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PHOTOVOLTAIC TESTS AND APPLICATIONS PROJECT
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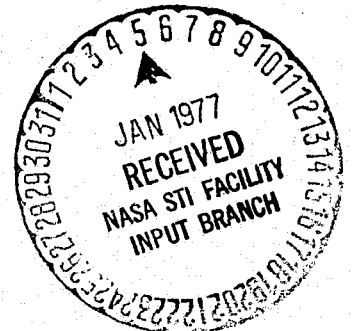
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**STATUS OF THE ERDA/NASA PHOTOVOLTAIC TESTS AND
APPLICATIONS PROJECT**

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SUMMARY

The Tests and Applications Project of the ERDA Photovoltaic Program is concerned with the testing of photovoltaic systems and the growth of their use in real terrestrial applications. This activity is an important complement to the development of low cost solar arrays by providing requirements based on application needs and stimulating markets to create demand to absorb increasing production capacity. A photovoltaic system test facility is now operational, market stimulation has been initiated through applications, and standards for terrestrial cell measurements established.

INTRODUCTION

The Tests and Applications Project is concerned with the development of terrestrial applications for photovoltaic systems as part of the ERDA National Photovoltaic Energy Conversion Program. This work is being carried on through a series of coordinated activities to identify practical real applications, build and demonstrate systems in such applications, conduct tests to understand and improve the characteristics and performance of photovoltaic systems, and provide requirements and data from this activity as guidance to ERDA's development of low cost solar arrays. Solar cell modules for these application systems will be purchased by the ERDA program as part of the Low Cost Silicon Solar Array Project managed by JPL. These application development activities are designed to stimulate the terrestrial market for photovoltaics so that as costs are reduced there will be an increasing market demand to encourage the expansion of solar array production capacity by industry.

Supporting these application development activities are tasks concerned with: (1) establishing standards and methodology for terrestrial solar cell calibration, (2) conducting standard and diagnostic measurements on solar cells and modules, and (3) conducting real time and accelerated testing of solar cell modules and materials of construction under outdoor sunlight conditions.

Experience and information gained through this project will be used to evaluate emerging systems technology, provide systems-related guidance to the other projects of the national program, and develop information for future photovoltaic program planning.

Specific activities in each of the major subprojects follow.

APPLICATIONS

Near-Term Applications

Near-term applications are classified primarily as any terrestrial application which could utilize a photovoltaic power system and be cost-competitive

on a life cycle basis within the next ten years (by 1986). Some of these applications exist today but are generally small in power level (< 1000 W) and usually remotely located. In other instances, the cost-competitive time for photovoltaics is still 5 to 10 years away and users are unwilling or unable to pay the premium cost to install a photovoltaic system today. In still other cases, the market 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. Experiments and demonstrations specific to the application of a potential user should aid and speed the incorporation of solar electric power into the users' operational systems.

To examine the possibilities for stimulating the near-term market several thrusts are being developed.

Mini-applications: These involve the selection, design, assembly, and deployment of a small number of photovoltaic systems (100-1000W) powering equipment which is both useful and generally understood by the public. As examples of these systems, two photovoltaically powered small refrigerators have been assembled and deployed to Isle Royale National Park, Michigan (Fig. 1) and the Papago Indian Reservation, Arizona, (Fig. 2), respectively. Public information news releases thus far have generated many inquiries both nationally and foreign (Australia, Japan, South Africa, etc.). Another application to show to the public the versatility and availability of photovoltaic power is pictured in figure 3. The 1.7 KW solar array shown was used during July, August and September during the annual Festival of American Folk Life, in Washington, DC, to charge batteries on electric vehicles used by the National Park Service to manage the Festival. This display, while not cost-effective, did provide the many visitors to the festival with an opportunity to see photovoltaics at work. Other mini-applications, such as water purping, are being developed for deployment in the near future. This activity serves to introduce photovoltaics to the public, expand public awareness, and stimulate ideas for applications both domestic and foreign.

Cost-shared tests: A second thrust has involved implementation of cost-shared tests of photovoltaic applications relevant to near-term needs of user-agencies of government. Agreements have been reached with the National Weather Service (NWS) for tests of photovoltaic systems to power six remote automated meteorological observation stations (RAMOS) which NWS is developing (Fig. 4.). NWS expects to deploy several hundred such systems throughout the U.S. (many in remote areas) over the next several years. Solar cells appear to be attractive for powering many of these stations. Two systems have also been fabricated for use by the U.S. Forest Service on fire

lookout towers in Lassen and Plumas National Forests, California. (Figs. 5 and 6) These systems (300 watts each) are providing power for lighting, water pumping, refrigeration, and radio communications for the tower operator who lives at the lookout during the fire season (6 to 8 months each year). Other cost-shared application tests are being identified. In all cases the purpose of the cost-shared test is to provide a way for a user agency with a large number of applications to examine the possibilities of photovoltaics in his operational climate with the support and guidance of another agency. Following successful cost-shared tests the user agency will be expected to satisfy his operational needs for photovoltaic systems through purchases from commercial sources.

Mail solicitation: A third thrust has involved the identification of new applications in government through mailings of a descriptive brochure. The purpose of the mailing has been to solicit others for needs in order to identify a wide range of potential applications for development. Two mailings (800 each) have elicited a very encouraging interest and response. These responses are now in the process of followup and evaluation.

Other ideas for stimulating the market for photovoltaic systems are being considered and additional thrusts will be implemented for both domestic and foreign markets.

Department of Defense Applications

Energy resources and alternatives are an important concern in the operation of the Department of Defense (DOD). Part of DOD's interest in investigating energy alternatives is the consideration of photovoltaic power systems for military applications. To help DOD initiate their investigation of photovoltaics, support has been provided to design and construct photovoltaic arrays to power five initial applications which DOD has selected for demonstration. Peak power levels for these applications range from 160 watts to 12 KW. Total power requirements are about 26.5 KW.

System Test Facility

The objective of the System Test Facility (STF) is to provide a facility where photovoltaic systems may be assembled and electrically configured, without true physical configuration or arrangement, in a breadboard fashion for operation and testing to evaluate their performance characteristics. The STF provides a vital support function to the overall Applications Subproject. As a "breadboard" system it allows prompt preliminary investigation and check out of components subsystems and systems before they are mounted in more elaborate and visible experiments or demonstrations.

The STF will be one of the first of the large-scale installations (40KW peak in CY 77) of P/V systems and the test results and experience will be invaluable to the planning and execution of the later experiments for the larger applications that are identified by the Mission Analysis and System Definition projects. Operating experience and systems test data is needed to corroborate the results of the system analysis studies and to validate and refine the computational models used in the analyses. The facility will be available for conducting tests needed by all projects of the ERDA Photovoltaic Program.

The facility is presently operational with approximately 10 KW peak of solar cell modules installed. (Fig. 7) Construction is well under way to extend the capacity for installation of an additional 30KW of array.

Facility Configuration: The facility has been designed to test systems both with and without battery storage. For the system with energy storage, a 54 cell, 48-kW-hr lead-acid battery is used in parallel with the solar array. The approach chosen was to consider that all photovoltaic power generated would be used for test loads, battery charging, or, if in excess, dissipated as heat through a shunt regulator. Power to load banks will be furnished in the form of a two-wire, 120-volt single-phase 60 Hz AC developed through a self commutating DC/AC inverter. This arrangement provides instantaneous back-up power in the event of any photovoltaic power system interruption or to cover large peak test loads.

The facility also is capable of testing a system without energy storage by using a DC/AC inverter in parallel with the incoming utility line. Inverters of this type are designated line-commutated inverters. In this case, excess solar array power appearing at the inverter output is fed back through the incoming utility line to be used elsewhere in the utility system. In this mode the inverter will be controlled to extract power from the solar array at a voltage corresponding to maximum power generation.

A flexible wiring arrangement has been provided between the arrays and power conditioning equipment so that the field of solar cell modules may be configured into a variety of array arrangements of different voltage and power levels.

First tests and preliminary results: Following checkout of the first phase of the facility construction in August, testing was initiated in September with about 4KW of solar cell modules installed. (Subsequent installations of modules have now brought the peak power available up to about 10KW).

As a first system test, the field array was connected to an assortment of loads through an 8KW line commutated inverter designed to share the load with a utility power source. The test confirmed that when the loads required more power than the array could provide, the extra power was drawn from the utility. When excess power was generated by the array it was fed to the utility grid. The efficiency of the inverter (AC power out divided by DC power in) was measured to be approximately 70% at 20% of rated power and 90% at 50% of rated power. No attempt was made in this early test to filter out the harmonic distortion in the output of the inverter. This is planned for future tests.

Electromagnetic interference tests indicated that the level of radiated frequencies from the array was indistinguishable from background radiation when further than 20 feet from the solar array. In the vicinity of the line commutated inverter there was some interference picked up on the AM broadcast band. This disappeared when the AM receiver was removed a few feet from the control center where the inverter was located. There was no noticeable difference in the quality of TV or FM reception when the power was switched from the utility grid to the output of the inverter. Further tests on both radiated and conducted interference are planned, and will be done as a function of array capacity.

The effect of shadows on solar cells is presently being investigated. It has been observed that the typical terrestrial solar cell has a very high dark leakage current. It has also been found that it is rather difficult to get a true dark shadow on a single cell in a module. The cells, as they are encapsulated, in modules are typically mounted so that they are approximately 1/8 to 1/4 of an inch from the module surface. Some light gets to the shadowed cell from the edges in a normal installation. Therefore, the effects of shadowing are not likely to be as severe as in space applications where the shadows are deeper.

STANDARDS AND MEASUREMENTS

The objective of this subproject is to ensure the availability of reliable performance test methods and information for all participants in the ERDA National Photovoltaic Conversion Program. To carry out these objectives, a number of interrelated tasks are employed to acquire inputs from participants in the program, develop test methods, and provide guidance and information back to the program participants.

Workshops

Workshops are being employed as a primary means of acquiring technical input from program investigators with respect to terrestrial solar cell measurements. A first workshop was held in March of 1975 and an interim measurement procedure manual issued. A second workshop was held last week November 10-12, 1976 at Baton Rouge, LA. to refine the interim procedures. Topics addressed were (1) terrestrial sunlight and its effect on solar cell performance; (2) solar simulation; and (3) techniques for cell and array measurement and standard cell calibration. Results of this workshop are presented in another paper at this conference.

Reference Conditions and Methodology

Activities in this task have investigated the variation of standard cell calibration coefficients with atmospheric conditions and the error in cell measurements introduced by spectral mismatch between sunlight, simulator, test cells, and standard cells.

In an effort to determine the sensitivity of solar cell performance to a range of atmospheric conditions and insolation components, an insolation measurement facility has been set up. The approach is to measure the insolation using a solar cell and a black body detector in each of several different orientations. Detectors are in place in several orientations (horizontal; horizontal-shadow banded; inclined, 37° above horizontal, etc.). This facility is now operational and data is being acquired.

The cell measurement facility has been automated with a HP 9830 calculator-interface bus system. I-V curves, spectral response curves, cell dark forward I-V characteristics and cell V_{OC} - I_{SC} characteristics can readily be obtained. The data is acquired, calculations made and results presented or plotted using the 9830. Over 2000 measurements have been made for more than 40 different organizations in the past year.

During the last seven months, over 2600 modules from the 46 kW ERDA/JPL buy have been delivered to Lewis. I-V measurements have been made on about 13%

of the modules with a pulsed solar simulator. The simulator target area is being expanded from 32" in diameter to 5' x 9'. Module and array measurements can also be made outdoors using the HP calculator system. Temperature and irradiance are measured and corrections made.

Interim Reference Cells

Reference cells are being calibrated and distributed to investigators to use in their own facilities so as to standardize measurements and permit cell characteristics to be compared between investigators more accurately.

To date, interim reference cells have been calibrated and distributed to 17 organizations. Both silicon cell and cadmium sulfide cell standards have been delivered. The calibration coefficients are affected significantly by atmospheric water vapor content and turbidity. An updated standard cell holder has been designed and fabricated. The main improvement is the field of view which allows the cell to be used in any orientation. These holders will be distributed as replacements for the earlier unit.

Field Insolation Measurements

One problem in assessing the performance of photovoltaic systems in field applications is the lack of local insolation data. Generally, systems are sized based on national insolation data for the region of the test. Local conditions at the application site may not match the national data. Therefore, a low cost insolation recording instrument is being developed. The instrument is self-contained and uses a silicon solar cell as a sensor. Field instruments are being made for distribution to a variety of test sites. These include all application sites for the 46 kW buy and all endurance testing sites.

ENDURANCE TESTING

The objective of this subproject is to determine the endurance of solar cell modules and module materials under both accelerated and real-time environmental conditions of intended use.

Accelerated outdoor exposure will be used to test cells, modules, arrays and their component materials in concentrated sunshine. Accelerated testing of a number of solar cell encapsulant materials was started in July 1974 by the Lewis Research Center. Work in this area will be expanded with tests being made over a series of controlled environmental conditions (i.e., temperature, humidity) and in the presence of atmospheric pollutants.

Real-time outdoor exposure tests provide the most accurate measure of life for solar cell arrays and materials. Established testing companies with solar insolation and climatic reporting capability are conducting the real-time tests. Several hundred samples are presently being tested under both accelerated and real time conditions. Some solar cell modules from the JPL 46 KW buy are showing delamination of the encapsulant around the edges. So far, this has not resulted in any noticeable decrease in electrical output. However, the modules have yet to be exposed to winter conditions where moisture can be trapped in the delamination voids and subsequently frozen and thawed. This may lead to further delamination and, if the delamination occurs over a cell, cell fracture with a loss in electrical output may occur.

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Of the polymeric materials being tested (see table I) those that show promise are FEP Teflon, perfluoro alkoxy, polymethylmethacrylate, polyvinylidene fluoride and a sandwich of Tedlar-vexar-polyethylene.

Table I

Some Materials Undergoing Endurance Tests

Accelerated Tests

FEP-A Teflon with GE 574 adhesive
FEP-C Teflon with GE 574 adhesive
Polymethylmethacrylate
Polycarbonate - UV stabilized

Real Time Tests

Polyarethane
Quartz
Kapton
RTV silicone
Polyester
Polyvinylidene fluoride
Polyvinylidene fluoride copolymer
TVP - Sandwich of 1 mil UV stabilized Tedlar
Vexar plastic grid -3/4" mesh UV inhibited
polyethylene

CONCLUSIONS

Several near term applications have been fabricated and installed at field sites for testing. Arrays for DOD applications have been delivered and testing initiated. The System Test Facility at NASA-Lewis Research Center has become operational. Considerable progress and understanding has been gained regarding the problems and variables of terrestrial measurements of solar cells and modules. During the coming year, increased emphasis will be placed on the stimulation of the market for photovoltaics and the fielding of additional near term application tests. Emphasis will also be increased on breadboard system testing, endurance testing, and the refinement of measurement techniques. All of these activities will provide a greatly increased base of real terrestrial data concerning photovoltaic systems to help guide and focus the ERDA Program on the critical problems to be solved.

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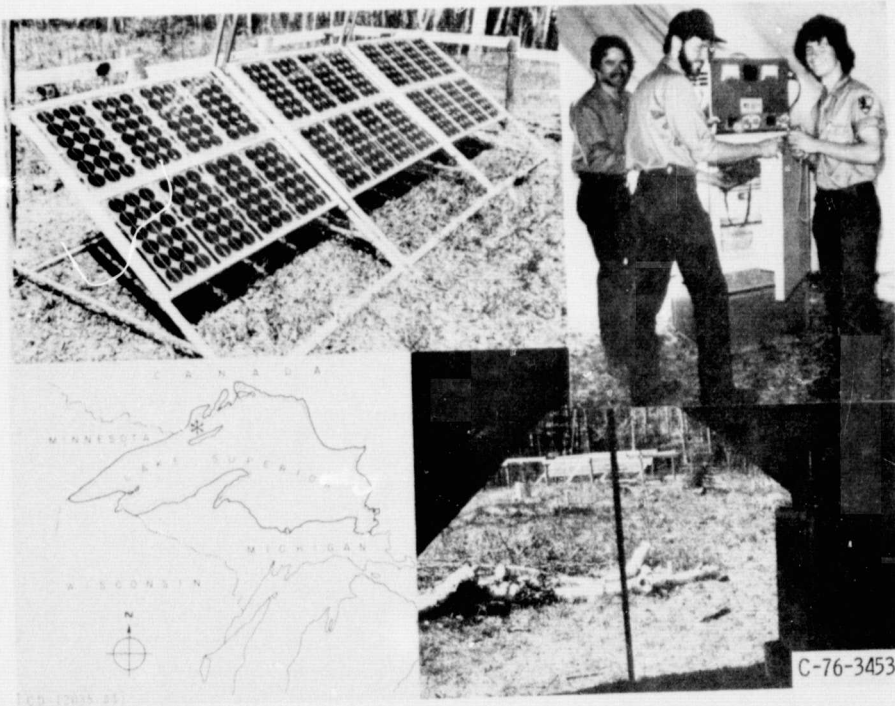


Figure 1. - Photovoltaic powered refrigerator used by park personnel - Isle Royale National Park, Michigan.



Figure 2. - Photovoltaic powered refrigerator in use on the Papago Indian Reservation - Sil Nayka, Arizona.

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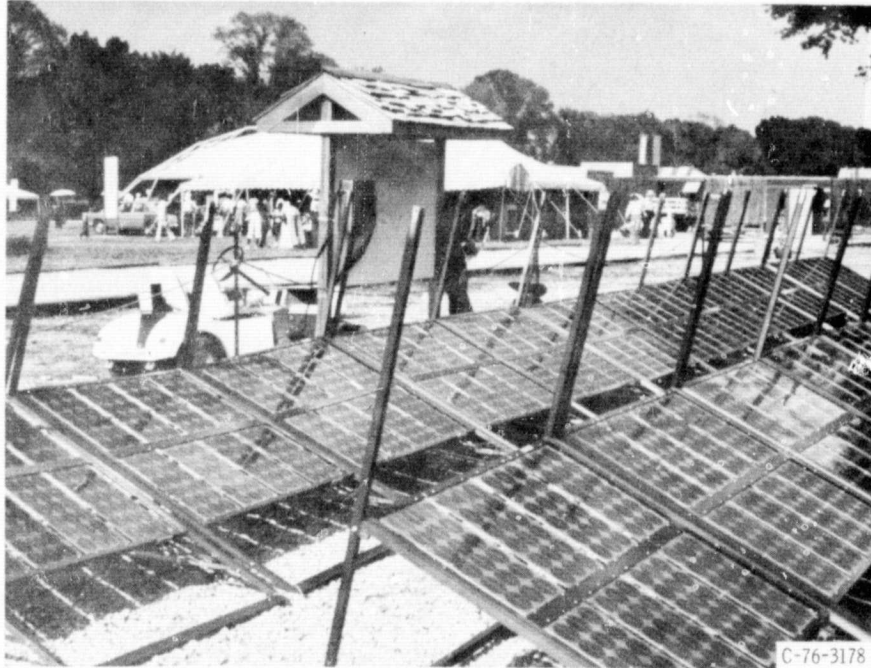


Figure 3. - Electric vehicle solar cell battery charging system - Festival of American Folk Life, Washington D.C.

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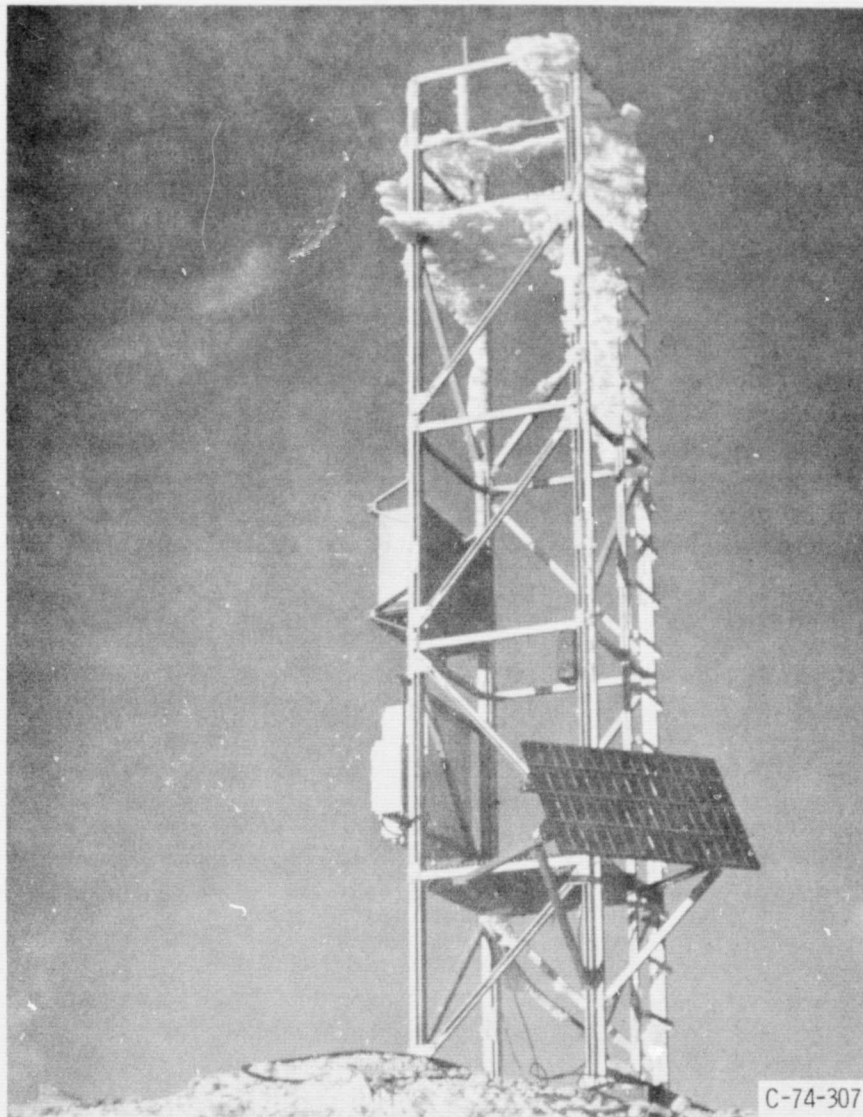


Figure 4. - National Weather Service remote weather station (RAMOS) - Mammoth Mountain, California. Similar to six additional units planned for ERDA application tests.

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Figure 5. - U. S. Forest Service fire lookout - Antelope Peak, Lassen National Forest, California.

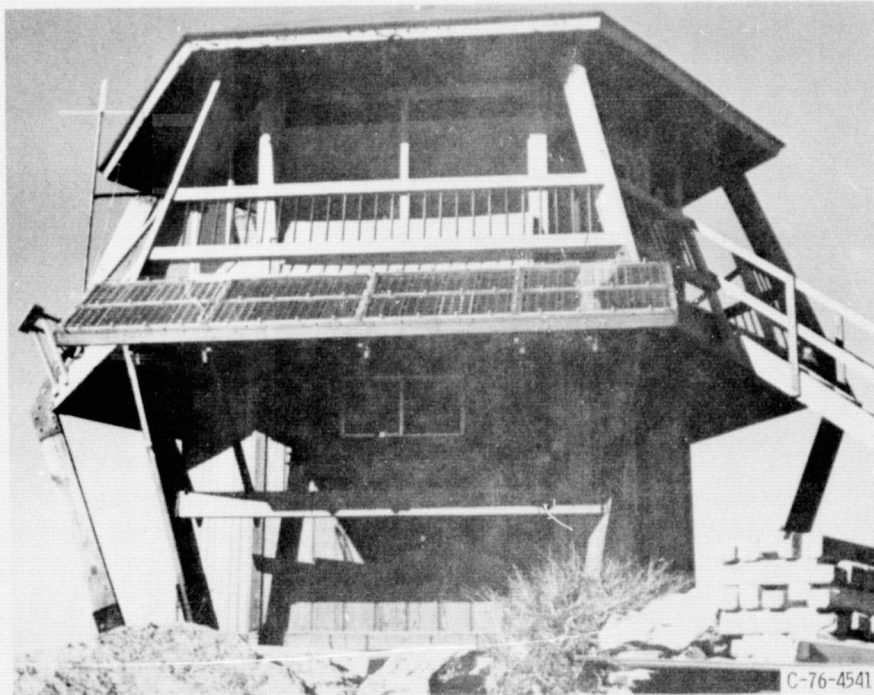


Figure 6. - U. S. Forest Service fire lookout - Pilot Peak, Plumas National Forest, California.

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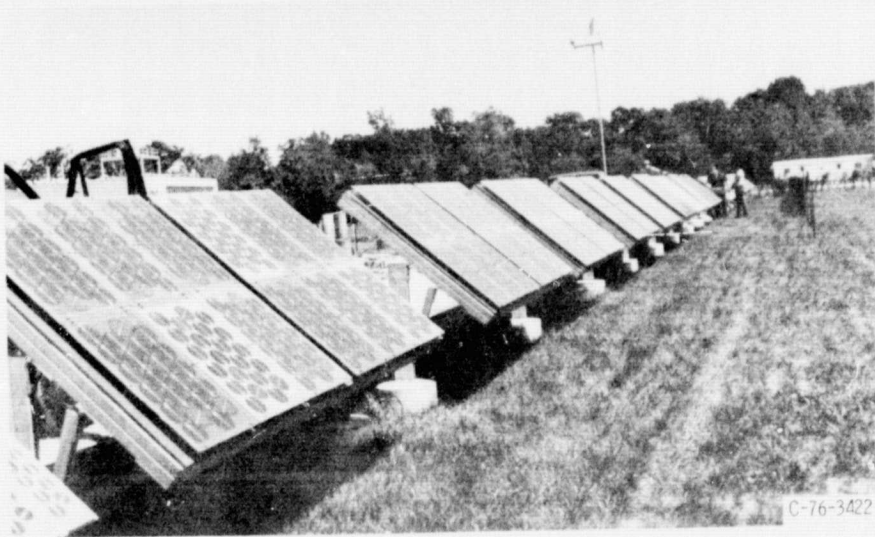


Figure 7. - Photovoltaic System Test Facility: NASA-Lewis Research Center, Cleveland, Ohio.

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