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Photovoltaics Program
Program Analysis and Integration Center

DOE/ET-20356-19
Distribution Category UC-63

What Should DOE Do to Help Establish Voluntary Consensus Standards for Measuring and Rating the Performance of PV Modules?

Issue Study

October 31, 1984

Prepared for
U.S. Department of Energy
Through an Agreement with
National Aeronautics and Space Administration
by

Jet Propulsion Laboratory
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This document reports on work done under NASA Task RE-152, Amendment 200, and sponsored by the U.S. Department of Energy under Interagency Agreement DE-AI01-76ET20356.

ABSTRACT

In response to concern expressed by the photovoltaics community over progress toward the establishment and issuance of concensus standards on photovoltaic performance measurements, a review of the status of and progress in developing these standards was conducted. It examined the roles of manufacturers, consumers and the national laboratories funded by the U.S. Department of Energy (DOE) in supporting this effort. This was done by means of a series of discussions with knowledgeable members of the photovoltaic community.

Results of these interviews are summarized and a new approach to managing support of standards activity is recommended that responds to specific problems found in the performance measurement standards area.

The study concludes that there is a positive role to be played by the U.S. Department of Energy in establishing collector performance measurement standards. It recommends that DOE continue to provide direct financial support for selected committees and for research at national laboratories, and that management of the activity be restructured to increase the authority and responsibility of the consensus committees.

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PART ONE

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

This report was prepared under the leadership of the Jet Propulsion Laboratory Photovoltaic Project Analysis and Integration (PA&I) Center in response to concern expressed by the photovoltaics community over progress toward the issuance of consensus standards on photovoltaic (PV) performance measurements. Staff from JPL in cooperation with staff from the Solar Energy Research Institute and Sandia National Laboratories, Albuquerque, reviewed the status and progress of the several bodies in developing these standards and examined the roles of manufacturers, consumers and the national laboratories funded by the U.S. Department of Energy (DOE) in supporting this effort. This was done by means of a series of discussions between PA&I staff and knowledgeable members of the photovoltaic community, including senior employees of photovoltaic manufacturing firms, architectural and engineering firms, independent consultants and members of the staff of national laboratories.

The report summarizes the results of these interviews and recommends a new approach to managing support of standards activity. The recommended approach responds to the specific problems found in the performance measurement standards area, and also is generic to the standards support area in general.

The study team has concluded that there is a positive role to be played by the National Photovoltaics Program in establishing collector performance measurement standards. This conclusion was reached after interviews with manufacturers of photovoltaic devices, users of photovoltaic devices and specialists at national laboratories in which the technical, commercial, political, and operational impediments to the development of such standards were probed. It is recommended that DOE continue to provide direct financial support for selected committees and for research at national laboratories. It is also recommended that management of the activity be restructured to increase the authority and responsibility of the consensus committees.

The main barriers to developing consensus power measurement standards are not technical; they are organizational. They include:

-- Diffusion of leadership

-- Lack of a priority for industry management

-- Lack of continuity of participation

-- Lack of resources to prepare the first draft

-- Lack of travel funds for participants

-- Proprietary positions of participants

Therefore it is concluded that organizational measures are necessary to accelerate the process. The measures proposed will make DOE a visible active partner in the effort to create the standards, but the role of DOE must not be misinterpreted as one in which it (the Government) is imposing standards. The role will encourage, even make possible, the continuity of participation in the consensus process by non-government contributors, and it will enhance the position of the United States in the international arena.

It is recommended that selected committees of The American Society for Testing Materials and The Institute of Electrical and Electronic Engineers be given direct financial support and authority over supporting research conducted at national laboratories.

A PV standards support program with the following features is recommended:

1. Annual invitations to consensus standards committees for proposals for funding work supporting their specific needs.

2. Standards committees with authority for technical direction of research and development performed or subcontracted by national laboratories, using a voucher system.

3. A budget for this work of $100,000 to $300,000 per year.

PART TWO

ISSUE STUDY

SECTION I

INTRODUCTION

This report was prepared under the leadership of the Jet Propulsion Laboratory (JPL) Photovoltaic Project Analysis and Integration (PA&I) Center in response to concern expressed by the photovoltaics community over progress toward the issuance of consensus standards on photovoltaic (PV) performance measurements. Staff from JPL in cooperation with staff from the Solar Energy Research Institute (SERI) and Sandia National Laboratories, Albuquerque (SNLA, or Sandia), reviewed the status and progress of the several bodies in developing these standards and examined the roles of manufacturers, consumers and the national laboratories funded by the U.S. Department of Energy in supporting this effort. This was done by means of a series of discussions between PA&I staff and knowledgeable members of the photovoltaic community, including senior employees of photovoltaic manufacturing companies, architectural and engineering companies, independent consultants and members of the staffs of national laboratories.

The report summarizes the results of these interviews and recommends a new approach to managing support of standards activity. The recommended approach responds to the specific problems found in the performance measurement standards area, and also is generic to the standards support area in general.

The preparation of performance measurement standards in the United States is generally the province of the American Society for Testing Materials (ASTM) and professional societies such as the Institute of Electrical and Electronics Engineers (IEEE). Although these entities may at times appear to compete, ASTM and IEEE seem to have established a compatible definition of their respective areas in the photovoltaic arena. At present ASTM is developing a family of performance measurement standards that are essential to the characterization of PV materials to the module level, and IEEE is directing its attention to modules and arrays in systems. The problem is that progress in developing PV performance measurement standards in either area is perceived by many as being very slow; so slow, in fact, that the builders of the largest utility-erected PV installation in the world, Sacramento Municipal Utility District (SMUD), saw fit for its second phase to use a performance measurement standard produced by the Commission of European Communities, since no domestic standard was available.

Both ASTM and IEEE rely upon industry, consumers and the government to provide the expertise to draft and to hone the standards. The protocols of these institutions require representation among the committees that are preparing standards that results in an unbiased document, created through a consensus process. This procedure itself can be an impediment to progress, especially if the persons involved take parochial positions because of personal bias or pressure from their organizations.

This study focused exclusively on performance measurement standards. These are precursors to other standards, which must later evolve, pertaining to quality assurance, performance, codes, and reliability. These are regarded as important parts of the whole family of standards for PV technology. However, for those standards to be drawn effectively, the performance measurement standards must first be developed. It is deemed that the latter standards can be produced with less Government support, and that they should be free of Government intervention.

Interviews were conducted with individuals selected for their interest in and knowledge of PV performance measurement problems. They comprised a balanced representation of opinion from the identifiable major interest groups.

These include:

National Laboratories

Jet Propulsion Laboratory
Sandia National Laboratories, Albuquerque
Solar Energy Research Institute

Photovoltaic Manufacturers

ARCO Solar, Inc.
Photowatt International, Inc.
Solavolt International

Photovoltaic Users

The BDM Corp.
Rogers and Company, Inc.
Acurex Solar Corp.

Standards Organization

Institute of Electrical and Electronics Engineers

Other

DSET Laboratories, Inc.
Arizona State University

Ten questions were used to focus the interviews:

(1) Why do we need standards?

(2) What are the technological problems that are impeding the development and adoption of photovoltaic standards?

(3) Are there solutions to these problems?

(4) Are there economic limitations to obtaining the solutions?

(5) Who should solve the technical problems?

(6) What is an appropriate reference spectrum?

(7) Is ASTM attempting to write too many detailed standards?

(8) Are the proper people involved in preparing standards?

(9) What is the greatest impediment to getting standards written?

(10) What is a possible role of the Government in furthering this effort?

SECTION II

INTERVIEW FINDINGS

In assessing the role that DOE and the National Photovoltaics Program could play in the development of PV performance standards, the discussions concerning certain questions turned out to be most relevant.

These discussions are summarized here:

1. Are PV standards needed? It was universally agreed that performance measurement standards are required to reduce or eliminate confusion in the marketplace, but it was also agreed that the concern is exclusively with the development of prescriptive standards developed by the voluntary consensus procedure. These standards describe a test method, a method of measurement, a method of evaluation etc. They provide a common language that allows a seller and a buyer to reach an understanding of the quality and characteristic of a product. A principal concern is that prescriptive standards not be written in a way that precludes product innovation. Photovoltaics has been born into a world dominated by, and conditioned to expect, standards for the purpose of facilitating trade. Because of this expectation, PV is not allowed the luxury of maturing before the development of standards.

2. What technological problems are impeding the development and adoption of PV standards? Generally speaking, the science required to make performance measurements on PV materials is in hand. The overwhelming problem at the moment is an engineering one to determine just what are the appropriate conditions to use when making PV measurements. This involves selecting level of irradiance, spectral distribution of the irradiance, and temperature of the device. Some believe that it is desirable to make a single measurement of power that can be related to the annual energy produced. However, all three of these variables fluctuate hourly, daily and annually and are different for every geographical site. How then does one pick out an appropriate irradiance, spectral distribution and temperature at which to make the measurement? Present trends point to resolving the issue by selecting the AM1.5 global spectrum rather than using the AM1.5 direct spectrum, which is the present general practice. However, justification for making either choice at this time is moot, even though both are very well defined.

3. Who should solve the technological problems? There was some sentiment for having the problems solved by industry using both industry and government supplied funding, but there was more weight on the side of the proposition that the national laboratories were the proper place. In fact, the suggestion was

made that funding be set up so that particular technical issues that prevent consensus could be solved at a national laboratory, using some kind of a voucher system.*

4. <u>What are the non-technical problems that are impeding the development of standards?</u> There are numerous problems, but the most important is perhaps a vacuum of leadership. The speed with which progress is made depends largely upon the enthusiasm and dedication of the individuals doing the work. They are the ones who perceive the need and do something about it. Particularly noted is the fact that our Government offers neither the leadership nor encouragement that is found in European countries and Japan. Yet, as a signatory to the General Agreement on Trade and Tariffs, the United States and its industries are committed to using internationally adopted standards as a medium of trade and thus have a significant stake in the process of establishing those international standards. In addition, U.S. corporate management, with its goals framed in single-year balance-sheet mentality, fails to provide the long-range, forward-looking support to performance measurement standard development. This lack of leadership results in inconsistent participation in standards efforts both on the domestic front and in the international arena.

There is a predisposition for R&D laboratories to work on problems that they see as interesting or that they perceive as pertinent. One interviewee, who has a long record of dedicated service to the development of standards, was especially critical of the fact that the national laboratories are not working on the right problems: the problems that pose a dilemma in the consensus process.

The operational problems at the consensus committee level are also numerous: The protocols or disciplines of the consensus process are often not understood by the participants. This can lead to frequent draft changes, nit-picking, striving for a perfect document, watering down, and a generally ineffective document. It was pointed out that a standard is not "chiseled in stone," never to be changed. It represents the state of the art today and is expected to be reviewed and improved. Infrequency of committee meetings is a deterrent to progress. As mentioned above, the chairman must be dedicated to the effort and must have support.

Another severe operational problem is changes in membership of standards committees. This problem has been exacerbated by industry priority shifts reflecting changes in the emphasis of the national program and by the shakeout of companies and personnel. One or two new representatives (additions or replacements) or the loss of an existing member usually requires slow and painful retracing of old ground or a serious loss of momentum if the person lost is responsible for a particular standards document.

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*See Section IV, Subsection E

5. <u>What is the greatest impediment to getting these performance measurements written?</u> Two general impediments exist: the consensus process and preparing the first draft. The consensus process relies upon the intelligence, judgment, tractability, and dedication of the persons involved and must be viewed as representing the balancing of conflicts of interest. Proprietary biases can impede consensus, and the marshalling of facts is seen as the most effective way in which these biases can be muted. Abandoning the consensus process is not an acceptable solution. The act of sitting down and writing the first draft requires dedication on the part of the author who must also have the support of his employer. Once the first draft is available, then the consensus process takes over.

6. <u>What is a possible role of government in furthering the standards effort?</u> This question evoked a number of conflicting answers. On the one hand it was suggested that the national laboratories prepare the performance measurement standards because (1) they have the technical expertise and (2) they presumably are a disinterested third party when compared with manufacturers and users. At the other extreme it was suggested that the government supply the money to fund the research required for standards and the preparation thereof. Between these were many other suggestions, including the Government being perceived as actively encouraging and promoting the development of performance measurement standards as well as actually contributing to their development. This contribution could take the form of continued support of the grant to the IEEE to support the secretariat of Technical Committee 82 of the International Electrotechnical Commission; it could provide a grant for the support of consultants, for travel to meetings, for competent consumer representation.

   The development of PV performance measurement standards is an activity that the DOE as a Government agency should promote actively to facilitate commerce. It is the responsibility of the Government to do this as an impartial, knowledgeable third party to assure equitable competition as well as to protect consumers from avaricious or unscrupulous vendors. The DOE can do this by voicing a positive policy of support for this work and by making available funds to support (1) consensus standards activity and (2) international standards activity.

It is pertinent to recall that in July 1981 SERI sponsored a Commercial Photovoltaics Measurements Workshop, which addressed the full scope of the issue in a far more comprehensive way than has been possible in the present study. At that time a significant role for the government to play in the development of PV measurements standards was described. The case for such involvement was convincingly drawn. The summary of the workshop that was published in the proceedings, SERI/CP-214-1403, is provided as Appendix B of this document. In the intervening three years the observations of this workshop have been largely ignored and the same problems that existed in July 1981 are with the photovoltaic measurements community today.

SECTION III

PRELIMINARY ASSESSMENT OF PRIORITIES FOR RESEARCH NEEDED TO SUPPORT STANDARDS

The development of a complete set of photovoltaic standards and codes as apparently envisioned by the framers of the Photovoltaic Research Development and Demonstration (RD&D) Act of 1978 (PL 95-950) is a costly and time-consuming effort. It is also an effort that must proceed in a proper sequence and with some deliberation. Caution is required especially in the adoption of certification, quality assurance, and reliability and performance standards. Premature adoption of these types of standards can stifle innovation and hinder the development of an emerging technology. On the other hand, standards defining the techniques of performance measurement are fundamental to the whole effort not only of developing the industry, but also of framing the remaining family of standards and codes.

In general terms, the broad objective of a program to support the development of consensus standards should give priority to those standards needed to achieve consistency of measurements. Consistency can only be achieved when there is an understood and accepted set of basic conditions under which measurements are made.

One of the major impediments to consensus in photovoltaic measurement standards is the lack of agreement on appropriate measurement conditions. Since this disagreement is usually founded in biases that arise from absence of information, it is necessary to provide the facts required to ameliorate the conflict. Central to most of the disagreements are spectral distribution, level of irradiance, and temperature to be used in making the performance measurement. Although much work has been done in an effort to understand the relationships among the solar irradiance, water vapor, turbidity, air mass and other factors affecting spectral distributions and intensity, insufficient work has been done to determine if there is a reasonable way to standardize (for performance measurement purposes) the spectral distribution and to define what it should be. Even where there is agreement on a spectrum there are occasional disagreements on procedural criteria that affect the processes being defined. These disagreements also are founded in lack of information.

Concentrator cell testing still remains an enigma for standards activities. Much effort has been expended in the past, but standards discussions have been inhibited by an absence of technical documentation. For concentrator technology to have as firm a footing as flat-plate technology, it must also have a test basis in harmony with a consensus standard. Expertise is available at the national laboratories and universities to examine the critical issues of testing.

A similar problem exists with amorphous silicon cells. This technology has even less experience with test methods, yet is rocketing into commercialization. Questions such as stability, accurate spectral response measurements, blue-response enhancements, and other basic issues must be

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addressed. By examining these issues now, on a well defined research basis, the job of writing standards that do not inhibit development of new techniques will be easier.

Examples of technical work needed to resolve controversies in standards deliberations are:

(1) The standard that defines the calibration procedure for reference cells calibrated in the AM1.5 direct normal spectrum of ASTM Standard E 891-2 is held up by a disagreement on the allowable tolerance for water vapor and turbidity during calibration. In view of the fact that the values presently specified rarely exist at SERI and at the National Aeronautics and Space Administration (NASA) Lewis Research Center, and are extremely rare at DSET (three of the national facilities having calibration capability), the actual spectral mismatch created by relaxing the tolerance must be determined.

(2) To decide if there is a spectral distribution that can be used as a standard or as one of several standards, data must be accumulated that give the spectral distribution existing in different locations throughout the United States or the world. These data could be collected for the same sites and at the same intervals as used in collecting the data found in solar radiation surface meteorological observations (SOLMET) tapes. Both global and direct normal spectra should be accumulated.

(3) Determine a set of criteria and a routine by which the spectral distribution data can be processed to establish a reasonable average spectrum or set of spectra for use in performance measurement of photovoltaic devices. Apply the criteria and routine and develop an average spectrum or a family of average spectra.

(4) The atmospheric parameter data base needs improvement, especially as it relates to reference cell calibration. More national and international data on water vapor, turbidity, air mass, etc. are required for determining the practicality of calibration procedures and the validity of potential power rating methodologies.

(5) Considering the results of (3) and (4) above, develop a rationale for selecting either an average spectrum or a family of spectra to be used in making performance measurements.

(6) Apply the rationale developed in (5) above and recommend a standard spectrum (or spectra) for use.

(7) Develop an improved design for a reference-cell housing to provide a high-quality hermetic seal to enable prolonged use outdoors.

(8) An investigation into possible configurations and calibration methods for thin-film (e.g., amorphous Si) reference cells is desperately needed.

It should also be noted that the National Bureau of Standards (NBS) is conspicuously absent from the consensus standards process for photovoltaics. The talent lost by their inactivity is significant, and to be able to leverage on its other activities in semiconductor technologies would be desirable. Furthermore, NBS has not participated in the solar radiation intercomparisons that are crucial for uniform measurement practices.

SECTION IV

OPTIONS FOR U.S. DEPARTMENT OF ENERGY ACTION

Four principal courses of action or options are open to DOE in support of the development of performance measurement standards:

A. OPTION A: PROGRAM APPROACH TO THE DEVELOPMENT OF CONSENSUS STANDARDS

(1) DOE would establish an annual budget for (1) research work that has its origin in requests by standards organizations in the United States and that enhances directly the development of consensus PV standards, and (2) supports the United States in the process of establishing international standards.

(2) DOE would assign one of its Washington staff to administer the fund; however, the technical direction would come exclusively from standards committees.

(3) DOE would invite proposals from standards committees for the funding of two categories of effort:

- (a) Administrative support of the particular standards committee.
- (b) Specific technical research, to be performed at one or more of the national laboratories funded by DOE and directed by the standards committee requesting the work.

(4) Proposals would be addressed to the assigned DOE Headquarters program administrator and would detail the following:

- (a) The identity of the standards committee requesting the funding.
- (b) Identification of the standard for which the work would be performed (if for technical work).
- (c) A statement of work that defines the problem, proposes a methodology for solution, and establishes the scope of the effort.
- (d) A budget for performance of the work.
- (e) A schedule.
- (f) Identity of the committee chairman or member to be responsible for the technical direction of the work.
- (g) Recommendation of the organizations to perform the work.

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(h) Subcontractors to be used in the performance of the work and the level of their participation.

(i) A statement signed by the committee membership affirming a consensus of the membership on the need for the work.

(5) Proposals received are to be funded by DOE, based upon the urgency of the need for the supporting research as indicated in Section III. Funding for administrative support would be provided directly to the employer of the committee chairman. Funding for technical research would be by amendment to the Annual Operating Plan (AOP) of the performing institution (SERI, SNLA, JPL), to be implemented by vouchers issued to the committee that are redeemable at the performing institution. The funds provided to the institution are only for "voucher" work.

(6) To assure a critical mass of effort, funding for proposals should be on the basis of all or nothing.

(7) Separately identified funding within the allocated budget should be obligated to the national laboratories. Funding not committed by way of vouchers would automatically carry over to the next year.

(8) Under these rules of operation, there is a distinct possibility that the standards community would get together and decide how best to divide up the budget. This form of collusion appears to be in the interest of the Government and therefore should be allowed.

B. OPTION B: GOAL-DIRECTED LEADERSHIP

Continue with the present framework, but with stronger goal-directed leadership from DOE. This can be manifested by introducing into the program goals a line item for the support of standards activities at the national laboratories and their contractors. This activity would include research to solve specific problems encountered by standards bodies, funding support for the actual work of writing standards and travel to domestic standards meetings, and general support to participants in international standards organizations. The elevation of this activity to a line item in the goals of the National Photovoltaics Program will give the continuity essential to an evolutionary process like developing standards.

C. OPTION C: PRESENT APPROACH

Continue as at present, with no directed support to the standards work--except as deemed advisable and necessary by the management of the national laboratories receiving DOE funding.

D. OPTION D: NO STANDARDS WORK

Direct that no support for standards work should be done by the national laboratories or their contractors.

E. RECOMMENDATION

This report recommends that Option A be implemented. In support of this recommendation three appendices are provided. The first (Appendix A) is a thoughtful white paper by Gary Nuss of SERI, which summarizes the background of standards work, reports on the status of committee efforts, relates the work to public law and OMB Circular 119-A, and shows the interaction with international standards organizations. Appendix B is the summary of a Commercial Photovoltaic Measurements Workshop held in July 1981, which recommended more DOE support at that time and which is a valid plea for support today. Appendix C is a paper by Runkle and Ross that addresses the problem of definition of conditions of measurement.

APPENDIX A

PHOTOVOLTAIC STANDARDS AND CODES

Gary Nuss
Solar Energy Research Institute
Golden, Colorado 80401

Background

The successful integration of photovoltaics (PV) into the nation's energy service will require a sound effort to develop quality assurance, standards, codes and reliability (QAS). Since solar energy systems must compete in the marketplace with conventional systems of proven performance and reliability, in which users have an established degree of confidence, solar energy applications also will demand a high degree of quality assurance.

Conventional QAS requirements are designed to provide reliability, safety, and interchangeability for users. In addition, institutional lenders, insurance organizations, taxing authorities, as well as users, desire early standards support to provide information on performance and design factors. This information provides a realistic basis for tax incentives, codes development, and insurability--all critical elements in the process to utilize PV energy systems.

A critical QAS element in promoting practical deployment of PV energy conversion systems is a base of well-documented and widely accepted measurement and performance standards. It is desirable that such a base of voluntary standards be developed by the private sector consensus process to ensure widespread acceptability. When these standards are in place, they will help to ensure reliable and consistent measurements, providing viable comparisons between manufacturers' product types and energy output determinations.

In photovoltaic development, the articles of the Photovoltaic Research Development and Demonstration (RD&D) Act of 1978 (PL 95-590) include a commitment to the development of quality assurance, consensus standards, and certification. This legislative directive is designed to enhance the development rate of photovoltaic technologies, to which end it is either expressed or implicit that codes and standards leading to performance, quality, safety, and reliability need to be developed. The initial satisfaction of these legislative needs was embodied in the Performance Criteria Document (PCD) prepared by SERI under the direction of the Photovoltaic Division Office of DOE. The final version of this document was in two volumes: Volume I contained performance criteria (or characteristics) with explanatory commentary; Volume II contained approximately 30 test methods for performance evaluation.

It is against this background that the status and effectiveness of standards making efforts should be viewed. The spectrum of applicable standards bodies spans from the large, self supporting organizations such as ASME, IEEE, and ASTM to smaller organizations, often industry associations, that are not integrated into the ANSI organization and have limited funds. Technical inputs also are varied with regard to the depth of knowledge and to the breadth of consensus. Thus, it is appropriate and desirable to assist the standards-development process by making the technical resources and products of government energy programs available to it and, if necessary, to accelerate this process through funding support. These support actions represent a particular aspect of technology transfer by DOE.

Standards Considerations

In addition to the normally accepted benefits of an early, established QAS program, standards also provide evidence to utilities, instititional lenders, insurers, and local authorities that sound engineering practices will be applied from the outset. The technological characteristics of PV energy utilization also require specific development of performance requirements, standards, or codes to permit value judgements of systems and resource availability. In such cases DOE-funded development of standards is a logical support function in the absence of normal market forces and actions.

In each stage of the developmental process, participants must examine the process and the kinds of standards needed. If standards are developed too early, they may inhibit industry growth. Further, if lifetime performance criteria are postulated in the development phase, expectations may arise without sufficient support. Such lifetime criteria may limit the development of systems with more competitive costs but shorter lifetimes, thereby excluding low cost innovations. Conversely, if the industry does not begin testing for lifetime performance characteristics in the development phase, it will be unable to develop requirements for certification programs in the market introduction phase. Thus, standards activities must be designed to raise user confidence and to support the development of a strong industry infrastructure.

The inception and development of standards for PV thus far has taken place almost at the same time and at the same pace as development of much of the specific technology. Normally the need for a standard within an industry is generated through the combined experience of a diverse group of organizations and individuals representing users, producers, and the general interest. Such a broad base of experienced users does not yet exist across the board in the PV industry. However, public utilities still want to know the expected performance and reliability of systems attached to their grids; institutional lenders and tax assessors need a base of reference for establishing financial considerations; and research and demonstration projects can benefit from the use of standard equipment where possible and from use of standard methods of evaluation or testing. In an emerging technology comparisons of research results and between different technical concepts is critical and requires standard methods of testing.

Government's Role in Standards Development

DOE has endorsed the concept of voluntary consensus standards and is committed to working through industry and user groups and through existing code organizations to assist development of the standards and code base necessary for successful PV implementation. A proper role is to provide performance and safety criteria (as mandated by the RD&D Act of 1978) to accelerate the voluntary consensus standards development process in a constructive manner and to support federal regulations and procurements. In this capacity DOE has worked with the private sector: to determine standard and code needs and requirements; to establish priorities for their development; to support standards development through the consensus standards process; to coordinate standards implementation in codes; and to assist U.S. efforts in international standards work.

OBM Circular 119-A, issued in early 1983, enumerates appropriate ways in which governmental agencies and personnel can become involved with standards development:

- Direct financial support: e.g., grants, sustaining memberships, and contracts;
- Administrative support: e.g., travel costs, hosting of meetings, and secretarial functions;
- Technical support: e.g., cooperative testing for standards evaluation and participation of agency personnel in the activities of standards developing groups; and
- Joint planning with voluntary standards bodies to facilitate a coordinated effort in identifying and developing needed standards.

Moreover, 119-A encourages such involvement since it is in the public interest and it is relevant to the pursuit of agencies' missions.

A fifth means by which government can support the development of standards and codes is through the direct development of performance and safety criteria and test methodologies. These activities are legitimate elements of technology transfer for the photovoltaic research centers and appear to be implicit in the program goal of performance verification as a part of the technology base for further development by industry.

DOE has employed each of these five means of standards support. This support has been crucial for standards and code development because of the immaturity of the PV industry and its markets and because much of the research and technology development has been funded--directly or indirectly--by the government. Standards and code development lags technology development, but is dependent upon it for information and data which are the basis of sound standards development. Thus, DOE has filled a key role in standards efforts because at this stage of PV development it is the source of significant technological resources needed to sustain an effective standards development effort. Policies on standards development activities should make use of the traditional institutional framework for standards and codes but should attempt to speed their development. For example, complete development of a standard by a consensus group can take several years; a major objective of DOE supported activity should be that this time be reduced by as much as one-third to one-half.

Status of Photovoltaic Standards Development

Prior to 1978, photovoltaics standards activity was virtually nil; but considerable progress has been made in the past five years--due in no small part to the stimulus provided by the DOE PV Program. Although the number of consensus organizations relevant to photovoltaic standards and codes is few, all have been working actively on photovoltaics. These groups include ANSI, ASTM, IEEE, NFPA, and SEMI on the domestic front and IEC at the international level. Several standards are in place and several others are at various stages of the consensus development process.

Figures 1 and 2 present the current structure of standards and code organizations for solar electric technologies (See Table I for the key to abbreviations). Although wind energy is included, most work is being done in PV. A summary of activity by organizations follows.

ANSI -- This organization acts as a clearing-house and coordinator for U.S. domestic standards and represents the U.S. internationally--through the U.S. National Committee--in the IEC. At the outset of the DOE/SERI PV standards effort, ANSI was petitioned to establish a PV submcommittee under its Steering Committee on Solar Energy. This subcommittee was disbanded in 1983 and its responsibilities are being transferred to a PV group within the Electrical and Electronics Standards Board (EESB). The ANSI Standards Boards have planning and coordination responsibilities for standards in their particular area of technology and they work to minimize duplication and to resolve conflicts and overlap in standards. It is expected that the EESB will establish a PV subgroup in the near future.

ASTM -- Subcommittee E-44.09 on photovoltaics is chaired by Steve Hogan (SERI); the first chairman was Charles Bishop (formerly SERI). The subcommittee has developed several test methods and specifications which are directed at performance measurements for cells and modules (see Table II for enumeration and status). These documents are for cell materials which behave in a linear fashion, basically single- and multi-crystalline silicon. Measurement techniques have not been addressed as yet for thin film devices.

All of the ASTM standards work in PV is based on technology transferred from the DOE program, either from research and development results or from direct contracts for specific measurement techniques. After development of performance testing standards, ASTM efforts in PV will concentrate on environmental stress test methods which are documented in the Performance Criteria Document, and on review/revision of existing standards for spectral irradiance and performance testing.

IEEE -- A PV Standards Coordinating Committee (SCC) was established by IEEE in 1979 with a contract from SERI to help defray administrative and operating expenses for its operation. The SCC established four subcommittees: PV arrays; storage; power conditioning; and systems. The systems subcommittee (chaired by Richard DeBlasio, SERI) has been the most active since greater need was perceived in the systems area; however, the other three subcommittees have become more active in the past twelve months. The systems subcommittee has sent two standards documents to the SCC for approval and forwarding to the IEEE Standards Board; these two documents are:

- o P928 Performance Criteria for Terrestrial Photovoltaic Power Systems; and
- o P929 Terrestrial Photovoltaic System Utility Interface for Residential and Intermediate Applications.

Two other standards in process are:

- o P926 Photovoltaic Power/Energy Systems Performance Rating; and
- o P927 Terrestrial Photovoltaic System Electrical Power Energy Performance Calculations.

The Array subcommittee first will address outdoor performance measurements and bypass diode arrangements for arrays. The Storage and Power Conditioning subcommittees have various documents under consideration, but none are advanced far enough for balloting as yet.

<u>NFPA</u> -- The National Electrical Code (NEC) is developed and published under the auspices of the National Fire Protection Association (NFPA). Its purpose is to establish provisions for the safeguarding of persons and property from hazards arising from the use of electricity and electrical apparatus. The NEC is published every three to four years and the most recent edition is 1984.

The 1984 NEC contains a new article, Article 690 entitled "Solar Photovoltaic Systems," which covers PV interactive or stand-alone systems. Code, or inspection, guidance is provided for installation, circuit requirements, disconnecting means, wiring methods, grounding, marking, and connection to other sources.

This article was developed by an Ad Hoc Subcommittee on Solar Photovoltaics which first met in December 1980. The elements of the article were developed by Underwriters Laboratories, Inc. (UL) under contract to SERI. UL provided technical support (under the subcontract) to the subcommittee by adapting DOE program results and experience for a draft code article. Work will begin on the 1987 NEC in 1984; proposals to revise articles are due November 23, 1984. The Ad Hoc Subcommittee on PV met in February 1984 to begin revisions (as necessary).

<u>SEMI</u> -- Three standards have been established by the Semiconductor Equipment and Materials Institute by their Solar Grade Substrate Subcommittee. These standards apply to material and dimension specifications:

- o Specification for Solar Cell Grade Silicon Slices--which covers three structural classes, monocrystalline, substantially monocrystalline, and polycrystalline;

- Solar Cell Defect Limits -- which addresses characteristics such as saw marks, contamination, edge clips/indents, and cracks/crowsfeet;

- Dimensional Specifications -- for rectangular polycrystalline cells, and for 100mm, 125mm, 150mm and 3 in. round silicon slices.

Work is underway to determine the appropriate limits for warp in silicon solar cells. This group has reduced its meeting frequency to just once a year, usually at the May SEMICON/WEST conference and show.

International Standards -- Responsibility for development of international PV standards resides with Technical Committee 82 (TC-82) of the International Electrotechnical Commission (IEC). TC-82 is chaired by France and the Secretariat is held by the United States. IEEE administers the Secretariat as well as the U.S. Technical Advisory Group (TAG) under a three-year subcontract from SERI. This contract expires at the end of FY84 and the U.S. National Committee (official member of IEC) will need to decide prior to that time whether to retain the Secretariat, which is a position of considerable influence since it controls documentation flow and timing and, to a certain degree, ballot actions.

Three working groups (WG) were established under TC-82 at its first meeting in Stresa, Italy in 1982: WG-1, Nomenclature (Canada); WG-2, Modules (France); and WG-3, Systems (Switzerland). Working Groups 2 and 3 have met once in Europe, once in the U.S., and once at the TC-82 meeting at the IEC annual meeting in Tokyo in 1983. Working Group One has met once, in Tokyo; most of its work has been done by correspondence. Each working group is scheduled to meet again in late March 1984 in Valbonne, France.

Due to the early start and the progress made in developing U.S. standards, they are being used as basic drafts for WG-2 and 3. In addition, most of the glossary prepared by WG-1 retains definitions developed for the Performance Criteria Document. This situation is extremely favorable to the U.S. PV industry since drafts reflecting U.S. consensus are providing the baseline for international efforts. WG-2 priorities for work on future documents follow very closely the sequence of development in ASTM subcommittee E44.09. In WG-3, the first document on which action will be taken is IEEE's proposed standard P928 on performance criteria. Document actions taken in Tokyo are summarized in Table III.

Initiatives Beyond FY84

For fiscal 1984, the Photovoltaic Standards and Code Task has been reduced to a one-person maintenance effort; specific task funding (including GSO) is targeted for one FTE for FY84. This level of effort is sufficient only for coordination, monitoring, and consultative activities with the various consensus organizations. Other laboratory personnel (at SERI, SLA, JPL) are involved in committee work and are supported by their specific task funding.

Numerous standard and code related projects are appropriate for DOE support beyond FY84, and the number and mix of tasks can be tailored to accommodate a variety of budget levels. The areas in which additional work and support can be useful include: direct support of domestic and international standards efforts with the eventual goal of industry self-sufficiency; assistance in developing and revising code regulations to permit/facilitate photovoltaic applications; development and refinement of performance test methods, particularly for thin-film technology; and refinement of resource assessment techniques.

Direct Support of Standards/Code Development -- Probably no better use can be made of limited funds for standards/code support than to use it for direct support to consensus standard/code organizations, particularly ASTM and IEEE. Direct funding can be used to ensure that key participants attend working meetings and develop the working documents that provide the basis for committee deliberations. A corollary use of funds is direct support to the parent organization to defray costs of administrative support for the committees. This cost is appreciable for IEEE which administers the IEC/TC-82 Secretariat and the USNC TAG.

The reduction in the DOE photovoltaic budget has taken its toll of industry participants in consensus committee work. It is important to maintain the momentum of domestic standards development since it is providing the foundation for U.S. contributions to international standards. Effective United States input into international standards provides the basis for effective entry of American products and services in the international market and ensures that sound American standards and engineering practices receive due recognition in international trade.

Industry has been a significant cost-sharing partner of DOE in this work to date through its underwriting of staff time and expenses. However, it is becoming harder for smaller firms to meet these expenses and they are the first to withdraw from involvement.

Similarly, the industry itself is small and in no position to undertake the entire support for international standards work. Holding the TC-82 Secretariat is a distinct advantage to U.S. interests and -- as stated above -- the early start of U.S. standards work has resulted in U.S. documents being used as initial international draft documents. These twin advantages will fade if U.S. participation falters, as it appears it will if some level of government support is not continued.

Industry spokesmen* believe this continued support through a central program coordinating point is an absolute necessity if the U.S. is to take a place in the international PV market consistent with its advanced technology

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*Arco-Solar, Solar Power, Solarex, Solavolt (and Photowatt before its dissolution) are all active in standards development work and support strongly continuation of DOE funding of and involvement in these activities.

and marketing capability. Failure to provide continuing support for U.S. participation in international standards development at this time will surely place the U.S. at a disadvantage in the developing world PV market. In addition, the U.S. will, as a nation, find itself in the embarrassing position of being unable to enforce properly terms of the "General Agreement on Tariffs and Trade" (GATT) that was promoted by the Nixon and Ford Administrations. Article Two, paragraphs 2.2 and 2.3 of the Agreement on Technical Barriers to Trade (a section of GATT) states

> 2.2 Where technical regulations or standards are required and relevant international standards exist or their completion is imminent, Parties shall use them, or the relevant parts of them . . . .
>
> 2.3 With a view to harmonizing technical regulations or standards on as wide a basis as possible, Parties shall play a full part within the limits of their resources in the preparation by appropriate international standardizing bodies of international standards for products for which they either have adopted, or expect to adopt, technical regulations or standards.

Photovoltaic Code Development -- The most important code document for photovoltaics is the National Electrical Code. The 1984 edition contains a new article covering PV residential and stand-alone systems, and work on the 1987 NEC article will begin in February 1984. It is important that PV program technical staff be involved in the work leading to the 1987 code so that the scope of the article can be increased and that it will reflect the current state-of-the-art.

The model building codes which govern mechanical and structural practices for building construction are also important since these codes will apply to the installation of PV systems. No PV proposals have been made as yet for inclusion into the three major model building codes. A considerable amount of code work has been done for solar thermal building applications, and much of this work will be applicable to PV. However, the thermal code material has not been incorporated into the Model Energy Code (MEC) although portions have been adopted in the mechanical codes of the three model building codes.

Some PV program effort should be directed at the 1987 NEC article and at code proposals for the model building codes and for the MEC. These codes will provide coverage for residential, stand-alone, and some intermediate load applications.

The National Electrical Safety Code is published by IEEE and covers safety code issues for installation, operation, and maintenance of equipment used for electric-supply stations. This code should be examined to determine what provisions need to be added or revised to accommodate PV central station systems.

Test Method Development -- U.S. standards in PV are based, for the most part, on techniques developed at NASA-Lewis and at JPL. Their respective work on test methods was adapted for the PV Performance Criteria Document to provide an inventory of test methods. These methods are being used as a basis for domestic consensus standards development. This process of PV Program research documentation and use by private sector groups provides an excellent example of successful technology transfer.

The PCD did not cover all necessary test methods, however. Existing methods are based on current applied technology, i.e., single or multi-crystalline flat plate cells and modules. Concentrator test methods have not been similarly documented and much work remains on balance of system elements and on arrays and total systems.

Test methods for cells and modules cover a family of methods all necessary for performance measurement; this family includes reference cell specification and calibration, irradiance characteristics, spectral response, and finally device electrical performance. An entirely different family of methods may be needed to measure performance of thin-film and innovative devices.*

Consistent measurement results for these devices have not been achieved between different laboratories, and techniques which can yield consistent results are necessary for consensus standard development as well as for research comparisons of new devices. Work should begin immediately to make formal and to document measurement methods for these devices. Other measurement activities that are necessary or, at the very least will be useful, are:

- Use data from tests in the climatic test facility at Wyle Labs, funded by JPL. These data can be used to update test procedures in Volume II of the PCD and can establish generic functional relationships between temperature, humidity, bias, and time for observed failure mechanisms such as ion migration of metallization, etc.

- Development of an internationally certifiable energy-based PV rating method for use in the worldwide deployment of crystalline-silicon flat plate modules and, equally important, for concentrating systems and thin-film modules in the near future. The SERI PV outdoor test site can be used for verification and validation functions on the existing IEEE standards work and on the AM/PM method which uses the concept of a standard solar day.

- Implementation of a PV energy rating measurement procedure requires an enhanced broad band and spectral solar irradiation data base, together with further study on the effects of air mass,

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*A considerable amount of work has been done at SERI and at Battelle-Columbus to develop a test method for CdS/$CuInSe_2$; this work may be appropriate for other thin film technologies.

turbidity, water vapor, etc. Also, although pyranometry is a measurement area of seemingly great simplicity, there are many pitfalls which are surely causing problems in the PV area. One dilemma is lack of agreement in the calibration and characterization of reference pyranometers for different applications (such as for resource assessment integrated over long periods of time as compared to instantaneous measurements of irradiance on a tilted surface).

- Research is needed as to the problems associated with pulsed simulation for long time constant PV technologies such as heterojunction devices and into the temporal and spatial stability characteristics of various lamp plasma's under pulsed conditions and their effects upon I-V curve generation.

- A standard method to measure effectively module spectral response needs to be developed as well as the effects of non-linearity of module response to input illumination and spectral response mismatch between PV reference cells and test modules. This work also could be done at the SERI PV outdoor test site and could incorporate thin-film technologies as well.

- Recent work by the electromagnetic hazards divison of NBS Boulder has indicated EMI problems in the AM broadcast band with certain types of inverters. The remedies likely are relatively simple, but they need to be understood by systems fabricators. Also, further work in the upper VHF and UHF parts of the spectrum may be useful to determine if an actual problem does, or can, exist. Completion of this work can, if appropriate, lead to a set of EMI resistant design guidelines and standards for PV systems.

- Development of test structure standards for photovoltaic devices will prove of value in insuring reliability performance. Test structures can be of particular importance in the measurement of critical production performance parameters, such as interfacial contact resistance.

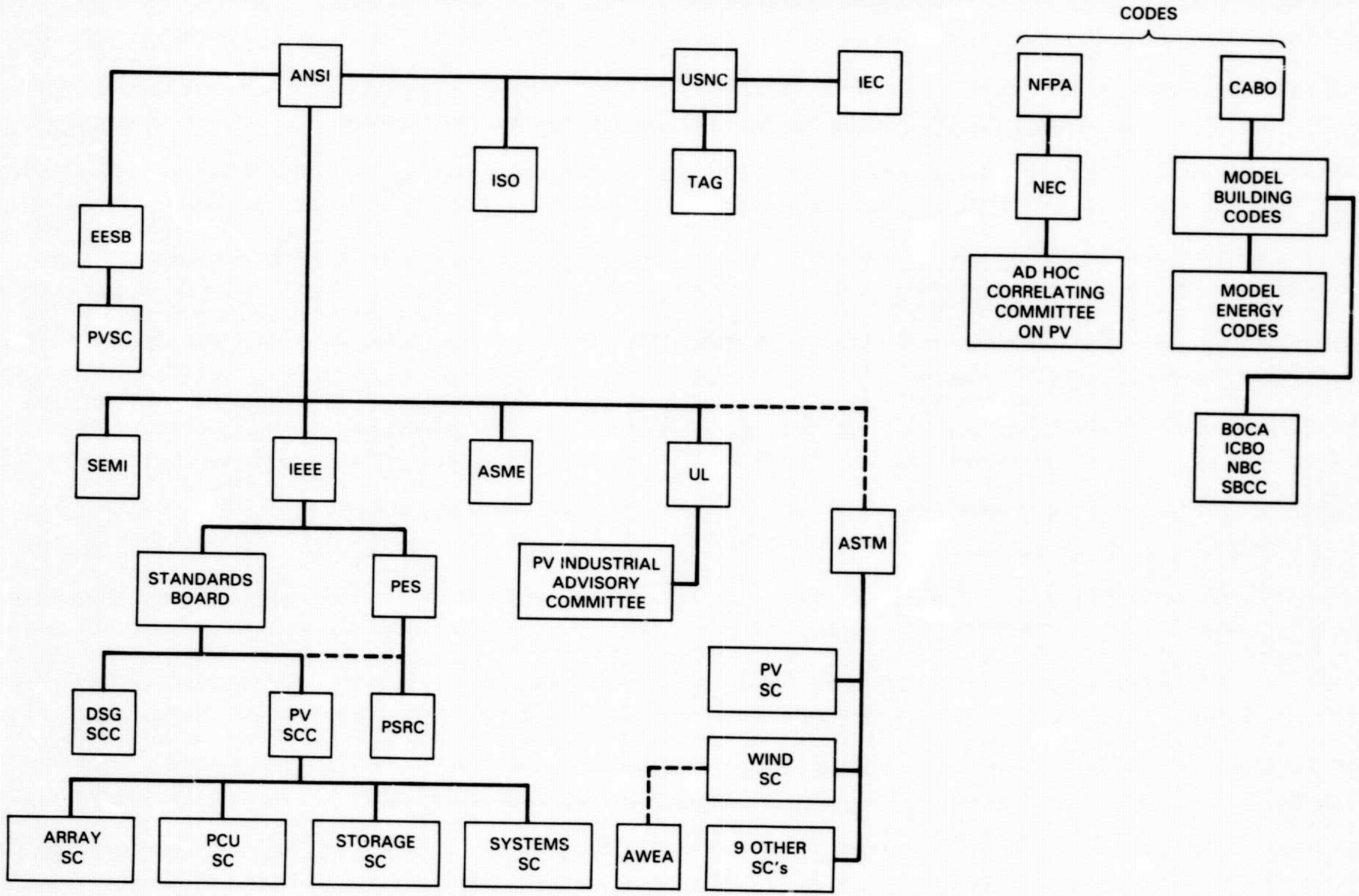
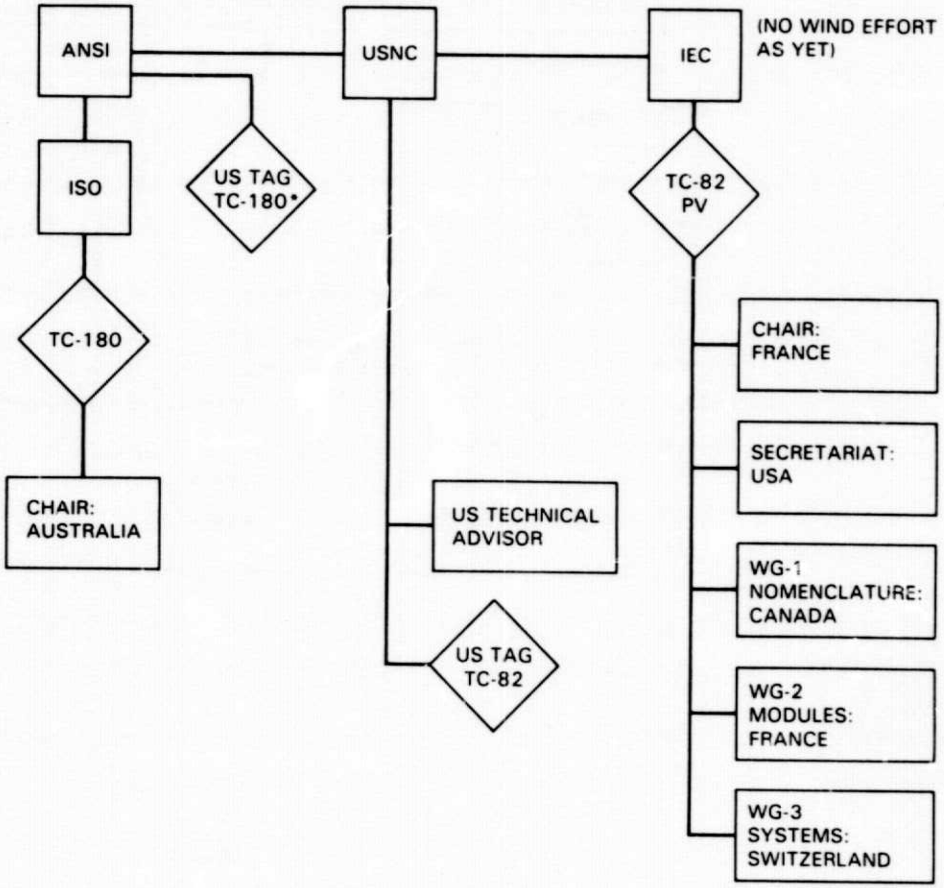


Figure 1. Domestic Standards Development: Solar Electric Technologies



*INTERNATIONAL STANDARDS FOR MECHANICAL/STRUCTURAL ELEMENTS: POSSIBLY WOULD COVER PHYSICAL INSTALLATION OF PV MODULES, ESPECIALLY ROOF-MOUNTED.

Figure 2. International Standards Development

Table I. Key

STANDARDS

ANSI	American National Standards Institute
EESB	Electrical and Electronic Standards Board
PVSC	Photovoltaic Subcommittee of the EESB
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWEA	American Wind Energy Association
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
DSG SCC	Dispersed Storage and Generation Standards Coordinating Committee
PV SCC	Photovoltaic Standards Coordinating Committee
PES	Power Engineering Society
PSRC	Power Systems Relaying Committee
ISO	International Standards Organization
PCU	Power Conditioning Units
SEMI	Semiconductor Equipment and Materials Institute
SC	Subcommittee
TAG	Technical Advisory Group
TC	Technical Committee
UL	Underwriters Laboratories
USNC	United States National Committee
WG	Working Group

CODES

CABO	Council of American Building Officials (the ANSI of building codes)
BOCA	Building Officials and Code Administrators
ICBO	International Conference of Building Officials
NBC	National Building Code (American Insurance Association)
NFPA	National Fire Protection Association
NEC	National Electrical Code
SBCC	Southern Building Code Congress

Table II. Status of ASTM E44.09 Documents, October 1983

Document No.	Title	Status
ASTM Society Standards		
Proposal (Gray pages)	Specification for Physical Characteristics on Non-Concentrator Terrestrial Photovoltaic Reference Cells	
E 948-83	Standard Methods for Testing the Electrical Performance of Non-Concentrator Terrestrial Photovoltaic Cells Using Reference Cells	
E 927-83	Specification of Direct Normal Spectrum Solar Simulation for Terrestrial Photovoltaic Testing	
Documents in Progress		
130	Standard Method for the Calibration and Characterization of Non-Concentrator Terrestrial Photovoltaic Reference Cells Under Direct Normal Irradiance	Passed Subcommittee ballot, submitted for committee ballot
131	Test Method for Concentrator Photovoltaic Devices	Inactive
139	Standard Methods for Measuring the Spectral Response of Photovoltaic Cells	Passed committee ballot, submitted for Society ballot
155	Standard Practice for Determination of a Spectral Response Mismatch Parameters for Selecting Photovoltaic Reference Cells	Passed committee ballot, submitted for Society ballot
156	Standard Method of Determining the Linearity of a Device Parameter with a Test Parameter	Draft for subcommittee review in preparation
161	Standard Methods of Testing Non-Concentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells	Passed subcommittee ballot, submitted for committee ballot
170	Standard Practice for Determining Resistance of Photovoltaic Modules to Hail by Impact with Propelled Ice Ball	Passed subcommittee ballot, submitted Committee ballot

Table II. Status of ASTM E44.09 Documents, October 1983 (Continued)

Document No.	Title	Status
177	Standard Specification for the Calibration of Photovoltaic Reference Cells Using a Tabular Standard Spectrum	Draft to be revised
178	Standard Methods for the Calibration and Characterization of Non-Concentrator Terrestrial Photovoltaic Reference Cells Under Global Irradiance	Passed subcommittee ballot, submitted for committe ballot
Other Standards Relevant to PV[1]		
E 891-82	Terrestrial Direct Normal Solar Spectral Irradiance Tables for Air Mass 1.5	
E 892-82	Terrestrial Solar Spectral Irradiance Tables at Air Mass 1.5 for a 37^{o} Tilted Surface	

[1]Both of these standards are being revised to reflect current research results.

Table III. IEC/TC-82 Document Actions--October 1983, Tokyo

Working Group	Document Number	Title	Action
1	82(Sec)7	Test Specimen Measurement Procedure	Circulated under[1] Six Months Rule
2	82(Sec)8	Proposal for Temperature and Irradiance Corrections to Measured I-V Characteristics	Circulated under Six Months Rule
2	82(Sec)9	Proposal for Measurement Principles for Terrestrial PV Solar Cells and Modules Along with Reference Spectral Irradiance Data	Circulated under[2] accelerated procedure
2	82(Sec)10	Description, Classification, Selection, and Requirements for Reference Solar Cells and Modules	Returned to WG for further study
3	82(Sec)11	General Description (Criteria; Ed.) of Terrestrial Photovoltaic (PV) Systems	Circulated under accelerated procedure
3	82(Sec)12	Proposal for Performance and Safety Requirements for Photovoltaic (PV) Arrays	Returned to WG for further study

[1]The Six Months Rule is used when it is clear that the largest practical measure of agreement has been obtained in the discussions of the Committee. A draft circulated under the Six Months Rule is bilingual (French and English) and is accompanied by a voting paper to be returned to the Central Office by the National Committees within six months of date of dispatch, accompanied by any comments they deem to be essential.

[2]The Accelerated Procedure is applied when reasonably good agreement has been reached (but insufficiently good agreement for the circulation of a Six Months Rule draft). If no substantial adverse comments are received within three months, it will automatically be regarded as being circulated under the Six Months Rule without the circulation of a new modified Secretariat draft.

APPENDIX B

COMMERCIAL PHOTOVOLTAIC MEASUREMENTS WORKSHOP

Harry A. Schafft
National Bureau of Standards
Washington, DC 20234

Steve Hogan
Solar Energy Research Institute
Golden, CO 80401

A workshop was held to provide the photovoltaics industry and others with a vehicle to examine the status and the needs for the development of measurements and standards for flat-plate solar cells, modules, and systems. Over 80 participants from the photovoltaics community took part in presentations and discussions on the following topics: measurement equipment needs, interactions with customers of photovoltaic products, quality assurance, silicon materials characterization, solar data, reference cells, cell and module output measurements, module certification, and the role of the Government in measurements. This report includes the presentations given, the results of the discussion sessions, and overview and assessment statements. The workshop demonstrated the need and desire for a base of measurement methods, standards, instruments, and data for the widespread utilization of photovoltaics. It also demonstrated the recognition that much needs to be done to make this base sufficiently complete and reliable and that the Federal Government has a necessary and important function in the development of this base.

INTRODUCTION

A measurements workshop was held on July 27 to 29, 1981, in Vail, Colorado. The purpose of this meeting was twofold: (1) to examine the status of photovoltaic measurements, data, and standards development, and (2) to identify gaps in the measurement technology that impede the widespread utilization of photovoltaics. The intent was also to make more visible the importance of a reliable measurement technology in permitting (1) a better understanding and control of photovoltaic materials, processes, and devices, (2) an improved productivity, (3) a fair and accurate comparison of photovoltaic products, and (4) a greater user confidence in acceptance of photovoltaics.

To ensure that the workshop was aimed at relevant measurement needs, the topics covered were selected on the basis of inputs from visits to a cross section of the photovoltaics industry. The results of these visits were included in the introductory paper to the workshop. Although this workshop is the first to be aimed specifically at the measurement needs of the photovoltaics industry, it does follow a series of workshops and meetings* that were concerned with measurements and were sponsored by various parts of the National Photovoltaic Program of the Department of Energy.

Over 80 representatives from industry, national laboratories, government, universities, and elsewhere participated in the discussions and presentations of the workshop. In particular, 11 companies involved with the manufacture or development of commercial and near-commercial photovoltaic devices were represented. The list of attendees is provided as an appendix.

The workshop was organized in the following manner. Eight discussion sessions were held during the day as shown by the schedule given in table 1. In each of the sessions, a number of presenters gave brief talks on assigned topics to provide the perspective and context for the discussions that followed, which were guided by a discussion leader. The first six sessions were held with the audience divided into two groups to encourage discussions in the more informal atmosphere that a smaller group can provide. For each of these six sessions, the presenters and the discussion leader worked first with one group and then with the other. To provide continuity and to assist the discussion leaders, a group representative was assigned to each of the two groups. It was found convenient to hold the remaining two discussion sessions in plenary meetings. In addition, two evening sessions were also held: one to provide tutorial material for the discussion session on solar data, the other to discuss the role of the Government in measurements. At the conclusion of the last discussion session, the discussion leaders summarized the results of their respective sessions, and John Meakin, who served as one of the group representatives and as the chairman of the evening session on the role of the Government, provided an overall assessment of the workshop.

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*Terrestrial Photovoltaic Measurements, Workshop Proceedings, NASA TMX71802 (1975). Available from NTIS using order number N767161526; cost of document is $15.50.

Terrestrial Photovoltaic Measurements II, Workshop Proceedings, NASA CP-2010 (1976). Available from NTIS using order number N77-30521-7; cost of document is $27.50.

Sawyer, D.E., and Schafft, H.A., Eds., Semiconductor Measurement Technology: NBS/DoE Workshop, Stability of (Thin Film) Solar Cells and Materials, NBS Spec. Publ. 400-58 (August 1979).

Reliability of Materials for Solar Energy Workshop Proceedings, Vol. 1 Summary and Recommendations. Available from NTIS using order number SERI-TP-31-248; cost of document is $15.50.

Photovoltaic Material and Device Measurement Workshop (1979). Available from NTIS using order number SERI-TP-49-185; cost of document is $14.00.

The proceedings which follow include an overview measurements perspective of the workshop, the introductory paper of the workshop on the status of measurements for commercial photovoltaics, and sections for each of the day sessions held at the workshop. Each of these sections contains the contributions by the presenters and a report by the discussion leader on the results of the session. The section on solar data includes the papers presented in the evening tutorial session. The proceedings are completed with a summary of the remaining evening session and the presentation by John Meakin on his assessment of the workshop.

A PERSPECTIVE OF THE WORKSHOP

Based on the comments and discussions at the workshop, it is clear that there is a consensus that standard methods of measurement are important. They are a necessary part of doing business. They are the common language at the buyer-seller interface.

It is also clear that despite the extensive work in measurements, data, and standards development that has been conducted - mostly with the support of the National Photovoltaic Program and other programs of the Federal Government - a great deal still needs to be done. As the photovoltaic community has gained in experience and sophistication, it has begun to recognize that a reliable measurement technology is important to its ability to function effectively and with confidence. The industry has also begun to recognize that a larger number of "measurement tools" are needed than were at first anticipated and that more will be needed as it prepares for the high volume production expected in the near future.

The following are some examples of the measurement needs identified. The high production of the near future will create new requirements on test and process monitoring techniques and on equipment for the rapid taking, processing, and analyzing of a variety of data. The test methods to characterize starting silicon material are deficient to the extent that they cannot yet be used with confidence to determine whether the material can be used to fabricate satisfactory solar cells. The accuracy of cell and module output measurement will remain in question while better methods are developed to measure spectral response of solar cells, to match spectral responses of test and reference devices, and to measure the spectral distribution of solar simulators. Many feel that module certification will ultimately be needed, for example, to satisfy codes and other regulations such as those promulgated by the National Electric Code. Before a certification program can be established, however, difficult questions need to be answered about the selection of criteria for certification and then about the validity of the test methods to determine compliance with these criteria. Finally, to satisfy adequately the requirements for the optimization, design, sizing, and operation of photovoltaic systems, significant advances are needed in the accuracy, completeness, and timeliness of solar data.

The workshop also showed that the photovoltaics community, as represented by the attendees, looks to the Federal Government to continue to play a significant role in measurement development.

A number of aspects of this role for the Government's photovoltaics program were identified. One is to provide for recognized centers of measurement expertise so that the industry and testing laboratories can rely on them to verify and confirm the validity of their measurements. A specific example of this service was identified in a unanimous vote at the evening session on the role of the Government. The vote called for the Government's program to provide a referee function to certify the measurement validity of any testing laboratory that would undertake to provide the community with calibrated reference cells.

Another identified aspect of this role is to support, in particular, the development of needed measurement technology that is of such an extensive or broad nature that any one manufacturer or group cannot reasonably divert sufficient resources to do the job. This aspect would apply, for example, to produce a new or to refine an existing test method that requires significant research, development, and analysis. Two other specific examples were identified by the attendees: the development and collection of field experience with photovoltaic products, and the nationwide collection of solar data. The attendees in a unanimous vote during the same evening session passed another resolution that the Government not only continue but expand its solar data collection activities.

Another aspect of the role for the Government is to support standards development and to promote information and technology transfer. An example mentioned of the former is the support that has been provided for the United States to undertake the responsibility of the Secretariat for the new technical committee on photovoltaics of the International Electrotechnical Commission. An example of the latter is the sponsoring of meetings such as this workshop, thereby providing a neutral ground for industry to meet. This workshop, for example, allowed a large segment of the community to assess the value of global calibration of reference cells (in the reference cell session), and to be alerted (in the cell and module measurements session) to a new and portable instrument for measuring the current-voltage characteristic curve of arrays - an instrument-need identified in an earlier discussion session.

How does one explain the rather explicit support for Government involvement in measurements that was exhibited at the workshops? The explanation can be found in four observations:

(1) The photovoltaics industry is "embryonic," as Meakin states in his assessment of the workshop, and the supporting measurement technology may be viewed to be at a similar stage. As a result, manufacturers see the cost to develop the measurements needed in the many and diverse areas as prohibitively high when weighed with the costs to develop their products, production facilities, and markets.

(2) There is no private organization within the photovoltaics community that possesses the technical and fiscal resources to do jointly what is not realistic to do individually in the development of the extensive measurements base that is needed.

(3) The Government, primarily through the National Photovoltaic Program, has been involved extensively in a variety of measurement development activities. The value of this involvement, and its continuance, has come to be recognized by the photovoltaics community.

(4) The benefit of measurement standards and other components of the photovoltaic measurement technology is in its acceptance and use by all concerned. This, however, works against significant individual involvement to develop this technology.

The last observation represents a fundamental dilemma for the industry. While it needs a reliable, well-developed measurements base, it is prevented from responding adequately to such needs because of intrinsic disincentives. Individually, a manufacturer can place himself at a competitive disadvantage by diverting resources, for example, to develop or refine a test method and then seek to have it accepted and used by competitors and customers. If a test method is offered by a manufacturer, it may likely be oriented to his product or application and so be limited for general use. Even if the method is actually well suited for all to use, its acceptance may nevertheless be frustrated because it will normally be viewed with suspicion by the manufacturer's competitors and by his customers. If one manufacturer devotes significant resources to develop his measurement capabilities in an area, he also may have to pay a penalty for his conscientiousness. He may pay because he has diverted resources that could otherwise be spent to enhance sales. He may pay through a loss of sales because his competitors, with less measurement expertise, may claim in good conscience superior product performance when in fact this may not be true.

For all these reasons a natural inclination is to seek to develop the needed measurements through the assistance of an agent that will represent the common interests of the industry and community in an unbiased and technically competent manner. The Federal Government is seen as the only available organization that can adequately provide this function. It is altogether reasonable to expect the Federal Government to play a significant role in the development of measurements and standards, here in photovoltaics as in other technologies, because of their diffuse application in the economy and because of their use as facilitators of commerce. What is needed now in the photovoltaics arena is a better mutual understanding of the nature and extent of that role in what needs to be a joint enterprise between industry and government.

APPENDIX C

PHOTOVOLTAIC PERFORMANCE MEASUREMENT PRACTICE AND PROBLEMS

L.D. Runkle and R.G. Ross, Jr.
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

ABSTRACT

The function of solar cells, modules and arrays is to produce useful electrical energy. Because photovoltaic conversion efficiency is used to discriminate between competitive photovoltaic technologies as well as between alternate means of producing electrical energy, it is important that the means used to measure the performance of these devices be understood. This paper traces the evolution of photovoltaic performance measurement from its early application in space arrays to its present status in terrestrial applications. Although the discussion is generally addressed to the problem of measuring the power of flat plate modules and arrays, the technology of measuring the characteristics of cells provides the basis for much of the discussion. The problem of developing voluntary concensus performance measurement standards is also discussed and suggestions for enhancing their development are offered.

1. Introduction

The performance of photovoltaic solar cell modules is delineated by their current-voltage characteristic curve, Figure 1. Aside from the intrinsic properties of the module itself, this characteristic is a function of three extrinsic variables; (1) the total irradiance reaching the module, (2) the spectral distribution of the irradiance and (3) the temperature of the module. In order to compare the performance of different modules, these three extrinsic variables must remain the same from sample to sample. It is apparent from Figure 1 that the short-circuit current increases linearly with the intensity of the irradiance. Likewise, from Figure 2 it can be observed that a temperature increase causes a decrease in voltage amounting to about 0.5% per 1°C. The effect of changing the spectral distribution of the irradiance is more subtle and is illustrated in Figure 3 which displays relative power as a function of air mass (from Ross & Gonzalez, (1)). Air mass is a normalized parameter denoting the ratio of the path length traversed by the incident sun through the earth's atmosphere to the thickness of the atmosphere. It serves as a convenient measure of different solar spectral distributions ranging from the bluish sun of outer space (air mass zero or AM 0), to the white light of an overhead sun (AM 1), to the redish sun of afternoon (AM 6). To compare the performance of different modules, a common set of conditions is required; thus a level of irradiance must be specified, the spectral distribution or air mass of the irradiance defined, and a temperature selected.

Presented at the ASES 1984 Annual Meeting,
Anaheim, California, June 5-9, 1984.

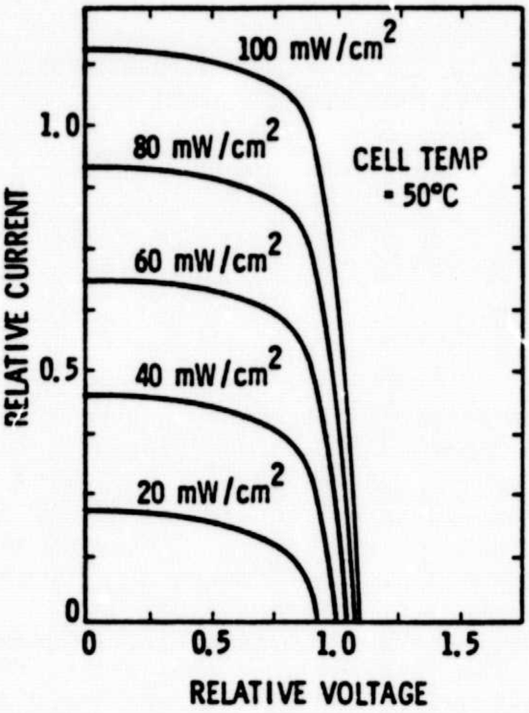

Fig. 1. Typical current-voltage characteristics of a solar cell module as a function of intensity.

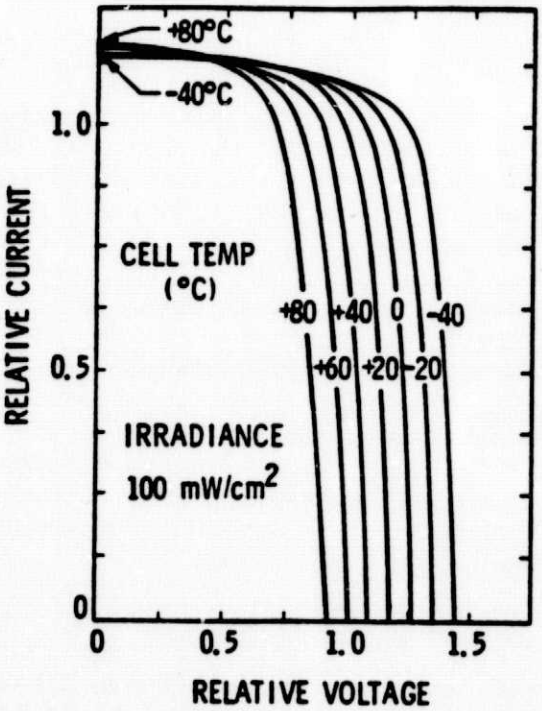

Fig. 2. Typical current-voltage characteristics of a solar cell module showing effects of temperature.

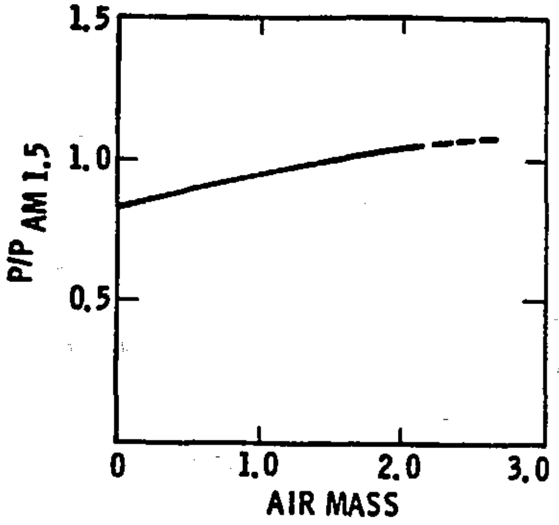

Fig. 3. Normalized power output as a function of air mass.

2. Background

The first widespread use of large solar panels or arrays to power electrical equipment occurred in the various spacecraft programs, where the determination of the performance of solar cells and arrays in space was crucial because of the limitation imposed upon the size of the array by the lifting capability of the rockets that boosted the spacecraft into orbit. It was in this program that the techniques and procedures for making photovoltaic measurements were first developed. The intensity and spectral distribution of the irradiance in outer space was determined: then earthbound simulators and measuring techniques were developed to facilitate evaluation of the evolving solar cell technology and to proof test the spacecraft arrays. Everyday measurements of cells were facilitated by the use of calibrated reference cells, temperature controlled plates and steady-state lightsources simulating the AM 0 spectrum of space. The reference cells were calibrated on balloon flights that carried appropriate instrumentation to the edge of the earth's atmosphere.

Testing of the arrays was more difficult than testing cells. Cells could be put in fixtures, the temperature controlled, the intensity of the irradiance adjusted, the spectrum evaluated and the performance measurements thus obtained. For arrays there was only the sun, with the spectrum and intensity of the particular moment, and at a temperature depending not only on the ambient and the irradiation but on the wind as well. This led to hours of data taking at the mercy of the weather and laborious calculation or data processing to evaluate the anticipated performance of the solar panel in space.

The arduous process of sunlight testing coupled with electronic instrumentation advances led to the development of the large-area pulsed solar simulator (LAPSS). This device uses a xenon light source pulsed by a current discharged from a capacitor bank to irradiate the solar panel. During a part of the time that the light pulse is on, an electronic load sweeps the panel from no load to short circuit, and the voltage and current characteristics of the panel are sampled several hundred times. The pulse is about three milliseconds and the sweep takes about one millisecond. The intensity of the flash during the sweep is adjusted to be near 100 mW cm^{-2}. A calibrated reference cell is used to measure the effective AM 0 intensity at the sampling times, and the temperature of the panel is measured by a thermocouple. The sampled data is stored, then processed by a computer that normalizes the printout of the I-V curve to the selected intensity and temperature. The great virtue of this equipment is that the measurement is made in seconds, not hours. Further, the spectral distribution of the irradiance is known, the intensity is selected and the temperature of the module or array is known and does not change during the course of data taking.

3. Terrestrial Measurements

Although the measuring equipment of the space program is directly applicable to making measurements of terrestrial modules, some accommodation was required since the spectrum of the irradiance at the surface of the earth is modified by the atmosphere and depends upon such things as the length of the path the light takes in traversing the atmosphere (the air mass), the water vapor encountered and the turbidity.

In response to the need for definition of both a standard reference spectrum and a measurement procedure, an ad hoc committee of photovoltaic specialists met in 1976. An interim standard for performance measurement was formulated and reported in NASA Document 73702 which set the standard irradiance level at 100 mW cm^{-2}, defined the standard spectrum as that of direct normal sunlight at AM 1.5 and certain water vapor and turbidity, and adopted 28^{o} C as the standard temperature (2). The procedure also adopted the concept of the reference cell as the standard means of measuring the effective AM 1.5 irradiance level of illumination sources which do not have a standard AM 1.5 spectral distribution. The reference cell, of known dimensions and fabricated of the same photovoltaic material as was used in the module to be measured, had to be calibrated against a precision pyrheliometer under sunlight conditions closely approximating those associated with the AM 1.5 reference spectrum. The turbidity and the water vapor content were to be determined by a sun photometer.

This process could only be carried out when the proper atmospheric conditions and sun position occurred. As a result, the calibration was often long and actually impossible in some regions. The virtue of such a reference cell was that it could be used with any reasonable light source to establish the AM 1.5 irradiance to which the module under test was being exposed. Since both the reference cell and the module were made of the same photovoltaic material they respond to the light in the same way. The drawback, of course, is that each module tested requires a matching reference cell.

For about ten years, this interim standard has provided a basis for uniform performance measurements and comparisons. Recently, with the planning and installation of larger photovoltaic power systems, attention has been directed to annual energy production as a more realistic measure of the worth of a solar cell module than peak power measured at arbitrary conditions such as those appearing in the interim standard. The peak power does not necessarily correlate well with annual energy at all locations at which photovoltaic arrays might be used. In fact the claim is made that modules produced by one process may be unfairly discriminated against by measuring at the 100 mW cm^{-2}, AM 1.5 conditions defined.

4. Issues

The issues that must be resolved in order to standardize performance measurements for terrestrial applications continue to focus on the selection of the irradiance level, the spectral distribution of the irradiance, and the temperature.

Irradiance-level Issues

Although short-circuit current is a highly linear function of irradiance over a wide range of levels, maximum power is only modestly linear with irradiance. At irradiance levels below 40 mW cm^{-2}, module power becomes quite sensitive to the shape of the module I-V curve. At low irradiance levels, high series resistance leads to proportionately increased power (lower I^2R losses) whereas a low shunt resistance (high current leakage) leads to proportionately lower power under the same conditions. Because an important amount of annual electrical energy is generated at irradiance levels below 40 mW cm^{-2}, there is a valid argument for measuring modules at an irradiance level closer to the annual average than at 100 mW cm^{-2} so as to properly include these low-irradiance-level power trends.

Another problem involves the determination of the ultimate arbiter of the validity of the measurements. Naturally one assumes that the National Bureau of Standards is that authority. In actuality, the NBS has absolved itself of the responsibility for making precise measurements of the irradiance of the sun, and this chore has devolved upon a group of dedicated independent concerned organizations and people who meet annually to make intercomparison measurements, and establish a standard irradiated watt. Each year representatives of concerned national laboratories, certain industry participants, representatives from foreign national labs and others gather at New River, Arizona, with their cavity radiometers to conduct a series of intercomparison measurements to establish a basis for the irradiance of the sun. Once in five years this takes place at the World Radiation Center in Davos, Switzerland. These instruments are then the standards against which the pyrheliometers and pyranometers are calibrated. Reference cells may then be calibrated against the pyrheliometers.

Solar Spectrum Issues

The present practice of using a direct normal AM 1.5 spectrum to measure flat-plate photovoltaic modules as defined by NASA Document 73702 is widely disputed by those who forsee the future use of amorphous silicon and other more blue-sensitive materials. They insist, with justification, that a bluer spectrum, which more properly recognizes the important contribution from blue-sky diffuse radiation should be used. The ASTM has adopted standards which define both of these spectra at AM 1.5. Standard E 891-82, "Terrestrial Direct Normal Solar Spectral Irradiance Tables for Air-Mass 1.5", is based upon work by Bird and Hulstrom (3) at SERI and has superceded the spectrum published in NASA 73702 as the standard. Likewise, E 892-82, "Terrestrial Solar Spectral Irradiance Tables at Air-Mass 1.5 for a 37 degree Tilted Surface", provides a standard for a "global" solar spectrum.

It is instructive to observe the difference in calculated short circuit current developed in a variety of cells when "exposed" to these two different spectra. These variations - shown in Table 1 for six different single crystal silicon reference cells, selected to represent the gamut of response characteristics available - reveal a small effect, from -0.4% to +1.4%, when global is compared with direct. The poly-crystalline cell included in the sample is seen to perform similarly to its single crystal (Cz) companions.

Table 1. Cell Response to Different Spectra

Cell Number	Cell Mat.	Short Circuit Current $mA/mW/cm^2$ Direct Spectrum	Short Circuit Current $mA/mW/cm^2$ Global Spectrum	Change %
MS 431	Cz- Si	1.349	1.360	+0.8
GQ 420	Cz- Si	1.087	1.082	-0.4
RS-425	Cz- Si	1.205	1.221	+1.3
SS-1440	Cz- Si	1.325	1.337	+0.9
US-417	Cz- Si	0.939	0.937	-0.2
YB-451	Poly Si	0.990	1.004	+1.4
UR-489	Cz- Si	1.013	1.028	+1.4
Exp.	a - Si	0.048	0.054	12.0

On the other hand, calculations run on an experimental sample of amorphous-silicon (a-Si) cells show that the ASTM global spectrum results in a 12% higher short circuit current than that obtained using the ASTM direct normal spectrum. This sample was characterized by the manufacturer as mediocre, and not as responsive in the blue region as could be expected from better material.

Since a global spectrum is what is seen by all flat-plate arrays, it would appear to be appropriate to adopt that spectrum for performance measurements. However, before this can be done, revised reference cell calibration procedures must be developed and demonstrated.

Temperature Issues

Recognizing that the ambient temperature varies from site to site as well as diurnally for any one site, points up the difficulty in selecting a temperature to use as a standard in measuring module performance. However, temperature compensations are less contentious than spectral and irradiance level considera-
tions and can be applied with acceptable ease. Formulae have been developed to calculate P_{max} at a second temperature from measurements made at a first temperature. These rely upon a knowledge of the short circuit current, the open circuit voltage and the series resistance dependencies on temperature. As pointed out earlier, the NASA document specified that 28°C was the temperature at which the measurements were to be made. Shortly later another temperature was defined to more realistically represent operating conditions. This is called the nominal operating cell temperature, or NOCT, and is defined as the actual cell temperature when the solar module is irradiated at 80 mW cm^{-2} in an ambient air temperature of 20°C, and at a wind velocity of 1 m s^{-1}. These conditions, designed to reflect an annual average operating temperature, usually result in a value of approximately 48°C depending upon the thermal design of the module. Given the fact that the maximum power produced by a module decreases by about 0.5% for each degree Celsius that the temperature increases, the useful power at NOCT is approximately 10% less than that measured at 28°C.

STATUS

At the present time, the standards committees of the American Society for Testing Materials (ASTM) and the Institute of Electrical and Electronic Engineers (IEEE) are working on a family of standards applicable to the measurement of the performance of solar cells and modules, the International Electrotechnical Commission (IEC) has formally convened Technical Committee 82 to address photovoltaic standardization, and at least two propositions have surfaced which address the rationalization of module power ratings to annual energy.

ASTM Committee E-44 has been set up to develop standards on Solar Energy Conversion and comprises fourteen subcommittees, one of which is Subcommittee 44.09 - Photovoltaic Electric Power Systems. At the present time 44.09 has ten standards in preparation. Two standards were issued in 1983 and a third has been approved for issue. Standard E 948-83, "Standard Methods for Testing the Electrical Performance of Non-Concentrator Terrestrial Photovoltaic Cells Using Reference Cells" is a step toward replacing the NASA document. However, the standard on module testing and a number of other documents in preparation must be issued in order to completely define the measurement procedure.

The IEEE activity, in contrast to that of ASTM, is generally focused on the larger elements of the system such as arrays, power conditioning and storage as well as the total system itself. No photovoltaic standards have been issued by the IEEE to date; however, the several subcommittees are actively striving to bring standards into being.

In an effort to address the problem of establishing ratings that are related to annual energy, at least two propositions have been put forth. Charles Gay (4) of ARCO has proposed what is termed an AM/PM rating. It features the selection of a "standard day" with irradiance level, temperature and spectrum based on an analysis of worldwide conditions, followed by adjustment to site-specific conditions, which may or may not be less cumbersome than an adjustment from the present peak conditions. Gonzalez and Ross (5) at JPL have suggested a somewhat simpler adjustment based on fine tuning NOCT ratings using temperature and fill factor of modules. Such schemes as those proposed must be simple to be useful, given the variation in annual solar energy input to a device.

All in all, progress in developing standards appears to be painfully slow. This slowness is attributed to a number of factors. The consensus process, which requires that producers, users and unbiased third parties agree, is by itself an arduous negotiation. Often technical information is needed before a proper decision can be made, and there are some who contend that the photovoltaic area is too young to have standards applied. Frequently there is a lack of corporate support for participation in the activity, which requires travel and time that is often regarded as nonproductive.

One of the forces that should be driving the United States to more aggressive standardization activities is the international interest in photovoltaic standards. The IEC is actively considering a number of European standards as candidates for international adoption. The U.S. has been woefully weak in its ability to propose standards for international consideration. As a signatory of the General Agreement on Trade and Tariffs, the U.S. has agreed that standards adopted by international organizations are the medium of international trade. Therefore, our standards must be in harmony with the internationally adopted standards. This becomes important in a number of areas, including trade with developing countries that should be an important market for us.

The timely adoption of consensus performance measurement standards was the subject of a recent study by a JPL task force which interviewed numerous individuals representing manufacturers, users and national laboratories. No report has been issued to date, however preliminary results indicate that there is agreement at the working level of the need for standards, that the problems impeding the development of standards are acknowledged and that there is, a need for continuing government presence in the development of PV measurement standards.

Of particular concern is the fact that support by the U.S. government of photovoltaic standards activities is eroding. Although in the past, the DOE has supported substantial standards-related activities within the National

Laboratories and funded the position of the Secretariat of Technical Committee 82 of the IEC, continued support is in jeopardy. This is in sharp contrast to the position taken by the European governments which support these efforts actively. Since standards exist for the purpose of facilitating commerce both national and international, it was felt that they are a proper and important concern of the government. Recommended ways in which the DOE could enhance the development of standards included: a) encourage participation in standards work, b) continue to provide financial assistance to the societies and groups who organize the standards work, particularly in the international arena, c) make available resources at the national laboratories to answer technical questions that pose a dilemma to the standards committees, and d) provide travel funds so that technically competent people from small businesses and consumer advocates can contribute to the standardization process.

6. Concluding Remarks

The photovoltaic performance measurement practice is subject to confusion because of the absence of relevant voluntary consensus standards. The technology for making measurements is understood; however, the selection of the conditions under which measurements should be made is an impediment. This selection must be made in order to provide a common basis of comparison between modules. It must be made with the understanding that the actual energy produced in any one year will depend upon the geographical location as well as the variation of the energy input from its average. A consensus standard defining the conditions is needed so that the measurements can be made.

7. Acknowledgements

This paper presents the results of one phase of research conducted at the Jet Propulsion Laboratory, California Institute of Technology, and sponsored by the U.S. Department of Energy, through an agreement with the National Aeronautics and Space Administration.

L.D. Runkle is Reliability and Engineering Sciences Deputy Manager, Flat-Plate Solar Array Project, and Supervisor Photovoltaic Operations Group and R.G. Ross, Jr. is Reliability and Engineering Sciences Manager, Flat-Plate Solar Array Project, and Supervisor, Photovoltaic Engineering Group.

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APPENDIX D

LIST OF PERSONS INTERVIEWED

Acurex Solar Corp.

Robert Spencer

ARCO Solar, Inc.

James C. Arnett

Arizona State University

Robert Sanderson

The BDM Corp.

M.G. Semmens
Donald Forrester

DSET Laboratories, Inc.

Gene A. Zerlaut
William Putman

IEEE

Robert J. Klein

Jet Propulsion Laboratory

R. Gil Downing
Robert Mueller
Ronald G. Ross, Jr.

Photowatt International, Inc.

M.C. Keeling

Rogers and Company, Inc.

Raymond Bahm

Solar Energy Research Institute

Gary Nuss
Richard DeBlasio
Steve Hogan
Roland Hulstrom
Paul Longrigg
Carl Osterwald
Carol Riordon

Solavolt International

William Kaszeta
Rusty Schmit

Sandia National Laboratories

Dan Arvizu
Mike Edenburn
Howard Gerwin
David King
James Lee
Benny Rose