DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150511

INDOOR THERMAL PERFORMANCE EVALUATION OF DAYSTAR SOLAR COLLECTOR

Prepared by Wyle Laboratories, Solar Energy Systems Division, Huntsville, Ala.

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Huntsville, Alabama 35805

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George C. Marshall Space Flight Center, Alabama 35812

for the U. S. Department of Energy

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16. ABSTRACT

This report presents the test procedures used and results obtained from a test program to obtain thermal performance data on a Daystar Model 21B, S/N 02210, Unit 2, liquid solar collector under simulated conditions. The test article is a flat plate solar collector using liquid as a heat transfer medium. The absorber plate is copper and coated with black paint. Between the tempered low iron glass and absorber plate is a polycarbonate trap used to suppress convective heat loss. The collector incorporates a convector heat dump panel to limit temperature excursions during stagnation. The following tests were conducted:

a. Collector thermal efficiency
b. Collector time constant
c. Collector incident angle modifier
d. Collector heat loss coefficient
e. Collector stagnation.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

1.0 PURPOSE

The purpose of this report is to present the test procedures used and test results obtained during a collector evaluation test program. The test program was conducted to obtain thermal performance data on a Daystar Model 21B, S/N 02210, Unit 2, liquid solar collector under simulated conditions. The tests were conducted utilizing the Marshall Space Flight Center Solar Simulator in accordance with the test requirements specified in Reference 2.1 and the procedures contained in Reference 2.2.

2.0 REFERENCE

2.1	ASHRAE 93-P	Method of Testing Solar Collectors Based on Thermal Performance
2.2	MTCP-DC-SHAC-414	Test Procedure for the Performance Evaluation of the Daystar Solar Collector
2.3	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator Facility

3.0 MANUFACTURER

Daystar Corporation
41 Second Avenue
Burlington, Massachusetts 01803

3.1 Description of Test Specimen

The test article is a flat plate solar collector using liquid as the heat transfer medium. The absorber plate is copper and coated with black paint. Between the tempered low iron glass and absorber plate is a polycarbonate trap used to suppress convective heat loss. The collector incorporates a convector heat dump panel to limit temperature excursions during stagnation. The absorber plate has the aborption coefficient of .985, the glass cover has the transmission coefficient of .90 and the effective transmission coefficient of the heat trap is .935. Hence, the product of transmissitivity and absorptivity will be .829. The overall dimension of the collector is 44 1/2" x 80 3/4" x 5 1/4". The gross surface area is 24.95 square feet with an aperture area of 21 square feet. The collector weighs approximately 145 pounds.

4.0 SUMMARY

This program was conducted to evaluate the thermal performance of a Daystar liquid collector under simulated conditions. The following tests were conducted:

1) Collector Thermal Efficiency Test: The results of this test are presented in Table II and Figure 6.

2) Collector Time Constant Test: The results of this test are presented in Table III and Figure 7.

3) Collector Incident Angle Modifier Test: The results of this test are presented in Table IV and Figures 8 and 9.

4) Collector Heat Loss Coefficient Test: The results of this test are presented in Table V.

5) Collector Stagnation Test: The results of this test are presented in Tables VI, VII and VIII.

5.0 TEST CONDITIONS AND TEST EQUIPMENT

5.1 Ambient Conditions

Unless otherwise specified herein, all tests were performed at ambient conditions existing in Building 4619 at the time of the tests.

5.2 Instrumentation and Equipment

All test equipment and instrumentation used in the performance of this test program comply with the requirements of MSFC-MMI-5300.4 C, Metrology and Calibration. Table I contains instrumentation identification and data acquisition connection data. Figures 1 and 2 depict instrumentation locations. A listing of the equipment used in each test follows.

Collector Stagnation Test

Apparatus	Manufacturer/Model	Range/Accuracy*
Reference Junction	Pace/150	150 ±1°F
Thermocouple	Supplied by Collector Manufacturer, Type T	0-700°F ±1°F
Pyranometer	Eppley - PSP	0-800 BTU/Ft^2·Hr ±3%

Collector Time Constant Test

Apparatus	Manufacturer/Model	Range/Accuracy*
Liquid Loop	MSFC Supplied	.1-1.2 GPM
Reference Junction	Pace/150	150 ±1°F
Thermocouple	Supplied by Collector Manufacturer, Type T	0-700°F ±1°F
Flowmeter	Foxboro/1/2-2 81T361	.1-1.2 ±1% GPM FS
Resistance Thermometer	TSI 7082-3	0-500 ±.05°F
Thermopile	Medtherm	0-20°F/±.05°F
Pyranometer	Eppley- PSP	0-800 BTU/Ft^2·Hr ±3%
Directional Anenometer	MSFC Supplied	0-30 MPH ±.5% FS

*These are instrument accuracies only. Does not include data acquisition system error.

5.0 TEST CONDITIONS AND TEST EQUIPMENT (Continued)

5.2 Instrumentation and Equipment (Continued)

Collector Time Constant Test (Continued)

Apparatus	Manufacturer/Model	Range/Accuracy*
Strip Chart Recorder	Mosley 680	N/A
Solar Simulator	MSFC Supplied	See SHC 3006

Collector Efficiency Test

Apparatus	Manufacturer/Model	Range/Accuracy*
Liquid Loop	MSFC Supplied	.1-1.2 GPM
Reference Junction	Pace/150	150 ±1°F
Thermocouple	Supplied by Collector Manufacturer, Type T	0-700°F ±1°F
Flowmeter	Foxboro/1/2-2 81T361	.1-1.2 ±1% GPM FS
Resistance Thermometer	TSI 7082-3	0-500 ±.05°F
Thermopile	Medtherm	0-20°F/±.05°F
Pyranometer	Eppley - PSP	0-800 BTU/Ft^2·Hr ±3%
Directional Anenometer	MSFC Supplied	0-30 MPH ±.5% FS
Strip Chart Recorder	Mosley 680	N/A
Floor Fan	MSFC Supplied	N/A
Solar Simulator	MSFC Supplied	See SHC 3006

Collector Incident Angle Modifier Test

Apparatus	Manufacturer/Model	Range/Accuracy*
Liquid Loop	MSFC Supplied	.1-1.2 GPM
Reference Junction	Pace/150	150 ±1°F
Thermocouple	Supplied by Collector Manufacturer, Type T	0-700°F ±1°F
Flowmeter	Foxboro/1/2-2 81T361	.1-1.2 ±1% GPM
Resistance Thermometer	TSI 7082-3	0-500 ±.05°F

5.0 TEST CONDITIONS AND TEST EQUIPMENT (Continued)

5.2 Instrumentation and Equipment (Continued)

Collector Incident Angle Modifier Test (Continued)

Apparatus	Manufacturer/Model	Range/Accuracy*
Thermopile	Medtherm	0-20°F/±.05°F
Pyranometer	Eppley - PSP	0-800 BTU/Ft^2·Hr ±3%
Directional Anenometer	MSFC Supplied	0-30 MPH
Strip Chart Recorder	Mosley 680	N/A
Solar Simulator	MSFC Supplied	See SHC 3006

Collector Heat Loss Coefficient Test

Apparatus	Manufacturer/Model	Range/Accuracy*
Heater	Supplied by Collector Manufacturer	N/A
Thermocouple	Supplied by Collector Manufacturer, Type T	0-700°F ±1°F
Reference Junction	Pace/150	150 ±1°F
Wattmeter	MSFC Supplied	2000 Watt ±1%

5.3 Data Acquisition System

A Hewlett-Packard digital computer system was furnished and operated by MSFC for the data acquisition system. Unless otherwise specified in the test request, the data accuracy was the best obtainable with the available equipment.

5.4 Flux Levels and Wind Speed

Combined simulations of solar flux levels and wind speed conditions were prescribed test conditions to be imposed during these tests. Prior to initiation of testing, a new set of simulator lamps (GE tungsten-halogen ELH lamps) were installed in the simulator array. Consequently, total heating rate surveys were made on the test plane to establish the uniformity and total heat flux levels. Results of these measurements are plotted in Figure 3 to show the typical flux contours. This plot indicates the degree of heat flux uniformity achieved over the test plane. An additional plot was prepared from the heat flux measurements to show the average intensity level over the test area as a function of the lamp array power controller dial setting. This plot is presented in Figure 4 and was used during testing to set the prescribed heat flux level.

5.0 TEST CONDITIONS AND TEST EQUIPMENT (Continued)

5.4 Flux Levels and Wind Speed (Continued)

It is noted that, during the incident angle modifier test, the heat flux level was determined including effects of the insolation angle and reflections from surroundings. Correction was made for the insolation angle by the cosine law. Correction factors due to reflections from surroundings were predetermined to be 2%, 11% and 35% for east-west angles of 45, 60 and 75°, respectively.

Floor fans were utilized to simulate wind speeds to 7 1/2 MPH. Wind velocity distribution measurements at the collector surface are shown in Figure 5.

6.0 REQUIREMENTS AND PROCEDURES

6.1 Collector Thermal Efficiency Test

Tested by ____________________
Started ____________________
Completed ____________________

6.1.1 Test Requirements

The thermal performance evaluation data shall be obtained at inlet temperatures of 0, 25, 50 and 100°F above ambient temperature, at a liquid flow rate of 308.7 lb/hr of 50% by volume or 52.7% by weight ethylene glycol water, at insolation rates of 150, 200, and 300 BTU/Ft^2·Hr and a wind speed of 7.5 mph. In addition, three data points without wind were also obtained. The following data were recorded during the test at each test condition.

1. Absorber surface temperature - 15 locations.
2. Heat rejection loop temperature - 8 locations.
3. Ambient temperature.
4. Collector inlet liquid temperature.
5. Collector outlet liquid temperature.
6. Collector differential temperature.
7. Liquid flow rate.
8. Insolation rate.

6.1.2 Test Procedure

1. Mount test specimen on test table at a 45° angle with respect to the floor.
2. Start liquid flow loop and establish a flow rate of 308.7 Lb/Hr.
3. Establish the wind speed of 7.5 mph.
4. Power up simulator in accordance with Reference 2.3 and establish the required flux level.
5. Establish the required inlet temperature.
6. Record data for a minimum of five minutes at above stabilized conditions.
7. Repeat steps 4, 5, and 6 to change the flux level and liquid inlet temperature as necessary until data has been obtained for each test condition specified.

6.0 REQUIREMENTS AND PROCEDURES (Continued)

6.1 Collector Thermal Efficiency Test (Continued)

6.1.3 Test Results

The results obtained during these tests are contained in Figure 6 and Table II.

6.0 REQUIREMENTS AND PROCEDURES (Continued)

6 2 Collector Time Constant Test

Tested by ________________
Started ________________
Completed ________________

6.2.1 Test Requirements

According to ASHRAE 93-P, the time constant test shall be conducted by abruptly reducing the flux level to zero. The inlet temperature shall be kept to within ±2°F of ambient, or the best achievable with the existing system, with a liquid flow rate of 308.7 Lb/Hr. The differential temperature across the collector were recorded to determine the time required to reach the condition of

$$\frac{Te - Ti}{Te_{ini} - Ti} = .368$$

where

Te = Outlet temperature

Te_{ini} = Initial outlet temperature

Ti = Inlet temperature

The following data were recorded during the test:

1. Absorber surface temperature 15 locations.
2. Heat rejection loop temperature - 8 locations.
3. Ambient temperature.
4. Collector inlet temperature.
5. Collector outlet temperature.
6. Collector differential temperature - Thermopile.
7. Liquid flow rate.
8. Insolation rate.

6.2.2 Test Procedure

1. Mount the collector on test table at 45° from the horizontal and assure that solar simulator surface is parallel to the collector surface.

2. Adjust the liquid flow rate to 308.7 Lb/Hr.

6.0 REQUIREMENTS AND PROCEDURES (Continued)

6.2 Collector Time Constant Test (Continued)

6.2.2

3. Adjust the liquid inlet temperature to within $\pm 2°F$ of ambient.

4. Adjust the flux level to 250 $BTU/Ft^2 \cdot Hr$.

5. Monitor the differential temperature on strip chart recorder.

6. Allow the system to stabilize at above conditions for at least 5 minutes.

7. Turn off the solar simulator.

8. Monitor the differential temperature until the ratio of

$$\frac{Te - Ti}{Te_{ini} - Ti} = \text{is less than } .30.$$

6.2.3 Test Results

The result obtained during this test is contained in Figure 7 and Table III.

6.0 REQUIREMENTS AND PROCEDURES (Continued)

6.3 Collector Incident Angle Modifier Test

Tested by ____________________
Started ____________________
Completed ____________________

6.3.1 Test Requirement

The collector incident angle modifier shall be conducted at north-south radiation incident angles of 0, 15, 30 and 45°. At 0 and 45° angles, the east-west (angle changes parallel to heat trap folds and along constant length station) radiation incident angle were 0, 30, 45, 60 and 75°. At 15 and 30° north-south incident angles the east-west angles were 0°. The liquid flow rate will be 308.7 Lb/Hr with the inlet temperature controlled to within ±2°F of ambient, or the best achievable with the existing system, at the insolation rate of approximately 300 BTU/Ft^2·Hr at normal incidence and 0 mph wind speed. The following data were recorded during the test at each test condition.

1. Absorber surface temperature - 15 locations.
2. Heat rejection loop temperature - 8 locations.
3. Ambient temperature.
4. Collector inlet liquid temperature.
5. Collector outlet liquid temperature.
6. Collector differential temperature.
7. Liquid flow rate.
8. Insolation rate.

6.3.2 Test Procedure

1. Mount the collector on test table at 45° from the floor.
2. The solar simulator angle was adjusted to obtain the proper north-south incident angles.
3. At 0 and 45° north-south incident angles the east-west was adjusted to 0, 30, 45, 60 and 75°. At 15 and 30° north-south incident angles, the east-west angles are 0°.
4. Establish the required liquid flow rate.
5. Establish the required liquid inlet temperature.
6. Power up the solar simulator to obtain an insolation rate

6.0 REQUIREMENTS AND PROCEDURES (Continued)

6.3 Collector Incident Angle Modifier Test (Continued)

7. Record data for a minimum of five minutes at above stabilized conditions.

8. Repeat above steps to complete all the required tests.

6.3.3 Test Results

The results obtained during the test are depicted in Figure 8 and 9, and Table IV.

6.0 REQUIREMENTS AND PROCEDURES (Continued)

6.4 Collector Heat Loss Coefficient Test

Tested by ____________________
Started ____________________
Completed ____________________

6.4.1 Test Requirements

With the built-in electric heater on the absorber plate, the collector heat loss coefficient can be determined. The collector was tilted at 45° from the floor with the wind speed of 7 1/2 mph. The power input to the absorber plate electrical heater was adjusted so as to maintain the absorber plate at average temperatures of 200°and 160°F. The following data were recorded during the test.

1. Surface temperature - 15 locations.
2. Heat rejection loop temperature - 8 locations.
3. Ambient temperature.
4. Power input to absorber surface.

6.4.2 Test Procedure

1. Mount the collector on the test table at 45° from the floor.
2. Assure that the flow passages are dry.
3. Establish the required wind speed.
4. Adjust the heater power controller to obtain the required average absorber plate temperature.
5. Record data for a minimum of five minutes at stabilized conditions.

6.4.3 Test Result

The results obtained during these tests are presented in Table V.

6.0 REQUIREMENTS AND PROCEDURES (Continued)

6.5 Collector Stagnation Test

Tested by ____________
Started ____________
Completed ____________

6.5.1 Test Requirement

Utilizing the MSFC Solar Simulator, conduct the stagnation tests at collector tilt angles of 30, 45 and 60° from the horizontal. For each tilt angle, the collector panel was irradiated by the insolation rates of 250, and 300 $BTU/Ft^2 \cdot Hr$ normal to the collector. The following data were recorded during the test at each test condition.

1. Collector tilt angle
2. Insolation rate.
3. Ambient temperature.
4. Absorber surface temperature - 15 locations.
5. Convector tube surface - 8 locations.

6.5.2 Test Procedure

1. Mount test specimen on test table at required tilt angle.
2. Fill the collector flow passage with liquid.
3. Power up simulator in accordance with Reference 2.3 and establish the required solar flux level.
4. Monitor data until the surface temperatures reach steady state.
5. Data was recorded continuously during the test.

6.5.3 Test Results

The results obtained during these tests are contained in Tables VI, VII and VIII. Due to the loss and degradation of lamps, the flux levels dropped. Refer to Tables VII and VIII for the insolation rate at 30 and 60° tilt angles.

7.0 ANALYSIS

7.1 Thermal Performance Test

The analysis of data contained in this report is in accordance with the National Bureau of Standards recommended approach. This approach is outlined below.

The efficiency of a collector is stated as:

$$\eta = \frac{q_u/A}{I} = \frac{\dot{m}\, C_{tf}\, (t_{f,e} - t_{f,i})}{IA} \qquad (1)$$

where:

q_u = rate of useful energy extracted from the Solar Collector (BTU/Hr)

A = overall total collector area including convector = 24.95 Ft^2 (A)

I = Total solar energy incident upon the plane of the solar collector per unit time per unit area ($BTU/Hr \cdot Ft^2$)

$\dot{m}$ = Mass flow rate of the transfer liquid through the collector per unit area of the collector = 14.7 $Lbm/Hr \cdot Ft^2$ (A)

C_{tf} = Specific heat of the transfer liquid (BTU/Lb·°F)

$t_{f,e}$ = Temperature of the transfer liquid leaving the collector (°F)

$t_{f,i}$ = Temperature of the transfer liquid entering the collector (°F)

Rewriting Equation (1) in terms of the total collector area yield:

$$\eta = \frac{(\dot{m}A)\, C_{tf}\, (t_{f,e} - t_{f,i})}{(IA)} = \frac{\dot{M}\, C_{tf}\, (t_{f,e} - t_{f,i})}{P_i} \qquad (2)$$

Notice that:

P_i = IA = Total Power Incident on the Collector

$\dot{m}A = \dot{M}$ = Total Mass Flow Rate through the Collector

Therefore $\dot{M}\, C_{tf}\, (t_{f,e} - t_{f,i})$ = Total Power Collected by the Collector

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

Substitution in Equation (2) results in:

$$\eta = \frac{P_{abs}}{P_{inc}} \qquad (3)$$

where:

P_{abs} = Total collected power

P_{inc} = Total incident power

This value of efficiency is expressed as a percentage by multiplying by 100. This expression for percent efficiency is:

$$\text{Collector Efficiency} = \frac{P_{abs}}{P_{inc}} \times 100 \qquad (4)$$

or from Equation (2), collector efficiency is defined by the equation:

$$\%\ \text{Eff.} = \frac{\dot{M}\, C_{tf}\ (t_{f,e} - t_{f,i}) \times 100}{P_i} \qquad (5)$$

Each term in Equation (5) was measured and recorded independently during the test. The calculated values of efficiency were determined at eighty-second intervals. The mean value of efficiency was determined over a five-minute period during which the test conditions remained in a quasi-steady state. Each five-minute period constitutes one "data point' as is graphically depicted on a plot of percent efficiency versus

$$\left((t_{f,i} - t_a)/I\right),\ \frac{\frac{t_{f,i}+t_{f,e}}{2} - t_a}{I} \text{ and } \frac{\bar{t}_p - t_a}{I}$$

where:

$t_{f,i}$ = Liquid inlet temperature (°F)

$t_{f,e}$ = Liquid outlet temperature (°F)

t_a = Ambient temperature (°F)

$\bar{t}_p$ = Average absorber plate temperature (°F)

I = Incident flux per unit area (BTU/Hr·Ft^2)

The abscissa terms $(t_{f,i} - t_a)/I$, $\left(\frac{t_{f,i}+t_{f,e}}{2} - t_a\right)/I$ and $\frac{\bar{t}_p - t_a}{I}$ were used to normalize the effect of operating at different values of I, $t_{f,i}$, $t_{f,e}$, t_p and t_a. The results are found in Figure 6.

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

The first and second order polynomial to best describe the test results are

$$\text{Efficiency} = a_0 + a_1\Gamma$$

$$\text{and Efficiency} = a_2 + a_3\Gamma + a_4\Gamma^2$$

where:

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$$\Gamma = (t_{f,i}-t_a)/I \text{ or } \left(\frac{t_{f,i}+t_{f,e}}{2} - t_a\right)/I \text{ or } \frac{\bar{t}_p-t_a}{I}$$

and the coefficients are determined to be:

Γ Coefficient	$(t_{f,i}-t_a)/I$	$\frac{(t_{f,i}+t_{f,e})/2-t_a}{I}$	$\frac{\bar{t}_p-t_a}{I}$
a_0	.6852	.7100	.7654
a_1	-.6905	-.7167	-.7736
a_2	.6777	.6998	.7504
a_3	-.6155	-.6317	-.6793
a_4	-.1057	-.1128	-.1116

where:

$$\bar{t}_p = \frac{t_{4A} + t_{6A} + t_{7A} + t_{8A} + t_{9A}}{5}$$

The performance of a flat-plate solar collector under steady state conditions can be described as

$$q_u = A_i I (\alpha\tau)_e - A_i U_L (\bar{t}_p - t_a) \quad (6)$$

where:

A_i is the absorber plate area = 21 Ft^2

$(\alpha\tau)_e$ is the product of transmissivity and absorptivity at normal incident angle

Since the efficiency is defined as the ratio of the useful energy extracted from the collector to the total incident energy.

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

Equation 6 becomes

$$\eta = \frac{q_u}{IA} = \frac{A_i}{A}(\alpha\tau)_e - \frac{A_i}{A} U_L \frac{(\bar{t}_p - t_a)}{I} \qquad (7)$$

It is convenient to introduce two parameters F_R and F'

where:

$F_R = \dfrac{\text{actual useful energy collected}}{\text{useful energy collected if the entire collector surface were at the inlet liquid temperature}}$

$$q_u = F_R \; A_i I(\alpha\tau)_e - U_L \; A_i \; (t_i - t_a)$$

or

$$\eta = \frac{q_u}{AI} = \frac{A_i}{A} F_R(\alpha\tau)_e - \frac{A_i}{A} F_R U_L \; \frac{(t_i - t_a)}{I} \qquad (8)$$

and

$F' = \dfrac{\text{actual useful energy collected}}{\text{useful energy collected if the entire collector surface were at the average liquid temperature}}$

$$q_u = F' \left[A_i I(\alpha\tau)_e - A_i U_L \left(\frac{t_{f,i} + t_{f,e}}{2} - t_a \right) \right]$$

or

$$\eta = \frac{q_u}{AI} = \frac{A_i}{A} F'(\alpha\tau)_e - \frac{A_i}{A} F' U_L \left(\frac{\frac{t_{f,i} + t_{f,e}}{2} - t_a}{I} \right) \qquad (9)$$

As shown in Figure 6, if the efficiency is plotted against $\dfrac{t_{f,i} - t_a}{I}$, $\dfrac{\frac{t_{f,i} + t_{f,e}}{2} - t_a}{I}$, and $\dfrac{\bar{t}_p - t_a}{I}$, a linear regression can be applied to determine the coefficients in equations 7, 8, and 9.

From equation 7

$$\frac{A_i}{A}(\alpha\tau)_e = .7654$$

$$\frac{A_i}{A} U_L = .7736$$

$$(\alpha\tau)_e = .91$$

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

$$U_L = .92$$

From equation 8

$$\frac{A_i}{A} F_R(\alpha\tau)_e = .6852 \qquad \therefore F_R = .895$$

$$\frac{A_i}{A} F_R U_L = .6905 \qquad \therefore F_R = .892$$

From equation 9

$$\frac{A_i}{A} F'(\alpha\tau)_e = .7100 \qquad \therefore F' = .927$$

$$\frac{A_i}{A} F' U_L = .7167 \qquad \therefore F' = .925$$

7.0 ANALYSIS (Continued)

7.2 Time Constant Test

Two methods are proposed by ASHRAE 93-P for conducting a time constant test. However, due to facility limitations, only the first method could be used. This method consisted of shutting down the simulator and maintaining a constant flow rate and inlet temperature while obtaining data.

According to the definition of time constant given in 93-P, it is the time required for the ratio of the differential temperature at time τ to the initial differential temperature to reach .368. It can be expressed as:

$$\frac{T_{f,e,\tau} - T_{f,i}}{T_{f,e,ini} - T_{f,i}} = .368 \qquad (1)$$

If the inlet liquid temperature can not be controlled to equal the ambient air temperature, then the following equation must be used

$$\frac{F_R U_L\,(t_{f,i}-t_a) + \frac{\dot{m}C_p}{A_i}\,(t_{f,e,\tau} - t_{f,i})}{F_R U_L\,(t_{f,i}-t_a) + \frac{\dot{m}C_p}{A_i}\,(t_{f,e,ini} - t_{f,i})} = .368 \qquad (2)$$

where:

$T_{f,e,\tau}$	Exit liquid temperature at time τ
$T_{f,i}$	Inlet liquid temperature
$T_{f,e,ini}$	Initial exit liquid temperature
$\dot{m}$	Liquid mass flow rate = 307.8 Lb/Hr
C_p	Specific heat of liquid = .79 BTU/Lb·°F
A_i	Absorber area = 21 Ft^2
$F_R U_L$	Negative of the slope determined from the thermal efficiency curve

During the time constant test, the inlet liquid temperature can not be controlled to within ±2°F of ambient air temperature, hence equation (2) was used for evaluation. From the performance curve, it is found that $F_R U_L$ = .62. Equation (2) becomes

$$\frac{.62\,(93.1-82.6) + 11.58\,(t_{f,e\tau} - 82.6)}{.62\,(93.1-82.6) + 11.58\,(16.75)} = .368$$

7.0 ANALYSIS (Continued)

7.2 Time Constant Test (Continued)

or

$$\frac{t_{f,e\,\tau} - t_{f,i}}{t_{f,e,ini} - t_{f,i}} = .347$$

From Figure 2 the time constant was determined to be 3 minutes and 22 seconds.

7.0 ANALYSIS (Continued)

7.3 Incident Angle Modifier Test

Two methods are proposed by ASHRAE 93-P for incident angle modifier tests. For the MSFC Solar Sinulator Facility, only method 1, (tilting the collector) is applicable. The collector was adjusted so that the north-south incident angles were 0, 15, 30, and 45°. At 0 and 45° north-south angles the east-west angles were adjusted to 30, 45, 60 and 75°.

According to 93-P, the performance of a flat-plate solar collector at incident radiation angles other than normal is defined as

$$\eta = \frac{q_u}{AI} = \frac{A_i}{A} F_R K_{\alpha\tau}(\alpha\tau)_n - \frac{A_i}{A} F_R U_L \frac{(t_{f,i} - t_a)}{I} \quad (1)$$

Rearrange equation (1), the incident angle modifier, $K_{\alpha\tau}$, can be exprcssed as

$$K_{\alpha\tau} = \frac{\eta + \frac{A_i}{A} F_R U_L \frac{(t_{f,i} - t_a)}{I}}{\frac{A_i}{A} F_R (\alpha\tau)_n} \quad (2)$$

If the inlet liquid temperature is controlled to within ±2°F of ambient temperature, equation (2) becomes

$$K_{\alpha\tau} = \frac{\eta}{\frac{A_i}{A} F_R (\alpha\tau)_n} \quad (3)$$

Table IV shows that the inlet liquid temperatures were not within ±2°F of ambient air temperatures. Hence, equation (2) was used for evaluation.

$$K_{\alpha\tau} = \frac{\eta + .519 \frac{t_{f,i} - t_a}{I}}{.676}$$

The results of this computation are shown on Table IV and plotted against east-west incident angles in Figure 8 and plotted against $\frac{1}{\cos \theta_i} - 1$ in Figure 9.

For the 45° north-south incident angle with a 75° east-west incident angle, the data plot was found to be anomalous and is not reported herein.

7.0 ANALYSIS (Continued)

7.4 Heat Loss Coefficient Test

The heat loss coefficient is determined at a given input heater power when the absorber plate temperature reaches a steady state condition. The heat balance equation describes this steady state condition is

$$P_{in} = A_i U_L (\bar{t}_p - t_a)$$

where:

P_{in} = Input power BTU/Hr

A_i = Absorber surface area = 21 Ft^2

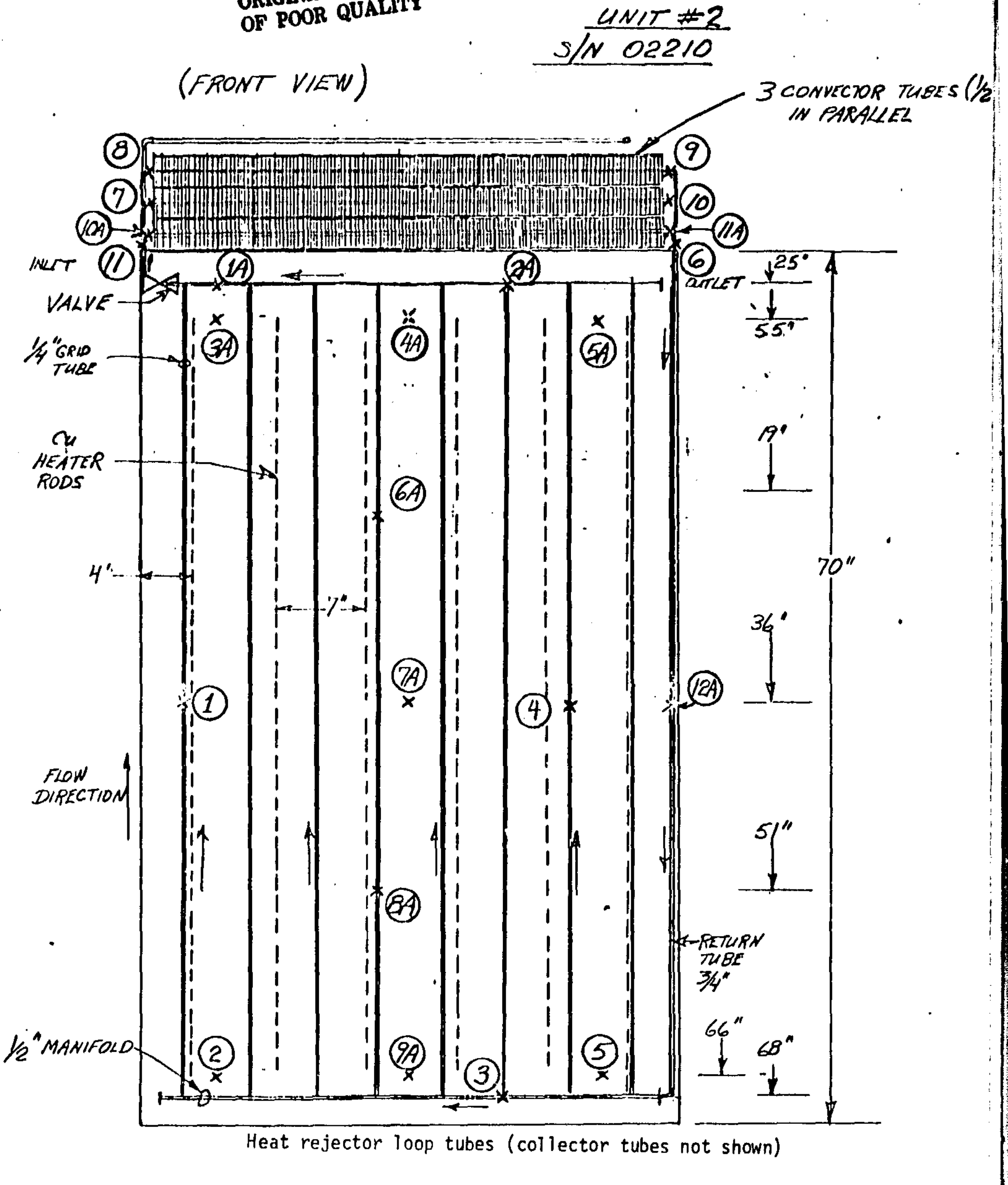
U_L = Heat loss coefficient $\frac{BTU}{Ft^2 \cdot Hr \cdot {}^\circ F}$

$\bar{t}_p$ = Average plate temperature °F

During the test the heater power was set to 600 watt and 400 watt. The heat loss coefficients can be calculated as following:

$$U_L = \frac{600 \times 3.413}{21 \times (196.9 - 89.9)} = .91 \frac{BTU}{Ft^2 \cdot Hr \cdot {}^\circ F}$$

$$U_L = \frac{400 \times 3.413}{21 \times (162.7 - 82.8)} = .81 \frac{BTU}{Ft^2 \cdot Hr \cdot {}^\circ F}$$



Heat rejector loop tubes (collector tubes not shown)

SCALE: 1/10

FIGURE 1. Thermocouple Locations for Daystar 21B Collector.

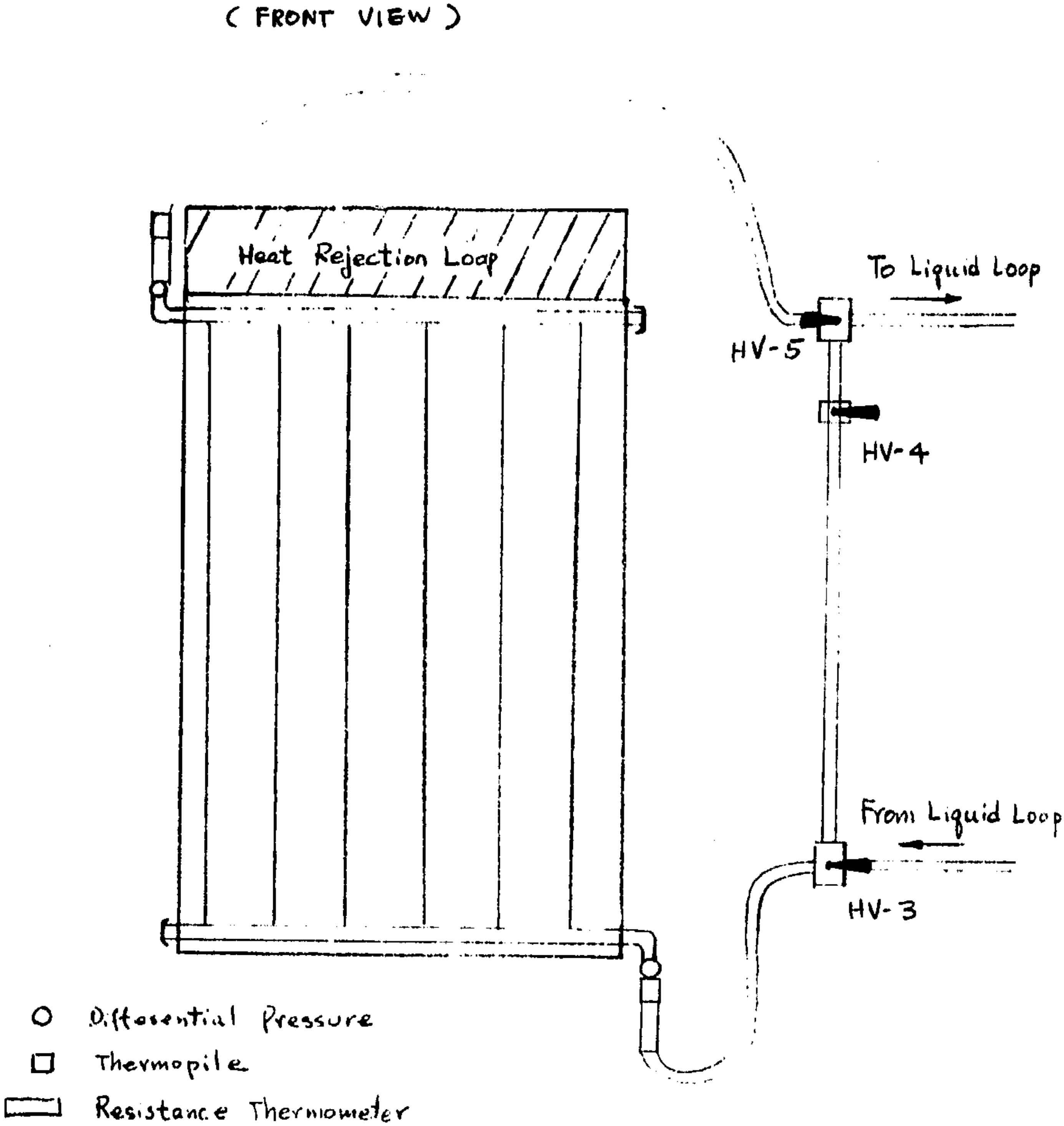


FIGURE 2. Instrumentation Locations for Daystar 21B Collector

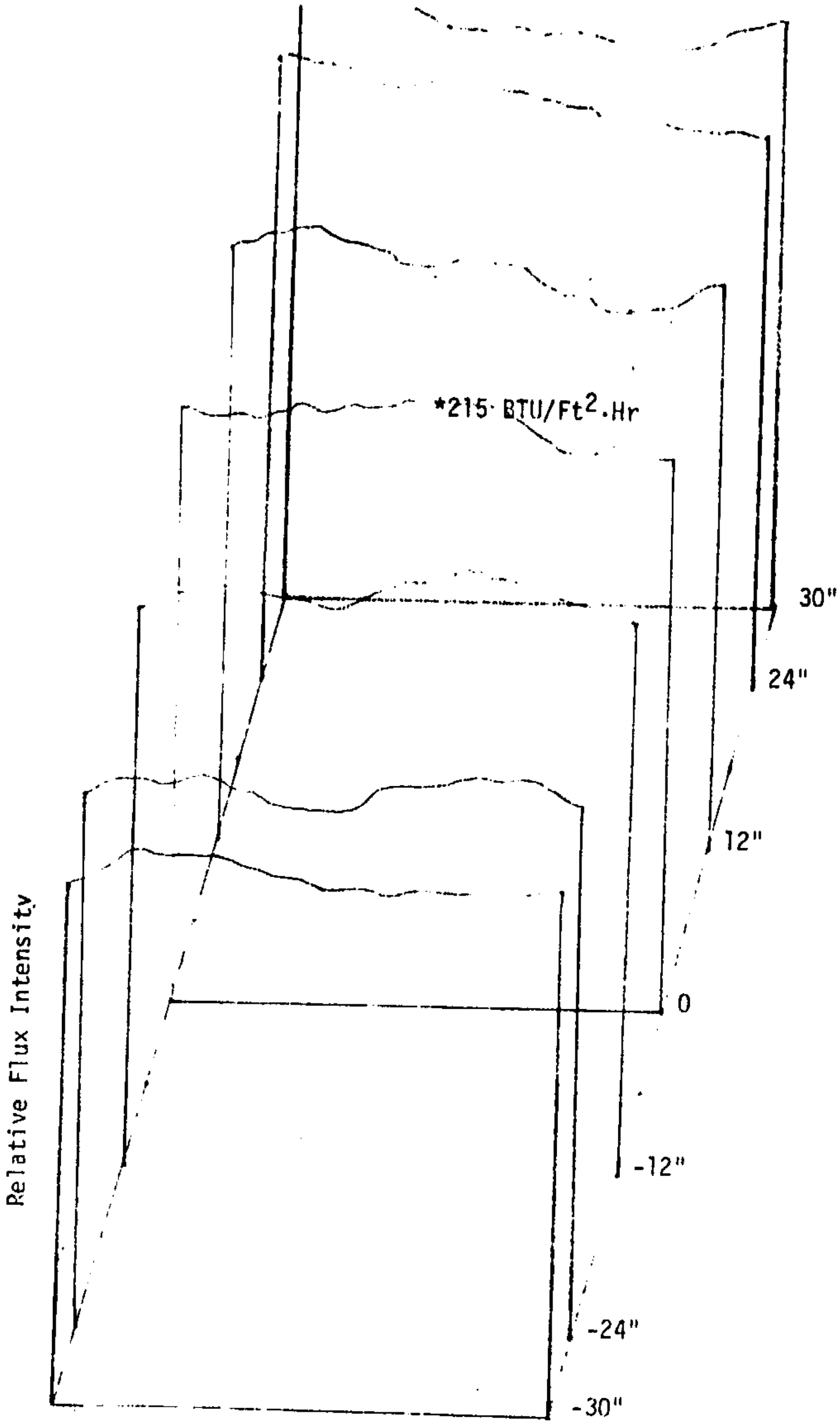


FIGURE 3. Contours of Flux Level at Collector Surface

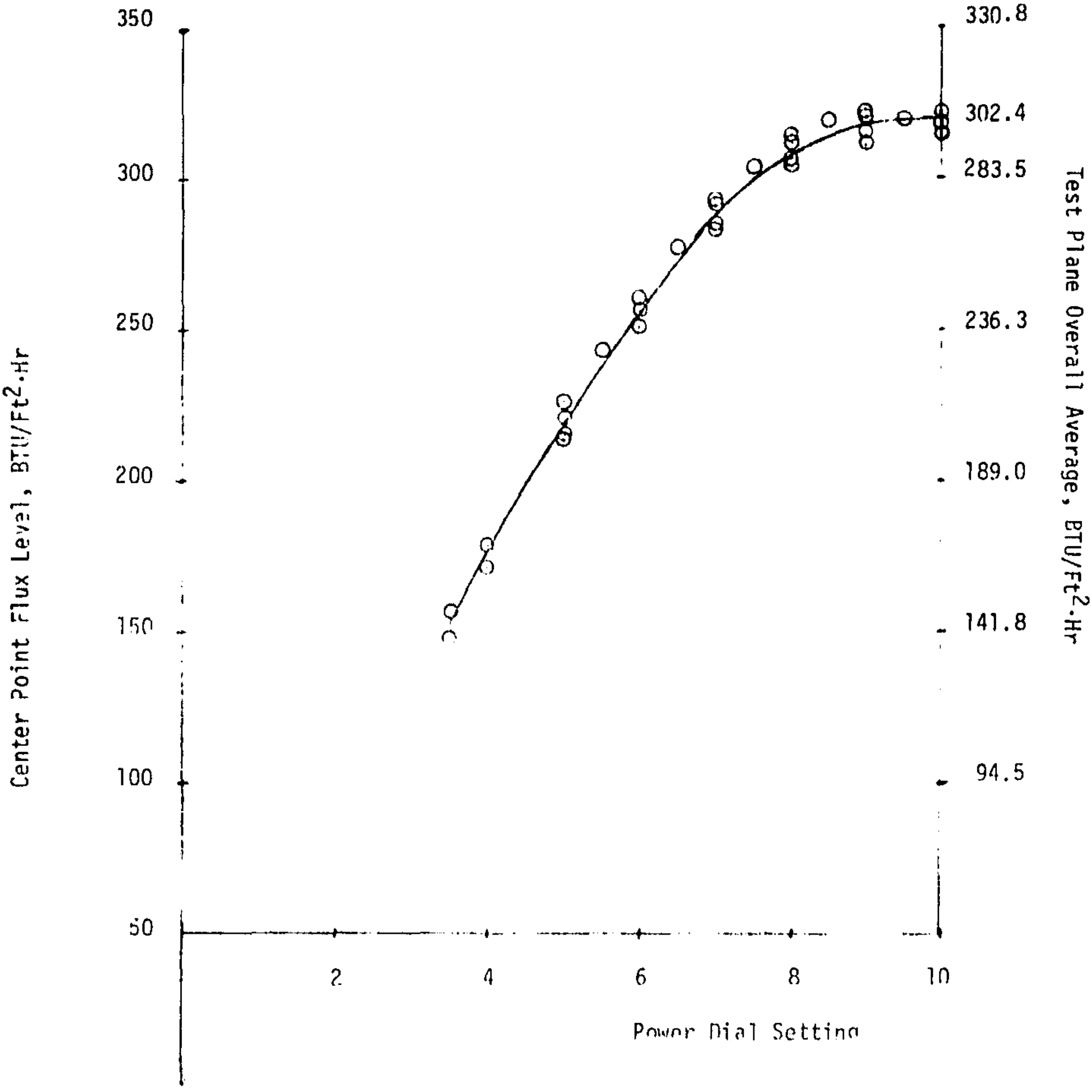
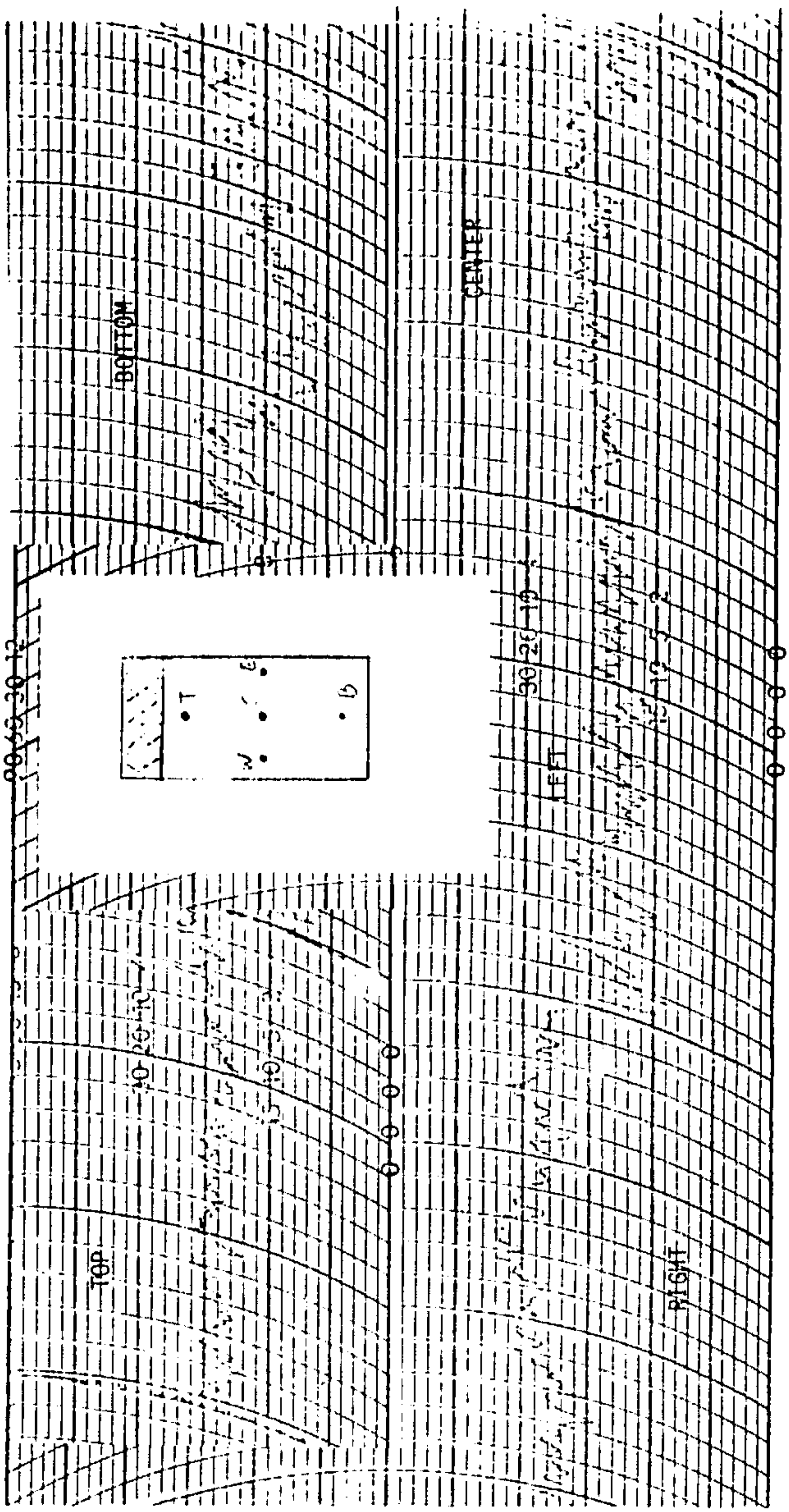


FIGURE 4. Initial Test Plane Overall Flux Level vs. Power Setting*

*As a result of lamp loss curve degraded with time



30 MPH Maximum Scale

FIGURE 5. Wind Distribution at Five Locations on the Collector Surface

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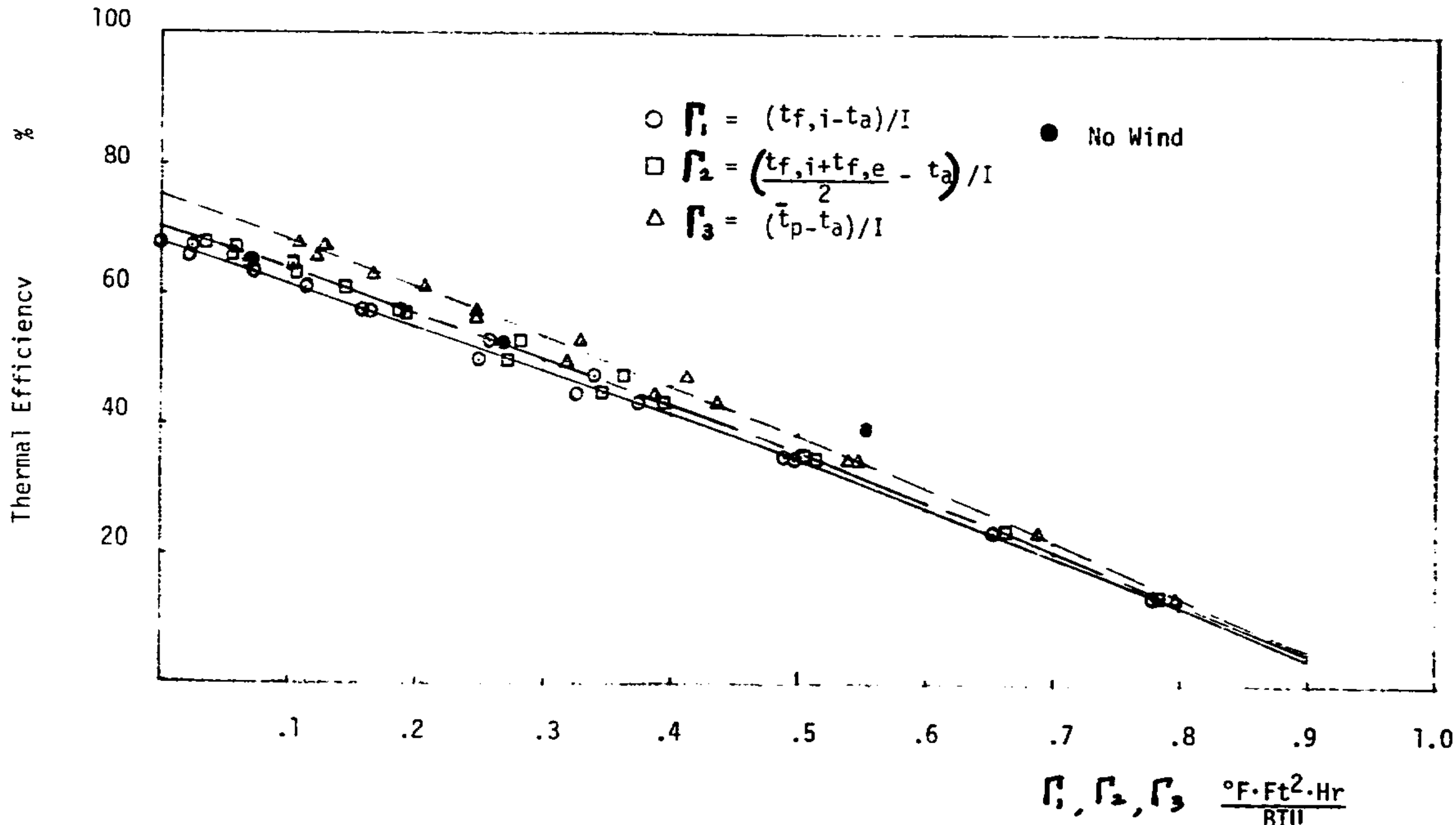

FIGURE 6. Daystar Collector Indoor Thermal Performance Test -- 7.5 MPH Wind, 14.7 LBM/Hr·Ft^2, Area 24.95 Ft^2

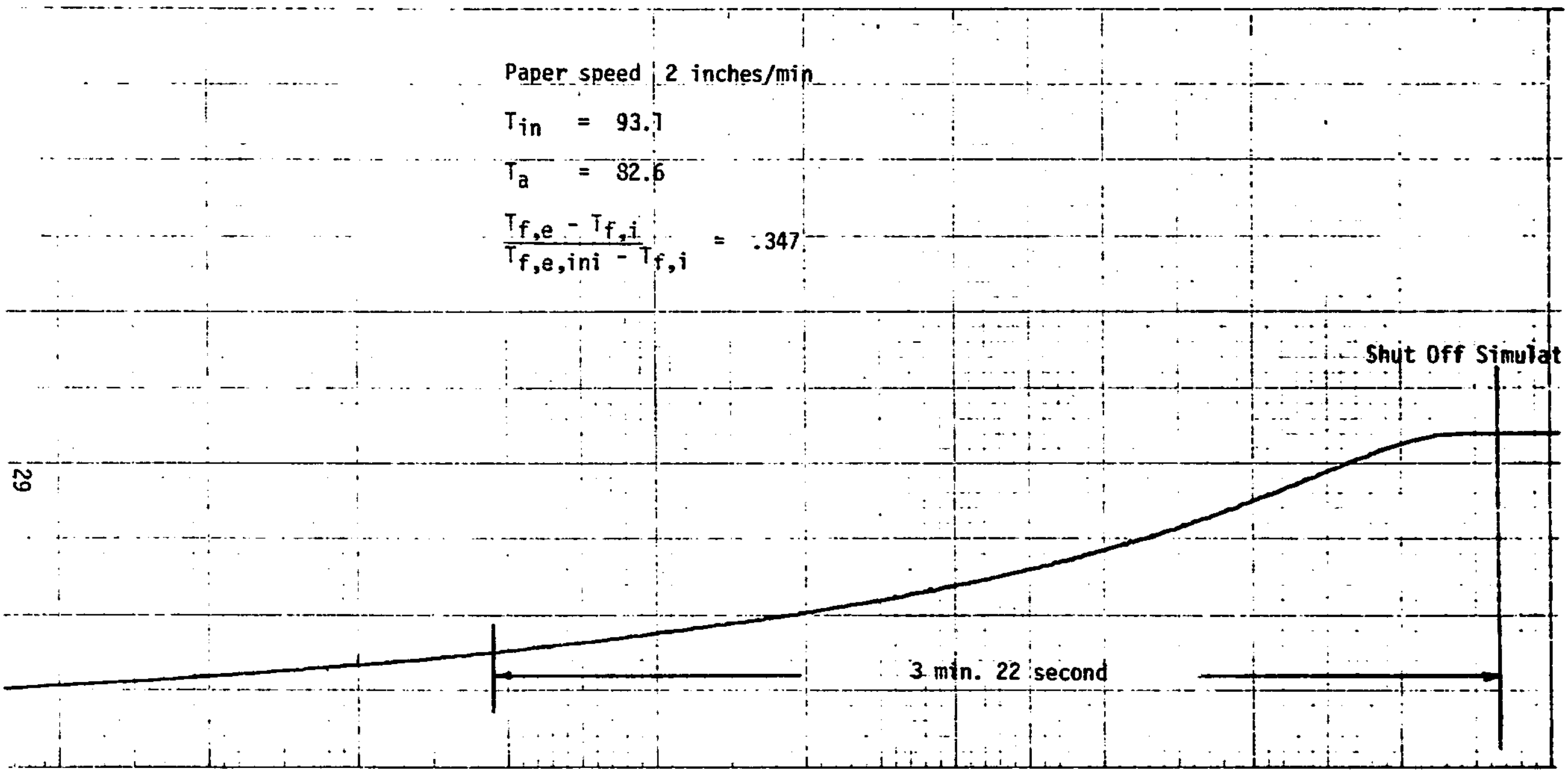

FIGURE 7. Daystar Collector Time Constant Test Result

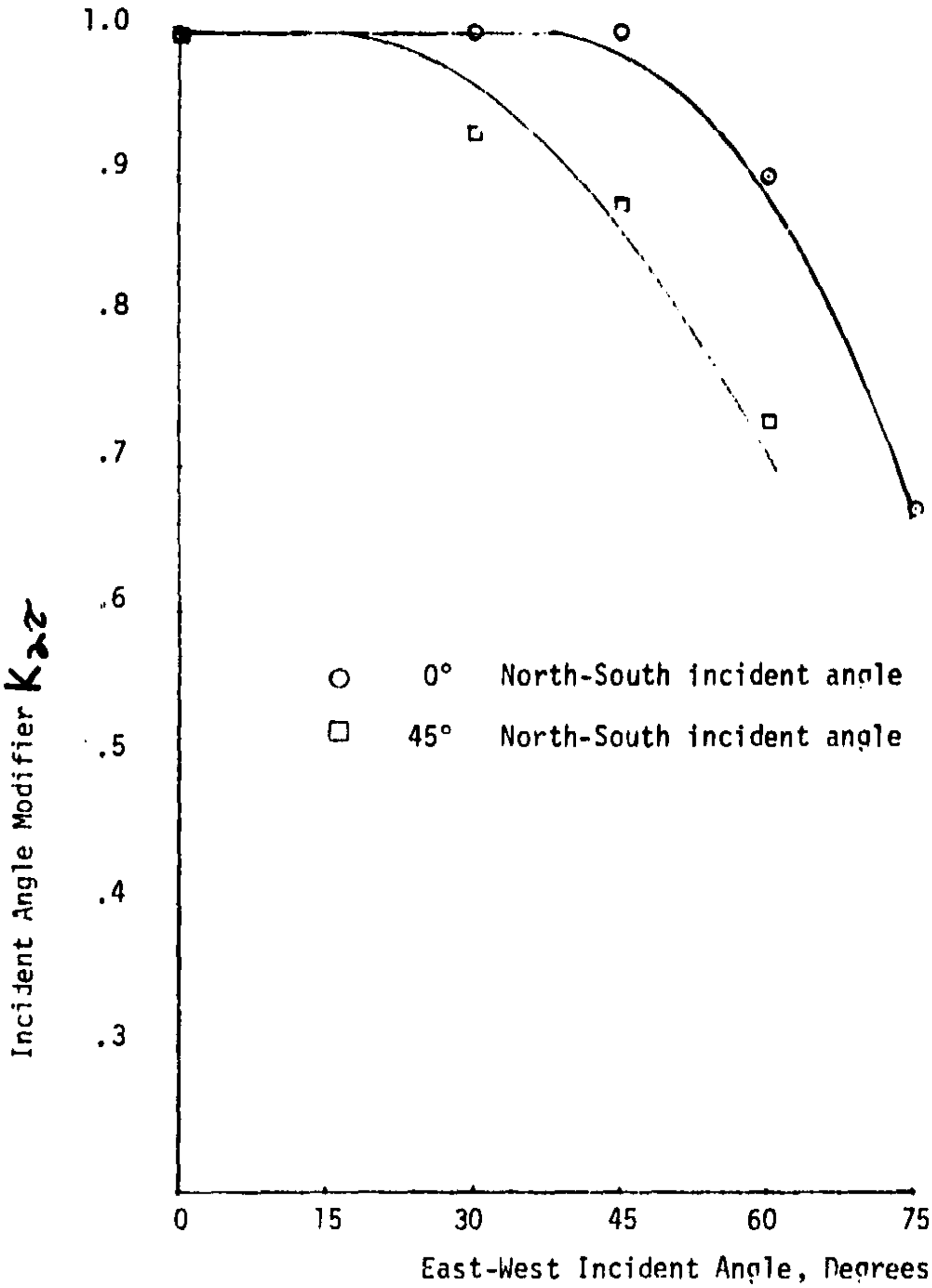

FIGURE 8. Daystar Collector Incident Angle Modifier Test Results

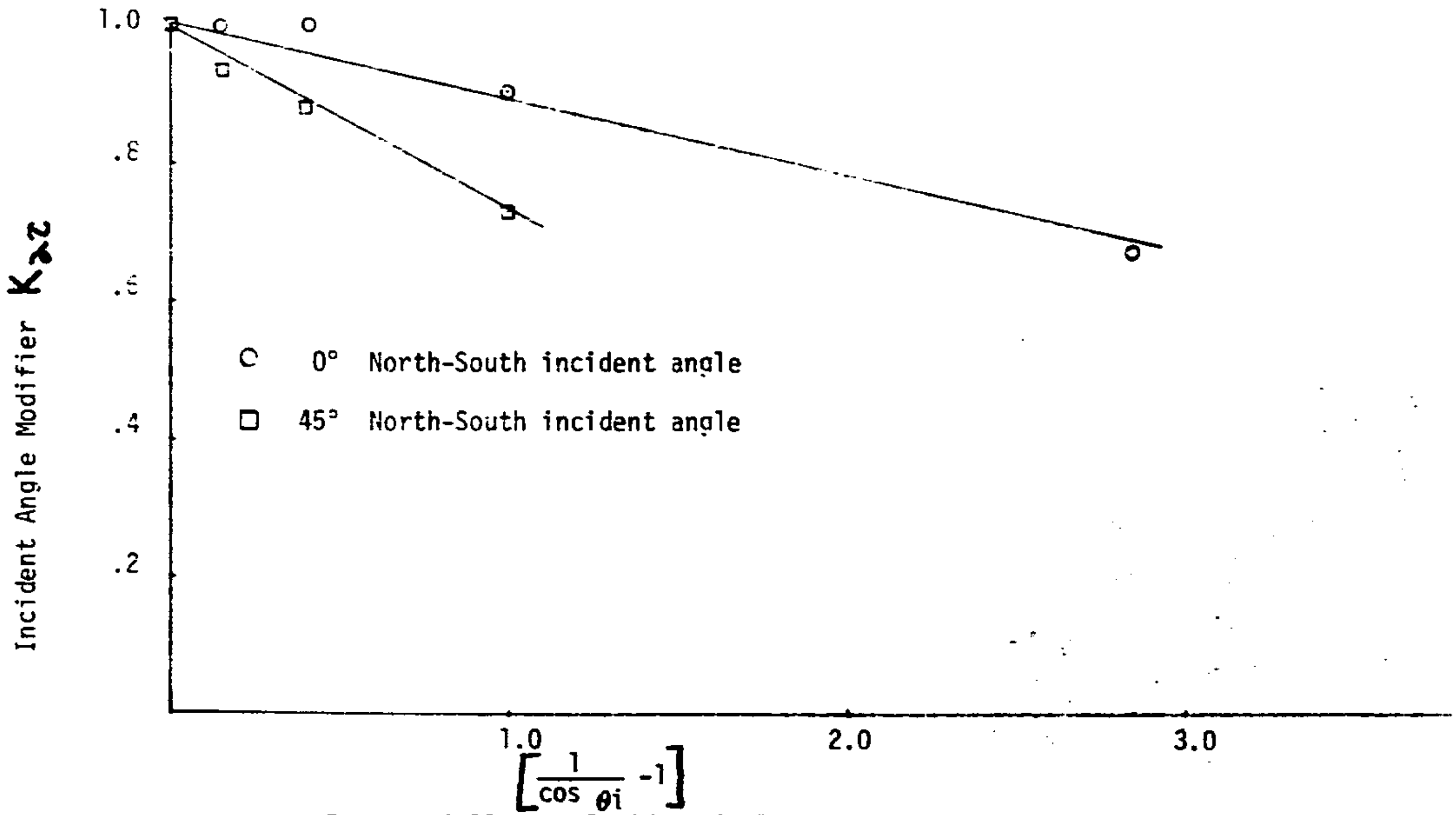

FIGURE 9. Daystar Collector Incident Angle Modifier Test Results

TABLE I

DAYSTAR COLLECTOR INSTRUMENTATION

HP No.	COMPUTER LINE	INST. ID	FUNCTION
26	107B	1	Absorber surface temperature °F
2	109B	2	Absorber surface temperature °F
3	110A	3	Absorber surface temperature °F
4	110B	4	Absorber surface temperature °F
5	111A	5	Absorber surface temperature °F
6	111B	6	Convector tube surface temp. °F
7	112A	7	Convector tube surface temp. °F
8	112B	8	Convector tube surface temp. °F
9	113A	9	Convector tube surface temp. °F
10	113B	10	Convector tube surface temp. °F
11	114A	11	Convector tube surface temp. °F
12	114B	1A	Absorber surface temperature °F
13	115A	2A	Absorber surface temperature °F
14	115B	3A	Absorber surface temperature °F
15	116A	4A	Absorber surface temperature °F
16	116B	5A	Absorber surface temperature °F
17	117A	6A	Absorber surface temperature °F
18	117B	7A	Absorber surface temperature °F
21	119A	8A	Absorber surface temperature °F
22	119B	9A	Absorber surface temperature °F

TABLE I (Continued)

HP No.	COMPUTER LINE	INST. ID	FUNCTION
23	120A	10A	Convector tube surface temp. °F
24	120B	11A	Convector tube surface temp. °F
25	107A	12A	Absorber surface temperature °F
27	108A		Ambient temperature °F
66	138	Q	Insolation rate $BTU/Ft^2 \cdot Hr$
67	133A	F	Flowrate Lb/Hr.
68	135	TR-2	Collector inlet temperature °F
69	134	TR-3	Collector outlet temperature °F

Refer to Figure 1 for surface temperature measurement locations.

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TABLE II

Daystar Collector Indoor Thermal Efficiency Test Results - 7.5 mph wind

ID	#1	#2	#3	#4	#5	#6	#7	#8	#9
1A	107.0	115.5	128.8	105.4	125.1	136.3	146.6	152.5	162.5
2A	109.8	119.0	133.4	120.7	128.0	140.6	147.9	154.5	166.0
3A	108.6	116.9	129.3	119.6	125.9	136.7	146.8	152.5	162.0
4A	109.0	117.5	130.4	120.7	127.0	137.7	148.3	154.0	163.5
5A	108.7	117.4	130.6	120.4	126.8	137.9	148.1	154.0	163.8
6A	112.4	121.8	136.5	123.6	130.9	143.5	150.6	157.2	168.3
7A	107.5	115.3	126.9	119.5	124.9	134.4	147.0	152.0	160.1
1	109.0	117.5	130.4	120.0	126.3	137.2	146.2	152.0	161.7
4	110.1	118.8	132.1	121.6	128.1	139.4	149.0	154.9	164.9
12A	92.9	95.7	98.9	89.6	92.8	95.5	99.8	101.3	103.8
8A	107.9	116.0	128.2	119.5	125.3	135.3	146.7	151.9	160.5
9A	96.4	101.6	108.4	109.6	112.3	116.7	138.5	140.7	144.0
2	97.4	104.3	112.6	111.7	115.1	121.0	140.6	143.5	148.2
3	97.5	102.3	108.3	104.8	108.1	112.7	126.4	128.9	133.4
5	97.3	102.7	109.7	109.8	112.7	117.4	137.7	140.0	143.4
Amb	90.4	88.6	89.6	81.4	82.4	83.1	84.4	85.0	85.4
T_{in}	90.3	93.3	96.2	104.9	105.2	105.3	135.3	136.2	134.7
T_{out}	100.7	107.1	116.3	113.7	117.5	124.3	142.4	145.8	151.6
ΔT	10.4	13.7	20.1	8.7	12.3	19.0	7.0	10.4	16.8
T_p	106.6	114.4	126.1	118.6	124.1	133.5	146.2	151.2	159.3
Q	150	200	300	150	200	300	150	200	300
F	309.2	309.5	309.4	308.7	308.5	309.6	310.0	309.2	310.0
η	67.8	67.2	65.7	57.7	61.0	63.0	47.7	53.0	57.1
I_1	.000	.024	.022	.157	.114	.074	.340	.256	.164
I_2	.035	.058	.056	.186	.145	.106	.363	.282	.192
I_3	.108	.129	.122	.248	.208	.168	.412	.331	.246

TABLE II
(Continued)

ID	#10	#11	#12	#13	#14	#15	#17	6a*	#18*
1A	164.1	170.2	180.5	185.0	190.7	201.4	261.5	137.1	192.3
2A	164.6	171.4	182.9	184.8	191.2	203.2	200.7	141.6	195.0
3A	164.3	170.2	180.0	185.3	190.7	201.0	202.2	137.8	191.4
4A	165.9	171.8	181.5	187.0	192.5	202.7	203.9	138.6	192.8
5A	165.7	171.8	182.0	186.8	192.6	203.3	203.7	138.8	193.4
6A	167.4	174.2	185.4	188.0	194.3	206.0	204.3	144.5	196.8
7A	164.9	170.1	178.6	186.1	191.0	199.8	203.3	135.1	189.3
1	162.9	168.9	178.9	183.0	188.7	199.3	199.4	138.4	190.2
4	166.7	172.8	183.1	187.7	193.5	204.2	204.6	140.3	194.1
12A	102.2	103.6	105.6	109.0	110.1	112.7	116.6	100.2	127.3
8A	164.1	169.6	178.4	184.6	189.7	199.0	201.0	136.2	189.4
9A	157.4	159.9	163.7	179.4	181.5	185.7	197.3	117.0	174.8
2	159.5	162.7	167.9	181.5	184.4	190.0	199.2	121.4	178.7
3	138.0	140.6	145.0	151.8	154.3	159.2	164.2	113.9	160.0
5	156.1	158.5	162.1	177.3	179.3	183.4	194.6	118.1	173.3
Amb	81.7	81.7	82.0	81.9	82.1	82.6	82.4	84.4	86.4
T_{in}	156.2	156.5	156.5	179.7	179.9	180.5	198.8	105.4	167.0
T_{out}	161.2	164.9	171.0	183.1	186.5	193.1	200.7	125.0	182.1
ΔT	5.0	8.4	14.5	3.3	6.6	12.7	1.9	19.6	15.2
$\bar{T}_p$	163.9	169.1	177.5	185.0	189.8	198.6	202.0	134.3	188.6
Q	150	200	300	150	200	300	150	300	300
F	311.1	310.4	311.3	312.2	310.1	310.9	307.6	308.9	308.0
η	34.4	43.8	50.0	23.6	35.0	44.9	13.4	64.7	52.4
I_1	.497	.374	.248	.652	.489	.326	.776	.070	.267
I_2	.514	.395	.272	.663	.506	.347	.782	.103	.293
I_3	.548	.437	.318	.688	.599	.387	.797	.166	.339

* No Wind

TABLE II
(Continued)

ID	#19*
1A	177.3
2A	177.7
3A	177.5
4A	178.9
5A	178.4
6A	180.2
7A	177.7
1	175.2
4	178.9
12A	122.0
8A	177.1
9A	170.2
2	172.4
3	151.6
5	169.0
Amb	89.9
T_{in}	168.5
T_{out}	173.8
ΔT	5.3
$\bar{T}_p$	176.8
Q	141.5
F	3076
η	39.3
I_1	.555
I_2	.574
I_3	.614

* No Wind

MSFC - Form 209 (July 1960)

Sheet ___ of ___

TABLE III

Time Constant Test

ID \ Time	12:59:32	13:0:51	13:2:10	13:3:29	13:4:49	13:6:8	13:7:27	13:8:46	13:10:5
1A	120.1	120.2	120.3	120.3	120.3	120.3	115.2	109.9	106.1
2A	123.6	123.7	123.8	123.8	123.9	123.9	121.3	118.0	114.8
3A	121.4	121.5	121.5	121.6	121.6	119.0	109.8	105.0	101.9
4A	121.8	121.8	121.9	122.0	122.1	119.9	110.9	105.8	102.5
5A	121.7	121.8	121.8	121.9	121.9	119.3	110.4	105.7	102.6
6A	127.0	127.1	127.2	127.2	127.2	125.4	115.1	108.1	103.7
7A	119.1	119.1	119.2	119.2	119.3	115.6	107.0	102.3	99.4
1	121.8	121.9	121.9	122.0	122.0	118.9	109.8	104.3	100.8
4	123.1	123.3	123.4	123.4	123.4	123.4	112.6	106.0	101.9
12A	92.3	92.5	92.7	92.9	93.1	93.2	93.3	93.2	93.1
8A	120.2	120.2	120.3	120.3	120.4	117.4	107.8	102.2	99.0
9A	103.0	103.1	103.1	103.1	103.2	100.0	96.1	94.9	94.3
2	106.4	106.4	106.5	106.5	106.5	106.6	98.6	96.5	95.3
3	101.7	[illegible]	102.0	102.1	102.2	102.3	100.7	99.4	98.2
5	104.1	104.2	104.3	104.3	104.3	103.8	97.2	95.2	94.3
Amb	82.5	82.5	82.5	82.6	82.7	82.7	82.8	82.7	82.6
T_{in}	92.95	93.00	93.02	93.06	93.12	93.13	93.19	93.18	93.09
T_{out}	109.65	109.71	[illegible]	109.84	109.91	104.90	100.61	98.33	96.82
ΔT	16.69	16.71	16.77	16.78	16.80	11.77	7.42	5.15	3.73
Q	250	250	[illegible]	250	250	0	0	0	0
F	309.3	308.9	309.0	308.8	308.0	307.9	307.4	305.9	305.2

MSFC - Form 209 (July 1960)

Sheet ____ of ____

TABLE IV

Incident Angle Modifier Test

N-S	0	0	0	0	0	15	30	45	45
E-W	0	30	45	60	75	0	0	0	30
1A	126.0	123.4	119.4	108.7	96.8	126.4	126.4	129.8	113.4
2A	130.2	125.1	121.1	111.1	99.4	131.8	131.2	124.0	115.0
3A	127.3	124.7	120.2	108.4	95.2	128.0	128.1	121.8	115.0
4A	127.5	123.9	119.7	109.0	96.9	128.2	128.4	122.0	114.6
5A	127.5	123.0	119.2	109.5	99.0	128.4	128.3	122.0	113.9
6A	133.9	129.7	124.2	112.1	98.4	133.9	133.0	125.5	117.3
7A	124.0	120.9	117.0	107.4	96.3	123.6	123.1	117.0	110.4
1	127.8	124.2	118.7	106.1	95.0	127.7	126.8	120.0	112.4
4	129.3	125.1	120.5	109.9	98.6	128.8	127.7	120.5	112.4
12A	94.5	108.8	94.9	86.4	89.8	99.2	100.0	99.5	90.6
8A	125.4	—	118.1	108.9	—	124.2	123.9	—	110.5
9A	105.1	104.8	103.9	97.6	91.0	105.4	106.7	103.3	99.0
2	109.4	108.5	106.7	99.1	91.0	109.0	109.7	105.6	100.7
3	104.1	109.9	109.8	102.2	92.7	106.5	107.1	104.6	102.5
5	106.8	104.3	103.4	97.9	91.8	107.0	107.8	104.2	99.2
Amb	82.3	86.4	89.1	82.4	85.7	86.5	90.5	92.6	86.9
T_{in}	92.8	92.9	94.2	91.3	88.4	94.1	96.4	94.9	92.1
T_{out}	113.0	110.8	109.0	101.2	93.4	113.7	114.4	109.6	103.9
ΔT	20.2	17.9	14.8	10.0	4.7	19.6	18.0	14.8	11.8
F	311.7	309.7	309.6	306.7	309.6	309.3	309.0	310.3	308.3
Q	300	259.8	216.4	166.5	104.8	289.8	259.8	216.4	187.4
η	66.6	67.6	67.1	58.1	44.1	66.2	67.8	67.2	61.4
$K_{\alpha\tau}$	1	1.0	1.0	.90	.67	.993	1.0	1.0	.93

CALCULATION OR DATA SHEET

TABLE IV
(Continued)

N-S	45	45
E-W	45	60
1A	109.1	101.6
2A	111.2	103.6
3A	110.2	101.8
4A	110.0	102.1
5A	109.5	102.2
6A	112.1	103.7
7A	106.7	99.9
1	107.6	99.5
4	108.3	101.4
12A	94.9	96.2
8A	106.6	95.6
9A	97.5	[illegible]
2	98.7	[illegible]
3	100.9	95.8
5	97.9	94.2
Amb	85.6	86.2
Tin	92.3	90.6
Tout	101.4	[illegible]
ΔT	9.1	[illegible]
F	309.4	[illegible]
η	156.1	120.1
Kaz	57.1	42.7

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CALCULATION OR DATA SHEET

TABLE V

Heat Loss Coefficient Test

ID	#1	#2
1A	197.0	152.6
2A	201.1	161.8
3A	195.5	160.3
4A	204.5	[illegible]
5A	204.3	[illegible]
6A	209.9	[illegible]
7A	201.0	[illegible]
1	198.7	[illegible]
4	212.7	[illegible]
12A	111.8	[illegible]
8A	194.5	[illegible]
9A	174.5	[illegible]
2	188.0	[illegible]
3	152.4	[illegible]
5	151.1	[illegible]
Amb	89.9	82.8
P_{in}	600	400
T_p	193.9	[illegible]
U_L	.91	[illegible]

TABLE VI

[illegible] Collector Stagnation Test - 45°

ID \ Time	11:52	12:32	12:52	13:18	13:23*	13:53	14:23	14:53	15:4*
1	201.0	205.7	208.3	210.1	207.9	223.0	223.1	227.3	226.7
2	191.8	203.9	207.4	208.5	206.3	225.4	224.8	226.4	225.6
3	159.8	188.3	[illegible]	194.6	190.6	203.9	205.1	210.5	208.9
4	206.5	207.2	210.0	212.3	210.3	225.1	227.4	230.9	230.9
5	187.0	201.7	205.7	209.2	205.9	225.3	224.3	226.8	226.9
6	126.3	184.6	[illegible]	188.5	187.3	200.4	200.0	205.1	204.7
7	128.8	212.3	214.3	215.1	214.7	227.3	229.6	232.3	232.4
8	132.2	210.3	212.4	213.5	212.7	225.0	227.4	230.1	230.3
9	124.1	[illegible]	[illegible]	199.3	197.9	208.7	210.1	214.0	214.0
10	124.6	[illegible]	[illegible]	191.5	192.2	203.2	203.9	208.5	207.2
11	130.9	211.7	[illegible]	215.5	214.2	227.0	229.3	232.4	232.2
1A	200.2	[illegible]	[illegible]	218.6	217.4	229.4	231.9	234.5	235.1
2A	200.5	[illegible]	[illegible]	217.3	216.5	227.9	230.5	233.0	233.9
3A	204.3	[illegible]	[illegible]	227.8	226.6	237.2	242.5	241.7	245.6
4A	210.2	[illegible]	[illegible]	227.7	227.4	238.6	239.2	238.2	239.8
5A	208.2	[illegible]	[illegible]	226.1	225.9	234.3	239.3	239.0	240.2
6A	209.2	[illegible]	[illegible]	218.8	216.4	230.7	232.6	235.9	236.1
7A	207.5	[illegible]	[illegible]	220.3	218.0	234.3	236.8	240.1	240.3
8A	198.7	[illegible]	[illegible]	207.0	204.0	218.6	220.0	224.3	223.6
9A	184.3	[illegible]	[illegible]	210.0	207.3	223.3	226.9	230.0	229.1
10A	128.3	210.7	[illegible]	213.5	212.9	226.2	228.6	231.8	230.8
11A	125.7	[illegible]	[illegible]	[illegible]	183.4	195.5	194.9	201.0	198.9
12A	128.6	[illegible]	181.7	184.0	182.6	194.5	194.5	199.6	198.7
Amb	87.1	87.9	[illegible]	89.0	89.0	89.6	90.7	90.8	91.4
Q					250				300
$\bar{T}_p$					214.6				233.8

* End of test

Sheet ___ of ___

CALCULATION OR DATA SHEET

TABLE VII

Daystar Collector Stagnation Test - 30°

ID \ Time	8:20	8:50 **	9:20	9:50	10:13	10:19 *	10:50	11:20	
1	107.2	198.9	196.7	196.5	199.1	199.1	212.6	217.2	
2	104.9	196.4	192.0	193.2	195.7	196.2	208.8	214.0	
3	86.4	147.1	174.6	176.5	178.6	179.4	189.1	195.0	
4	105.1	228.3	198.3	199.5	203.0	202.2	217.0	221.6	
5	105.6	194.4	189.2	190.6	193.1	193.6	206.2	219.3	
6	101.2	110.9	171.5	172.2	175.9	176.0	184.4	189.1	
7	85.1	195.4	203.8	205.2	207.1	207.8	219.4	224.2	
8	86.0	182.4	202.6	203.7	205.9	206.0	218.5	223.0	
9	87.6	121.7	182.6	182.2	186.6	186.3	196.1	199.6	
10	103.6	112.9	174.9	175.0	179.4	178.9	186.5	191.6	
11	83.4	211.4	204.2	205.1	206.4	207.5	219.9	224.5	
1A	91.6	217.1	209.4	210.6	212.5	212.8	226.5	230.8	
2A	90.0	[illegible]	[illegible]	210.7	212.9	212.5	227.1	230.0	
3A	103.7	210.[illegible]	217.6	217.7	219.5	219.8	233.7	239.3	
4A	104.1	221.4	218.5	219.7	221.3	221.6	232.7	237.4	
5A	103.7	214.2	218.1	220.0	221.7	221.7	235.4	235.8	
6A	107.8	[illegible]	205.8	205.7	208.1	208.3	223.0	227.0	
7A	110.6	[illegible]	[illegible]	205.4	207.9	208.2	222.7	226.7	
8A	110.3	[illegible]	[illegible]	191.1	193.5	193.9	206.1	211.2	
9A	105.0	[illegible]	[illegible]	192.6	195.0	195.6	208.2	215.0	
10A	84.2	210.[illegible]	200.2	201.4	202.7	203.7	213.2	218.5	
11A	84.9	[illegible]	[illegible]	168.4	174.0	173.0	180.7	186.7	
12A	81.1	119.2	166.8	168.0	171.3	170.2	179.4	184.8	
Amb	81.8	83.8	85.5	86.3	86.6	87.2	88.0	89.2	
Q						227.7			
$\bar{T}_p$						205.5			

* End of test

** Heat rejector valve open

CALCULATION OR DATA SHEET

TABLE VII
(Continued)

ID \ Time	11:50	12:20	12:50	10:57*
1	218.8	[illegible]	224.5	224.0
2	216.3	[illegible]	231.3	222.4
3	196.7	[illegible]	[illegible]	203.2
4	224.1	[illegible]	[illegible]	229.5
5	222.7	[illegible]	[illegible]	224.1
6	191.1	[illegible]	[illegible]	199.3
7	226.4	[illegible]	[illegible]	227.8
8	225.4	[illegible]	[illegible]	228.0
9	202.1	[illegible]	[illegible]	207.2
10	193.8	[illegible]	[illegible]	198.8
11	226.2	[illegible]	[illegible]	228.4
1A	232.2	[illegible]	[illegible]	236.2
2A	230.5	[illegible]	[illegible]	[illegible]
3A	241.0	[illegible]	[illegible]	245.9
4A	239.7	[illegible]	[illegible]	241.8
5A	235.5	[illegible]	[illegible]	240.3
6A	231.2	[illegible]	[illegible]	235.4
7A	229.9	[illegible]	[illegible]	[illegible]
8A	214.4	[illegible]	[illegible]	220.0
9A	218.3	[illegible]	[illegible]	[illegible]
10A	221.1	[illegible]	[illegible]	221.6
11A	188.9	[illegible]	[illegible]	194.8
12A	185.7	[illegible]	193.1	193.1
Amb	89.3	[illegible]	[illegible]	90.6
Q				220.2
$\bar{T}_p$				231.9

CALCULATION OR DATA SHEET

TABLE VIII

[illegible] Collector Stagnation Test - 60°

ID \ Time	8:44	9:14	9:39	10:4	10:34	11:0	11:42	11:47 *
1	86.6	[illegible]	200.8	204.5	200.3	201.2	205.0	202.4
2	88.5	198.9	195.9	202.4	197.8	198.5	201.9	199.7
3	84.8	[illegible]	184.5	189.9	184.2	185.8	188.9	185.7
4	86.8	[illegible]	[illegible]	207.5	203.1	204.4	207.8	205.0
5	88.6	167.1	[illegible]	200.3	196.0	196.5	199.8	197.4
6	83.0	[illegible]	181.4	183.1	180.9	181.4	186.3	181.9
7	83.0	[illegible]	208.0	211.6	207.4	208.2	211.3	208.6
8	83.0	142.1	206.6	210.3	206.2	207.1	210.2	207.3
9	83.2	115.0	[illegible]	191.6	187.7	188.8	192.6	189.4
10	83.2	110.5	187.2	189.5	186.1	187.7	191.4	188.2
11	83.0	175.3	207.1	211.0	207.2	208.0	211.3	208.7
1A	85.8	[illegible]	[illegible]	214.2	210.7	211.5	214.6	212.4
2A	84.4	[illegible]	[illegible]	214.0	210.9	211.7	214.7	212.5
3A	87.2	[illegible]	[illegible]	223.7	220.0	220.7	223.4	221.9
4A	87.4	222.0	[illegible]	225.9	222.6	223.3	226.0	224.6
5A	87.5	215.8	221.2	224.6	222.0	222.5	225.0	223.8
6A	86.6	216.3	208.6	212.5	208.5	209.6	213.1	210.7
7A	87.5	[illegible]	[illegible]	213.7	209.3	210.6	214.3	211.9
8A	87.5	[illegible]	[illegible]	201.5	196.7	197.9	201.6	198.8
9A	88.8	[illegible]	[illegible]	202.1	197.7	198.6	201.9	199.8
10A	83.1	149.7	[illegible]	210.3	206.1	204.2	209.4	207.2
11A	83.2	[illegible]	[illegible]	178.5	177.0	183.0	180.3	176.3
12A	82.1	109.3	176.7	178.9	176.5	177.0	181.2	178.9
Amb	82.4	[illegible]	[illegible]	86.3	87.1	87.1	88.2	88.5
Q								237.4
T_p								209.2

* End of test

** Heat [illegible] valve open

TABLE VIII
(Continued)

ID \ Time	12:17	12:47	13:17	13:30 ***	13:43 **	14:14	14:44	15:22	15:28 *
1	218.6	222.0	224.6	225.2	185.6	219.3	228.8	231.2	232.8
2	216.1	222.0	225.9	225.7	185.5	215.0	231.9	231.3	231.6
3	203.2	210.6	[illegible]	211.1	183.2	203.2	214.0	218.0	220.3
4	223.1	[illegible]	[illegible]	229.1	187.0	221.6	231.7	235.3	236.5
5	218.0	[illegible]	[illegible]	222.2	181.2	212.3	224.9	227.4	228.8
6	195.0	[illegible]	[illegible]	209.3	143.9	201.6	210.6	214.6	217.0
7	224.7	[illegible]	[illegible]	224.4	141.4	224.5	228.3	229.5	232.4
8	223.7	[illegible]	[illegible]	224.3	143.3	223.3	227.6	228.9	231.6
9	205.6	[illegible]	[illegible]	211.5	143.8	206.7	215.3	217.3	219.6
10	203.6	[illegible]	[illegible]	210.4	143.2	205.8	212.5	216.1	218.9
11	224.6	[illegible]	[illegible]	228.6	145.5	223.2	228.4	232.6	234.0
1A	227.5	[illegible]	[illegible]	232.2	185.6	226.2	233.4	237.2	238.7
2A	226.8	[illegible]	[illegible]	231.4	188.5	225.8	234.0	236.4	237.9
3A	238.1	[illegible]	[illegible]	243.9	185.8	225.4	240.3	248.5	250.0
4A	238.8	[illegible]	[illegible]	244.7	189.1	236.4	244.8	249.0	250.7
5A	236.7	[illegible]	240.7	244.8	190.4	235.9	243.1	246.2	248.3
6A	227.5	[illegible]	[illegible]	233.8	189.9	226.9	235.5	239.2	240.4
7A	229.7	[illegible]	[illegible]	237.4	190.1	229.4	239.6	243.0	243.9
8A	215.7	[illegible]	[illegible]	223.9	187.9	216.4	227.1	229.9	231.5
9A	216.2	[illegible]	[illegible]	225.9	188.9	216.1	230.2	231.6	232.4
10A	219.4	[illegible]	[illegible]	216.0	141.8	220.6	216.9	222.7	219.9
11A	201.3	[illegible]	[illegible]	209.2	141.5	196.4	210.2	216.6	218.3
12A	191.4	[illegible]	200.5	201.8	166.7	194.6	204.3	207.8	210.2
Amb	88.9	[illegible]	90.0	90.7	90.4	90.9	92.3	92.6	92.6
Q				0.					283.6
$\bar{T}_p$									234.8

*** Simul[illegible] control failure
** [illegible]est [illegible]esume
* End [illegible]

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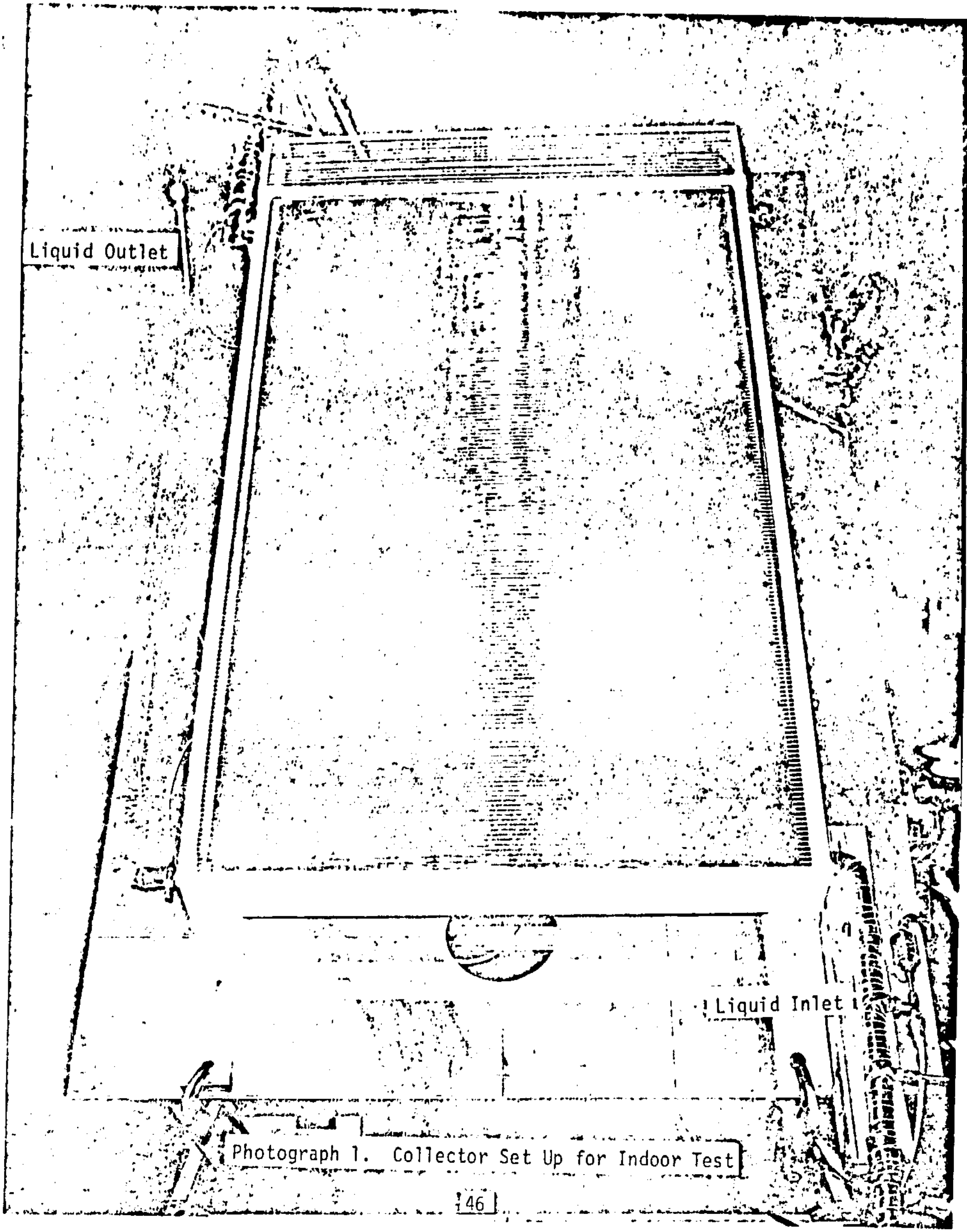
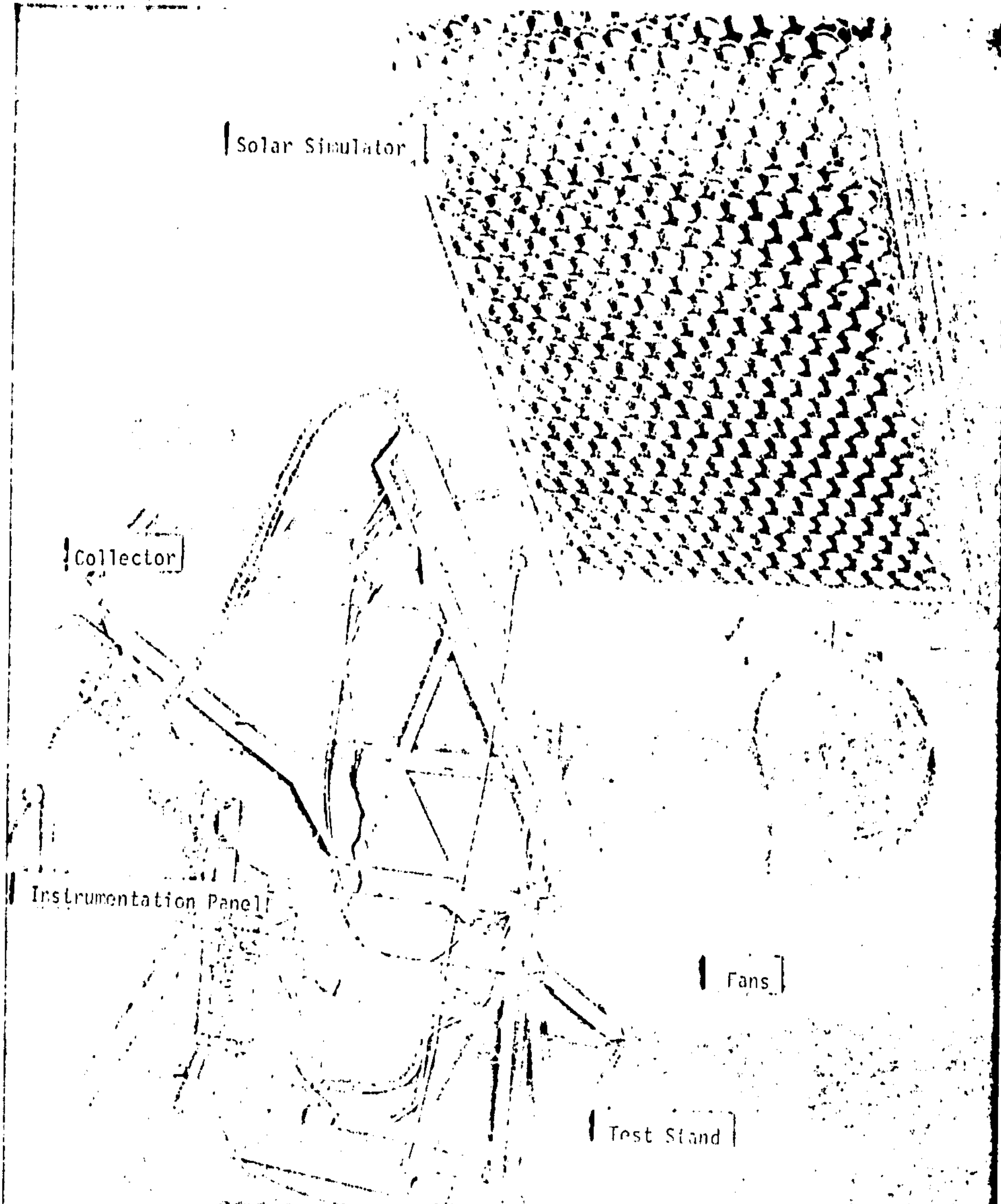


Photograph 1. Collector Set Up for Indoor Test



Photograph 2. Overall View of Indoor Test Site

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