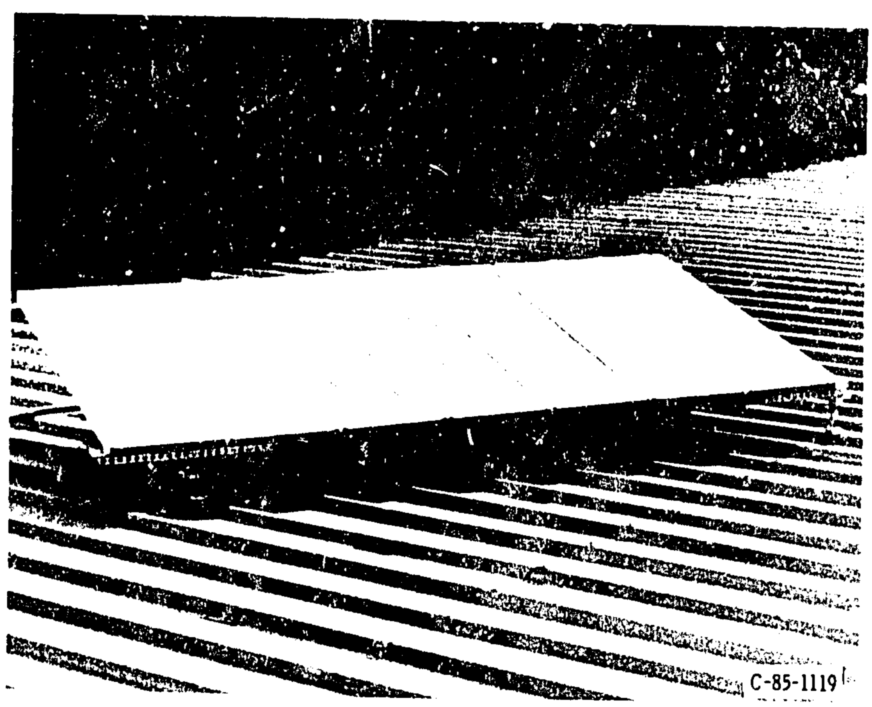
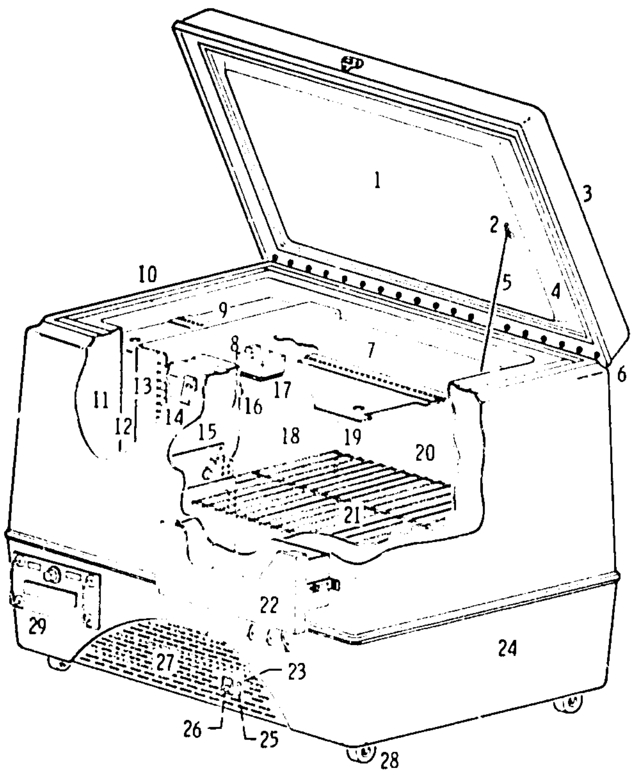
(c) Mali.




(d) Ivory Coast.

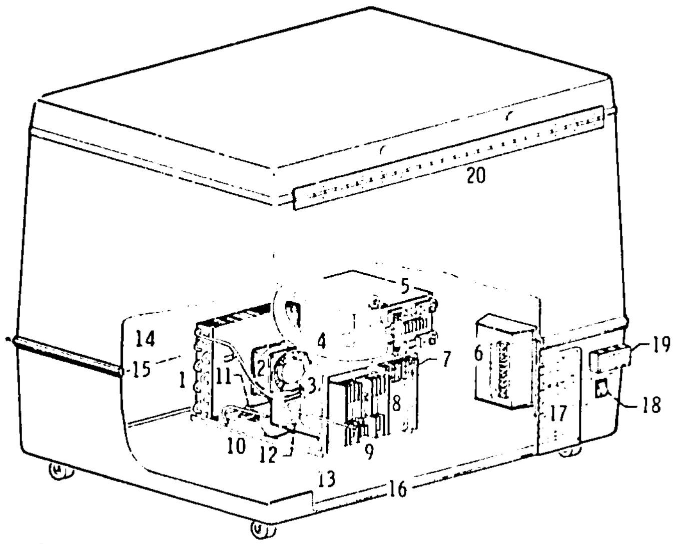
Figure 7. - Concluded.




1 - A.B.S. PLASTIC LINER
2 - BRASS PADEYE
3 - SELF CLOSING LID
4 - MAGNETIC GASKET
5 - BRASS CHAIN
6 - STAINLESS STEEL PIANO HINGE
7 - HINGED PLEXIGLASS COVER
8 - COVER SUPPORTS
9 - HINGED FREEZER COVER
10 - STAINLESS STEEL STRIP
11 - POLYURETHANE FOAM INSULATION
12 - FREEZER COMPARTMENT
13 - EUTECTIC CELL
14 - LATCH/HASP
15 - AIR VALVE DAMPER
16 - CABLE CLAMP
17 - COLD AIR CIRCULATING FAN
18 - INSULATED BARRIER
19 - SENSING PROBE (WEKSLER CHART RECORDER)
20 - REFRIGERATOR COMPARTMENT
21 - WIRE SHELF
22 - TEMPERATURE RECORDER
23 - GREEN LIGHT (FULL CHARGE INDICATOR)
24 - FIBERGLASS CABINET
25 - RED LIGHT (LOW BATTERY INDICATOR)
26 - ON/OFF SWITCH
27 - FRONT VENT GRILL
28 - CASTERS
29 - INSTRUMENTATION

(a) Front view.

Figure 8. - Solavolt International/Marvel PV powered vaccine refrigerator/freezer.




NOTE: ALL WIRING HAS BEEN OMITTED FOR SIMPLICITY

1 - CONDENSER
2 - CONDENSER FAN
3 - COMPRESSOR
4 - INSULATED SUCTION LINE
5 - INSTRUMENTATION
6 - VOLTAGE REGULATOR
7 - TERMINAL BLOCK
8 - PRINT CIRCUIT BOARD
9 - ELECTRONIC MODULE
10 - FILTER/DRIER
11 - CIRCUIT BREAKER
12 - REVERSE POLARITY DIODE
13 - CHARGE TUBE
14 - POLYURETHANE INSULATION
15 - VAPOR BARRIER
16 - REINFORCED BOTTOM
17 - BACK VENT GRILL
18 - PULL DOWN/MAINTENANCE SWITCH
19 - TERMINAL BLOCK
20 - STAINLESS STEEL PIANO HINGE

(b) Rear view.

Figure 8. - Concluded.

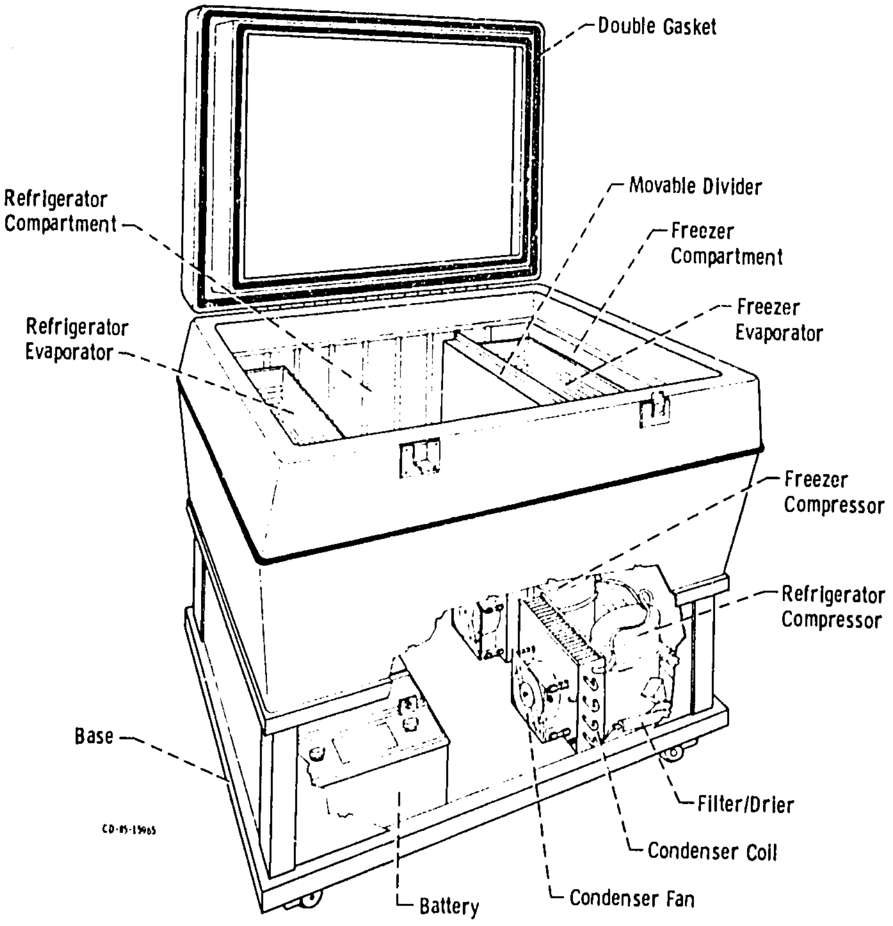



Figure 9. - Solavolt International/Polar Products PV powered vaccine refrigerator/freezer.

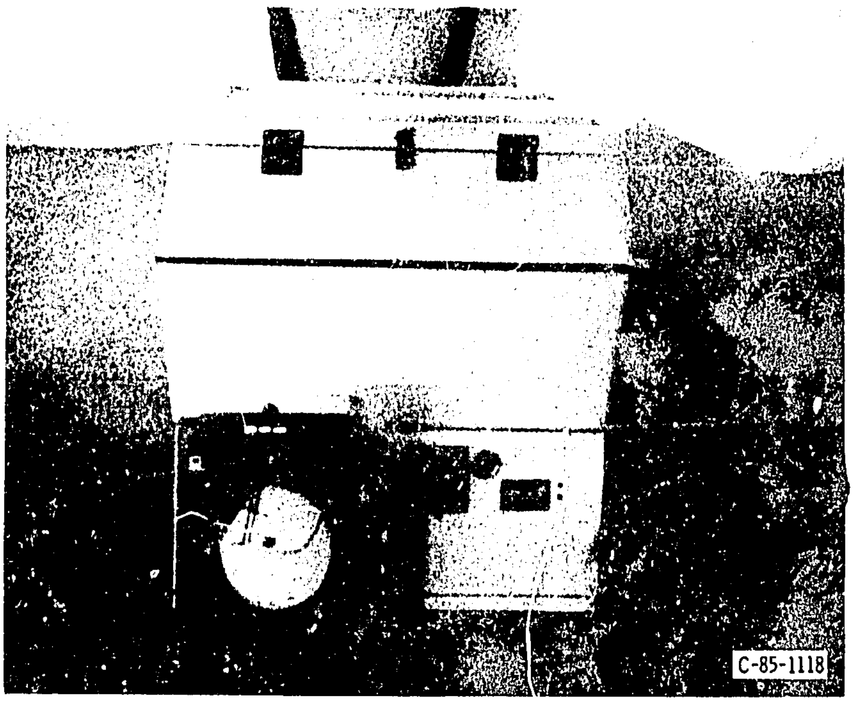



Figure 10. - Solavolt International - Polar Products refrigerator/freezer.

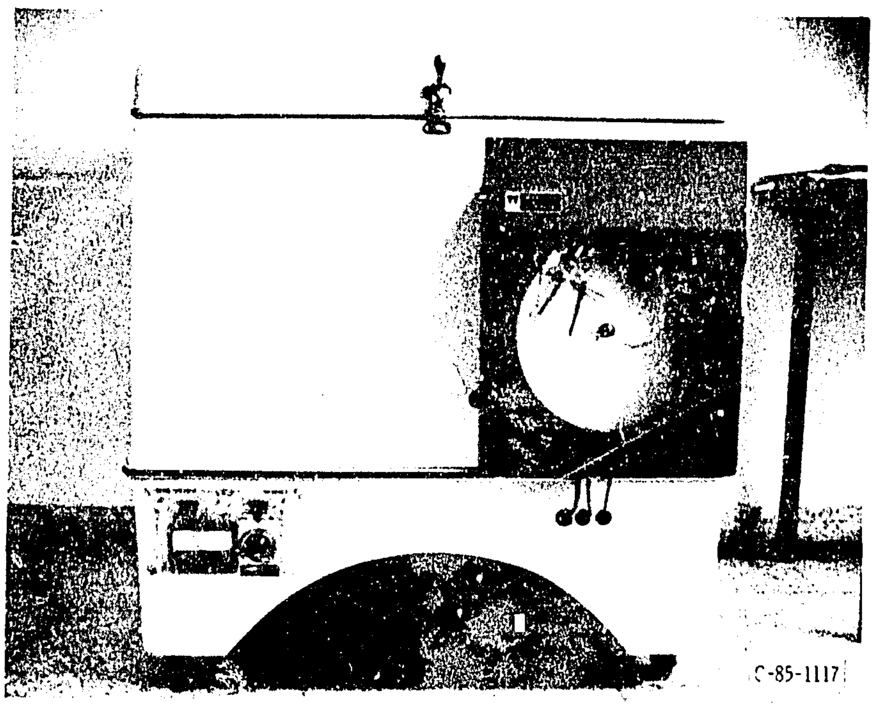



Figure 11. - Solavolt International - Marvel refrigerator/freezer.

However, refrigerator compartment temperature in the Marvel can be manipulated by means of a thermostatically controlled air door between the freezer and refrigerator compartments.

## INSTALLATION EXPERIENCES

For the purposes of this discussion, the shipping of the hardware from the contractors' facilities to the sites will be considered part of the installation activity. All of the SPC and SVI systems were shipped from the U.S. by air freight except for the system to Liberia which was surface shipped. The batteries for the Maldives' system were surface shipped from Singapore and for the Moroccan system from Marsielles, having been, in both cases, air freighted from the U.S. to those transhipment locations.

### Solar Power Corp. Systems Installations

The SPC overall installation effort extended over an enormously long period of time for every reason that can be imagined. Delays included; reaching accords with host countries, making shipping arrangements, shipping the equipment, customs documentation and clearances, scheduling SPC and NASA Lewis personnel for installation travel so as to minimize the total number of installation trips and awaiting construction completion of a health post.

The original plan called for a NASA Lewis engineer to accompany the SPC installer on all installations. In some instances, events conspired against this plan. For instance, while installing the system in Columbia, NASA Lewis, SPC and PAHO personnel were advised that the equipment for the next installation (Peru) was in transit from Lima to Pucara and that the installation crew should arrive on a particular date to meet the equipment at the site. In fact, the equipment became hopelessly lost in transit between Lima and the site with the result that after waiting several days at the site (Pucara), the installation team had to leave Peru to attend to other scheduled installation activities. The equipment arrived at Pucara some time later. Because of scheduling problems, only the SPC installer was able to return to do the installation.

In Indonesia, the NASA Lewis engineer (but not the SPC installer) was advised to not visit one site (Batujaya) because of sensitivities concerning U.S. Government personnel being in the country during their national elections. Scheduling prevented NASA Lewis personnel from being present for the installations in Morocco, Guatemala, Guyana and Ecuador. SPC installed these systems alone. The exceptionally long delay installing the system in Liberia was mostly due to delays in completing construction of the health center and then scheduling a NASA Lewis engineer to do the installation and training.

All of the SPC hardware was packaged in wood containers and none of it experienced shipping damage although there were some mixups; e.g., the air carrier mistakingly delivered five of six batteries to Haiti and seven to the Dominican Republic, and the Dominican Republic array support structure to Haiti. In several instances batteries were mishandled by local personnel while being transported incountry or while being installed. Mishandling involved tipping the batteries with resultant spilling of electrolyte. Battery boxes were marked "this side up" in English with arrows pointing upward; however, in some cases local personnel who could not read English interpreted the arrow to mean that side down and so placed the batteries upside down (a situation hurriedly corrected by knowledgeable personnel). Nevertheless, two batteries were drained and damaged beyond use in the Dominican Republic and batteries in several other SPC and SVI sites suffered minor losses of electrolyte.

There were several instances of various pieces of small hardware that were lost in shipment. In all cases this happened when the individual boxes had been opened prior to receipt at the site. In several other instances, SPC neglected to send enough of or the proper hardware; e.g., bolts, nuts, battery nuts, etc. Missing hardware, whether lost in shipment or not packed at the factory, always creates problems. By definition, the systems are installed in remote locations where even the simplest items, e.g., bolts and nuts, are almost impossible to obtain.

## Solavolt International Systems Installations

The overall SVI installation effort progressed rapidly and smoothly for the first nine systems, with a slight delay for the tenth (Jordan) due to a last minute reassignment of that system to Jordan and subsequent rescheduling of SVI and NASA Lewis travel schedules. A NASA Lewis engineer accompanied SVI for all installations.

The system scheduled for Honduras presented a special problem. The health center that had been selected, Aldea Las Selvas, is very close to the Nicaraguan border. When the installation team arrived border area conflicts precluded their installing the system at that health center. Instead, they assembled and checked out the system and trained local personnel at a health facility in Tegucigalpa. On June 19, 1984, U.S. AID/Honduras notified NASA Lewis that the Hondurans had requested and been given permission to install the system in Marale, away from the border conflict zone. Word was received in November, 1984 that the system was installed in Guaimaca in October (no reason given for the change).

The SVI/Marvel systems were packaged in wood containers. One R/F container (Jordan) must have been dropped in shipment because the thermograph had been jarred loose from the front of the cabinet. The Polar Product R/F's were shipped in cardboard containers and suffered no shipping damage.

## Installation Experiences - General

Siting information that would guide the design and installation effort had been requested from all sites. In some cases detailed information was received, in other cases little or none. On the basis of available information both the SPC and SVI array structures were designed to be mounted on the ground. In several cases and for various reasons the arrays were mounted on roofs (India (SPC), fig. 2(a); Haiti (SPC), fig. 2(b); the Dominican Republic (SPC), fig. 2(c); both Tunisian systems (SVI), of which one is shown in fig. 7(a); Jordan (SVI), fig. 7(b); Mali (SVI), fig. 7 (c); and Ivory Coast (SVI), fig. 7(d)), or on raised structures (Columbia (SPC), fig. 3; and Indonesia (SPC), fig. 4).

One fear was that the batteries, which look like automotive batteries, would be "appropriated" in transit. In fact, only one battery was lost between the port-of-entry and the site (Peru).

In order to improve installation esthetics and to avoid problems hanging the heavy array power cables, NASA Lewis specified direct burial power cable. The specified 30 m of power cable used to connect the PV array to the R/F was adequate for all sites and excessive for some. The armored direct burial cables proved somewhat awkward to work with both from the standpoint of size and lack of flexibility. The cables did, at times, result in minor esthetic nuisances where they had to be taken along the side of a building and/or into a building through a window.

There were only three problems with the R/F's at startup. The R/F compressor electronic control modules for the Dominican Republic, Ivory Coast/Menee, and Indonesia/Batujaya systems malfunctioned and were replaced with spares carried by the installation team. The Maldive Islands' compressor would operate, but failed to cool because of a low freon charge. This problem apparently originated at the factory and was not identified and/or corrected during factory acceptance tests. The system was recharged at the site (albeit almost 16 months from date of installation) and then operated satisfactorily. And the condenser fan and the thermostat printed circuit board for the R/F in Honduras failed during checkout and had to be replaced by spares sent from the U.S.

There were a couple of instances where the door openings into the health centers were too small to pass the R/F with the thermograph mounted on the front. In some cases, the door frame was cut, removed and then replaced and in another case, the thermograph was removed and then replaced after passage.

Four or five days were allocated at each site for transporting equipment to the site, installation, startup and checkout, and training. Actual equipment installation took from one-half day (Mali and Tunisia) to 3 days (Thailand - hampered by rain and flooding in the array location). One or 2 days were allocated for checkout and training. Travel time to and from the site and logistics of transporting and/or unpacking equipment sometimes consumed as much as an extra day.

The training activity consisted of training ministries of health technicians in system maintenance, troubleshooting and repair, and training the user/operator(s) in how to use the R/F and how to take data. Part of the technician training occurred during system installation when they were encouraged to participate in that activity. The troubleshooting and repair training met with various degrees of success depending on the trainees' skills, prior experience, and affiliation. On occasion, the trainees were observed to have become "saturated" after one-half day of training. In Haiti, a local refrigeration entrepreneur who was in no way associated with the project was engaged to accompany the installation team.

User/operator training consisted of instruction in loading ice packs and vaccines, adjusting the air door to achieve the proper temperature range in the refrigerator compartment (Adler-Barbour and Marvel R/F's), defrosting and cleaning the evaporator, and data acquisition. In general, training the user/operator went fairly well although, as with technician training, the user/operators were sometimes observed to be saturated after one-half day of training or were anxious to complete the training so that they could return to their heavy workload. In many cases these systems offered the first exposure many of these people had had to refrigerators and instrumentation. The World Health Organization has materials available to ministries of health to train health center workers in the use of refrigerator/freezers for vaccine storage. But, it is unknown how many (if any) of the user/operators in this project had received any prior training in proper use of refrigerators and freezers.

Training at the SPC installations was somewhat hampered by the fact that SPC did not have manuals available during installation (they were mailed to the users in autumn of 1983). SVI had preliminary draft copies in English available during installation although these were of limited use in non-English speaking countries. The English and local language copies of the final SVI manuals were mailed in November 1984. Another factor that hampered training in many locations was the need to use an interpreter who most often was not only not familiar with the technology, but also not a technologist.

An assessment by NASA Lewis personnel of the training activity is that the amount of training that can be provided during installation cannot satisfy all of the technician and user/operator training needs, largely because of a lack of previous experience by these people with this type of equipment. The problem of lack of adequate training, especially for the user, was only made worse at several sites when the trained personnel were later replaced by untrained personnel.

## PERFORMANCE EVALUATION SUMMARY

NASA Lewis agreements with the CDC and U.S. AID and the AID Limited Scope Grant Project Agreements with the AID host countries all call for a one year period of performance evaluation following system installation. All of the systems were supplied with a complete ensemble of instrumentation and a year's supply of data sheets and blank thermograph charts. Each standardized data sheet provides for two sets of data daily for 7 days. A sample data sheet is shown in figure 12. User/operators were instructed to record data twice daily and to report problems and/or failures. Individuals were identified in the ministries of health or at AID who would receive data from the field and forward it to NASA Lewis weekly, biweekly, or monthly, as conditions permitted. Figures 13 and 14 show those periods of time for which data have been received for each system. Data have been received for about 63 percent of the installed time of the SPC systems (through Aug. 12, 1984), which is notable considering the systems' locations and the torturous mail paths. As of this writing, data has been received from only three of the 10 SVI systems.

Data processing was accomplished at NASA Lewis on the IBM 370 Central Computing System using software developed at NASA Lewis by James E. Martz (NASA Lewis Research Center), and Robert F. Cartwright, and Anthony Facca, (Cleveland State University Graduate Assistants who also accomplished most of the data processing).

NASA Lewis had planned to issue monthly reports summarizing system performance for each installation (see sample report appendix A). That objective proved unattainable for several reasons. First and most crucial was lack of adequate manpower to process and analyze the data and to draft the reports. Since early 1983, the NASA Lewis Photovoltaic Projects Office has

SPC RF-103

SOLAR POWERED REFRIGERATOR/FREEZER
REFRIGERATEUR/GLACIERE PHOTOVOLTAIQUE
NEVERA A BASE DE LA ENERGIA SOLAR

LOCATION: / LOCALISATION: / LOCALIDAD: Bocas Del Palo

| DATE / DATE / FECHA | TIME / HEURE / HORA | ARRAY CURRENT / COURANT - PANNEAU / CORRIENTE - CONJUNTO | LOAD CURRENT / COURANT - CHARGE / CORRIENTE - CARGA | BATTERY VOLTAGE / TENSION - BATTERIES / VOLTAGE - BATERIAS | ARRAY AMP-HOURS / AMPERE-HEURES - PANNEAU / AMPERIO-HORAS - CONJUNTO | LOAD AMP-HOURS / AMPERE-HEURES - CHARGE / AMPERIO-HORAS - CARGA | COMPRESSOR RUN TIME / HEURES DE L'OPERATION DU COMPRESSEUR / HORAS DE OPERACION DEL COMPRESOR | REFRIGERATOR TEMPERATURE / TEMPERATURE - REFRIGERATEUR / TEMPERATURA - REFRIGERADOR | FREEZER TEMPERATURE / TEMPERATURE - GLACIERE / TEMPERATURA - CONGELADOR | AMBIENT TEMPERATURE / TEMPERATURE - AMBIANT / TEMPERATURA - AMBIENTE | INSOLATION / INSOLATION / INSOLACION |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7-3-82 | 12:00 | 15.6 A | 5.6 A | 13.0 V | 109.2 | 77.4 | 38.2 | 3 °C | -12° C | 36 °C | 185 |
| | 2:47 pm | 14.2 A | 5.1 A | 13.2 V | 120.3 | 79.2 | 38.8 | 4° | -12° | 33° | 203 |
| 7-4-82 | 12:00 | 16.2 A | 0 | 14.1 V | 148.0 | 86.1 | 43.0 | 3° | -12° | 38° | 220 |
| | 3:08 pm | 14.7 A | 4.9 A | 13.6 V | 161.4 | 88.3 | 43.6 | 4° | -12° | 34° | 239 |
| 7-5-82 | 12:00 | 13.5 A | 5.4 A | 13.4 V | 186.3 | 94.7 | 47.8 | 4° | -12° | 32° | 257 |
| | 4:13 pm | 11.0 A | 0 | 13.8 V | 202.0 | 97.0 | 48.6 | 5° | -12° | 30° | 277 |
| 7-6-82 | 12:00 | 14.4 A | 5.2 A | 12.9 V | 223.4 | 104.1 | 52.6 | 4° | -12° | 33° | 296 |
| | 2:57 pm | 11.3 A | 0 | 14.0 V | 234.1 | 105.9 | 53.2 | 5° | -12° | 30° | 315 |
| 7-7-82 | 12:00 | 17.1 A | 0 | 13.7 V | 262.7 | 109.9 | 57.4 | 6° | -12° | 40° | 328 |
| | 3:36 pm | 15.8 A | 5.5 A | 13.6 V | 276.4 | 110.7 | 58.1 | 6° | -12° | 37° | 344 |
| 7-8-82 | 12:00 | 15.9 A | 4.7 A | 13.0 V | 298.5 | 115.0 | 62.2 | 5° | -12° | 36° | 363 |
| | 3:10 pm | 14.1 A | 5.1 A | 14.2 V | 311.4 | 117.3 | 62.8 | 6° | -12° | 33° | 382 |
| 7-9-82 | 12:00 | 14.9 A | 0 | 14.4 V | 340.1 | 120.6 | 67.0 | 6° | -12° | 35° | 401 |
| | 4:01 pm | 12.2 A | 5.4 A | 13.1 V | 360.7 | 122.3 | 67.8 | 6° | -12° | 31° | 415 |

WEEKLY
CHAQUE SEMAINE
SEMANAL

1. WASH PANELS WITH WATER
LAVEZ LE PANNEAU AVEC DE L'EAU
LIMPIE EL CONJUNTO CON AGUA

2. CHANGE RECORDER CHART
CHANGER LE TABLEAU DE L'APPAREIL ENREGISTREUR
CAMBIE EL CUADRO DEL INDICATOR

3. REMOVE FROST BUILDUP
ENLEVEZ LA GELEE
ELIMINE LA ESCARCHA

Figure 12. - Solar Power Corp. field test system sample data sheet.

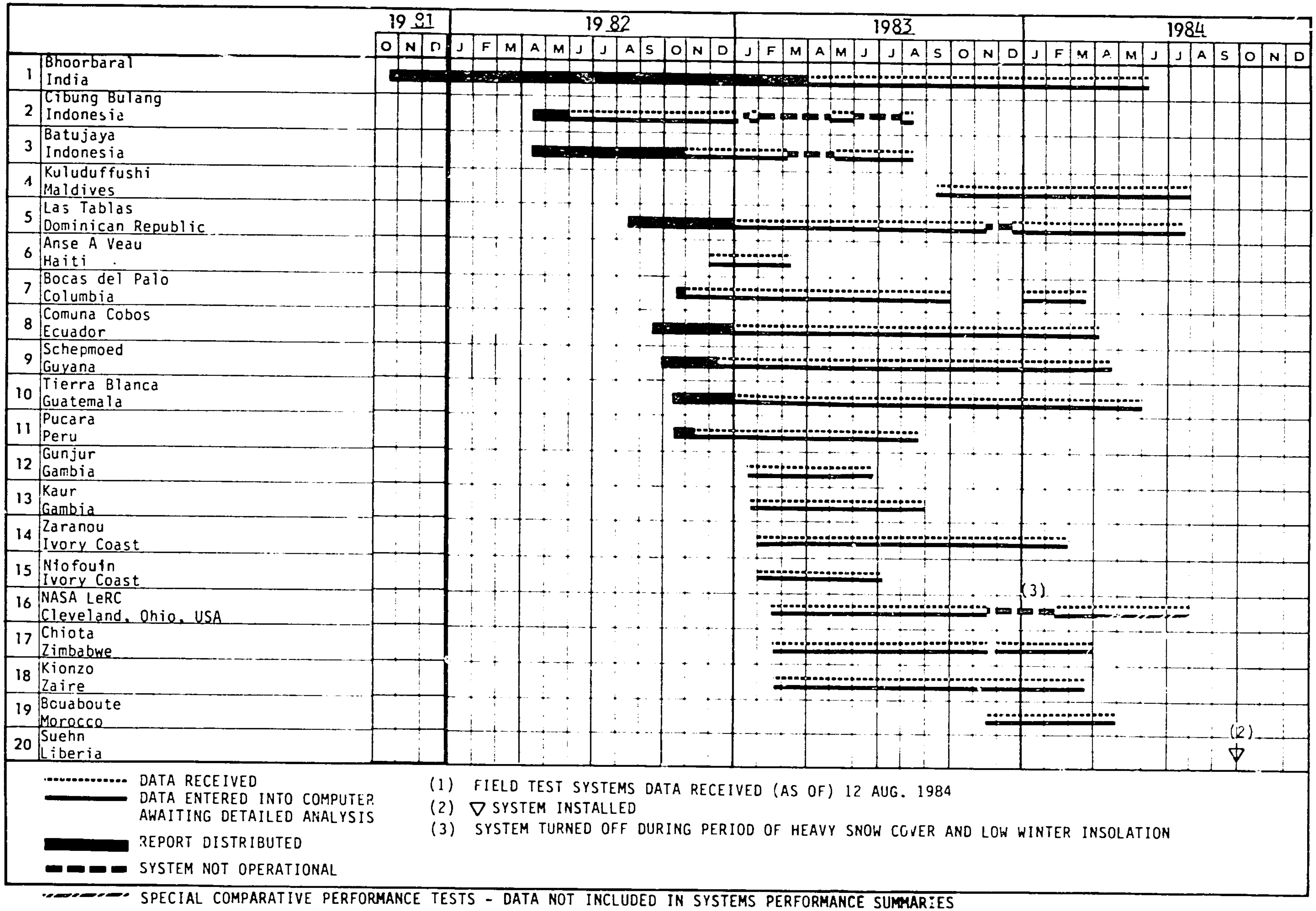



Figure 13. - Solar Power Corp./Adler-Barbour Systems reporting history.

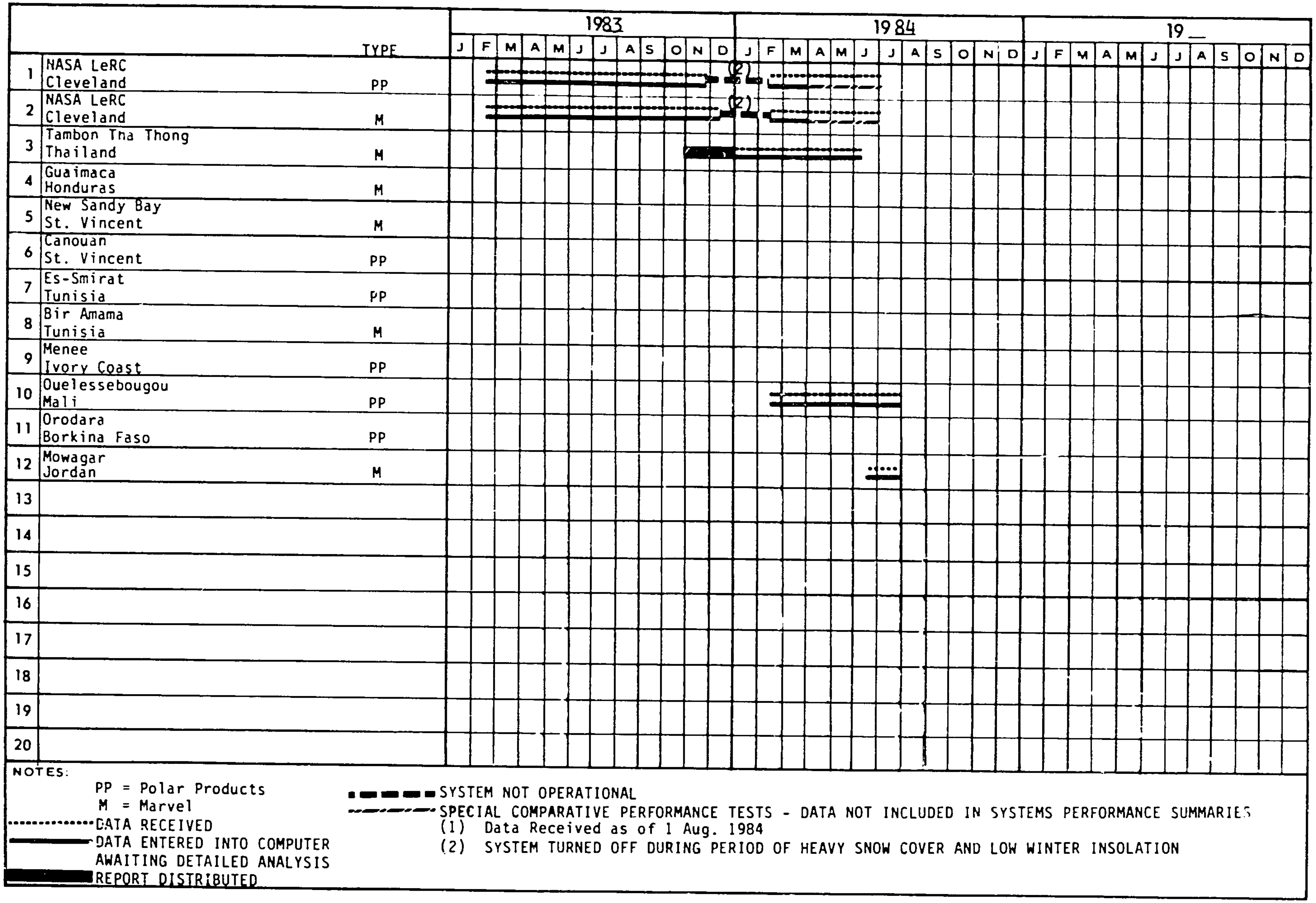



Figure 14. - Solavolt/Marvel and Polar Products Systems reporting history.

been implementing a phase out plan in accordance with NASA Headquarters policy directives, and DOE and AID funding limitations. This project suffered a dual fate in that not only was available manpower steadily reduced, but also that project responsibility had to be reassigned several times as personnel left the project office.

A second factor contributing to the reporting difficulty was instrument failures. Over one-half of the SPC ampere-hours meters have now failed. Prior to outright cessation of operation, however, they often would display erratic readings. Sometimes the data could be manipulated to restore its usefulness, but that consumed a lot of time. There were seven run-time meter failures on SPC systems which further hampered performance analysis. There have been three instances of ampere-hour meter problems with SVI systems, two of which have been corrected by installation of replacement instrument assemblies.

A third factor which hampered performance analysis was data quality and sporadic data submissions. Even when, in most cases, original copies of the data sheets were received at NASA Lewis, legibility often proved to be a trial and there were numerous erroneous readings. Sorting out these errors required a great deal of time as the more subtle errors were often not detectable until the graphics were examined, even though an attempt was made to correct errors at all stages of data processing, from data entry through graphics analysis. Receiving large amounts of data on widely separated dates created work load imbalance problems since the data processing was carried out by the part-time Cleveland State University Graduate Assistants Cartwright and Facca.

Figures 13 and 14 also show those periods of operation for which reports have been issued. It should be noted that the data have been processed for all the other periods indicated for the SPC systems, but have not been reported in individual system reports.

The performance results summarized herein are intended to provide an overall picture of the performance of the 18 SPC field test systems, the three reporting SVI systems, and the three NASA Lewis endurance test systems.

The reader should note that the results reported herein are for data that had been received as of 12 August 1984. Additional data has been received for some systems since then. However, for those SVI systems for which no data had been received as of 12 August 1984, it should be noted that neither has any data been received as of late December 1984. It should be noted further that the NASA Lewis endurance test systems were used for a series of comparative performance tests for the period April through July 1984 and some performance data for that period is not included in the system performance summaries, but is in part shown in the figures 17, 18(a) and (b).

Figures 15(a) and (b), and tables III(a) and (b) display the operational history of the SPC and SVI systems. Periods of verified operation of the SPC systems, including the NASA Lewis test system, indicate that they have been in operation (but not necessarily within proper refrigerator compartment temperature limits) 62.8 percent of the time. If periods of no data are assumed to indicate operation (and this is known to be not entirely true), then the systems have been in operation somewhat less than 85.6 percent of the time.

Data from the SVI systems, including the NASA Lewis test system, indicate that they have been in operation 51.6 percent of the time. And, again, if periods of no data are assumed to indicate operation (and there is no evidence to counter that assumption) then the field test and the NASA Lewis test systems have been in operation 98.1 percent of the time.

The most important performance factor is refrigerator compartment temperature. Tables IV(a) and (b) display the amount of time the SPC and SVI systems refrigerators were within the WHO revised acceptable temperature range of 0 to 8 °C. These data were taken from 3-hr intervals on the thermograph charts. If the refrigerator compartment air temperature was within range any time during a 3-hr interval, it was counted as in range for that whole period. Data for the three systems on test at NASA Lewis have been included for reference. The SPC/Adler-Barbour R/F's were within the acceptable temperature range 84 percent of the time for which temperature data is available. And the SVI Polar Products and Marvel R/F's were within the acceptable temperature range of 83 percent the time for which temperature data is available. Some of the out-of-limits temperatures can be accounted for as follows:

(1) India, 29.62 percent of the time low: Temperature measurements in December 1981 showed that the freezer compartment was actually 16 °C colder than the temperature controller indicated. The controller was recalibrated during an April 1982 NASA Lewis/SPC visit.

(2) Dominican Republic, 31.6 percent of the time high: Use analysis and a visit by a NASA Lewis engineer on February 2, 1984 revealed that the health center staff was putting large amounts of water in the freezer late in the day causing the compressor to run all night. The batteries had become discharged such that compressor operation would cease during part of each night resulting in rising refrigerator compartment temperatures. When the solar array had recharged the batteries back to 11.5 V during the day, the compressor would restart.

(3) Guyana, 37.8 percent of the time high: The Guyana system was plagued with several minor problems which separately and together resulted in a significant amount of time when voltages were too low to sustain compressor operation. These problems were as follows:

(a) Lack of adequate training and/or lack of grasp of training by technicians and user resulting in operator errors and problem misdiagnosis by technician (comment 4, table VII).

(b) Replacement of originally trained user personnel with personnel having no training.

(c) Lack of SPC manual until Autumn 1983.

(d) Incorrect data entries (comment 4, table VII) and inconsistent data submissions.

(e) Difficultly in receiving diagnostic data from installation site.

(f) Design error (comment 4, table VII).

(g) Unsatisfactory communications between NASA Lewis and AID/Guyana.

(4) Gambia/Kaur, 36.1 percent of the time high: Very soon after installation, the health center staff lowered freezer compartment temperature setting to -20 °C and apparently readjusted the air door setting. This low temperature setting for the freezer resulted in excessive compressor operation and eventual battery discharge which, in turn, resulted in intermittent compressor operation and corresponding periods of high refrigerator compartment temperatures.

(5) Thailand, 10.8 percent of the time high: Data indicates that at times large amounts of warm materials might have been placed in the freezer temporarily raising refrigerator compartment temperature.

(6) Thailand, 24.5 percent of the time low: The thermostatically controlled air door was apparently defective as adjustments by the health center staff were unable to raise the temperature. A replacement air door was installed in May 1984.

(7) Mali, 31.5 percent of the time high: This problem is not yet completely understood, because correspondence from Mali is not clear on all issues and the data record is not complete. Thermograph data clearly shows periods during which the compressors failed to operate. One or both of the voltage regulators was replaced in July and the R/F is reported to have operated properly since. However, the data available does not clearly indicate the problem (see comments to table XI).

The next most important performance factors are compressor runtime and compressor energy consumption. The R/F performance specification limits runtime to 16.8 hr/day (70 percent) when the R/F is in a 43 °C environment with no ice making and no door openings.

Tables V(a) and (b) display compressor runtime and average ambient temperatures for the SPC and SVI field test systems and the NASA Lewis endurance test systems. These tables show that all systems met the 70 percent or less runtime (disregarding ambient temperatures) except the Dominican Republic and Ivory Coast/Niofouin systems. The cause for the high runtime for the Dominican Republic system was excessive use of the freezer in late 1983 and early 1984 (see comments above). The cause for the high runtime for the Niofouin system was that the freezer was adjusted to operate at -23 °C from shortly after installation to the end of the period for which there is data. Although all but two of the systems operated at less than 70 percent runtime, several of them were very close to 70 percent runtime and at ambient temperatures well below 43 °C. Without good data on how the systems were actually used, one can only speculate that these high run-time systems were being used more intensively than planned.

During the qualification tests, each of the three R/F's were operated at three ambient temperatures spanning 23 to 43 °C. These tests were steady state tests in that the freezer and refrigerator compartments were loaded with already frozen ice packs and sterile water vials respectively. To gain a better understanding of how the R/F's performed under conditions more nearly approximating actual use and to have reference data with which to compare field test data, a simulated use test was conducted with the three endurance test systems at NASA Lewis in the summer of 1984.

That test was designed to compare the operating characteristics of all three R/F's under identical ambient conditions and under simulated usage conditions. The test procedure was to load the freezer compartment of each R/F with six 350-ml cold packs containing ambient temperature water each morning for two consecutive days. Ambient temperature water in this case means the ambient temperature of the test chamber at each of the three temperatures at which the test was conducted. The refrigerator compartments of each R/F contained 6 liters of sterile water in 30-ml vials. At noon of each day, both the refrigerator and freezer compartments were opened for ~1 min to simulate user access.

Figures 16(a) and (b) display the results of that test. There it can be seen that the Polar Products and Marvel R/F's meet the maximum 70 percent runtime at 43 °C specification when making 2 kg of ice each day. The Adler/Barbour R/F, however, runs about 90 percent of the time in a 43 °C environment when making 2 kg of ice per day. Thermocouples inserted in all of the ice packs established that all three R/F's could make the required 2 kg of ice in a 24-hr period.

Figures 17, 18(a) and (b) display field test systems compressor runtimes as a function of average ambient temperatures. Superimposed on each figure are the results from the NASA Lewis simulated use test.

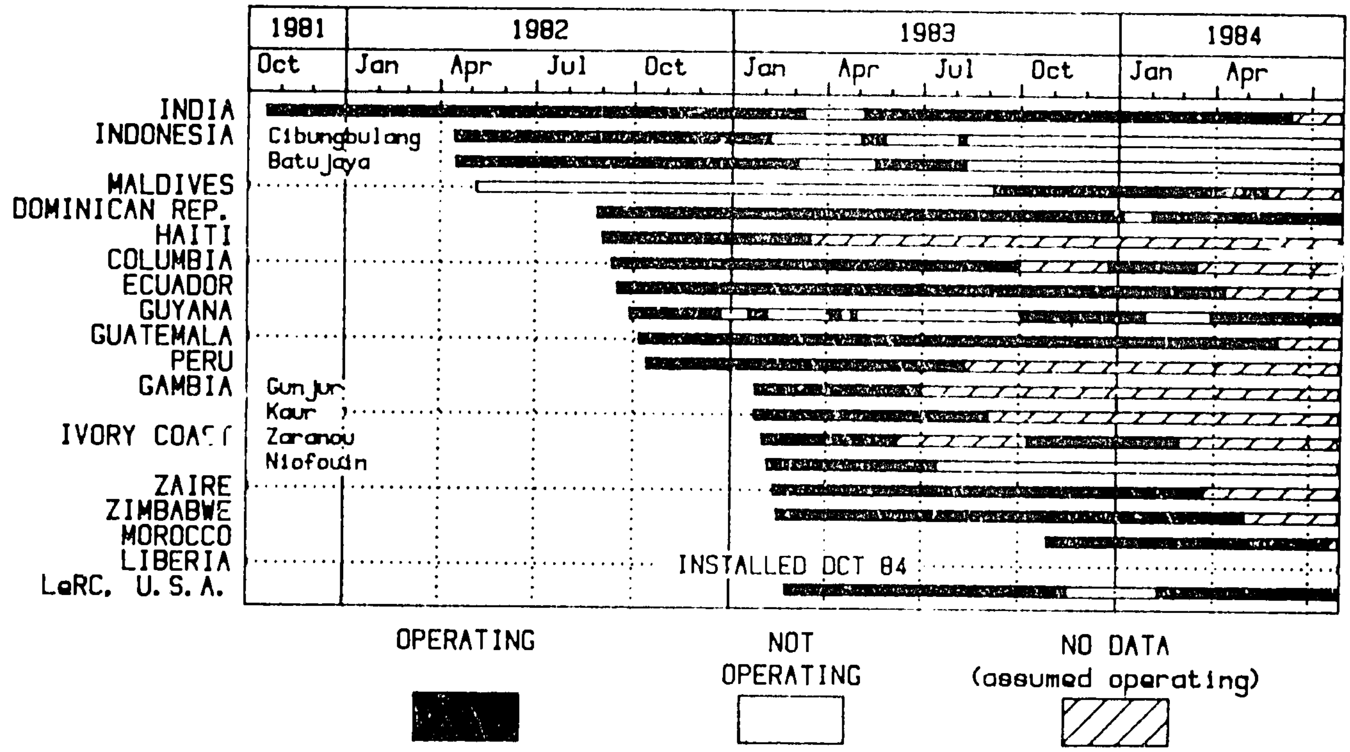
Figure 17 shows that operation of the SPC field test R/F's generally follows the trend of the laboratory test system except for the Ivory Coast (Niofouin) and the Maldives R/F's The Niofouin data is the result of the freezer temperature controller being set for -23 °C instead of -12 °C. The reason for the low runtime for the Maldives systems cannot be determined from the available data and information. Differences in compressor runtimes for the other systems presumably reflect differences in use patterns. Figure 18(a) shows a considerable difference between laboratory and field test system runtimes, and again probably reflects more intense R/F use.

Tables VI(a) and (b) display average daily array and R/F ampere-hour generation and consumption. These data were obtained from the ampere-hour data for days for which there are both array and R/F ampere-hour data.

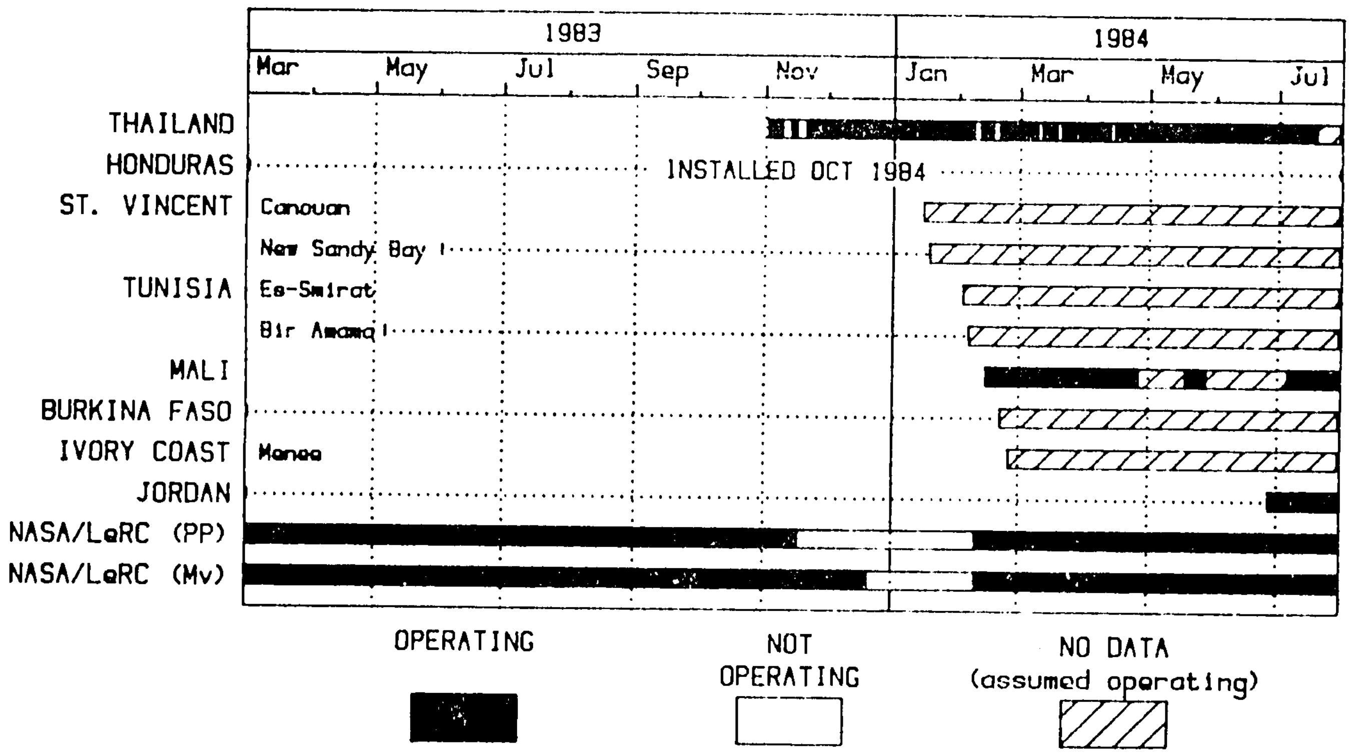
The range of average array ampere-hours per day is the result primarily of varying insolation patterns, instrumentation problems, and data recording errors. Since the insolation data was not useable, it is not possible to separate and quantify these factors.

The range of average R/F ampere-hours per day is the result of differences in ambient temperatures, R/F use patterns, instrumentation problems and data recording errors. Again, it is not possible to separate and quantify these factors.

In general, the data on tables VI(a) and (b) show that the PV arrays generated enough ampere-hours to meet R/F demands. Table VI(a) (SPC systems) indicates an array shortfall for the Ivory Coast/Niofouin system. The Niofouin data indicates that shortly after installation the freezer temperature setting was changed from -12 °C to approximately -23 °C with a resultingly high compressor runtime. However, the available data indicates that the compressor never failed to operate due to discharged batteries.




(a) Solar Power Corp.




(b) Solavolt International.

Figure 15. - Refrigerator/freezer systems operating history.

TABLE III(a). - SOLAR POWER CORP./ADLER-BARBOUR REFRIGERATOR/FREEZER OPERATIONAL TIME SUMMARY

| Location | Percent time verified operational[a] | Percent time known to be out of operation[a] | Percent time assumed operational[b] |
|---|---|---|---|
| India | 94.9 | 0 | 100.0 |
| Indonesia | | | |
| Cibung Bulang | 39.1 | 60.9 | 39.1 |
| Batujaya | 48.4 | 51.6 | 48.4 |
| Maldives | 77.4 | 0 | 100.0 |
| Dominican Republic | 88.9 | 6.2 | 93.8 |
| Haiti | 27.6 | 0 | 100.0 |
| Columbia | 52.9 | 0 | 100.0 |
| Ecuador | 83.3 | 0 | 100.0 |
| Guyana | 51.6 | 48.4 | 51.6 |
| Guatemala | 88.2 | 0 | 100.0 |
| Peru | 45.7 | 0 | 100.0 |
| Gambia | | | |
| Gunjur | 28.3 | 0 | 100.0 |
| Kaur | 39.9 | 0 | 100.0 |
| Ivory Coast | | | |
| Zaranou | 49.2 | 0 | 100.0 |
| Niofouin | 28.0 | 72.0 | 28.0 |
| Zaire | 81.9 | 0 | 100.0 |
| Zimbabwe | 77.2 | 0 | 100.0 |
| Morocco | 95.3 | 0 | 100.0 |
| Liberia[d] | | | |
| Averages, field test systems | 61.3 | 15.0 | 84.5 |
| NASA Lewis | 100.0 | [c]0 | 100.0 |
| Averages, all systems | 62.8 | 14.4 | 85.6 |

[a]Based on available data.
[b]R/F assumed to be operational from date of installation to 1 August 1984 in the absence of contrary information.
[c]Excluding period during winter when R/F was shut off due to heavy snow cover on PV array and low winter insolation.
[d]Installed October 1984.

TABLE III(b). - SOLAVOLT INTERNATIONAL MARVEL AND POLAR PRODUCTS REFRIGERATOR/FREEZER OPERATIONAL TIME SUMMARY

| | R/F manufacturer | Percent time verified operational[a] | Percent time known to be out of operation[a] | Percent time assumed operational[b] |
|---|---|---|---|---|
| Thailand | M | 87.9 | 8.3 | 92.7 |
| Honduras[e] | M | | | |
| St. Vincent | | | | |
| Canouan | PP | (c) | | 100 |
| New Sandy Bay | M | (c) | | 100 |
| Tunisia | | | | |
| Es-Smirat | PP | (c) | | 100 |
| Bir Amama | M | (c) | | 100 |
| Mali | PP | 96.4 | 3.6 | 96.4 |
| Burkina Faso | | (c) | | 100 |
| Ivory Coast | PP | (c) | | 100 |
| Menee | | | | |
| Jordan | M | 100 | 0 | 100 |
| Averages, | | | | |
| field test systems | | 22.8 | 3.1 | 96.9 |
| NASA Lewis | PP | 100 | [d]0 | 100 |
| NASA Lewis | M | 100 | [d]0 | 100 |
| Averages all systems | | 51.6 | 1.9 | 98.1 |

M = Marvel
PP = Polar Products

[a]Based on available data.
[b]R/F assumed to be operational from day of installation to 1 August 1984 in the absence of contrary information.
[c]No data available.
[d]Excluding period during winter when systems were shut off due to heavy snow cover on PV array and low winter insolation.
[e]Installed October 1984.

TABLE IV(a). - SOLAR POWER CORP./ADLER-BARBOUR SYSTEMS
REFRIGERATOR COMPARTMENT TEMPERATURE PERFORMANCE

| Location | Percent time in range | Percent time high | Percent time low | Total number of days of temperature data |
|---|---|---|---|---|
| India | 68.11 | 2.62 | 29.26 | 438.25 |
| Indonesia | | | | |
| Cibung Bulang | 93.52 | 6.48 | 0.00 | 61.75 |
| Batujaya | 99.06 | 0.94 | 0.00 | 160.13 |
| Maldives[a] | | | | |
| Dominican Republic | 68.36 | 31.64 | 0.00 | 483.13 |
| Haiti | 91.03 | 8.97 | 0.00 | 9.75 |
| Columbia | 98.56 | 1.37 | 0.06 | 409.13 |
| Ecuador | 98.02 | 1.98 | 0.00 | 252.25 |
| Guyana | 52.33 | 37.78 | 9.88 | 227.63 |
| Guatemala | 100.00 | 0.00 | 0.00 | 6.75 |
| Peru | 100.00 | 0.00 | 0.00 | 164.88 |
| Gambia | | | | |
| Gunjur | 97.99 | 2.01 | 0.00 | 198.63 |
| Kaur | 63.86 | 36.14 | 0.00 | 207.50 |
| Ivory Coast | | | | |
| Zaranou | 96.89 | 3.11 | 0.00 | 124.50 |
| Niofouin | 100.00 | 0.00 | 0.00 | 146.00 |
| Zimbabwe | 100.00 | 0.00 | 0.00 | 48.63 |
| Zaire[a] | | | | |
| Morocco | 65.13 | 0.00 | 34.87 | 119.00 |
| Liberia[b] | | | | |
| Averages for field test systems | 82.25 | 11.45 | 6.29 | 3057.91 |
| NASA Lewis | 99.65 | 0.35 | 0.00 | 248.00 |
| Averages for all SPC systems | 83.56 | 10.61 | 5.82 | 3305.91 |

[a]No thermograph charts were ever received nor was any reason ever given why they were not forwarded with other data.
[b]Installed October 1984.

TABLE IV(b). - SOLAVOLT INTERNATIONAL SYSTEMS REFRIGERATOR COMPARTMENT TEMPERATURE PERFORMANCE

| Location | Percent time in range | Percent time high | Percent time low | Total number of days of temperature data |
|---|---|---|---|---|
| Marvel R/F units | | | | |
| Thailand | 64.69 | 10.80 | 24.51 | 245.00 |
| Honduras[a] | | | | |
| St. Vincent New Sandy Bay[a] | | | | |
| Tunisia Bir Amana[a] | | | | |
| Jordan | 100.00 | | | 16.00 |
| U.S.A. NASA Lewis[a] | 95.02 | 2.99 | 1.99 | 201.00 |
| Marvel averages | 79.11 | 7.03 | 13.86 | 462.00 |
| Polar Products R/F units | | | | |
| St. Vincent Canouan[a] | | | | |
| Tunisia Es-Smirat[a] | | | | |
| Ivory Coast Menee[a] | | | | |
| Mali | 68.45 | 31.55 | 0.00 | 94.42 |
| Burkina Faso[a] | | | | |
| U.S.A. NASA Lewis[b] | 100.00 | 0.00 | 0.00 | 201.00 |
| Polar products averages | 89.92 | 10.08 | 0.00 | 295.42 |

[a]No data available.
[b]Instantaneous temperature data taken from data sheets since no thermograph is mounted on R/F.

TABLE V(a). - SOLAR POWER CORP. SYSTEMS
COMPRESSOR RUN-TIME PERFORMANCE SUMMARY

| Location | Number of[a] days data | Hours[a] runtime | Percent runtime | Average ambient temperature |
|---|---|---|---|---|
| India | 944 | 10389.4 | 45.9 | [c]25.0 |
| Indonesia | | | | |
| Cibung Bulang | 255 | 2568.6 | 42.0 | 27.8 |
| Batujaya | 396 | 6196.4 | 65.2 | 31.3 |
| Maldives | 159 | 2340.6 | 61.3 | 41.9 |
| Dominican Republic | 577 | 10422 | 75.3 | 29.5 |
| Haiti | 103 | 1637.3 | 65.2 | [c]27.0 |
| Columbia | 537 | 4117 | 31.9 | 25.6 |
| Ecuador | 565 | 3407 | 25.1 | 17.6 |
| Guyana | 297 | 2939.3 | 41.2 | 28.4 |
| Guatemala | 555 | 2370.2 | 17.8 | 16.8 |
| Peru | 300 | 924.4 | 12.8 | 15.5 |
| Gambia | | | | |
| Gunjur | 154 | 1888 | 51.1 | 28.0 |
| Kaur | 80 | 1278 | 66.6 | 30.4 |
| Ivory Coast | | | | |
| Zaranou | 268 | 2744 | 42.7 | 29.7 |
| Niofouin | 146 | 3438.6 | 98.1 | 31.2 |
| Zimbabwe | 412 | 2950 | 29.8 | 24.5 |
| Zaire | 405 | 6312.5 | 64.9 | [c]24.0 |
| Morocco | 170 | 981.1 | 24.1 | 19.9 |
| Liberia[b] | | | | |
| Summary of field test systems | 6323 | 66903.4 | 44.1 | Not applicable |
| U.S.A. NASA Lewis | 319 | 4327.4 | 56.5 | 32.9 |
| Summary of all systems | 6642 | 71230.8 | 44.7 | Not applicable |

[a]Only operational periods of the run-time meter are considered.
[b]Installed October 1984.
[c]Average noon-time temperature.

TABLE V(b). - SOLAVOLT INTERNATIONAL SYSTEMS
COMPRESSOR RUN-TIME PERFORMANCE SUMMARY

| Location | Number of days data | Hours runtime | Percent runtime | Average ambient temperature |
|---|---|---|---|---|
| Marvel R/F units | | | | |
| Thailand | 235.0 | 2926.0 | 51.88 | 27.4 |
| Honduras | | | | |
| St. Vincent | | | | |
| New Sandy Bay[a] | | | | |
| Tunisia | | | | |
| Bir Amana[a] | | | | |
| Jordan | 16.0 | 180.2 | 46.93 | [b]27.0 |
| U.S.A. NASA Lewis | 354.0 | 1977.4 | 23.30 | 32.9 |
| Marvel summary | 554.0 | 5789.4 | 43.54 | |
| Polar Products R/F units - combined refrigerator and freezer compressors runtimes | | | | |
| St. Vincent | | | | |
| Canouan[a] | | | | |
| Tunisia | | | | |
| Es-Smirat[a] | | | | |
| Ivory Coast[a] | | | | |
| Mali | 105.0 | 1194.4 | 45.61 | [b]35.0 |
| Burkina Faso[a] | | | | |
| U.S.A. NASA Lewis | 321.0 | 2554.8 | 33.16 | 32.9 |
| Polar Products summary | 480.0 | 3603.1 | 31.28 | |

[a]No data available.
[b]Average noon-time temperature.

TABLE VI(a). - SOLAR POWER CORP./ADLER-BARBOUR REFRIGERATOR/FREEZER SYSTEMS AMPERE-HOUR DATA SUMMARY

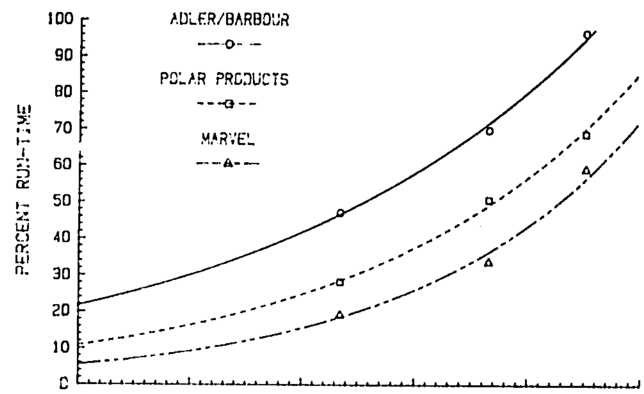
| Location | Array ampere-hours per day | R/F ampere-hours per day | Number of days of data |
|---|---|---|---|
| India | 88.3 | 72.6 | 56 |
| Indonesia | | | |
| Cibung Bulang | 85.7 | 33.5 | 137 |
| Batujaya | 70.5 | 60.2 | 107 |
| Maldives[a] | | | |
| Dominican Republic | 92.7 | 76.8 | 186 |
| Haiti | 70.0 | 61.7 | 104 |
| Columbia | 89.4 | 36.6 | 154 |
| Ecuador | 60.6 | 24.8 | 564 |
| Guyana | 70.7 | 49.6 | 127 |
| Guatemala | 66.4 | 17.8 | 523 |
| Peru | 44.1 | 14.3 | 300 |
| Gambia | | | |
| Gunjur | 103.3 | 55.9 | 154 |
| Kaur | 107.8 | 79.0 | 219 |
| Ivory Coast | | | |
| Zaranou[a] | | | |
| Niofouin | 110.5 | 121.3 | 146 |
| Zimbabwe | 102.2 | 34.5 | 384 |
| Zaire | 103.2 | 80.7 | 24 |
| Morocco | 20.6 | 24.0 | 151.0 |
| Liberia[b] | | | |
| NASA Lewis | 81.4 | 67.5 | 319 |

[a]Meter never functioned.
[b]Installed October 1984.

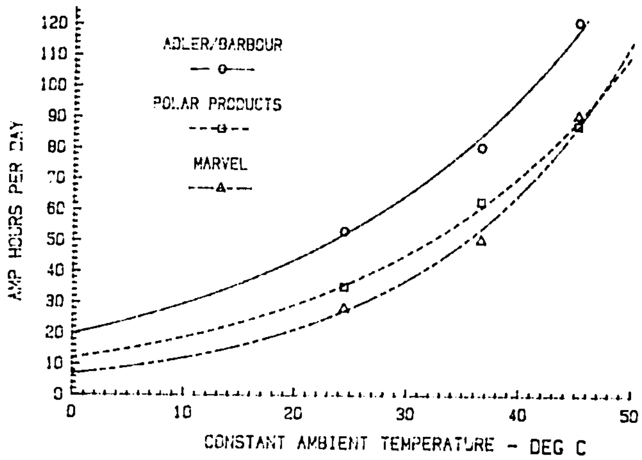
TABLE VI(b). - SOLAVOLT INTERNATIONAL SYSTEMS
AMPERE-HOUR DATA SUMMARY

| Location | Array ampere-hour per day | R/F Ampere-hour per day | Number of days of data |
|---|---|---|---|
| Marvel R/F units | | | |
| Thailand | 55.0 | 45.4 | [b]72 |
| Honduras[a] | | | |
| St. Vincent | | | |
| New Sandy Bay[a] | | | |
| Tunisia | | | |
| Bir Amana[a] | | | |
| Jordan | 62.8 | 56.1 | 53 |
| NASA Lewis | 46.0 | 43.3 | 303 |
| Polar Products R/F units - combined refrigerator and freezer | | | |
| St. Vincent | | | |
| Canouan[a] | | | |
| Tunisia | | | |
| Es-Smirat[a] | | | |
| Ivory Coast | | | |
| Menee[a] | | | |
| Mali | 49.5 | 45.3 | [b]59 |
| Burkina Faso[a] | | | |
| NASA Lewis | 46.8 | 42.0 | 331 |

[a]No data received.
[b]Defective meter portion of total installed time.




(a) Compressor run-time performance.




(b) Ampere-hour performance.

Figure 16. - PV powered vaccine refrigerator/freezers, comparative simulated use.

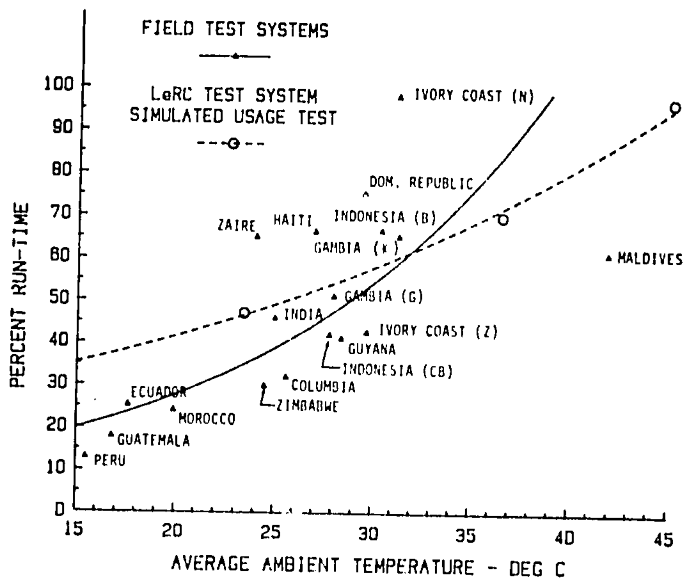
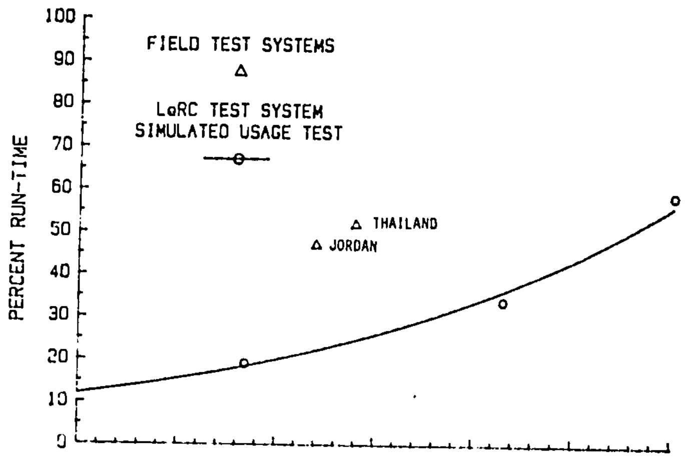
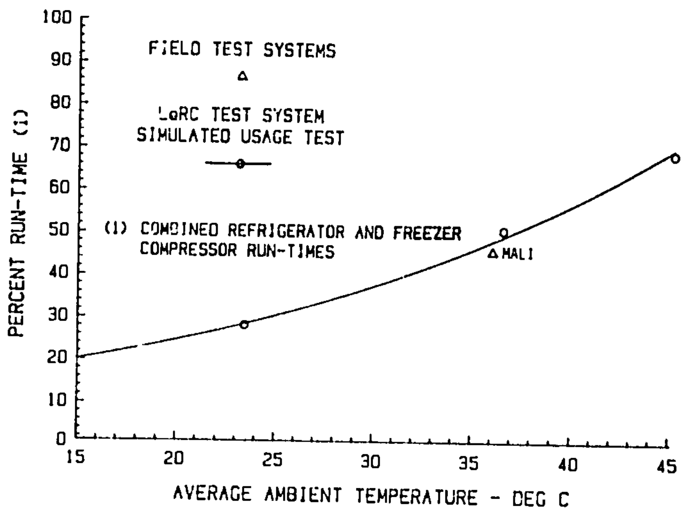



Figure 17. - Solar Power Corp./Adler-Barbour Systems compressor run-time performance.




(a) Marvel refrigerator/freezer.




(b) Polar Products refrigerator/freezer.

Figure 18. - Solavolt International Systems compressor run-time performance.

The general validity of the assertion that the PV arrays have met R/F energy requirements is supported by the fact that there are only two documented instances of battery discharge brought on by array output deficit and which resulted in R/F shutdown. These were the Dominican Republic and Mali systems, and in both cases, discharge was brought on by apparent excessive use of the freezer.

## MEDICAL CLINIC SYSTEMS REFRIGERATOR/FREEZERS

Referring to table I, six Adler/Barbour R/F's were installed in larger clinic systems. These R/F's were identical to the field test R/F's except that they did not have any attached instrumentation. They all operate from 120-V dc systems through 120- to 12-V dc converters and each has two 6-V, 200 A-hr batteries connected in series to provide a 12-V dc buffer for the refrigerator compressor electronic module.

Information gained from NASA Lewis visits and correspondence indicates that all the R/F's are operating satisfactorily except that in Zimbabwe where an electronic control module was reported failed in late November 1984. There have been reports from Ikutha, Kenya of the fuse in the electronic control module blowing occasionally.

## OPERATIONAL RELIABILITY SUMMARY

There have been relatively few problems with these systems (excluding instrument failures, none of which affected systems operations). The minor problems that did develop, however, required a disproportionate effort to resolve because of the difficulty in achieving timely and effective communication with the in-country people responsible for or using the systems. Notices of problems with the systems were most often sent by telex, but frequently letters attached to the data or notes on the data sheets also commented on system operation. These notices of problems often reached NASA Lewis weeks after the actual occurrence and very frequently either did not contain enough information to make problem analysis possible and/or contained confusing or contradictory information. Sometimes problems, especially relating to how the system was being used, were discovered by the NASA Lewis staff in the course of data analyses. Due to the often sporadic receipts of data, problems thus discovered would have been in existence for quite some time. A follow-up telex or telephone inquiry was almost always required and often the response was inadequate. Thus problem resolution often took very long, or, as in the case of Indonesia, was completely frustrated.

The communications problems were multifold; e.g., people reporting or investigating the problems were often not familiar enough with the systems to obtain the correct information (most often they were not even technicians); the SPC manuals were not available until some time after installation thereby inhibiting understanding of the systems by users and others; the people reporting problems did not describe the problems clearly nor provide the correct and/or enough supporting information; and transportation to the installation site by locals for problem analysis or confirmation was often difficult and time consuming.

There were only five instances (Ecuador, Guyana, Ivory Coast, India, and Dominican Republic) where NASA Lewis or contractor personnel revisited an installation to correct problems and these only in conjunction with other travel to those countries.

Except for Guyana, NASA Lewis or contractor personnel were generally able to easily determine the nature of the problem and either fix the system or send replacement parts upon return to the U.S. The thermograph in Ecuador, which has a broken gear pivot and ratchet in the drive mechanism, was left inoperative due to a lack of repair funds.

Tables VII through XIII show critical system components or functions and list by site those which experienced problems with those components or functions. Attachments to the tables contain short notes describing the problems. The most striking feature of these tables is the overall paucity of problems. Referring to tables VII and XI, there have been virtually no problems with the PV modules. There have been no problems with array structures. There were only three instances of reported voltage regulator problems, but only one of these (Mali) has been confirmed by laboratory analysis of the reportedly failed regulator. The power cable problem is the tendency of the SPC twist-lock connector to come loose from the R/F socket. No batteries have failed although in some systems they have been discharged deeply, and sometimes often, as a result of other system problems as was the Guyana connector problem or over use (i.e., attempting to freeze more than 2 kg of water a day and/or doing so overnight). Instrumentation has been a major problem and is described in more detail below.

Referring to tables IX and XII, there has been a similar paucity of problems with the R/F's. There have been only three instances of electronic control module failure (two of which were during system checkout), no compressor problems, only one refrigerant loop problem, two condenser fan failures, one air door problem and two thermostat/alarm problems, one of which was a factory wiring error.

Tables VIII and XIII show that apparent user error is a problem, but not that big a problem overall, although the local effects can be serious if the batteries are discharged and vaccines are lost. These apparent user caused problems point out the need for ensuring that replacement users are trained and for additional training (reinforcement) for all users.

Table X shows the extent of the SPC systems instrumentation problems. Unfortunately, those instruments which would have provided the most useful data (the cumulative instruments) were the most failure prone. The SPC ampere-hour meter liquid crystal display failed in most high temperature and high humidity environments. There were also apparent failures of the meter printed circuit board. SPC attempted without success to qualify a replacement meter. The compressor run-time meters also experienced a relatively high failure rate, but, since no meters were ever returned to NASA Lewis, the failure modes are unknown. The Indonesian system voltmeters are noted as having failed on the basis of written communication from Indonesia, August 1983. Data received through August 1983, however, indicates that one meter may have experienced a corrosion problem. The other meter appears to have an open circuit.

The insolometer counters are powered by four mercury cells and have several design flaws which result in accelerated discharge of one of the cells. The problem was discovered after several insolometers had been installed. The manufacturer refused to effect a solution to the problem, so NASA Lewis modified the insolometer count rate which helped extend battery life, but which did not solve the basic problem. Adding to the problem were two other factors. First, the count rate increases when the one cell becomes discharged. Thus it is not always apparent from the data that a cell has discharged. Users were instructed to check cell voltages weekly to detect and replace discharged cells, but apparently rarely if ever, actually did so. Second, even though NASA Lewis checked all battery cells under load prior to shipment, tests at NASA Lewis showed battery cell lifetime to be very erratic. Regretably, most of the insolation data is suspect and of little or no use.

## USER REACTION TO SOLAR POWER CORP. SYSTEMS

In May 1984, NASA Lewis telexed all SPC installation sites indicating that the field test period was concluded and solicited information regarding the operational status of the system. The questions and replies are summarized in Table XIV. There it can be seen that of the 19 SPC systems, 12 systems are operating, three are not operating (spare parts have been sent to one and it should be operating by the time this report is published), there is no information on the status of three systems, and one system remained to be installed at that time.

Following the telex questionnaire, a detailed questionnaire drafted by NASA Lewis with inputs from the CDC, WHO and the Pan American Health Organization (PAHO) was sent to CDC, MOH, and AID personnel (as appropriate) at all SPC site countries. Appendix B is a sample of the questionnaire addressed to CDC or PAHO personnel. Slightly different versions were sent to AID and Ministries of Health. Of the 20 questionnaires mailed, only seven responses have been received as of this writing. A separate report will document the results of that questionnaire.

Miscellaneous comments that have been received via telexes, correspondence, and notes on data sheets have been generally favorable. Ecuador, for instance, reports that, because the system has operated with 100 percent reliability, they plan to make that health post (and R/F) a central storage facility for vaccines for that area. U.S./AID in Haiti indicates they are very satisfied with the system. Guatemala's Ministry of Health reports the system there is working well. U.S./AID in Zimbabwe reports that Ministry of Health officials there are satisfied with the system.

The only negative comment received was from Indonesia where it is said the Government health officials are not satisfied with results of the trial because the R/F systems are now nonfunctional because of problems with instrumentation and because costs remain too high. There were problems with the instrumentation in Indonesia as elsewhere, but these did not affect R/F operation. Several of the outages experienced with these systems were the result of the power cable connector coming loose.

TABLE VII. - SOLAR POWER CORP. PV POWER SYSTEMS

COMPONENT RELIABILITY SUMMARY

| Location | Modules | Array structure | Voltage regulator | Power cable | Batteries | Instruments |
|---|---|---|---|---|---|---|
| India | | | | | 5 | 6 |
| Indonesia | | | | | | |
| Cibung Bulang | | | 2 | | | 6 |
| Batujaya | | | | 4 | | 6 |
| Maldives | | | | | | 6 |
| Dominican Republic | | | | | | 6 |
| Haiti | | | | | | 6 |
| Columbia | | | | | | 6 |
| Ecuador | | | | | | 6 |
| Guyana | | | 3 | 4 | 5 | 6 |
| Peru | | | | | | 6 |
| Gambia | | | | | | |
| Gunjur | | | | | | 6 |
| Kaur | | | | | | 6 |
| Ivory Coast | | | | | | |
| Zaranou | 1 | | | | | 6 |
| Niofouin | | | | 4 | | 6 |
| Zaire | | | | | | 6 |
| Morocco | | | | | | 6 |
| Liberia[a] | | | | | | |
| Zimbabwe | | | | | | 6 |
| Guatemala | | | | | | 6 |

[a]Installed October 1984.

COMMENTS FOR TABLE VII

1. Apparent impact damage to glass cover; module serviceable and left in array. Each SPC PV array includes an installed spare, therefore, no replacement was necessary.

2. Voltage regulator reported defective in March 1983, and replaced with a spare by local personnel in May 1983. Local personnel attempted to "repair" defective regulator and in so doing destroyed whatever evidence there may have been to indicate what, if anything, had failed.

3. Voltage regulator reported defective, removed in March 1983, and taken to SPC for analysis. No defect found (see comments on Guyana from table III(a)).

4. During installation of the Haiti and Dominican Republic systems in September 1982, the NASA Lewis engineer noted that the twist-lock connector which is used to connect the PV array power cable to the R/F cabinet did not, in fact, lock when twisted to the "locked" position. Slight movement of the power cable (which lies on the floor) and/or the R/F (which is on casters, can loosen the connector enough to cause an open circuit between the PV array and the R/F cabinet, but not enough to cause the connector to come cut of the

socket on the R/F cabinet. Such open circuit could be intermittent depending on further movement of the cable and/or R/F, or long term if things are not moved or not moved in such a way as to close the circuit, (or if the loose connector is not noted and reconnected).

An outage resulting from a loose connector was first reported at the Batujaya, Indonesia installation where the R/F was out of operation from March 3, 1983, to May 17, 1983. The problem was reported as "This socket kept disconnecting. It has since been repaired." There was no mention of what the repairs were. The interpretation at NASA Lewis was that there had been a problem with that connector that was repairable and it never occurred to anyone that it was the same problem observed at Haiti and the Dominican Republic.

In December 1983, 3 months after installation, the Guyana R/F was reported out of operation. Data for the 3 months preceding shutdown showed several periods of 2 or more days of zero array current accompanied by modest increases in array ampere-hours. System voltage was always reported as 12.5 V. Thus, when the R/F stopped operating on December 21, 1982, on a day when array current was 5 A, but which had been preceded 3 or 6 days (a dataless weekend intervened) of zero array current but with increases in array ampere-hours, no one at NASA Lewis gave even a thought to the array power cable connector. Correspondence with AID/Guyana indicated that the operator had shut off both the PV array and R/F following automatic shutdown. There ensued considerable correspondence and a visit by an SPC engineer who replaced the voltage regulator thinking it might be defective (see note 3 above). The R/F operated for a short time afterwards and then resumed a period of one year of intermittent operation during which time there flowed from the SPC, NASA Lewis, and AID/Guyana a constant stream of telexes and letters directing diagnostic procedures and requesting specific data and information, and from Guyana, numerous requests for on-site assistance and R/F replacement. During this period the system operator persisted in shutting off the PV array when the R/F automatically shutdown despite repeated requests by NASA Lewis and SPC to leave the PV array turned on to charge the batteries. And, the local technician was convinced that the problem was associated with the high temperature alarm, compressor and thermostat. The loose PV array power cable connector was discovered by local personnel in March 1983 and the system has apparently operated satisfactorily since then.

In June 1984, during an inspection trip to the Niofouin Ivory Coast system, the same NASA Lewis engineer found the PV array power cable connector electrically disconnected, but physically in place.

The problem with the twist-lock connector is basically one of design selection. It was (and still is) a satisfactory approach to connecting the array to the R/F. The shortcomings were with component selection and qualification/acceptance testing.

This somewhat lengthly discussion of this seemingly minor problem belies the amount of grief it gave NASA Lewis and AID/Guyana. Obviously, if the PV array becomes disconnected from the R/F and batteries, the system quickly becomes useless and in the process risks loss of vaccines with subsequent health implications. But it also points out the difficulties which can be encountered when placing such equipment in rural settings, e.g. inadequate user and technician training which results in improper use and faulty diagnoses by locals, lack of training reinforcement, untrained replacement users, lack of manuals, and communications problems resulting in an inability to obtain specific technical information from the site even when questions are clearly spelled out. The problem with the equipment was simple and in retrospect we (NASA Lewis) probably should have been able to identify it since we had in fact encountered loose connectors in three previous instances. However, the engineer who noted loose connector in the Domincan Republic and Haiti was not the same one responsible for reviewing R/F problems when first reported.

5. Slightly corroded battery terminals with powdery covering. Terminals were cleaned and greased by local personnel.

6. See table X for details on instrument reliability.

TABLE VIII. - SOLAR POWER CORP. REFRIGERATOR/FREEZER RELIABILITY SUMMARY

| Location | Electronic control module | Compressor | Refrigerant loop | Condenser fan | Air door | Thermostat and alarm | Other |
|---|---|---|---|---|---|---|---|
| India | | | | | | | |
| Indonesia | | | | | | | |
| Cibung | | | | | | | |
| Bulang | 1 | | | | | | 9 |
| Batujaya | 2 | | | | | | 9 |
| Maldives | | | 6 | | | | 10 |
| Dominican Republic | | | | | | | |
| Haiti | | | | | | | |
| Columbia | | | | | | | |
| Ecuador | | | | | | 8 | |
| Guyana | 3 | | | | | | |
| Peru | | | | | | | |
| Gambia | | | | | | | |
| Gunjur | | | | | | | |
| Kaur | | | | | | | |
| Ivory Coast | | | | | | | |
| Zaranou | 4 | | | | | | |
| Niofouin | 5 | | | 7 | | | |
| Zaire | | | | | | | |
| Morocco | | | | | | | |
| Liberia[a] | | | | | | | |
| Zimbabwe | | | | | | | |
| Guatemala | | | | | | | |

[a]Installed October 1984.

COMMENTS FOR TABLE VIII

1. Fuse blown on three occasions which resulted in the R/F being out of operation for the following periods:

January 6 to January 26, 1983;
February 1 to February 5, 1983;
May 26 to August 4, 1983.

No cause was ever determined for this problem and the electronic control module was not replaced.

2. Installed new electronic control module during checkout.

3. Fuse found blown in February 1984; replaced by local personnel. No cause determined.

4. Fuse blew in electronic control module approximately June 6, 1983. Refrigerator/Freezer was shutdown for 2 days until MOH staff member arrived to diagnose problem and replace fuse.

5. Electronic control module failed sometime after July 1983. Local personnel to replace module with spare resupplied by NASA Lewis in July 1984. Available spare returned to NASA Lewis for checkout following site visit by NASA Lewis staff, February 1984 .

6. R/F received at site with low freon pressure in refrigerant loop. Refrigeration system recharged by local (Maldive Islands) refrigeration service 16 months after installation. Approximately 2 kg of Freon added and filter changed.

7. Condenser fan failed sometime after July 1983. Local personnel to replace failed fan with spare supplied by NASA Lewis following site visit by NASA Lewis staff, February 1984.

8. High refrigerator temperature alarm wired backwards at factory; alarm would sound when refrigerator compartment in temperature range and silent when too high. Alarm had been placed in OFF position to avoid its being a nuisance. Repaired during site visit by NASA Lewis engineer, September 1983.

9. R/F reported not operating on April 19, 1984; no reasons given.

10. Rusting of lower part of cabinet reported April 28, 1983.

TABLE IX. - SOLAR POWER CORP. PV-POWERED
REFRIGERATOR/FREEZER SYSTEMS
MISCELLANEOUS OPERATIONAL PROBLEMS

| Location | User erorr | Other |
|---|---|---|
| India | | |
| Indonesia | | |
| Cibung Bulang | | |
| Batujaya | | |
| Maldives | | |
| Dominican Republic | 1 | |
| Haiti | | |
| Columbia | | |
| Ecuador | | |
| Guyana | 2 | |
| Peru | | |
| Gambia | | |
| Gunjur | | |
| Kaur | | |
| Ivory Coast | | |
| Zaranou | | |
| Niofouin | 3 | |
| Zaire | 4 | |
| Morocco | | |
| Liberia[a] | | |
| Zimbabwe | | |
| Guatemala | | |

[a]Installed October 1984.

COMMENTS FOR TABLE IX

1. System out of operation January 5, 1984, to February 2, 1984, due to discharged batteries which resulted from excessive use of freezer at night. Personnel had been instructed to limit ice making to 2 kg/day and to load freezer in the morning.

2. Untrained operator shut off PV array preventing battery recharge when high refrigerator temperature alarm sounded. Apparent cause for high temperature alarm sounding was discharged batteries (note 4, table VII).

3. Replaced trained personnel with untrained personnel. Set freezer temperature to -23 °C.

4. Freezer compartment temperature control set for -20 °C resulting in excessive run-time and subsequent battery discharge. Instructed to raise temperature setting to -12 °C and adjust airdoor to achieve better control in refrigerator compartment which was at the same time too warm.

TABLE X. - SUMMARY OF SOLAR POWER CORP. SYSTEMS INSTRUMENTATION PROBLEMS

| Location | Instrument | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| India | | | | F | F | P | P | P(c) | NS |
| Indonesia | | | | | | | | | |
| Cibung Bulang | | F | (a) | F | F | F | P | P(c) | |
| Batujaya | | F | | F | F | P | P | P(c) | |
| Maldives | | | | F | F | P | P | P(d) | |
| Dominican Republic | | | | F | F | P | P | | |
| Haiti | | | | | | | P | | |
| Columbia | | | | F | F | P | P | | P |
| Ecuador | | | | | | | P | P(e) | |
| Guyana | | | | F | F | | P | | P |
| Guatemala | | | | | | | P | P(c)(e) | P(e) |
| Peru | | | | | | | | P | |
| Gambia | | | | | | | | | |
| Gunjur | | | | | | | P | | |
| Kaur | | | | F | F | F | | | |
| Ivory Coast | | | | | | | | | |
| Zaranou | | | | F | F | | | | |
| Niofouin | | | | | | | | P(d) | |
| Zimbabwe | | | | | | | P | P(e) | P(e) |
| Zaire | | | | F | F | | P | | |
| Morocco | | | | P | | | | | |
| Liberia[f] | | | | | | | | | |
| NASA Lewis | | | | (b) | | | | | |

Instrument:

1. Array ampere meter (instantaneous)
2. System voltage (instantaneous)
3. Load amperage (instantaneous)
4. Array ampere-hours (cumulative)
5. Load ampere-hours (cumulative)
6. Compressor runtime (cumulative)
7. Insolometer (cumulative)
8. Thermograph (refrigerator/freezer)
9. Thermograph (ambient)

Notes:

[a]This instrument was reported failed by Indonesian authorities but such failure is not substantiated by the available data.

[b]Back-up meter in use.

[c]Thermograph spring drive mechanism is easily overwound which results in the drive mechanism not operating. User personnel were instructed in how to unwind the mechanism enough to start the drive mechanism.

[d]Temperature channel(s) failure.

[e]Drive mechanism failure.

[f]Installed October 1984.

NS Not supplied

P Problem

F Failed

TABLE XI. - SOLAVOLT INTERNATIONAL PV POWER SYSTEMS
COMPONENT RELIABILITY SUMMARY

| Location | R/F mfgr. | Modules | Array structure | Voltage regulator | Power cable | Batteries | Instruments |
|---|---|---|---|---|---|---|---|
| Thailand | M | | | | | | 1 |
| Honduras[a] | M | | | | | | |
| St. Vincent | | | | | | | |
| New Sandy Bay[a] | M | | | | | | |
| Canouan[a] | PP | | | | | | |
| Mali | PP | | | 2 | | | 3 |
| Burkina Faso | PP | | | | | | |
| Tunisia | | | | | | | |
| Es Smirat[a] | PP | | | | | | 4,5 |
| Bir Amama[a] | M | | | | | | |
| Ivory Coast | | | | | | | |
| Menee[a] | PP | | | | | | 6 |
| Jordan | M | | | | | | 7 |

[a]No information or data received since installation.

COMMENTS FOR TABLE XI

1. The array ampere-hour meter failed approximately 2 weeks after installation. About 3 months after installation, the run-time meter also started acting erratically. A replacement instrument assembly was shipped April 13, 1984, and installed on May 8, 1984.

2. Local personnel replaced one or both voltage regulators June 1984. One regulator was returned to the manufacturer for failure analysis and repair. The logic chip had failed. In regard to the other regulator, we have been unable to receive either the failed regulator or confirmation of its failure.

3. Loose connection to ampere-hour meter rendered some data useless. Problem corrected by local technician.

4. The array ampere hour meter failed during checkout. A replacement instrument assembly was shipped in mid-March 1984 and reported installed in late July 1984.

5. Temperature recorder defective (it makes two revolutions per week instead of one) and will probably not be repaired due to lack of funds.

6. The freezer temperature thermostatic element in the temperature recorder failed in shipment and will probably not be replaced due to lack of funds.

7. The refrigerator temperature thermostatic element in the temperature recorder failed in shipment and will probably not be replaced due to lack of funds.

TABLE XII.- SOLAVOLT INTERNATIONAL REFRIGERATOR/FREEZER RELIABILITY SUMMARY

| Location | Electronic control module | Compressor | Refrigerant loop | Condenser fan | Air door | Thermostat and alarm | Other |
|---|---|---|---|---|---|---|---|
| Thailand | | | | | 3 | | |
| Honduras[a] | | | | 2 | | 4 | |
| St. Vincent[a] | | | | | | | |
| Canouan[a] | | | | | | | |
| Mali | 6 | | | 5 | | | |
| Burkina Faso | | | | | | | |
| Tunisia | | | | | | | |
| Es Smirat[a] | | | | | | | |
| Bir Amama[a] | | | | | | | |
| Ivory Coast[a] | | | | | | | |
| Menee | 1 | | | | | | |
| Jordan[a] | | | | | | | |

[a]No information or data received since installation.

COMMENTS FOR TABLE XII

1. The electronic control module failed during checkout in Abidjan and was replaced with an available spare.

2. Fan found to be drawing too much current during checkout. Replacement sent and installed prior to moving system to Guaimaca.

3. Air door reported unable to properly regulate refrigerator compartment temperature (maintained too cold a temperature). Replacement assembly shipped February 17, 1984, and reported installed on June 27, 1984.

4. Thermostat control transistor failed during checkout - replacement sent in February 1984. Replacement thermostat board was presumably installed prior to the system being installed in Guaimaca in October 1984.

5. Condenser fan reported "blocked" shortly after installation. Blockage removed by local technician.

6. Fuse holder contacts corroded. Fuse holder replaced.

TABLE XIII. - SOLAVOLT INTERNATIONAL PV-POWERED REFRIGERATOR/FREEZER SYSTEMS MISCELLANEOUS OPERATIONAL PROBLEMS

| Location | User Error | Other |
|---|---|---|
| Thailand | | 1 |
| Honduras[a] | | |
| St. Vincent[a] | | |
| Canouan[a] | | |
| Mali | 2 | |
| Burkina Faso | | 3 |
| Tunisia | | |
| Es Smirat[a] | | |
| Bir Amama[a] | | |
| Ivory Coast | | |
| Menee[a] | | |
| Jordan | | |

[a]No information or data received since installation.

COMMENTS FOR TABLE XIII

1. For several weeks following installation and several times thereafter, user personnel apparently shut off the R/F over the weekend. No reason was ever given for that action and they were encouraged to leave the R/F turned on continuously.

2. Apparent excessive loading of freezer compartment late in the day causing battery discharge and high refrigerator compartment temperatures.

3. The system stopped operating sometime after a severe storm. The technician cleaned the array and within 15 minutes, the system restarted and has operated satisfactorily since. We speculate that the storm blew leaves and other debris onto the array, covering at least some cells of every array string resulting in essentially complete loss of array output and discharge of the batteries.

TABLE XIV. - QUESTIONS AND RESULTS OF TELEX QUESTIONNAIRE TO SOLAR POWER CORP. SYSTEM SITES

| Location | Is R/F operating | If "no" when and why did it stop | Is data still being recorded | Are vaccines routinely stored | If "no" why not | Comments |
|---|---|---|---|---|---|---|
| India | Yes | | Yes | Yes | | |
| Indonesia | | | | | | |
| Cibung Bulang | No | | No | No | | |
| Batujaya | No | | No | No | | |
| Maldives | Yes | | | | | 1 |
| Dominican | | | | | | |
| Republic | Yes | | Yes | Yes | | |
| Haiti | Yes | | No | Yes | | |
| Columbia | Yes | | Yes | | | 2 |
| Ecuador | Yes | | Yes | Yes | | 3 |
| Guyana | Yes | | Yes | | | |
| Peru[a] | | | | | | |
| Gambia | | | | | | |
| Gunjur[b] | | | | | | |
| Kaur[b] | | | | | | |
| Ivory Coast | | | | | | |
| Zaranou | Yes | | | | | 4 |
| Niofouin | No | 5 | No | No | | 4 |
| Zaire | Yes | | Yes | Yes | | |
| Morocco | Yes | | | | | 6 |
| Liberia[c] | | | | | | |
| Zimbabwe | Yes | | Yes | Yes | | |
| Guatemala | Yes | | Yes | Yes | | |

[a]AID attempting to get information
[b]No response.
[c]Not installed at time of questionnaire.

COMMENTS FOR TABLE XIV

1. Information based on last data (May 5, 1984).

2. On basis of most recent data.

3. Because of high reliability plan to make central vaccine for area.

4. Information per NASA Lewis visit.

5. Electronic control module failure.

6. R/F operation based on April 30, 1984, data.

## RECOMMENDATIONS

The following recommendations regarding PV powered R/F systems, components, installation procedures, documentation and training are offered based on the experiences and observations of NASA Lewis, SPC, and SVI engineers involved in this project. These recommendations do not necessarily reflect deficiencies in the designs of any of the systems used in these field tests nor in the installation procedures, documentation or training. Rather they are intended to suggest system or procedural improvements which will enhance the reliability and acceptability of such systems.

(1) Package the R/F and other system components to be carried by no more than four men; i.e., no container should be heavier or larger than can be easily lifted and carried by four men.

(2) Make absolutely sure that all required spare parts and components are shipped with the system including extras of easily lost items (bolts, nuts, screws, etc.).

(3) Label battery boxes with handling instructions in the local language and also package the batteries in such a way as to avoid their being tipped (since many dock workers cannot or do not read).

(4) Consider using locally procured batteries or cells which are suitable for use with photovoltaic systems, i.e., batteries or cells with lead-calcium grids for minimum self-discharge and hydrogen generation.

(5) Develop a PV array structure design which easily allows the array to be roof or ground mounted and provide all of the parts for either mounting scheme with each system. Label all parts and provide an easily understood array structure assembly diagram for roof and ground mounting.

(6) Provide a junction box on the PV array structure which receives the PV array wiring harness and the PV array power cable to the R/F. Prewire the PV array wiring harness into the junction box.

(7) Bring the array power cable to a junction box in the health services building which can be permanently mounted on a wall near the R/F and then use a short flexible power cord with a positive lock connector to connect the R/F to the junction box.

(8) The refrigerator/freezer should be designed to pass through a "standard" size door (not necessarily U.S. standard) without major disassembly of the door or the refrigerator/freezer.

(9) Design the battery compartment so that (a) the R/F can accept a variety of sizes and types of batteries or individual battery cells, and (b) so that the batteries or cells can be easily accessed for voltage measurements and servicing; e.g. locate the batteries on a cart on wheels which can be rolled under the R/F and locked in place so that the cart can be moved with the R/F.

(10) Design the equipment enclosure in the base of the R/F so that the voltage regulator(s) and the R/F compressor electronic control module(s) are easily accessible for servicing, troubleshooting, or replacement.

(11) For production systems (as opposed to these field test systems) provide only a voltmeter and compressor run-time meter as instrumentation. We (and others) have given the subject of instrumentation a good deal of thought. Some say no instruments. Everyone agrees the amount of instrumentation supplied with these systems is only justified for field test systems. At issue is the middle ground. As a result of supporting the operation of these systems and field test data, we have concluded that a voltmeter and run-time meter are sufficient and desirable for the following reasons:

The voltmeter will tell a trained user at a glance the general status of his power system and allow him/her to effect a modest amount of energy management during periods of low insolation. It can also confirm compressor automatic disconnect and indicate the rate of recharge and, therefore, approximate time to reconnect. Note, though, that this information will be apparent to the trained user, and, based on our experience, such training is of greater depth than can be given at the health post during installation. Hence the need for a training facility (see last recommendation).

A run-time meter can likewise be used to manage the system. More importantly, it is an important and relatively inexpensive diagnostic instrument and can be used by a trained user and/or a technician to detect overuse or other system problems; e.g. low Freon level (high run time and warming temperatures); no runtime at night (automatic disconnect and a problem with the auto-disconnect/reconnect alarm light circuit); using runtime and manufacturers R/F current data, calculated energy consumption compared with approximate battery state-of-charge can indicate adequacy of the array size, etc.

(12) Provide a low power light which indicates when the compressor has been automatically disconnected due to low system voltage and equip the light with an interlock which keeps the light illuminated until the interlock has been manually reset. This feature would alert the user to a problem if the compressor should be automatically disconnected during nonworking hours (nights or weekends) and then automatically reconnected when the PV array charges the batteries to their operating voltage during the day.

(13) Operate all controls, alarms, etc. from system 12-V dc power rather than from separate dry cells.

(14) Provide stacking baskets in the refrigerator compartment for storing vaccine vials.

(15) Provide holders or some other mechanism for holding cold packs against the evaporator plate to accelerate freezing. This is especially necessary in R/F's using eutectic cold plates.

(16) Provide with each system complete user and troubleshooting and repair manual(s) in the local language. These manuals should contain a complete and easy to understand description of how the system operates, its controls and its alarms, easily understood troubleshooting and repair instructions, a complete system wiring diagram, and a major components parts list with parts, numbers, and otherwise complete reordering information.

(17) Installation team should carry sufficient tools, spare parts, and instruments to install the system and perform diagnosis and repair should the system have been damaged in transit.

(18) Personnel (technicians) to be trained and who will have responsibility for maintaining and troubleshooting the system should already have a basic understanding of electricity, batteries, refrigeration, etc. so that the system training can be absorbed and not result in a "snow job".

(19) Health post administration must make users and technicians available for training either at a central facility or without interruption at the health post during installation.

(20) Training materials: Even if only one system is installed in a country, the manufacturer should provide training materials with the system; e.g. an instructors guide to the user and troubleshooting and repair manuals. These training materials are needed by the organization administering the vaccine refrigerator program to train additional and/or replacement personnel and to conduct reinforcement training.

(21) Establish a PV Powered R/F Training Facility: For countries or organizations embarking on large scale PV powered vaccine R/F programs, a complete system should be installed in a central location and used to conduct initial and reinforcement training for users and technicians. The instructors at that facility should receive extensive training by the system manufacturer and possibly even visit the manufacturing facilities to gain a complete and thorough familiarity with the system and its components.

## CONCLUDING REMARKS

The photovoltaic powered vaccine refrigerator/freezer systems field test results indicate a high level of systems reliability. Since October 1981 and through July 1984, all reporting systems sites have accumulated 488 system-months of operation and have been in service 83.6 percent of the time. On the basis of available data, the field test systems refrigerator compartments have been within the World Health Organization recommended temperature range of 0 to 8 °C, 80 percent of the time with known operator induced causes contributing to a portion of the out-of-range time. There have been no photovoltaic module or refrigerator compressor failures and there have been only a very few other component failures. The most significant problem identified during this field test project is the need for adequate initial training for both users and technicians, the need for reinforcement training, and the need to train replacement user personnel and technicians.

National Aeronautics and
Space Administration

**Lewis Research Center**
Cleveland, Ohio
44135

NASA

APPENDIX A

SAMPLE REPORT

Reply to Attn of DOE/CDC/AID MEDICAL REFRIGERATOR PROJECT

Site: Comuna Cobos, Ecuador

Date of report: 25 May 83

Address Label

Period: 28 Sept 82 to 5 Mar 83

SUBJECT: Photovoltaic Powered Medical Refrigerator/Freezer System Data Report

## SUMMARY

The Solar Power/Adler-Barbour system was installed 16 September 1982 and has operated satisfactorily except that there appear to be problems with several of the instruments. There were significant problems with the data received, however, in that data and the times at which data was recorded were not recorded on data sheets. Copies of four data sheets illustrating the problems are being returned for information and so that these problems can be corrected on future data sheets.

## 1.0 Comments on Data Received

1.1 Data for the period 28 September 1982 to 3 January 1983 has been entered into the NASA computer and processed. Data for the period 23 September 82 and 24 September 82 and 11 January 83 to 5 March 83 was received 11 April 83 and has not yet been processed.

1.2 There are significant number of gaps or blank spaces on the data sheets. These are shown as #'s in Table 2. Several of the temperature readings are also missing the minus (-) sign on the data sheets. Data sheets for the period 30 November 82 to 3 January generally do not include the time of day.

1.3 The voltage readings recorded show a possible need for more precision. Explanations on how to interpolate the voltage reading and how to read the thermographs are attached.

## 2.0 Problems/Failures Reported and/or Observed

2.1 Some electric cables were reported damaged by mules during the period 8 to 18 October. The extent of damage and/or any repair actions has not been reported. Project funds are not available for construction of fences.

2.2 Ampere-hour meter data for both the PV array and the load and compressor run-time meter data indicate that all three meters are malfunctioning on an intermittent basis. Data indicating the malfunctions are noted in Table 2.

2.3 The insolometer data suggests there may be dirt on the insolometer sensor (see section 4.4).

3.0 Comments on System Performance

3.1 The system appears to have operated satisfactorily during the period from September 1982 through December 1982. There are, however, either instrument malfunctions or data recording errors (or both) which are complicating data analysis (see sections 2.2, 4.2, 4.3, 5.2).

4.0 Recommendations and Requests

4.1 Please provide a description of the extent of damage to electrical cables.

4.2 All of the data should be recorded on the data sheets. If a meter stops working or operates erratically, please note that on the report form and submit a problem/failure report.

4.3 The time at which a reading is taken is a critical element of data because the time interval between readings is used in several calculations. Please insure that times the readings are taken are accurately entered on future data sheets.

4.4 Insolometer data indicates that there may be dirt or bird droppings on the insolometer sensor. Please inspect the sensor and clean it if necessary and note on the data sheet the date it is cleaned. If it is not dirty, please also note that on the data sheet.

4.5 The attached explanations on reading the thermographs and the voltmeter should be used as a guide to obtain more precise readings.

4.6 Four marked-up data sheets showing typical examples of situations creating problems for data processing are being returned for your information and action.

4.7 Please insure that the ampere-hour meters are not being reset.

5.0 General Comments/Information

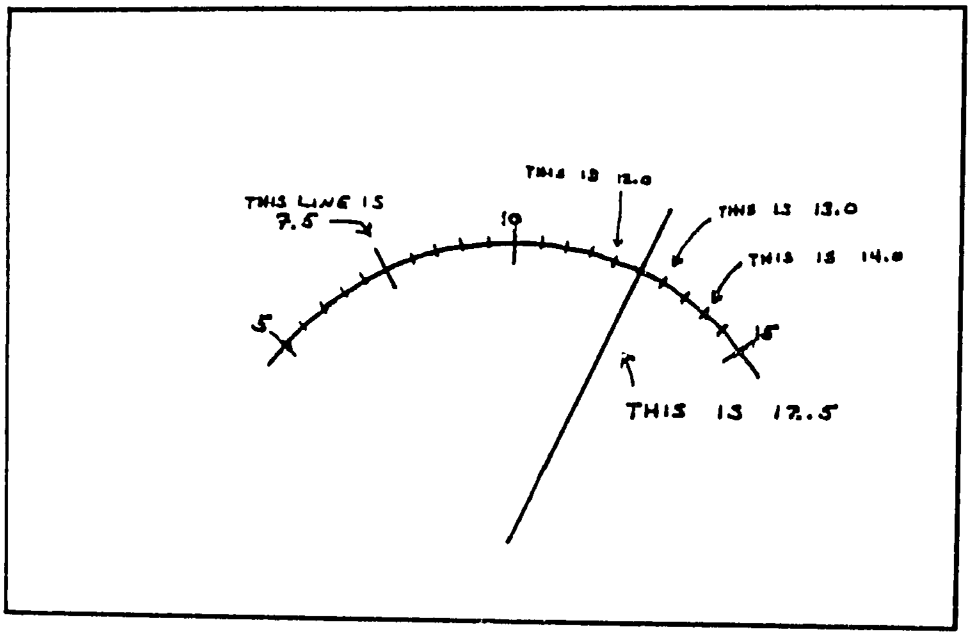
5.1 Due to administrative workload involved in processing and reporting data, data Summaries (Table 1) will be distributed only to sites to which they pertain.

5.2 Several different sites having similar photovoltaic-powered refrigerator/freezer systems are also beginning to report erratic ampere-hour meter and compressor run-time data. We are working with Solar Power Corp. to correct the problem. In the meantime, please instruct operating personnel to take data carefully so that we can accurately assess the nature of the problem.

6.0 Data Package*

1. Voltmeter explanation
2. Thermograph explanation
3. Table 1, Data Summary
4. Table 2, Data Listing
5. Figures 1, Insolation, from October, November, December 1982
   2, Array Output, from October, November, December 1982
   3, Load Consumption, from October, November, December 1982
   4, Compressor Run-time, from October, November, December 1982
   5, Compressor Operating Current, from October, November, December 1982
   6, Estimated Battery State-of-Charge, from October, November, December 1982
   7, System Voltage, from October, November, December 1982
6. Thermographs, week ending October 5, 12, 19, 26
   November 2, 9, 16, 23, 30
   December 7, 14, 21
   January 3, 11, 18, 25
   February 1, 8, 16, 22, 28
   March 7

*Data from October 1982, only.




ESTIMATE THE READING WHEN THE NEEDLE IS
BETWEEN LINES

FOR EXAMPLE:

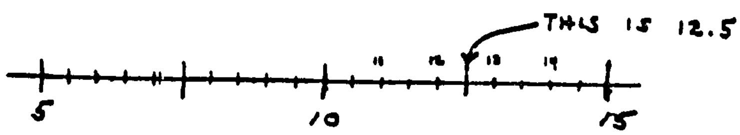
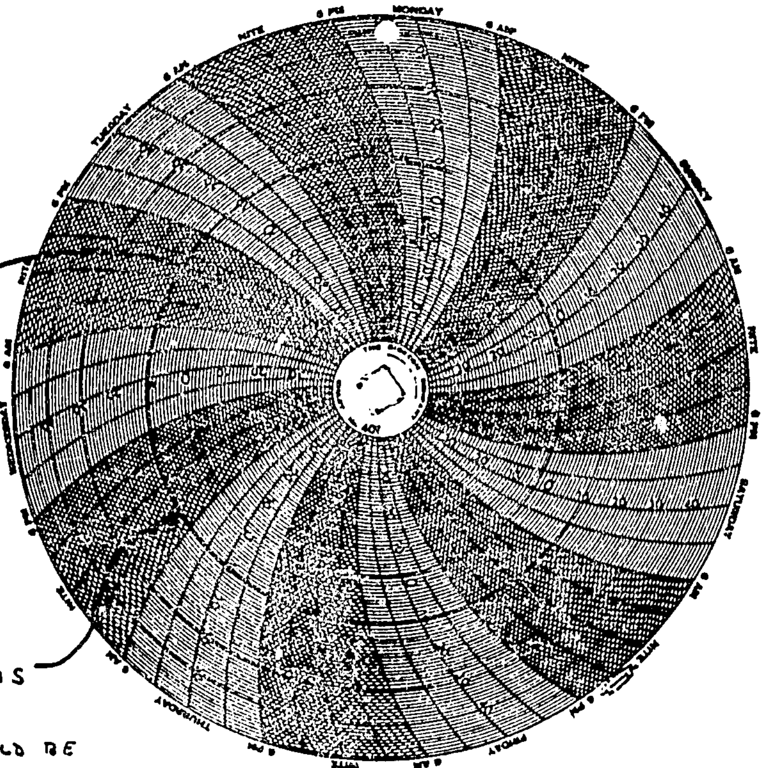



Figure A-1. - Voltmeter explanation.

THIS CIRCLE IS −3°C

THE RED PEN SHOULD BE THE FREEZER TEMPERATURE.



THIS CIRCLE IS +10°C

THE BLUE PEN SHOULD BE THE REFRIGERATOR TEMPERATURE.

TEMPERATURES GET COLDER TOWARD THE CENTER OF THE CHART

FOR EXAMPLE:

CENTER

TIME/DAY

−40. −30. −20. −10. 0 +10. +20. +30. +40. +50.

Figure A-2. - Refrigerator/freezer thermograph explanation.

## TABLE A-I. - PHOTOVOLTAIC POWERED MEDICAL REFRIGERATOR DATA SUMMARY (COMUNA COBOS, ECUADOR)

| | | 1982 Sep* | 1982 Oct. | 1982 Nov. | 1982 Dec. | 1983 Jan. | 1983 Feb. |
|---|---|---|---|---|---|---|---|
| TEMPERATURES (Centigrade)[c] | | | | | | | |
| Refrigerator: | Maximum | +3 | +12 | +7 | +9 | +5 | +6 |
| | Minimum | +3 | +3 | +6 | +2 | +3 | +3 |
| | % Days thermograph charts used | 100 | 100 | 93 | 100 | 100 | 96 |
| Freezer: | Maximum | -12 | -8 | -12 | -9 | -11 | -10 |
| | Minimum | -13 | -20 | -14 | -15 | -12 | -11 |
| | % Days thermograph charts used | 100 | 100 | 93 | 100 | 100 | 96 |
| Ambient: | Maximum | +21 | +24 | +23 | +22 | +24 | +23 |
| | Minimum | +16 | +11 | +13 | +14 | +12 | +13 |
| | % Days thermograph charts used | 100 | 81 | 83 | 90 | 100 | 82 |
| COMPRESSOR RUNTIME | | | | | | | |
| % Runtime | | 22.6 | 22.5 | 22.2 | R | NP | NP |
| % Possible data points available[b] | | 13 | 69 | 70 | 82 | | |
| LOAD CONSUMPTION | | | | | | | |
| Watt-hours per day[d] | | 272 | 276 | 269.3 | R | NP | NP |
| % Possible data points available[b] | | 13 | 71 | 68 | 82 | | |
| COMPRESSOR OPERATING CURRENT | | | | | | | |
| Amperes | | 3.9 | 3.8 | 4.1 | 4.1 | NP | NP |
| INSOLATION | | | | | | | |
| Langleys per day | | 477.7 | R | 264.1[a] | 332.8[a] | NP | NP |
| % Possible data points available[b] | | 13 | R | 42 | 63 | | |
| ARRAY OUTPUT | | | | | | | |
| Watt-hours per day[d] | | 1013 | 849 | R | 761.7 | NP | NP |
| % Possible data points available[b] | | 13 | 79 | 92 | 85 | | |
| SYSTEM VOLTAGE | | | | | | | |
| Average of readings (volts) | | 13.3 | 13.2 | 13.2 | 12.9 | NP | NP |
| % Possible data points available[b] | | 13 | 83.9 | 95 | 82.2 | | |
| ESTIMATED BATTERY STATE-OF-CHARGE | | | | | | | |
| % Maximum | | 100 | 100 | 100 | 100 | NP | NP |
| % Minimum | | 100 | 100 | 96.7 | R | | |

a - Indication of probable instrument failure
b - Percent possible data points available = [(number of data points available) divided by (number of days per month x2)] x 100
c - Temperatures from readings and/or thermograph charts
d - Assumes constant voltage of 13 volts
* - Partial month (system start-up)
NP - Data not processed
R - Data error(s) - data requires reprocessing

NASA LeRC 25 May 1983

TABLE A-II. - MEDICAL REFRIGERATOR/FREEZER PROCESSED DATA

(COMUNA COBOS, ECUADOR)

NASA LERC 2 MARCH 1983

| YEAR | MONTH | DAY | TIME | | ARRAY CURRENT | SYSTEM VOLTAGE | LOAD CURRENT | ARRAY AMP HOUR | LOAD AMP HOUR | COMPRESSOR RUN TIME | REFRIGERATOR TEMPERATURE | FREEZER TEMPERATURE | AMBIENT TEMPERATURE | INSOLOMETER COUNT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1982 | 9 | 23 | 10 | 13 | 7.5 | 12.5 | 4.9 | 19.6 | 3.3 | 9.8 | 13 | -5 | 17 | 5 |
| 1983 | 9 | 24 | 12 | 0 | 7.5 | 14.0 | 0.0 | 86.6 | 30.1 | 16.7 | 3 | -12 | 18 | 61 |
| 1982 | 9 | 28 | 12 | 0 | # | # | # | # | # | # | 3 | -12C | 16 | # |
| 1982 | 9 | 28 | 16 | 0 | # | # | # | # | # | # | 3 | -12C | 16 | # |
| 1982 | 9 | 29 | 12 | 0 | # | # | # | # | # | # | 3 | -12C | 17 | # |
| 1982 | 9 | 29 | 16 | 0 | # | # | # | # | # | # | 3 | -12C | 17 | # |
| 1982 | 9 | 30 | 12 | 0 | # | # | # | # | # | # | 3 | -12C | 21 | # |
| 1982 | 9 | 30 | 16 | 0 | # | # | # | # | # | # | 3 | -12C | 21 | # |
| 1982 | 10 | 1 | 12 | 0 | # | # | # | # | # | # | 3 | -13C | 17 | # |
| 1982 | 10 | 1 | 16 | 0 | # | # | # | # | # | # | 3 | -13C | 15 | # |
| 1982 | 10 | 2 | 12 | 0 | # | # | # | # | # | # | 3 | -13C | 19 | # |
| 1982 | 10 | 2 | 16 | 0 | # | # | # | # | # | # | 3 | -13C | 19 | # |
| 1982 | 10 | 3 | 12 | 0 | # | # | # | # | # | # | 3 | -13C | 11 | # |
| 1982 | 10 | 3 | 16 | 0 | # | # | # | # | # | # | 3 | -13C | 11 | # |
| 1982 | 10 | 4 | 12 | 0 | # | # | # | # | # | # | 3 | -13C | 11 | # |
| 1982 | 10 | 4 | 16 | 0 | # | # | # | # | # | # | 3 | -13C | 11 | # |
| 1982 | 10 | 5 | 12 | 0 | 11.0 | 13.5 | 0.0 | 810.8 | 229.6 | 67.4 | 5 | -12 | 21 | 637 |
| 1982 | 10 | 5 | 16 | 30 | 2.0 | 14.5 | 0.0 | 855.5 | 233.5 | 68.4 | 4 | -13 | 23 | 669 |
| 1982 | 10 | 7 | 12 | 0 | 16.0 | 13.0 | 0.0 | 988.6 | 270.8 | 78.0 | 3 | -13 | 21 | 772 |
| 1982 | 10 | 7 | 16 | 20 | 0.0 | 12.5 | 5.0 | 10.8 | 275.2 | 79.2 | 3 | -13 | 18 | 788 |
| 1982 | 10 | 8 | 12 | 0 | 16.0 | 13.0 | 0.0 | 49.2 | 292.8 | 83.7 | 3 | -13 | 20 | 817 |
| 1982 | 10 | 8 | 16 | 15 | 0.0 | 12.5 | 5.0 | 73.9 | 297.9 | 85.1 | 3 | -12 | # | 836 |
| 1982 | 10 | 9 | 12 | 0 | 16.0 | 14.5 | 0.0 | 84.2C | # | # | 3 | -13 | # | 876 |
| 1982 | 10 | 9 | 16 | 0 | 4.0 | 13.0 | 0.0 | 134.5 | 318.6 | 90.4 | 3 | -14 | # | ∂ |
| 1982 | 10 | 10 | 12 | 0 | 10.0 | 13.0 | 5.0 | 157.3 | 336.4 | 94.9 | 3 | -14 | # | 902 |
| 1982 | 10 | 10 | 16 | 0 | 2.0 | 14.0 | 0.0 | 181.0 | 339.7 | 95.7 | 3 | -14 | # | 920 |
| 1982 | 10 | 11 | 12 | 0 | 10.0 | 14.0 | # | 201.1 | 356.8 | 100.0 | 3 | -13 | # | 936 |
| 1982 | 10 | 11 | 16 | 0 | 6.0 | 15.0 | 0.0 | 229.9 | 359.9 | # | 3 | -14 | # | 958 |
| 1982 | 10 | 12 | 12 | 0 | 14.0 | 13.0 | 0.0 | 265.5 | 376.7 | 105.1 | 3 | -12 | # | 936 |
| 1982 | 10 | 12 | 16 | 0 | 3.0 | 14.0 | 0.0 | 298.5 | 380.6 | 106.1 | 3 | -12 | # | 1011 |
| 1982 | 10 | 13 | 12 | 0 | 16.0 | 13.0 | 0.0 | 352.4 | 398.1 | 110.6 | 3 | -13 | # | 1051 |
| 1982 | 10 | 13 | 16 | 19 | 2.5 | 14.5 | 0.0 | 393.8 | 401.9 | 111.5 | 3 | -13 | 21 | 1084 |
| 1982 | 10 | 14 | 12 | 0 | 7.6 | 13.5 | 5.2 | 423.7 | 419.8 | 115.9 | 3 | -13 | 19 | 1108 |
| 1982 | 10 | 14 | 16 | 0 | 3.0 | 12.5 | 0.0 | 461.6 | 436.7 | 117.0 | 3 | -12 | # | 1135 |
| 1982 | 10 | 15 | 12 | 0 | 10.0 | 14.0 | 5.3 | 482.2 | 442.0 | 121.4 | 3 | -13C | # | 1153 |
| 1982 | 10 | 15 | 16 | 15 | 5.0 | 13.0 | 0.0 | 512.9 | 446.0 | 122.4 | 3 | -13C | # | 1177 |
| 1982 | 10 | 16 | 12 | 0 | 9.0 | 13.0 | 0.0 | 555.3 | 463.7 | 127.0 | 3 | -13C | 18 | 1209 |
| 1982 | 10 | 16 | 16 | 5 | 3.0 | 13.0 | 0.0 | 581.0 | 466.9 | 127.0 | # | -13 | # | 1228 |

READING ERROR CODES:
* INSTRUMENT FAILURE/MALFUNCTION
# MISSING READING
$ MISTAKE IN READING, NOT CORRECTABLE
? READING NOT LEGIBLE
∂ READING SUSPECT, DATA POINT DISCARDED
C READING CORRECTED WITH ASSUMED VALUE

Table A-II - Continued

NASA LERC 2 MARCH 1983

| YEAR | MONTH | DAY | TIME | ARRAY CURRENT | SYSTEM VOLTAGE | LOAD CURRENT | ARRAY AMP HOUR | LOAD AMP HOUR | COMPRESSOR RUN TIME | REFRIGERATOR TEMPERATURE | FREEZER TEMPERATURE | AMBIENT | INSOLOMETER COUNT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1982 | 10 | 17 | 12 0 | 7.0 | 14.0 | 0.0 | 602.7 | 483.9 | # | # | -13 | # | 1246 |
| 1982 | 10 | 17 | 16C 0C | 4.0 | 13.0 | 0.0 | 619.0 | 487.3 | 133.0 | # | -13 | # | 1259 |
| 1982 | 10 | 18 | 12 0 | 10.0 | 12.5 | 0.0 | # | # | # | # | -13 | # | ∂ |
| 1982 | 10 | 18 | 16C 0C | 3.0 | 14.0 | 0.0 | 677.7 | 506.6 | 138.0 | # | -12 | # | ∂ |
| 1982 | 10 | 19 | 12 0 | 6.5 | 13.0 | 5.8 | 704.9 | 522.6 | 142.2 | 8 | -17C | 18 | 1328 |
| 1982 | 10 | 19 | 16 0 | 2.5 | 12.5 | 0.0 | 729.7 | 525.6 | 143.0 | 8 | -18C | 19 | 1347 |
| 1982 | 10 | 20 | 12 0 | 15.0 | 13.0 | 0.0 | 790.6 | 543.3 | 147.5 | 8 | -18C | 19 | 1393 |
| 1982 | 10 | 20 | 16 15 | 3.0 | 12.5 | a 3.0 | 802.9 | 546.4 | 149.0 | 8 | -18C | 19 | 1402 |
| 1982 | 10 | 21 | 12 0 | 7.5 | 13.5 | 0.0 | 858.5 | 561.8 | 153.2 | 8 | -18C | 20 | 1442 |
| 1982 | 10 | 21 | 16 14 | 2.5 | 12.5 | 5.6 | 873.8 | 564.5 | 155.0 | 8 | -18C | 16 | 1465 |
| 1982 | 10 | 22 | 12 0 | 10.0 | 13.0 | 0.0 | 911.3 | 587.1 | 158.2 | 9 | -18C | 19 | 1487 |
| 1982 | 10 | 22 | 16C 0C | 3.0 | 13.5 | 4.0 | 935.6 | 590.4 | 159.0 | 8 | -19C | 19 | 1505 |
| 1982 | 10 | 23 | 12 0 | 3.0 | 12.5 | a 3.0 | 937.4 | 624.4 | # | 8 | -19C | 19 | 1534 |
| 1982 | 10 | 23 | 16C 0C | 4.0 | 13.0 | 0.0 | 1.0 | # | 164.0 | 9 | -18C | 18 | 1545 |
| 1982 | 10 | 24 | 12 0 | 3.0 | 13.5 | 4.6 | 19.2 | # | # | 8 | -19C | 19 | ∂ |
| 1982 | 10 | 24 | 16C 0C | 2.5 | 12.0 | a 3.0 | # | # | # | 8 | -19C | 16 | 1568 |
| 1982 | 10 | 25 | 12 0 | 13.0 | 14.0 | 0.0 | 64.1 | # | 174.0 | 9 | -19C | 18 | 1609 |
| 1982 | 10 | 25 | 16C 0C | 0.0 | 12.0 | # | 88.1 | 653.0 | 174.8 | 8 | -19C | 18 | 1619 |
| 1982 | 10 | 26 | 12 0 | 18.0 | 13.0 | 0.0 | 131.9 | 669.8 | 179.1 | 7 | -21C | 18 | 1652 |
| 1982 | 10 | 26 | 16 10 | 2.0 | 12.5 | 5.0 | 147.0 | 675.3 | 180.4 | 7 | -22C | 18 | 1663 |
| 1982 | 10 | 27 | 12 0 | 16.5 | 13.0 | 0.0 | 184.1 | 693.0 | 184.9 | 8 | -18C | 17 | 1691 |
| 1982 | 10 | 27 | 16 0 | 3.0 | 13.0 | 0.0 | 224.1 | 700.7 | 186.6 | -1 | -8C | 20 | 1720 |
| 1982 | 10 | 28 | 12 0 | 9.0 | 13.0 | 0.0 | 256.1 | 718.7 | 191.2 | 6 | -8 | 17 | 1745 |
| 1982 | 10 | 28 | 16 0 | 2.5 | 12.5 | 5.0 | 276.2 | 722.3 | 192.1 | 6 | -12 | 18 | 1760 |
| 1982 | 10 | 29 | 12 0 | 10.0 | 13.0 | 0.0 | 309.5 | 738.7 | 196.3 | 6 | -13 | 19 | 1786 |
| 1982 | 10 | 29 | 16C 0C | 1.0 | 12.5 | 5.0 | 343.7 | 744.4 | 197.7 | 6 | -13C | 20 | 1810 |
| 1982 | 10 | 30 | 12 0 | 17.0 | 13.0 | 0.0 | 391.4 | 762.4 | 202.2 | 6 | -13C | 21 | 1847 |
| 1982 | 10 | 30 | 16C 0C | 4.0 | 14.0 | 0.0 | 439.9 | 766.3 | # | 6 | -13C | 19 | 1865 |
| 1982 | 10 | 31 | 12 0 | 0.0 | 13.0 | 5.0 | # | # | # | 6 | -13 | # | * |
| 1982 | 10 | 31 | 16C 0C | 4.0 | 14.0 | 0.0 | 498.6 | # | 208.4 | 6 | -12 | # | * |
| 1982 | 11 | 1 | 12 0 | 7.0 | 14.0 | 0.0 | 523.5 | 804.0 | 212.9 | 6 | -12 | # | * |
| 1982 | 11 | 1 | 16C 0C | 4.0 | 14.0 | 0.0 | 547.0 | 807.4 | # | 6 | -12 | # | * |
| 1982 | 11 | 2 | 12 0 | 18.0 | 13.0 | a 3.0 | 593.4 | 824.3 | 218.7 | # | -13C | # | * |
| 1982 | 11 | 2 | 16C 0C | 1.0 | 13.0 | 0.0 | 612.8 | 827.0 | 219.0 | # | -13C | # | * |
| 1982 | 11 | 3 | 12 0 | 0.0 | 13.0 | 0.0 | 647.3 | 845.2 | 223.9 | # | -13 | # | * |
| 1982 | 11 | 3 | 16C 0C | 12.0 | 13.0 | 0.0 | 659.2 | 848.0 | 224.0 | # | -13 | # | * |
| 1982 | 11 | 4 | 12 0 | 8.5 | 13.5 | 5.4 | 704.8 | 862.5 | 227.8 | 6 | -13 | 20 | * |
| 1982 | 11 | 4 | 16 15 | 3.0 | 13.5 | 0.0 | 730.8 | 866.2 | 228.0 | 6 | -14C | 21 | * |

READING ERROR CODES:
- * INSTRUMENT FAILURE/MALFUNCTION
- # MISSING READING
- $ MISTAKE IN READING, NOT CORRECTABLE
- ? READING NOT LEGIBLE
- ∂ READING SUSPECT, DATA POINT DISCARDED
- C READING CORRECTED WITH ASSUMED VALUE

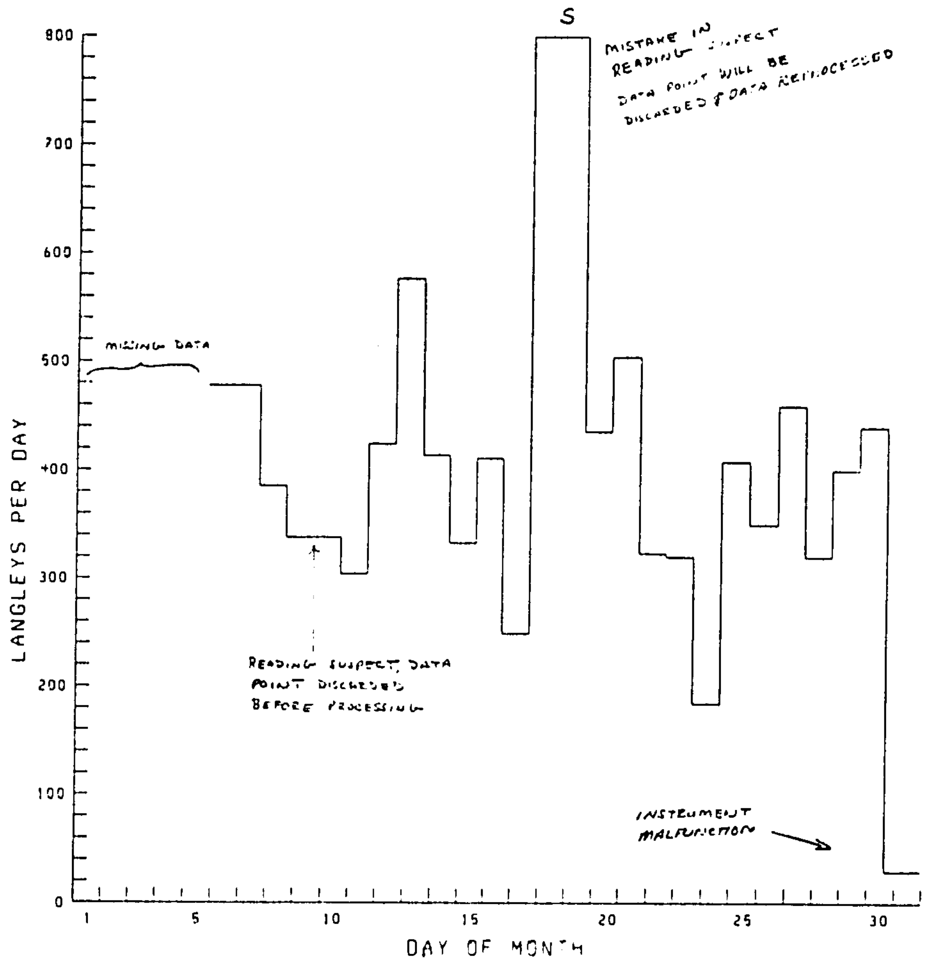



Figure A-3. - Isolation from October 1982, Comuna Cobos, Ecuador. (S, indicates suspect data point.)

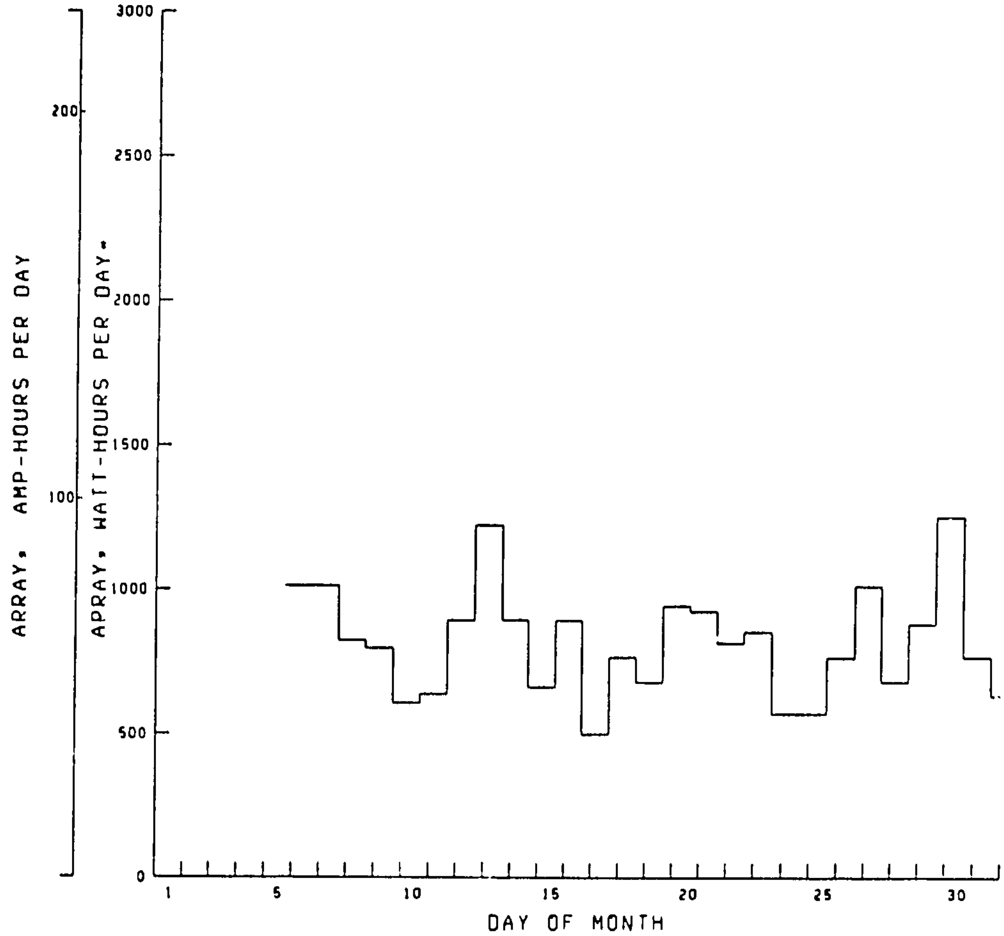



Figure A-4. - Array out put from October 1982, Comuna Cobos, Ecuador. (*Assumes average of 13 volts.)

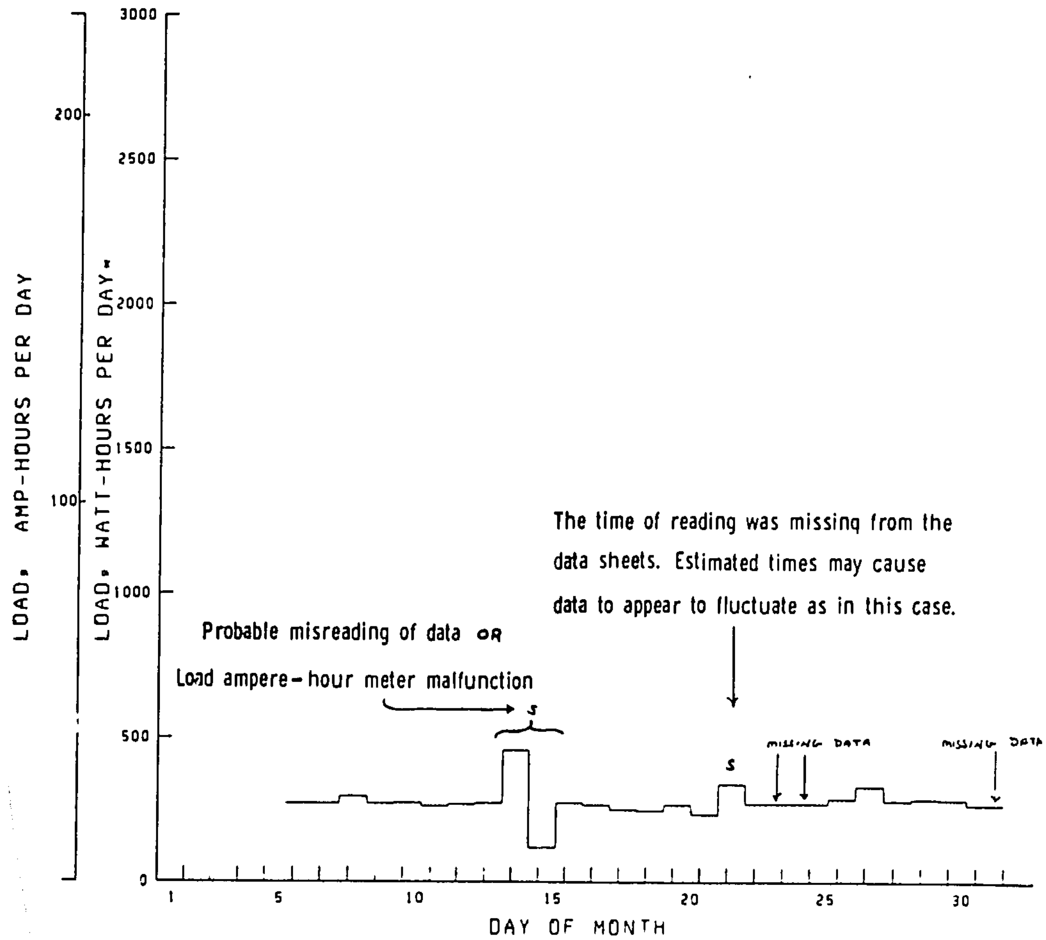



Figure A-5. - Load consumption from October 1982, Comuna Cobos, Ecuador. (*Assumes average of 13 volts; S, indicates suspect data point.)

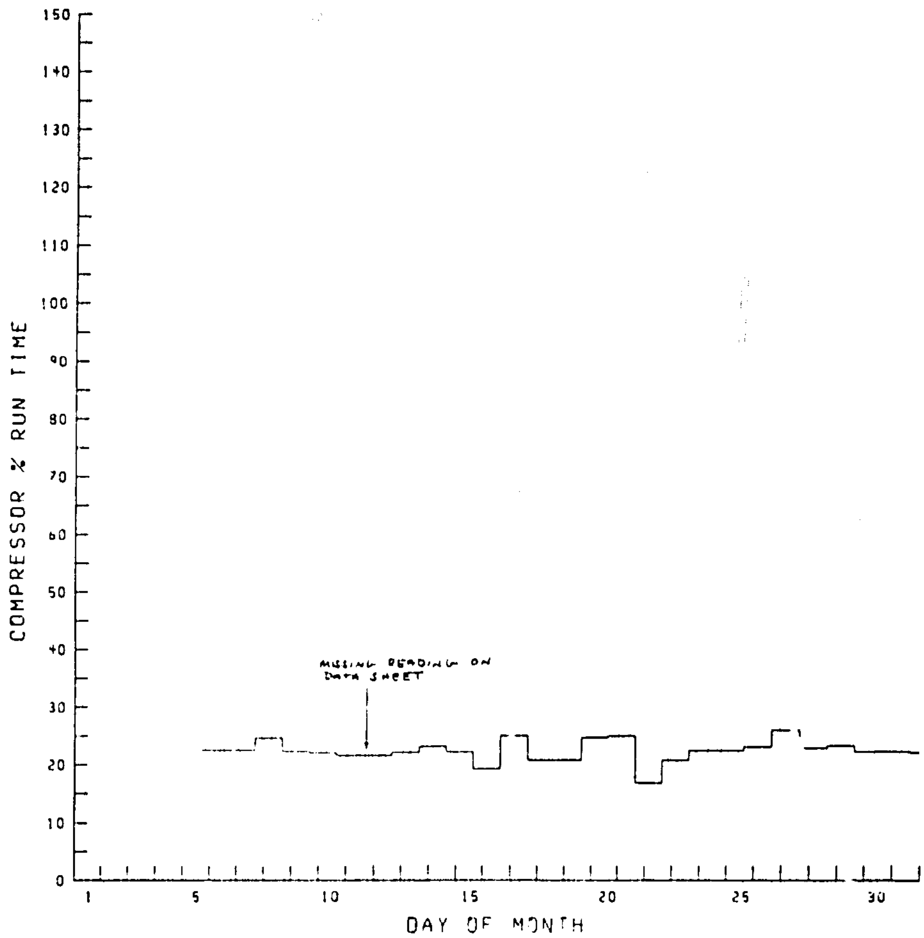



Figure A-6. - Compressor run time from October 1982, Comuna Cobos, Ecuador.

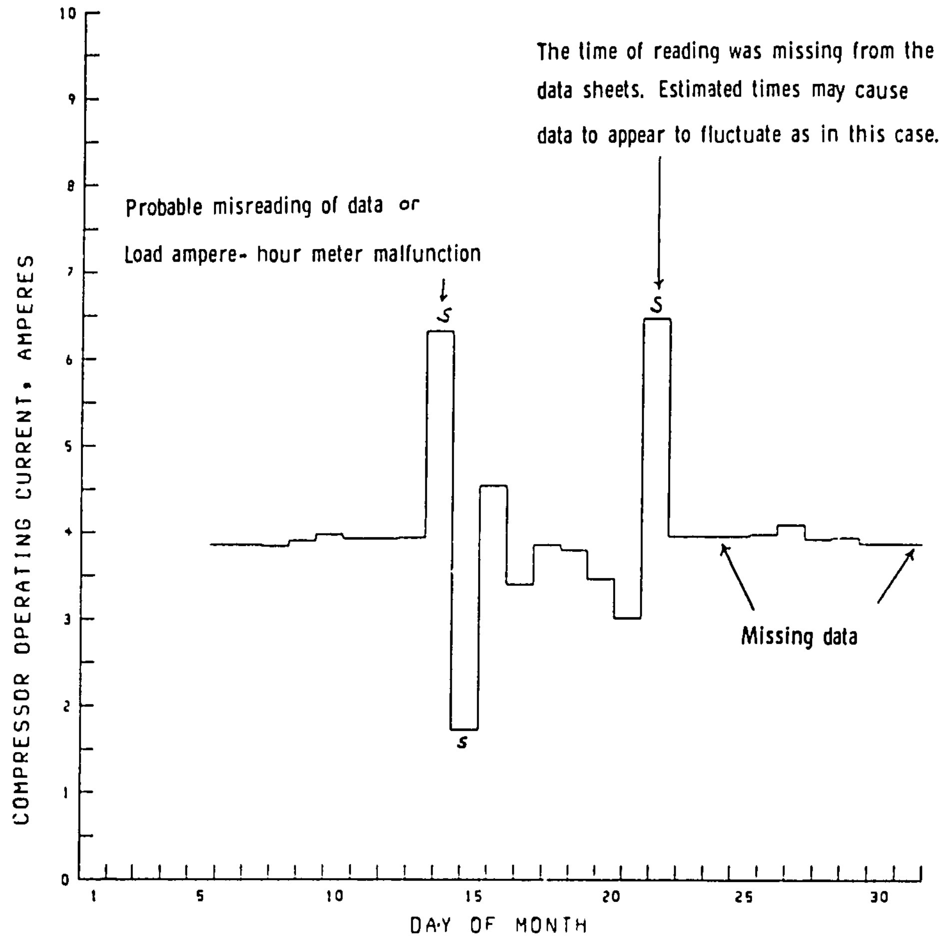



Figure A-7. - Compressor operating current from October 1982. Comuna Cobos, Ecuador. (S, indicates suspect data point.)

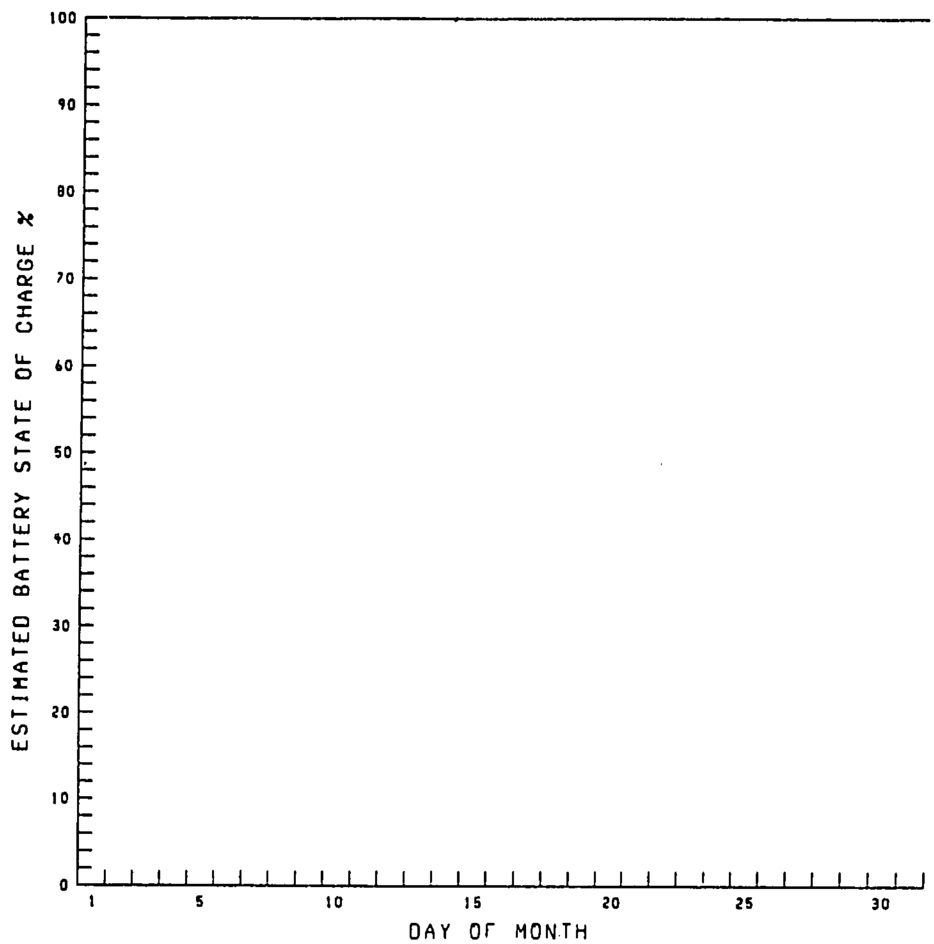



Figure A-8. - Estimated battery state of charge from October 1982, Comuna Cobos, Ecuador.

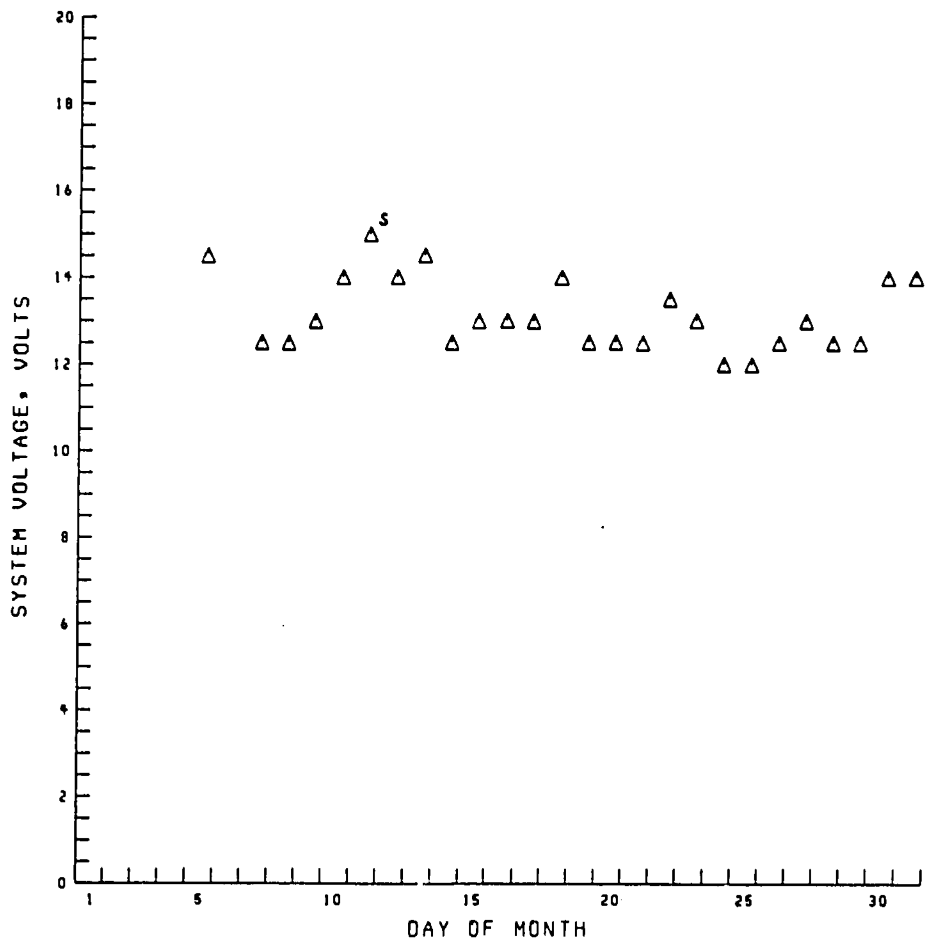



Figure A-9. - System voltage (instantaneous) from October 1982, Comuna Cobos, Ecuador. (S, indicates suspect data point.)

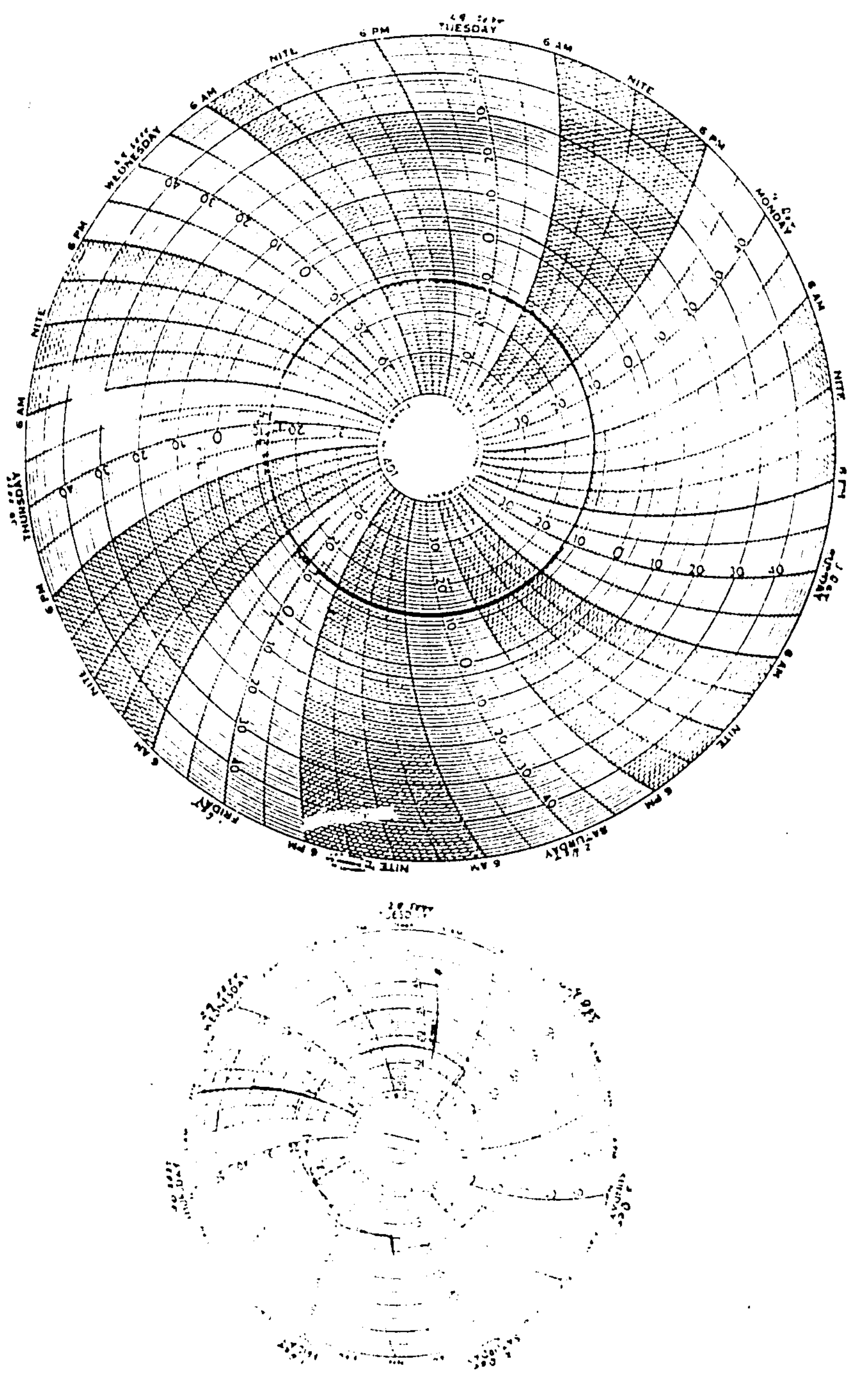


Figure A-10. - Refrigerator/freezer and ambient thermographs installed September 28, 1982; removed October 4, 1982.

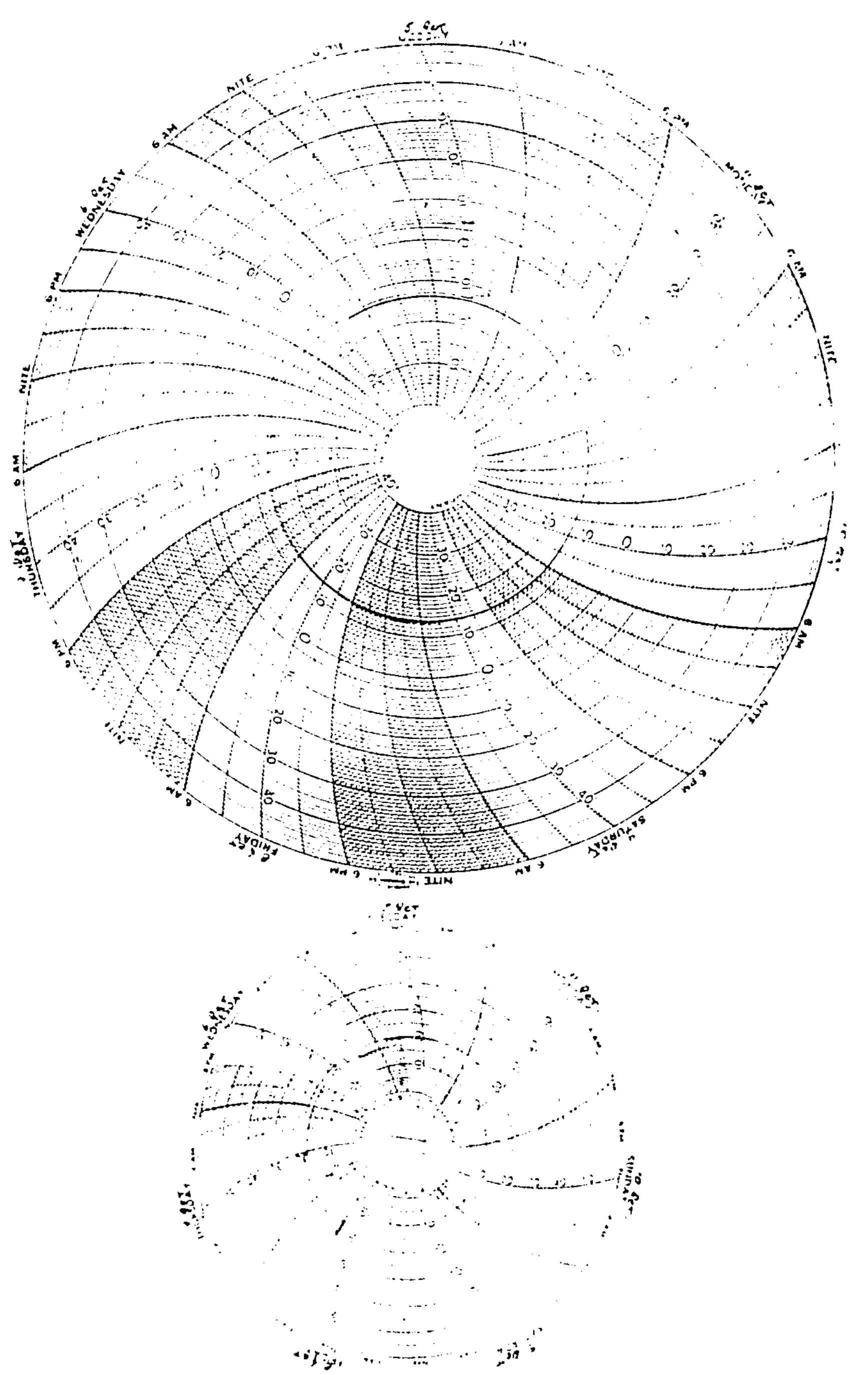


Figure A-11. - Refrigerator/freezer and ambient thermographs installed October 5, 1982; removed October 11, 1982.

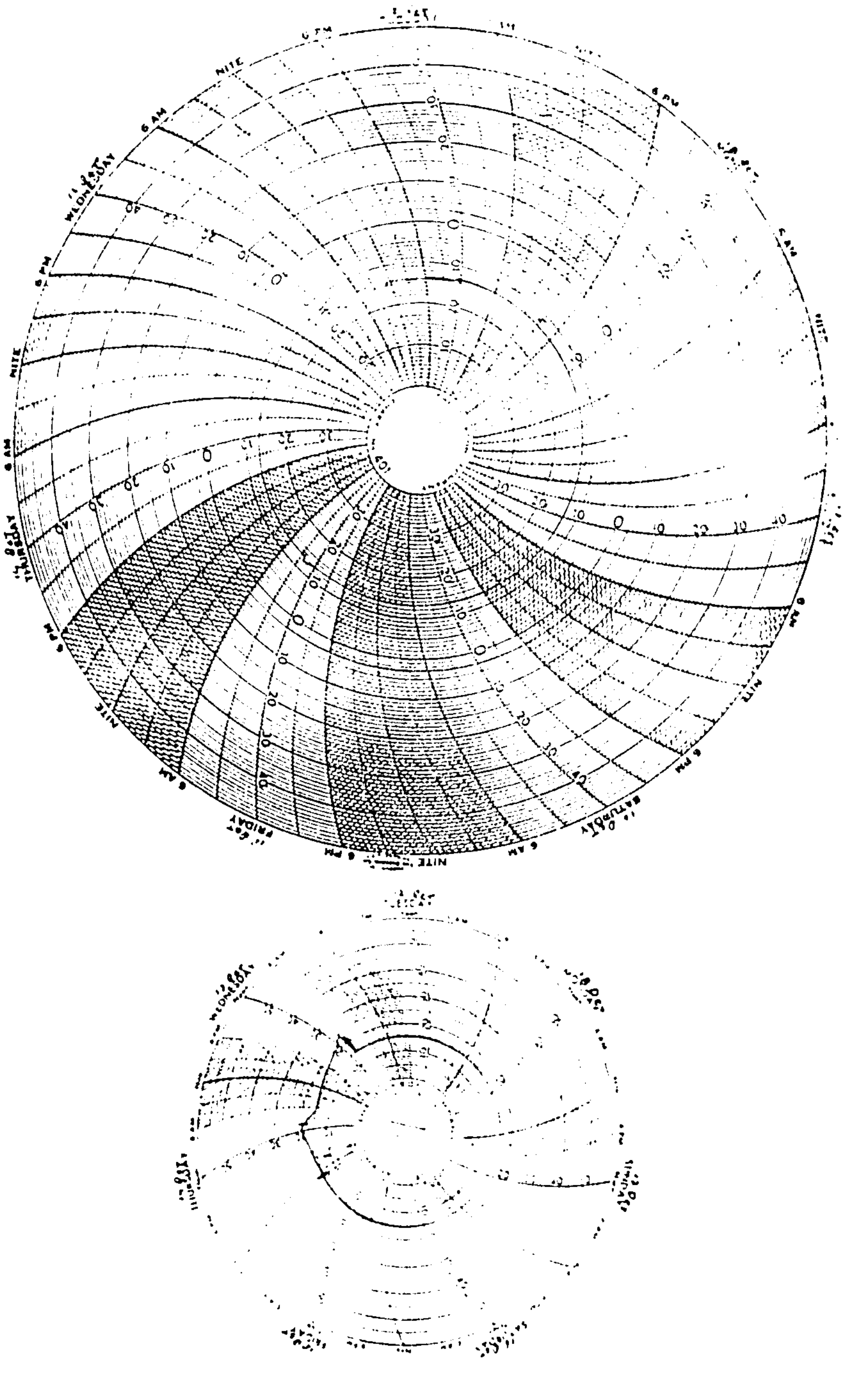


Figure A-12. - Refrigerator/freezer and ambient thermographs installed October 12, 1982; removed October 18, 1982.

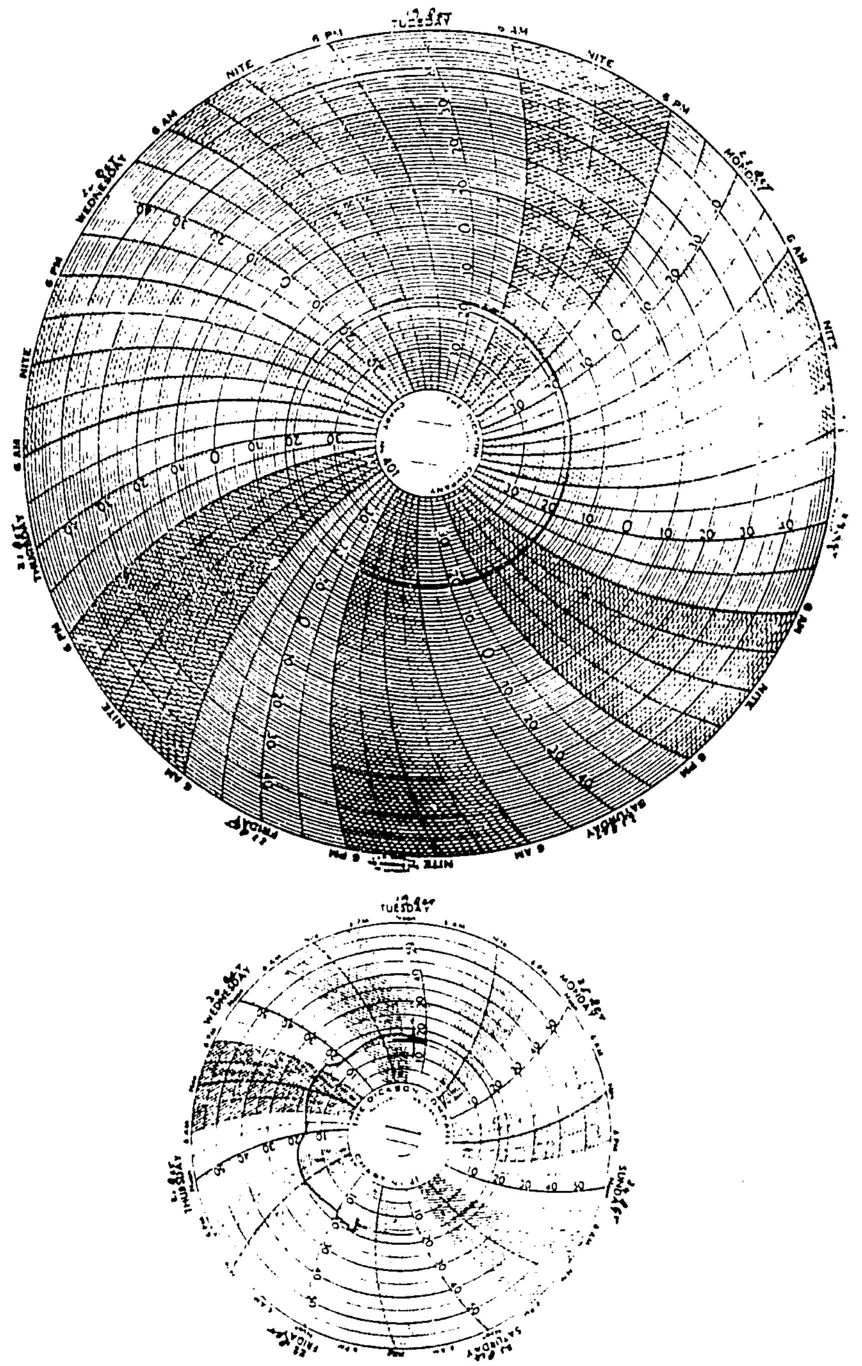


Figure A-13. - Refrigerator/freezer and ambient thermographs installed October 19, 1982; removed October 25, 1982.

# APPENDIX B

## PHOTOVOLTAIC-POWERED VACCINE REFRIGERATOR/FREEZER USER EVALUATION QUESTIONNAIRE

1. Have you had an opportunity to follow the progress of the photovoltaic (PV)-powered refrigerator/freezer (R/F) system field test at Pucara, Peru.
   Yes ___ No ___

   Approximately how many times did you or your staff visit the site since the system was installed? ______________________

2. Have National level representatives from the MOH Immunization Program followed the field test?

   Yes ___ No ___ If no, why not? ______________________

   ______________________________________________

   ______________________________________________

   ______________________________________________

   ______________________________________________

3. Does the MOH have an established program for vaccine preservation in rural (electricityless) areas? Yes ___ No ___

   If yes, please describe the program, type of equipment used for vaccine storage and approximate annual cost per site: ______________________

   ______________________________________________

   ______________________________________________

   ______________________________________________

   ______________________________________________

   ______________________________________________

4. Have vaccines been routinely stored in the PV-powered R/F? Yes ___ No ___

If no, why not ________________________________________

If yes,

4.1 Approximately what percentage of the time? ____________________

4.2 Approximately how often are vaccines delivered to Pucara?

________________________________________

4.3 Please indicate, by type of vaccine, approximately how many vaccinations are administered per week at Pucara.

| | | Vaccinations/Week |
|---|---|---|
| 4.3.1 | DPT | ________ |
| 4.3.2 | Polio | ________ |
| 4.3.3 | Measles | ________ |
| 4.3.4 | BCG | ________ |
| 4.3.5 | TT | ________ |
| 4.3.6 | MR | ________ |
| 4.3.7 | Others (please list) | |
| | ________ | ________ |
| | ________ | ________ |
| | ________ | ________ |

5. Does Pucara have an outreach program? Yes ___ No ___

If yes,

5.1 Approximately how large an area is administered? ____________________

5.2 Approximately how large a population is administered? ______________

5.3 Approximately how many cold packs are frozen each week? ____________

6. Has the PV-powered R/F system at Pucara allowed immunization services to be offered on a routine basis? Yes ___ No ___

6.1 If yes, has immunization coverage increased? ________________

________________________ ________________________

________________________________________________

6.2 If no, please explain why immunization has not been offered on a routine basis: ________________________

________________________________________________

________________________________________________

________________________________________________

________________________________________________

As a consequence of offering immunization services routinely, has the community consulted on or demanded other health services?

6.3 Yes ___ Please explain ________________________

________________________________________________

________________________________________________

________________________________________________

________________________________________________

6.4 No ___ Please explain ________________________

________________________________________________

________________________________________________

________________________________________________

________________________________________________

7. How did the local community receive (or perceive) the installation and/or use of the system?

7.1 Accepted without comment or problems ___

7.2 Problems(s) Accepting ___ Please explain ______________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

7.3 Do not know ___

8. Please indicate what you view as the system's strong or weak points?

| | STRONG | WEAK | Please Explain |
|---|---|---|---|
| 8.1 Photovoltaic power system: | | | |
| 8.1.1 PV modules structure and cabling | ___ | ___ | ______________________ |
| | | | ______________________ |
| | | | ______________________ |
| | | | ______________________ |
| 8.1.2 PV system controls | ___ | ___ | ______________________ |
| | | | ______________________ |
| | | | ______________________ |
| | | | ______________________ |
| 8.1.3 Batteries | ___ | ___ | ______________________ |
| | | | ______________________ |
| | | | ______________________ |
| | | | ______________________ |
| 8.1.4 PV system instrumentation | ___ | ___ | ______________________ |
| | | | ______________________ |
| | | | ______________________ |
| | | | ______________________ |
| 8.1.5 Thermograph | ___ | ___ | ______________________ |
| | | | ______________________ |
| | | | ______________________ |
| | | | ______________________ |

| | STRONG | WEAK | Please Explain |
|---|---|---|---|
| 8.2 Refrigerator/Freezer: | | | |
| 8.2.1 Design | ___ | ___ | ___ |
| 8.2.2 Size | ___ | ___ | (Too Small ___)<br>(Too Large ___) |
| 8.2.3 Frost/ice removal | ___ | ___ | ___ |
| 8.3 Ability to store non-EPI medications and/or vaccines (e.g., rabies and veterinary vaccines): | ___ | ___ | ___ |

8.4 System cost:

Please explain any other strong or weak points you may have observed. ___

8.5 What would you do to improve the system? ___

9. How do you view MOH's reaction to PV-powered vaccine R/F systems? Are problems real or perceived? ______________________________

______________________________________________________________

______________________________________________________________

10. Are the people who were trained in R/F system operation and use by the installation team still at the health post? Yes ___ No ___

If not, were the replacements trained in R/F operation and use? Yes ___ No ___

If yes, who trained them? ______________________________

______________________________________________________________

If no, why were they not trained? ______________________________

______________________________________________________________

______________________________________________________________

11. Please summarize operating problems with the system under the following categories:

11.1 Instrumentation problems which <u>did not</u> affect system operation.

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

11.2 Equipment problems which <u>did</u> affect system operation. __________

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

11.3 Operator practices which affected system operation. ____________

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

11.4 Other, or combinations of above. ____________________________

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

12. Please list system problems which the following personnel corrected:

12.1 Operator personnel ________________________________

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

12.2 MOH personnel ____________________________________

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

12.3 Other, or combinations of above ______________________

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

13. How is system reliability viewed by you in regard to:

13.1 Vaccine storage: Very Good ___ Good ___ Fair ___ Poor ___

13.2 Ice making: Very Good ___ Good ___ Fair ___ Poor ___

14. How many health posts in Peru are without electricity? ________

14.1 How many of these health posts could use PV-powered R/F systems?

________________________________________________

15. Does the MOH have funds to procure PV-powered vaccine R/F systems?

Yes ___ No ___

If yes, how much? ______________________

16. Would you endorse the procurement of and/or order additional systems?
Endorse: Yes ___ No ___ Order: Yes ___ No ___
If yes, how many? __________________
Over what period of time? ____________________
If no, why not? ________________________________
________________________________________________
________________________________________________
If no because of cost (present systems cost about $5000 each) at what cost would additional procurement be considered? ______________

17. Would the MOH order additional systems? Yes ___ No ___

If yes, how many? ______________
Over what period of time? ______________________

If no, why not? ________________________________
________________________________________________
If no because of cost (assuming systems cost $5000 each), at what cost would procurements be considered? ______________________

18. Would you or the MOH be more receptive to ordering these systems if a manufacturer would train a technical cadre and/or provide a central store of spares in the country?

Training: Yes ___ No ___
Maintain spares: Yes ___ No ___

If yes, what spares do you believe should be stocked? ______________________
____________________________________________________________
____________________________________________________________

19. Are there needs for additional electrical services at rural health posts?
Yes ___ No ___

| | | Yes | No |
|---|---|---|---|
| If yes, what type? | Area lighting | ___ | ___ |
| | Exam lights | ___ | ___ |
| | Sterilizer | ___ | ___ |
| | 2-way radio | ___ | ___ |
| | Other | | |

If no, why not? ______________________________________________
____________________________________________________________
____________________________________________________________
____________________________________________________________
____________________________________________________________

20. Would the inclusion of additional electrical services with the PV-powered vaccine R/F system make the systems more attractive even though these services would increase system cost? Yes ___ No ___

21. What comments do you and/or the MOH have regarding:

21.1 How the field test project was managed: ______________________

______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________

21.2 System performance: ______________________________________

______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________

21.3 System design: ___________________________________________

______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________

21.4 User training: ___________________________________________

______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________

21.5 System manuals: __________________________________________

______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________

21.6 Operational support: ____________________

____________________

____________________

____________________

____________________

21.7 Other: ____________________

____________________

____________________

____________________

____________________

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| NASA TM-86972 (Revised) | | |

| 4. Title and Subtitle | 5. Report Date |
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| | 6. Performing Organization Code<br>776-54-01 |
| 7. Author(s)<br>Anthony F. Ratajczak | 8. Performing Organization Report No.<br>E-2498 |
| | 10. Work Unit No. |
| 9. Performing Organization Name and Address<br>National Aeronautics and Space Administration<br>Lewis Research Center<br>Cleveland, Ohio 44135 | 11. Contract or Grant No. |
| | 13. Type of Report and Period Covered<br>Technical Memorandum |
| 12 Sponsoring Agency Name and Address<br>U.S. Department of Energy, Division of Photovoltaic Energy Technology, Washington, D.C. 20545 and U.S. Agency for International Development, Office of Energy, Washington, D.C. | 14. Sponsoring Agency ~~Code~~ Report No.<br>DOE/NASA/20485-18 |

15. Supplementary Notes

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16. Abstract

In 1979 the NASA Lewis Research Center, in cooperation with the U.S. Centers for Disease Control and the U.S. Department of Energy, began a project to develop and field test photovoltaic-powered refrigerator/freezers suitable for vaccine storage. Development contracts were awarded to Solar Power Corp. and Solavolt International. Three refrigerator/freezers were qualified; one by Solar Power Corp. and two by Solavolt. Follow-on contracts were awarded to Solar Power Corp. for 19 field test systems and to Solavolt for 10 field test systems. The U.S. Agency for International Development joined in the field tests systems effort. A total of 29 systems were installed in 24 countries between October 1981 and October 1984. This report includes an explanation of the project, systems descriptions, installation experiences, performance data for the 22 systems for which field test data was reported, an operational reliability summary, and recommendations relative to system designs and future use of such systems. Performance data indicates that the systems are highly reliable and are capable of maintaining proper vaccine storage temperatures in a wide range of climatological and user environments.

| 17. Key Words (Suggested by Author(s)) | 18. Distribution Statement |
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