A SUMMARY OF THE INTERNATIONAL WORKSHOPS ON SPACE SOLAR CELL CALIBRATION AND MEASUREMENT TECHNIQUES

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ABSTRACT

The first two of a planned series of international workshops concerning space solar cell calibration and measurement techniques have been held within the past year. The need for these workshops arose from the increasing complexity of space solar cells coupled with the growing international nature of the market for space cells and arrays. The workshops, jointly sponsored by NASDA, ESA and NASA, have the objective of obtaining international agreement on standardized values for the AM0 spectrum and constant, recommendations for laboratory measurement practices and the establishment of a set of protocols for making interlaboratory comparison measurements. The results of the first two workshops, held in Waikiki, Hawaii, USA in 1994 and Madrid, Spain in 1995, are presented.

INTRODUCTION

The market for both space solar cells and arrays has become more international in recent years. At the same time, space cell design is becoming increasingly complex with a corresponding increase in the difficulty of providing accurate on-orbit performance predictions. Thus the need for the universality of calibration and laboratory measurements was recognized and a series of workshops concerning these issues has been initiated. The workshops, of which two have been held and a third is planned, have been jointly sponsored by the European Space Agency (ESA), the National Space Development Agency of Japan (NASDA) and the National Aeronautics and Space Administration (NASA). The objectives of the workshops include agreement on standardized values of the Air Mass Zero (AM0) solar constant and spectral intensity distribution, recommendations for laboratory measurement practices and establishment of a set of protocols for making interlaboratory comparison measurements. The international intercomparison will include both primary reference standards and laboratory techniques. The workshops were to be held at approximately one year intervals in conjunction with major space photovoltaic conferences in order to maximize attendance.

1st WORKSHOP

The First International Workshop on Space Solar Cell Calibration and Measurement Techniques was organized by the NASA Lewis Research Center. It was held on December 12-13, 1994 in Waikiki, Hawaii, directly following the 1st World Conference on Photovoltaic Energy Conversion. Thirty-four participants from England, France, Germany, Japan, Spain and the United States attended the workshop. Their affiliations are listed in Table I. During an opening plenary session, each of the sponsoring agencies presented their objectives for the workshop. Furthermore, it was decided that smaller working groups would be optimum in light of the diverse topics to be addressed and the short time (two days) allotted for the workshop. The three

Table I - Affiliations of 1st Workshop Participants

Japan	United States	Europe
Adv. Eng Services Co.	Hughes Space & Com.	Deutsche Aerospace
Hi-Reliability Comp.	NASA LeRC	DRA
ISAS	NREL	EEV Ltd.
JQA	Spectrolab	ESA-ESTEC
NASDA	USAF/Phillips Lab	ESTI
Opto Research Corp.		Fraunhofer Institute
Sharp Corp.		INTA/Spasolab
Wacom R&D Corp.		
M. Wantanabe & Co.		

working groups would discuss primary standard solar cells, multijunction devices and laboratory practices. Reports from each of the three groups would be presented at a closing plenary session, with written reports to be prepared and distributed after the close of the workshop.

Primary Standard Solar Cells

The need for accurate laboratory measurement of space cells is increasing as the cells become more complex and mission planners demand ever more precise guarantees of on-orbit performance as the margins in power systems shrink. These laboratory measurements are possible only with the use of primary (or reference) standard cells. Historically, primary standards have been made through the use of high altitude balloons (JPL and CNES), Shuttle experiments (NASA and ESA) and high altitude aircraft (LeRC). The two balloons and the aircraft are the only methods currently utilized. Concerns of primary standard cell users were voiced in the working group and include: the seasonal nature and limited space available on calibration flights, the cost of an independent calibration program prohibits users from generating their own standards, and the aging of standard cells, creating the need for regular re-flight. An indoor (laboratory) method of primary cell calibration was proposed. It is based on the the measurement of the spectral response of the cell and the spectral irradiance of the solar simulator lamp. A number of disadvantages and concerns with this method were identified and a comparison with traditional methods was recommended before any further action could be taken on the proposal. The conclusions and recommendations of the working group were: 1) increased opportunities to create space-based primary standards are needed, 2) a research effort to measure the AM0 spectrum should be advocated, 3) an international standard for the AM0 spectrum and constant needs be chosen and, 4) an international intercomparison of primary standards should be established.

Multijunction Devices

Multijunction solar cells present new problems because of the requirement for current matching of the two or three cells of the devices currently under development. Not only are primary standards of complete devices necessary, but calibrated subcells will most likely be required. Because the different subcells in the multijunction device generally have different radiation-hardness characteristics, care must be taken in differentiating between Beginning of Life (BOL) and End of Life (EOL) performance, with each condition requiring a set of primary standards. Accurate determination of temperature coefficients is also required, with the different subcells having different temperature coefficients. Most single source solar simulators, unless carefully filtered, are inadequate for determination of these coefficients. Precision current-voltage characterization of subcells and full MJ devices will require spectrally tunable solar simulators and subcell standards. The working group presented the following issues and recommendations to the full workshop: 1) determination of how well reference cells must be spectrally matched to test cells to avoid spectral mismatch corrections, 2) optimization of spectral adjustment of simulator for production testing, 3) perform an

uncertainty analysis to allow extrapolation of laboratory measurements to actual space performance and, 4) round robin cross-checking.

Laboratory Practices

It was recommended in that the World Meteorological Organization's (WMO) solar spectrum and constant (136.7 mW/cm^2) be adopted as a standard. However, each organization will continue to use its own standards until formal agreement is reached. For intercomparison, a cell temperature of 25 °C will used. Full area illumination for spectral response/quantum efficiency measurements and total area for efficiency calculations was also recommended. A round robin intercomparison was proposed for current-voltage and spectral response measurements. Each of the three sponsoring agencies will provide cells as follows:

Cell type	Irradiated	Japan	Europe	United States
Silicon	No	X	X	X
Silicon	Yes	X	X	X
GaAs	No		X	X
GaAs	Yes		X	X
Hi Eff. Si	No	X		
Hi Eff. Si	Yes	X		

A solar cell holder compatible with both the JPL and CNES balloons was designed and will be used to mounting the cells designated for the intercomparison.

2nd WORKSHOP

The final action of the 1st Workshop was agreement as to the necessity of a second workshop, to be held within the next year. This workshop, organized by the European Space Agency and hosted by the Spanish National Institute of Aerospace Technology (INTA), was held in Madrid on September 12-13, 1995, directly following the Fourth European Space Power Conference. Twenty-five participants from China, England, France, Germany, Japan and the United States attended; the affiliation of these attendees is given in Table II. The three working groups from the 1st Workshop reported their findings at an opening plenary session. The primary objectives of the Workshop were to conclude the discussions begun in the 1st Workshop and to finalize and implement plans for the round robin comparisons. As in the case of the 1st Workshop, smaller working groups were formed. These groups were primary standards, AM0 solar spectrum and constant; laboratory measurement practice; multijunction devices and round robin measurements.

Primary Standards, AM0 Solar Spectrum and Constant

The tentative agreement on the WMO solar spectrum and constant from the 1st Workshop was reaffirmed. Participants in this workshop agreed to survey the "radiometry" communities in their respective countries for recommendations on AM0 spectrum and intensity. A temperature of 25 °C was decided upon for all laboratory current-voltage and spectral response measurements. The calibration of primary standards was discussed, with continued reservations about the indoor methods expressed. It was decided that calibration methods be designated as either "synthetic" (laboratory-based, spectrally corrected) or "space-based" (high altitude balloon or aircraft, Shuttle or similar flight experiment).

Laboratory Measurement Practice

A general agreement was reached on 25 °C as a reference temperature for all round robin measure-

Table II - Affiliations of 2nd Workshop Participants

Japan	United States	Europe
Adv. Eng Services Co.	NASA LeRC	CNES
Hi-Reliability Comp.		Deutsche Aerospace
ISAS		EEV Ltd.
JQA	China	ESA-ESTEC
NASDA	China Acad. Space Tech.	Fraunhofer Institute
Opto Research Corp.		INTA/Spasolab
Sharp Corp.		

ments. After a discussion of laboratory practices at the various institutions represented in the working group, it was decided that two areas that would best benefit from a comparison of results would be the determination of temperature coefficients and spectral response characteristics. The cell complement would be the same as that designated during the 1st Workshop, except the cells would not be mounted. The temperature range for temperature coefficient determination would be +20 to +80 °C, all results would be blind until full completion of the testing. ESA, NASDA and NASA LeRC would participate. The same cell set will be used for the spectral response measurements, with test conditions left up to the individual agencies but fully documented. An exchange of test procedures for common laboratory measurements was agreed to by ESA, NASDA and NASA.

Multijunction Devices

Various measurement techniques and equipment are in use for characterizing multijunction solar cells. The strengths and weaknesses of the techniques, as well as any previously unforeseen anomalies, need to be identified. This can best be accomplished through a MJ solar cell measurement investigation. It will not be a comparison of results, but a practical opportunity to assess measurement techniques for real space cells. NASA LeRC will obtain and mount about 10 GaInP/GaAs two junction solar cell. LeRC will test the cells on the Lear aircraft (both Isc and IV measurements) and distribute them to the following possible collaborators:

	United States	Europe	Japan
Agencies:	LeRC	ESTEC	NASDA
	JPL	INTA	ISAS
		CNES	
		DRA	
		ISE (Freiburg)	

After testing at the various agencies, the cells will be returned to LeRC for reflight on the Lear aircraft. All results will be distributed to all participants.

Round Robin Measurements

A working group devoted to round robin measurements was created at the 2nd Workshop. However, its results mirrored some of those from the working groups previously discussed. They suggested blind round robin of current-voltage and spectral response measurements be conducted and agreed with the MJ working group that a around robin for multijunction cells is premature. A round robin of primary calibration standards would be conducted between the agencies currently calibrating cells, i.e., CNES, JPL and NASA LeRC. Each participant will provide two cells, one silicon and one gallium arsenide, six cell in all. The intercomparison will be conducted fully blind, with all data to be distributed only after the calibrations are complete.

The 2nd Workshop ended with a plenary session at which time the four working groups reported their results. Preliminary written reports from two of the groups were distributed, with a final, complete Workshop Report to be distributed by year's end. A third workshop was decided upon, as a forum for reporting and discussion of the results of the several measurement activities begun at this workshop. The 3rd Workshop will be held in Japan in November, 1996, following the 9th International Photovoltaic Science and Engineering Conference. The workshop will be hosted by NASDA.

CONCLUSION

The first two of a planned series of International Workshops on Space Solar Cell Calibration and Measurement Techniques have been held during the past year with some forty participants from six countries. The need for these workshops arose from the increasing complexity of space solar cells coupled with the growing international nature of the market for space cells and arrays. The objectives of the workshops include agreement on standardized values of the (AM0) solar constant and spectral intensity distribution, recommendations for laboratory measurement practices and establishment of a set of protocols for making interlaboratory comparison measurements. Toward meeting these goals, three round robin measurement activities have been started: 1) primary calibration standards, 2) laboratory current-voltage and spectral response characterization and 3) laboratory temperature coefficient determination. A multijunction cell measurement investigation will also be conducted. The results of these activities will be reported and discussed at a third workshop, to be held in Japan during November of 1996.