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TEST FACILITY FOR SOLAR-CELL REFERENCE CONDITIONS

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TEST FACILITY FOR SOLAR-CELL REFERENCE CONDITIONS

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ABSTRACT

A test facility, intended primarily for long-term monitoring of the global insolation and its components and the concurrent solar-cell performance under a wide variety of measureable atmospheric and weather conditions, is described. Instruments for the measurement of insolation, cell performance, turbidity, water vapor, and cloud cover are described. Preliminary evaluation of the hourly data base generated over a two-month period for a range of sky conditions from clear to overcast is presented.

SUMMARY

This report describes the Solar-Cell Reference-Condition Test Facility built for the purpose of long-term monitoring of global insolation (at a given location, the total insolation impinging on a horizontal surface) and concurrent solar-cell performance under a wide variety of atmospheric and weather conditions. Instruments to measure insolation, cell performance, atmospheric turbidity, water vapor and cloud cover are described. Preliminary evaluation of hourly data generated over a two-month period has shown (1) a 9% decrease in cell sensitivity (current output-to-insolation intensity ratio) as sun elevation angle decreases from 56.5° to 19.3° on clear or partly cloudy days and (2) cell sensitivity increases up to 15% with decrease in intensity for overcast skies. Based on these early results, it appears that atmospheric conditions should be clearly established when making cell performance measurements under global insolation.

INTRODUCTION

At present, there is no long-term data base available which can be used to determine the sensitivity of solar cells to variations in the components of global solar radiation. Furthermore, solar cell performance data are usually obtained only under clear-sky conditions. Such measurements are generally used to establish an index of cell performance for comparisons between cells. While there is a need for these comparative performance indices, there is also a need to determine the sensitivity of cells under the range of atmospheric conditions which may be encountered throughout the year. Such information is valuable not only to those whose main interest is generation of power from solar arrays, but also to the photovoltaic investigator who wishes to relate the performance index of a particular cell with typical insolation conditions.

A reference condition test facility was constructed in June 1976, at the NASA Lewis Research Center (LeRC), Cleveland, Ohio, to meet these needs. The facility, located on the roof of the Energy Conversion Laboratory, is intended primarily for acquisition of averaged hourly data on global insolation and its components and the concurrent silicon solar-cell performance under a wide variety of measured atmospheric and weather conditions. This report describes the capability of the system and instruments for acquisition of insolation, cell performance, turbidity, water vapor and cloud cover data. Typical results of hourly data generated over a two-month period for sky condition from clear to overcast are presented.

SYSTEM DESCRIPTION

As shown in Figure 1, the data source portion of the system consists of a number of data generation channels, each channel containing a sensor, a voltage controlled oscillator, and a counter which integrates the data continuously. The data processing subsystem, located in the computing center at the LeRC, consists of a minicomputer which controls the sampling rate of the integrated data, a data collector which receives the data, and the TSS/360 computer used for data base storage and analysis.

The sensor subsystem (Figure 2), is divided into two assemblies, a tracking assembly and a nontracking assembly. The tracking assembly, which is being fabricated, will continuously track the sun and record the direct normal insolation and concurrent solar-cell short-circuit current, and the atmospheric turbidity and water vapor content. The nontracking assembly, which is operational, records the global insolation for surfaces pointed due south at tilt angles of 0°, 37° and 60°. The diffuse sky radiation is also measured. Finally, a camera to record sky conditions will be included in the facility in the near future.

Sensor Subsystem Description

The nontracking insolation and solar cell assembly is shown in Figure 3. Three precision pyranometers measure global insolation received at 0°, 37° and 60° tilt angles. The diffuse component is measured by a fourth pyranometer horizontally mounted and equipped with a shadow band. Solar cell performance is determined with four sensor packages oriented identical to the pyranometers. The solar cell sensors are 1 cm^2 in area, soldered on Kovar blocks, and mounted in housings nearly identical to the pyranometer, as shown in Figure 4. Solar cell temperature is measured with a thermocouple attached to the Kovar block and is used to correct cell output for temperature variations. The tilted sensors are equipped with artificial horizons to eliminate surface reflection effects.

RESULTS AND DISCUSSION

Solar cell sensitivity is defined as the ratio of cell short circuit current, I_{sc}, to insolation intensity I_n. The sensitivity of horizontally mounted (0°) sensors under differing sky conditions is shown in Figures 5-8. These sensitivities are average values for hourly intervals. The differing symbols stand for different days. Figure 5 shows cell sensitivity as a function of air mass for clear sky days. Clear sky days include those days with light cirrus clouds. It can be seen that cell sensitivity drops from about 0.272 amps/watt at air mass 1.2 (solar elevation of 56.5°) to about 0.247 amp/watt at air mass 3 (solar elevation of 19.3°). The variation at a fixed air mass is caused by changes in the atmospheric turbidity and water vapor. These effects are described in references 1 and 2.

Figure 6 shows the solar cell sensitivity as a function of air mass under partly cloudy skies (~ 30% cloud cover). For this case sensitivity drops from about 0.269 amps/watt at air mass 1.2 to about 0.245 amps/watt at air mass 3. The sensitivity at air mass 1.2 is about 1% lower than for clear skies. For both clear and partly cloudy skies the percentage decrease in sensitivity is about 9% from air mass 1.2 to air mass 3. This loss in sensitivity is probably due to departures from a cosine response for solar cells with nonnormal incident light. Such departures from cosine behavior have been previously reported (references 3, 4, and 5). The magnitude of the loss and its behavior with air mass are consistent with results in those references.

Figures 7 and 8 demonstrate the sensitivity of the solar cell for several different days under overcast skies. The intensities measured with the pyranometers ranged from 20 to 320 W/m^2. The global readings and diffuse readings were practically identical, indicating that essentially no direct solar radiation was incident on the solar cell and pyranometer. Both figures show considerable scatter in the data; this is probably due to the relatively large errors in the low intensity readings. In figure 7, a plot of the sensitivity versus intensity level appears to display a gradual increase in sensitivity from around 0.27 to about 0.31 as the intensity decreases from 200 to 20 W/m^2. In figure 8, the change in sensitivity with air mass may be obscured by the considerable data scatter. The cell current to intensity ratio under global radiation is seen in Figures 5, 6, 7 and 8 to be dependent upon sky condition and sun-cell orientation. Based on these preliminary results, it appears that the atmospheric conditions should be defined when measuring cell performance or performance index by calibration relative to a pyranometer under global insolation.

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4. Tallent, R. J.: Optical Electrical Design Considerations for Concentrating Solar Cell Panels. Paper 62-123, AIEE Summer General Meeting, Denver, Colo., June 17-22, 1962.
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APPENDIX - DEFINITIONS

Insolation - Incoming solar radiation flux received by unit area.

Global Insolation - The sum of the solar radiation fluxes received direct from the solid angle of the sun's disk (direct component) and from the solar radiation which has been scattered over the hemispherical sky in traversing the atmosphere (diffuse, or sky, component).

Air Mass - A measure of the length of path through the atmosphere to sea level traversed by light rays from a celestial body, expressed as a multiple of the path length for a light source at the zenith.

Turbidity - Any condition of the atmosphere which reduces its transparency to radiation due to scattering by atmospheric gases, dust and aerosols.

Tilt Angle - The angle which the plane of a sensor makes relative to the horizon.

Sun Photometer - An instrument used to measure the turbidity in the atmosphere.

Pyrheliometer - An instrument for measuring the intensity of direct solar radiation at normal incidence.

Pyranometer - An instrument for measurement of the solar radiation received from the whole hemisphere.

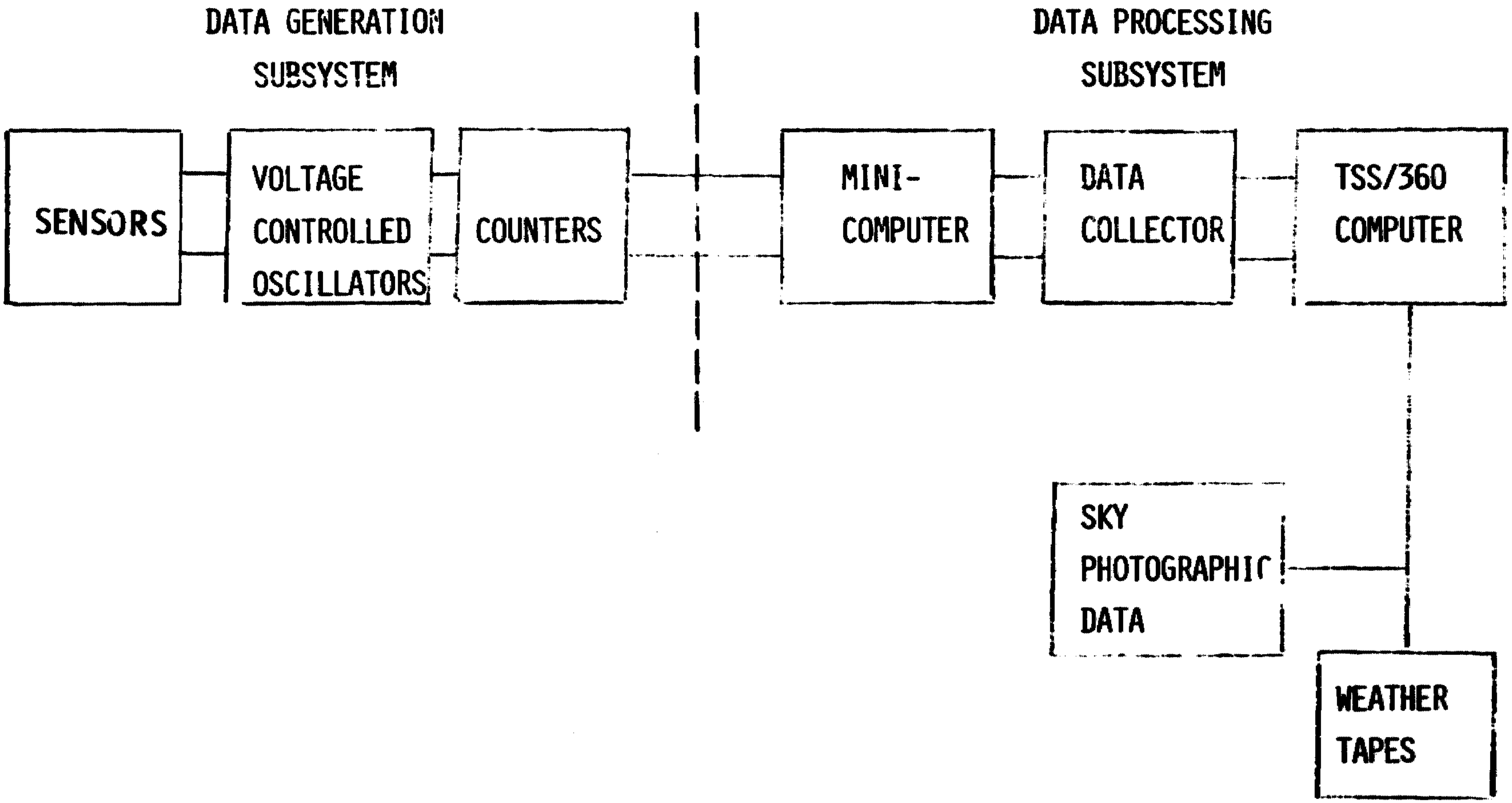

Figure 1. - Reference conditions test facility

Sensor	Measurement
TRACKING ASSEMBLY	
PYRHELIOMETER	DIRECT SOLAR RADIATION
SOLAR CELL (COLLIMATED)	&
THERMOCOUPLE	SOLAR CELL PERFORMANCE
SUNPHOTOMETER	TURBIDITY
WATER VAPOR METER	WATER VAPOR
NON-TRACKING ASSEMBLY	GLOBAL SOLAR RADIATION & SOLAR CELL PERFORMANCE AT
PYRANOMETERS (4)	0°, 37°, 60° TILT
SOLAR CELLS (4)	DIFFUSE SKY RADIATION & SOLAR CELL PERFORMANCE
SKY CAMERA	CLOUD COVER

Figure 2. - Sensor Subsystem

Figure 3. - Non-tracking sensor subsystem (pyranometers & solar cells)

Note: Symbols represent different days

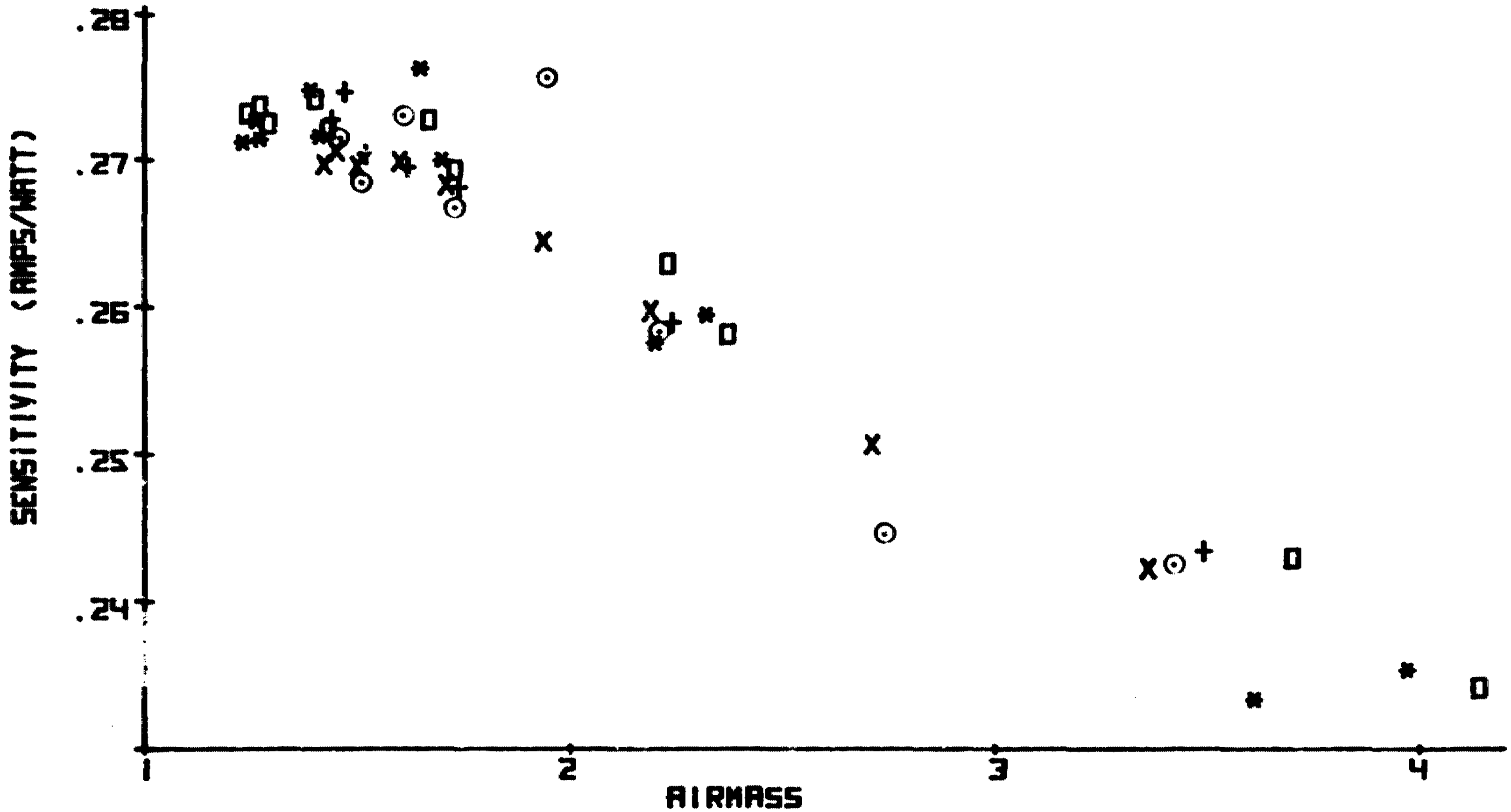

Figure 5. - Sensitivity versus air mass under clear sky (global - 0 tilt)

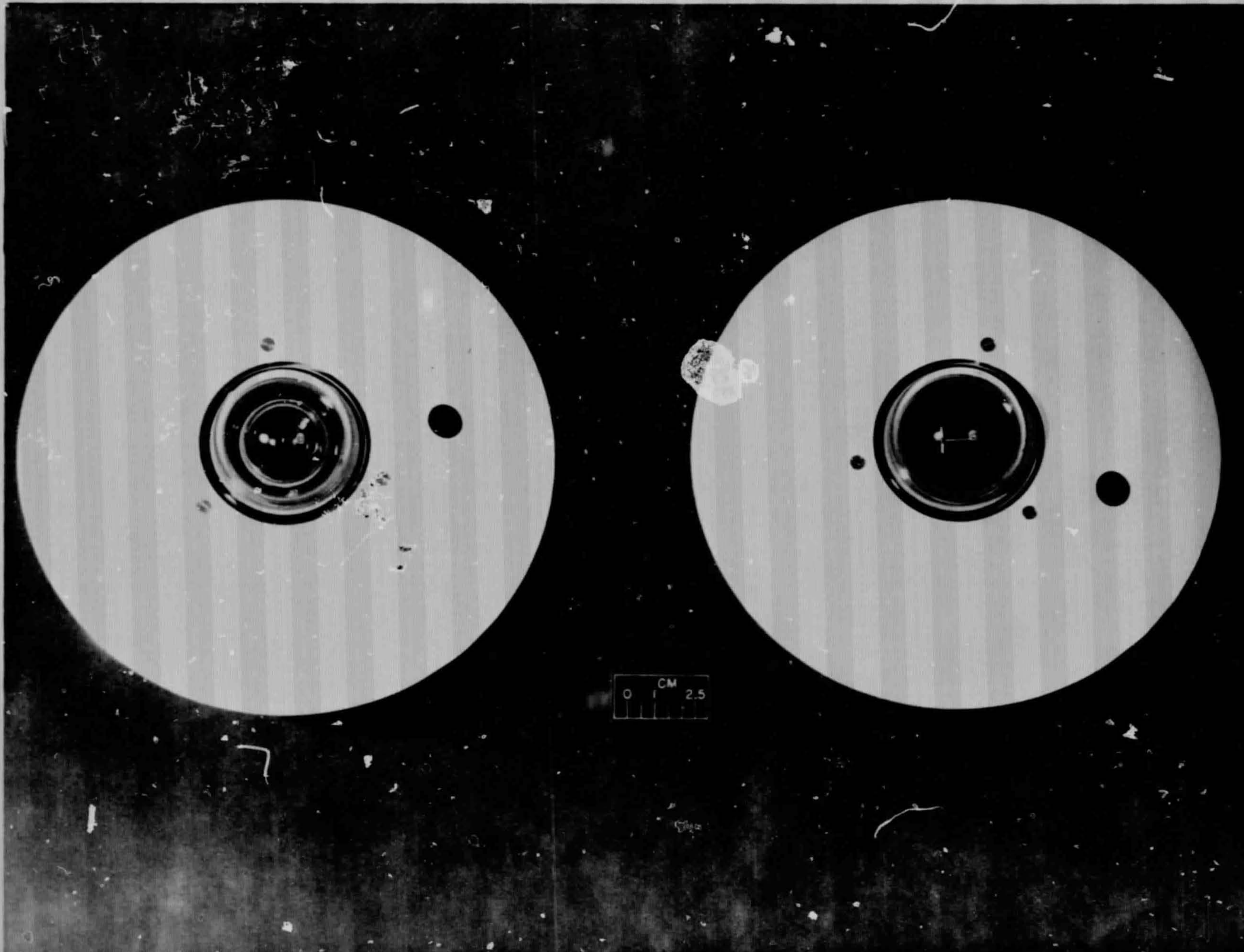

Figure 4. - Pyranometer and solar cells used in solar cell reference conditions test facility

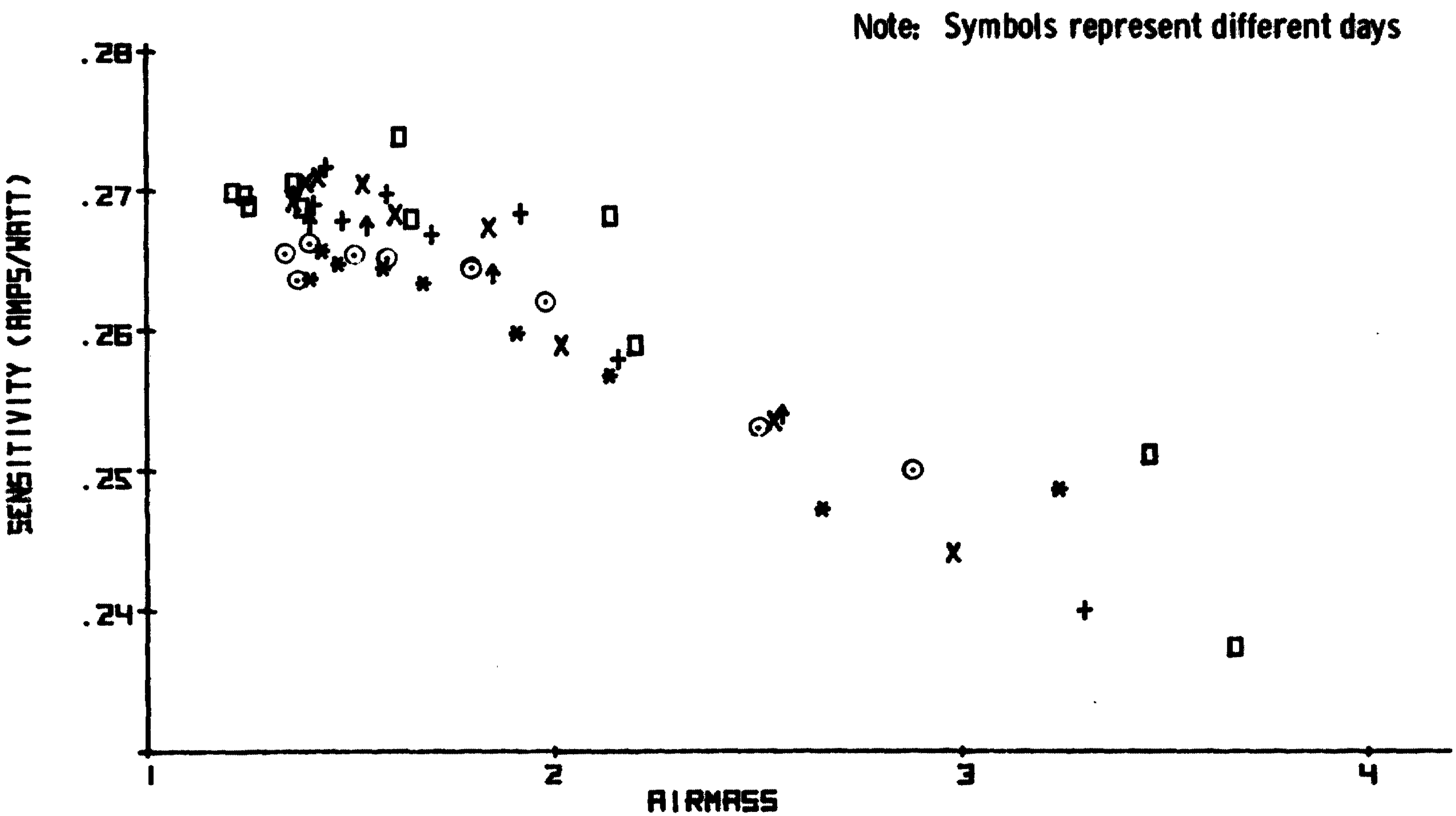

Figure 6. - Sensitivity versus air mass under variable clouds (global - 0 tilt)

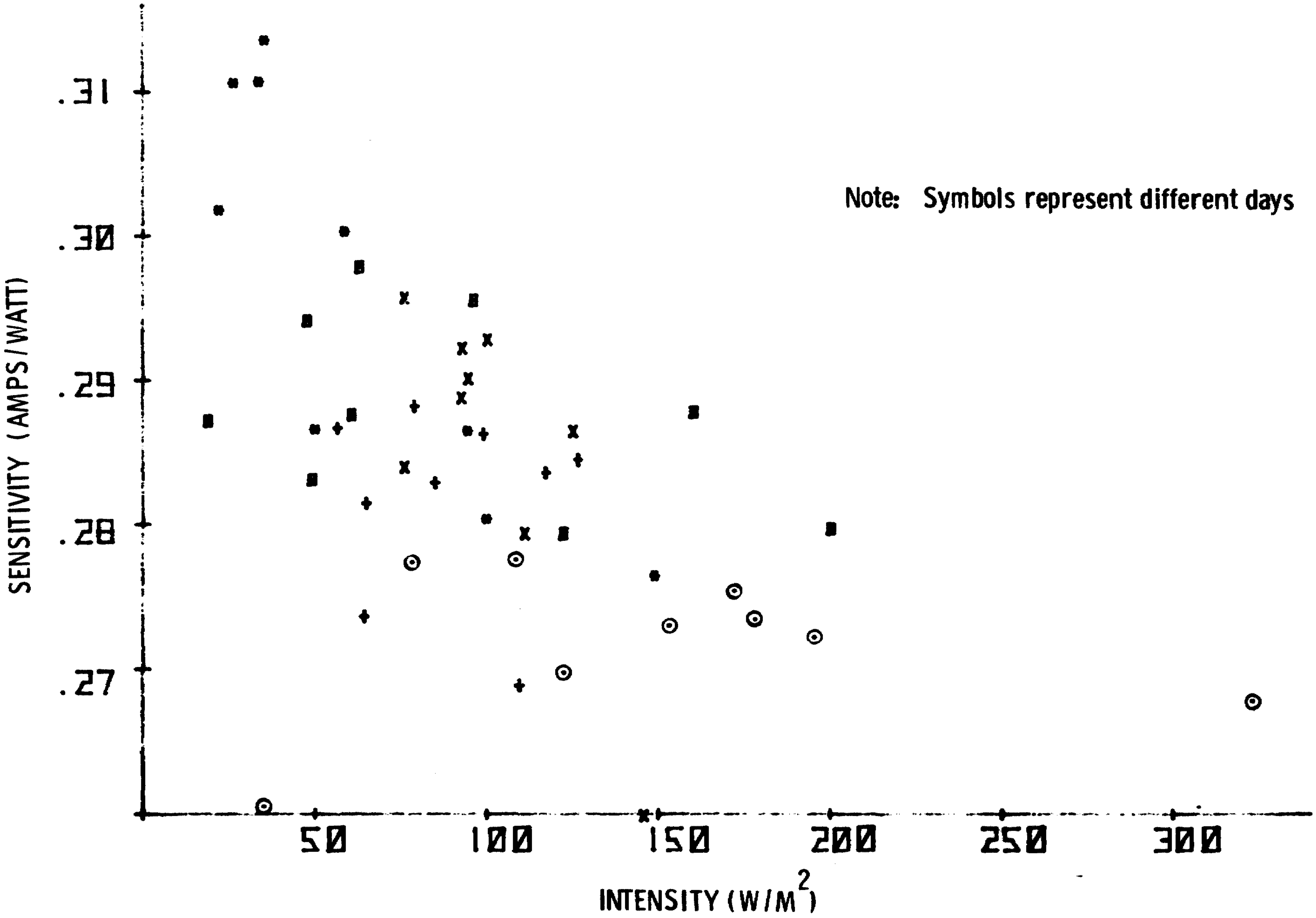

Figure 7. - Sensitivity versus intensity under overcast sky (global - 0 tilt)

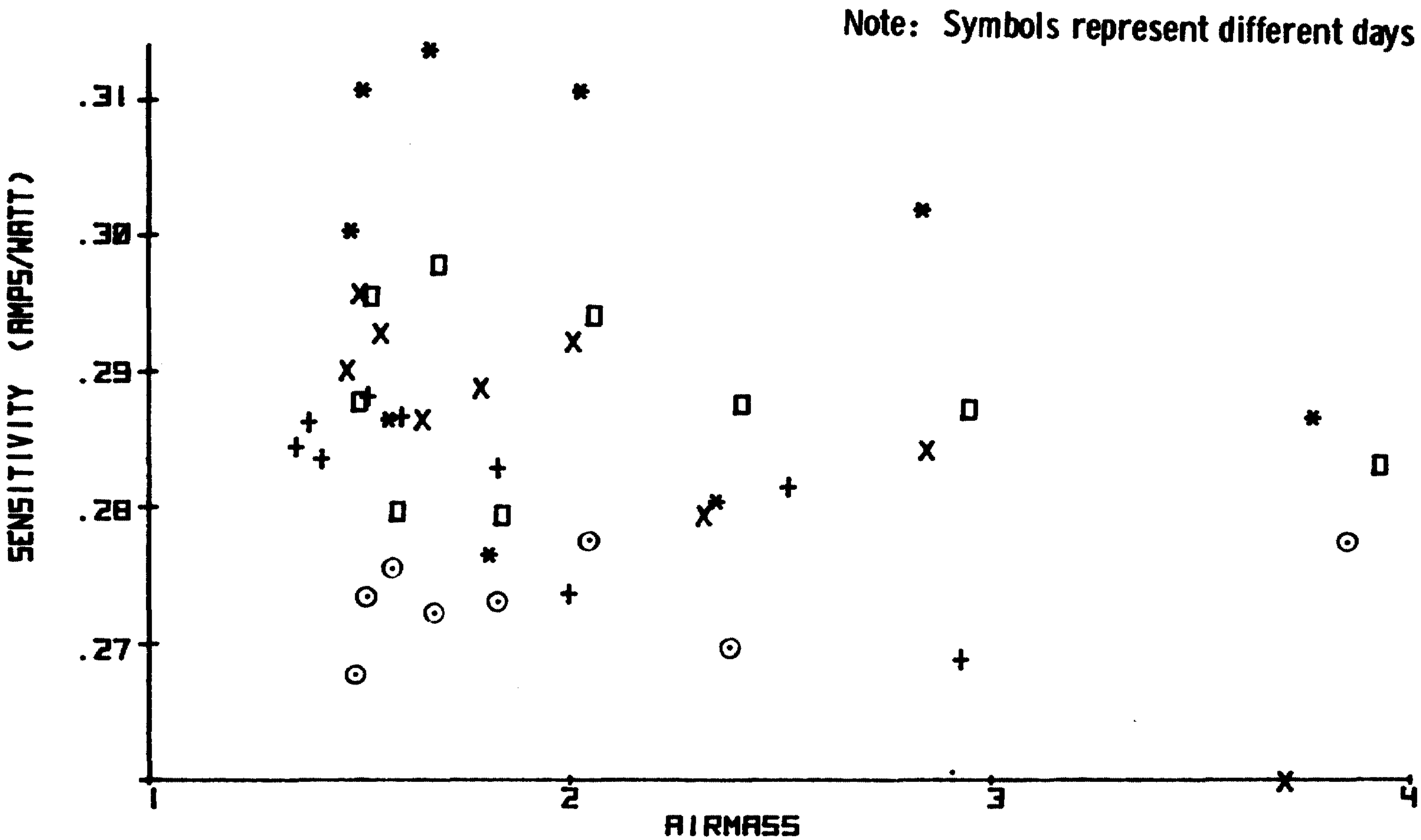

Figure 8. - Sensitivity versus air mass under overcast sky (global - 0 tilt)