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DEVELOPMENT OF PHOTOVOLTAIC ARRAY AND MODULE SAFETY REQUIREMENTS

Flat-Plate Solar Array Project. Engineering Sciences Area. Final Report

June 1982

Work Performed Under Contract No. NAS-7-100-955392

Underwriters Laboratories, Inc.
Melville, New York

U.S. Department of Energy

Solar Energy

DOE/JPL/955392--1

DE82 020735

DOE/JPL/955392-1
(DE82020735)
Distribution Category UC-63b

DEVELOPMENT OF PHOTOVOLTAIC ARRAY AND MODULE SAFETY REQUIREMENTS

JPL CONTRACT NO. 955392

FLAT-PLATE SOLAR ARRAY PROJECT

ENGINEERING SCIENCES AREA

FINAL REPORT

June 1982

The JPL Flat-Plate Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of flat-plate solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE.

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ACKNOWLEDGEMENTS

R. Sugimura of the Jet Propulsion Laboratory was the Technical Manager for this study and R. Ross, Jr. is the Manager of the Engineering Sciences Area of the Flat-Plate Solar Array (FSA) Project for which this study was performed. Their guidance and technical input to this study was deeply appreciated.

The assistance provided by Dr. S. Forman and his associates at MIT/Lincoln Laboratory is acknowledged and appreciated. This assistance, and access to their arrays, allowed field evaluations of proposed protective hardware.

ABSTRACT

Underwriters Laboratories Inc. has conducted a study to identify and develop module safety requirements for photovoltaic module and panel designs and configurations likely to be used in residential, intermediate, and large-scale applications.

The National Electrical Code and Building Codes were reviewed with respect to present provisions which may be considered to affect the design of photovoltaic modules. Limited testing, primarily in the roof fire resistance field was conducted. The generation of engineering safety requirements included a safety workshop which encompassed a broad cross-section of the photovoltaic community. Comments from the workshop resulted in additional studies and further investigations which led to the development of a UL Proposed Standard for Safety - Flat-Plate Photovoltaic Modules and Panels.

Additional work covered the initial investigation of conceptual approaches and temporary deployment, for concept verification purposes, of a differential dc ground-fault detection circuit suitable as a part of a photovoltaic array safety system.

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SUMMARY

Underwriters Laboratories Inc. (UL) has studied future trends in module designs and state-of-the-art photovoltaic modules and panels; and from this has developed concepts concerning acceptable constructions and test performances with the goal minimizing fire and shock hazards. These concepts are reflected in a UL Proposed Standard for Safety - Flat-Plate Photovoltaic Modules and Panels that forms a part of this report. The UL Proposed Standard contains provisions describing items such as insulating materials, current-carrying parts, connection means, accessibility, temperature limits, and dielectric-withstand capability.

Specifics on certain rationales and certain newly conceived test procedures are described.

Simultaneously, ideas concerning installation procedures including the incorporation of accessory components to minimize hazards have been formulated. These ideas have been presented to National Fire Protection Association (NFPA) committees and panels for consideration for incorporation in the National Electrical Code (NEC) (the installation specification). The ideas have also led to the development of safety schemes including preliminary development of necessary hardware such as a differential dc ground-fault detection system for photovoltaic arrays. These safety schemes may be utilized in future specifications for photovoltaic array installations.

Methods of implementation of the Standard, that is, procedures for UL investigations of products (modules and panels), along with the significance of the various types of UL coverage are described.

Evaluations of several modules to the UL Proposed Standard, in both construction aspects, and to certain of the test specifications, particularly roof fire test procedures, were undertaken. For various reasons described, e.g. - inappropriate load connection means and markings, the products are readily identified as unacceptable for Listing. Additional inappropriate items might be noted during the conduct of an actual investigation, with tests, of these products.

Existing UL Standards for Safety which may have a bearing on the construction of photovoltaic modules or panels (if such modules or panels are submitted for UL Listing) are enumerated, with an explanation of how these Standards would be applicable.

1. INTRODUCTION

1.1 General

Research into safety-related proposals for photovoltaic modules has been conducted for the Jet Propulsion Laboratory's (JPL) Flat-Plate Solar Array (FSA) project . In this work, Underwriters Laboratories Inc. (UL) has identified areas of photovoltaic module construction and performance which may compromise safety of both human life and property. Resolution of technology/performance trade-offs have resulted in: the description of acceptable constructions in a UL Proposed Standard for Safety - Photovoltaic Modules and Panels; and guidelines for installation in the form of proposals for revisions to the National Electrical Code (NEC) with the intent of reducing or eliminating the potentials for hazards.

The objective in writing a Standard is to provide guidance to manufacturers concerning features of construction of the product deemed desirable to reduce the risk of a hazard to an acceptable level. Product compliance to the Standard is usually verified by an independent third party. The certification as to compliance of any particular piece of the product may be shown by a mark of the testing agency (third party) affixed to the product.

As a part of the writing of the UL Proposed Standard, evaluations of a representative sampling of Block III modules were conducted.

1.2 Report Format

This report is divided into 7 Sections and 7 Appendices. The Sections reference one or more Appendices, which provide details and additional material.

Section 2 of the Report describes the methods applied by UL in the writing of standards and the interaction between UL, industry, and code-making organizations to complete the standards development process. Also described are the four types of services provided by UL to identify products investigated by and manufactured under its Follow-Up Service. In addition, a brief description of the product submittal process for Listing, the method tentatively selected for coverage of photovoltaic modules and panels, is provided.

Section 3 of the Report describes rationale behind some of the more significant safety requirements proposed for photovoltaic modules and summarizes the highlights of a safety workshop that addressed safety design concepts.

Section 4 of the Report discusses the National Electrical Code (NEC). This discussion includes a description of the NEC, an overview of the present code-making proposal activity relative to photovoltaics and an examination of the sections of the 1981 NEC deemed applicable to photovoltaics.

Section 5 of the Report examines array subsystem grounding by describing benefits of a solidly grounded system and by presenting several grounding scenarios and identifying the possibility of a shock hazard relative to these grounding schemes.

Section 6 of the Report describes basic ground-fault detection concepts as a method of improving photovoltaic array safety.

Section 7 provides summation and recommendations.

2. FUNCTIONS AND OPERATIONS OF UNDERWRITERS LABORATORIES INC.

2.1 General

The following is partially taken from Underwriters Laboratories Inc. Publication "Method of Development, Revision, Implementation, Standards for Safety".

"The principle business of Underwriters Laboratories Inc. (UL) is the evaluation of electrical and mechanical products, building materials, construction systems, fire protection equipment, and marine products, to determine that their design provides for reduction of the risk of injury to persons and damage to property incident to their use; to identify such products correctly through a system of marking that permits their recognition by consumers, authorities having jurisdiction, and others; and to establish, through contractual arrangements with manufacturers, UL's audit of production for conformance of the products with applicable requirements. UL's Standards for Safety play an important part in UL's process of evaluation, identification, and audit."

Items whose construction are complete as they leave the factory, and items essentially completed at the factory, but requiring final assembly at the installation site because of size, mounting, or other considerations, may be judged for safety-related construction and performance features to one or more of the Standards for Safety of UL. Where any field assembly is necessary, instructions are provided on or with the product.

UL requirements cover the construction and performance of the product, permitting it to be installed per a certain method, while the accepted procedures for installations of the product (i.e. - the use of the product) are described in the National Electrical Code (NEC), or one of the model building codes.

UL's standards are written and revised to insure that the products covered can be used in conformance with the NEC and building codes if applicable. When revisions to the NEC occur which necessitate product changes, UL requirements are revised accordingly.

2.2 Standards Development

UL's evaluation of a new product usually precedes the establishment of a formalized (Published) product safety standard. When the first submittal of a new product is received, UL's engineers draw upon laboratory and field experience and upon appropriate safety requirements in existing standards of UL and other organizations, to devise and apply criteria suitable for judging the product.

In developing the standard, UL works with an Industry Advisory Conference (IAC) or Group (IAG), comprised of interested manufacturers and possibly representatives of other groups such as utilities, material and component suppliers, and government bodies.

This IAC or IAG works with UL engineers and is responsible for screening and reviewing the initial draft. In most cases the initial draft of requirements proposed by UL engineers is based on (1) requirements that UL has applied in evaluating products previously investigated by UL in the category, (2) reported field experience with the product, (3) a survey of known existing standards in the product category, and (4) compatibility with applicable nationally-recognized installation and use codes.

Unlike those of most other standards-developing organizations, UL standards and requirements represent the basis upon which UL's registered marking may be affixed to complying products by subscribers to UL's services. Accordingly, UL must be careful that its standards provide a reduction of risk acceptable for the using public.

2.3 American National Standards Institute Approval

UL desires that each of its Standards for Safety be approved as an American National Standard, and to this end so submits its standards. In seeking American National Standard (ANSI) status, UL may choose ANSI's canvass method; or it may choose ANSI's accredited organization method. Both methods afford due process to all those who will be affected by the standard; and both methods develop evidence of a consensus. Using either method, UL publicly announces its intent to develop a standard.

UL's standards development activities are open to participation by persons from the many diverse interests that may be involved, and by the general public, not only when the accredited organization method is followed, but also when the more often used canvass method is employed.

If the canvass method is to be used, UL announces its intent to develop the standard by sending a press release, including some details about the scope of the standard, to publications likely to be seen by those having substantial interest in the subject of the standard. These publications include ANSI's Standards Action, the Consumer Product Safety Guide of the Commerce Clearing House, the Product Safety and Liability Reporter of the Bureau of National Affairs, trade journals, government publications such as the Federal Register, and other publications as appropriate. The press release invites those interested to contact UL and volunteer to participate in the work. This work is generally done through correspondence. The names and addresses of those who respond are placed on a mailing list for use when a draft of the standard is available for review and comment.

For the canvass method, a draft of the proposed standard is first prepared by UL for discussion with the IAC or IAG. Following this, the draft, which will be modified if necessary or desirable, is circulated for review and comment to the appropriate Engineering Council(s) of UL, to concerned government agencies not represented on such Council(s), to all manufacturers who subscribe to UL's service in the product category, to representatives of nonsubscriber manufacturers who have expressed an interest in the standard, and to those on UL's open forum list. Where a draft covers a product used by consumers, it will be circulated to the Consumer Advisory Council of UL, to the Conference of Technical Users of Consumer Products of UL, or to both. If the draft covers a product used by industrial or commercial groups, it is circulated to the appropriate Commercial and Industrial Equipment Users Conference of UL, to the Conference of Technical Users of Consumer Products of UL, or to both. The draft is also sent to all persons who expressed a desire to participate by responding to the public announcement that the standards development project will be undertaken.

UL's authorization to utilize ANSI's Accredited Organization Method in developing ANSI approved standards was granted by ANSI on the basis of UL's procedures in its standards development process. These procedures provide for participation, review and comment by members of industry, government insurance groups, consumers, other interested parties and the general public in the process.

For this accredited organization method, UL issues a notice of intent to develop a product safety standard. In this notice, UL requests (a) comments on its intent, and (b) an indication of a desire to participate in the standards project. The notice is sent to:

A. Organizations known to be concerned with the Scope of the proposed standard. ANSI is asked to assist UL in developing a list of such organizations.

B. Members of the involved UL "Open Forum".

C. UL subscribers in the product category covered by the Scope of the proposed standard.

D. Concerned government agencies that are not already represented on the involved UL Engineering Council(s).

E. Known representatives of nonsubscriber manufacturers and national interests substantially concerned with the Scope of the proposed standard.

F. Involved trade associations, if not already included in the list developed with the aid of ANSI.

G. The appropriate UL Engineering Council or Councils.

H. The Conference of Technical Users of Consumer Products, if appropriate.

I. The Consumer Advisory Council of UL, if a consumer product is the subject of the proposed standard.

J. The appropriate Commercial and Industrial Equipment Users Conference of UL, if a product used by industrial or commercial groups is the subject of the proposed standard.

K. The American National Standards Institute.

An initial draft of the proposed standard is submitted to the UL-Technical Advisory Group, which group is charged with seeing that the document (a) provides a proper reduction of risks, (b) will allow the product to perform in the intended manner, and (c) will allow the product to be installed in accordance with a nationally recognized installation code.

If passed by the Technical Advisory Group, the document is sent on to the UL-Product Safety Standard Committee which prepares a summary report. This summary report includes a disposition of all negative comments, and the reasons for nonacceptance of any such comments. The summary report includes a new draft of the standard, and is sent to:

A. All members of the Technical Advisory Group and Product Safety Standard Committee.

B. All UL subscribers known to be affected by the standard.

C. Others known to have an interest.

Additional reports and revised drafts are prepared and a final report and draft submitted to the UL-Standards Review Council. Upon approval by the Standards Review Council, the document is submitted to ANSI's Board of Standards Review as a proposed American National Standard. The submittal includes a record of the results of the voting of the various groups to which the standard was submitted for review, the comments received, and information as to disposal of the comments, including those comments that were accepted and those that could not be resolved. Upon notification that the product safety standard is recognized as an American National Standard, it is published by UL and ANSI, and made available to all interested parties.

2.4 Issuance as UL Standard

After receipt of comments and suggestions from all these sources, UL makes such modifications or revisions in the draft as appear to be proper, necessary, or desirable. If technical changes are involved, a revised draft is prepared and is then submitted to all who have participated in the development of the standard, for additional comments and suggestions. One or more additional meetings with the IAC or IAG may be required at this point.

Meetings with an Ad-Hoc Standards Development Committee may be called as necessary to resolve problems that may arise during standards development. An Ad-Hoc Standards Development Committee may include concerned interests who have not otherwise participated. After UL has given consideration to all comments and made any necessary changes, the draft is issued as an official published Standard for Safety of UL. The published Standard is made available to all manufacturers, inspection authorities, insurance interests, and others who are concerned with the subject matter of the standard.

2.5 Particulars for Photovoltaic Module Standard

In the case of photovoltaics, the above scenario has not been precisely followed. An "Interim Standard for Safety: Flat-Plate Photovoltaic Modules and Panels" (JPL 5101-164) was developed and presented to the photovoltaic community before any product submittal was made.

An impetus for the development of this "Interim Standard", was provided by UL's work under contract to JPL. Since the term "Interim Standard" is not used by or applied to UL Standards, the JPL document constituted a tentative draft set of requirements by which UL would have, at that time, judged any products so covered. Thus this document might be thought of as "... UL's experience ..." in this field. (Further refinements of this documents have resulted in a new document.)

This "Interim Standard", drafted January 15, 1981 and revised February 20, 1981 was the result of a safety workshop at which input was received from photovoltaic module manufacturers, system installers, architect/engineers, utilities, component suppliers, private testing organizations, universities, as well as government laboratories. Further refinements of this document resulted in a UL Proposed Standard for Safety - Flat-Plate Photovoltaic Modules and Panels, included as Appendix A of this report. Industry input and comment was and continues to be sought, particularly, for sections of the UL Proposed Standard which may be incomplete or lack detail.

Development of a UL Standard generally progresses together with submittals of the product that it covers. Thus, the greater the number of investigations, the more rapid will be the development of the standard.

UL has taken the initial step in the standards development process, by inviting representatives from module manufacturers and others to serve on an IAG. All have accepted the invitation. The group convened on June 29 and 30, 1982 to discuss the UL Proposed Standard which had been distributed to the members.

A report of this meeting, as well as a copy of the revised UL Proposed Standard that resulted from the meeting discussion will be forwarded to IAG members, other photovoltaic module and panel manufacturers known to UL, and others known to have an interest in the topic, such as government laboratories. Additional copies will be available on request. The calling of additional meetings, the issuance of a final standard and the like, will depend upon the comments received, and the revisions necessary to resolve these comments.

2.6 National Electrical Code and Building Code Interface

UL personnel work on and with the NEC panels and committees, and with model building code groups providing ideas to these groups where appropriate and collecting ideas that may be needed for developing or revising product requirements (standards). However, UL does not control the conduct or output of the NEC Code-Making Panels. An Ad-Hoc Subcommittee on Photovoltaics, formed under the aegis of the NEC Correlating Committee, has developed proposals which were assigned to Code-Making Panel 3, to be a part of the 1984 edition of the NEC. Another NEC Ad-Hoc Subcommittee on "Cogeneration" (sic) (i.e. - Utility Interactive Systems) has developed proposals, which were assigned to Code-Making Panel 15, for NEC articles that address the interactive aspect of photovoltaic installations. UL has worked under contract to the Solar Energy Research Institute (Subcontract XX-1-9429-1) to provide material for consideration by the Ad-Hoc Subcommittee on Photovoltaics.

Code-making bodies generally write their document(s) independently of any standards writing body, it being the responsibility of the standards writing body to correlate its documents with the appropriate Code. This correlation is necessary to ensure that the product is built so that it can be installed in accordance with the Code. UL Standards are written and updated, as necessary, to provide this correlation.

2.7 Methods of Investigation and Coverage

UL offers four types of services to identify products investigated by it and manufactured under its Follow-Up Service. These are Listing, Component Recognition, Classification, and Certification.

Listing Service (for Listed products) is appropriate for items which comply with standards that are intended to eliminate or reduce to an acceptable degree, all foreseeable hazards. Listed products generally serve in a direct field-installed capability, e.g. - television receivers, radio receivers, fuses, hair dryers. Listed products are identified by the symbol UL in a circle, Figure 2.1.

A "regular form" Listing Report would be issued in most cases, and would describe only the product, not the method of installation. The presumption is that the method(s) of product use and installation are described elsewhere, such as in the National Electrical Code.

FIGURE 2.1
LISTING MARK

Component Recognition (for Recognized products) is appropriate for items which are incomplete in construction, or deficient in performance, so that they might not comply with the Standard unless used with additional apparatus. Examples are: a radio chassis, which is not protected against physical abuse or does not protect the user against contact with electrically hazardous parts; and a motor whose load is unknown. Component Recognition is also appropriate for items not suited for direct installation, or items that are not, per the NEC, contemplated for field installation. An example is a thermal protector for motors, which would be factory installed in the motor to be protected.

Recognized products may carry the symbol of a merged mirror image UR (Figure 2.2), but are primarily identified by inclusion of their model, catalog, etc. number under the appropriate category name and manufacturer in the UL Recognized Component Directory.

FIGURE 2.2
RECOGNIZED COMPONENT MARK

Classification (Classified products) covers products which are evaluated for certain hazard aspects only. Examples are X-Ray equipment (X-ray emissions are not evaluated by UL) and automatic telephone dialers and message centers (emergency signaling functions are not evaluated by UL). Classified products carry a statement "Classified by Underwriters Laboratories Inc. with respect to (nature of hazard) only". (Necessary rating or classification.)

Certificate Service is appropriate for field installed systems or where UL determines it necessary to identify sites. Such installations are identified by a certificate issued for each site. Products under Certificate Service include central station burglar alarm systems and hold-up alarm systems.

All products Listed, Recognized, etc. by UL are subject to follow-up. Follow-up involves a comparison between products currently in production to the product originally tested. Follow-up may be an examination only, as in the case of power transformers; examination and testing on the scale of a complete original investigation, as in the case of branch-circuit fuses; or anything in between.

To address all foreseeable electrical hazards and most fire hazards, UL has tentatively assigned Listing as the proper method for coverage of photovoltaic modules and panels. Roof fire resistance, the other major hazard category, would be addressed at the manufacturer's option, in recognition of the fact that roof rating requirements vary from community to community between Class A and nothing.

2.8 Installation Acceptability

For Listed electrical products whose installation is described in the NEC (e.g. - fuses, circuit breakers), UL only disseminates information relative to the manufacturer's name, product designation and, in some cases, rating. The acceptability of the installation is determined by, for example, a municipal inspector using the NEC or applicable municipal code.

Where the NEC does not address the product or use involved, UL requires that information be provided so that the inspector may properly oversee the product installation. This can be accomplished in either of two ways, and may be necessary for a Listing of the photovoltaic array installation until 1984, when the NEC is expected to cover such.

One method may involve coverage under Certificate Service, and an inspection of each installation by a local UL inspector. In the inspection, the UL Listing Report is used as a guide in determining acceptability of the system. The drawback in such a procedure is the added expense for each UL inspection.

Another method is the UL "Listing by Report" procedure, in which the report would describe the information essential for the proper installation and use of the system. This assumes that essential information cannot be adequately described otherwise, for example, by a marking on the product. Although the Report is a UL document, input from the manufacturer is solicited and accepted.

If a "Listing by Report" is established, and a recognized installation standard is subsequently established, the Listing will be changed to regular form.

A "Listing by Report" is not permitted to be used to circumvent an established installation code.

A "Listing by Report" identifies and describes the complete product or complete system, provides a list of components which comprise the system, and gives instructions for the proper installation. It does not describe, in detail, the construction features of the complete product or the components other than those features which are involved in the assembly of the complete product or system.

The Listee (the entity in whose name the Listing is maintained) must agree to maintain a stock of the reports, including any and all revised pages or illustrations issued by UL. The current stocks are dated to correspond with that shown in the List and on the Listing Mark. Reports are to be made available free of charge, to anyone requesting a copy.

The parts of a system covered by "Listing by Report" are not permitted to carry a UL in a circle symbol. Rather, the following is to be affixed to the major component parts:

> "Underwriters Laboratories Listed (product name and model number) when installed and used in accordance with UL Report, reference number _____________, dated _____________."

In either case, parts of the photovoltaic system (e.g. - the modules or panels) are subject to UL inspection at their point of manufacture.

2.9 Engineering Councils

Certain circumstances may warrant a Council Report. In this situation, UL proposes to List a product and asks for comment from one or more of the UL Councils, and their concurrence to the Listing. Listing is not established unless all outstanding comments are resolved. It is expected that the first proposal for the Listing of a photovoltaic module or panel will be via a Council Report. Both the Electrical Council and the Fire Council are likely to be involved with photovoltaic modules.

2.10 Fact-Finding Work

UL also undertakes "Fact-Finding" investigations for manufacturers, trade associations, government agencies, and others to develop product or system information and data for use in seeking recognition or an amendment of a nationally recognized installation code or standard. In this activity, UL, relying upon both in-house and outside research data, develops basic information, properties, and characteristics of materials, products, and systems as they relate to safety to life or property. A report is issued upon completion of the investigation. No conclusions are published, no follow-up inspection is made, nor is use of the UL Listing Mark authorized.

This service may be used by a manufacturer of photovoltaic system components; for example, wiring systems, to demonstrate the appropriateness of the product for the service.

2.11 Product Submittal Details

An individual or organization, desiring to secure a product Listing or to have UL undertake a Fact-Finding investigation, may address Underwriters Laboratories Inc., giving a description of the product or system in order that its character, purpose, size, rating, and other features may be understood. Such information makes it possible to determine in a general way the probable nature and extent of the necessary examination and tests.

An application form is sent to the potential submitter specifying a preliminary deposit, the maximum cost of the engineering services, the work to be performed under the application, and in the case of submittals for Listing that Follow-Up Service will be established if the product is found eligible for Listing.

For product submittals, at the submitter's option, the tests proposed will be discussed with him either by correspondence or interview. The submitter's representative may witness any tests.

Fact-Finding investigations require a detailed discussion with the applicant concerning the work to be undertaken, and the tests to be conducted.

Listings or Classifications which result from UL investigations are promulgated in UL's publications: Electrical Construction Materials Directory, Electrical Appliance and Utilization Directory, etc. Information concerning Listing of photovoltaic modules and panels, when effected, would be included in one of these lists. These lists are published yearly, with intervening supplements.

The costs of any UL investigation are borne by the submitter. Further detail is contained in the UL publication "Testing for Public Safety".

3. MODULE SAFETY

3.1 General

As with other products, it is improbable that all conceivable hazards associated with the operation and maintenance of photovoltaic modules and panels and an array system can be avoided, if the system is to retain its utility. A reasonable approach, followed by UL in the formulation of engineering safety requirements for photovoltaic modules and panels, is the development of requirements that photovoltaic modules and panels include components and/or have construction features to reduce the risk of hazards associated with shock, fire, and casualty during installation, operation and maintenance, and to a degree, shipping.

3.2 Module Construction, New Standard for Photovoltaic Modules and Panels

Research to establish a set of safety requirements for photovoltaic modules began with laboratory examinations to determine the degree to which the modules, as constructed, comply with general safety criteria. A listing of the modules examined is provided in Appendix B, entitled "Module Evaluation List". Results from this examination have identified the need to research areas unique to photovoltaics both at the module level, for example in the form of a module surface cut tester, and at the array subsystem level in the form of a ground fault detector and response device.

The identification of overall safety concerns from existing UL Standards and the results of laboratory examination of photovoltaic modules, coupled with the examination of current installation methods and application practices, led to the formulation of safety-related photovoltaic module design requirements. These requirements were first documented in an Interim Standard for Safety; Flat-Plate Photovoltaic Modules and Panels, JPL 5101-164, February 20, 1981.

This Interim Standard, like UL product safety standards, is divided into two basic parts. One part, Construction Requirements, covers features whose conformance can be judged by examination, including measurements of physical dimensions. The other part describes test procedures and the acceptance criteria.

The Interim Standard was the basis for a safety workshop held in February, 1981. Forty-eight organizations were represented by eighty-nine persons which included photovoltaic module manufacturers, system installers, architect-engineers, utilities, component suppliers, private testing organizations, universities, and government laboratories. The primary objective of the workshop was to identify appropriate safety design concepts and to investigate the rationale behind certain safety-related construction practices. The Interim Standard (JPL 5101-164) has been superseded by a UL Proposed Standard for Safety, Flat-Plate Photovoltaic Modules and Panels that forms Appendix A of this report. It should be noted that as a result of the IAG meeting modifications to the UL Proposed Standard, Appendix A will be made. The following paragraphs highlight portions of the workshop and provide background for some of the requirements which are contained in the UL Proposed Standard.

Significant areas addressed at the workshop included:

1. Electrical hazards
   - (a) Exposed live parts
   - (b) Inadequate or deteriorated insulation including effects of weather (including thermal) stress
   - (c) Arcing paths including conductive paths established by wetting of parts.

2. Fire Hazard
   - (a) Internally caused, for example, from deteriorated insulation and arcing parts
   - (b) Externally caused, for example, burning brands alighting on the structure

3. Casualty Hazards
   - (a) Inadequate strength
   - (b) Deterioration as a result of corrosion
   - (c) Physical abuse and breakage
   - (d) Sharp edges
   - (e) Burn hazards from high temperature accessible parts.

3.3 Rationales for Key Module Safety Requirements

A part of the background for the establishment of safety requirements included an examination of the then state-of-the-art modules to ascertain how their construction and performance would measure up to acceptable levels of safety. The requirements cover flat-plate photovoltaic modules and panels intended for use in systems with a maximum voltage of 1000 volts.

Comments following concern items of construction not in accord with the requirements of the UL Proposed Standard. It is to be inferred that items of construction of the evaluated modules not commented on were judged to be in compliance with the provisions of the UL Proposed Standard.

3.3.1 Connection Means and Marking

Results of module examination have indicated the need to identify connection means and marking requirements which are generally accepted as good engineering practice.

3.3.1.1 Connection Means

Photovoltaic modules should be provided with terminals (screw or plug type) or leads, suitable for field-wiring connection in accordance with the provisions of the National Electrical Code. The terminals or leads should be properly identified as to polarity. The following comments are made on the screw terminals and their accommodating means of the several modules so equipped.

Where used to accommodate field-wiring, wire-binding screws and their accommodating means should have sufficient strength to withstand expected tightening torques. It is expected that this may be met in part if the module or panel binding screw terminals comply with the following (from paragraph 9.7 of the UL Proposed Standard):

(a) A threaded screw or stud shall be of nonferrous metal appropriate for the application, shall not have more than 32 threads per inch, and shall not be smaller than No. 8 for accommodating No. 10 or No. 12 AWG (5.3 and 3.3 mm^2 respectively) wire and not smaller than No. 6 for accommodating No. 14 AWG (2.1 mm^2) and smaller wire. A wire-binding screw or stud-and-nut terminal shall be provided with upturned lugs, a cupped washer, a barrier or other equivalent means to retain the wire in position even though the screw or nut becomes slightly loose. The head of a wire-binding screw for accommodating No. 12 AWG or smaller wire shall have a minimum diameter of 0.275 inch (7.0 mm) and that of a screw for accommodating No. 10 AWG wire shall have a minimum diameter of 0.327 inch (8.3 mm).

(b) A tapped terminal plate shall be of nonferrous metal, shall not have less than two full screw threads, and shall be of metal not less than 0.050 inch (1.27 mm) thick for accommodating No. 10 or No. 12 AWG (5.3 and 3.3 mm^2 respectively) wire and not less than 0.030 inch (0.76 mm) thick for accommodating a No. 14 AWG (2.1 mm^2) or smaller wire. Screw threads provided by extruding a hole are acceptable if the thickness of the unextruded metal is not less than the pitch of the screw thread.

One module includes a wire binding screw type terminal block mounted within a weatherproof outlet box. As the screws of the terminal block are considered too small (No. 4-36), the terminal block would not be acceptable.

The practice of mounting the terminal block to the interior surface of the outlet box by using what appears to be silicone rubber adhesive is questionable and adequate mechanical security of this mounting method would have to be demonstrated. In addition, one dimension of this box appears to have been reduced by cutting down the edges of the open face. Normally, modifying such a product might render it unfit for the application; for example, its water-tight integrity may be compromised and/or its volume reduced to below minimum acceptable standards. However, in this case, it appears not to be a problem.

Several modules include terminals on open insulating blocks. None of these modules had upturned lugs, a cupped washer, or a barrier or other equivalent means to retain the wire should the screw become slightly loose. Some did have lockwashers. Lockwashers are not an acceptable substitute.

Terminals should also be protected from wetting and insect nesting.

The terminals of these modules would also be unacceptable because of: (a) head size, 0.239-0.266 inch diameter head measured vs 0.275 inch diameter minimum proposed required; (b) lack of upturned ears or the equivalent to retain the wire with the screw slightly loose; and (c) lack of facility to properly accommodate a flat-blade screwdriver. Screw heads intended to accept Philips type drivers only would not be acceptable, but a head intended to accept both a flat-blade and Philips type driver would be acceptable.

Accessible (e.g. - open) terminals would be unacceptable on modules rated 30 volts or more, system voltage. Field applied "guarding" of terminals is not presently envisioned as an acceptable alternative. Reference may be made to Section 15, paragraph 15.1 of the UL Proposed Standard.

The plug type connector on some of the modules would be unacceptable per the UL Proposed Standard and the proposed provisions for the NEC, since they are not Listed or Component Recognized for such use. Any investigation of the connectors with Listing or Component Recognition as the goal would likely include connector temperature measurements at rated current, and environmental conditioning of materials. The connectors are unacceptable in at least the fact that they are not of the latching or locking type (proposed NEC provision).

Although each of the samples examined included either a screw terminal or a plug type connector, the use of leads is proposed an an acceptable means of connection. Reference may be made to paragraphs 9.3, 9.4, 9.6, and 9.10 of the UL Proposed Standard, see Appendix A.

Dedicated grounding terminals would be required unless modules or panels had no exposed dead-metal parts.

3.3.1.2 Marking

Each module was examined with respect to terminal identification and other markings. Some modules were provided with a grounding terminal, but none had been marked indicating the intended use. Each should be marked "G", "GR", "GROUND", or "GROUNDING", or the like or have a green colored part that is not readily removable. The ground symbol of Fig. 3.1 would not be acceptable.

FIGURE 3.1
UNACCEPTABLE GROUND SYMBOL

The module with wiring terminals contained in an outlet box did not have marking indicating terminal polarity. Coloring of internal wire insulation up to the terminal block, as used in this product, would not be an acceptable method of terminal identification.

Other modules did not carry terminal identification. This would be unacceptable under the provisions of the proposed requirements.

The module with terminals in the outlet box was not marked relative to the volume of the wiring compartment (outlet box). This is proposed as a requirement. Reference may be made to paragraph 45.11 of the UL Proposed Standard. This marking is intended to assist a local inspector in making the determination of whether an installation is in compliance with the provisions of Section 370-1 of the NEC.

None of the modules were marked with a catalog number or the equivalent, an electrical rating, the date of manufacture (in a plainly identifiable manner), the types, size, and number of conductors which may be connected to the terminals, the minimum acceptable bypass diode configuration, the maximum acceptable series fuse, and a roof fire rating. These markings would be required under the provisions of the UL Proposed Standard. Specifics on proposed marking requirements are included in Section 45 of the UL Proposed Standard (see Appendix A).

3.3.2 Electrical Hazards

3.3.2.1 Accessibility

Accessibility of electrically hazardous parts would generally be judged by means of the UL articulate accessibility probe. The probe was developed as the result of research involving 100 each of men, women and children; and measuring maximum finger penetration through holes and slots representing openings in enclosures that might give access to potentially hazardous parts. Appendix C of this report entitled "Statistical Development of an Accessibility Probe" provides the analysis supporting the proportions and dimensions of the probe.

Although accessibility to hazardous parts is generally precluded, the UL Proposed Standard recognizes that it will likely be necessary to allow access to hazardous parts during installation and assumes that the installer will take adequate and proper safety measures.

3.3.2.2 Shock Hazard Levels

The UL Proposed Standard presently defines a hazardous part (for electrical shock purposes) as one with a potential of 30 volts or more with respect to any other accessible part or earth ground, and capable of delivering a current between these parts that exceeds the values of Table 3.1. The 30 volt figure is consistent with that of Article 725 of the National Electrical Code. The proposed maximum current values of 0.5 mA ac and 1 mA dc are based on a reaction or startle level. Specifics are included in Section 15, paragraph 15.4, and Section 21 of the UL Proposed Standard, see Appendix A.

3.3.2.3 Leakage Current Limits

For parts liable to be connected together, such as frames of modules, a limit of 10 microamperes per module is proposed. This assumes that the collective currents from a number of modules will be present on structural metal by way of metal-to-metal mounting. This collective leakage current may be a shock hazard if the frame grounding is lost.

'Large' standing leakage currents that may be caused by the installed array components with large individual leakage currents may inhibit the implementation of proper ground-fault systems by requiring that a ground fault detector in the circuit have a low sensitivity (i.e., a high value trip level). Thus, module leakage current should be limited to deter nuisance tripping of ground-fault systems when they are used for personnel protection.

TABLE 3.1
ALLOWABLE LEAKAGE CURRENT

Surface or Part from Which Measurement is Made	Maximum Current ac(rms)	dc
Accessible conductive frame, pan, or the like	10 μA	10 μA
Accessible circuit parts	0.5 mA	1 mA
Conductive foil over accessible insulating surfaces	0.5 mA	1 mA

For example, an assumed array containing 6000 modules would permit a ground-fault sensor with a 30 milliampere sensitivity if the modules' frame leakage currents were within the 10 microampere limit. This is so because although the modules would be tested for leakage current at the system voltage, collectively they will be used at an average of one-half of this value. That is, one-half of the modules will operate (to ground reference) in a stepped fashion above one-half of the system voltage while the other half of the modules will operate, in a stepped fashion, below one-half of the system voltage.

Since ground fault systems are not covered in the proposed NEC article, and because near-term photovoltaic arrays are not envisioned to contain 6000 modules, consideration might be given to increasing the allowable module frame leakage current limit. A decision will include consideration of the margin presently afforded against false tripping of the ground fault device.

For modules without conductive frames, the 10 microampere limit is not applied.

AC current limits would be applied because ac voltages may be on the modules and panels from operation of the power conditioning unit. The level of the ac voltage would be dependent upon the power conditioning unit circuit configuration, the nature of the utility interface, and the filtering between the power conditioning unit and the array. The level of ac leakage current would be proportional to the ac voltage and the module circuit-frame capacitance. Modules with large foil areas adjacent to cells may be expected to have relatively high ac leakage currents. Data from measurements from photovoltaic arrays at the Southwest Residential Experimental Station (SW-RES) indicates that ac voltages in the order of 4 volts are present on arrays interactive with 120/240 volt center grounded ac systems. Arrays with transformerless power conditioning units interactive with 120 volt one-side grounded ac systems should have a considerably greater ac voltage on the modules. In this case the ac voltage level may equal the array dc voltage level.

Each of the examined modules was individually tested for leakage current in the "as received" condition by connecting all current-carrying parts to the ungrounded side of the 120 volt, ac, rms and 120 volt dc, grounded sources in turn, and measuring current from (a) module frame and, (b) foil over insulating surfaces to the grounded conductor. (No exposed circuit parts other than the wiring terminals are provided on any of these modules.) (The 120 volt sources were used for convenience even though they may not represent any actual array voltage values.) Since module capacitance and resistance is, in general, a constant (not dependent upon applied voltage), leakage currents at other levels are calculable by direct proportioning. The foil was a 10 by 13 inch piece, placed over and then where possible, behind the cells of the module. The results of these tests are as follows:

All dc measurements showed a zero reading on a meter of 0.3 milliampere full scale, 0.005 milliampere smallest division.

All ac measurements on modules with glass encapsulant, and frame measurements on modules with silicone rubber encapsulants showed a zero reading on a meter of 0.3 milliampere full scale, 0.005 milliampere smallest division.

For the silicone rubber encapsulated modules, an ac current of 0.3 milliampere was measured between the foil over the cells and the grounded circuit conductor.

None of these modules were constructed with any conductive foil that might result in 'high' ac leakage currents. However, some did have metal over the entire rear surface.

As measured data is accumulated it may be possible to eliminate certain aspects of the leakage current measurement test procedure, such as measurements from foil applied over glass of certain minimum thickness.

3.3.2.4 Dielectric Voltage Withstand Requirements

The historically accepted formula of 2 x V system + 1000 volts and an arbitrarily assumed dc system voltage of 1500 volts was used to arrive at a 4000 volt test level. Each of the modules was subjected to this voltage potential by application of the 4000 volts between all parts of the module's circuit and (a) the metal frame and (b) metal foil over insulating parts. The applied voltage was started at zero and gradually increased toward 4000 volts and, unless breakdown occurred, held at the 4000 volt level for two minutes. The two minute duration is less than the 5 minutes presently being considered in the UL Proposed Standard.

Application of the dielectric test voltage to one of the modules resulted in an internal breakdown in the module. Specifically, the breakdown was between live parts and the metal backing (and frame) approximately 20 seconds after the voltage had reached the 4000 volt level. Application of the dielectric test voltage to another module resulted in a breakdown at 2500 volts, between live parts and the metal backing (and frame). The dielectric tests on the other modules did not result in any insulation failures (breakdowns) or arc-overs.

The modules were examined for: (a) polymeric materials used in compression where the creep of the material may reduce the insulation level to less than the required value; and (b) inadequate spacings due to cut or torn backing material.

Although one module included a frame crimped over live circuit parts, in this particular case, material flow did not appear to be a problem. No module appeared to have a spacing deficiency due to cut or torn foil backing.

No ac dielectric withstand testing was conducted on the samples. Subsequent examinations of other modules however have been used to verify ability to pass an ac plus dc dielectric voltage withstand test. This test procedure is believed necessary to represent cases where ac from a power conditioning unit appears on the modules.

3.3.3 Casualty Hazards

Modules should be capable of withstanding expected physical abuses without the creation of an electrical hazard. This is addressed in part by tests, such as: penetration of the encapsulant from a sharp device, impact from a steel ball and hail, and static loading. Under these conditions shards shall not be produced, nor shall a hazardous condition be created.

The materials which serve as the barrier against user contact with live parts of the cell and innerconnects must continue to function as a barrier following the application of physical, chemical, and ultraviolet test agents.

Examination of the silicone rubber superstrate of three of the modules left some doubt as to the ability of the modules to withstand puncture and cut-through from sharp edge conductive parts. In addition, tear, delamination and weardown from abrasion (e.g. - from sand being blown around, etc.) of the silicone rubber encapsulant are of concern.

To judge the encapsulant's performance in these regards, the module would likely be subjected to the application of a sharp edge cutting tool drawn across the surface and to the application of a force applied with a small (approximately 1/8 inch diameter) rounded end rod. For the cutting tool, the sharp edge would be specified in terms of (a) angle between the faces, (b) maximum radius of curvature at the tip and (c) possibly, radius of curvature of the blade. The cutting edge would be maintained on the module for a specified period of time and then pulled at a specified uniform rate parallel to the surface of and across the module. Neither the rod nor blade should contact electrically hazardous parts of the module, nor should they otherwise render hazardous parts accessible.

For example, penetration of the surface (front or rear) can expose the user to a shock hazard. Examination of the literature on the subject of cut and penetration tests for elastomers, did not reveal any standard test(s) considered applicable for evaluating photovoltaic module encapsulants. As a result, an encapsulant cut test was devised which subjects the module to a 2 pound-force from the point of a blade drawn across the module surface. These considerations form the basis for the requirements and procedures found in the UL Proposed Standard. Additional details on the development of a cut tester are contained in Appendix D, entitled "Conceptional Development of Cut Tester".

3.3.4 Roof Material Fire Hazards

Several model building codes have provisions calling for "rated" roof coverings on certain structures. A "rated" roof covering is one that has certain fire resistant characteristics. These characteristics are determined according to the procedure described in UL Standard 790, "Tests For Fire Resistance of Roof Covering Materials". Three classes are described: Class A, effective against severe fire exposure; Class B, effective against moderate fire exposure; and Class C, effective against light fire exposure.

In determining a rating, a relatively large piece of the fully equipped roof structure including supports, is used for tests. An air current which flows uniformly over the top surface of the roof covering at 12 ± 1/2 miles per hour simulating a wind is applied.

The Burning-Brand Test is intended to simulate burning material alighting on a roof. This is a high likelihood occurrence in certain areas such as the mountain fire districts of Los Angeles, California, where high winds can carry brands from brush and forest fires considerable distances.

The Spread-of-Flame Test is intended to simulate flames lapping on the roof. Such flames might be generated by the burning of an adjacent structure or by the burning of debris inside the structure.

In general, during and after the Burning-Brand and Spread-of-Flame Tests, no portion of the roof covering material shall have blown or fallen from the test deck in the form of flaming or glowing brands or particles, and the roof deck shall not be exposed by breaking, sliding, or cracking or warping of the roof covering.

Although one set of particulars is presented in the UL Proposed Standard, the method of test for both the spread-of-flame and burning-brands tests has since been revised. Specifically, for the spread-of-flame test, there is to be no application of the test flame between the modules and the roof deck. For the burning-brand test, a brand of size equal to the rating is to be applied to the module.

A module or panel intended for stand-off, rack, or direct mounting in combination with a prescribed roof, and a module intended for mounting as part of the roof covering itself, shall comply with the requirements for Class A, B or C roof covering if it is indicated or implied as being fire rated. For the combination situation, this rating need not be coincident with the basic roof covering material rating. The fire resistance shall be determined by the test procedures identified in Tests for Fire Resistance of Roof Covering Materials, UL 790, as modified by Section 31 of the UL Proposed Standard (to be revised).

3.3.4.1 Results of Exploratory Testing

The performance of roofs equipped with photovoltaic arrays was evaluated by conducting laboratory burning-brands and spread-of-flame tests. These tests were exploratory in nature and were intended to gain information on how, generically, modules and panels affect the fire resistance performance of a roof.

Two series of tests have been conducted on modules from several manufacturers. The first series of tests were conducted for stand-off designs in which the modules were mounted four (4) inches above a Class A shingle roof section. In each case four modules were mounted in an aluminum frame to form a panel.

The conclusion reached from the first series of tests is that acceptable performance to Class A burning-brands requirements is attainable for stand-off modules. As the spread-of-flames test was conducted under an obsolete procedure, (the flame was applied between the stand-off array and the shingle decking), results of this tests are not geramane. Per the latest procedure the flame is to be applied only to the top of the array. Details of this series of tests are in Appendix E, entitled "Results of Tests for Fire Resistance of Roof Covering Materials - 1980."

The second series of tests were conducted for a direct mount (shingle) design attached to a plywood deck, and an integral mount design attached directly to simulated rafters. The insufficient number of tests, and the improper construction of the deck accommodating the shingle modules did not allow any specific conclusion which may show acceptance of the module for any rating (Class A, Class B, or Class C).

The intent of the tests conducted on these shingle modules was a demonstration of an acceptable performance to Class A tests, and one sample did shown an acceptable result under the Spread-of-Flame Test. However, the result of one Class A burning-brands test was marginally acceptable (on an incorrectly built specimen) while one Class B Burning-Brands Test had an unacceptable result. Ordinarily, additional samples would be tested to resolve this, however, in this case the additional samples were not available.

The intent of the tests conducted on the ethylene-vinyl-acetate (EVA) encapsulated, glass superstrate, Tedlar/Mylar/aluminum substrate integral-mount module was a demonstration of burning-brands performance, and this product showed general compliance with Class C requirements, but failure when tested to Class B requirements.

Because of the test performance, that is, the dropping of flaming particles during the burning-brands test, the use of hydrocarbon materials, such as EVA and PVB in integral mount applications as a part of a roof may not be advisable.

Details of this series of tests are in Appendix F, entitled "Results of Tests for Fire Resistance of Roof Covering Materials - 1981."

3.4 Module Construction; Existing UL Standards

To achieve appropriate safety levels, both the components (modules, panels, connectors, support structures, cables, etc.) and their overall assembly into a specific system configuration were considered simultaneously. To provide a basis for the establishment of engineering safety requirements, a review of existing UL standards was undertaken to identify those which contain requirements pertinent to photovoltaic modules or panels and their installation. Table 3.2 is the result of this effort. It indicates whether the standard contains generic safety requirements; requirements applicable to components of a system, such as UF cables; or requirements which may be applied to the photovoltaic module or panel itself, such as fire resistance as a roof covering. Certain UL standards, identified by an "X" in more than one column, may be applicable to items which may be a part of the module, such as wiring (but tested separately), and also included separately as a part of the photovoltaic array.

TABLE 3.2
APPLICABILITY OF UL STANDARDS TO PHOTOVOLTAIC SUBSYSTEM/COMPONENTS

Standard Number	Title	Generic Safety Requirements	Applied to Components of System	Applied to Module or Panel
1	Flexible Metal Electrical Conduit		X	
3	Flexible Nonmetallic Tubing for Electric Wiring		X	
4	Armored Cable		X	
6	Rigid Metal Electrical Conduit		X	
44	Rubber-Insulated Wires and Cables		X	X
50	Electrical Cabinets and Boxes		X	X
83	Thermoplastic-Insulated Wires		X	X
94	Tests for Flammability of Plastic Materials for Parts in Devices and Appliances	X		
96	Lightning Protection Components		X	
310	Quick-Connect Terminals		X	X
360	Liquid-Tight Flexible Steel Conduit, Electrical		X	
467	Electrical Grounding and Bonding Equipment		X	
486A	Wire Connectors and Soldering Lugs for Use with Copper Conductors		X	X
486B	Wire Connectors for Use with Aluminum Conductors		X	X
493	Thermoplastic-Insulated Underground Feeder and Branch-Circuit Cables		X	
514	Electrical Outlet Boxes and Fittings		X	X
580	Tests for Wind-Uplife Resistance of Roof Assemblies			X
651	Rigid Nonmetallic Electrical Conduit		X	

Standard		Generic Safety	Applied to Components	Applied to Module or
Number	Title	Requirements	of System	Panel
719	Nonmetallic-Sheathed Cables		X	
723	Tests for Surface Burning Characteristics of Building Materials			X
746A	Polymeric Materials - Short Term Property Evaluations	X		
746B	Polymeric Materials - Long Term Property Evaluations	X		
746C	Polymeric Materials - Use in Electrical Equipment Evaluations	X		
790	Tests for Fire Resistance of Roof Covering Materials			X
797	Electrical Metallic Tubing		X	
854	Service Entrance Cables		X	
943	Ground Fault Circuit Interrupters		X	
969	Marking and Labeling Systems		X	X
997	Wind Resistance of Prepared Roof Covering Materials			X
1059	Electrical Terminal Blocks		X	X
1097	Double Insulation Systems for Use in Electrical Equipment	X		
1439	Determination of Sharpness of Edges on Equipment	X		
1446	Systems of Insulation Material - General	X		

4. NATIONAL ELECTRICAL CODE PROVISIONS

4.1 Background

The latest (1981) edition of the National Electrical Code (NEC) prepared by National Fire Protection Association Panels is the guiding document by which the acceptability of most private sector commercial, industrial, and residential electrical installations is judged. Provisions of the NEC may be enforced by municipal or state electrical codes, which may either copy and quote the NEC, or refer to it. The municipal or state codes may either utilize the entire NEC or modify it for their own use. The municipal or state codes may also refer to the NEC of a particular date, even though that version of the NEC might have been superseded by a later version.

A new edition of the NEC is published every 3 years. These new editions, plus Temporary Interim Amendments allow for the introduction of provisions covering new technology and new product designs. They also provide a mechanism for improving provisions found inappropriate.

When a product or system whose acceptability is newly described in the NEC is installed in a locality using an older version of the NEC, the local inspector might not be prepared to evaluate its installation. In such cases, it would be prudent for the prospective installer to contact the local inspector beforehand, to discuss the features of the installation, how it might be judged, and determine whether a variance is required. With either a formal variance, or an acceptance based on a new product technology not described in the applicable electrical code, it would be reasonable to expect that the municipal inspectors of a particular locality, acting in concert, would accept the new technology product using the provisions of the latest NEC as a guide.

A similar scenario may arise with new technologies that are not addressed at all in the NEC, in which case, there are no defined requirements. When this occurs, more involved discussions may be needed with local inspectors. This discussion might cover the safety features contemplated for the system, and how these features provide a level of safety commensurate with the existing code.

The present (1981) edition of the NEC does not include any provisions specifically relating to photovoltaic systems. It has been judged desirable to eliminate this void in order to:

1) describe a uniform minimum level of safety,

2) remove inconsistencies concerning inspector judgment,

3) assist and inform inspectors,

4) allow uniformity in products (e.g. - provisions for wiring means, mounting).

As a result, an Ad-Hoc Subcommittee on Photovoltaics was formed by the NEC Correlating Committee to draft a set of proposals (which became proposed Article 690) on photovoltaics for consideration for inclusion in the 1984 Edition of the NEC. Proposed Article 690 has been assigned to NEC Code Making Panel 3 and is scheduled for public review and comment in June, 1982. Because of its preliminary nature, the text of proposed Article 690 is not included in this report and references to specific sections are paraphrased.

The paragraphs which follow are intended to provide some understanding as to the pertinent sections of the 1981 edition of the NEC and how the sections affect photovoltaic installations. Statements reflecting the contents of proposed Article 690 are [<u>in brackets and underlined</u>], to signify their "preliminary" nature.

4.2 <u>Specifics</u>

The following sections of the 1981 NEC are considered generally applicable to all electrical installations, and thus should be adhered to in any photovoltaic installation:

> 110-7, Insulation Integrity; 110-11, Deteriorating Agents; 110-12, Mechanical Execution of Work; and 215-2, Feeder Ratings and Sizes.

The following provisions as contained in sections of the 1981 NEC are considered particularly applicable to photovoltaic systems rated up to 600 volts.

For working clearances and spaces, the minimum required ingress space may be as described in Section 110-16(a).

Section 200-10 covers devices (components of an electrical system which are intended to carry but not utilize electrical energy) and appliances (utilization equipment built to perform a function, such as food mixing, air conditioning, etc.) but not specifically, equipment used to generate electrical energy. However, the provisions of this Section, basically terminal identification, should be applied to photovoltaic modules and panels. The UL Proposed Standard includes an item on terminal marking (paragraphs 9.9 and 9.10) that would provide for the desired module terminal identification. (See Section 3.3.1.2 of this report.)

To apply the provisions of Article 210, the wiring between the service entrance and the power conditioning unit might be considered a "branch circuit". However, application of this term for the power conditioning unit output circuitry might lead to a great deal of confusion since it is not in accord with the NEC definition. Therefore, the pertinent parts of Article 210 have been restated in proposed Article 690. [Specifically, that part of Section 210-6 relating to maximum voltage to ground appears in Section 690-7; those of Section 210-19 on conductors - minimum ampacity and size appear as Section 690-8; and those of Section 210-20 on overcurrent protection appear as Section 690-9.] With regard to Section 690-9, the proposal is formulated recognizing that photovoltaic modules are inherently current limiting, and thus under certain circumstances overcurrent devices may be unnecessary.

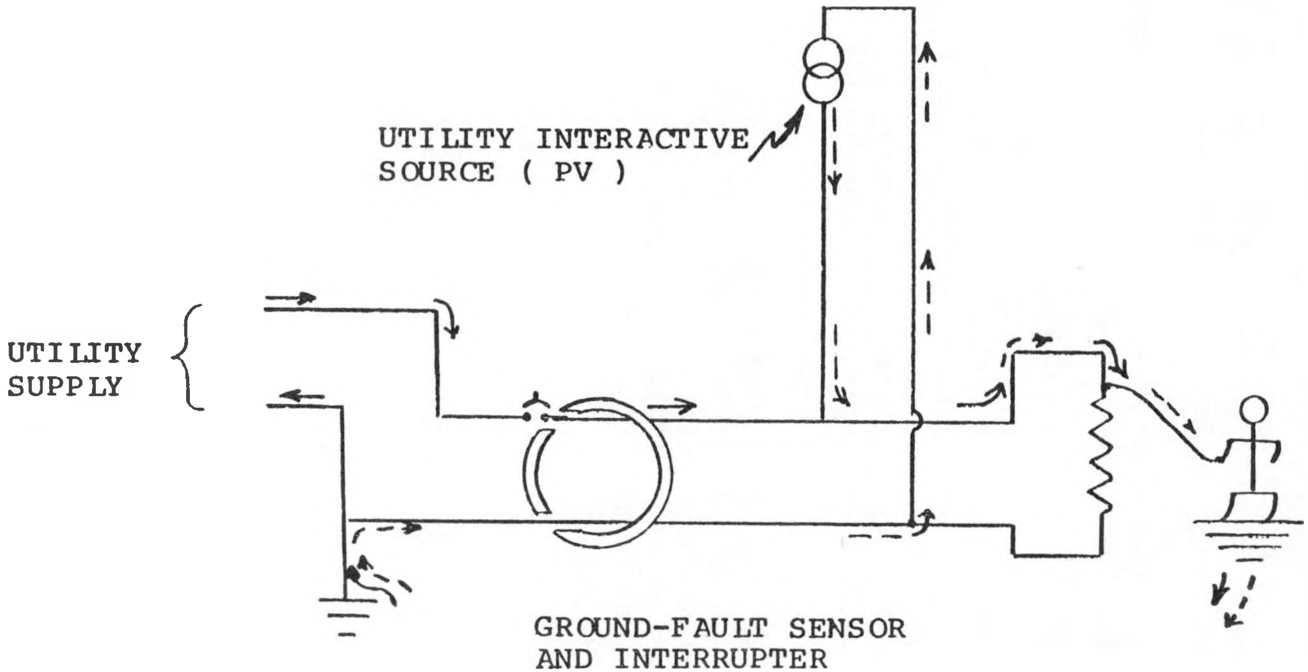
Per Section 210-6, in dwelling units, the maximum voltage to ground shall not exceed 150 volts for a branch circuit supplying screwshell lampholders, standard receptacles, or appliances. Where a transformerless power conditioning unit is involved, the switching action of the power conditioning unit may create a condition where at any one time a portion of the circuit of the array is at more than 150 volts to ground. [Although the array does not fall under the lampholder, etc. category, the Ad-Hoc Subcommittee has proposed that a reference to 150 volts be maintained, and has proposed that photovoltaic source and output circuits over 150 volts to ground not be accessible, while energized, to other than qualified persons, Section 690-7(d). To provide some reasonable limit on the risk of electrocution, the voltage to ground (within the array) may be permitted up to 600 volts, Section 690-7(c).]

Section 210-8 states that receptacles installed in certain locations in dwelling units are to be provided with ground-fault protection. The presence of a utility interactive photovoltaic source cannot be permitted to compromise the ground-fault protection. As shown in Fig. 4.1, a photovoltaic source placed on the load side of a single pole ground-fault circuit interrupter (GFCI) in a branch circuit can compromise such ground-fault protection. Upon the occurrence of a ground fault, the GFCI would operate to interrupt the utility supply which causes (some time later) the photovoltaic supply to drop out. However, the total time between the initiation of the fault and the termination of the output of the photovoltaic source may exceed 25 milliseconds, the longest time permitted for a 264 milliampere fault. [The proposal for the 1984 Edition of the NEC includes specifics on how the power conditioning unit output is to be connected to the utility supply so that GFCI operation is not compromised, Section 690-64.]

This use of ground-fault circuit interrupters in the ac branch circuit should not be confused with ground-fault systems incorporated to provide protection in the dc array wiring. A further discussion is provided in Section 6 of this report.

Section 210-22(c) generally limits continuous loads on a branch circuit to 80% of the rating of the branch. This restriction is applied to insure that overcurrent devices (fuses and circuit breakers) used side-by-side in a panelboard will not be mutually overheated and operate. Although the conductors from the service equipment (see National Electrical Code definition) to the power conditioning unit are not literally a branch circuit, the 80% figure is valid to ensure that overcurrent and short-circuit protective devices (fuses and circuit breakers) in the power conditioning unit output circuit are not overheated and operated. This stipulation should thus be applied to the power conditioning unit output circuit and to the photovoltaic source and output circuits. [The proposal for the 1984 NEC specifies that conductors and overcurrent devices have an ampacity 125% (the reciprocal of 80%) of the rating of the modules, Section 690-8.]

The requirements of Article 225, Outdoor Circuits, are likely to have an overall bearing on photovoltaic installations. Portions considered relevant and which may be applied without modification are Sections 225-4, Conductor Covering; 226-6, Overhead Spans; 225-10, Wiring on Buildings, 225-11, Circuit Exit and Entrances; 225-12, Open-Conductor Supports; 225-14, Open-Conductor Spacings; 225-15, Supports Over Buildings; 225-16, Point of Attachment to Buildings; 225-17, Means of Attachment to Buildings; 225-18, Clearance from Ground; 225-19, Clearances from Buildings for Conductors of Not Over 600 Volts; 225-20, Mechanical Protection of Conductors; 225-21, Multi-Conductor Cables on Exterior Surfaces of Buildings; and 225-22, Raceways on Exterior Surfaces of Buildings.



– – ➤ FAULT CURRENT FROM UTILITY INTERACTIVE (PV) SOURCE

——➤ FAULT CURRENT FROM UTILITY SOURCE

FIGURE 4.1
UTILITY INTERACTIVE SOURCE ON LOAD SIDE OF GROUND-FAULT CIRCUIT INTERRUPTER

The general provisions of Article 230, Part H Service Equipment - Disconnecting Means, have been proposed as applicable to photovoltaic systems. [Exceptions made are that the disconnecting means not be required to be suitable for use as service equipment, and that certain equipment, e.g., blocking diodes, isolating switches, overcurrent devices, be permitted ahead of the disconnecting means. Part C, Disconnecting Means, of proposed Article 690, specifically, Sections 690-13 through 690-17 covers this.]

Provisions of Section 230-71 and 230-72 are considered applicable to photovoltaic systems, thus the array shall be disconnectable from the power conditioning unit by a maximum of 6 switches (or handle throws). It is to be noted that the present "grouping requirement" of Section 230-72, requires that all six movements be made in a single location.

The provisions of Section 230-95, applied to services rated 1000 amperes or more, and thus generally applicable to commercial, industrial, or load center installations only, will not be achieved unless the interactive (photovoltaic) source is also interrupted on the occurrence of a ground fault. (Other requirements are likely to mean that this will be automatic with loss of service.) In addition to interrupting the circuit at the service, the interactive source should be interrupted as close to the power conditioning unit as possible. However, the overcurrent devices to protect the service entrance to conditioner wiring should be as close to the service entrance or remote panel as possible.

Section 240-21 states that an overcurrent device shall be provided at a point where the conductor to be protected receives its supply. In the case of a photovoltaic array with its inherently-limited current output, and where the conductors are sized on the basis of the short-circuit current, it is considered unnecessary to require overcurrent protection in the array-to-power conditioning unit conductors or at the power conditioning unit end of the service-to-power-conditioning-unit conductors. However, fuses to protect individual photovoltaic source circuits may be warranted.

Circuit breakers (main and branch) used where there is a possibility of a reversed power flow, as in the service of a photovoltaic equipped residence, etc., may have to be rated as acceptable for reversed line-load connection.

When an array is mounted on a building and the array-to-power conditioning unit wiring takes the status of premises wiring (for example, in the case where the array to power conditioning unit wiring is permanently attached to a building), application of Section 200-2 (premises wiring shall have a grounded conductor) is feasible if the array is transformer isolated from the utility supply. However, with certain types of transformerless power conditioning units, direct grounding of the array circuit may prevent system operation. In this case an indirect ground reference effected through the power conditioning unit, including a means to dissipate static charges, may be sufficient to meet the objective of Section 250-51. [The proposal for the 1984 edition of the NEC is "Other methods which accomplish equivalent system protection, and which utilize equipment listed and identified for the use shall be permitted". Section 690-41.] Where the array circuit ground is carried through the power conditioning unit, provision should be made for an array circuit ground connection even with the power conditioning unit turned off. A resistive connection effected between the array subsystem and ground might be used to accomplish this.

In any case, both circuit and array frame should be connected to earth (grounded) through a conducting means capable of carrying any current likely to be imposed on them by any other part likely to contact them.

Generally, a grounding connection is made as close to the source as possible. To permit the installation of various protective systems ... [the proposal for the 1984 edition of the NEC permits the grounding connection to be made anywhere on the photovoltaic output circuit, Section 690-42.]

A ground at the electrical center of a dc or single phase ac circuit restricts the voltage between any part of the circuit and earth to half the circuit value. This is a benefit not obtained with a positive or negative ground. [To ensure this benefit, the NEC proposal for photovoltaic systems specifies that a neutral conductor of a 3-wire system (the center of the circuit) is to be grounded, Section 690-41.]

Section 250-26, "Grounding Separately Derived Alternating Current Systems", is not applicable. The interactive source does not constitute a "separately derived" system. Thus, assuming that the circuit is grounded at the first source, no conductive path is to be provided between the grounding and grounded conductors at this interactive source. See Section 250-23.

The following definition has been prepared for this report and does not appear in this form in the NEC.

Separately Derived System - A system whose power is derived from windings or cells, and which has no direct electrical connection, including no solidly connected grounded circuit conductor, to supply conductors of another system.

In explanation of this prohibition against the grounding of the neutral at the interactive source, a grounding of the second source, e.g. the power conditioning unit interactive with the utility supply, will cause a loss of protection normally provided by ground fault detection and relaying systems. The loss of protection coupled with a line-ground fault may result in fault currents that may cause damage to the grounding or grounded conductors. The three problem items are (1) size of conductors, (2) lengths of conductors, and (3) location of faults. See Figure 4.2. Concerning ground-fault detectors, paths interconnecting the grounding and grounded conductors (i.e. - the bonding jumper) and located between (a) the detection toroid(s) and (b) the loads or the second source, are likely to render ground-fault detection systems ineffective by allowing the fault current to re-enter the normal current path through the detectors, thereby eliminating the imbalance. Concerning ground-fault current exceeding the grounding and grounded conductors current-carrying ability, a grounded conductor to grounding conductor path (i.e. - a bonding jumper) at a low output power conditioning unit, in relation to building's entire electrical system (that is photovoltaic system is a small part of building's electrical system), may allow such overburdening of the power conditioning unit conductors when the photovoltaic array power conditioning unit and load are connected to a panelboard remote from the service. As shown in Figure 4.3, with for example 500 feet of wire between the service and the panelboard and 10 feet of wire between the panelboard and the power conditioning unit and with a bonding jumper at the power conditioning unit, the fault current will seek a return through the unprotected small diameter neutral and grounding conductors serving the power conditioning unit. This condition would be aggravated by the fact that in many instances the grounding conductor need not be as large as the current-carrying conductors, see NEC Table 250-95.

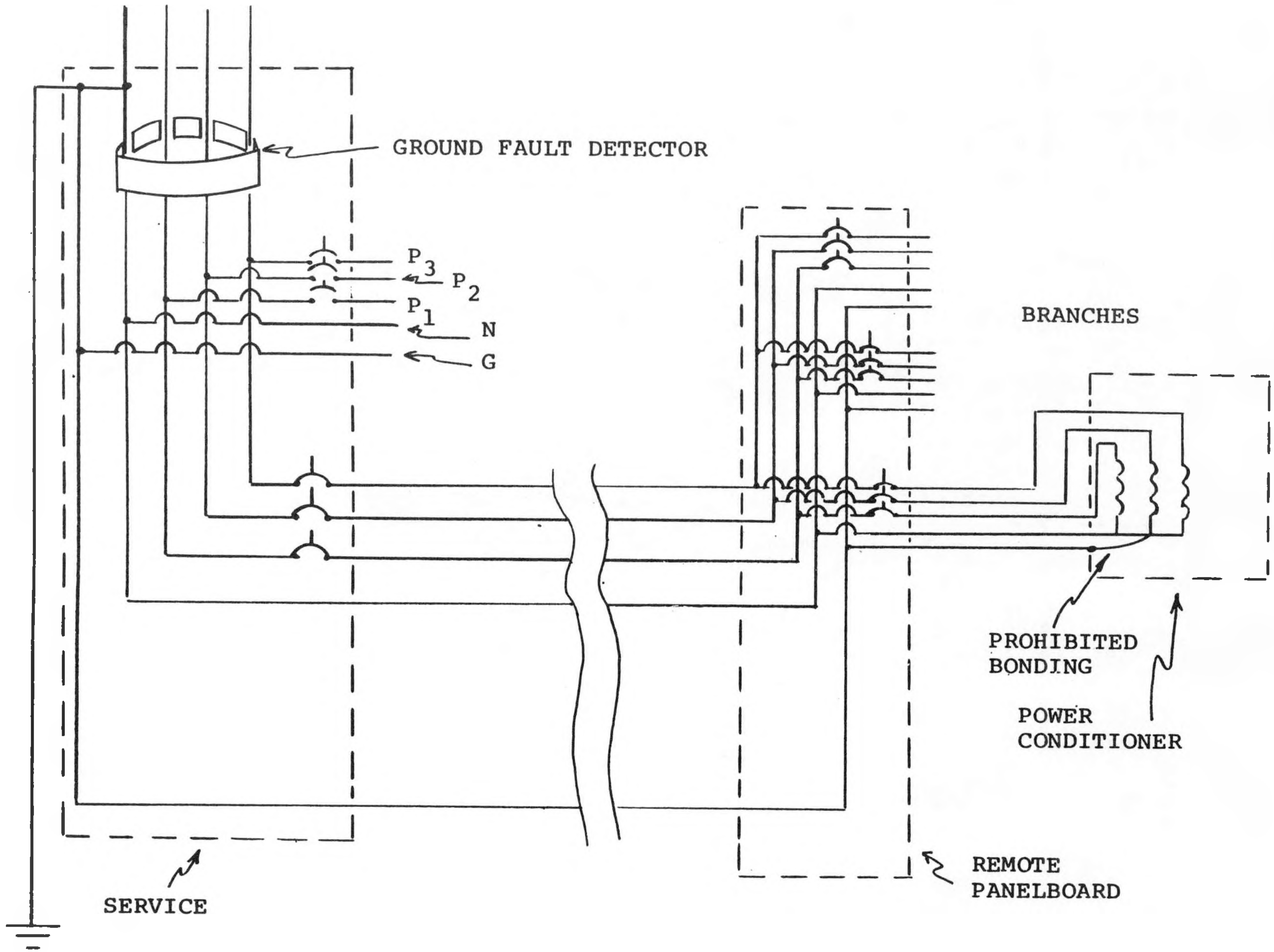


FIGURE 4.2

GROUNDING SEPARATELY DERIVED SYSTEMS

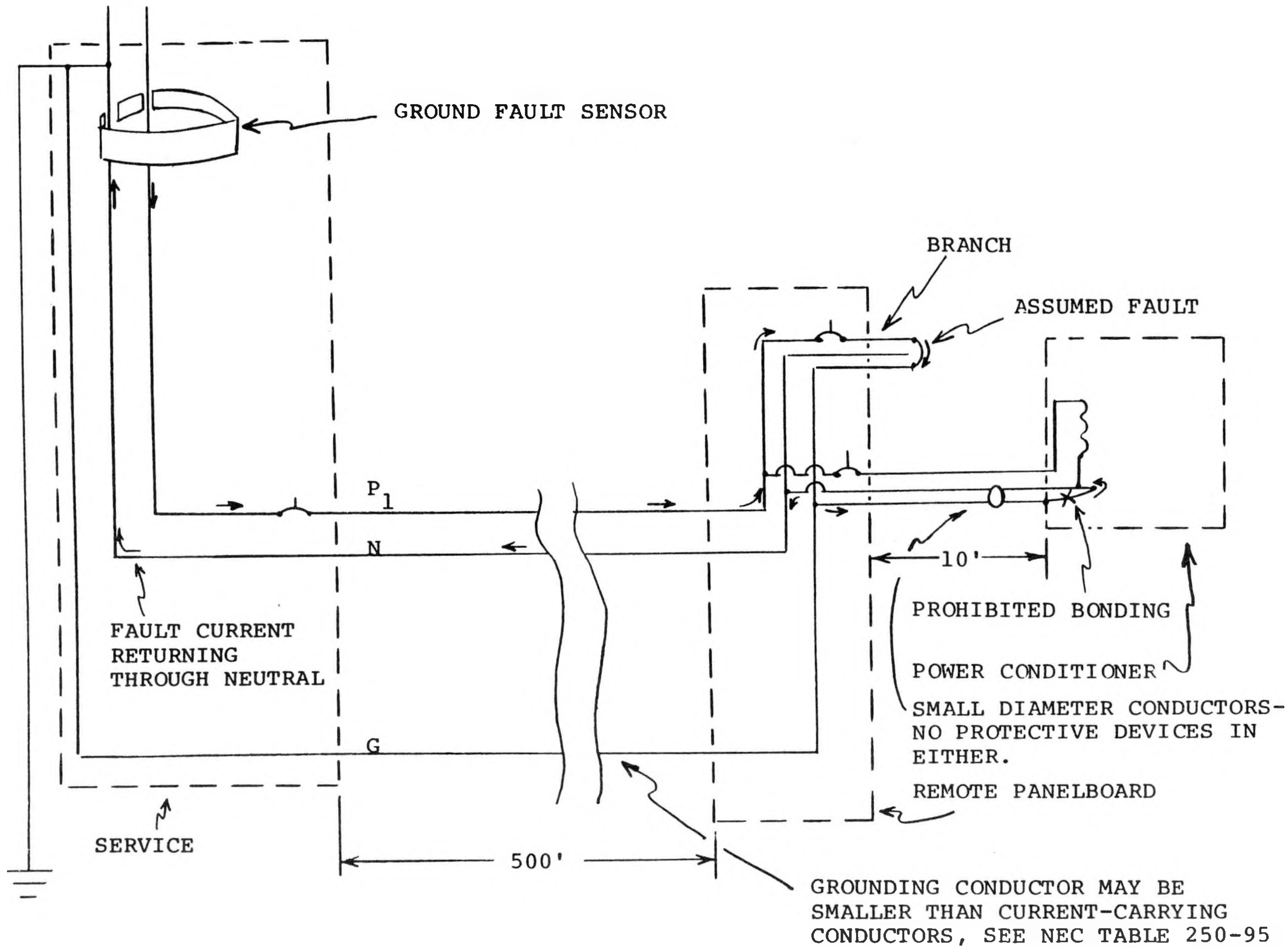


FIGURE 4.3
GROUNDING SEPARATELY DERIVED SYSTEMS-
CURRENT FLOW WITH FAULT

For a separately derived system, a bond should be provided at the source between the grounding and grounded conductors, Sections 250-5, Part (d) and 250-26. A stand-along power conditioning unit is likely to be the source for a separately derived system.

Other NEC provisions relating to grounding and considered applicable to photovoltaic systems are 250-21, Objectionable Current; 250-22, Point of Connection for Direct-Current Systems; 250-42, Equipment Fastened in Place or Connected by Permanent Wiring Methods (Fixed); 250-46, Spacing from Lightning Rods; 250-58, Equipment Considered Effectively Grounded; 250-72, Method of Bonding Service Equipment; 250-91, Material (For Grounding Conductors); and 250 Part K, Grounding Conductor Connections.

Portions of Articles 300, Wiring Methods; and 310, Conductors for General Wiring, are also considered applicable to a photovoltaic installation. They are Sections 300-15, Boxes or Fittings - Where Required; 310-5, Minimum Size Conductors; and 310-12(b), Conductor Identification (Grounding Conductors).

Portions of Articles 318, Cable Trays; 320, Open Wiring on Insulators; 338, Service Entrance Cable; 339, Underground Feeder and Branch-Circuit Cable; and 480, Storage Batteries, may also be applicable to photovoltaic installations. If battery installations become a feature of residential systems, it would appear that more detail would be necessary in Article 480.

Because of possibilities of phase imbalance, single phasing of a three phase power conditioning unit and certain connections of a single phase power conditioning unit to a three phase system are undesirable.

[Unless the interconnected system is designed so that significant unbalanced voltages will not result, the NEC proposal would not permit the connection of the output of a single-phase power conditioning unit to a three phase three or four wire delta connected system. The NEC proposal also would require that for a three-phase power conditioning unit, all ungrounded conductors of the interconnected system automatically disconnect when one of the phases opens in either source. Reference, proposed Section 690-63.]

[Proposed Section 690-61 for the NEC covers the prohibition on reversed power flow.] The customer's power conditioning unit shall not energize otherwise dead power lines.

Cable and raceway wiring may be used within the limitations described in the NEC. The only presently acceptable "open wiring" scheme for outdoor use would be one utilizing multiple conductor Type UF (underground feeder) cable. Because of the economic penalties involved with the use of both multiple conductor cables and other presently acceptable methods (conduit, raceways), there is an incentive to develop new wiring methods specifically aimed at photovoltaic systems.

[The proposal for the 1984 Edition of the NEC permits single conductor Type UF cable, Section 690-31(b).]

5. ARRAY SUBSYSTEM GROUNDING

5.1 Background

A primary concern, having direct impact on module/array subsystem safety concepts, and also related to installation methods and application practices, is the subject of grounding. An effective grounding scheme, incorporating both a system (circuit) ground and a frame ground, serves to reduce the risk of fire hazard resulting from insulation failures and minimize the risk of shock hazard resulting from contact with the frames of an electrical system. Shock hazard resulting from contact with an array is a function of the electrical isolation capability of the photovoltaic module, which is prescribed not by the individual module voltage, but by the maximum voltage with respect to some electrical reference, usually earth ground. The array subsystem grounding configuration is an installation-oriented concern under the purview of the NEC which directly affects module insulation requirements.

5.2 System Ground

A system (circuit) ground is incorporated to prevent system voltage from rising above the insulation capability as a result of lightning, line surges, and induced voltages from adjacent circuits, static charges, and unintentional contact with higher voltage lines; to stabilize the voltage to ground during normal operation; and to facilitate the opening of overcurrent devices. A system ground is usually established by physically connecting one side (the positive or negative of the circuit), or some other part of the circuit such as the center, to earth. A ground at the electrical center of a dc or single-phase ac circuit restricts the voltage between any part of the circuit and earth to half the circuit value, a benefit not obtained with circuits using a positive or negative ground.

For some photovoltaic applications the concept of 'virtual' ground may be appropriate. A virtual ground provides a point that is electrically at ground potential, but has no physical connection to earth ground. For a photovoltaic array, a virtual ground provides the same benefits as a solid ground, in that it stabilizes system voltages and provides a path to dissipate static charges.

An example of a system using a virtual ground is the MIT/LL prototype located at the Northeast Residential Experimental Station (NE RES). A schematic diagram detailing this system is presented in Appendix G, Development of DC Ground Fault Detector. A transformerless power conditioning unit provides interaction between the single phase, center grounded 120/240 volt utility supply and the array. The midpoint of the array is at grounded potential in this arrangement.

While neither the present (1981) NEC nor the proposal for the 1984 NEC either mentions 'virtual ground' by name or otherwise describes it, it is expected that such could be accepted under the Exception to proposed Section 690-41; see commentary in Chapter 4.

5.3 Frame Ground

A frame ground is incorporated to limit the voltage to ground on exposed metal parts by providing a low impedance path to earth and thus, generally, to facilitate overcurrent device operation in the case of ground faults. A frame includes all noncurrent-carrying metal electrical equipment structures, supports and enclosures. The requirement for an effective frame ground is a permanent and continuous path of sufficiently low impedance to (1) limit shock voltage to a safe value; and (2) conduct ground-fault current to assure fast operation of overcurrent devices.

At present, the consensus (NEC Ad Hoc Subcommittee on Photovoltaics) is that exposed noncurrent-carrying metal parts of equipment and conductor enclosures should be grounded to the grounding electrode of the direct-current system.

5.4 Grounding Techniques

The following examples serve as a means of illustrating several basic safety schemes and grounding techniques applicable to photovoltaic systems. These may or may not include devices or circuits covered in the present NEC or proposed Article 690.

CASE 1:

A grounded array system (Figures 5.1 and 5.2) illustrates the basic concepts of array subsystem grounding. The array circuit is grounded through the transformerless power conditioning unit by grounding resistance R_1, and the array frame is grounded by resistance R_5 (conductor, frame, and soil resistance). An assumed array circuit-to-frame fault, R_4, may result in an electrical shock hazard to persons contacting the array frame, (current through body resistance R_b) unless the frame grounding resistance R_5 is low relative to body ground paths, or body paths are paralleled by other low resistance paths. Table 5.1 identifies relative values for the resistances R_2, R_3, and R_5 representing ground paths, and whether or not the probability for shock hazard is high or low for various values of these resistances.

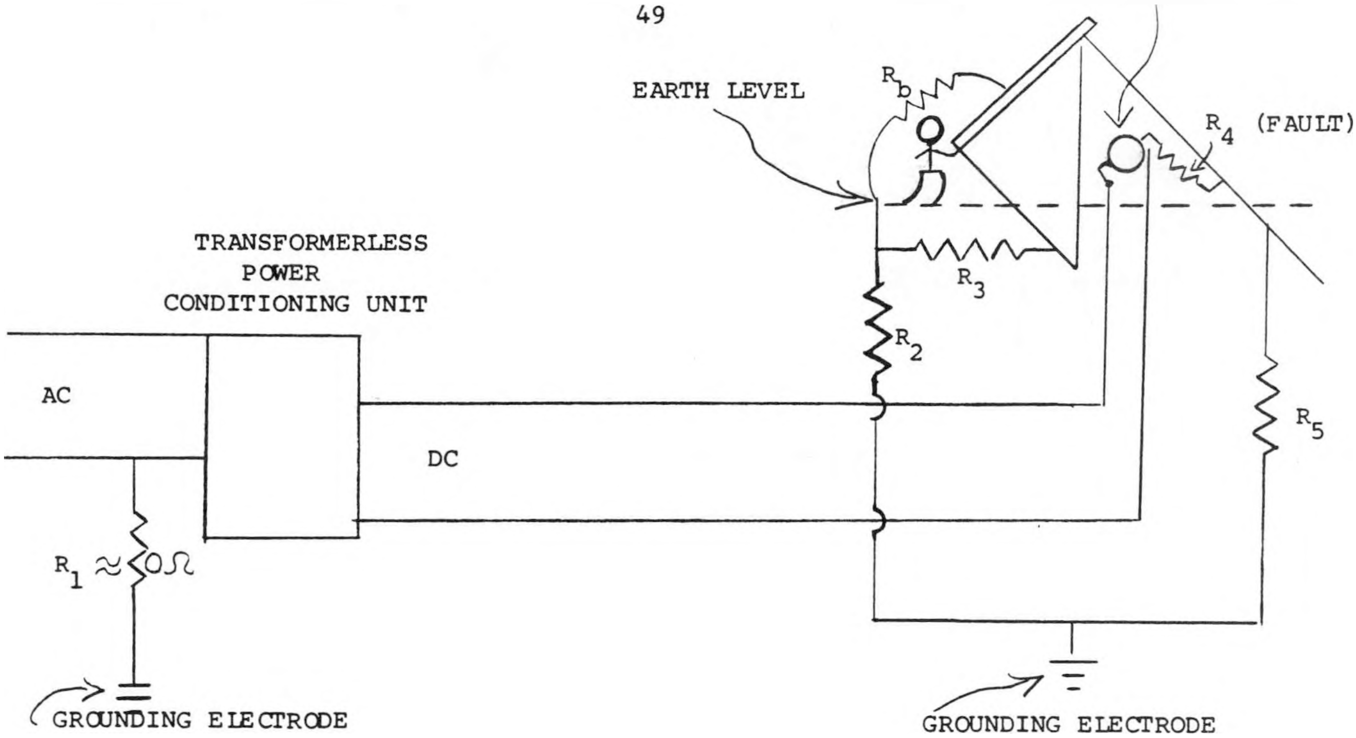


FIGURE 5.1
GROUNDED ARRAY SYSTEM

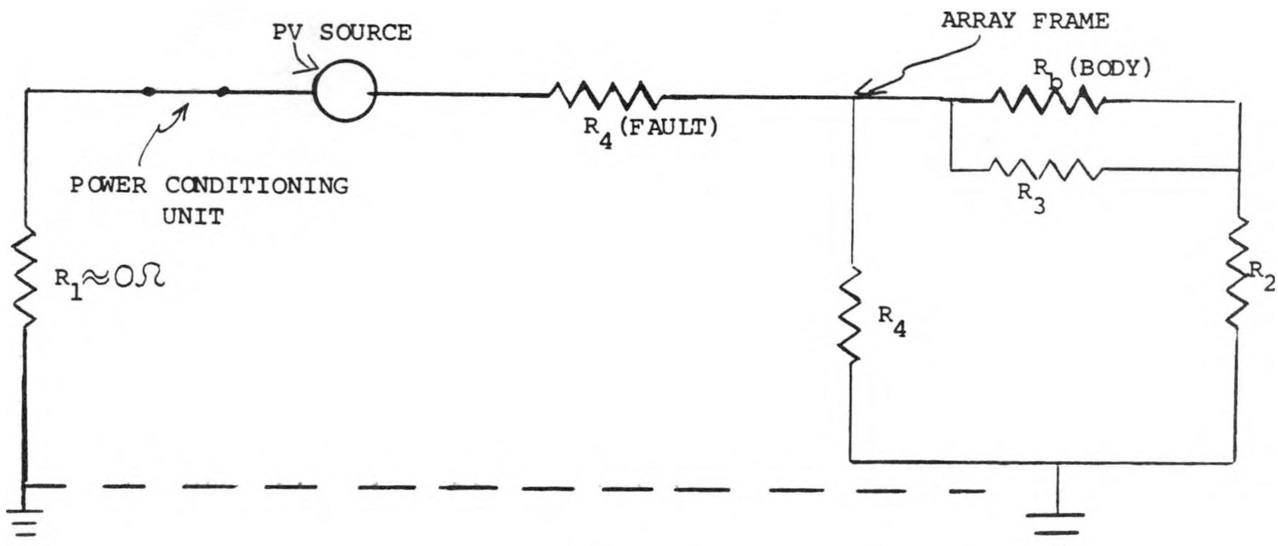


FIGURE 5.2
EQUIVALENT CIRCUIT OF FIGURE 5.1

TABLE 5.1
RESOLUTION OF HAZARD CONDITIONS
Figures 5.1 and 5.2

Value of Resistance						Shock Hazard
R_1	R_2	R_3	R_4	R_5	R_b	Probability
0	Low	High	Fault*	High	Low	High
0	High#	Any	Fault*	Any	Low	Low
0	Any	Low#	Fault*	Any	Low	Low
0	Any	Any	Fault*	Low#	Low	Low

Characteristic that reduces shock hazard probability.
* Near short circuit.
R_2 is resistance between earth's surface and deep earth.
R_3 is resistance across earth's surface.

* * * * *

Because of the hazard possibilities described, an installation as described above would be effectively proscribed by the provisions of Sections 250-57 and 250-91(c) of the NEC, 1981; which describe equipment frame grounding methods. Basically, there shall be an equipment grounding conductor connected between the array frame and earth at the building source.

CASE 2:

The array frame is additionally grounded through R_6 to the grounding electrode at the service entrance, see Figures 5.3 and 5.4. This scheme reduces the probability of electrical shock by providing an alternate ground path. It is of benefit in situations where soil conditions could result in the corrosion and elimination of the grounding electrode R_5. If R_6 is low (and assuming R_1 is low) shock hazard situations at the array frame are minimal.

CASE 3:

Buried cables around the array keep the soil at the same electrical potential as the array frame. See Figures 5.5 and 5.6. Because of the buried cables, there will be no voltage difference between the array frame and local earth, regardless of the condition of the local ground from the array to true earth, R_5 or the condition of the local ground immediately under the buried cables to true earth, R_2. Thus shock hazard situations at the array frame are minimal.

Again, the provisions of Sections 250-57 and 250-91(c) would render the above described installation unacceptable in that there is no equipment grounding conductor between the array frame and earth at the building source.

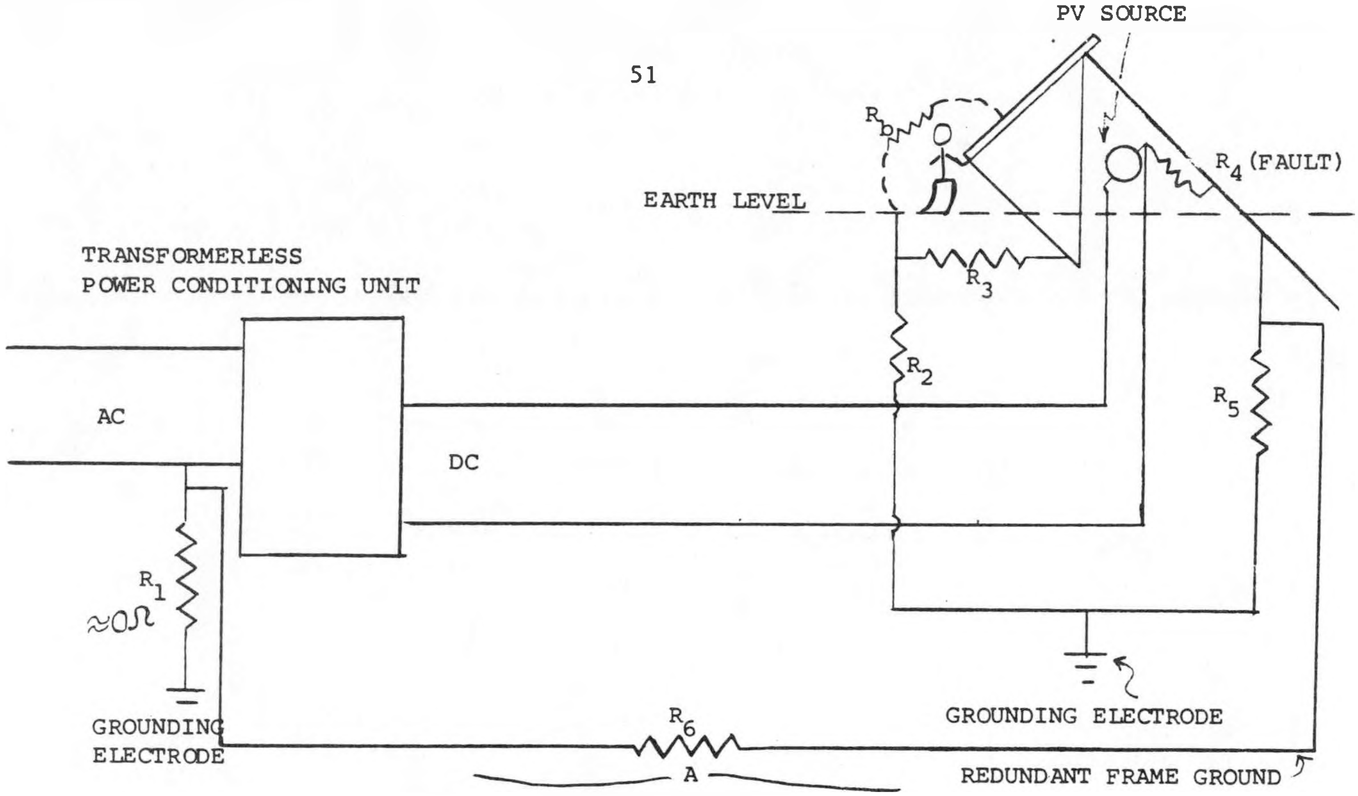


FIGURE 5.3
GROUNDED ARRAY SYSTEM-REDUNDANT FRAME GROUND

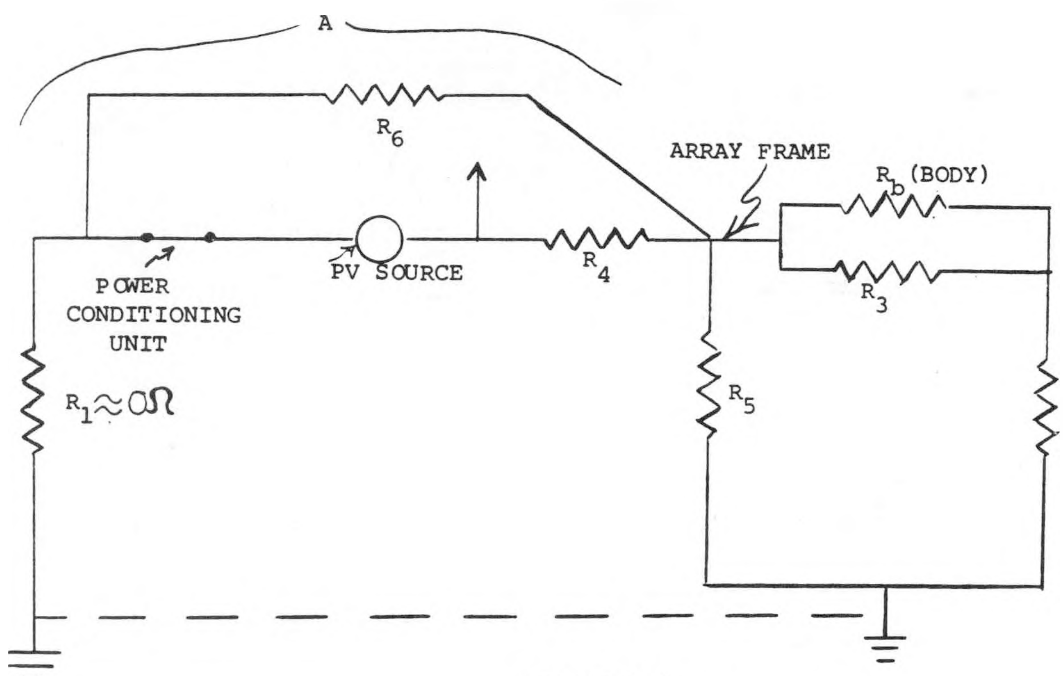


FIGURE 5.4
EQUIVALENT CIRCUIT OF FIGURE 5.3

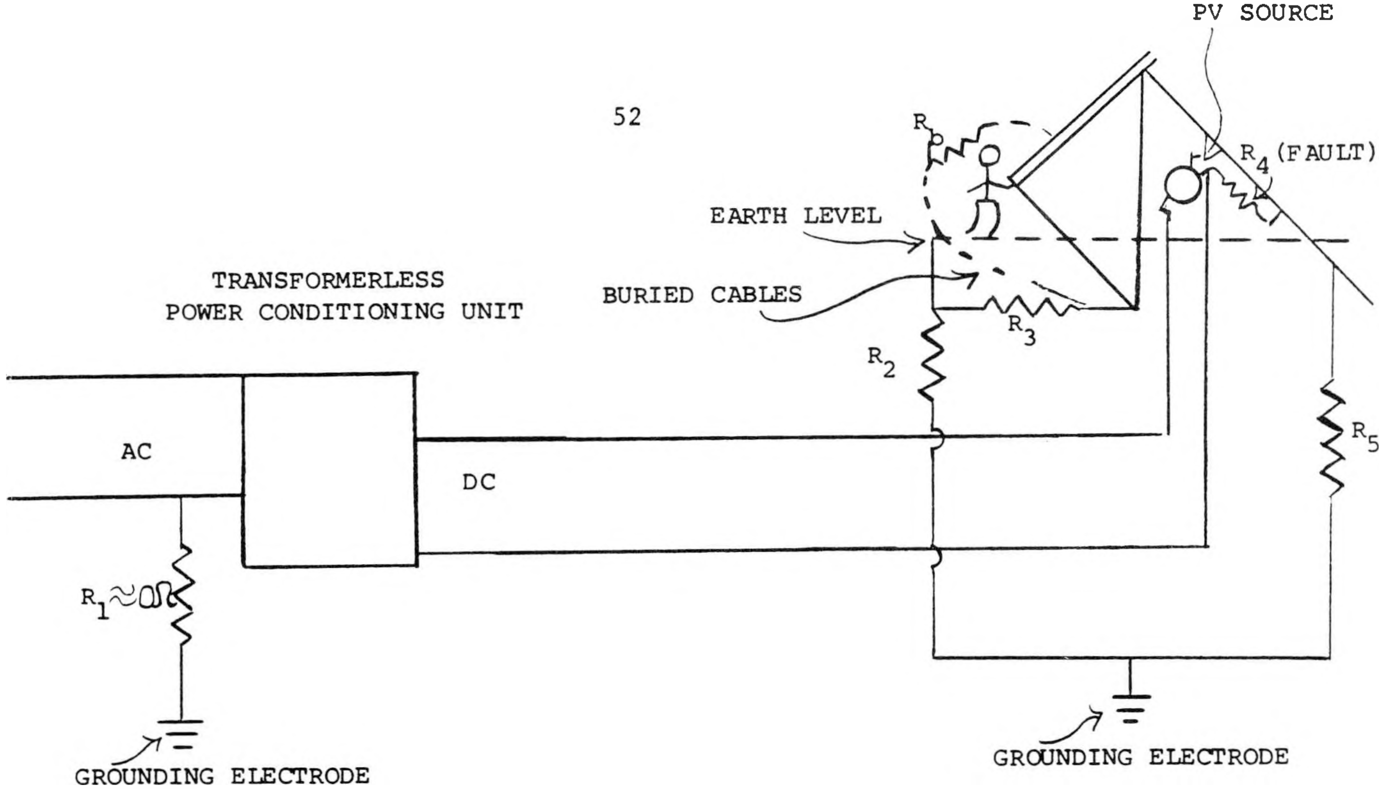


FIGURE 5.5
GROUNDED ARRAY SYSTEM-BURIED CABLES

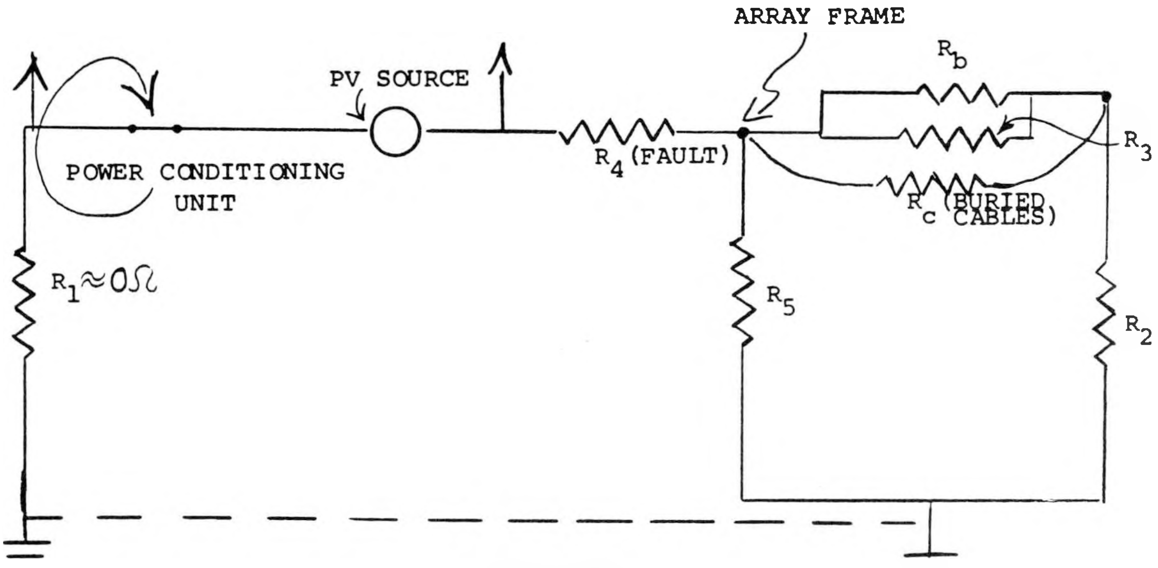


FIGURE 5.6
EQUIVALENT CIRCUIT OF FIGURE 5.5

6. GROUND FAULT SYSTEMS

6.1 Background

To complement system and frame grounding, one or more of the following should be considered for incorporation in the photovoltaic array system: redundant grounding, ground fault detection and reaction circuitry, overcurrent sensors and circuit interrupters, array configuration and component location, and adequate insulation and barriers to preclude contact with live circuit parts.

In conventional power systems, arcing faults to ground and to parts of different potential within the dedicated current path are frequently cleared by overcurrent protective devices. The action of the overcurrent device is made possible by the relatively high fault currents available from the source. In the case of photovoltaic sources that are inherently current-limited, action by overcurrent protective devices to clear faults to ground and within the path might not occur, and other means may be necessary to prevent sustained arcs, and their resultant fire hazard possibility. In this section the use use of ground fault systems is examined with respect to photovoltaic arrays.

Current flow in a single phase (ac) or dc electrical circuit involves currents of equal magnitudes in the two provided conductors. When the circuit is provided with a ground connection at only one point, as in ordinary power systems where one conductor (the grounded conductor) is deliberately connected to ground, this equal magnitude condition remains true. In this circumstance, the points of this ground connection are restricted and controlled. However, if the circuit contains a ground connection at more than one point, this equal magnitude condition is no longer satisfied. Figure 6.1 shows how an additional ground connection, a fault R_1, at the load, results in unequal magnitude currents.

The unequal magnitude currents may be detected and used to effect desired reaction such as circuit shut-down. The allowable magnitude and duration of the fault is dependent upon whether such current is flowing through a body, in which case it may constitute a shock hazard, or through another conductive path, in which case it may constitute a fire hazard.

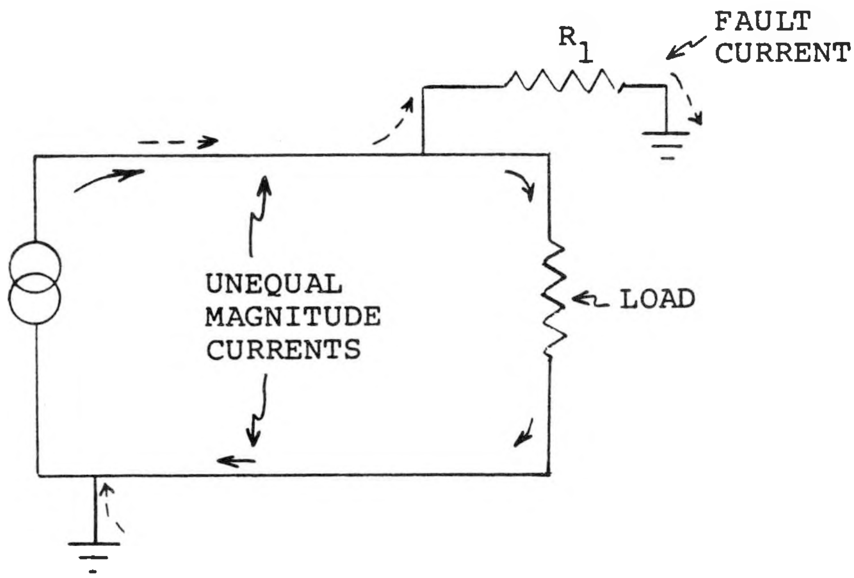


FIGURE 6.1
FAULT AT LOAD RESULTING IN UNEQUAL
MAGNITUDE CURRENTS

If a shock hazard condition is to be eliminated, the magnitude and/or duration of the current must be severely restricted. For nominal 120 volt ac circuits, fault currents of as low as 6 milliamperes must be interrupted within 5.6 seconds while times as short as 25 milliseconds are required where the fault current is 264 milliamperes. For dc circuits higher currents may be allowed. Levels of up to 30 milliamperes may be acceptable, depending upon ripple voltages present. Only where the potential for fire hazards alone are to be considered, can longer times and/or higher currents be tolerated.

Although a curve defining acceptable current duration versus current levels for dc has not been established, a starting point might be the emperically derived curve for voltages from 30 to 200 volts specifying operation for 60 hertz ac ground fault circuit interrupters:

$$T = \left(\frac{20}{I}\right)^{1.43}$$

where I is fault current in rms milliamperes and T is maximum response time in seconds.

The present NEC describes ground fault systems for powered (use) equipment in ac circuits, with the reaction being an interruption of the power to that circuit. It appears feasible to extend the uses of ground fault systems to provide protection in source circuits such as dc arrays. Where the circuit to be protected is a source that is not easily or quickly capable of being turned off, other reactions need to be taken to correct a hazardous situation.

Ground fault systems as applied to photovoltaic systems may be used for fire hazard purposes only, or for both fire and personnel protection.

In general power systems, fire hazard situations are created by either 'bolted fault' or arcing conditions. Bolted fault conditions are not considered a fire hazard problem in photovoltaic power systems because of the inherent current limitation of the source. Arcing conditions are considered undesirable, and assuming the arc has commenced, the extent of the problem is dependent upon the materials involved in the arc path, the intensity of the arc, and climatic factors. Whether the arc is ac or dc may also be of concern, as a dc arc may be more severe.

Shock hazard situations are also considered undesirable, and assuming that insulation has failed which will allow personal contact, the extent of the problem is dependent upon the body current, which is a function of applied voltage, and body resistance. Body resistance may be influenced by climatic factors, and is likely to be nonlinear with applied voltage, decreasing with increasing voltage. While acceptable levels of dc currents versus application time have not yet been established, they are likely to be more than the permitted ac values.*

Because of power conditioning unit operation, the voltages on an array may be a composite of ac and dc, and any ac component will greatly reduce the allowable dc current component. Figure 6.2 describes what may be maximum allowable body currents, where the currents are a composite of alternating and direct components.

6.2 Principles of Operation

Ground fault systems may be either the differential type or the direct ground current detection type. An example of a differential type applied to provide protection in an array circuit is shown in Figure 6.3. Differential types function by sensing the difference in currents between the two conductors of the circuit, and by generating a "trip" signal if the magnitude of the differential (fault) current exceeds a preselected value. An example of a direct ground current detection type is shown in Figure 6.5. Direct ground detection types function by sensing the current through the provided grounding path. If this current exceeds a preselected figure (the fault current) a "trip" signal is generated.

*Standard for Safety - Ground-Fault Circuit Interrupters, UL 943-1972.

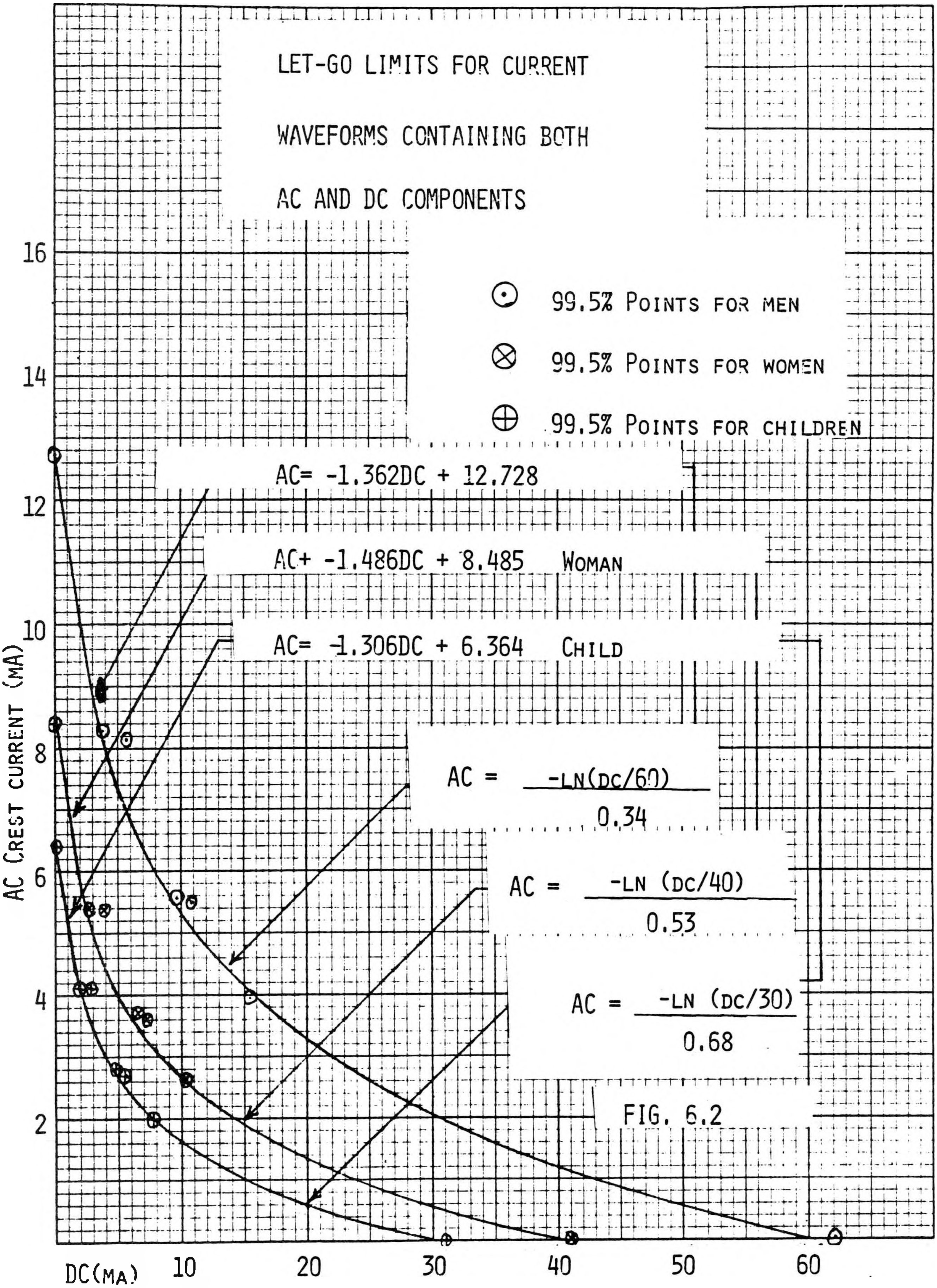

LET-GO LIMITS FOR CURRENT
WAVEFORMS CONTAINING BOTH
AC AND DC COMPONENTS
99.5% POINTS FOR MEN
99.5% POINTS FOR WOMEN
99.5% POINTS FOR CHILDREN
AC= -1.362DC + 12.728
AC+ -1.486DC + 8.485 WOMAN
AC= -1.306DC + 6.364 CHILD
AC = -LN(DC/60) / 0.34
AC = -LN (DC/40) / 0.53
AC = -LN (DC/30) / 0.68
AC CREST CURRENT (MA)
DC(MA)
16
14
12
10
8
6
4
2
10
20
30
40
50
60

FIG. 6.2

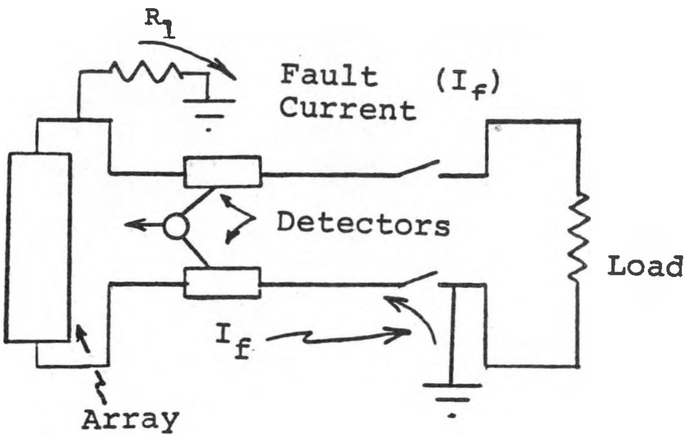


Figure 6.3
Array with Differential Ground-Fault
Detector

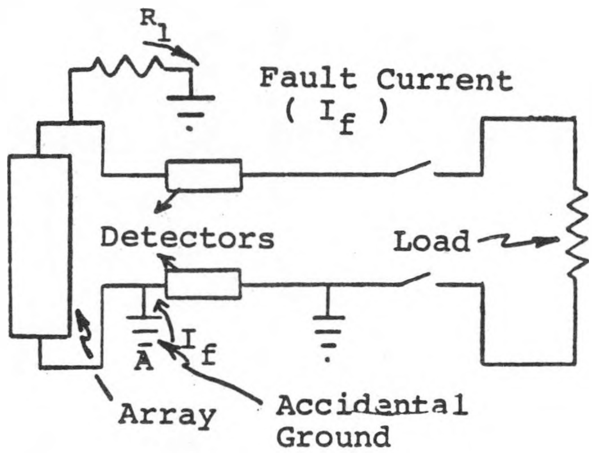


Figure 6.4
Differential Ground-Fault
Detector - Added Ground

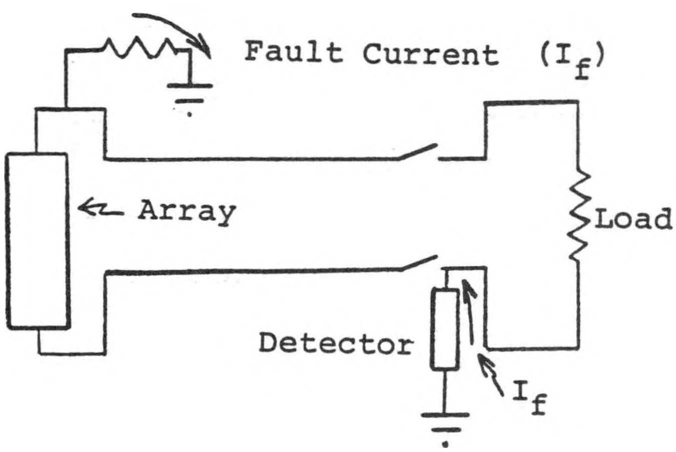


Figure 6.5
Array with Direct Ground-Fault
Detector

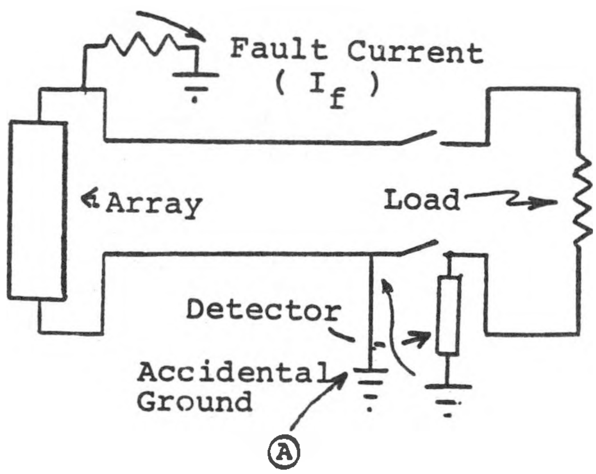


Figure 6.6
Direct Ground-Fault Detector-
Added Ground

In utilizing ground fault systems, it is necessary to control the location of both the circuit grounds and detector(s). Their location will determine the specific circuit areas afforded protection. (No ground fault system will respond in the case of line-to-line fault currents.) The effectiveness of a differential type ground fault sensor is limited to ground faults on the side of the ground fault sensor away from the provided ground. For this reason, this type of detector should be located as close to the power conditioning unit as is practical, or perhaps be a part of the power conditioning unit. For the circuit of Figure 6.3, ground fault protection would be provided only in the circuit on the array side of the detector, and only if there are no grounds in the grounded conductor on this array side of the detector. As shown in the circuit of Figure 6.4, a redrawing of the circuit of Figure 6.3 that contains an additional unwanted ground A on the array side of the detector, a fault current, (current through resistor R_1), if it develops, may re-enter the normal current path on the array side of the ground fault sensor, resulting in insufficient imbalance for fault current detection. Unwanted ground connections may occur as a result of deterioration of insulation or misconnections. With this situation, a ground fault system might fail to operate upon the occurrence of a ground fault. (The likelihood of such an added ground developing in a circuit with a "virtual ground" may be minimal, as described following.)

Because of this, UL requirements for ac ground fault circuit interrupters, (GFCI's) state that ground fault protection shall be provided when the circuit conductor that is normally grounded at the service only, is also grounded at a point in the load circuit of the ground fault circuit interrupter. To apply this stipulation to arrays,"service" should be replaced by "load" (power conditioning unit may be the load), and "load" should be replaced by "array".

Contemporary differential type ac GFCI's may achieve this protection capability by including an oscillator circuit which goes into operation if the extra ground is in place. This oscillator creates a sufficiently unbalanced current flow through the detector to activate the device.

For a direct ground current detection sensor Figure 6.5, ground fault protection is provided throughout the circuit, but only if there are no other grounds in the circuit. As shown in the circuit of Figure 6.6, (a redrawing of the circuit of Figure 6.5 with an added accidental ground), an added ground anywhere will defeat the direct ground current detection type GFCI. We do not know of any ground fault system of this type which includes an ability to detect the added ground. However, there does not appear to be any technical obstacle to the incorporation of such a feature.

Ground fault devices built for photovoltaic systems should include the capability of functioning with the added accidental ground, or should be restricted to use where grounding of the grounded conductor at other than prescribed points is unlikely.

In house wiring systems, staples through conductors plus uninsulated terminals within grounded metal boxes and the misuse of ground as a grounded conductors are conceivable sources for the "grounding" of the grounded conductor at other than the source. With a photovoltaic array interactive by way of a transformerless power conditioning unit and having a virtual ground, only limited lengths of wire and terminals are likely to be at the virtual ground point. A slight imbalance in voltage output of the modules may remove the virtual ground from the module terminals, but whether there would be sufficient current to activate the ground fault system by contact between a terminal near "virtual ground" and ground is questionable. With an odd number of modules in a series string, the "virtual ground" is confined to the center of a module (or modules) and if the module voltage is high, contact between any module terminals or wire and ground is likely to activate the ground fault system without the need for the supplementary oscillator circuit. The concept of using an odd number of modules in a series string to facilitate the use of ground fault systems is being investigated further.

6.3 Uses

A typical photovoltaic array interactive with a 120/240 volt utility installation by way of a transformerless power conditioning unit is shown in Figure 6.7. Ground fault current is presumed to result from failure of the insulation system. The source of the fault current may be either the array or interactive ac source, or both. Differential detectors B_1 and B_2 in conjunction with interruption switch S_2 would provide ground fault protection at any point in the array except at the "virtual ground".

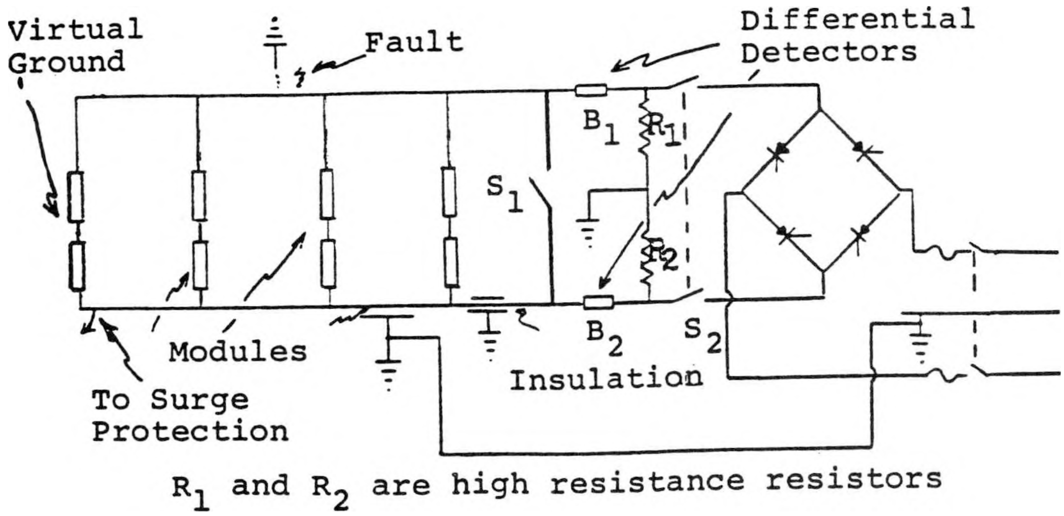


FIGURE 6.7
ARRAY WITH TRANSFORMERLESS POWER CONDITIONING UNIT - INTERACTIVE WITH 120/240 VOLT CENTER GROUNDED SUPPLY

Protection at the "virtual ground" is unnecessary because the virtual ground is at earth potential and therefore no current will flow through a body interposed between the virtual and physical grounds.

For an effective system, no ground can be permitted to remain at the "virtual ground" on the array side of differential detectors B_1 and B_2. With the presumption that there are an even number of modules in a series string, virtual ground exists at a terminal and can be touched or otherwise connected to physical ground. The adverse consequence of a ground on the array side of the detectors is shown in the circuit of Figure 6.8. With such a ground, ground fault currents may bypass the differential detectors. Whether or not the ground fault system might include a supplementary circuit, such as the oscillator previously mentioned to sense a physical ground at the "virtual ground" point, is in question in this case. This will be a topic for further work.

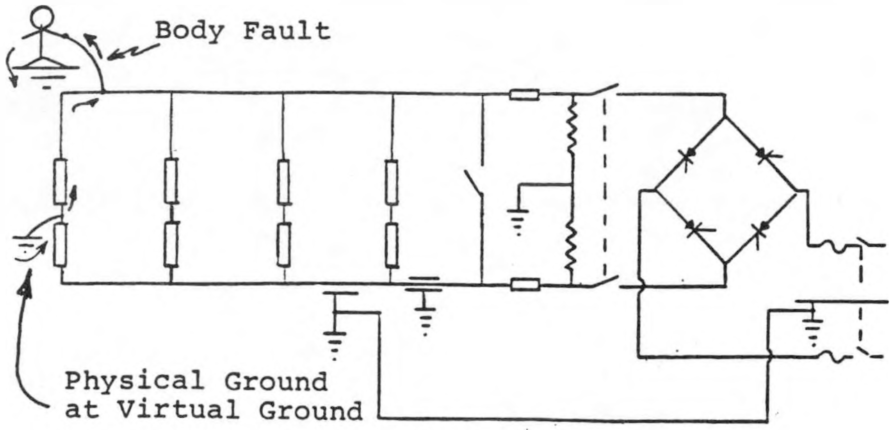


Figure 6.8
Consequences of Physical Ground at Virtual Ground

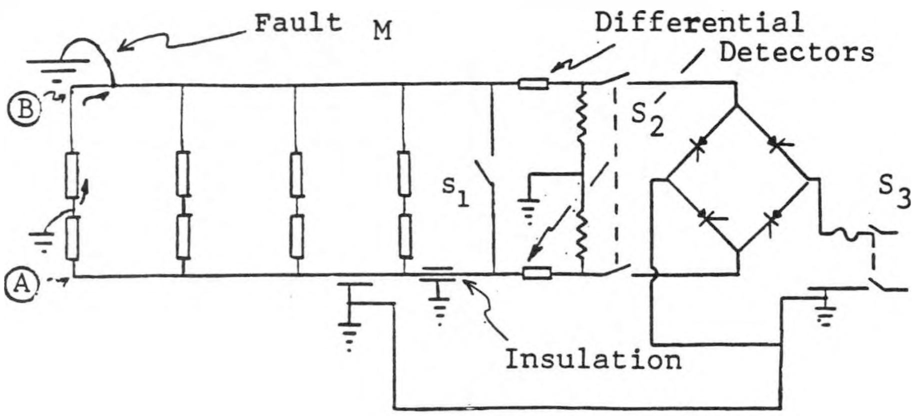
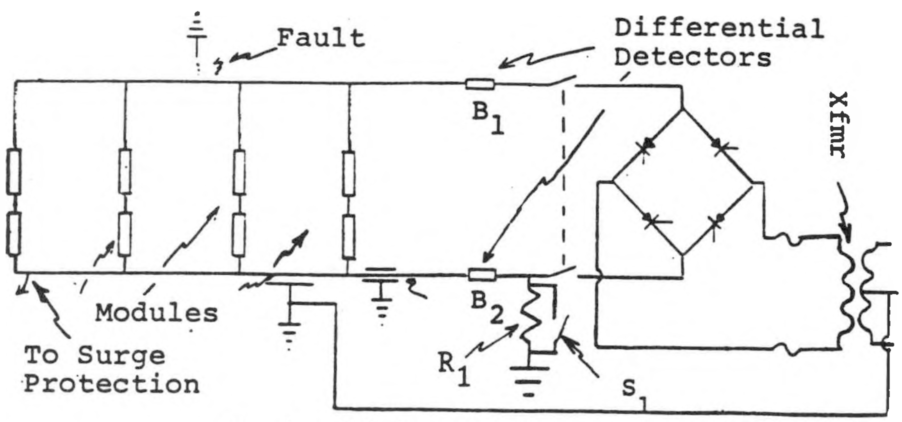


Figure 6.9
Array with transformerless power conditioning unit- interactive with 120 volt supply



R_1 is high resistance resistor

Figure 6.10
Array with transformer type power conditioning unit-Utility Interactive

6.4 Alternate Circuit Configurations

The circuit of Figure 6.9 includes a transformerless power conditioning unit interactive with a grounded 120 volt ac supply circuit. The comments described previously for the 120/240 volt transformerless interactive situation apply here, except that no point is a virtual ground. With the inverter operating and with the overcurrent protective devices and switch closed, points A and B are varying in voltage with respect to earth. Resistors R_1 and R_2 would provide a different voltage reference with the inverter off.

Because the voltages at points A and B will be time varying, modules and panels used in this manner would need to be subjected to dielectric voltage withstand and leakage current tests more severe than may be obvious. That is, they will have to withstand ac plus dc dielectric voltage and leakage current tests.

A transformer isolated interactive system is shown in Figure 6.10. A direct path may be provided through switch S_1 to provide the ground, but this path should be interruptable. This path should be paralleled by a high resistance resistor, 1 megohm or the like, to provide a ground reference with the switch open.

6.5 Comparison - Differential and Direct Ground Current Type Devices

A differential type ground fault detector (a) has the ability to function in circuits whose basic ground is not directly under the installer's control, as for example with a transformerless power conditioning unit and a utility controlled ground, (b) with the supplementary circuit, can in certain cases detect spurious grounds which might otherwise negate its operational capability, and (c) permits each sub-division (of the array) to be separately protected. However, the differential type device (a) is more expensive because its circuitry must have the capability of sensing differential currents in the low milliampere range out of total currents in tens or hundreds of amperes, and (b) has the need to keep losses in the detector to a minimum as the normal load current passes through the detectors. We do not know of any differential dc ground fault sensing unit commercially available. One experimental model has been developed by UL.

A direct ground current measuring type (a) has a low cost, basically because of ease of measurement, (b) does not need to keep losses in the detector low as current is normally not passing through the detector, and (c) can provide protection in the entire circuit regardless of where it is located. However, the direct ground type (a) does not allow as much freedom in the methods of circuit grounding (it is not compatible with a utility interactive system with a transformerless power conditioning unit), and (b) cannot be used where the array circuit is to be divided into separately protected sections.

6.6 Laboratory Experimental Work - Concept Verification of a Differential DC Ground Fault Circuit

Concern for the detection of ground fault conditions which may be a hazard to personnel or result in a fire led to research into utilizing a ground fault detection and response system specifically to detect dc ground faults in photovoltaic arrays. Resulting from this effort was a ground fault detection circuit which was experimentally verified in a laboratory field test.

The feasibility of using a dc differential type ground fault protection circuit in a photovoltaic array was partially demonstrated by a laboratory experiment that consisted of breadboarding a dc differential ground fault sensor with a 100 mA imbalance sensitivity and installing it in the Massachusetts Institute of Technology, Lincoln Laboratory (MIT/LL) prototype at the Northeast Residential Experimental Station; Concord, Massachusetts. Details are presented in Appendix G entitled "Development of DC Ground Fault Detector".

The experiment showed the feasibility of such an installation as the ground fault system is believed to have responded to true faults. However, some limitations were incorporated in the experiment, such as restricted sensitivity and no circuit interruptions.

7. SUMMATION, RECOMMENDATIONS AND FUTURE WORK

7.1 Summation

1. A UL Proposed Standard for Safety - Flat-Plate Photovoltaic Modules and Panels, Subject 1703; March, 1982, and proposed National Electrical Code provisions for photovoltaic systems, Article 690, have been prepared. These documents are expected to provide appropriate levels of safety for the installed system.

2. Local ordinances relating to electrical installations may require that the photovoltaic installation adhere to the provisions described in an electrical code such as the National Electrical Code (which provisions would include the use of Listed components). Additionally, building code provisions, especially those relating to roof fire ratings, are likely to be applicable.

3. Where an installation would be made prior to the adaptation of provisions in an appropriate local code (such as the National Electrical Code), 'before the fact' discussions between the installer and the municipal inspector are suggested.

4. The scope of the UL Proposed Standard describes coverage of modules rated for use in systems up to 1000 volts. Although improbable, this 1000 volts may be the voltage of a single module. The proposals for the National Electrical Code would specifically allow systems up to 600 volts. The NEC proposals do not prohibit higher voltage systems, but additional requirements may be applicable.

5. Hazard levels, generally in regard to all aspects of the module performance are mitigated by the UL Proposed Standard. Thus, photovoltaic modules and panels are expected to be covered under the Listing Service of Underwriters Laboratories Inc. The single exception relates to performance as a roof covering, fire testing. This exception exists as requirements for roofing materials vary from community to community, from Class A to no rating.

6. Other Standards of Underwriters Laboratories Inc. may be applicable to photovoltaic modules and other system components.

7. Photovoltaic systems should be provided with both system (circuit) and frame (dead metal) grounding. Alternately, other methods which provide equivalent protection may be substituted for the system ground.

8. A break point exists at 30 volts, separating circuits below this voltage which are not considered a shock hazard from those above this voltage, which will likely be a shock hazard.

7.2 Recommendations

While the foregoing presents concepts for features which should enhance the safety of photovoltaic systems, none has been field tested and proven as to its adequacy or facility for implementation. In order to gain this information (1) modules should be evaluated to the UL Proposed Standard, (2) the safety related performance of both UL Listed and other modules should be monitored, and (3) the conditions of installation (essentially the provisions of the National Electrical Code) evaluated to determine the effect of such on the safety performance. Additional interaction between (a) standards and code writing bodies, and (b) module and photovoltaic system component manufacturers and photovoltaic system installers is desired to achieve this. It is expected that some of this interaction will be through the UL Industry Advisory Group (IAG).

Modification to the present proposals for standards and codes may be warranted depending upon the observed safety-related performances.

Requirements for ancillary components including blocking and bypass diodes should be prepared.

7.3 Future Work

Additional research by UL has begun in the following areas: array safety system concepts applicable to flat-plate photovoltaic modules and panels, including functional and technical descriptions identifying specific safety system responses to each failure mechanism or hazardous situation; grounding concepts for the module/array subsystem; characterization of arc phenomena associated with both ground fault and in-circuit arc generation, detection and prevention; and characterization of intermodule/array, wire/cable systems.

APPENDIX A

PROPOSED STANDARD FOR SAFETY
FLAT-PLATE PHOTOVOLTAIC MODULES AND PANELS

[Note: Material in brackets is not a part of this Proposed Standard. It is included in this draft for explanatory purposes.]

[Note: This document was used as the basis of discussion at the June 29 and 30, 1982 Industry Advisory Group meeting. A new UL Proposed Standard will result from discussions at that meeting.]

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FOREWORD

A. This Standard contains basic requirements for products covered by Underwriters Laboratories Inc. (UL) under its Follow-Up Service for this category within the limitations given below and in the Scope section of this Standard. These requirements are based upon sound engineering principles, research, records of tests and field experience, and an appreciation of the problems of manufacture, installation, and use derived from consultation with and information obtained from manufacturers, users, inspection authorities, and others having specialized experience. They are subject to revision as further experience and investigation may show is necessary or desirable.

B. The observance of the requirements of this Standard by a manufacturer is one of the conditions of the continued coverage of the manufacturer's product.

C. A product which complies with the text of this Standard will not necessarily be judged to comply with the Standard if, when examined and tested, it is found to have other features which impair the level of safety contemplated by these requirements.

D. A product employing materials or having forms of construction differing from those detailed in the requirements of this Standard may be examined and tested according to the intent of the requirements and, if found to be substantially equivalent, may be judged to comply with the Standard.

E. UL, in performing its functions in accordance with its objectives, does not assume or undertake to discharge any responsibility of the manufacturer or any other party. The opinions and findings of UL represent its professional judgment given with due consideration to the necessary limitations of practical operation and state of the art at the time the Standard is processed. UL shall not be responsible to anyone for the use of or reliance upon this Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon this Standard.

F. Many tests required by the Standards of UL are inherently hazardous and adequate safeguards for personnel and property shall be employed in conducting such tests.

GENERAL

1. Scope

1.1 These requirements cover flat-plate photovoltaic modules and panels intended for installation on or integral with buildings, or to be free-standing (i.e. not attached to buildings), in accordance with the National Electrical Code and Model Building Codes.

1.2 These requirements cover modules and panels intended for use in systems with a maximum voltage of 1000 volts.

1.3 These requirements also cover components intended to provide electrical connection to and mounting facilities for flat-plate photovoltaic modules and panels.

1.4 These requirements do not cover equipment intended to accept the electrical output from the array, such as power conditioners (inverters) and batteries, nor do they cover any tracking mechanism.

1.5 These requirements do not cover receivers, nor do they cover optical concentrators.

1.6 These requirements do not cover combination photovoltaic-thermal modules or panels.

2. Glossary

2.1 For the purpose of this standard, the following definitions apply.

2.2 Air Mass (AM) -- A dimensionless quantity, the ratio of the actual path length of radiation through the atmosphere, to the vertical path length of radiation through the atmosphere to sea level. For all but very high zenith angles (θ_z) (the angle subtended by the zenith and the line of sight to the sun),

$$AM = \sec \theta_z, \text{ at sea level.}$$

2.3 Ampacity -- Current-carrying capacity in amperes.

2.4 Array -- A mechanically-integrated assembly of modules and panels, together with support structure and foundation, tracking, thermal control, and other components, if used, to form a dc power-producing unit.

2.5 Blocking Diode -- A diode connected in series with module(s) or panel(s) to prevent reverse current in such module(s) or panel(s).

2.6 Bypass Diode -- A diode connected across one or more cells, modules, or panels in the forward current direction, to allow current to bypass such cells, modules, or panels.

2.7 Cell -- The basic photovoltaic device that generates electricity when exposed to sunlight.

2.8 Encapsulant -- The insulating material enclosing the cells and cell interconnects.

2.9 Interconnect -- A conductor within a module that provides a mechanism for conducting electricity between cells.

2.10 Metallization -- Electrically conductive metal coating on the surface of a cell.

2.11 Minor Dimension (As applied to an opening) -- The diameter of the largest sphere that can be inserted through the opening.

2.12 Module (Flat-plate) -- The smallest environmentally protected, essentially planar assembly of solar cells and ancillary parts such as interconnects and terminals, intended to generate dc power under unconcentrated sunlight.

2.13 Nominal Operating Cell Temperature (NOCT) -- The equilibrium cell junction temperature corresponding to nominal module service operating conditions in a reference environment of 80 mW/cm^2 irradiance, 20°C ambient air temperature, 1 m/s wind, and electrically open circuit.

2.14 Panel (Flat-plate) -- A collection of modules fastened together, assembled and wired, intended to provide a field-installable unit.

2.15 Receiver -- A cell assembly intended to operate under concentrated sunlight.

2.16 Superstrate -- The transparent material forming the top (light facing) outer surface of the module.

2.17 Temperature, Ambient Air -- The temperature of the air immediately surrounding the object being tested.

3. Units Of Measurement

3.1 If a value for measurement is followed by a value in other units in parentheses, the second value may be only approximate. The first stated value is the requirement. SI units are in accordance with the American National Standard for Metric Practice, ANSI/ASTM E380.

CONSTRUCTION

4. Components

4.1 A component of a product covered by this standard shall comply with the requirements for that component and shall be used in accordance with its recognized rating and other limitations of use.

Exception: A component need not comply with a specific requirement that involves a feature or characteristic not needed in the application of the component in the product covered by this standard.

5. General

5.1 A module shall be completely assembled when shipped from the factory. A panel may be completely assembled when shipped from the factory, or may be provided in subassemblies, providing assembly of the panel does not involve any act that is likely to affect compliance with the requirements of this standard.

Exception: An assembly part need not be affixed to the module at the factory.

5.2 Assembly instructions shall be provided with a product shipped in subassemblies, and shall be detailed and adequate to the degree required to facilitate total assembly of the product.

5.3 A module or panel assembly bolt, screw, or other part shall not be intended for securing the complete device to the supporting surface or frame.

5.4 Incorporation of a module or panel into the final assembly shall not require any alteration of the module or panel unless specific details describing necessary modification(s) for alternate installation(s) are provided in the installation instructions. If a module or panel must bear a definite relationship to another for the intended installation and operation of the array (e.g. - to allow connectors to mate), it shall be constructed to permit it to be incorporated into the array in correct relationship without the need for alteration.

5.5 The construction of a product shall be such that during installation it will not be necessary to alter or remove any cover, baffle, insulation, or shield that is required: (1) to prevent excessive temperatures, or (2) guard against unintentional contact with parts that may involve a risk of electric shock.

Exception: A cover of a wiring compartment providing access to a connection means that may involve a risk of electric shock may be removable to allow for the making of electrical connections.

5.6 Parts shall be prevented from loosening or turning if such loosening or turning can create a risk of electric shock or fire.

5.7 Friction between surfaces is not acceptable as the sole means to inhibit the turning or loosening of a part, but a lock washer properly applied is acceptable for this purpose.

5.8 An adjustable or movable structural part shall be provided with a locking device to reduce the likelihood of unintentional shifting, if any such shifting may result in a risk of electric shock, fire, or injury to persons.

5.9 Metals used in locations that may be wet or moist shall not be employed in combinations that could result in deterioration of either metal such that the product would not comply with the requirements in this standard.

5.10 An electrically active part within an insulating base shall be prevented from loosening, and shall be insulated or spaced from accessible parts or parts of other potential. The insulation may be provided by countersinking such a part not less than 1/8 inch (3.2 mm) in the clear and then covering it with a waterproof, insulating sealing compound that does not flow or creep at a temperature 15°C (27°F) higher than the normal operating temperature of the part in the product, but not less than 65°C (149°F) in any case.

6. Insulating Materials

6.1 Systems for the support, enclosure, and/or insulation of a live part shall withstand the most severe conditions likely to be met in service. Among the characteristics required is the ability to resist degradation caused by ultraviolet radiation, salt fog, beating rain, elevated temperatures, and physical abuse (including impact, pushing, and cutting). Systems of polymeric materials shall have a thermal index (electrical and mechanical) as determined in accordance with the Standard for Polymeric Materials - Long Term Property Evaluations, UL 746B, of at least; 90°C (194°F), 20°C (36°F) above the operating temperature of the material as measured during the open-circuit mode Temperature Test, or the operating temperature of the material as measured during the short-circuit mode Temperature Test, whichever is greatest. Systems of polymeric materials shall have a High-Current arc ignition of 60 minimum. For modules or panels with a system voltage rating of 600 volts or less, the systems of polymeric materials shall have a Comparative Track Index of the system voltage rating, minimum. For modules or panels with a system voltage rating of 601-1000 volts the systems of polymeric materials shall have a minimum Inclined Plane Tracking (ASTM D2303) rating of 1 hour using the time to track method at 2.5 kV. The foregoing are as determined in accordance with the Standard for Polymeric Materials - Short Term Property Evaluations, UL 746A. Systems of polymeric materials shall have a maximum flame spread index of 100 as determined under the Standard Method of Test for Surface Flammability of Materials Using a Radiant Heat Energy Source, ASTM E162-1981A.

6.2 Polymeric materials that are exposed to the weather and are required for structure, enclosure of live parts, or insulation, are to be subjected to the Solar Weathering Test described in Section 34. Polymeric materials that are exposed to sunlight but are protected by glass, or other transparent medium, may be tested with an equivalent layer of that medium attenuating the ultraviolet exposure during the test.

6.3 Cells, interconnects, and other live parts shall not be accessible as defined in Section 15, if the open circuit voltage between the part and any other accessible part, including earth, in any described or implied use of the module or panel (i.e. - the system voltage rating), is 30 volts or more, and if the current between such parts exceeds the values contained in Table 21.1. See paragraph 20.3.

6.4 Polymeric encapsulating materials shall not be used in compression if creep of the material under the pressure may reduce the insulation level to less than the required value.

6.5 A barrier or liner of electrical grade fiber providing the sole insulation between a live part and an accessible metal part or between uninsulated live parts not of the same potential shall not be less than 0.028 inch (0.71 mm) thick. The barrier or liner shall be held in place and shall not be adversely affected to the extent that its necessary properties may fall below the minimum values required for the application.

6.6 A barrier or liner of polymeric insulating material providing the sole insulation between a live part and an accessible metal part or between uninsulated live parts not of the same potential shall be of adequate thickness for the application. The barrier or liner shall be held in place and shall not be adversely affected to the extent that its necessary properties may fall below the minimum values required for the application.

6.7 Absorptive materials such as cork or fiber shall not be used in contact with an electrically live part.

7. Current-Carrying Parts (Including Internal Wiring)

7.1 A current-carrying part (including a wire) shall have the mechanical strength and ampacity necessary for the service.

7.2 Wiring used in a module or panel shall be insulated and acceptable for the purpose, when considered with respect to temperature, voltage, and the conditions of service to which the wiring is likely to be subjected within the equipment. Aluminum conductor wire shall not be used if there is a possibility of water accumulation and if it is in contact with other materials that could cause galvanic action.

7.3 A splice shall be provided with insulation equivalent to that required for the wires involved.

7.4 A joint or connection shall be mechanically secure and shall provide electrical contact without strain on connections and terminals. Soldered connections between interconnects and metallizations are considered mechanically secure when held in encapsulation systems.

7.5 An uninsulated live part, including a terminal, shall be secured to its supporting surface by a method other than friction between surfaces so that it will be prevented from turning or shifting in position if such motion may result in reduction of spacings to less than required in Tables 11.1 and 11.2.

7.6 Strain relief shall be provided so that stress on a lead intended for field connection, or otherwise likely to be handled in the field, including a flexible cord, is not transmitted to the connection inside the module or panel.

7.7 The wiring of a module or panel shall be located so that after installation of the product in the intended manner it will not be exposed to the degrading effects of the direct ultraviolet component of sunlight.

8. Wireways

8.1 An enclosure for wire shall be smooth and free from sharp edges, burrs, or the like that may damage insulation or conductors.

9. Connection Means

9.1 In paragraphs 9.2-9.8, connection means are considered to be those to which field-installed wiring is connected when the product is installed.

9.2 A module or panel shall be capable of accommodating at least one of the acceptable wiring systems described in the National Electrical Code (NEC).

9.3 A photovoltaic module or panel shall be provided with wiring terminals, connectors, or leads to accommodate current-carrying conductors of the load circuit.

9.4 The connection means for a module or panel shall be so located that after installation of the product in the intended manner they will not be exposed to the degrading effects of the direct ultraviolet component of sunlight.

9.5 A lead that is intended to be spliced in the field to a circuit conductor shall not be smaller than No. 18 AWG (0.82 mm^2) and the insulation shall not be less than 1/32 inch (0.8 mm) thick.

9.6 The free length of a lead for field connection shall be at least 6 inches (152 mm).

9.7 A binding screw terminal for connection means shall comply with the following:

A. A threaded screw or stud shall be of nonferrous metal appropriate for the application, shall not have more than 32 threads per inch, and shall not be smaller than No. 8 for accommodating No. 10 or 12 AWG (5.3 and 3.3 mm^2 respectively) wire and not smaller than No. 6 for accommodating No. 14 AWG (2.1 mm^2) and smaller wire. A wire-binding screw or stud-and-nut terminal shall be provided with upturned lugs, a cupped washer, a barrier, or other equivalent means to retain the wire in position even though the screw or nut becomes slightly loose. The head of a wire-binding screw for accommodating No. 12 AWG or smaller wire shall have a minimum diameter of 0.275 inch (7.0 mm) and that of a screw for accommodating No. 10 AWG wire shall have a minimum diameter of 0.327 inch (8.3 mm).

B. A tapped terminal plate shall be of nonferrous metal, shall not have less than two full screw threads, and shall be of metal not less than 0.050 inch (1.27 mm) thick for accommodating No. 10 or No. 12 AWG (5.3 and 3.3 mm^2 respectively) wire and not less than 0.030 inch (0.76 mm) thick for accommodating a No. 14 AWG (2.1 mm^2) or smaller wire. Screw threads provided by extruding a hole are acceptable if the thickness of the unextruded metal is not less than the pitch of the screw thread.

9.8 A wire connector intended to accommodate copper conductors only shall comply with the requirements for wire connectors and soldering lugs for use with copper conductors, UL 486A. A wire connector intended to accommodate aluminum and copper conductors shall comply with the requirements for wire connectors for use with aluminum conductors, UL 486B.

[NOTE: Although requirements covering means for accommodating aluminum wire have been included, such wiring method may in fact be unacceptable due to the potential consumption (galvanic corrosion) of the aluminum conductors or overheating of the connections.]

9.9 A wiring terminal of a module or panel intended to accommodate a current-carrying conductor shall be identified by a marking:

"+" or	"-" or
"POS" or	"NEG" or
"POSITIVE"	"NEGATIVE"

9.10 The surface of a lead of a module or panel intended for the connection of a current-carrying conductor shall be identified by:

Red stripe on yellow colored insulation for the positive conductor, and

Black stripe on yellow colored insulation for the negative conductor.

Exception: Other colors for lead insulation may be used if (a) none is white or green, (b) none is one of the mentioned color combinations used for the opposite polarity, and (c) polarity identification is provided by flag labels on the leads or labels at the point of lead emergence.

10. Bonding For Grounding

10.1 A module or panel shall have provision for grounding all accessible conductive (e.g. - metal) parts. The grounding means shall be bonded to each such conductive part of the module or panel that is accessible during normal use.

10.2 Any act of routine maintenance of a module or panel shall not involve breaking or disturbing the bonding path. A bolt, screw, or other part used for bonding purposes shall not be intended for securing the complete device to the supporting surface or frame.

10.3 Bonding shall be by a positive means, such as clamping, riveting, bolted or screwed connections, or welding, soldering (see paragraph 10.6) or brazing. The bonding connection shall penetrate nonconductive coatings, such as paint or vitreous enamel.

10.4 A bolted or screwed connection that incorporates a star washer under the screwhead or a serrated screwhead may be acceptable for penetrating nonconductive coatings. If the bonding means depends upon screw threads, two or more screws or two full threads of a single screw shall engage the metal.

10.5 A splice shall not be employed in a wire conductor used for bonding.

10.6 All joints in the bonding path shall be mechanically secure independent of any soldering.

10.7 A bonding conductor shall be of copper, copper alloy, or other material acceptable for use as an electrical conductor. A ferrous metal part in the grounding path shall be protected against corrosion by metallic or nonmetallic coatings, such as painting, galvanizing or plating. A separate bonding conductor or strap shall: (1) be protected from mechanical damage, and (2) not be secured by a removable fastener used for any purpose other than bonding unless the bonding conductor is unlikely to be omitted after removal and replacement of the fastener.

10.8 A metal-to-metal multiple-bearing pin-type hinge is considered to be an acceptable means for bonding.

10.9 A terminal of a module or panel (for example, a wire-binding screw, a pressure wire connector, or a nut-on-stud) intended to accommodate an equipment grounding conductor shall be identified by being marked "G", "GR", "GROUND", "GROUNDING", or the like, or shall have a green-colored part. No other terminal shall be so identified.

10.10 If a marking is used to identify an equipment grounding terminal, it shall be located on or adjacent to the terminal, or on a wiring diagram affixed to the module or panel near the terminal.

10.11 If a green-colored part is used to identify the equipment grounding terminal, it shall be readily visible during and after installation of the equipment grounding conductor and the portion of the terminal that is green shall not be readily removable from the remainder of the terminal.

10.12 The surface of a lead of a module or panel intended for the connection of an equipment grounding conductor shall be identified by insulation colored green, or green with yellow stripe(s). No other lead shall be so identified.

11. Spacings

11.1 The spacings between uninsulated live parts not of the same potential and between a live part and an accessible metal part, shall not be less than the values specified in Tables 11.1 and 11.2.

Exception: These spacing requirements do not apply to the inherent spacings of a component, such spacings shall comply with the requirements for the component in question.

11.2 The spacings at a field-wiring terminal are to be measured with and without wire connected to the terminal. The wire is to be connected as it would be in actual use. If the terminal will properly accommodate it, and if the product is not marked to restrict its use, the wire is to be one size larger than that required; otherwise, the wire is to be the size required.

11.3 Enamel-insulated and similar film-insulated wire is considered to be an uninsulated live part in determining compliance with the spacing requirements in this standard.

11.4 Surfaces separated by a gap of 0.013 inch (0.33 mm) or less are considered to be in contact with each other for the purpose of judging over-surface spacings.

11.5 In Tables 11.1 and 11.2, the potential involved is the maximum voltage that may exist between parts during any anticipated use of the module or panel.

TABLE 11.1

MINIMUM ACCEPTABLE SPACINGS AT WIRING TERMINALS

Potential Involved Volts	Through Air and Over Surface Inch	(mm)
0-50	1/4	(6.4)
51-300	3/8	(9.5)
301-600	1/2	(12.7)
601-1000	5/8	(15.9)

TABLE 11.2

MINIMUM ACCEPTABLE SPACINGS ELSEWHERE THAN AT WIRING TERMINALS

Potential Involved	Through Air		Over Surface	
Volts	Inch	(mm)	Inch	(mm)
0-50	1/16	(1.6)	1/16	(1.6)
51-300	1/8	(3.2)	1/4	(6.4)
301-600	1/4	(6.4)	3/8	(9.5)
601-1000	3/8	(9.5)	1/2	(12.7)

12. Wiring Compartments

General

12.1 At least 2 cubic inches (32.8 cm^3) for each intended No. 14 AWG (2.1 mm^2) or smaller conductor and at least 2.25 cubic inches (36.9 cm^3) for each intended No. 12 AWG (3.3 mm^2) conductor including integral conductors of the module or panel shall be provided in a wiring compartment. In the space comprising the minimum required volume, no enclosure dimension shall be less than 3/4 inch (19.1 mm).

12.2 A wiring compartment shall be provided with means for connection to a wiring system.

12.3 A wiring compartment intended for use with open wiring shall have provision for the separate entry of each conductor through a hole.

12.4 A wiring compartment shall have provision for securing conductors entering the compartment. In determining compliance to this provision, wire binding screw terminals, pigtail leads, and the like, to which the field installed leads are connected are not considered a means for securing the conductors.

Exception No. 1: A wiring compartment intended for use with conduit (metallic or nonmetallic) or for use with electrical metallic tubing need not have provision for securing conductors entering the box.

Exception No. 2: For a wiring compartment intended for use with sheathed cable, the compartment shall have provision for securing the sheathed conductors.

12.5 An unthreaded hole for open wiring shall not be located in the top of the wiring compartment unless a hood fitting is provided; if an unthreaded hole is located in a side above live parts, it shall provide for the wire leaving the enclosure in the downward direction.

12.6 There shall be provision for drainage of a compartment if a knockout or an unthreaded conduit opening is provided. The minor dimension of a drainage opening shall be not less than 1/8 inch (3.2 mm).

12.7 A wiring compartment shall have no more than one opening when the module or panel is shipped from the factory. Tapped holes with screwed-in plugs are not considered openings.

Exception: Two openings where open wiring is intended to be accommodated.

12.8 Gaskets and seals shall not deteriorate beyond limits during accelerated aging, and shall not be used where they may be subject to flexing during normal operation. See Section 33.

Metallic Wiring Compartments

12.9 A wiring compartment of sheet steel shall have a wall thickness of not less than 0.053 inch (1.35 mm) if measured uncoated, or 0.056 inch (1.42 mm) if measured with a zinc coating.

12.10 A wiring compartment of sheet aluminum shall have a wall thickness of not less than 0.0625 inch (1.59 mm).

12.11 A wiring compartment of cast iron, aluminum, brass, or bronze shall have a wall thickness of not less than 3/32 inch (2.4 mm).

12.12 A hole intended for the connection of rigid metal conduit in the enclosure of a metal wiring compartment shall be threaded, unless it is located entirely below the lowest live part in the compartment other than insulated wires.

12.13 A threaded hole in a metal wiring compartment intended for the connection of rigid metal conduit shall be reinforced to provide metal not less than 1/4 inch (6.4 mm) thick, and shall be tapered unless a conduit end stop is provided.

12.14 If threads for the connection of conduit are tapped all the way through a hole in a compartment wall, or if an equivalent construction is employed, there shall not be less than 3-1/2 nor more than 5 threads in the metal and the construction shall be such that a conduit bushing can be attached as intended.

12.15 If threads for the connection of conduit are not tapped all the way through a hole in a compartment wall, there shall not be less than five full threads in the metal and there shall be a smooth, rounded inlet hole for the conductors which shall afford protection to the conductors equivalent to that provided by a standard conduit bushing. The throat diameter of an inlet hole shall be within the limits specified in the Standard for Outlet Boxes and Fittings, UL 514.

12.16 For a non-threaded opening (where permitted) in a metal wiring compartment intended to accommodate rigid metallic conduit, a flat surface of sufficient area as described in the Standard for Outlet Boxes and Fittings, UL 514 shall be provided around the opening to accept the bearing surfaces of the bushing and lockwasher.

Nonmetallic Wiring Compartments

12.17 A wiring compartment of a nonmetallic (polymeric) material shall have a wall thickness of not less than 0.125 inch (3.18 mm).

12.18 A nonmetallic wiring compartment intended to accommodate nonmetallic conduit shall either (1) have one or more unthreaded conduit-connection sockets that comply with the requirements in paragraphs 12.20-12.22, integral with the compartment, (2) have one threaded or unthreaded opening for a conduit-connection socket, or (3) be blank for use with a conduit connection socket.

12.19 If a conduit connection socket may be used, the accommodating wall of a nonmetallic compartment shall have a sufficient flat surface to accommodate the bearing surfaces of the locknut and male adapter.

12.20 In a nonmetallic compartment, a socket for the conection of nonmetallic conduit shall provide a positive end stop for the conduit; and the socket diameters, the throat diameter at the entrance to the box, and the wall thickness of the socket shall be within the limits specified in Table 12.1.

12.21 The socket depth shall be within the limits specified in Table 12.1.

12.22 The wall thickness of the socket shall not be less than specified in Table 12.1.

TABLE 12.1
DIMENSIONS OF CONDUIT CONNECTION SOCKETS, NONMETALLIC WIRING COMPARTMENTS

Trade Size of Conduit, Inches	Socket Wall Minimum Thickness in. (mm)	Socket Diameter, Inches (mm)				Socket Depth, Inches (mm)		Minimum Throat Diameter, Inches (mm)	
		At Entrance		At Bottom				For Use With Heavy-Wall Conduit	For Use With Thin-Wall Conduit
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum		
1/2	0.095	0.860	0.844	0.844	0.828	1.500	0.652	0.630	0.728
	(2.41)	(21.84)	(21.44)	(21.44)	(21.03)	(38.10)	(16.56)	(16.00)	(18.49)
3/4	0.095	1.074	1.054	1.056	1.036	1.500	0.719	0.834	0.840
	(2.41)	(27.28)	(26.77)	(26.82)	(26.31)	(38.10)	(18.26)	(21.18)	(21.34)
1	0.100	1.340	1.320	1.320	1.300	1.875	0.875	1.059	1.205
	(2.54)	(34.04)	(33.53)	(33.53)	(33.02)	(47.63)	(22.23)	(26.90)	(30.61)
1-1/4	0.120	1.689	1.665	1.667	1.643	2.000	0.938	1.392	1.532
	(3.05)	(42.90)	(42.29)	(42.34)	(41.73)	(50.80)	(23.83)	(35.36)	(38.91)
1-1/2	0.120	1.930	1.906	1.906	1.882	2.000	1.062	1.622	1.752
	(3.05)	(49.02)	(48.41)	(48.41)	(47.80)	(50.80)	(26.97)	(41.20)	(44.50)
2	0.130	2.405	2.381	2.381	2.357	2.000	1.125	2.097	2.187
	(3.30)	(61.09)	(60.48)	(60.48)	(59.87)	(50.80)	(28.58)	(52.81)	(55.55)
2-1/2	0.165	2.905	2.875	2.883	2.853	3.000	1.469	2.484	2.670
	(4.19)	(73.79)	(73.03)	(73.23)	(72.47)	(76.20)	(37.31)	(63.09)	(67.82)
3	0.216	3.530	3.500	3.507	3.477	3.125	1.594	3.083	3.365
	(5.49)	(89.66)	(88.90)	(89.08)	(88.32)	(79.38)	(40.49)	(78.31)	(85.47)
3-1/2	0.226	4.065	3.965	4.007	3.977	3.250	1.687	3.598	3.760
	(5.74)	(103.25)	(100.71)	(101.78)	(101.02)	(82.55)	(42.85)	(91.39)	(95.50)
4	0.237	4.565	4.465	4.506	4.476	3.375	1.750	4.076	4.250
	(6.02)	(115.95)	(113.41)	(114.45)	(113.69)	(85.73)	(44.45)	(103.53)	(107.95)
5	0.258	5.643	5.543	5.583	5.523	3.625	1.937	5.097	-
	(6.55)	(143.33)	(140.79)	(141.81)	(140.28)	(92.80)	(49.20)	(129.46)	-
6	0.280	6.708	6.608	6.644	6.584	3.750	2.125	6.115	-
	(7.11)	(170.38)	(167.84)	(168.76)	(167.23)	(95.25)	(53.98)	(155.32)	-

13. Corrosion Resistance

[While several options are presented concerning corrosion protection schemes, not all may be acceptable (i.e. - some may be rejected by the municipal inspector) in a particular location.]

13.1 Sheet steel having a thickness of 0.120 inch (3.05 mm) or more that may be exposed to the weather shall be made corrosion-resistant by one of the following coatings:

A. Hot-dipped mill-galvanized sheet steel conforming with the coating designation G60 in Table I of ASTM A525-76, with not less than 40% of the zinc on any side, based on the minimum single spot-test requirement in this ASTM specification. The weight of zinc coating may be determined by any method; however, in case of question, the weight of coating shall be established in accordance with the test method of ASTM A90-69.

B. A zinc coating, other than that provided on hot-dipped mill-galvanized sheet steel, uniformly applied to an average thickness of not less than 0.00041 inch (0.010 mm) on each surface with a minimum thickness of 0.00034 inch (0.009 mm). The thickness of the coating shall be established by the Metallic Coating Thickness Test in Section 39.

C. An organic or inorganic protective coating system on both surfaces, applied after forming. The results of an evaluation of the coating system shall demonstrate that it provides protection at least equivalent to that afforded by the zinc coating described in item A. See Sections 34 and 38.

D. Any one of the means specified in paragraph 13.2.

13.2 Sheet steel having a thickness of less than 0.120 inch (3.05 mm) which may be exposed to the weather shall be made corrosion resistant by one of the following coatings:

A. Hot-dipped mill-galvanized sheet steel conforming with the coating designation G90 in Table I of ASTM A525-76, with not less than 40% of the zinc on any side, based on the minimum single spot-test requirement in this ASTM Specification. The weight of zinc coating may be determined by any method; however, in case of question, the weight of coating shall be established in accordance with the test method of ASTM A90-69.

B. A zinc coating, other than that provided on hot-dipped mill-galvanized sheet steel, uniformly applied to an average thickness of not less than 0.00061 inch (0.015 mm) on each surface with a minimum thickness of 0.00054 inch (0.014 mm). The thickness of the coating shall be established by the Metallic Coating Thickness Test in Section 39. An annealed coating shall also comply with paragraphs 13.4 and 13.5.

C. A cadmium coating not less than 0.0010 inch (0.025 mm) thick on both surfaces. The thickness of the coating shall be established by the Metallic Coating Thickness Test in Section 39.

D. A zinc coating conforming with Item A or B of Paragraph 13.1 with one coat of outdoor paint. The coating system shall comply with Paragraph 13.2, Part F.

E. A cadmium coating not less than 0.00075 inch (0.019 mm) thick on both surfaces with one coat of outdoor paint on both surfaces, or not less than 0.00051 inch (0.013 mm) thick on both surfaces with two coats of outdoor paint on both surfaces. The thickness of the cadmium coating shall be established by the Metallic Coating Thickness Test in Section 39 and the coating system shall comply with Item F.

F. With reference to Parts D and E, the results of an evaluation of the coating system shall demonstrate that it provides protection at least equivalent to that afforded by the zinc coating as described in Part A (G90). See Sections 34 and 38.

13.3 With reference to paragraphs 13.1 and 13.2, other finishes, including paints, special metallic finishes and combinations of the two may be accepted when comparative tests with galvanized sheet steel (without annealing, wiping, or other surface treatment) conforming with Item A of paragraph 13.1 or 13.2 as applicable, indicate they provide equivalent protection. See Sections 34 and 38.

13.4 An annealed coating on sheet steel that is bent or similarly formed or extruded or rolled at edge of holes after annealing shall additionally be painted in the bent or formed area if the bending or forming process damages the zinc coating.

13.5 If flaking or cracking of a zinc coating at the outside radius of a bent or formed section is visible at 25 power magnification, the zinc coating is considered damaged. Simple sheared or cut edges and punched holes are not required to be additionally protected.

13.6 Iron or steel serving as a necessary part of the product but not exposed to the weather shall be plated, painted, or enameled for protection against corrosion.

13.7 Aluminum may be used without special corrosion resistance.

13.8 Materials not specifically mentioned in Section 13 shall be evaluated on an individual basis. The tests described in Sections 34 and 38 may be used in this evaluation.

14. Edges

14.1 Edges, projections, and corners of photovoltaic modules and panels shall be such as to reduce the risk of cuts to personnel. Compliance is to be determined as described in the Standard, Determination of Sharpness of Edges on Equipment, UL 1439.

15. Accessibility

15.1 No accessible part of a module or panel shall involve a risk of electric shock.

Exception: A part that is not energized when it is accessible.

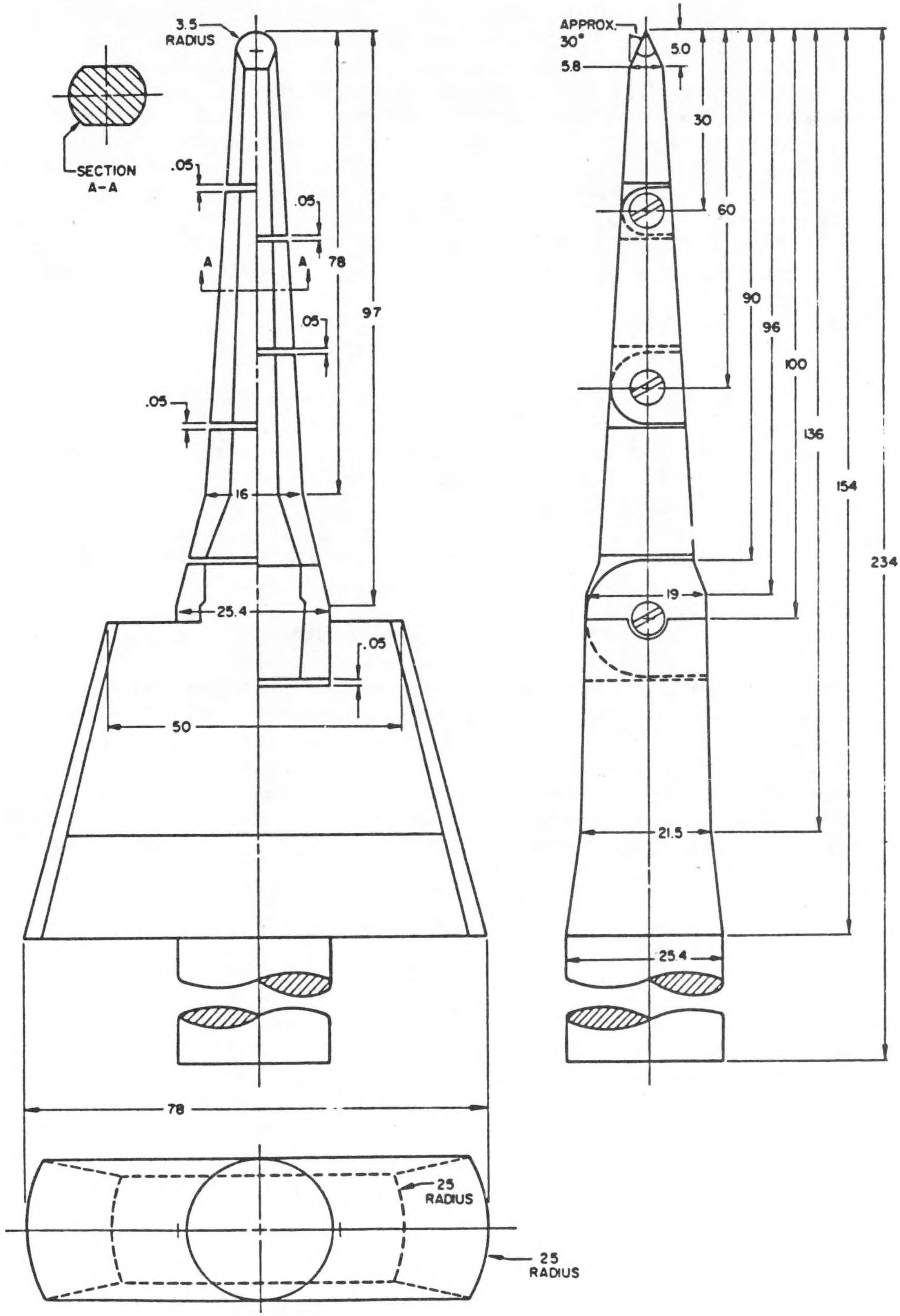
15.2 A part is considered accessible if, in a fully assembled module or panel (that is, with all covers in place) the part may be touched by the probe illustrated in Figure 15.1.

Exception No. 1: A cover that may be removed without the use of a tool is to be removed for purposes of this requirement.

Exception No. 2: A cover that may be removed (with or without a tool) for routine maintenance such as cleaning, or to gain access to tools, is to be removed for purposes of this requirement.

15.3 The probe illustrated in Figure 15.1 shall be applied to any depth that the opening will permit; and shall be rotated or angled before, during, and after insertion through the opening to any position that is necessary to examine the product. The probe shall be applied in any possible configuration; and, if necessary, the configuration shall be changed after insertion through the opening. The probe shall be used as a measuring instrument to judge the accessibility provided by an opening, and not as an instrument to judge the strength of a material; it shall be applied with the minimum force necessary to accurately determine accessibility.

FIGURE 15.1
PROBE FOR DETERMINING ACCESSIBILITY OF LIVE PARTS



Dimensions in millimeters

15.4 A part is considered to involve a risk of electric shock if it does not comply with the requirements of Section 21.

16. Fire Resistance

16.1 A module or panel intended for stand-off, rack, or direct mounting in combination with a prescribed roof, and a module intended for mounting as part of the roof covering itself, shall comply with the requirements for a Class A, B, or C roof covering if it is indicated or implied as being fire rated. For the combination situation, this rating need not be coincident with the basic roof covering material rating. The fire resistance shall be determined by the procedure of tests for fire resistance of roof covering materials, UL 790, as modified by Section 31.

17. Superstrate

17.1 A module or panel if of glass superstrate shall:

A. Comply with the requirements in Performance Specifications and Methods of Test for Safety Glazing Material Used in Buildings, ANSI Z97.1-1975,

B. Comply with the requirements in the Safety Standard for Architectural Glazing Materials, CPSC, Standard Part 1201, or

C. Comply with the Impact Test, Section 30.

Exception No. 1: Thin-film flexible glazing material having a thicknesses of 0.01 inch (0.254 mm) or less need not comply with this requirement.

Exception No. 2: Encapsulant that is protected with wire screen or other similar means having openings that will not pass a 1/2 inch (12.7 mm) diameter hemispherically tipped probe applied with a force of 1 lb (4.4 N).

PERFORMANCE

18. General

18.1 The uniformity of the irradiance over the surface of the module or panel during the temperature and voltage and current measurements tests, Sections 19 and 20, is to be such that the difference between the maximum and minimum irradiance over the surface is not more than four percent of the sum of the maximum and minimum irradiance. The aperture of the instrument used to determine uniformity shall be

_______________.

18.2 The angle of incidence of the radiation at any point on the module or panel during the temperature and voltage and current measurements tests, Sections 19 and 20, is not to be more than 30 degrees.

18.3 The order of presentation of tests is for convenience only, and is not intended to imply that any one sample need be subjected to the complete sequence or a partial sequence of tests unless specifically stated. Except where a sample is to be subjected to a sequence of tests, separate samples may be used; for example, one for each test, if desired.

19. Temperature

19.1 When a photovoltaic module or panel is at thermal equilibrium in its intended application mounting, referenced to 100 mW/cm^2 irradiation, AM 1.5 spectrum, 40°C air temperature, nominal still air, electrical open circuit, and also hot-spot heating associated with operation at short-circuit; no part shall attain a temperature that would:

A. Ignite materials or components.

B. Cause the temperature limits of surfaces, materials, or components, as described in Table 19.1, to be exceeded.

C. Cause creeping, distortion, sagging, charring or similar damage to any part of the product, if such damage or deterioration may impair the performance of the product under the requirements of this Standard.

D. Impose, by virtue of the module or panel, a temperature on an adjacent structural member that would impair that member.

TABLE 19.1. MAXIMUM TEMPERATURE

Part, Material, or Component	Temperature °C	(°F)
1. Insulating materials:		
Polymeric	(a)	(a)
Varnished cloth	85	185
Fiber	90	194
Wood and similar material	90	194
Laminated phenolic composition	125	257
Molded phenolic composition	150	302
2. Sealing compound	(b)	(b)
3. Field wiring terminals (c)	60	140
4. Field wiring compartment that wires may contact (c)	60	140
5. Metals (d)		
Galvanized steel (e)	292	557
Aluminum alloys		
1100	208	407
3003	264	507
2014, 2017, 2024, 5052	319	607
6. Insulated conductors		
Temperature Rating		
75°C	75	167
80°C	80	176
90°C	90	194
105°C	105	221
200°C	200	392
250°C	250	482
7. Flexible cord of Types SO, ST, SJO, SJT (f)	60	140
8. Other types of insulated wires	(g)	(g)
9. Surfaces accessible to contact	(h)	(h)

Notes for Table 19.1:

(a) For the open-circuit mode, the relative thermal index, less 20°C (36°F). For the short-circuit "hot spot" mode, the relative thermal index. [The relative thermal index describes the maximum temperature, for a specific time, at which a material can be expected to retain its characteristics.]

(b) The maximum sealing compound temperature, when corrected to a 40°C (104°F) ambient temperature, is to be 15°C (27°F) less than the softening point of the compound as determined by the Standard Test Method for Softening Point by Ring and Ball Apparatus, ASTM E28-1967 (1977).

(c) If a marking is provided in accordance with paragraph 45.4, the temperatures observed on the terminals and at points within a wiring compartment may exceed the value specified but shall not attain a temperature higher than 90°C (194°F).

(d) Higher temperatures than specified are acceptable if it can be determined that the higher temperatures will not cause a risk of shock or fire or conditions not in compliance with Items A, C, or D of paragraph 19.1.

(e) The specified maximum temperature applies if the galvanizing is required as a protective coating or the reflectivity of the surface is utilized to reduce the temperatures on other materials.

(f) Higher temperatures than specified are acceptable if flexible cord is marked as being rated for such use.

(g) For insulated conductors other than those mentioned, reference should be made to the National Electrical Code, ANSI/NFPA No. 70-1981.

(h) Only for hot-spot heating under short-circuit conditions; for nonmetallic surfaces 40°C (72°F) above temperature achieved during open-circuit conditions; for metallic surfaces, 20°C (36°F) above temperature achieved during open-circuit conditions.

19.2 Material and component temperatures are to be determined for an ambient temperature of 40°C and 100 mW/cm^2 irradiance, measured in the plane of the panel, 1 meter/sec (2.237 mph) average wind speed. The ambient temperature may be in the range of 10°C to 55°C, in which case each observed temperature shall be corrected by the addition (if the ambient temperature is below 40°C) or subtraction (if the ambient temperature is above 40°C) of the difference between 40°C and the observed ambient temperature. If the irradiance is other than 100 mW/cm^2, temperature rises for numerous irradiance levels are to be determined, and a linear extrapolation conducted to determine temperature rise under 100 mW/cm^2 irradiance.

19.3 Should an unacceptable performance be encountered during the temperature test, and the performance be attributed to a test condition that, although within the limits specified, may be considered more severe than necessary; for example an ambient temperature near the bounds allowed (10°C or 55°C), the test may be reconducted under conditions closer to the norm.

19.4 The ambient temperature is to be measured by an iron-constantan thermocouple of No. 30 AWG wires, with the junction located centrally within a 6 inch (152 mm) length of 2 inch (trade size) steel pipe complying with ANSI B36.10. The pipe is to be open at both ends, and aluminum painted inside and outside.

19.5 The ambient temperature thermocouple junction is to be covered by a close-fitting, polished, nickel sphere, 5 mm (0.197 in.) in diameter and is to be located, with the axis of the pipe vertical with the pipe midway between the top and bottom of the module or panel under test. The bottom of the pipe shall be at least 3 inches (76 mm) from any horizontal surface and 12 inches (305 mm) horizontally from the module, panel, or support structure, at least 12 inches (305 mm) from any other object except the horizontal supporting surface, and not in any path of heat flow. If the temperature of the ambience of the product is not uniform, several thermocouples, placed around the product, shall be used, and the mean value of the several readings represents the ambient temperature.

19.6 A module or panel is to be operated in both of the following modes until constant temperatures (see paragraph 19.15) are attained:

A. Open-Circuited.

B. Short-Circuited.

19.7 For the test under short-circuit:

A. One-half of one of the cells of the module or panel is to be covered with black vinyl adhesive tape, 0.007 inches (0.18 mm) thick in direct contact with the superstrate so that this cell is not irradiated, and

B. Modules or panels shall be connected in series without bypass diodes to the extent that would be permitted by the marking affixed to them. See paragraph 45.8.

COMMENTARY: The object of the partial shadowing of a cell under short-circuit operation is inducement of reverse voltage heating of this cell. Thus, as this cell may be expected to achieve a higher temperature than the forward operating cells, the temperatures on and about this shaded cell should be measured.

[NOTE: Consideration is being given to change the level of cell shading from 50% to that which results in maximum power dissipation in the shaded cell.]

19.8 A module or panel is to be installed according to the instructions provided with it. If the instructions do not describe the accommodating structure, spacings, and the like, the module or panel is to be mounted as described in paragraphs 19.10-19.12.

19.9 With reference to paragraphs 19.10-19.11, the type of mounting intended, (for example, stand-off, direct, and the like) is to be determined from the construction of the module or panel. If more than one type of mounting is possible, the module or panel is to be tested in each such mounting, unless one mounting can be shown to represent all.

19.10 A module or panel intended for direct mounting on a roof or wall surface is to be mounted on a platform constructed of wood, pressed wood, or plywood, 3/4 inch (19 mm) thick (see Figure 19.1). The platform is to be painted flat black at the side facing the test sample. The platform is to extend at least 2 feet (0.6 m) beyond the module or panel on all sides.

19.11 A module or panel intended for stand-off or rack mounting on a roof, wall, or the ground is to be mounted on a frame constructed from 2 by 4-inch (trade size) lumber. Two frame members are to be located at the outside edges of the underside of the module or panel, and are to be oriented longitudinally along the long axis of the module or panel. Additional frame members are to be located at the outside edges of the underside of the module or panel along its short axis. If the distance between the two outer short axis members exceeds 2 feet (0.6 m), an additional frame member is to be located at the center line of the module or panel assembly. The frame is to be secured to a platform as described in paragraph 19.10 with a 4-foot (1.22 m) spacing between the back of the module or panel and the platform (see Figure 19.2). The frame is to be painted flat black on the side facing the test sample.

19.12 A module or panel intended for integral mounting within a roof or wall is to be tested while mounted on a platform constructed as described in paragraph 19.10 with the module or panel boxed in on all sides by 1-inch thick (trade size) wood boards that are wide enough to cover the entire outer edge. The boards are to be painted flat black on the side facing the sample.

[NOTE: Insulation may need to be included in the test installation, representing the insulation that may be incorporated in the installation of the module as in service. This item is under study.]

19.13 Temperatures are to be measured by means of thermocouples. Thermocouples exposed to irradiation are to be shielded from the direct effect of such irradiation by _______________ tape. A thermocouple junction is to be securely held in positive thermal contact with the surface of the material the temperature of which is being measured. Thermal contact may be achieved by securely cementing the thermocouple in place. For a metal surface, brazing, welding, or soldering the thermocouple to the metal may be used. A thermocouple junction may be secured to wire insulation or wood surfaces by taping.

19.14 Commonly, thermocouples consisting of iron and constantan wires No. 30 AWG (0.05 mm^2), and a potentiometer-type instrument are employed. If it is not practical to use iron and constantan thermocouples some other type described Temperature Measurement Thermocouples, ANSI MC96.1-1975, may be used.

19.15 A temperature is considered to be constant when three successive readings taken at 15-minute intervals indicate that there is 1 degree C or less of temperature change.

FIGURE 19.1
FIXTURE FOR TEST
PRODUCTS FOR DIRECT MOUNTING

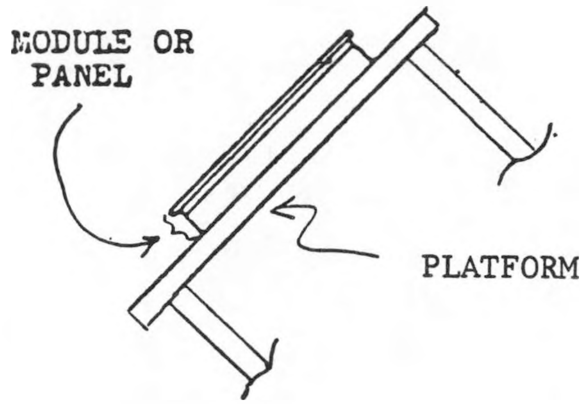


FIGURE 19.2
FIXTURE FOR TEST
PRODUCTS FOR STAND-OFF OR RACK MOUNTING

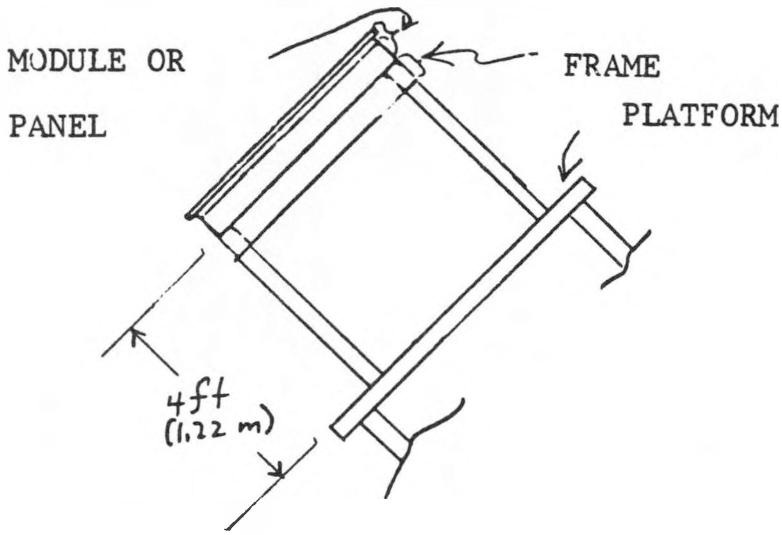
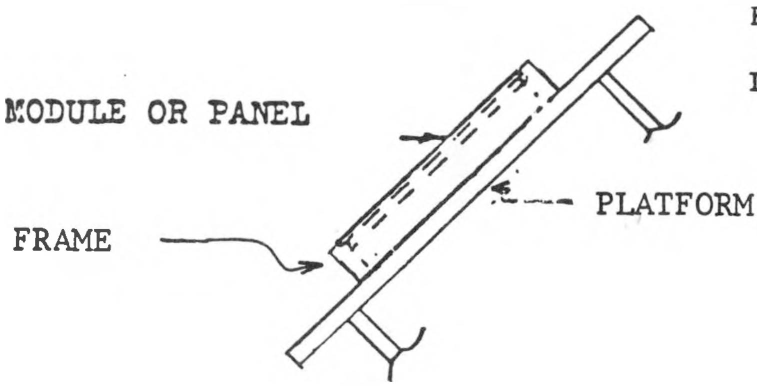


FIGURE 19.3
FIXTURE FOR TESTS
PRODUCTS FOR
INTEGRAL MOUNTING



20. Voltage and Current Measurements

20.1 The output currents of a module or panel shall not be less than 85 percent nor more than the rated values under conditions of:

A. Short circuit, and

B. Maximum power output,

both in an environment of 100 mW/cm^2 irradiance, 20°C air temperature, and 1 m/s (2.237 mph) average wind speed.

20.2 The output voltages of a module or panel shall be within ±10 percent of the rated values under conditions of:

A. Open circuit, an irradiance of 100 mW/cm^2, a cell temperature of 0°C, and

B. Maximum power output, in an environment of 100 mW/cm^2 irradiance, 20°C air temperature, and 1 m/s average wind speed.

20.3 For purposes of accessibility to live parts, paragraph 6.3, voltage shall be determined under conditions of open circuit, an irradiance of 100 mW/cm^2, and a cell temperature of -20°C.

20.4 Voltage and current values may be measured at temperatures other than those specified in paragraphs 20.1-20.3, and values at the specified temperatures calculated by way of temperature correction coefficients.

21. Leakage Current

21.1 The leakage current of a module having a marked maximum system voltage of 30 volts or more, shall not be greater than the values specified in Table 21.1 when tested as described in paragraphs 21.3-21.8.

21.2 The test is to be conducted on three unconditioned specimens of a module, and the specimens that have been subjected to Voltage Surge, Section 28; and Exposure to Water Spray Test, Section 32. Where panels are used for the Exposure to Water Spray Test, modules of these panels are to be used for the Leakage Current Test that follows.

21.3 Leakage current refers to all current, including steady state ac capacitive currents, that may be conveyed between accessible surfaces and accessible circuit parts of a module when the module is connected to the sources as described in paragraphs 21.4 and 21.5.

21.4 Both the ac and dc test voltages are to be at a level equal to the rated maximum acceptable voltages (ac rms and dc system).

[NOTE: Leakage current requirements are based on the maximum voltage to ground to which a module may be subjected; therefore, the critical dc voltage is the maximum array dc voltage, not the module voltage. The maximum ac voltage will be associated with the maximum ac ripple voltage on the array. The level of ac may be equal to the array voltage, depending upon the grounding scheme.]

TABLE 21.1
ALLOWABLE LEAKAGE CURRENT

Surface or Part from Which Measurement Is Made	Maximum Current ac (rms)	Maximum Current dc
Accessible conductive frame, pan, or the like.	10 μA	10 μA
Accessible circuit parts	0.5 mA	1 mA
Conductive foil over accessible insulating surfaces	0.5 mA	1 mA

21.5 All accessible parts and surfaces are to be tested for leakage current. The positive and negative terminals of an unilluminated module are to be connected together and to one terminal of first a 60 hertz sinusoidal power supply and second a dc power supply. For the dc tests, both polarities of the source connection are to be used, unless it can be shown that one polarity will represent both. Leakage currents are to be measured between the part or surface and the other terminal of the power supply. Leakage current is to be measured with the meters described in paragraphs 21.7 and 21.8.

21.6 When leakage current is measured at an insulating surface, a 40 by 20 cm conductive foil is to be in contact with the surface, and the measurement is to be made from the foil. If the surface is less than 40 by 20 centimeters, the foil is to be the same size as the surface.

21.7 The meter for the dc measurement is to be responsive to dc only, and is to have an input impedance of 500 ohms.

21.8 The meter for ac measurement is to indicate the rms value of the current, and is to have an input impedance of 500 ohms resistive.

22. Strain Relief

22.1 A lead for connection to external wiring, or an internal lead that may be subject to handling during installation or routine servicing of a module or panel, including a flexible cord, shall withstand for one minute a force of 20 pounds (89 newtons) applied in any direction permitted by the construction, without damage to either the lead, its connecting means, or the module or panel.

23. Push and Cut

23.1 Any point on the surface of the complete module or panel shall be capable of withstanding for one minute the application of a 20 pound (89 newton) force applied by a 1/2 inch (12.7 mm) diameter rod, the end of which is rounded to a 1/2 inch (12.7 mm) diameter hemisphere, and the application of a 4 pound (17.8 newton) force applied by a 1/16 inch (1.6 mm) diameter rod, the end of which is rounded to a 1/16 inch (1.6 mm) diameter hemisphere, without resulting in the accessibility (transitory or permanent) (see Section 15) of a part involving a risk of electric shock and without resulting in contact between the rod and a part involving a risk of electric shock.

23.2 The front and rear surfaces of a module or panel shall be capable of withstanding the test described in paragraph 23.3 without resulting in the accessibility (transitory or permanent) (see Section 15) of a part involving a risk of electric shock and without resulting in contact between the tool and a part involving a risk of electric shock.

23.3 The module or panel is to be positioned in a horizontal plane with the surface under test facing upward. The tool described in Figure 23.1 is to be placed on the surface for one minute, and then drawn across both the front and rear surfaces of the module or panel at a speed of 6 ± 1.2 inches/sec (152.4 ± 30.5 mm/sec).

Exception: The test is not to be conducted on the rear cell encapsulant for a module or panel whose rear surface is not exposed after any expected installation of the product.

24. Bonding Path Integrity

24.1 The integrity and ampacity of the bonding path shall be such that when a current equal to twice the module or panel rated short-circuit current is caused to flow through the grounding path, the voltage across the path does not exceed one (1.0) volt.

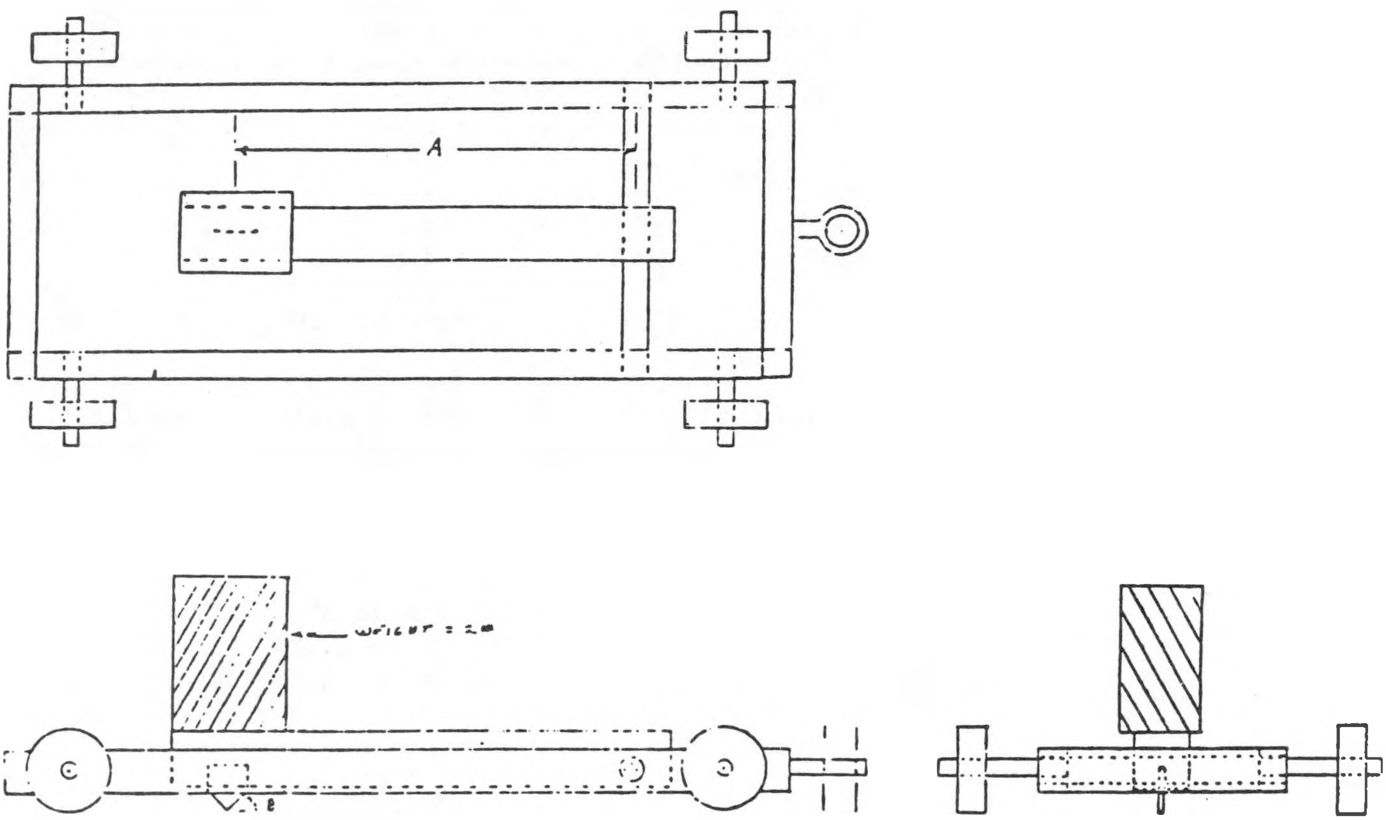
24.2 A direct current shall be caused to flow from the terminal or lead intended to accept the grounding conductor, to any accessible metal part that is likely to become energized by a fault of the insulation system and that is located farthest away from the grounding point.

24.3 The current shall be increased from zero to a value equal to twice the rated short circuit current of the module or panel at 100 mW/cm^2 and NOCT. The rate of increase shall be uniform and be such as to obtain the specified current in approximately 5 seconds. The specified current shall be maintained for 2 minutes.

24.4 At no time during the test shall the voltage between the points of application of current exceed 1 volt. The voltage measurement is to be made on the module or panel within a distance of 1/2 inch (12.7 mm) from the point of current injection.

24.5 If more than one test is deemed necessary to evaluate all the paths of conduction between accessible metal parts, a cooling time of at least 15 minutes between tests shall be observed.

FIGURE 23.1
CUT TEST TOOL
[Dimensions to be added]



24.6 The test is to be conducted on three unconditioned specimens.

25. Dielectric Voltage Withstand

25.1 The insulation and spacings between live parts and accessible conductive parts and between live parts and exposed nonconductive surfaces shall withstand the application of test voltages equal to 2 x system voltage + 1000 volts without evidence of breakdown. The voltages are to be both dc and a composite of ac and dc.

25.2 The dc test voltage is to be 2V+1000 volts, where V is the rated maximum acceptable system voltage. The dc voltage is to be applied separately, and in both polarities.

25.3 The composite (dc plus ac) test voltage is to be a dc voltage of $2V_1 + A$ volts (where V_1 is the rated maximum acceptable dc system voltage), on which is imposed a 60 hertz sinusoidal alternating voltage of $2V_2 + B$ volts rms (where V_2 is the rated maximum acceptable ac rms voltage). A and B are determined as follows:

$$A + B = 1000 \text{ volts, and}$$

$$\frac{A}{B} = \frac{\text{rated maximum acceptable dc system voltage}}{\text{rated maximum acceptable rms voltage}}$$

25.4 The test voltage is to be applied between all current carrying parts and all accessible parts.

25.5 The voltage is to be increased from zero at a substantially uniform rate so as to arrive at the specified test potential in approximately 5 seconds, and then held at the required test voltage for 5 minutes. The module or panel is to be observed during the test and there are to be no signs of arcing or flash-over.

25.6 The test voltage is to be gradually and smoothly increased to the specified value so that (a) there are no transients that might cause the instantaneous voltage to exceed the peak value specified, and (b) the flow of capacitive current, as due to charging, does not cause the test device to indicate breakdown.

25.7 The test is to be conducted on three unconditioned specimens, and the specimens that have been subjected to Voltage Surge, Section 28; Exposure to Hail, Section 29; Exposure to Water Spray, Section 32; Temperature Cycling, Section 35; Humidity, Section 36; and Corrosive Atmosphere, Section 38. The unconditioned samples are to be at both room temperature and also as heated from the short circuit operation portion of the temperature test in Section 19.

25.8 For tests on exposed surfaces of insulating parts, the part is to be covered with conductive foil or the equivalent.

25.9 Each of the pieces of test equipment for conducting the dielectric voltage-withstand test is to have the following features and characteristics:

A. A means for indicating the test voltage that is being applied to the product under test. This may be accomplished by sensing the voltage at the test leads or by an equivalent means.

B. For an AC machine, an output voltage that (1) has a sinusoidal waveform, (2) has a frequency that is within the range of 40-70 hertz, and (3) has a peak value of the waveform that is not less than 1.3 and not more than 1.5 times the root-mean-square value.

C. For a DC machine, an output voltage that has a maximum of __________ percent ripple. Percent ripple is defined as 100 times the ratio of the rms value of the ac voltage to the dc voltage.

D. A sensitivity such that when a 1 megohm resistor is connected across the output, the test equipment does not indicate unacceptable performance for any output voltage less than the specified test voltage, and the test equipment does indicate unacceptable performance for any output voltage equal to or greater than the specified test value. The resistance of the calibrating resistor is to be adjusted as close to 1 megohm as instrumentation accuracy can provide, but never more than 1 megohm.

26. Inverse Current Overload

26.1 There shall be no flaming of the cheesecloth or tissue paper in contact with a module or panel, or flaming of the module or panel itself for 15 seconds or more, when a current equal to 135 percent of the module or panel series fuse rating current (see paragraph 45.9) is caused to flow in a reverse direction through a module or panel (4th quadrant operation).

26.2 A module or panel is to be placed on a single layer of white tissue paper over a 3/4 inch (19.1 mm) thick pine board and covered with a single layer of cheesecloth. The cheesecloth is to be untreated cotton cloth running 14-15 square yards per pound (26-28 square meters per kilogram) and having what is known to the trade as a count of 32 by 28.

26.3 Any blocking diode provided as a part of the module or panel is to be defeated (short-circuited).

26.4 The test is to be conducted in an area free of drafts, and the irradiance on the module or panel is to be less than 5 mW/cm^2.

26.5 The test is to be continued for two hours or until ultimate results are known, whichever occurs first.

27. Installation and Maintenance

27.1 A part that is detachable, hinged, or the like for routine maintenance shall be tested to verify ability to withstand 300 complete cycles of operation without breakage or otherwise making the part incapable of functioning in the intended manner, if such would result in noncompliance with any other requirement in this Standard. If a screw is used to secure such a part, it shall be tightened to and released from the values specified in Table 27.1. If more than one screw is used, a single screw may be subjected to the test, if such screw can be shown to be representative of the others.

27.2 A wire-binding screw or nut on a wiring terminal shall be capable of withstanding 10 cycles of tightening to and releasing from the values specified in Table 27.1 without damage to the terminal supporting member, without loss of continuity and without short circuiting of the electrical circuit to accessible metal.

TABLE 27.1

TORQUE REQUIREMENTS

	Torque	
Screw Size	lb-in.	(N-m)
No. 6	12	(1.36)
No. 8	20	(2.3)
No. 10	25	(2.8)
1/4 in.	100	(11.3)
5/16 in.	200	(22.6)
3/8 in.	350	(39.5)
7/16 in.	550	(62.1)
1/2 in.	800	(90.4)
9/16 in.	1200	(135.6)

28. Voltage Surge

28.1 A module or panel shall be subjected to the application of electrical impulse energy as described in paragraphs 28.2-28.3; and

A. The test shall not result in:

1. Sustained arcing on or within the module or panel. Sustained arcing is defined as arcing continuing for more than five seconds after the last discharge. The presence of arcing is to be determined visually, by current flow from the V_{sys} power supply, or by any other appropriate method, and

B. Following the application of the impulses, the module or panel shall comply with:

1. The Leakage Current Test in Section 21, and

2. The Dielectric Voltage Withstand Test in Section 25.

28.2 The impulse is to be applied between the connection means (terminals), connected together; and all accessible conductive parts, connected together. See Figure 28.1.

28.3 The module or panel is to be connected to a dc power supply as described in paragraph 28.4 and then subjected to four discharges from a 0.1 μf dump capacitor which has been charged to 6 kv. The test apparatus is as described in paragraph 28.4 and Figure 28.1. The polarities are to be as shown. The interval between successive discharges is to be five seconds.

28.4 In reference to Figure 28.1, the test apparatus is as follows:

V_{DC} - 6 kv dc power supply capable of recharging a 0.1 μf capacitor to 6 kv ± 500 v within 5 seconds or less.

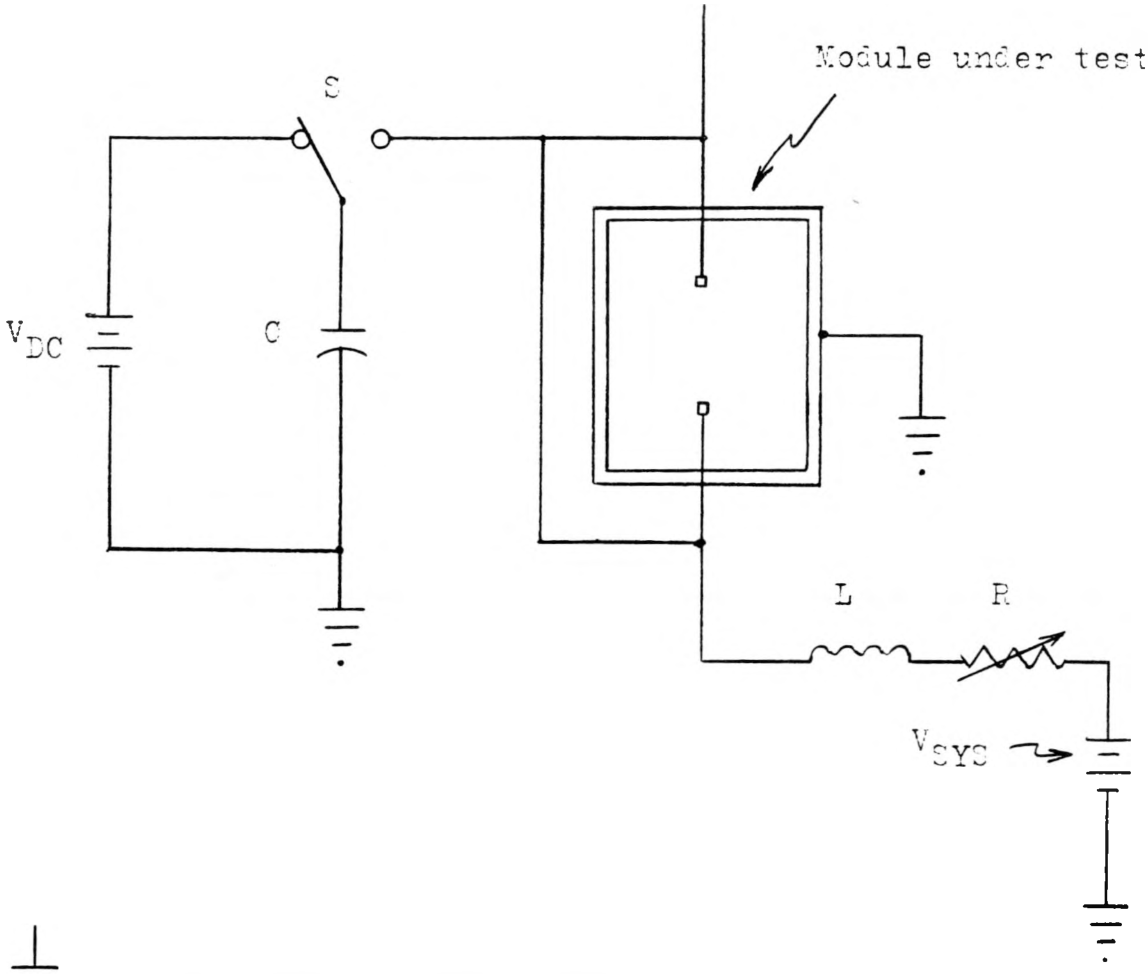
C - 0.1 μf ± 10%, 10 kv capacitor.

V_{SYS} - DC power supply, open-circuit voltage set to the maximum acceptable system direct voltage, short-circuit current set to 200 mA.

S - High voltage switch.

L - Choke (parameters and construction of the choke are to be determined at a later time).

FIGURE 28.1



Indicates common connection;
not neccesarily ground

29. Exposure to Hail

29.1 There shall be no accessibility to live parts as defined in Section 15, nor shall any piece of a module or panel be released from its normal position as a result of a module or panel being impacted with simulated hail (ice balls) as described in paragraphs 29.2-29.5.

29.2 A module or panel is to be mounted in a manner representative of its intended use and is to be subjected to normal (right angle) impacting with 25 mm (1 in.) diameter ice balls traveling at a terminal velocity of 23.2±1.16 m/sec (52±2.6 mph). The ice balls may be propelled by pneumatic or spring-actuated guns, or by other means acceptable to those concerned. Ten of a modules' or panels' most sensitive points are to be impacted. Each point shall be subjected to only one impact.

29.3 An ice ball is to be spherical with a maximum deviation in diameter from spherical of ±3 mm (0.125 in.). The ice balls are to be cooled to -10±2°C (14±3.6°F) by storage in a compartment maintained at this temperature for a minimum of 5 hours. The ice balls are to be fired within 1 minute after removal from the chamber.

29.4 After each impact, the sample is to be inspected for visible evidence of damage.

29.5 The most sensitive exposed points on a sample may be determined experimentally through destructive testing of a sample panel. Ice balls having a 25 mm (1 in.) diameter are to be fired at candidate sensitive points with increasing velocity until the sample breaks. Several different points on the sample are to be broken, and the points broken at the lowest velocities are to be used for subsequent testing. The candidate points are to include (if applicable) the following:

A. Center points of cells.

B. Corners and edges of the module.

C. Edges of cells, especially around electrical contacts.

D. Points of minimum spacing between cells.

E. Points of support for any superstrate material.

F. Points of maximum distance from points of support in E.

30. Impact

30.1 There shall be no accessibility to live parts as defined in Section 15, nor shall any piece of a module or panel weighing more than ________ be released from its normal position as a result of a module or panel being impacted as described in paragraph 30.2.

30.2 A module or panel is to be mounted in a manner representative of its intended use and is to be subjected to a 5 ft lb (6.78 joules) impact from a 2 inch (51 mm) diameter smooth steel sphere weighing 1.18 pounds (535 grams) falling through a distance of 51 inches (1.295 m). The module or panel is to be struck at any point considered most vulnerable. If the construction of a module or panel does not permit it to be struck freely from above by the freely falling sphere, the sphere is to be suspended by a cord and allowed to fall as a pendulum through the vertical distance 51 inches (1.295 m).

31. Fire

31.1 A module or panel intended for roof mounting and designated as being intended for installation above, upon, or integral with a building roof structure surfaced with Class A, Class B, or Class C type material shall be subjected to a spread-of-flame test as described in the tests for fire resistance of roof covering materials, UL 790 modified as described herein, or as may otherwise be appropriate for the particular module or panel being tested. At no time during or after the tests shall:

A. Any portion of the module or panel or the roof covering material be blown or fall off the test deck in the form of flaming or glowing brands,

B. The roof deck, (including any part under a module or panel) be exposed by breaking, sliding, cracking, or warping of the roof covering, or

C. Portions of the roof deck or portions of a module or panel intended for installation integral with or forming a part of the building structure fall away in the form of glowing particles.

31.2 At the conclusion of the spread-of-flame tests, the flaming shall not have spread beyond 6 feet (1.82 m) for Class A, 8 feet (2.4 m) for Class B, and 13 feet (3.9 m) for Class C. (See also paragraph 31.5.) There shall have been no significant lateral spread-of-flame from the path directly exposed to the test flame.

31.3 The test severity (Class A, B, or C) is to be commensurate with the intended designated class of roof covering material.

31.4 For these tests the module or panel is to be installed in accordance with the instructions provided with it. Any mounting hardware furnished with the module or panel is to be used to mount the module or panel for tests. The slope of the module or panel with respect to the horizontal is to be the minimum slope specified in the installation instructions. The slope of the simulated roof deck is not to exceed 5 inches per foot (416 mm/m).

31.5 For a module or panel intended for installation above a building roof structure, the spread-of-flame test is to be conducted with the module or panel oriented with respect to the test flame such that the flame impinges first on the top surface of the module or panel and then on the bottom surface of the module or panel. (Two tests.) When the spread-of-flame test is conducted with module or panel oriented with respect to the test flame such that the flame impinges on the bottom surface of the module or panel, the test deck is to extend 6 feet (1.82 m) (Class A), 8 feet (2.4 m) (Class B), or 13 feet (3.9 m) (Class C) beyond the end of the module or panel and the spread-of-flame is to be measured starting at a line on the test deck directly beneath the end of the module or panel farthest from the test flame.

Exception: Where the module or panel orientation that will result in the greatest spread-of-flame can be identified, testing is required only with that orientation.

31.6 A module or panel intended for roof mounting and marked as being intended for installation upon or integral with a building roof structure surfaced with Class A, Class B, or Class C type of roof covering material shall be subjected to a burning-brand test as described in the tests for fire resistance of roof covering materials, UL 790, modified as described herein or as may otherwise be appropriate for the particular module or panel being tested. For the test a single brand (equivalent of Class B, UL 790) shall be used. At no time during or after the tests shall:

A. Any portion of the module or panel or the roof covering material be blown or fall off the test deck in the form of flaming or glowing brands,

B. The roof deck including any part under a module or panel, be exposed by breaking, sliding, cracking, or warping of the roof covering,

C. Portions of the roof deck or portions of a module or panel intended for installation integral with or forming a part of the building roof structure fall away in the form of glowing particles, or

D. There be sustained flaming of the underside of the roof deck, or the underside of the module or panel.

[Note: Consideration is being given to changing the size and number of brands to correspond to those specified in UL 790 for the rating desired.]

31.7 A module or panel is not required to be useable after any of the tests of this section.

31.8 For each mode of test only one test need be conducted except as indicated in paragraph 31 5.

32. Exposure to Water Spray

32.1 A module or panel shall be subjected to a water spray test as described in paragraphs 32.2-32.6, and

A. The test shall not result in

(1) Water on uninsulated live parts or the collection of water in a compartment containing live parts, and

B. Immediately following the test, the module or panel shall comply with

(1) The dielectric voltage withstand test in Section 25, and

(2) The leakage current test in Section 21.

Both tests are to be conducted without any drying of the samples.

32.2 A module or panel is to be mounted in a manner representative of its intended use. If one mounting does not represent all, the test shall be conducted with each mounting deemed necessary.

32.3 If a module or panel is intended to be mounted as an integral part of the roof with an adjacent module or panel in an array using factory-designed joining sections, the test is to be conducted using the joining hardware in accordance with the installation instructions.

32.4 Field wiring connections are to be made in accordance with the wiring method specified for the product. If more than one method is specified, the method least likely to restrict the entrance of water is to be used. A threaded opening intended to terminate in conduit is to be sealed, unless a possible use of the threaded opening is with a wiring method likely to allow the entrance of water.

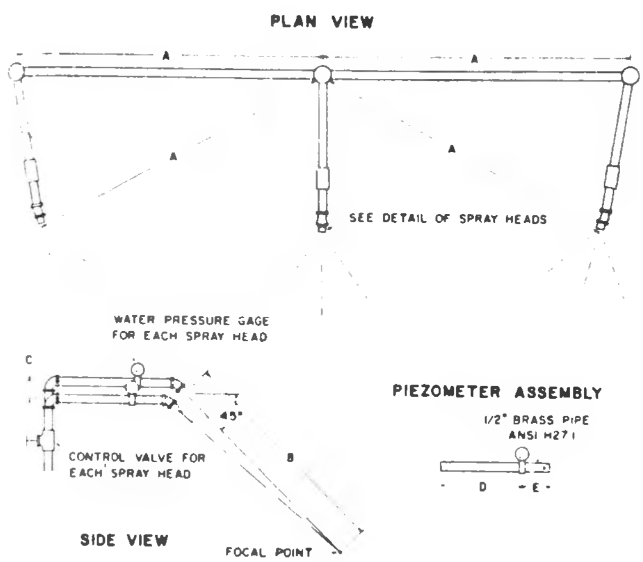
32.5 The test is to be conducted for 1 hour. If the position of the module or panel under the water spray may affect the results, the test is to be conducted with the module or panel in each position.

32.6 After exposure, the module or panel shall be examined for evidence of water penetration to and above uninsulated live parts and for evidence of the collection of water in any compartment containing live parts. If drain holes are provided, consideration is to be given to their preventing the water level from reaching uninsulated live parts.

32.7 The rain test apparatus is to consist of three spray heads mounted in a water supply rack as illustrated in Figure 32.1. Spray heads are to be constructed in accordance with Figure 32.2. The water pressure for all tests is to be maintained at 5 psig (34.5 kPa) at each head. The distance between the center nozzle and the product is to be approximately 3 feet (0.9 m). The product is to be brought into the focal area of the three spray heads in such position and under such conditions so as to present the greatest quantity of water to entrances to the product. The spray is to be directed toward the module or panel at an angle of 45 degrees to the vertical.

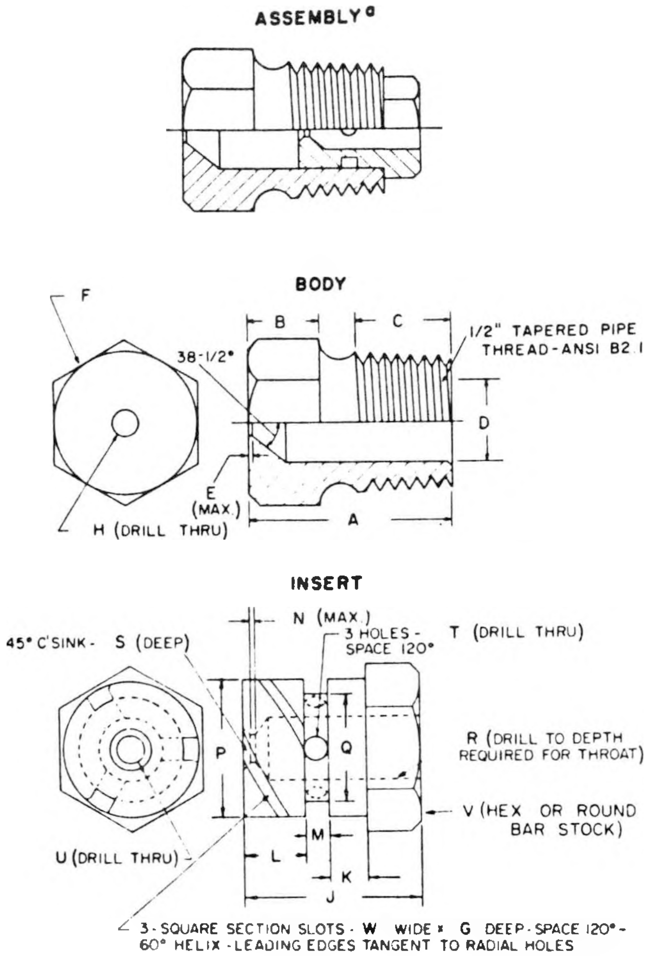
32.8 The water for the test is to have a resistivity before the test, of 3500±175 ohm-centimeters at 25°C (77°F). At the conclusion of the test, the resistivity of the water is not to be less than 3200 ohm-centimeters nor more than 3800 ohm-centimeters at 25°C (77°F).

FIGURE 32.1
RAIN-TEST SPRAY-HEAD PIPING



Item	inch	mm
A	28	710
B	55	1400
C	2-1/4	55
D	9	230
E	3	75

FIGURE 32.2
RAIN-TEST SPRAY HEAD



Item	inch	mm	Item	inch	mm
A	1-7/32	31.0	N	1/32	0.80
B	7/16	11.0	P	.575	14.61
C	9/16	14.0		.576	14.63
D	.578	14.68	Q	.453	11.51
	.580	14.73		.454	11.53
E	1/64	0.40	R	1/4	6.35
F	c	c	S	1/32	0.80
G	.06	1.52	T	(No. 35)[b]	2.79
H	(No.9)[b]	5.0	U	(No. 40)[b]	2.49
J	23/32	18.3	V	5/8	16.0
K	5/32	3.97	W	0.06	1.52
L	1/4	6.35			
M	3/32	2.38			

[a] - Molded nylon Spray Heads are available from Underwriters Laboratories Inc.

[b] - ANSI B94.11 Drill Size.

[c] - Optional - To serve as wrench grip.

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33. Accelerated Aging of Gaskets and Seals

33.1 Materials used for gaskets, seals, and the like (except for cork, fiberous material and similar products) shall have the physical properties as specified in Table 33.1, and shall comply with the physical property requirements of Table 33.2. The material shall not deform, melt, or harden to a degree which would affect its sealing properties.

33.2 The temperature values in column 1 of Table 33.2 correspond to the temperatures measured during the Temperature Tests.

TABLE 33.1
Physical Property Requirements

Min. Tensile Strength[a]	Min. Ultimate Elongation[a]	Compressive Set[c], Maximum Set
A. For Silicone Rubber:		
500 psi (3.45 MPa)	100%	15%
B. For Other Elastomers:		
1500 psi[b] (10.3 MPa)	300%[b]	15%
C. For Nonelastomers (excluding cork, fiber and similar materials):		
1500 psi (10.3 MPa)	200%	15%

a Tensile strength and ultimate elongation are to be determined using Die C specimens described in the Standard Test Methods for Rubber Properties in Tension, ASTM D 412-1975 or Type I specimens described in the Standard Test Method for Tensile Properties of Plastics ASTM D 638-1977.

b As an alternate, an ultimate elongation of 200% is acceptable providing that the tensile strength is at least 2,200 psi (15.1 MPa).

c Compressive set is to be determined 30 minutes after specimen release using the Standard Test for Rubber Property-Compression Set ASTM, D 395, Method B.

TABLE 33.2

PHYSICAL REQUIREMENTS AFTER CONDITIONING

Indentation Temperature Hardness on Material During Temperature Test	Conditioning Procedure	Minimum Percent of the Result with Unaged Specimens		Maximum Change (Duro) from Unconditioned Value[a]
		Tensile Strength	Ultimate Elongation	
60°C (140°F) or less	Oxygen bomb, 96 hrs. at 70°C (158°F) and 300 PSI (2.07 MPa) gauge	60	60	5
61-75°C (142-167°F)	Oxygen bomb, 168 hrs. at 80°C (176°F) and 300 PSI (2.07 MPa) gauge; and air bomb, 20 hrs. at 127°C (260°F) in atmospheric	50	50	5
76-90°C (169-194°F)	Air circulating convection oven, 168 hrs. at 121°C (250°F)	50	50	10
91-105°C (196-221°F)	Air circulating convection oven, 168 hrs. at 136°C (277°F)	50	50	10
Above 105°C (221°F)	20 degrees C, greater than use temperature in circulating convection oven, 168 hrs. exposure	50	50	10

[a] Determined by the Standard Method for Rubber Property Durometer Hardness, ASTM D-2240.

34. Solar Radiation Weathering

34.1 One complete module or specimen samples of material representative of that used in the module are to be used for this test. Plastic specimen size and configuration is to be as specified in the Standard for Polymeric Material - Short Term Property Evaluation (UL 746A). Steel specimens with an organic coating system are to be 4 by 12 inch (102 by 305 mm) with the cut edges protected with paint, wax or other effective medium.

34.2 The specimens are to be exposed to ultraviolet light from two enclosed carbon arcs formed between vertical electrodes, 0.5 inch (12.5 mm) diameter, located at the center of a revolveable vertical metal cylinder 31 inch (0.79 meter) in diameter and 17.75 inch (0.45 meter) high. The arcs are to operate with approximately 15 to 17 amperes and the potential across the arcs is to be approximately 120 to 145 volts, 50 to 60 Hz. Each arc is to be enclosed by a clear globe of heat resistant optical glass (9200-PX Pyrex glass or its equivalent) that is opaque at wave lengths shorter than 2,750 angstrom units and whose transmittance is at least 91 percent at 3700 angstrom units.

34.3 The cylinder is to be rotated about the arcs at one revolution per minute and a system of nozzles is to be provided so that each specimen is sprayed, in turn, with water as the cylinder revolves. The temperature within the cylinder while the apparatus is in operation is to be approximately 60 C (140 F).

34.4 The specimens are to be mounted vertically on the inside of the cylinder with the width of the specimens facing the arcs, and so that they do not touch each other.

34.5 During each operating cycle of the apparatus (20 minutes), the specimens are to be exposed only to light from the carbon arcs for 17 minutes, and to water spray with ultraviolet light for 3 minutes. Tests on organically coated steel specimens are to continue until they have been exposed to ultraviolet light alone for a total of 306 hours and ultraviolet light and water for a total of 54 hours (360 hours total). Tests on plastic samples are to continue until they have been exposed to ultraviolet light alone for 612 hours and ultraviolet light and water for 108 hours (720 hours total). After the test exposure, the samples are to be removed from the test apparatus and retained under conditions of ambient room temperature for not less than 16 nor more than 96 hours before being subjected to the comparison criteria mentioned below.

34.6 For organically coated steel samples, there shall be no separation of the organic coating and no corrosion of the underlying metal.

34.7 For plastic samples, the flammability classification of the material shall not be reduced and the physical property values shall not be less than 70 percent of the unconditioned values as determined by the small scale physical tests as described in the Standard for Polymeric Materials - Short Term Property Evaluations (UL 746A). The following properties are to be included in the evaluation.

A. Tensile strength.

B. Flexural strength.

C. Impact.

D. Flammability as described in the Standard, Tests for Flammability of Plastic Materials for Parts in Devices and Appliances (UL 94).

35. Temperature Cycling

35.1 A module or panel shall be subjected to 100 cycles of temperature change as described in paragraphs 35.2-35.5; and

A. The test shall not result in:

1. Loss of circuit continuity.

2. Accessibility of live parts that may involve a risk of electric shock, including a reduction in the resistance between live and accessible parts such that the module or panel would not comply with dc Leakage Current Requirements, Section 21.

3. Delamination or separation of parts.

4. Deterioration of insulation below acceptable values.

5. Reduction in thickness of a nonmetallic wiring compartment wall below acceptable values.

6. Reduction in volume of a nonmetallic wiring compartment below acceptable values, or

7. Creation of a gap greater than 1/16 inch (1.6 mm) or an increase of 1/16 inch (1.6 mm) or more in an existing opening between nonmetallic wiring compartment walls and the cover, and

B. The module or panel shall comply with:

1. The dielectric voltage withstand test in Section 25, immediately following the last excursion to 90°C (or -40°C as appropriate) and also at room temperature.

35.2 Three samples of a module or panel are to be placed in a circulating air chamber, the temperature of which can be varied and controlled. Leads are to be connected to the terminals, and frame where necessary, of the samples, to allow for a continuous individual detection of loss of circuit continuity; and loss of resistance between the electrical circuit and accessible metal.

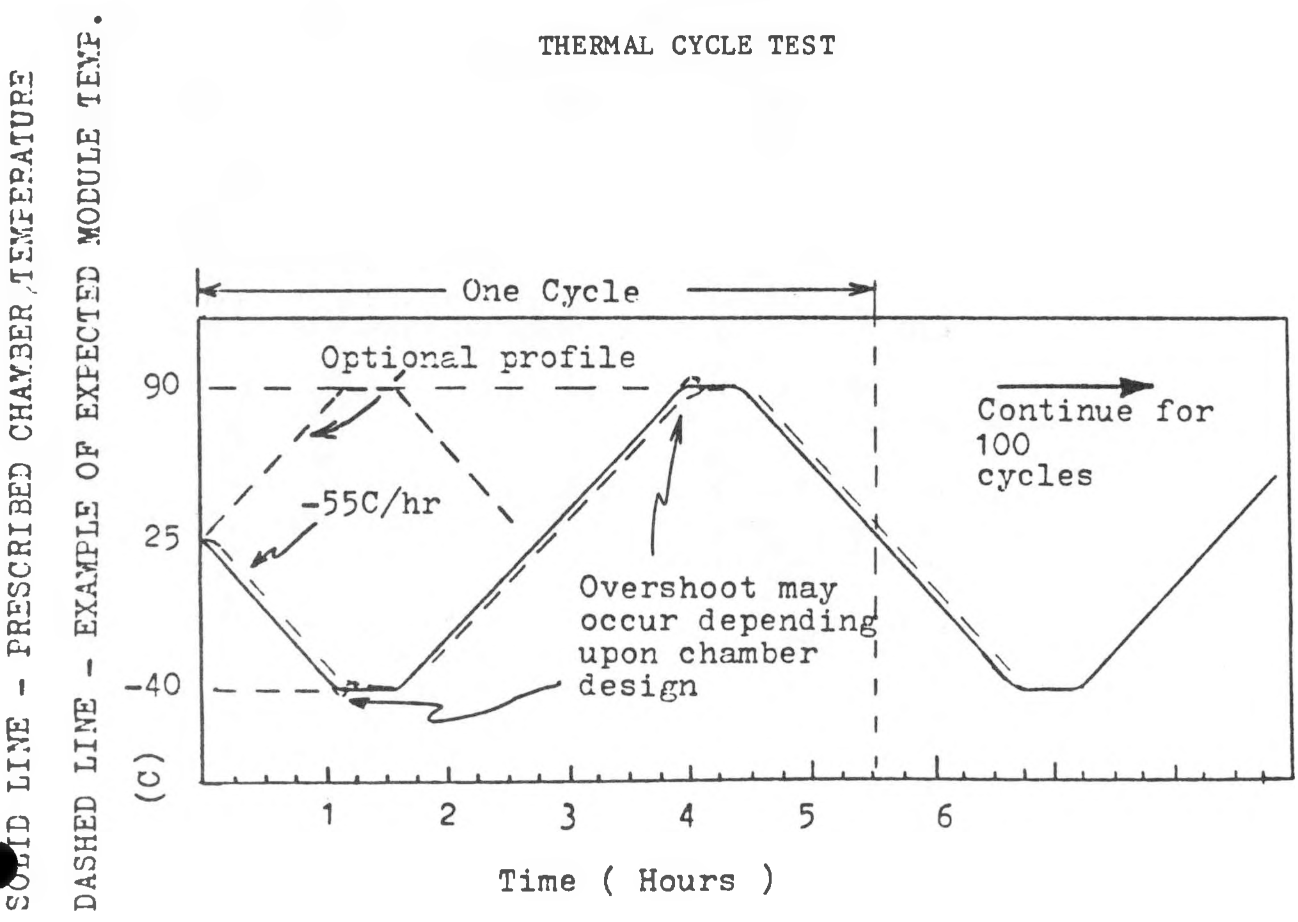
35.3 The samples are to be mounted in a test frame that simulates the support rigidity and differential thermal expansion likely to occur in service between the product and its support structure.

35.4 Each cycle is to consist of a transition from 25°C to -40°C, a dwell at -40°C for 30 minutes or until the module or panel attains a temperature within 2°C of the chamber temperature, whichever is longer, a transition from -40°C to 90°C, a dwell at 90°C for 30 minutes or until the module or panel attains a temperature within 2°C of the chamber temperature, whichever is longer, and a transition from 90°C to 25°C. Alternately, the temperatures may be interchanged so that the 90°C dwell is achieved first, followed by the -40°C dwell. Where the 25°C temperature is the start or end of the 100 cycles, any nominal room temperature in the range of 15-35°C may be used. For all transitions, the instantaneous rate of temperature change with respect to time shall be 55°C/hour. All temperatures and temperature dwell times refer to chamber temperatures. A temperature vs time profile assuming 30 minute dwell times is described in Figure 35.1.

35.5 The dew point of the chamber air is to be between 9 and 15°C, except that when the chamber air temperature is below this value the dew point is to be the chamber temperature.

FIGURE 35.1

THERMAL CYCLE TEST



36. Humidity

36.1 A module or panel shall be subjected to 10 cycles of humidity-freezing as described in paragraphs 36.2-36.6; and

A. The test shall not result in:

1. Loss of circuit continuity.

2. Accessibility of live parts that may involve a risk of electric shock, including a reduction in the resistance between live and accessible parts such that the module or panel would not comply with the Leakage Current Requirements, Section 21.

3. Delamination or separation of parts.

4. Deterioration of insulation below acceptable values.

5. Corrosion of metal parts.

6. Reduction in thickness of a nonmetallic wiring compartment wall below acceptable values.

7. Reduction in volume of a nonmetallic wiring compartment below acceptable values, or

8. Creation of a gap greater than 1/16 inch (1.6 mm) or an increase of 1/16 inch (1.6 mm) or more in an existing opening between nonmetallic wiring compartment walls and the cover, and

B. The module or panel shall comply with:

1. The dielectric voltage withstand test in Section 25.

36.2 Three samples of a module or panel are to be placed in a chamber, the humidity and temperature of which can be varied and controlled. Leads are to be connected to the terminals, and frame where necessary, of the samples, to allow for a continuous individual detection of loss of circuit continuity; and loss of resistance between the electrical circuit and accessible metal.

36.3 The samples are to be mounted in a test frame that simulates the support rigidity and differential thermal expansion likely to occur in service between the product and its support structure.

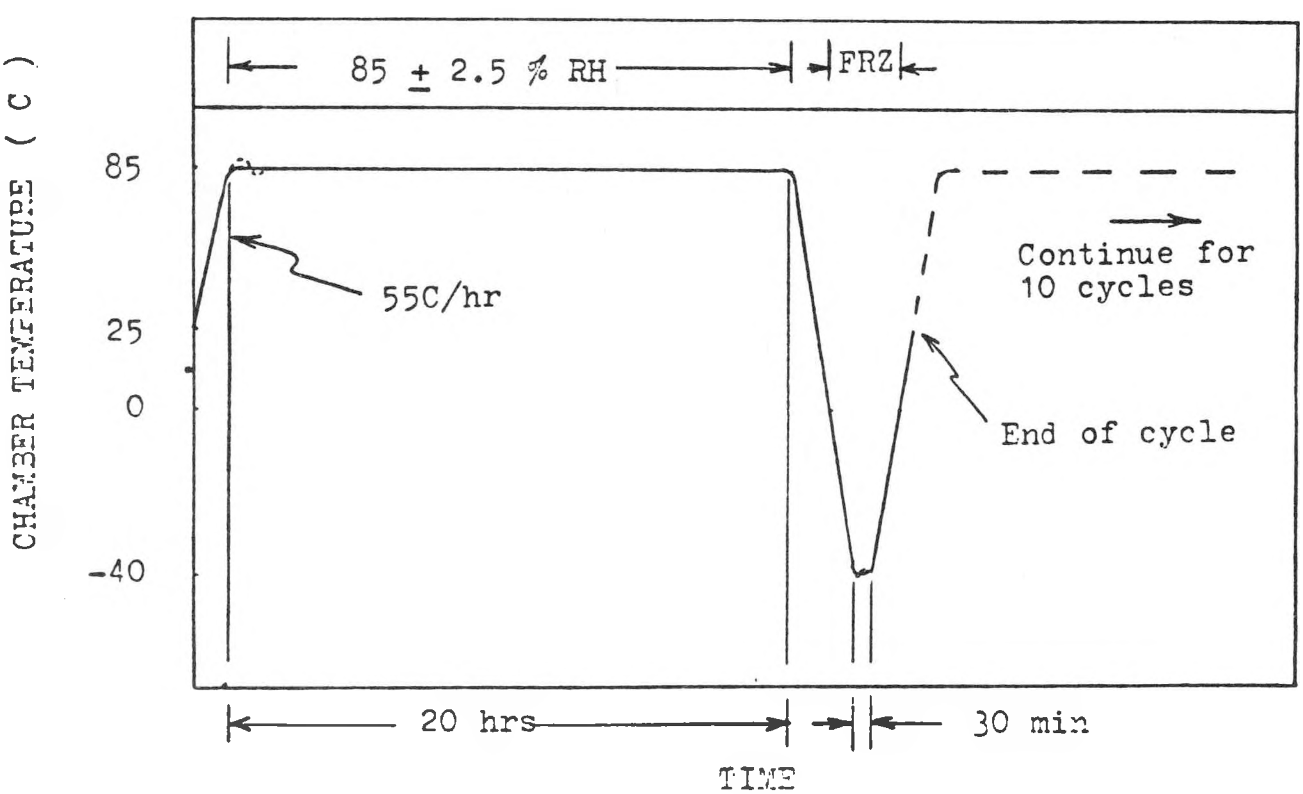
36.4 The test apparatus and arrangement of samples is to be such that dripping of condensate on a sample is prevented. Terminations are to be afforded the least degree of protection against condensation of water as they would be in any intended installation of the product.

36.5 Each cycle is to consist of a transition from 25°C to 85°C, a dwell at 85°C for 20 hours a transition from 85°C to -40°C, a dwell at -40°C for 30 minutes, and a transition from -40°C to 25°C. Where the 25°C temperature is the start or end of the 10 cycles, any nominal room temperature in the range 15-30°C may be used. For all transitions, the instantaneous rate of temperature change with respect to time shall be 55°C/hour. All temperatures and temperature dwell times refer to chamber temperatures. A typical temperature vs time profile is described in Figure 35.1.

36.6 The humidity of the chamber air when the chamber air temperature is 85°C is to be 85% R.H. During all temperature transitions the chamber air is to be isolated from the outside air (no make-up air) to allow condensing water vapor to freeze in the module or panel.

FIGURE 36.1

HUMIDITY-FREEZING CYCLE TEST



37. Water Absorption and Exposure

Water Absorption

37.1 Systems of polymeric materials of a module or panel functioning as electrical insulation or as a barrier against contact with parts involving a risk of electric shock shall be tested as described in paragraph 37.2, and when so tested shall not increase in weight by more than 2 percent, nor show any linear dimension change, including thickness, of more than 2 percent.

37.2 Three specimens of the system, each 1 inch (25 mm) by 3 inches (76 mm) and having a thickness equal to the minimum thickness used, are to be dried in a calcium chloride desiccator for 24 hours. After being dried the dimensions and weight of the specimens are to be accurately determined. The specimens are then to be immersed for 24 hours in distilled water maintained at a temperature of 23±2°C (73±4°F). Following removal from the water, the samples are to be wiped dry and the change in the dimensions and weight are to be determined. The percentage of change is then to be determined in accordance with the method for measuring water absorption of polymeric materials in the Standard for Polymeric Materials - Short Term Property Evaluations, UL 746A.

Water Exposure

37.3 Systems of polymeric materials of a module or panel functioning as insulation or as a barrier against contact with parts involving a risk of electric shock hazard shall be tested as described in paragraph 37.4, and after being so tested shall have a High-Current arc ignition index, Comparative Track Index, and Flame Classification as specified in paragraph 6.1.

37.4 The property values for the material mentioned in paragraph 37.3 are to be determined as described in the Standard for Polymeric Materials - Short Term Property Evaluations, UL 746A, and the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, as appropriate. Additional samples 1 inch (25 mm) by 3 inches (76 mm) with a thickness equal to the minimum thickness used are to be immersed in distilled water at 82.0±1.0°C (180.0±1.8°F) for 7 days. A complete change of water is to be made on each of the first 5 days. Following the immersions, the specimens are to be conditioned in air at 23.0±2.0°C (73.4±3.6°F) and 50±5 percent relative humidity for 2 weeks. Following this conditioning, the samples are to be subjected to the tests for High-Current arc ignition, Comparative Track Index, and Flame Classification.

38. Corrosive Atmosphere

Salt Spray Test

38.1 One complete sample of the module or specimen samples of materials representative of that used in the module are to be subjected to this test.

38.2 The apparatus for salt spray testing consists of a chamber with inside measurements of 48 by 30 by 36 inches (1.22 by 0.76 by 0.91 meter) or larger if required; a salt solution reservoir; a supply of conditioned compressed air; one dispersion tower constructed in accordance with ASTM designation B117-1973, for producing a salt fog; specimen supports; provision for heating the chamber; and necessary means of control.

38.3 The dispersion tower for producing the salt spray is to be located in the center of the chamber and is to be supplied with humidified air at a gauge pressure of 17 to 19 pounds per square inch (117 to 131 kilopascals) so that the solution is aspirated as a fine mist or fog into the interior of the chamber.

38.4 The salt solution is to consist of 5 percent by weight of common salt (sodium chloride) in distilled water. The pH value of the collected solution is to be between 6.5 and 7.2 and have a specific gravity between 1.026 and 1.040 at 95 F (35 C). The temperature of the chamber is to be maintained within the range of 92 to 97 F (33 C to 36 C)throughout the test.

38.5 The test sample is to be supported on plastic racks at an angle of 15 degrees from the vertical.

38.6 Drops of solution which accumulate on the ceiling or cover of the chamber are to be diverted from dropping on the specimen and drops of solution which fall from the specimens are not to be recirculated, but are to be removed by a drain located in the bottom of the apparatus.

38.7 Reference specimens, 4 by 12 inches (102 by 305 mm) of commercial zinc coated sheet steel are used for comparison. The specimens are selected to be representative of the minimum acceptable amount of zinc coating under requirements for G90 or G60 coating designation (as applicable, see Section 13) as determined by test using ASTM Method A90-73, "Test for the Weight of Coating on Zinc Coated Iron or Steel Articles". Such zinc coatings are considered as providing acceptable corrosion protection.

38.8 The zinc coated reference specimens are cleaned with soap and water, rinsed with ethyl alcohol and ethyl ether, dried and the cut edges protected with paint, wax or other effective medium before being placed in the salt spray chamber.

38.9 Both the reference specimen and the samples under test are to be scribed with a single groove, approximately 6 inches (152 mm) long to expose the underlying steel.

38.10 The test is to continue until the coating on the test samples or reference samples are broken down and corrosion products are formed on the underlying steel.

38.11 The corrosion products formed on the test sample shall be no more than that formed on the reference sample as determined by visual observation. Corrosion in the scribed line area is judged by the spread of corrosion from the scribed line.

Moist Carbon Dioxide/Sulphur Dioxide:

38.12 One complete sample of the module or specimen samples of materials representative of that used in the module are to be subjected to this test.

38.13 A chamber measuring 48 by 30 by 36 inches (1.22 by 0.76 by 0.91 meter) or larger if required, having a water jacket and thermostatically controlled heater in order to maintain a temperature of 95 ± 3 F (35 ± 1.7 C) is to be used.

38.14 Sulphur dioxide and carbon dioxide are to be supplied to the test chamber from commercial cylinders containing these gases under pressure. An amount of sulphur dioxide equivalent to 1 percent of the volume of the test chamber and an equal volume of carbon dioxide are to be introduced into the chamber each day. Prior to introducing the new charge of gas each day, the remaining gas from the previous day is to be purged from the chamber. A small amount of water is maintained at the bottom of the chamber for humidity. The samples are to be supported on plastic racks at an angle of 15 degrees from the vertical.

38.15 Reference specimens 4 by 12 inches (102 by 305 mm) of commercial zinc coated sheet steel are used for comparison. The specimens are selected to be representative of the minimum acceptable amount of zinc coating under requirements for G90 or G60 coating designation (as applicable, see Section 13) as determined by tests using ASTM Method A90-73. Such zinc coatings are considered as providing acceptable corrosion protection.

38.16 The zinc coated specimens are cleaned with soap and water, rinsed with ethyl alcohol and ethyl ether, dried, and the cut edges protected with paint, wax or other effective media before being placed in the chamber.

38.17 Both the reference specimen and sections of the module being tested are to be scribed with a single groove, approximately 6 inches (152 mm) long to expose the underlying steel.

38.18 The test is to continue until the coating on the module or reference specimen is broken down and corrosion products are formed on the underlying steel.

38.19 The corrosion products formed on the test sample shall be no more than that formed on the reference sample as determined by visual observation. Corrosion in the scribed line area is to be judged by the spread of corrosion from the scribed lines.

39. Metallic Coating Thickness

39.1 The method of determining the thickness of a zinc or cadmium coating mentioned in paragraphs 13.1 and 13.2 is described in paragraphs 39.2-39.9.

39.2 The solution to be used for the metallic coating thickness test is to be made from distilled water and is to contain 200 grams per liter of reagent (or better) grade chromium trioxide (CO_3) and 50 grams per liter of reagent (or better) grade concentrated sulphuric acid (H_2SO_4). (The latter is equivalent to 27 milliliters per liter of reagent grade concentrated sulphuric acid, specific gravity 1.84, containing 96 percent of H_2SO_4.)

39.3 The test solution is to be contained in a glass vessel such as a separatory funnel with the outlet equipped with a stopcock and a capillary tube of approximately 0.025 inch (0.64 mm) inside bore and 5.5 inches (150 mm) long. The lower end of the capillary tube is to be tapered to form a tip, the drops from which are about 0.05 milliliter each. To preserve an effectively constant level, a small glass tube is inserted in the top of the funnel through a rubber stopper and its position is to be adjusted so that, when the stopcock is open, the rate of dropping is 100±5 drops per minute. If desired, an additional stopcock may be used in place of the glass tube to control the rate of dropping.

39.4 The sample and the test solution are to be kept in the test room long enough to acquire the temperature of the room, which should be noted and recorded. The test is to be conducted at a room temperature of 70.0-90.0°F (21.2-32.0°C).

39.5 Each sample is to be thoroughly cleaned before testing. All grease, lacquer, paint, or other nonmetallic coatings, including skin oils, are to be removed completely by means of solvents. Samples are then to be thoroughly rinsed in water and dried with clean cheesecloth.

39.6 The sample to be tested is to be supported from 0.7 to 1 inch (17 to 25 mm) below the orifice. The surface to be tested shall be inclined at approximately 45 degrees from the horizontal so that the drops of solution strike the point to be tested and run off quickly.

39.7 The stopcock is to be opened and the time in seconds is to be measured until the dropping solution dissolves the protective metal coating, exposing the base metal. The end point is the first appearance of the base metal recognizable by the change in color at that point.

39.8 Each sample of a test lot is to be subjected to the test at three or more points, excluding cut, stenciled, and threaded surfaces, on the inside surface and at an equal number of points on the outside surface, at places where the metal coating may be expected to be the thinnest. (On enclosures made from precoated sheets, the external corners that are subjected to the greatest deformation are likely to have thin coatings.)

39.9 To calculate the thickness of the coating being tested, select from Table 39.1 the thickness factor appropriate for the temperature at which the test was conducted and multiply by the time in seconds required to expose base metal as noted in paragraph 39.7.

40. Twist

40.1 A module or panel shall be tested as described in paragraphs 40.2 and 40.3, and the test shall not result in:

A. Loss of bonding or current-carrying circuit continuity,

B. Short circuiting of the electrical circuit to accessible metal or between parts of the electrical circuit not of the same potential, as determined by a measurement of such resistance with a low voltage ohmmeter,

C. Delamination or separation of parts, or

D. Accessibility of parts that may involve a risk of electric shock, including leakage currents on exposed parts in excess of specified limits.

TABLE 39.1
COATING THICKNESS FACTORS

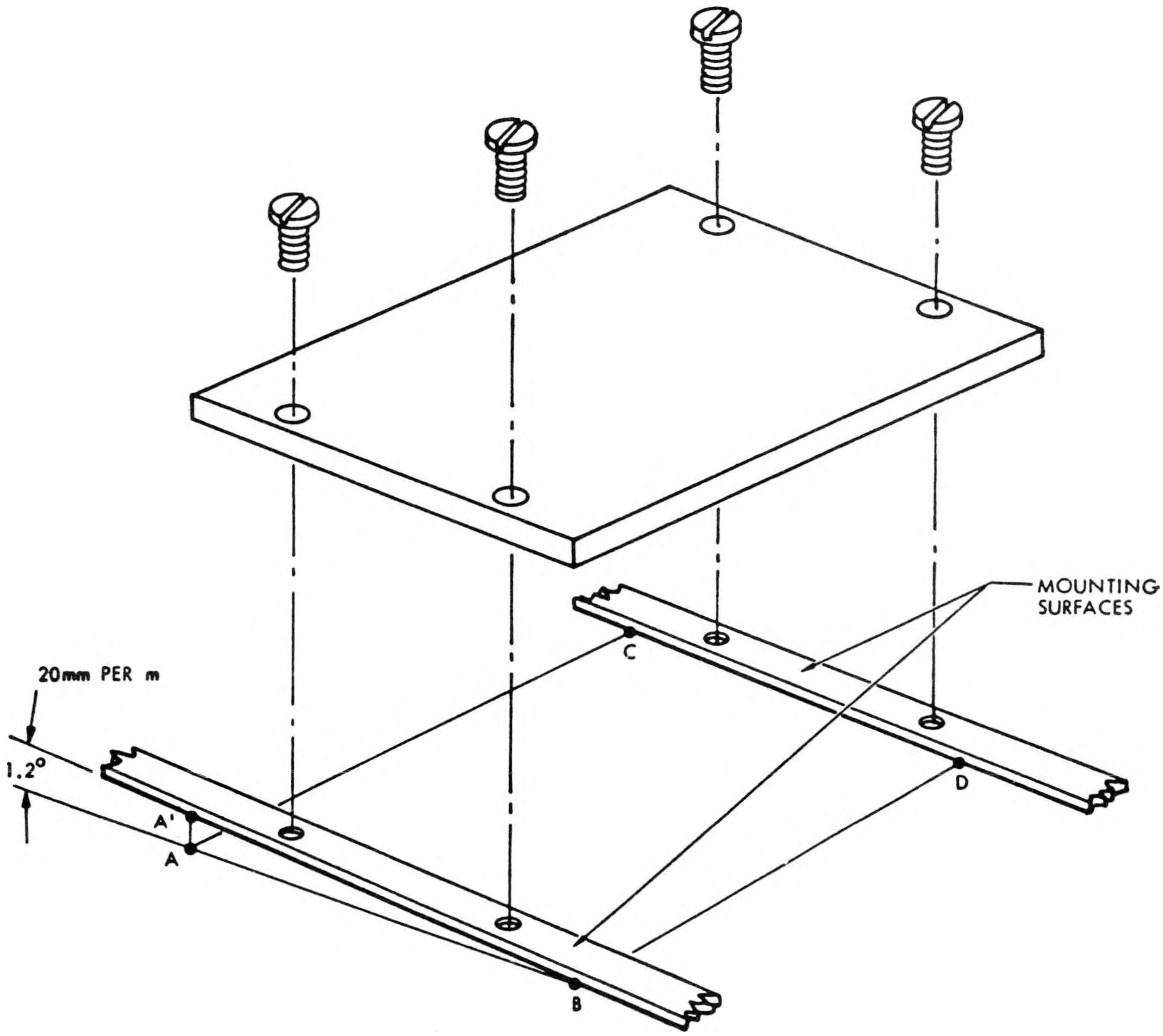
Temperature, °F	°C	Thickness Factors 0.00001 Inches (0.00025 mm) per second: Cadmium Platings	Zinc Platings
70	21.1	1.331	0.980
71	21.7	1.340	0.990
72	22.2	1.352	1.000
73	22.8	1.362	1.010
74	23.3	1.372	1.015
75	23.9	1.383	1.025
76	24.4	1.395	1.033
77	25.0	1.405	1.042
78	25.6	1.416	1.050
79	26.1	1.427	1.060
80	26.7	1.438	1.070
81	27.2	1.450	1.080
82	27.8	1.460	1.085
83	28.3	1.470	1.095
84	28.9	1.480	1.100
85	29.4	1.490	1.110
86	30.0	1.501	1.120
87	30.6	1.513	1.130
88	31.1	1.524	1.141
89	31.7	1.534	1.150
90	32.2	1.546	1.160

40.2 A module or panel is to be mounted as illustrated in Figure 40.1. If the module or panel has flanges on the four sides, the flanges on the two shorter sides are to be used for mounting. Leads are to be connected to the terminals of the module or panel to determine loss of continuity or short circuiting of any part of the electrical circuit to accessible metal.

40.3 A flexible module restricted (by marking or mounting provision) to mounting in a prescribed frame is to be tested while mounted in such frame.

40.4 With one of the mounting surfaces held fixed, the other mounting surface is to be moved in an arc to attain a 20 mm/meter twist as measured along the mounted side. The module or panel is to be maintained in this position for one minute and the twist then released. The twist is then to be applied in the reverse direction, held in the reverse direction for one minute, and then released.

FIGURE 40.1
MOUNTING FOR TWIST TEST



Points A, B, C, D are in a Plane; Point A' is out of Plane by the Amount Shown

41. Hot-Spot Endurance

General

41.1 The cells of a module or panel shall be subjected to simulated reverse voltage hot spot heating conditions for a total of 100 hours, intermittently, as described in paragraphs 41.2-41.17. The test shall not result in:

A. delamination of the encapsulants, superstrate and substrate that would render live parts accessible,

B. cell cracking,
[Note: This criterion is being considered for deletion.]

C. melting of solder, or

D. any other indication of a risk of fire or electric shock.

COMMENTARY: The intent of this test is to determine the ability of the module or panel to endure the long term effects of periodic hot-spot heating associated with deliberate or uncontrolled fault conditions such as a short circuit deliberately placed on the module for servicing or to otherwise disable the array, cracked or mismatched cells, or nonuniform illumination (partial shadowing). The procedure for conducting this test includes a series of steps, first to select and instrument appropriate cells for testing, then to determine the hot-spot test levels, and last to conduct the hot-spot endurance test.

Field experience indicates that periodic circuit faults such as partial shadowing, and cracking of cells may be expected to occur even in highly reliable arrays. Under these fault conditions it is desirable to ensure, to as reasonable a degree as possible, that possible hot-spot heating due to reverse voltage does not cause propagation of the fault or a risk of electric shock or fire hazards through such mechanisms as solder melting or encapsulant deterioration. Hot-spot heating is caused when operating current levels exceed the reduced short-circuit capability of an individual cell or group of cells in an array circuit. The reduced short-circuit current fault condition can be the result of a variety of causes including non-uniform illumination (local shadowing), individual cell degradation due to cracking or soiling, or loss of a portion of series-parallel circuit due to individual interconnect open circuits. Under this condition power is dissipated in the over-currented cell(s) at a level equal to the product of the current and the reversed voltage that develops across the cell(s). This can heat the cell(s) to elevated temperatures.

Cell Selection and Instrumentation

COMMENTARY: The degree of hot-spot heating within an affected cell is dependent upon a variety of conditions including the module series-paralleling, the degree of overall illumination, the degree of over-current in the affected cell, and the reverse-voltage I-V characteristics of the affected cell(s). Because the reverse-voltage I-V characteristics vary considerably from cell to cell within a given module, it is necessary first to determine the dark reverse-voltage I-V curve for a representative sample of cells (at least 10) within the test module. This should be done by directly accessing individual cells.

41.2 The dark reverse voltage I-V curves for at least 10 cells within the module(s) or panel are to be determined for reverse voltages from 0 to V_L or currents from 0 to I_L, whichever limit is reached first, where:

I_L = I_{SC} (short circuit current) of an average cell at 100 mW/cm^2, NOCT.

V_L = N x V_{mp} of an average cell at 100 mW/cm^2, NOCT. (V_{mp} is the average maximum power voltage.)

N = Number of series cells per bypass diode as either (1) an integral part of the module or panel, or (2) as is described for use with the module or panel in marking affixed to the module or panel; whichever is less. (See paragraph 45.8)

41.3 For the determination of paragraph 41.2, each cell tested is to be provided with individual positive and negative electrical leads, to allow it to be accessed independently of other cells.

41.4 The reverse voltage I-V curves from the tested cells are to be plotted. The cells are to be identified as Type A (voltage limited) or Type B (current limited). (A graph similar to Figure 41.1 should be obtained.)

COMMENTARY: The cells of a module may be all voltage limited (Type A), all current limited (Type B), or a combination of both. In general, the cells associated with the highest hot-spot heating levels are those with the highest shunt resistance, although low shunt resistance may be associated with highly localized heating.

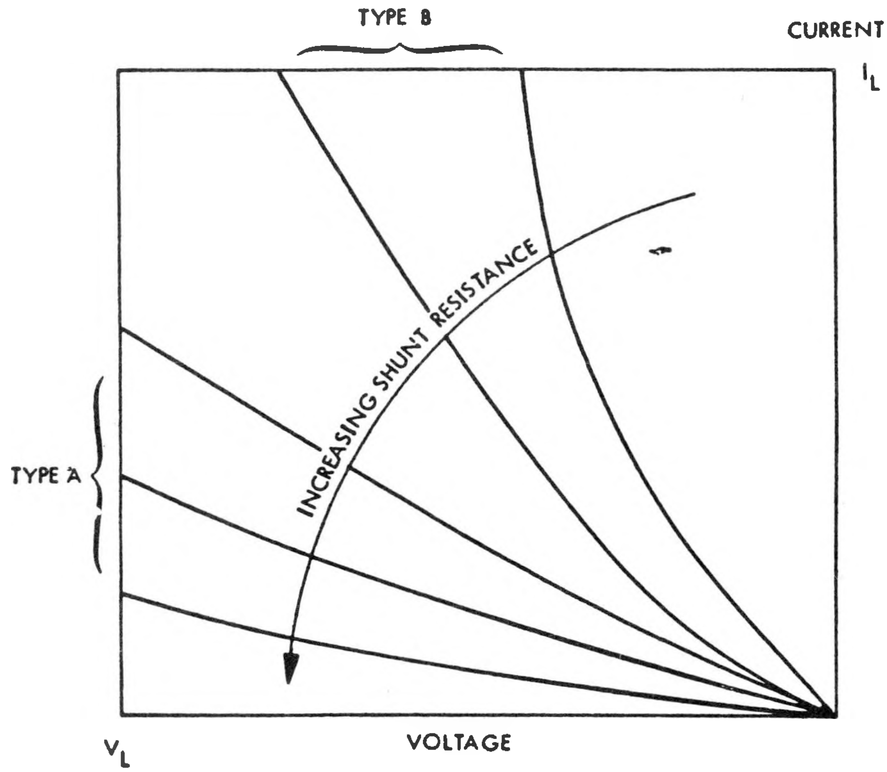
41.5 Three non-adjacent individual cells within the test module or panel are to be selected: one representative of the highest shunt resistance obtained, one representative of the average, and one representative of the lowest. Each cell to be tested is to be provided with individual positive and negative electrical leads to allow the cells to be connected individually and directly to separate power supplies. Parallel current paths around the cells to be tested are to be eliminated by disrupting cell-to-cell connections as necessary. The lead attachment should minimize disruption of the heat transfer characteristics of the cell or the hot-spot endurance of the encapsulant system.

Selection of Hot-Spot Test Level

COMMENTARY: The objective of this portion of the test procedure is to select the level of heating and the corresponding test condition that will stress the module or panel in a manner similar to a severe hot-spot field condition. The severity of the field condition will depend on the array circuit configuration, the array I-V operating point, the ambient thermal conditions, the overall irradiance level, and the previously described characteristics of the affected cells. When a module is incorporated into a photovoltaic source circuit, the maximum reverse voltage imposed on an individual cell can approach the system voltage unless bypass diodes are properly used. V_L is set to yield the maximum reverse voltage that can be applied across a single cell when the module is applied in a circuit with the minimum number of bypass diodes as specified by its marking.

In the paragraphs below the detailed levels are separately specified for Type A and Type B cells.

FIGURE 41.1
TYPICAL REVERSE-VOLTAGE I-V PLOT FOR SAMPLE OF CELLS



Type A Cells (High Shunt Resistance)

41.6 The governing parameters concerning reverse voltage heating are (1) the maximum cell reverse voltage (V_L), (2) the cell irradiance level, and (3) the ambient thermal environment.

41.7 V_L is to be set equal to N times the V_{mp} of an individual cell, where N is the number of series cells per specified or integral bypass diode.

41.8 The irradiance level on the test cell is then to be adjusted to achieve an I_L equal to the average cell maximum power current at 100 mW/cm^2, NOCT.

COMMENTARY: The irradiance level directly controls the hot-spot current level, and therefore the power level. As illustrated in Figure 41.2, there is a unique irradiance level that corresponds to worst-case power dissipation for any particular Type A photovoltaic cell.

41.9 The test is to be conducted in an ambient air temperature of 20±5°C and with a radiant heating source that will result in a uniform background module cell temperature equal to NOCT ±2°C.

Type B Cells (Low Shunt Resistance)

41.10 The irradiance is to be not more than 5 mW/cm^2, this level allows for room lighting and an IR heating source, and the current (I_L) is to be equal to the short-circuit current of an average cell at 100 mW/cm^2, NOCT.

COMMENTARY: The cell shunt resistance is so low that the maximum reverse voltage is set by the I-R drop across the cell associated with the available current level. Worst-case heating occurs when the test cell is totally shadowed, and the current level is at a maximum.

41.11 The test is to be conducted in an ambient air temperature of 20±5°C with a radiant heating source that will result in a uniform background module cell temperature equal to NOCT ±2°C.

Test Execution

COMMENTARY: Detailed steps for execution of the test involves subjecting the three selected test cells to cyclic hot-spot heating at the levels determined above for a period of 100 hours total on-time as follows:

41.12 A constant voltage power supply (for Type A cells) and a constant current power supply (for Type B cells) is to be connected to the cell under test, with polarity arranged to drive the cells with reverse voltage. The voltage and current are to be adjusted to the limits of V_L and I_L values determined in paragraphs 41.6 and 41.10.

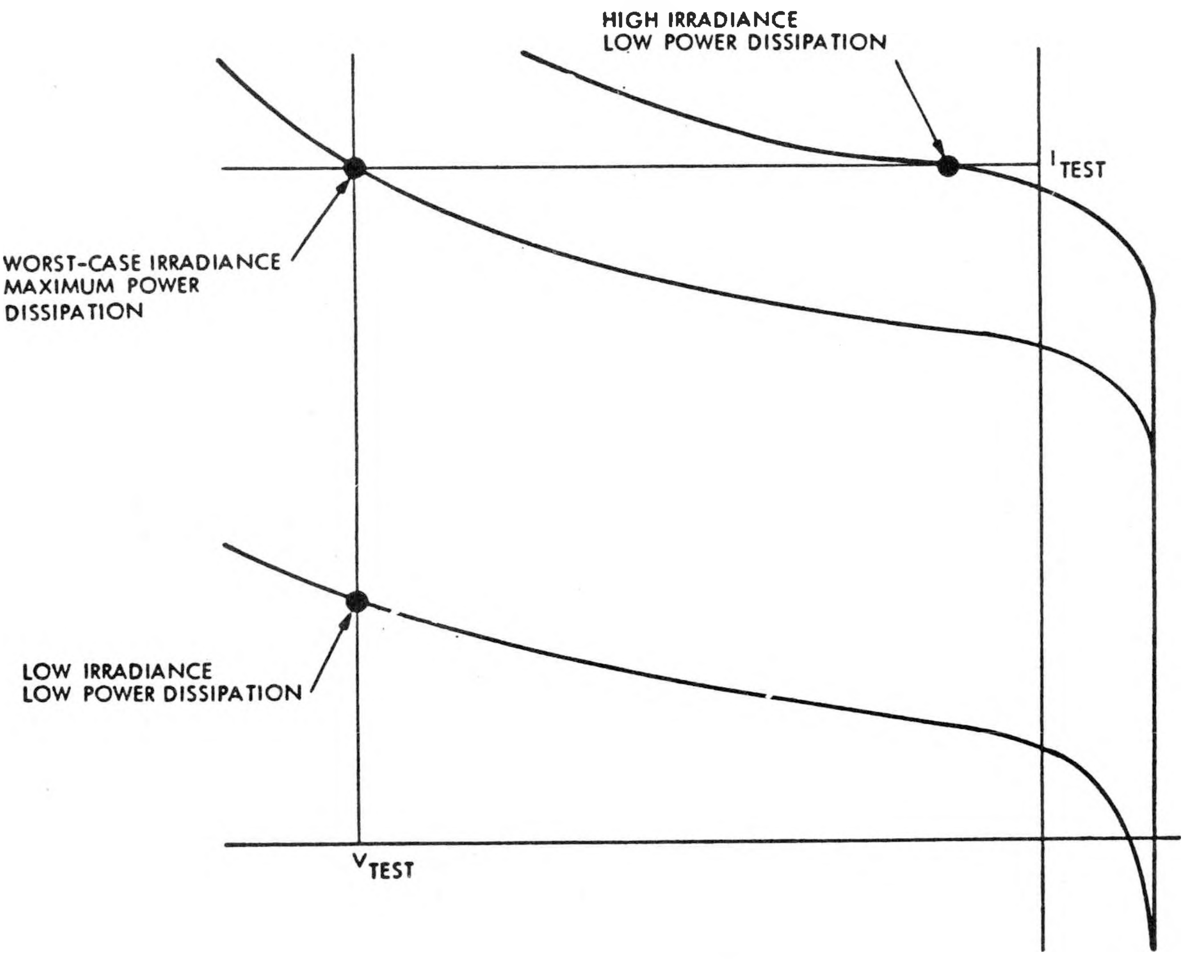
41.13 An infra-red radiant heating source with a visible light contribution below 5 mW/cm^2 is to be applied to the module or panel and adjusted to result in a uniform module cell temperature equal to NOCT ±2°C. The ambient air is to be still and at a temperature of 20±5°C.

41.14 For Type A cells only, an additional light source is to be used to illuminate each test cell to the level determined in paragraph 41.8 (Figure 41.2). This is most easily accomplished after the power supply and IR source are turned on by adjusting the irradiance level to achieve I_L after equilibrium test conditions stabilize.

41.15 The power supply, IR source, and irradiance source are to be energized for one hour followed by an off-period sufficient to allow the cells under test to cool to within 10°C of the ambient temperature.

41.16 The operation is to be repeated until a total of 100 hours of on-time have been accumulated.

FIGURE 41.2
EFFECT OF TEST-CELL ILLUMINATION LEVEL ON HOT-SPOT POWER DISSIPATION



41.17 The test cells and the adjacent areas of the encapsulation system are to be visually inspected at 24 hour intervals during the test while the cells are under impressed voltage conditions and also upon completion of the 100-hour sequence.

42. Arcing

42.1 If the point of (a) current at maximum power and (b) voltage that can appear across a cell or interconnect fracture is in the 'ARC TEST' zone in Figure 42.1, the module or panel shall comply with the provisions of paragraphs 42.2-42.9. In determining the voltage, the value is to be the maximum that can be achieved considering the specified use of bypass diodes, see paragraph 45.8.

42.2 Under conditions of simulated cell or interconnect fracture, there shall be no ignition of the module or panel.

Method A

42.3 Similar modules or panels under test are to be connected in series to achieve an open-circuit voltage across the fracture equal to that which is present in the normal use of the modules or panels with the specified bypass diodes. All the modules and panels are to be irradiated at 80 mW/cm^2 minimum at 20°-30°C.

Method B

42.4 At the manufacturer's option, a single module or panel can be used with a separate power supply connected in series to provide the remainder of the source.

42.5 In reference to paragraph 42.4, the power supply is to be a constant voltage supply with a series connected current limiting resistor. The module or panel under test is to be irradiated at 80 mW/cm^2 minimum at 20°-30°C and the parameters of the total system are as follows:

Open-Circuit Voltage - Adjusted to that which is present across the fracture in the normal use of the modules or panels with the specified bypass diodes.

Short Circuit Current - Not less than 85 percent nor more than the rated module or panel short-circuit current, when the current limiting resistor is adjusted so that the voltage across the module or panel under test is zero.

Method A or B

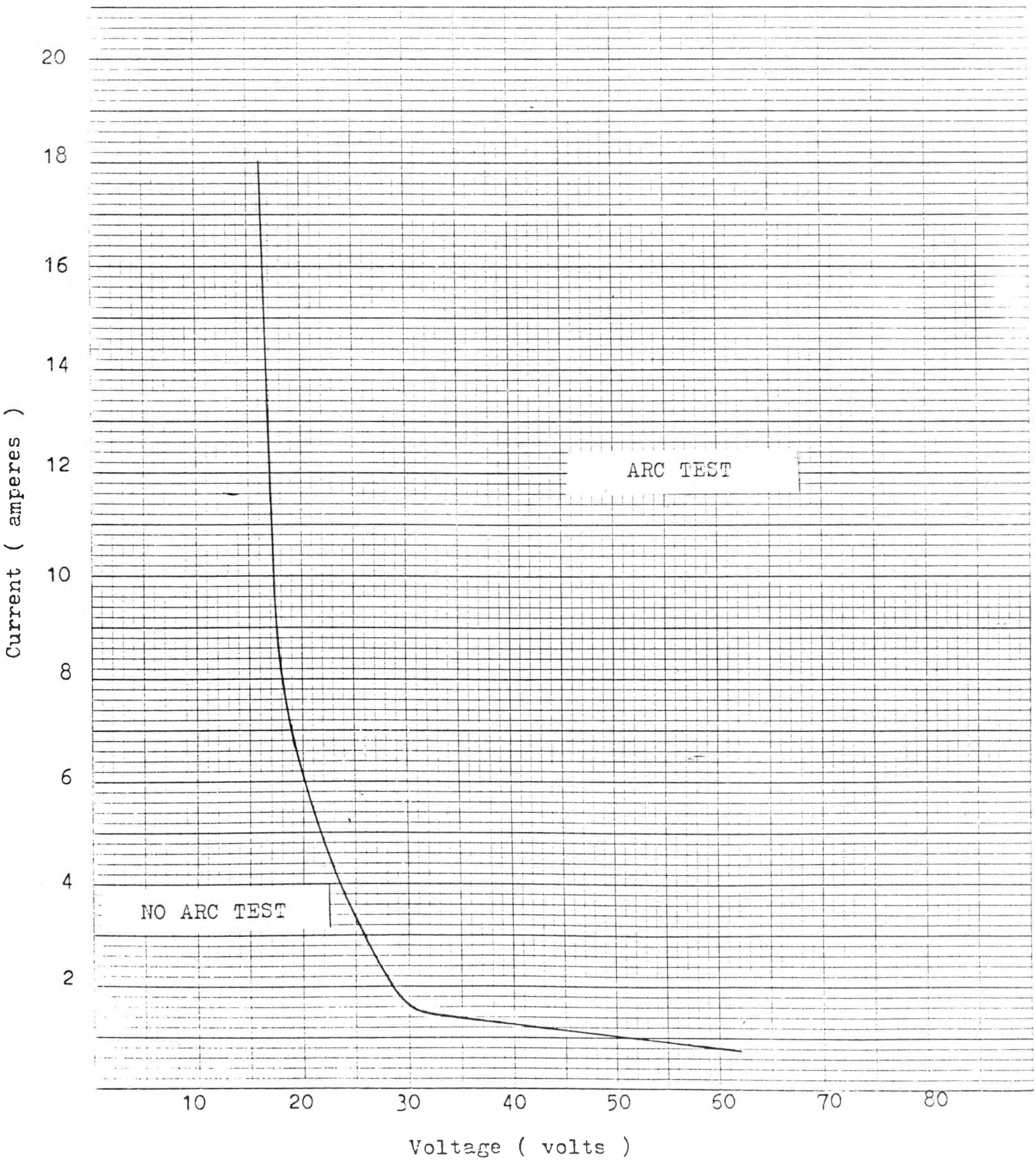
42.6 All blocking and bypass diodes, either included with the module or panel or described in the markings shall be included in the test circuit.

42.7 The system load is to be a short circuit.

42.8 Any connection(s) within the module or panel may be broken (fractured). The breaks are to be chosen to achieve a worst case condition of maximum open circuit voltage and/or maximum short circuit current at one of the chosen break points.

Exception: Any electrical connection made with wire of circular cross section or flexible braided construction that is mechanically secured to its connection points is not to be broken. Braided or stranded wire shall not have any process performed on it which reduces its flexibility. Solder coating of a portion of the wire at the connection points is acceptable.

FIGURE 42.1   CURRENTS AND VOLTAGES FOR ARC TEST



42.9 An arc is to be drawn across the breaks, the arc is to be across that material of the module or panel with which it might contact in the use of the module or panel. The arcing shall be continued for 15 minutes at each location tested.

43. Mechanical Loading
[To Be Developed]

RATING

44. Details

44.1 The electrical rating of a module or panel shall include the open circuit and maximum output power voltages, the short circuit and maximum output power current, the maximum power output at NOCT, the maximum acceptable system direct voltage, and the maximum acceptable ac rms voltage.

MARKING

45. Details

45.1 A module or panel shall have a plain legible marking that includes: (1) the manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product can be identified; (2) the model number or the equivalent; (3) the electrical rating; and (4) the date of manufacture which may be abbreviated or in a nationally accepted conventional code or in a code affirmed by the manufacturer, that will enable the module or panel to be identified as being manufactured within a consecutive 3 month period. Items (1) and (2) of the marking shall be located so that they will be readily visible after the module or panel has been installed as intended.

45.2 The repetition time cycle of a date code shall not be less than 10 years.

45.3 If a module or panel is manufactured at more than one factory, it shall have a marking indicating its point of manufacture.

45.4 If, during the temperature test, the temperature on a field-installed lead or on any part of the wiring compartment that the lead might contact is more than 60°C (140°F), the module or panel shall be marked with one of the statements indicated in items (a) or (b) below or the equivalent. The marking shall be located at or near the points where field connections will be made, and located so that it will be readily visible during installation.

(a) "For field connections, use No. _____ AWG wires insulated for a minimum of 75°C",

(b) "For field connections, use No. _____ AWG wires insulated for a minimum of 90°C".

45.5 If the pressure wire connectors of a module or panel are not acceptable for use with aluminum wire, or if the module or panel manufacturer intends the use of only copper wire, the module or panel shall be marked, at or adjacent to the terminals, with the statement "Use copper wire only", "CU only" or the equivalent. This marking may be combined with that required by paragraph 45.4.

45.6 If the pressure wire connectors of a module or panel are acceptable for accommodating both copper and aluminum wire and if the manufacturer intends such use, the module or panel shall be marked (independent of any marking of the terminal) with the statement "Use aluminum or copper wire", "AL-CU", or the equivalent. This marking may be combined with that required by paragraph 45.4.

[NOTE: Although requirements covering means for accommodating aluminum wire have been included, such wiring method may in fact be unacceptable due to the potential consumption of the aluminum conductors or overheating of the connections. Further work appears necessary in this regard if aluminum wire is to be considered for acceptance.]

45.7 Wiring terminals shall be marked to indicate the maximum number and size of conductors that may be used. The marking shall be at the wire connector if practical, or if not practical in another visible location, such as next to the terminal or on a wiring diagram.

45.8 A module or panel shall be marked relative to (a) the minimum acceptable diode bypassing, or (b) shall be marked to make reference to manufacturer's literature where information on diode bypassing can be found. If option (b) is chosen, the manufacturer shall provide this literature with the modules or panels.

45.9 A module or panel shall be marked relative to the maximum electrical rating of an acceptable series fuse (for protection against backfeed).

45.10 A module or panel shall be marked relative to its fire rating. A module or panel shall be marked "Not Fire Rated", unless it complies with the requirements for fire rating. If a module or panel is fire rated and if its use is so intended by the manufacturer, it shall be marked accordingly, for example - "Modules mounted free standing 6 inches above a Class B roof constitute a Class C roof".

45.11 A wiring compartment provided as a part of a module or panel shall be marked indicating its volume in cubic inches. Supplementary marking in other units (e.g. - cubic centimeters) is permitted.

45.12 A module provided as a part of a panel shall be provided with all of the markings which would be required for its existence as a separate entity.

46. Installation Instructions

46.1 Installation instructions shall be provided describing the method of mechanical installation of the module or panel. Detail on the acceptable accommodating structure, spacings, etc. shall be included for any module or panel provided with a fire rating. Such detail on the acceptable accommodating structure is optional for modules and panels not fire rated.

46.2 The installation instructions shall include a statement advising that concentrated sunlight shall not be directed on the module or panel.

PRODUCTION LINE TESTS

47. Factory Dielectric Voltage Withstand Test

47.1 Each module or panel having a maximum acceptable system direct voltage rating of 30 volts or more shall withstand for one minute without electrical breakdown as a routine production line test, the application of a test potential between parts involving a risk of electric shock and accessible metal parts. The test period may be reduced to one second if the potential shown below is increased to 120 percent of the value described.

47.2 The test potential is to be 2 V + 1,000 v dc. "V" is the rated maximum acceptable system direct voltage.

47.3 The test equipment is to include a means of indicating the test voltage that is being applied to the product under test. This may be accomplished by sensing the voltage at the test leads or by an equivalent means. The test equipment is also to include a means of effectively indicating unacceptable performance. The indication is to be (1) audible if it can be readily heard above the background noise level; (2) visual, if it commands the attention of the operator; or (3) a device that automatically rejects an unacceptable product. If the indication of unacceptable performance is audible or visual, the indication is to remain active and conspicuous until the test equipment is manually reset.

47.4 When the test equipment is adjusted to produce the test voltage and a resistance of 1 megohm is connected across the output, the test equipment is to indicate unacceptable performance within 0.5 seconds. The test equipment is to be considered to have an acceptable sensitivity setting when a test resistor that has any value of resistance not less than 1 megohm produces an indication of unacceptable performance.

47.5 The test is to be conducted when the module is complete and ready for packing, or when it is complete except for covers or other parts that may interfere with the performance of the test.

48. Continuity of Grounding Connection

48.1 Each module or panel provided with a connection for grounding accessible conductive parts shall be subjected to a routine production line test to demonstrate electrical continuity between the grounding connection and all accessible conductive parts.

48.2 Any appropriate indicating device, ohmmeter, low voltage battery and buzzer combination or the like may be employed for the test described in paragraph 48.1.

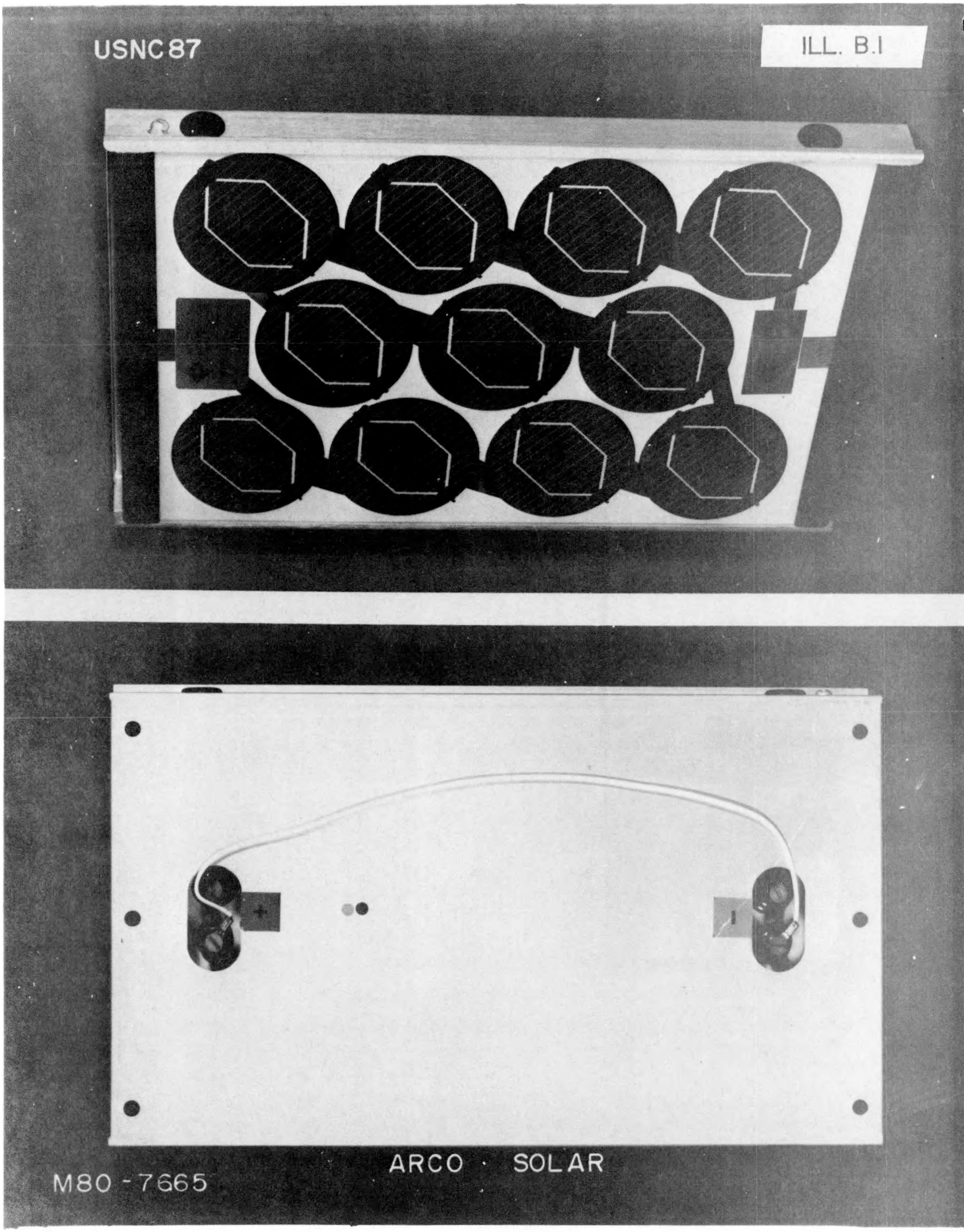
APPENDIX B

MODULE EVALUATION LIST

JPL Block III Modules served as models in the early development stages of the draft Proposed Standard for Safety - Flat-Plate Photovoltaic Modules and Panels, and in concepts for National Electrical Code proposals and safety system features, such as ground-fault and arc detectors.

Modules used in laboratory examinations included:

Module	Serial No.	Illustration No.
ARCO Solar, Inc.; 11 cell, 6.4 volts	107440	B.1
Sensor Technology (A); 24 cell, 13.5 volts	113G	B.2
Sensor Technology (B); 24 cell, 13.5 volts	022	B.3
Sensor Technology (C); 24 cell, 12.5 volts	050	B.4
Solar Power Corp.; 8 cell, 4.7 volts	0352	B.5
Solarex Corp.; 12 cell, 6.8 volts	YM-023	B.6
Spectrolab, Inc., (A); 24 cell, 5.7 volts	2303-61	B.7
Spectrolab, Inc., (B); 120 cell, 23.5 volts	1388	B.8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ILL. B.1
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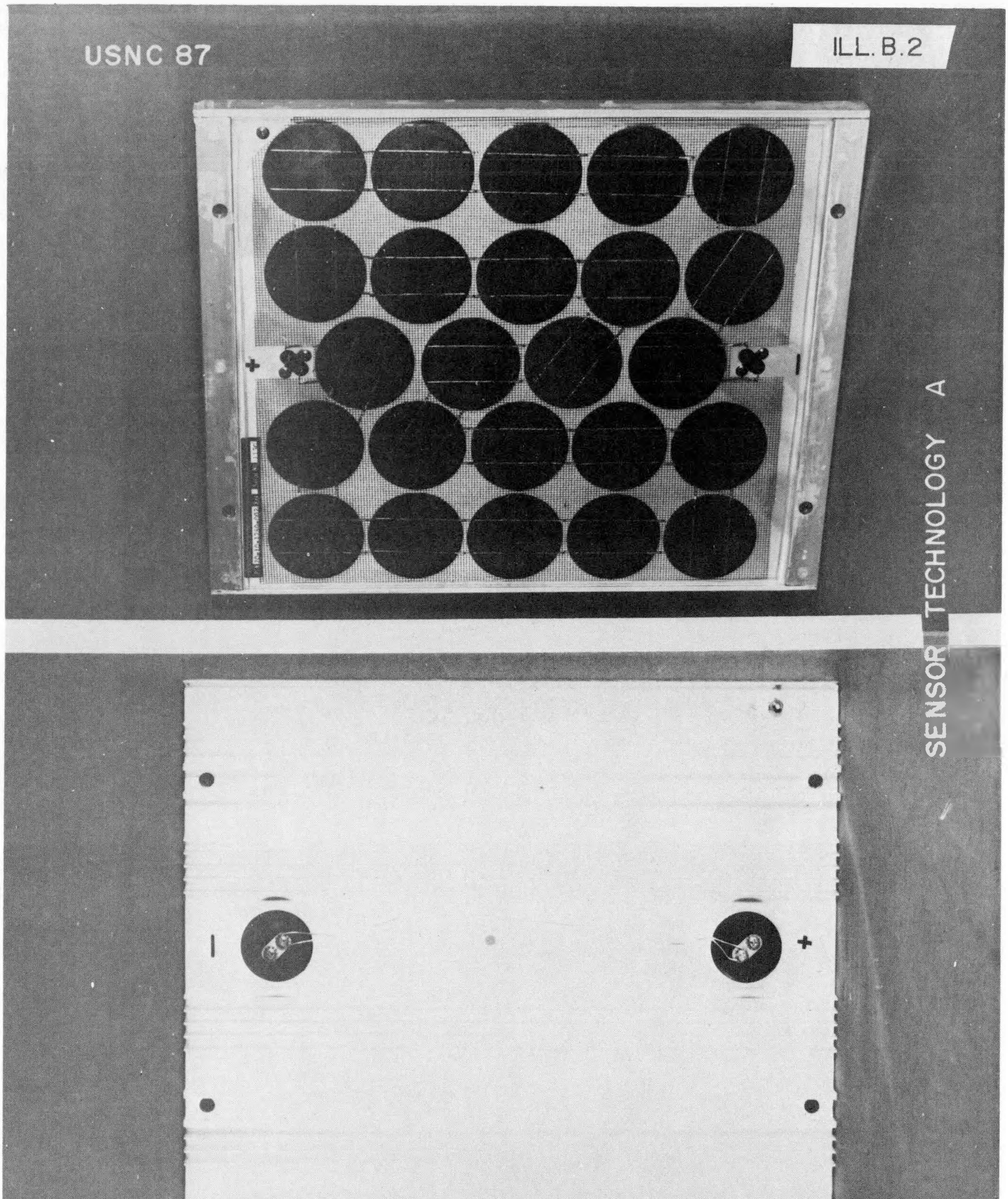
ARCO · SOLAR
M80-7665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ILL. B.2
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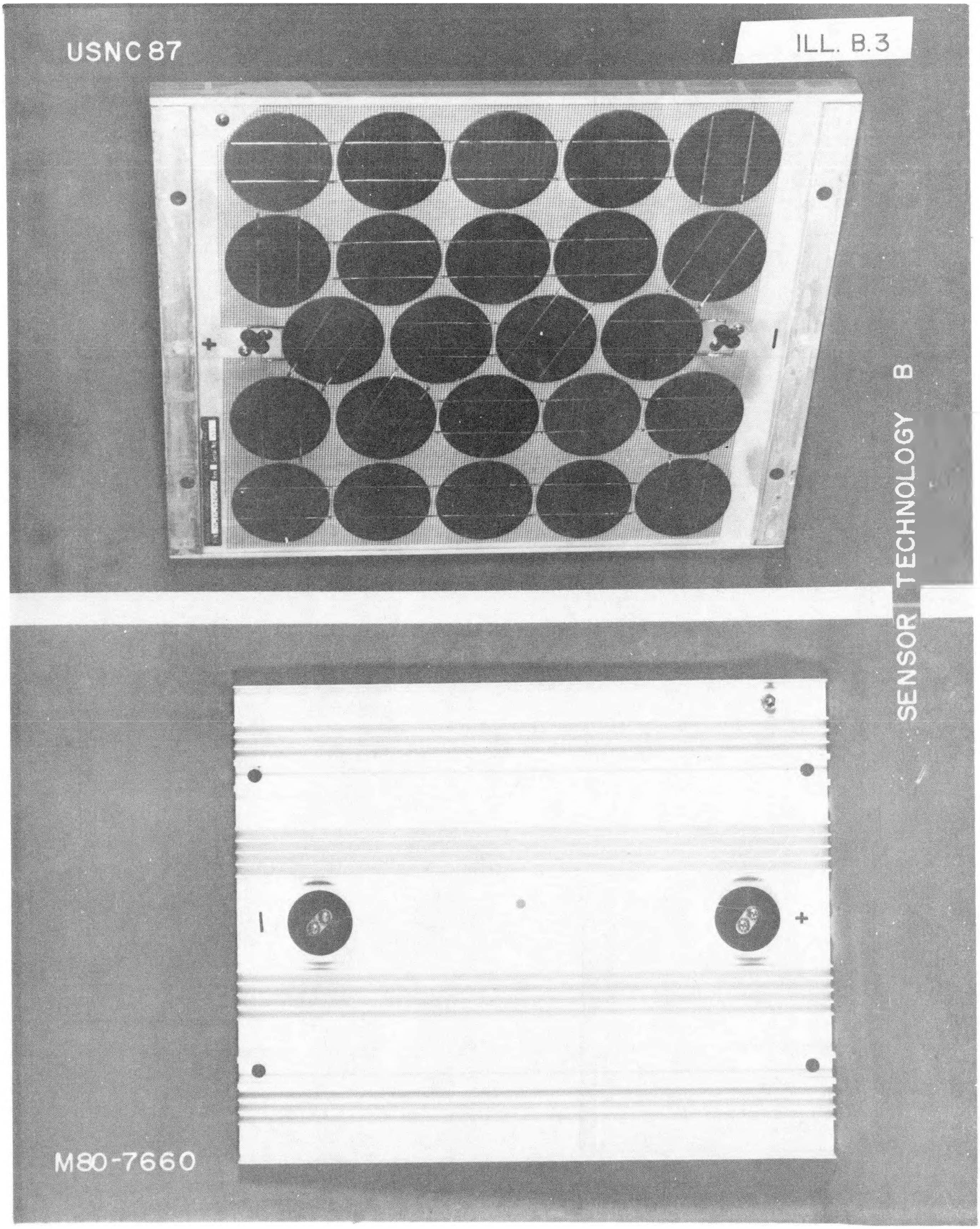
SENSOR TECHNOLOGY A
M80 -7664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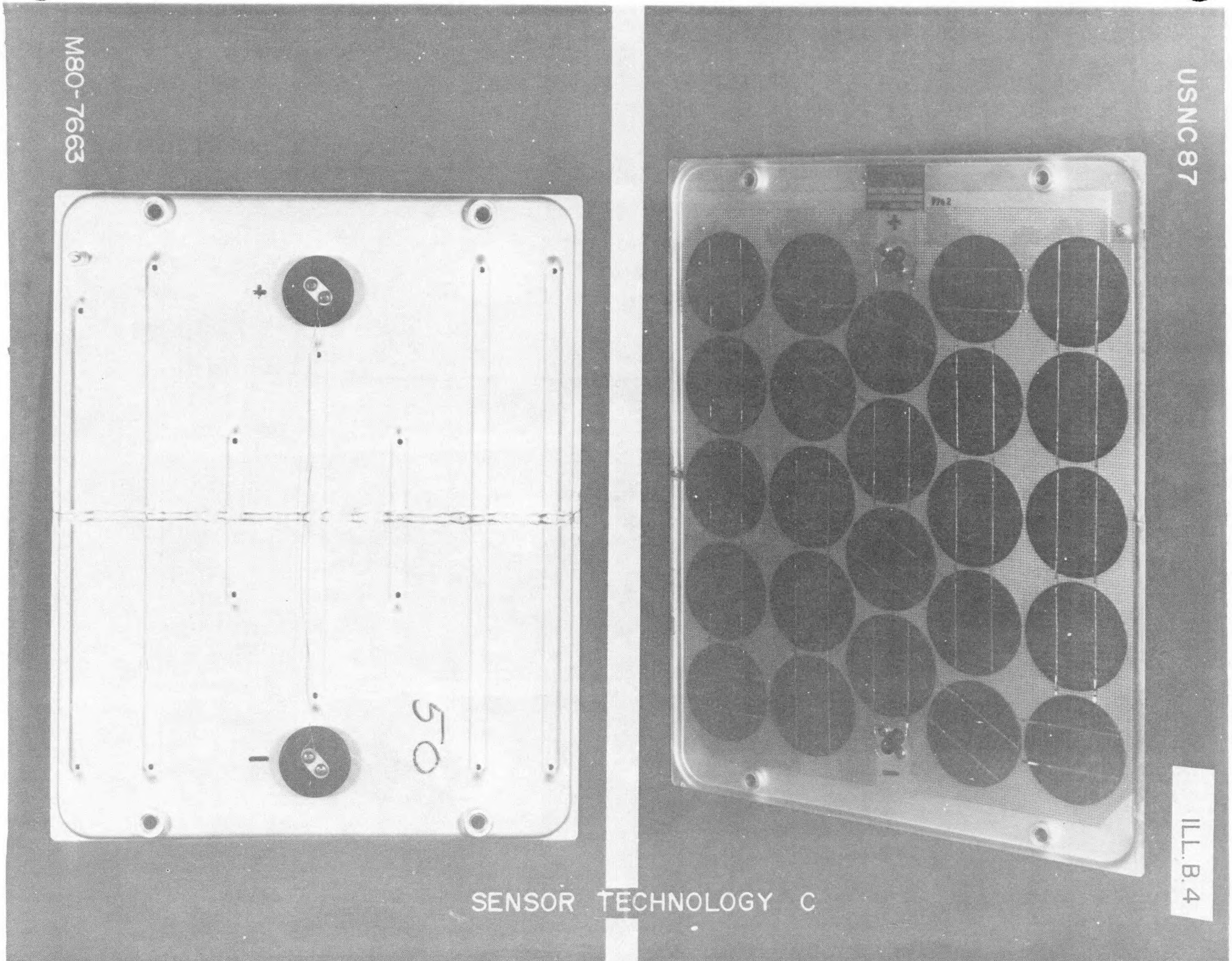
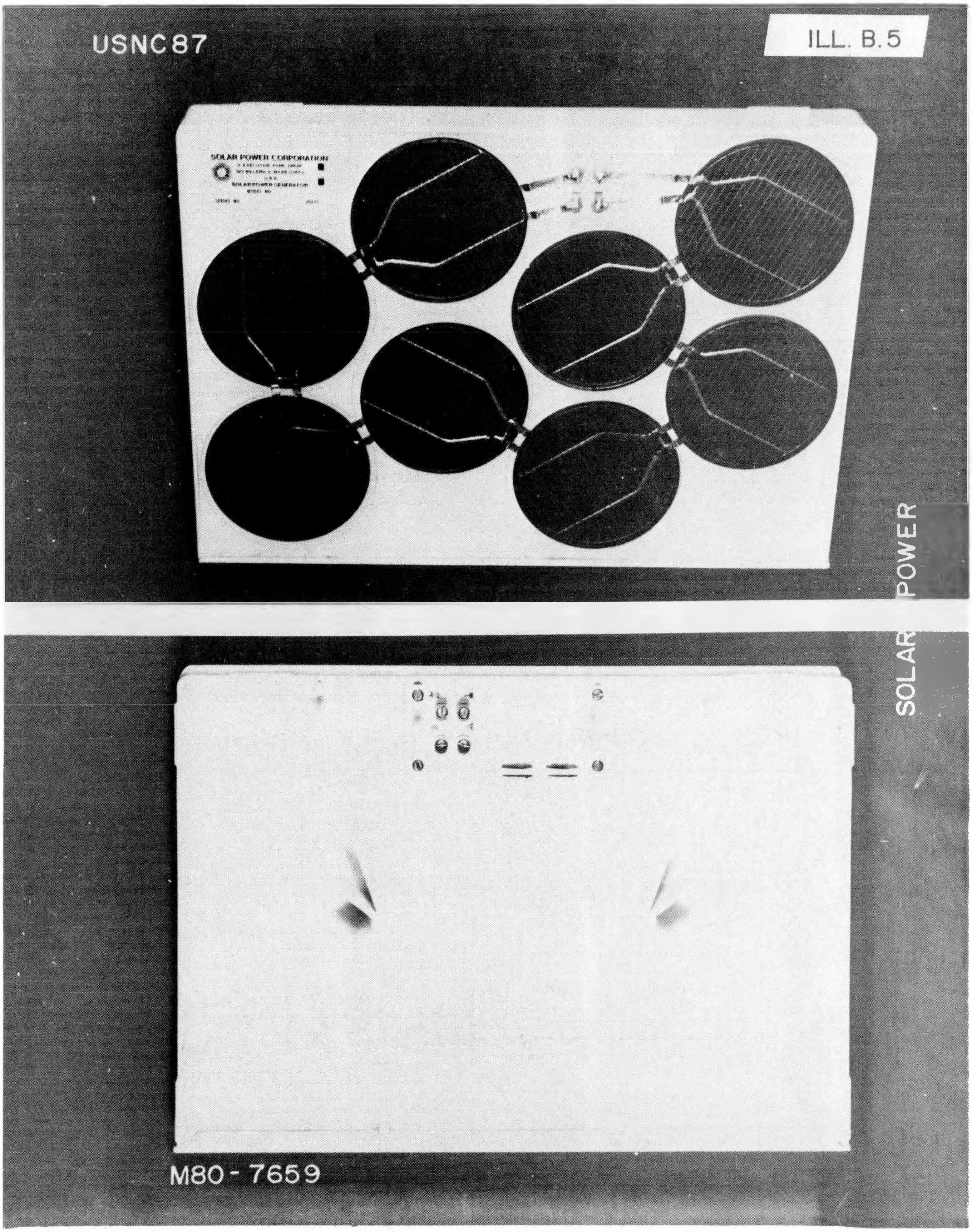
ILL. B.3
+
-
SENSOR TECHNOLOGY B
-
+
M80-7660


M80-7663
USNC87
ILL.B.4
SENSOR TECHNOLOGY C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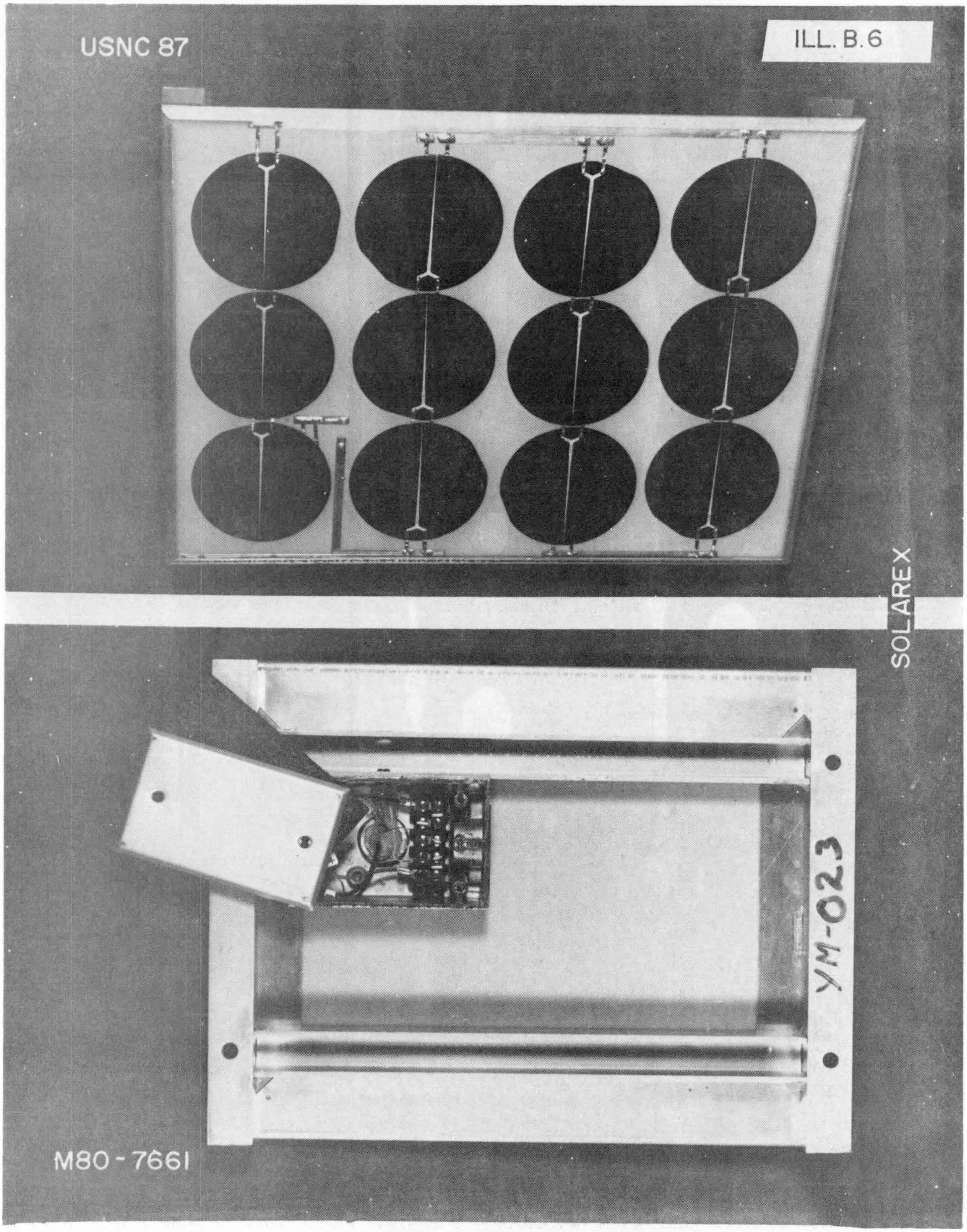
ILL. B.5
SOLAR POWER CORPORATION
SOLAR POWER
M80-7659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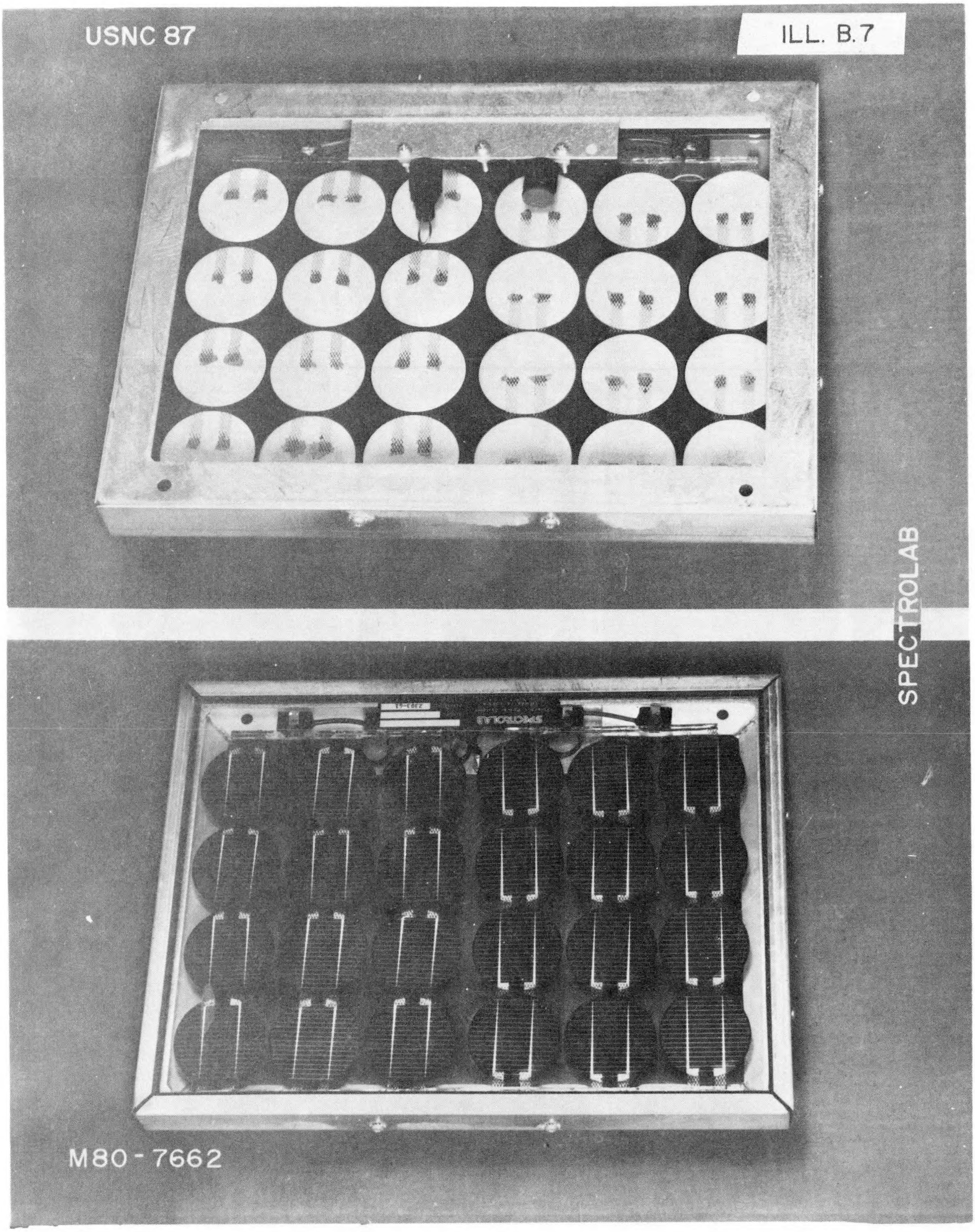
ILL. B.6
SOLAREX
YM-023
M80-7661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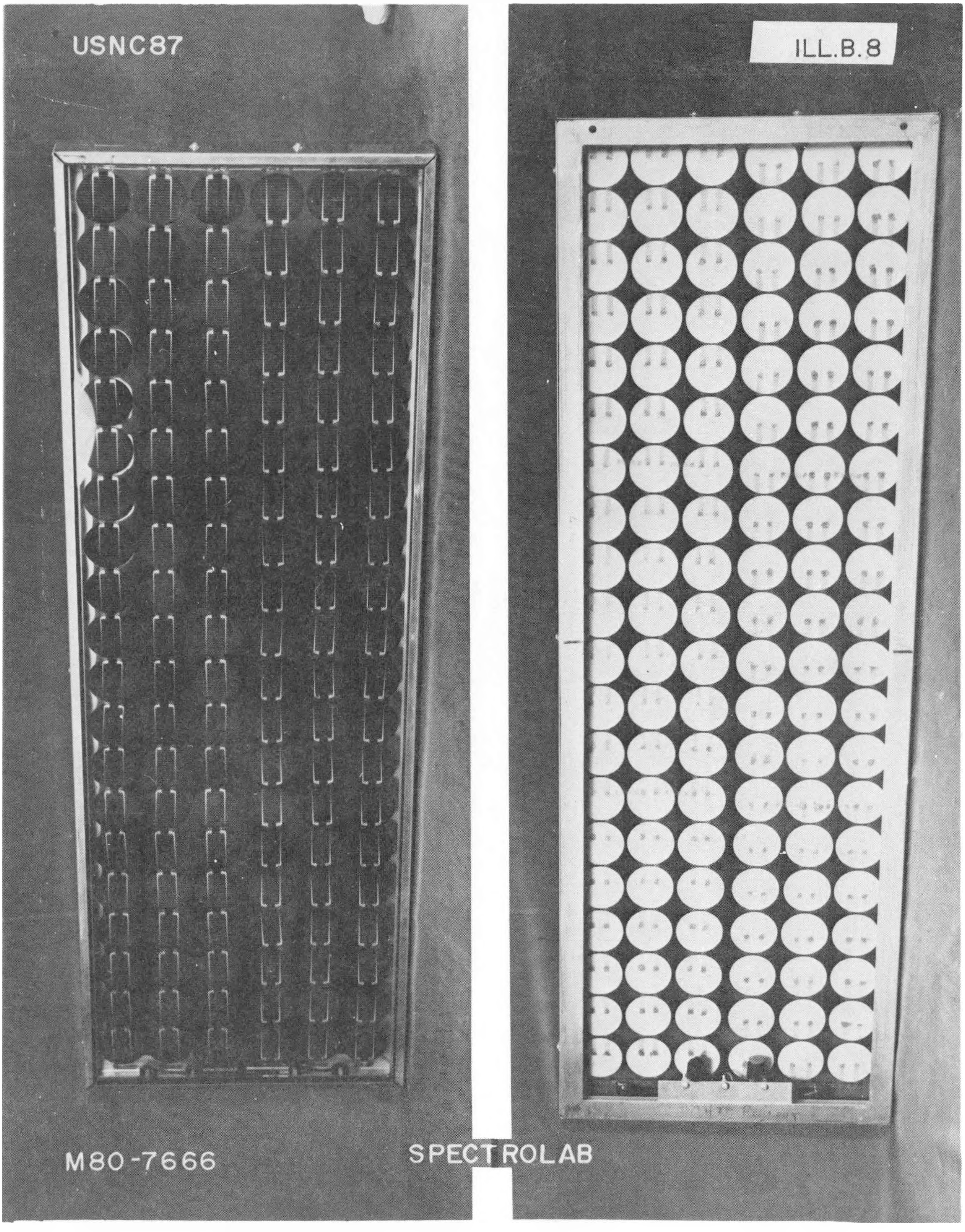
USNC87
ILL.B.8
M80-7666
SPECTROLAB

APPENDIX C

STATISTICAL DEVELOPMENT OF AN ACCESSIBILITY PROBE

STATISTICAL DEVELOPMENT OF AN ACCESSIBILITY PROBE

PURPOSE

The purpose of this investigation was to determine the ability of the human finger to penetrate openings in enclosures and thereby contact live parts within the enclosure or encounter parts within the enclosure which could be a casualty hazard.

METHOD OF OBTAINING DATA

A simplified testing method was used which directly related to the problem of access. Two 1.6 millimeter phenolic panels were constructed, one with rounded edged holes having diameters of 3.2, 4.8, 6.4, 7.9, 9.5, 11.1, 12.7, 14.3, 15.9, 17.5, 19.1, 20.6, 22.2, 23.8, and 25.4 millimeters, and the other having rounded edged slots with these same dimensions of slot width.

One hundred adult female subjects, one hundred adult male subjects, and one hundred children were asked to penetrate each of these holes with any finger, and each of these slots with any finger or fingers to the maximum extent. The penetration was measured by having the subject press against a wooden dowel with an end diameter of approximately 3.2 millimeters so as to move the dowel and a scale attached to it.

The measurements on the one hundred men and one hundred women had been completed before the children's measurements were started. These adult subjects were employees of Underwriters Laboratories, Inc. who interrupted their working day to take the test. The 100 children were obtained from a variety of sources. They were chosen with ten in eac' age group from one to ten years old.

The testing apparatus is pictured in Figure 1, which shows the hole board apparatus being used by a subject, and in Figure 2 which is a drawing of the test apparatus. The 1.6 millimeter thick phenolic was backed by 6.4 millimeter plywood and, in the case of the slot board, further stiffened with ribbing in order that bending of the phenolic would not be a significant factor. Thin phenolic was chosen to simulate an enclosure and to minimize the problem of defining the starting, or zero penetration position. For penetration measurements the scale was set at zero with the dowel tip 1/2 way through the phenolic panel. The hole or slot in the plywood was made 3 to 12 millimeters larger than the hole or slot in the phenolic so that the plywood would not interfere with the subject's finger nor affect the measurement.

The subject was generally seated for the test, but he was invited to stand if he had difficulty in orienting his fingers so as to make contact with the dowel. The subject was encouraged to penetrate as far as possible, and to manipulate his fingers in order to gain entrance through the holes and slots, without the use of excessive pressure, and without using fingernails to increase penetration. Each hole and slot edge was rounded so that a sharp edge would not be a deterrent to aggressive penetration.

SUBJECT INTERACTION WITH THE TEST

In the case of holes, it was generally found that the little finger penetrated further than the other fingers for the smaller openings, but that the other fingers generally penetrated further at larger openings. Occasionally, an aggressive subject would need aid in releasing his finger from a hole after having gained entrance.

Only one hole was utilized at one time. The subject was directed to attempt his penetration at the smallest hole, and after he had produced the maximum penetration with any finger at that opening, he was asked to move to the next larger opening. After completing the measurements with the holes, the subject was asked to start at the smallest slot and repeat the process. Any finger or combination of fingers was used at the slots. The observer recorded the maximum movement of the scale at the particular opening and recorded whether or not joints or knuckles had passed through the opening.

If the observer noted a decreased penetration with an increased opening size, the observer asked the subject to try a little harder since he had already exceeded that penetration at a smaller opening. The adults complied with this request, but the children tended to lose interest, and rather than jeopardize the completion of the test, it was decided to encourage the children to produce consistent results, but not to stress the point. For the children, (10 years of age and younger) the data utilized in plotting the curves was the penetration at the particular hole or slot, or at any previous smaller hole or slot respectively.

The children's data was tagged with the age of the child so that the distribution of penetrations with respect to children's age could be seen. It will be recognized that the one and two year old children represented a rather unique problem. Motivation for this age group was achieved by such means as placing a bear's head over the tapered dowel, with the dowel forming the bear's nose, and by the use of small stuffed animals peeking through the holes. Edible rewards and verbal encouragement helped. The child's mother generally aided by holding and straightening the child's fingers sufficiently for the measurement to be made. There was a noticeable tendency for the younger children to use the index finger in their exploration of the holes and slots. The other fingers were generally inserted with the child's mother directing the insertion.

The slots, with their long dimensions vertical, were 127 millimeters high so as to accept all fingers at once. The subject was encouraged to try the fingers singly or in any combination, whichever produced the maximum penetration. Again, the little finger was found to be effective on the narrow slots. Many adults pushed all of their fingers and the palm of their hand, with the exception of the heel, through the 25.4 millimeter slot.

PRESENTATION OF DATA

The original data was ranked for each group at each hole and slot in order of increasing penetration. This means that the individual subject would probably change his rank position at successive hole or slot openings. Portions of these tabulations for the children's data are presented as Table 1, (Samples of Children's Finger Penetration Data). Note that the age of the child involved follows the penetration he obtained. Age 10 is identified as "-0". Only the subjects who achieved penetrations in the top 10 percent of the group (for the particular hole or slot) are presented here. The entire data from these tables was then plotted on normal probability paper at the center of 1 percent cells, thus the subject with rank No. 1 (minimum penetration) was plotted at the 0.5 percentile point. Several different vertical scales were utilized in order to display the information to best advantage. Samples of these plots are presented as Figure 3 (Penetration of Children's Fingers Through Slots) and Figure 4 (Penetration of Adult Male Fingers Through Slots).

It would have been ideal to find that these plots produced straight lines on the normal probability paper, which would have indicated a normal distribution of subject penetrations. It was found however, that the plots exhibited irregular variations, and it was later determined that these occurred especially at the points where finger joints first achieved a penetration through the hole or slot. In other words, once a joint passed through a hole or slot the increase in penetration was

TABLE 1 - SAMPLES OF CHILDREN'S FINGER PENETRATION DATA

	Rank No.	3.2 mm	4.8 mm	6.4 mm	7.9 mm	9.5 mm	11.1 mm	12.7 mm	14.3 mm	15.9 mm	19.1 mm	22.2 mm	25.4 mm
HOLE PENETRATION - AGE	90	1.0-4	1.5-2	2.5-7	6.0-5	19.0-5	33.5-2	45.0-8	53.5-5	65.3-7	69.2-8	70.9-9	72.5-9
	91	1.0-7	1.5-3	2.5-6	6.0-7	19.0-3	34.0-2	45.0-7	54.0-6	65.6-0	70.0-9	71.5-9	72.5-9
	92	1.0-3	1.5-5	2.5-2	6.0-1	19.0-2	34.2-6	45.0-2	54.0-5	66.0-0	70.0-8	71.5-9	73.0-0
	93	1.0-9	1.5-4	2.5-3	6.3-1	19.0-5	35.0-2	45.3-3	54.0-7	66.0-8	70.0-9	72.0-8	73.8-9
	94	1.0-8	1.5-3	3.0-3	7.0-1	19.0-3	35.0-3	46.5-8	54.8-6	67.0-9	70.0-9	72.0-9	74.0-0
	95	1.0-4	1.7-9	3.0-6	7.5-1	19.0-2	35.0-4	46.5-5	55.0-5	67.0-9	70.3-0	73.0-0	74.0-0
	96	1.0-7	1.8-8	3.0-3	7.5-1	20.0-5	35.2-2	47.5-0	56.0-6	67.5-9	70.7-0	73.0-0	74.0-0
	97	1.0-5	1.8-0	3.0-5	8.0-3	20.0-3	38.0-5	48.5-5	56.7-6	67.5-0	71.5-0	73.7-0	74.5-8
	98	1.0-6	2.0-8	3.5-5	8.0-1	20.0-2	38.0-3	48.7-2	56.8-7	68.8-0	72.0-0	73.7-0	75.0-0
	99	1.0-2	2.0-7	3.5-7	9.0-2	21.0-3	38.0-5	49.0-9	57.0-7	70.0-9	72.0-0	74.0-0	77.0-0
	100	1.0-6	2.5-3	3.5-1	13.5-1	23.0-1	38.0-5	49.2-9	58.3-8	71.0-0	73.0-0	77.0-0	78.0-9
SLOT PENETRATION - AGE	90	2.0-7	3.5-1	10.5-4	25.0-7	39.0-5	52.5-3	60.0-8	69.6-9	75.5-2	98.0-7	116.5-9	147.5-2
	91	2.0-1	3.5-2	11.0-8	25.0-4	39.0-3	53.5-3	60.0-9	70.0-8	76.0-0	99.0-8	117.5-0	148.0-3
	92	2.0-9	3.5-6	11.0-7	25.0-7	39.0-6	53.5-4	60.5-0	70.0-0	76.0-9	99.5-9	118.0-9	151.0-2
	93	2.0-5	3.5-2	11.0-8	25.5-9	39.5-3	53.5-3	61.0-5	70.5-7	76.0-2	99.5-7	118.0-8	152.0-5
	94	2.0-8	3.5-7	11.0-8	25.5-5	40.0-4	53.5-6	61.0-0	71.0-0	76.0-9	99.3-7	118.0-9	152.5-7
	95	2.0-1	4.0-1	11.0-8	25.5-0	41.0-6	54.0-4	61.0-5	71.0-8	76.0-0	101.5-7	118.0-0	154.0-4
	96	2.0-4	4.0-7	12.0-9	26.5-3	41.0-5	54.0-5	61.6-9	71.0-0	76.5-0	101.5-8	119.5-0	155.0-4
	97	2.0-6	4.0-9	12.0-7	26.7-0	42.0-5	55.0-5	62.0-0	71.0-0	77.0-0	108.5-9	122.5-9	158.0-2
	98	2.0-8	4.5-2	14.5-3	28.0-9	43.0-0	55.0-4	62.5-7	71.5-0	77.0-3	114.4-0	126.5-0	158.5-5
	99	2.0-9	4.5-3	15.0-1	28.0-7	45.2-8	55.0-5	63.0-7	72.0-9	77.0-2	116.0-0	126.5-0	158.7-6
	100	2.2-8	5.0-1	15.5-2	36.0-2	52.0-1	57.0-5	69.0-1	72.0-9	78.0-0	120.0-9	128.0-1	175.0-5

significantly greater than it would have been if the joint had not passed.

Data was extracted from these percentile plots by drawing the most likely curve and noting the point at which the curve crossed the percentile line of interest. We have chosen the 95 percentile point for our probe development work, although any other percentile value could have been used. Figures 3 and 4 have a vertical line at the 95 percentile point. This information was then plotted for each subject group; men, women, and children, representing a penetration which had been achieved by only 5% of the subjects tested in each group, and a penetration which had not been achieved by 95% of the subjects in each group. These 95 percentile plot points are shown in Figure 5 (Penetrations Unattainable by 95% of Each Group at Each Hole) and Figure 6 (Penetrations Unattainable by 95% of Each Group at Each Slot). It will be noted that each slot or hole diameter is represented by three plotted values, a triangle for the men, a square for the women, and a circle for the children.

In the case of children, where necessary, the plotted point was modified slightly to insure that at least 80% of each age group would be unable to achieve the penetration indicated.

An attempt was made to utilize the information to develop a probe which would prevent access by 99.5% of the subjects, but the data appeared somewhat more erratic, suggesting that many more subjects would be required to properly define a 99.5 percentile probe.

A variety of probes were considered, such as a probe matching the adult finger for industrial items and a probe matching the child's fingers for accessible appliances in the home. Separate probes were initially considered for slot openings with a separate set for hole openings. The presumption that separate probes would be necessary, assumes that there are major differences in penetration between the three groups of people. A review of the data indicates that these differences are not as great as one might expect, and that in many cases penetrations achieved by the children were exceeded by the penetrations achieved by the adults, particularly the women. This can be seen in Figure 5 (Penetrations Unattainable by 95% of Each Group at Each Hole) and Figure 6 (Penetrations Unattainable by 95% of Each Group at Each Slot).

It was decided that the first probe to be made should incorporate the information from all three groups. Two probes (not illustrated) with circular cross sections, one for slots and one for holes were produced. These were rigid probes which followed the 95 percentile line of the group requiring the minimum diameter at any particular penetration. Because of the curves introduced, these probes proved to be difficult to construct, and it was decided that a simplification of the shapes involved would be beneficial. It was also decided that both probes should be incorporated into one probe unit with one set of dimensions at right angles to the other. The hole data now defines the major diameter of the test probe at any point along its length (see Figure 7, Probe Derived From Composite Data, Plan View). Since slot openings always permitted greater penetration than hole openings of the same size, the information from the slots was incorporated into the probe by making the probe with two flats which represented the sides of the slot. This minor dimension of the probe is shown in Figure 7, Side view.

ARTICULATION

Articulation was next considered, and it had been hoped that some guidance would be obtained from the knowledge of locations at which the finger joints had passed through the openings. It soon became evident that this was an unworkable concept, and that any assignment of articulation points would have to be made arbitrarily. The most desirable situation would have been to have a flexible probe which could articulate at any point, but this becomes mechanically unworkable. It is also evident in working with a rigid probe, that a considerable volume within any enclosure is contactable by a rigid probe without any articulation, provided that it is withdrawn slightly to allow some movement. With these thoughts in mind, articulation was provided for this probe at 30 millimeters, 60 millimeters, and 100 millimeters, the first two of which are identical to the articulation in the IEC and CEE probe. It is felt that this amount of articulation is sufficient to permit a realistic assessment of whether the human finger could contact the part.

One of the difficulties with a probe incorporating articulation has been that the probe could be bent into configurations which could not be assumed by the human finger. One has a choice of incorporating stops to prevent abnormal configurations, or so specifying in the requirements that abnormal configurations such as a reverse bend are forbidden. Our drawing shows the stop incorporated in the probe, but it is expected that the stops will be eliminated in the future since they present unwanted restrictions over the entrance of a probe into an opening while the probe is in other than a straight condition.

In order to determine the usefulness of the probe, 1200 samples were constructed of a high impact polystyrene. The actual cost was approximately $10.00 each, which permitted a wide distribution of the samples. It is recognized that in some circumstances the insulating material of the probe makes it difficult to determine if a live part has been contacted, and it will be necessary to construct some probes, or at least the tip, of a conductive material. Metal probes would obviously be much more expensive, but necessary for these applications.

Figure 8 shows the outline of this combination probe with the outline of the IEC probe superimposed over it. It will be noted that the probe developed as a result of this work is more stringent than the IEC probe for the initial 40 to 60 millimeters, and that the IEC probe is more stringent for the remaining distance up to the first stop plate at 80 millimeters. The effect of the IEC stop plate may or may not then make one probe more stringent than the other depending upon whether the stop plate is able to enter the opening.

Since the largest openings explored with the subjects were 25.4 millimeter slots and 25.4 millimeter diameter holes, no new information is added once this probe has reached a circular cross section at 154 millimeters from the tip. In practice, the standards would call for other requirements to take precedence over the probe if the minor dimension of the opening being tested were 25.4 millimeters or larger.

It should be kept in mind that the gentle taper of the probe is dictated by the measurements, and represents a mechanical analog of those measurements. The effect of forcing the probe into an opening is to wedge apart the sides of the opening. The mechanical advantage in this case could be as great as 16. It is evident that care must be exercised in applying pressure to the probe to determine the acceptability of an opening.

Another factor to be considered is that the subjects attempted to achieve maximum penetrations. The penetrations were not the result of a casual approach to the openings. This aggressive attempt to contact parts beyond the opening in an enclosure will probably not be duplicated in most field situations, and therefore can result in an additional safety factor, which would be proper for a probe being used in safety testing.

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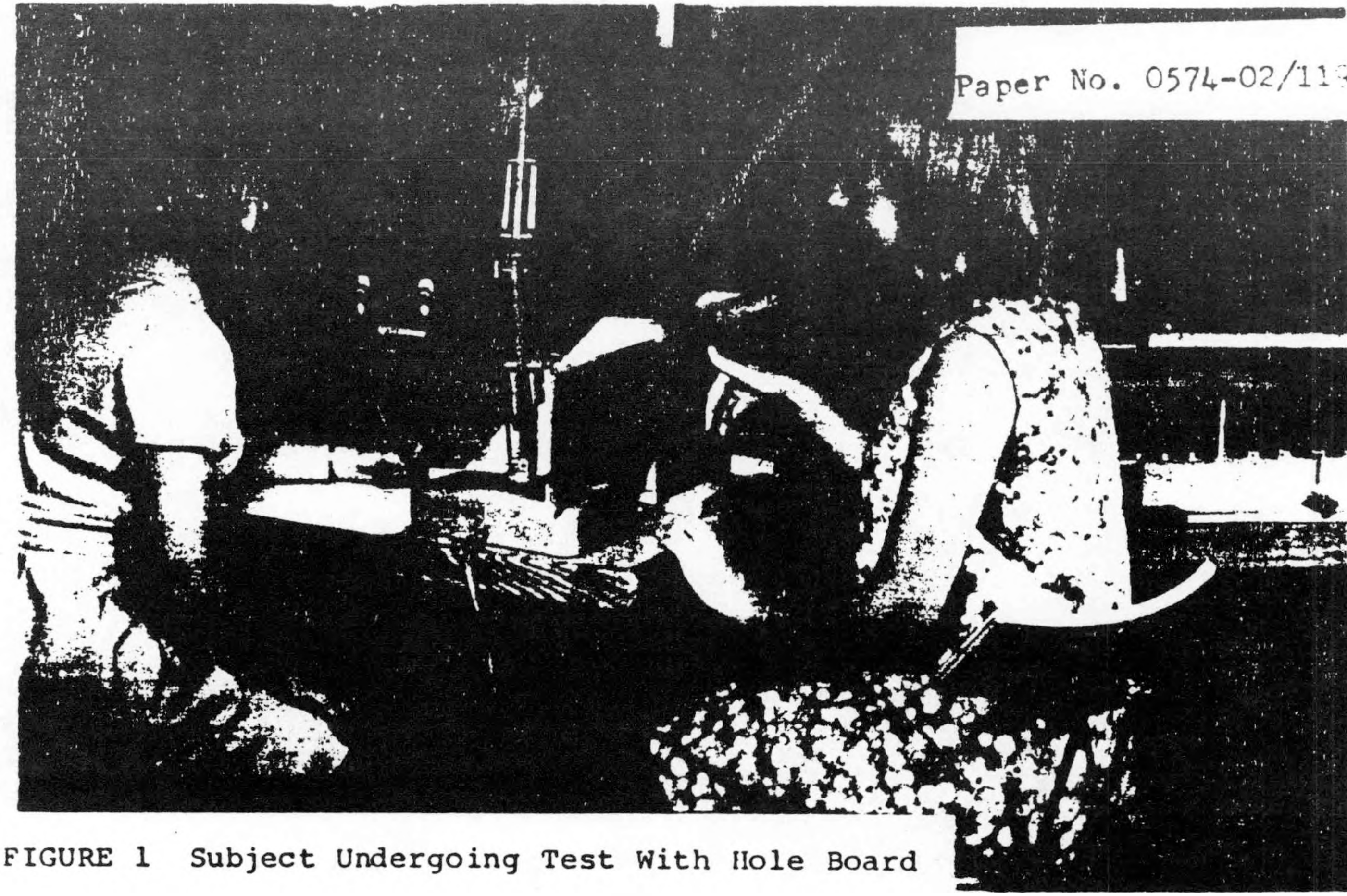


FIGURE 1 Subject Undergoing Test With Hole Board

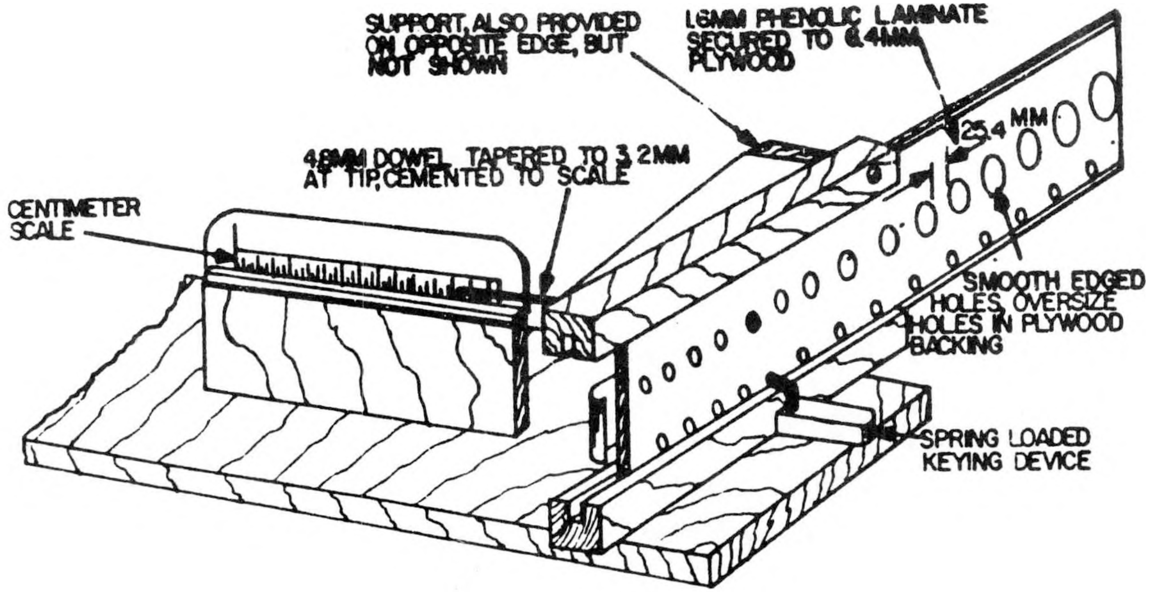
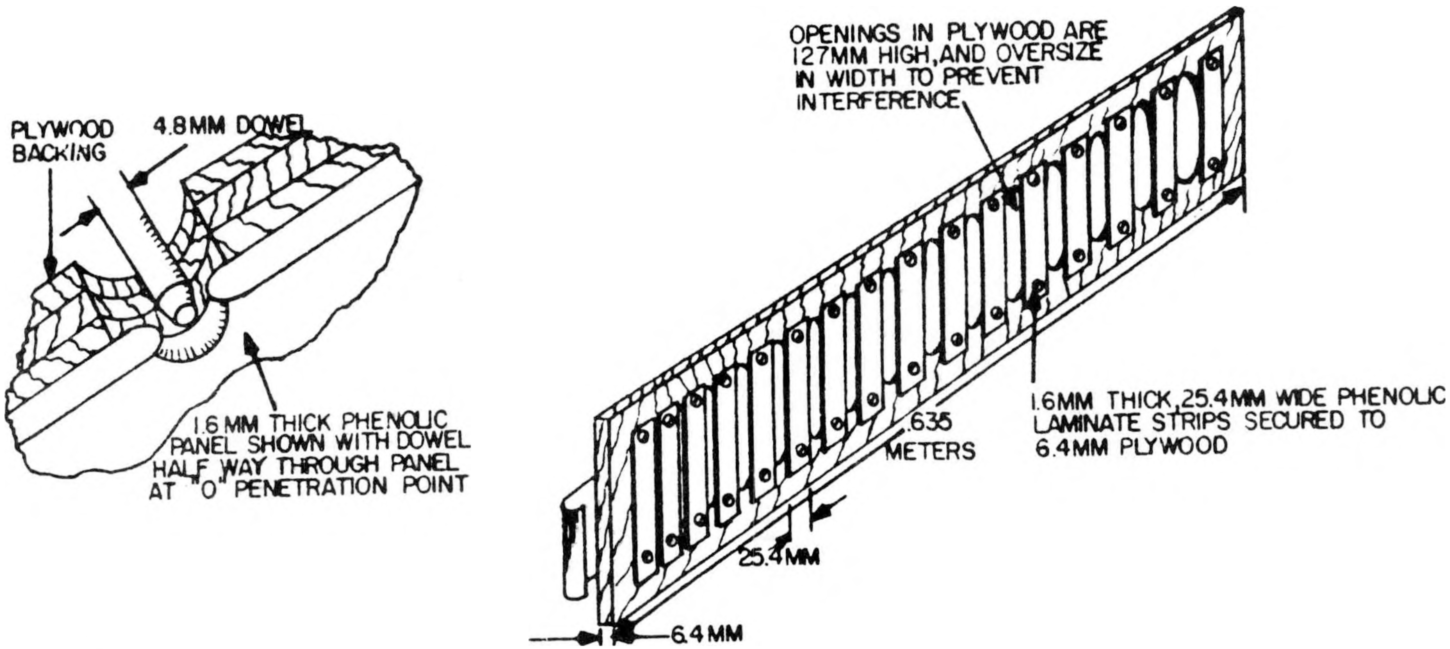


FIGURE 2 Testing Apparatus



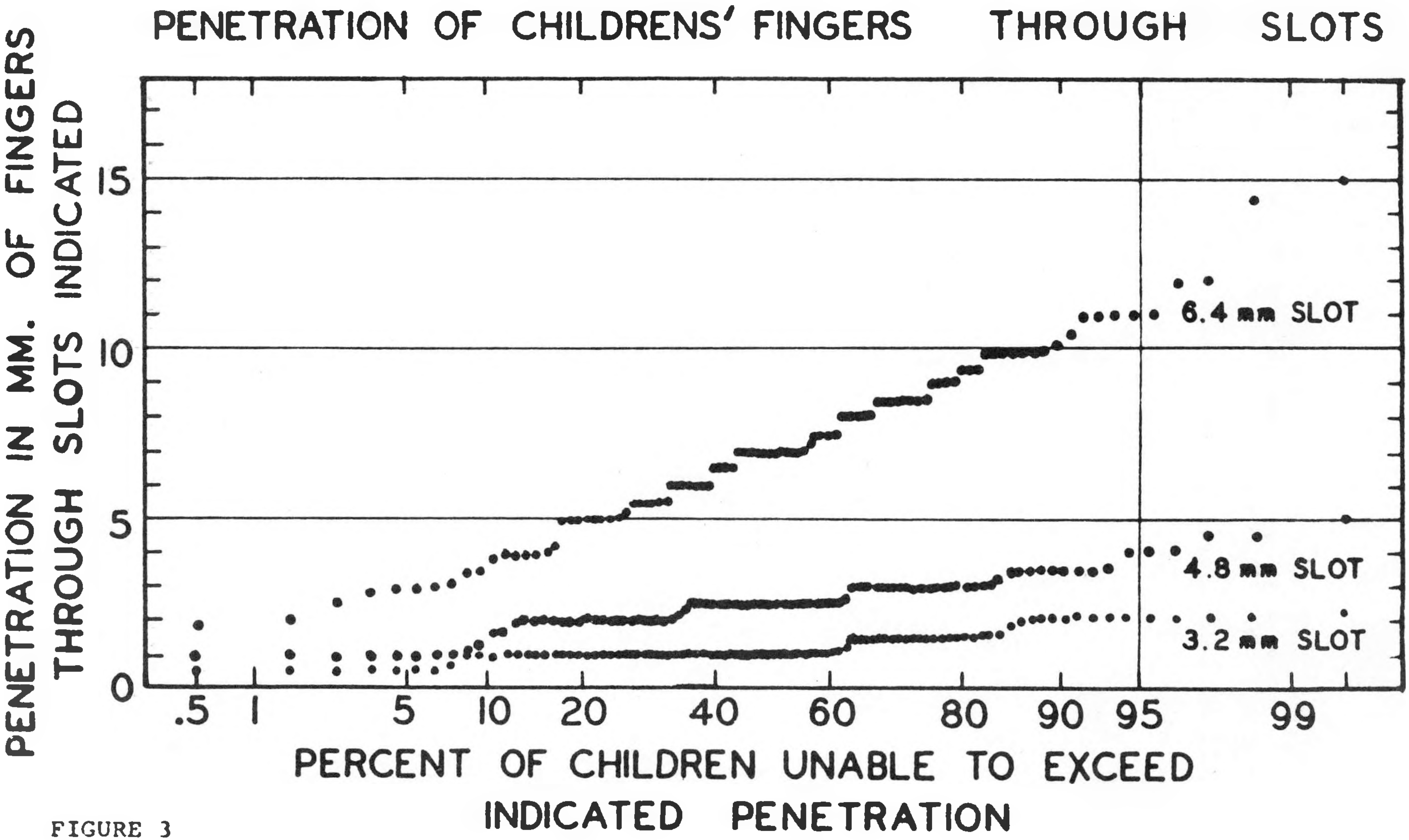

PENETRATION OF CHILDRENS' FINGERS THROUGH SLOTS
PENETRATION IN MM. OF FINGERS THROUGH SLOTS INDICATED
0
5
10
15
6.4 mm SLOT
4.8 mm SLOT
3.2 mm SLOT
.5
1
5
10
20
40
60
80
90
95
99
PERCENT OF CHILDREN UNABLE TO EXCEED INDICATED PENETRATION

FIGURE 3

PENETRATION OF ADULT MALE FINGERS THROUGH SLOTS

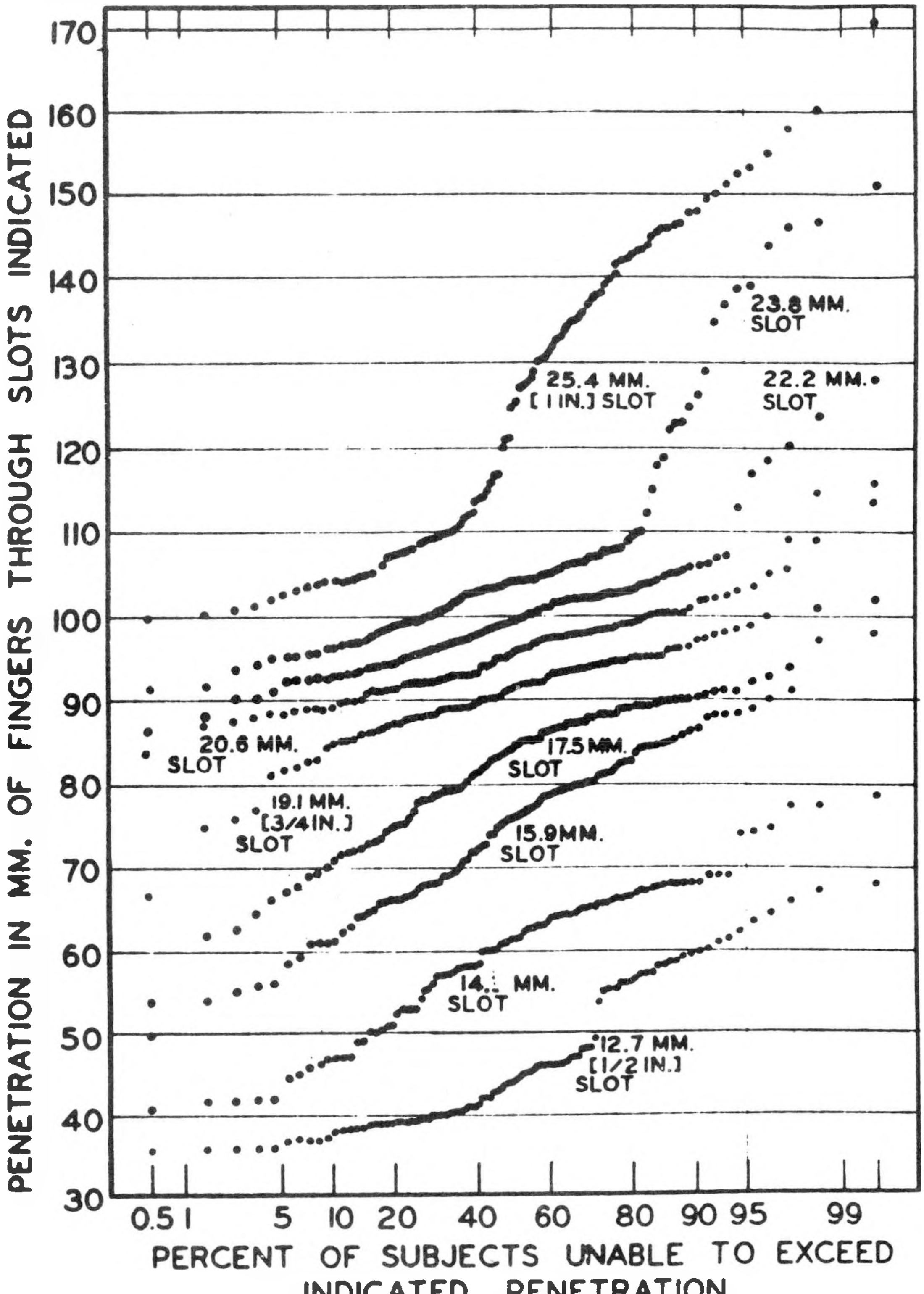


FIGURE 4

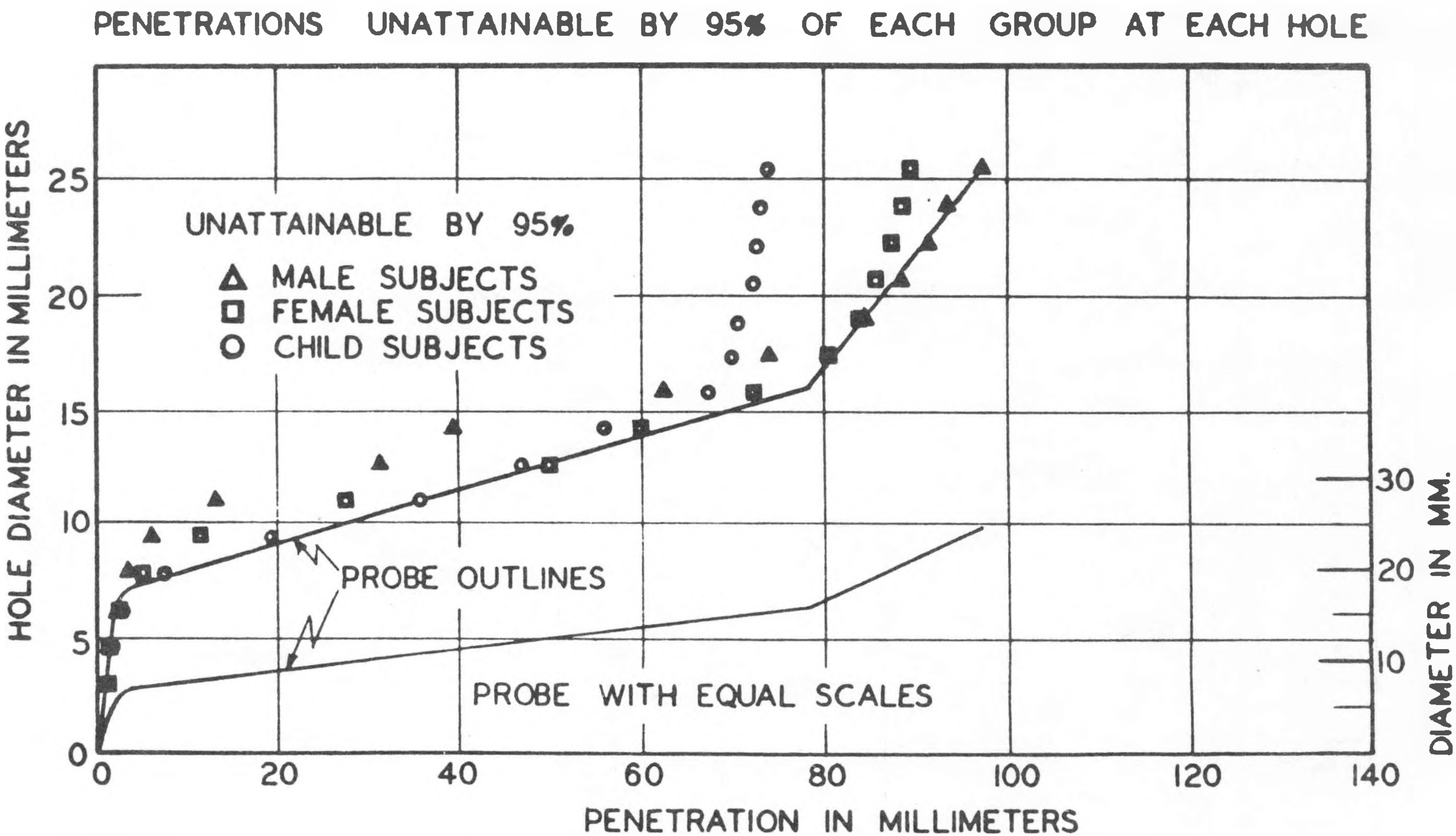

PENETRATIONS UNATTAINABLE BY 95% OF EACH GROUP AT EACH HOLE
UNATTAINABLE BY 95%
MALE SUBJECTS
FEMALE SUBJECTS
CHILD SUBJECTS
PROBE OUTLINES
PROBE WITH EQUAL SCALES
HOLE DIAMETER IN MILLIMETERS
PENETRATION IN MILLIMETERS
DIAMETER IN MM.
0
5
10
15
20
25
0
20
40
60
80
100
120
140
10
20
30

FIGURE 5

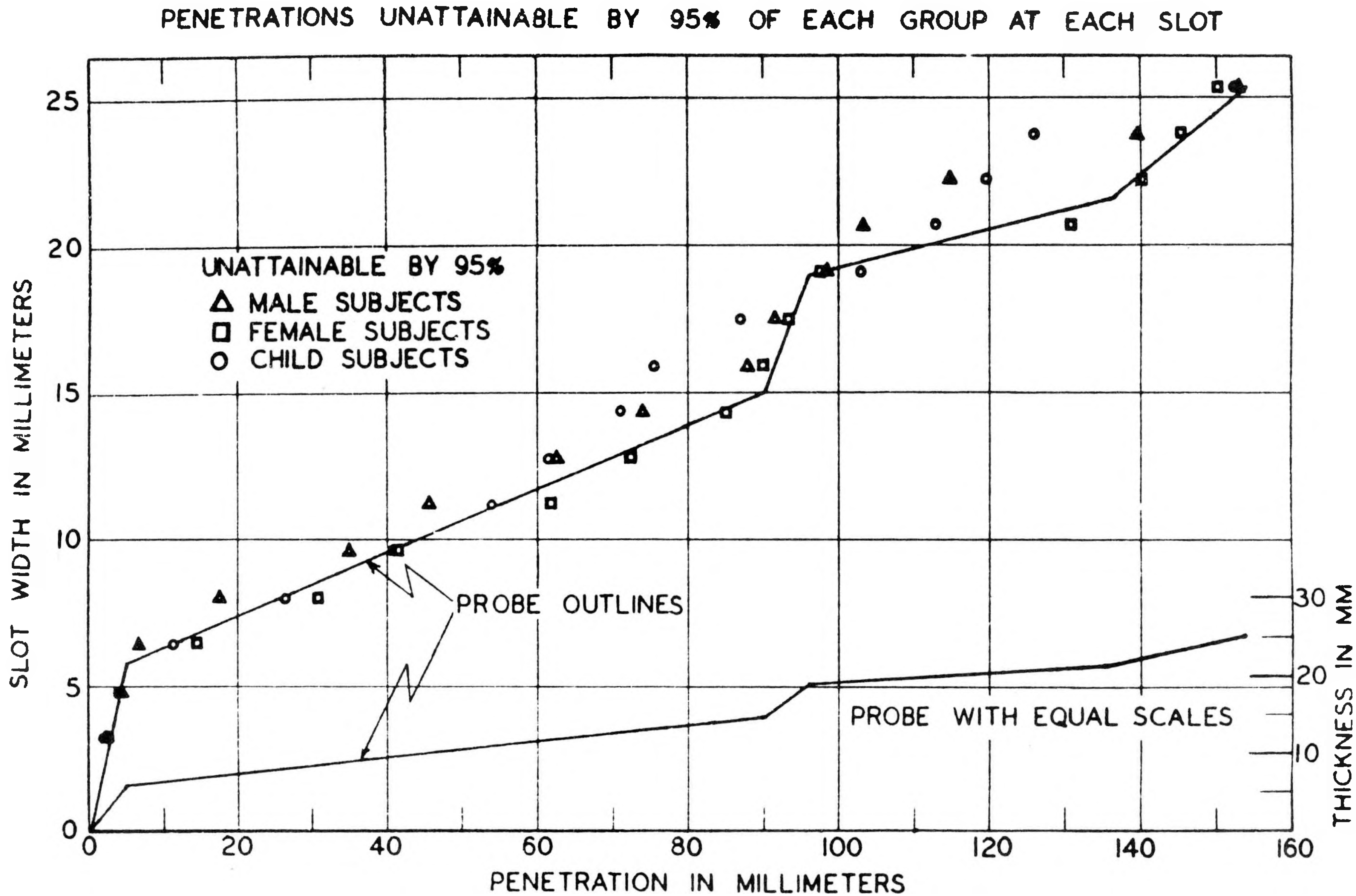

PENETRATIONS UNATTAINABLE BY 95% OF EACH GROUP AT EACH SLOT
UNATTAINABLE BY 95%
MALE SUBJECTS
FEMALE SUBJECTS
CHILD SUBJECTS
PROBE OUTLINES
PROBE WITH EQUAL SCALES
SLOT WIDTH IN MILLIMETERS
PENETRATION IN MILLIMETERS
THICKNESS IN MM

FIGURE 6

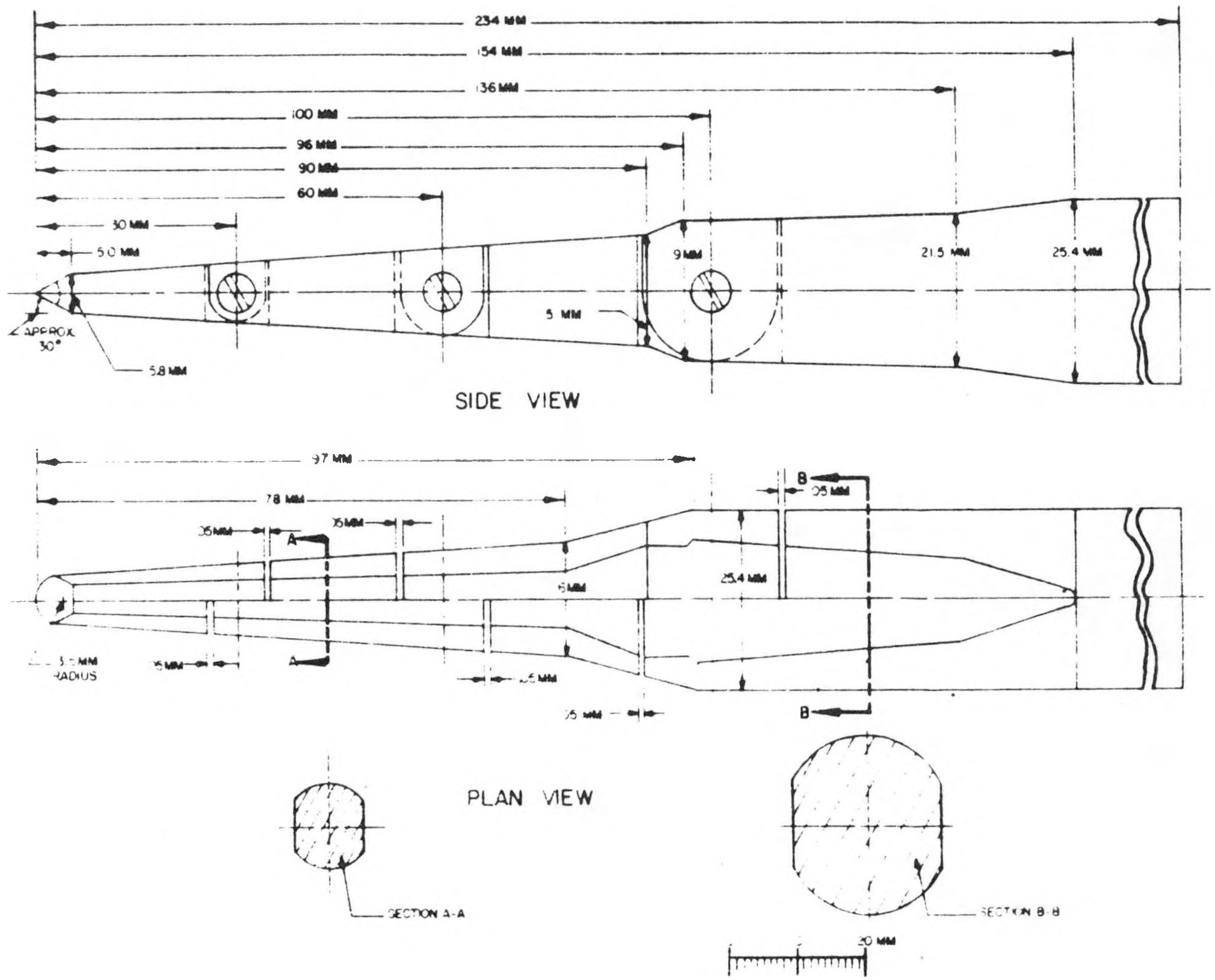


FIGURE 7 Probe Derived From Composite Data

COMPARISON OF PROBE DERIVED FROM COMPOSITE 95 PERCENTILE DATA AND IEC-CEE TEST FINGER

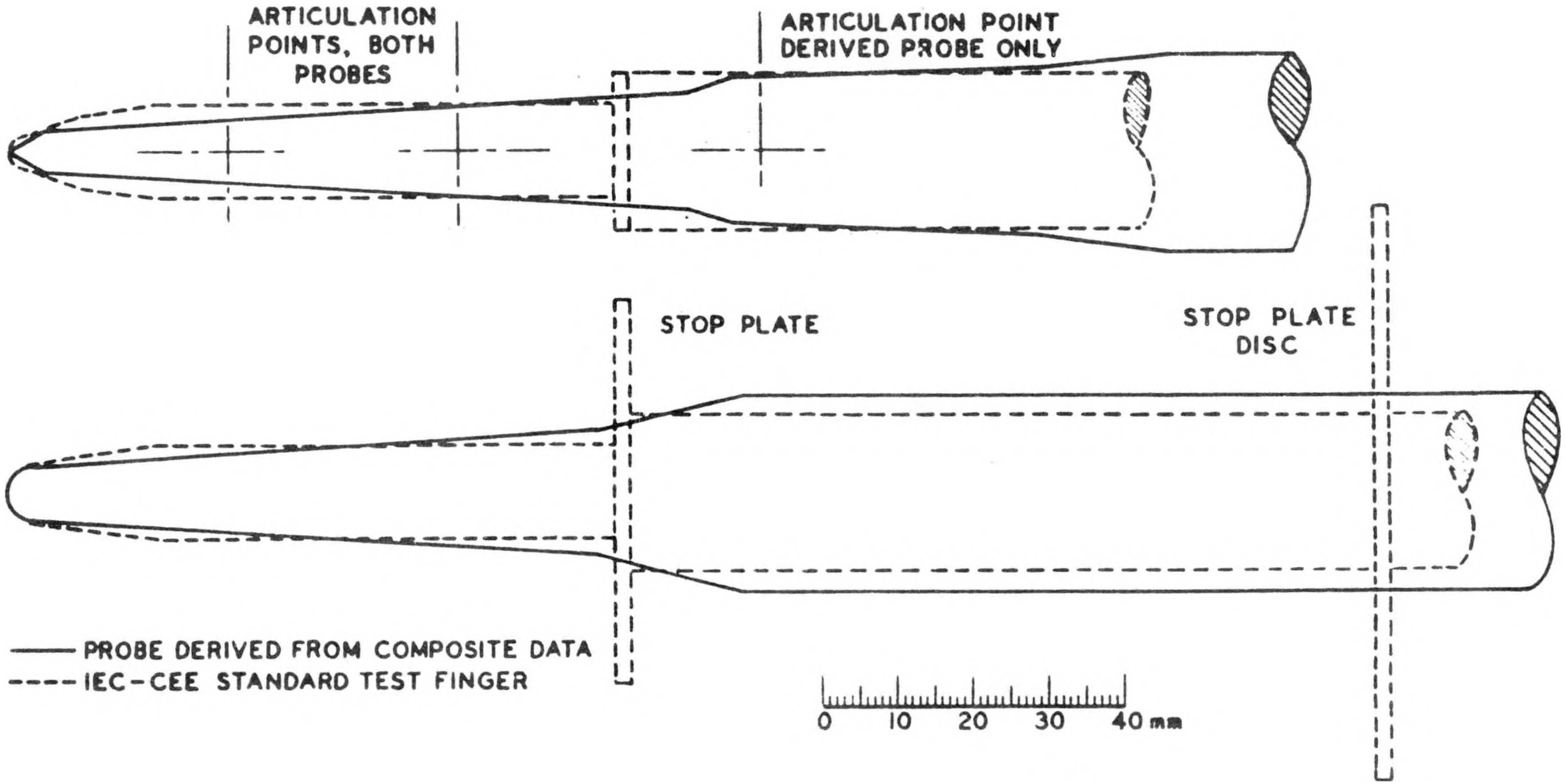


FIGURE 8

ADDITION OF THE FINGER WEB STOP TO THE ARTICULATE PRCBE

During the development of the articulate probe, it was recognized that subjects were being asked to develop maximum penetrations through slots without regard to the length of the slot. It would have been possible although very inconvenient to have measured the length of the slot being used to make the measured penetration, but it is also possible that the added complication would have detracted from the accuracy of the more important penetration measurement. A decision was made to proceed without the measurement, recognizing that the probe to be developed with the data would be a slightly more restrictive probe than would be required for 95% percentile rejection, but this was accepted as erring on the side of safety. It also should be noted that for most of the probe length, this increase in stringency was never greater than that observed by rotating the probe through 90° and noting the difference in penetration. Another way of assessing the situation is that for penetrations up to about 80 mm. It is unlikely that more than one finger was necessary for the slot penetration test.

The longest single finger penetration information used in the design of the probe is at 97 mm. Penetrations deeper than this required the use of a slot opening and more than one finger, therefore a stop plate which takes into account the width of the hand would appear to be a relaxation of the probe design which could be permitted. The section involved is from 97 mm up to the end of the probe's useful length at 154mm.

Since the completion of the probe design, additional information has become available from a University of Michigan Study[1]. This study provides measurements of children's hands, in ages of 1 to 13, separated by sex and also provides measurements at 5 percentile and 95 percentile of the population. See Figure 1. The only difficulty with the information is that the <u>entire length</u> of the hand was measured for the study, it <u>does not</u> give the portion of the hand length which might be expected to penetrate a slot when stopped by the web between the fingers and the thumb or the thickening of the hand at this point. This particular point was a natural limit during the original slot measurements at the largest (1 inch) slot.

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1. PB 242 221 - Physical Characteristics of Children as Related to Death and Injury for Consumer Product Safety Design, prepared for the Consumer Product Safety Commission by the Food and Drug Adm., 31 May 1975, Highway Safety Research Institute, The University of Michigan.

In order to proportion the University of Michigan measurements properly, reference was made to a Dryfuss[2] Study. Drawings from this study are presented as Figure 2, and it will be noted that the following relationsips appear to apply in determining the fraction of the overall hand length which is applicable to the distance from the fingertips to the web between the thumb and the remainder of the hand.

	Males	Females
Web to Fingertips / Overall Hand Length	$\frac{4.5 + \frac{3.0}{2}}{7.5} = \frac{6}{7.5}$	$\frac{4.0 + \frac{2.9}{2}}{6.9} = \frac{5.45}{6.9}$

Picking 97mm as the first point at which web information could be used without destroying the utility of the probe as an indicator of the acceptability of holes, and taking the liberty of rounding this off to 100mm for mechanical reasons, it next becomes necessary to determine the width of hand necessary for a penetration of 100mm as measured to the web of the thumb. Since the Michigan Study gives only the overall length from the wrist, it is necessary to translate this 100mm web to fingertip length to an overall hand length of $100 \times \frac{7.5}{6} = 125$mm for the males and 100mm $\times \frac{6.9}{5.45} = 126.6$ for the females. It is then necessary to match this average length with a particular age child and then determine the hand width for a 5 percentile child in that age group. Another approach to the problem would be to assume that the penetration was produced by a 95 percentile child, determine his age group and then determine the average hand width for that age group.

This study utilized both approaches. Figure 3 provides a table of the logic used in arriving at the conclusion that a stop plate of 50mm diameter could be located at a distance of 100mm from the probe tip and still be considered to prevent contact by more than 5% of the children involved.

This logic rejects the premis that the longest childs hands are also the narrowest and assumes that within an age group the child with the longest hand will have an average width. This still may be a somewhat conservative estimate, since it is probably more accurate to say that the child with the longest hand probably is larger overall and possesses a wider than average hand. The course chosen, that of linking an average width

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2. Henry Dryfuss, "The Measure of Man", 1960, 2nd edition.

with a long hand, or a narrow width with an average length hand would appear to be a cautious approach.

Since Figure 3 gives the dimensions of the finger web stop for only one point along its length, it is also necessary to compute the width of the finger web stop for other useful points. This is done in Figure 4 and plotted on Figure 5.

It will be noted that since the data on the children stops at age 13, that the data does not carry to 154mm which would match the present useful length of the probe. Another study is useful at this point, this one conducted by Appliance Testing Laboratories in Leatherhead, England. This study shows that none of the 357 adult men and women subjects were able to penetrate to 100mm through a 19.5mm by 49.5mm opening with one finger, and that for a slot with an opening 20mm high, that it required a width of greater than 50mm for any of the 278 men and 355 women to contact a back plate 100mm away from the opening. These data supplement the children's data obtained from the Michigan Study and reassure that no major error is being made at the 50mm diameter point.

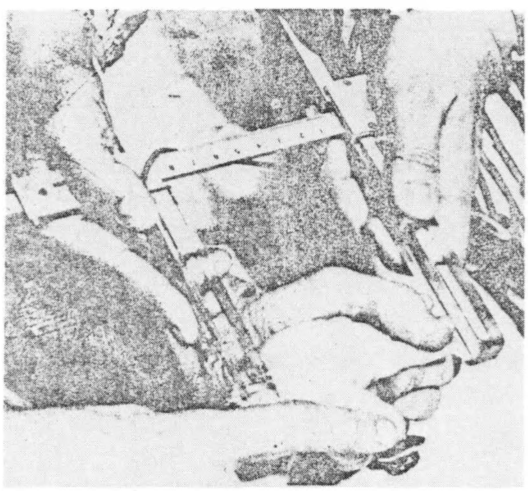
A probe drawing is provided as Figure 6 which incorporates the web stop construction.

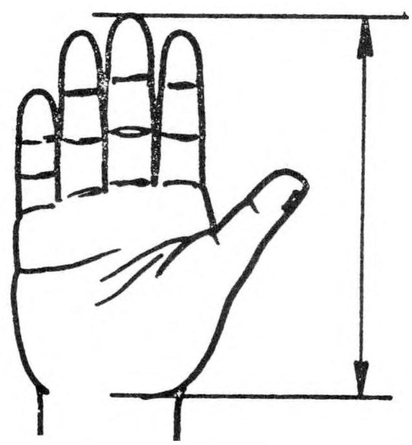
John Stevenson
September, 1978

FIGURE 1a
HAND LENGTH

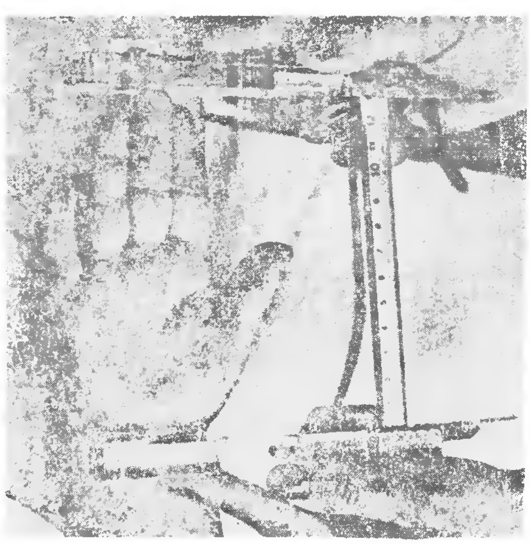
Device: Automated sliding caliper. Measurements are recorded automatically by computer.

Description: INFANT: Infant lies on back with right hand fully extended, palm up. Measure the parallel distance from the wrist crease to the tip of the third right digit. Paddle-blades firmly contact the two body surfaces for measurement. An assistant is required to assure that the infant is in the correct position.





Description: CHILD: Child sits erect, right hand is extended with palm up. Measure the parallel distance from the wrist crease to tip of third digit with an automated sliding caliper. The paddle-blades firmly contact the two body surfaces for measurement.



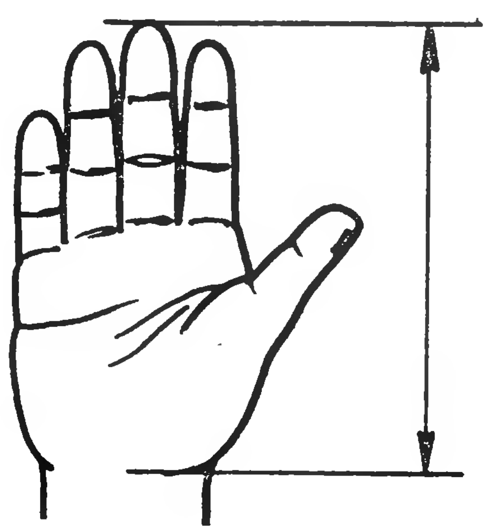


FIGURE 1b

HAND LENGTH, IN CMS. - FEMALES

AGE(MO/YRS)		N	MEAN	S.D.	5%	50%	95%
0- 3		63	6.7	0.6	5.7	6.6	7.7
4- 6		57	7.5	0.6	6.5	7.4	8.5
7- 9		28	8.2	0.5	7.1	8.3	9.0
10- 12	1	22	8.8	0.5	7.4	8.8	9.4
13- 18		23	9.1	0.6	7.5	9.2	9.9
19- 24	2	29	9.7	0.7	8.3	9.7	10.9
25- 30		32	10.1	0.7	8.9	10.0	11.3
31- 36	3	54	10.5	0.7	9.2	10.4	11.5
37- 42		141	10.9	0.6	9.8	10.8	12.0
43- 48	4	170	11.1	0.6	10.1	11.0	12.1
49- 54		186	11.4	0.6	10.3	11.3	12.6
55- 60	5	175	11.8	0.6	10.7	11.7	12.9
61- 66		120	12.1	0.7	10.6	12.0	13.3
67- 72	6	82	12.4	0.7	11.3	12.3	13.5
73- 78		99	12.7	0.8	11.5	12.5	14.2
79- 84	7	94	13.0	0.7	11.8	12.9	14.3
85- 96	8	147	13.6	0.8	12.2	13.5	14.8
97-108	9	144	14.3	0.8	13.0	14.2	15.8
109-120	10	155	14.5	0.8	13.2	14.5	15.8
121-132	11	108	15.3	0.9	13.7	15.4	17.0
133-144	12	63	15.8	0.9	14.2	15.7	17.2
145-156	13	32	16.8	0.9	15.0	16.7	18.4

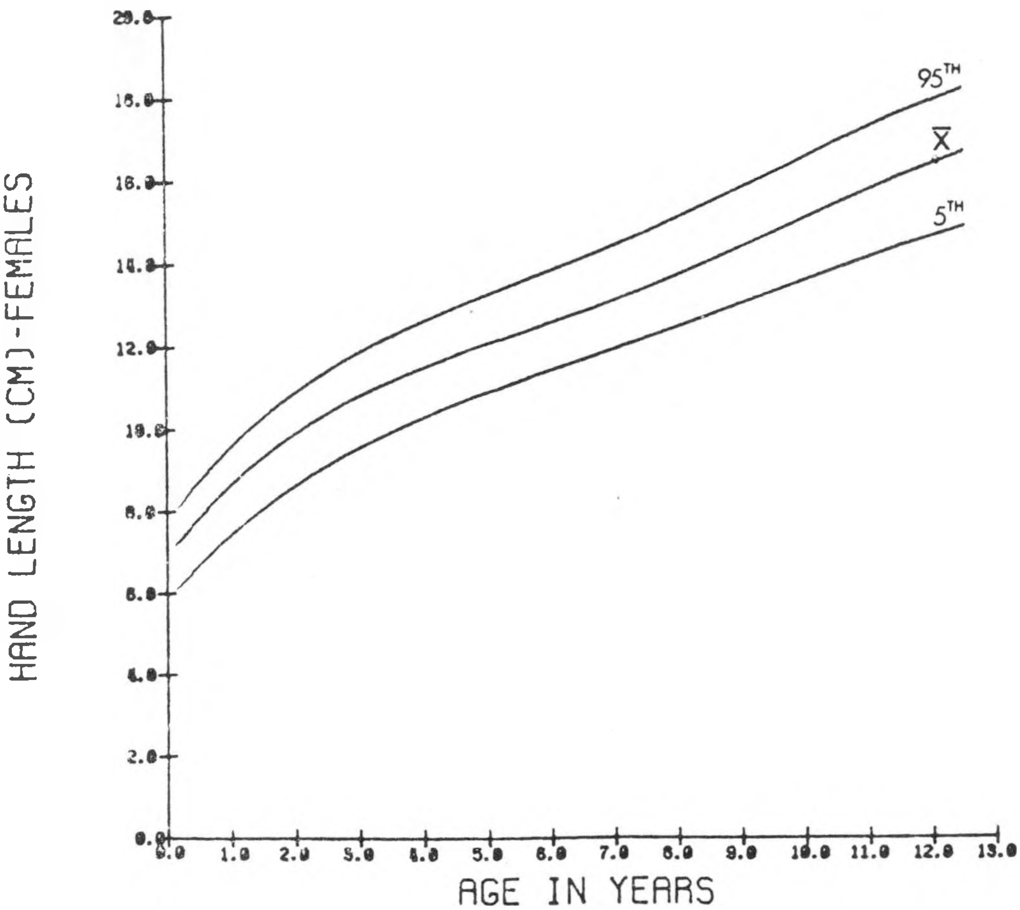


FIGURE 1c

HAND LENGTH, IN CMS, - MALES

AGE(MO/YRS)		N	MEAN	S.D.	5%	50%	95%
0- 3		76	6.8	0.6	5.7	6.7	7.7
4- 6		42	7.8	0.6	6.7	7.7	8.9
7- 9		25	8.5	0.5	7.6	8.4	9.5
10- 12	1	19	8.8	0.4	8.1	8.7	9.8
13- 18		30	9.3	0.6	7.9	9.3	10.2
19- 24	2	42	9.9	0.5	9.1	9.9	10.7
25- 30		34	10.3	0.7	9.2	10.2	11.3
31- 36	3	49	10.8	0.7	9.5	10.8	11.9
37- 42		131	11.0	0.6	9.8	10.9	12.0
43- 48	4	123	11.3	0.7	10.2	11.2	12.4
49- 54		173	11.7	0.6	10.6	11.6	12.7
55- 60	5	154	12.0	0.7	10.8	11.9	13.1
61- 66		126	12.3	0.7	11.0	12.2	13.4
67- 72	6	94	12.6	0.6	11.4	12.6	13.6
73- 78		76	12.9	0.6	11.6	12.8	14.0
79- 84	7	77	13.2	0.7	11.9	13.1	14.6
85- 96	8	136	13.8	0.8	12.4	13.7	15.3
97-108	9	133	14.2	0.8	12.8	14.1	15.9
109-120	10	108	14.7	0.8	13.5	14.6	16.0
121-132	11	98	15.4	0.8	14.1	15.4	16.8
133-144	12	55	15.7	1.0	14.0	15.4	17.2
145-156	13	21	15.9	1.0	14.3	15.8	17.4

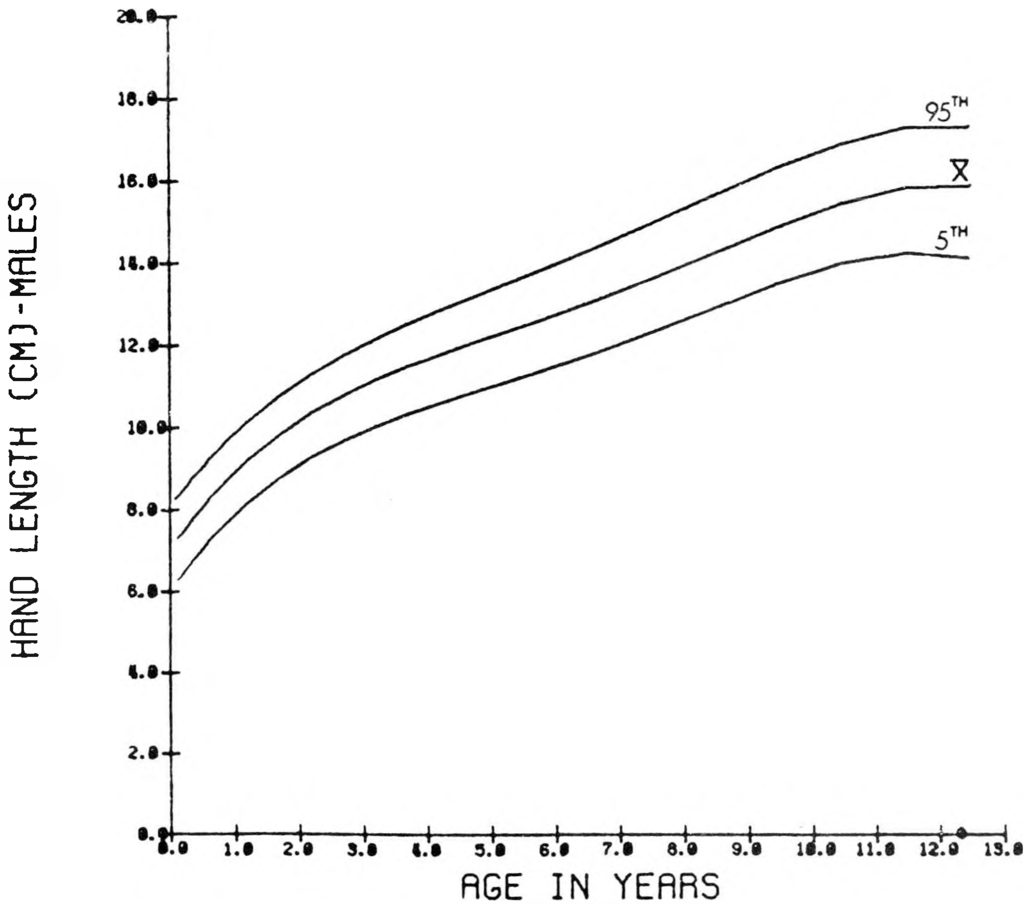
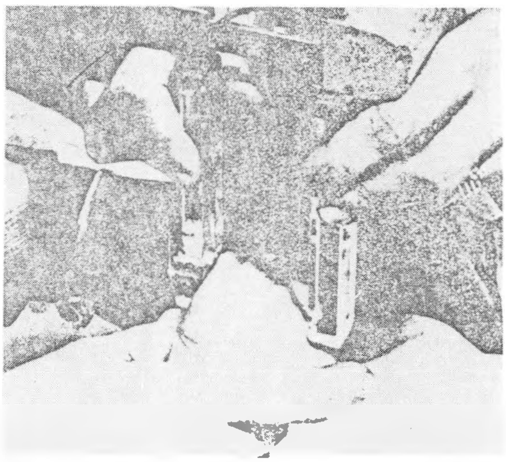


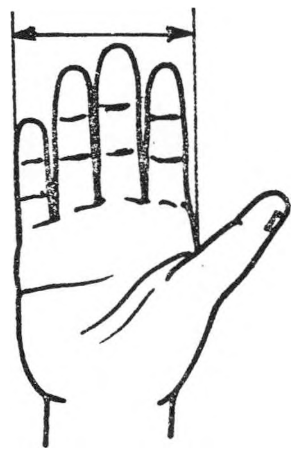
FIGURE 1d

HAND WIDTH

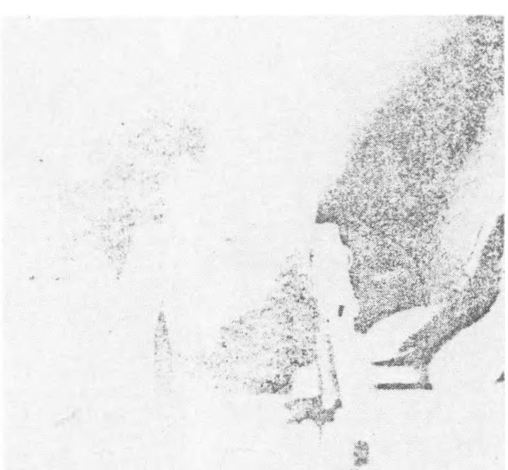
Device: Automated sliding caliper equipped with pressure transducer in paddle blade. Measurements are recorded automatically by computer at fixed pressure values.

Description: INFANT: Infant lies on back with right hand fully extended, palm up, thumb abducted from hand. Measure the maximum width across the metacarpal-phalongeal with an automated sliding caliper. The paddle-blades firmly contact the two body surfaces for measurement. An assistant is required to assure that the infant is in the correct position.





Description: CHILD: Child sits erect, hand and fingers extended with palm up, thumb abducted from hand. Measure the maximum width across the metacarpal-phalangeal joints II and V with an automated sliding caliper. The paddle blades firmly contact the two body surfaces for measurement.



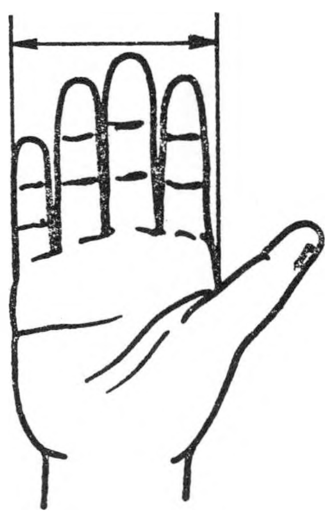


FIGURE 1e

HAND WIDTH, IN CMS. - FEMALES

AGE(MO/YRS)		N	MEAN	S.D.	5%	50%	95%
0- 3		61	3.5	0.5	2.7	3.5	4.5
4- 6		51	4.0	0.4	3.2	4.0	4.6
7- 9		27	4.4	0.4	3.4	4.3	5.0
10- 12	1	21	4.3	0.3	3.9	4.1	4.8
13- 18		22	4.5	0.3	3.9	4.4	5.0
19- 24	2	29	4.7	0.3	4.0	4.6	5.3
25- 30		30	5.0	0.3	4.2	4.9	5.5
31- 36	3	55	5.0	0.3	4.3	4.9	5.5
37- 42		141	5.1	0.4	4.4	5.0	5.8
43- 48	4	170	5.2	0.4	4.5	5.1	5.8
49- 54		184	5.3	0.4	4.5	5.3	5.9
55- 60	5	173	5.5	0.4	4.7	5.4	6.1
61- 66		120	5.6	0.4	4.8	5.6	6.3
67- 72	6	82	5.7	0.3	5.1	5.7	6.2
73- 73		99	5.9	0.3	5.2	5.8	6.5
79- 84	7	95	6.0	0.4	5.3	6.0	6.7
85- 96	8	144	6.2	0.4	5.4	6.1	6.9
97-108	9	143	6.4	0.4	5.8	6.4	7.1
109-120	10	144	6.6	0.4	5.9	6.5	7.3
121-132	11	103	6.9	0.4	6.1	6.8	7.6
133-144	12	60	7.2	0.4	6.5	7.1	7.7
145-156	13	32	7.6	0.4	7.0	7.6	8.2

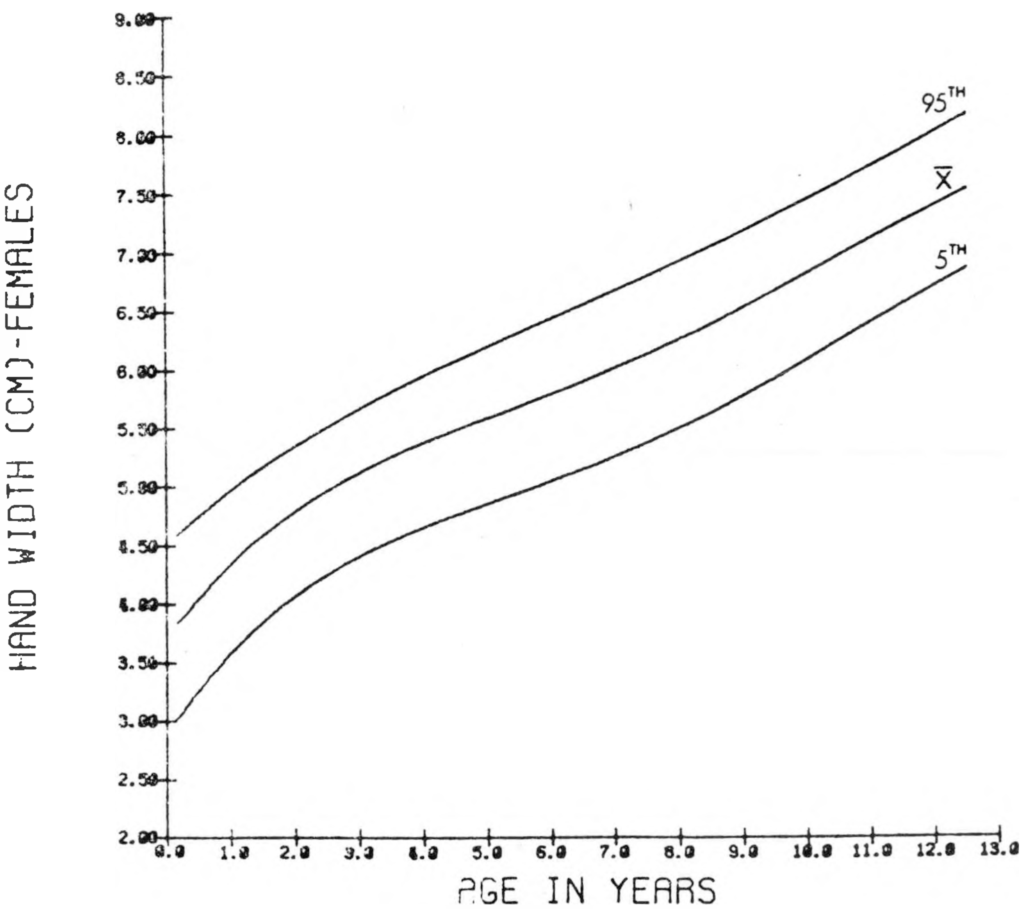
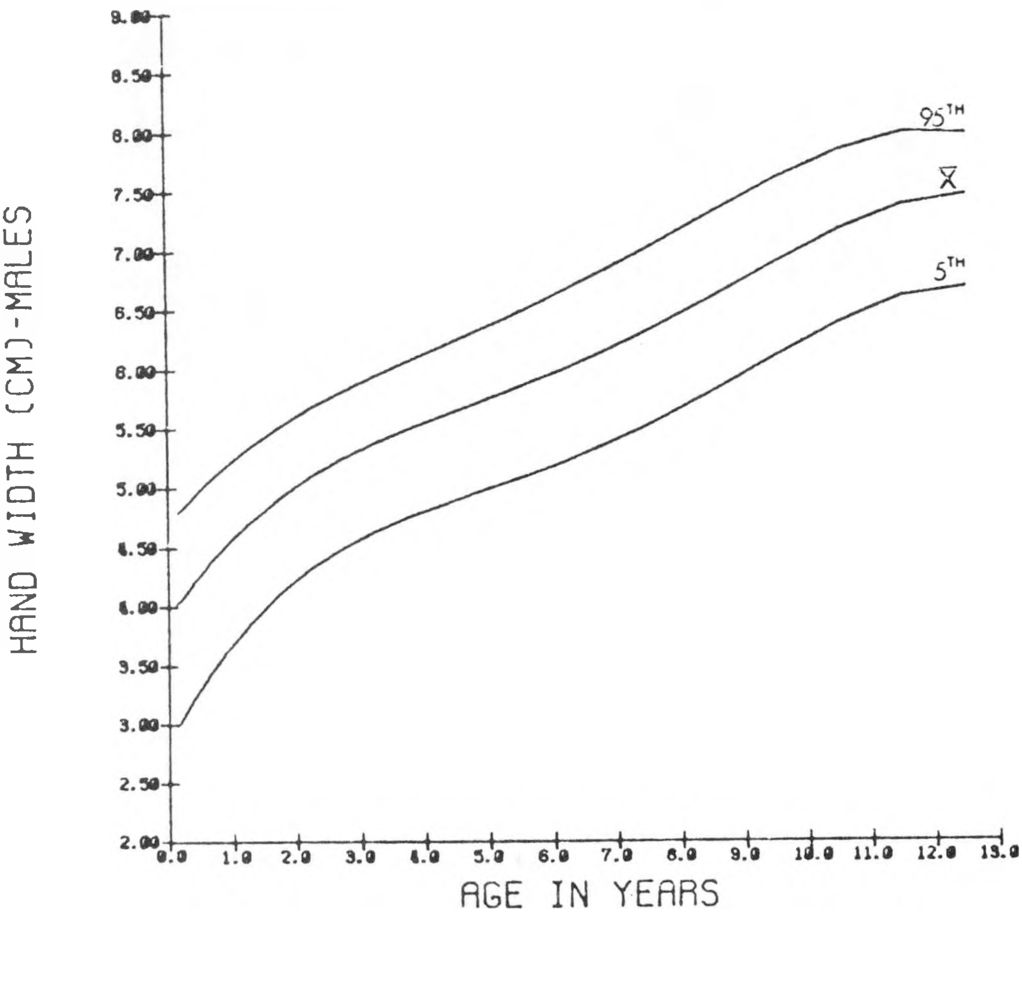


FIGURE 1f

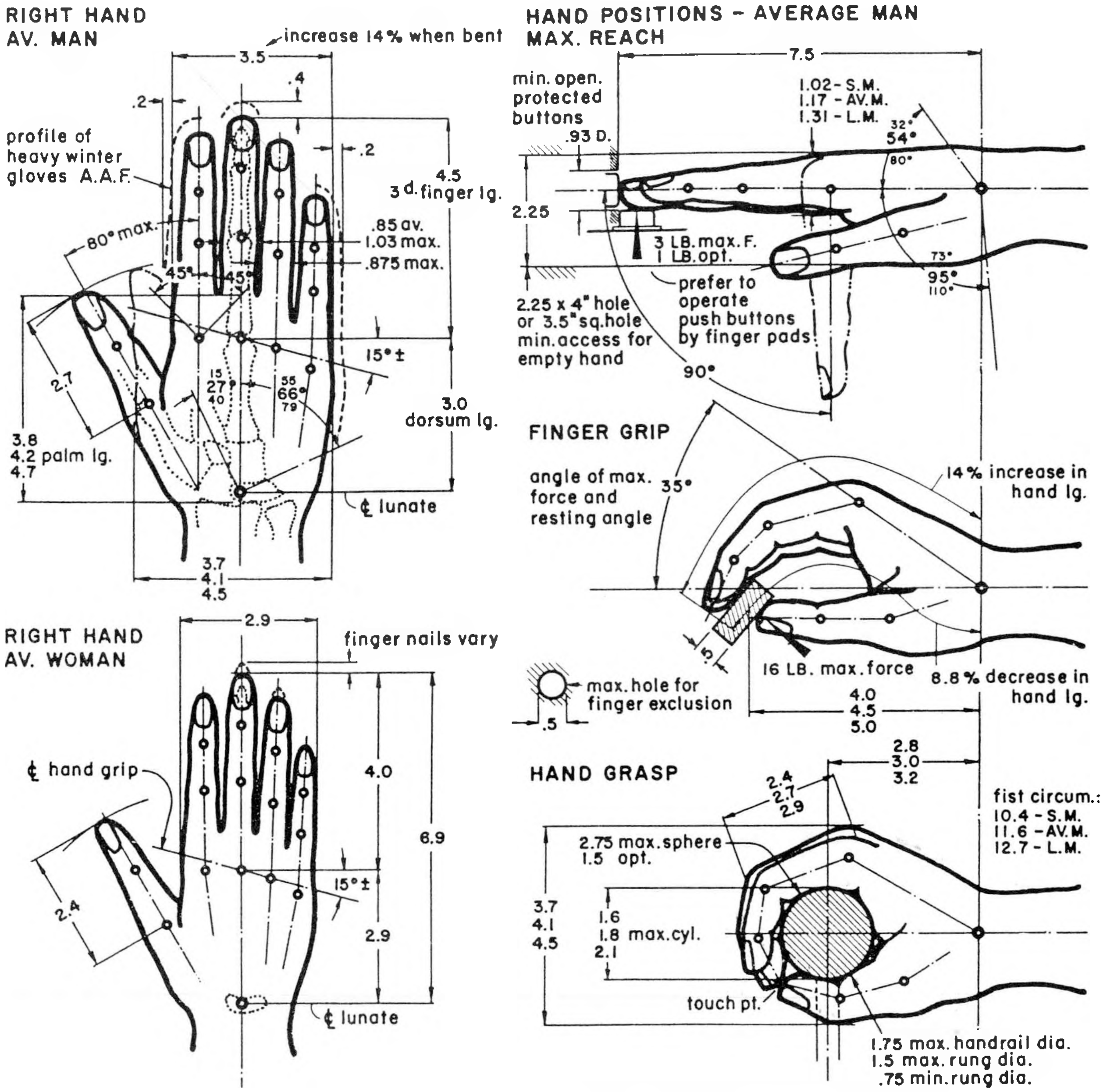
HAND WIDTH, IN CMS. - MALES

AGE(MO/YRS)		N	MEAN	S.D.	5%	50%	95%
0- 3		73	3.7	0.5	2.5	3.6	4.5
4- 6		40	4.2	0.4	3.4	4.2	5.0
7- 9		22	4.5	0.4	3.5	4.5	5.1
10- 12	1	16	4.6	0.4	3.8	4.6	5.2
13- 18		30	4.7	0.3	3.8	4.7	5.2
19- 24	2	39	5.0	0.3	4.4	4.9	5.7
25- 30		33	5.1	0.4	4.2	5.0	5.7
31- 36	3	48	5.1	0.4	4.2	5.2	5.8
37- 42		131	5.2	0.3	4.5	5.2	5.8
43- 48	4	123	5.3	0.4	4.6	5.3	6.0
49- 54		171	5.5	0.3	4.9	5.5	6.1
55- 60	5	153	5.6	0.3	5.0	5.5	6.2
61- 66		124	5.8	0.4	5.0	5.7	6.3
67- 72	6	93	5.8	0.4	5.0	5.9	6.3
73- 78		74	6.0	0.4	5.2	6.0	6.8
79- 84	7	76	6.2	0.4	5.4	6.2	6.9
85- 96	8	133	6.4	0.4	5.6	6.4	7.1
97-108	9	131	6.6	0.4	5.7	6.5	7.4
109-120	10	103	6.7	0.3	6.0	6.7	7.3
121-132	11	98	7.1	0.4	6.3	7.0	7.8
133-144	12	55	7.4	0.4	6.6	7.3	7.9
145-156	13	21	7.5	0.4	6.7	7.5	8.0



HAND MEASUREMENTS OF MEN, WOMEN AND CHILDREN

Figure 2



	MEN			WOMEN			CHILDREN			
	2.5 %tile	50. %tile	97.5 %tile	2.5 %tile	50. %tile	97.5 %tile	6 yr.	8 yr.	11 yr.	14 yr.
hand length	6.8	7.5	8.2	6.2	6.9	7.5	5.1	5.6	6.3	7.0
hand breadth	3.2	3.5	3.8	2.6	2.9	3.1	2.3	2.5	2.8	—
3d. finger lg.	4.0	4.5	5.0	3.6	4.0	4.4	2.9	3.2	3.5	4.0
dorsum lg.	2.8	3.0	3.2	2.6	2.9	3.1	2.2	2.4	2.8	3.0
thumb length	2.4	2.7	3.0	2.2	2.4	2.6	1.8	2.0	2.2	2.4

EXAMPLE OF LOGIC USED TO DETERMINE POINTS

MALES*

$100\text{mm} \times \frac{7.5}{6} = 125\text{mm}$

95% 4 yr. old boy has hand length of 124mm

5% 4 yr. old boy has hand width of 46mm

50% 4 yr. old boy has hand width of 53mm

50% 6 yr. old boy has hand length of 126mm

5% 6 yr. old boy has hand width of 50mm

50% 6 yr. old boy has hand width of 58mm

FEMALES*

$100\text{mm} \times \frac{6.9}{5.45} = 126.6\text{mm}$

95% 4½ yr. old girl has hand length of 126mm

5% 4½ yr. old girl has hand width of 45mm

50% 4½ yr. old girl has hand width of 53mm

50% 6½ yr. old girl has hand length of 125mm

5% 6½ yr. old girl has hand width of 52mm

50% 6½ yr. old girl has hand width of 58mm

This seems to indicate that a stop plate located at 100mm from the tip and with an outer diameter of 50mm would match or exceed any 5%, 50% combination of hand length and width for boys and girls independently.

*Michigan Study

FIGURE 3

FEMALES - $\frac{\text{Hand Length} \times 5.45}{6.9}$ = Plot Distance

Age	50% Hand Length	5% Hand Width	Plot Distance	95% Hand Length	50% Hand Width	Plot Distance
4½	-	-	-	12.6	5.3	9.9
5	-	-	-	12.9	5.4	10.1
5½	-	-	-	13.3	5.6	10.5
6	-	-	-	13.5	5.7	10.7
6½	12.5	5.2	9.8	14.2	5.8	11.2
7	12.9	5.3	10.1	14.3	6.0	11.3
8	13.5	5.4	10.6	14.8	6.1	11.7
9	14.2	5.8	11.2	15.8	6.4	12.5
10	14.5	5.9	11.4	15.8	6.5	12.5
11	15.4	6.1	12.1	17.0	6.8	12.4
12	15.7	6.5	12.4	17.2	7.1	13.6
13	16.7	7.0	13.1	18.4	7.6	14.5

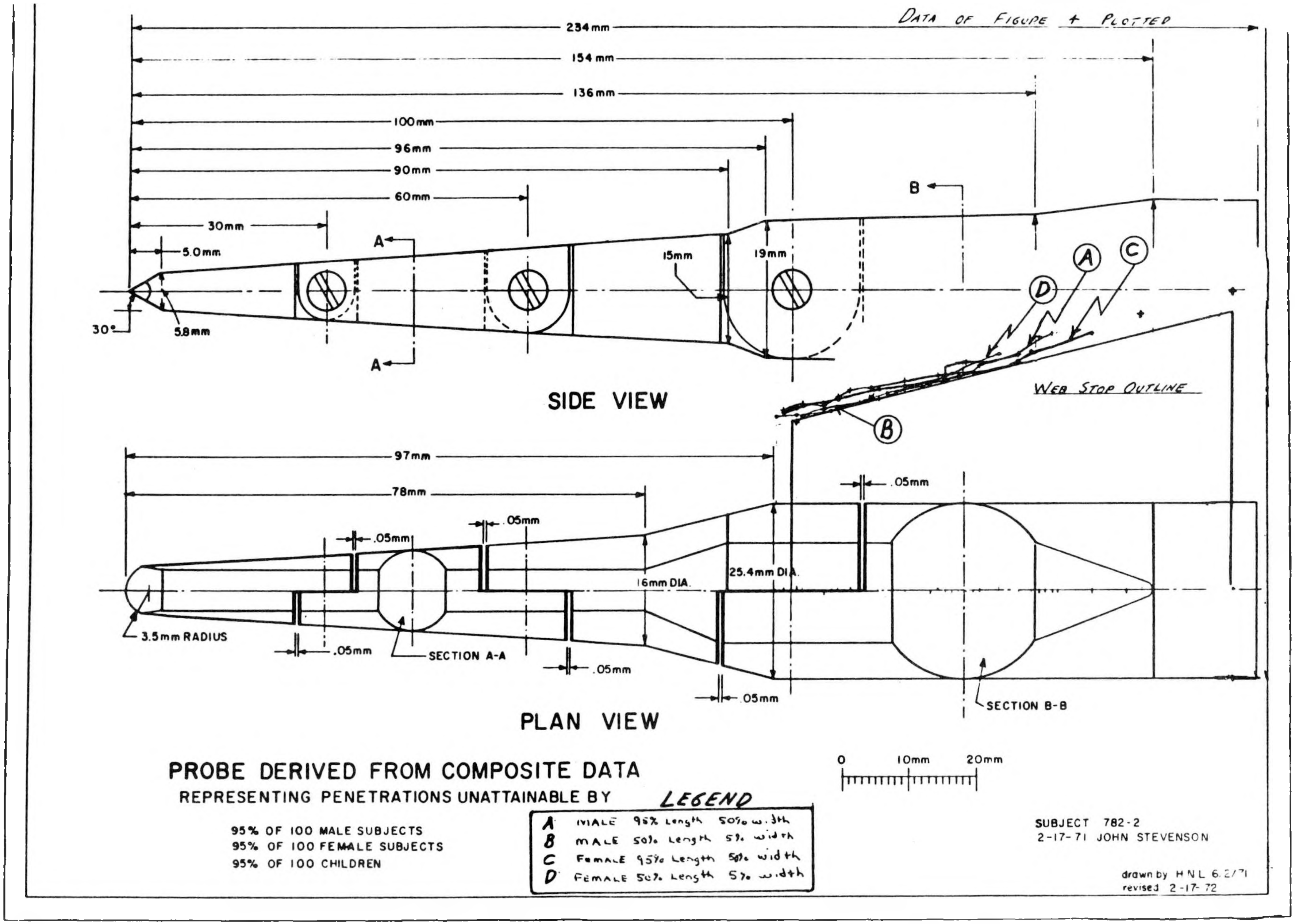
FIGURE 4a

MALES - $\frac{\text{Hand Length} \times 6}{7.5}$ = Plot Distance

Age	50% Hand Length	5% Hand Width	Plot Distance	95% Hand Length	50% Hand Width	Plot Distance
4	-	-	-	12.4	5.3	9.9
4½	-	-	-	12.7	5.5	10.2
5	-	-	-	13.1	5.5	10.5
5½	-	-	-	13.4	5.7	10.7
6	12.6	5.0	10.1	13.6	5.9	10.9
6½	12.8	5.2	10.2	14.0	6.0	11.2
7	13.1	5.4	10.5	14.6	6.2	11.7
8	13.7	5.6	11.0	15.3	6.4	12.2
9	14.1	5.7	11.3	15.9	6.5	12.7
10	14.6	6.0	11.7	16.0	6.7	12.8
11	15.4	6.3	12.3	16.8	7.0	13.4
12	15.4	6.6	12.3	17.2	7.3	13.7
13	15.8	6.7	12.6	17.4	7.5	13.9

FIGURE 4b

FIGURE 5



DATA OF FIGURE 4 PLOTTED
234mm
154 mm
136mm
100mm
96mm
90mm
60mm
30mm
5.0mm
30°
5.8mm
A
A
B
15mm
19mm
D
A
C
B
WEB STOP OUTLINE
SIDE VIEW
97mm
78mm
.05mm
.05mm
.05mm
16mm DIA.
25.4mm DIA.
3.5mm RADIUS
.05mm
SECTION A-A
.05mm
.05mm
SECTION B-B
PLAN VIEW
PROBE DERIVED FROM COMPOSITE DATA
REPRESENTING PENETRATIONS UNATTAINABLE BY
95% OF 100 MALE SUBJECTS
95% OF 100 FEMALE SUBJECTS
95% OF 100 CHILDREN
LEGEND
A MALE 95% Length 50% width
B MALE 50% Length 5% width
C Female 95% Length 50% width
D Female 50% Length 5% width
0 10mm 20mm
SUBJECT 782-2
2-17-71 JOHN STEVENSON
drawn by H N L 6.2/71
revised 2-17-72

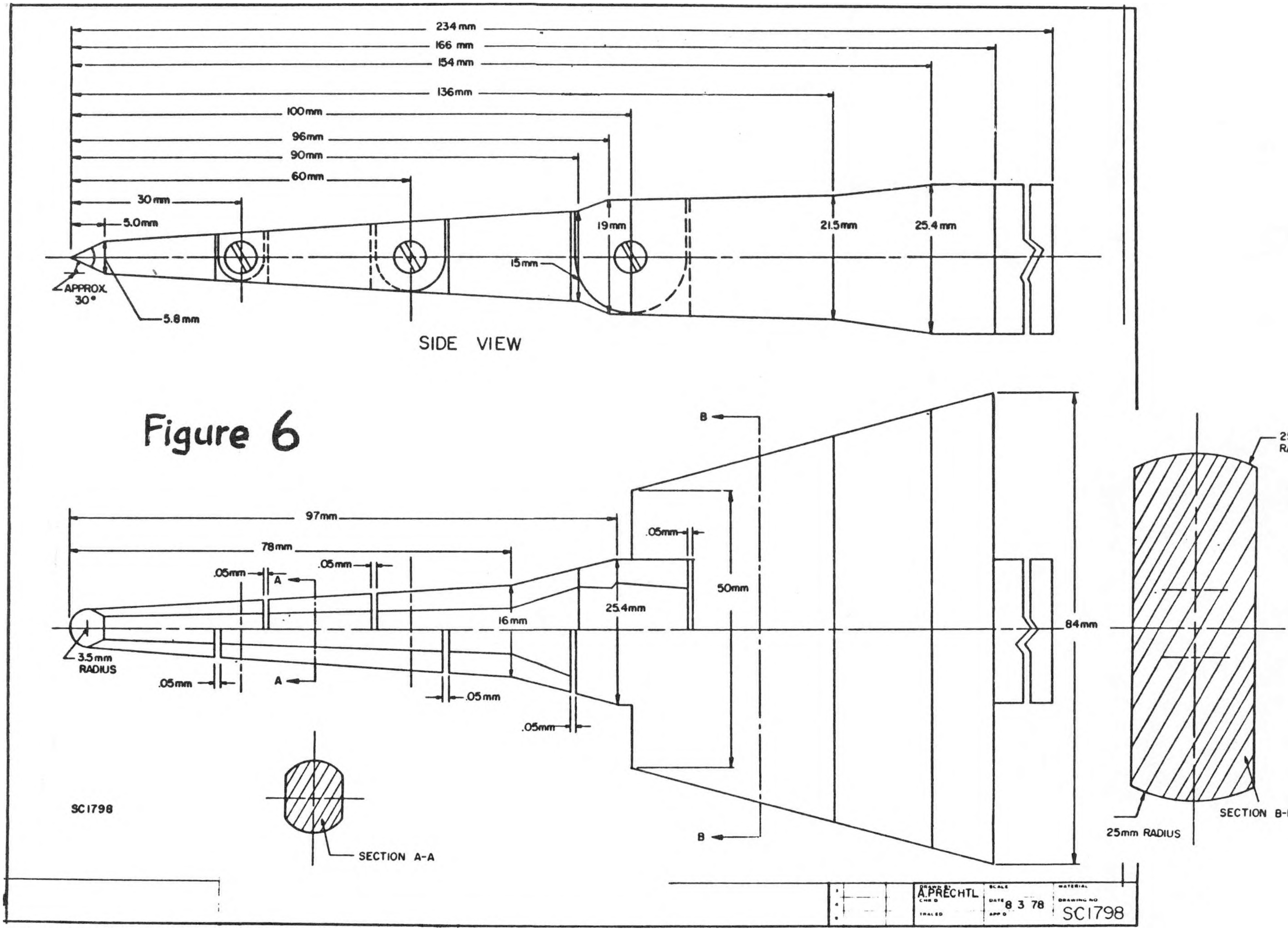

234 mm
166 mm
154 mm
136 mm
100 mm
96 mm
90 mm
60 mm
30 mm
5.0 mm
APPROX. 30°
5.8 mm
19 mm
15 mm
21.5 mm
25.4 mm
SIDE VIEW
B
97 mm
78 mm
.05 mm
A
16 mm
25.4 mm
50 mm
84 mm
3.5 mm RADIUS
SECTION A-A
25 mm RADIUS
SECTION B-B
SC1798
A. PRECHTL
8 3 78
SC1798

Figure 6

182

APPENDIX D

CONCEPTUAL DEVELOPMENT OF CUT TESTER

GENERAL:

Since a module surface may be subjected to physical abuse, and a penetration of the surface can expose the user to a shock hazard, a test to establish a minimum level of superstrate/encapsulant resistance to cutting is deemed warranted.

LITERATURE REVIEW:

A review of the literature on the subject of cut and penetration tests for elastomers*, such as silicone rubber, did not reveal any Standard tests considered applicable for evaluating module encapsulants. Candidate tests as found in the American Society for Testing and Materials (ASTM) Standards were rejected for the following reasons:

1. Some of the tests required that the samples be precut and then subjected to tear resistance. We feel that there is no correlation between pre-cut tear resistance and the ability of a photovoltaic module superstrate/encapsulant to resist cutting.

2. Many of the tests do not take into account a rigid or a semi-rigid backing. A material which may exhibit a relatively poor test result when tested alone, may provide fairly substantial resistance to cutting by a moderately sharp instrument when tested in conjunction with the substrate on which the superstrate/encapsulant is placed.

3. Some of the tests were not physically compatible with the samples which could be tested.

4. Some of the tests examined simply did not relate to puncture resistance problem at hand.

A. Standard Test Method For Rubber Property-Tear Resistance (ASTM D624) -

This describes a test for tear resistance on three different die cut specimens, two of which have been razor cut to start the tear.

* In ASTM Standards, the term "rubber" is a generic term that includes any elastomer or elastomeric compounds.

B. Puncture Resistance of Rubber Insulating Gloves, Part of "Standard Specification For Rubber Insulating Gloves" (ASTM D120, Paragraph 19.2.4); Specification of Rubber Insulating Blankets (ASTM D1048) and Specification For Rubber Insulating Gloves (ASTM D1051) -

These tests are designed to check the absolute puncture resistance of the material only. In photovoltaic modules,. the superstrates/ encapsulants are backed by a rigid mounting plate or cell which would not allow the test to be performed as described. Testing separate sheets of the superstrate/encapsulant material would not represent the superstrate/encapsulant's performance in the product, as there may be no correlation between absolute puncture resistance and puncture resistance of a material backed by a rigid substrate.

C. Test For Rubber Property, Pusey & Jones Indentation (ASTM D531); Test For Rubber Property - International Hardness (ASTM D1415) and Impact Resistance of Polyethylene Film (ASTM D1709) -

These tests were found inapplicable for reasons described under B.

D. Underwriters Laboratories Outline For The Investigation of Thermoplastic Insulated Wire -

This document includes a "penetration" test. The test however is designed to determine insulation flow at elevated temperature and under pressure and as such is not applicable to photovoltaic modules.

Therefore, it was concluded that a new test method, suitable for testing cut resistance of a PV module encapsulant should be developed.

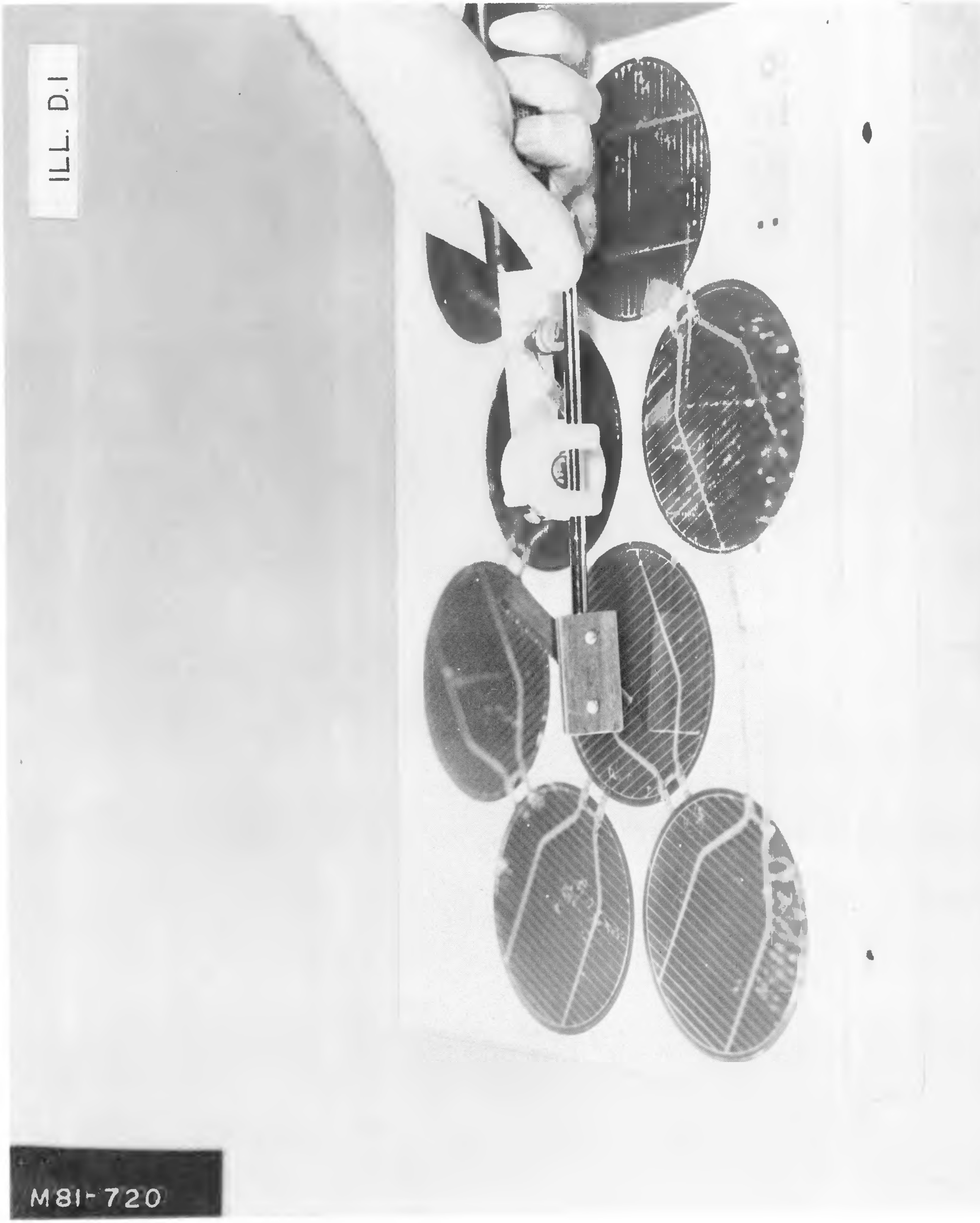
NEW TEST DEVELOPMENT:

A cut tester was developed and constructed (see Ills. D.1 through D.4) using a modification of a tool which UL uses as a "sharp edge tester". Various shaped blades and blade thicknesses were considered, keeping in mind the possible objects that might cause a penetration of the encapsulant, for example, the brackets and hardware of a household mop which might be used for cleaning the module surface, keys, random fingernail "testing" of the surface, etc.

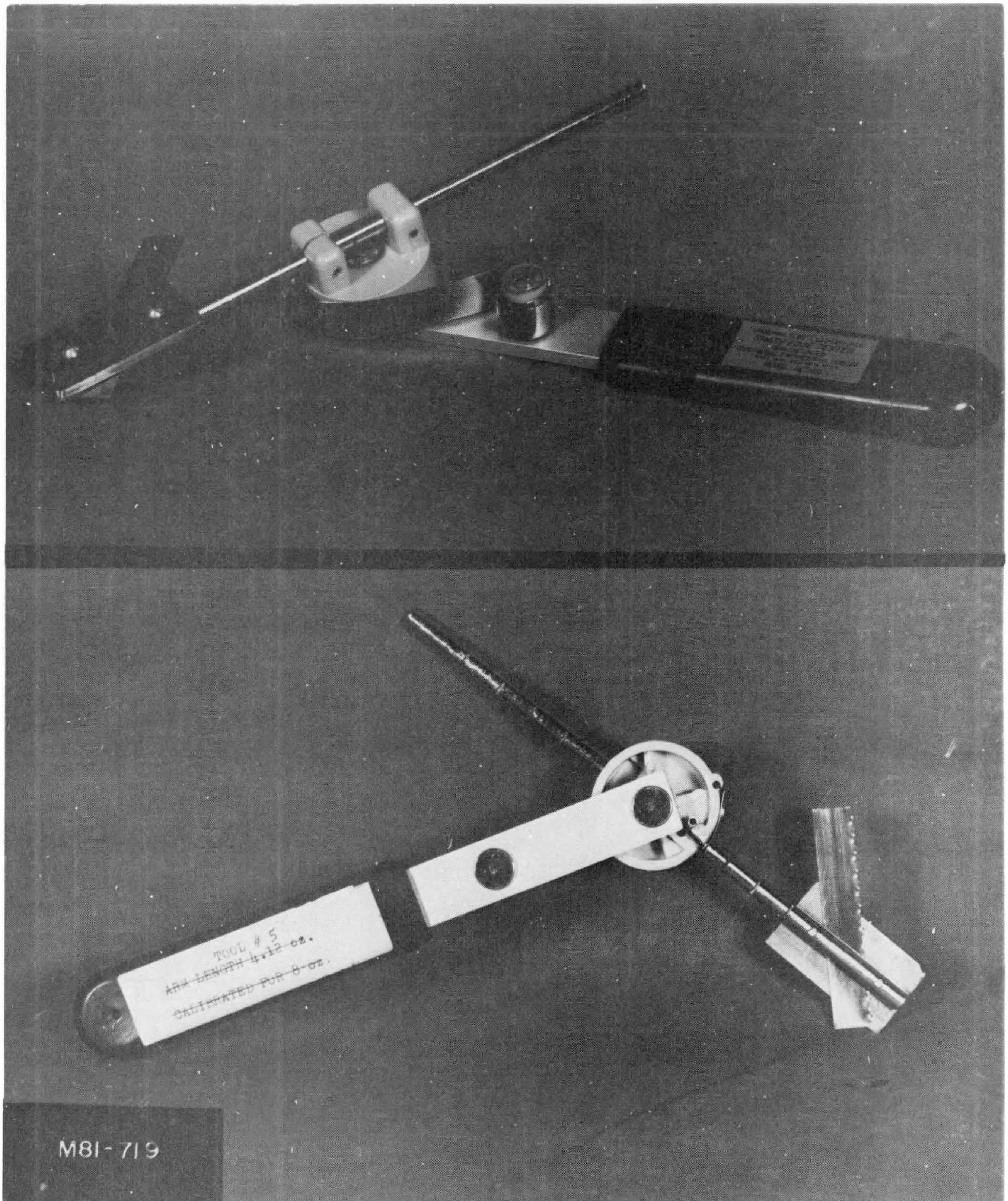
The blade configuration selected is described in Ills. D.2 and D.5. Force on the blade is varied by adjusting the length of the pressure arm (Item B in Ill. D.4). The configuration of the blade was determined by trial and error, again using the modules on hand which had silicone rubber encapsulation. A 2 pound force on the point of the blade was selected as a reasonable force which may be used during accidental or intentional abuse of the module.

The tester was used by gently applying the point of the blade to the encapsulant surface, pressing down on the handle until the pressure arm was parallel with the handle, and drawing the tool across the module at a slow rate of motion. Penetration was determined by connecting a voltmeter between the tool and one of the module output terminals. Normal room light provided enough solar cell output to cause a deflection on the meter when either a cell or conductor was contacted. A continuity tester could also have been used.

In use, the cut tester described above is very difficult to apply. It is difficult to keep the pressure arm parallel with the handle, the blade perpendicular to the encapsulant surface and try to maintain a constant speed, all simultaneously. Therefore, a different tool was developed based on the same principals (see Ill. D.5). This device is designed to keep the pressure arm parallel with the handle and the blade perpendicular to the encapsultant surface. The effect of varying speed has not been determined because of the difficulties described, but for the present a speed of 6 inches per second (15.2 cm per second) is being proposed.


ILL. D.1
M81-720

ILL. D. 2



Subject Ill. D.3

LIST OF MATERIALS - SHARP EDGE TESTER (SC0509B, ISSUED 5-7-73)

Item	Note	Description	Quantity
A	a	Plate, Retaining, Pressure Arm (SA0510)	1
B	a	Arm, Pressure (SB0511)	1
C	a	Head, Pressure Pad (SB0512)	1
D	a	Spring, Negator (SB0513)	1
E	a	Drum, Main (SB0514A)	1
F	a	Drum, Storage (SA0515)	1
G	a	Spindle, Storage Drum (SB0516)	1
H	a	Base (SB0517A)	1
1	b	Screw, Machine, Pan HD, 4-40 UNC2A X 1/4 LG	2
2	b	Spring Pin, .032 Dia. X 3/8 LG	1
3	b	Screw, Machine, Pan HD, 8-32 UNC2A X 5/16 LG	2
4	b	Dowel Pin, $\frac{.1565}{.1562}$ Dia. X 5/8 LG	1
5	b	Shoulder Screw, (Stripper Bolt) $\frac{.248}{.247}$ Dia X 1/2 LG	1
6	b	Nut, Plain, Hexagon	2
7	c	Bearing, Ball, Radial, (R4, ABEC 1) .125 Bore .625 O.D. X .196 W, Double Shield	2
8	d	Spacer, $\frac{.130}{.125}$ I.D., .187 O.D. X .188 LG	1
9	c	Bearing, Ball, Radial, (R2, ABEC 1) .125 Bore, .375 O.D. X .156 W, Double Shield	2
10	d	Spacer, $\frac{.255}{.250}$ I.D. X .375 O.D. X .063 LG	2
11	e	Handle, Tool, Adjustable, 1/4 inch	1
12	b	Washer, Lock, Split, No. 10 Medium	2
13	b	Nut, Plain, Hexagon	2

Note:

a. Items A Through H, drawings are available from: Underwriters' Laboratories, Inc., (1285 Walt Whitman Road, Melville, Long Island, New York 11746.

b. Available through hardware suppliers.

c.

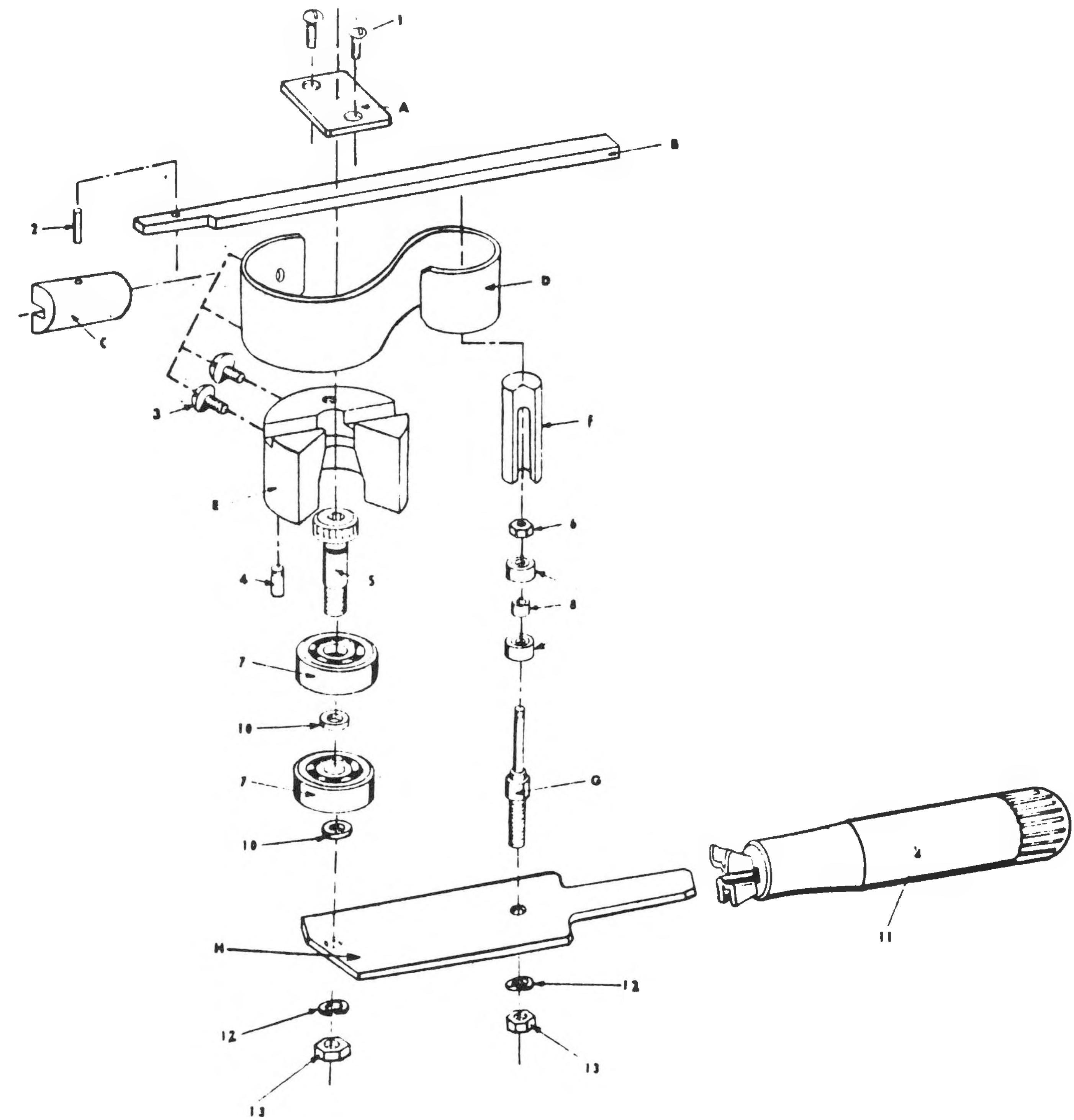
Available From:	Size of Bore	Part Number
(1) Fafnir Ball Bearing	.125	33KDD3
New Britain, Connecticut	.250	S1KDD7
(2) New Hampshire Ball Bearing	.125	SR21PPK25/122
Peterborough, New Hampshire	.250	SR41PPDK25/122
(3) Miniature Precision Bearing	.125	SR2CHH
Bristol, Connecticut	.250	SR4RHH

d.

Available From:	Size	Part Number
(1) Allied Devices Corporation	.125 I.D.	811
Baldwin, New York	.250 I.D.	838
(2) PIC Design Corporation	.125 I.D.	B4-12
Ridgefield, Connecticut	.250 I.D.	B8-9
or, Van Nuys, California		
(3) W. M. Berg, Inc.	.125 I.D.	SS1-31
E. Rockaway, New York	.250 I.D.	SS2-32
or Van Nuys, California		

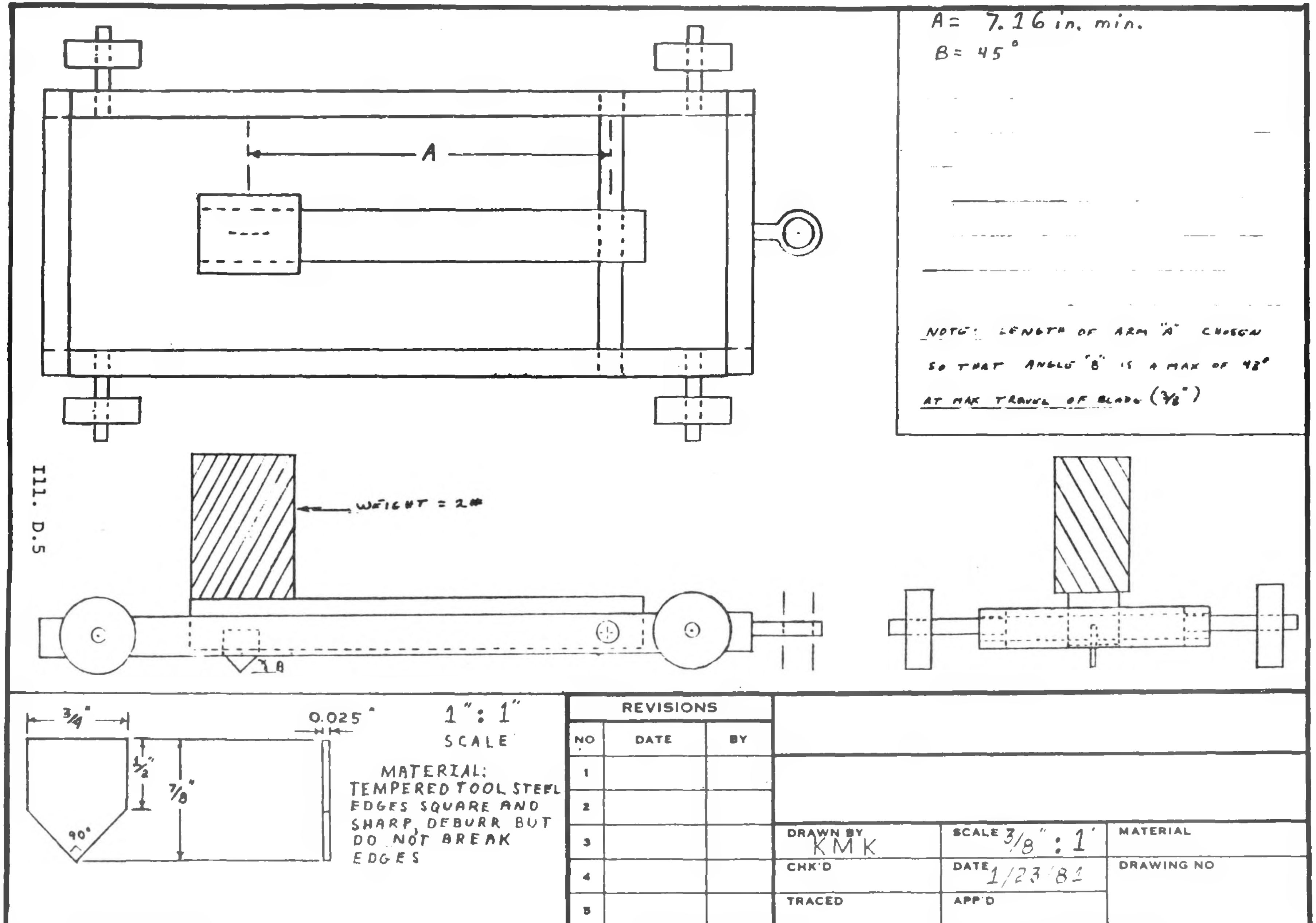
e.

Available From:	Part Number
(1) Sears Roebuck & Company	Craftsman 9G6775
(2) General Hardware Manufacturing Company	890
New York City, New York	



Ill. D.4

III. D.5



A = 7.16 in. min.
B = 45°
A
NOTE: LENGTH OF ARM "A" CHOSEN SO THAT ANGLE "B" IS A MAX OF 45° AT MAX TRAVEL OF BLADE (3/8")
WEIGHT = 2#
B
3/4"
1/2"
7/8"
90°
0.025"
1" : 1"
SCALE
MATERIAL:
TEMPERED TOOL STEEL
EDGES SQUARE AND SHARP, DEBURR BUT DO NOT BREAK EDGES
REVISIONS
NO
DATE
BY
1
2
3
4
5
DRAWN BY KMK
SCALE 3/8" : 1"
MATERIAL
CHK'D
DATE 1/23/81
DRAWING NO
TRACED
APP'D

APPENDIX E

RESULTS OF FIRE TESTS; ROOF MOUNTED MODULES - 1980

GENERAL:

On June 13, 1980, laboratory testing of Motorola and Solarex photovoltaic modules to certain of the procedures described in the Standard; "Tests for Fire Resistance of Roof Covering Materials", UL 790-1978, as modified according to the procedure contained in the draft Proposed Standard for Safety - Flat-Plate Photovoltaic Modules and Panels, was conducted at Underwriters Laboratories Inc., Northbrook, Illinois.

SAMPLES:

Panels of Motorola (glass superstrate and metal substrate) and Solarex (fiberglass super and substrate) photovoltaic modules, (see Illustrations E.6 to E.9). Each panel includes four modules in an aluminum frame.

The panels were spaced 4 inches above a Class A roof deck (including Class A shingles). For the spread-of-flame test, the deck-shingle assembly was thirteen (13) feet long, rather than eight (8) feet, as normally specified for a Class A deck, the rating sought.

TESTS:

The panel of Solarex modules on the deck was subjected to burning-brands test, the panel of Motorola modules on the deck was subjected to burning-brands and spread-of-flames tests.

BURNING BRAND TEST:

METHOD - GENERAL

(Class A Test)

A deck, 3-1/3 feet wide by 4-1/3 feet long was made of 3/8 inch thick (A-C grade, Group 1, exterior) plywood. The face and back veneers of the plywood were of Douglas fir. The deck had 1/8 inch vertical and horizontal joints, with all vertical joints centered on 2 by 4 inch (trade size) wood battens. A vertical joint centered on the deck and extending from the leading edge of the deck to the horizontal joint was provided.

The vertical edges of the plywood were across two 2 by 4 inch (trade size) wood battens located under and flush with the outer edges of the deck. See Illustration E.4.

Listed, Class A rated shingles were affixed over the entire surface of the deck.

The deck-shingle assembly was mounted on a carriage including an inclined plane, the incline being 3 inches per foot. Mortar was applied into the joint formed by the leading edge of the shingle and the framework of the carriage.

The photovoltaic panel was placed over the deck-shingle assembly, and separated 4 inches from the assembly by four bricks, one at each corner.

An air current was passed over this assembly, such that at points midway up the slope of the deck and 3-11/16 inches above the shingle surface, the velocity of the air was 12 ± 1/2 miles per hour.

A brand was prepared, consisting of a grid, 12 inches square and 2-1/4 inches thick, of kiln-dried Douglas fir lumber free from knots and pitch pockets. It was made of thirty six 3/4 by 3/4 by 12 inch dressed strips, placed in three layers of 12 strips each, with strips spaced 1/4 inch apart. These strips were placed at right angles to those in adjoining layers and were stapled, using No. 16 gauge steel wire staples having a 7/32 inch crown and 1-1/4 inch legs, at each end of each strip on one face, and in a diagonal pattern on the other face. The dry weight of the finished brand before ignition was 4.4 ± 0.33 pounds.

The brand was ignited by placement in a gas burner shielded from drafts, so that during the process of ignition, the brand was nearly enveloped in the burner flame. The temperature of the igniting flame was 1630 ± 50 degrees F, measured 2-5/16 inches above the top of the burner.

The brand was exposed to the flame for 5 minutes, during which time it was rotated so as to present each surface to the flame. At the conclusion of the 5 minute period, the brand was burning freely in still air.

METHOD I
(Solarex Module)

The brand was applied to the center of the panel of Solarex modules.

RESULTS I

Time as taken from application of brand.

Time (Minutes:Seconds)	Notes
0:00	Brand centered on panel
0:39	Charring of module cover upstream from brand
1:58	Blistering of module cover upstream from brand
2:12	Ignition of module cover upstream from brand, cover blistering up under brand, lifting up brand
3:57	Flaming to end of panel
5:00	Brand 1/3 consumed
5:22	Fire subsiding, flames extend halfway between brand and end of array. Flames licking through slots between modules, but not reaching deck
7:06	Brand 1/2 consumed, fire extending 5 inches beyond brand
11:30	Brand 3/4 consumed
15:00	Brand 7/8 consumed
19:00	Brand reduced to embers
20:00	Test terminated, no effect on shingles in any manner

There was no flaming on the underside of the test deck, no production of flaming or glowing brands of roof covering or panel material, nor displacement of the test sample. There was no exposure or falling away of the roof deck.

METHOD II
(Solarex Module)

The brand was applied to the center of a lower module on the panel of Solarex modules (same panel as in test of Method I).

RESULTS II

Time (Minutes:Seconds)	Notes
0:00	Brand in place
2:00	Blistering of module cover under brand
2:35	Ignition of module at area damaged during test of Method I
4:23	Module covering flame to approximately 12 inches beyond brand, and in slots between modules. No flaming of roof deck assembly
7:15	Brand 1/2 consumed, flaming of module cover reduced to approximately 6 inches beyond brand
10:00	Brand 3/4 consumed, no penetration to or flaming of roof deck. Flames 3-4 inches beyond brand
13:00	Brand 7/8 consumed
17:00	Test terminated

Burned area had extended through to base material under cells. There was no flaming on the underside of the test deck, no production of flaming or glowing brands of the roof covering or the panel material, nor displacement of the test sample. There was no exposure or falling away of the roof deck.

CONCLUSION FOR RESULTS I AND II

When installed over Class A shingles, the Solarex module met the requirements of the Class A burning brands test.

NOTE

The procedure and results of Methods I and II are shown in Ill. E.1.

METHOD III
(Motorola Module)

Brand applied to center of a lower module on the panel of Motorola modules.

RESULTS III

Time (Minutes:Seconds)	Notes
0:00	Brand in place
0:45	Module cover flaming upstream from brand
4:00	Brand only flaming, module cover blistering upward in brand area, brand pushed upward and away from large area contact with module by blister
7:00	Glass cover of module distorted into dome shape, brand 5/8 consumed
8:40	Flash flame penetration through module cover
10:02	Glass cover cracked, flaming at leading edge between module cover and metal edge. Module cover cracked in numerous places, flaming through each crack
12:15	Flaming continuing through cracks
13:00	Flames subsiding
13:54	Module flaming ceased, brand flaming continuing
15:03	Brand glowing, no flaming
15:45	Intermittent flaming within module
20:00	Test terminated

There was no flaming on the underside of the test deck, no production of flaming or glowing brands of the roof covering or panel material, nor displacement of the test sample. There was no exposure or falling away of the roof deck.

CONCLUSION

When installed over Class A shingles, the Motorola module met the requirements of the Class A burning brands test.

NOTE

The procedure and results of Method III are shown in the first seven frames of Ill. E.2.

SPREAD-OF-FLAME TEST:

METHOD
(Motorola Module)
(Class A Test)

A deck, 3-1/3 feet wide by 13 feet long, was made of 3/8 inch thick (A-C grade, Group 1, exterior) plywood. The face and back veneers of the plywood were of Douglas fir. The deck had a 1/8 inch horizontal joint, with the joint centered on a 2 by 4 inch (trade size) wood batten. The vertical edges of the plywood were across two 2 by 4 inch (trade size) wood battens located under and flush with the outer edges of the deck. See Ill. E.5. Listed, Class A rated shingles were affixed over the entire surface of the deck.

The deck-shingle assembly was mounted on a carriage including an inclinded plane, the incline being 5 inches per foot.

Mortar was applied into the joint formed by the leading edge of the shingles and the framework of the carriage.

The Motorola photovoltaic module was placed over the deck-shingle assembly, with the lower edge of the module 1 foot from the lower edge of the assembly. The module was spaced 4 inches from the deck-shingle assembly by four bricks, one at each corner.

The assembly was subjected to an air current flowing uniformly over its top surface. At a point 2 feet, 2 inches up the center of the test deck, and 3-11/16 above the surface of the shingles, the velocity of the air current was 12 ± 1/2 miles per hour.

The assembly was then subjected to a luminous gas flame approximately the width of the deck and applied at its bottom edge. The gas supply was so regulated that the flames, when not augmented by the combustion of the roof covering, developed a temperature of 1400 ± 50 degrees F. The temperature of the flame was determined by a No. 14 B&S gauge chromel-alumel wire thermocouple located 1 inch above the surface and 1/2 inch toward the source of the flame from the lower edge of the first board of the test deck.

RESULTS

Time (Minutes:Seconds)	Notes
0:00	Flame on
4:12	Shingles ignited, underside of modules burning at edges
4:58	2 foot flame spread on shingles
5:37	3 foot flame spread on shingles
5:50	5 foot flame spread on shingles
6:02	6 foot flame spread on shingles
6:12	8 foot flame spread on shingles
6:20	9 foot flame spread on shingles
6:40	10 foot flame spread on shingles
6:54	12 foot flame spread on shingles
7:04	13 foot flame spread on shingles
8:00	Test terminated

Note: Flame spread as measured from leading edge of test deck.

There was no production of flaming or glowing brands. Portions of the aluminum frame work supporting the modules had been severed, which allowed displacement of a portion of the panel.

CONCLUSION

No judgment is made as to acceptability, since the requirements for the spread-of-flane test are under review.

NOTE

The procedure and results are shown in frames 9-12 of Ill. E.2.

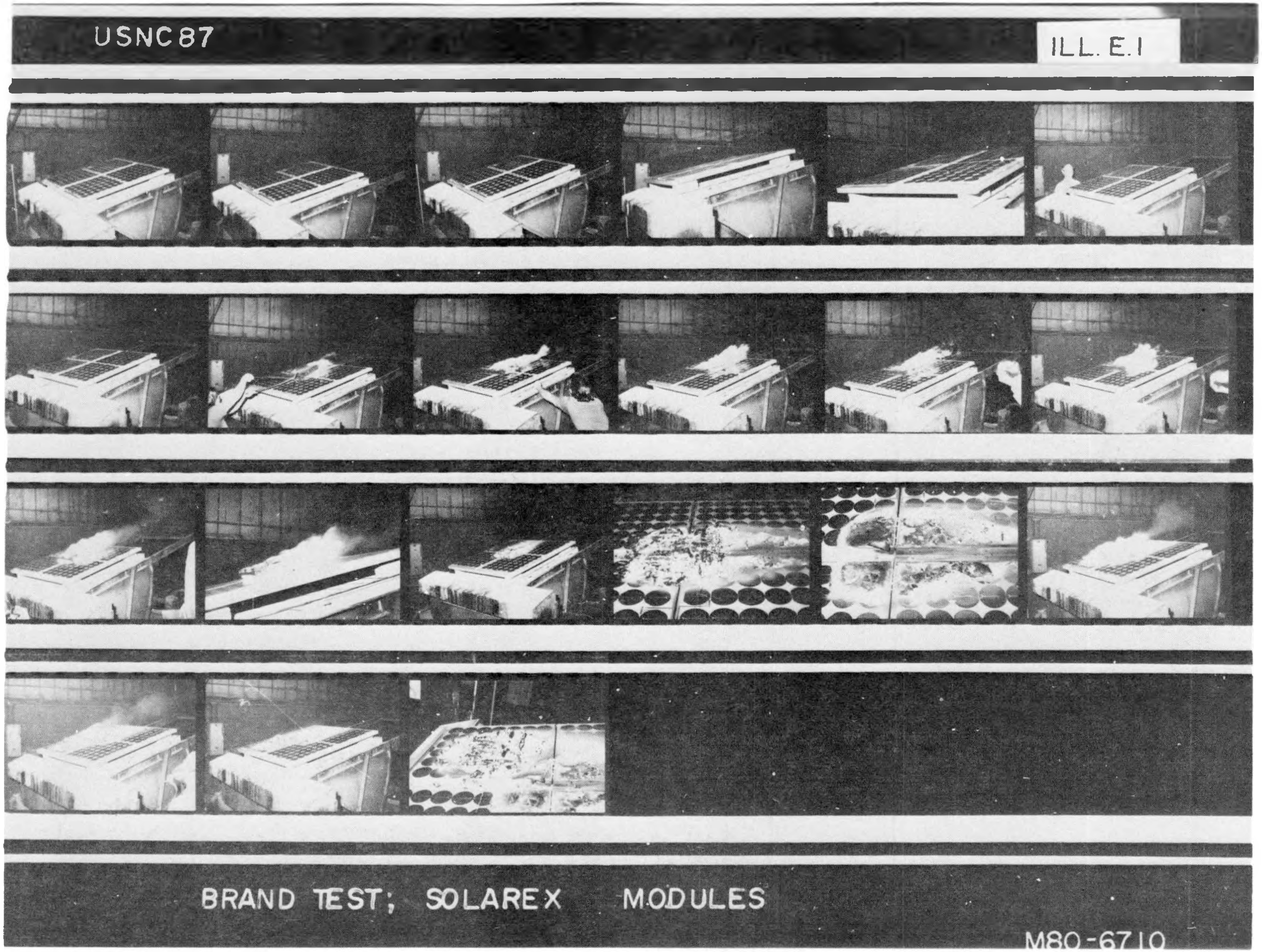
ALL TESTS:

NOTE

The condition of the panel following the tests is shown in frames 13-17 of Ill. E.2. The cracked dome glass of the Motorola module is shown in Ill. E.3.

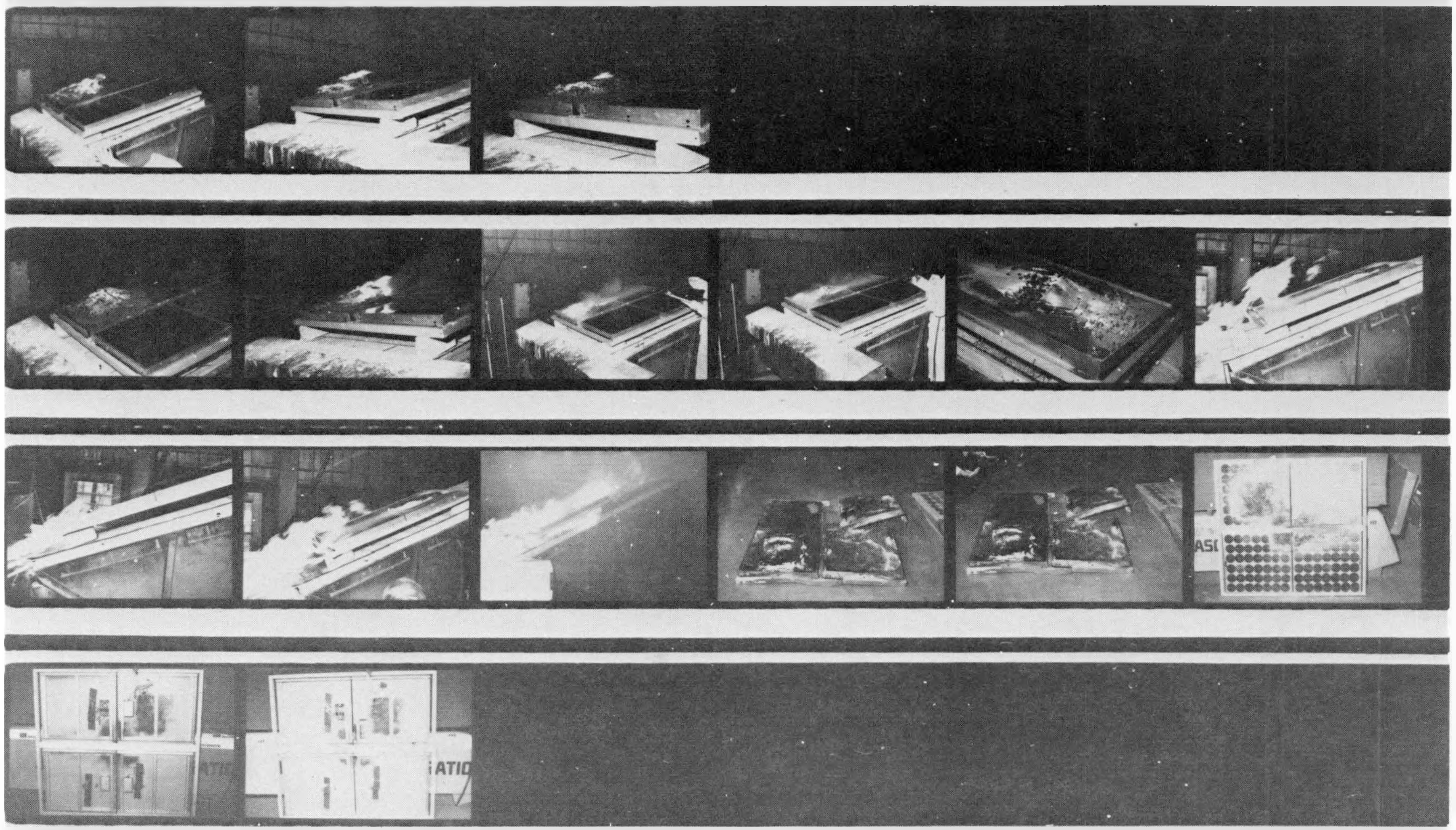
COMMENT:

If necessary, spread-of-flame between the roof covering and the stand-off mounted modules might be restricted by the use of skirts around the modules, fire stops within the array, or a greater or lesser spacing between the array and the roof. (A 4 inch spacing was used for the test.) Unfortunately, some of these modifications (e.g. - fire stops or decreased spacings) may result in increased array temperatures, and thus decreased power output from the array and/or array operation at temperatures which may themselves constitute a risk of fire hazard. These modifications may also result in the collection of debris and/or water between the modules and roof, and deteriorate the roof.

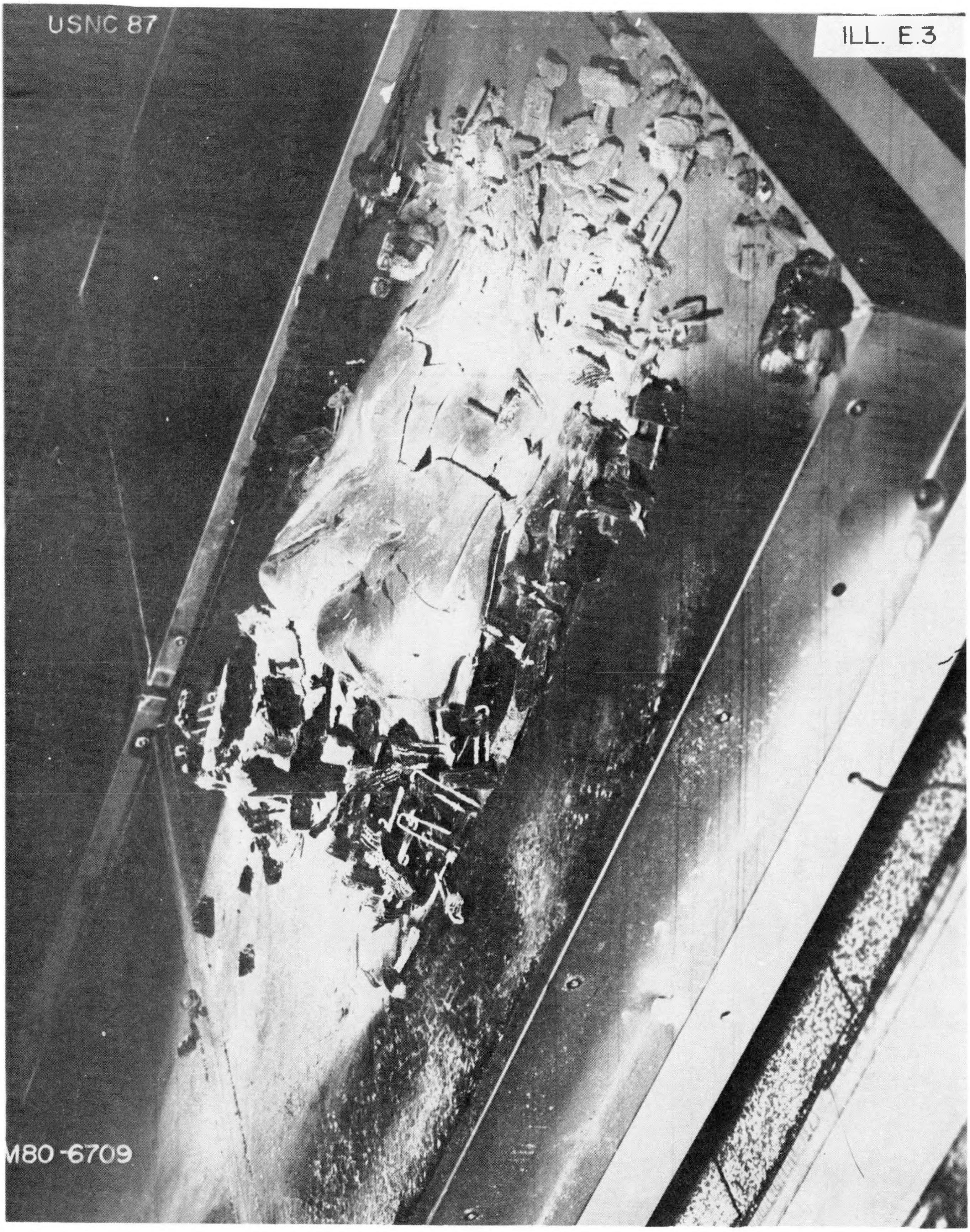

USNC87
ILL. E.1
BRAND TEST; SOLAREX MODULES
M80-6710

USNC 87

ILL. E.2

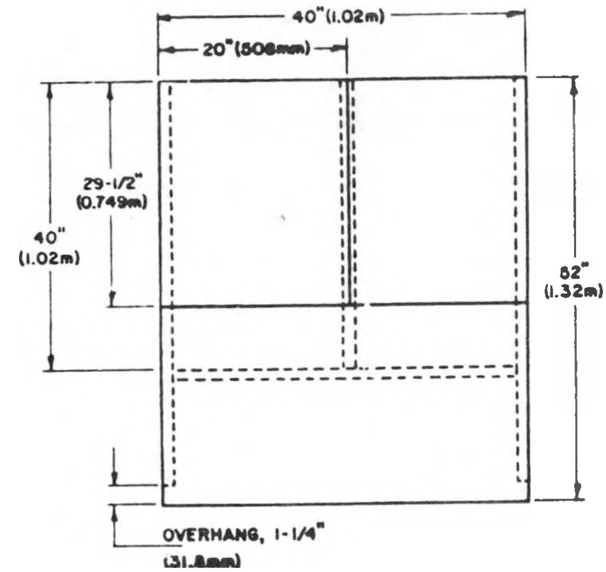


BRAND AND SPREAD-OF-FLAMES; MOTOROLA MODULES M80-6711


USNC 87
ILL. E.3
M80-6709

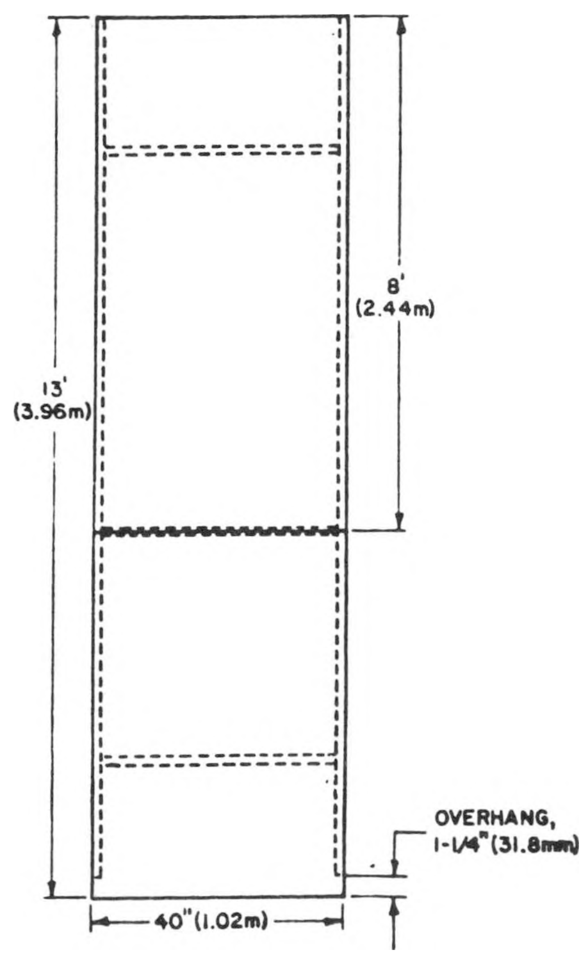
Ill. E.4

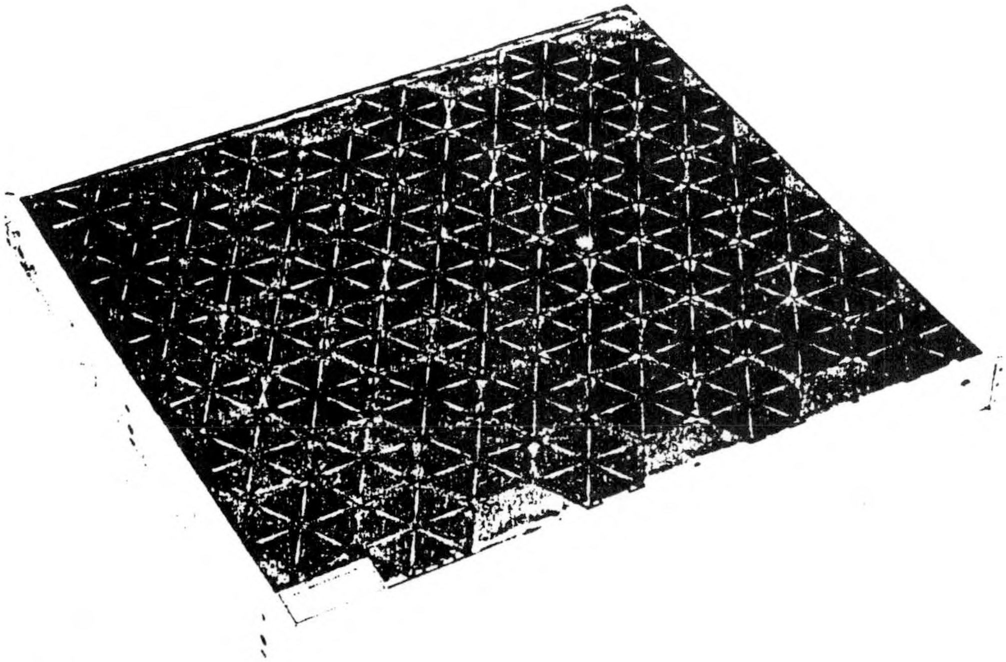
CLASS A BURNING BRAND PLYWOOD DECK



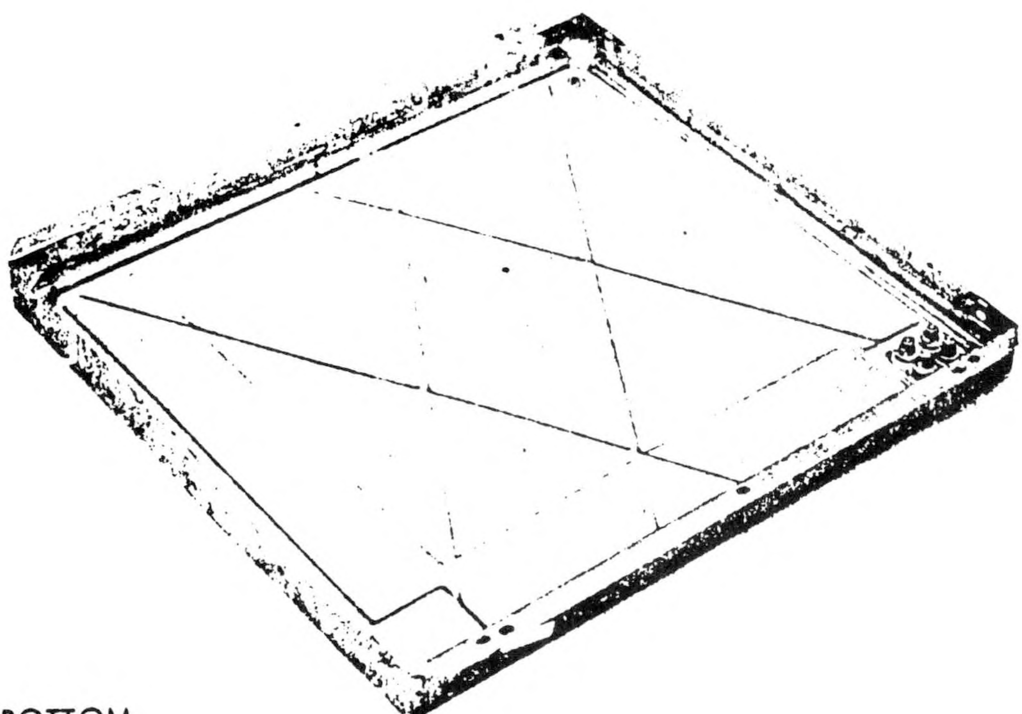
Ill. E.5

SPREAD-OF-FLAME PLYWOOD DECK



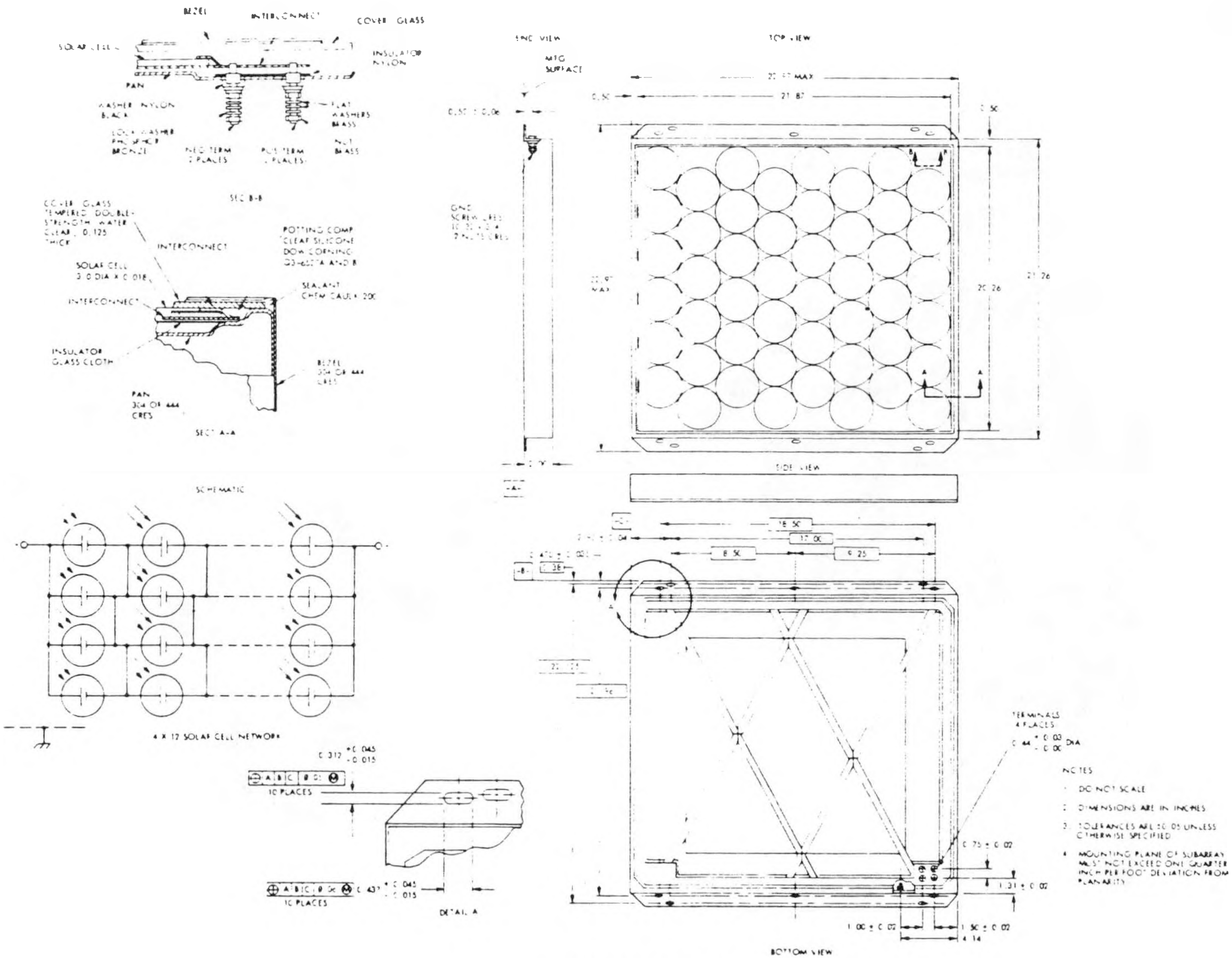


TOP



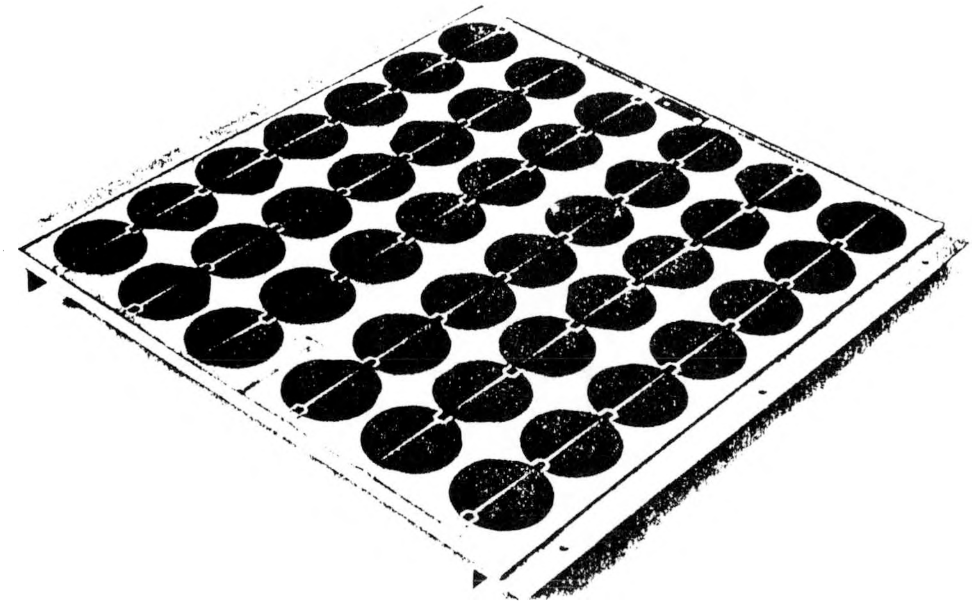
BOTTOM

Ill. E.6
Motorola Module: Photographic Views

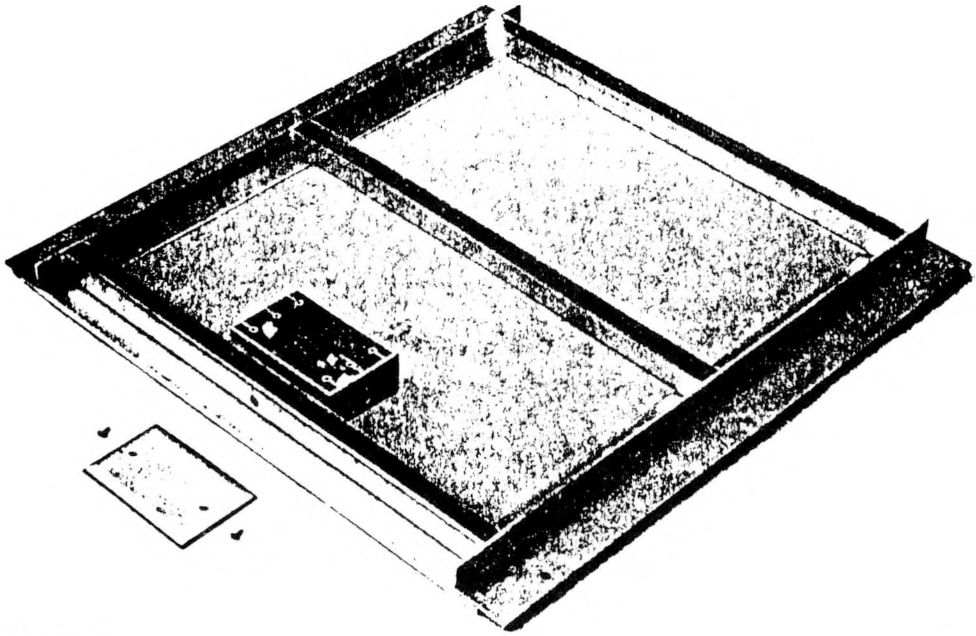


Motorola Module: Drawing

Ill. E.7

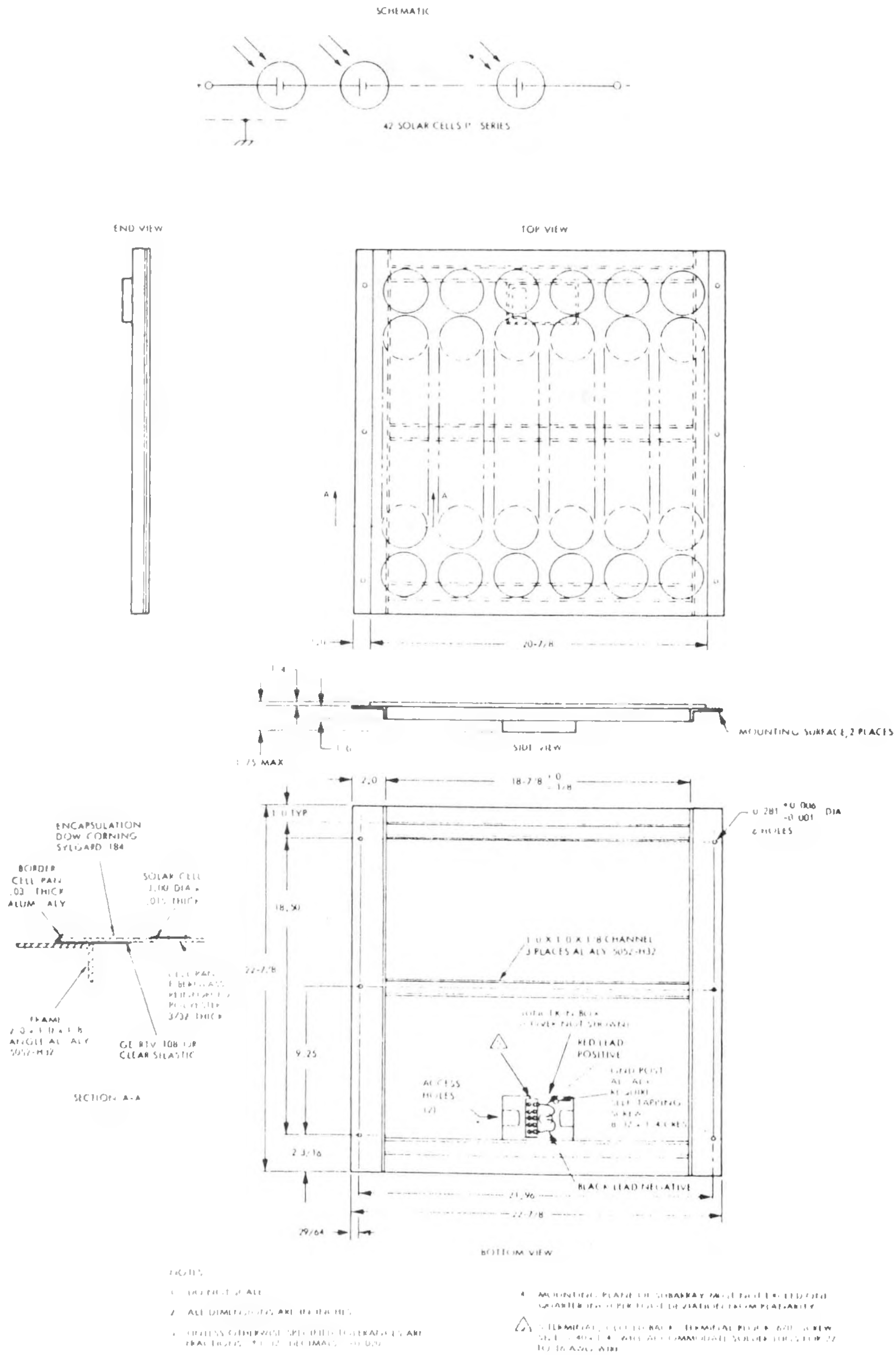


TOP



BOTTOM

Ill. E.8
Solarex Module: Photographic Views



Ill. E.9
Solarex Module: Drawing

APPENDIX F

RESULTS OF FIRE TESTS; ROOF-MOUNTED MODULES - 1981

GENERAL:

On August 14, 1981, laboratory testing of General Electric shingle type and Solarex Corporation integral mount type photovoltaic modules to certain of the procedures described in the Standard; Tests for Fire Resistance of Roof Covering Materials", UL 790-1978, as modified according to the procedure contained in the draft Proposed Standard for Safety - Flat-Plate Photovoltaic Modules and Panels, was conducted at Underwriters Laboratories Inc., Northbrook, Illinois.

SAMPLES:

Simulated roof sections of General Electric glass-silicone-panelboard shingle style and Solarex ethylene vinyl acetate (EVA) encapsulant, glass superstrate and Tedlar, Mylar, and aluminum substrate integral mount style photovoltaic modules.

The General Electric shingle type modules were mounted to a plywood deck, with the deck construction and shingle mounting performed by the Jet Propulsion Laboratory. Because of the size and character of the shingle modules, the deck-shingle assembly was wider than that ordinarily used for these tests.

The Solarex integral mount module was tested mounted directly to simulated rafters, without back decking.

TESTS:

* * * * * * * * * * * * *

Tests conducted in the order presented.

SPREAD-OF-FLAME TEST:

GE Shingle Modules
METHOD
(Class A Test)

A deck 65 inches wide by 92 inches long was made of three pieces of 3/8inch thick plywood. The face and back veneers of the plywood were of Douglas fir. The pieces of plywood butted together at the joints, with the joint along the long (vertical) dimension over a 2 by 4 inch (trade size) wood batten. (The butt joint is an improper construction, a 1/8 inch width gap is specified for the joints.) Wood battens, 2 by 4 inches were located centered under the deck, 40 inches apart. See Ill. F.1.

The GE photovoltaic shingle-modules were applied over as large a portion of the surface of the deck as possible, with asbestos sheet filling the remaining surface area. This procedure was necessary because the GE shingle-modules cannot be used cut. In actual installations, nonelectrically active asbestos edge pieces would be used.

The deck-shingle assembly was mounted on a carriage including an inclined plane, the incline being 5 inches per foot.

Mortar was applied into the joint formed by the leading edge of the shingles and the framework of the carriage.

The assembly was subjected to an air current flowing uniformly over its top surface. At a point midway up the slope and 3-11/16 inches above the surface of the assembly, the speed of the air current was 12±1/2 miles per hour.

The assembly was then subjected to an approximately 40 inch wide luminous gas flame applied at a point on the deck where the shingle-module is at the leading edge. The gas supply was so regulated that the flame, when not augmented by any combustion of the roof covering, developed a temperature of 1400±50 degrees F. The temperature of the flame was determined by a No. 14 B&S gauge chromel-alumel wire thermocouple located 1 inch above the surface and 1/2 inch toward the source of the flame, measured from the lower edge of the first board of the test deck.

RESULTS

Time (Minutes-Seconds)	Notes
0:00	Flame on.
2:15	Discoloration of cells in immediate flame area.
6:00	Discoloration of cells to approximately 2 feet.
6:30	Flaming of edges of shingles in area of application of gas flame.
8:00	Flame spread of 1 foot at and from edges of shingles.
8:45	Flame spread of 1-1/2 feet at and from edges of shingles.
10:00	Gas flame extinguished.
10:15	Self sustaining shingle flaming at edges, shingle flames extinguished.

No portion of the roof covering was blown off or fell off the roof in the form of flaming or glowing brands. No portion of the roof deck fell away in the form of glowing particles. The roof deck was not exposed by breaking, sliding, cracking, or warping of the roof covering. There was no sustained flaming on the underside of the test deck.

Flame spread was limited as described above, thus there was no spread-of-flame beyond 6 feet nor any significant lateral spread of flame.

CONCLUSION

It appears that the product conforms with the Class A Spread-of-Flame requirements.

BURNING-BRAND TESTS:

METHOD I
(Class A Test)

Since only a small section was damaged in the previous test, and in order to make maximum use of the sample, the photovoltaic single-module deck assembly described under the "SPREAD-OF-FLAME TEST", was turned 180 degrees from its position in that test, but maintained on the inclined carriage with the shingle-modules on the top surface. The incline was maintained at 5 inches per foot. Mortar was applied into the joint formed by the leading edge of the shingle and the framework of the carriage.

An air current was passed over this assembly, such that at points midway up the slope of the deck and 3-11/16 inches above the shingle surface, the speed of the air was 12$\pm$1/2 miles per hour.

A Class A brand was prepared, consisting of a grid, 12 inches square and 2-1/4 inches thick, of kiln-dried Douglas fir lumber free from knots and pitch pockets. It was made of 36 nominal 3/4 by 3/4 by 12 inch dressed strips, placed in three layers of 12 strips each, with strips spaced 1/4 inch apart. These strips were placed at right angles to those in adjoining layers and were stapled, using No. 16 gauge steel wire staples having a 7/32 inch crown and 1-1/4 inch legs, at each end of each strip on one face, and in a diagonal pattern on the other face. The dry weight of the finished brand before ignition was 4.4$\pm$0.33 pounds.

The brand was ignited by placement in a gas burner shielded from drafts, so that during the process of ignition, the brand was nearly enveloped in the burner flame. The brand was rotated so that each face was exposed to the burner flame. The temperature of the igniting flame was 1630$\pm$50 degrees F, measured 2-5/16 inches above the top of the burner.

After 5 minutes in the igniting flame, and while the brand was burning freely, it was placed on a previously undamaged section of the assembly, over a joint of the shingle-modules.

RESULTS I

Time (Minutes:Seconds)	Notes
0:00-5:00	Ignition of brand.
5:20	Brand in place on sample.
6:52	Cracking of glass of shingle-modules.
11:15	Flaming of shingle edges in brand area, flaming of edges extending 3-4 inches beyond brand.
13:25	Additional glass cracking, flaming of edges extends 6 inches.
14:30	Brand 1/4 consumed, flaming of shingle extends 6 inches beyond brand.
17:00	Brand 1/2 consumed, flaming of shingle subsiding.
18:00	Brand broken up, some sliding of brand fragments down shingle surface.
21:00	Dark spot and 'light' smoking on underside of test deck.
23:00	Second dark spot and 'medium' smoking on underside of test deck. Brand 3/4 consumed.
24:00	Glowing on underside of deck at first dark spot.
26:30	Area of glowing increasing.
27:30	Sporadic flickering of flame on underside of deck, no sustained ignition.
28:30	Brand almost completely consumed, flaming of brand almost terminated.
29:45	Brand glowing only.
31:50	Brand out.
36:00	Glowing terminated on underside of deck.
45:00	Test terminated.

The results were inconclusive because of improper construction of deck, combined with flame flickering and glowing on underside of deck.

METHOD II
(Classes A and B Tests Combined)

Again the area damaged by the previous test was small enough to permit the assembly to be reused, thus the photovoltaic shingle-module deck assembly of the test of Method I was maintained in the orientation and inclination of the test of Method I.

An air current was passed over this assembly, such that at points midway up the slope of the deck and 3-11/16 inches above the shingle surface, the speed of the air was $12 \pm 1/2$ miles per hour.

Two brands were prepared, one a Class A, the other a Class B.

The Class A brand was constructed as described under METHOD I.

The Class B brand consisted of a grid, 6 inches square and 2-1/4 inches thick, made of kiln-dried Douglas fir lumber free from knots and pitch pockets. It was made of 18 nominal 3/4 by 3/4 by 6 inch strips placed in three layers of 6 strips each, with strips spaced 1/4 inch apart. The strips were placed at right angles to those in adjoining layers and stapled, using No. 16 gauge steel wire staples having a 7/32 inch crown and 1-1/4 inch legs, at each end of each strip on one face, and in a diagonal pattern on the other face. The dry weight of the finished brand before ignition was 1.1 ± 0.11 pounds.

The brands were individually ignited by placement in a gas burner shielded from drafts, so that during the process of ignition, the brands were nearly enveloped in the burner flame. The brands were rotated in the flame so that each face was exposed to the burner flame. The temperature of the igniting flame was 1630 ± 50 degrees F, measured 2-5/16 inches above the top of the burner.

After 5 minutes in the case of the Class A brand, and 4 minutes in the case of the Class B brand, and while the brands were burning freely, they were placed on previously undamaged sections of the assembly, above the horizontal joint in the plywood deck.

RESULTS II

	Notes	
Time (Minutes:Seconds)	Class A	Class B
0:00-5:00	Ignition of brand.	-
5:00	Brand in place.	-
6:20	Cracking of glass of shingle-module.	-
7:15	Slight flaming at edges of shingles.	-
9:45	Flaming extending 1 foot beyond brand, smoking at joint in plywood on underside of deck.	-

Time (Minutes:Seconds)	Notes: Class A	Notes: Class B
11:00	Heavy smoking on underside of deck, brand 1/2 consumed. Flaming at edges of shingles 1 foot beyond brand. Moisture spots on plywood deck.	-
11:35-15:35	-	Ignition of brands.
13:00	Heavy smoking continuing on underside of deck, glowing at joint in plywood deck.	-
15:00	Brand 7/8 consumed.	-
15:35	Flaming at edges of shingles. Flaming of brand ceased.	Brand in place.
17:30	Brand pieces glowing, light smoking at underside of plywood deck. Glowing at joint.	-
19:25	Brand almost out.	Smoke coming from under shingle beyond brand.
21:00	Glowing at only 2-3 embers of brand.	Brand 7/8 consumed, moisture spots on underside of plywood deck, glowing only of brand.
25:00	Char area, 3-4 inches long on underside of deck. Glowing in only small area on underside of deck. No flaming or glowing of brand.	-
29:00	Glowing in underside of deck almost out.	Brand out, light smoking and charring at underside of plywood deck joint.

Time (Minutes:Seconds)	Notes: Class A	Notes: Class B
31:00	-	Light glowing at underside of plywood deck joint.
32:45	-	Flaming at underside of plywood deck joint. Test failure.

NOTE: Deck was improperly built in that there were no gaps between the pieces of plywood (at the joints). Further, the plywood appeared to have an excessive moisture content.

Solarex Glass Superstrate Modules

BURNING BRANDS TESTS:

METHOD I
(Class B)

The module was mounted directly to simulated rafters without any decking under the module. The module on the rafters was mounted on a carriage including an inclined plane, the incline being 5 inches per foot.

An air current was passed over this module, such that at points midway up the slope of the module and 3-11/16 inches above the module surface, the speed of the air was $12\pm1/2$ miles per hour.

A Class B brand was prepared, constructed as described under METHOD II, General Electric shingle-module tests.

The brand was ignited by placement in a gas burner shielded from drafts, so that during the process of ignition, the brand was nearly enveloped in the burner flame. The brand was rotated so that each face was exposed to the burner flame. The temperature of the igniting flame was 1630 ± 50 degrees F, measured 2-5/16 inches above the top of the burner.

After 4 minutes in the igniting flame, and while the brand was burning freely, it was placed on the module.

RESULTS I

Time (Minutes:Seconds)	Notes
0:00-4:00	Ignition of brand.
4:00	Brand in place on sample.
7:00	Indentations forming on underside of sample directly under brand.
7:43	Glass superstrate cracking and bending upwards.
8:41	Penetration through module, flaming on underside of module.
8:59	Portions of module substrate ignited, substrate dripping to floor.
10:05	Test terminated. Test failure.

* * * * * * * * * * * * *

In view of the 'failure' results, a test for a Class C rating was conducted as described following.

* * * * * * * * * * * * *

METHOD II
(Class C)

Sufficient undamaged area remained in the Solarex integral mount module to allow its use in further tests, Thus, the sample of the test of Method I was maintained in the same mounting position.

An air current was passed over this module, such that at points midway up the slope of the module and 3-11/16 inches above the module surface, the velocity of the air was $12 \pm 1/2$ miles per hour.

Four brands were prepared, each consisting of a piece of kiln-dried nonresinous white pine lumber, free from knots and pitch pockets, 1-1/2 by 1-1/2 by 25/32 inch thick, with a saw kerf 1/8 inch wide one-half the thickness of the brand across the center of the top and bottom faces. The saw kerfs on opposite faces were at right angles to each other. The dry weight of each of the finished brands before ignition was 0.326 ± 0.044 ounces.

The brands were ignited by placement in a gas burner shielded from drafts, so that during the process of ignition, each brand was enveloped in the burner flame. The brands were rotated so that each 1-1/2 by 1-1/2 inch face was exposed to the burner flame for one minute. The temperature of the igniting flame was 1630 ± 50 degrees F, measured 2-5/16 inches above the top of the burner.

After 2 minutes in the igniting flame, and while the brands were burning freely, they were placed on previously, undamaged areas of the module.

RESULTS II

All brands burned out without affecting the test sample.

* * * * * * * * * * * * *

Because of successful performance to Class C requirements, a repeat of the Class B test procedure was sought to substantiate performance at that level.

* * * * * * * * * * * * *

METHOD III
(Class B)

Sufficient undamaged area remained in the Solarex integral mount module to allow its further use. Thus, the sample of the tests of Methods I and II was maintained in the same mounting position.

An air current was passed over this module, such that at points midway up the slope of the module and 3-11/16 inches above the module surface, the velocity of the air was 12±1/2 miles per hour.

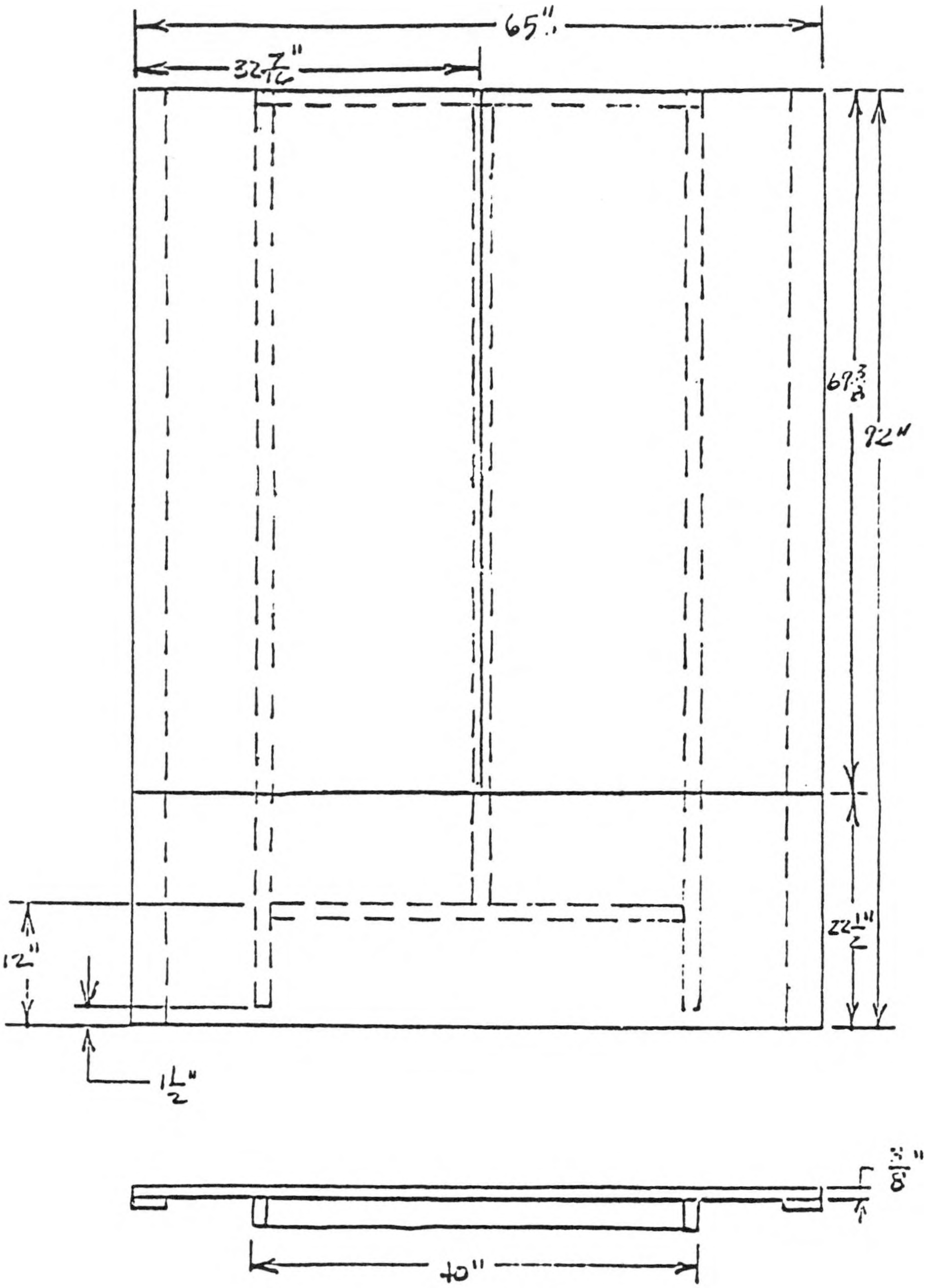
A Class B brand was prepared, constructed as described under METHOD II, General Electric shingle-module tests.

The brand was ignited by placement in a gas burner shielded from drafts, so that during the process of ignition, the brand was nearly enveloped in the burner flame. The brand was rotated so that each face was exposed to the burner flame. The temperature of the igniting flame was 1630±50 degrees F, measured 2-5/16 inches above the top of the burner.

After 4 minutes in the igniting flame, and while the brand was burning freely, it was placed on the module.

RESULTS III

Time (Minutes:Seconds)	Notes
0:00-4:00	Ignition of brand.
4:00	Brand in place on sample.
7:21	Indentations forming on underside of module.
7:45	Glass superstrate bending upwards.
10:14	Module substrate split open, liquid dripping through split, heavy smoking.
10:29	Substrate ignited.
10:40	Burning pieces of substrate dripping and falling from module.
10:55	Test terminated. Test failure.



Ill. F.1

Deck - General Electric Shingle Module Tests

APPENDIX G

DEVELOPMENT OF DC GROUND-FAULT DETECTOR

BACKGROUND:

The feasibility of incorporating differential type ground fault protection in a photovoltaic installation has been demonstrated by constructing such a device and installing it in the Massachusetts Institute of Technology/Lincoln Laboratory (MIT/LL) prototype at the Northeast Residential Experimental Station; Concord, Massachusetts. This device was installed on September 23, 1981 and removed on December 23, 1981. The device did not include any means to interrupt the circuit, but merely responded to faults by stepping a counter. During the time it was in place we believe that it did not respond to anything which was not a true fault. Further it was verified that it did properly respond to true faults which were created.

This MIT/LL prototype includes a transformerless inverter, and is represented by the circuit in Ill. G.1. No automatic interruption switches were provided, and because of device limitations (current handling ability) the ground-fault sensor installation was in one photovoltaic source circuit (branch) rather than in the photovoltaic output circuit (array). See Ill. G.2 for installation location (Ills. G.2 and G.3 present the circuit of MIT/LL prototype).

The device did not include a provision to detect a grounding of the "virtual ground" point, nor was it sensitive to 'faults' in both polarities. We believe these features can be added by simple modifications to the circuit, currently in process.

The circuit shown in Ill. G.4 is sensitive to a current imbalance of 100 milliamperes. While this threshold of operation appears suitable for detecting an arcing condition to ground, it is unlikely to be suitable for protecting personnel against shock hazards. This circuit could be reconfigured to increase sensitivity to a current imbalance of 20-30 milliamperes, a more suitable value for personnel protection.

DIFFERENTIAL GROUND FAULT DETECTION SYSTEM

(References are to the circuit of Ill. G.4)

Theory of Operation - The sensing element consists of two coils of 65 turns each, wound on a toroidal iron core. A Hall effect sensor is located in the toroid air gap (0.095 inch) and with the windings properly phased, will detect the dc magnetic flux caused by a current imbalance. R_1, a 10 ohm, 10 turn trimpot is used to initially balance the two coils to account for mismatch in the number of turns or the coefficient of coupling. This trimpot will accommodate up to a two turn imbalance in the two coils. Since the coils are out of phase, the total flux in the core is zero due to normal current loads at balance. Therefore, there is no limit on the maximum current that can be handled by the sensor, provided that the wire size is large enough. 65 turns was chosen as a compromise between sensitivity, the total size of the sensing element and the ability to compensate the coil for mismatches in the windings. More turns would increase the sensitivity but would also increase the bulk and the heat dissipated due to I^2R losses. Fewer turns would make for a smaller element but would make compensating the coils more difficult.

A Hall effect sensor is a semiconductor device that has an output voltage proportional to the product of the bias current and the magnetic field impinging on its face. If the bias current is held constant, the output voltage is then proportional to the magnetic flux only. Sprague Type UGN-3501 Hall effect sensor has a constant current source designed into the package and its flux sensitivity constant is approximately 1.4 mv per gauss. R_2 is used to balance the Hall sensor output to zero with a zero flux input.

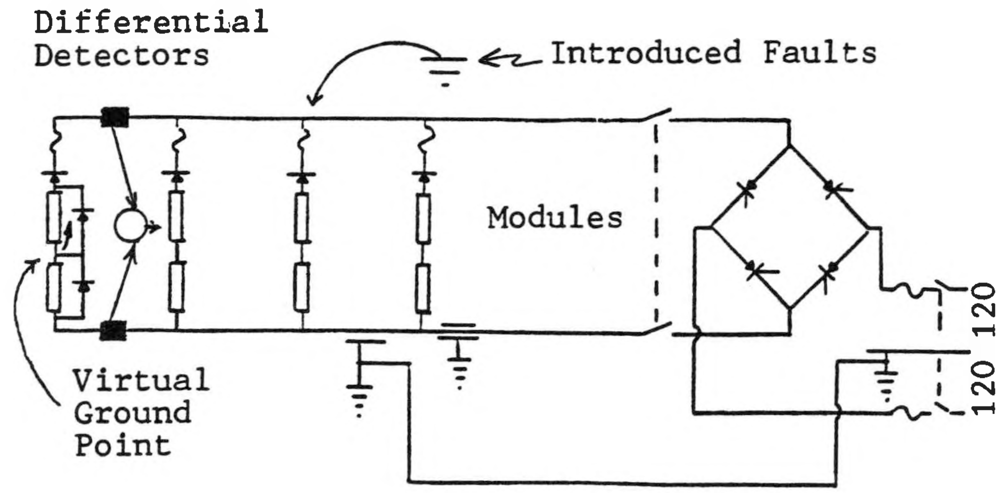
The output of the Hall sensor is fed to an operational amplifier stage (LM324) with a gain of approximately two. The operational amplifier output drives the input of a differential comparator. Resistors R_7 and R_8 determine the comparator trip level.

The positive reference voltage is fed to the comparator inverting input (Pin 3). With a low voltage on the noninverting input (Pin 2), the comparator output (Pin 7) is low, approximately ground level. Q_1 is then in the off state. When Pin 2 goes more positive than Pin 3 (44 mv), the comparator switches and the junction of D3, R10, and C1 starts to rise in voltage. When the integrating circuit of R_9 and C_1 has accumulated sufficient charge, Q_1 turns on, energizing relay K_1. This in turn advances the counter.

The 'slow-down' achieved by the inclusion of capacitor C_1 is to make the circuit compatible with the mechanical counter used. It is not intended that this 'slow-down' necessarily be a feature of the circuit which would respond by disconnecting the array.

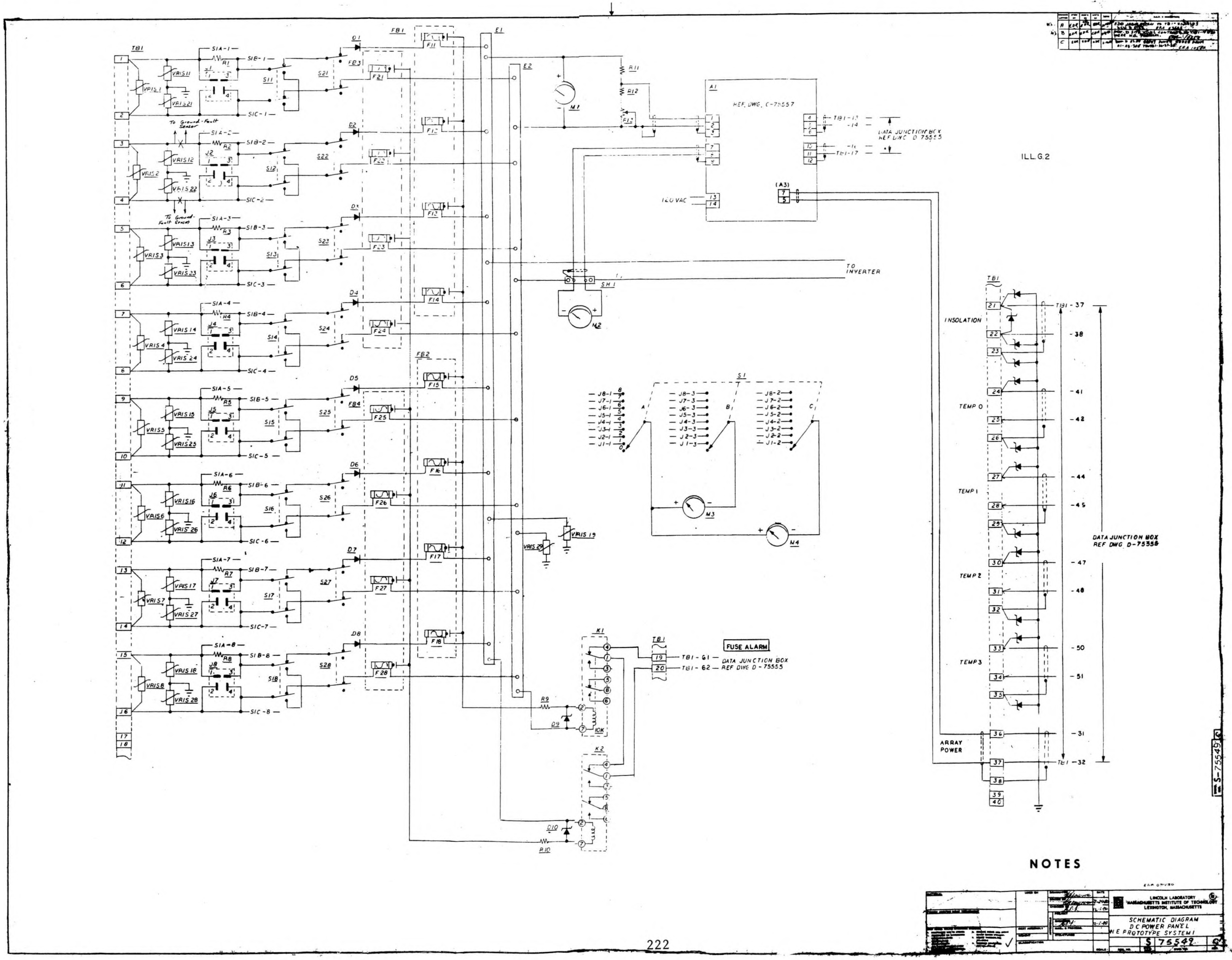
Resistor R_{11} and LED D_2 act as an indicator light for the 'tripped' mode.

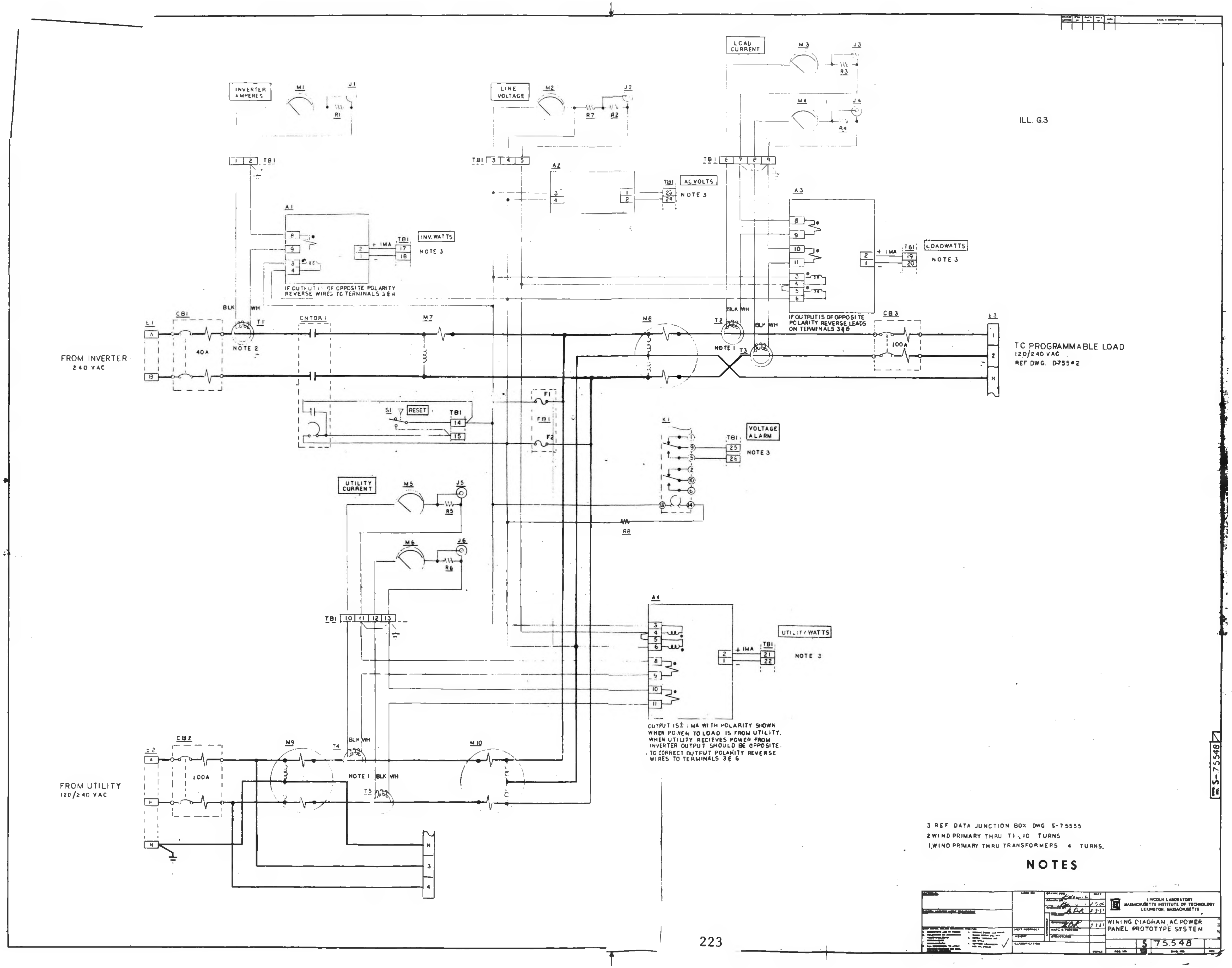
The circuit has a 100 ma sensitivity, i.e., when the current in one leg of the sensing coil exceeds the other by 100 ma, the circuit will respond.

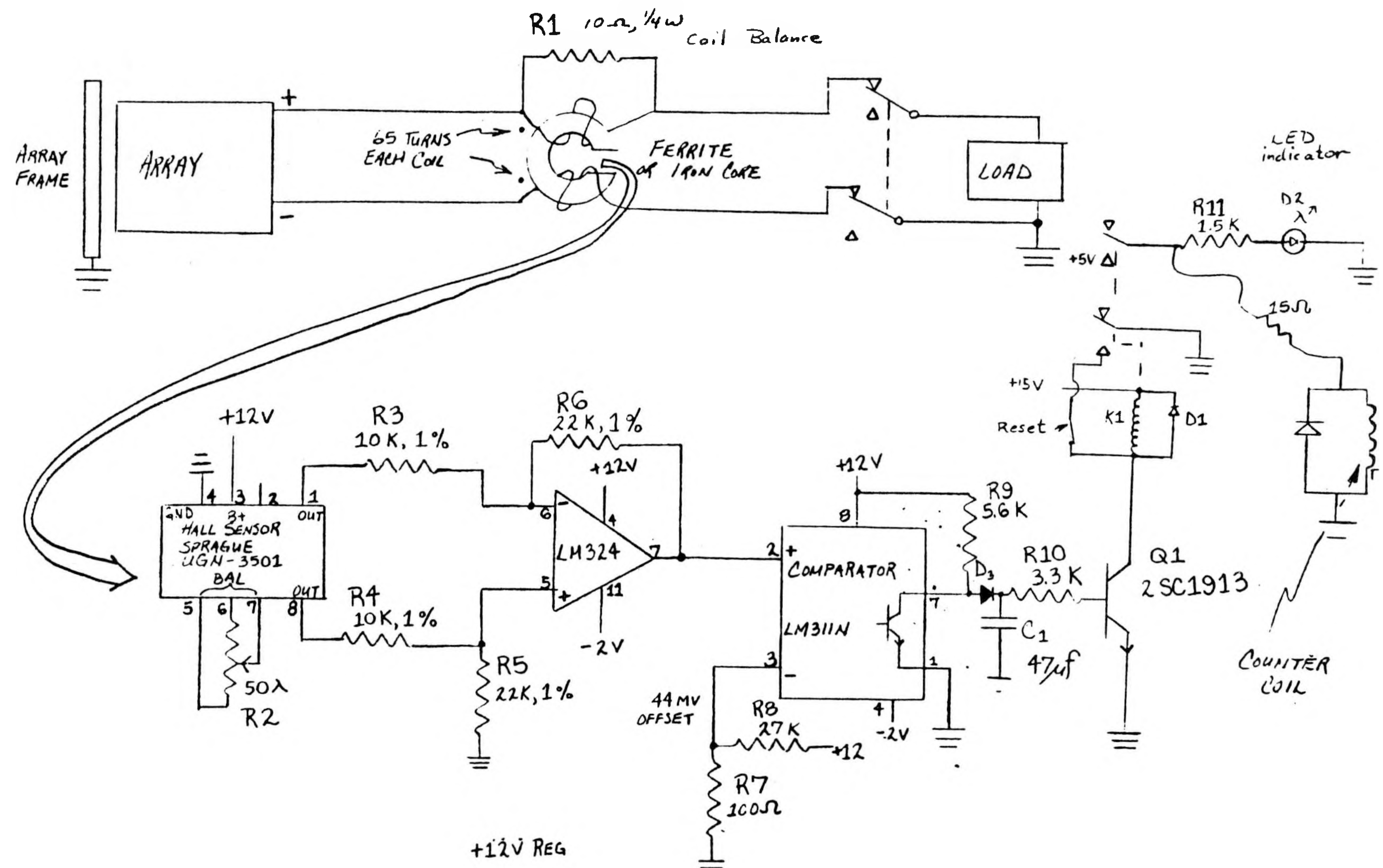


Ill. G.1

Simplified Circuit - Lincoln Laboratory Prototype

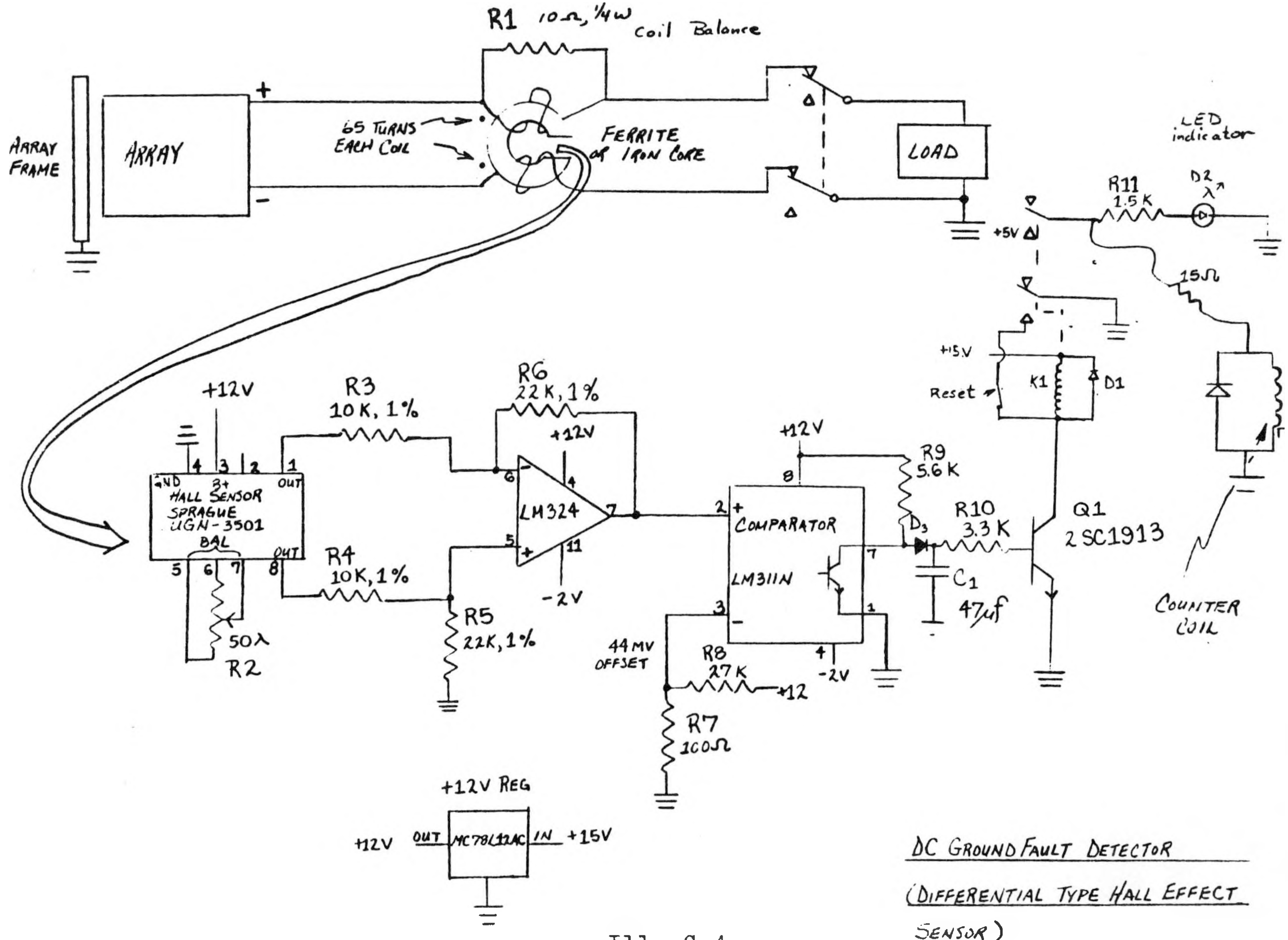

ILL.G.2
TB1
E1
E2
FB1
FB2
FB4
REF. DWG. C-75557
DATA JUNCTION BOX REF DWG D 75555
120 VAC
(A3)
TO INVERTER
SH1
M1
M2
M3
M4
S1
INSOLATION
TEMP 0
TEMP 1
TEMP 2
TEMP 3
ARRAY POWER
DATA JUNCTION BOX REF DWG D-75558
FUSE ALARM
TB1-61
TB1-62
DATA JUNCTION BOX REF DWG D-75555
K1
K2
NOTES
LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS
SCHEMATIC DIAGRAM
D C POWER PANEL
NE PROTOTYPE SYSTEM I
S 75549


ILL. G3
INVERTER AMPERES
LINE VOLTAGE
LOAD CURRENT
AC VOLTS
NOTE 3
INV. WATTS
LOAD WATTS
IF OUTPUT IS OF OPPOSITE POLARITY REVERSE WIRES TO TERMINALS 3 & 4
IF OUTPUT IS OF OPPOSITE POLARITY REVERSE LEADS ON TERMINALS 3 & 6
FROM INVERTER
240 VAC
TC PROGRAMMABLE LOAD
120/240 VAC
REF DWG. D-75542
RESET
VOLTAGE ALARM
UTILITY CURRENT
UTILITY WATTS
OUTPUT IS ± 1MA WITH POLARITY SHOWN WHEN POWER TO LOAD IS FROM UTILITY. WHEN UTILITY RECIEVES POWER FROM INVERTER OUTPUT SHOULD BE OPPOSITE. TO CORRECT OUTPUT POLARITY REVERSE WIRES TO TERMINALS 3 & 6
FROM UTILITY
120/240 VAC
3 REF DATA JUNCTION BOX DWG S-75555
2 WIND PRIMARY THRU T1 - 10 TURNS
1 WIND PRIMARY THRU TRANSFORMERS 4 TURNS.
NOTES
LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS
WIRING DIAGRAM, AC POWER PANEL PROTOTYPE SYSTEM
S 75548



Ill. G.4

DC Ground Fault Sensor



Ill. G.4

DC Ground Fault Sensor