NBS TECHNICAL NOTE 1136

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

NBS Solar Collector Durability/Reliability Test Program Plan

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NBS Solar Collector Durability/Reliability Test Program Plan

David Waksman
Elmer Streed
James Seiler

Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
Washington, DC 20234

Prepared for:
U.S. Department of Energy
Office of Solar Applications for Buildings
Office of the Assistant Secretary
Conservation and Solar Applications
Washington, DC 20585

t Technical note

U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, Secretary
Jordan J. Baruch, Assistant Secretary for Productivity, Technology and Innovation
U.S. NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director
Issued January 1981

National Bureau of Standards Technical Note 1136
Nat. Bur. Stand. (U.S.), Tech. Note 1136/85 pages/(Jan. 1981)
CODEN: NBTNAE

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1981

For sale by the Superintendent of Documents, U.S. Government Printing Office,
Washington, DC 20402 Price $4
(ADD 25 percent for other than U.S. mailing)

PREFACE

Public Law 93-409, "Solar Heating and Cooling Demonstration Act of 1974," provides for the development of definitive performance criteria and standard testing methods for use by industry in evaluating materials, components and systems. Responsibility for the development of these performance criteria and many of these standards has been assigned to the National Bureau of Standards (NBS) by the Department of Energy (DoE) and the Department of Housing and Urban Development (HUD).

The goal of the experimental program described in this document is to help provide an experimental basis that can be used to prepare consensus standards for assessing the reliability and durability of solar collector assemblies and their materials. The program will correlate the results of laboratory, accelerated field and simulated operational exposure tests with the actual operating performance of collectors used for building heating and cooling applications. This work is intended to be complementary to other collector materials standards development projects underway at NBS and elsewhere in that it provides a link to the degradation that takes place in commercially available solar collectors.

This report is intended for use as a baseline document describing in detail the experimental work being conducted and summarizing the types of analyses that are being performed. The test program described in this plan was initiated in 1977. The experimental work described in the plan has either been completed or is currently underway. Current program status is discussed in Chapter 6 of this report.

ACKNOWLEDGMENTS

This report was prepared by the National Bureau of Standards, Washington, D.C., with the assistance of the Solar Energy Systems Division, Wyle Laboratories, Huntsville, Alabama. The comments and assistance of Larry W. Masters and Elizabeth J. Clark of NBS, and Wayne L. Swenson, Louis L. Ullman, Dr. Howard Yen and Joe H. Johnson of Wyle Laboratories are gratefully acknowledged.

Major contributions to the design and construction of exposure boxes for cover and absorber materials were made by Frank A. Rankin of NBS.

The financial support of the Department of Energy, Office of Solar Applications for Buildings, is gratefully acknowledged.

ABSTRACT

The test program described in this plan is designed to evaluate both approved and proposed solar collector test procedures and to correlate laboratory, accelerated field and simulated operational exposures with actual field data.

The tests and exposure procedures described herein are intended to determine the influence of environmental exposure parameters that could affect the degradation of solar collectors and their materials. They are also intended, to the extent possible, to provide a correlation between changes that occur at the materials and the collector component levels. It is expected that the data obtained through their use will lead to more meaningful reliability/durability tests for solar collectors and their materials.

A wide variety of commercially available solar collectors and multiple material coupons of collector components are being tested at sites in different climatic regions. Appropriate laboratory tests are being conducted during the same time frame to determine physical and material properties for comparison with field test data and operational collector experience. The data obtained from these tests will be analyzed and correlated with that obtained from the current Government Demonstration Program and other related government-sponsored programs.

Key words: Accelerated aging; durability; environmental exposure; reliability; solar collectors; solar materials; stagnation testing.

SI CONVERSION UNITS

In view of the present accepted practice in this country for building technology, common U.S. units of measurement have been used throughout this document. In recognition of the position of the United States as a signatory to the General Conference of Weights and Measures, which gave official status to the metric SI system of units in 1960, assistance is given to the reader interested in making use of the coherent system of SI units by giving conversion factors applicable to U.S. units used in this document.

LENGTH

1 in. = 0.0254 meter (exactly)

1 ft = 0.3048 meter (exactly)

AREA

1 in.^{2} = 6.45 x 10^{-4} meter^2

1 ft^2 = 0.09290 meter^2

VOLUME

1 in.^{3} = 1.639 x 10^{-5} meter^3

1 gal. (U.S. liquid) = 3.785 x 10^{-3} meter^3

MASS

1 ounce-mass (avoirdupois) = 2.835 x 10^{-2} kilogram

1 pound-mass (avoirdupois) = 0.4536 kilogram

PRESSURE OR STRESS (Force/Area)

1 inch of mercury (60°F) = 3.377 x 10^3 pascal

1 pound-force/inch^2 (psi) = 6.895 x 10^3 pascal

1 pound-force/foot^2 (psf) = 47.88 pascal

ENERGY

1 foot-pound-force (ft-lbf) = 1.356 joule

1 Btu (International Table) = 1.055 x 10^3 joule

POWER

1 Watt = 1 x 10^7 erg/second

1 Btu/hr = 0.2931 Watt

TEMPERATURE

t°C = 5/9 (t°F - 32)

HEAT

1 Btu in./hr·ft^2·°F = 1.442 x 10^{-1} W/m·K (thermal conductivity)

1 Btu/lbm·°F = 4.187 x 10^3 J/kg·K (specific heat)

1 langley = 4.184 x 10^4 J/m^2 = 1 cal/cm^2 = 3.69 BTU/ft^2

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1. INTRODUCTION

1.1 BACKGROUND

The Solar Energy Research, Development and Demonstration Act (Public Law 93-473) signed into law in October 1974 authorized a vigorous Federal program of research, development and demonstration to establish solar energy as a viable energy resource for the nation. The primary goal of the program, as stated in the National Program for Solar Heating and Cooling of Buildings (ERDA 76-6) [1]*, is to work with industry in the development and early introduction of economically competitive and environmentally acceptable solar energy systems to help meet national energy requirements.

Responsibility for the management and coordination of the total program has been assigned to the Department of Energy (DoE). The Federal program involves many elements of government, industry and universities. At the Federal government level, major participants assisting DoE in the program are the Department of Housing and Urban Development (HUD), the Department of Defense (DoD), the National Aeronautics and Space Administration (NASA) and the National Bureau of Standards (NBS).

Interim performance criteria have been developed and published for both residential and commercial solar energy systems [2, 3]. NBS and other Federal agencies are cooperating with various private sector organizations in the development of consensus standards for the installation, performance and testing of solar equipment. This effort has resulted in the publication of ASHRAE Standard 93-77, "Methods of Testing to Determine the Thermal Performance of Solar Collectors" [4] and ASHRAE Standard 94-77, "Methods of Testing Thermal Storage Devices Based on Thermal Performance" [5]. The American Society for Testing and Materials (ASTM) is developing durability and reliability test methods at the materials and collector levels [6]. Laboratory and field test methods for the evaluation of collector materials are currently under development at NBS in support of these ASTM consensus standard activities. Collector material studies are also being performed by the Illinois Institute of Technology Research Institute (IITRI) under DoE contract [7]. Field test requirements, developed by NBS for the reliability of collectors, have been incorporated in the HUD Minimum Property Standards (MPS) [8] and the Interim Performance Criteria (IPC) [2, 3]. Provisional test procedures [9] for durability and reliability testing of solar collectors have been published by NBS and are currently undergoing evaluation in a DoE collector testing program [10].

The reliability and long-term performance of solar collectors (up to 20 years) have not generally been demonstrated. One of the few U.S. systems in which the performance was initially measured and compared with the performance after 18 years experienced about a 30 percent decrease in efficiency [11]. Outdoor exposure tests [12] of seven collector designs performed under no-flow conditions for time periods of three to nine weeks resulted in significant decreases in thermal performance as shown in Table 1-1. In some cases, condensation from material outgassing products or absorber coating change were visually detected; however, detailed analytical information on property changes were not reported.

*Figures in brackets indicate references contained in Chapter 7.

TABLE 1-1. COLLECTOR THERMAL PERFORMANCE CHANGES AFTER EXPOSURE TO NO-FLOW CONDITIONS [12]

N	COLLECTOR TYPE	EFFICIENCY* %		MAX. PLATE TEMPERATURE (°C)
		INITIAL**	AFTER EXPOSURE***	
1	2 Glass, Selective Paint	49	43	160
2	1 Glass, Black Chrome	65	59	182
3	2 Glass, Black Chrome	57	53	199
4	1 Glass, Black Nickel	47	40	166
5	2 Lexan, Alcoa Selective	52	44	166
6	2 Glass, Black Paint	40	36	149
7	2 Glass, Optical Black	43	43	157

* $t_i = 60°C$, $T_a = 27°C$, $I = 882\ W/m^2$

** Thermal performance tests performed with an indoor simulator

***Exposure outdoors for three to nine weeks at Langley, Virginia under no-flow conditions

1.2 PURPOSE

The purpose of this program is to evaluate and compare existing and proposed test methods which can be used to predict the long-term durability and reliability of collectors and materials within as short an interval as possible. Specific objectives of the program are to:

- o evaluate test procedures for predicting material deterioration rates and/or collector performance reliability
- o evaluate the effects of collector material deterioration on collector thermal performance
- o determine the influence of environmental exposure conditions on collector materials deterioration
- o compare thermal performance measurements of outdoor natural exposure with those obtained from exposure using a solar simulator
- o correlate data between accelerated tests and normal operation of collectors and materials
- o determine the influence of thermal shock and moisture penetration

1.3 SCOPE

The test program described in this plan is intended to evaluate both approved and proposed solar collector test procedures and to correlate laboratory, accelerated field and simulated operational exposures with actual field data. The program is planned to make full use of existing government and industry studies and facilities related to collector materials and assembly studies. A wide variety of commercially available solar collectors and multiple material coupons of collector components will be tested at sites in different climatic regions and in solar simulators. Appropriate laboratory tests will be conducted during the same time frame to determine physical and material properties for comparison with field test data and operational collector experience. The data obtained from these tests will be analyzed and correlated with that obtained from the current Government Demonstration Program and other related government-sponsored programs. A block diagram depicting major program elements and sources for supporting data is presented in Figure 1-1.

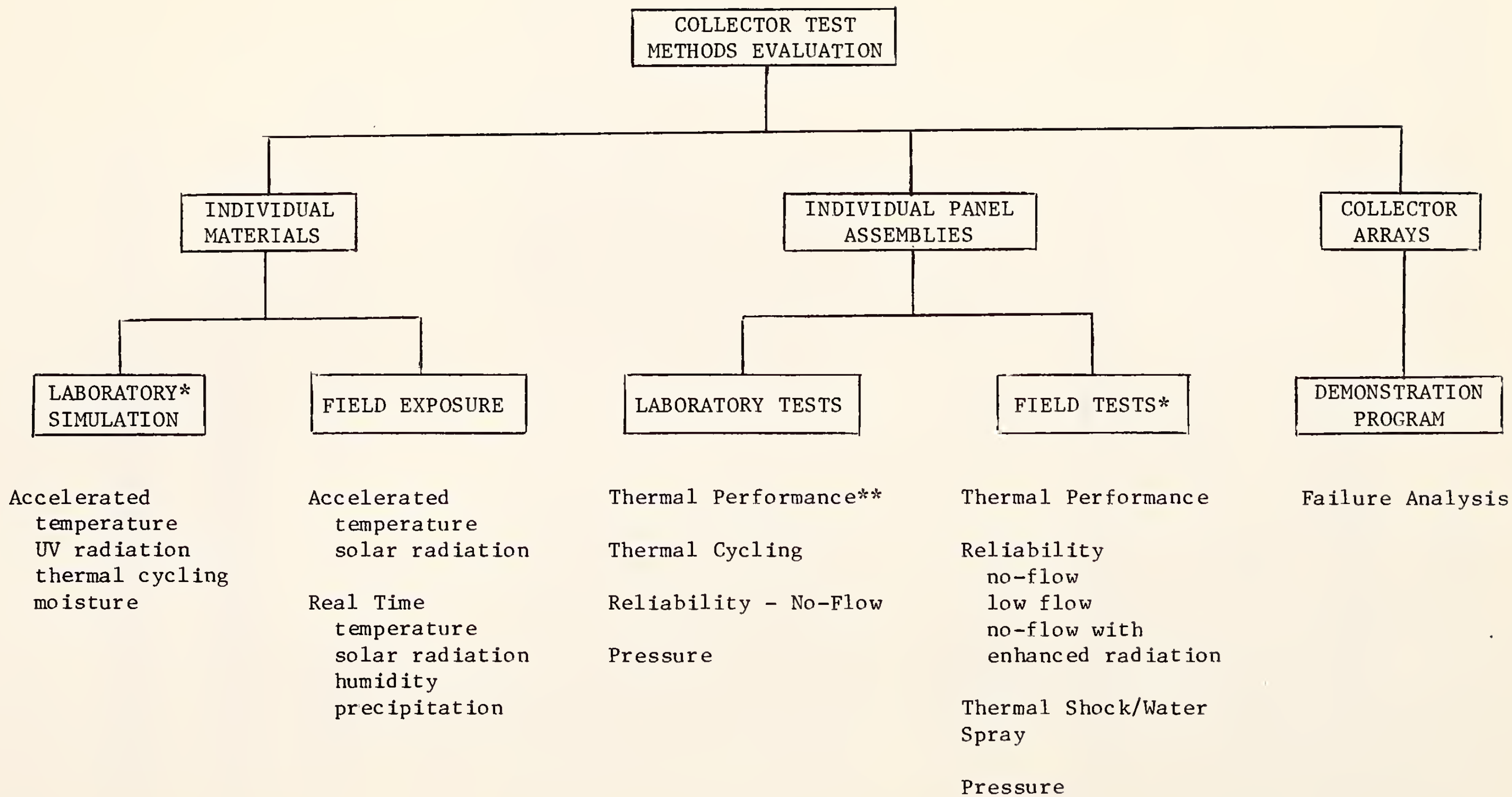
1.4 TEST PROGRAM OVERVIEW

This document is organized as follows:

Chapter 1. INTRODUCTION, contains background information, program goals and objectives.

Chapter 2. TEST PROCEDURES AND EXPOSURE, contains detailed descriptions of both field and laboratory tests required to validate durability and reliability test methods.

Chapter 3. TEST SPECIMEN SELECTION, presents the rationale used to select test specimens and identifies specimens to be tested.



*Tests conducted in accordance with this program plan

**Using solar simulator

FIGURE 1-1 MAJOR PROGRAM ELEMENTS AND DATA SOURCES

Chapter 4. OUTDOOR TEST SITE SELECTION, describes the effects of various environmental variables on solar collectors and presents criteria and the rationale for selecting different climatic regions for test sites. Criteria are presented for choosing test site locations within these regions and representative locations that meet these criteria are identified.

Chapter 5. DATA ANALYSIS, describes the types of data that will be collected and compared, the types of changes that often result from test conditions such as those described in Chapter 2 and the fundamental causes often identified for such changes.

Chapter 6. CURRENT STATUS, discusses the work performed to date on this program and on related NBS programs.

Chapter 7. REFERENCES.

Appendix A contains detailed data forms that will be used during the program to characterize site environmental exposure conditions and to report measurements made on solar collector and materials performance at specified time intervals.

2. TEST PROCEDURES AND EXPOSURE

2.1 GENERAL

Environmental exposure testing at both the collector component and materials levels is required to ensure the satisfactory long-term performance of solar collectors. It is desirable that such tests be capable of predicting the effects of long-term exposure in a relatively short time and at a reasonable cost.

The stagnation testing of solar collectors is often considered to be an accelerated test in that it exposes solar collectors to temperatures that would not occur with the heat transfer fluid flowing. However, solar collectors may frequently be exposed to stagnation conditions in normal service. This can occur either when the collectors are initially installed, before system start-up, or when the system is shut down for maintenance or for seasonal considerations. In commercial buildings, time periods of up to a year between the installation and start-up of equipment have been experienced. Thus, only that portion of stagnation exposure time which would not be attributed to normal service can be considered to represent accelerated aging.

It is possible to devise relatively simple accelerated tests to predict long-term performance in cases where property changes are independent of the input stress level, i.e. are dependent only on cumulative dose and not on intensity. However, this situation seldom occurs because of synergistic effects and changes in the intensity frequently results in changes in the degradation mechanism that predominates. For example, exposure of a test specimen to concentrated solar radiation to accelerate UV degradation can result in abnormal overheating of the specimen and subsequent thermal degradation that would not occur in normal service. Similarly, reaction rates in plastics at temperatures above the glass transition temperature are generally much faster than those below this temperature.

The tests and exposure procedures described herein are intended to determine the influence of environmental exposure parameters that could affect the degradation of solar collectors and their materials. They are also intended, to the extent possible, to provide a correlation between changes that occur at the materials and the collector component levels. It is expected that the data obtained through their use will lead to more meaningful reliability/durability tests for solar collectors and their materials.

2.2 SOLAR COLLECTOR TESTS

2.2.1 OUTDOOR EXPOSURE TESTS

The four different collector test series selected for use in the program and the purpose of each test series are summarized in Table 2-1.

Series 1 and 2 are intended to evaluate the effects of "normal" stagnation conditions. The collectors in Series 1 are allowed to stagnate dry, whereas the collectors in Series 2 are filled, allowed to stagnate under filled conditions with a pressure relief valve set to the maximum allowable collector pressure and are subjected to thermal shock/cold fill and thermal shock/water spray tests at specified time intervals. The purpose of exposing filled collectors to stagnation conditions is to evaluate the combined effects of the temperatures and pressures that would occur under stagnation conditions.

Series 3 is intended to determine whether or not changes in collector performance will occur under the reduced plate temperatures characteristic of operational conditions. Augmentation reflectors are used to amplify the solar radiation to which stagnating collectors are exposed in Series 4. This series is intended to determine the effects that such reflectors would have when they are used in actual systems and to determine whether or not reflectors are a practical way of accelerating the degradation of stagnating collectors.

These exposure conditions are intended to subject the solar collectors and their materials to different thermal stress levels at each outdoor exposure site. The thermal stress level that would occur in normal use most likely lies between the Series 1 and 2 and the Series 3 test conditions, with some stagnation being a normal occurrence.

2.2.1.1 Thermal Performance Measurements

Thermal performance measurements are being made on the collectors in each test series in accordance with the schedule summarized in Table 2-1 and described more fully in Tables 2-2, 2-3, 2-4 and 2-5.

The ASHRAE Standard 93-77 thermal performance test procedure [4] is used in this program both as a full test (four temperatures, four data points at each temperature) and as a three-point performance re-test (three temperatures, four data points at each temperature). The re-test is conducted to demonstrate the magnitude of changes in the intercept and slope of the efficiency curve as a function of environmental exposure time. The measurements are required to be spread over the range of 0.02 to $0.07°C \cdot m^2/W$. The ASHRAE Standard 93-77 requirements for three-day pre-exposure and measurement of incident angle modifier and time constant are being performed only when explicitly called for in Tables 2-2, 2-3, 2-4 and 2-5. The term "performance re-test" will be used throughout this document when the three-point test is specified.

2.2.1.2 Test Specimens

Test specimens include the eight solar collector types whose characteristics are identified in Table 3-1. Type T thermocouples are attached to the center of the underside of the absorber plate for the measurement of stagnation temperature.

TABLE 2-1 SUMMARY DESCRIPTION OF FIELD TEST SERIES ON SOLAR COLLECTORS

TEST SERIES	COLLECTOR PERFORMANCE MEASUREMENT	CONDITIONS FOR WEATHERING EXPOSURE	PURPOSES OF TEST SERIES***
Series 1 "dry stagnation"	Initial measurement in accordance with ASHRAE 93-77 except delete 3-day pre-exposure and measurement of time constant. Performance re-test after 3, 15, 30, 60, 120 and 240 dav exposures.*	Each collector pre-conditioned for each weathering exposure by purging with dry air to remove the remaining heat transfer fluid. Successive weathering exposures between performance re-tests provide cumulative exposures of 3, 15, 30, 60, 120, and 240 days.*	1. Observation of effects of dry stagnation on collector performance and other characteristics for various weathering times. 2. Provide data for comparison of solar simulator performance measurement with field data. 3. Provide data for comparing collector initial performance with and without 3-day pre-exposure per ASHRAE 93-77.
Series 2 "no-flow stagnation"	Initial measurement in accordance with ASHRAE 93-77 after 3-day pre-exposure. Delete measurement of time constant. Performance re-tests same as in Series 1.	Collectors pre-conditioned for weathering exposure by filling per NBSIR 78-1305A [9], capping and allowing to boil dry. Weathering exposures same as in Series 1 except that Thermal Shock Tests per NBSIR 78-1305A will be performed during first 30-day exposure on Series 2 test collectors only.	1. Observation of effects of no-flow stagnation on collector performance and other characteristics. 2. Observation of effects of Thermal Shock Tests representing (a) filling a hot collector with cool heat transfer medium and (b) summer rain on a hot collector. 3. Observation of static pressure leakage after 30 and 120 days of exposure.
Series 3 "controlled flow"	Performance of test collectors measured in accordance with ASHRAE 93-77, taking only 3 points. Delete 3-day pre-exposure and time constant measurement. Performance re-tests same as in Series 1.	During weathering exposure heat transfer flow rate maintained at 25% of operational flow rate for liquid.	1. Observation of effects of normal operation on collector performance and other characteristics.
Series 4 "dry stagnation with augmentation reflectors"	Initial measurement same as in Series 1. Performance re-tests same as in Series 1.	Pre-conditioning and weathering exposures same as in Series 1, except that a reflector** will be used on each collector during each day of weathering exposure*. Solar radiation measurements required both with and without reflector.	1. Observation of effects of dry stagnation on collector performance and other characteristics with solar radiation amplified by a reflector. 2. Obtaining temperature history within collectors for most severe exposure conditions.

* Individual days with solar radiation of 17,000 $KJ/m^2 \cdot day$ or greater as measured in the plane of the collector aperture without the influence of a reflector.

** The reflector is described in Paragraph 2.2.1.3.

*** All series include provision of data for comparisons between test series, test sites (climatic regions), collector designs, etc.

TABLE 2-2. SERIES 1 COLLECTOR LOG SHEET

Date ____________________

Collector Code Number ________________________

Collector Manufacturer Name ________________________

Collector Serial Number ________________________

Test Lab Name ________________________

Form Filled Out By ________________________

Step No.	Test Procedure	Date Completed
1	Initial Performance Test (full 93-77 without 3-day pre-exposure and time constant; with incident angle modifier). . .	______________
2	Purge with Dry Air.	______________
3	3-Day* Performance Re-test	______________
4	Purge with Dry Air.	______________
5	15-Day* Performance Re-test	______________
6	Purge with Dry Air.	______________
7	4-Hour 946 W/m^2 Exposure**.	______________
8	30-Day* Performance Re-test	______________
9	Purge with Dry Air.	______________
10	4-Hour 946 W/m^2 Exposure**.	______________
11	60-Day* Performance Re-test (plus measure incident angle modifier, if applicable).	______________
12	Purge with Dry Air.	______________
13	4-Hour 946 W/m^2 Exposure**.	______________
14	120-Day* Performance Re-test.	______________
15	Purge with Dry Air.	______________
16	4-Hour 946 W/m^2 Exposure**.	______________
17	240-Day* Performance Test (full 93-77 without pre-exposure and time constant; with incident angle modifier)	______________

*Total number of cumulative days of exposure at 17,000 $KJ/m^2 \cdot day$ prior to testing.

**First 4-hour 946 W/m^2 exposure is mandatory. Subsequent 4-hour exposures are not mandatory. However, it is desired that the number of times this condition is met be reported.

Form 101

TABLE 2-3. SERIES 2 COLLECTOR LOG SHEET

Date ____________________

Collector Code Number _________________________

Collector Manufacturer Name _________________________

Collector Serial Number _________________________

Test Lab Name _________________________

Form Filled Out By _________________________

Step No.	Test Proceudure	Date Completed
1	Static Pressure Leak Test	
2	Performance Re-test (after 3-day exposure)	
3	Fill and Allow to Boil Dry*	
4	15-Day** Performance Re-test.	
5	Thermal Shock/Cold Fill Test.	
6	Static Pressure Leak Test	
7	Thermal Shock/Water Spray Test #1	
8	Thermal Shock/Water Spray Test #2	
9	Thermal Shock/Water Spray Test #3	
10	4-Hour 946 W/m^2 Exposure***	
11	30-Day** Performance Re-test.	
12	Fill to Allow to Boil Dry*.	
13	4-Hour 946 W/m^2 Exposure***	
14	60-Day** Performance Re-test.	
15	Fill to Allow to Boil Dry*.	
16	4-Hour 946 W/m^2 Exposure***	
17	120-Day** Performance Re-test	
18	Static Pressure Leak Test	
19	Fill to Allow to Boil Dry*.	
20	4-Hour 946 W/m^2 Exposure***	
21	240-Day** Performance Re-test	

*Some of the collectors will not reach high enough temperatures to boil dry with the pressure relief valve settings used. These collectors shall be kept filled for at least one 17,000 $KJ/m^2 \cdot day$ and may then be drained at the option of the test lab, e.g. to prevent collector freeze up.

**Total number of cumulative days of exposure at 17,000 $KJ/m^2 \cdot day$.

***First 4-hour 946 W/m^2 exposure is mandatory. Subsequent 4-hour exposures are not mandatory. However, it is desired that the number of times this condition is met be reported.

Form 102

TABLE 2-4. SERIES 3 COLLECTOR LOG SHEET

Date ____________________

Collector Code Number _________________________

Collector Manufacturer Name _________________________

Collector Serial Number _________________________

Test Lab Name _________________________

Form Filled Out By _________________________

Step No.	Test Procedure	Date Completed
1	Performance Re-test (without 3-day pre-exposure, time constant and incident angle modifier)	______________
2	15-Day* Performance Re-test	______________
3	Connected Back in Test Loop**	______________
4	30-Day* Performance Re-test	______________
5	Connected Back in Test Loop**	______________
6	60-Day* Performance Re-test	______________
7	Connected Back in Test Loop**	______________
8	120-Day* Performance Re-test.	______________
9	Connected Back in Test Loop**	______________
10	240-Day* Performance Re-test (full 93-77 without pre-exposure and time constant with incident angle modifier).	______________

*Total number of cumulative days of exposure at 17,000 $KJ/m^2 \cdot day$ prior to testing.

**Maintain at 25% of recommended operational flow rate.

Form 103

TABLE 2-5. SERIES 4 COLLECTOR LOG SHEET

Date ____________________

Collector Code Number _________________________

Collector Manufacturer Name _________________________

Collector Serial Number _________________________

Test Lab Name _________________________

Form Filled Out By _________________________

Step No.	Test Procedure	Date Completed
1	Static Pressure Leak Test	______________
2	Initial Performance Test (full 93-77 without 3-day pre-exposure and time constant, with incident angle modifier). . .	______________
3	Purge with Dry Air.	______________
4	Install Augmentation Reflector**.	______________
5	15-Day** Performance Re-test.	______________
6	Purge with Dry Air.	______________
7	Install Augmentation Reflector**.	______________
8	4-Hour 946 W/m^2 Exposure*	______________
9	30-Day*** Performance Re-test	______________
10	Purge with Dry Air.	______________
11	Install Augmentation Reflector**.	______________
12	4-Hour 946 W/m^2 Exposure*	______________
13	60-Day*** Performance Re-test	______________
14	Purge with Dry Air.	______________
15	Install Augmentation Reflector**.	______________
16	4-Hour 946 W/m^2 Exposure*	______________
17	120-Day*** Performance Re-test.	______________
18	Static Pressure Leak Test	______________
19	Purge with Dry Air.	______________
20	Install Augmentation Reflector**.	______________
21	4-Hour 946 W/m^2 Exposure*	______________
22	240-Day*** Performance Test (full 93-77 without pre-exposure and time constant, with incident angle modifier)	______________

*946 W/m^2 flux level as measured without the contribution from the reflector. First 4-hour 946 W/m^2 exposure is mandatory. Subsequent 4-hour exposures are not mandatory. However, it is desired that the number of times this condition is met be reported.

**Maintain reflector at an angle of 120° to the plane of the collector aperture.

***Total number of cumulative days of exposure at 17,000 $KJ/m^2 \cdot day$ prior to testing.

Form 104

2.2.1.3 Environmental Exposure

Each type of collector will be exposed using the tests listed for Series 1 and Series 2 in Tables 2-2 and 2-3 at all four outdoor test sites. Series 3 and Series 4 tests (shown in Tables 2-4 and 2-5) will be performed at sites 1 and 2 only.* This will result in each collector being exposed for up to 240 days of 17,000 $KJ/m^2 \cdot day$ or greater incident solar radiation flux.

Series 1 and Series 2 collectors are being exposed in accordance with the schedules given in Tables 2-2 and 2-3, respectively. It is desired that the collectors in these two series be exposed to identical amounts of solar radiation for purposes of comparison of the results of the two test series. For this reason, the Series 1 collectors are being kept covered while the Series 2 collectors are subjected to the Thermal Shock/Cold Fill, Thermal Shock/Water Spray and Static Pressure Leakage tests specified in Table 2-3. These tests are being performed in accordance with the procedures given in NBSIR 78-1305A [9].

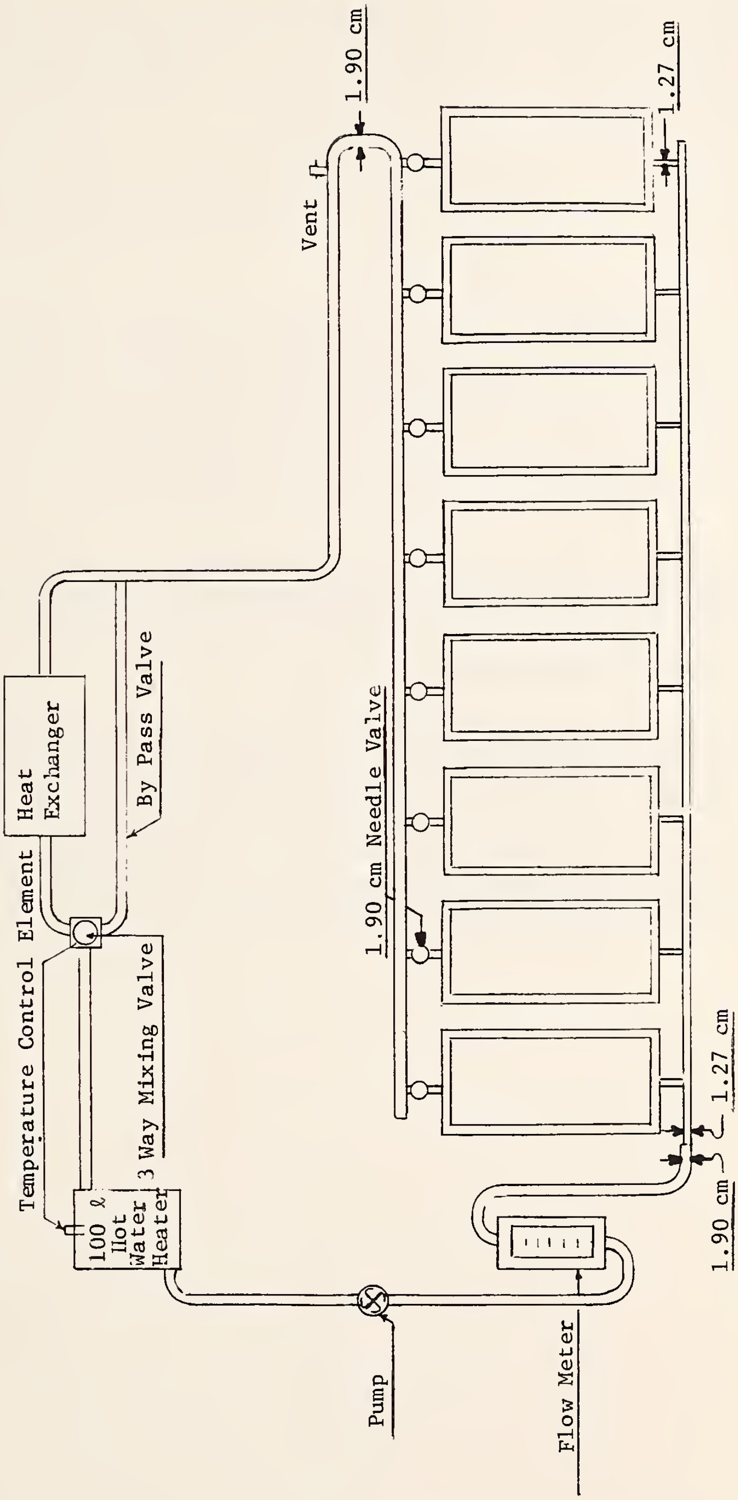
Series 3 collectors are being subjected to the exposure cycles specified in Table 2-4. During the daytime exposure periods, heat transfer liquid maintained at a temperature of $71 \pm 3°C$ and at 25 percent of the manufacturer's recommended operational flow rate is being input into each collector. Morning start-up temperatures are kept in the 49°C - 71°C range, following which the inlet temperature is maintained at the 71°C point. This is intended to lower the costs of heating the heat transfer fluid overnight. The maximum temperature attained in each collector will thus be a function of collector performance with these inlet conditions. A typical flow loop for performing this test is shown in Figure 2-1.

Series 4 collectors will be tested in accordance with the schedule given in Table 2-5. This test series consists of using a solar augmentation reflector to increase the solar radiation level on the solar collector during dry stagnation exposure.

Each collector undergoing Test Series 4 is fitted with a flat reflector constructed from a commercially available material that has a reflectance of about 0.70 or greater. The width of this reflector is twice the width (horizontal dimension) of the collector aperture. The length of the reflector is equal to the length of the collector aperture, measured along the vertical axis of the collector. This reflector is maintained at an angle of 120° to the plane of the collector aperture. The collector is mounted to a rack and the tilt angle adjusted monthly such that the incident solar radiation at solar noon is within $\pm 10°$ of the normal to the plane of the aperture.

*Test sites are identified in Chapter 4 of this report.

FIGURE 2-1 SERIES 3 "LOW FLOW" TEST APPARATUS



2.2.1.4 Data Requirements

Detailed data are required to characterize the exposure conditions for correlation within sites and between sites. In addition to the schedule information requested in the forms given in Tables 2-2, 2-3, 2-4 and 2-5, data sheets are presented in Appendix A. Forms 201, 201A, 202 and 202A of Appendix A are concerned with collector thermal performance. Site environmental exposure conditions are addressed by Forms 301, 305, 306 and by the Supplementary Data Requirements shown in Amendment A-1 of Appendix A.

Weekly visual inspections are being made of each collector and all discernable changes in the physical characteristics and appearance of the collector recorded.

2.2.2 INDOOR SIMULATOR EXPOSURE TESTS

These tests are intended to evaluate two types of commercially available solar simulators representing extremes in exposure conditions which have been proposed for use in the environmental exposure testing of solar collectors. One of these simulators, (Test Site A) utilizes xenon arc lamps which yield a higher ultraviolet radiation content than would be found in the terrestrial spectrum (8.6% instead of 2.7% at wavelengths less than 0.4um). The other simulator (Test Site B), which was designed to perform tests to Mil-Std-810c [13] utilizes a tungsten lamp array whose output has virtually no ultraviolet radiation content.

Changes in materials and thermal performance of solar collectors caused by outdoor exposure will be compared with those resulting from solar simulation to determine if the results can be correlated.

2.2.2.1 Thermal Performance Measurements

Thermal performance testing at Test Site A were performed at the time intervals specified in Table 2-6 using the xenon arc simulator. The number of data points required for the full ASHRAE 93-77 performance test and for the re-test are discussed in Section 2.2.1.1 of this report.

Thermal performance testing at Test Site B were performed outdoors in accordance with the schedule specified in Table 2-7 since this indoor simulator is not equipped for such testing.

TABLE 2-6 TESTING AND EXPOSURE SCHEDULE*: TEST SITE A

<u>Step No.</u>

1. Static Pressure Leak Test Per NBSIR 78-1305A
2. Initial Performance Test (full 93-77 without 3-day pre-exposure and time constant, with incident angle modifier).
3. Purge with nitrogen
4. Expose for 3 days** ***
5. 3-Day Performance Re-test
6. Purge with nitrogen
7. Expose for 12 days**
8. 15-Day**** Performance Re-test
9. Purge with nitrogen
10. Expose for 15 days** ***
11. 30-Day**** Performance Re-test
12. Purge with nitrogen
13. Expose for 30 days***
14. 60-Day Performance Test (full 93-77 without 3-day pre-exposure and time constant; with incident angle modifier).
15. Static Pressure Leak Test

* All thermal performance measurements and exposure to be conducted using an indoor simulator. The performance tests to be made using a spectrum approximating that of air mass two and then repeated with one approximating air mass zero. The performance re-tests and environmental exposure to be conducted using the air mass zero spectrum. The simulator chamber temperature is to be maintained at approximately 30°C.

** <u>Exposure Day Cycle</u>: Irradiance will be set at 946 W/m^2 and slowly increased for 2.5 hours to 1,108 W/m^2 and then decreased back to 946 W/m^2 over the next 2.5 hours. The beam will then be doused for one hour to allow the collector to cool and then the cycle repeated.

*** Monitor absorber plate temperature, time, ambient temperature and irradiance at 5 minute intervals on the first, thirtieth and sixtieth exposure day cycles.

**** Cumulative exposure day cycles.

TABLE 2-7 TESTING AND EXPOSURE SCHEDULE: TEST SITE B

Step No.

1. Initial Performance Test (full ASHRAE 93-77 without 3-day pre-exposure, time constant and incident angle modifier)
2. Drain collectors
3. Expose for 30 days* **
4. 30-Day*** Performance Test as in initial test
5. Drain collectors
6. Expose for 30 days* **
7. 60-Day*** Performance Test as in initial test

* Exposure Day Cycle: Average irradiance shall be maintained at 1010 W/m^2 for five hours. The beam will then be doused for one hour to allow the collector to cool. The chamber shall be maintained at ambient temperatures between 26°C and 38°C.

** Monitor absorber plate temperature, time, ambient temperature and irradiance at 5 minute intervals on the first, thirtieth and sixtieth exposure day cycles.

*** Cumulative exposure day cycles.

2.2.2.2 Test Specimens

Four of the eight different types of solar collectors exposed outdoors were used for solar simulator exposure tests. The characteristics of these collectors (code letters B, D, E and H) are described in Table 3-1. These collectors were selected from the eight used in the outdoor exposure test program primarily because they used different types of cover plate materials having different spectral characteristics and varying degrees of sensitivity to exposure to ultraviolet radiation and temperature.

2.2.2.3 Environmental Exposure

Environmental exposure at Test Site A was performed using the xenon arc simulator in accordance with Table 2-6. Collector thermal performance was checked after 0, 3, 15, 30, and 60 simulated exposure day cycles as described in Table 2-6.

Testing and exposure at Test Site B was conducted in accordance with Table 2-7. A plate glass filter was placed between the tungsten lamp source and the solar collectors to absorb the infrared radiation beyond 2.7 μm given off by the source to provide a better spectral match with the terrestrial solar spectrum.

2.2.2.4 Data Requirements

Thermal performance was reported in accordance with the requirements of ASHRAE Standard 93-77. Forms 201, 201A, 202 and 202A of Appendix A show typical reporting formats for these data. On the first, thirtieth and sixtieth exposure day cycles, absorber plate temperatures, time, ambient temperature and irradiance were reported at 5 minute intervals.

Visual inspections were made of each collector and all discernable changes in the physical characteristics and appearance of the collector recorded.

2.2.3 INDOOR SIMULATOR COMPARABILITY TESTING

These tests are intended to:

(a) determine whether or not thermal performance test data obtained with a xenon arc lamp solar simulator are comparable to those obtained at outdoor test sites and

(b) determine the influence of individual outdoor test site environmental parameters on thermal performance test results.

The test program outlined in Table 2-8 is intended to determine the influence of ambient temperature, tilt, percent diffuse radiation, wind and solar irradiance level on collector thermal performance.

Two types of solar collectors were used for these studies. The first of these has a single glass cover and a black chrome selective surface on a steel absorber and was used in a round robin test program previously conducted by NBS [14]. The second of these collectors, which has two glass covers and a flat black paint on copper absorber, is described in Table 3-1 as collector type B.

All of the thermal performance tests were performed on a xenon solar simulator filtered for the air mass zero spectrum. The conditions maintained during thermal performance testing are defined in Table 2-8. Data points were taken in accordance with ASHRAE Standard 93-77.

TABLE 2-8. INDOOR SIMULATOR COMPARABILITY TEST CONDITIONS*

Run #	Selective	Non Selective	Tilt (°)	Diffuse (%)	Flux (W/m^2)	Ambient (°C)	Wind (m/s)	$\Delta T/I$ $\left(\frac{°C \cdot m^2}{W}\right)$
A-1	X	X	60	0	630	5		0.06
A-1A	X	X	60	0	630	5	5	0.06
B-1	X	X	60	40	630	5		0.06
D-1	X	X	60	0	1100	5		0.06
D-1A	X	X	60	0	1100	5	5	0.06
E-1	X	X	60	0	1100	35		0.06
E-1A	X	X	60	0	1100	35	5	0.06
F-1	X	X	0	0	1100	35		0.06
E-2	X	X	60	0	1100	35		0.02
E-2A	X	X	60	0	1100	35	5	0.02
F-2	X		0	0	1100	35		0.02
D-2		X	60	0	1100	5		0.02
D-2A		X	60	0	1100	5	5	0.02
A-2		X	60	0	630	5		0.02
A-2A		X	60	0	630	5	5	0.02
B-2		X	60	40	630	5		0.02
B-2A		X	60	40	630	5	5	0.02

* Perform with the air mass zero solar spectrum

2.3 COLLECTOR MATERIAL TESTS

2.3.1 GENERAL

These tests are intended to lead to the development of accelerated materials level tests that can be used to evaluate the long term performance of cover and absorber materials in flat plate solar collectors. Indoor laboratory and outdoor environmental exposure tests will be conducted on materials coupon samples. Analytical studies, as discussed in Chapter 5 of this report, will be conducted (1) to determine the correlations that exist between the various materials level exposure tests and (2) to determine whether or not changes observed in small scale materials samples are indicative of those which occur in full sized solar collectors. This work is intended to be complementary to work currently underway at NBS to develop draft standards for absorber and cover materials in that it provides a link to the degradation that takes place in commercially available solar collectors.

Coupon specimens of cover plate and absorber materials cut from full sized collectors of the same make and model as the collectors exposed outdoors, together with several additional materials, are being subjected to several different types of laboratory and outdoor environmental exposure tests. Changes in the optical properties of these materials are being measured as a function of exposure time.

Outdoor exposure conditions at the materials coupon specimen level include "real time" exposure in simulated collectors and exposure to concentrated radiation in machines having a six to one concentration level. Indoor laboratory tests being conducted include exposure to (1) temperature, (2) combined temperature and humidity, (3) combined temperature and radiation, and (4) thermal cycling (absorber materials only). Additional materials level exposure tests are being conducted using the solar simulators described in Section 2.2.2 of this report. Both the outdoor "real time" and the solar simulator materials level exposures are being conducted concurrently with those on full scale collectors at each test site.

The exposure conditions used for the cover and absorber materials are summarized in Tables 2-9 and 2-10, respectively. The exposure conditions summarized in these tables are intended to simulate a broad range of environmental stress conditions. Primary emphasis was placed on exposure to temperature, solar radiation and moisture. Other degradation factors such as hail, pollutants and dust are localized in nature and will be assessed via their occurrence at the "real time" outdoor exposure test sites participating in the program.

2.3.2 COVER MATERIALS

The sections which follow contain descriptions of the test procedures and apparatus that will be used for the environmental exposure testing of cover materials. The specific materials to be used for each test are identified in tables contained in Chapter 3. A set of control specimens has been provided to each test site performing property measurements for purposes of comparison with the results of measurements after environmental exposure. These control specimens are being stored in a dark environment at 21 $\pm$ 3°C until required for comparison testing. All outdoor exposure test specimens are being cleaned using a 0.1% solution of nonionic detergent made with distilled water, using a brush, followed by rinsing and air drying.

TABLE 2-9. EXPOSURE TESTS FOR COVER MATERIALS

Exposure Condition	Value or Range	Exposure Time
Temperature (indoor)	a) 70°C b) 90°C c) 125°C	500, 1,000 and 2,000 hr.
Temperature and Humidity (indoor)	a) 50°C and 98% RH b) 70°C and 95% RH c) 90°C and 95% RH	500, 1,000 and 2,000 hr.
Temperature and Radiation (indoor)	Xenon arc weathering machine a) 70°C b) 90°C	500, 1,000 and 2,000 hr.
Solar Simulator	a) Tungsten b) Xenon simulators with irradiance of $\sim$950 W/m^2 and $\sim$70°C	30, 60 and 120 cycles*
"Real Time" Outdoor	1 sun at $\sim$60°C	80, 160 and 240 days**
Accelerated Outdoor	$\sim$6 suns at $\sim$70°C	6, 12 and 24 equivalent months***

*Each cycle consists of 5 hrs. irradiation and 1 hr. cooling, as defined in Tables 2-6 and 2-7.

**Radiant exposure must exceed 17,100 kJ/m^2 for each day.

***One equivalent month equals 6.625 x 10^8 J/m^2 (15,835 Langleys)

TABLE 2-10. EXPOSURE TESTS FOR ABSORBER MATERIALS

Exposure Condition	Value or Range	Exposure Time
Temperature (indoor)	a) 150°C b) 175°C	500, 1,000 and 2,000 hr.
Temperature and Humidity (indoor)	90°C and 95%	500, 1,000 and 2,000 hr.
Thermal Cycling (indoor)	-10°C to 175°C	5, 15 and 30 cycles
Temperature and Radiation (indoor)	Xenon arc weathering machine at 90°C	500, 1,000 and 2,000 hr.
Solar Simulator	a) Tungsten b) Xenon simulators with irradiance of ~950 W/m^2 and ~130°C	30, 60 and 120 cycles*
"Real Time" Outdoor	1 sun at ~140°C and ~160°C	80, 160 and 240 days
Accelerated Outdoor	6 suns at ~150°C	6, 12 and 24 equivalent months***

*Each cycle consists of 5 hours irradiation and 1 hour cooling, as defined in Tables 2-6 and 2-7.

**Radiant exposure must exceed 17,100 kJ/m^2 for each day.

***One equivalent month equals 6.625 x 10^8 J/m^2 (15,835 Langleys)

2.3.2.1 <u>"Real Time" Outdoor Exposure</u>

Cover materials are being exposed to temperatures simulating operational conditions using the mini-boxes, as described in 2.3.2.1.1, at each of the four outdoor exposure sites chosen for participation in the program. In addition, property measurements are being made on materials samples taken from the full size collectors following the completion of outdoor exposure testing.

2.3.2.1.1 Small Scale Samples

a. Exposure Conditions

These exposures are being conducted concurrently with the outdoor exposure of full size solar collectors at each of the four outdoor exposure test sites identified in Chapter 4. The mini-boxes are being exposed at the same tilt and orientation as the full sized collectors in Section 2.2. Four mini-boxes are being exposed for each material with one box being pulled after 80, 160 and 240 cumulative days of exposure to a minimum incident solar radiation flux of 17,000 $kJ/m^2 \cdot day$. Depending on the materials property changes measured after 160 days of exposure, the fourth mini-box will either be pulled at 240 days or exposed for an additional 240 (17,000 $kJ/m^2 \cdot day$) days.

b. Apparatus and Specimens

Test specimens consist of cover materials mounted onto eight collector mini-boxes as shown in Figure 2-2. Cover plate test materials are identified in Table 3-2. Four mini-boxes have been prepared for each test material. One of the four boxes is instrumented with a type T thermocouple.

c. Property Measurements

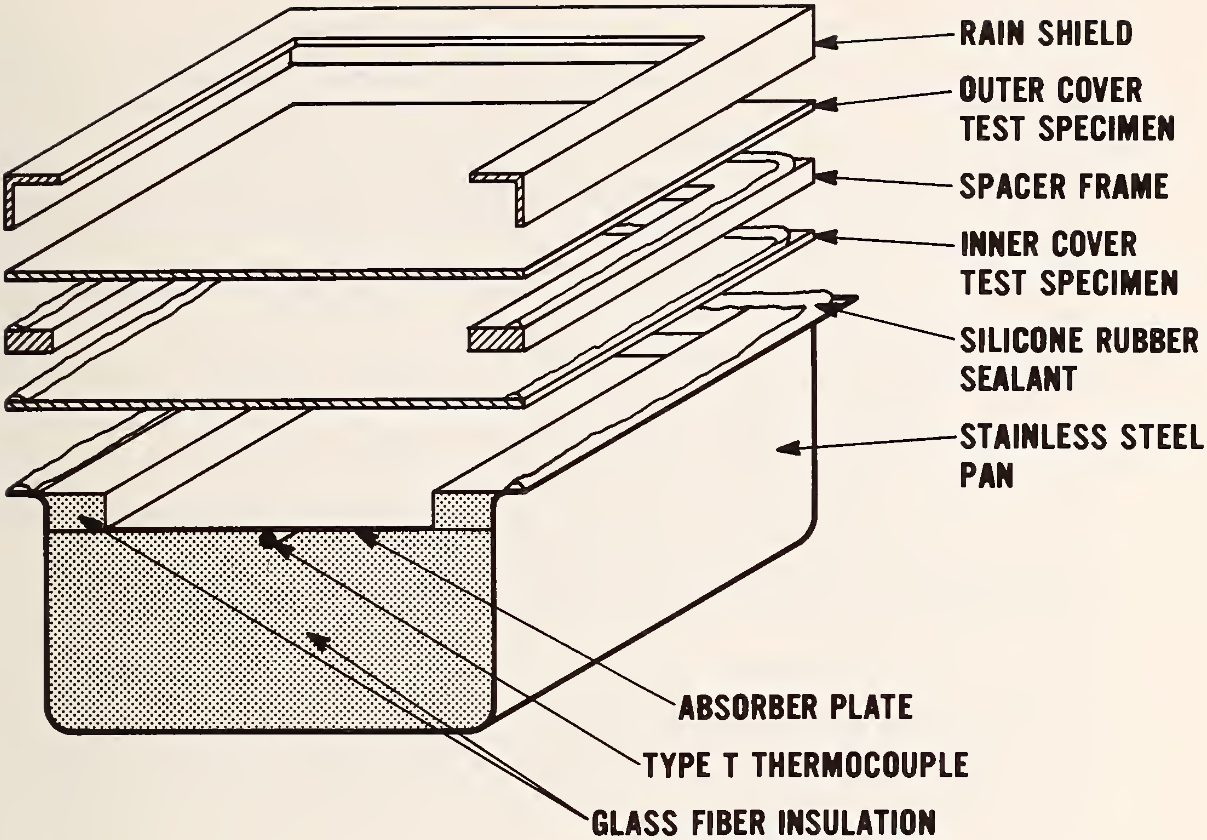
Routine evaluation of the cover materials includes visual observation and total solar transmittance. Visual observation and total solar transmittance are being determined after each set of test specimens is removed from exposure. Visual observations include marked changes in appearance, color or shape and notation of other surface flaws and other changes. The total solar transmittance is being measured as described in ASTM E424, Method A [15]. Non-routine measurements which may be performed to further characterize observed changes are discussed in Section 2.3.4.

d. Test Reports

Test results are to include the following information:

- o Test specimen code number (per Chapter 3)
- o Location and dates of exposure
- o Exposure condition data
- o Mini-box absorber plate temperature at solar noon each day
- o Notations recorded during visual observation
- o Total solar transmittance per ASTM E424, Method A, for both exposed and control samples
- o Actual solar transmittance curves for both exposed and control samples

Data are to be provided in accordance with the formats given in Appendix A, where appropriate.



Notes:

Stainless Steel Pan:	22 x 12 x 10 cm without rim
Glass Fiber Insulation:	64 kg/m^3 density
	Bottom thickness 10 cm
	Edge thickness 2.5 cm wide x 2.5 cm thick
	Baked out at 230°C for 24 hours

Absorber Plate: Black chrome on copper
Silicone Rubber Sealant: Between covers and pan, and covers and spacer
Cover Test Specimens: 26 x 16 cm
Rain Shield: 16 ga stainless steel, clamped to pan
Spacer Frame: 6 mm thick aluminum

FIGURE 2-2 COVER EXPOSURE MINI-BOX

2.3.2.1.2 Full Size Collectors

Weekly inspections are being made of the solar collectors during the environmental exposure specified in 2.2.1 and any visual evidence of materials degradation reported.

Following completion of environmental exposure and testing of these collectors, the collectors will be disassembled and inspected for degradation of materials. Materials coupon specimens will be cut from those collectors having polymer cover materials and total transmittance measurements will be performed in accordance with ASTM E424. Additional non-routine tests may be performed where appropriate (see 2.3.4).

2.3.2.2 Solar Simulator

a. Exposure Conditions

Test specimens were exposed concurrently with the full size collectors utilizing the daily cycles given in Tables 2-6 and 2-7 for Sites A and B, respectively. At Test Site A, where two sets of 60-day cycles are required to expose all four collectors, test specimens were pulled after 30, 60 and 120 daily cycles of exposure for property measurements. At Test Site B, test specimens were pulled after 30 and 60 daily cycles of exposure for property measurements.

b. Apparatus and Specimens

Test specimens consisted of cover materials mounted onto the collector mini-boxes shown in Figure 2-2. Cover plate test materials are identified in Table 3-2. One of the mini-boxes for each test material was instrumented with a type T thermocouple attached to the back of the absorber plate. This box was the last test specimen pulled.

c. Property Measurements

Routine evaluation of the cover materials included visual observation and total solar transmittance per ASTM E424. Non-routine measurements which may be performed to further characterize changes observed are discussed in Section 2.3.4. Peak mini-box absorber plate temperatures were measured for daily cycles 15, 30, 60 and 120 (Site A) and 15, 30 and 60 (Site B)

d. Test Reports

Test reports are to include the following information:

- Test specimen code number
- Location and dates of exposure
- Exposure condition data
- Peak mini-box absorber plate temperatures
- Notations recorded during visual observation
- Total solar transmittance per ASTM E424, Method A, for both exposed and control samples
- Solar transmittance curves for both exposed and control samples

2.3.2.3 Accelerated Outdoor

a. Exposure Conditions

Test specimens are being exposed to concentrated solar radiation in Phoenix, Arizona (Test Site 1) for periods of 30, 60 and 120 test days (5 test days $\approx$ 1 month "real time" $\approx 6.625 \times 10^5$ kJ/m^2). The test specimens are being air cooled and subjected to periodic water spray during exposure.

b. Apparatus and Specimens

Cover materials used are identified in Table 3-2. Test specimens are being exposed to concentrated natural solar radiation using the device referenced in ANSI Z-97.1-1975, Paragraph 4.3.2 [16]. Two types of test specimen configurations are mounted onto the accelerated weathering device. Duplicates of each test material are being used for each of the two types of specimen configurations shown in Figures 2-3a and 2-3b. Type T thermocouples are mounted on each specimen.

c. Property Measurements

Routine evaluation includes visual observations and total solar transmittance per ASTM E424, Method A. Measurements are being made on the same duplicate specimens after 30, 60 and 120 cumulative test days of exposure. The cover materials are remounted and exposure continued following property measurements until the 120 day cumulative exposure is reached. Temperature measurements are being made at solar noon on a clear exposure day prior to each time the specimens are pulled for property measurements. Non-routine measurements per 2.3.4 may be performed to further characterize changes observed.

d. Test Reports

Test reports are to include the following information:

- Test specimen code number
- Location and dates of exposure
- Total cumulative radiative exposure
- Thermocouple temperature at solar noon prior to pulling the sample
- Notations recorded during visual observation
- Total solar transmittance per ASTM E424, Method A, for both exposed and control samples
- Solar transmittance curves for both exposed and control samples

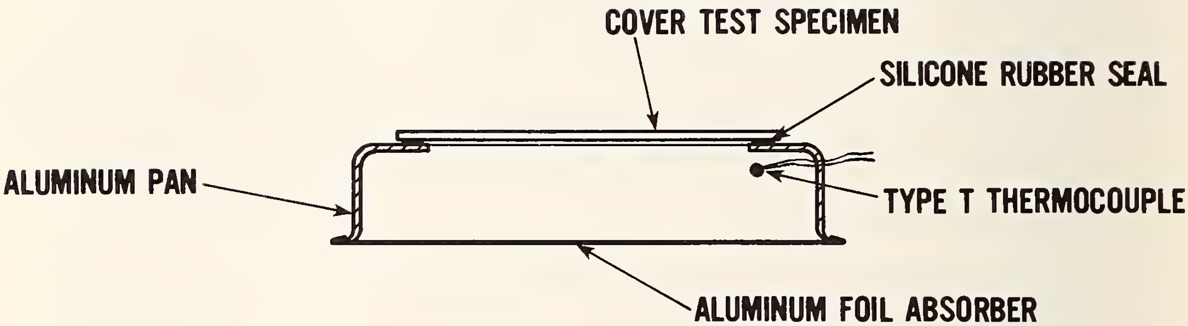
2.3.2.4 Laboratory Exposure

The test conditions which follow are intended to subject the cover test specimens to several different levels of environmental stress. Emphasis has been placed on the primary degradation factors, i.e. temperature, moisture and ultraviolet radiation. Depending on the test results obtained and their correlation with properties measured under outdoor "real time" conditions, additional environmental exposure tests of either lesser or greater severity may be conducted.

2.3.2.4.1 Temperature

a. Exposure Conditions

Two temperature conditions are being used; 70°C and 90°C. Test specimens are being pulled after 500, 1,000 and 2,000 hours of exposure at each of the above test temperatures.



Notes:

Cover Size: 7.6 x 5.1 cm
Aluminum Pan: 11.5 x 6.5 x 2 cm
Aluminum foil painted black and baked at 230°C for 24 hours

FIGURE 2-3a ACCELERATED EXPOSURE COVER MINI-BOX

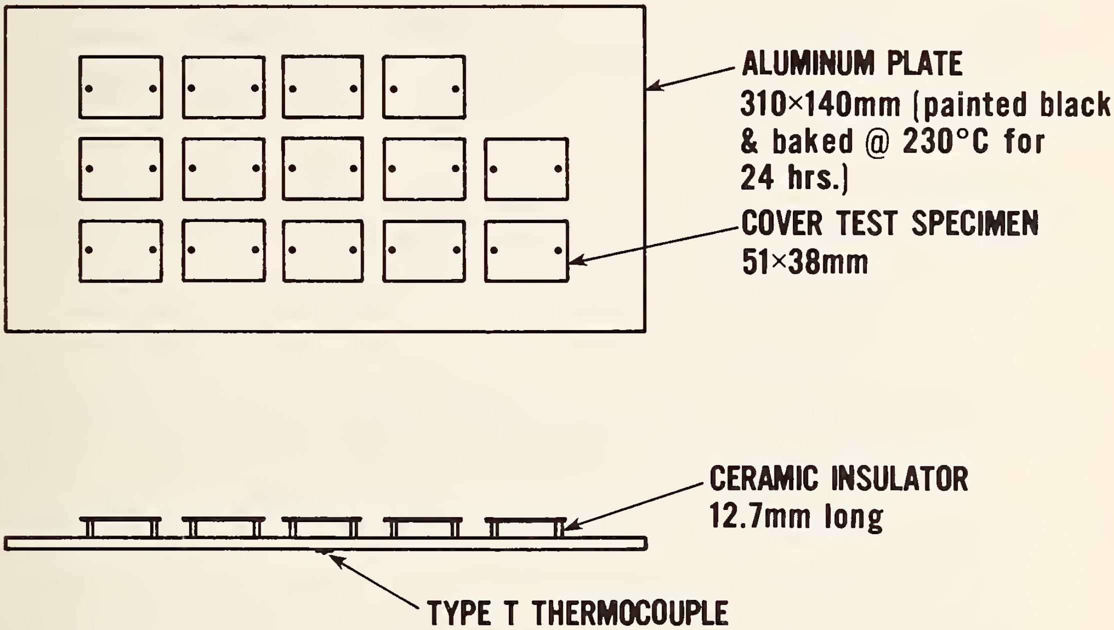


FIGURE 2-3b ACCELERATED EXPOSURE TEST PLATE

b. Apparatus and Specimens

Cover materials being used are identified in Table 3-2. Three test specimens were provided for exposure at each test temperature; one specimen to be pulled at each of the exposure time intervals specified (500, 1,000 and 2,000 hours). The test specimens are being allowed to hang freely in an oven capable of maintaining the above mentioned test temperatures $\pm$ 3°C.

c. Property Measurements

Routine evaluation includes visual observations and total solar transmittance per ASTM E424, Method A. Measurements are being made after each exposure time period. The test specimens are being stored and not returned to the oven following property measurements. Non-routine measurements per 2.3.4 may be performed to further characterize changes observed.

d. Test Reports

Test reports are to include the following information:

- Test specimen code number
- Location and dates of exposure
- Total cumulative exposure time
- Exposure conditions
- Notations recorded during visual observation
- Total solar transmittance per ASTM E424, Method A, for both exposed and control samples
- Solar transmittance curves for both exposed and control samples

2.3.2.4.2 Temperature and Humidity

a. Exposure Conditions

Three test conditions are being used: 50°C and >95% relative humidity (RH); 70°C and >95% RH; and 90°C and >95% RH. Test specimens are being pulled after 500, 1,000 and 2,000 hours of exposure at one of the above test temperatures. The 70°C and 90°C test conditions are being conducted first and only those materials which exhibit significant changes are to be run at the 50°C test condition.

b. Apparatus and Specimens

Cover materials being used are identified in Table 3-2. Three test specimens are being provided for exposure at each test temperature; one specimen to be pulled at each of the exposure time intervals specified (500, 1,000 and 2,000 hours). The test specimens are being allowed to hang freely with all surfaces exposed in a humidity chamber capable of maintaining the above mentioned temperatures $\pm$ 3°C and >95% relative humidity.

c. Property Measurements

Routine evaluation includes visual observations and total solar transmittance per ASTM E424, Method A. Measurements are being made after each exposure time period. The test specimens are being stored and not returned to the humidity exposure cabinet after property measurements are completed. Non-routine measurements per 2.3.4 may be performed to further characterize changes observed.

d. Test Reports

Test reports are to include the following information:

- o Test specimen code number
- o Location and dates of exposure
- o Total cumulative exposure time
- o Exposure conditions
- o Notations recorded during visual observation
- o Total solar transmittance per ASTM E424, Method A, for both exposed and control samples
- o Solar transmittance curves for both exposed and control samples

2.3.2.4.3 Temperature and Radiation

a. Exposure Conditions

Test specimens are being exposed at 70°C and at 90°C (chamber temperature) to xenon arc radiation under dry conditions in an accelerated weathering machine in accordance with ASTM D2565 [17]. Test specimens are being pulled after 500, 1,000 and 2,000 hours of exposure at one of the above test temperatures.

b. Apparatus and Specimens

Cover materials being used are identified in Table 3-2. Three test specimens are being provided for exposure at each test temperature; one specimen to be pulled at each of the exposure time intervals specified (500, 1,000 and 2,000 hours).

The accelerated weathering machine used meets the requirements of ASTM D2565 and is capable of maintaining the required temperatures.

The test specimens are oriented so that the surface that would ordinarily face the sun in a solar collector is facing the xenon arc lamp.

In cases where double covers are to be evaluated, the outer and inner covers are separated by a 6 mm thick air gap and the outer cover faces the xenon arc lamp.

c. Property Measurements

Routine evaluation shall include visual observations and total solar transmittance per ASTM E424, Method A. Measurements are being made after each exposure time period. The test specimens are being stored and not returned to the accelerated weathering machine after property measurements are completed. Non-routine measurements per 2.3.4 may be performed to further characterize changes observed.

d. Test Reports

Test reportsare to include the following information:

- o Test specimen code number
- o Location and dates of exposure
- o Total cumulative exposure time
- o Exposure conditions
- o Notations recorded during visual observation
- o Total solar transmittance per ASTM E424, Method A, for both exposed and control samples
- o Solar transmittance curves for both exposed and control samples

2.3.3 ABSORBER MATERIALS

The sections which follow contain descriptions of the test procedures and apparatus that will be used for the environmental exposure testing of absorber materials. The specific materials being used for each test are identified in tables contained in Chapter 3. A set of control specimens was provided to each test site performing property measurements for purposes of comparison with the results of measurements after environmental exposure. These control specimens are being stored in a dark environment at 21 $\pm$ 3°C until required for comparison testing.

Prior to the installation of test specimens, ten specimens selected at random of each coating material were measured for absorptance in accordance with ASTM E424, Method A, and for emittance in accordance with ASTM E408, Method A [18] to determine the uniformity of coating optical properties. In cases where sample lot differences greater than 0.01 exist in absorptance or 0.02 in emittance, each test specimen was measured for absorptance and emittance prior to environmental exposure. The test specimens were indexed in the measurement apparatus in such a manner that the same area can be measured following environmental exposure.

2.3.3.1 "Real Time" Outdoor Exposure

Absorber materials are being exposed to temperatures simulating operational conditions using the test collector boxes described in 2.3.3.1.1, at each of the four outdoor exposure sites chosen for participation in the program. In addition, property measurements will be made on materials samples taken from full size collectors following the completion of outdoor exposure testing.

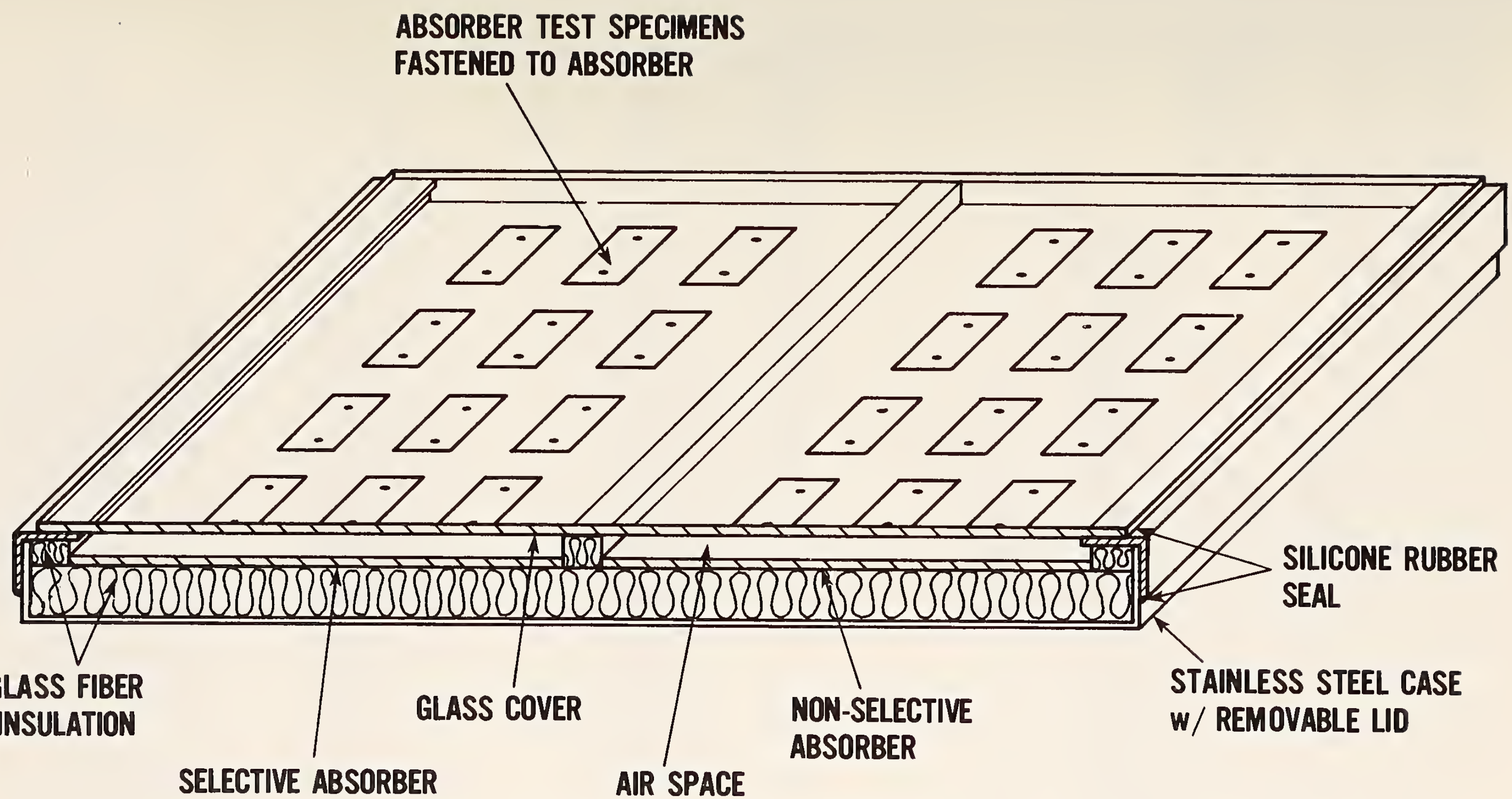
2.3.3.1.1 Small Scale Samples

a. Exposure Conditions

These exposures are being conducted concurrently with the outdoor exposure of full size solar collectors at each of the four outdoor exposure test sites identified in Chapter 4. The outdoor absorber exposure boxes are being exposed at the same tilt and orientation as the full size collectors in Section 2.2. Test specimens are being pulled from the selective surface and non-selective sides of the outdoor absorber exposure boxes after 80, 160 and 240 cumulative days of exposure to a minimum incident solar radiation flux of 17,000 kJ/m^2·day. Depending on the materials property changes measured after 240 days of exposure, the test specimens may be exposed for an additional 240 days of 17,000 kJ/m^2 exposure.

b. Apparatus and Specimens

Test specimens consist of coupon samples of absorber materials mounted onto the selective and non-selective surfaces of the outdoor absorber exposure box shown in Figure 2-4. Absorber test materials are identified in Table 3-3. In general, three test specimens are installed on both the selective and non-selective sides of the exposure box (a total of six). In some cases where a limited amount of test material was available, lesser numbers of samples were used as identified in Chapter 3. Where three samples were used, one is being pulled at 80, 160 and 240 cumulative days of exposure for property measurements. Type T thermocouples are attached to the centers of both the selective and non-selective test box absorber plates.



Notes:

Absorber Test Specimens: 7.6 x 5.1 cm
Stainless Steel Case: ≈190 x 84 x 9 cm
Glass Fiber Insulation: 64 kg/m^3 density
Baked out at 230°C for 24 hours
Edges and center 1.3 cm thick
Bottom 10 cm thick

Air Space: 1.3 cm
Cover: Water white glass
Absorber: Selective side - Black chrome on copper
Non-selective side - Black porcelain enamel on steel
Type T thermocouples attached to center of each absorber

FIGURE 2-4 OUTDOOR ABSORBER EXPOSURE BOX

c. Property Measurements

Routine evaluation of the absorber materials includes visual observation, total solar absorptance and emittance. Property determinations are being made after each set of test specimens is removed from exposure. Visual observations include any marked changes in appearance, color or shape, and notation of other surface flaws and other changes. The total solar absorptance is being measured in accordance with ASTM E424, Method A. Emittance is being measured in accordance with ASTM E408, Method A. Non-routine measurements which may be performed to further characterize changes observed are discussed in Section 2.3.4.

d. Test Reports

Test reports are to include the following information:

- o Test specimen code number
- o Location and dates of exposure
- o Selective and non-selective absorber plate temperature at solar noon each day
- o Notations recorded during visual observation
- o Total solar absorptance for both exposed and control samples
- o Solar reflectance curves for both exposed and control samples
- o Emittance for both exposed and control samples

Data are to be provided in accordance with the formats given in Appendix A, where appropriate.

2.3.3.1.2 Full Size Collectors

Weekly inspections are being made of the solar collectors during the environmental exposure specified in 2.2.1 and any visual evidence of materials degradation reported.

Following completion of environmental exposure and testing of these collectors, total solar absorptance and emittance measurements will be made on samples cut from the absorber plates using ASTM E424 and ASTM E408, respectively. Additional non-routine tests may be performed where appropriate (see 2.3.4).

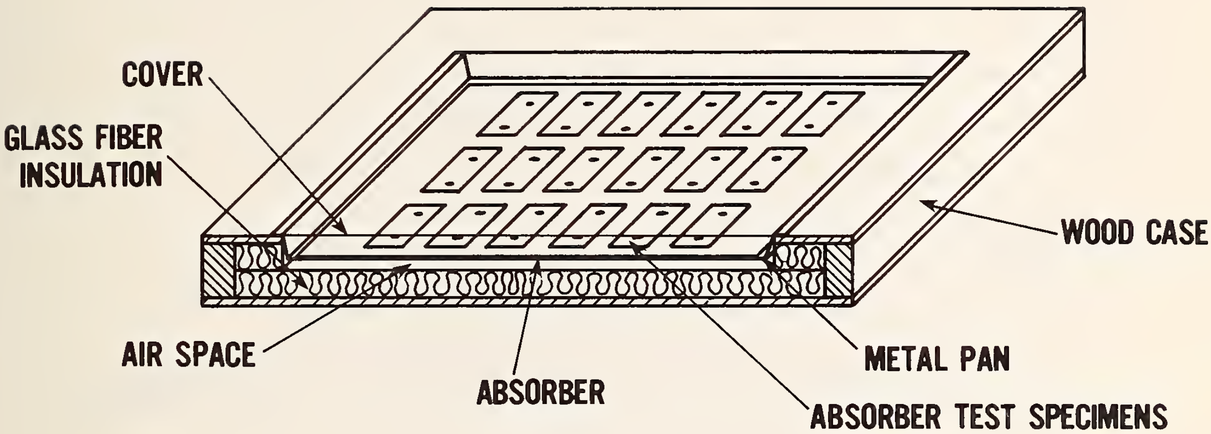
2.3.3.2 Solar Simulator

a. Exposure Conditions

Test specimens were exposed concurrently with full size collectors utilizing the daily cycles given in Tables 2-6 and 2-7 for Sites A and B, respectively. At Test Site A, where two sets of 60-day cycles were required to expose all four collectors, test specimens were pulled after 30, 60 and 120 daily cycles of exposure for property measurements. At Test Site B. test specimens were pulled after 30 and 60 daily cycles of exposure for property measurements

b. Apparatus and Specimens

Test specimens consisted of absorber materials mounted onto the absorbers of the test boxes shown in Figure 2-5. Two boxes were used at each site, one having a selective surface absorber and the other having a non-selective flat black absorber. Sufficient samples of each material were provided for each box to permit pulling a sample at each of the exposure time periods identified in a. above. Absorber test materials are identified in Table 3-3. A type T thermocouple was attached to the center of the absorber plate in each box.



Notes:

Cover Material: Polytetrafluoroethylene film
Wood Case: 122 x 61 x 10 cm
Glass Fiber Insulation: On bottom and edges
$64 \ kg/m^3$ density
5.1 cm thick
Baked out at 230°C for 24 hours
Absorber: Selective box - Black chrome on copper
Non-selective box - Black paint on pan baked out at 230°C for 24 hours
Type T thermocouple attached to center of absorber
Metal Pan: 43 x 28 x 2.2 cm
Test Specimens: 7.6 x 5.1 cm screwed to absorber

FIGURE 2-5 SOLAR SIMULATOR ABSORBER BOX TEST ASSEMBLY

c. Property Measurements

Routine evaluation of the absorber materials included visual observation, total solar absorptance per ASTM E424, Method A, and emittance per ASTM E408, Method A. Non-routine measurements which may be performed to further characterize changes observed are discussed in Section 2.3.4. Peak absorber plate temperatures were measured for daily cycles 15, 30, 60 and 120 (Site A) and 15, 30 and 60 (Site B).

d. Test Reports

Test reports are to include the following information:

- o Test specimen code number
- o Location and dates of exposure
- o Exposure condition data
- o Peak absorber plate temperatures
- o Notations recorded during visual observation
- o Total solar absorptance per ASTM E424, Method A, for both exposed and control samples
- o Solar reflectance curves for both exposed and control samples
- o Emittance per ASTM E408, Method A, for both exposed and control samples

2.3.3.3 Accelerated Outdoor

a. Exposure Conditions

Test specimens are being exposed to concentrated solar radiation in Phoenix, Arizona (Test Site 1) for periods of 30, 60 and 120 test days (5 test days 1 month "real time" $\approx 6.625 \times 10^5$ kJ/m^2).

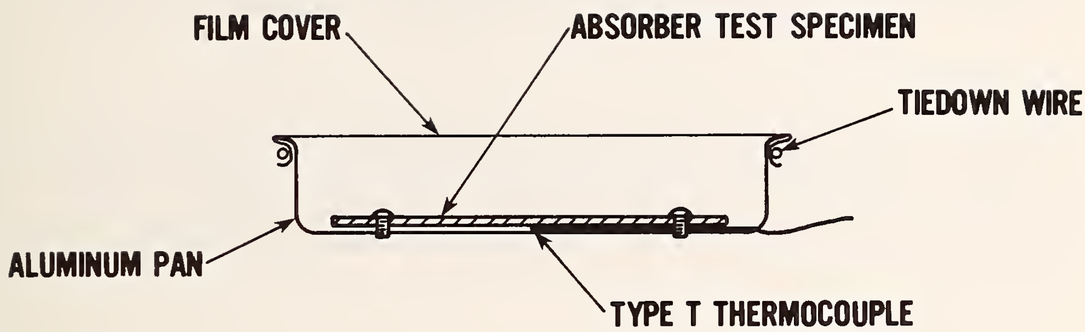
The test specimens arebeing air cooled and exposed without water spray.

b. Apparatus and Specimens

Absorber materials being used are identified in Table 3-3. Test specimens are being exposed to concentrated natural solar radiation using the device referenced in ANSI Z-97.1-1975, Paragraph 4.3.2. Test specimens, constructed in accordance with Figure 2-6, are mounted onto the accelerated weathering device. Type T thermocouples are mounted on each specimen as shown in Figure 2-6. Duplicate specimens of each test material are being used.

c. Property Measurements

Routine evaluation of the absorber materials includes visual observation, solar absorptance per ASTM E424, Method A, and emittance per ASTM E408, Method A. Measurements are being made on the same duplicate specimens after 30, 60 and 120 cumulative test days of exposure. The absorber materials are remounted and exposure continued following property measurements until the 120 day cumulative exposure is reached. Temperature measurements are being made at solar noon on a clear exposure day prior to each time the specimens are pulled for property measurements. Non-routine measurements which may be performed to further characterize changes observed are discussed in Section 2.3.4.



Notes:

Film Cover: Polytetrafluoroethylene
Absorber Test Specimen: 7.5 x 5.1 cm
Aluminum Pan: 11.5 x 6.5 x 2 cm
Interior painted black and baked at 230°C for 24 hours

FIGURE 2-6 ACCELERATED EXPOSURE ABSORBER MINI-BOX

d. Test Reports

Test reports are to include the following information:

- o Test specimen code number
- o Location and dates of exposure
- o Total cumulative radiative exposure
- o Thermocouple temperature at solar noon on a clear day prior to pulling the sample
- o Total solar absorptance per ASTM E424, Method A, for both exposed and control samples
- o Solar reflectance curves for both exposed and control samples
- o Emittance per ASTM E408, Method A, for both exposed and control samples

2.3.3.4 Laboratory Exposure

The test conditions which follow are intended to subject the absorber test specimens to several different levels of environmental stress. Emphasis has been placed on the primary degradation factors, i.e. temperature (both constant and cyclic), moisture and ultraviolet radiation. Depending on the test results obtained and their correlation with properties measured under outdoor "real time" conditions, additional environmental exposure tests of either lesser or greater severity may be conducted.

2.3.3.4.1 Temperature

a. Exposure Conditions

Two temperature conditions are being used: 150°C and 175°C. These temperatures approximate those that occur in the non-selective and selective absorbers, respectively, of the outdoor absorber test box (see 2.3.3.1.1) under clear day conditions. Test specimens are being pulled after 500, 1,000 and 2,000 hours of exposure at one of the above test temperatures.

b. Apparatus and Specimens

Absorber materials being used are identified in Table 3-3. Three test specimens are provided for exposure at each test temperature; one specimen to be pulled at each of the exposure time intervals specified (500, 1,000 and 2,000 hours). The test specimens are being allowed to hang freely in an oven capable of maintaining the above mentioned test temperatures ± 3°C.

c. Property Measurements

Routine evaluation includes visual observations, total solar absorptance per ASTM E424, Method A, and emittance per ASTM E408, Method A. Measurements are being made after each exposure time period. The test specimens are being stored and not returned to the oven following property measurements. Non-routine measurements per 2.3.4 may be performed to further characterize changes observed.

d. Test Reports

Test reports are to include the following information:

- o Test specimen code number
- o Location and dates of exposure
- o Total cumulative exposure time
- o Exposure conditions
- o Notations recorded during visual observations
- o Total solar absorptance per ASTM E424, Method A, for both exposed and control samples
- o Solar reflectance curves for both exposed and control samples
- o Emittance per ASTM E408, Method A, for both exposed and control samples

2.3.3.4.2 Temperature and Humidity

a. Exposure Conditions

Test specimens are being pulled after 500, 1,000 and 2,000 hours of exposure in a chamber maintained at 90°C and >95% RH.

b. Apparatus and Specimens

Absorber materials being used are identified in Table 3-3. Three test specimens are provided for exposure at the test temperature; one specimen to be pulled at each of the exposure time intervals specified (500, 1,000 and 2,000 hours). The test specimens are being allowed to hang freely with all surfaces exposed in a humidity chamber capable of maintaining 90° ± 3°C and >95% RH.

c. Property Measurements

Routine evaluation includes visual observations, total solar absorptance per ASTM E424, Method A, and emittance per ASTM E408, Method A. Measurements are being made after each exposure time period. The test specimens are being stored and not returned for further exposure following property measurements. Non-routine measurements per 2.3.4 may be performed to further characterize changes observed.

d. Test Reports

Test reports shall include the following information:

- o Test specimen code number
- o Location and dates of exposure
- o Total cumulative exposure time
- o Exposure conditions
- o Notations recorded during visual observations
- o Total solar absorptance per ASTM E424, Method A, for both exposed and control samples
- o Solar reflectance curves for both exposed and control samples
- o Emittance per ASTM E408, Method A, for both exposed and control samples

2.3.3.4.3 Temperature and Radiation

a. Exposure Conditions

Test specimens are being exposed at 90°C to xenon arc radiation under dry conditions in an accelerated weathering machine in accordance with ASTM D2565. Test specimens are being pulled after 500, 1,000 and 2,000 hours of exposure in the machine.

b. Apparatus and Specimens

Absorber materials being used are identified in Table 3-3. Three test specimens are provided for exposure; one to be pulled at each of the exposure time intervals specified (500, 1,000 and 2,000 hours).

The accelerated weathering machine used meets the requirements of ASTM D2565 and is capable of maintaining the required temperature. The test specimens are oriented so that the absorber surface is facing the xenon arc lamp.

c. Property Measurements

Routine evaluation includes visual observations, total solar absorptance per ASTM E424, Method A, and emittance per ASTM E408, Method A. Measurements are being made after each exposure time period. The test specimens are being stored and not returned for further exposure following property measurements. Non-routine measurements per 2.3.4 may be performed to further characterize changes observed.

d. Test Reports

Test reports are to include the following information:

- o Test specimen code number
- o Location and dates of exposure
- o Total cumulative exposure time
- o Exposure conditions
- o Notations recorded during visual observations
- o Total solar absorptance per ASTM E424, Method A, for both exposed and control samples
- o Solar reflectance curves for both exposed and control samples
- o Emittance per ASTM E408, Method A, for both exposed and control samples

2.3.3.4.4 Thermal Cycling

a. Exposure Conditions

Test specimens are being exposed to test cycles consisting of the following:

- o ~8 hours at 175°C
- o 5 minutes to equilibrate at room temperature
- o ~16 hours at -10°C
- o 5 minutes to equilibrate at room temperature

Test specimens are being pulled after 5, 15 and 30 test cycles as specified above.

b. Apparatus and Specimens

Absorber materials being used are identified in Table 3-3. Three test specimens are being provided for each material; one specimen to be pulled at each of the exposure intervals (5, 15 and 30 cycles). Two test chambers are being used; one maintained at 175 $\pm$ 3°C and the other at -10 $\pm$ 3°C.

c. Property Measurements

Routine evaluation includes visual observations, total solar absorptance per ASTM E424, Method A, and emittance per ASTM E408, Method A. Measurements are being made after each of the specified exposure intervals. The test specimens are being stored and not returned for further exposure following property measurements. Non-routine measurements per 2.3.4 may be performed to further characterize changes observed.

d. Test Reports

Test reports are to include the following information:

- o Test specimen code number
- o Location and dates of exposure
- o Total cumulative exposure cycles
- o Exposure conditions
- o Notations recorded during visual observations
- o Total solar absorptance per ASTM E424, Method A, for both exposed and control samples
- o Solar reflectance curves for both exposed and control samples
- o Emittance per ASTM E408, Method A, for both exposed and control samples

2.3.4 NON-ROUTINE PROPERTY MEASUREMENTS

Many techniques are available that can be used to characterize degradation phenomena in materials [19, 20]. The techniques identified below will be used, as required, to characterize initial composition and topography, and changes in cover and absorber materials resulting from environmental exposure.

2.3.4.1 Surface Appearance Changes

Techniques that will be considered to characterize changes include:

- o Stereoscopic Microscopy
- o Nomanski Differential Phase Interference Microscopy
- o Scanning Electron Microscopy (SEM)

The Nomanski and SEM techniques have the advantages of high resolution and good depth of field.

2.3.4.2 Surface Chemical Composition Changes

Techniques that will be considered to characterize changes include:

- o X-Ray Fluorescence (XRF) in conjunction with an electron microprobe
- o Auger Electron Spectroscopy (AES)
- o Electron Spectroscopy for Chemical Analysis (ESCA)
- o Attenuated Total Reflectance (ATR)

The AES and ESCA techniques are suitable for analyzing elements having an atomic number greater than two, whereas XRF is primarily of value with relatively heavy elements. The electron probe can be used to get a picture of the material surface, however, it will not be of the quality that can be obtained with a SEM. The ATR technique is an infrared spectroscopy technique that will primarily be of value in analyzing surface degradation of cover materials, i.e. carbonyl formation and hydrolysis.

2.3.4.3 Bulk Material Chemical Changes

Techniques that will be considered to characterize these changes include:

- o Secondary Ion Mass Spectrometry (SIMS)
- o Electron Spin Resonance (ESR)
- o Infrared Transmittance

The SIMS technique will primarily be used to characterize localized degradation such as pitting of coatings. By etching through the defect with an ion beam, it is possible to get an in-depth profile of the chemical composition of the defect. SIMS is an especially powerful tool when used in conjunction with AES or ESCA.

ESR and Infrared Transmission will primarily be used to characterize compositional changes in polymeric cover materials.

Potassium bromide pellet techniques may be of value for those materials which exhibit poor infrared transmission.

2.3.4.4 Mechanical Property Changes

Primary emphasis will be placed on tensile properties of organic cover materials using ASTM Methods D638 [21], D882 [22] or D1708 [23].

The D638 method is primarily applicable to sheet materials (up to 14 mm thick) whereas the D882 method is intended for use with films (less than 1 mm thick). The D1708 method is a microtensile technique that can be used on specimens up to 3.2 mm thick; however, it cannot be used for the determination of modulus of elasticity unlike the D638 and D882 methods. Additional stiffness and/or bending tests will be devised where appropriate.

3. TEST SPECIMEN SELECTION

3.1 GENERAL

Solar collectors presently available on the commercial market show a wide range of variation in materials, construction and operational characteristics. These variables include type of solar collector (flat plate, concentrating, evacuated tube, etc.), heat transfer medium (air or various liquids), absorber plate materials, absorptive coatings, number of cover plates and their materials, type of insulation, and flow tube/passage material and design. With this vast number of variables, it is not possible to define a typical solar collector that is representative of all collectors commonly in use. Due to the large number of variables, it is necessary to develop selection criteria to optimize the choice of a limited number of test specimens.

3.2 SOLAR COLLECTOR SELECTION ATTRIBUTES

The criteria which follow were used to select test specimens:

Criterion 1: The collectors selected for testing must be commercially available and have a history of "real time" use in the solar heating and cooling demonstration program. This is to permit a comparison of changes observed as a result of environmental exposure in the test program with those that occur in operational systems.

Criterion 2: The manufacturer's specification must not prohibit prolonged stagnation exposure. This criterion eliminates the use of tracking concentrators which would not ordinarily be designed to track the sun under stagnation conditions.

Criterion 3: The collectors must be capable of being tested for thermal performance by ASHRAE Standard 93-77 by qualified test laboratories located in each of the climatic regions selected for use in the test program. This criterion would eliminate those collectors which require non-aqueous heat transfer fluids as well as air collectors since a limited number of test sites have these capabilities.

Criterion 4: Cover and absorber materials coupon specimens removed from the collectors must not require special protection during environmental exposure. In addition, the test specimens must be amenable to optical and mechanical property measurements using standard test methods. This would eliminate the use of evacuated tube collectors where the test specimen configuration requires special measurement techniques and a vacuum is required to simulate the actual in-use environment.

Criterion 5: The products selected must be representative of the broad range of materials and construction commonly in use. Primary emphasis is to be placed on cover and absorber materials.

3.3 SELECTION OF TEST SPECIMENS

Consideration of the criteria in 3.2 has narrowed down the choice to the following primary variables:

Collector Type: Flat Plate

Heat Transfer Fluid: Aqueous Liquid

Number of Covers: One and Two

Cover Materials: Glass
- o Ordinary Plate Glass
- o Water White
- o Low Iron

Sheet Plastics
- o Glass Fiber Reinforced Plastic (FRP)
- o Polymethyl Methacrylate
- o Polycarbonate

Films
- o Polytetra Fluorethylene (FEP)
- o Polyethylene Terephthalate (polyester)
- o Polyvinyl Fluoride

Absorber Coatings: Selective
- o Black Chrome
- o Black Nickel
- o Copper Oxide
- o Lead Oxide
- o Aluminum Oxide (conversion coating)
- o Aluminum Oxide (anodized)
- o Selective Paint

Non-Selective
- o Porcelain Enamel
- o Paint - Alkyd
- o Paint - Epoxy
- o Paint - Urethane
- o Paint - Silicone

Absorber Substrate: Aluminum
Copper
Carbon Steel
Stainless Steel
Polymeric Material

Insulation Material: Glass Fiber
Glass Foam
Organic Foam

There are many other secondary variables such as collector case material, gasket and sealant materials, etc., that were not considered in the selection process since they do not normally directly affect thermal performance.

A total of eight different types of solar collectors were selected for use in the test program. Key features of these collectors are summarized in Table 3-1. Testing will be performed at the materials coupon specimen level on as many other cover and absorber materials as can be obtained. Materials level test specimens are identified in Tables 3-2 and 3-3 for cover and absorber materials respectively.

TABLE 3-1. SOLAR COLLECTOR TEST SPECIMENS

Code	Cover Material [5]		Absorber Material [5]	
	Outer	Inner	Coating	Substrate
A	Glass [1]	---	Black Nickel	Steel
B	Glass [2]	Glass [2]	Black Velvet Paint	Copper
C	Glass [3]	FEP Film Heat Trap	Black Velvet Paint	Copper
D	Glass [2,4]	Glass [2,4]	Black Chrome	Steel (nickel flashed)
E	FRP - Type Ia	---	Flat Black Paint (lacquer primer)	Copper
F	Glass [1]	---	Copper Oxide	Copper
G	FRP - Type II	FEP Film	Procelain Enamel	Steel
H	Polyester Film	FEP Film	Flat Black Paint (siliconized polyester)	Aluminum

[1] Water White Glass

[2] Low Iron Glass

[3] Ordinary Plate Glass

[4] Etched Anti-Reflection Treatment

[5] Obtained from collector manufacturer literature

TABLE 3-2. COVER TEST MATERIALS

Code [1]	Cover Material	Transmittance [3] (Controls)
E	FRP Type Ia	0.85
G	FRP Type II	0.84
H [2]	Polyester/FEP (outer) (inner)	0.85/0.96
J	Polycarbonate	0.88
K	Polyvinyl Fluoride	0.89
L	FRP Type Ib	0.84
M	FRP Type III	0.78
N	Polymethyl methacrylate (acrylic)	0.90
O [2]	Glass [4]/Polyvinyl Fluoride (outer) (inner)	0.86/0.89

[1] Code letters E, G and H indicate materials coupon specimens cut from solar collectors E, G and H. Codes J, K, L, M, N and O tested at the materials level only.

[2] Materials to be exposed as a combination in the cover mini-boxes (see 2.3.2.1 and 2.3.2.2) and in the accelerated weathering machine (see 2.3.2.4). Materials to be exposed individually in all other tests. Glass and FEP materials are not to be used for individual tests because of proven stability.

[3] These properties are dependent on the formulations and manufacturing processes used. Other products within a generic class of materials may have significantly different properties.

[4] Ordinary plate glass.

TABLE 3-3. ABSORBER TEST MATERIALS

Code [1]	Absorber Material		Optical Properties [2]	
	Coating	Substrate	Absorptance [3]	Emittance [3]
A	Black Nickel	Steel	0.87	0.13
C	Flat Black Paint	Copper	0.98	0.92
D	Black Chrome	Steel (nickel flashed)	0.97	0.07
E	Flat Black Paint	Copper	0.95	0.87
F	Copper Oxide	Copper	0.96	0.75
G	Black Porcelain Enamel	Steel	0.93	0.86
H	Flat Black Paint	Aluminum	0.95	0.89
I	Black Chrome	Stainless Steel	0.88	0.19
J	Black Chrome	Aluminum	0.98	0.14
L	Lead Oxide	Copper	0.99	0.29
M	Oxide Anodized	Aluminum	0.94	0.10
N	Oxide Conversion Coating	Aluminum	0.93	0.51
P	Black Chrome	Copper	0.96	0.08

[1] Code letters A through H indicate materials coupon specimens cut from solar collectors A through H. Codes I through P tested at the materials level only.

[2] These properties are dependent on the formulations and manufacturing processes used. Other products within a generic class of materials may have significantly different properties.

[3] Average values based on a minimum of ten test specimens.

4. OUTDOOR TEST SITE SELECTION

4.1 SITE CONSIDERATIONS

Factors that have been considered in the selection of test sites include:

- o Climatic conditions in major regions of the United States
- o Population density in these areas
- o Test site availability in these major climatic regions

The first factor is concerned with the environmental exposure conditions to which solar collectors will be exposed. The second with the probability that solar will be used and the third with whether or not testing can be performed in areas having desired climatic and population characteristics.

4.1.1 CLIMATIC CHARACTERISTICS

The six major divisions of world climates have been identified by Trewartha [24] as follows:

A. Tropical Rainy Climates
B. Dry Climates
C. Humid Mesothermal Climates
D. Humid Microthermal Climates
E. Polar Climates
F. Undifferentiated Highlands

Examination of the population distribution for the 1970 census as a function of climatic region indicates that about 96% of the people in the U.S. live in two major climatic regions: C, Humid Mesothermal, and D, Humid Microthermal, as shown in Table 4-1 [25]. The more extreme climates in terms of precipitation such as A, Tropical Rainy, and B, Dry, account for about 4%. The Polar and Undifferentiated Highlands contain a relatively small percentage of the continental U.S. population. The tropical Savanna subdivision of Tropical Rainy Climates are found in Hawaii and the southern tip of Florida. The Dry Climates include large areas of New Mexico, Arizona and Nevada, and portions of Texas, Colorado, Utah, Oregon, Idaho, Montana, Wyoming, California, the Dakotas, Nebraska and Kansas. Humid Mesothermal Climates prevail in the Southeast, northern California and the western part of Oregon and Washington. Humid Microthermal Climates include the New England states, New York, Michigan, Minnesota, Iowa, Pennsylvania, Wisconsin, and parts of Maryland, West Virginia, Ohio, Illinois, Indiana, Missouri, Kansas, Nebraska, Alaska and the Dakotas. Highlands Climate occurs in Arizona, Colorado, Utah, Wyoming, Idaho, Montana, California, Oregon and Washington. The Polar Climate is found in Alaska only.

4.1.2 CLIMATIC REQUIREMENTS

A meaningful validation of durability/reliability tests for solar collectors and their materials must consider the broad range of climatic and other environmental exposure conditions that can be found in the United States. These variables in the approximate order of decreasing importance are:

- o The annual solar radiation at a test site and its seasonal distribution
- o Humidity
- o Ultraviolet radiation in the solar flux
- o Average and extreme high temperatures
- o Low temperatures
- o Total and seasonal precipitation (and type)

TABLE 4-1. ESTIMATED DISTRIBUTION OF POPULATION IN THE UNITED STATES* AMONG VARIOUS CLIMATES [25]

A.	TROPICAL RAINY CLIMATES		1.1 percent
	Am, Monsoon Rainforest	0.3 percent	
	Aw, Tropical Savanna	0.8 percent	
B.	DRY CLIMATES		2.9 percent
	BSh, Tropical and Subtropical Steppe	0.6 percent	
	BSk, Middle Latitude Steppe	1.6 percent	
	BWh, Tropical and Subtropical Desert	0.7 percent	
C.	HUMID MESOTHERMAL CLIMATES		46.2 percent
	Cs, Mediterranean	9.3 percent	
	Caf, Humid Subtropical (no dry season)	35.5 percent	
	Cb, Marine West Coast (cool summer)	1.4 percent	
D.	HUMID MICROTHERMAL CLIMATES		49.6 percent
	Daf, Humid Continental (warm summer; no dry season)	31.9 percent	
	Dbf, Humid Continental (cool summer; no dry season)	17.5 percent	
	Dcf, Subarctic (no dry season)	0.2 percent	
	Total		99.8 percent

*Including all 50 states, the District of Columbia and Puerto Rico.

- o Average and maximum wind velocities and their directions
- o Concentrations of suspended particulate matter from dust and pollution
- o Pollution oxidants and acid gases (ozone, nitrogen oxides and sulfur oxides) that attack collector materials, particularly plastic cover plates

The importance of these environmental variables to collector durability and reliability, and their wide variation throughout the United States require that: 1) test sites be selected that represent suitable combinations of these variables and 2) their effects on collector performance be carefully monitored during the test program.

An important caution is that climatological data and pollution data can vary widely, depending on the local terrain and locations with respect to major bodies of water, heat-producing sources (such as a steel mill) and other geographical factors. Weather characteristics (which are typically measured at airports) show wide variations even over a distance of a few miles. Such variations are even more evident in pollution measurements which are usually taken near sources of suspected air pollution. Accordingly, if any test site is to rely upon another location for data on climatological or other environmental conditions, the organization conducting the test must demonstrate that the recorded data is valid for that test site.

4.1.3 SITE DESCRIPTIONS

A comparison of the major populated climatic regions and the availability of exposure sites with the capability of performing thermal performance tests in accordance with the ASHRAE Standard 93-77 [26] resulted in the selection of four test sites. The location of these sites with respect to U.S. geographic and climatic regions is shown in Figure 4-1.

A summary of the major climatic features of each site is listed below.

DSET Labs, Inc., Phoenix, Arizona (Test Site 1):

- o Hot, dry
- o High solar radiation
- o High UV
- o Rural, desert environment

Florida Solar Energy Center, Cape Canaveral, Florida (Test Site 2):

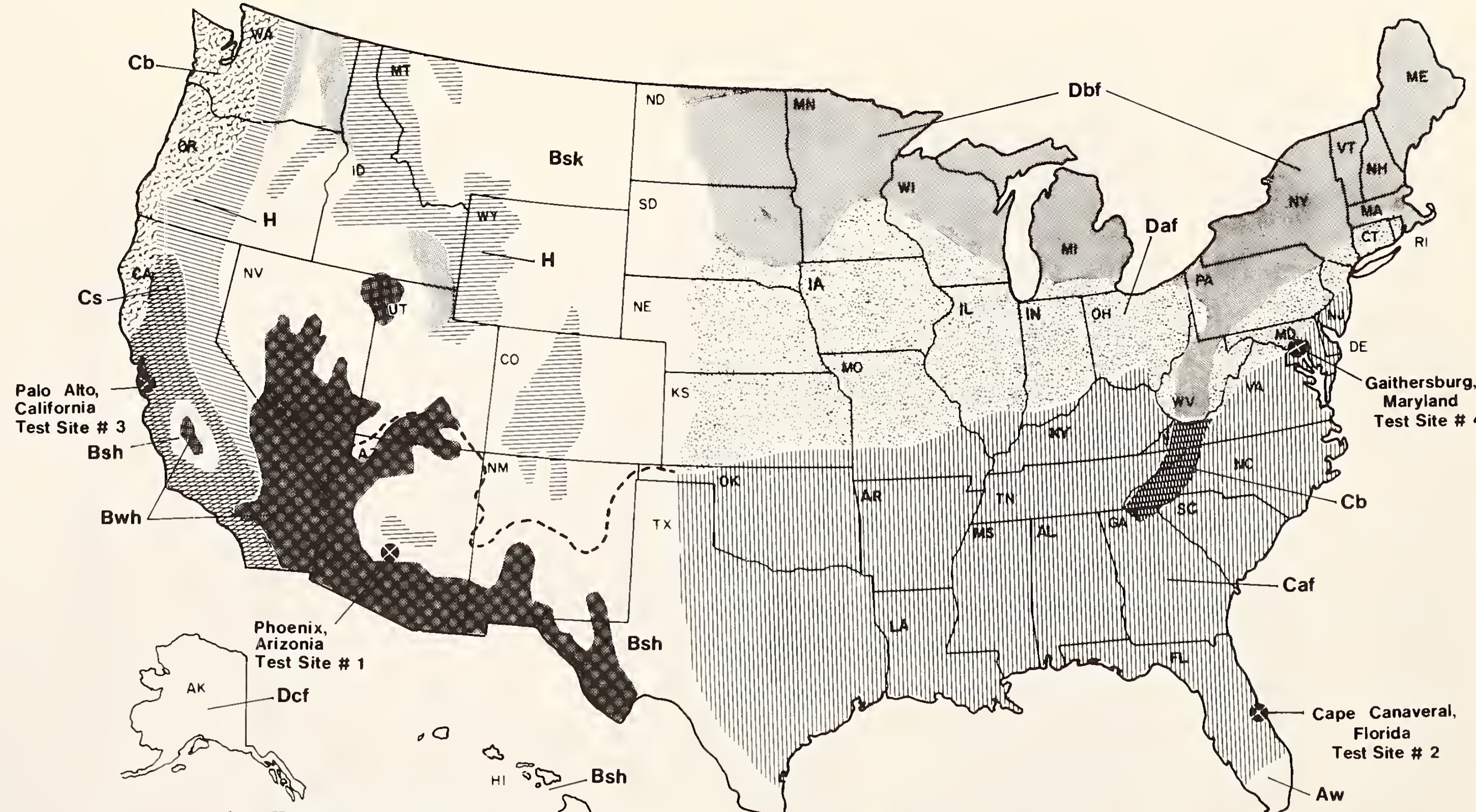
- o Hot, humid
- o High solar radiation
- o Low to moderate UV
- o Coastal, salt air environment

Lockheed Palo Alto Research Laboratory, Palo Alto, California (Test Site 3):

- o Moderate, dry
- o High solar radiation
- o Moderate UV
- o Urban environment

National Bureau of Standards, Gaithersburg, Maryland (Test Site 4):

- o Moderate, humid
- o Moderate solar radiation
- o Moderate to low UV
- o Suburban environment



A. TROPICAL RAINY—–1.1%
   Aw, Tropical Savanna

B. DRY CLIMATES—–2.9%
   Bsh, Tropical and Subtropical Steppe
   Bsk, Middle Latitude Steppe
   Bwh, Tropical and subtropical Desert

C. HUMID MESOTHERMAL—–46.2%
   Cs, Mediterranean
   Caf, Humid Subtropical
   Cb, Marine west Coast

D. HUMID MICROTHERMAL—–31.9%
   Daf, Humid Continental (warm summer)
   Dbf, Humid Continental (cool summer)
   Dcf, Subarctic

H. Undifferentiated Highlands—–0.2%

NOTE: NUMBERS REPRESENT THE PERCENT OF THE U.S. POPULATION BASED UPON THE 1970 CENSUS.

FIGURE 4-1 TEST SITE LOCATION WITHIN THE MAJOR U.S. CLIMATIC REGIONS AS CLASSIFIED BY TREWARTHA

5. DATA ANALYSIS

5.1 GENERAL

The large amounts of thermal performance, material properties and environmental data to be collected during the entire program and the associated correlations between variables will require the data reduction to be computerized. To the extent feasible, this computer data reduction and analysis will be performed concurrently with the experimental program to improve the quality of subsequent data and to identify modifications in procedures if they become apparent. A summary of the available data, and the purpose and application of the results is shown in Table 5-1.

A general description of the three categories of data analysis and correlations are described as follows.

5.2 ANALYSES OF MEASURED COLLECTOR EFFICIENCIES

The data and results of measuring thermal efficiencies of 96 collectors in a series of from 4 to 6 tests on each collector (approximately 640 efficiency graphs) will be analyzed to correlate thermal performance changes with elapsed time and the collector environment. Graphical and statistical analyses of the data will be completed to identify effects of the different test series including enhanced solar radiation by plane reflectors, thermal shock and simulated solar radiation.

A. Data Organization and Standardization

The results from the efficiency tests will be organized and arranged for correlation studies. The measured efficiency curves for the individual collectors will be plotted on a common graph with accumulated exposure days as a parameter. Linear and second-order polynomial "least-squares" curve fits to the data will be used. The primary performance parameters $F_R(\tau\alpha)_e$ and F_RU_L will be tabulated for linear fits. The appropriateness of second-order fits and the corresponding performance parameters will be considered in tabulating results. The relative scatter of efficiency values around the correlating curves will be evaluated by the Chi-square, i.e. $\Sigma_n[\eta(\text{experiment}) - \eta(\text{curve})]^2$.

B. Analyses of Change in Thermal Performance Parameters

Various trial correlations will be carried out to investigate the change with respect to time of the primary collector performance parameters. The specific correlations to be emphasized depend on the results of initial trials and analyses. The following analyses and correlations will be considered:

1. Representative graphs for individual collectors will be prepared to show the change of $F_R(\tau\alpha)$ and F_RU_L with elapsed time and the effects of the four test series. The parameters will be normalized with initial values and survey plots made to identify overall similarities and differences in trends. Graphs will also be prepared for each of the eight collector models with the results from all test sites shown collectively. The scatter in the results is a measure of site dependence. Furthermore, for each of the test sites, changes with respect to time in the normalized values will be depicted collectively for all collectors. Finally, these results will be depicted collectively for all sites and collectors. The measured changes in the

TABLE 5-1. SUMMARY OF AVAILABLE DATA, PURPOSE AND RESULTS

Available Data	Purpose
1. Solar simulator measured performance and outdoor measured performance.	1. Comparison of thermal performance measured on the solar simulator and that measured at the outdoor test sites.
2. Measured performance before and after 3-day exposure on the same collector [Series 1]; also initial performance with [Series 2] and without [Series 3] pre-exposure on same type of collector.	2. Determine requirement for 3-day pre-exposure before thermal performance measurements in ASHRAE 93-77.
3. Measured performance on the same type of collector at different outdoor test sites [all series and applicable sites].	3. Comparison check of instrumentation, technique and analysis of performance at different test locations.
4. Measured performance after dry stagnation without reflector [Series 1], no-flow [Series 2], controlled flow [Series 3] and dry stagnation with reflector [Series 4].	4. Evaluation of solar collector performance degradation and durability under different accelerated aging conditions and when exposed in different climatic regions. Validate 30-day exposure test.
5. Temperature history of internal collector components (cover plates and absorber plate) [all series and applicable sites].	5. Evaluation of test criteria for testing solar collector components in the laboratory. Comparison of test conditions with maximum and minimum temperatures specified in ASTM E44.04 test methods.
6. Weather data: Total solar radiation history UV solar radiation history Maximum daily ambient temperature Minimum daily ambient temperature Rainfall Snow, sleet, hail, etc. Wind speed and direction Pollutants [all series and sites]	6. Correlate maximum temperature of collector components with solar radiation and ambient temperature for each collector type. Correlate performance and material degradation with UV dosage. Correlate performance and material degradation with pollutant measurements.
7. Thermal shock/cold fill test results	7. Evaluation of test procedure in NBSIR 78-1305A for testing the ability of the solar collector to withstand the thermal shock induced through filling a hot collector with relatively cool heat transfer fluid during daytime start-up.
8. Thermal shock/water spray results	8. Evaluation of test procedure in NBSIR 78-1305A for testing the ability of the solar collector to withstand thermal shock caused by heavy rains falling on the heated collector.
9. Static pressure leakage test results [all four series at applicable sites]	9. Evaluation of test procedure in NBSIR 78-1305A for determining leakage and indication of damage induced by other tests.

TABLE 5-1 (Contd.)

Available Data	Purpose
10. Property measurements of material coupon specimens exposed to the same environments as solar collectors.	10. Evaluation of outdoor weathering methods of material coupons. Assess value of various measurement techniques as indicators of change.
11. Property measurements of material coupon specimens exposed to accelerated field and laboratory tests.	11. Evaluation of accelerated aging methods for materials. Assess value of various measurement techniques as indicators of change.
12. Collectors with significant degradation available for tear down unless exposure to recontinue [all series]. Results of laboratory tests on collector components.	12. Identify fundamental causes of collector performance and other changes. Estimate whether such changes would increase if aging had been continued. If possible, verify by continuing aging at some sites.
13. Incident angle modifier data for pre- and post-exposure.	13. Provide a basis for correlating change in incident angle modifier with change in thermal performance, exposure time and conditions.

efficiency parameters will be compared with the changes justified by differences in the test environments during various tests. Bands corresponding to the most and least favorable environments will be established and used to identify changes in collector performance or possible experimental error.

The results of the studies involving changes in the key performance parameters will be used to validate or refute currently-recommended test procedures. The significance of the HUD-prescribed thirty-day thermal exposure test procedure will be considered. Efficiency tests obtained with natural (outside) solar radiation will be compared for several identical collector models with the results using a solar simulator.

2. The kinetics and mechanisms of changes in the collector performance parameters will be correlated with environmental characteristics during the exposure period. The weather data base furnished by the test sites will be used along with test results to make selected cross-plots of the changes versus elapsed hours at incremental weather parameters. Tabulations showing the time above incremental solar radiation levels and ambient temperature combinations will be used to identify weather parameters which are important in correlating material property changes. The integrated total daily radiation over the elapsed exposure time will be compared with elapsed time at incremental exposure levels as a means of correlating changes. Comparisons will be made to establish possible dependence on humidity and UV levels, design configurations, mounting and array effects. The differences in material property deterioration resulting from the four test series, which include the effects of thermal shock, solar radiation (and UV) enhancement by reflectors, etc., will be evaluated.

   After the stronger correlating weather parameters have been identified, analyses will be carried out in an attempt to establish functional dependence on the environmental parameters. For example, plots will be made to determine whether the key collector performance parameters have an Arrhenius type rate dependence on solar radiation and stagnation temperature.

   Data and results from the test program will be compared with the limited results available from actual field experience. Trends in the change of collector parameters from the different test procedures will be compared with data from actual operating systems to determine which test series corresponds closer to actual aging trends.

5.3 CHANGES IN MATERIAL PROPERTIES

Property changes in samples of solar collector materials will be analyzed in an approach similar to that described above. The effects of cover and absorber material deterioration on the thermal performance of typical solar collectors will be evaluated with a mathematical model.

A. Kinetics of Material Property Changes

The primary properties of material samples that will be considered are absorptance (α), emittance (ε) and solar transmittance (τ_s). Investigations will be made to correlate property changes with exposure time above selected values of solar radiation and ambient temperatures. The effects of concentrated radiation will be evaluated and compared with the conventional aging methods and with field experience. Investigations will be made to identify possible dependences on regional weather characteristics such as humidity and UV level. Similar studies may be performed using the non-routine property measurements discussed in 2.3.4.

B. Effect of Material Property Changes on Collector Thermal Performance

Measured changes in material properties will be used in a mathematical model to calculate corresponding changes in the thermal efficiency of the types of collectors used in the test program. The accuracy of the mathematical model will be established by comparing results with the initial measured efficiencies. Subsequently, the primary performance parameters, $F_R(\tau\alpha)$ and F_RU_L, will be calculated on the basis of measured values of sample material properties and compared with those from the collector efficiency measurements after various exposure times. While most of the collectors used in the test program are of conventional design, three (C, G and H) have unusual design features which may necessitate a more approximate mathematical model. In these cases, the experimental results will be used to identify effective properties such as solar transmittance and convection suppression effects, and confirm the model.

The overall results will be reviewed and recommendations made as to the applicability of the material exposure procedures for predicting changes in materials during long-term collector operation.

5.4 Investigation of Stagnation Temperatures of Collector Materials

Analytical and experimental data will be evaluated to compare the stagnation temperatures of absorbers, covers and insulating materials for conventional tube-in-sheet collectors. This study is useful to apply modeling results to collector designs which are different from those used in the program.

A. Mathematical Model

In contrast to thermal performance models, transient effects, longwave radiation transmittance and temperatures of specific components of the collector are important considerations in developing an accurate model for predicting stagnation temperatures. A tentative mathematical model incorporating these essential features currently under development will be compared to experimental results and, if necessary, further developed to support the overall objectives of the research program.

B. Experimental Applications

It is anticipated that stagnation temperature is an important parameter in correlating changes in material properties. The experimentally-verified mathematical model would then become an essential tool to develop accelerated aging procedures. The model, consisting of a FORTRAN computer code and supporting documentation, would likely be useful to establish the long-term durability of collector materials.

6. CURRENT STATUS

This chapter summarizes the status (as of August 1, 1980) of the various elements of the reliability/durability test program described in this plan and of related solar collector materials test programs also being conducted at NBS.

6.1 THIS PROGRAM

The status of various program elements is summarized in Table 6-1. As a result of thermal performance test results obtained following the exposure of full size solar collectors for periods of up to 120 days (>17,000 $KJ/m^2 \cdot day$), the outdoor exposure of the Series 1 and Series 2 collectors as well as the small scale "real time" cover and absorber specimens has been extended for an additional 240 days. Additional property measurements will be made following that exposure. Materials level tests will also be conducted with somewhat less extreme combined temperature and humidity exposure conditions because of the severe degradation observed with several materials [27]. Exposure to combined temperature, radiation and humidity using the accelerated weathering machine referred to in 2.3.2.4.3 will also be studied.

6.2 RELATED NBS WORK

An experimental program was recently completed in which the properties of ten types of cover materials were evaluated following exposure to natural weathering, heat aging and combined heat and xenon-arc radiation [28]. Properties measured included solar energy transmittance, dimensional stability, warpage and dirt retention. Laboratory work to aid in the development of evaluation standards for absorber materials [29] has also been completed. In this program, coupon specimens of twelve different absorber materials were subjected to various types of laboratory exposure (temperature, moisture, xenon-arc radiation) and to natural weathering in simulated collectors. Optical properties (absorptance and emittance) and visually detectable changes were determined following this exposure. Data from these two programs are being incorporated into the analyses being performed in the present program. Comparisons will be made to ascertain that the degradation observed at the materials level is indicative of that which occurs in actual solar collectors.

TABLE 6-1 TEST PROGRAM STATUS*

Element Evaluated	Exposure Test Condition	Test Reference Paragraph	Status
Full Size Solar Collector	Outdoor Exposure	2.2.1	120 day exposure completed. Will expose an additional 240 days.
	Indoor Simulator Exposure	2.2.2	Completed.
	Indoor Simulator Comparability	2.2.3	Completed.
Cover Material	Small Scale Sample - "Real Time"	2.3.2.1.1	240 day exposure completed. Will expose an additional 240 days.
	Full Size Collector - "Real Time"	2.3.2.1.2	Status per 2.2.1.
	Solar Simulator	2.3.2.2	Completed.
	Accelerated Outdoor	2.3.2.3	60 day exposure completed.
	Laboratory: Temperature	2.3.2.4.1	2,000 hour exposure completed at 70°C. 1,000 and 2,000 hour exposures underway at 90°C and 125°C.
	Laboratory: Temperature & Humidity	2.3.2.4.2	90°C completed. 1,000 and 2,000 hour exposures at 70°C underway. 50°C exposure to be done.
	Laboratory: Temperature & Radiation	2.3.2.4.3	2,000 hour exposure at 90°C completed. 1,000 and 2,000 hour exposure at 70°C underway.
Absorber Material	Small Scale Sample - "Real Time"	2.3.3.1.1	240 day exposure completed. Will expose an additional 240 days.
	Full Size Collector - "Real Time"	2.3.3.1.2	Status per 2.2.1.
	Solar Simulator	2.3.3.2	Completed.
	Accelerated Outdoor	2.3.3.3	60 day exposure completed.
	Laboratory: Temperature	2.3.3.4.1	Completed.
	Laboratory: Temperature & Humidity	2.3.3.4.2	Completed.
	Laboratory: Temperature & Radiation	2.3.3.4.3	Completed. Additional testing to be done at lower humidity levels.
	Laboratory: Thermal Cycling	2.3.3.4.4	To be done.

*As of August 1, 1980.

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APPENDIX A. DETAILED DATA REQUIREMENTS

Form 105, Coupon Specimen Log Sheet

Form 201, Instantaneous Efficiency Data

Form 201A, Instantaneous Efficiency Plot

Form 202, Incident Angle Modifier Data

Form 202A, Incident Angle Modifier Plot

Form 203, Coupon Data Form

Form 204, Coupon Optical Properties Data Sheet

Form 301, Monthly Test Site Weather Conditions

Form 302, Maximum Daily Cover Plate Box and Absorber Box Temperature

Form 303, Maximum Daily Collector Absorber Plate Temperature

Form 304, Maximum Daily Collector Absorber Plate Temperature

Form 305, Exposure Conditions for 4-Hour 300 $Btu/ft^2 \cdot hr$ Exposure

Form 306, Pollutants

Amendment A-1, Supplementary Data

COUPON SPECIMEN LOG SHEET

Specimen Code No.	Date	Time	Test Description	Sample Disposition

Form 105

INSTANTANEOUS EFFICIENCY DATA

Date ____________________

Number of 1500 Btu/ft^2 days at Time of Test ____________________

Collector Code Number ____________________

Test Site ____________________

Form Filled Out By ____________________

RUN NO.	DATE DAY NO.	SOLAR TIME hr:min		* SOLAR FLUX	* DIFFUSE SOLAR	* MASS FLOW	* WIND SPEED	* AMBIENT TEMP.	* INLET TEMP.	* EXIT TEMP.	* TEMP. DIFF.	TILT ANGLE	AZIMUTH ANGLE	INCIDENT ANGLE	** EFFICIENCY	$\frac{t_{f,i}-t_a}{I_t}$
		Start	Finish	BTU/hr ft^2	BTU/hr ft^2	lbm/hr	mph	°F	°F	°F	°F	deg.	deg.	deg.	%	°F-ft^{2}hr/BTU
11 12 13	14 15 16	17 18 19 20	21 22 23 24	25 26 27	28 29 30	31 32 33	34 35	36 37 38 39 40	41 42 43 44 45	46 47 48 49 50	51 52 53 54	55 56 57 58	59 60 61 62	63 64 65 66	67 68 69 70	71 72 73 74 75

* Average values

** $\eta_g = q_u/A_g/I_t$

Form 201

Experimental Data

Instantaneous Efficiency Plots

Baseline

First Order η = ____________

Second Order η = ____________

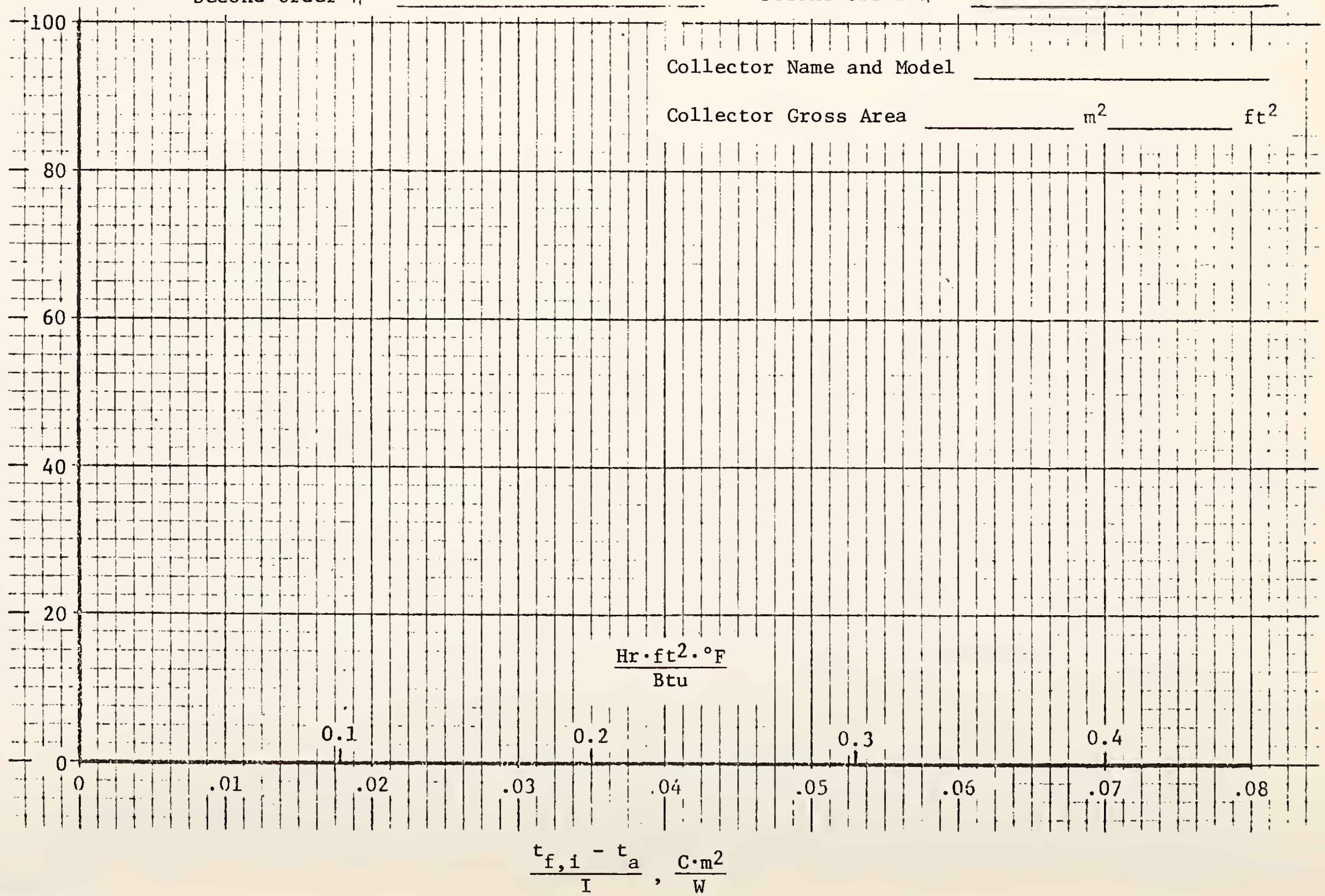
Post Stagnation

First Order η = ____________

Second Order η = ____________

Collector Name and Model ____________

Collector Gross Area ________ m^2 ________ ft^2



Form 201A

INCIDENT ANGLE MODIFIER DATA

Date ________________

Collector Code Number ________________

Test Site ________________

Form Filled Out By ________________

Number of 1500 Btu/ft^2 days at Time of Test ________________

RUN NO.	DATE DAY NO.	SOLAR TIME hr:min Start	SOLAR TIME hr:min Finish	* SOLAR FLUX	* DIFFUSE SOLAR	* MASS FLOW	* WIND SPEED	* AMBIENT TEMP.	* INLET TEMP.	* EXIT TEMP.	* TEMP. DIFF.	TILT ANGLE	AZIMUTH ANGLE	INCIDENT ANGLE	** EFFICIENCY	$\frac{t_{f,i}-t_a}{I_t}$	MODIFIER
				BTU/hr ft^2	BTU/hr ft^2	lbm/hr	mph	°F	°F	°F	°F	deg.	deg.	deg.	%	°F-ft^{2}hr/BTU	
11 12 13	14 15 16	17 18 19 20	21 22 23 24	25 26 27	28 29 30	31 32 33	34 35	36 37 38 39 40	41 42 43 44 45	46 47 48 49 50	51 52 53 54	55 56 57 58	59 60 61 62	63 64 65 66	67 68 69 70	71 72 73 74 75	76 77 78 79 80

*Average values

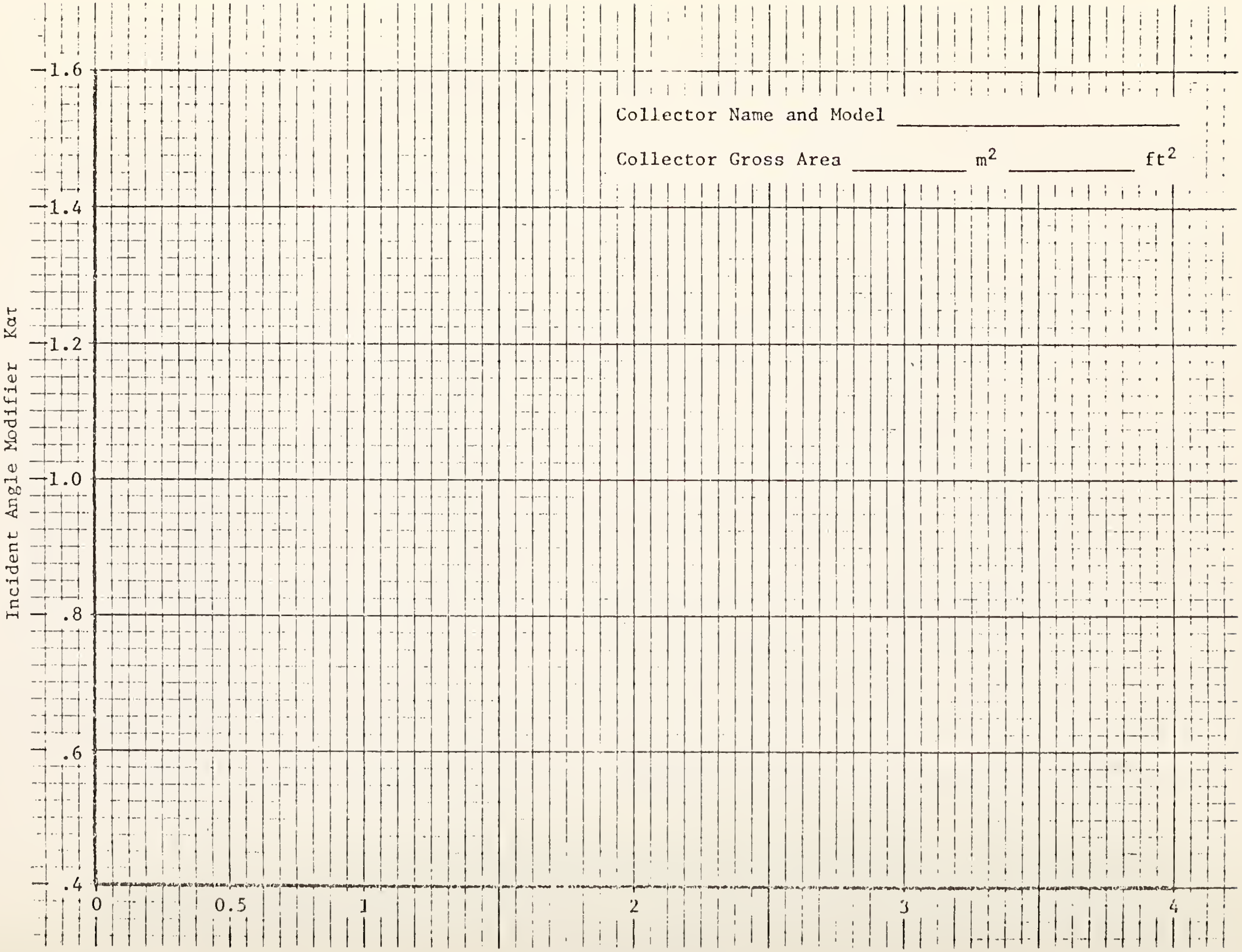
$^{**}\eta_g = q_u/A_g / I_t$

Form 202

Incident Angle Modifier Plot

Collector Name and Model ____________________

Collector Gross Area __________ m^2 __________ ft^2



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Form 202A

COUPON DATA FORM

(use when changes are observed or measurements made)

Test Site ______________________________ Date ____________________

Total Days Exposure (1500 Btu/ft^2 minimum) _________________________

Total Calendar Days Exposure _________________________

Date Exposure Started _________________________

Form Filled Out By _________________________

Cover Materials

Specimen Code No.	Visual Change Report	Transmission Measured*		Comments
		Yes	No	

Absorber Coatings

Specimen Code No.	Visual Change Report	α, ε Measured*		Comments
		Yes	No	

*If yes, report on Form 204

Form 203

COUPON OPTICAL PROPERTIES DATA SHEET

Test Site ______________________ Date ______________

Form Filled Out By ____________________

Cover Coupons							
Sample Code No.	Number Removed for Test	Samples Returned to Test		Days Exposure 1500 Btu/ft^2	Calendar Days Exposure	* τ	Comments
		Yes	No				

Absorber Coating Coupons								
Sample Code No.	Number Removed for Test	Samples Returned to Test		Days Exposure 1500 Btu/ft^2	Calendar Days Exposure	* α	* ε	Comments
		Yes	No					

*Describe method (equipment) used

Form 204

MONTHLY TEST SITE WEATHER CONDITIONS
(Justify Numbers Right)

Date ____________________

Test Site ____________________

Form Filled Out By ____________________

Month ____________________

Year ____________________

DAY OF MONTH	* AMBIENT TEMPERATURE °F		* HUMIDITY %		SOLAR RADIATION BTU/FT^2·DAY					PEAK SOLAR RADIATION MEAN FOR PEAK HOUR			PRECIPITATION INCHES			** AVERAGE WIND DAILY VELOCITY	SKY AND WEATHER CONDITIONS (VISUAL)
	HIGH	LOW	HIGH	LOW	TOTAL W/O REFLECTOR	*** TOTAL WITH REFLECTOR	*** ULTRA-VIOLET	DIFFUSE	TILT ANGLE DEG	PEAK BTU/FT^2·HR	TEMP °F	MEAN WIND VELOCITY MPH	RAIN	SNOW	OTHER	MPH	
11 12	13 14 15	16 17 18	19 20 21	22 23	24 25 26 27	28 29 30 31	32 33 34 35	36 37 38 39	40 41	42 43 44	45 46 47	48 49 50	51 52 53 54	55 56	57 58	59 60 61	62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
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Form 301

*Over 24-hour day

**Daylight average

***If measured

MAXIMUM DAILY COVER PLATE BOX AND ABSORBER BOX TEMPERATURES

Date ________________

Test Site ________________ Month ________________

Form Filled Out By ________________ Year ________________

DAY	COVER BOX CODE NUMBER										ABSORBER BOX	
	**T C 4	T E 4	T G 4	T H 4	T J 4	T K 4	T L 4	T M 4	T N 4	T O 4	SEL	NON SEL
	* °F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
11 12	13 14 15 16	17 18 19 20	21 22 23 24	25 26 27 28	29 30 31 32	33 34 35 36	37 38 39 40	41 42 43 44	45 46 47 48	49 50 51 52	53 54 55	56 57 58
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31												
11 12	13 14 15 16	17 18 19 20	21 22 23 24	25 26 27 28	29 30 31 32	33 34 35 36	37 38 39 40	41 42 43 44	45 46 47 48	49 50 51 52	53 54 55	56 57 58

SEL - Selective Surface Side NON-SEL - Non-Selective Surface Side

* °F to nearest whole number - justify numbers right

**Test Site Number: 1-DSET; 2-FSEC; 3-LMSC; 4-NBS

Form 302

MAXIMUM DAILY COLLECTOR ABSORBER PLATE TEMPERATURE

Date ____________________ Month ____________________

Test Site ____________________ Year ____________________

Form Filled Out By ____________________

DAY*	COLLECTOR CODE NUMBER															
	SERIES 1								SERIES 2							
	A 1	B 1	C 1	D 1	E 1	F 1	G 1	H 1	A 2	B 2	C 2	D 2	E 2	F 2	G 2	H 2
	**°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
11 12	13 14 15	16 17 18	19 20 21	22 23 24	25 26 27	28 29 30	31 32 33	34 35 36	37 38 39	40 41 42	43 44 45	46 47 48	49 50 51	52 53 54	55 56 57	58 59 60
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*Site Code Number: 1-DSET; 2-FSEC; 3-LMSC; 4- NBS

**°F to nearest whole number - justify numbers right

Form 303

MAXIMUM DAILY COLLECTOR ABSORBER PLATE TEMPERATURE

Date ______________ Month ______________

Test Site ______________ Year ______________

Form Filled Out By ______________

DAY	COLLECTOR CODE NUMBER															
	SERIES 3								SERIES 4							
	*A 3	B 3	C 3	D 3	E 3	F 3	G 3	H 3	A 4	B 4	C 4	D 4	E 4	F 4	G 4	H 4
	**°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
11 12	13 14 15	16 17 18	19 20 21	22 23 24	25 26 27	28 29 30	31 32 33	34 35 36	37 38 39	40 41 42	43 44 45	46 47 48	49 50 51	52 53 54	55 56 57	58 59 60
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*Site Code Number: 1-DSET; 2-FSEC; 3-LMSC; 4-NBS
**°F to nearest whole number - justify numbers right

Form 304

EXPOSURE CONDITIONS FOR
4-HOUR 300 BTU/FT^2·HR EXPOSURE

Collector Code Number ____________________________

#1500 Btu/ft^2·day - Exposure Days ______________________

Test Site ____________________________

Form Filled Out By ____________________________

Date of 4-Hour Exposure ______________________

* Solar Time hr:min	** I_t	T_{amb} (°F)	Wind (mph)
21 22 23 24	25 26 27	28 29 30	31 32 33
:			
:			
:			
:			
:			
:			
:			
:			
:			

* Record at half hour intervals during the 4-hour exposure period.
**Instantaneous solar flux (Btu/ft^2·hr).

Form 305

POLLUTANTS

(To the extent available from a local EPA or other facility)

Test Site ______________________________ Date ____________________

Month ____________________

Form Filled Out By ______________________________ Year ____________________

Day of Month	Pollution					
	Particulate $\mu g/m^3$	Sulfur Dioxide $\mu g/m^3$	Carbon Dioxide mg/m^3	Oxident/ Ozone $\mu g/m^3$	Nitrogen Dioxide $\mu g/m^3$	Total Hydrocarbons $\mu g/m^3$
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
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Form 306

AMENDMENT A-1
SUPPLEMENTARY DATA

The following detailed measurements shall be made and reported in addition to the data previously requested

1. Solar Radiation
   a) The irradiance of the incident solar radiation at the exposure tilt angle shall be measured at 5 minute intervals or less. A daily plot of irradiance (W/m^2) as a function of time during the sunlight hours shall be provided as indicated in Figure A-1.

   b) A determination of the number of hours each month with irradiance values greater than 950, 1000, 1050, and 1100 W/m^2 shall be made. Time intervals at each of the specified irradiance levels must exceed 15 minutes to be counted. In addition the time shall be segregated by occurrence above ambient temperature levels of 15°, 20°, 25°, and 30°C. The data shall be reported by total hours per month as indicated in Table 1.

   c) The integrated total daily radiation in W hr/m^2 shall be determined and reported in tabular form for each month as illustrated in Table 2. The data shall be obtained from measurements made at 5 minute intervals or less.

2. Ambient Temperature
   a) Ambient temperature measurements shall be made at intervals not greater than 30 minutes during the sunlight hours. The measurements shall be made at coincident times with the plate temperature measurements described in Section 3(a) below. The data shall be reported in daily plots of the temperature versus time as shown in Figure A-1.

3. Absorber Plate Temperature
   a) Absorber plate temperatures shall be made at intervals of not greater than 30 minutes during the sunlight hours. The data shall be obtained for each Series 1 and Series 4 collector of each manufacturer. The data shall be plotted on the same curve as the ambient temperature and irradiance shown in Figure A-1.

4. Wind
   a) The average hourly wind velocity for the sunlight hours shall be measured and reported for each day. The data shall be reported as a curve plotted as shown in Figure A-1.

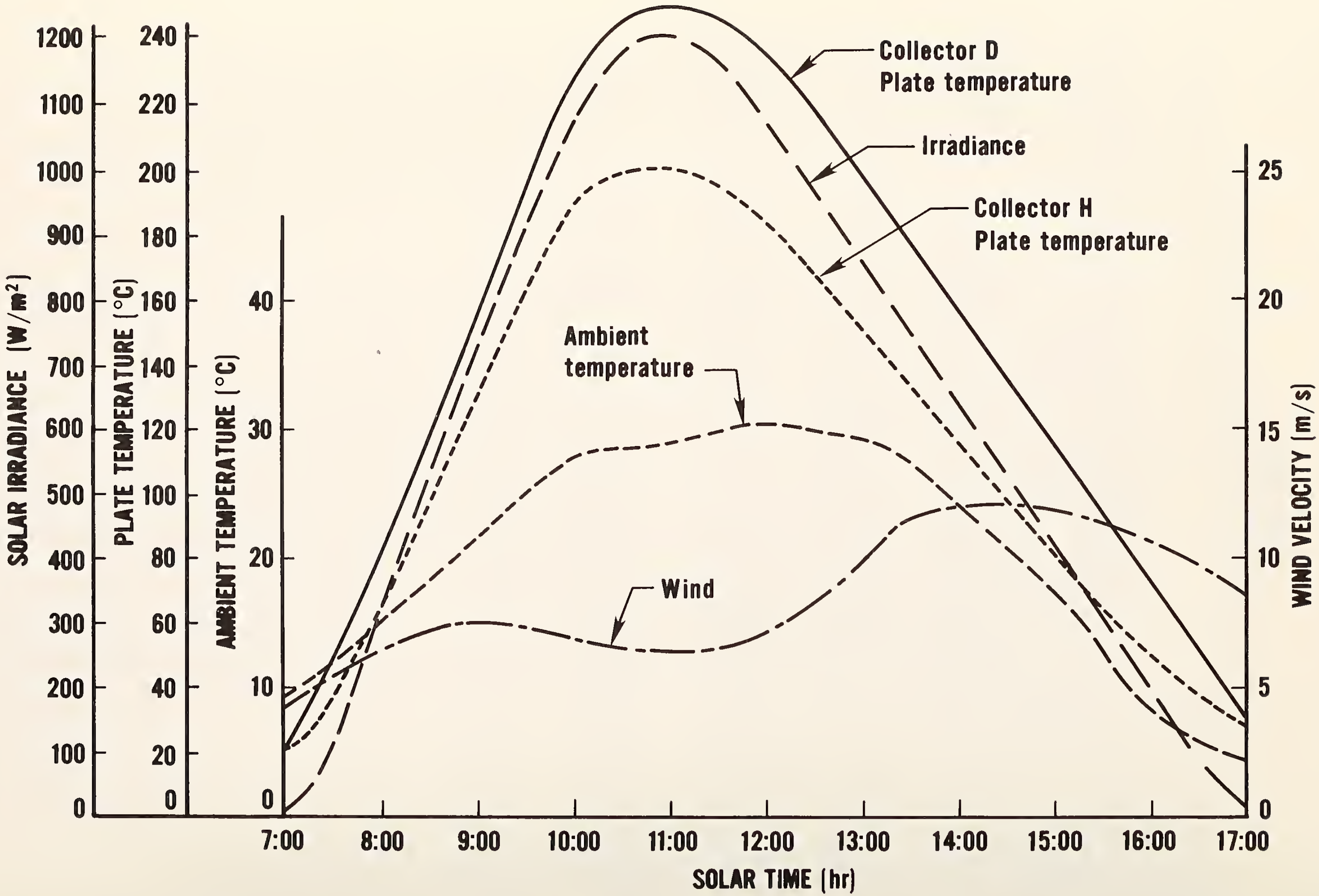

FIGURE A-1 DAILY PLOT FOR COLLECTOR PLATE TEMPERATURE AND EXPOSURE CONDITIONS (TYPICAL)

Ambient Temp °C	Irradiance (W/m^2)			
	950	1000	1050	1100
15				
20				
25				
30				

Table 1 Hours of exposure with conditions exceeding the conditions shown, June 1979.

MONTHS 1979

Total Daily Radiation ($W.hr/m^2$)	J	F	M	A	M	J	J	A	S	O	N	D
< 4700												
4700 to 5000												
5000 to 5500												
5500 to 6000												
6000 to 6500												
6500 to 7000												
7000 to 7500												
7500 to 8000												
8000 to 8500												
> 8500												

Table 2 Number of days with total daily radiation in the range of values shown.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1981 340-997/364

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBS TN 1136	2. Performing Organ. Report No.	3. Publication Date January 1981

4. TITLE AND SUBTITLE

NBS Solar Collector Durability/Reliability Test Program Plan

5. AUTHOR(S)

David Waksman, Elmer Streed, James Seiler

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

Office of Solar Applications for Buildings
Department of Energy
Forrestal Building
Washington, DC 20585

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The test program described in this plan is designed to evaluate both approved and proposed solar collector test procedures and to correlate laboratory, accelerated field and simulated operational exposures with actual field data.

The tests and exposure procedures described herein are intended to determine the influence of environmental exposure parameters that could affect the degradation of solar collectors and their materials. They are also intended, to the extent possible, to provide a correlation between changes that occur at the materials and the collector component levels. It is expected that the data obtained through their use will lead to more meaningful reliability/durability tests for solar collectors and their materials.

A wide variety of commercially available solar collectors and multiple material coupons of collector components are being tested at sites in different climatic regions. Appropriate laboratory tests are being conducted during the same time frame to determine physical and material properties for comparison with field test data and operational collector experience. The data obtained from these tests will be analyzed and correlated with that obtained from the current Government Demonstration Program and other related Government-sponsored programs.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Accelerated aging; durability; environmental exposure; reliability; solar collectors; solar materials; stagnation testing.

13. AVAILABILITY

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