NASA TECHNICAL MEMORANDUM

NASA TM X-71608

NASA TM X-71608

(NASA-TM-X-71608) TERRESTRIAL APPLICATIONS OF FEP-ENCAPSULATED SOLAR CELL MODULES (NASA) 23 p HC $3.00

N74-32470

CSCL 10A

Unclas

G3/03 48763

TERRESTRIAL APPLICATIONS OF FEP-ENCAPSULATED SOLAR CELL MODULES

by A. F. Forestieri and A. F. Ratajczak
Lewis Research Center
Cleveland, Ohio

TECHNICAL PAPER proposed for presentation at
International Conference on Photovoltaic Power Generation
Hamburg, Germany, September 25-27, 1974

E-8086

TERRESTRIAL APPLICATIONS OF FEP-ENCAPSULATED SOLAR CELL MODULES

by A. F. Forestieri and A. F. Ratajczak

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

ABSTRACT

The NASA Lewis Research Center is engaged in a program aimed at transferring the FEP-encapsulated solar cell technology developed for the space program to terrestrial applications. FEP-encapsulated solar cell modules and arrays have been designed and built expressly for terrestrial applications. System design including solar cell array mechanical design and the approach to system sizing is outlined. Such solar cell systems have been installed at six sites. Individual modules have undergone marine environment tests. Results from seven months of operation in Sterling, Virginia indicate that that system is meeting its electrical design requirements. No mechanical degradation has been reported. The array on Mammoth Mountain, California has been damaged by rime ice but shows no loss in electrical output. Marine environment tests on single modules have shown that elements of the module must be completely sealed by the FEP. Based on the limited test data available, the FEP-encapsulated solar cell module appears well suited to terrestrial applications.

INTRODUCTION

Photovoltaic power systems for terrestrial applications have been in use, both in this country and abroad, for about ten years. Even though solar cell arrays are relatively high cost items ($25-$50/watt), the total cost of a solar cell power system for remote locations over a lifetime of ten years or so can be considerably lower when one has to consider the cost of fuel, transportation, etc. for alternate power sources. Late in 1970 the Solar Cell Branch at the NASA Lewis Research Center (LeRC) designed a terrestrial solar cell power system in response to a request from the NASA Flight Research Center. With this work as background we began rooftop tests of some of our latest space type solar cell module designs using FEP (fluorinated ethylene propylene) encapsulation (ref. 1). The rooftop tests indicated that this type of module was suited for terrestrial applications.

The LeRC then initiated a program of near-term terrestrial applications to encourage and stimulate expansion of markets for solar cells. The main thrust of the program was to demonstrate that terrestrial solar cell power systems could be useful and economical. As part of this program, government agencies were contacted that had a need for small power systems at remote sites. The Equipment Development Laboratory of the

National Oceanographic and Atmospheric Administration (NOAA) requested that we support them in the design, fabrication, and installation of a solar cell power supply for their Remote Automatic Meteorological Observation Stations (RAMOS). Similar arrangements were made with other government agencies.

This paper discusses solar cell array and system design, and results obtained during operation of the applications noted above.

ELECTRICAL POWER SYSTEM DESIGN

Power output from a solar cell array is limited by the amount of sunshine (insolation) available. Batteries are therefore used in conjunction with the solar cells to supply power during periods of low insolation, nighttime, and for peak load requirements. The sizing of the array and batteries depends upon careful budgeting of the energy requirements of the load and a good estimate of the sunshine available. For most applications the load profile can be easily defined. The available sunshine, on the other hand, is uncertain and must be predicted on the basis of past insolation data, which are not as complete as desired. Therefore the design of solar cell systems cannot be precise and must be on the conservative side.

Our approach to power system design is to size a system on the basis of an annual ampere-hour budget. That is, the array, over the course of a year, must generate enough ampere-hours to satisfy the total annual load requirements, including battery charging inefficiencies. The design objective is to end up with the smallest, least expensive system that will reliably meet the load requirements.

The sizing of array and batteries entails three operations: calculating monthly load ampere-hour requirements, calculating monthly solar cell ampere-hour output, and combining these data to determine system size. For each month the ampere-hour load requirement is computed for the prescribed or assumed load profile. Loads supplied by the battery are differentiated from those supplied directly by the array to provide a better definition of battery requirements and losses. The daytime continuous load is generally assumed to be supplied by the array while the nighttime and peaking loads are supplied by the battery.

From local insolation data, the ampere-hour output of a single solar cell or a unit area of the array is calculated for each month and for several array inclination angles. The mean daily solar radiation and mean monthly sky cover data for these calculations are taken from the Climatic Atlas (ref. 2).

System sizing combines the compilations of the load requirements and the solar cell outputs to determine the number of solar cells, the optimum array inclination angle, and the battery storage capacity.

The minimum number of paralleled solar cells is determined from the total load requirements and cell output. The number of series solar cells is an independent function of battery charging voltage and maximum solar cell operating temperature.

The optimum inclination angle is not only a function of latitude, but also depends on the load profile and the monthly variations in insolation and sky cover. The angle selected is that which yields the smallest monthly array ampere-hour output deficit during the winter months and which requires the fewest number of solar cells and the smallest battery storage capacity.

The batteries are sized to maintain continuous systems operation. They must have adequate capacity to absorb peaking loads, nighttime operation, and array output deficits during winter or cloudy months. The calculated capacity may require adjustment to account for specific knowledge of local weather conditions, and any peculiarities of the load profile. A conservative battery size is generally used to provide margin for lower-than-expected insolation, and temperatures. It also minimizes gasing problems during periods of high charging rates caused by high array outputs. A voltage regulator is always included in the power system design to prevent battery overcharge.

ARRAY MECHANICAL DESIGN

The array mechanical design is based on a modular approach so as to be adaptable to a variety of applications and provide ease of transportation and field assembly and repair. The basic element is a 1-watt module composed of 2×2 cm cells with 3 cells in parallel and 8 cells in series (figs. 1 and 2). This size is convenient for designing for different system voltages and currents. Five modules connected in series (fig. 3) form a nominal 12-volt module, i.e., one capable of charging a 12-volt battery. Since many systems run on 12 or 24 volts, the 12-volt module becomes a second level building block.

Protection of the solar cells from the environment is provided by encapsulating the 1-watt modules in FEP plastic film. The electrically interconnected cells are laminated under heat and pressure between 5-mil sheets of FEP. Details of the lamination procedure are given in reference 1. A second lamination process is used to mount the encapsulated cells to the substrate, with the FEP acting as the adhesive. This process provides complete encapsulation of the cells and a smooth surface on the top of the module. This smooth FEP surface is easily cleansed by rain, melting snow, or snow sliding off the array.

Two types of modules are presently made. The type shown in figure 1 uses an aluminum substrate and is used where high strength is required. The type shown in figure 2 is of identical configuration but uses a less expensive fiberglass cloth substrate.

The main array structure is a welded framework of anodized aluminum angle. The 1-watt modules are bolted to anodized aluminum frames to constitute 12-volt modules (fig. 3). These 12-volt modules are in turn bolted to the main framework.

POWER SYSTEMS DESCRIPTIONS AND OPERATIONAL RESULTS

The first terrestrial solar cell power system designed and built by NASA Lewis Research Center (LeRC) was for the NASA Flight Research Center (FRC) and was to power remote radar beacons. It was built in 1970 just as the FEP encapsulation technology was being developed and thus was of a different design. Program changes at FRC precluded the originally intended use, so the solar cell modules were used instead to power a weather station on the shore of Lake Erie in Cleveland, Ohio (figs. 4(a) and (b)).

In this system uncovered solar cell modules are in an O-ring-sealed compartment with a clear acrylic window (ref. 3). The system has been in place for over a year and a half and there have been no signs of solar array deterioration. Although this type of solar cell module operates satisfactorily in a terrestrial environment, it is heavier, bulkier, and more expensive than the FEP-encapsulated solar cell modules.

At the present time there are FEP modules on test at six different locations and hardware is being fabricated for an additional test. The tests in progress include both environmental durability of single modules and complete systems tests. Table I lists the systems with their operating requirements, and array and battery sizes.

The first FEP-encapsulated solar cell power system installation was for a NOAA RAMOS weather station at the NOAA test facility at Sterling, Virginia (fig. 5). This 40-watt array has both 12-volt (10-watt) and 24-volt (30-watt) sections and the 1-watt modules all have aluminum substrates.

Short-circuit current readings are taken monthly by NOAA personnel and are listed in table II. Because instrumentation simultaneously measuring insolation was not included in these tests, strong conclusions cannot be drawn from these data. Definitive evaluation of array degradation will have to await remeasurement under the controlled conditions of a solar simulator facility.

Nevertheless, the data in table II should indicate if serious degradation were occurring. The preinstallation current measurement under an air mass zero solar (AMO) simulator is shown for reference in table II. The AMO value represents the output in space, that is, with no losses due to the atmosphere and weather. The December current measurement was 67 percent of AMO, which is not an unreasonable winter value for that site. The outputs of the 12- and 24-volt array sections were compared to see whether one was damaged or degrading faster than the other. The ratio of their outputs should be 1.5. For most of the readings, including the clear-day reading, the ratio was 1.5. For some, however, the ratio varied between 1.2 and 1.7, which may well be due to variation in the sky condition during the measurements. Within the limits of these field measurements, there is no indication of serious array degradation.

Mercury column coulombmeters were included in the Sterling system to measure array ampere-hour output. NOAA personnel reported irregular coulombmeter operation shortly after installation. Following this initial problem, coulombmeter operation appeared to be normal. Attempts to correlate measured array output with predicted output, design insolation data, and monthly measured insolation later proved unsuccessful. In mid-April 1974, NOAA installed digital ampere-hour meters to measure array output. At this writing, there is not sufficient data available to establish a correlation between predicted and measured output.

A second solar cell powered RAMOS weather station is on Mammoth Mountain, California (fig. 6). Installed in November 1973 on the 11,053-foot-high peak, it has experienced winds in excess of 92 mph and severe rime ice conditions. This array, which also contains all aluminum substrate modules, generates a total peak power of approximately 60 watts.

The NOAA chose Mammoth Mountain as a test site for their RAMOS because of its severe climatic conditions. Forest Service personnel at Mammoth have courteously provided photographs of the station following one of their not-too-severe storms in December 1973 (fig. 7). They have observed that the rime ice does not appear to form directly on the FEP-covered modules. Rather, it appears to build up on the tower and array support structure. Gradually, it emerges through the openings between modules and then builds up out over the array (fig. 8). Typically, storms last 1 to 4 days and are followed by periods of clear weather. The black anodizing of the array frame plus the high absorptivity of the solar cells absorbs enough heat so that the array quickly clears itself of rime ice accumulations.

The exceptionally severe winter just past has resulted in malfunctions of the RAMOS equipment which disrupted both load and generating profiles. It has not been possible, therefore, to correlate coulombmeter readings from the array with predicted power system performance. The weather has also resulted in damage to the array from rime ice following an early spring storm.

Inspection of the array on July 5, 1974 revealed 8 bent and damaged modules containing cracked cells and cut FEP, and several bent, but otherwise undamaged modules. Figure 9(a) shows the overall damage to the array framework from ice. Figure 9(b) shows cracked cells and a bent module substrate typical of 6 of the damaged modules. Of the other two damaged modules, one had a less severely cracked cell, and the other a 1/4 inch cut in the FEP covering with local FEP-cell delamination limited to a 1/4 inch diameter spot.

Although several cells in each of the six damaged modules were severely cracked, the FEP covering remained intact with no cracks in all six cases. Although the cells were severely cracked, the FEP encapsulation prevented most of the grid lines from breaking. Thus, array electrical output, as shown by the July 5 (prerepair) and July 6 (postrepair) readings of table III, was not measurably degraded. Subsequent measurements of the damaged modules at the LeRC showed short-circuit current losses ranging from 0.5 to 7.3 percent. The eight damaged modules were replaced on July 5, 1974. The modules which are bent, but which showed no evidence of other damage, were left in place.

The array was originally to have been mounted near the top of the tower to minimize the possibility of such damage. High winds and lack of sufficient personnel during installation, however, mandated its present position. The array was to have been moved to the top of the tower following its repair in July, but high winds and snow again precluded that action. It will, however, be raised to the top of the tower before winter.

Short-circuit current readings, taken by Forest Service personnel when weather permitted, are shown in table III. The large difference between the 12 and 24 V sections for the May 3 readings was caused by partial array shadowing. The very high outputs on November 4 (92 to 96 percent of AMO output) are indicative of the high outputs possible at high altitudes with thin clouds that significantly increase insolation.

A fully instrumented solar cell powered simulated RAMOS 12-volt system has been installed on a laboratory roof at the LeRC (fig. 10). This array contains both aluminum and fiberglass substrate modules. The solar cell modules were installed on the roof in early March 1974, but were not connected to the system loads until mid-April. Since then, the array has experienced three relatively severe storms with hail and winds to 67 mph. Neither the fiberglass cloth nor aluminum substrate modules have shown any mechanical or electrical degradation. This system has not been in operation long enough to yield correlation data.

Another solar cell powered simulated RAMOS 12-volt system has been built and was installed in July on a NOAA experimental buoy (fig. 11(a)), which will be moored in the Gulf of Mexico 60 miles east of New Orleans. This array is mounted horizontally atop the buoy superstructure and consists of a single 12-volt module made up of 2 aluminum and 3 fiberglass cloth substrate modules (fig. 11(b)). In addition to the five modules making up the 12-volt module, a module has been added which contains two groups of six cells each. One group of cells, operating at open-circuit voltage, will be used to measure solar cell operating temperature. The other group of cells, operating at short-circuit current, will be used as an independent insolation monitor.

Two power system projects have been completed for the U.S. Forest Service at the Inyo National Forest in California. The two projects, shown in table I, are power supplies for a mountain top voice repeater station and a backpack charger for portable transmitter/receivers for

Forest Service back-country guards. The voice repeater station, which is located atop 14,242-foot White Mountain Peak, will be used as a communications link for all mobile and personal transmitter/receivers in the National Forest (fig. 12). Its load profile is a function of the season, the weather, number of visitors/day, and other undefinables. The solar cell array consists of eight aluminum substrate 1-watt modules and eight fiberglass cloth substrate 1-watt modules.

The backpack modules are specially designed FEP-encapsulated aluminum substrate modules to be used by Forest Service back-country guards. Back-country guards are dispatched to wilderness areas for up to 2 weeks at a time. Limited battery capacity of their portable radios has precluded their monitoring the radios continuously thereby reducing their mission effectiveness.

Two different module configurations were made for Forest Service evaluation. The long narrow configuration shown in figure 13 is intended primarily for guards that move their campsite daily. The second module configuration (fig. 14) is intended for both moving guards and for semipermanent camps. This module can be either mounted on a pack or hung on a tree. Either module can charge two radios at a time.

The radio case was modified by the LeRC so that the battery is being charged as long as the radio is in the case and the case connected to the module through the charge regulator. The battery charge regulator, also shown in figure 14, was designed for another application and is not of optimum weight and size for backpacking. The weights of the solar cell modules less mounting hardware are 155 gr (5.48 oz) for the long configuration and 143 gr (5.05 oz) for the rectangular configuration. The weight of a spare battery is 260 gr (9.10 oz).

A Langley drift buoy project entails building small solar cell arrays for each of three different drift buoys which will be used to trace ocean and river currents off Norfolk, Virginia. These very low profile buoys will use aluminum substrate modules and will have the arrays mounted on the deck of the buoy and in one case about 12 inches above the deck. Their deployment is planned for the summer of 1974, but because their designs are being modified at the time of this writing, they are not listed in table I.

In addition to these system tests, the LeRC has single FEP module environmental tests in progress in cooperation with the Coast Guard and the NASA Langley Research Center. The test with the Coast Guard involves three 1-watt aluminum substrate modules mounted about 8 feet above the water on a navigation buoy in Boston Harbon. One module is mounted on the buoy permanently (fig. 15). Two other modules are alternately mounted on the buoy and returned to LeRC for measurements. The modules were installed in January 1974. Both have been returned to LeRC for examination after being on the buoy for 3 months each. Both showed little evidence of dirt or salt accumulation. However, the wires leading from the modules showed minor corrosion where they connect to the solar cells. This occurred because the wire connections to the solar cells, which are thicker than the FEP encapsulant, are occasionally not completely covered by FEP. The problem has been remedied by lead wire connection redesign and a thicker FEP covering.

At the NASA-Langley Research Center, an aluminum substrate module was mounted flush into the top of a small styrofoam buoy which was designed so that the surface of the module would be just barely awash. The buoy was tethered in sea water between two docks in a boat slip at Langley for two weeks after which it was returned to Lewis for examination. It showed some mechanical degradation and was covered with a blotchy layer of dried slime. This module was one which used silver mesh as a cell interconnect material. During fabrication of the module, some of the ends of the cut mesh legs were bent upward and protruded through the FEP following lamination. Exposure to sea water induced corrosion of the mesh legs at these protrusion sites. The effect of the salt water continued down the mesh leg, to the cell contacts, and down the cell grid lines. FEP delamination occurred in these areas. This was the only delamination observed after this short test and points out the importance of complete encapsulation of the active module elements.

The module was then returned to Langley, mounted on the under side of the buoy, and immersed under water for 4 weeks. At the end of the 4 week period, barnacles and other forms of marine growth had formed on the module (fig. 16). The corrosion noted following the first test had continued to cause FEP delamination. The void between the FEP and the cell, however, is so thin that interference fringes are formed in the delaminated area.

Following return of the module to the LeRC and while it was being photographed, several of the by then dry barnacles fell off the FEP surface. Following the as-received electrical measurements, the module was washed under clear cold water with a wet paper towel. All the remaining barnacles and marine growth washed off easily and the FEP surface showed no trace of their former presence.

Electrical measurements were taken of both the Coast Guard buoy and Langley buoy modules after salt water exposures. The modules were measured in an as-received condition, and after a clear water wash and rinse. The results of these measurements are shown in table IV. Considering the differences in appearance in the as-received condition of the two modules, it is interesting to note that the Langley buoy module does not show significantly lower current output. The meaning of the approximate 2.5 percent loss in short-circuit current for all the modules cannot be assessed at this time since this difference is near the level of reproducibility of short-circuit current measurements. Longer exposures in the ocean environment are necessary to establish whether or not electrical degradation is occurring.

CONCLUSIONS

The Solar Cell Branch at the NASA-LeRC has designed, built, and installed six terrestrial solar cell power systems using FEP-encapsulated solar cell modules. An additional system is being completed for installation during the summer of 1974. Results from 7 months of operation in Sterling, Virginia indicate that the system is meeting its electrical design requirements. No mechanical degradation has been reported at the Virginia installation. Ice damaged the array on Mammoth Mountain, but did not measurably degrade its electrical performance. A rooftop test at the LeRC is operating satisfactorily, albeit for only a short time. Results of marine environment tests on single modules have shown that the electrically active elements of the module must be completely sealed by the FEP. Interconnect protrusions through the FEP or cuts in the FEP which allow salt water access to the electrically active components induce FEP delamination. Based on the limited test data available, the FEP-encapsulated solar cell module appears well suited to terrestrial applications.

REFERENCES

1. Forestieri, A. F.; Broder, J. D.: Improvements in Silicon Solar Cell Coverglass Assembly and Packaging Using FEP Teflon, NASA TM X-52875, July 1970.

2. Climatic Atlas of the United States, U.S. Department of Commerce, June 1968.

3. Bernatowicz, D. T.: The NASA-Lewis Terrestrial Photovoltaics Program, Conference Record of the 10th Photovoltaic Specialists Conference, November 13-15, 1973.

TABLE I. - FEP-ENCAPSULATED SOLAR CELL POWERED SYSTEMS

Name and location	Installed	Volts	Current		No. of 1-watt modules	Battery capac., AH
			Contin. mA	Periodic		
RAMOS, Sterling, Va.	Oct. 1973	12 24	46 83	6.3 A, 6 sec/hr 0.556 6 sec/hr	10 30	60 80
RAMOS, Mammoth Mtn., Calif.	Nov. 1973	12 24	46 83	6.3 A, 6 sec/hr 0.556 A, 6 sec/hr	20* 40*	60 100
NASA-Lewis roof, Ohio	Apr. 1974	12	39	3.31 A, 6 sec/hr	10	40
Back-pack, Inyo Nat'l. Forest	Jul. 1974	13	25	0.31 A, variable	Special design	0.5
Repeater Inyo Nat'l. Forest	Jul. 1974	8.5	20	1.9 A, variable	16	45
NOAA Buoy, Gulf of Mexico	Jul. 1974	12	24	2.35 A, 6 sec/hr	5	40

*Design requirements same as for Sterling, Va. with addition of unscheduled operation. Additional modules added to accommodate latter requirement.

TABLE II. - SHORT CIRCUIT CURRENT READINGS

OF RAMOS SYSTEM AT STERLING, VIRGINIA

	Short-circuit current, mA		Sky conditions
	12-volt array	24-volt array	
Oct. 11, 1973	123	183	Overcast
Nov. 8, 1973	82	122	Overcast
Dec. 6, 1973	560	850	Clear, scattered clouds
Jan. 3, 1974	8	12	Overcast, dark clouds
Feb. 1, 1974	360	470	Overcast, breaks in dark clouds
Mar. 7, 1974	380	470	Overcast, breaks in dark clouds
Apr. 13, 1974	355	600	High, thin overcast
May 16, 1974	460	720	Hazy, broken overcast
June 20, 1974	320	510	Hazy, scattered clouds
July 25, 1974	184	288	Overcast
	840	1260	Air mass zero simulation

TABLE III. - SHORT CIRCUIT CURRENT READINGS OF RAMOS

SYSTEM ON MAMMOTH MOUNTAIN, CALIFORNIA

Date	Short-circuit current, mA		Sky conditions
	12-volt array	24-volt array	
Nov. 4, 1973	1610	1556	Clear, very thin clouds
Dec. 19, 1973	1568	1482	Clear
Jan. 24, 1974	1100	1100	Clear (some ice on array)
Jan. 29, 1974	320	320	Overcast
Feb. 14, 1974	600	600	Overcast
May 3, 1974	465	1005	Clear
July 5, 1974	1153	1165	Clear
July 6, 1974	1155	1207	Clear
	1680	1680	Air mass zero simulation

TABLE IV. - OUTPUT OF FEP ENCAPSULATED MODULES

AFTER EXPOSURE TO MARINE ENVIRONMENT

	Short-circuit current, mA	10 Ω-load current, mA
Coast Guard buoy		
Pre-exposure		
#L-5	410	366
#L-8	411	365
As-received		
#L-5	395	360
#L-8	400	362
Post-wash		
#L-5	399	366
#L-8	400	362
NASA-Langley buoy		
Pre-exposure		
Above water	417	365
Under water	406	368
As-received		
Above water	385	355
Under water	325	320
Post-wash		
Above water	406	368
Under water	406	360

Coast Guard buoy exposure: 3 months each module.
NASA-Langley buoy exposure: 2 weeks above water followed by 4 weeks under water.

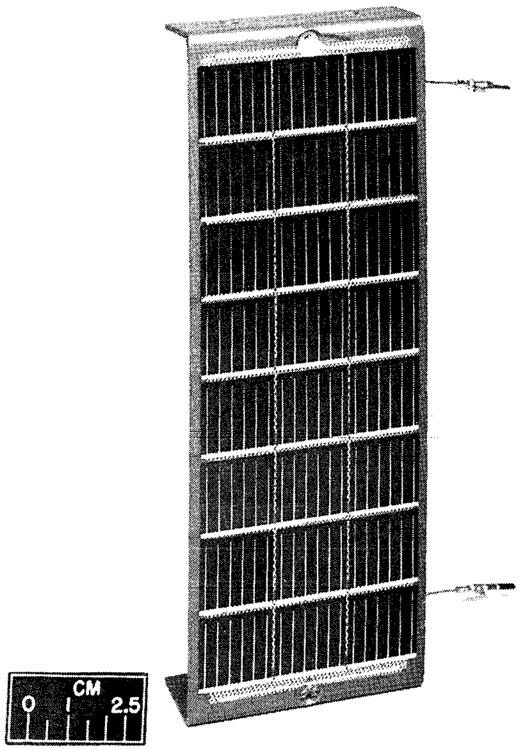

Figure 1. - A 1-watt aluminum substrate FEP-encapsulated module.

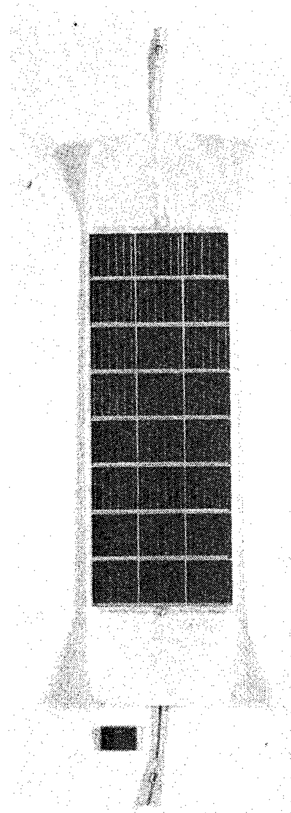

Figure 2. - A 1-watt fiberglass cloth substrate FEP-encapsulated module.

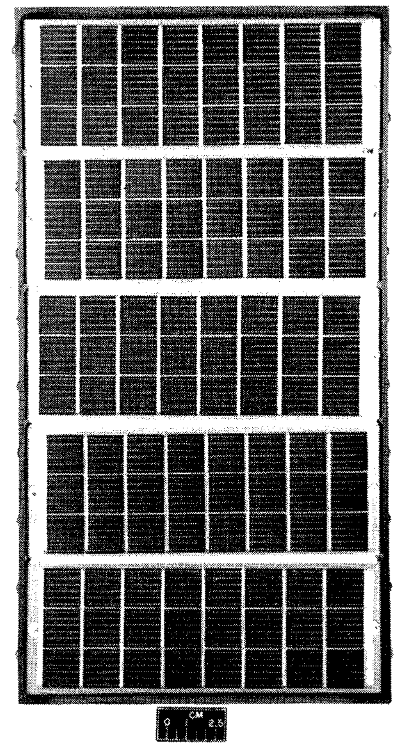

Figure 3. - A 12-volt module of five 1-watt FEP-encapsulated modules.

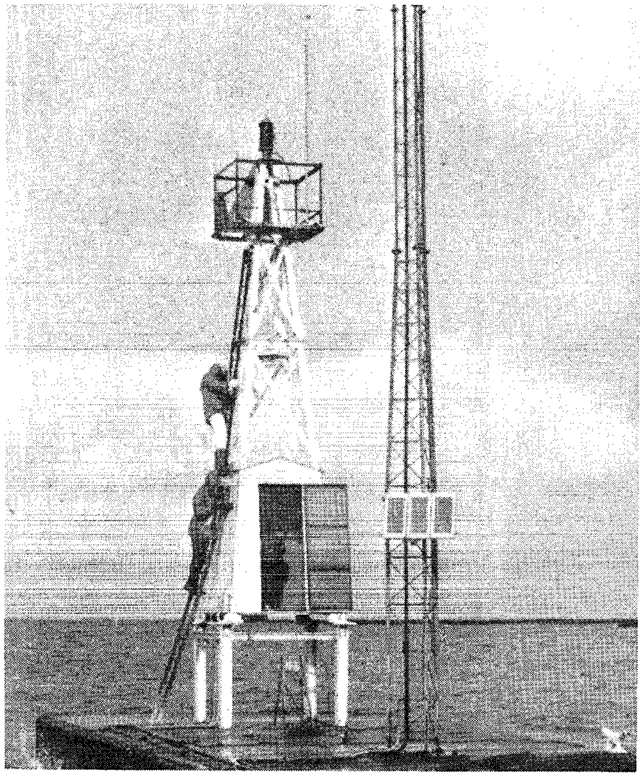

Figure 4(a). - Solar cell powered weather station at Cleveland, Ohio lakefront.

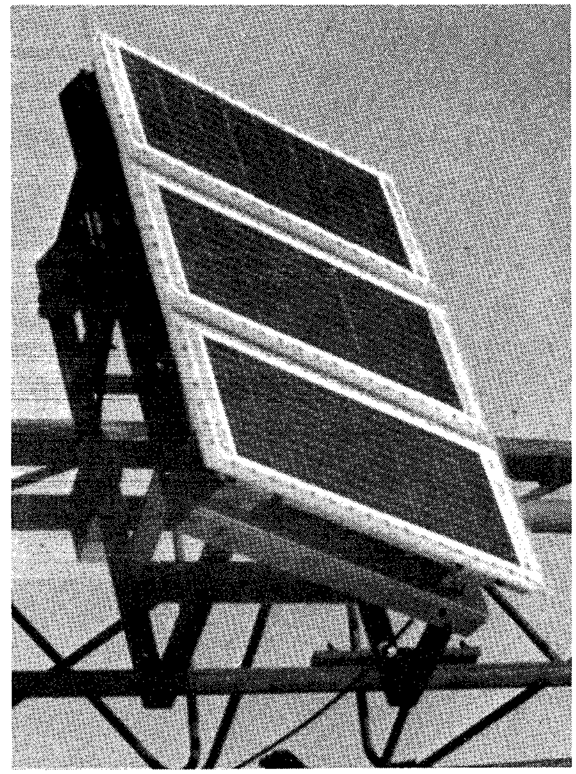

Figure 4(b). - Lucite-covered solar cell array at Cleveland lakefront.

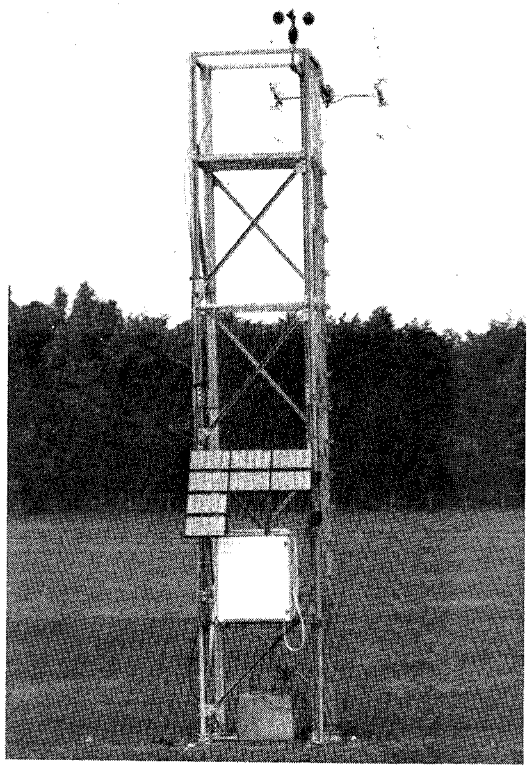

Figure 5. - Solar cell powered RAMOS weather station, Sterling, Virginia.

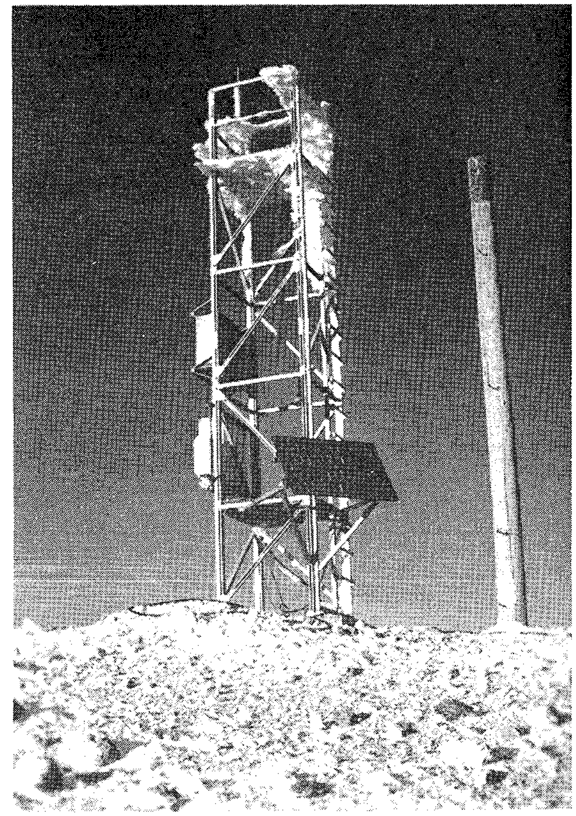

Figure 6. - Solar cell powered RAMOS weather station, Mammoth Mountain, California.

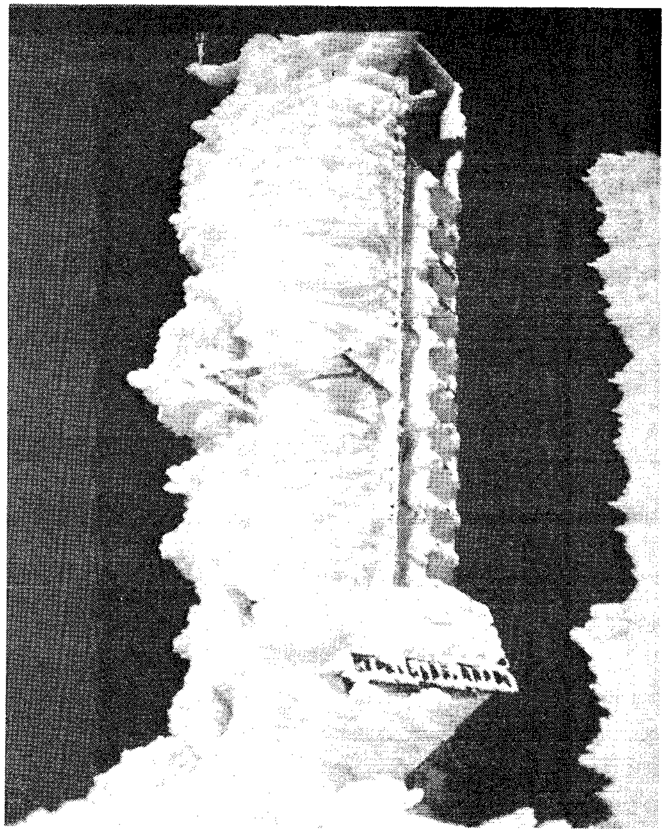

Figure 7. - Mammoth Mountain installation following winter storm.

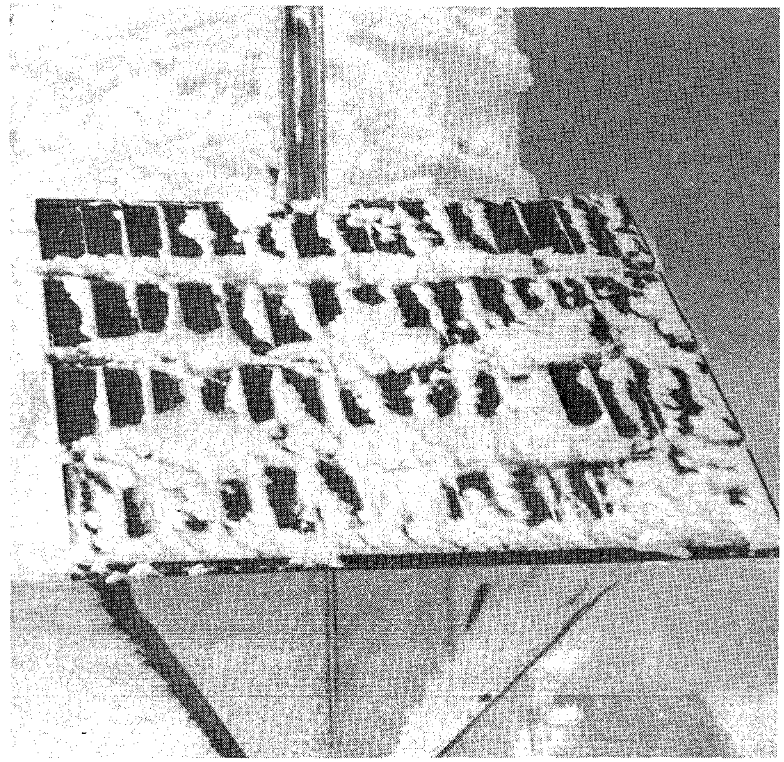

Figure 8. - Detail of rime ice build-up, Mamoth Mountain array.

E-6086

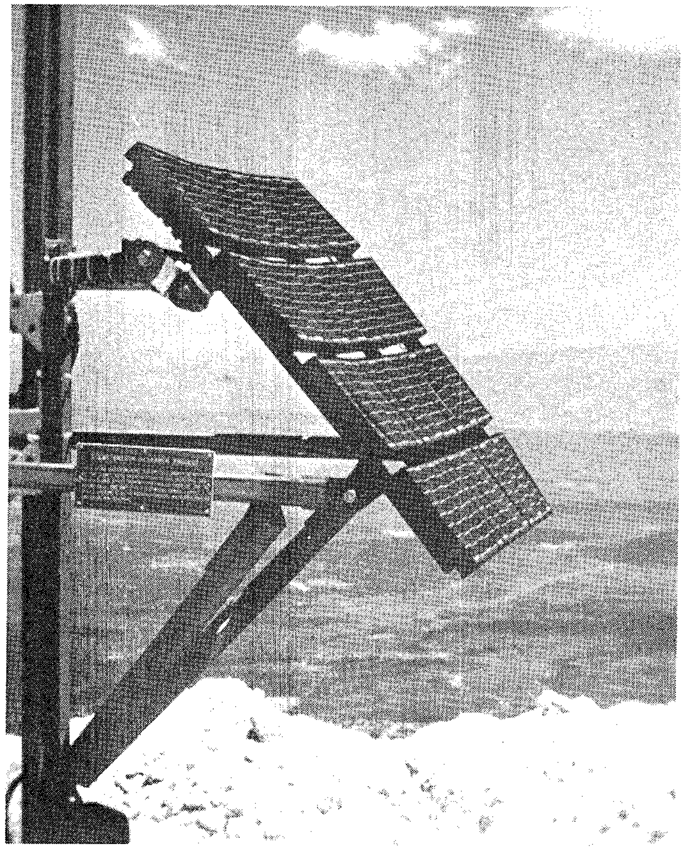

Figure 9(a). - Rime ice structural damage to Mammoth Mountain array.

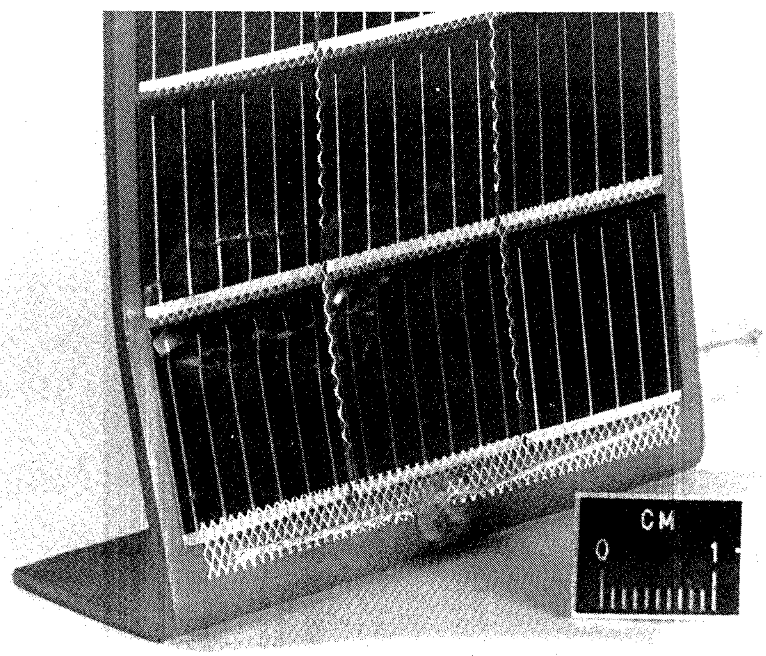

Figure 9(b). - Detail of rime ice damage to a module, Mammoth Mountain array.

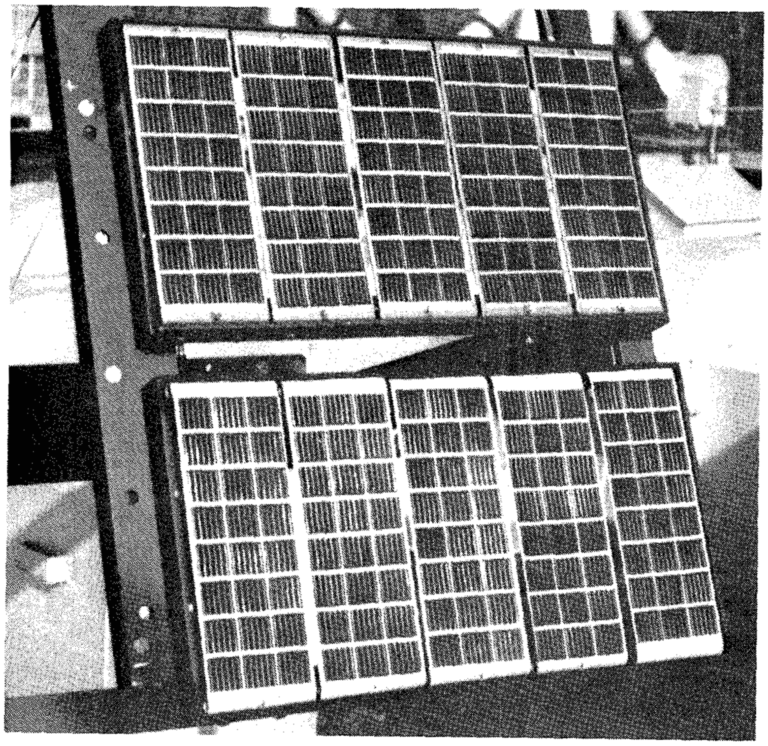

Figure 10. - Solar cell power system experiment of NASA-LeRC laboratory roof. Upper 12-volt module contains aluminum substrate modules. Lower 12-volt module contains fiberglass cloth substrate modules.

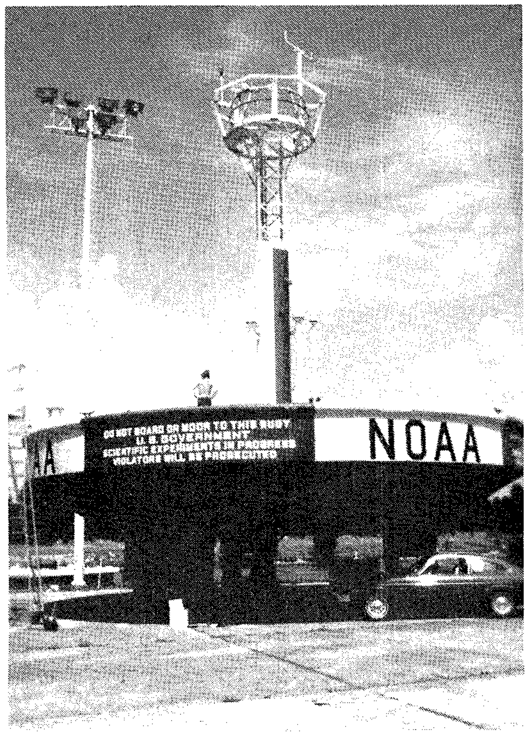

Figure 11(a). - NOAA experimental buoy with solar cell powered simulated RAMOS system.

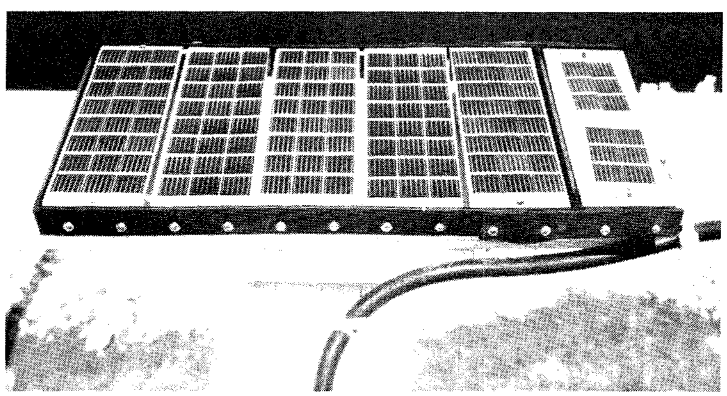

Figure 11(b). - Solar cell array mounted on uppermost rail of NOAA experimental buoy.

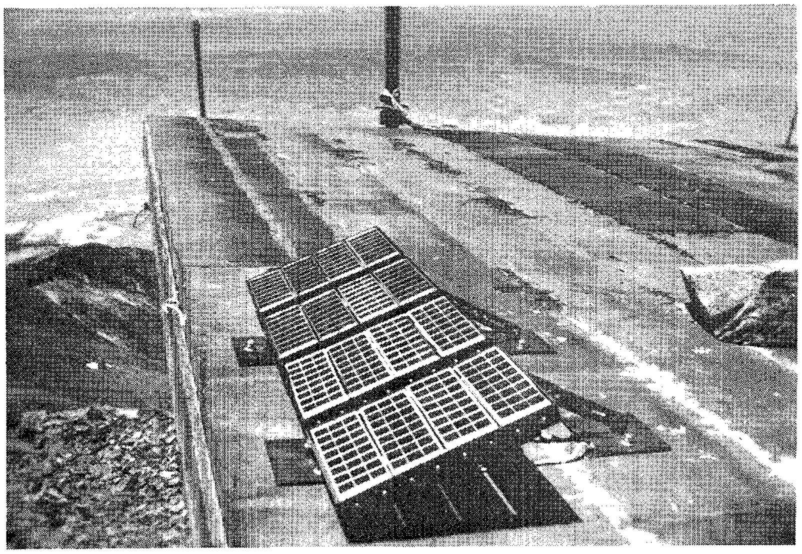

Figure 12. - Solar cell array for U. S. Forest Service voice repeater station, White Mountain Peak, California.

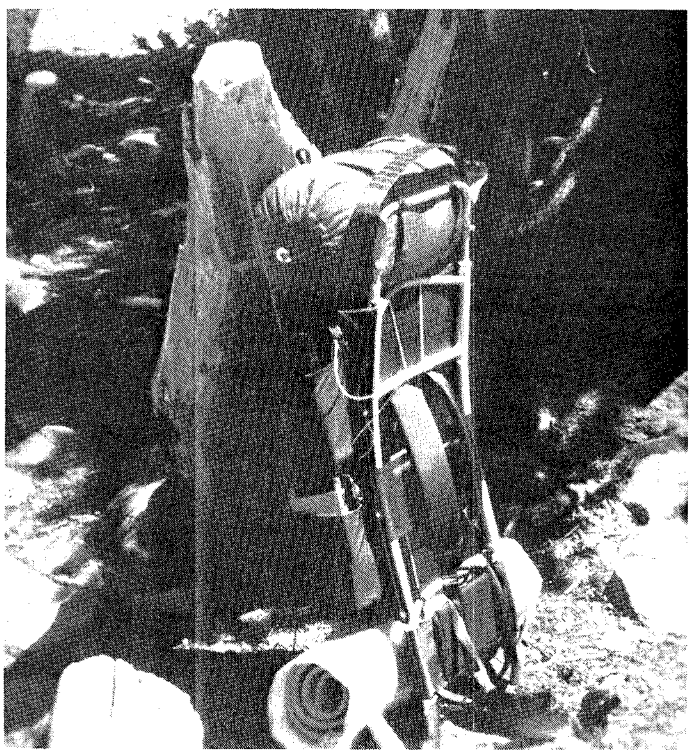

Figure 13. - Back pack mounted solar cell module for portable radio power supply for U. S. Forest Service; narrow configuration module.

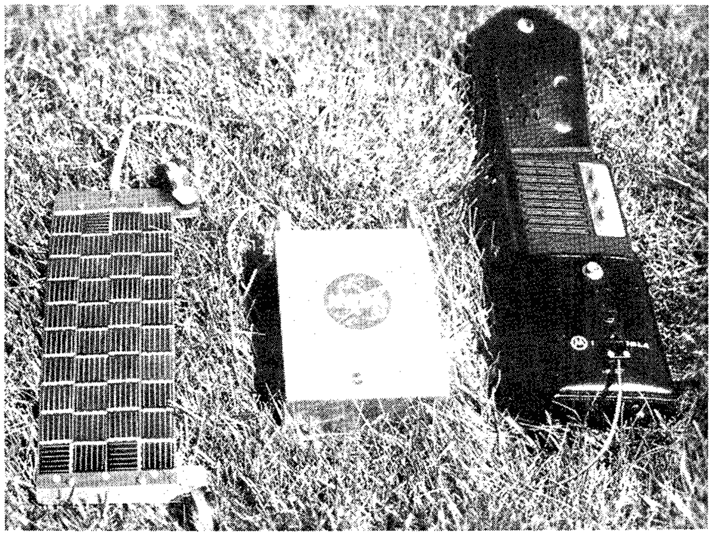

Figure 14. - Back pack solar cell power supply for portable radios for U. S. Forest Service; rectangular configuration module.

E-8086

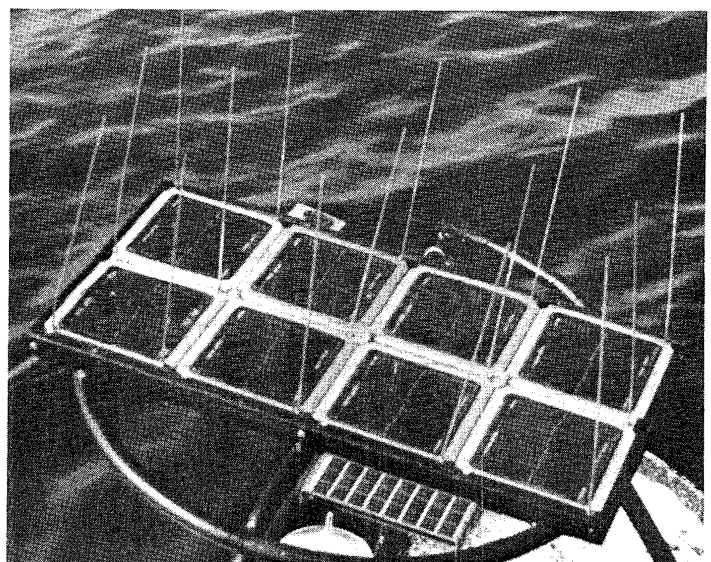

Figure 15. - A 1-watt FEP-encapsulated solar cell module mounted on a Coast Guard Navigation Buoy, Boston Harbor, Massachusetts.