DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150572

INDOOR TEST FOR THERMAL PERFORMANCE EVALUATION OF THE SOLARON (AIR) SOLAR COLLECTOR

Prepared by

Wyle Laboratories
Solar Energy Systems Division
Huntsville, Alabama 35805

Under subcontract with IBM Federal Systems Division, Huntsville, Alabama

Contract NAS8-32036

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Deparment of Energy

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This work was done under the technical management of Mr. Charles N. Thomas, of the Marshall Space Flight Center, Alabama.

16. ABSTRACT

This report describes the test procedure used and the results obtained from an evaluation test program, conducted to obtain thermal performance data on a Solaron double glazed air solar collector under simulated conditions. These tests were made using the Marshall Space Flight Center Solar Simulator. A time constant test and incident angle modifier test were also conducted to determine the transient effect and the incident angle effect on the collector. These results and the results of the collector load test are also discussed.

The Solaron collector absorber plate is made of 24-gage steel, the coating is baked-on black paint, the cover consists of two sheets of 1/8-inch low-iron tempered glass, and the insulation is one thickness of 3 5/8-inch fiberglass batting.

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1.0 PURPOSE

The purpose of this report is to present the test procedures used and the test results obtained during an evaluation test program. The test program was conducted to obtain thermal performance data on a Solaron double glazed air 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 REFERENCES

2.1	ASHRAE-93-77	Method of Testing to Determine the Thermal Performance of Solar Collectors
2.2	MTCP-DC-SHAC-419	Test Procedure For The Performance Evaluation of Air Collectors under Simulated Conditions
2.3	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator Facility

3.0 MANUFACTURER

Solaron Corporation
Stapleton Field Industrial Park
4850 Olive Street
Commerce City, Colorado 80022

3.1 DESCRIPTION OF TEST SPECIMEN

The Solaron Collector, Model 2001, is an air type, double glazed, flat plate. The gross collector area is 19.00 square feet (35.25" x 77.625") with an aperture area of 16.91 square feet (32.625" x 74.625"). The approximate weight of each collector is 160 pounds.

4.0 SUMMARY

This test program was conducted to evaluate the thermal performance of a Solaron air collector under simulated conditions. The test conditions and the data obtained during the tests conducted on the simulator are listed in Table II for stagnation test and Tables III and IV for thermal performance test. A graphic presentation of the data obtained is also presented in Figure 2. In addition, a time constant test and incident angle modifier test were conducted to determine the transient effect and the incident angle effect on the collector. The results of these tests are presented in Figures 4 through 6 and Table V. Results of the collector load test are listed in Table VI.

5.0 TEST CONDITIONS AND TEST EQUIPMENT

5.1 Ambient Conditions

Unless otherwise specified herein, all tests will be performed at ambient conditions existing in Building 4619 at the time of the tests and listed in Tables II through V.

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-5300.4C, Metrology and Calibration. Table I contains instrumentation identification and data acquisition connection data. Instrumentation locations on the test loop and collector are depicted in Figure 1. A listing of the equipment used in each test follows.

Apparatus	Manufacturer/Model	Range/Accuracy
Platinum Resistance Thermometer	Supplied by Collector Manufacturer	0-300°F ± 0.5°F
Pyranometer	Eppley - PSP	0-800 $BTU/Ft^2 \cdot Hr$ ± 3%
Air Loop	MSFC Supplied	N/A
Thermopile	Medtherm	0-20°F/± .05°F
Directional Anemometer	MSFC Supplied	0 - 30 MPH
Flow Measurement Nozzle	Air Filter Testing Labs, 1.59" dia.	35 - 130 CFM
Platinum Resistance Thermometer	Hy-Cal	0-300°F ± 0.5°F
Strip Chart Recorder	Mosley 680	5-500 MV ± 2%
Floor Fan	MSFC Supplied	N/A
Solar Simulator	MSFC Supplied	See SHC 3006
Inclined Manometer	MSFC Supplied	0-4" H_2O ± .01"
Differential Pressure Transducer	AMETEK/52D0010AML	0-10 in. H_2O ± 0.5%

5.0 **TEST CONDITIONS AND TEST EQUIPMENT** (Continued)

5.3 **Data Systems**

Test data obtained during simulator tests will be transmitted from MSFC Building 4619 (test site) through primary data acquisition system #3 to the real time data link and the DDP-224 computer located in Building 4646. A separate data link between Building 4646 and 4619 provides for printout of real time data at the test site. A listing of all instrumentation by function, type and corresponding data recording system is indicated in Table I.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS

6.1 Collector Stagnation Test

6.1.1 Test Requirement

Utilizing the MSFC Solar Simulator, the stagnation tests shall be conducted at a collector tilt angle of 45 degrees from the horizontal. The collector panel shall be irradiated by the insolation rates of 275, 300 and 325 BTU/Hr·Ft^2 normal to the collector. The following data shall be recorded during the test at each test condition.

1. Insolation rate (BTU/Hr·Ft^2)
2. Ambient temperature (°F)
3. Absorber surface temperature - 5 locations (°F)

6.1.2 Test Procedure

1. Mount test specimen on test table at a 45° angle with respect to the floor.
2. Connect instrumentation leads to data acquisition system.
3. Assure that data acquisition system is operational.
4. Close air supply valve.
5. Power up simulator and establish the required solar flux level.
6. Monitor data until the surface temperatures reach steady state.
7. Data shall be recorded continuously during the test.
8. Repeat above steps as necessary to complete all the required test conditions.
9. Upon completion of testing, power down simulator and air loop.
10. Inform data control group that simulator operation has terminated.

6.1.3 Results

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

6.0 REQUIREMENTS AND PROCEDURES (Continued)

6.2 Collector Thermal Efficiency Test

6.2.1 Test Requirements

Thermal performance evaluation data shall be obtained at inlet temperatures of 0, 25, 50, and 100°F above ambient temperature at air flow rates of 38 and 95 SCFM at insolation rates of 240 and 300 BTU/Hr·Ft^2 and a wind speed of 7.5 mph. The following data shall be recorded during the test at each test condition.

1. Ambient temperature.
2. Collector inlet air temperature.
3. Collector outlet air temperature.
4. Collector differential temperature.
5. Differential pressure across collector.
6. Air flow rate.
7. Insolation rate.
8. Wind speed.

6.2.2 Test Procedure

1. Mount test specimen on test table at a 45° angle with respect to the floor.
2. Assure that simulator lamp array is adjusted to an angle of 45° with respect to the floor.
3. Align the test table so that the test specimen's vertical centerline coincides with the vertical centerline of the lamp array and the distance from the top of the test specimen to the lens plane of the lamp array is 9 feet.
4. Insulate all ducts.
5. Assure that data acquisition system is operational.
6. Start air flow loop and establish a flow rate of 38 SCFM.
7. Establish the wind speed of 7.5 mph.
8. Power up simulator and establish a solar flux level of 240 BTU/Ft^2·Hr.

6.2.2 Test Procedure (Continued)

9. Determine the ambient air temperature.

10. Adjust the inlet temperature of the collector to the ambient air temperature value.

11. After steady state conditions have been established, record data for a minimum of five minutes.

12. Repeat steps 8, 9, 10, and 11, changing the flux level and air inlet temperature as necessary until data has been obtained for each test condition specified in Paragraph 6.2.1.

13. Repeat steps 7, 8, 9, 10, 11, and 12 with flow rate of 95 SCFM.

14. Upon completion of testing, power down simulator and liquid loop.

15. Inform data control group that simulator operation has terminated.

6.2.3 Test Results

The results obtained during these tests are contained in Figure 2 and Tables III and IV for thermal performance data and Figure 3 for pressure drop data.

6.0 REQUIREMENTS AND PROCEDURES (Continued)

6.3 Collector Time Constant Test

6.3.1 Test Requirements

In accordance with ASHRAE 93-77, the time constant test shall be conducted by abruptly reducing the flux level to zero. Inlet temperature shall be kept to within ± 2°F of ambient, with an air flow rate of 38 SCFM. The differential temperature across the collector shall be 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 shall be recorded during the test:

1. Absorber surface temperature - 4 locations.
2. Ambient temperature.
3. Collector inlet temperature.
4. Collector outlet temperature.
5. Collector differential temperature.
6. Differential pressure across collector.
7. Air flow rate.
8. Insolation rate.

6.3.2 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. Assure that data acquisition system is operational.
3. Adjust the air flow rate to 38 SCFM.
4. Adjust the air inlet temperature to within ± 2°F of ambient.

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6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.3.2 Test Procedure (Continued)

5. Adjust the flux level to 250 BTU/Ft^2·Hr.

6. Monitor the differential temperature across the collector.

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

8. Turn off the solar simulator.

9. Monitor the differential temperature until the ratio

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

10. Upon completion of testing, power down simulator and air loop.

11. Inform data control group that simulator operation has terminated.

6.3.3 Test Results

The results obtained during this test are shown in Figure 4.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.4 Collector Incident Angle Modifier Test

6.4.1 Test Requirement

The collector incident angle modifier test shall be conducted at north-south radiation incident angle of 45 degrees. The east-west radiation incident angles shall be 30, 40, 50 and 60 degrees. The air flow rate shall be 38 SCFM with inlet temperature controlled to within ± 2°F of ambient at the insolation rate of 250 BTU/Ft^2·Hr and 0 mph wind. The following data shall be recorded during the test at each test condition.

1. Ambient temperature.
2. Collector inlet air temperature.
3. Collector outlet air temperature.
4. Collector differential temperature.
5. Air flow rate.
6. Insolation rate.

6.4.2 Test Procedure

1. Mount the collector on the test table at incident angle of 30°.
2. Adjust the air flow rate to 38 SCFM.
3. Adjust the solar simulator flux level to 250 BTU/Hr·Ft^2.
4. Adjust the inlet temperature to ambient ± 2°F.
5. Measure the flux level at 9 locations on the test plane.
6. Record data for 5 minute stabilized period.
7. Repeat above steps for incident angles of 40°, 50° and 60°.
8. Upon completion of testing, power down simulator and liquid loop.
9. Inform data control group that simulator operation has terminated.

6.4.3 Test Results

Data obtained from this test program were analyzed according to ASHRAE 93-77 and reported in Table V and graphic format in Figures 5 and 6.

6.0 TEST REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.5 Collector Load Test

6.5.1 Test Requirements

One solar collector shall be subjected to load testing. The specified load requirements are listed in Table VI. The collector shall be mounted as indicated in Figure 7 but oriented such that the glazing is horizontal. Uniform loads shall be applied by means of a transparent flexible diaphragm which can be covered with a uniform layer of transparent liquid of varying depths to obtain the desired load variations.

6.5.2 Test Procedure

1. Mount the collector in the horizontal plane.
2. Place the load frame with liner over the collector.
3. Fill the load frame liner with water to a level corresponding to the Step 1 load of Table VI and let stand for five minutes.
4. Drain and remove the load frame.
5. Flush the collector exposed surface with water and inspect for leaks.
6. If the collector leaked or was damaged due to the load, record and indicate what the load level is.
7. If the collector does not leak and is not damaged, record the load level and repeat steps 3 through 5 for the next load level.

6.5.3 Test Results

The results of this test are tabulated in Table VI.

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:

$$\eta = \frac{q_u/A}{I} = \frac{\dot{m}\, C_{tf} \left(T_{f,e} - T_{f,i}\right)}{I} \quad (1)$$

where:

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

A = Gross collector area (Ft^2)

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

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

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

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

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

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

$$\eta = \frac{(\dot{m}A)\, C_{tf} \left(T_{f,e} - T_{f,i}\right)}{(IA)} = \frac{\dot{M}\, C_{tf} \left(T_{f,e} - T_{f,i}\right)}{P_i} \quad (2)$$

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:

$$\eta = \frac{Pabs}{Pinc} \qquad (3)$$

where:

Pabs = Total collected power

Pinc = Total incident power

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

$$\text{Collector Efficiency} = \frac{Pabs}{Pinc} \times 100 \qquad (4)$$

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

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

Each term in Equation (5) was measured and recorded independently during the test. The calculated values of efficiency were determined at sixty-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

$$\left((T_i - T_a)/I \right)$$

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where:

T_i = Air inlet temperature (°F)

T_a = Ambient temperature (°F)

I = Incident flux per unit area ($BTU/Hr \cdot Ft^2$)

The abscissa term $\left((T_i - T_a)/I\right)$ was used to normalize the effect of operating at different values of I, T_i and T_a. The results are found in Figure 2.

The result of second order polynomial analysis is shown in Figure 2. The second order polynomial to best describe the test results is:

$$\text{Efficiency} = a_0 + a_1 \mathcal{T} + a_2 \mathcal{T}^2$$

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

where:

$$\tau = (T_i - T_a)\ I$$

and the coefficients are determined to be:

Flow Rate (SCFM)	38	95
a_0	0.458	0.562
a_1	-0.738	-0.842
a_2	-0.301	-0.470

7.0 ANALYSIS (Continued)

7.2 Time Constant Test

Two methods are proposed by ASHRAE 93-77 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 93-77, 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 air temperature cannot be controlled to equal the ambient air temperature, then the following equation must be used

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

where:

$T_{f,e,\tau}$ = Exit air temperature at time, τ

$T_{f,i}$ = Inlet air temperature

$T_{f,e,ini}$ = Initial exit air temperature

$\dot{m}$ = Air mass flow rate = 171 Lb/Hr

C_p = Specific heat of air = .24 BTU/Lb·°F

A = Collector area = 19 Ft^2

$F_R U_L$ = Negative of the slope determined from the thermal efficiency curve

During the time constant test, the inlet air temperature cannot be controlled to within ± 2°F of ambient air temperature; hence equation (2) must be used for evaluation. From the performance curve, it is found that $F_R U_L$ = .86. Equation (2) becomes

$$\frac{.86(84.9-77.8) + 2.16\ (T_{f,e,\tau} - 84.9)}{.86\ (84.9-77.8) + 2.16\ (32)} = .368$$

7.0 **ANALYSIS** (Continued)

7.2 **Time Constant Test** (Continued)

or

$$\frac{T_{f,e,\tau} - T_{f,i}}{T_{f,e,ini} - T_{f,i}} = .312$$

From Figure 4 the time constant was determined to be 7 minutes and 54 seconds.

7.0 ANALYSIS (Continued)

7.3 Incident Angle Modifier Test

Two methods are proposed by ASHRAE 93-77 for incident angle modifier tests. For the MSFC Solar Simulator Facility, only method 1 (tilting the collector) is applicable. The collector was adjusted so that the incident radiation angles were 30°, 40°, 50° and 60° to the normal of the collector surface.

According to 93-77, the incident angle modifier is defined as

$$K\alpha\tau = \frac{\eta}{F_R(\tau\alpha)n} \qquad (1)$$

where η = efficiency at tilted angle.

$F_R(\alpha\tau)\ n$ = Intercept of efficiency curve at normal incident angle = .46

For equation (1) to be applicable, the inlet air temperature must be controlled to within ± 2°F of the ambient air temperature. In cases where the inlet air temperature cannot be controlled to within ± 2°F, the following equation must be used to evaluate the incident angle modifier.

$$K\alpha\tau = \frac{\eta + F_R U_L \dfrac{T_{f,i} - T_a}{I}}{F_R(\alpha\tau)n} \qquad (2)$$

where:

$F_R U_L$ is the negative of the slope determined from the thermal efficiency curve.

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

$$K\alpha\tau = \frac{\eta + .86 \dfrac{T_{f,i} - T_a}{I}}{.46}$$

The results of this computation are shown on Table V and plotted against incident angle in Figure 5 and plotted against $\dfrac{1}{\cos \theta i} - 1$ in Figure 6.

TABLE I

SOLARON AT SIMULATOR

Mean No.	Test	Location	Elect. Range	Full Scale	Mach Range	S/N	Mfg. M/N
T101	Simulator	Coll. Internal 1	0 - 20	20 MV	-50 - 400°	Mfg.	RTS-4175-100
T102	"	" " 2	"	"	"	"	"
T103	"	" " 3	"	"	"	"	"
T104	"	" " 4	"	"	"	"	"
T105	"	" " 5	"	"	"	"	"
T106	"	Coll. Inlet	"	"	60 - 250	35	RTS-4135-100
T107	"	Coll. Outlet	"	"	60 - 250	85	RTS-4135-100
T009	"	Amb	0 - 20	20 MV	40 - 100	100	RTS-4135-100
F001	"	Coll. Inlet	0 - 5	5 VDC	35 - 130 ACFM		Air Filter
I001	"	Solar Flux	0 - 20	20 MV	0 - 743 BTU/Hr.	14134F3	PSP
T008		Nozzle Temp.	0 - 20	20 MV	60 - 250°	50	RTS-4135-100
TD100	"	Across Collector	TO BE RECORDED ON STRIP CHART				

TABLE II

STAGNATION TEST DATA
SOLARON SOLAR COLLECTOR

Solar Flux BTU/Hr·Ft^2	275	300	325
Ambient Temp. °F	78.5	79.2	78.6
Absorber Temp. North °F	305	329	345
Absorber Temp. East °F	276	299	314
Absorber Temp. Center °F	289	312	328
Absorber Temp. West °F	303	329	346
Absorber Temp. South °F	254	275	291
Average Absorber Temp. °F	285	309	325

TABLE III

THERMAL PERFORMANCE TEST DATA
38 SCFM

Ambient °F	79.4	80.7	80.6	81.6	80.7	80.6	80.2	81.6		
T_{in} °F	84.5	86.1	104.4	104.1	127.2	127.2	174.5	175.0		
T_{out} °F	135.5	146.1	148.7	157.9	161.3	170.2	191.5	198.2		
ΔT °F	51.0	60.0	44.3	53.8	33.8	43.0	17.0	23.2		
Solar Flux $BTU/Hr \cdot Ft^2$	244.4	295.4	244.4	295.4	244.4	295.4	244.4	295.4		
Flow Rate SCFM	38	38	38	38	38	38	38	38		
Wind Speed MPH	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5		
Efficiency %	45.1	43.9	39.2	39.4	29.9	31.4	15.0	17.0		
$(Ti-Ta)/I$ $°F \cdot Hr \cdot Ft^2/BTU$	0.021	0.018	0.097	0.076	0.191	0.158	0.386	0.316		

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TABLE IV

THERMAL PERFORMANCE TEST DATA
95 SCFM

Ambient °F	70.9	72.6	74.1	73.6	76.2	77.1	78.9	79.2	79.0	78.4
T_{in} °F	78.1	80.5	97.2	97.3	124.8	124.8	151.6	151.8	172.8	173.5
T_{out} °F	101.9	110.0	120.2	124.1	140.7	147.0	166.2	170.2	180.9	184.1
ΔT °F	23.8	29.5	23.0	26.8	15.9	22.2	14.6	18.4	8.1	10.6
Solar Flux BTU/Hr·Ft^2	244.4	295.4	245.4	296.0	243.0	295.0	254.0	294.0	143.0	291.0
Flow Rate SCFM	95	95	95	95	95	95	95	95	95	95
Wind Speed MPH	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Efficiency %	52.6	53.9	50.6	48.9	35.3	40.6	31.0	33.8	18.0	19.7
(Ti-Ta)/I°F·Hr·Ft^2/BTU	0.029	0.027	0.094	0.080	0.200	0.162	0.286	0.247	0.386	0.328

TABLE V

INCIDENT ANGLE MODIFIER TEST DATA

Incident Angle Degree	30	40	50	60
Ambient °F	74.5	78.5	73.8	79.9
T_{in} °F	79.6	81.7	78.6	80.2
T_{out} °F	124.7	116.9	110.0	103.2
ΔT °F	45.1	39.0	31.5	23.0
Solar Flux $BTU/Hr \cdot Ft^2$	224	194	161	123
Flow Rate SCFM	38	38	38	38
Wind Speed MPH				
Efficiency %	43.5	43.4	42.2	40.4
Incident Angle Modifier $K_{\alpha\tau}$	0.988	0.974	0.973	0.913

TABLE VI

SERVICE LOAD STEPS AND TEST RESULTS

Step No.	Load (Lb/Ft^2)	Pass/Fail	Comments
1	10	Pass	See Note 1.
2	20	Pass	
3	30	Pass	
4	50	Pass	
5	80	Pass	
6	120	Pass	

Tested By ____________________ Date ______________

Note 1: The construction of the Solaron air collector permits water to leak around the glass gasket onto the absorber plate under no load conditions. Drain holes are provided to drain this water out at top and bottom of collector. There is a seal between the absorber plate and the air passages and insulation. This seal did not leak under any of the load conditions above. The seal between the two glass cover plates did develop minor leaks at two of the corners but this was judged to be due to the cycling of the load during the test and not likely to occur during normal usage.

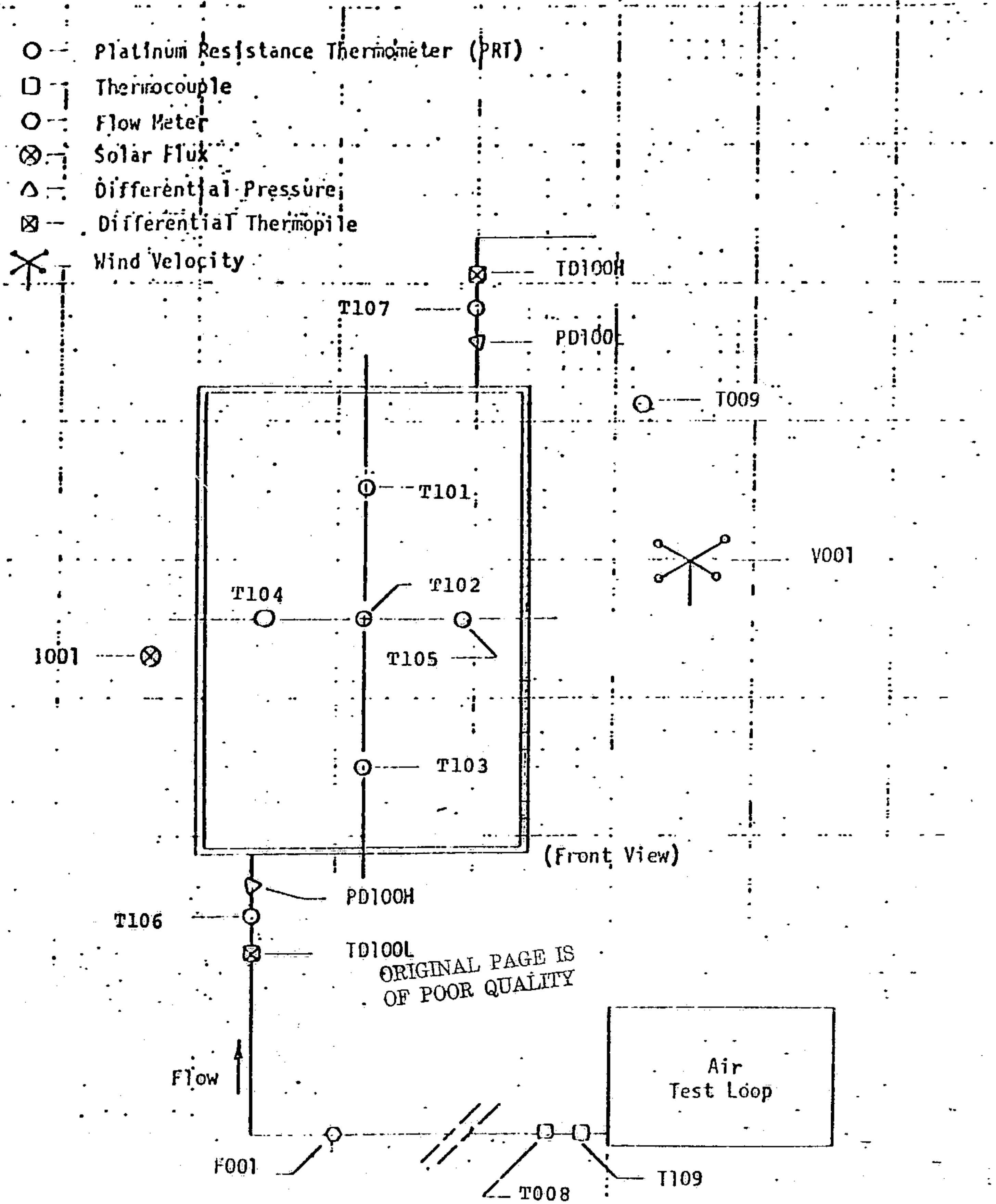

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Figure 1. Instrumentation Locations for Solaron Air Collector Test

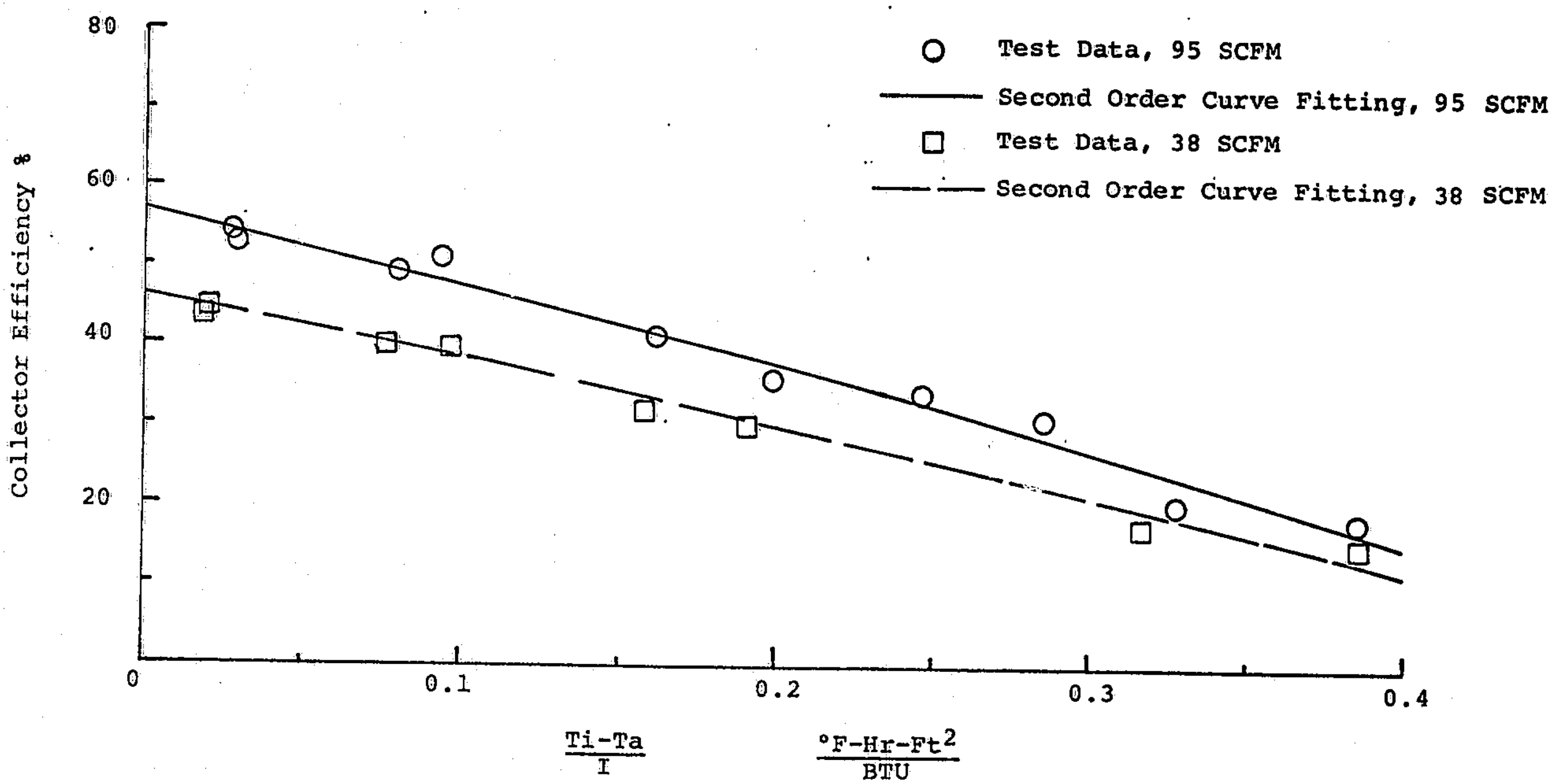

FIGURE 2 . Solaron Collector Indoor Thermal Performance Test

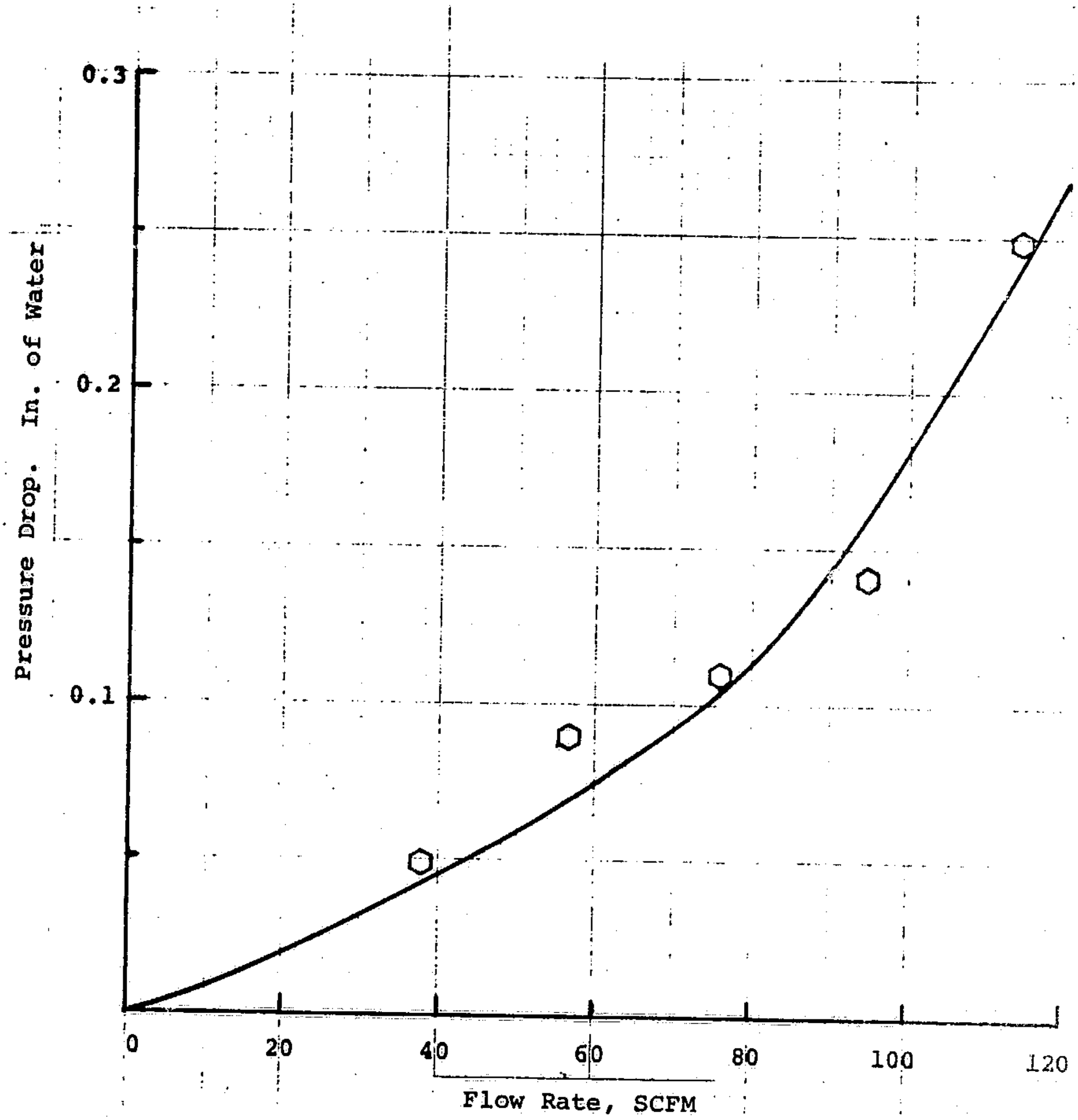

Figure 3. Solaron Collector Pressure Drop Test

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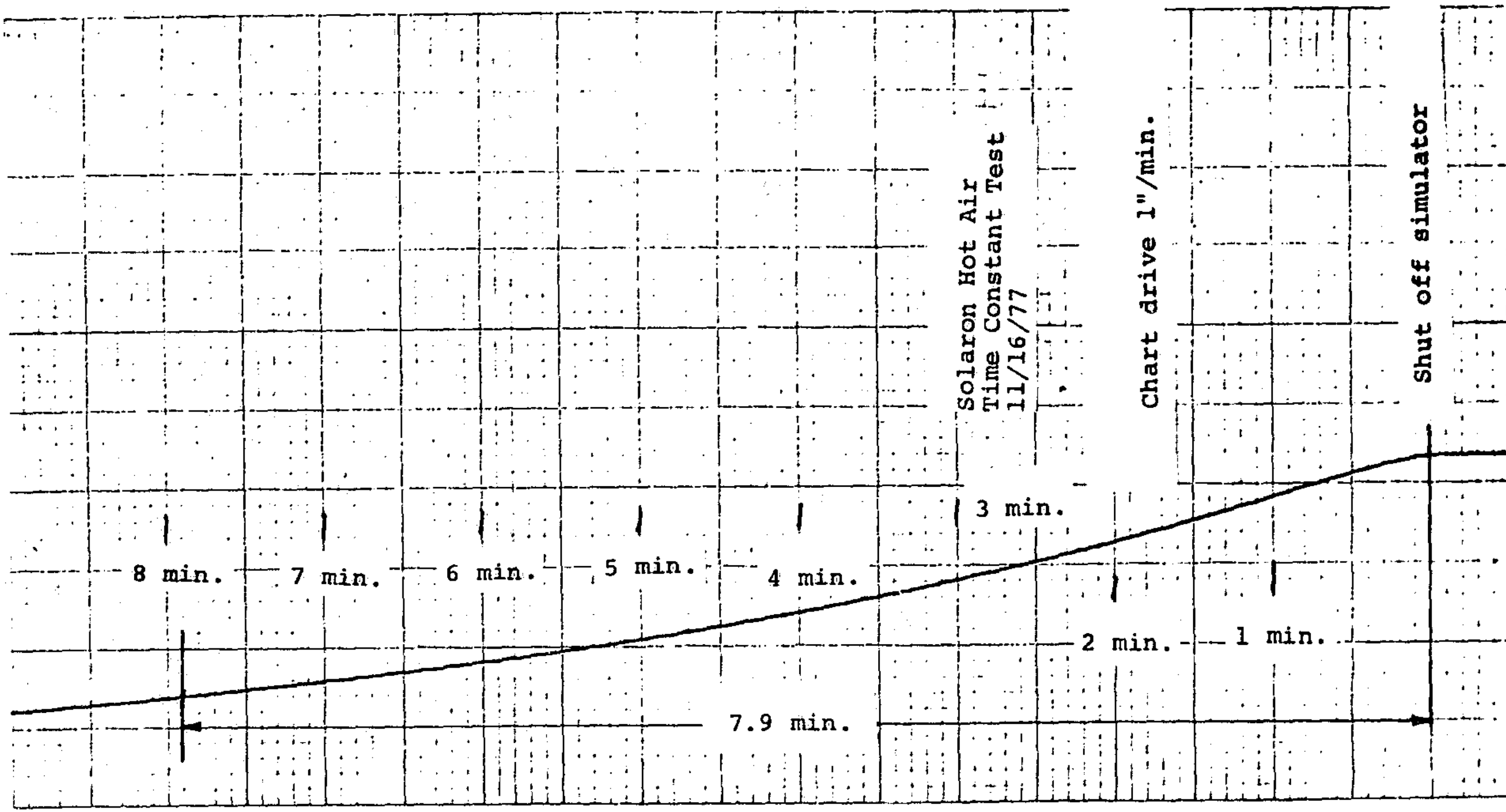


FIGURE 4. Solaron Collector Time Constant Test.

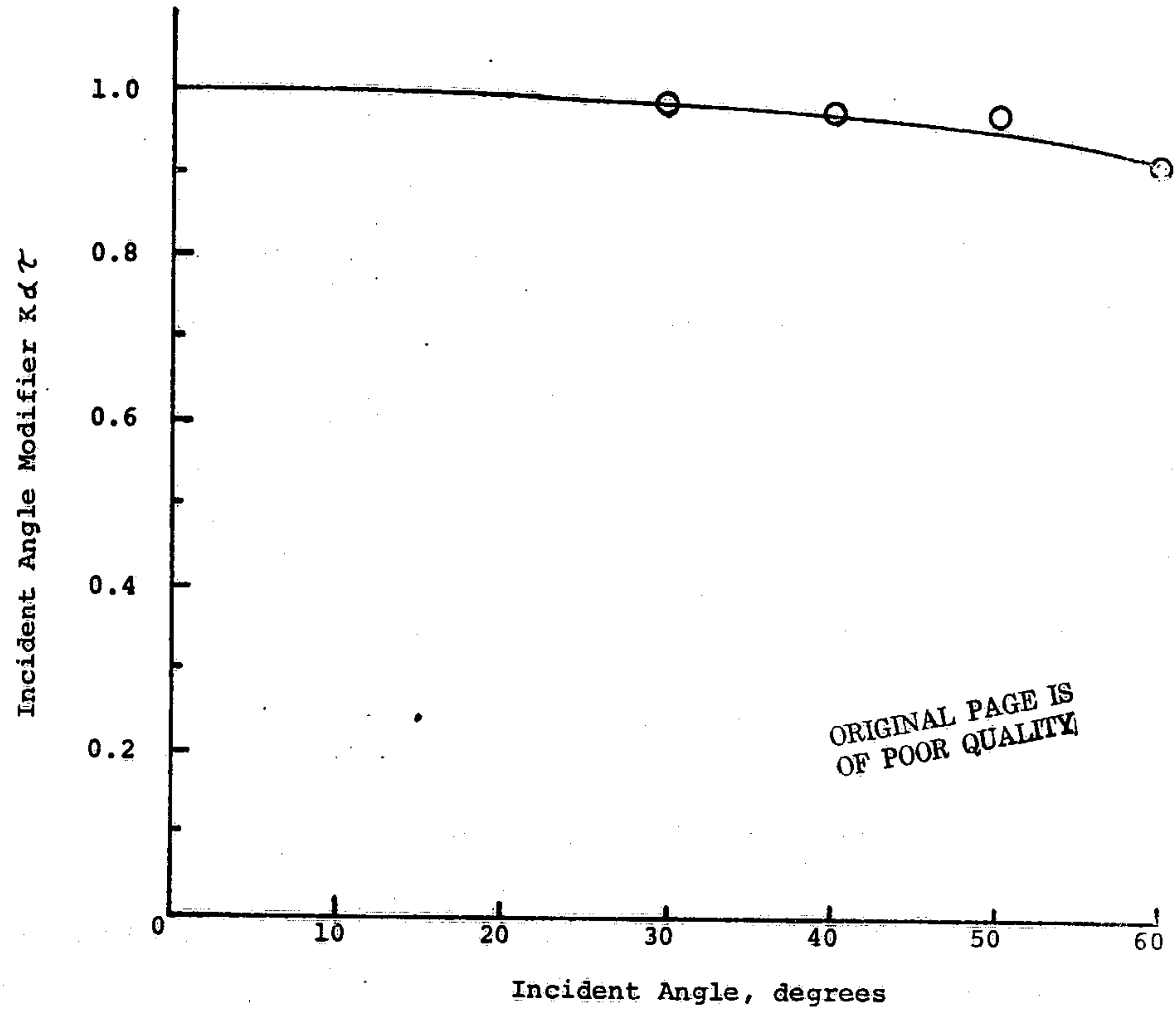


Figure 5. Incident Angle Modifier for Solaron Collector

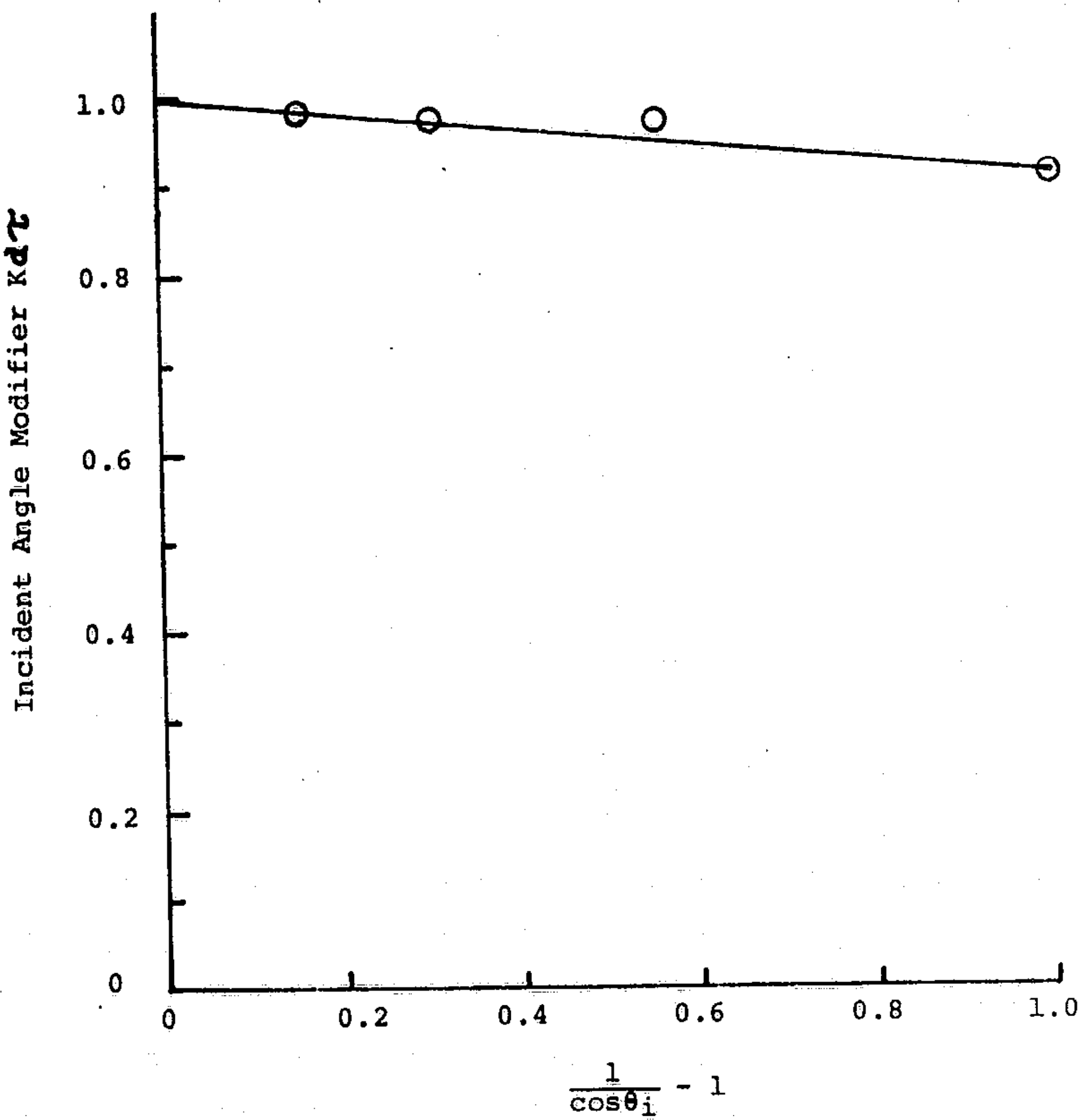


Figure 6. Incident Angle Modifier for Solaron Collector.

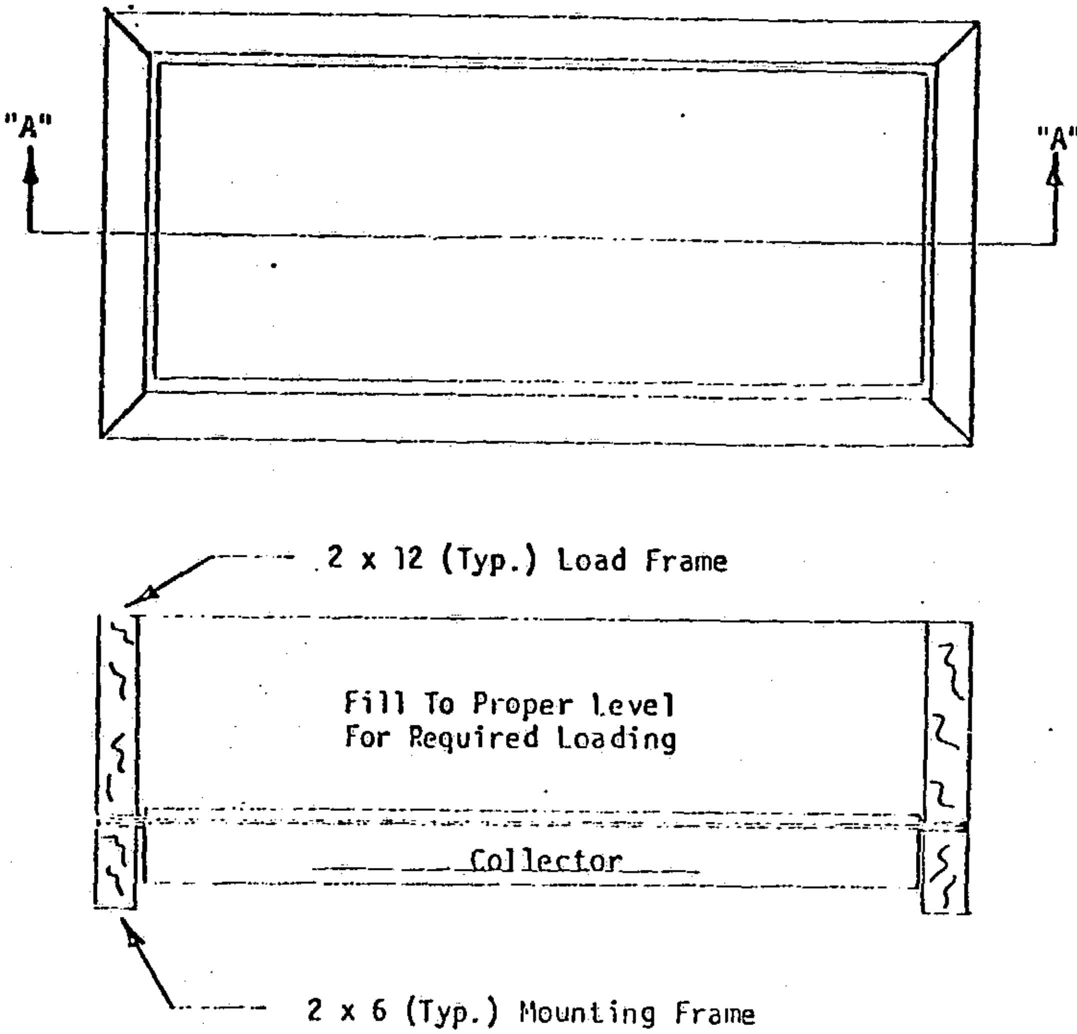
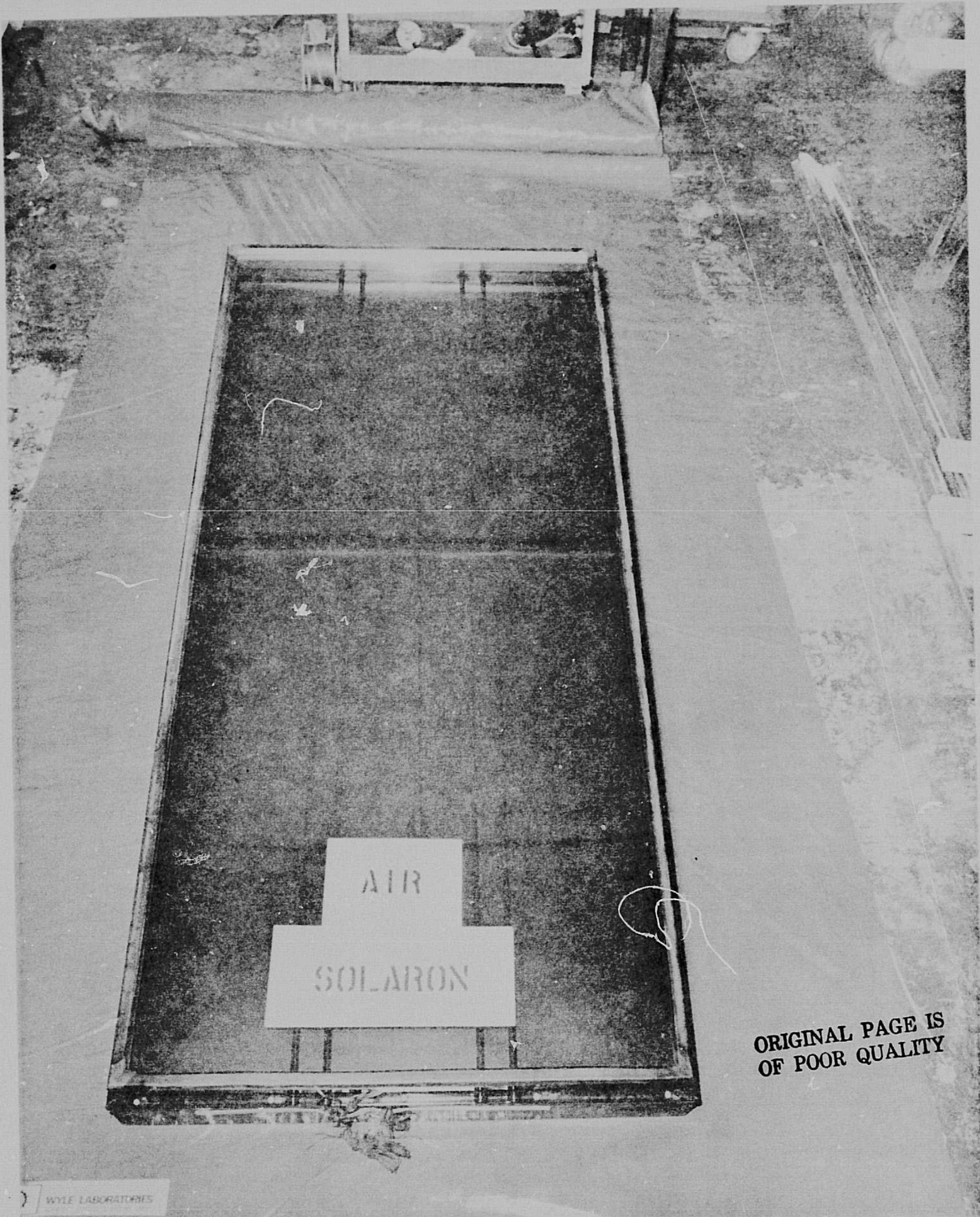


FIGURE 7. Test Setup for Static Loads.



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