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THE NASA-LEWIS TERRESTRIAL PHOTOVOLTAICS PROGRAM

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SUMMARY

Those parts of the present NASA-Lewis research and technology effort on solar cells and arrays having relevance to terrestrial uses are outlined. These include raising cell efficiency, developing the FEP-covered module concept, and exploring low cost cell concepts. Solar cell-battery power systems for remote weather stations have been built to demonstrate the capabilities of solar cells for terrestrial applications.

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INTRODUCTION

The NASA-Lewis Research Center has been conducting a program on solar cells and arrays for a number of years. In 1971 the program was focussed on reducing the cost of silicon solar cells and arrays for space missions. The main thrust was to reduce costs by improved technology. However, it was also recognized that major cost reductions by mechanization and automation were not possible without an expansion of the solar cell market. The space market was not growing and the terrestrial uses of solar cells languished because of their high cost. The market would not grow without a reduction in cost and cost reductions were deterred by the small production volume. Therefore, Lewis initiated a program on near-term terrestrial applications to encourage and stimulate a new, expanding market. About the same time interest began to grow on the potential of solar cells to supplement our energy resources later in this century. This new interest reinforced our motivation to reduce cell and array costs and enlarge their use as quickly as possible.

Both our space goals and our terrestrial goals require reduction in solar array cost. Although the ultimate cost reductions for the two are vastly different (a factor of two or three for space and two or three orders of magnitude for terrestrial) the appropriate efforts for the near future include raising cell efficiency, reducing cell and array fabrication costs, and stimulation of a new, near-term market for solar arrays.

The purpose of this talk is to outline those parts of the Lewis Research Center research and technology program that apply to terrestrial uses as well as space and to describe what we have done recently on near-term terrestrial applications.

RESEARCH AND TECHNOLOGY ON SILICON SOLAR CELLS AND ARRAYS

Our research effort seeks to raise the efficiency of silicon solar cells to the practical limit of 18% in space or 21% on Earth. The present efforts are listed in Table I and include identifying and understanding the loss mechanisms in low resistivity silicon, especially those contributing to high leakage currents, and constructing an analytical model for the solar cell that includes all loss mechanisms. We have found that some small areas of low resistivity cells have low leakage currents and therefore would yield high efficiency (1). We are trying to determine the cause of the high leakage in the other areas. We also find that the understanding of all the processes taking place in a solar cell is inadequate. As a significant example, there is not yet a definitive explanation for the higher output with a back surface field (2, 3). We regard these observations with optimism; we have not found a reason to limit the efficiency to less than our goals, and there is increasing evidence to suggest the goal is attainable.

Our technology effort seeks to develop higher efficiency cells, lower cost cell fabrication methods, and lower cost array fabrication methods. The present efforts are listed in Table II and include development of a 13 1/2% cell with wraparound contacts, development of the plastic (FEP)-covered solar cell module, and investigation of other cell fabrication methods. In the cell development work available technology on shallow junctions, anti-reflection coatings, narrow grid fingers, back surface fields, and wraparound contacts are being refined and combined into a cell that should not cost more than conventional cells.

We are developing the FEP-covered solar cell module concept to eliminate the material and labor costs associated with glass covers. Rauschenbach et al. (4) will describe at this conference the progress under the contract at TRW. In the in-house efforts ways are being investigated to further reduce array assembly costs by incorporating wraparound cells into the FEP module. This FEP technology is suitable to terrestrial uses as well as space. An FEP module in an ongoing test has experienced no degradation in rooftop exposure at Lewis Research Center for eleven months and, according to the manufacturer, FEP should withstand Florida sun for at least seven years.

Other in-house efforts include exploration of low cost cell fabrication methods. One is the chemical vapor deposition of thin film polycrystalline silicon cells; the major problem is still that of growing a good, adherent silicon layer on a low cost substrate. The other effort is the investigation of techniques to make primitive cells, that is, cells of simple design made by a few simple processes. The intent is to explore the possibilities of a cell with moderate efficiency but very low cost. This effort has barely started.

The low cost array contracts shown on Table II are studies of what cell and array technology is needed for economic large scale generation of electricity by solar cells. These studies, to be completed a few months from now, will define as well as is possible the necessary technology advancements, production approaches, and costs for producing arrays that are several orders of magnitude less expensive than present arrays. They will serve as guides to the directions for a technology program for large-scale uses.

PHOTOVOLTAIC TERRESTRIAL APPLICATIONS

The Lewis Research Center terrestrial applications program was initiated to encourage further uses of solar cells so that production volume would grow to where more cost reduction techniques would be economically justified. We firmly believe that there are numerous low power applications where the long-life, no-maintenance advantages of solar cell-battery power systems outweigh their presently high initial cost. It is further believed that the major barrier to wider use of solar cells at this time is not really their cost but rather the potential users' unawareness of solar cell capabilities. Therefore we are confident that several successful demonstrations of solar cells in real applications will spark the interest of many users.

Our present efforts in the applications area are listed in Table III. The contract effort is a survey of terrestrial applications that could be commercially feasible within five years. These applications will be catalogued and evaluated, and the most attractive ones identified. The results of the study will be summarized by Moore et al. later in this session (5).

The other present effort listed is an in-house effort to build solar cell-battery power systems for remote weather stations. However, our first terrestrial system was intended for a remote radar beacon for the Flight Research Center of NASA. Solar cell panels were designed and built for use in the mountains of the Southwest. Because of changes in the program the system was not installed. However, a power system was mounted on the roof at Lewis Research Center and powered a load simulating the beacon's load profile. The system has operated for two years in the Cleveland weather with only three interruptions of service. These were due to battery discharge, twice because of improper adjustment of the electronics and once because of 3 1/2 weeks of continuous overcast.

Similar panels were used to power a "remote" weather station on the Cleveland lakefront shown in figure 1. An anemometer, windvane, temperature sensor, humidity sensor, and the solar cell-battery power system were mounted on existing towers at the Cleveland Coast Guard Station in the Fall of 1972.

The original intent was to use a commandable receiver-transmitter for data transmission. However, because of the lead time needed for FCC approval, a hardwire data link was used.

Two 70 ampere-hour, lead-acid, automotive batteries and the electronics were mounted in the existing enclosure on the tower. Figure 2 shows the solar panels. Each of the three panels is identical to the panel designed for the radar beacon and tested on the roof at Lewis Research Center. Each contains 240 2x2 cm cells soldered together and mounted on a heavy aluminum substrate, 10" wide and 23" long. The front cover of 3/8" lucite is bolted down against a Viton-A O-ring for sealing.

The system has been in place for a year and has suffered some malfunctions. High winds toppled the anemometer and subsequent repairs induced failure in the electronics package. Other malfunctions were due to inadequacies of the design of the breadboard electronics system. Also inadequate weather-proofing of the data cable conduit resulted in internal ice formation and rupture of the cable. None of the malfunctions cast any doubt on the inherent utility of the power system for this kind of service. There are no signs of solar panel deterioration in either this one-year exposure on the lakefront or the two-year exposure on the roof. Dirt accumulation on the arrays has been no problem. The tilted arrays are readily cleansed naturally by rain and snow.

We have also provided solar cell panels to the National Weather Service of NOAA for use on their developmental remote weather stations called RAMOS (Remote Automatic Meteorological Observation System). Over the next decade the Weather Service plans to deploy 1100 RAMOS's into a nationwide meteorological network including many remote and hostile weather locations. Their interest in solar cells stems from the difficulty and cost of refueling or replacing batteries in other power systems.

An array was installed in October 1973 on a RAMOS at their test site in Sterling, Virginia and an array has been installed in November 1973 on a RAMOS on Mammoth Mountain, California. A similar system is planned for Alaska next year.

Figure 3 shows the solar cell array mounted on the RAMOS at Sterling, Virginia. The overall array dimensions are 3.6' x 2.6' to accommodate the 9 sq. ft. of solar array needed for Mammoth Mountain (Figure 4). For Virginia only 2/3 the area is needed and the array is L-shaped.

These arrays are built considerably differently from those used earlier. Modules of 2x2 cm cells, 3 in parallel and 8 in series, are interconnected by parallel gap welding. These are encapsulated in FEP, a 5-mil sheet on top and bottom. The bottom sheet serves also as the cement to bond the module to a preformed, anodized aluminum substrate. A completed module is shown in figure 5. These modules have been laminated in a two-step process. One lamination cycle is used to encapsulate the cells and a second, similar lamination cycle is used to bond the module to the substrate.

Each module has a nominal output of 1 watt. Five of these modules are bolted to an aluminum frame to make a 5-watt, 12-volt subarray, as shown in figure 6. These subarrays are bolted to a larger aluminum frame to make the complete array. In the RAMOS for Mammoth Mountain 4 subarrays are connected to serve 12-volt loads and 8 are connected to serve 24-volt loads. Based on a cell price of 65 cents, fabrication time required, and technician labor rates current in the aerospace industry the cost of these arrays is $40/watt of peak output.

While we know these RAMOS tests will be very important demonstrations, we are looking for others as well. We feel that there are more applications that will benefit, perhaps be made feasible, by the availability of solar cell-battery systems that have a maintenance-free life measured in years. Some we are considering for further demonstrations are the NASA-Ames Forest Fire Hazard Monitor, The NASA-Langley Remote Marshland Water Sampling Station and the NASA-Lewis Buoy-mounted Water Quality Monitoring Platform, as well as those identified in the Heliotek survey contract.

CONCLUSION

Most of the NASA-Lewis Research Center solar cell work has relevance to terrestrial uses as well as space. The work on raising cell efficiency, and developing the FEP-covered module concept, are major thrusts toward our space goals that are equally important to terrestrial applications. Exploratory work on low cost cell concepts (the thin film silicon cell and the primitive or simple cell) is aimed toward terrestrial requirements.

Demonstration units have been built for terrestrial applications and there is no doubt solar array-battery power systems are practical for many low power applications at remote sites. A lucite-covered solar array has provided power to a weather station on the Cleveland lakefront during last winter. Minor system breakdowns cast no doubt on the life and capability of the array and battery to function properly in that environment. Two FEP-covered arrays have recently been installed in remote weather stations in Sterling, Virginia and on Mammoth Mountain, California. These weather stations are part of the RAMOS program of the National Weather Service and will be important demonstrations.

Our experience with terrestrial arrays and the interest shown by potential users leaves us confident solar arrays provide a needed capability for remote systems and that terrestrial uses of solar cells will proliferate.

REFERENCES

1. Peter Iles: Effects of Processing on the Lifetime of Silicon Solar Cells. NASA CR-134520 (To be published).

2. Joseph Mandelkorn; John H. Lamneck; and Larry R. Scudder: Design, Fabrication and Characteristics of New Types of Back Surface Field Cells. Tenth IEEE Photovoltaic Specialists Conference, November 1973.

3. Michael P. Godlewski; Cosmo R. Baraona; and Henry W. Brandhorst, Jr.: Low-High Junction Theory Applied to Solar Cells. Tenth IEEE Photovoltaic Specialists Conference, November 1973.

4. Hans S. Rauschenbach; and Anthony F. Ratajczak: FEP-Teflon Covered Solar Cell Array Advancements. Tenth IEEE Photovoltaic Specialists Conference, November 1973.

5. Wayne Moore; Robert M. Masters; and Americo F. Forestieri: Terrestrial Applications of Solar Cell Powered Systems. Tenth IEEE Photovoltaic Specialists Conference, November 1973.

TABLE I

NASA-LeRC SOLAR CELL RESEARCH

OBJECTIVE: RAISE THE EFFICIENCY OF SI SOLAR CELLS TO NEAR 18% (AMO) or 21% (AMI).

APPROACH: FIND, UNDERSTAND, ELIMINATE LOSSES.

TASKS IN PROGRESS:

CONTRIBUTING CAUSES OF LEAKAGE CURRENT-CENTRALAB - $58K

CONTRIBUTING CAUSES OF LEAKAGE CURRENT - IH

EFFECT OF DIFFUSION PROFILE AND SURFACE TREATMENT - IH

STUDY OF SURFACE STATES AND SURFACE LEAKAGE - IH

EFFECT OF GUARD RING STRUCTURES ON LEAKAGE CURRENT - WAYNE STATE UNIV. - $13K

INTERPRETATION OF MEASURED L - IH

THEORETICAL ANALYSIS OF SOLAR CELLS-N. CAR. ST.U. - $27K

THEORETICAL ANALYSIS OF SOLAR CELLS - IH

TABLE II

NASA-LeRC SOLAR CELL AND ARRAY TECHNOLOGY

OBJECTIVE: REDUCE THE COST OF SOLAR CELL ARRAYS FOR SPACE AND TERRESTRIAL APPLICATIONS.

APPROACH: DEVELOP HIGH EFFICIENCY CELLS.
DEVELOP LOW COST CELL FABRICATION METHODS.
DEVELOP LOW COST ARRAY FABRICATION METHODS.

TASKS IN PROGRESS:

ADVANCED Si CELL DEVELOPMENT	- CENTRALAB	- $81K
ADVANCED Si CELL DEVELOPMENT	- HELIOTEK	- $86K
ADVANCED Si CELL DEVELOPMENT	- IH	
FEP-COVERED SOLAR CELL MODULE	- TRW	- $250K
FEP MODULE IMPROVEMENTS	- IH	
VAPOR DEPOSITED Si SOLAR CELLS	- IH	
PRIMITIVE SOLAR CELL FABRICATION	- IH	
LOW COST SILICON SOLAR CELL ARRAYS	- SPECTROLAB	- $37K
LOW COST SILICON SOLAR CELL ARRAYS	- CENTRALAB	- $32K

TABLE III

NASA-LeRC PHOTOVOLTAIC TERRESTRIAL APPLICATIONS

OBJECTIVE: ENCOURAGE TERRESTRIAL MARKET FOR SOLAR CELL POWER SYSTEMS.

APPROACH: BUILD AND OPERATE DEMONSTRATION SYSTEMS.

TASKS IN PROGRESS:

TERRESTRIAL APPLICATIONS OF SOLAR CELL POWERED SYSTEMS	- HELIOTEK	- $39K
SOLAR CELL POWERED WEATHER STATION	- IH	

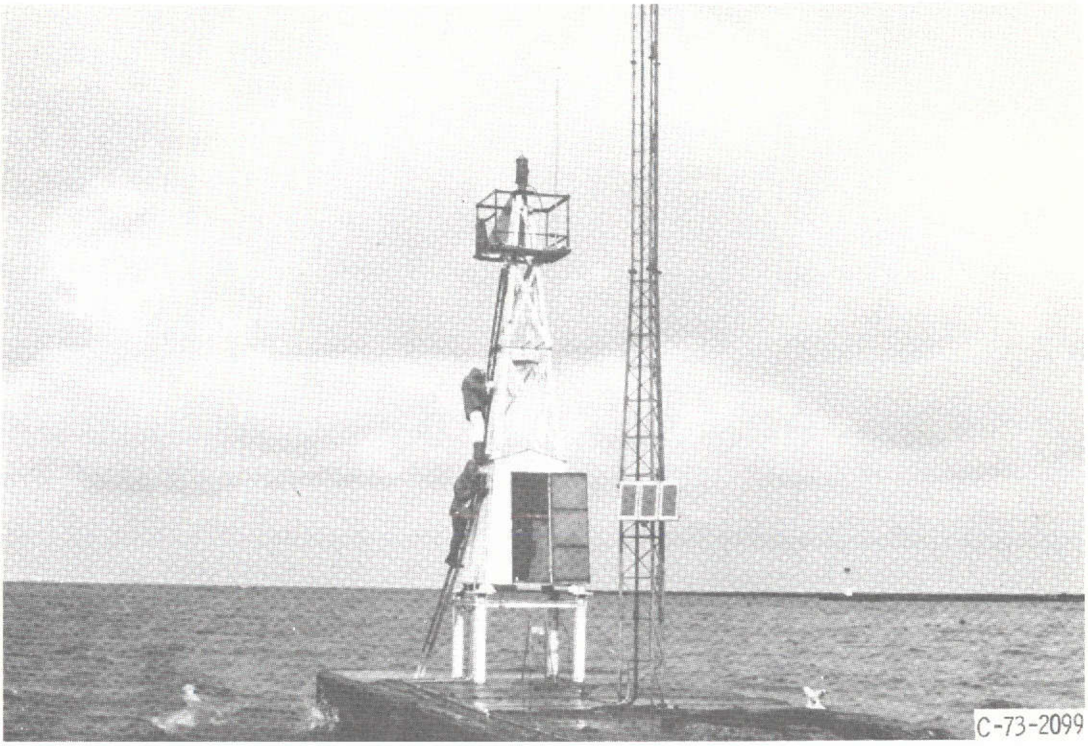

Fig. 1 - Solar-cell powered weather station at the Cleveland lakefront.

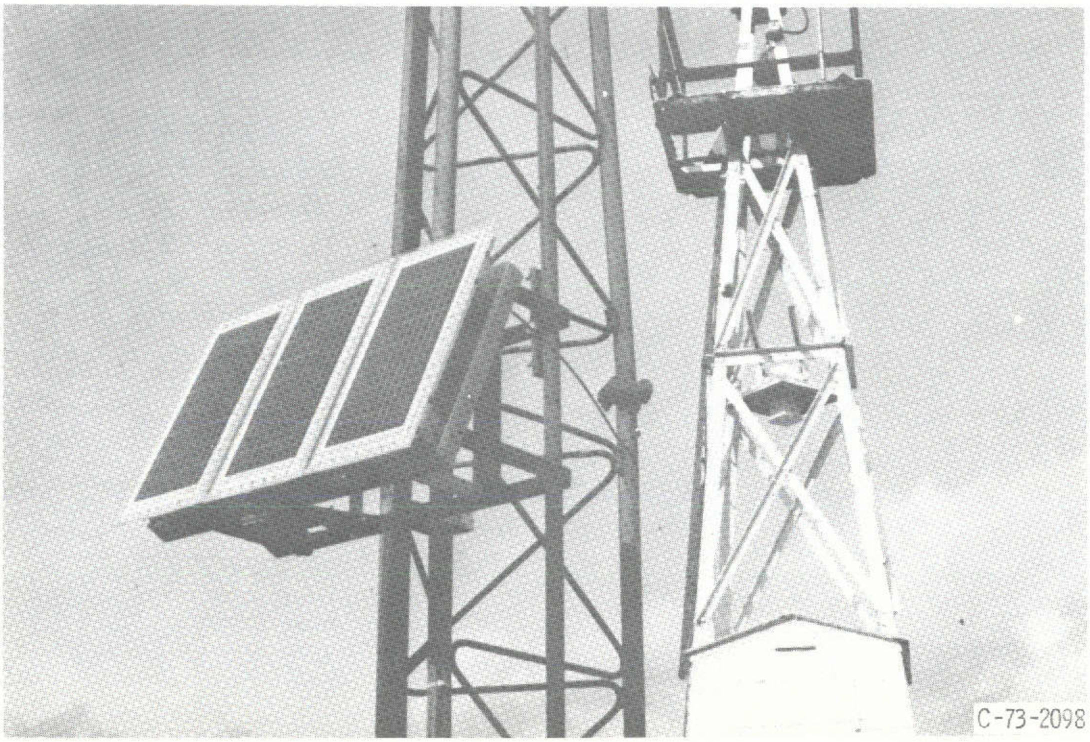

Fig. 2 - Lucite covered solar cell panel at the lakefront weather station.

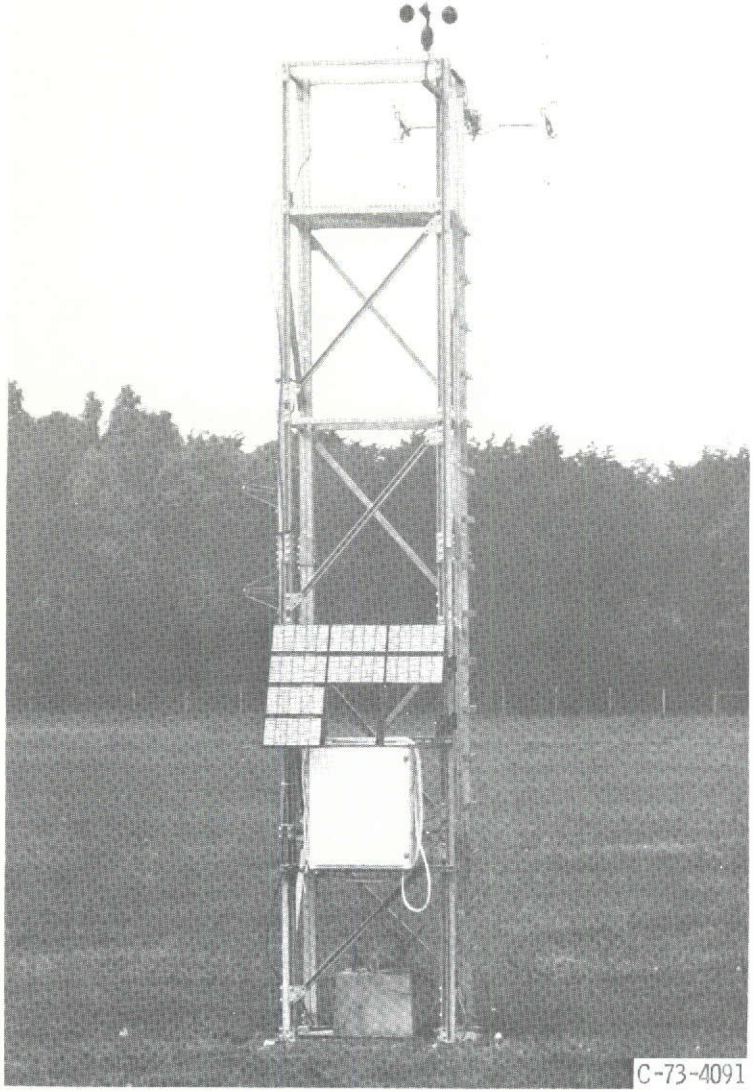

Fig. 3 - A solar cell powered RAMOS weather station at the Sterling, Va. test site of the National Weather Service. The L-shaped surface is the FEP-covered solar cell array.

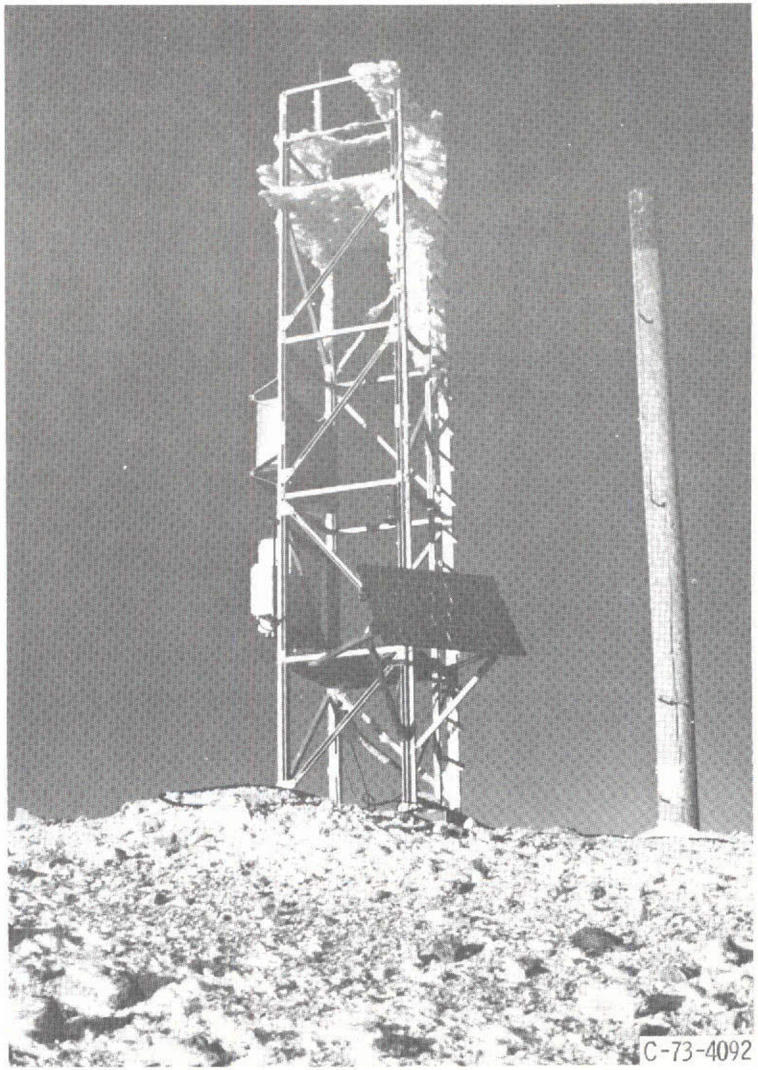

Fig. 4 - A solar cell powered RAMOS weather station on Mammoth Mountain, California.

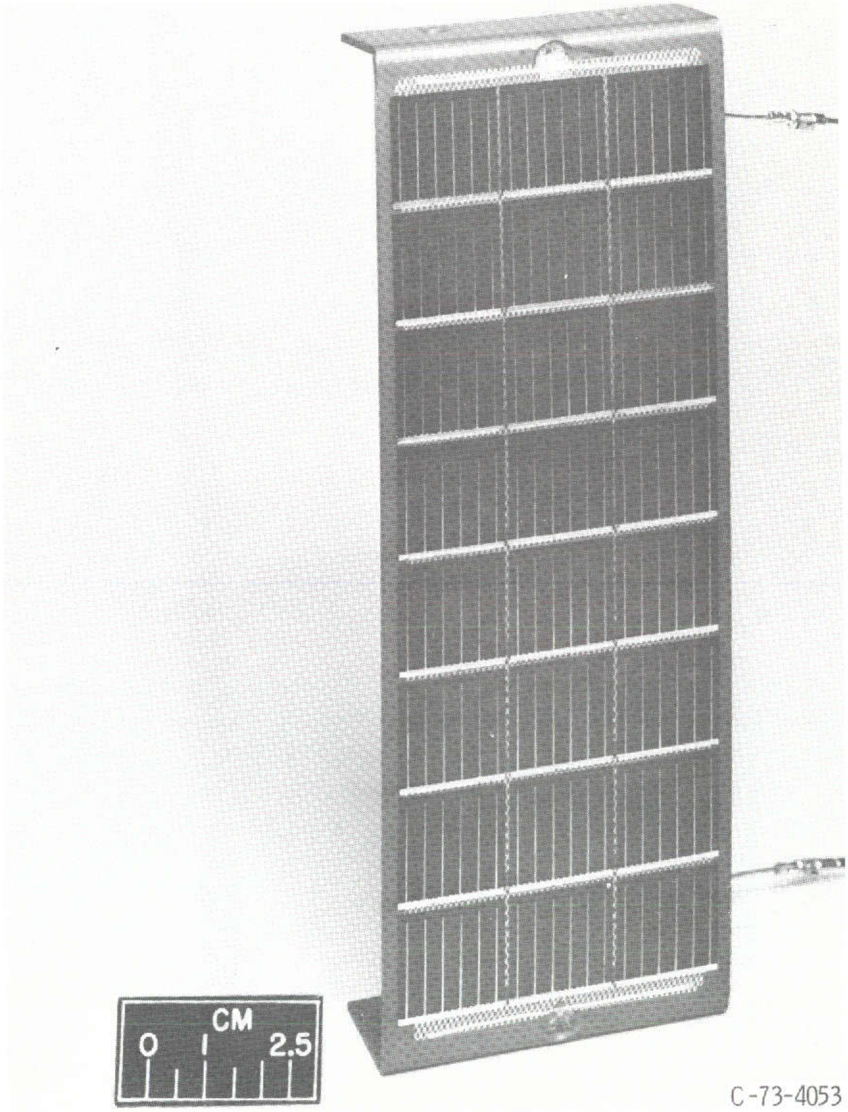

Fig. 5 - A one-watt FEP-covered module for terrestrial applications.

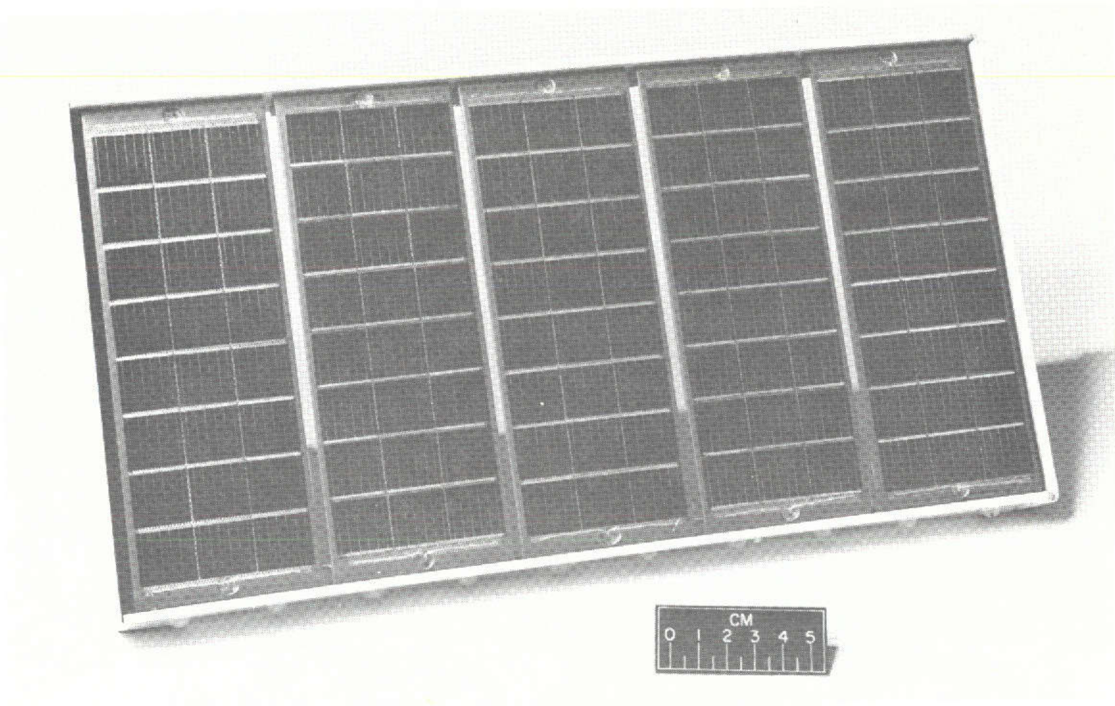

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Fig. 6 - A sub-array of five FEP-covered modules.