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PHOTOVOLTAIC TESTS AND APPLICATIONS PROJECT PROGRESS REPORT FOR APRIL 1976 - JUNE 1977

National Aeronautics and Space Administration
Lewis Research Center

November 1978

Prepared for
U.S. DEPARTMENT OF ENERGY
Office of Energy Technology
Division of Distributed Solar Technology

NOTICE

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Washington, D.C. 20545
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I. INTRODUCTION

This progress report summarizes the activities and accomplishments of the Photovoltaic Tests and Applications Project during the period April 1976 through June 1977. It is the second report in a continuing series to periodically report on the activities of the Project. The project is being conducted at Lewis Research Center as a part of the National Photovoltaic Energy Conversion Program formulated by the U. S. Energy Research and Development Administration (ERDA).* The National Program seeks to develop economically viable photovoltaic power systems suitable for a variety of terrestrial applications. Two of the Program's primary goals are:

- To develop low-cost, reliable solar photovoltaic systems **
- To stimulate the creation of a viable industrial and commercial capability to produce and distribute these systems for widespread use

In order to achieve these goals, the Photovoltaic Program is designed to expand the commercial use of photovoltaic systems as rapidly as possible through a program of research, process development in support of the manufacturing industry, tests, and applications. A concerted R&D effort is being conducted to reduce system costs and improve system performance. Involved in this effort is the parallel pursuit of several technologies that have the potential for significant array price reductions. Manufacturing technology development, system

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* ERDA was placed within the new Department of Energy (DOE) as of October 1, 1977. This report will, however, retain the ERDA designator since it covers a time period prior to the formation of DOE.

** Solar "Photovoltaic" systems are also commonly referred to as "solar cell" systems. The two terms are used interchangeably in this report.

analyses, field tests, and analyses of barriers to incentives for adoption of photovoltaic systems are also being conducted. Application experiments are being implemented to develop information on operational costs, reliability, and performance, and to acquaint potential users with the characteristics and feasibility of photovoltaic power systems.

The Photovoltaic Tests and Applications Project, established at Lewis in June 1975, is one of several subordinate projects of the National Program. Currently the Program consists of the following projects:

- Mission Analysis Project - Aerospace Corporation, El Segundo, California
- Systems Definition Project - Sandia Laboratories, Albuquerque, New Mexico
- Low-Cost Silicon Solar Array Project - NASA - Jet Propulsion Laboratory (JPL), Pasadena, California
- Tests & Applications Project - NASA - Lewis Research Center (LeRC), Cleveland, Ohio
- Department of Defense Applications Project - U. S. Army, Mobility Equipment Research and Development Command (MERADCOM), Ft. Belvoir, Virginia
- MIT/Energy Laboratory Photovoltaics Economics & Policy Analysis Project - Massachusetts Institute of Technology, Energy Laboratory (MIT-EL), Cambridge, Massachusetts
- Field Tests and Applications Project - Massachusetts Institute of Technology, Lincoln Laboratory (MIT-LL), Lexington, Massachusetts
- Concentrator Systems Technology Development - Sandia Laboratories, Albuquerque, New Mexico
- Advanced Materials & Devices - ERDA Photovoltaic Advanced Materials R & D Branch, Washington, D. C.
- Overall Management - ERDA Photovoltaic Program, Washington, D. C.

The primary objectives of the Tests and Applications Project are:

- To stimulate near-term markets for cost-effective applications of photovoltaic systems
- To determine operating characteristics for a variety of solar cell systems and subsystems
- To devise and implement the methodology, techniques and equipment to make (a) accurate and reproducible measurements of solar cell and array performance, and (b) diagnostic measurements on solar cells, modules and arrays
- To determine the endurance of solar cell modules, component parts, and materials thereof under environmental conditions of their intended use.

In general then, the role of Lewis Research Center (LeRC) in the National Program is directed toward increasing demand for solar cells by testing experimental photovoltaic energy systems to show feasibility to potential users; and development of photovoltaic energy conversion measurement methods and standards for the program.

At NASA-Lewis Research Center the Photovoltaic Tests and Applications Project is managed by the Solar and Electrochemistry Division within the Energy Programs Directorate. The Solar and Electrochemistry Division has overall management responsibility for LeRC photovoltaic technology activity for both NASA and ERDA programs. The Tests and Applications Project is organized to accomplish its objectives through the following major functional activities:

- Applications and User Identification
- Applications Implementation
- General Engineering
- Measurements and Standards
- Project Management

The Applications and User Identification function is responsible for publicizing the capability of photovoltaic energy conversion, assisting potential users in preliminary feasibility analyses, providing general guidance to potential users, and identifying and selecting suitable application experiments. The Applications Implementation function implements selected experiments of photovoltaic energy systems with users after approval of the experiment by ERDA. This function negotiates the user cost-sharing agreement, completes detail design, fabricates and installs the systems, and provides continual monitoring and technical assistance to the user during operation. The General Engineering function is responsible for photovoltaic energy conversion systems design technology for the LeRC project. It provides technical support to Applications Implementation, analysis and evaluation of systems performance, identification of system technology needs, and development of tasks to address these needs. To assist in carrying out these responsiblities a National Systems Test Facility (STF) has been established at NASA-Lewis to investigate the performance and characteristics of photovoltaic power systems, components and subsystems. Terrestrial solar cell standards and procedures are developed by the Measurements and Standards function. This responsiblity includes the development of procedures to provide for intercomparison and repeatability in the measurement of solar cells and arrays. It provides standard cells, data on cell performance as a function of several variables, and solar cell endurance data. The Project Management function provides planning, scheduling, control activities, resource management, and reporting. It provides information transfer and coordination with all other elements of the ERDA Photovoltaic Energy Conversion Program and with all groups providing support to the Project at LeRC. A brief summary of accomplishments in each of these functional activity areas will next be presented.

II. SUMMARY

From the formation of the project in June of 1975 to April 1976, the beginning of this report period, the basic thrusts of the Project toward photovoltaic system applications, measurements and standards, and endurance testing of solar cell modules were defined and initiated. During the early part of this report period, these basic activities were further defined and the functional activities noted in the introduction developed as organizational elements of the Project to carry out the work. Extensive coordination also took place during this time with NASA-Jet Propulsion Lab (JPL). JPL, through their Low-Cost Silicon Solar Array Project (LSSA), supplied solar cell modules to NASA-LeRC for use in all of the application and test activities of the Tests and Applications Project.

Specifically, by functional element, the major activities and accomplishments of the Project were:

A. APPLICATIONS AND USER IDENTIFICATION

1. An extensive survey of federal government agencies was conducted through mailings of some 1600 informational brochures for the purpose of identifying latent potential applications for solar cells. Approximately 100 positive responses were received, several of which have been developed into cooperative experiments representing applications having a near-term market potential.

2. Procedures were developed for the systematic analysis and evaluation of candidate near-term applications.

3. Fifty-eight presentations of the potential of photovoltaic systems were made to interested governmental and technical organizations. These presentations were supplemented by brochures and an audio-visual slide program

produced by the Project. Numerous tours of the photovoltaic facilities at LeRC were also conducted.

4. Proposed plans for the near-term application development of photovoltaic systems for highway, refrigeration, remote instrumentation, water pumping, and village power applications were prepared at ERDA's request.

B. APPLICATION IMPLEMENTATION

1. Design, fabrication, installation, and operation support of solar cell arrays for 34 systems was completed using a total of 27 kW of the Block I modules purchased by the LSSA project (JPL) from industry. (See page 30.) Of these, 17 were complete systems for civilian applications and 17 were arrays fabricated for the Department of Defense Applications Project.

2. A design was initiated for a Papago Indian village power system.

3. A statement of work was prepared to provide module measurement, solar cell panel fabrication, and panel measurement through a future contract with a light industrial fabrication concern to be selected from outside the photovoltaic industry. This effort represents the first attempt to diffuse these technologies to new sources in order to expand the base of industrial expertise.

4. A series of standard photovoltaic panel designs was developed for a range of system voltages to be used with modules from the Block II JPL module procurement.

C. GENERAL ENGINEERING

1. Parallel contracts were completed for residential photovoltaic experiment definition studies performed by General Electric Company and Martin-Marietta Corporation. These were the first studies specifically designed to define experiments for photovoltaic-powered residences in several regions of the U. S. In addition, LeRC prepared a proposed national program plan, at ERDA's

request, which defined and described the activities required to lead to the attainment of photovoltaic energy conversion commercialization for residential applications.

2. Contracts were awarded for design and fabrication of a high efficiency 10 KVA self-commutated inverter and controller designed for use with photovoltaic systems. This is the first such inverter to be developed.

3. Design and construction (Phase I) of a photovoltaic Systems Test Facility (STF) at NASA-LeRC was completed. This facility is capable of "breadboard" testing proposed power system designs up to 10 kW peak power. This was the first such test facility to become operational (December 1976) in the United States specifically designed and designated for the testing of photovoltaic systems in power levels up to 10 kWp. During the report period additional construction was nearly completed for Phase II of the facility which will add capacity for installing an additional 30 kWp of solar cell modules.

4. Initial tests were completed in the STF to investigate the performance of: a state-of-the-art 8 kW line-commutated inverter; the electromagnetic interference generated by a solar cell array; the operating nature of a low power photovoltaic system having a utility tie-in; and evaluation of the causes of solar array power degradation due to environmental exposure over a period of months.

D. MEASUREMENTS AND STANDARDS

1. More than 4,000 confirmatory cell, module, and array performance measurements were provided as a service to investigators involved in the National Program. Included also were measurements in support of NASA-JPL's Block I module procurement.

2. Construction of a Solar Cell Reference Conditions Test Facility was completed and operation was initiated for long-term monitoring of global insolation and its components as well as the concurrent performance testing of solar cells under a wide variety of atmospheric conditions.

3. Operation of the solar cell test laboratory was improved by using a desk-top computer to automatically collect routine solar cell performance measurements and rapidly convert them to final plotted data.

4. Design of a standard solar reference cell and a rugged standard cell package was completed. Sixty of these reference cells have been fabricated and calibrated to meet immediate requests of investigators. Thirty-five have been distributed as of June 30, 1978.

5. The Second Terrestrial Solar Cell Measurement Procedures Workshop in November 1976 was managed for ERDA. Proceedings were reported in ERDA/NASA-1022/76-10, "Terrestrial Photovoltaic Measurements-II."

6. Revised measurement procedures resulting from the Procedures Workshop were published. These procedures are reported in ERDA/NASA-1022/76-16, "Terrestrial Photovoltaic Measurement Procedures."

7. The American Society for Testing Materials (ASTM) was encouraged and has agreed to consider the revised ERDA/NASA Terrestrial Solar Cell Measurement Procedures Manual as the basis for issuance of ASTM photovoltaic standard measurement procedures. This interest by ASTM represents the first consideration of terrestrial solar cell measurement procedures by a national standards organization outside the federal government.

8. The endurance testing program at various sites in the continental U. S. and Puerto Rico was initiated.

E. PROJECT MANAGEMENT

1. Technical information was provided from the Project activities to all other segments of the ERDA National Photovoltaic Conversion Program and the photovoltaic community as a whole. A complete list of reports is presented in the Appendix.

2. Personnel participated in ERDA semi-annual review meetings at Orono, Maine in August 1976, and San Diego, California in January 1977.

3. Personnel participated in the 12th IEEE Photovoltaic Specialists Conference and managed the 2nd ERDA Measurements Workshop. Both events were held at Baton Rouge, Louisiana in November 1976.

4. Project Operating Plans were proposed.

5. Monthly management reviews of LeRC activities were conducted with ERDA program management.

These activities represent the major activities and accomplishments of each of the Project functional areas during the reporting period. In the next section, details of each of these summary items will be presented together with other significant events and activities which occurred.

III. PROJECT ACTIVITIES AND ACCOMPLISHMENTS

In this section the activities and accomplishments of each functional element of the Tests and Applications Project will be described. Primarily the work has focused on determining the feasibility of photovoltaic power systems to serve terrestrial applications in which the power system could be cost-effective in the next 5 to 10 years. The work has involved both the identification of such applications as well as the fielding of a number of experimental systems in selected application categories. Supporting this activity has been the development of a facility at LeRC in which to test: (1) the feasibility of proposed photovoltaic systems, (2) ideas related to the development of terrestrial measurement procedures and standards, and (3) solar cell module environmental endurance. In all cases, the photovoltaic systems developed have made use of commercially available components as much as possible with one goal of the work being to identify component technology gaps or shortcomings for future attention. In this respect it should be noted a shortcoming was found in that there are fewer commercial sources in the marketplace of DC devices of all sorts, as compared to AC devices; e.g., motors, appliances, instrumentation (such as ampere-hour meters), high voltage switches, relays, controls, and the like.

A. APPLICATIONS AND USER IDENTIFICATION

A major goal of the ERDA Photovoltaic Energy Conversion Program is to stimulate the demand for solar cells so that production by private industry will increase from the 1975 level of approximately 0.1 megawatt (100 kW) per year to 500 megawatts (500,000 kW) per year by 1986. Experience indicates that there are many potential applications for which solar cell power systems are cost-effective even at present prices of approximately $15 per peak watt.

Furthermore, as projected prices decrease to $2 per watt in the early 1980's, a dramatic market increase should be possible. The market, however, is latent. Many potential users are unaware or unsure of the benefits and the readiness of solar cell power for their applications. Unless such users are fully apprised of the solar electric option, their entry into the solar cell market may be greatly delayed.

The Applications and User Identification function is responsible for publicizing the capability of photovoltaic energy conversion, assisting potential users in preliminary feasibility analyses, and providing guidance to potential users.

In order to determine cost-effective applications of photovoltaic systems in the government sector, which could aid in the attainment of 1986 production goals, a multi-faceted user search and contact effort was undertaken. This contact plan was aimed at potential users as well as scientific personnel and the general public. It included:

- correspondence with potential solar cell users
- preparation and distribution of an informational brochure describing solar electric energy systems ("Usable Electricity from the Sun")
- personal presentations summarizing photovoltaic power capability
- public display of small photovoltaic power systems coupled to easily recognized applications
- contact with solar cell manufacturers to explore cooperative approaches to early market development

During this report period, a total of 1600 informational mailings were made to federal agencies. Approximately 175 responses were received. Of these, about 100 indicated some degree of interest. In addition, 160 unsolicited inquiries were received from individuals in other organizations, including state agencies and representatives of foreign governments and international agencies. A summary of the potential applications identified are tabulated in Table 1. During the report period candidate application experiments have been identified by staff review of the potential for replacement of existing power sources by photovoltaic power systems. Identified applications have been evaluated relative to criteria for near-term impact, namely:

Cost

- unit price at which system is cost-effective
- experiment cost (includes user cost-sharing formula)

Technical

- performance compared with competitive systems.
- amount of additional technical information which will be generated
- time required to bring application "on-line"

Market

- estimated number of potential installations
- estimated total power of these applications
- time until application will be competitive

Promotional

- potential number of viewers (general public)
- impact of the system; i.e., regional, national, international
- promotion potential; i.e., local, regional, national

Applications which favorably satisfy these criteria continue through the total evaluation process illustrated in Figure 1.

TABLE 1

Government Application Candidates by Agency and Application Type

	Visitor Center	Comfort Station	Food Processing	Radar/Radio Communications	Insect Traps	Monitoring Instruments	Light Signals & Signs	Cathodic Protection	Pumping
National Park Service	X	X							
U. S. Coast Guard				X			X	X	
Louisiana State Parks	X	X							
Department of Interior	X	X		X		X	X	X	X
U. S. Forest Service		X		X		X			
U. S. Department of Agriculture				X	X	X			X
Department of Transportation					X		X		
National Oceanic & Atmospheric Admin.					X		X		
Texas State Parks	X	X						X	
Federal Highway Administration		X		X		X	X	X	
Environmental Protection Agency						X			
Bureau of Indian Affairs-Health, Education & Welfare	X			X			X		X
Federal Aviation Administration				X			X		
Agency for International Development			X	X					X
New Hampshire Public Works		X				X	X		
Arizona Department of Transportation							X		
New York Dept. of Environmental Conservation						X			
World Bank		X	X	X		X	X		X

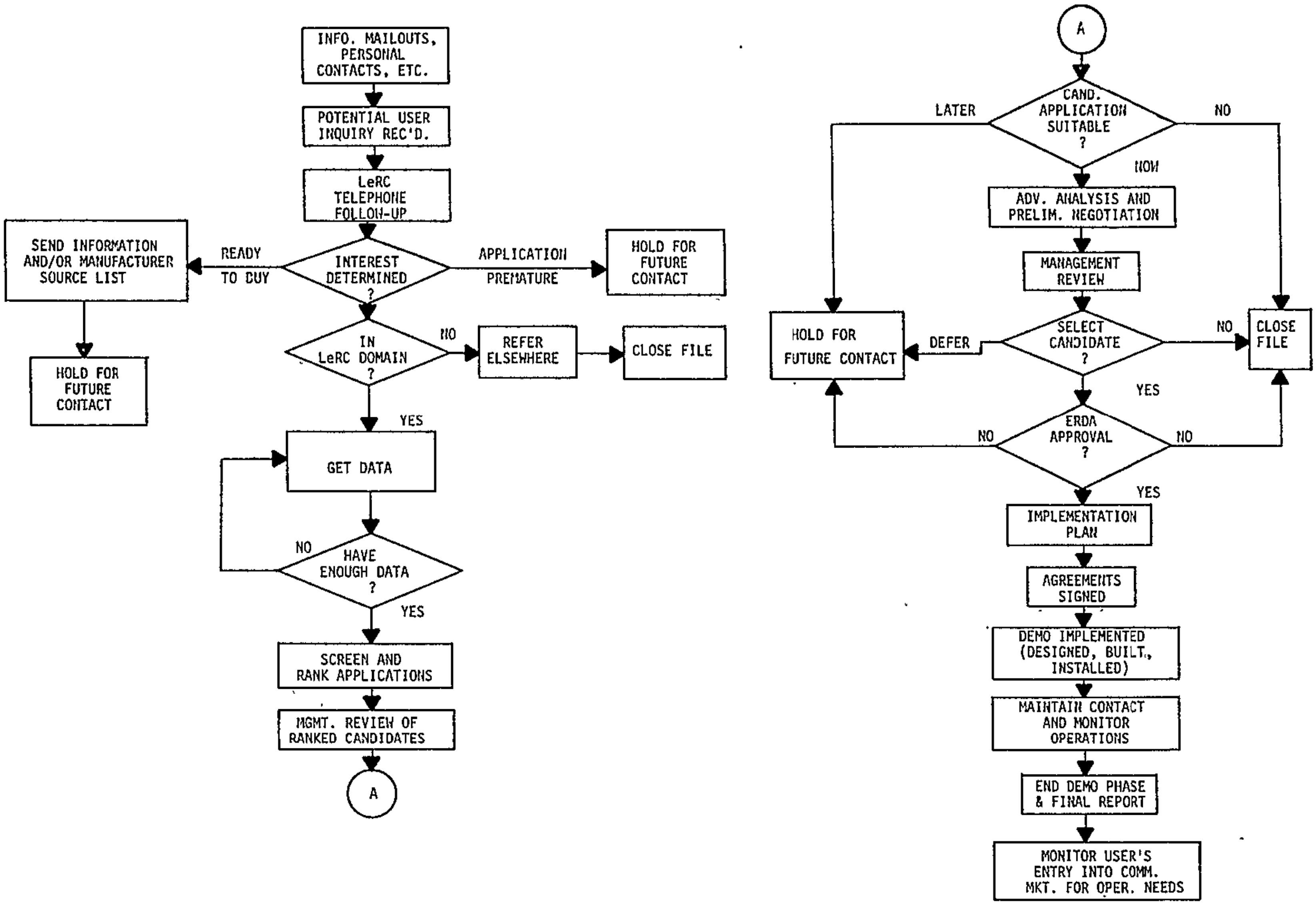


FIGURE 1

Applications Processing Flow

To assist in evaluating the economic viability of an application, an economic analysis algorithm has been developed for use at LeRC. The economic analysis algorithm provides a tool to assist in estimating the approximate date to expect cost-effectiveness of each potential experiment. Applications of photovoltaic systems have been divided by ERDA into three time-related groups with respect to cost-effectiveness:

- near term (now to 1986)
- intermediate term (1986 to 2000)
- far term (beyond 2000)

The number of applications in each range may vary considerably. The economic information is needed to determine the proper time to perform experiments that relate to potentially cost-effective applications.

The purpose of this model is to:

- aid in the selection of potential applications for field experiments
- assist the user in evaluating the adoption of photovoltaic energy sources
- provide comparative cost data to support user contact efforts

The model is oriented toward a specific user application and compares photovoltaic and user-defined alternative systems. For each application the following input data is computed for each year from the current date through 1986. For each alternate starting date, or "start year," the model provides initial and cumulative cost and savings data. All cost data are stated in selected base year dollars and include:

- initial cost
- operating cost for each year of operation
- current worth
- equivalent annual cost
- equivalent annual energy cost
- depreciation schedule
- annual energy cost based on book value over the lifetime

The cost analysis output provides a graphic presentation of initial cost and annual energy cost for competing power systems. Typical examples are presented in Figures 2 and 3 for a presently installed application, Solar Powered Dust Storm Warning Sign, which is further detailed in Section III-B.

Project personnel provided technical support as needed throughout the application experiment period. However, the overall objective of any application experiment is to have the user, upon completion of the experiment, expand his utilization of photovoltaic energy conversion devices by obtaining additional systems from the commercial market. As shown in Figure 1, Project personnel monitor this entry into the commercial market also.

The Project staff has also made a total of 58 presentations. In some cases, these have included use of a 35mm audio-visual photovoltaic energy conversion presentation especially prepared for this purpose. These presentations are made at the request of interested governmental and technical organizations. In addition, tours of the LeRC Systems Test Facility and measurement laboratories have been conducted. The impact of these contact activities is summarized in Table 2. Two active photovoltaic displays have been developed to provide extensive public exposure to the capabilities of photovoltaic solar energy conversion. These display activities have been in addition to the formal user

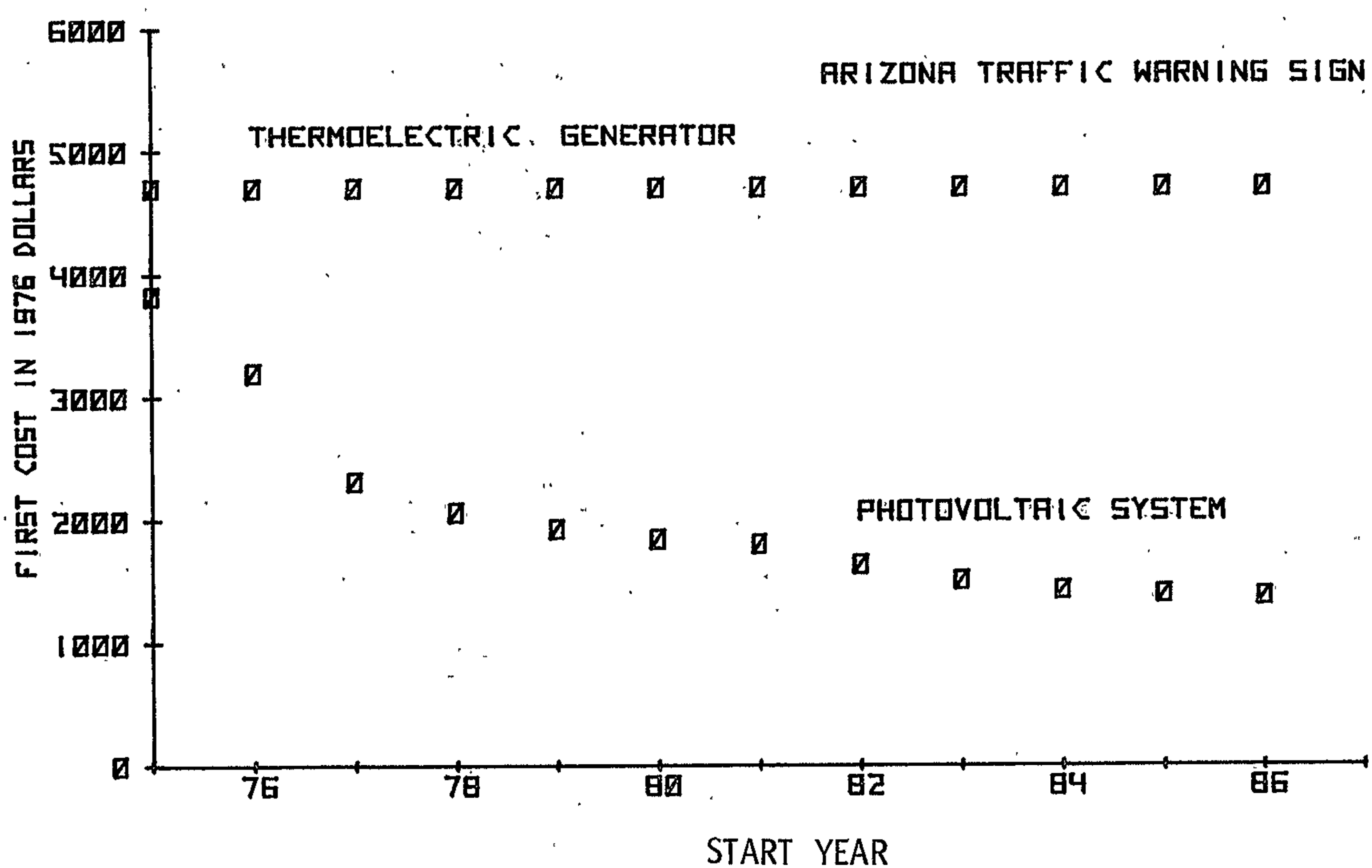


FIGURE 2
Economics Analysis Presentation of First Cost Comparison of Alternative Energy Sources

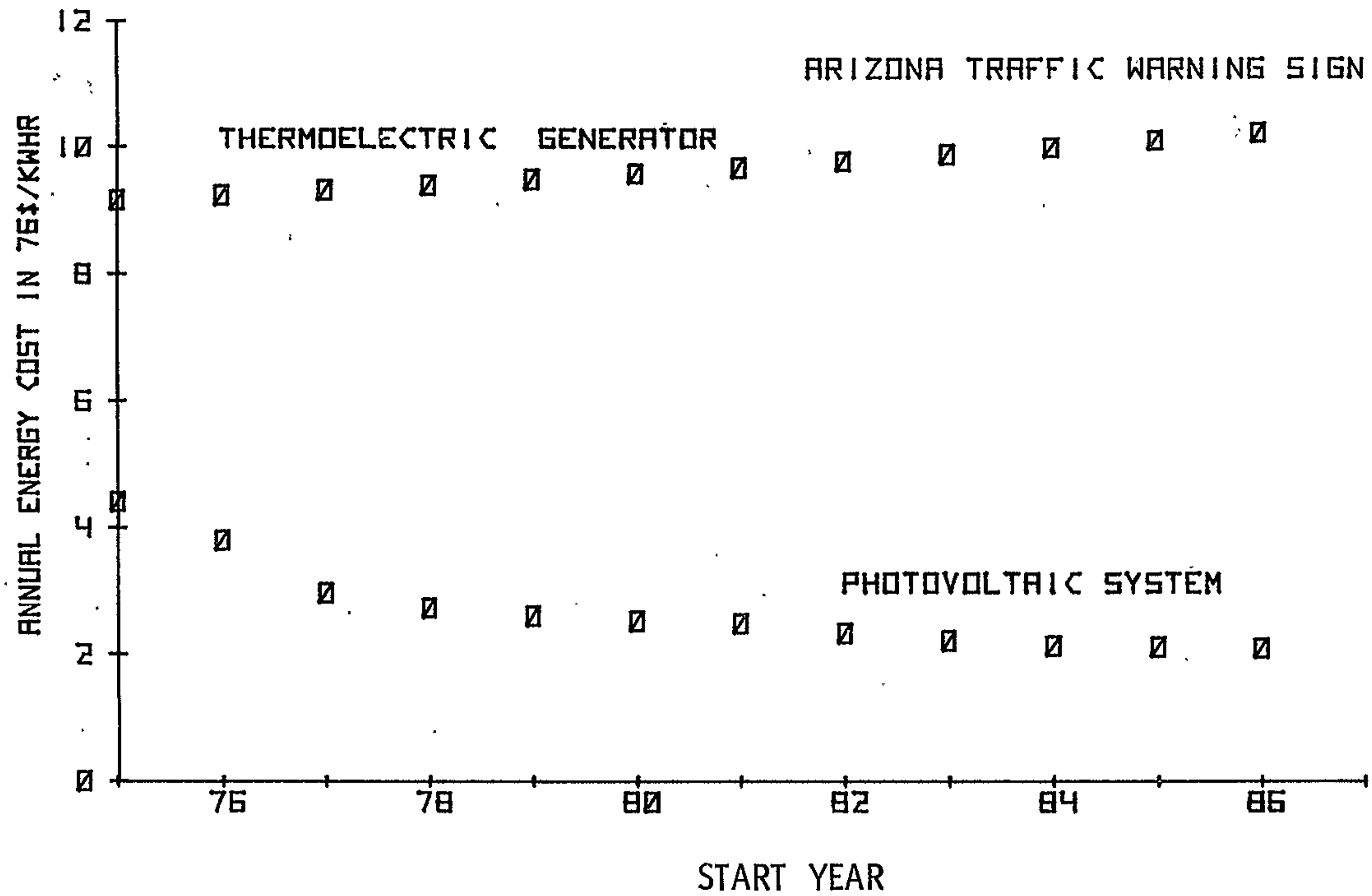


FIGURE 3

Economics Analysis Presentation of Annual Energy Cost Comparison of Alternative Energy Sources

TABLE 2
User Contact Activities During Period
April 1976 - June 1977

Search Activity	Total Performed	Estimated Attendance and Exposure
Informational Mailing	1,600	3,200 (est.)[1]
Unsolicited Inquiry	160	160
Staff Presentation	58	3,914
Facility Tours	75 (est.)[2]	750 (est.)[2]
Total		8,024 (est.)

1. Assumed exposure of at least two individuals per brochure.

2. Formal records not made prior to May 1977. During period May-June 1977, 15 tours consisting of 147 individuals were conducted.

contact effort and have consisted of a Photovoltaic-Powered Electric Vehicle Display at the Festival of American Folklife in Washington, D. C. (July-September 1976) and a Photovoltaic-Powered Water Cooler at the Interagency Visitor Center in Lone Pine, California, both of which are reported further in Section III-B.

Data was provided by LeRC for the daily reporting of local solar energy insolation by WJW-TV, Cleveland, Ohio to further increase public awareness of the potential of solar energy. LeRC personnel have been making daily measurements of solar insolation for the past two years as part of the National Photovoltaic Energy Conversion Program. The energy measured is totaled over the course of each day to yield the amount available for that day. This value was converted into a "Solar Energy Index" for reporting to the public. The Lewis Research Center, the Ohio Solar Energy Association, and WJW-TV (Channel 8, Cleveland, Ohio) cooperated in this effort to promote the use of solar energy by reporting daily solar energy information on WJW-TV's late evening weather reports. (See Figure 4.)

Applications and User Identification planning activities have been directed primarily toward those potential uses of photovoltaic energy which have unique advantages over conventional power sources and/or show strong possibilities of near-term commercial adoption. During this period, the Project staff developed detailed plans and schedules for its assigned applications and also contributed to the planning activities of the ERDA Photovoltaic Planning Group (PPG). The PPG, established by the ERDA Photovoltaic Program Office, serves as an advisory planning arm to the Program office.

In addition to these planning activities, the Project was requested by ERDA to develop a general photovoltaic applications development plan for the near-term (through 1986). The purpose of the plan was to establish a methodology

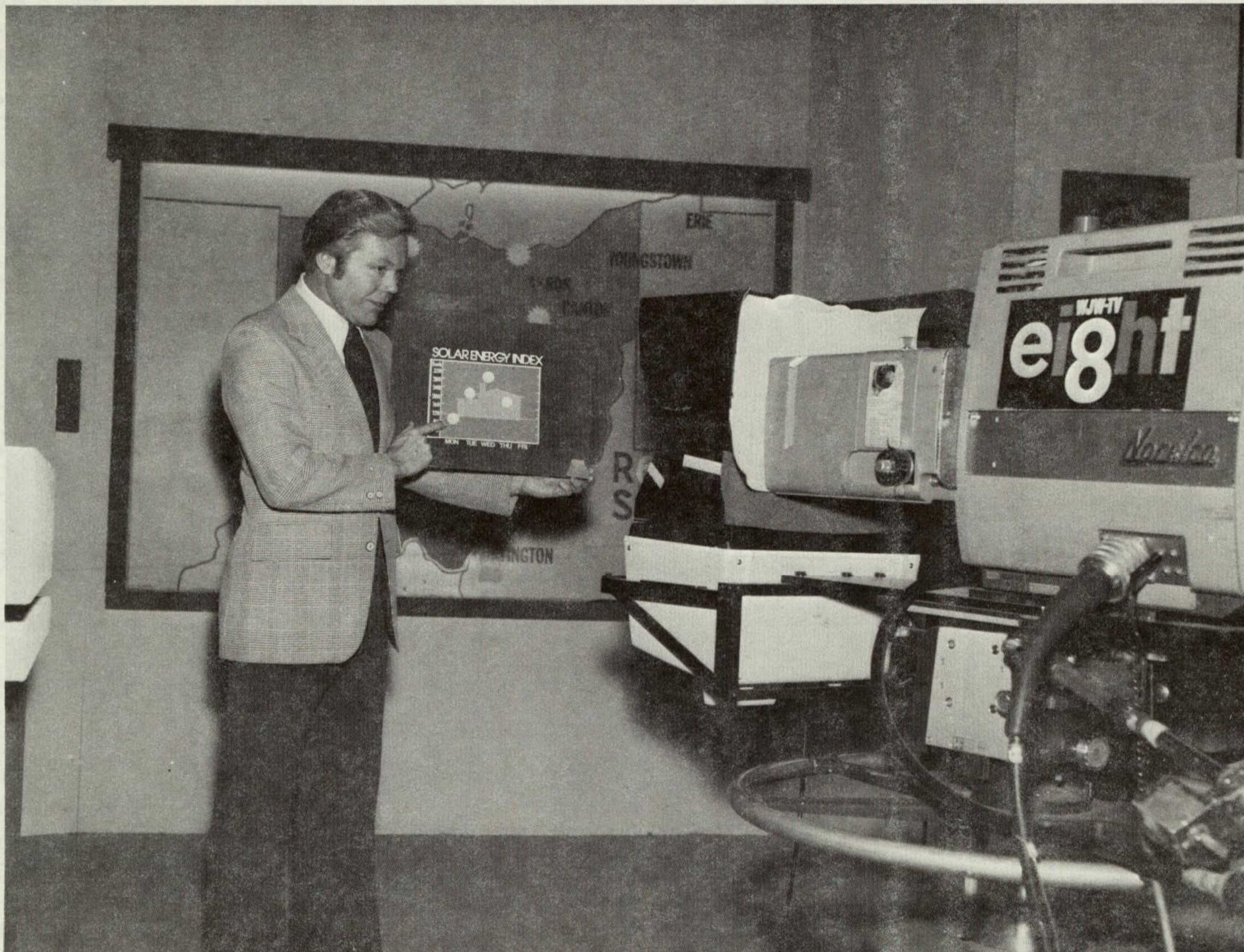


FIGURE 4
Daily Solar Energy Information Reported on Late Evening Newscast

which could be applied to guide a variety of application categories from early government supported experiments through to commercially feasible products produced and sold by industry.

Market studies indicate a probable dramatic increase in the size of the photovoltaic market for new and existing applications for the near-term. Due to the complexity of getting photovoltaic systems into the marketplace, the government has an important role to fulfill. It must share the risk of new venture development and facilitate the transfer of new technology to users and manufacturers.

The plan developed is structured to support the ERDA 1986 production goal through the achievement of the following major objectives:

- provide technical, economic, and institutional data and information from specific application experiments
- stimulate the near-term market growth for photovoltaics

The plan engages the interest and active participation of the private sector in experiments and information exchange which are intended to lead to commercial development and the marketing of photovoltaic-powered products. Also, the plan provides a mechanism for the flow of information to the technical community, which includes the ERDA Photovoltaic Program Project participants and contractors.

The overall approach is illustrated in Figure 5. Once a photovoltaic application category has been selected by ERDA as having potential for significant market capture in the near term, the illustrated systematic approach is employed for market stimulation of the given application. It is clear that market potential cannot merely be described to the producing industry with the expectation that they will quickly make a commercialization decision. Rather, the government

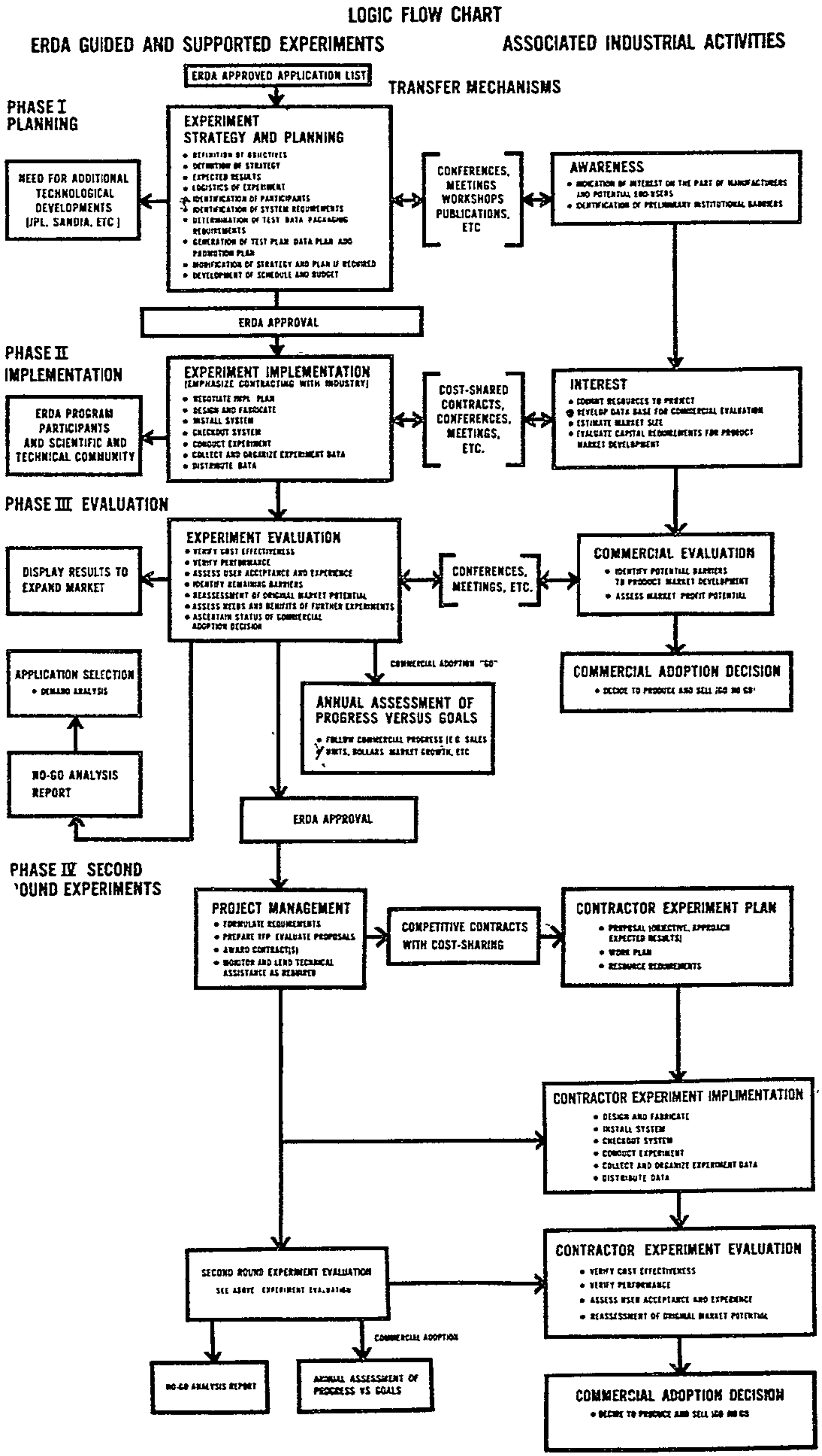


FIGURE 5
Near Term Photovoltaic Application Development Plan

must nurture early growth in the new product area. The logic shown is based on the precept that hardware must be assembled, put into use, and evaluated in order to provide the information and confidence that potential producers or users need prior to entering the marketplace.

As a result of this general plan the Tests and Applications Project was next requested by ERDA to develop detailed applications development plans for "target" market segments. These plans implement the strategy of the Near-Term, Photovoltaic Application Development Plan for the following categories of applications which appear potentially attractive for the early introduction of photovoltaic power sources:

- highway applications
- refrigeration applications
- remote instrument applications
- water pumping applications
- village power applications

The nature of each of these categories which appear promising for photovoltaic systems will next be described.

1. <u>Highway Applications</u>

Use of photovoltaic power sources for signs and motorist aids appears potentially attractive as examples of highway applications. The signs considered require electrical power for their function, e.g., for illumination or motion. Highway signs fall into two general user sectors: government and commercial. The government sector is composed of federal, state and municipal highway signs which may be characterized as information, hazard caution, or control. The sign illuminated at night which alerts drivers as they approach highway interchanges is an example of an information sign. The Arizona Dust Storm Warning Sign (see Section III-B) which functions on remote command is an example of a hazard caution sign. The open/closed/change lane sign is an example of a control sign.

The major portion of the commercial sector highway signs consist of billboards and other advertising signs. Also included in the commercial sector are railroad crossing signs and signals.

Motorist aids include call boxes, rest stops, and information stops. Most, if not all, applications in this category fall in the government sector. Call boxes are those communication links placed strategically along highway systems in remote areas to enable motorists in trouble to call for assistance. Rest and information areas are sometimes combined, but in any case are often not situated near utility power. Power is used by both types of areas for illumination and occasionally for potable water pumping and sewage treatment. In the case of information areas, power is also used for displays such as those dispensing recorded information regarding selected areas of interest.

2. Refrigeration Applications

The greatest market potential for refrigeration applications appears to be preservation of perishables in remote areas and refrigerators for recreational vehicles. The three types of cooling processes that are currently used are vapor-compression, absorption, and Peltier (or thermoelectric). The vapor-compression and Peltier methods require electrical power for their operation, while the absorption method requires a thermal input, usually supplied by burning propane or natural gas or by electric resistance heating. The cooling efficiency of the vapor-compression process is more than four times that of either the absorption or Peltier method. Refrigerators are defined to be single integrated units which provide low temperature storage for medicines, foodstuffs, or other perishable items. Refrigeration systems are systems which provide cooling for commercial applications such as mobile milk coolers, reefer cars and trucks, field chilling of harvested crops, and trout farming.

Three user sections have been identified for consideration in the refrigeration application plan. These sectors are (1) government, (2) commercial/ institutional, and (3) general public. Within the government sector, principal user agencies would be the Department of the Interior (Bureau of Indian Affairs, National Park Service), Department of Agriculture (National Forest Service) and the Department of Health, Education and Welfare (Indian Health Service). Within the commercial/institutional sector would be reefer cars, remote hunting and fishing lodges and camps, and medical field services. Within the public sector would be camping and recreational vehicle (RV) refrigerators and remote or cabin household refrigerators.

3. Remote Instrument Applications

Solar cell arrays provide a unique source of power for monitoring instruments in isolated areas. Remote instrument systems are characterized as either environmental monitoring instrument systems or as surveillance instrument systems. Remote implies that the instrument is located such that it cannot be operated economically by utility power.

Environmental monitoring instrument systems provide in situ measurements and data germane to areas of interest such as:

- agriculture
- environmental quality
- forestry
- geology

- hydrology
- meteorology
- oceanography
- seismology

Surveillance instrument systems sense and signal or provide data for applicatons such as:

- pipeline and oil or gas well status
- security (e.g., intrusion sensors and perimeter surveillance)
- traffic (e.g., vehicle number and rate)
- failure detection
- insect control surveys

Photovoltaic power sources have already penetrated the remote instrument application market to a small extent. However, the highly varied and insular nature of the user groups poses a significant barrier to the rapid distribution of this technology. Therefore, market stimulation is needed.

4. Water Pumping Applications

Applications in this category include pumping for potable water, irrigation, drainage, waste treatment, and industrial processes. Waste treatment and drainage applications include treatment systems for recreational areas and highway comfort stations and drainage pumping for land reclamation and other purposes. Remote industrial waste treatment and process pumping for aeration, sediment ponds and cooling towers are also included. Though not waste treatment, other pumping such as in fish hatcheries for water circulation and in mining operations for ore separator aeration may have merit as photovoltaic pumping applications and are included as well. Potable water pumping applications consider small villages and public recreational and rest areas. Also included is potable water pumping for livestock watering both on the range and in feed lots, as well as power for water purification which is frequently required when surface water sources are used. Irrigation applications vary from low lift pumping of surface water to deep well turbine pumps. Water distribution requires pump power which varies from low lift, low volume pumps for drip irrigation to high pressure, high volume pumps for sprinkler systems.

5. Village Power Applications

The introduction of small-scale decentralized photovoltaic power sources appears attractive for satisfying basic needs of remote villages or camps such as youth conservation corps, logging, etc. An implicit feature of the photovoltaic village power system concept is modularity; the system can be initially sized to provide power for basic needs (e.g., food processing, potable water pumping, lighting, refrigeration, educational television) with provisions for the addition of increments of power as required (e.g., cottage industry, communications). Remote implies that the village is located such that it cannot be supplied economically with central station utility power.

A photovoltaic village power system is an electrical power source designed for remote, on-site applications. The system also includes provisions for power distribution to various locations within the village for operating the local loads, e.g., lighting, refrigerators, water pumps, or other equipment. Figure 6 provides a schematic representation of a likely power system for a village of 250 people. (The solar photovoltaic array for "basic needs" is estimated to be 3.5 kW peak in the southwestern U. S. or other areas receiving about 500 langleys per day.) Additional capacity would provide for cottage industry and other needs. For purposes of discussion a 6 kW peak village power system is assumed for a community of 250 people, i.e., 24 watt peak/person.

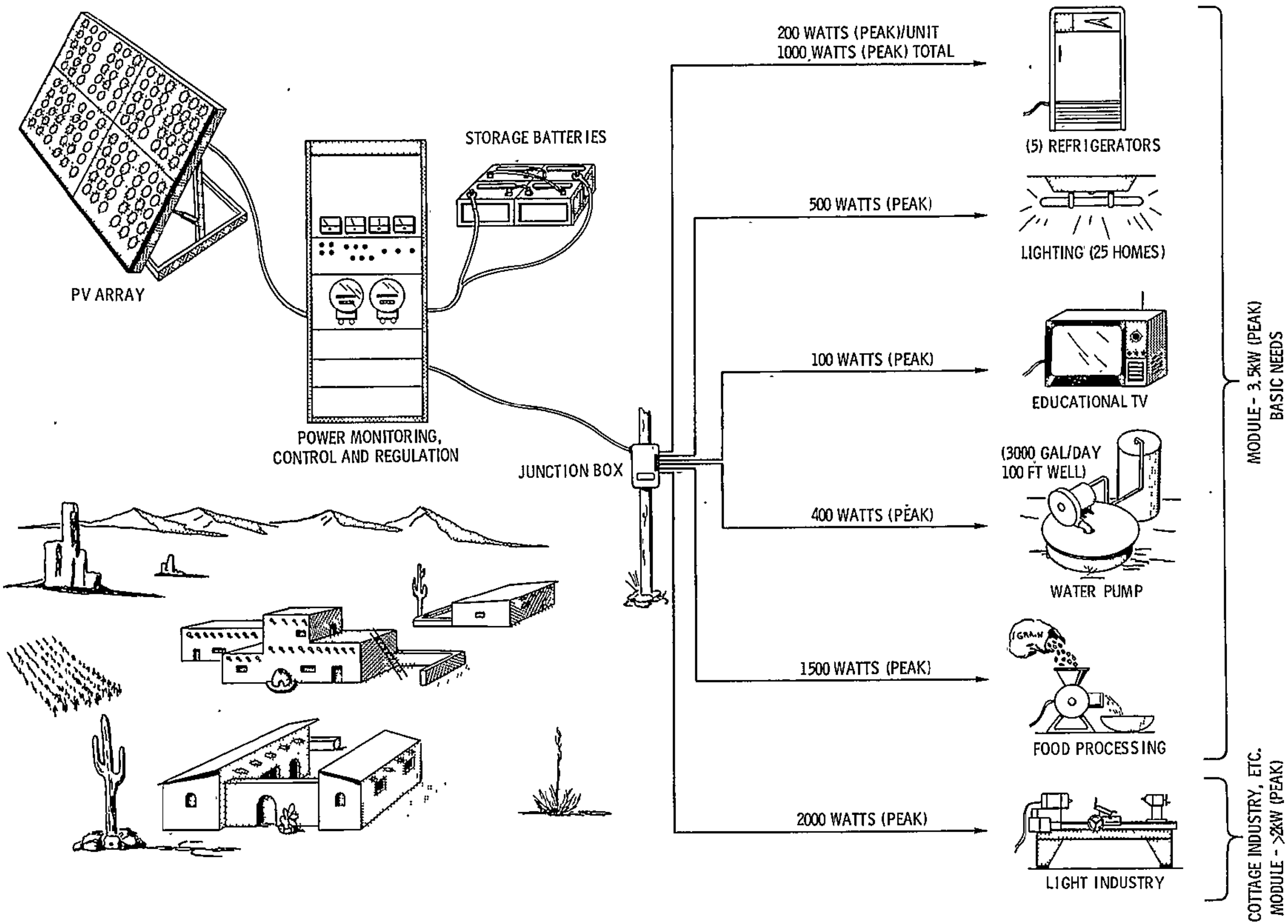


FIGURE 6

Representative Photovoltaic Village Power System (Pop. 250)

Based on comparison with competing systems, market penetration is economically feasible at present.

B. APPLICATIONS IMPLEMENTATION

Responsibilities of the Application Implementation activity involve the detailed design, specification, fabrication, installation and support of photovoltaic power systems for ERDA-approved application experiments. Approved applications are those which have passed the screening procedure noted in the previous section (III-A) and have been approved by ERDA. Upon approval, joint agreements with the user are negotiated and the photovoltaic power system designed. Modules for the proposed system are then obtained from the solar cell module purchases made by the Jet Propulsion Laboratory under the ERDA/JPL LSSA Project. These solar cell modules, some 46 kilowatts (peak), were the first large block procurement (Block I) from industry by the ERDA national program. The purchase represented a sampling of the state-of-the-art of solar cell modules then being produced by four different U. S. manufacturers for the commercial terrestrial solar cell market. Each brand represented a different manufacturing approach to the production of a solar cell module. Common elements included only the module nominal voltage (6 VDC), the use of single crystal silicon solar cells, and the assembly of the cells into a flat-plate module producing at least 5 watts peak without employing any form of sunlight concentration.

Following initial performance characterization, the modules are assembled into an array and coupled to the balance of the system which typically includes controls, batteries, wiring and instrumentation. When fabrication is complete, the photovoltaic system is checked at LeRC under simulated operating conditions before being installed at the application site. The design of these systems and the sizing of the solar cell array are particularly dependent upon site location, atmospheric conditions, and the accuracy with which the load can be defined. The size of the photovoltaic array and the battery storage capacity required for a given system are determined using a LeRC-developed computerized technique. The program determines:

- the number of parallel solar cells needed to meet the total ampere-hour requirements of the load, including battery charging losses
- the optimum array tilt angle
- the battery "depth-of-discharge;" or array surplus ampere-hours generated each month

The inputs to this program for any site being considered are:

- average daily insolation
- average daily cloud cover
- atmospheric turbidity
- atmospheric precipitable water
- site latitude
- power system load and load profile

During this report period, Applications Implementation activities involved the development of a total of 34 photovoltaic arrays. Of these, 17 were complete photovoltaic power systems for civilian applications and 17 were arrays fabricated for DoD. The civilian applications included both "display-demonstrations" of photovoltaic systems at high "visibility" locations as well as systems for operational needs in remote, unelectrified areas. Assistance was provided for DoD selected applications chosen to investigate the use of photovoltaic energy to power military support functions such as field communications, water purification, training radar, and battery charging. Individual civilian and DoD applications ranged in array size from 23 to 10,633 watts (10.6 kW). Although system design, power conditioning, battery charge regulators, and instrumentation and control are specified by LeRC personnel, systems operation is exclusively by users in order to provide the user staff experience with photovoltaic systems. Each application experiment provides the user with learning experiences in photovoltaic technology as training to stimulate future user adoption of photovoltaic systems for operational needs. Joint experiments of photovoltaic energy-powered applications implemented during the report period are summarized in Table 3. A more detailed description of each of these experiments is presented below.

1. Civilian Applications

a. Refrigerator for Trail Crew Camp

During the summer of 1976, a 4 cu. ft. portable commercial refrigerator was installed at a trail construction camp in Isle Royale National Park, Michigan. The power system utilized a 220 watt solar array. Isle Royale National Park is a wilderness island in northern Lake Superior. Electrical power, generated on site, is available only at the Park Headquarters, the visitor center, and the lodge area. Each year the island is visited by many thousands of visitors, 90% of whom hike and camp in the back country. Wilderness trails are constructed and maintained by trail crews working out of camps like the one at which the refrigerator is located. The remoteness of the camps allows for food resupply only once a week. With refrigeration, the crew enjoyed a more varied and nutritious diet, including perishable foods. A technical report of this experiment is presented in "Photovoltaic Powered Refrigerator Experiment at Isle Royale National Park," ERDA/NASA 1022/77-15, June 1977.

TABLE 3

Summary of Special and Government Applications Experiments

Description	User	Location	Total Power (Watts)	System Voltage	Battery Storage Size (Amp-Hrs)	Operational Period
Refrigerator for trail crew camp	National Park Service	Isle Royale, Lake Superior, Michigan	220	12	600	5/76-10/76
Refrigerator for remote Indian village	Indian Health Service	Papago Indian Reservation, Sil Nakya Arizona	330	12	600	7/76
Electric vehicle battery recharging	National Park Service	Washington, D. C.	1,776	36	None	7/76-9/76
Forest lookout tower & services (2)	U. S. Forest Service	Antelope Peak, Lassen National Forest & Pilot Peak, Plumas National Forest, California	294 ea.	12	3,015 ea.	10/76
Highway warning sign	Arizona Department of Transportation	Interstate 10 between Phoenix and Tucson	116	12	200	4/77
Insect survey traps (4)	U. S. Department of Agriculture	College Station, Texas Blacklight (2) Charged Grid (2)	 163 ea. 23 ea.	 12 12	 400 ea. 100 ea.	 5/77
Water cooler	Owens Valley Inter-agency Committee	Visitor Center, Lone Pine, California	446	120	100	Sched. for 10/77
Remote area meteorological observation system (RAMOS) (6)	National Oceanic & Atmospheric Admin.	Halfway Rock, Me. Stratford Shoals, N.Y. Loggerhead Key, Fla. Clines Corner, N. Mex. South Point, Hawaii Pt. Retreat, Alaska	111 111 74 74 74 148	24 24 24 24 24 24	60 60 60 60 60 1065	Sched. for 9/77 5/77 Sched. for 10/77 4/77 6/77 Sched. for 7/77
Charge Multiple Size "D" Nicad Batteries (4)	Dept. of Defense	Fort Belvoir, Va.	1@ 163 ea. 3@ 147 ea.	12 12	None None	7/76
Radio console (2)	Dept. of Defense	Ft. Belvoir, Va.	163 ea.	12	None	7/76
Radio relay (8)	Dept. of Defense	Ft. Belvoir, Va.	1@ 37 ea. 7@ 23 ea.	24	None	7/76
Telephone central station	Dept. of Defense	Ft. Belvoir, Va.	2,651	48	375	7/76
Reverse osmosis water purification system	Dept. of Defense	Ft. Belvoir, Va.	10,633	240	90	1/77
Remote radar	Dept. of Defense	China Lake, Calif.	8,131	240	300	3/77

The refrigerator operated from May to October 1976 and is shown in Figure 7. The Park Service was pleased with the experiment and believes the system to be well-suited for wilderness areas. Plans are being developed by the Park Service to power an Isle Royale backcountry ranger camp refrigerator and light with a photovoltaic system.

b. Refrigerator for Indian Village Community Building

A refrigerator similar to the unit used at Isle Royale was installed in the community building of the Papago Indian Village of Sil Nakya, Arizona. Sil Nakya, located 60 miles northwest of Tucson, is home to about 25 people and does not have electrical service. Although the traditional Papago diet does not depend on foods needing refrigeration, several of the residents of Sil Nakya require medicines which must be kept at or below room temperature to preserve effectiveness. Until now these people had to travel 64 miles to and from the Public Health Service Hospital at Sells, Arizona for their medications. The photovoltaically powered refrigerator not only provides for better medical services, but also allows perishable foods to be kept on hand thereby improving the diet of the whole village.

This application brings refrigeration to a people for the first time and provides a dramatic example of the potential impact of such a service on those living in less developed parts of the world. It is illustrated in Figure 8. The application experiment has resulted in plans being made to provide a village power system for the Papago Indian village of Schuchuli. These plans are described in Section III-B-1-i.

c. Electric Vehicle Recharging

A 1.78 kW solar cell array operated as a display from July through September 1976 at the Festival of American Folklife on the Mall in Washington,

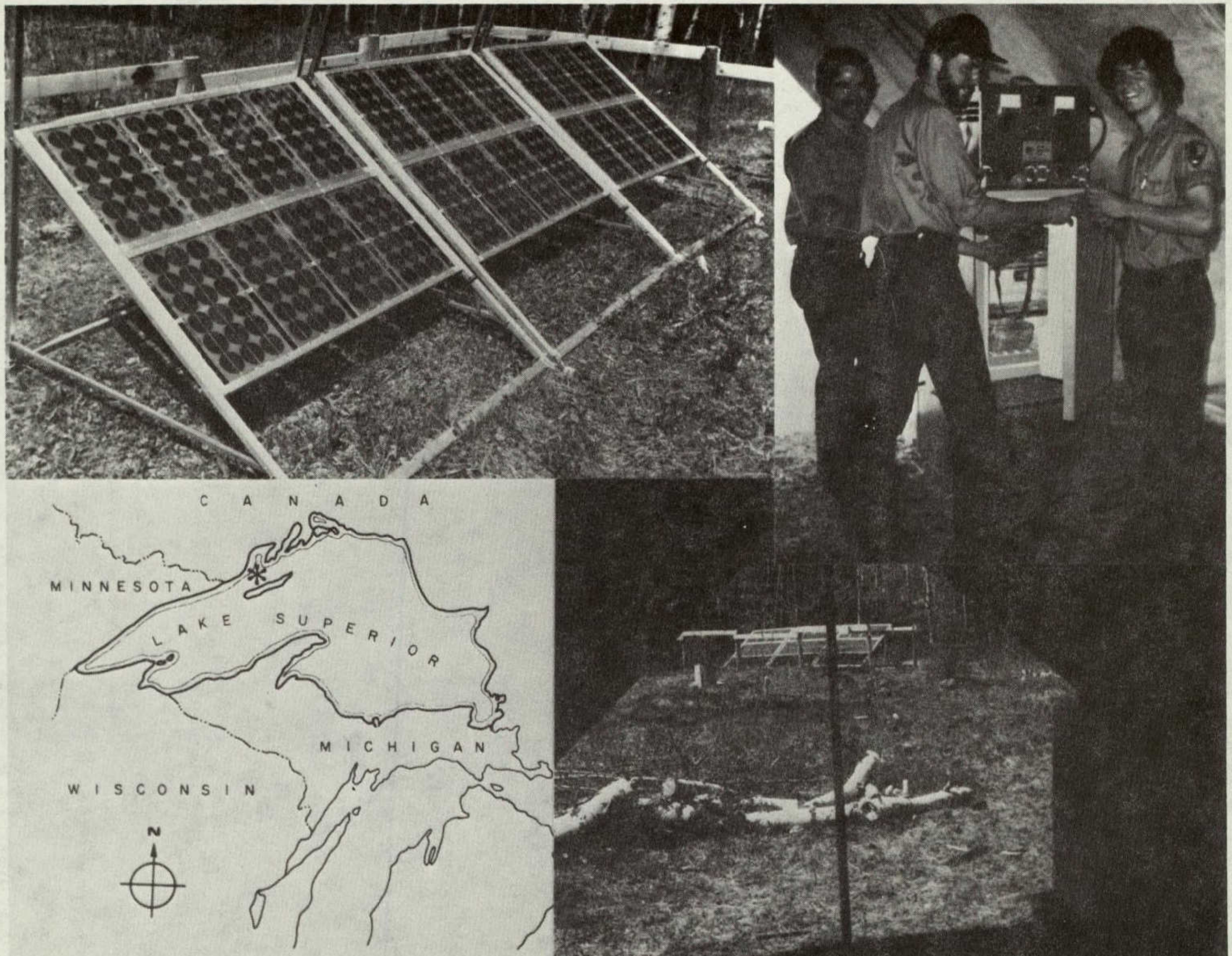


FIGURE 7

Photovoltaic Powered Refrigerator

At Wilderness Trail Construction Camp - Isle Royale National Park - Michigan

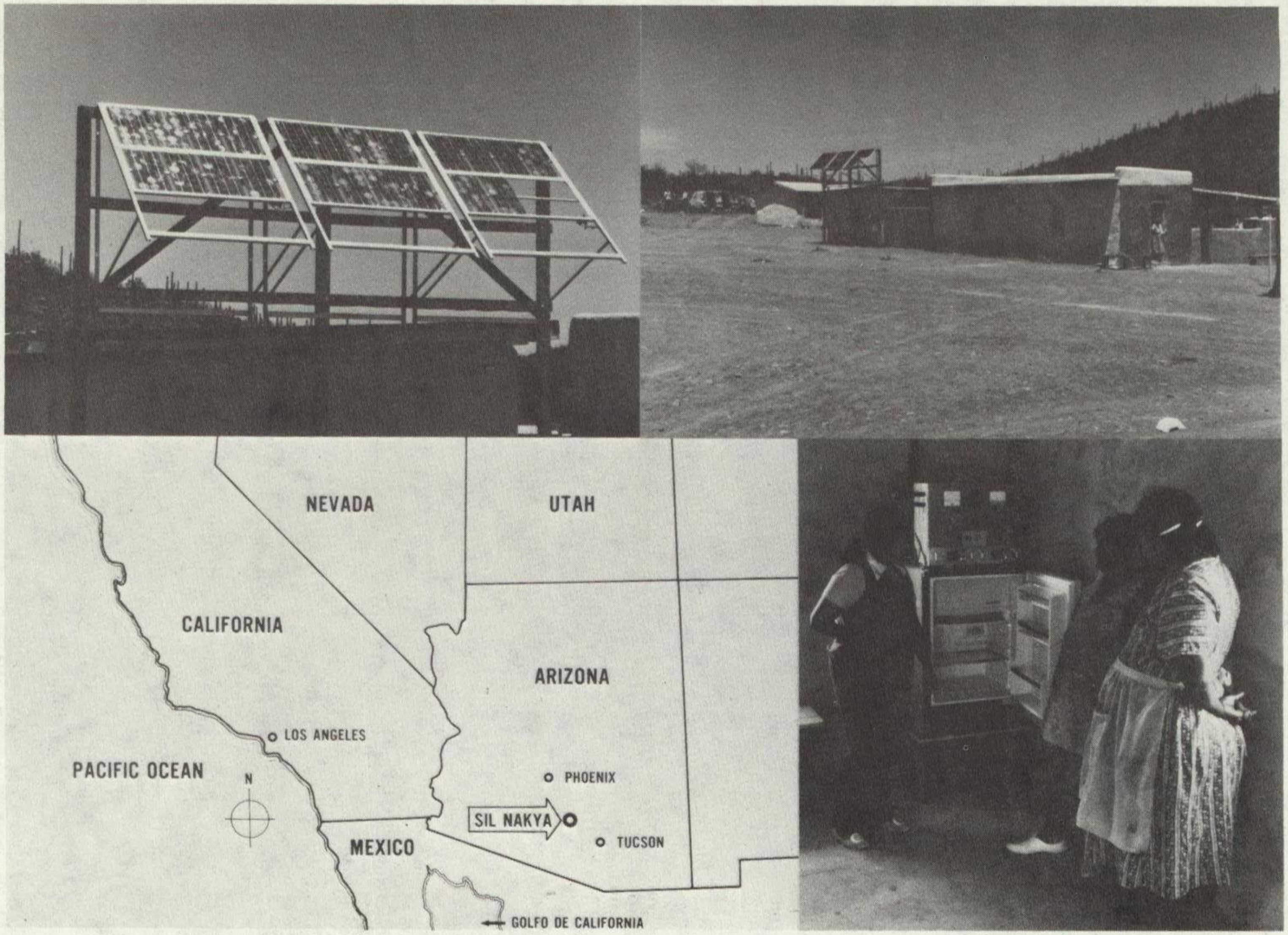


FIGURE 8

Photovoltaic Powered Refrigerator

At Papago Indian Village of Sil Nakya, Arizona

D. C. The National Park Service, responsible for Festival operations and maintenance, employed a large number of electric vehicles for personnel transportation, security, trash pickup, and other jobs. The solar array was used to recharge batteries for several of these service vehicles. This is shown in Figure 9. A display panel mounted adjacent to the solar array provided a brief explanation of the application, basic information about solar photovoltaic power, and ERDA's role in promoting the development of solar cell power.

The Festival of American Folklife, a showcase of the nation's cultural heritage, attracted visitors from all parts of the USA. Thus, the setting provided high visibility to this display of photovoltaics at work. At the close of the Festival, the solar array was shipped to DoD for use with a military application.

d. Forest Lookout Towers

Solar cell arrays are providing complete electrical power for each of two newly designed U. S. Forest Service forest lookout towers. The systems were installed in September 1976 on Antelope Peak in the Lassen National Forest and Pilot Peak in the Plumas National Forest (both in northern California). The towers are manned continuously throughout the fire season (5-6 months per year). They are among the first of a new design which will eventually replace many old towers. The solar cell array was designed to blend harmoniously with the architecture of the building shown in Figure 10. Photovoltaic power is provided for a refrigerator, lights, water pump and Forest Service radio.

Each complete photovoltaic power system consists of a 294 watt solar cell array, 3000 ampere-hours of battery storage, a battery charge controller and instrumentation to indicate the status of the power system. The

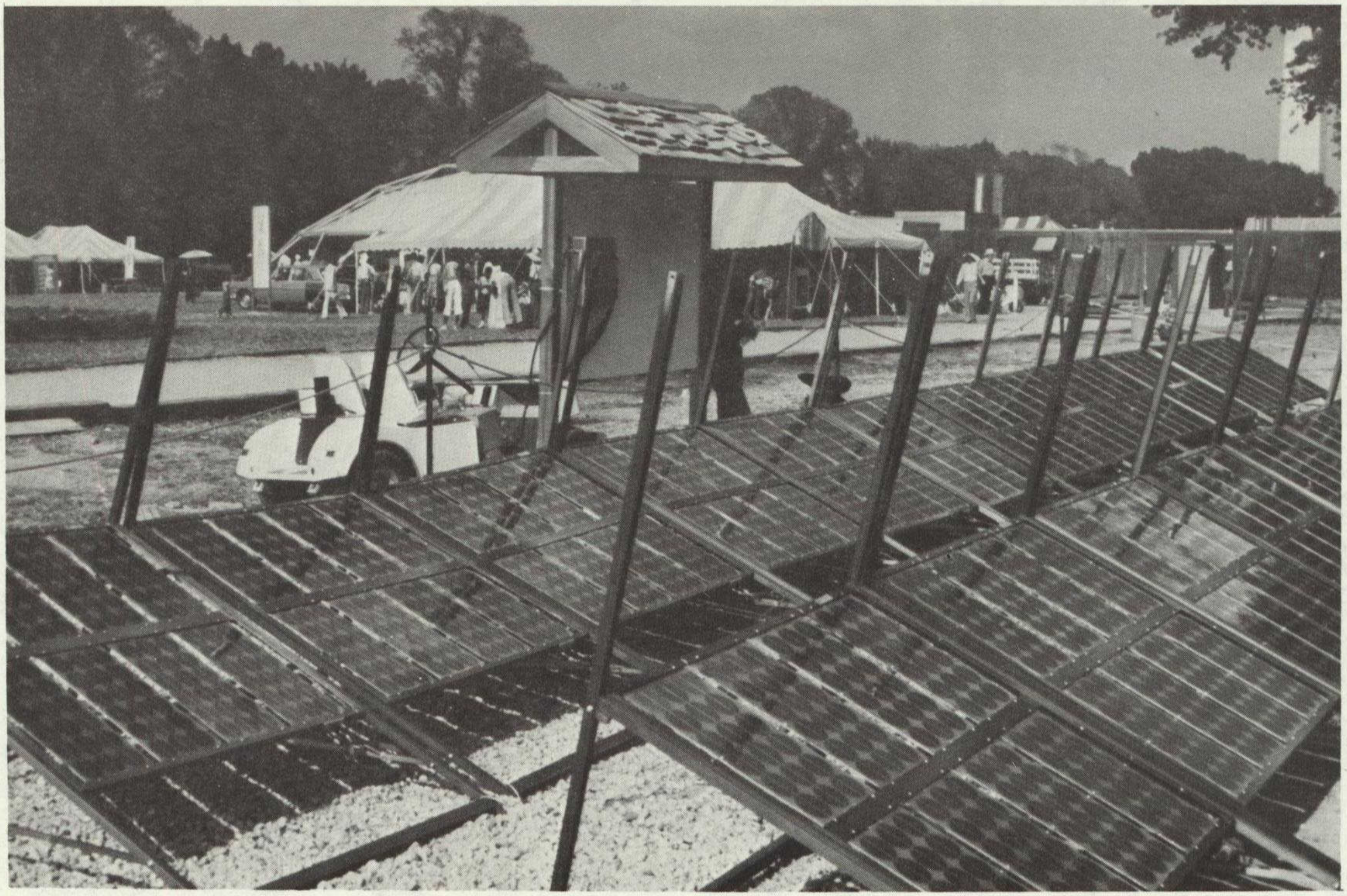


FIGURE 9

Solar Array Used To Recharge Batteries Of Service Vehicles

Festival Of American Folklife, Washington, D.C.

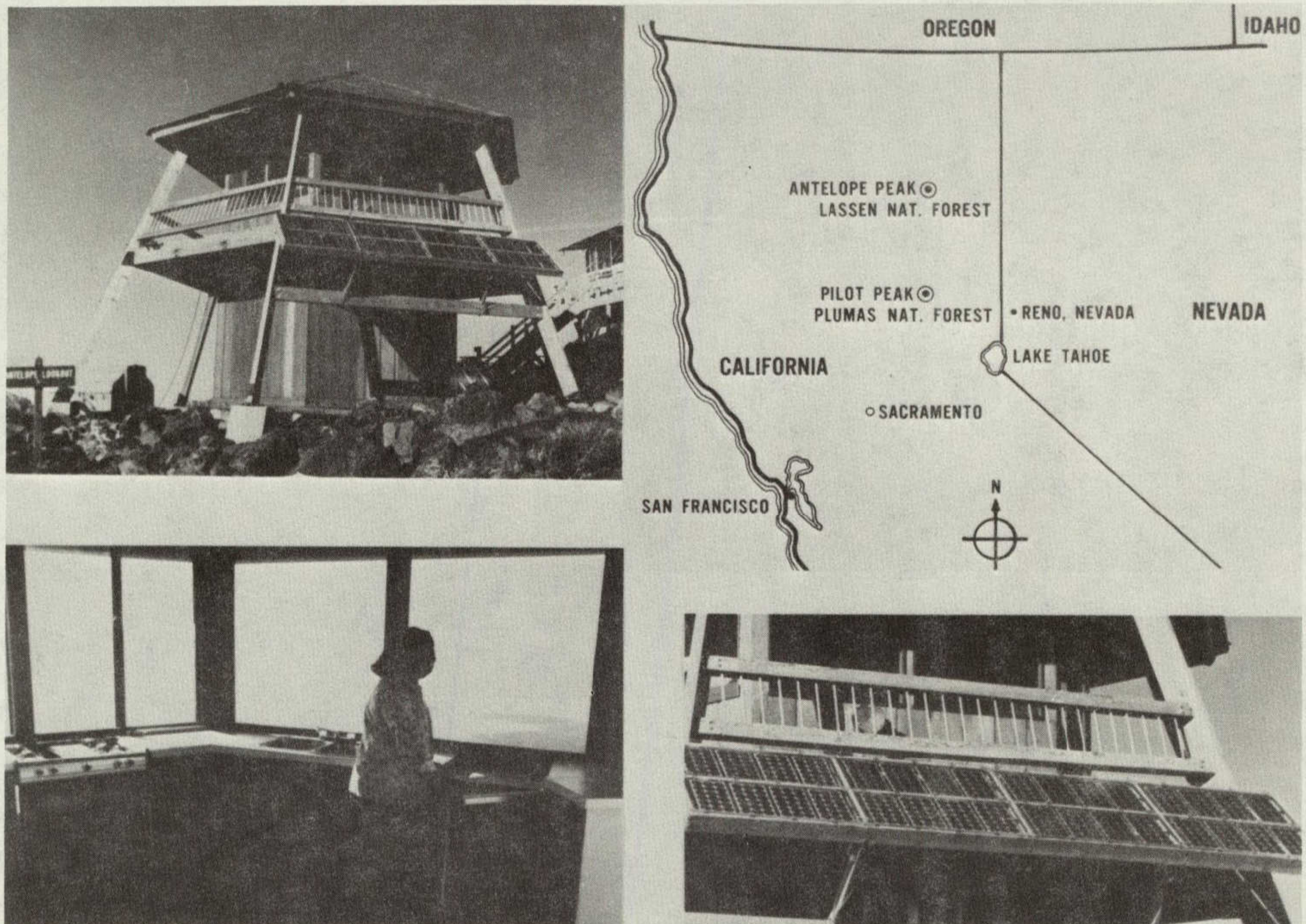


FIGURE 10
Photovoltaic Powered Forest Lookout Towers
Lassen And Plumas National Forests, California

Forest Service has been extremely well satisfied with the systems, and is planning to use photovoltaics to provide partial power for another tower and to power several radio repeaters.

Photovoltaic power for forest lookouts not only makes living conditions considerably more pleasant for lookout personnel, but also saves the Forest Service the considerable time, trouble and expense of procuring, storing and transporting fuels to these remote locations for other types of electrical generators.

e. Arizona Dust Storm Warning Sign

Solar energy is now providing electric power to operate a dust storm warning sign on Interstate 10 in Arizona between Phoenix and Tucson. The sign, powered by a photovoltaic power system, has been operational since April 19, 1977, as a joint experiment with the Arizona Department of Transportation (ADOT). This is shown in Figure 11.

The sign, operated by a 116 watt solar cell array, is one in a network of 40 radio-controlled highway signs in the Phoenix-Tucson-Gila Bend region erected 2 to 3 years ago by ADOT to alleviate chain-reaction accidents caused by low visibility driving conditions resulting from blowing dust. When conditions are such that dust storms are possible, the warning system is activated by a radio control link from a Department of Public Safety dispatcher in Phoenix. On signal, the signs change from a normal "Interstate 10" directional information mode to "Dust Storm Alert, Radio 550/620/910" or "Gusty Winds - Use Caution." In addition to powering the changeable message feature, the photovoltaic power system also supplies electricity for sign lighting in the "Dust Storm Alert" mode and for radio communications. The original power source

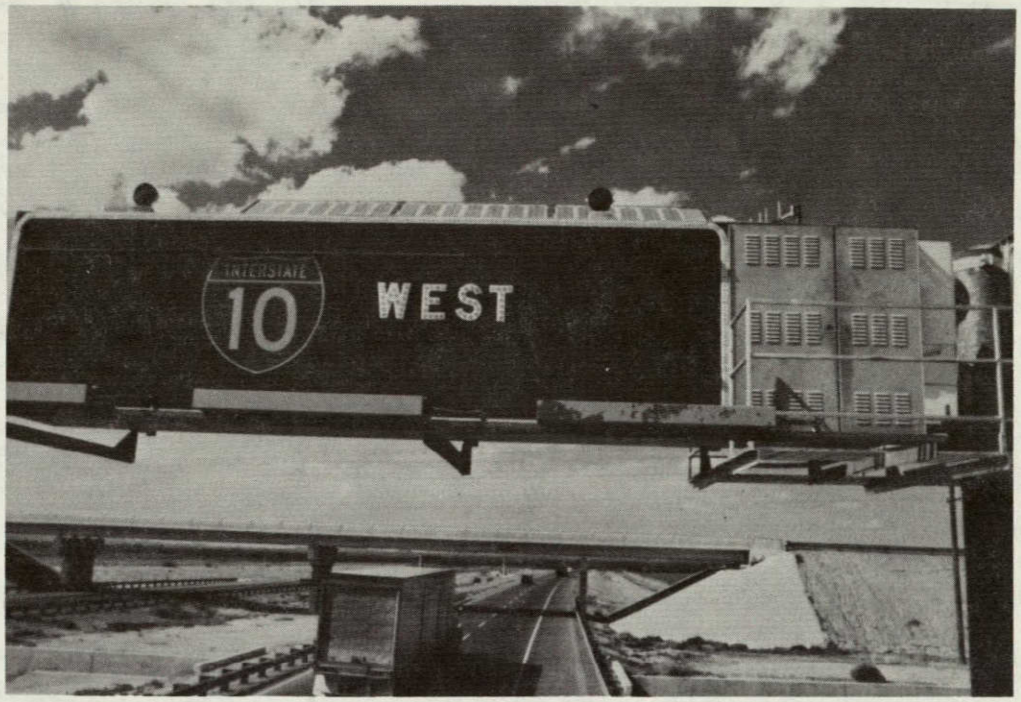


FIGURE 11

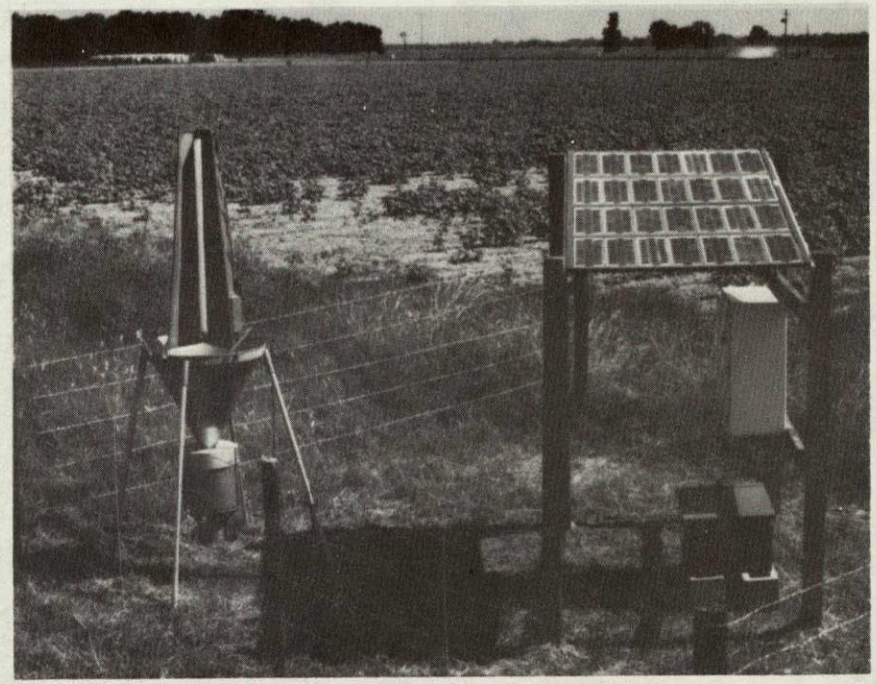
Photovoltaic Powered Dust Storm Warning Sign On
Interstate 10 Between Phoenix and Tucson

for the sign was a propane fueled, 60-watt, thermoelectric generator. Now, solar cell power provides a less expensive operating system. The Arizona Department of Transportation is currently investigating other potential applications of photovoltaic power sources.

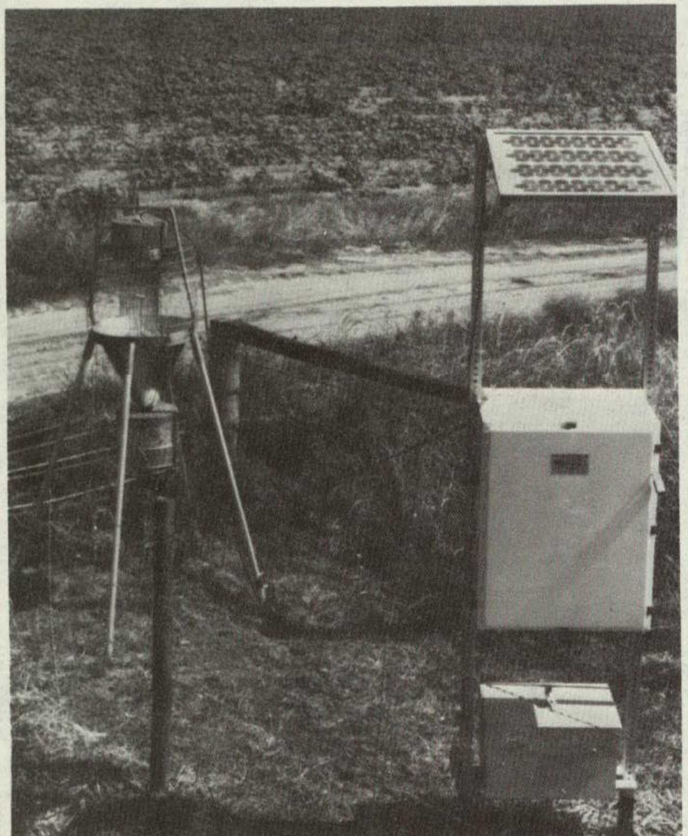
f. Insect Survey Traps

Solar cell arrays are now providing electric power for four insect survey traps near Texas A&M University in College Station, Texas. The traps were designed and built by the Agricultural Research Service (ARS-Cotton Pest Control Equipment and Methods Research Unit) of the U. S. Department of Agriculture at College Station and are shown in Figure 12. The four traps are of two different types. Two are charged grid traps each requiring a 23 watt solar cell array and two are fluorescent light traps each requiring a 163 watt array.

Insect survey traps are used to determine population patterns of harmful insects so that effective pest control programs can be initiated thereby reducing damage to crops. One type of trap utilizes a fluorescent black-light to attract insects; another kills the insects on an electric grid after they have been attracted by a synthetic pheromone (sex attractant). To date, a network of these types of traps have been utility-powered by means of long extension cords; consequently, flexibility of siting was greatly limited. With photovoltaic power ARS scientists are not constrained in the conduct of insect studies; traps can be placed in the most advantageous and effective locations. The data gathered on insects collected by the network of traps is used in computer programs which allow ARS scientists to predict future insect populations. Preliminary reactions to the photovoltaic powered survey traps by ARS have been favorable based on the one month's operation to date.



BLACKLIGHT TYPE
(140 Peak Watt Array)



CHARGED GRID TYPE
(20 Peak Watt Array)

FIGURE 12

Photovoltaic Powered Insect Survey Traps

Although the insect survey trap network near Texas A&M is concerned particularly with the cotton boll weevil, similar traps are also used for many other crop-destroying pests; consequently, the overall potential market for solar-powered units is believed to be significant.

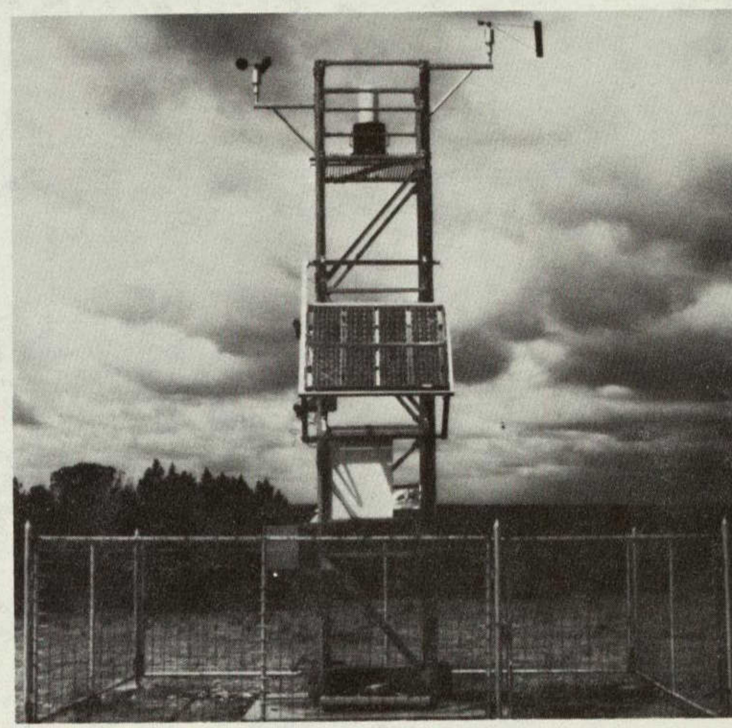
g. National Oceanic and Atmospheric Administration (NOAA) Remote Automatic Meteorological Observation System (RAMOS)

The National Weather Services (NWS) of NOAA is examining the use of solar cell arrays as power sources for RAMOS, which is the heart of a planned nationwide network of advanced weather stations. Six new solar cell powered stations are the first of a new series of 39 automatic weather stations developed by the NWS. These six test sites located offshore in Maine, New York, and Florida and land-based in New Mexico, Alaska, and Hawaii, will provide the Weather Service with field information needed to further evaluate the applicability of photovoltaics. Typical installations are shown in Figure 13. The meteorological load is continuous with instrument interrogation occurring hourly. Data collected consists of wind speed and direction, dew point temperature, ambient temperature, atmospheric pressure, rainfall, and rainfall last 10 minutes. In addition, the photovoltaic system instrumentation and RAMOS data transmitter are powered by this system. As of June 30, 1977, the New Mexico, New York, and Hawaii RAMOS were operational. The Alaska, Maine, and Florida stations are scheduled to begin operation in the period July 1977 - October 1977.

h. Lone Pine Visitor Center

A photovoltaic-powered water cooler has been designed and fabricated for installation at the Owens Valley Interagency Visitor Center, Lone Pine, California. The experiment is intended as a display for the

STRATFORD SHOALS, LONG ISLAND SOUND



CLINES CORNERS, NEW MEXICO

FIGURE 13

Photovoltaic Remote Automatic Meteorological Observation System Stations, National Weather Service general public visiting the center to show the capabilities of photovoltaic power. Particularly, it demonstrates one way to use solar energy for cooling purposes. The system utilizes a 446-watt solar array and has been designed to operate year round. Installation is scheduled for September of 1977.

i. Papago Indian Village Power System

A photovoltaic system is being designed to supply power for water pumping and auxiliary domestic loads for an Indian village (Schuchuli) located on the Papago Indian reservation in Arizona. This village, home to about 95 people, is 20 miles from the nearest power line. The purpose of this experimental system is to demonstrate the suitability of photovoltaic systems for supplying power to remote villages. This experiment, approved by ERDA in June of 1977, is now in the preliminary design phase. The array size and storage battery capacity is being determined to satisfy estimated village electrical requirements for community water pumping, refrigeration, sewing machine, and laundry as well as lighting in individual homes.

Conceptual designs are being established for array panels, the array field, system control, instrumentation, cabling and intercomponent wiring.

2. Department of Defense Applications Support

The Photovoltaic Tests and Applications Project is also responsible for providing support to DoD applications implemented by the Mobility Equipment Research and Development Command (MERADCOM) located at Ft. Belvoir, Virginia. Six different functional experiments involving a total of 17 arrays were initiated by MERADCOM with design support and photovoltaic array fabrication by LeRC. These applications were summarized in Table 1 and are presented in greater detail below. It should be noted that the technology transfer involved in supporting these experiments has aided DoD in developing their own photovoltaic expertise.

a. Battery Charger

This low-power application was selected for use as a service indoctrination tool and to investigate the possibility of recharging "D" size nickel-cadmium batteries. It is intended to expose all branches of service to photovoltaic power supplies, investigate the characteristics of simple photovoltaic systems, and determine the military feasibility of a photovoltaic power source for recharging secondary batteries in the field. Four systems have been fabricated. Peak power is 147-163 watts with a 12 volt DC system. Two 4 ft. x 4 ft. solar cell panels weighing a total of 120 lbs. are used.

b. Radio Console

A second low-power application was selected, similar in size and power capability to the battery charger. This unit also consists of two 4 ft. x 4 ft. panels having a total peak power of 163 watts. System voltage is 14 volts DC. Since the source is designed for continuous operation, an 85 A-H storage capability is provided. Two of these consoles have been fabricated for use with radio relays.

c. Radio Relay

This system, also of extremely low power, is intended as an experiment to:

- determine the viability of a photovoltaic system as an independent "critical" military power source
- investigate the adequacy of array and storage sizing
- evaluate reliability and performance degradation during an extended operating period

Eight units have been fabricated for evaluation. The initial unit was a single 2 ft. x 4 ft. panel of 37 watts peak power. The remaining seven units each consisted of a single 2 ft. x 2 ft. panel of about 23 watts peak power. All eight units were 24 volt DC systems.

d. Telephone Central Van

The objectives of the telephone central project are to:

- investigate the feasibility of permanently mounting a solar cell array on vehicles (see Figure 14)
- determine the ability of a photovoltaic system to power an intermittent small load with a limited array
- evaluate the adequacy of the storage batteries and the need for a backup power source

This system powers a continuous variable load of 0 to 600 watts. The photovoltaic array consists of 24 4 ft. x 5 ft. panels providing peak power of about 2.6 kW. The system operates at 48 volts DC with a storage capacity of 375 A-H and is shown in Figure 14.

e. Water Purification System

This experiment involves a high power system for a large, mobile, reverse osmosis water purification unit. Design operating period is eight hours per day with a small storage capacity of two hours. This experiment is intended to:

- determine the feasibility of operating a semi-critical load with a photovoltaic array and product, i.e., purified water, storage
- evaluate the size and weight impact of photovoltaic systems used with large, mobile military applications

FIGURE 14
Truck-Mounted Solar Cell Array

- investigate the adequacy of array and storage sizing
- determine if or how often a backup power source is needed during adverse weather conditions

The solar cell array consists of 133 4 ft. x 4 ft. panels providing about 10.6 kW (peak) power at 240 volts DC. Single panel weight is 45 - 60 lbs. depending on module type. A 90 A-H storage capacity is provided. Storage batteries weigh 960 lbs. and have a volume of 5 cubic feet.

f. Remote Training Radar

A remote radar using an 8.1 kW (peak) array is being tested at China Lake, California. This experiment will:

- evaluate array and storage sizing based on seasonal variations
- evaluate reliability and performance degradation in a desert environment
- determine operation and maintenance costs savings compared to motor-generator power supplies

The array consists of 99 4 ft. x 4 ft. panels, each weighing 45 - 60 lbs. depending on module type. System voltage is 240 volts DC. A storage capacity of 300 A-H is provided. Design operating mode is three hours per day, two days per week, during daylight hours.

3. Field Problems and Operating Experience

Continuing technical field support is provided to the user during the operation of an experiment as well as assistance in correcting photovoltaic system performance problems as they occur. Performance data is received and evaluated to determine if the system is operating properly. For example, analysis of actual measured insolation compared to predicted values is a continuous requirement. Any indication of malfunction, failure, or operational problem is analyzed to determine the appropriate corrective action, which may either be undertaken by LeRC personnel or by the user operating staff under LeRC direction. In addition, field inspections of on-going applications are conducted on an annual basis.

The photovoltaic array of the Isle Royale Refrigerator Experiment did not receive predicted insolation values because of greater than expected shade conditions at the site. However, the local temperatures were below normal which caused lower system power demand from the refrigerator. Also, the refrigerator was accidentally left open one day and a substantial battery discharge occurred, although the system continued to operate satisfactorily. Operating experience on this experiment is further detailed in ERDA/NASA 1022/77/15 (See Appendix.)

The Electric Vehicle Recharging Demonstration at the Festival of American Folklife (Section III-B-1-c) encountered no real difficulties. The only problems that occurred were several instances of vehicle battery overcharging due to lack of proper attention by on-site personnel and a reduction in array output current due to dust accumulating on the array surface from a nearby unimproved road.

For the Papago Indian Village Refrigerator Experiment, greater than anticipated summer power demand by the refrigerator due to the high ambient local temperature, was corrected by changing the array tilt angle and by increasing array size to 331 watts. The refrigerator itself was also replaced under warranty because of a mechanical defect.

The Forest Lookout Tower Experiments were installed in September 1976 at the end of the fire season and the towers were unmanned until May 1977. During the unmanned period, array output was used solely to maintain a charge on the storage batteries. Since the reopening of the towers, the systems have been performing satisfactorily.

The Arizona highway dust storm warning sign has been operating according to design. The same is true for the insect survey traps. Those RAMOS experiments installed to date have also been operating satisfactorily.

C. GENERAL ENGINEERING

The General Engineering function provides the technology base for future applications by systems performance evaluation and continuing design analysis. This responsibility requires the continuous review of applications operating data, the identification of technology "gaps," design of test programs to obtain needed data, and the subsequent generation of component equipment designs for improved photovoltaic power systems operation. A major tool used by the function, the Systems Test Facility (STF), will be described in Section III-D.

1. Design Improvements

Support to application experiments through analysis of requirements, problems, and failures provides a means for improving future LeRC applications. From this effort tasks are developed to study, design and test improved components and methods to establish a basis for their incorporation in future systems. Testing of prototype components as well as subsystems using the Systems Test Facility is undertaken to obtain operating experience for definition of operating parameters. As part of these activities, the need for a high efficiency versatile power inverter designed for photovoltaic systems has been recognized. A contract has been awarded to Abacus Controls, Incorporated for the design and fabrication of a 10 KVA self-commutated inverter, custom-tailored for photovoltaic application. A contract has also been awarded to DANMAR, Inc. for the detailed design and fabrication of an associated controller, based on a conceptual design prepared at LeRC. Major operating features of the self-commutated inverter are:

- high efficiency both at full load and light loads
- "stand alone" and utility connection capability
- provision for external control of the operating power level when connected to the utility power line
- use of off-the-shelf technology

The inverter will be designed to an input voltage of 200 to 300 VDC and 240 VAC, single phase, output. Design performance goals are:

- Overload capability
  - peak loads of 150% for one minute and 125% for 15 minutes without damage
- Losses
  - maximum of 250 watts at no load and 1100 watts at full load
- Harmonic distortion
  - maximum of 5%

Performance goals are plotted in Figure 15. Note that the efficiency remains at a high level even at very low loadings, which is a requirement unique to photovoltaic operating applications where the power available from the array is frequently less than peak power rating. Operating parameters of the controller are:

- continuous adjustment of the inverter input power, when connected to the utility line, to equal the power capability of the solar array
- automatic start-up of the inverter at sunrise and shutdown at sunset

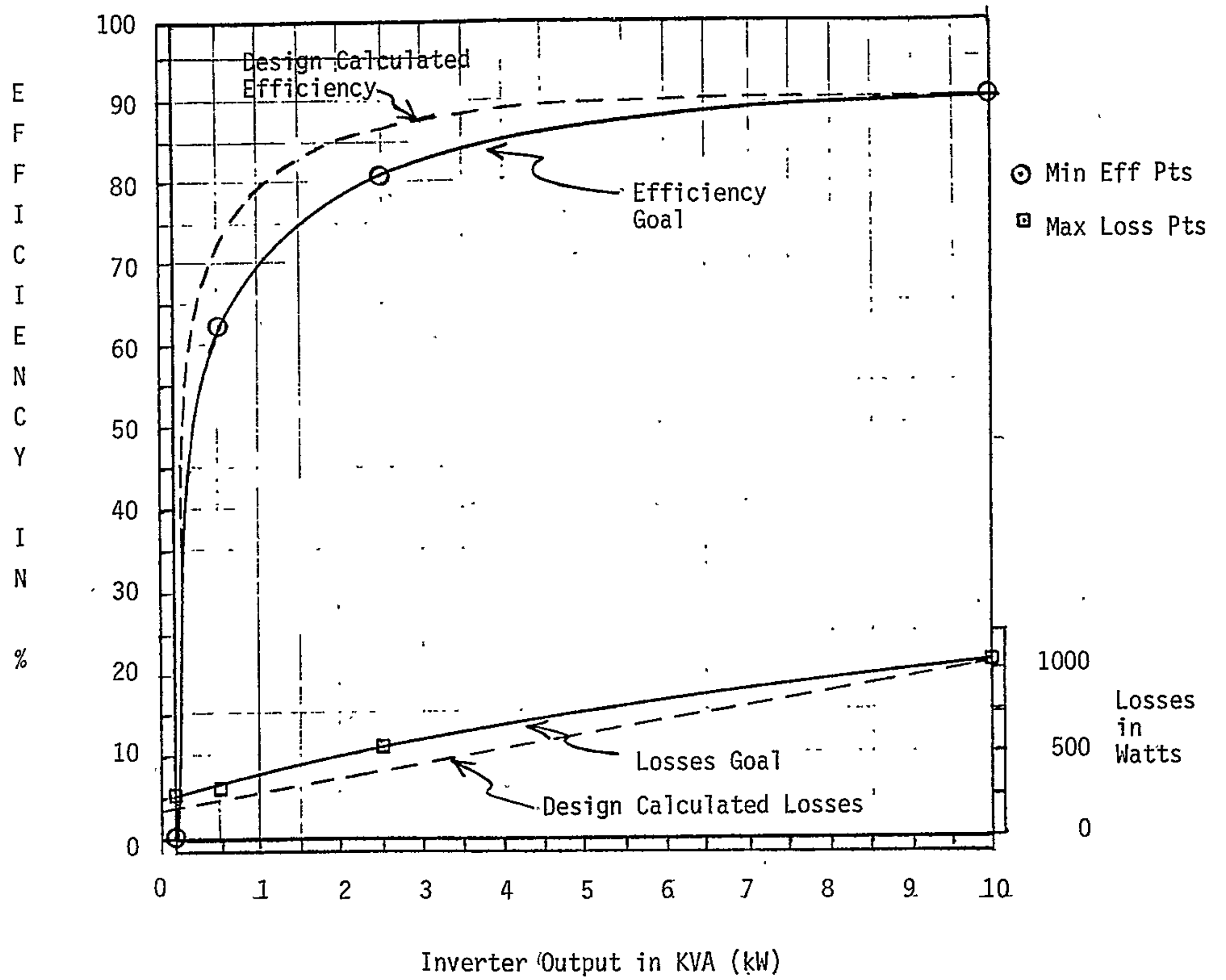


FIGURE 15

10 KVA Self-Commutated Inverter Goals for Efficiency and Losses

The system control concepts from which the contractor is designing the controller are as follows:

- Solar cell voltage at which maximum power is obtained (V_{MP}) can be expressed as fraction of open circuit voltage (V_{OC}): $V_{MP}/V_{OC} = K$ for a given set of temperature and insolation conditions
- The controller will derive a solar array target voltage level from the pilot cell array output for comparison with the solar array voltage and will generate an error signal for control purposes
- The controller will set the solar array operating voltage at maximum power voltage (V_{MP}) by causing the inverter to draw current from the solar array, which will drive the solar array to its maximum power voltage
- The inverter will transfer the power from the solar array to the utility bus. The power level will be that at which the solar array output voltage equals the target voltage set by the controller

Figure 16 shows the current and voltage characteristics for a range of insolation conditions and the associated maximum power points. Examination shows that a relation exists between the open circuit voltage and the voltage at which maximum power is obtained. The variation of that relation with operating conditions is shown in Figure 17.

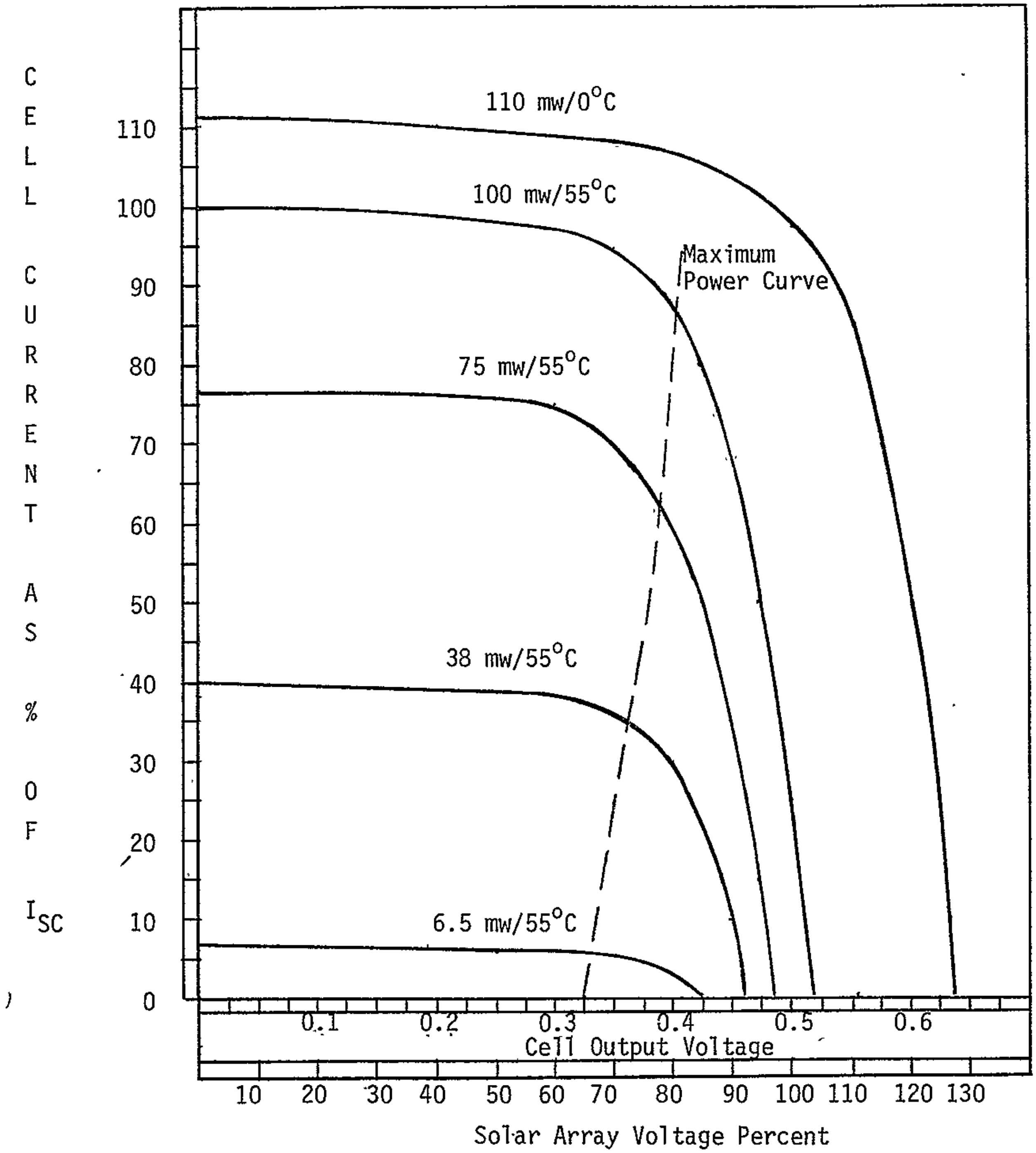


FIGURE 16
Typical Cell I-V Curves Used for Design

LeRC experimental data (measured)
with cell temperature as parameter.

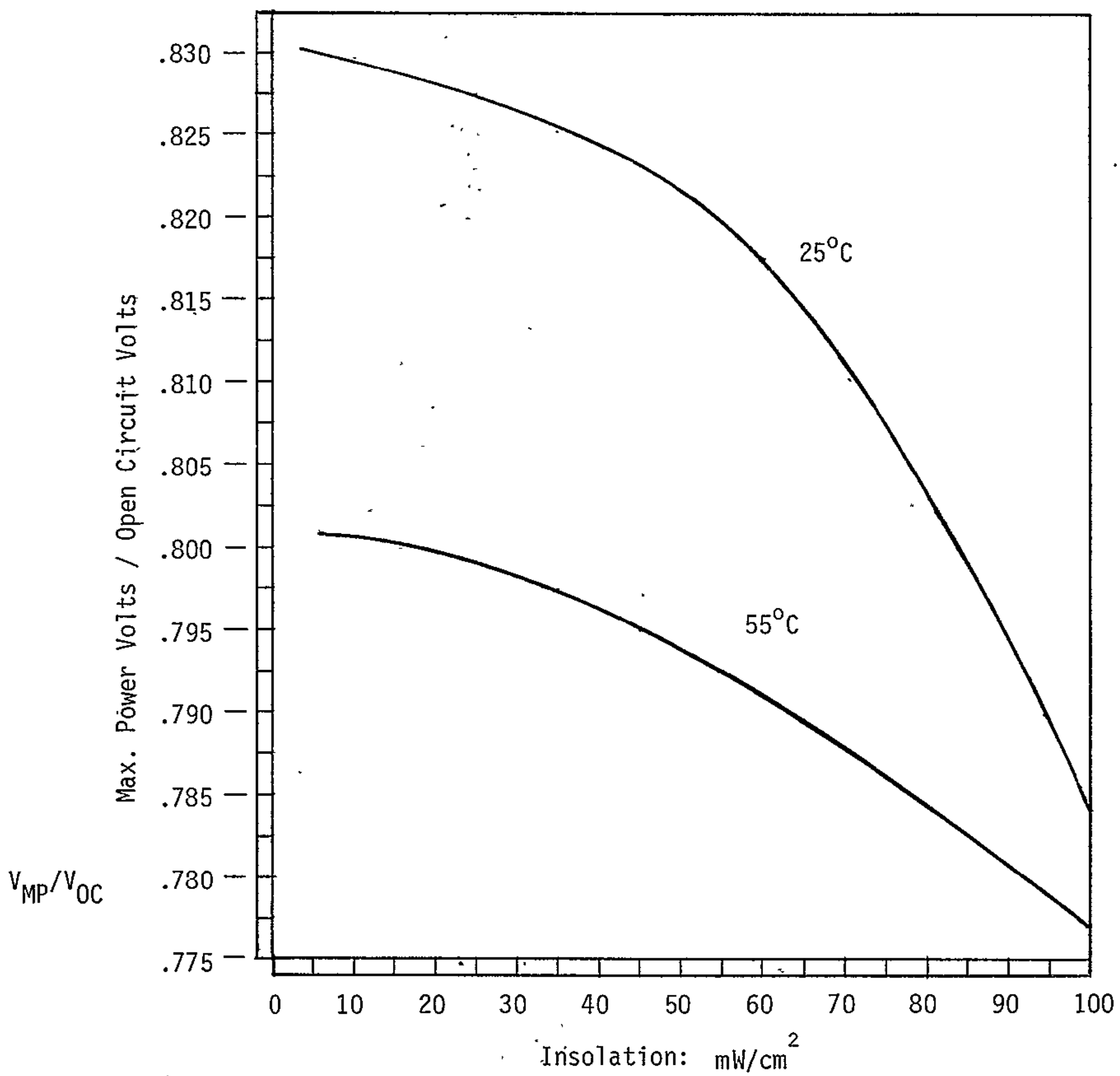


FIGURE 17

Variation of Maximum Power to Open Circuit Voltage
Relationship With Operating Conditions

These curves show that if an arbitrary value of 0.8 (V_{MP}/V_{OC}) is chosen for control, the deviation of actual maximum power voltages with temperature and insolation will be less than 2.5% for most operating points. Likewise, if most of the power were delivered at insolation levels of 70 MW/cm^2 and 50^{o}C then the effective maximum power tracking error using this concept would be less than 1%.

An analog computer simulation has been developed to investigate the stability of the design for the 10 KVA inverter and controller being fabricated. As of June 1977, these units were in the preliminary design phases with delivery to LeRC expected by December 1977.

2. Residential Activities

Another task of the General Engineering function was to assess the technical feasibility of photovoltaic power systems for use in residential applications.

Specific activities conducted in this area were:

- award and monitoring of residential photovoltaic experiment definition studies
- planning for residential prototype tests
- preparation of a proposed national program plan for residential solar photovoltaic power systems implementation

Contracts were awarded in November 1975 for two parallel system studies, Definition Studies for Photovoltaic Residential Prototype Systems, to the General Electric Company and Martin-Marietta Corporation. These studies included the following tasks:

- site selection
- parametric sensitivity analysis of system configurations

- conceptual design of Residential Prototype System Test structure
- development of test plan
- test equipment requirements and test procedures
- institutional problems

Results of the studies were published in December 1976 (see Appendix). Concurrent with these system definition studies, Lewis Research Center undertook related residential application tasks. Effort was directed toward planning for testing and evaluation of photovoltaic energy conversion systems in a residential structure containing typical residential loads. The work involved surveying commercial sources for suitable equipment and components; determining typical residential load profiles based on various loads and sources of heating and cooling; examining stand-alone versus utility-backup modes of operation, and other factors.

In addition to the residential studies and experiment planning activity, the Project was requested by ERDA to draft a proposed National Photovoltaic Residential Development Plan. The plan was to set forth the scope of activities, stages, and phasing required to carry photovoltaic power systems for residences from early small experiments through regional tests and on to demonstrations for commercialization. The draft proposed plan was completed early in December 1976 and submitted to ERDA for their consideration.

At approximately the same time (November 1976) ERDA completed a reassessment of all residential activity and concluded that the Tests and Applications Project should focus on applications which offered the potential for cost-effectiveness in a time frame significantly shorter than that forecast for residential applications at the time. Further work on residential activities was therefore discontinued with the exception of completion of the General Electric and Martin-Marietta studies and the draft national residential plan.

D. SYSTEMS TEST FACILITY

The Systems Test Facility (STF) is designed to permit "breadboard" testing of photovoltaic systems and components in order to evaluate design methods, system operating characteristics, and system performance. The STF has been constructed at LeRC as a national facility for use by participants in the ERDA National Photovoltaic Program. A section of the facility's solar array field is shown in Figure 18. Present array power capability is 10 kW peak. Photovoltaic power systems for most of the applications in the ERDA program have never been built before. In essence, the STF solar array provides a permanent calibrated power source by which equipment and other system components can be powered to simulate field operating conditions. The facility officially became operational in December 1976, at the 10 kWp level. To provide additional test capability, the solar array field has been extended to accommodate an additional 30 kW (peak) of array. It is planned that modules will be allocated from future JPL procurements for installation in STF. Total solar array capability will be 40 kWp when all of the present field capacity is filled.

1. Facility Design

The STF has been designed to provide a highly versatile solar energy source and testing device to satisfy developing needs of photovoltaic power systems. The STF array field consists of 240 south-facing 4 ft. x 8 ft. support frames which may be set at any angle from 5° to 85° from the horizontal.

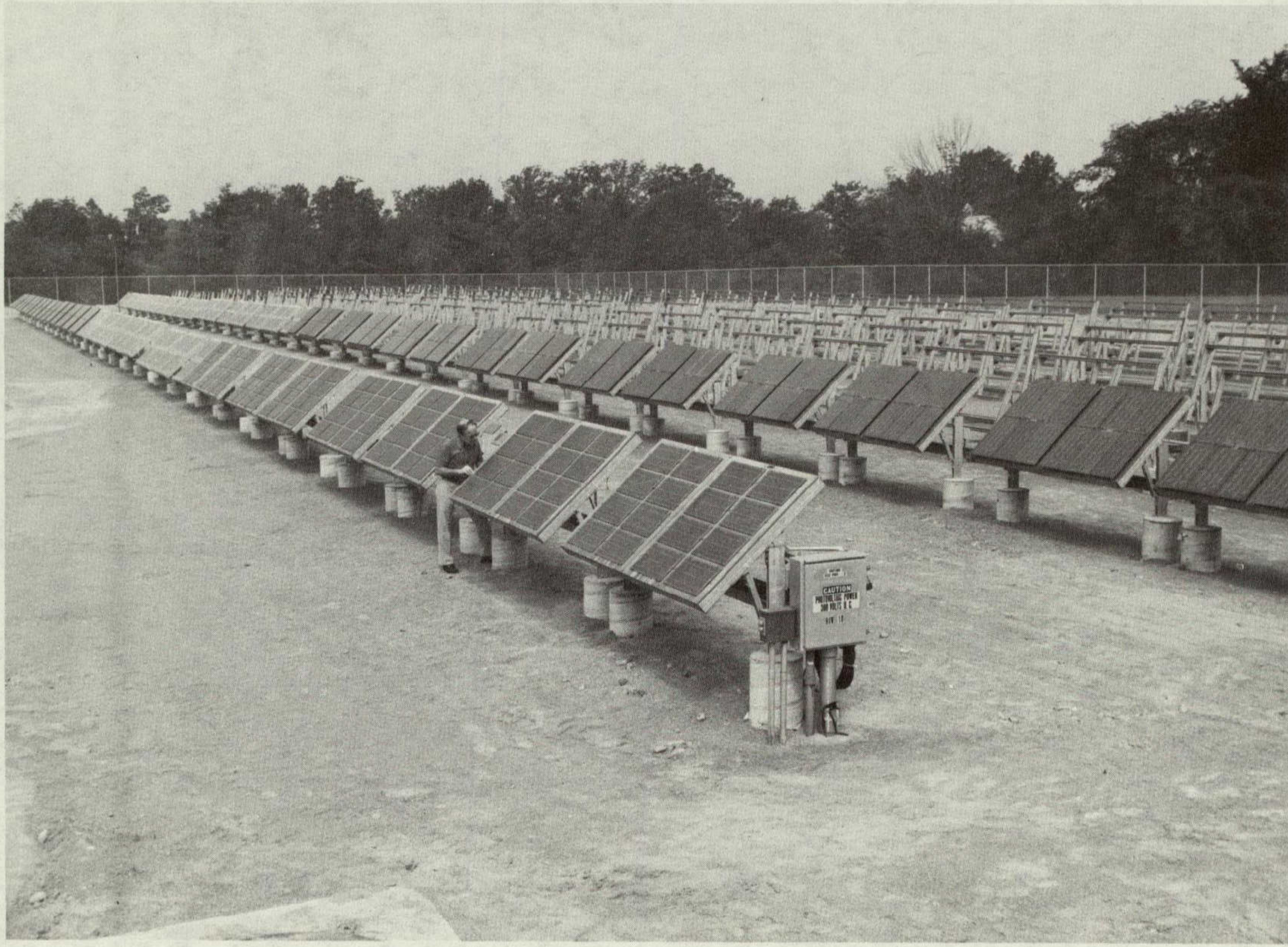


FIGURE 18
Systems Test Facility Solar Array Field

There are eight rows of 30 frames each. Each frame can be equipped with modules of nearly any design. The present 10 kWp array utilizes modules from three manufacturers. The remaining six rows (30 kW) when equipped with modules will bring the array capability to 40 kW peak. The entire field is fenced to prohibit unauthorized access to the high voltages which are a safety hazard.

The modules may be interconnected electrically in various configurations. As of June 1977, the configuration in place produces an array output voltage (at maximum power point) of about 170 volts. Since the series strings are not all identical due to variations in voltage between module brands, there is a power loss due to mismatch estimated to be about 4%. Four wires per 4 ft. x 8 ft. frame have been installed to the control room to provide flexibility in array electrical configuration.

Wiring from each frame is routed along wiring trays to a terminal cabinet at the end of each row. From there the wiring is routed underground to the control room. Each series string is connected to a solar array busbar in the control room through a switch, an isolation diode and a fuse. The output voltage of the solar array can be changed by reconfiguring the array interconnection in the field or in the control room. The array can also be electrically split into several independent arrays. Many photovoltaic power systems require on-site energy storage. The STF has 48 kWh of lead-acid storage batteries for this purpose. The battery cells are designed to tolerate many deep-discharge cycles. The batteries are housed in a battery shed immediately adjacent to the control room. The battery shed is provided with forced air ventilation and a safety alarm which is triggered by loss of ventilation. Plastic acid-resistant trays are also provided to contain accidental acid spills. Room is available in the shed to expand the on-site storage to as high as 500 kWh.

The batteries may be charged either from the solar array or from the electric utility grid. Each charging method requires separate charging equipment. For the STF as it is presently configured, the batteries are charged by a commercial battery charger operating from the utility power source or from a shunt battery charge controller when charging is supplied by the solar array.

The facility also contains a full complement of instrumentation and data acquisition equipment. Data acquisition can be accomplished through local readout and recording in the control room as well as automatic data processing and reduction through the LeRC central data facility.

Provisions have been made in the control room for interfacing with any type of power conditioning equipment. Since power conditioning specifically tailored for photovoltaic systems is not generally available commercially, none has been provided as a facility component to date. However, some evaluation of one class of inverter has been done and will be discussed in the next subsection.

The facility also contains a 10 kW resistive and inductive variable load bank as well as provisions for utility tie-in to run test configurations involving a utility interconnection. An additional 30 kW programmable load bank is being planned for installation to support the future expansion of the solar array.

2. Initial Testing

a. Line Commutated Inverter

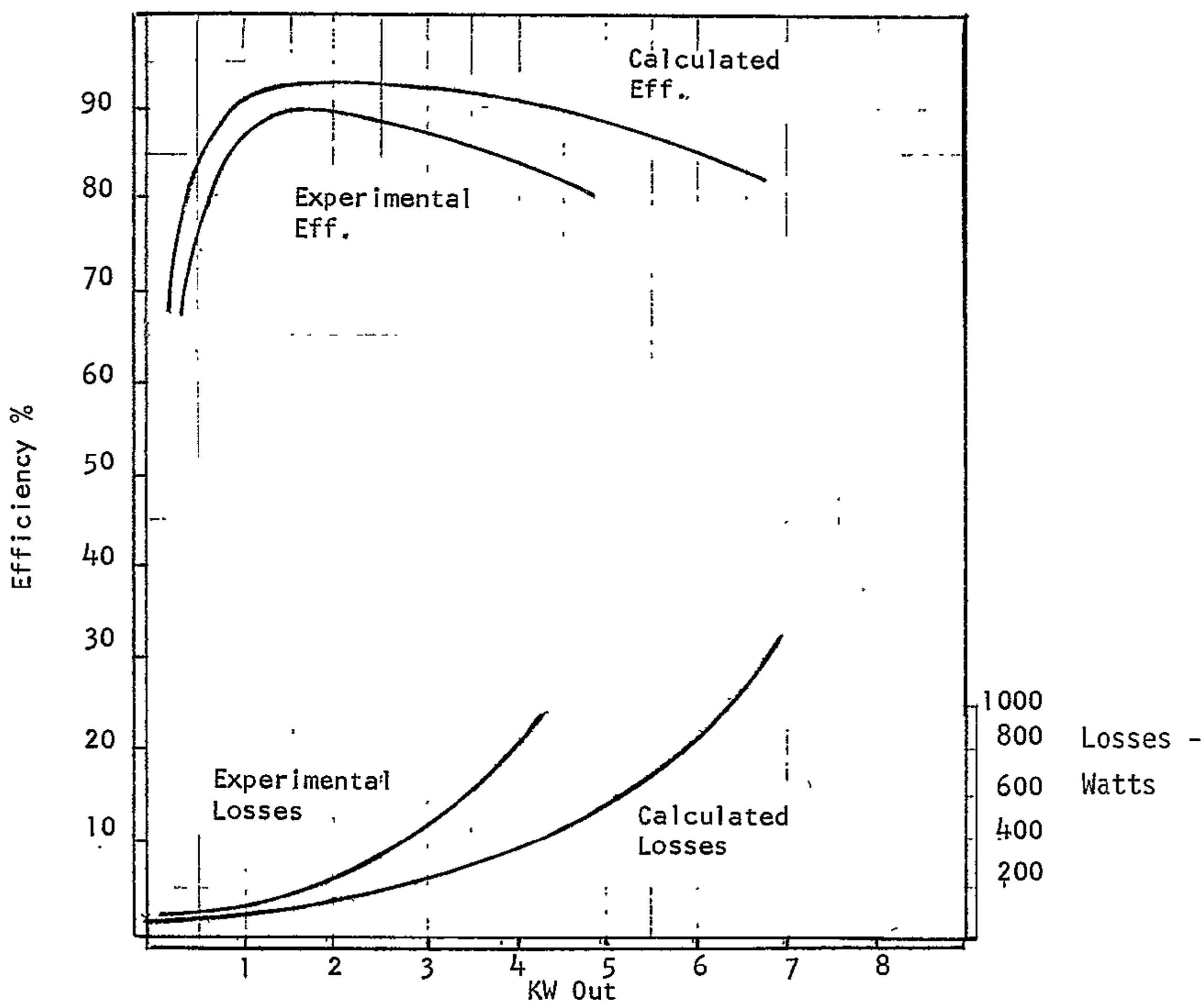
The first component test in the facility involved the baseline performance evaluation of an 8 kW line-commutated inverter. The inverter was a commercial unit originally designed for operation with wind generators and required a utility interface connection for proper operation. The unit thus far has been tested to 5 kW at 170 volts DC input. Performance and efficiency curves for this unit are plotted in Figure 19. This inverter delivers power over a wide range of input voltage which, together with simplicity and low cost, is its major advantage. It was found necessary to connect a capacitor across the array output (or inverter input) for proper operation (Figure 20). In addition the inverter requires a series inductance to increase the performance to acceptable levels.

The interface with the electric utility is achieved through proper matching of transformers and circuit breakers. Various loads, which are used as part of the system test, can be supplied with power from the solar array and/or the utility. With the line commutated inverter in use, the load sharing is accomplished as follows. When the solar array can supply more power than is called for by the load, the excess power is fed into the utility grid. When there is insufficient power from the solar array the load accepts what is available from the array and makes up the difference from the utility network automatically. The self-commutated Abacus 10 KVA inverter, discussed in Section III-C, will have the capability to operate alone or in parallel with an electric utility grid. It is being designed also for efficient operation at partial as well as full loads. This inverter will permit efficient and reliable power conditioning for photovoltaic power systems and will be the first unit using present technology to be specifically tailored for use in photovoltaic systems.

b. <u>Array Environmental Effects</u>

The first array tests initiated have been to study the effects of environmental factors on solar cell array degradation and performance. A number of factors affecting the solar cell array such as wind, ambient temperature,

8 KW LINE COMMUTATED INVERTER



PERFORMANCE CURVES

FIGURE 19

Line Commutated Inverter Performance

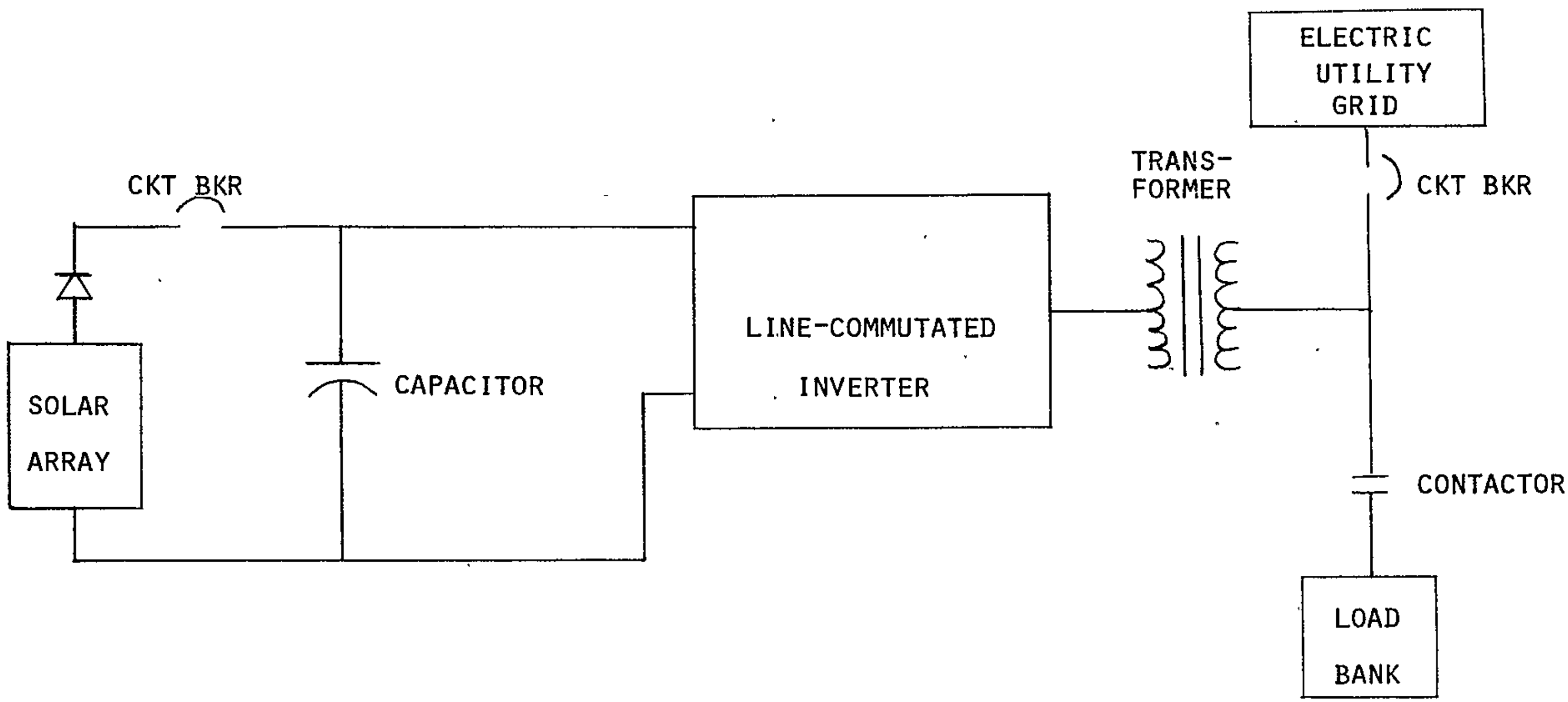


FIGURE 20
Typical Connection of Photovoltaic System With Electric Utility

snow and dirt are being investigated as well as radiated electromagnetic interference and power losses.

The temperature of the solar array depends on the way the solar cell modules are packaged by the manufacturer and the way they are mounted in the STF. The temperature of one type of module with an epoxy-glass substrate which was mounted on plywood with 1/8" standoffs was typically about $30^{o}C$ above ambient temperature. Another with a finned aluminum back not mounted on plywood ran about $10^{o}C$ above ambient temperature. These measurements were made with insolation of 1000 W/m^2 and wind velocity of about 8 miles per hour.

Snow was found to adhere more to the epoxy-glass substrate modules than to the aluminum substrate modules, even though both types used a silicone rubber encapsulant. The array, for all of these observations, was maintained at an angle of 41^{o} to the horizontal.

The effect of dirt on the solar cell modules was very dependent on the construction of the module cover. After about three months exposure in the STF the power loss due to dirt on the modules was about 8%. With washing, most of this loss could be recovered.

Although the effect of environmental factors on the STF are of primary interest it is also necessary to investigate the effect of the STF on the environment. For example, radiated electromagnetic interference (EMI), which could affect communication, was investigated as a function of array size and system component operation. Preliminary results show no EMI problems were detected in operating the line-commutated inverter with the solar array. The EMI levels measured were well below the limits established by the Federal Communications Commission for spurious and harmonic emissions. Testing of the effects of the environment will continue.

E. MEASUREMENTS/STANDARDS/ENDURANCE

1. Measurements

The Measurements task provides reliable, standard measurements of cell and array performance. Independent validation measurements of solar cell and array performance are made in facilities at LeRC which have been dedicated to the purpose and serve the needs of the terrestrial photovoltaic community in the United States. More than 4,000 confirmatory cell, module and array performance measurements have been provided as a service to investigators involved in the National Photovoltaic Energy Conversion Program during the report period. Additionally, approximately 10% of the modules from the Jet Propulsion Laboratory Block I initial procurement were measured to characterize their performance with respect to contract specifications. Many of the measurements conducted in the solar cell test laboratory are performed using a pulsed xenon simulator operated by computer control for both operation and data reduction. The data reduction system, using a Hewlett-Packard 9830 Desk-Top Computer, is the first anywhere to automate nearly all routine solar cell measurements and has more than tripled the number of measurements possible per day with existing personnel. The system takes the measurements, makes all necessary calculations and presents the results in both tabular and graphical formats. Well over a thousand complete sets of data -- including current/voltage (I-V) curves, spectral responses, standard cell calibrations, cell dark characteristics and outdoor array characterizations -- have been made since the system became operative in February 1976. Typical computer plots are presented as Figures 21 to 23 for I-V, spectral response, and cell dark characteristics.

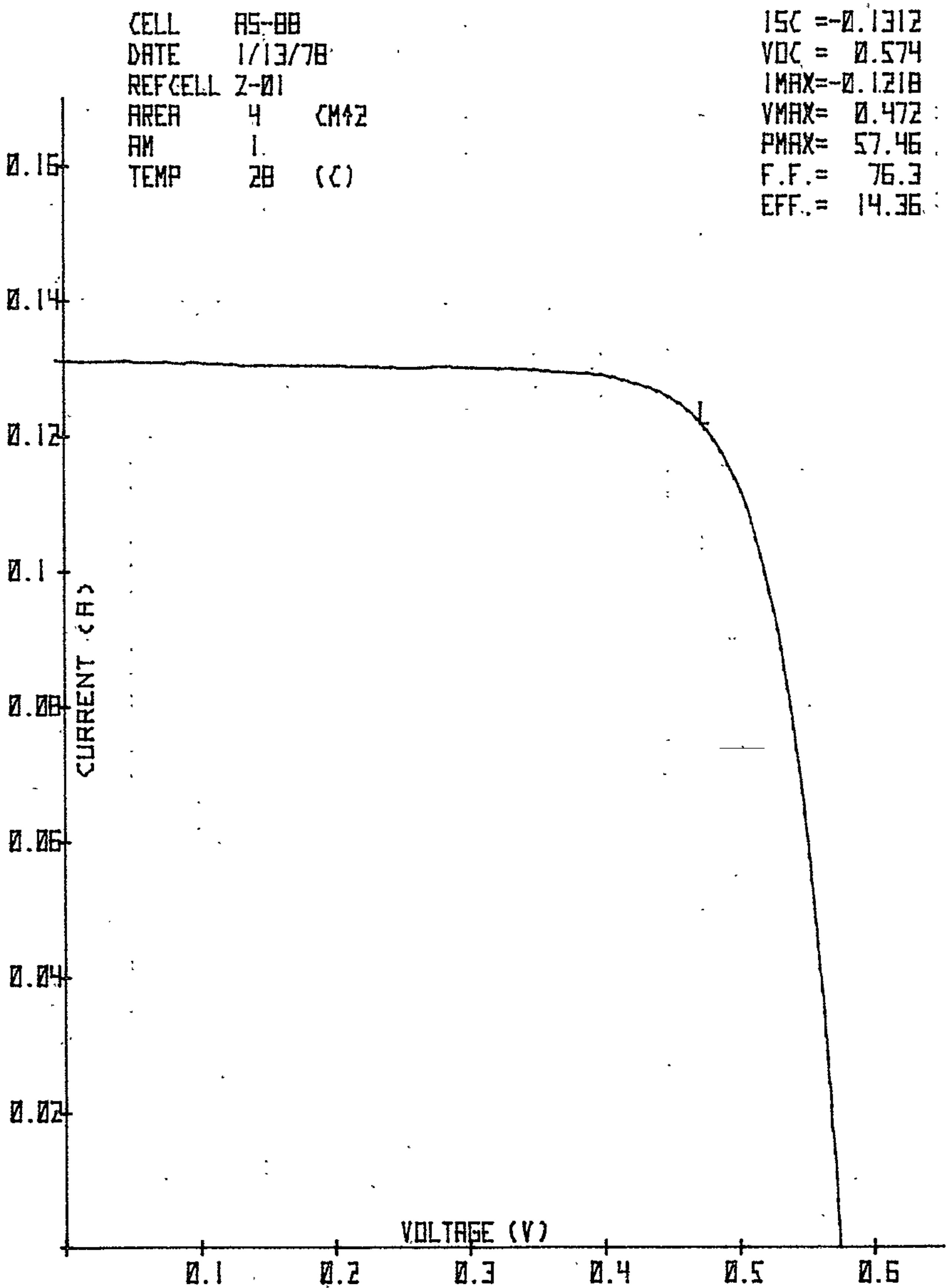


FIGURE 21

Typical Computer Printed I/V Curve

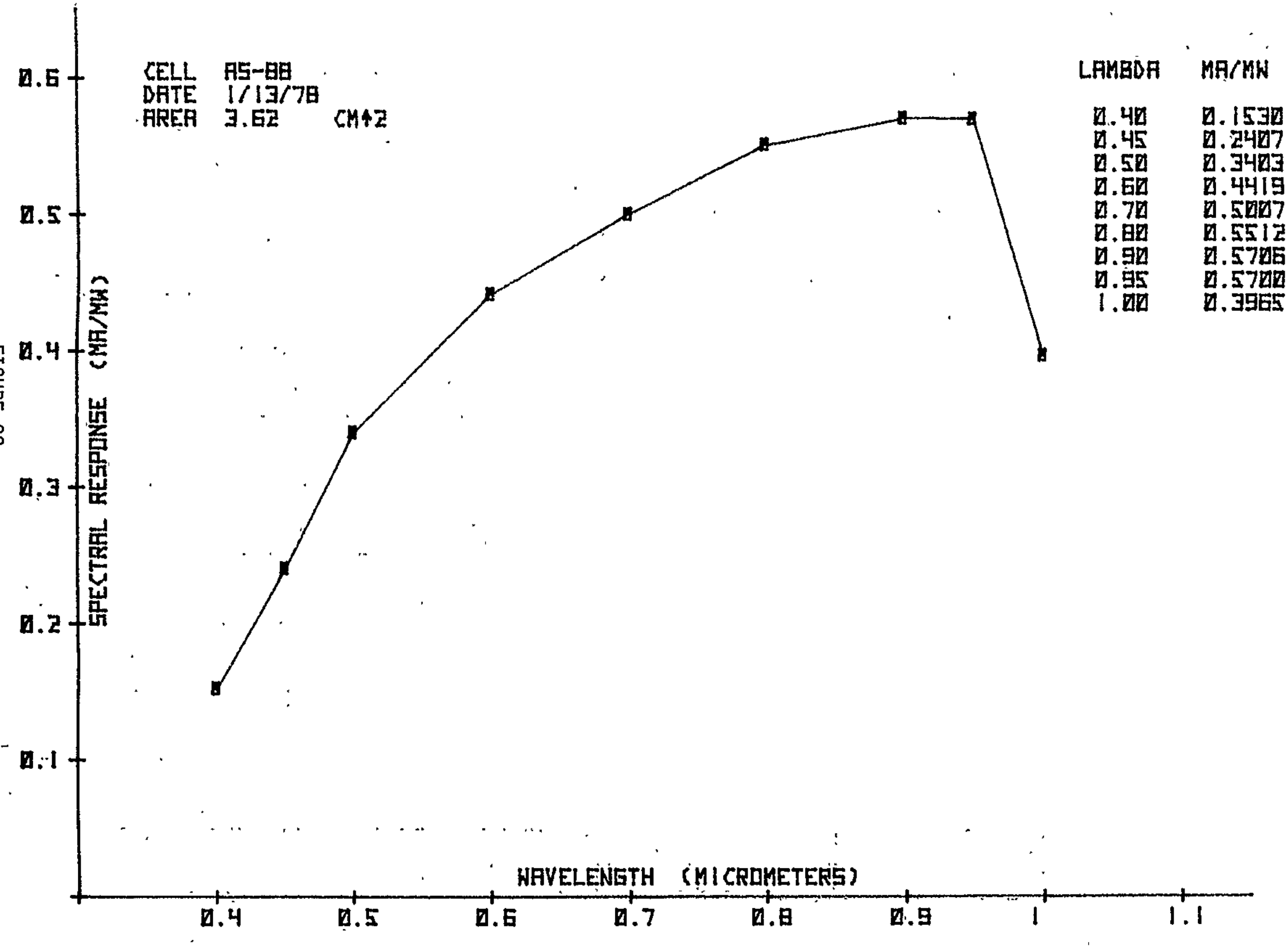


FIGURE 22
Typical Computer Printed Spectral Response Curve

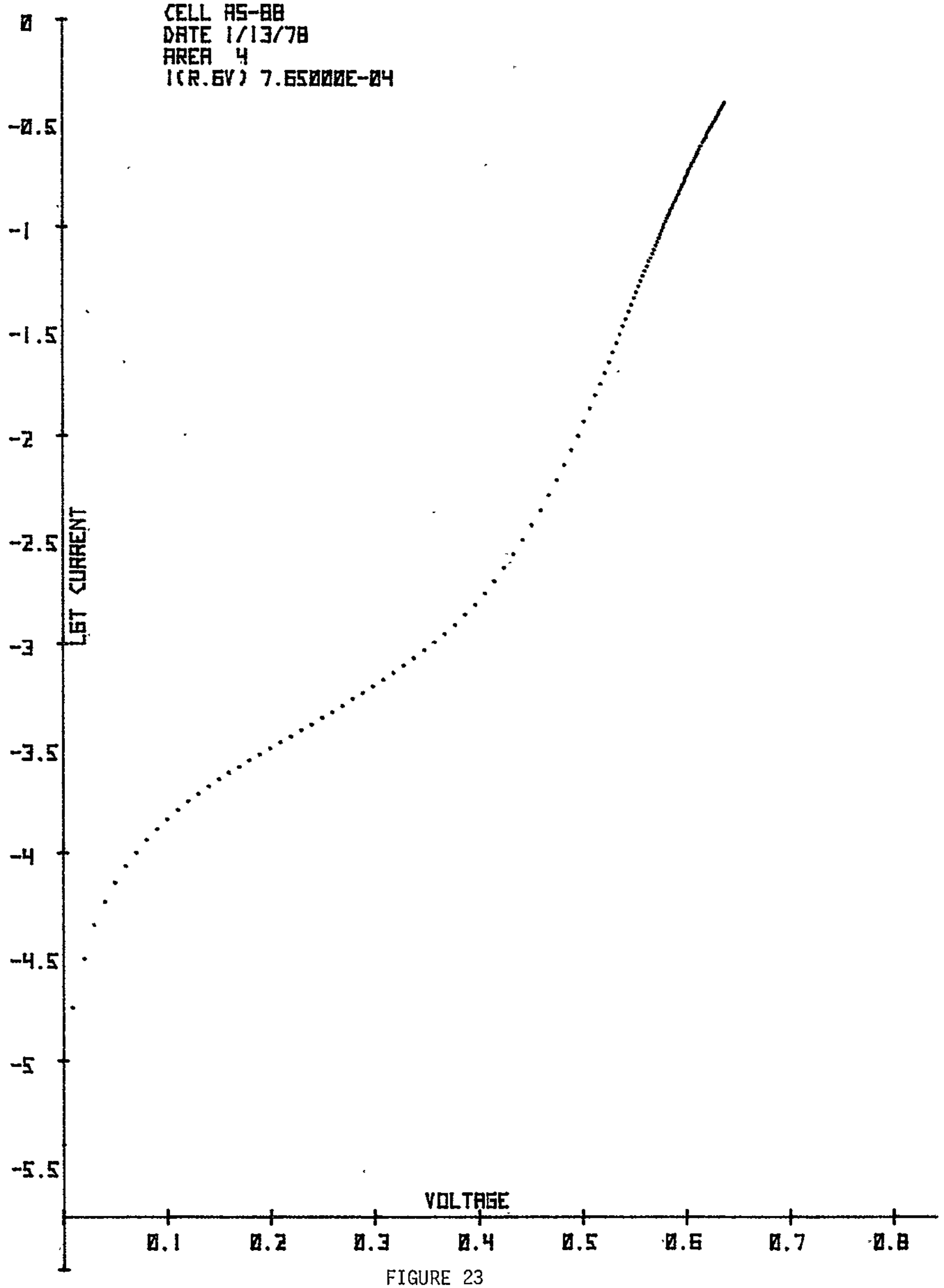


FIGURE 23

Typical Computer Printed Standard Cell Calibration Curve

The services of this laboratory are available to all investigators in the ERDA program. Both primary and secondary standard cells have been calibrated in this laboratory in support of the Standards function. Modules can be routinely characterized using this automated system. Thus, the data needed to characterize arrays for application experiments prior to startup of the experiment in the field can be quickly and accurately obtained by utilizing the equipment of this laboratory.

Guiding the measurements activity has been an on-going effort to develop a comprehensive set of measurement procedures for making measurements of the performance of solar cells in the terrestrial environment. Initial guidelines were established as the result of a workshop held at NASA-Lewis in March 1975. During this reporting period, a second terrestrial solar cell Measurement Procedures Workshop was held (November 1976) to consider the problem further, examine the experience of investigators who had been using the initial procedures, and develop a revised and improved set of measurement procedures. Proceedings of this second workshop are reported in ERDA/NASA-1022/76-10, "Terrestrial Photovoltaic Measurements-II." The output from the workshop has been used to refine the standard procedures for:

- natural sunlight measurement
- indoor measurement
- concentrator system measurement
- calibration of reference cells
- solar simulation
- common test equipment

In addition, a revised terrestrial solar spectrum is defined for purposes of theoretical calculations. These procedures are reported in ERDA/NASA 1022/77-16, "Terrestrial Photovoltaic Measurement Procedures," June 1977. These measurement procedures have been furnished to the American Society for Testing Materials (ASTM) for their consideration as the basis for issuance of ASTM photovoltaic standard measurement procedures. Continuing contacts with technical societies such as ASTM represents one way in which technical information developed in the National Program is transmitted to the technical community outside the Program.

2. Standards

The primary objective of this task is to provide calibrated reference cells to those involved in the Photovoltaic Energy Conversion Program and to establish the standard atmospheric conditions and measurement methods to be used for calibration. Theoretical and empirical guidelines are also developed for accurate and reproducible measurement of solar cells and arrays under a variety of atmospheric conditions.

Reference solar cells, calibrated under controlled conditions, are essential to insure accuracy, comparability, and reproducibility of measurements obtained by investigators throughout the photovoltaic program. The seemingly simple operation of measuring the performance of a solar cell is made complex by the variability of the spectral distribution of sunshine at the earth's surface. This variability is caused by atmospheric components such as water vapor, haze, and ozone. Without the knowledge of how these factors affect solar cell performance, comparability of measurements made around the country is not possible. To this end, LeRC has established facilities for monitoring these atmospheric variables. The knowledge gained from these measurements has gone into the design and calibration method used in the Standard Reference Cell system.

The standard cell package has been ruggedly designed using hermetic sealing techniques to prevent damage to the cell from both physical abuse and atmospheric corrosives. A quartz window permits equal transmission of all wavelengths of the sun's spectrum. The package incorporates a temperature monitoring system as well as all necessary electrical connections. The standard cell and its instrument kit are shown in Figure 24 and 25. The further definition and measurement of atmospheric composition and its effect on solar cell performance continues under both direct beam and global sunlight. A Solar Cell Reference Conditions Test Facility has been constructed at the Lewis Research Center to provide long-term monitoring of global insolation. The facility obtains hourly integrated data on global insolation and its components. Sensors currently consist of precision pyranometers and solar cells mounted in pyranometer housings. Pairs of sensors (pyranometer and solar cell) are pointed south at tilt angles of 0°, 37°, and 60° and are non-tracking. Additional sensors mounted horizontally are equipped with shadow bands to obtain the diffuse sky radiation.

Analysis of six months' hourly integrated data has shown that certain current analytical models used for calculating the amount of radiation falling on tilted surfaces from data for radiation striking horizontal surfaces are inadequate. The Liu-Jordan* isotropic sky model, that assumes the diffuse component to be uniformly distributed around the hemisphere, leads to errors of about 7% under clear, sunny sky conditions, but is satisfactory for overcast conditions.

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* Liu, B.Y.H., and Jordan, R.C.: "The Long Term Average Performance of Flat-Plate Solar Energy Collectors" Solar Energy, 7, #2, 1963, pp. 53-74.

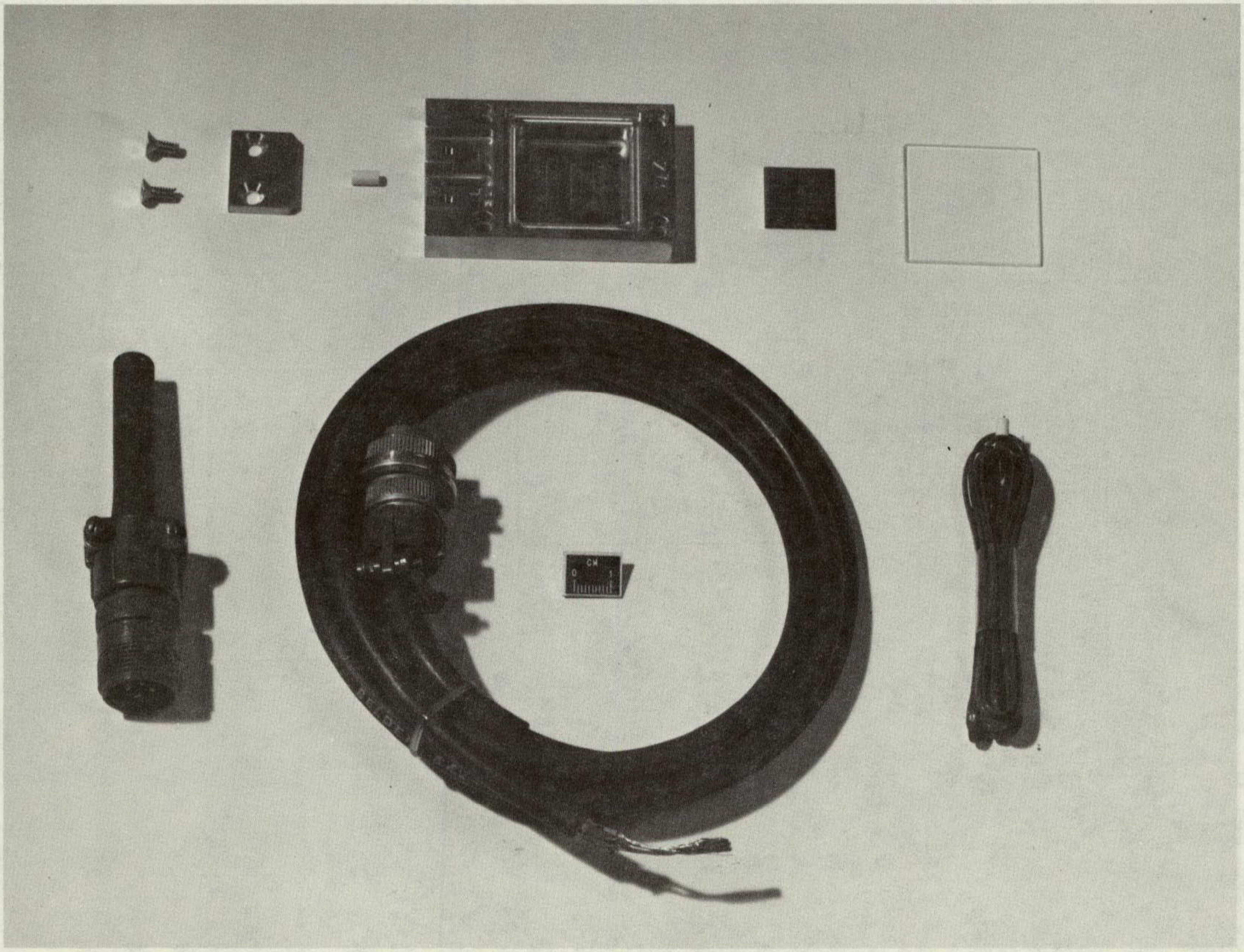

FIGURE 24
Standard Solar Reference Cell

FIGURE 25

Standard Reference Cell Kit

An anisotropic sky model proposed by Temps and Coulson* is excellent for clear, bright sky but fails under partly cloudy conditions.

A new model, developed at LeRC, overcomes the difficulty of both these models and accurately predicts (within 2%) the insolation falling on a tilted surface using only the global and diffuse, horizontal insolation values. The data obtained on the solar cell sensors yields identical results and preliminary analyses indicate that solar cell sensitivity (cell short circuit current divided by irradiance) is almost constant (within 2%) from winter to summer. This result, if accurate after additional conformation testing, will have a significant bearing on simplifying future cell calibration procedures.

3. Endurance Testing

The objective of endurance testing is to determine the performance life of modules and module materials under conditions representative of sites for their intended long-term use. This work supports the Program goal of a 20-year usable lifetime for solar cell modules.

Outdoor exposure testing of solar cell modules, materials and samples is being conducted at Desert Sunshine Exposure Tests, Inc. (DSET), Phoenix, Arizona, using both real-time and accelerated conditions. The accelerated testing is accomplished using patented equipment which concentrates sunlight by a factor of eight. In addition, real-time testing of solar cell modules and materials is being conducted at established testing companies located

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* Temps, R. C. and Coulson, K. L.: "Solar Radiation Incident Upon Slopes of Different Orientation." Solar Energy, 19, 1977, pp. 179-184.

in Florida and Puerto Rico. Modules are also being exposed at the STF site at LeRC and at the Air Pollution Control Center in Cleveland, Ohio. The latter site is located adjacent to steel mills and other industrial activity and represents a heavily polluted urban environment. In order to expand the exposure of solar cell modules to additional climatic and environmental conditions, a total of 16 sites have been selected for the real-time endurance testing program. All of the locations are federally controlled sites and are listed below. Preliminary work is underway to prepare module support frames for future installation at the sites and develop logistic and monitoring procedures with local site personnel. Installation of test modules is anticipated to begin in the fall of 1977 at these locations:

- Mines Peak, Colorado
- Ft. Greely, Alaska
- Ft. Clayton, Canal Zone
- Cleveland, Ohio (2)
- Houghton, Michigan
- New London, Connecticut
- Dugway, Utah
- Ft. Lewis, Washington
- Crane, Indiana
- Albuquerque, New Mexico
- San Nicolas Island, California
- Key West, Florida
- New Orleans, Louisiana

- Phoenix, Arizona
- Pasadena, California

In all of the real-time endurance testing, the effects of extended exposure on samples are determined from the degradation of electrical and optical properties. Current-voltage traces and transmission measurements are obtained and compared with the standard or original values. Visual inspection is also conducted for signs of physical deterioration. Results are disseminated through periodic technical reports (see Appendix).

F. PROJECT MANAGEMENT ACTIVITIES

The management function provides the control and direction of activities needed to attain Project objectives established by the ERDA Photovoltaic Energy Conversion Program. Specific activities comprising the overall project management responsibility include:

- Project Planning and Scheduling

Develop various work plans and procedures and the approach to achievement of milestones, as well as maintenance, review, and updating of Project Operating Plans.

- Technical Control and Coordination

Establish goals, measure accomplishments, evaluate results, resolve problems, establish and monitor reporting systems, and redirect effort, as required.

- Resource Management

Establish and maintain resource accounting and control systems.

- Management Control

Direct and monitor in-house and contract activity, as required, for all project tasks.

- Procurement Management

Monitor and review progress of all project contracting activities.

- Work Assignments

Assign project tasks and subtasks to qualified organizations both within and outside Lewis Research Center.

- Reporting

Provide liaison with and report regularly to the ERDA Program Manager, other ERDA projects, and higher NASA management levels. In addition, technical reports of all applications, standards, and engineering developments are prepared. Documentation of this type is listed in the Appendix.

- Program Planning and Support

Develop and review inputs in support of the ERDA Photovoltaic Program Planning activities and other assignments. LeRC support to program planning has included membership in the ERDA Photovoltaic Program Planning Group (PPG) and participation in a number of ad hoc planning activities.

- Program Interfacing

Coordinate and provide technical liaison with all segments of the ERDA National Photovoltaic Conversion Program and the photovoltaic community as a whole. External information dissemination in particular is carefully coordinated with the ERDA program office and ERDA public information personnel.

IV. CONCLUSIONS

In conclusion, the Tests and Applications Project has moved significantly during the report period toward attainment of Project objectives related to:

- implementing application experiments with users
- stimulating interest in photovoltaics among potential users
- developing the Systems Test Facility as a tool for determining the operating characteristics of various solar cell systems
- definition and implementation of the methodology and equipment to measure solar cell performance
- determination of solar cell endurance

The Project staff has effectively "told the photovoltaic energy story" to government and industrial organizations and, as a result, has increased their awareness of the feasibility of solar energy applications. Numerous practical applications have been identified and are being considered by potential users who are enthusiastic about solar energy.

Staff efforts to develop measurement techniques and performance criteria have provided a firm foundation for further advancement of photovoltaic energy conversion technology and utilization.

Progress during this report period provides the impetus for greater advancement in solar cell technology and utilization now and in the future. The success of photovoltaic-powered applications to date has tended merely to "scratch the surface" of exploitation of this unique energy source.

APPENDIX

DOCUMENTATION

Major publications completed and disseminated during the report period are listed chronologically.

- Usable Electricity from the Sun. SE-104, Energy Research and Development Adm., 1977.
- Deyo, J. N.; Brandhorst, H. W., Jr.; and Forestieri, A. F.: Status of the ERDA/NASA Photovoltaic Tests and Applications Project. NASA TM X-73567, 1976.
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- Imamura, M. S.; et. al.: Definition Study of Photovoltaic Residential Prototype System. (MCR-76-394, Martin-Marietta Corp., NASA Contract NAS3-19768.) NASA CR-135056, 1976.
- Klucher, T. M.: Test Facility for Solar-Cell Reference Conditions. Terrestrial Photovoltaic Measurements-II. NASA CP-2010, 1976, pp. 67-78. (also ERDA/NASA 1022/76/1)*
- Curtis, H. B.: Effect of Atmospheric Parameters on Silicon Cell Performance. Terrestrial Photovoltaic Measurements-II. NASA CP-2010, 1976, pp. 93-108. (also ERDA/NASA 1022/76/2)*
- Curtis, H. B.: Errors in Short Circuit Current Measurements Due to Spectral Mismatch Between Sunlight and Solar Simulators. Terrestrial Photovoltaic Measurements-II. NASA CP-2010, 1976, pp. 161-182. (also ERDA/NASA 1022/76/3)*

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* Presented at 2nd. ERDA/NASA Workshop on Terrestrial Photovoltaic Measurement Procedures, Baton Rouge, Louisiana, November 10-12, 1976.

- Weizer, V. G.: Consideration of Design and Calibration of Terrestrial Reference Solar Cells. Terrestrial Photovoltaic Measurements-II. NASA CP-2010, 1976, pp. 203-222. (also ERDA/NASA 1022/76/4)*

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- Klucher, T. M.: Sensitivity of Solar-Cell Performance to Atmospheric Variables-I. Single Cell. Terrestrial Photovoltaic Measurements-II. NASA CP-2010, 1976, pp. 247-249. (also ERDA/NASA 1022/76/6)*

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- Brandhorst, H. W., Jr.: Introduction to Basic Solar Cell Measurements. Terrestrial Photovoltaic Measurements-II. NASA CP-2010, 1976, pp. 275-300. (also ERDA/NASA 1022/76/8)*

- Curtis, H. B.: Indoor and Outdoor Measurements of Performance of Photovoltaic Arrays. Terrestrial Photovoltaic Measurements-II. NASA CP-2010, 1976, pp. 309-322. (also ERDA/NASA 1022/76/9)*

- Terrestrial Photovoltaic Measurements-II. NASA CP-2010, 1976. (also ERDA/NASA 1022/76/10)

  "Proceedings of the ERDA Semiannual Solar Photovoltaic Program Review Meeting," Silicon Technology Programs Branch, Univ. of California, San Diego, California, January 18-20, 1977, reports the following LeRC presentations: (also CONF-770112)

  Weinberg, I.: Visual Defects in 46 kW Buy Modules, pp. 206-215.

  Forestieri, A. F.: Results of Outdoor Real Time and Accelerated Testing, pp. 222-230.

  Curtis, H.; and Weinberg, I.: 46 kW Module Performance, pp. 231-249.

  Weizer, V.: Matching of Reference Cells to Modules Under Test, pp. 250-259.

  Mueller, R.; and Curtis, H.: Interlaboratory Comparison Measurements, pp. 260-268.

* Presented at 2nd. ERDA/NASA Workshop on Terrestrial Photovoltaic Measurement Procedures, Baton Rouge, Louisiana, November 10-12, 1976.

Curtis, H.: Problems in Measurements of Modules and Arrays, pp. 269-276.

Forestieri, A. F.: Meaning and Significance of the ERDA/LeRC Systems Test Facility, pp. 277-286.

Forestieri, A. F.: Effect of Environmental Factors on Performance of the ERDA/LeRC System Test Facility, pp. 287-295.

Forestieri, A. F.: Power Losses in the ERDA/LeRC System Test Facility, pp. 296-303.

Weinberg, I.: Module Performance Deterioration in the ERDA/LeRC System Test Facility, pp. 304-311.

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Pickrell, R. L.: STF Power Conditioning Hardware, pp. 421-436.

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- Anagnostou, E.; and Forestieri, A. F.: Preliminary Results of Accelerated Exposure Testing of Solar Cell Systems Components. ERDA/NASA 1022/77/14, NASA TM X-73674, 1977.
- Ratajczak, A. F.: Photovoltaic-Powered Refrigerator Experiment at Isle Royale National Park. ERDA/NASA 1022/77/15, NASA TM X-73703, 1977.
- Terrestrial Photovoltaic Measurement Procedures. ERDA/NASA 1022/77/16, NASA TM X-73702, 1977.

1. Report No. NASA TM-79018	2 Government Accession No.	3. Recipient's Catalog No.
4 Title and Subtitle PHOTOVOLTAIC TESTS AND APPLICATIONS PROJECT PROGRESS REPORT FOR APRIL 1976 - JUNE 1977		5 Report Date November 1978
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No E-9811
		10 Work Unit No
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address U.S. Department of Energy Division of Distributed Solar Technology Washington, D.C. 20545		14 Sponsoring Agency ~~Code~~ Report No. DOE/NASA/1022-78/42
15. Supplementary Notes Final report. Prepared under Interagency Agreement E(49-26)-1022.		

16. Abstract

This report summarizes the activities and accomplishments of the Photovoltaic Tests and Applications Project during the period April 1976 through June 1977. Results of efforts to identify potential near-term photovoltaic applications and users are discussed, including the outcome of an extensive survey of Federal government agencies. The status of application experiments is presented, with descriptions being given of 34 experiments either in operation or being readied for operation. Various general engineering efforts are reported, including the design and construction of a photovoltaic Systems Test Facility at LeRC. Efforts to develop a high efficiency 10 kVA self-commutated inverter and controller specifically designed for photovoltaic systems are also discussed. The results of a wide variety of activities in the area of photovoltaic measurements and standards are related, including performance measurements, endurance testing, design of a standard solar reference cell, and the development of terrestrial measurement procedures. Documents generated by the Project during the reporting period are listed in an Appendix.

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