DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150860

December 1978

QUALIFICATION TEST AND ANALYSIS REPORT-- SOLAR COLLECTORS

Prepared from documents furnished by

Owens-Illinois, Inc.
Solar Energy Products Group
Toledo, Ohio 43666

Under Contract NAS8-32259 with

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

For the U. S. Department of Energy

(NASA-CR-150860) QUALIFICATION TEST AND ANALYSIS REPORT: SOLAR COLLECTORS (Owens-Illinois, Inc.) 147 p HC A07/MF A01 CSCL 10B

N79-16360

Unclas
G3/44 43619

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TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. DOE/NASA CR-150860	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Qualification Test and Analysis Report-- Solar Collectors		5. REPORT DATE December 1978 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS Owens-Illinois, Inc. Solar Energy Products Group Toledo, Ohio 43666		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. NAS8-32259
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 20546		13. TYPE OF REPORT & PERIOD COVERED Contractor Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This work was done under the technical management of Mr. John Caudle, George C. Marshall Space Flight Center, Alabama.

16. ABSTRACT

Test results show that the Owens-Illinois Sunpak™ Model SEC 601 air-cooled collector meets the national standards and codes as defined in the Subsystem Performance Specification and Verification Plan of NASA/MSFC Contract NAS8-32259, dated October 28, 1976. The architectural and engineering firm of Smith, Hinchman and Grylls, Detroit, Michigan, acted in the capacity of the independent certification agency.

The program calls for the development, fabrication, qualification and delivery of an air-liquid solar collector for solar heating, combined heating and cooling, and/or hot water systems.

17. KEY WORDS	18. DISTRIBUTION STATEMENT UC-59c Unclassified-Unlimited WILLIAM A. BROOKSBANK, JR. Mgr, Solar Heating and Cooling Project Office

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	146	NTIS

MSFC - Form 3292 (Rev. December 1972)

For sale by National Technical Information Service, Springfield, Virginia 22151

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Certification Test Report

The Owens-Illinois, Inc., SUNPAK™ Model SEC 601 air cooled collector has been certified it meets national standards and codes as defined by the Subsystem Performance Specification and Verification Plan of contract NAS8-32259. The design, fabrication, installation and verification test and analysis of the Model SEC-601 collector were accomplished under contract NAS8-32259, dated October 28, 1976. The Architectural and Engineering firm , Smith, Hinchman and Grylls, Detroit, Michigan, acted in the capacity of the independent certification agency.

The SUNPAK™ Model SEC-601 collector was tested and evaluated to the applicable sections of the Interim Performance Criteria for Solar Heating and Combined Heating and Cooling Systems and Dwellings prepared for the U. S. Department of Housing and Urban Development by the National Bureau of Standards, dated January 1, 1975. The Model SEC-601 collector successfully completed all requirements and criterion of the Verification Test Program as evidenced by the documentation which follows.

The SUNPAK™ Model SEC-601 air cooled collector is a marketable subsystem for solar heating and combined heating and cooling systems for dwellings and commercial installation.

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P.E. (Ohio 5203)
O.I. Approval

David C. Miller, Ph.D.
SH&G Certification Officer

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1.3 Collector Performance.

1.3.1 Collector efficiency.

The thermal performance of the Model SEC-601 air cooled collector was investigated on the basis of its operating performance on an all day basis. That is, the useful energy gain of the collector:

$$q_u = \dot{m}C\ (To - Ti) \tag{1}$$

was evaluated in five (5) minute increments from sunrise to sunset. Test points were obtained for relatively clear day operating conditions for $(\overline{T}i - \overline{T}a)/\overline{I}_{TP}$ near 0.04, 0.05, 0.3, 0.44, 0.48, 0.60. Additional test points were also obtained under cloudy and intermittent cloudy day conditions. Solar radiation was measured in the plane of the collector using an Eppley PSP with integrator for the total radiation measurement and an Eppley 8-48 with shadow band and integrator for the diffuse solar radiation measurement.

The five minute incremental data were summed over the day from sunrise to sunset. The approximate collector fluid inlet temperature for a given test day was established during the night time hours prior to the test day. The near zero intercept test point data was obtained by ingesting ambient air into the air fan inlet and dumping the effluent from the collector overboard to ambient. The collector inlet temperature thus fluctuated throughout the day with ambient temperature. The higher collector fluid inlet temperatures were obtained by using a liquid energy source and an air liquid heat exchanger to establish the collector air inlet temperature. Near constant inlet temperatures were obtained by using city water to dilute the liquid energy source and dumping the excess water to the sewer.

Figures 1.3.1(a) through (f) contain the computer output data for the six specific days used to establish the Model SEC 601 air cooled collector characteristic efficiency curve. The curve is presented in Figure 1.3.1(g). The data points are noted by open circles. Added experimental data points are indicated in Figure 1.3.1(g) by the "X" symbol. The computer output data has been summed in half hour increments to reduce the volume of data resulting from 5 minute increment evaluation. Note that the time column is solar time for each day of test.

The test loop schematic is indicated in Figure 1.3.1(h). The Model SEC-601 air cooled collector was mounted on a south facing roof sloped at 45°. The roof was faced with Alcoa Bone White #K2028-30 (fluorocarbon) diffuse radiation material. The as received total reflectance which approximates the value of diffuse reflectance was 78.57%. See Figure 1.3.1(i) for the receiving test report.

The collector temperature rise was measured with a 4 element thermopile constructed from Type T copper constant wire. The thermocouples were calibrated by the Instrument Services Standards Lab of O.I. The calibration data is attached as Figure 1.3.1(j) [3 sheets]. The thermopiles were constructed using couples 1 through 8.

The experimental data is captured on magnetic tape using a Fluke Data Logger, Model 2240A, John Fluke Company, Mt. Lake Terrace, Washington, 98043. The Fluke is calibrated in approximately 6 month intervals.

See Figure 1.3.1 (k) [3 sheets] for the calibration data.

Radiation data is obtained using Eppley Pyronometers mounted in the tilt plane of the collector. A PSP pyronometer is used to measure total radiation and an 8-48 pyronometer with shadow band is used to measure diffuse radiation. The radiation levels are integrated over the 5 minute interval between data points. The calibration data for the pyronometers are attached as Figure 1.3.1 (l) for total and Figure 1.3.1 (m) for the diffuse measurements.

The air mass flow is measured using a Model Fan-E unit manufactured by the Air Monitor Corporation, Santa Rose, CA. Descriptive literature is attached as Figure 1.3.1(n). The circular - 6 inch diameter model is used. The Special FAN-E unit was purchased. It was mounted in accordance with the manufacturer's instructions as contained in Figure 1.3.1(o).

The analytical model for collector efficiency based on the experimental test data is:

$$\bar{\eta} = \sum[\dot{m}Cp\ (To - Ti)]/\Sigma I_{TP} \times A_c$$

The emperical relationship for the Nodel SEC-601 collector is:

$$\bar{\eta} = .58 - .14\ (Tin - Ta)/I_{TP}$$

The thermal performance curve of the Model SEC-601 air cooled collector is indicated as the dashed line in Figure 1.3.1(g). The solid line indicates the thermal performance as required by Appendix H of the contract. The dash-dot line indicates the thermal performance developed for the 144 tube ERDA collector array over a long period of time.

Review of items 1.3 and 1.3.1 successfully completed.

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HALF-HOURLY DATA SUMMARY FOR 5-22-78 DAY NO. 142

SOLAR TIME	ITP	IDP	RD	AIR FLOW	INLET TEMP	AMB TEMP	OUT TEMP	QU	EFF	DT/I
15	0.	0.	0.0	893.	62.	52.	62.	-133.	0.00	0.00
45	0.	0.	0.0	892.	62.	51.	61.	-128.	0.00	0.00
115	0.	0.	0.0	891.	61.	51.	61.	-134.	0.00	0.00
145	0.	0.	0.0	893.	61.	50.	60.	-150.	0.00	0.00
215	0.	0.	0.0	894.	61.	50.	60.	-152.	0.00	0.00
245	0.	0.	0.0	895.	60.	50.	60.	-146.	0.00	0.00
315	0.	0.	0.0	896.	60.	49.	59.	-119.	0.00	0.00
345	0.	0.	0.0	898.	59.	48.	59.	-143.	0.00	0.00
415	0.	0.	0.0	899.	59.	48.	58.	-144.	0.00	0.00
445	1.	0.	0.3	900.	58.	48.	58.	-110.	-1.45	12.08
515	6.	5.	0.9	899.	58.	47.	59.	74.	0.14	1.82
545	13.	11.	0.8	904.	58.	47.	59.	267.	0.25	0.85
615	31.	20.	0.6	900.	59.	50.	62.	642.	0.25	0.31
645	57.	27.	0.5	895.	60.	52.	68.	1755.	0.37	0.14
715	77.	32.	0.4	890.	61.	53.	77.	3511.	0.54	0.09
745	117.	36.	0.3	882.	60.	55.	87.	5747.	0.58	0.04
815	150.	42.	0.3	875.	61.	57.	97.	7676.	0.61	0.02
845	189.	51.	0.3	873.	62.	59.	105.	8951.	0.57	0.02
915	198.	48.	0.2	868.	63.	60.	104.	8638.	0.52	0.01
945	218.	66.	0.3	867.	64.	61.	107.	8970.	0.49	0.01
1015	273.	77.	0.3	860.	65.	63.	116.	10566.	0.46	0.01
1045	274.	96.	0.3	852.	66.	64.	121.	11307.	0.49	0.01
1115	229.	96.	0.4	859.	66.	64.	112.	9415.	0.49	0.01
1145	264.	83.	0.3	856.	66.	64.	114.	9856.	0.44	0.01
1215	301.	70.	0.2	851.	67.	64.	123.	11499.	0.45	0.01
1245	289.	77.	0.3	849.	67.	65.	124.	11537.	0.48	0.01
1315	254.	86.	0.3	850.	68.	65.	119.	10549.	0.49	0.01
1345	257.	78.	0.3	850.	68.	65.	119.	10475.	0.48	0.01
1415	237.	77.	0.3	852.	68.	65.	119.	10513.	0.53	0.01
1445	230.	60.	0.3	850.	68.	65.	118.	10249.	0.53	0.01
1515	197.	48.	0.2	845.	71.	65.	119.	9656.	0.58	0.03
1545	148.	41.	0.3	842.	73.	66.	115.	8516.	0.69	0.05
1615	123.	36.	0.3	847.	73.	66.	110.	7548.	0.73	0.06
1645	88.	32.	0.4	852.	73.	66.	102.	5943.	0.81	0.09
1715	56.	29.	0.5	854.	73.	65.	92.	3793.	0.81	0.14
1745	27.	24.	0.9	856.	72.	65.	82.	2024.	0.89	0.28
1815	18.	19.	1.0	862.	72.	64.	77.	1096.	0.72	0.41
1845	8.	8.	1.0	868.	71.	64.	74.	570.	0.85	0.96
1915	1.	1.	1.0	870.	70.	62.	71.	136.	1.65	8.30
1945	0.	0.	0.1	872.	70.	61.	69.	-33.	0.00	0.00
2015	0.	0.	0.1	870.	69.	60.	69.	-66.	0.00	0.00
2045	0.	0.	0.0	877.	68.	60.	68.	-80.	0.00	0.00
2115	0.	0.	0.0	876.	68.	59.	67.	-91.	0.00	0.00
2145	0.	0.	0.0	879.	67.	59.	67.	-107.	0.00	0.00
2215	0.	0.	0.0	875.	67.	56.	66.	-107.	0.00	0.00
2245	0.	0.	0.0	884.	67.	58.	66.	-115.	0.00	0.00
2315	0.	0.	0.0	877.	66.	58.	66.	-110.	0.00	0.00
2345	0.	0.	0.0	0.	0.	0.	0.	0.	UUUUU	0.00

FIGURE 1.3.1 a

HALF-HOURLY DATA SUMMARY FOR 4-14-78 DAY NO. 104

SOLAR TIME	ITP	IDP	RD	AIR FLOW	INLET TEMP	AMB TEMP	OUT TEMP	QU	EFF	DT/I
15	0.	0.	0.0	750.	69.	38.	67.	-407.	0.00	0.00
45	0.	0.	0.0	752.	69.	38.	67.	-409.	0.00	0.00
115	0.	0.	0.0	756.	69.	37.	67.	-419.	0.00	0.00
145	0.	0.	0.0	751.	69.	37.	67.	-415.	0.00	0.00
215	0.	0.	0.0	751.	69.	37.	67.	-416.	0.00	0.00
245	0.	0.	0.0	756.	69.	37.	67.	-415.	0.00	0.00
315	0.	0.	0.0	757.	69.	37.	67.	-412.	0.00	0.00
345	0.	0.	0.0	753.	69.	37.	67.	-410.	0.00	0.00
415	0.	0.	0.0	753.	64.	38.	67.	-402.	0.00	0.00
445	0.	0.	0.0	753.	70.	39.	67.	-388.	0.00	0.00
515	0.	0.	0.0	750.	70.	39.	68.	-377.	*****	112.10
545	4.	3.	0.8	753.	70.	38.	68.	-263.	-0.77	7.70
615	16.	11.	0.7	754.	70.	39.	71.	20.	0.02	1.96
645	46.	19.	0.4	750.	73.	40.	78.	1025.	0.26	0.70
715	83.	30.	0.4	740.	77.	42.	93.	2866.	0.41	0.43
745	111.	39.	0.4	736.	83.	43.	109.	4702.	0.51	0.36
815	130.	43.	0.3	728.	88.	44.	124.	6403.	0.59	0.33
845	188.	44.	0.2	722.	91.	45.	137.	7932.	0.50	0.24
915	119.	67.	0.6	728.	92.	46.	132.	7098.	0.71	0.38
945	173.	72.	0.4	724.	88.	46.	124.	6381.	0.44	0.24
1015	267.	74.	0.3	724.	93.	48.	149.	9703.	0.43	0.17
1045	263.	88.	0.3	719.	97.	49.	156.	10332.	0.47	0.18
1115	251.	98.	0.4	714.	98.	51.	157.	10293.	0.49	0.19
1145	266.	90.	0.3	712.	96.	51.	152.	9597.	0.43	0.17
1215	320.	73.	0.2	709.	99.	53.	165.	11337.	0.42	0.14
1245	309.	69.	0.2	708.	102.	54.	173.	12067.	0.46	0.16
1315	286.	81.	0.3	706.	103.	55.	170.	11574.	0.48	0.17
1345	256.	89.	0.3	711.	101.	56.	165.	10912.	0.51	0.18
1415	236.	74.	0.3	718.	100.	56.	160.	10431.	0.53	0.19
1445	225.	60.	0.3	710.	99.	57.	158.	9977.	0.53	0.19
1515	204.	40.	0.2	708.	99.	57.	158.	9982.	0.58	0.21
1545	164.	40.	0.2	710.	98.	56.	150.	8976.	0.65	0.25
1615	126.	31.	0.2	707.	96.	56.	145.	8377.	0.79	0.32
1645	83.	36.	0.4	711.	91.	55.	125.	5774.	0.83	0.43
1715	44.	21.	0.5	712.	87.	54.	110.	3859.	1.04	0.75
1745	25.	19.	0.7	720.	83.	53.	93.	1743.	0.82	1.17
1815	7.	7.	1.0	719.	80.	52.	83.	661.	1.07	3.79
1845	1.	1.	0.5	722.	77.	50.	77.	1.	0.01	29.67
1915	0.	0.	0.0	729.	76.	49.	75.	-214.	0.00	0.00
1945	0.	0.	0.0	727.	76.	47.	74.	-312.	0.00	0.00
2015	0.	0.	0.0	723.	75.	46.	73.	-345.	0.00	0.00
2045	0.	0.	0.0	728.	75.	45.	73.	-366.	0.00	0.00
2115	0.	0.	0.0	726.	75.	44.	73.	-377.	0.00	0.00
2145	0.	0.	0.0	728.	75.	43.	73.	-384.	0.00	0.00
2215	0.	0.	0.0	731.	75.	43.	73.	-395.	0.00	0.00
2245	0.	0.	0.0	728.	75.	42.	72.	-403.	0.00	0.00
2315	0.	0.	0.0	735.	75.	42.	72.	-412.	0.00	0.00
2345	0.	0.	0.0	0.	0.	0.	0.	0.	UUUUU	0.00

Figure 1.3.1 (b)

HALF-HOURLY DATA SUMMARY FOR 4-15-78 DAY NO. 105

SOLAR TIME	ITP	IDP	PD	AIR FLOW	INLET TEMP	AMB TEMP	OUT TEMP	QU	EFF	DT/I
15	0.	0.	0.0	735.	74.	40.	72.	-431.	0.00	0.00
45	0.	0.	0.0	734.	74.	40.	72.	-440.	0.00	0.00
115	0.	0.	0.0	735.	74.	39.	72.	-446.	0.00	0.00
145	0.	0.	0.0	733.	74.	38.	71.	-455.	0.00	0.00
215	0.	0.	0.0	736.	74.	38.	71.	-457.	0.00	0.00
245	0.	0.	0.0	737.	74.	38.	71.	-452.	0.00	0.00
315	0.	0.	0.0	734.	74.	37.	71.	-452.	0.00	0.00
345	0.	0.	0.0	736.	74.	37.	71.	-450.	0.00	0.00
415	0.	0.	0.0	738.	74.	37.	71.	-458.	0.00	0.00
445	0.	0.	0.0	736.	74.	37.	71.	-467.	0.00	0.00
515	0.	0.	0.0	738.	73.	36.	71.	-453.	*****	135.60
545	4.	3.	0.7	740.	74.	35.	72.	-334.	-0.95	9.08
615	15.	11.	0.7	740.	74.	37.	74.	-38.	-0.03	2.44
645	44.	17.	0.4	735.	76.	38.	82.	947.	0.25	0.87
715	81.	20.	0.3	730.	81.	39.	97.	2836.	0.42	0.51
745	123.	24.	0.2	725.	88.	42.	118.	5308.	0.51	0.38
815	161.	26.	0.2	721.	94.	43.	137.	7397.	0.55	0.32
845	198.	28.	0.1	719.	100.	45.	150.	8778.	0.53	0.28
915	234.	29.	0.1	713.	104.	46.	160.	9691.	0.49	0.25
945	263.	31.	0.1	709.	108.	47.	169.	10417.	0.47	0.23
1015	282.	37.	0.1	709.	112.	48.	175.	10844.	0.46	0.23
1045	318.	43.	0.1	703.	115.	49.	183.	11466.	0.43	0.21
1115	275.	72.	0.3	699.	118.	49.	184.	11101.	0.48	0.25
1145	185.	87.	0.5	704.	116.	49.	167.	8576.	0.55	0.36
1215	210.	95.	0.5	704.	112.	49.	152.	6845.	0.39	0.30
1245	185.	94.	0.5	699.	115.	50.	161.	7722.	0.50	0.35
1315	237.	88.	0.4	698.	117.	50.	165.	8133.	0.41	0.28
1345	189.	82.	0.4	700.	119.	51.	167.	8011.	0.50	0.36
1415	151.	85.	0.6	694.	117.	51.	153.	6027.	0.48	0.44
1445	110.	66.	0.6	699.	116.	51.	147.	5194.	0.56	0.59
1515	105.	66.	0.6	698.	115.	51.	142.	4560.	0.52	0.61
1545	115.	61.	0.5	697.	115.	51.	141.	4405.	0.46	0.55
1615	108.	38.	0.3	696.	116.	51.	144.	4689.	0.52	0.60
1645	85.	25.	0.3	696.	118.	50.	148.	5005.	0.70	0.79
1715	50.	19.	0.4	692.	116.	50.	135.	3272.	0.78	1.31
1745	22.	14.	0.6	690.	112.	49.	122.	1611.	0.88	2.87
1815	6.	8.	1.3	696.	108.	48.	110.	279.	0.55	9.87
1845	1.	1.	1.0	698.	105.	47.	103.	-265.	-5.41	98.69
1915	0.	0.	0.0	698.	103.	47.	100.	-538.	0.00	0.00
1945	0.	0.	0.0	701.	102.	46.	98.	-632.	0.00	0.00
2015	0.	0.	0.0	701.	101.	45.	97.	-653.	0.00	0.00
2045	0.	0.	0.0	706.	100.	45.	97.	-651.	0.00	0.00
2115	0.	0.	0.0	701.	100.	44.	96.	-655.	0.00	0.00
2145	0.	0.	0.0	704.	99.	44.	95.	-666.	0.00	0.00
2215	0.	0.	0.0	708.	99.	43.	95.	-672.	0.00	0.00
2245	0.	0.	0.0	708.	98.	42.	94.	-668.	0.00	0.00
2315	0.	0.	0.0	708.	98.	42.	94.	-666.	0.00	0.00
2345	0.	0.	0.0	0.	0.	0.	0.	0.	UUUUU	0.00

FIGURE 1.3.1(c)

HALF-HOURLY DATA SUMMARY FOR 4-16-78 DAY NO. 106

SOLAR TIME	ITP	IDP	RO	AIR FLOW	INLET TEMP	AMB TEMP	OUT TEMP	QU	EFF	DT/I
15	0.	0.	0.0	713.	97.	40.	92.	-694.	0.00	0.00
45	0.	0.	0.0	712.	96.	40.	92.	-694.	0.00	0.00
115	0.	0.	0.0	708.	96.	39.	92.	-694.	0.00	0.00
145	0.	0.	0.0	713.	95.	38.	91.	-700.	0.00	0.00
215	0.	0.	0.0	712.	95.	38.	91.	-698.	0.00	0.00
245	0.	0.	0.0	714.	94.	38.	90.	-702.	0.00	0.00
315	0.	0.	0.0	715.	94.	38.	90.	-702.	0.00	0.00
345	0.	0.	0.0	715.	94.	38.	90.	-703.	0.00	0.00
415	0.	0.	0.0	716.	94.	37.	89.	-705.	0.00	0.00
445	0.	0.	0.0	712.	93.	37.	89.	-705.	0.00	0.00
515	0.	0.	0.0	717.	93.	36.	89.	-713.	0.00	0.00
545	0.	0.	0.0	721.	92.	36.	88.	-708.	*****	205.51
615	4.	3.	0.7	719.	92.	35.	89.	-595.	-1.68	13.43
645	18.	12.	0.7	720.	93.	37.	91.	-245.	-0.16	3.11
715	43.	17.	0.4	717.	94.	38.	98.	597.	0.16	1.30
745	80.	21.	0.3	717.	98.	40.	113.	2456.	0.37	0.73
815	116.	26.	0.2	712.	104.	42.	132.	4672.	0.48	0.54
845	152.	29.	0.2	707.	110.	43.	149.	6633.	0.52	0.44
915	195.	32.	0.2	702.	116.	45.	165.	8253.	0.50	0.36
945	224.	35.	0.2	698.	120.	46.	174.	9091.	0.48	0.33
1015	271.	49.	0.2	699.	124.	48.	185.	10247.	0.45	0.28
1045	255.	84.	0.3	694.	128.	49.	191.	10625.	0.50	0.31
1115	205.	75.	0.4	695.	126.	50.	176.	8297.	0.48	0.37
1145	337.	92.	0.3	682.	131.	51.	199.	11129.	0.39	0.24
1215	196.	96.	0.5	686.	134.	52.	194.	9874.	0.60	0.42
1245	96.	80.	0.8	698.	126.	52.	158.	5319.	0.66	0.78
1315	158.	86.	0.5	689.	123.	50.	150.	4504.	0.34	0.46
1345	185.	99.	0.5	687.	128.	52.	171.	6977.	0.45	0.42
1415	163.	93.	0.6	684.	129.	51.	168.	6433.	0.47	0.48
1445	86.	66.	0.8	684.	127.	49.	154.	4448.	0.62	0.91
1515	130.	86.	0.7	685.	125.	49.	151.	4297.	0.39	0.59
1545	105.	62.	0.6	685.	127.	49.	155.	4626.	0.53	0.75
1615	93.	61.	0.7	682.	125.	49.	146.	3423.	0.44	0.82
1645	79.	48.	0.6	687.	126.	49.	147.	3550.	0.53	0.97
1715	80.	41.	0.5	688.	125.	49.	146.	3473.	0.52	0.96
1745	48.	27.	0.6	688.	125.	48.	140.	2608.	0.64	1.57
1815	28.	19.	0.7	690.	122.	48.	131.	1457.	0.62	2.67
1845	8.	9.	1.1	690.	118.	47.	119.	186.	0.29	9.37
1915	1.	1.	1.5	690.	115.	46.	113.	-406.	-6.70	96.29
1945	0.	0.	0.0	692.	113.	45.	109.	-716.	0.00	0.00
2015	0.	0.	0.0	690.	112.	44.	107.	-793.	0.00	0.00
2045	0.	0.	0.0	693.	111.	43.	106.	-826.	0.00	0.00
2115	0.	0.	0.0	692.	110.	43.	105.	-838.	0.00	0.00
2145	0.	0.	0.0	692.	110.	42.	105.	-840.	0.00	0.00
2215	0.	0.	0.0	696.	109.	42.	104.	-838.	0.00	0.00
2245	0.	0.	0.0	695.	108.	41.	103.	-835.	0.00	0.00
2315	0.	0.	0.0	697.	108.	41.	103.	-831.	0.00	0.00
2345	0.	0.	0.0	695.	107.	40.	102.	-832.	0.00	0.00
	0.	0.	0.0	0.	0.	0.	0.	0.	UUUUU	0.00

FIGURE 1.3.1 (d)

HALF-HOURLY DATA SUMMARY FOR 4-17-78 DAY NO. 107

SOLAR TIME	ITP	IDP	RD	AIR FLOW	INLET TEMP	AMB TEMP	OUT TEMP	QU	EFF	DT/I
15	0.	0.	0.0	700.	106.	39.	101.	-838.	0.00	0.00
45	0.	0.	0.0	701.	106.	39.	101.	-834.	0.00	0.00
115	0.	0.	0.0	705.	105.	39.	100.	-835.	0.00	0.00
145	0.	0.	0.0	704.	105.	38.	100.	-830.	0.00	0.00
215	0.	0.	0.0	704.	104.	38.	99.	-824.	0.00	0.00
245	0.	0.	0.0	704.	104.	38.	99.	-823.	0.00	0.00
315	0.	0.	0.0	703.	103.	37.	98.	-821.	0.00	0.00
345	0.	0.	0.0	702.	103.	37.	98.	-815.	0.00	0.00
415	0.	0.	0.0	707.	102.	37.	97.	-820.	0.00	0.00
445	0.	0.	0.0	712.	102.	36.	97.	-833.	0.00	0.00
515	0.	0.	0.0	710.	101.	36.	96.	-820.	*****	224.56
545	5.	4.	0.8	709.	101.	35.	97.	-630.	-1.55	12.62
615	17.	13.	0.8	706.	101.	36.	99.	-357.	-0.24	3.73
645	40.	23.	0.6	705.	103.	37.	105.	345.	0.10	1.64
715	76.	28.	0.4	707.	106.	39.	118.	2010.	0.32	0.88
745	115.	29.	0.3	706.	112.	42.	137.	4330.	0.45	0.61
815	155.	32.	0.2	702.	117.	43.	157.	6765.	0.52	0.48
845	191.	33.	0.2	700.	118.	43.	167.	8188.	0.51	0.39
915	225.	36.	0.2	701.	120.	44.	175.	9195.	0.49	0.34
945	251.	38.	0.2	701.	122.	45.	181.	9928.	0.47	0.31
1015	277.	39.	0.1	701.	125.	46.	187.	10484.	0.45	0.29
1045	301.	39.	0.1	696.	129.	46.	194.	10984.	0.43	0.27
1115	315.	40.	0.1	689.	132.	47.	199.	11218.	0.42	0.27
1145	321.	42.	0.1	691.	135.	48.	203.	11397.	0.42	0.27
1215	320.	42.	0.1	685.	137.	49.	207.	11489.	0.43	0.28
1245	315.	42.	0.1	681.	137.	50.	209.	11717.	0.44	0.28
1315	304.	41.	0.1	680.	134.	50.	204.	11599.	0.45	0.28
1345	288.	38.	0.1	680.	132.	50.	201.	11301.	0.47	0.28
1415	267.	39.	0.1	683.	131.	50.	199.	11146.	0.50	0.30
1445	232.	48.	0.2	688.	129.	50.	193.	10556.	0.54	0.34
1515	137.	56.	0.4	689.	125.	50.	176.	8340.	0.72	0.55
1545	114.	65.	0.6	692.	118.	49.	153.	5851.	0.61	0.60
1615	87.	46.	0.5	696.	115.	49.	146.	5112.	0.70	0.76
1645	42.	34.	0.8	692.	111.	49.	126.	2506.	0.71	1.49
1715	28.	24.	0.9	696.	108.	48.	115.	1300.	0.56	2.13
1745	16.	13.	0.8	700.	105.	47.	108.	502.	0.38	3.63
1815	6.	5.	0.8	697.	103.	47.	103.	-52.	-0.10	9.33
1845	0.	0.	0.0	701.	101.	46.	99.	-413.	*****	120.13
1915	0.	0.	0.0	703.	100.	45.	97.	-572.	0.00	0.00
1945	0.	0.	0.0	706.	99.	44.	96.	-620.	0.00	0.00
2015	0.	0.	0.0	707.	99.	44.	95.	-635.	0.00	0.00
2045	0.	0.	0.0	707.	98.	44.	95.	-637.	0.00	0.00
2115	0.	0.	0.0	703.	98.	44.	94.	-627.	0.00	0.00
2145	0.	0.	0.0	717.	98.	44.	94.	-641.	0.00	0.00
2215	0.	0.	0.0	708.	97.	44.	94.	-630.	0.00	0.00
2245	0.	0.	0.0	709.	97.	44.	93.	-625.	0.00	0.00
2315	0.	0.	0.0	709.	97.	44.	93.	-621.	0.00	0.00
2345	0.	0.	0.0	0.	0.	0.	0.	0.	UUUUU	0.00

FIGURE 1.3.1(e)

HALF-HOURLY DATA SUMMARY FOR 5-10-78 DAY NO. 130

SOLAR TIME	ITP	TCP	RH	AIR FLOW	INLET TEMP	AMB TEMP	OUT TEMP	QU	EFF	DT/I
15	0.	0.	0.0	0.	62.	52.	60.	0.	0.00	0.00
45	0.	0.	0.0	0.	61.	51.	59.	0.	0.00	0.00
115	0.	0.	0.0	0.	61.	51.	59.	0.	0.00	0.00
145	0.	0.	0.0	0.	61.	51.	58.	0.	0.00	0.00
215	0.	0.	0.0	0.	61.	50.	58.	0.	0.00	0.00
245	0.	0.	0.0	0.	60.	50.	58.	0.	0.00	0.00
315	0.	0.	0.0	0.	60.	50.	58.	0.	0.00	0.00
345	0.	0.	0.0	0.	60.	50.	58.	0.	0.00	0.00
415	0.	0.	0.0	0.	59.	51.	57.	0.	0.00	0.00
445	0.	0.	0.0	0.	59.	50.	58.	0.	0.00	31.06
515	3.	1.	0.5	0.	59.	50.	57.	0.	0.00	3.21
545	4.	6.	0.7	0.	59.	50.	57.	0.	0.00	0.92
615	23.	19.	0.8	0.	59.	51.	59.	0.	0.00	0.36
645	34.	28.	0.8	0.	59.	51.	59.	0.	0.00	0.24
715	81.	40.	0.5	541.	61.	52.	83.	4913.	0.72	0.11
745	117.	41.	0.4	893.	60.	53.	90.	6538.	0.66	0.06
815	129.	50.	0.4	893.	60.	54.	94.	7191.	0.66	0.05
845	100.	59.	0.6	889.	61.	55.	88.	5649.	0.67	0.06
915	113.	66.	0.6	891.	63.	55.	82.	4180.	0.44	0.07
945	63.	54.	0.9	892.	63.	56.	80.	3495.	0.67	0.12
1015	118.	84.	0.7	886.	64.	56.	84.	4231.	0.43	0.07
1045	199.	106.	0.5	879.	65.	58.	99.	7203.	0.43	0.04
1115	215.	103.	0.5	873.	66.	59.	104.	7858.	0.43	0.04
1145	262.	96.	0.4	865.	67.	60.	115.	9877.	0.45	0.03
1215	230.	101.	0.4	867.	69.	61.	114.	9488.	0.49	0.03
1245	184.	101.	0.5	857.	69.	62.	109.	8251.	0.53	0.04
1315	255.	88.	0.3	860.	70.	63.	117.	9655.	0.45	0.03
1345	251.	86.	0.3	856.	71.	65.	119.	10025.	0.48	0.02
1415	175.	77.	0.4	855.	72.	66.	113.	8602.	0.59	0.03
1445	147.	66.	0.5	859.	72.	66.	104.	6811.	0.55	0.04
1515	193.	64.	0.3	857.	72.	66.	111.	7984.	0.49	0.03
1545	123.	50.	0.4	855.	73.	67.	108.	7228.	0.70	0.05
1615	86.	42.	0.5	860.	73.	67.	99.	5443.	0.76	0.07
1645	85.	36.	0.4	863.	73.	67.	97.	5023.	0.70	0.07
1715	52.	25.	0.5	864.	73.	67.	91.	3663.	0.84	0.12
1745	25.	20.	0.8	872.	72.	66.	81.	1906.	0.92	0.25
1815	12.	13.	1.1	873.	72.	66.	76.	894.	0.92	0.54
1845	5.	7.	1.4	880.	71.	65.	73.	445.	0.99	1.20
1915	0.	0.	0.8	882.	70.	64.	71.	41.	2.24	15.29
1945	0.	0.	0.4	884.	70.	63.	69.	-45.	0.00	0.00
2015	0.	0.	0.4	881.	69.	62.	68.	-74.	0.00	0.00
2045	0.	0.	0.4	887.	68.	61.	68.	-89.	0.00	0.00
2115	0.	0.	0.3	889.	68.	60.	67.	-95.	0.00	0.00
2145	0.	0.	0.3	890.	67.	59.	67.	-105.	0.00	0.00
2215	0.	0.	0.2	893.	67.	58.	66.	-106.	0.00	0.00
2245	0.	0.	0.2	896.	66.	57.	66.	-105.	0.00	0.00
2315	0.	0.	0.2	899.	66.	57.	65.	-112.	0.00	0.00
2345	0.	0.	0.0	0.	0.	0.	0.	0.	0.0000	0.00

FIGURE 1.3.1 (F)

MODEL SEC-601 COLLECTOR EFFICIENCY

$$\bar{\eta} = \frac{\sum \dot{M} C_p \, (T_o - T_i)}{A_c \sum I_{TP}}$$

$\dot{M}$ = FLUID FLOW TO COLLECTOR; #/ DAY

C_p = SPECIFIC HEAT OF FLUID; BTU/#-°F

T_o = COLLECTOR OUTLET TEMPERATURE; °F

T_i = COLLECTOR INLET TEMPERATURE; °F

A_c = COLLECTOR AREA ; FT^2 (APERTURE AREA)

I_{TP} = INSOLATION; BTU/FT^2 - DAY

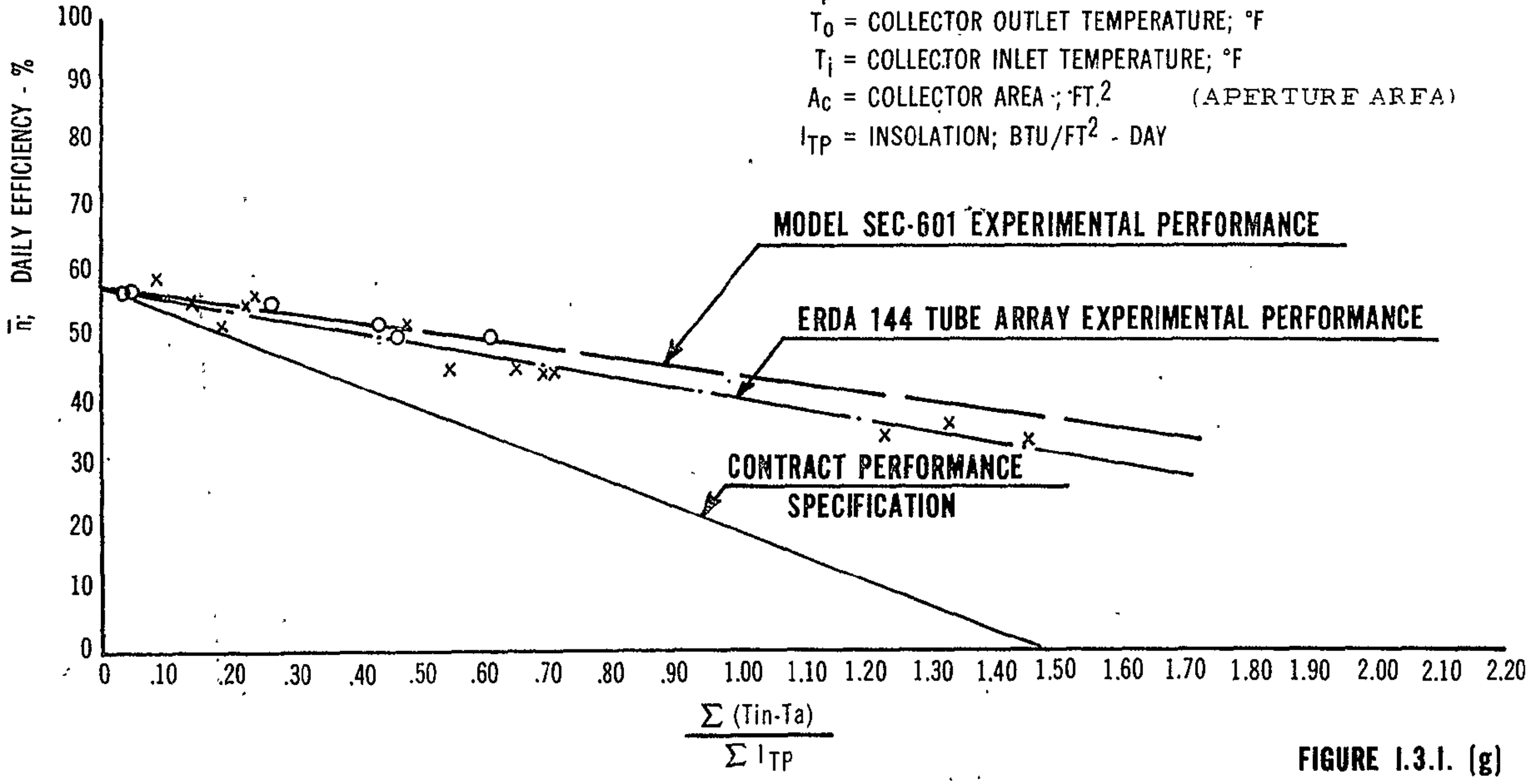


FIGURE 1.3.1. (g)

TEST LOOP SCHEMATIC
MODEL SEC 601 AIR COOLED COLLECTOR

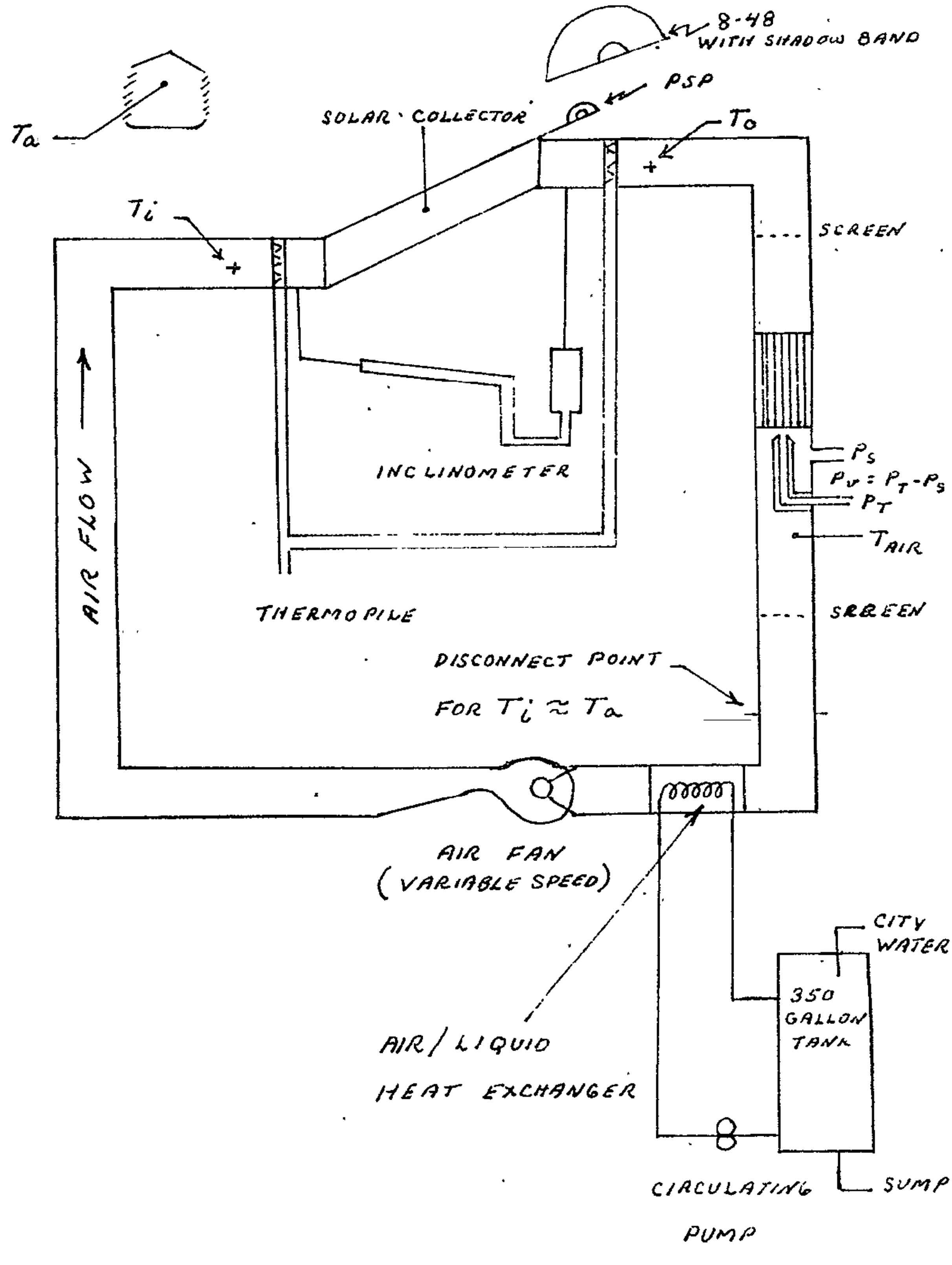


FIGURE 1.3.1 (h)

OWENS-ILLINOIS

February 28, 1978

Intra-Company

to G. R. Mather - Dev. Ctr.

cc: K. L. Moan - Dev. Ctr.
Y. K. Pei - Dev. Ctr.
L. Spanoudis - Dev. Ctr.
W. J. Zitkus - NTC

subject

SPECTRAL PROPERTIES OF A WHITE BACKGROUND MATERIAL

A white corrugated aluminum background was installed at the Development Center in February 1978. The material was Alcoa Bone White [K-2028, Desoto Paint].

Reflectance measurements were made on the sample as received. The reflectance was calculated using ASTM Designation E-424-71 (with a barium sulfate standard instead of magnesium oxide). The spectral curves are in our file.

Alcoa Bone White, Total Reflectance 78.57.

B. R. Emch

BRE:gs

FIGURE 1.3.1 (i)

OWENS-ILLINOIS

Corporate Technology

Toledo, Ohio

September 14, 1976

Intra-Company

to A. Lewis

subject Report of Calibration
Type "T" Thermocouples
Designation: ROB-4-976

Calibration was performed on 35 Type "T" copper-constantan thermocouples at 32°F, 175°F, and 350°F. The 32°F point was determined by immersing the thermocouples in melting ice. The 175°F and 350°F points were determined using a Rosemount oil bath, Mueller bridge, and a platinum resistance thermometer reference standard, S/N 1739336. The thermocouples were referenced to 32°F with a Kaye Ice Point Reference System and their emf was measured on a L&N 7556 potentiometer. The calibration is referenced to the IPTS 68, and is traceable to the National Bureau of Standards.

The temperature deviation of all 35 thermocouples is approximately the same for each point, .1° high at 32°F, .2° low at 175°F, .7° low at 350°F. The uncertainties of these values are estimated not to exceed .1°F at 32°F and 175°F and .2°F at 350°F.

Calibration Test Performed by

Mathias P. Welker

Instrument Services Standards Lab

FIGURE 13.1(j) 1 of 3

Table 1

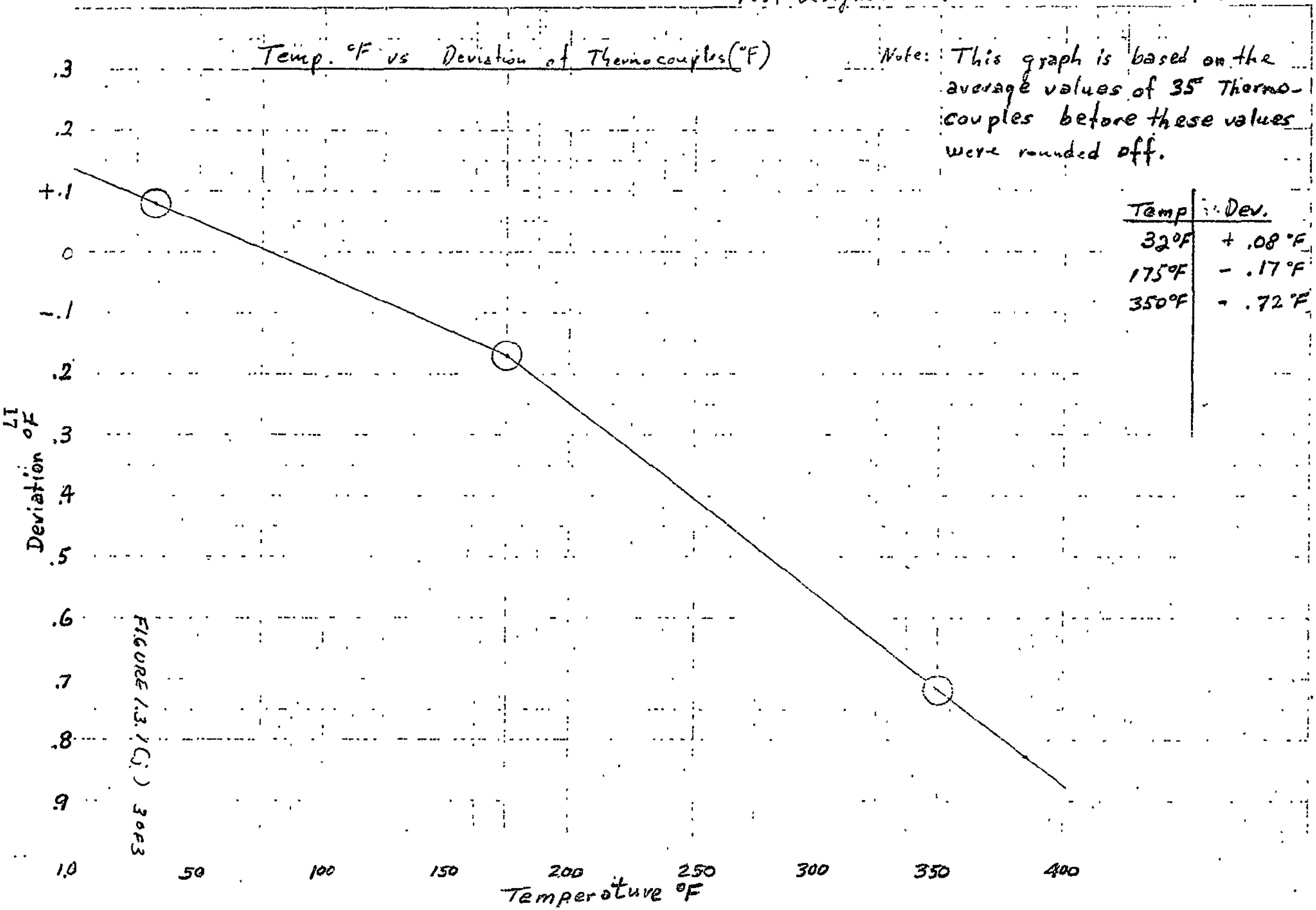
ROB-4-976

Temperature	32°F	175°F	350°F
T.C. #	T.C. Reading °F	T.C. Reading °F	T.C. Reading °F
1	32.1	174.8	349.3
2	32.1	174.8	349.3
3	32.1	174.8	349.3
4	32.1	174.8	349.3
5	32.1	174.8	349.3
6	32.1	174.8	349.3
7	32.1	174.8	349.3
8	32.1	174.8	349.3
9	32.1	174.8	349.3
10	32.1	174.8	349.3
11	32.1	174.8	349.3
12	32.1	174.8	349.3
13	32.1	174.8	349.3
14	32.1	174.8	349.3
15	32.1	174.8	349.3
16	32.1	174.8	349.3
17	32.1	174.8	349.3
18	32.1	174.8	349.3
19	32.1	174.8	349.3
20	32.1	174.8	349.3
21	32.1	174.8	349.3
22	32.1	174.8	349.3
23	32.1	174.8	349.3
24	32.1	174.8	349.3
25	32.1	174.8	349.3
26	32.1	174.8	349.3
27	32.1	174.8	349.3
28	32.1	174.8	349.3
29	32.1	174.8	349.3
30	32.1	174.8	349.3
31	32.1	174.8	349.3
32	32.1	174.8	349.3
33	32.1	174.8	349.3
34	32.1	174.8	349.3
35	32.1	174.8	349.3

FIGURE 1.3.1(j) 2 of 3

46 1320

Test Designation ROB-4-976 9-13-76



OWENS-ILLINOIS
Corporate Technology
Toledo, Ohio

June 29, 1977

Intra-Company

to K. Moan - Dev Ctr
cc: D. Stahl - NTC

subject

FLUKE CALIBRATION

On May 12, 1977 the six month internal calibration check was completed for the Fluke data acquisition system. The test was performed using a Leeds & Northrup millivolt potentiometer balanced to a standard reference cell. The following results were obtained and are within the instrument specifications.

STANDARD MV	FLUKE
1.000 MV	1.001 MV
10.000 MV	10.005 MV
30.000 MV	30.011 MV

J. A. Jacobs
Instrument Services

FIGURE 13.1(K) 1 of 3

OWENS-ILLINOIS
Corporate Technology
Toledo, Ohio

October 24, 1977
Intra-Company

to K. Moan - Dev. Ctr.
cc: D. Beekley - Dev. Ctr.
D. Stahl - NTC

subject

FLUKE CALIBRATION CHECK

On October 21, 1977 a calibration check was completed on the Fluke data system used for solar monitoring. The test was performed using a Leeds and Northrup millivolt potentiometer referenced to a standard cell. The following results were obtained and are within the instrument specifications.

Standard MV	Fluke Reading
1.00 MV	.999 MV
5.00 MV	5.000 MV
10.00 MV	10.001 MV
20.00 MV	20.004 MV
30.00 MV	30.007 MV

J. A. Jacobs
Instrument Services

FIGURE 1.3.1 (K) 2 OF 3

OWENS-ILLINOIS
Corporate Technology
Toledo, Ohio

May 4, 1978

Intra-Company

to K. Moan - Dev. Ctr.
cc: D. Beekley - Dev. Ctr.
subject D. Stahl - NTC

FLUKE CALIBRATION CHECK

On May 4, 1978 a calibration check was completed on the Fluke data system used for SUNPAK monitoring at the Development Center. The test was performed using a Leeds and Northrup millivolt potentiometer referenced to a Standard Cell. The following results are within the instrument specifications.

Standard MV	Fluke Reading
1 MV	1.000 MV
5 MV	4.999 MV
10 MV	10.003 MV
20 MV	20.007 MV
30 MV	30.016 MV

J. A. Jacobs
Instrument Services

FIGURE 1.3.1(c) 3 of 3

(401) 847-1020

EPLAB

THE EPPLEY LABORATORY, INC.
SCIENTIFIC INSTRUMENTS
NEWPORT, R I. 02840 U S A.

STANDARDIZATION
OF
EPPLEY PRECISION PYRANOMETER

(horizontal surface receiver-180°, twin hemisphere)

Model PSP Serial Number 15947F3 Resistance 615 ohm at 26 °C

Temperature Compensation

Range -20 to + 40 °C

This radiometer has been compared with the Eppley group of reference standards under radiation intensities of about 700 watts meter^{-2} (roughly one-half a solar constant), the adopted calibration temperature is 27 °C.

As a result of a series of comparisons, it has been found to develop an emf of.

MV X 30.7159 = BTU/ft²HR 10.32 x10^{-6} volts/watt meter^{-2}

7.20 millivolts/cal cm^{-2} min^{-1}

The calculation of this constant is based on the fact that the relationship between radiation intensity and emf is rectilinear to intensities of 1400 watts meter^{-2}. This pyranometer is linear to within ± 0.5 percent up to this intensity.

The calibration was made with both hemispheres of Schott WG295 (clear) glass. This value should be *increased* for other Schott hemispheres as follows: GG400 = 0.0 %, OG530 = 0.5%, RG610 = 1.5% and RG695 = 2.0%.

The calibration of this instrument is traceable to standard self-calibrating cavity pyrheliometers in terms of the Systems Internationale des Unites (SI units), which participated in the Fourth International Pyrheliometric Comparisons (IPCIV) at Davos, Switzerland in October 1975.*

Useful conversion facts: 1 cal-cm^{-2} min^{-1} = 697.3 watts/meter^2
1 BTU/ft^2-hr^{-1} = 3.153 watts/meter^2

Date of Test: July 6, 1977

IN CHARGE OF TEST
Richard H. Hatch

The Eppley Laboratory, Inc.

By: [signature]

S. O. 35000

Newport, R. I.

Date July 15, 1977

Shipped to: Owens Illinois Development Center
Toledo, Ohio

FIGURE 1.3.1(2) 1 OF 3

Remarks:

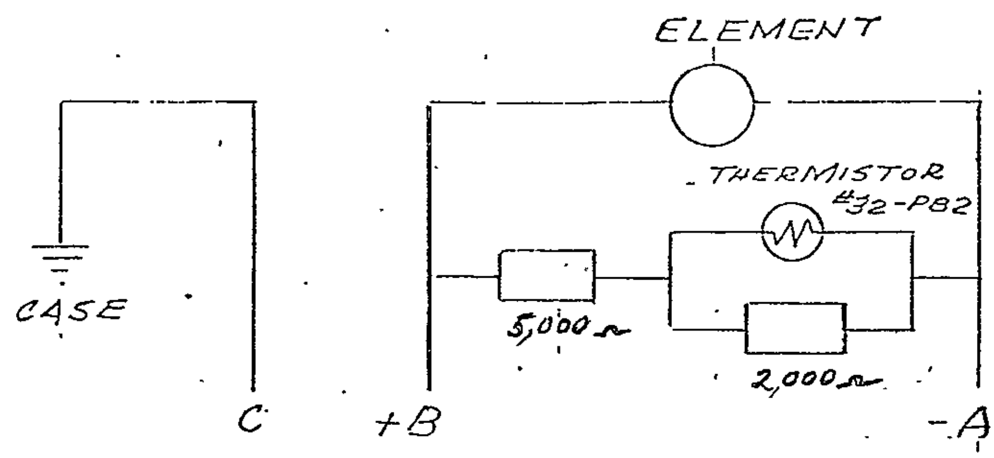
* See Reverse For Explanat

Explanation of change in calibration traceability

As of April 1, 1977, the calibration traceability of Eppley solar radiation measuring instruments has been changed from the International Pyrheliometric Scale of 1956 (IPS 1956) to the Absolute Scale (SI). This change based on the results of IPC IV is such that instruments calibrated in SI units yield irradiance values which are 2.1% higher than values which would be obtained using Eppley instruments calibrated previously and referenced to IPS.

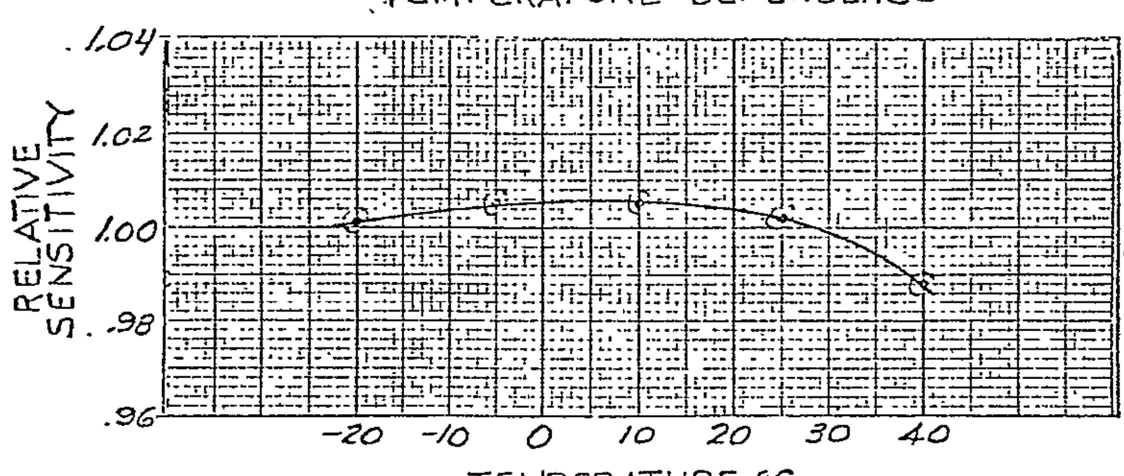
FIGURE 1.3.1(l) 2 of 3

EPPLEY PRECISION SPECTRAL PYRANOMETER- MODEL PSP - INSTRUMENT NO. 15947



INTERNAL WIRING

TEMPERATURE DEPENDENCE



TESTED BY

DATE JULY 1, 1977

FIGURE 1.3.1(2) 3 OF 3

DESERT SUNSHINE EXPOSURE TESTS, INC.

We Test Anything Under the Sun

BOX 185 • BLACK CANYON STAGE
PHOENIX, ARIZONA 85020
(602)465-7525

TAWA, THE SUN KACHINA

CERTIFICATE

OF

PYRANOMETER CALIBRATION

DSET Order No. 18011C

Pyranometer: Eppley Model 8-48, SN 15765

Client: Owens-Illinois
Date of Calibration: July 5-6, 1977
Tilt: 45° from horizontal at 180° azimuth
Latitude: 33° 50'
Time: 10:00 to 15:00 hrs apparent solar
Scale: Absolute
Ambient Temperature: 36.7°C - 42.2°C

INSTRUMENT CONSTANT: $8.405 \times 10^{-6} \pm 0.01\ V/wm^{-2}$ (10:00-15:00 hrs)
$8.357 \times 10^{-6} \pm 0.01\ V/wm^{-2}$ (10:30-13:30 hrs)

Traceability: Calibrated in 60 instantaneous increments to DSET's Eppley PSP working standard (SN 14391F3) itself maintained in calibration against DSET's Eppley Model H-F Absolute Cavity, Self-Calibrating Pyrheliometer, which is traceable to IPC IV, October 1975, Davos, Switzerland through NOAA's Kendall PACRAD SN 67502.

DESERT SUNSHINE EXPOSURE TESTS, INC.

Gene A. Zerlaut, Technical Director

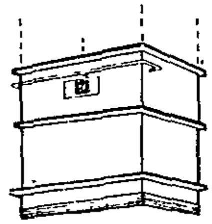
July 8, 1977
Date

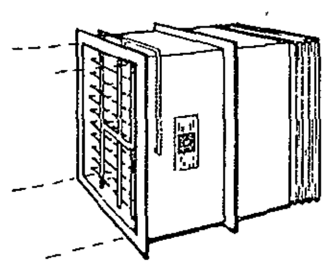
DSET, Inc. uses reasonable diligence in the manner of performing the services required but no warranties are given and none may be implied directly or indirectly relating to DSET services or facilities or to the tests or calibrations by DSET upon Buyer's equipment. In no event shall DSET be liable for collateral, special or consequential damage.

FIGURE 13.1 (m)

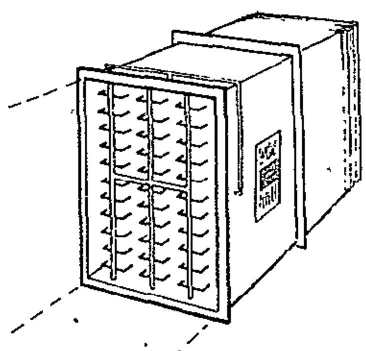
MONIT *Aire* FAN-E

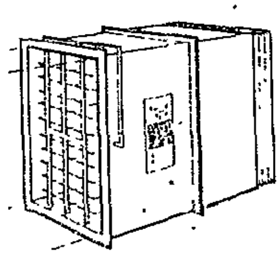
FAN *E*valuator





An Unique combination of:
- Air equalizer
- Air straightener
- Multi-point self-averaging pitot tube station
- Airflow meter



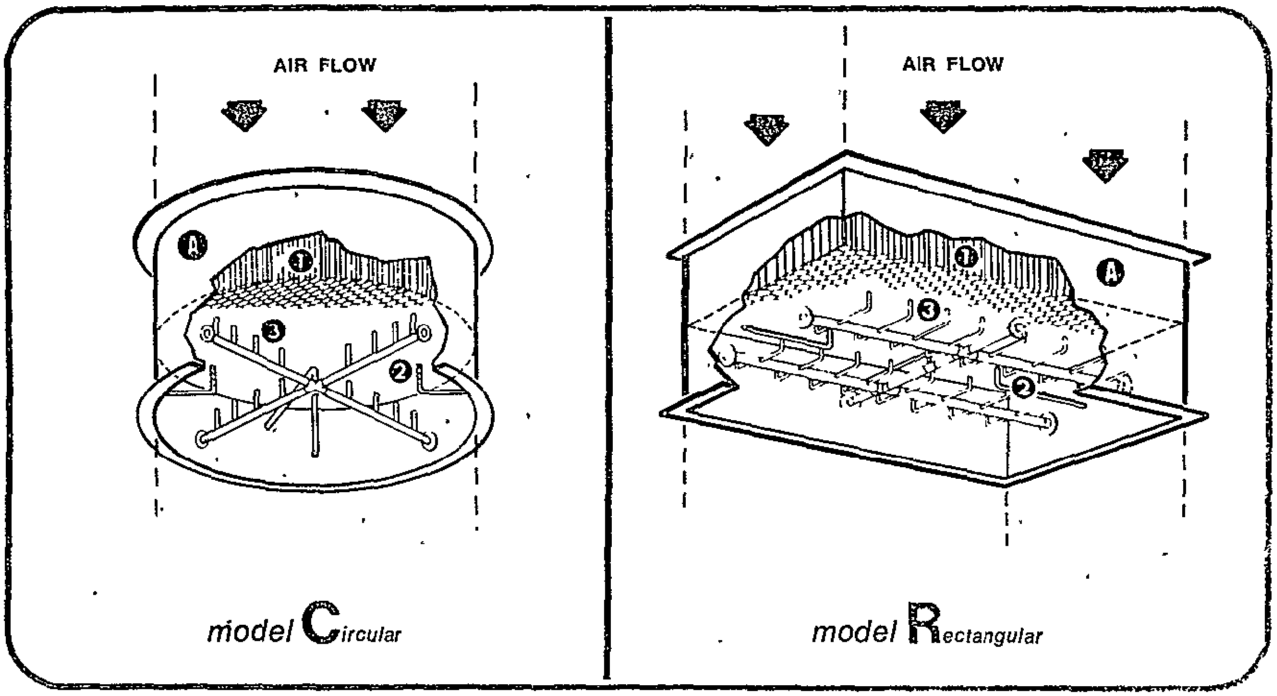


For accurate *Measurement* and *Control* of Fan Air Handling Capacity

FIGURE 1.3.1(n)

MONITAire FAN-E

Three Specialized Sections - One Integrated Unit



The model C FAN-E offers a circular configuration for mounting in round high (and low) velocity spiral and round duct while the model R FAN-E provides a rectangular (or square) configuration for installation in normal rectangular high (and low) velocity main duct or fan discharge ductwork.

Fabricated as a single integral unit, each FAN-E unit incorporates three distinct and highly specialized sections to assure measuring reliability and accuracy.

A. **CASING** — Rugged heavy gauge galvanized steel casing with connecting flanges on entering and leaving air sides for easy mounting in ductwork.

1. **AIR EQUALIZER AND STRAIGHTENER** — Expanded aluminum honeycomb with close parallel cell orientation and extended depth configuration has the capacity to equalize the velocity profile of the entering air while eliminating turbulent rotational air flow by directionalizing the air into laminar flow.

2. **STATIC PRESSURE SENSORS** — Static pressure sensors are placed along the perimeter of the FAN-E casing and interconnected by an external tube-header to produce a single accurate averaged static pressure measurement.

3. **TOTAL PRESSURE SENSORS** — The total pressure sensing section is comprised of a network of interconnected tube headers, each with a series of multiple total pressure sensors with sensor openings directed into the straightened air flow. Total pressure sensors are positioned so that each sensing point represents an equal measuring area.

FIGURE 1.3.1(n) 2 OF 8

how the FAN-E works...

The FAN-E, utilizing old established air flow principles in a new application concept combines in a single unit devices to condition or "treat" the air prior to its actual measurement. How it works is briefly outlined below

Fans (blowers, etc) move air by centrifugal force resulting in the air near the fan discharge being "piled-up" or stratified (Figure 1) It is the function of the combination air equalizing and straightening section of the FAN-E unit to simultaneously reduce the sharp variance in air velocity projections present in the stratified air flow while eliminating all turbulent or rotating air flow The individual wall surfaces of each of the long parallel tubes comprising this unique honeycomb section produces a separate wall friction or drag effect on the stream of air passing through that tube the amount of this resistance to flow varying with the square of the air velocity The result is a sharp reduction in the variances in the velocity profile of the air flow leaving the section Simultaneously with the passage through the long honeycomb tubes all air rotation (turbulence) is eliminated and uniform laminar air flow is delivered to the sensor sections (Figure 2) The air flow has now been fully processed for accurate measurement

The sensor sections function on the principle of a pitot tube (with separated static and total manifolds) With assured laminar air flow into the sensor sections the multi-point total and static sensors (up to 100 individual sensors for the largest FAN-E unit) can accurately measure the total and static pressures in the unit and average each by means of interconnecting manifolds to a single representative value (an application of Bernoulli s Equation and Tchebycheff's calculus for averaging of measurement). By transmission of these values (total and static pressure) by tubing to an air flow meter (differential gauge), the velocity pressure through the FAN-E unit can be accurately read or recorded By application of controls and relays the FAN-E can control fan capacity at constant volume or programmed volume changes

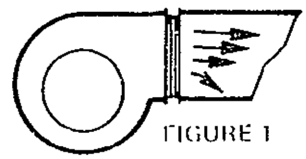


FIGURE 1

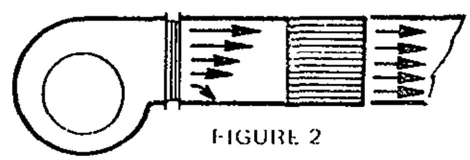


FIGURE 2

FAN-E Applications:

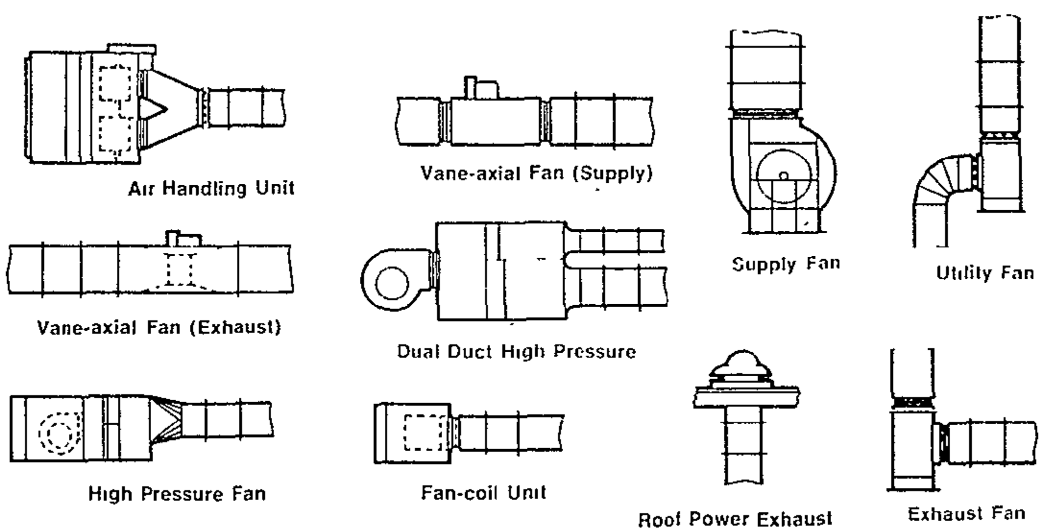


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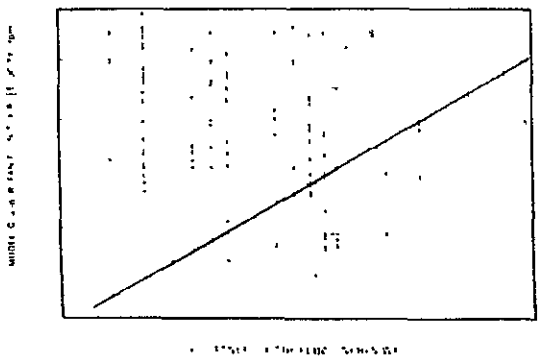
FIGURE 1.31(n)

RESISTANCE TO AIR FLOW

A physical structure placed across the flow of air in a duct will impede the flow; the magnitude of which, normally referred to as resistance to air flow, is a function of the size and shape of the structure and the quantity of air passing through it.

The MONIT-Aire FAN-E unit was designed to function while producing a minimum of resistance to air flow. The unique honeycomb air equalizing and straightening section has a free area of 96.6% while the total and static pressure sensors usually represent an area equivalent of less than 1 2% of the unit's total area

The unique non-restrictive characteristics of the FAN-E units are seen in the Resistance to Air flow versus Unit Velocity graph on the right.

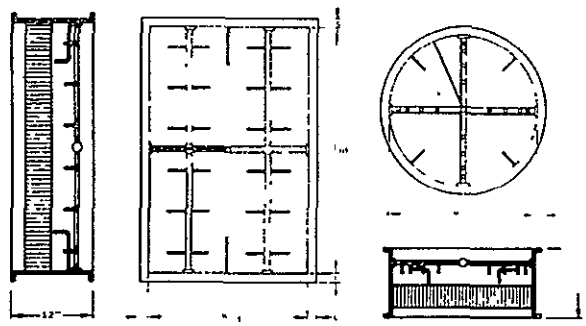


DIMENSIONAL DATA

The model C, FAN-E units are furnished in casings with a constant depth of 12 inches and are available in 2 inch increments of size (diameter) from 6 inches to 30 inches, in 6 inch increments of diameter from 30 inches to 60 inches; and in 12 inch increments of diameter from 60 inches to 96 inches.

The model R, FAN-E units are furnished in 1089 casing sizes, with a constant depth of 12 inches, and are available in 2 inch increments of width (J) and height (K) from 4 inches to 36 inches, in 4 inch increments from 36 inches to 60 inches; and in 6 inch increments from 60 inches to 120 inches.

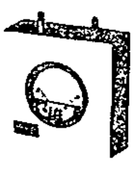
FAN-E units are only available with 90 degree connecting flanges on the air entering and leaving sides, varying from 1" to 2", depending upon unit size.



model Rectangular *model Circular*

AIR FLOW METERING SYSTEMS

Dealing in directly measurable values of total pressure, static pressure and unit area . . while being devoid of any special laboratory developed correction factors, conversion tables, or calibration curves the air flow metering arrangements that can be applied to FAN-E units and D.A.M.D. stations are essentially unlimited. Shown below are several of the more commonly applied systems



STATIONARY (DRY) METER

A diaphragm actuated differential pressure gauge mounted on a metal panel with calibrated scale to permit direct reading of unit velocity in feet per minute, or where specified, in unit or station air flow volume in cubic feet per minute For continuous monitoring of fan or duct capacity with effective range of 800 to 4000 fpm

CENTRAL READOUT OR CONTROL PANEL

The pressure transmitting tubes from multiple FAN E or D A M D installations are brought to a central panel capable of individual FAN E unit or D A M D station readout with a single air flow meter The panel consists of a diaphragm actuated differential pressure gauge flush mounted on a metal control panel with a series of push button valves, all with station designations To read the velocity at any remotely located FAN E unit or D A M D. station, the indicated unit or station buttons are pressed and the velocity is registered on the meter. There are no technical limitations to the number of readout stations on a single panel

CONTROL CIRCUIT [illegible] METER

A diaphragm actuated differential pressure gauge with dual photo-cell electronic amplifier and slave relay circuit Meter scale calibrated to permit direct reading of FAN-E or D A M D. velocity in feet per minute or where specified, in unit or station air flow volume in cubic feet per minute For use where high and/or low limit controls on air flow are required for actuating alarms, warning lights, damper motors, etc.

[illegible] READOUT METER

A diaphragm actuated differential gauge mounted in a metal carrying case with detachable leveling tripod stand Meter scale calibrated to permit the direct reading of the velocities in feet per minute of multiple FAN-E unit or D A M D station installations Meter complete with on off air meter switch and quick connect fittings

FIGURE 1.3.1(H) 4 OF 8

Automatic Air Flow Control

...with FAN-E D.A.M.D. & S.S.T

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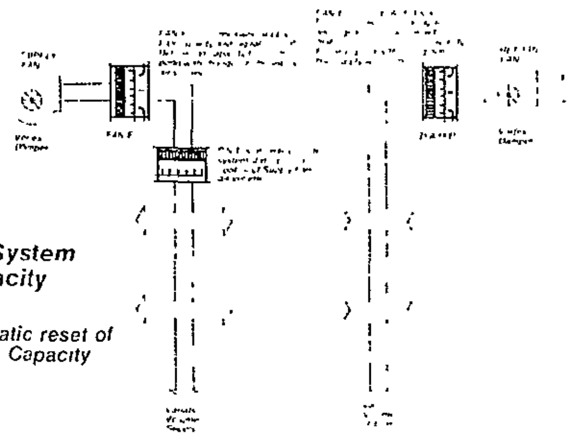
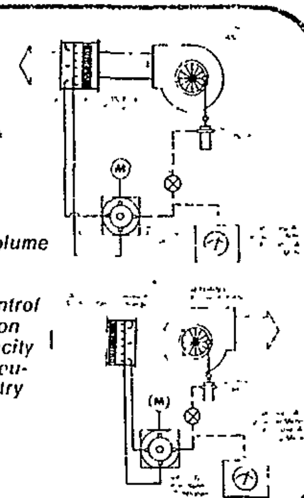
Variable Volume System Fan Capacity Control

With automatic reset of Return Fan Capacity



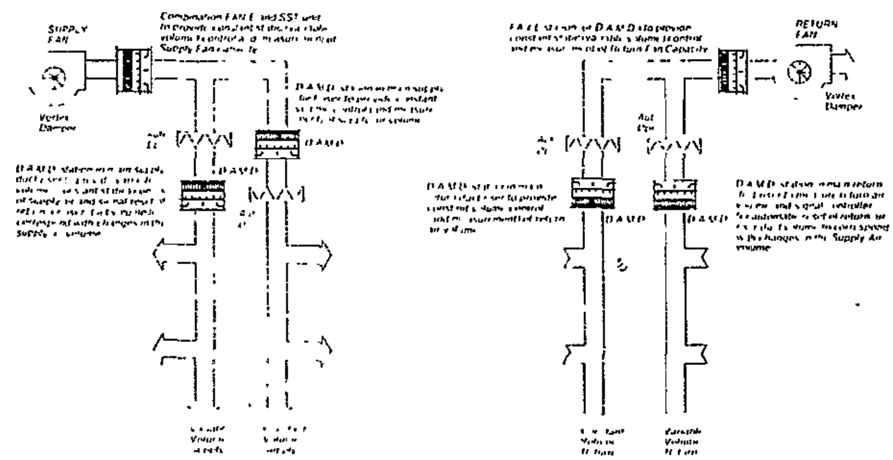
Constant Volume Control System

Constant Volume Supply and Return Fan capacity control with provision for fan capacity readout. Pneumatic circuitry shown.



Variable & Constant Volume System— Single Fan

With system demand control of Supply & Return Fan Capacity.



Variable & Constant Volume System— Single Fan

With automatic reset of return air volume at individual floors.
With system demand control of Supply & Return Fan Capacity.

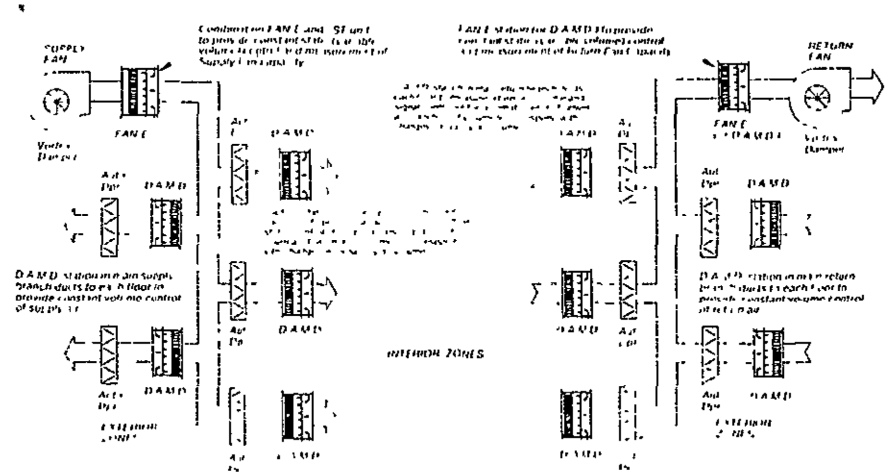


FIGURE 1.3.1(n)

FAN-E Evaluator Unit

Preface: FAN-E units can accurately measure air flow at any velocity. Pressure differential meters (inclined manometers, magnehelic gauges, etc.) are however limited as to their range of readability. For this reason we recommend FAN-E units be sized for operation within 800 to 4,000 feet per minute.

Unit area (sq. ft.) x desired operating velocity (fpm) = Unit Capacity (CFM)

To determine the CFM Capacity of a specific size FAN-E unit, multiply the Unit Area listed in the charts below by the desired operating velocity.

FAN-E UNIT AREAS, in square feet

HEIGHT Inches \ WIDTH Inches	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	40	44	48
4	.111	166	222	277	333	388	.444	500	.555	611	666	.722	777	833	888	944	1.0	1 11	1.22	1 33
6	166	250	333	.416	50	.583	666	.75	833	.916	1 0	1 08	1.16	1 25	1 33	1 41	1 5	1.66	1 83	2 00
8	222	.333	.444	.555	666	777	888	999	1 11	1 22	1.33	1.44	1 55	1 66	1.77	1 88	2 0	2 22	2 44	2 66
10	277	416	555	694	833	972	1.11	1 25	1 38	1 52	1.66	1.80	1 94	2 08	2 22	2 36	2 5	2.77	3 05	3 33
12	333	500	666	833	1.0	1 16	1.33	1.5	1 67	1 83	2 0	2 16	2.33	2.5	2 66	2 83	3 0	3 33	3 67	4 0
14	388	583	777	972	1 16	1 36	1.55	1 75	1.94	2 14	2 33	2 52	2.72	2 91	3 11	3.30	3.5	3 89	4.28	4 66
16	444	666	888	1.11	1 33	1.55	1 77	2 00	2 22	2 44	2.67	2.89	3 11	3 33	3 56	3 78	4 0	4.44	4 89	5 34
18	500	.750	.999	1.25	1 5	1.75	2 0	2 25	2 50	2 75	3 0	3 25	3 50	3.75	4 00	4 25	4 5	5 00	5.5	6 0
20	555	.833	1.11	1 38	1 66	1 94	2 22	2.50	2 78	3 05	3 33	3 61	3.89	4 16	4 44	4 72	5 0	5 55	6.11	6 77
22	611	916	1 22	1 52	1 83	2 14	2.44	2.75	3 05	3.36	3 66	3 97	4 27	4 58	4.88	5 19	5 5	6.11	6 72	7.33
24	666	1.0	1 33	1 66	2.0	2 33	2.67	3 0	3 33	3 66	4 0	4 33	4 67	5 0	5 34	5 66	6.0	6.66	7.34	8 0
26	722	1 08	1.44	1 80	2 16	2 52	2.89	3 25	3 61	3 97	4.33	4.67	5 05	5.42	5 77	6 14	6 5	7.22	7.94	8 66
28	777	1.16	1 55	1 94	2.33	2.72	3 11	3 50	3 89	4 27	4 67	5.05	5 45	5 83	6 23	6 61	7 0	7.77	8 55	9 33
30	833	1.25	1.66	2 08	2 5	2.91	3 33	3 75	4 16	4 58	5 0	5 42	5.83	6 25	6 66	7 08	7 5	8 33	9.17	10.0
32	888	1 33	1.77	2.22	2 66	3 11	3 56	4 0	4 44	4 88	5 34	5 77	6.23	6.66	7 12	7 55	8.0	8.88	9.78	10 68
34	944	1.41	1 88	2 36	2 83	3 30	3 77	4 25	4 72	5 19	5 66	6 14	6 61	7 08	7 55	8 03	8 5	9 44	10 4	11.3
36	1 0	1 5	2 0	2.5	3 0	3 5	4 0	4 5	5 0	5 5	6 0	6 5	7 0	7 50	8 0	8 5	9 0	10 0	11.0	12.0
40	1 11	1 66	2 22	2.77	3.33	3 89	4.44	5 0	5 55	6 11	6 66	7.22	7 77	8 33	8 88	9.44	10 0	11 1	12.2	13 3
44	1 22	1 83	2 44	3 05	3 67	4 28	4.89	5.5	6.11	6 72	7.34	7 94	8 55	9.17	9.78	10.4	11 0	12 2	13.4	14 7
48	1 33	2 0	2.66	3 33	4.0	4 66	5 34	6.0	6.77	7 33	8 0	8 66	9 33	10 0	10 68	11 3	12 0	13 3	14.7	16 0
52	1.44	2.16	2 88	3 60	4 34	5 05	5 78	6 5	7.22	7.94	8 67	9 39	10.1	10 8	11 57	12 3	13 0	14 4	15 9	17 3
56	1 55	2 33	3.11	3 88	4 67	5 44	6 22	7 0	7 67	8 55	9 34	10 1	10 89	11 7	12 46	13 2	14 0	15.5	17 1	18 7
60	1 66	2 5	3.33	4 16	5 0	5 83	6 67	7 5	8 34	9.16	10.0	10 8	11 66	12 5	13 35	14 2	15 0	16.6	18 3	20 0
66	1 83	2 75	3 66	4.58	5.5	6 41	7 33	8 25	9 16	10 1	11 0	11 9	12 8	13 75	14 7	15 6	16 5	18.3	20.2	22 0
72	2 0	3 0	4 0	5.0	6.0	7 0	8 0	9.0	10 0	11 0	12 0	13 0	14 0	15 0	16 0	17 0	18 0	20 0	22.0	24 0
78	2.16	3 25	4 33	5.41	6 5	7 58	8.66	9.75	10 8	11 9	13 0	14.1	15 1	16.25	17.3	18 4	19 5	21 6	23 8	26 0
84	2 33	3 5	4 66	5 83	7.0	8 16	9.33	10 5	11 6	12 8	14 0	15 2	16.3	17 5	18 7	19 8	21 0	23 3	25 7	28 0
90	2 50	3 75	5 00	6 25	7 5	8 75	10 00	11.25	12 5	13 7	15 0	16 2	17.5	18 75	20 0	21 2	22 5	25 0	27.5	30 0
96	2.66	4 0	5.33	6 66	8 0	9 33	10 6	12 0	13 3	14 7	16 0	17.3	18.7	20 0	21 3	22 7	24 0	26 6	29 3	32 0
102	2 83	4 25	5 66	7 08	8 5	9 91	11 3	12 75	14 2	15 6	17 0	18.4	19 8	21.25	22.6	24 1	25 5	28 3	31 2	34 0
108	3 00	4 5	6 0	7.5	9 0	10 5	12 0	13 5	15 0	16.5	18 0	19 5	21 0	22.5	24 0	25 5	27 0	30 0	33 0	36 0
114	3 16	4.75	6 33	7 91	9 5	11 1	12.7	14 25	15 8	17.4	19.0	20 6	22.2	23 75	25 3	27.0	26 5	31 6	34 8	38 0
120	3 33	5 0	6 66	8 33	10.0	11 6	13 3	15 0	16 7	18 3	20.0	21.7	23 3	25 0	26 7	28 3	30 0	33 3	36 7	40 0

FIGURE 1.3.1(n) 6 of 8

Areas and Capacity Formulations

Known Unit Capacity (CFM) ÷ desired operating velocity (FPM) = Unit Area selection (Sq. Ft.)

If the CFM Capacity of the fan is known, divide this value by the desired operating velocity to determine the unit area. Entering in the charts below, list (for final selection) those FAN-E unit sizes approximating the unit area figure obtained above.

Known Unit Capacity (CFM) ÷ Unit Area (Sq. Ft.) = Unit operating velocity (fpm)

If the CFM Capacity of the fan and the required FAN-E unit size is known, the operating velocity can be determined by dividing the CFM by the unit area listed in the charts below.

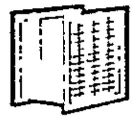
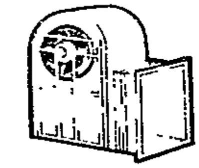
FAN-E UNIT AREAS, in square feet

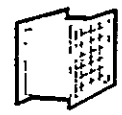
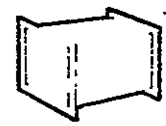
HEIGHT Inches													
4	1.44	1.55	1.66	1.83	2.00	2.16	2.33	2.50	2.66	2.83	3.00	3.16	3.33
6	2.16	2.33	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.75	5.0
8	2.88	3.11	3.33	3.66	4.0	4.33	4.66	5.00	5.33	5.66	6.00	6.33	6.66
10	3.66	3.88	4.16	4.58	5.0	5.41	5.83	6.25	6.66	7.08	7.50	7.91	8.33
12	4.34	4.67	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
14	5.05	5.44	5.83	6.41	7.0	7.58	8.16	8.75	9.33	9.91	10.5	11.1	11.6
16	5.78	6.22	6.67	7.33	8.0	8.66	9.33	10.0	10.6	11.3	12.0	12.7	13.3
18	6.5	7.0	7.5	8.25	9.0	9.75	10.5	11.25	12.0	12.75	13.5	14.25	15.0
20	7.22	7.67	8.34	9.16	10.0	10.8	11.6	12.5	13.3	14.2	15.1	15.8	16.7
22	7.94	8.55	9.16	10.1	11.0	11.9	12.8	13.7	14.7	15.6	16.5	17.4	18.3
24	8.67	9.34	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0
26	9.39	10.10	10.8	11.9	13.0	14.1	15.2	16.2	17.3	18.4	19.5	20.6	21.7
28	10.1	10.89	11.66	12.8	14.0	15.1	16.3	17.5	18.7	19.8	21.0	22.2	23.3
30	10.8	11.7	12.5	13.75	15.0	16.25	17.5	18.75	20.0	21.25	22.5	23.75	25.0
32	11.57	12.46	13.35	14.7	16.0	17.3	18.7	20.0	21.3	22.6	24.0	25.3	26.7
34	12.3	13.2	14.2	15.6	17.0	18.4	19.8	21.2	22.7	24.1	25.5	27.0	28.3
36	13.0	14.0	15.0	16.5	18.0	19.5	21.0	22.5	24.0	25.5	27.0	28.5	30.0
40	14.4	15.5	16.6	18.3	20.0	21.6	23.3	25.0	26.6	28.3	30.00	31.6	33.3
44	15.9	17.1	18.3	20.2	22.0	23.8	25.7	27.5	29.3	31.2	33.0	34.8	36.7
48	17.3	18.7	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0
52	18.8	20.2	21.7	23.8	26.0	28.2	30.3	32.5	34.7	36.8	39.0	41.2	43.3
56	20.2	21.8	23.3	25.7	28.0	30.3	32.7	35.0	37.3	39.7	42.0	44.3	46.7
60	21.7	23.3	25.0	27.5	30.0	32.5	35.0	37.5	40.0	42.5	45.0	47.5	50.0
66	23.8	25.7	27.5	30.25	33.0	35.75	38.5	41.25	44.0	46.75	49.5	52.75	55.0
72	26.0	28.0	30.0	33.0	36.0	39.0	42.0	45.0	48.0	51.0	54.0	57.0	60.0
78	28.2	30.3	32.5	35.75	39.0	42.3	45.5	48.7	52.0	55.2	58.5	61.7	65.0
84	30.3	32.7	35.0	38.5	42.0	45.5	49.0	52.5	56.0	59.5	63.0	66.5	70.0
90	32.5	35.0	37.5	41.25	45.0	48.7	52.5	56.3	60.0	63.8	67.5	71.3	75.0
96	34.7	37.3	40.0	44.0	48.0	52.0	56.0	60.0	64.0	68.0	72.0	76.0	80.0
102	36.8	39.7	42.5	46.75	51.0	55.2	59.5	63.8	68.0	72.2	76.5	80.7	85.0
108	39.0	42.0	45.0	49.5	54.0	58.5	63.0	67.5	72.0	76.5	81.0	85.5	90.0
114	41.2	44.3	47.5	52.75	57.0	61.7	66.5	71.3	76.0	80.7	85.5	90.3	95.0
120	43.3	46.7	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0	100.0
WIDTH Inches	52	56	60	66	72	78	84	90	96	102	108	114	120

SIZE dia. Inches	FAN-E UNIT AREA Square Feet
6	0.196
8	0.349
10	0.545
12	0.785
14	1.068
16	1.395
18	1.766
20	2.180
22	2.640
24	3.139
26	3.683
28	4.275
30	4.905
36	7.063
42	9.614
48	12.47
54	15.89
60	19.62
72	28.25
84	38.46
96	50.23

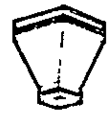
FIGURE 1.3.1(n).

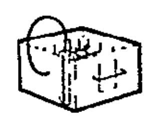
use a:

FAN-E  at the fan 

D.A.M.D.  in the duct 

S.S.T.  in the duct riser 

BAL-cone  with

CFMatic  at the outlet 

measure:

AIR VELOCITY . . . AIR VOLUME . . . SYSTEM STATIC PRESSURE

- **Instantaneously**— Direct readings in FPM (feet per minute) and/or CFM (cubic feet per minute) obtained in 10 seconds or less.
- **Accurately**—within 1% for FAN-E, D.A.M.D., and S.S.T.; within 3% for BAL-cone with CFMatic.
- **Reliably**— operates on basic principles of air measurement, without use of correction factors, calibration curves, etc.
- **Verifiably**—Readings are completely reproducible, void of instrument technique or human error.

control:

- fan capacity at constant volume regardless of system static changes or variations.
- programmed or manual reset of fan capacity.
- actuation of Audio or Visual safety alarms in critical air flow systems.
- maximum air filter replacement cycle based on actual air volume, decrease, rather than arbitrary filter resistance increase.
- supply and return fan capacities under variable and constant volume systems based on actual system demand
- rescheduling and reset of return fan capacities to match supply fan capacity changes in variable volume system operation
- return air duct or space quantity changes to match supply air quantity changes (in variable volume system).
- continuous or periodic monitoring of fan (duct, or outlet) capacities at a central control panel.
- control of fan, duct or system static pressures under variable or constant volume operation.
- predetermined positive, negative or neutral space pressurization regardless of system static or volume changes.

Air Monitor Corporation

P.O. Box 6358 Coddingtown Station
Santa Rosa, California 95406
(707) 544-2706

FIGURE 3.1(n)

Air Monitor Corporation

P. O. BOX 6358 CODDINGTOWN STATION
SANTA ROSA, CALIFORNIA 95406
AREA CODE (707) 544-2706

June 28, 1977

Mr. Ken Mohn
Owens-Illinois
200 North Westwood
Toledo, OH 43666

Subject: Special FAN-E supplied on wo#1552

Dear Mr. Mohn:

The FAN-E delivered to you has an accuracy of $\pm$ 1% in the range of 300 to 600 SCFM providing that the FAN-E is installed correctly. This special FAN-E requires twice the standard installation distance. Enclosed is a sheet of installation distances for standard units.

We recommend that your arrangement should be fan, 2 diameters of duct; screen unit, 4 diameters of duct; FAN-E, 4 diameters of duct; and screen mounted on the entrance to the plenium. For best results, we recommend that lab work should be done on the possibility of eliminating the plenium, since it may effect accuracy.

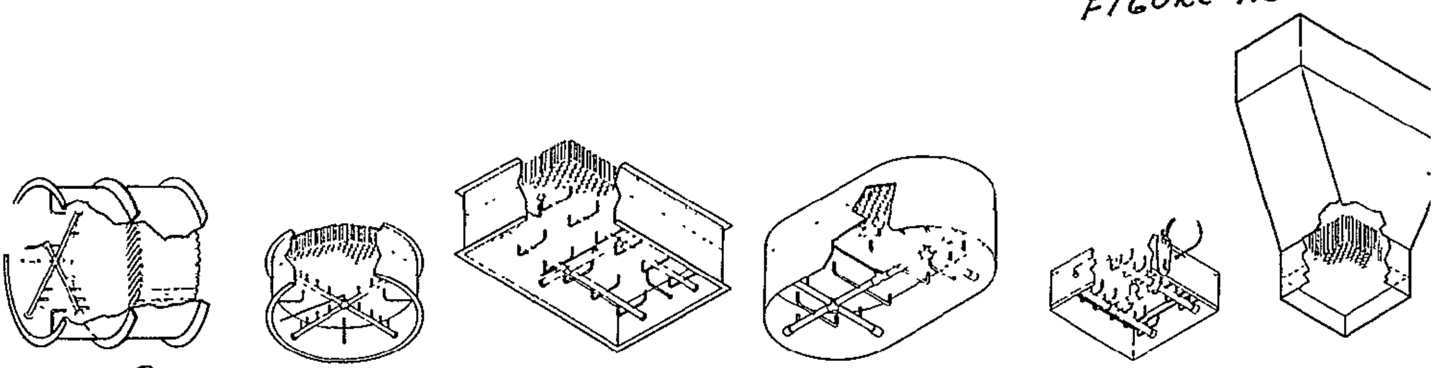
Very Truly Yours,
AIR MONITOR CORPROATION

Scott Kenyon
Customer Service

Enclosures: FAN-E brochure
Installation Guide

SK/jda

FIGURE 1.3.1(o)



2.1 System Design Conditions.

The Model SEC-601 air collector was roof-mounted south facing at a 45° tilt. Ducting, instrumentation, heat exchanger and air fan were installed. The duct between the flow meter and the heat exchanger was detached in order to provide access for smoke ingestion into the system. The ducting loading from the collector was blocked. The variable speed air fan was adjusted to provide 1.5 inches, w.g., above ambient in the collector manifold. A smoke bomb was activated at the inlet to the air fan. No evidence of collector or system leakage could be detected.

The system hook up was completed and all ducting and components insulated. A series of air mass flow versus collector pressure drop tests was completed. The test system schematic and the test data is contained in Figure 2.1(a). A plot of the data and the equation relating air mass flow to pressure drop is contained in Figure 2.1(b). The tests conducted under Section 5.2, temperature and pressure resistance are also applicable to the subject Section 2.1. Data from the thermal cycling test phase is contained in Figure 2.1(c).

2.1.1 Equipment Capabilities.

The design flow rate of the Model SEC-601 collector is approximately 8 Lbs./Hr.Ft.^{2} higher system flow rates may be used with an attendent gain in collector thermal performance. The fan theoretical pumping power is related to flow and pressure drop by the expression:

$$HP = 157.5 \times 10^{-6}\ p\ Q \quad (1)$$

p = Pressure drop, inches, w.g.

Q = Total air flow; $Ft.^3/min.$

Using the data of Figure 2.1(a)

ΔP_c	.03	0.5	.10	.15	.20	
Q	142	184	261	320	369	CFM
P	.29	.48	.95	1.35	1.75	in. w.g.
HP_a	.0065	.0139	.0391	.068	.1017	HP

However, system pressure drop, leakage and fan efficiency will affect the sizing of the fan. Most common electric motors will not survive the high temperatures within the air system ducting; an externally mounted motor with an extension shaft coupling to the air fan is recommended.. The temperature rise due to fan inefficiency is generally recoverable if a suitable heat barrier is employed in the extension shaft and motor mount. Relatively low fan pumping power is required to move the air through the collector.

2.1.2 Noise or Erosion-Corrosion.

During the air mass flow-pressure drop experiments, no sound emanating from the collector tube elements or the manifold could be detected at a system air flow rate up to 369 CFM. The 144 tube ERDA collector manifolds and tube elements were inspected after 17 months of test operation. No evidence of erosion-corrosion could be detected in

(1)Page 14-67?, Marks' Mechanical Engineers Handbook, Sixth Edition, McGraw Hill.

any of the working components. Some evidence of deterioration of the polyurethane foam insulation was noticed where the insulation was directly exposed to high temperature air flow. Where the insulation material was protected, no visible sign of deterioration of the insulation was detected. The Model SEC-601 collector design protects the polyurethane foam insulation from contact with high temperature air. Following completion of the 100 cycles of thermal cycling at exit air temperature of 325°F, the manifold was visually inspected. No sign of deterioration of materials or components could be detected.

2.1.3 Operating Conditions.

The components of the Model SEC-601 collector have been tested in excess of the pressure and temperature ranges expected in actual service without damage or loss in pressure that could impair their intended functions. Over pressure and high temperature thermal cycling test data of Figure 2.1(c) is provided as primary evidence along with other test data as contained principally in Section 5.2.

2.1.4 Fluid Flow in Collectors.

The 144 tube ERDA collector was highly instrumented with thermocouples to measure the temperature rise in a large number of tube pairs in many areas of the array. Each tube pair of the east half of the lower manifold was instrumented with thermocouples. A typical set of data is as follows:

36	31	31	31	31	36	37	35	37	40	40	45	40	41	41	40	41	45°F
96	100	98	101	101	105	95	112	108	108	115	103	113	102	94	105	102	93°F

Center-Air Inlet-Outlet End

The good correlation of temperature rise is evidence of excellent flow distribution in each of the collector tube elements at the design air flow rate. At about twice the design flow rate, the temperature rise data was:

33 30 30 30 30 34 35 32 35 37 38 41 38 38 38 37 38 40°F

89 91 91 92 92 94 95 104 102 100 107 102 110 96 100 99 99 91°F

Flow distribution remains excellent at the higher flow rates.

Comparative analysis of the ERDA air manifold and the Model SEC-601 air manifold indicate similarity of flow cross section and flow rates. The experimentally derived flow-pressure drop relationships for the two collectors are:

ERDA $$\Delta P = \frac{CFM^{1.84}}{27} \text{ in. w.g.}$$

CFM = Volume Flow Per Tube Pair, Ft.^{3}/min.

Δ P = Collector Pressure Drop, inches, w.g.

Model SEC-601

$$\Delta P = \frac{CFM^{1.92}}{10.5}$$

CFM - Volume Flow per Tube, Ft.^{3}/min.

Δ P = Collector Pressure Drop, inches, w.g.

The essentially identical exponent for flow rate suggests that the collector pressure drop is controlled by the flow in the tube elements. The difference in the constant is due to the difference in path length of the two tubes in series versus all tubes in parallel. Leakage flow in the ERDA collector also contributes to the larger value of the constant. Since flow distribution is controlled by the pressure drop in the tube elements rather than in the manifold, it can be implied that satisfactory flow distribution obtains in the Model SEC-601 collector by similarity. The flow distribution between modules of a large array is a systems design parameter. A variation in flow rate module to module of ± 25% will have little impact on overall system performance because of the very low loss coefficient characteristic of the collector.

2.1.7 Pressure Drops.

The air flow-pressure drop relationship of the Model SEC-601 collector is contained in the data of Figure 2.1(a) and the curve and equation of Figure 2.1(b).

Review of items 2.1, 2.1.1, 2.1.2, 2.1.3, 2.1.4, 2.1.7 successfully completed.

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MODEL SEC 601 COLLECTOR
PRESSURE DROP VS AIR FLOW RATE
NUMBER 3 MANIFOLD

INDICATED FLOW PRESSURE DROP, ΔP_V, IN. W.G.	.03	.05	.10	.15	.20
COLLECTOR PRESSURE DROP, ΔP_C, IN. W.G.	.29	.48	.95	1.35	1.75
AIR TEMPERATURE, °F	115	120	126	128	132
AIR MASS FLOW, $\dot{m}_a$, LBS./HR. FT.^{2}	7.01	9.01	12.67	15.49	17.83
AIR VOLUME FLOW, $\dot{m}_a$, SCFM/TUBE	1.80	2.32	3.26	4.02	4.59

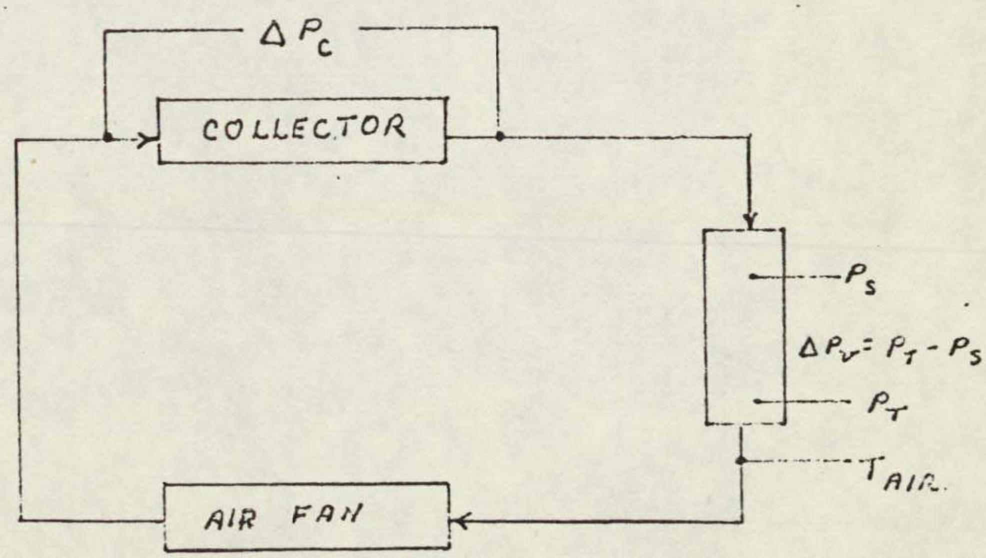
$$\dot{m}_a = 4005\, A \sqrt{\Delta P_V} \times \sqrt{\frac{530}{T_{AIR} + 460}} \times .075 \text{ LBS./MIN.}$$

$$A = \frac{36\pi}{4 \times 144} = .196 \text{ FT.}^2$$

$$A_{COLLECTOR} = 84 \text{ FT.}^2$$

$$\dot{m}_a = 42.19 \sqrt{\frac{\Delta P_V \times 530}{T_{AIR} + 460}} \text{ LBS./HR. FT.}^2$$

$$\dot{m}_a = 10.85 \sqrt{\frac{\Delta P_V \times 530}{T_{AIR} + 460}} \text{ SCFM/TUBE (72 TUBES/MODULE)}$$



TEST SYSTEM SCHEMATIC

FIGURE 2.1 (a)

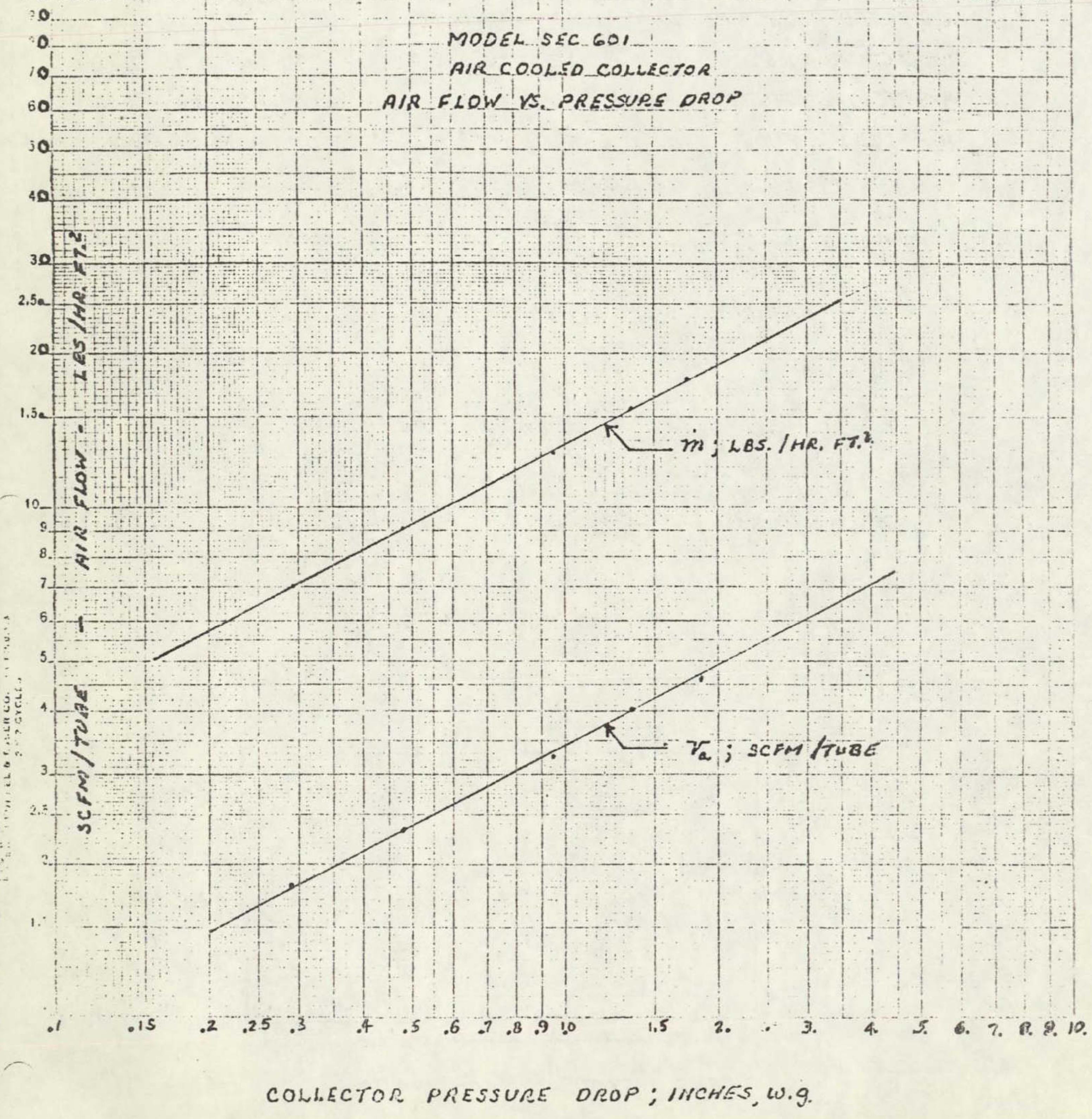

MODEL SEC 601
AIR COOLED COLLECTOR
AIR FLOW VS. PRESSURE DROP
AIR FLOW - LBS / HR. FT.²
SCFM / TUBE
ṁ ; LBS. / HR. FT.²
V_a ; SCFM / TUBE
COLLECTOR PRESSURE DROP ; INCHES, W.G.

FIGURE 2.1 (b)

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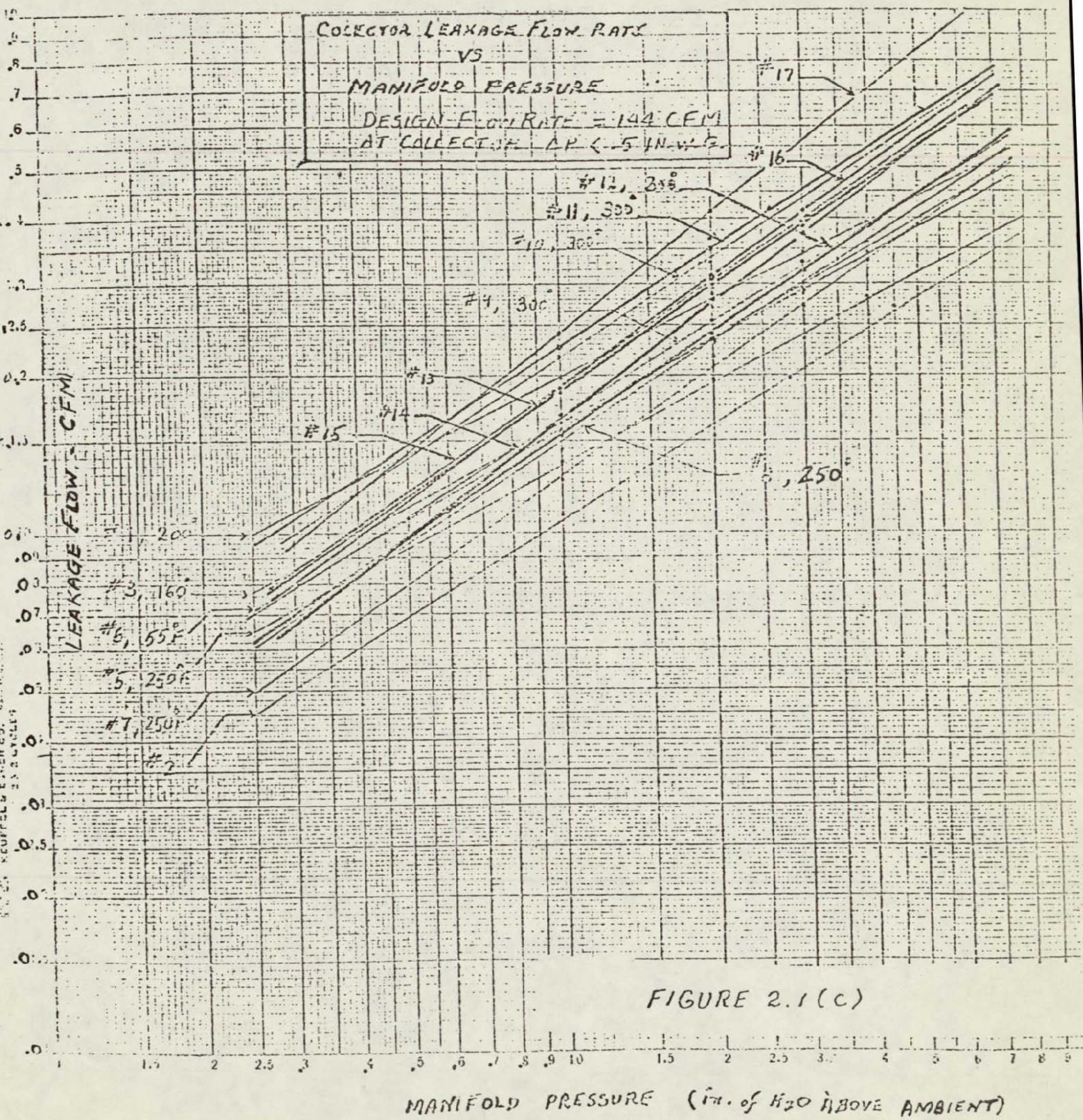

FIGURE 2.1(c)

DEFINITION OF TEST NUMBERS

#2.	FIRST CALIBRATED LEAKAGE FLOW TEST
#3	ONE CYCLE TO 160°F MAX. AIR TEMP.
#4	ONE CYCLE TO 200°F MAX. AIR TEMP.
#5	ONE CYCLE TO 250°F MAX. AIR TEMP.
#6	REPEAT AMBIENT AIR TEMP. LEAKAGE TEST
#7 + #8	REPEAT CYCLES AT 250°F MAX AIR TEMP.
#9	ONE CYCLE TO 325°F. MAX. AIR TEMP.
#10	ONE CYCLE TO 325°F MAX. AIR TEMP.
#11	TOTAL 11 CYCLES
#12	TOTAL 16 CYCLES
#13	TOTAL 27 CYCLES
#14	TOTAL 43 CYCLES
#15	TOTAL 51 CYCLES
#16	TOTAL 70 CYCLES
#17	TOTAL 101 CYCLES

2.2 Mechanical Stresses.

2.2.1 Vibration Stress Levels.

During the testing described in detail in Section 5.2.4, Leakage, the collector module was critically inspected for any audible evidence of vibration induced in any collector component due coupling with air ducts or fan. No audible sound could be detected. No evidence of vibration of any component of the collector could be detected by thorough inspection of the ERDA 144 tubular air collector. The potential problem of reinforced resonance vibration of the absorber tube was investigated. A collector tube element was instrumented with strain gages as shown in Figure 2.2.(a). No selective coating was applied and the evacuation process eliminated since the bonding agent used for applying the strain gages could not tolerate the bake out temperature.

The collector tube element was mounted on a vibration shake table and excited in the range of 0 to 300 Hz. Two resonant peaks were observed, one at 139 Hz. and one at 214 Hz. Prolonged exposure at these frequencies gave no evidence of damage. A frequency response plot of the tube assembly is shown in Figure 2.2(b). The modulus of elasticity of KG-33 is 9.5 X 10^6 lbs./in^2. The maximum detected strain was 27 micro inch/inch. The resulting maximum stress level is 227 psi, well below the modulus of rupture stress level of an abraded rod of 10,000 psi.

2.2.2 Vibration from Moving Parts.

There are no moving parts within the Model SEC-601 collector except air flow. No evidence of flow induced vibration could be detected up to air flow rates of 16 lbs./Hr.ft.^{2}, twice the design air flow rate. No evidence of coupling of the vibration due to moving parts such as the air fan could be detected.

2.2.4 Vacuum Relief Protection.

The installation and maintenance manuals specify that the air fan be located in the inlet ducting to the manifold. This will insure that the manifold will always be at a positive pressure. The manifold was exposed to a positive pressure of 5 inches w.g. repeatedly during the leakage tests of Section 5.2.4 with no evidence of structural stress or induced air leakage of greater than 1% of design flow rate.

2.2.5 Thermal Changes.

The collector was subjected to 100 cycles of thermal stress from ambient temperature to 325°F. No evidence of degradation of any component or sub-assembly could be detected as demonstrated by no change in the rate of leakage air flow from the collector. See Section 5.2 for substantiating experimental data.

2.2.6 Flexible Joints.

Connecting ducting was in place during the thermal cycling tests of Section 5.2. The flexing of the connecting ducting due to air flow and thermal cycling was accommodated by the interface and mounting provisions of the Model SEC-601 collector.

Review of items 2.2, 2.2.1, 2.2.2, 2.2.4, 2.2.5 and 2.2.6 successfully completed.

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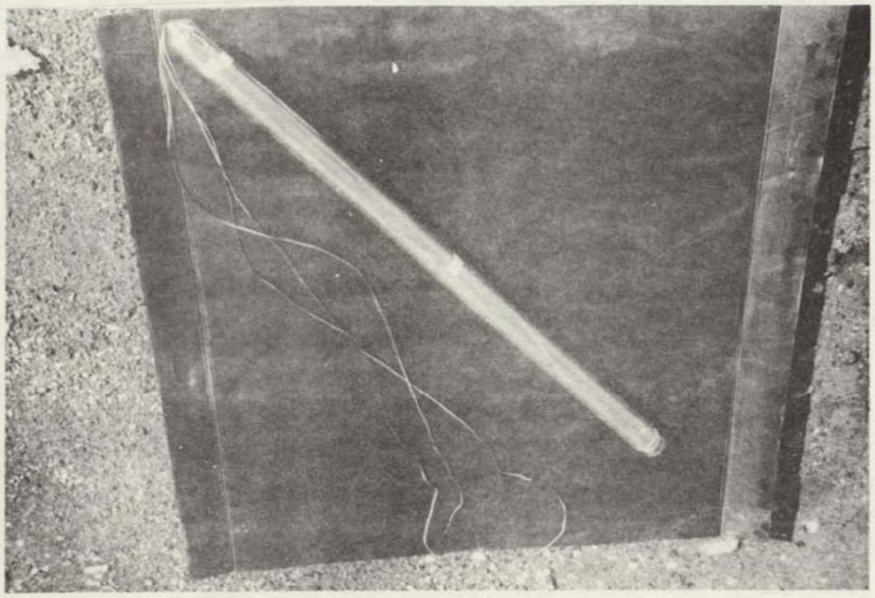

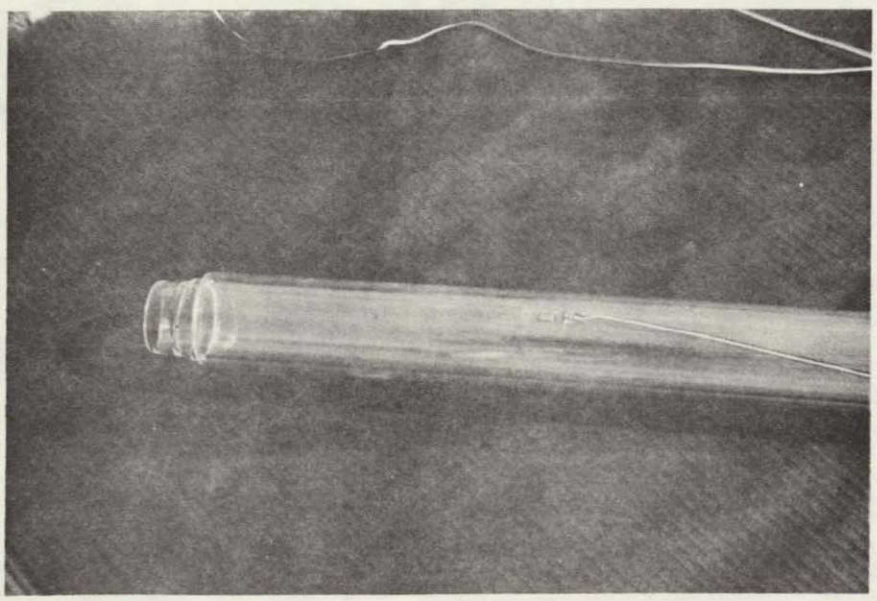

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FIGURE 2.2 (a)

2.3 Leakage Prevention.

The design leakage flow rate of the Model SEC-601 collector is 1% target. The measured leakage flow rate did not change substantially from the initial test to the test after 100 thermal cycles between room ambient and 325°F. The measured leakage flow rate was less than 0.2% design flow rate.

2.3.1 Pressure Test: Non-potable Fluids.

The criterion of 2.3.1 specifically excludes air as the heat transfer fluid from the requirements of the section. A small but controlled rate of air leakage is desired in an air cooled collector to minimize system pressure fluxuation as a function of air temperature.

2.3.2 Pressure Test: Potable Water.

The installation and operation manuals specify that the collector be operated at a positive pressure of 5 inches w.g. or less. The maximum pressure is specified to limit system air pumping power not for structural reasons. Any potable water leakage would occur at the air-liquid heat exchange interface not within the collector.

2.3.3 Air Transport Systems.

The transition ducting between the collector manifold and the system ducting is 0.21 Ft^2. At the design air flow rate of 144 CFM per module, the average air velocity in the transition section is 700 Ft./min. and within the limits of air flow velocity as contained within Section 615-4.3 of HUD MPS (3).

Review of items 2.3 through 2.3.3 successfully completed.

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2.4 Collector Adjustments.

2.4.1 Orientation and Tilt.

The drawings, specifications and installation of the Model SEC-601 collector were reviewed. The collector may be mounted in any fixed orientation or tilt required by the application. There are no structural or flow path imposed restrictions. A south facing orientation with the tube axis north-south optimizes the thermal performance on a daily basis.

2.4.2 Mutual Shadowing.

The problem of mutual shadowing between multiple collectors is negated so long as the collectors are installed in a single plane relative to the axis of the tube elements.

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2.6 Heat Transfer Fluid Quality.

2.6.2. The 144 ERDA collector array, under test for in excess of one year, was inspected and no significant accumulation of dust was detected. Review of thermal performance data for November, 1977, indicates no deterioration in thermal performance due to the accumulation of deposits of dust or dirt after eight months of operation. The critical absorber surface is protected in a vacuum environment; the cover tube surfaces appear to be self cleaning based on a review of the performance data taken over a period of approximately eight months. Air filtration to the collector should have a minimum ASHRAE arrestance of 60 percent. Pressure drop through the filtration unit should be minimized (0.1 inches watergage at 150 SCFM is recommended) in order to restrict air pumping power requirements.

Review of items 2.6 through 2.6.2 successfully completed.

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3.1 Structural Design Basis.

The capability of the Model SEC-601 collector to meet the provisions of MSP [1] and/or ANSIA119.1[4] has been demonstrated by the physical testing of a complete seventy two (72) tube module to the requirements of the applicable criterion of the sub-sections of Chapter 3 -- Structural, of the Interim Performance Criteria. A complete module was mounted in a load test fixture as shown in the sequence of photographs Figure 3.1(a) through 3.1(j). A steel reinforced concrete floor was used as the test fixture base. Two X ten inch boards were used as risers to elevate the collector module above the plane of the floor to provide clearance for the inlet and outlet transition ducts. Sections of the recommended diffuse backing screen (Alcoa 4-inch ribbed Bone White #K2028-30, flourocarbon) were attached to the top surface of the stringers. The twenty mounting pads of the Model SEC-601 collector module were attached to the stringers using blind hole (one per pad) Molly mounting bolts. A two section air bag was layed on top of the collector tube elements. A reaction element, isolated from the collector, was installed. This allowed an air pressure within the air bag to impose a uniform load on the collector elements with the magnitude of the load a direct function of the air pressure within the air bags. The air pressure in the air bag was controlled with a two stage pressure regulator operating off of shop line pressure. An air bleed to ambient, downstream of the pressure regulator, was added to improve the stability of the system. Dial indicators were mounted to determine the deflection under load at four representative locations of the collector module. These are indicated in Figures 3.1(h) and (i). The leakage flow rate at a manifold pressure of 1 inch w.g. was monitored constantly and was used as the primary evaluation of the effect of physical loading on collector operation.

3.1.1 Applicable Standards and 3.1.2 Service Loads were reviewed and the definitions and requirements found to be acceptable without exception.

1. Dead load. The dead load of the SEC-601 module, fully assembled is 300 pounds as determined by weighing a completed module.

2. Live loads. Since air is used as the heat transfer fluid, the cooling fluid does not contribute to any appreciable live load. Snow does not add a significant live load to the collector. Any snow build up first penetrates between the spaced tubular elements and acts upon the basic roof structure. Increased snow depths build up snow behind (roof side) of the tubular elements, surround the tubular elements and subsequently cover the tubular elements. Except for a minor degree of loading of the manifold, the live load due to snow on the collector is negligible. This condition was observed during the heavy snow conditions of the 1977-1978 winter season in Toledo, Ohio. For test purposes, a snow load equal to the dead load will be assumed.

3. Wind loads. A wind load equivalent to 40 pounds per square foot (the worst condition found in applicable specifications) will be used. The exposed cross section of the cover tube

per element is 2.13" X 42"/144 = .62 Ft^2. The wind loading per tube, assuming a drag coefficient of 1.3 is .62 X 1.3 X 40 = 32.31 lb. The maximum frontal area of the manifold is 13" X 12' = 13 Ft^2 and the wind loading is 520#. The total load is 72 X 32 .21 + 520 = 2846 pounds = .20 pounds/in^2.

4. Earthquake loads. "A common rule (for earthquake loads) is to provide in the associated structure for resistance to horizontal forces equal to one-tenth of the dead and live load supported." Page 12-21, Marks' Mechanical Engineers' Handbook, sixth edition, McGraw Hill. The earthquake load will be specified as 300 pounds dead load plus 300 pounds live load times 0.1 or 60 pounds.

5. Constraint Loads. Constraint loads caused by the environment and normal functioning of the system are accommodated by system design. The loads would be the result of differences in temperatures and coefficients of expansion of the materials of construction. The collector tube glass elements are attached in a single plane; the opposite (closed end) of the tubular elements are free to float axially and radially. The manifold design represents the only critical subassembly relative to strain induced by differential expansion. Evaluation of this parameter will be by test and similarity to the 144 tubes ERDA collector array.

6. Constraint loads, foundation settlement. The effect of foundation settlement equivalent to 2 inches per 50 feet in any

horizontal distance will be evaluated by test.

7. Hail loads. Hail loads are specified as resistance to 3/4" diameter hail without impairment to the functional capability of the collector.

3.2 Failure Loads and Load Capacity.

3.2.1 Ultimate load combinations.

(1) 1.4D + 1.7L = 300 (1.4 + 1.7) = 930 pounds = .067 psi.

(2) 0.9D + 1.7W = .9 X 300 + 1.7 X 2846 = 5108 pounds = .37 psi.

(3) 0.9D + 1.45E = .9 X 300 + 1.45 X 60 = 357 pounds = .03 psi.

(4) 1.1D + 1.3L + 1.7W = 1.1 X 300 + 1.3 X 300 + 1.7 X 2846 = 5558 pounds = .40 psi.

(5) 1.1D + 1.3L + 1.45E = 1.1 X 300 + 1.3 X 300 + 1.45 X 60 = 807 pounds = .06 psi.

3.2.2 Ice Loads.

The ice load acting on a tubular element for a one inch glazing thickness is:

$$\text{Load} = \frac{56\#}{\text{Ft.}^3} \left[\frac{\pi}{4} \frac{(4^2 - 2^2) \times 42}{1728}\right] = 12.83\#/\text{tube}$$

And on the manifold surfaces,

$$\text{Load} = \frac{56\#}{\text{Ft.}^3} \left[\frac{13'' \times 12'}{12} + \frac{2 \times 9'' \times 12'}{12}\right] \times \frac{1}{12} \Big] = 145\#$$

Total ice load = 12.83 X 72 + 145 = 1068 pounds = .08 psi.

(a) (1) 1.4 X 300 + 1.7 X 1068 = 2236# = .16 psi.

(4) 1.1 X 300 + 1.3 X 1068 + 1.7 X 2846 = 6557 = .45 psi.

(b) (1) 300 + 1068 = 1368# = .10 psi

(4) 300 + 1068 + 2846 = 4214# = .30 psi.

See Section 3.2.4 for test procedure and results.

3.2.4 Load capacity.

The air bag was inflated to a maximum pressure of 0.50 psi (6984 lbs. total load) in increments of 0.10 psi. The deflections at the four representative locations were monitored as was air leakage flow rate.

Air Bag Pressure psig	Total Load Pounds	(1)	(2)	(3)	(4)	Leakage Flow c.c./Min.
			INCHES			
0	0	0	0	0	0	8800
.10	1397	.061	.061	.088	.073	8800
.20	2794	.104	.108	.148	.110	8800
.30	4190	.135	.143	.211	.146	8800
.40	5587	.160	.170	.255	.170	8800
.50	6984	.183	.190	.335	.202	8800

A plot of the maximum deflection versus applied load (location 3) is contained in Figure 3.2.4(a). Neglecting the initial system slack which takes place near the origin, there is a linear relationship of deflection versus load within the limits of experimental error. A review of the experimental data of section 3.2.4 and 3.3.1 indicates an error band of deflection versus load of the order of .003"/0.1 psi. Thus, to a load factor of 1.7 times design, the load versus deflection curve indicates that all elements of the collector structure are well within their elastic region.

3.3 Damage control.

3.3.1 Resistance to Damage.

The collector was subjected to the loading conditions of Criterion 3.2.1, combination (4) with the load factors specified rather than the load factor of 1.0 as allowed by the criterion. The results of the load tests were:

Air Bag Pressure	Total Load	Dial Readings 1	2	3	4	Leakage Flow
psig	Pounds	I N C H E S				c.c./Min.
0	0	0	0	0	0	8700
.05	698	.037	.030	.046	.031	8700
.10	1397	.060	.067	.080	.055	8700
.15	2095	.083	.092	.113	.075	8700
.20	2794	.104	.116	.139	.090	8700
.25	3492	.121	.135	.165	.105	8700
.30	4190	.137	.155	.196	.123	8700
.35	4889	.152	.174	.228	.141	8700
0	Residual Deflection	.010	.019	.011	.010	8700

No significant change in leakage flow rate could be detected as a function of loading conditions. The residual deflection upon release of the load is considered to be within acceptable limits. No sub-assembly or component suffered damage of any kind which would require replacement or repair or which would impair the intended function during the service life.

3.3.2 Glazing design.

Steel ball drop tests were conducted on six collector tube elements mounted in a manifold section and in an end support bracket. Failure of the cover tube was experienced in each test case when a combination of ball size and drop height reached critical conditions. In no case was a failure of the absorber tube experienced. The fractured glass remained in close proximity to the failure point and in all cases within the installed area of the collector. No sign of flying glass representing a safety hazard was experienced.

3.4 Cyclic loads.

3.4.1 Deflection limitations.

Loading conditions

(1) 1.0D to 1.0D + 0.5L = 300 pounds to 450 pounds.

(2) 1.0D to 1.0D + 0.5W = 300 pounds to 1723 pounds.

A preload cycle from (1D) to (1D + 1W) = 300 + 2846 or 3146 pounds distributed load was applied to the collector module to reduce system slack. The gages were zeroed and the cyclic testing initiated. The air bags were pressurized to 0.115 psig. (3.19" w.g.) and pressure removed to less than 0.05" w.g. The cycle was approximately 6 minutes 40 seconds. The leakage air flow with the manifold pressurized to 1 inch, w.g. was 8700 c.c./min. A total of 1072 cycles was accumulated over approximately five days of testing. The deflections measured after 1072 cycles were:

Applied Load	Deflection 1	2	3	4	Leakage/ Flow
3.19" w.g. 1606#	.080"	.076"	.086"	.062"	8700 cc/min
24 hours after load removal	.020"	.008"	-.004"	0.0"	8800 cc/min.

The residual deflections were within 25% of the deflections with load applied and the leakage air flow test demonstrated that structural integrity was preserved during and after 1000 cycles of load testing.

3.6 Creep and residual deflection.

3.6.1 Deflection limitations.

The maximum allowable deflection per the subject criterion is:

$$d = \frac{1.25S}{180} \times \frac{0.2D + 1.5L}{L}$$

There are 20 mounting attachments between the collector rail support assembly and the structure to which the collector is attached. The deflection of the span of the rail assembly between the manifold and outboard support structure is represented by gage No. 2. The deflection of the span of the rail assembly between mounting pads of the outboard support structure is represented by gage No. 3. The span lengths are 44 inches and 36 inches respectively.

Since L = D, the equation for allowable deflection reduces to:

$$d = \frac{1.25S \times 1.7}{180}$$

d_2 = .519"

d_3 = .425"

A total distributed load of 700 pounds was applied to the collector for 24 hours. The measured deflections of d_2 = .041" and d_3 = .049" were recorded. These values are well below the allowable limits. The residual deflections measured three hours after removal of the load were d_2 = .005" and d_3 = -001". These values are well within the allowable limits for residual deflection of d_2 = .061" and d_3 = .050"

3.7 Hail resistance.

3.7.1 Hail size and loading.

The criterion for resistance to hail contained in the approved Verification Test Plan was that hail size up to 0.75" in diameter would not cause excessive damage to or impair the performance of the tubular collector elements, manifold or end support brackets. A representative section of the Model SEC-601 collector was subjected to testing under simulated hail conditions at the Center for Disaster Research, Texas State University. A copy of the test report issued by the center is contained in attachment 3.7.1(a). No excessive damage to any collector elements was experienced with hail sizes up to 1.25" in diameter.

3.8 Constraint loads.

3.8.1 Foundation settlement; contraction and expansion.

1. The effect of a differential foundation settlement of 2 inches in any horizontal distance of 50 feet was investigated. One corner of the collector was rigidly attached to a simulated support structure. All other attachments were removed and the remaining three corners shimmed above the plane of rigid attachment as indicated in Figure 3.8.1(a). The numerical values at each of the three unrestrained corners represents the effect of foundation settlement of 2 inches per 50 feet. The measured leakage flow rate was 8700 cc/min at a manifold pressure of 1 inch w.g. Shims were then added to each of the unrestrained through corners of the module and leakage air flow recorded. The shim

height in inches and the value in relation to the criterion of 2 inches per 50 feet were:

Shimed Height			Relative Deflection			Air Leakage Flow Rate
A	B	C	A	B	C	cc/Min.
.323"	.580"	.480"	2"	2"	2"	8700
.573"	.830"	.730"	3.55"	2.86"	2.52"	8700
.823"	1.080"	.980"	5.10"	3.73"	3.38"	8700
1.073"	1.330"	1.230"	6.64"	4.59"	4.24"	8700
1.323"	1.580"	1.480"	8.19"	5.45"	5.10"	8700
1.573"	1.830"	1.730"	9.74"	6.31"	5.97"	8700

The data demonstrates that the collector can withstand 3 to 5 times the criterion for foundation settlement without damage or impairment of performance of the collector.

2. The effect of constraint loads arising from thermal expansion or contraction is reported and evaluated in Section 5.2.

3.9 Ponding conditions.

3.9.1 <u>Design provisions.</u>

Physical inspection of the Model SEC-601 collector roof installed for the thermal performance testing of Section 1.3 demonstrates that no potential exists for the accumulation of water. Visual observation during and after severe rain conditions also confirms that no ponding conditions exist.

Review of items 3.1, 3.1.1, 3.2, 3.2.1, 3.2.2, 3.2.4, 3.3, 3.3.1, 3.3.2, 3.4, 3.4.1, 3.6, 3.7, 3.7.1, 3.8, 3.8.1, 3.9, 3.9.1 are successfully completed.

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John M. Caudle
John M. Caudle
Technical Manager
NASA Approval

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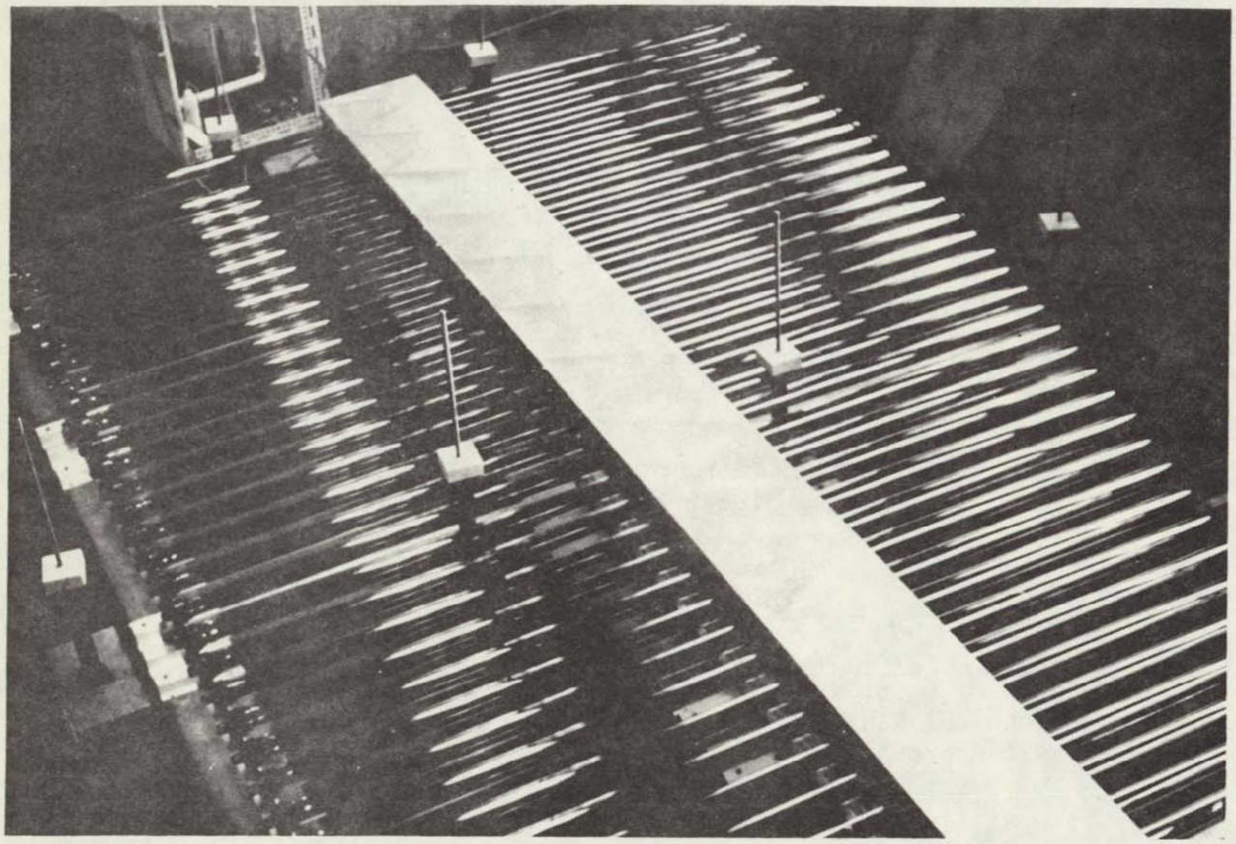

OVERVIEW: MODEL SEC 601 COLLECTOR
MOUNTED ON STRUCTURAL TEST RIG

Figure 3.1 (a)

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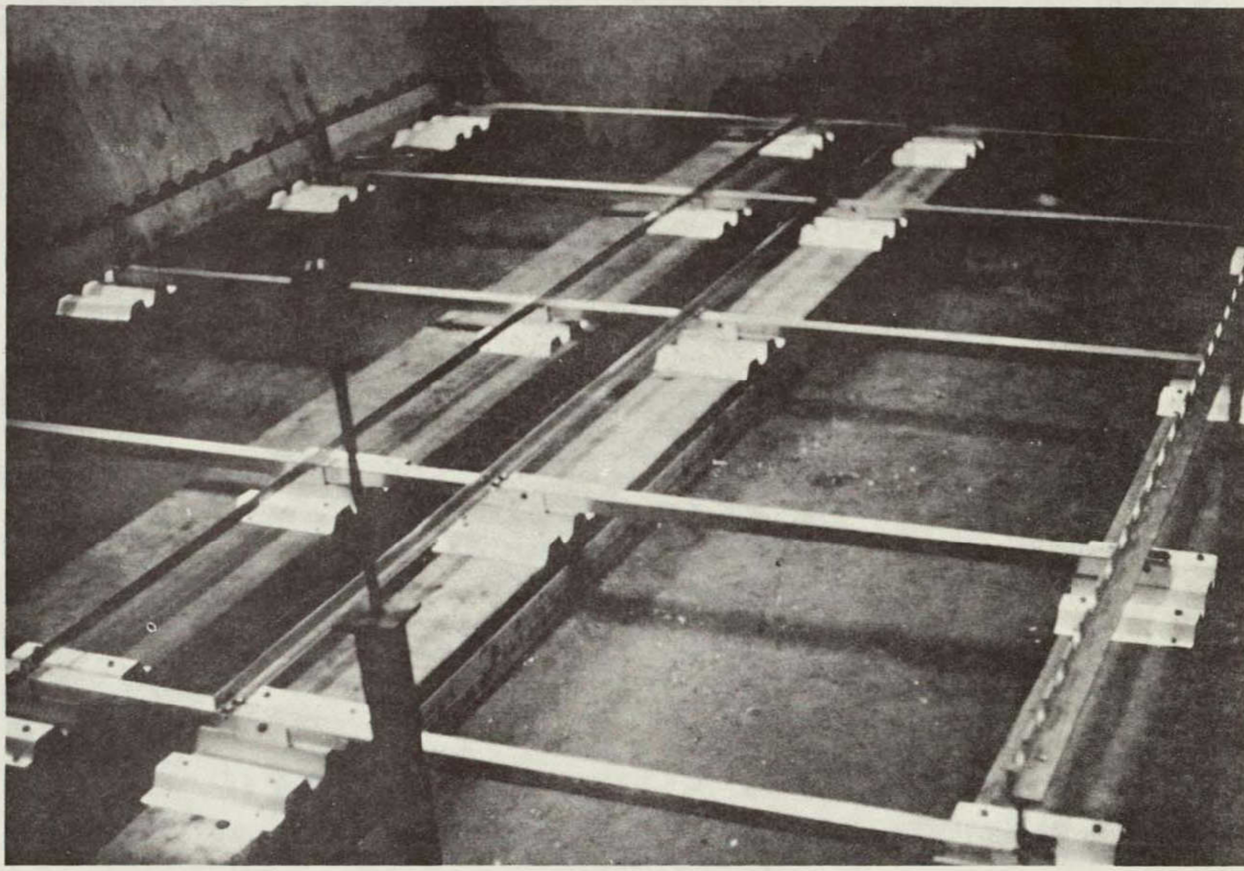
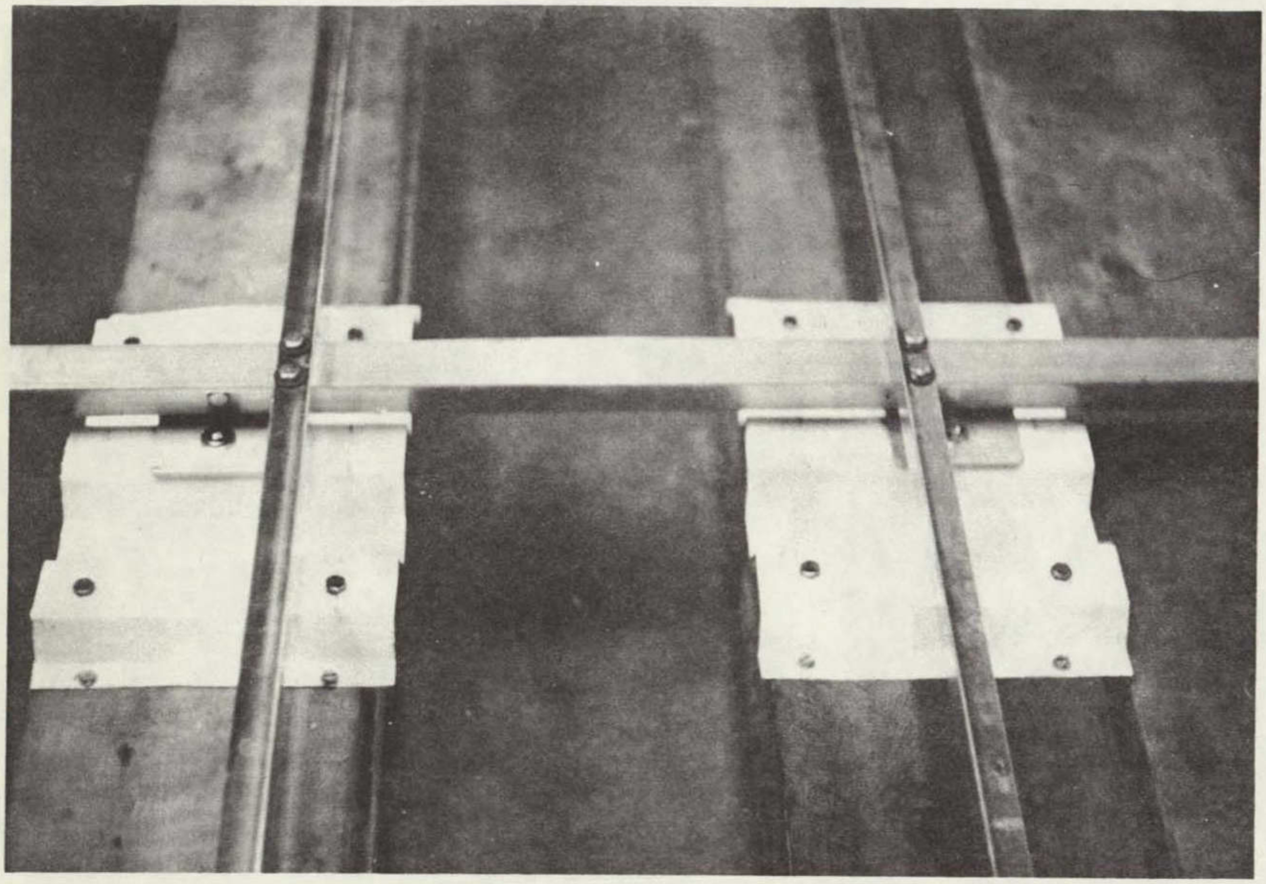


LOAD TEST FIXTURE BASE; 2" x 10" STRINGERS,
MODULE SUPPORT STRUCTURE.

Figure 3.1 (b)



CLOSE UP: T BAR SUPPORTS; MOUNTING PADS SECTIONS OF ALCOA 4-INCH RIB BONE WHITE #K2028-30, FLOUROCARBON DIFFUSE REFLECTANCE BACKING SCREEN.

Figure 3.1 (c)

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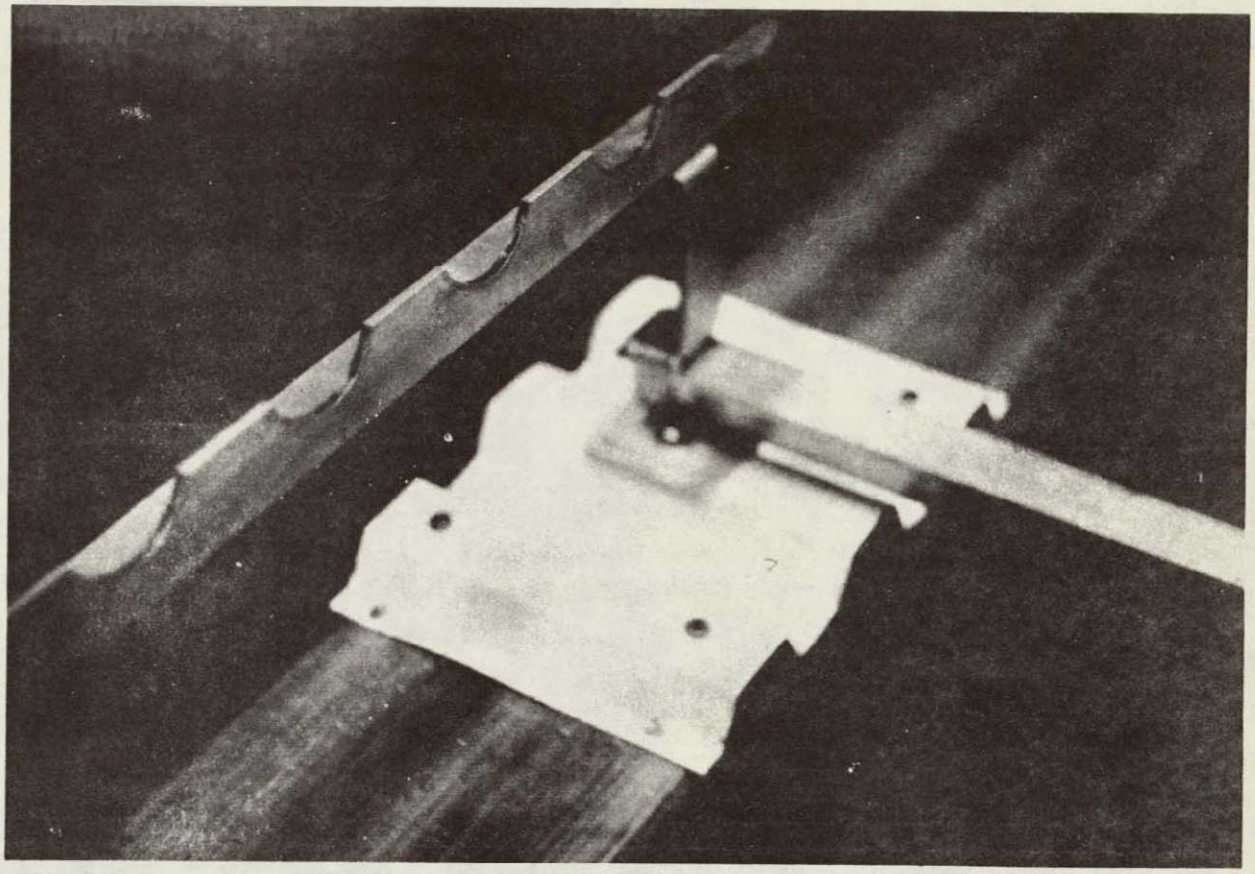

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CLOSE UP: OUTBOARD SUPPORT STRUCTURE, STAND OFF, T BAR, ROOF MOUNTING PAD, SECTION OF ALCOA BONE WHITE BACKING SCREEN.

Figure 3.1 (d)

TWO SECTION AIR BAG; REACTION ELEMENT STAND OFF SUPPORTS.

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Figure 3.1 (e)

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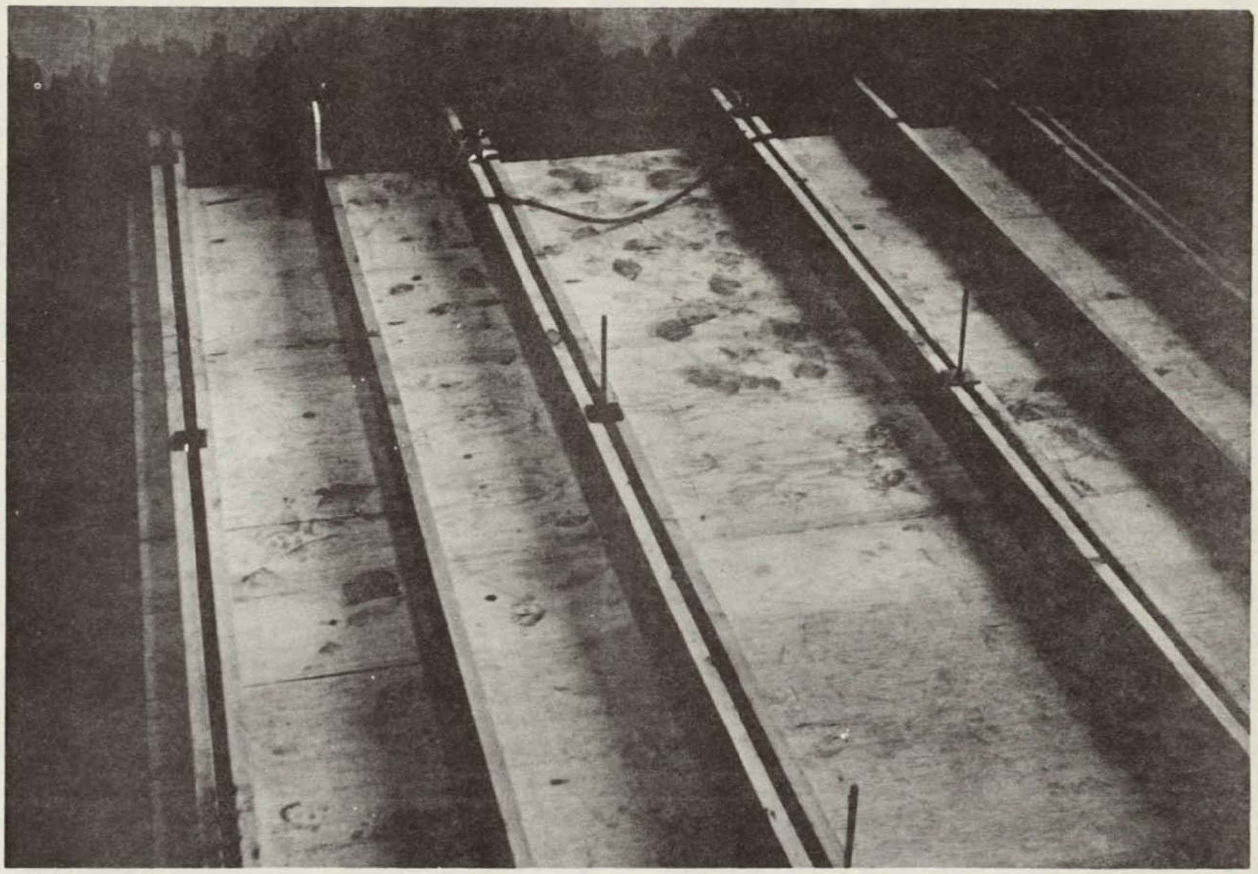
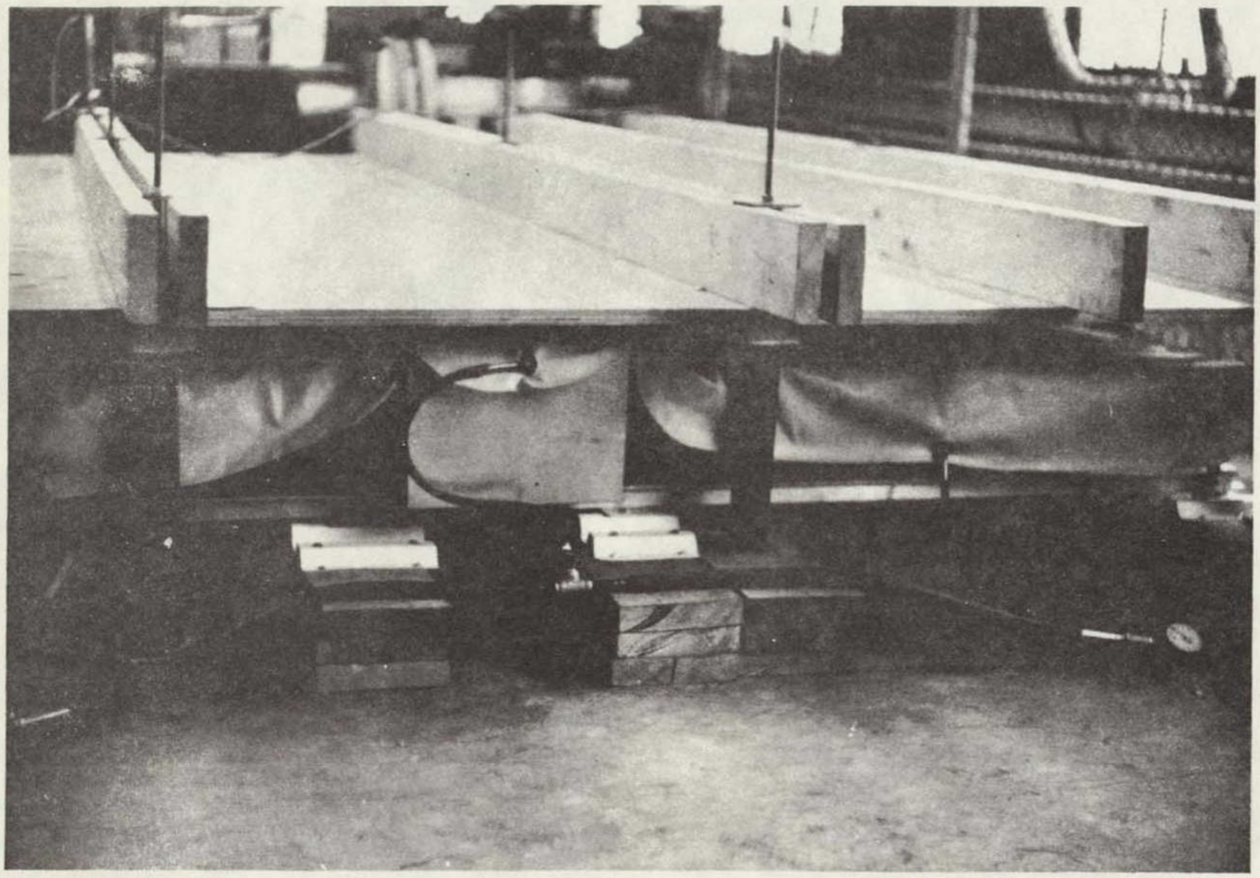


REACTION MEMBER MOUNTED IN PLACE

Figure 3.1 (f)



CLOSE UP: REINFORCED CONCRETE FLOOR; 2" x 10" STRINGERS;
MODEL SEC 601 COLLECTOR; AIR BAG; REACTION ELEMENT.

Figure 3.1 (g)

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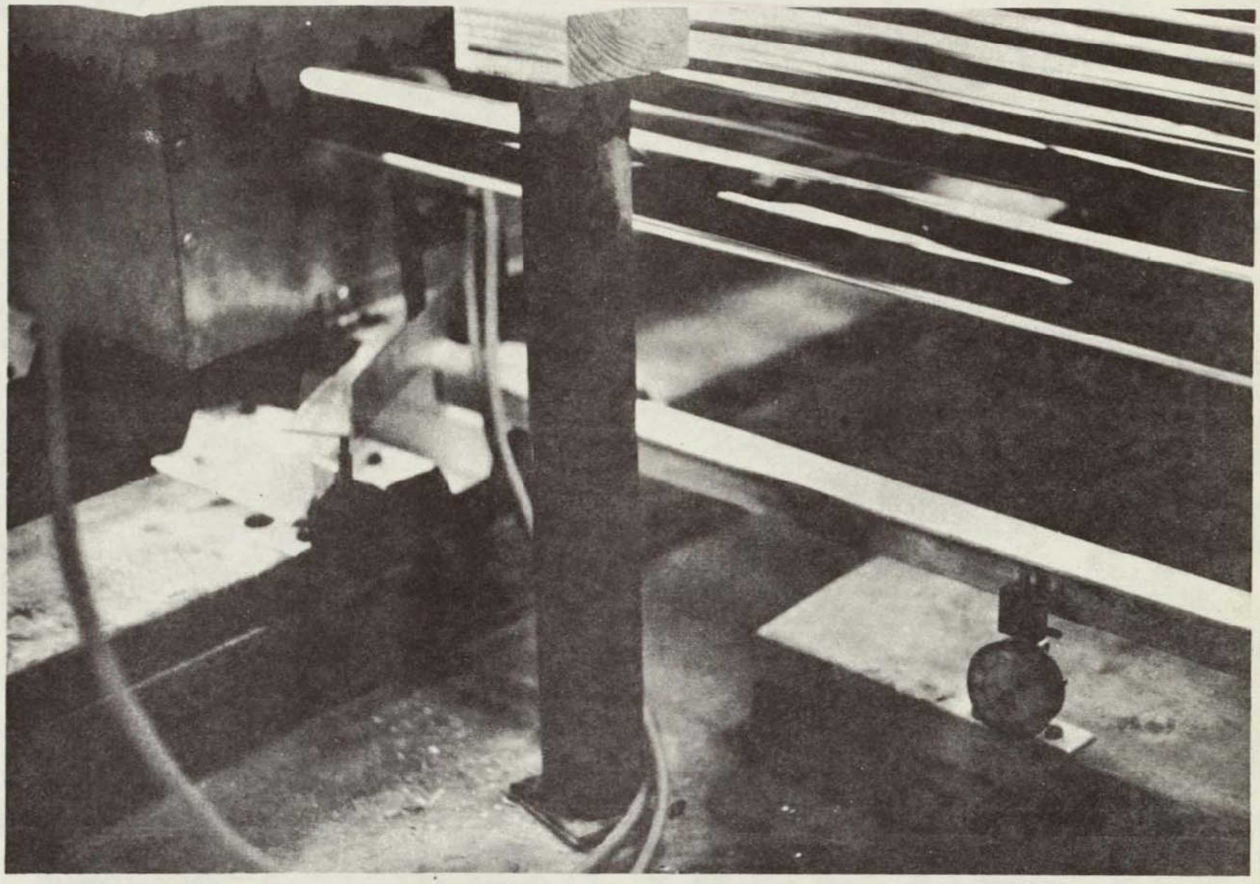
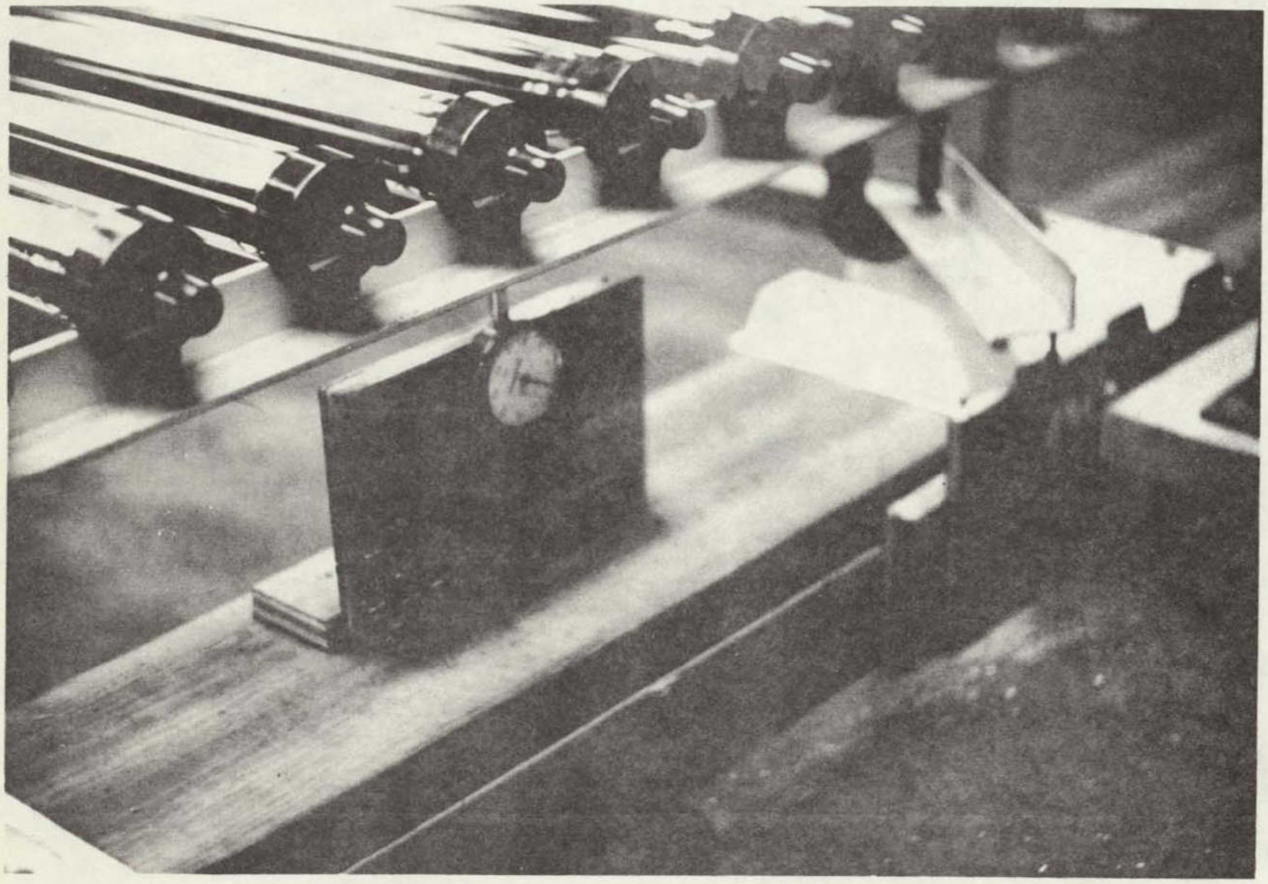


DIAL INDICATORS: DEFLECTION POSITIONS NO. 1 & NO. 2.

Figure 3.1 (h)



DIAL INDICATORS: DEFLECTION POSITIONS NO. 3 & NO. 4.

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Figure 3.1 (i)

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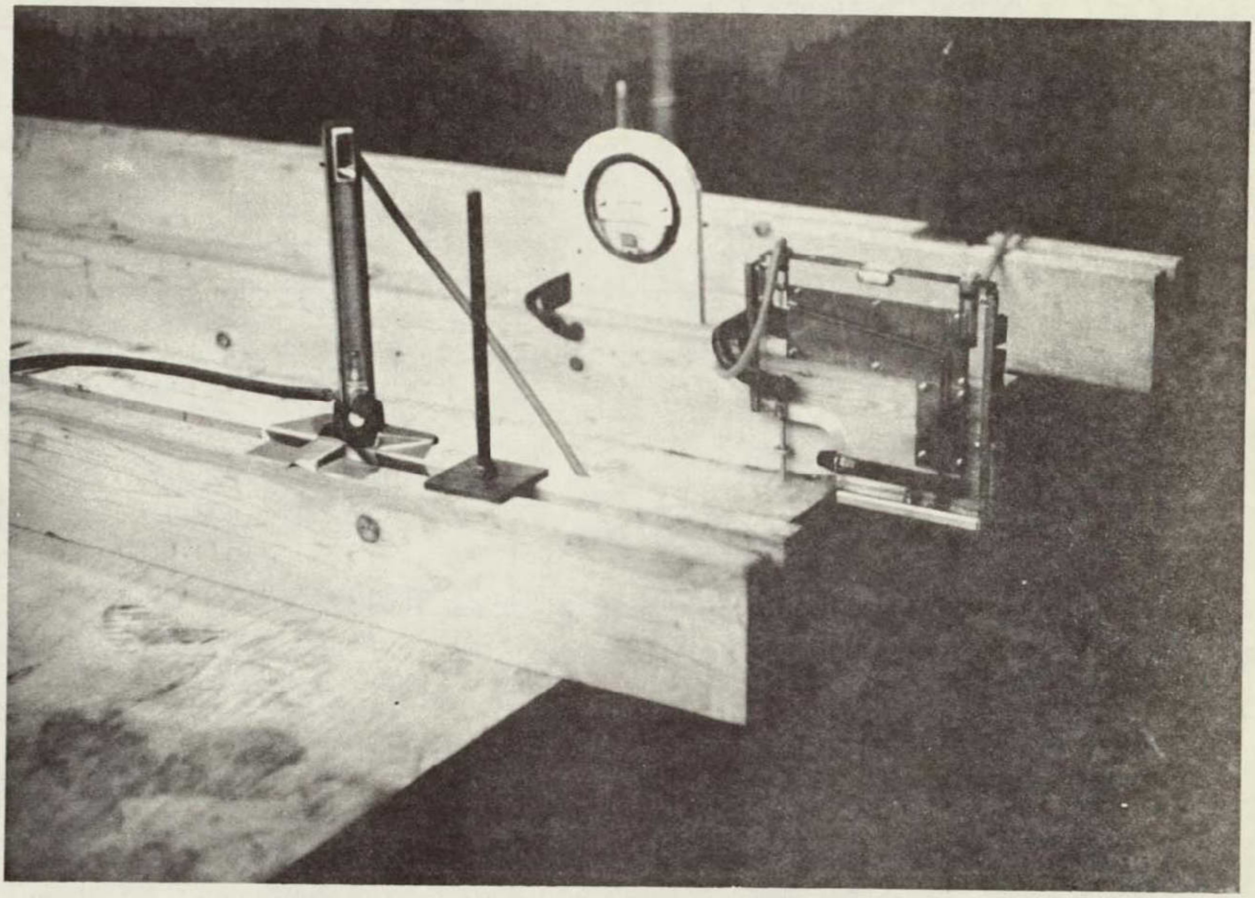


LOAD TEST FIXTURE; MEASUREMENT EQUIPMENT:

LEFT: MATHESON, BALL FLOAT FLOW METER
LEAKAGE FLOW

CENTER: PRESSURE GAGE, 0 to 30 INCHES, WATER COLUMN.
AIR/BAG PRESSURE / MANIFOLD PRESSURE

RIGHT: INCLINOMETER, 0 to 5 INCHES, WATER COLUMN.
MANIFOLD PRESSURE / AIR BAG PRESSURE.

Figure 3.1 (j)

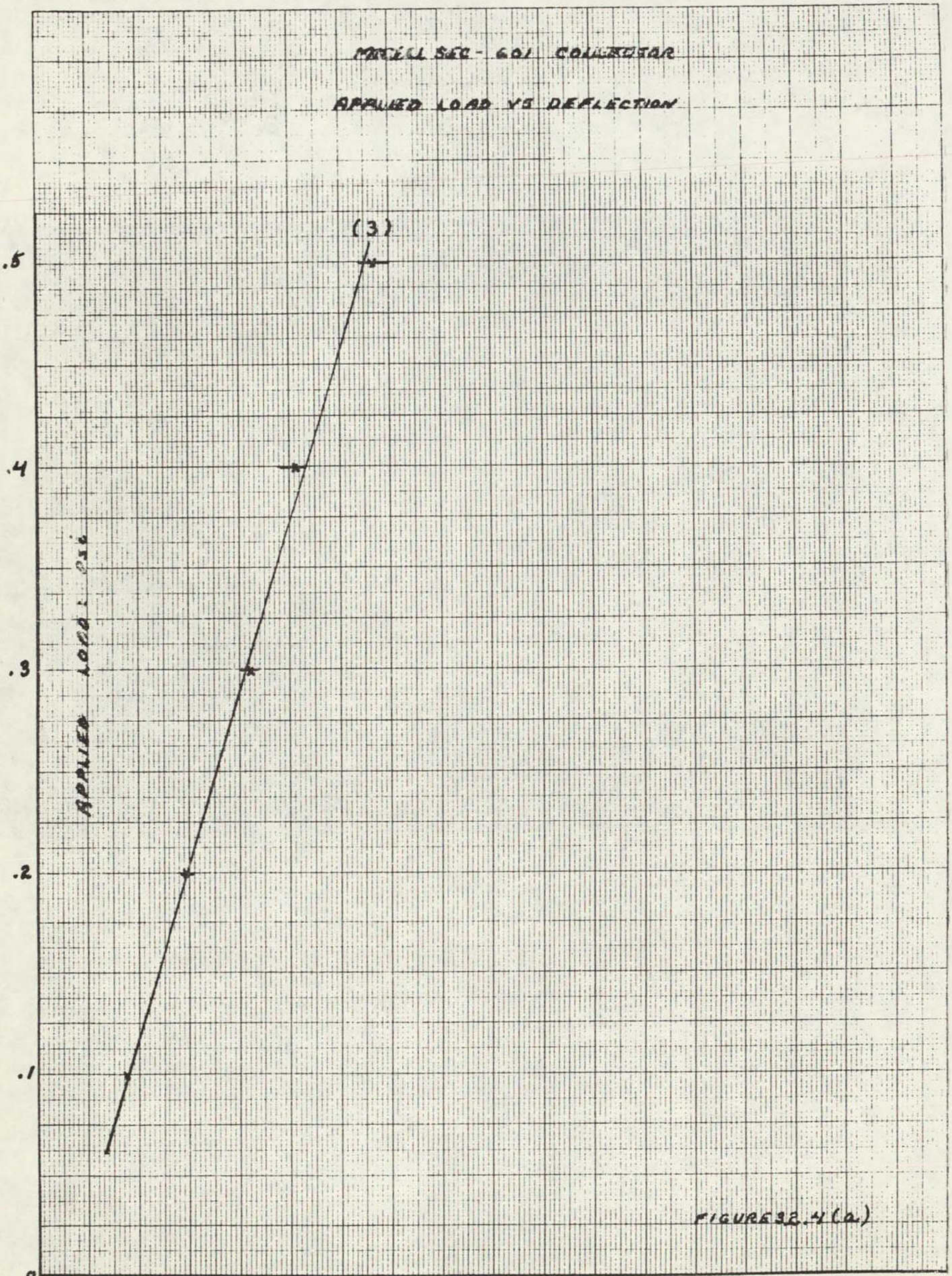


FIGURE 32.4(a)

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM 46 1513 MADE IN U.S.A. KEUFFEL & ESSER CO.

Report on Hail Impact Tests on Owens-Illinois Solar Energy Collectors

Impact tests were conducted on a 12 tube liquid collector and a 12 tube air collector for Owens-Illinois on March 23 and March 24, 1978 at Texas Tech University. The missiles used in the tests were spherical iceballs that simulate hailstones. Missile diameters of 1.0 inch, 1.2 inch and 1.5 inch were used.

A compressed air cannon and photocell timing device were used to fire the missile at a collector tube. In each trial a tube was selected and missiles were fired at increasing velocities until breakage occurred. The velocity resulting in breakage was recorded and photographs were made when the breakage was such that it would be apparent in a photograph.

All impacts were made approximately 9 inches from the top of the collector tube. Except where noted, the impacts were normal and were centered on the tube. This location of impact is thought to present one of the more severe cases for this type of collector.

Velocities of hailstones are affected by hailstone diameter and by wind giving the hailstone a horizontal velocity in addition to the vertical velocity. Vertical velocity is given by

$$V_T = 53.5\ D^{1/2}$$

where D is diameter in inches.

and V_T is in miles/hour

Resultant velocity V_R is

$$V_R = (V_T^{\,2} + W^2)^{1/2}$$

where W is wind speed in miles/hour

Another way to compute V_R is

$$V_R = \frac{V_T}{\cos \theta}$$

where θ is the angle from vertical of the hailstones trajectory. Figure 1 gives velocity curves for several cases.

Liquid Collector Tests

Table I presents test results on the liquid collector. The following conclusions can be made:

1. The 1.0 inch iceballs caused no damage even at velocities much higher than those normally encountered for this size hailstones. A horizontal wind of 86 miles per hour will be required to give a 1 inch hailstone a V_R of 101.2 miles per hour. It appears that the collector can survive 1.0 inch hailstones.

2. The 1.25 inch iceballs gave an average breaking velocity of 73.6 miles per hour; standard deviation was 9.1. V_T for this size hailstone is 60 miles per hour. Tubes 3 and 11 (Tests D and I) were broken at slightly above V_T. It is probable that 1.25 inch hailstones will break some tubes but will not break others due to the tube variation in strength.

3. The tubes appear vulnerable to hailstones with diameters of 1.50 inches and larger.

Air Collector Tests

Table II presents test results for the air collector. Conclusions from these results are:

1. The tubes should survive most 1.25 hailstones without damage. Average breaking velocity was 92.4 miles per hour with

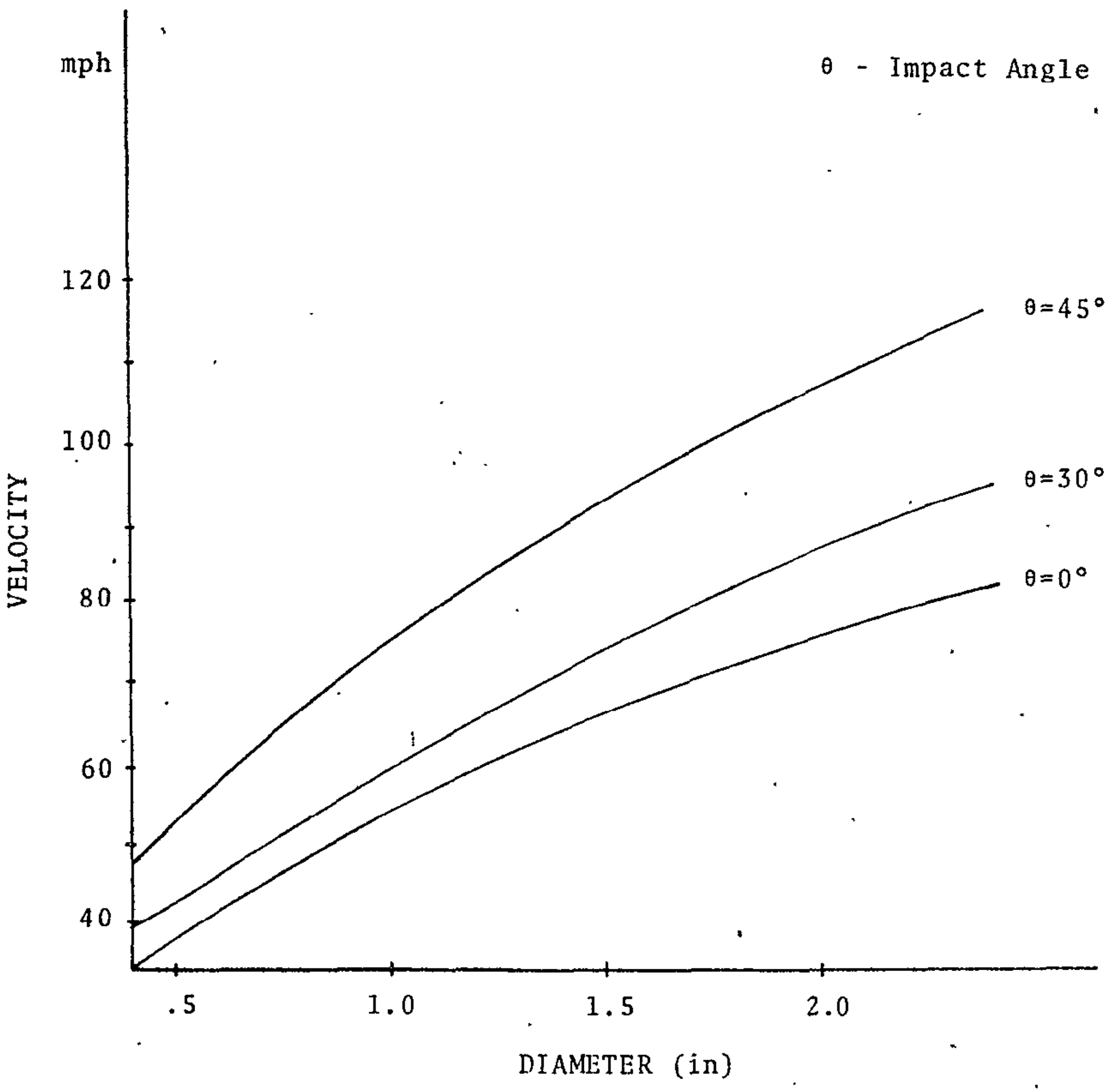


Figure I Theoretical Terminal Velocities of Hailstones

Table I Liquid Collector Test Results

Test	Tube Number	Missile Diameter (in)	Velocity (mph)	Comments
A	1	1.00	88.8	No breakage
B	2	1.00	101.2	No breakage
C	2	1.25	72.4	Internal breakage
D	3	1.25	63.5	Internal breakage
E	4	1.25	73.0	
F	5	1.25	73.3	
G	6	1.25	71.8	
H	8	1.25	92.6	
I	11	1.25	68.3	Internal breakage
J	8	1.25	83.7	Glancing impact side of tube; no breakage
K	1	1.50	59.9	Breakage on first impact; actual velocity for breakage may be lower

Table II Air Collector Tests Results

Test	Tube Number	Missile Diameter (in)	Velocity (mph)	Comments
A	1	1.00	94.0	No breakage
B	6	1.25	86.5	
C	7	1.25	103.3	No breakage
D	8	1.25	99.1	
E	9	1.25	79.7	
F	10	1.25	86.5	
G	11	1.25	99.1	
H	12	1.25	71.3	Impact with collector tilted back 45°
I	1	1.50	93.4	
J	2	1.50	75.6	
K	3	1.50	58.2	
L	4	1.50	73.5	
M	5	1.50	111.1	

a standard deviation of 9.4. The minimum breaking velocity was 79.7 miles per hour; a 1.25 inch hailstone will have a velocity V_R equal to 79.7 miles per hour when wind is blowing at 53.7 miles per hour. The second lowest breaking velocity was 86.5 miles per hour; a 62.5 mile per hour wind will result in 86.5 miles per hour from a 1.25 inch hailstone. These wind velocities are possible in thunderstorms; however they are the exception rather than the rule.

2. Average breaking velocity for 1.50 inch iceballs was 82.4 miles per hour; standard deviation was 20.3. Terminal velocity V_T for 1.50 inch hailstones is 65.5 miles per hour. It is expected that some tubes will be broken by 1.50 inch hailstones and that some will survive.

3. The test with the collector at a 45° angle produced breakage at 71.3 miles per hour. Although it was thought that an impact at an angle other than normal would require a higher velocity for breakage, this one test did not support that supposition.

Comments on the Tests

The Owens-Illinois evaucated tube collectors have some unusual characteristics concerning hail survivability due to the collector design. Most hailstones impacts will occur with glancing impacts on sides of the tubes rather than at a 90° angle. All tests except those noted were made at 90° impact angle. By chance some hailstones will miss the tubes and strike between adjacent tubes; others will strike at a severe angle as shown in Figure 2 and will cause no damage. Test J

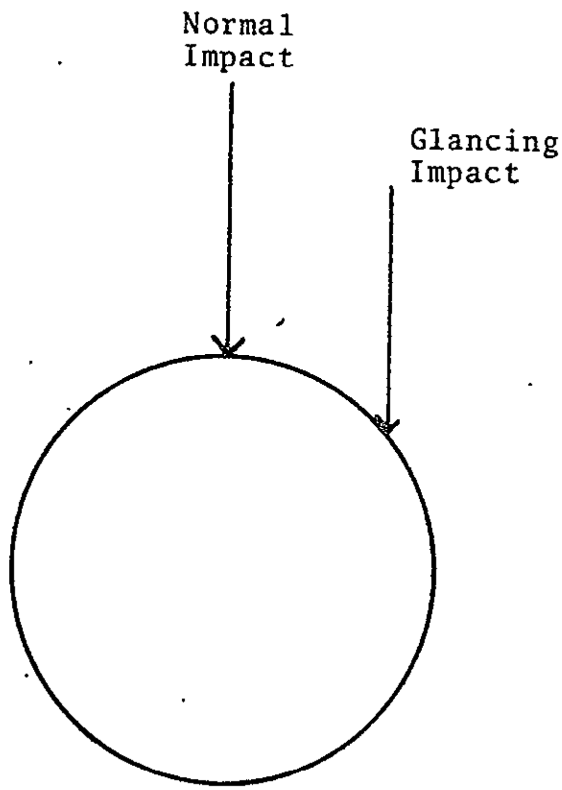


Figure 2. Tube Impacts

in Table I was made at such an angle, and no damage was observed.

A second unusual characteristic of the Owens-Illinois collectors is the ease of replacement of individual tubes. If one tube in a bank is broken, only that tube must be replaced. Also if breakage is internal and not on the exterior of the tube, operation can continue until the damaged tube can be replaced. In several cases breakage was internal with the outer tube surface remaining intact; there will be no loss of fluid, but there will be some decrease in performance due to the tubes having lost the vacuum.

The iceball impact tests likely produce a more severe test than that from a hailstone at the same velocity. Iceballs are cast uniformly and are at a density that is at the upper limit of the range of hailstone densities. Also the location of impact and impact angle were selected to present a worst case.

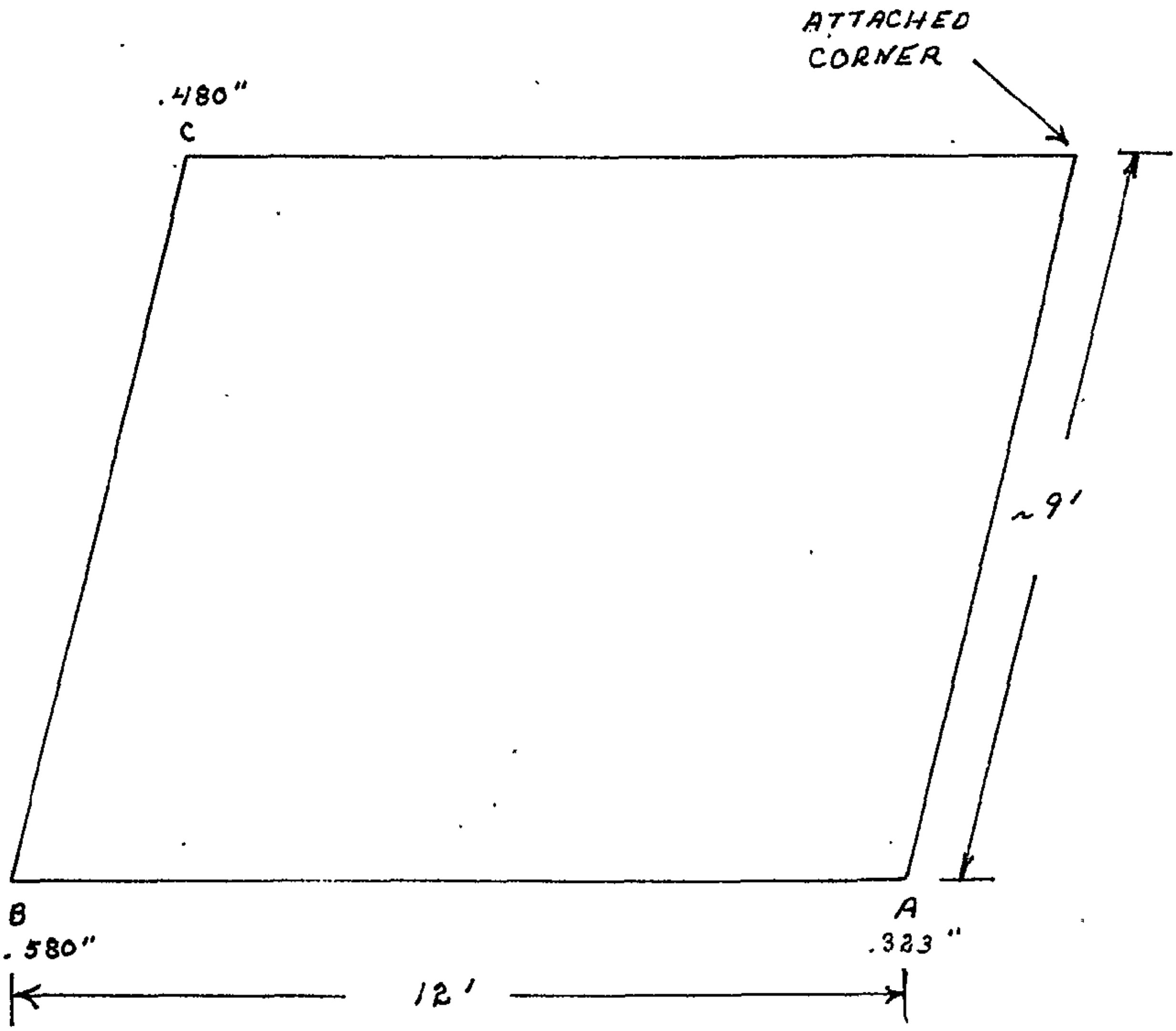
Results obtained from these tests should be used with caution in warranting survivability in a hailstorm. Hailstones in a given storm are of various sizes; there is no official measurement of sizes and no highly accurate method available for measurement. Also hailstones rapidly decrease in size due to melting. This results in a situation where it is very difficult to establish the size of a hailstone that caused breakage to a collector tube. It is suggested that some type of a hailpad be installed at each location of SunPac collectors to provide a record of hailstone sizes should this record be needed.

Photographs

The following photographs were made after breakage occurred.

Collector Type	Test	Tube Number	Figure Number
Liquid	A	1	3
Liquid	F	5	4
Liquid	I	11	5
Air	B	6	6
Air	B	6	7
Air	E	9	8
Air	F	10	9
Air	F	10	10
Air	G	11	11
Air	G	11	12
Air	H	12	13
Air	H	12	14
Air	J	2	15
Air	K	3	16
Air	L	4	17

Figure 18 shows the collector positioned for Test H.



SIMULATED SUPPORT ATTACHMENT

FIGURE 3.8.1(a)

4.2 Fail Safe Controls.

4.2.1 System Failure Prevention.

Accelerated life tests are conducted on collector tube elements as a continuing in house program. The DSET outdoor exposure test program, originally planned for use as documentation for this section, has been reduced in duration. The results of the O.I. ongoing accelerated life tests are now considered to be more appropriate as documentation. The test consists of heating the internal volume of the absorber tube by a calrod unit. Figure 4.2.1(a) contains a chart of the experimental test results for a standard production tubular element exposed for 2035 hours to 500°F and an additional 9242 hours at 600°F. The tubular element was tested periodically for the stagnation temperature it would reach when subjected to radiation from an indoor solar simulator. The change in the comparative stagnation temperature was from 320°F initially, a maximum of 342°F and down to a minimum of 300°F.

The collector tube element life is the most critical component in determining the long term thermal performance of the collector. The accelerated life test data of Figure 4.2.1(a) documents the capability of the collector tube elements to withstand long-term periods safely and reliably under no flow conditions.

Attached as Figure 4.2.1(b) is a chart of temperature data derived from the highly instrumented ERDA air collector. The manifold thermocouples were located in the annulus air flow paths as indicated schematically at the bottom of Figure 4.2.1(b). The tube on the inlet side of the manifold was upward facing. The highest temperature recorded for convection air reaching the manifold was 210°F when the recorded annulus temperature (not for the same tube pair) was 508°F. Under stagnation conditions the manifold temperature is limited and represents no safety hazard.

Figure 4.2.1(c) contains a plot of the exit air temperature of the air as it leaves the tube annulus and enters the manifold. The ERDA collector array was allowed to soak under no flow conditions until the air temperature in the tube annulus as measured at the axial midpoint of the tube element reached steady state. At solar noon, air flow at 8 lbs./min. Ft.^{2} was introduced. The decay in temperature of the air in the tube annulus and the transient air temperature at the tube annulus exit plane are recorded as a function of time. The temperature overshoot prior to reaching steady state will be noted. A thermocouple located in the tube annulus is provided with each Model SEC-601 collector. The Operations Manual specifies that the control system shall include the necessary logic and a suitable control element shall be provided to preclude the initiation of air flow when the air temperature in the annulus reaches or exceeds 400°F. In the event of a control failure, air flow could be initiated after a long period of exposure to high levels of radiation and the manifold could be subjected to a short term high temperature excursion as indicated in Figure 4.2.1(c). No failure mode of the collector will result from such short term exposure. However, repeated exposure to such overtemperature conditions could degrade the insulation properties of the manifold and/or induce an air leakage path. These changes could result in some loss in thermal performance of the collector.

Several collector tube elements were subjected to thermal shock. The tube elements were heated and cold air introduced as a worse case condition. A chart of the test conditions is contained in Figure 4.2.1(d).

The criterion of Section 4.2.1 are met by similarity of design, material selection, and construction of the ERDA air manifold and the collector tube elements with the Model SEC-601 collector.

Review of items 4.2 and 4.2.1 successfully completed.

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John M. Caudle
Technical Manager
NASA Approval

ACCELERATED LIFE TEST

TEST DATE	STAG. TEMP. °F	TEST TEMP. °F	ACC. TEST HOURS
3/22/76	320	INITIAL TEST	
3/30/76	328	500	24
4/9/76	336	"	254
4/19/76	340	"	490
5/10/76	342	"	985
5/20/76	335	"	1225
6/28/76	332	"	2035
	CHANGED	TEST	TEMP. TO 600°F
7/2/76	337	600	95
7/23/76	324	"	595
8/6/76	326	"	930
9/17/76	322	"	1935
10/18/76	302	"	2675
1/7/77	308	"	4587
4/18/77	300	"	6465
6/6/77	325	"	7615
8/16/77	305	"	9242

FIGURE 4.2.1 (a)

 Project 2420.005 Date SEP. 2 1977
Description ERDA CONTRACT (11-1) 2919 AIR SYSTEM

STAGNATION TEMPERATURES,

TIME	TOP MANIFOLD INLET	TOP MANIFOLD OUTLET	BOTTOM MANIFOLD INLET	BOTTOM MANIFOLD OUTLET	INSOLATION
11:15	131°F	133	130	124	240 BTU/...
	127	123	120	127	
	135	128	113	126	
	131	131	115	124	
	125	128	103	127	
	114	134	121	127	
ANNULUS →	419		123	127	
			136	133	
			ANNULUS →	413	
2:30	204	210	211	188	260 BTU
	206	193	185	195	
	213	207	189	193	
	210	210	204	192	
	204	202	202	201	
	153	202	198	200	
			199	200	
			203	198	
ANNULUS →		508	ANNULUS →	523	

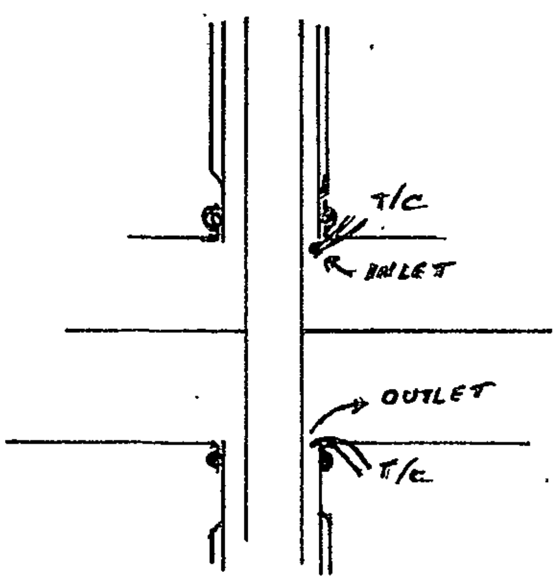

FIGURE 4.2.1(b)

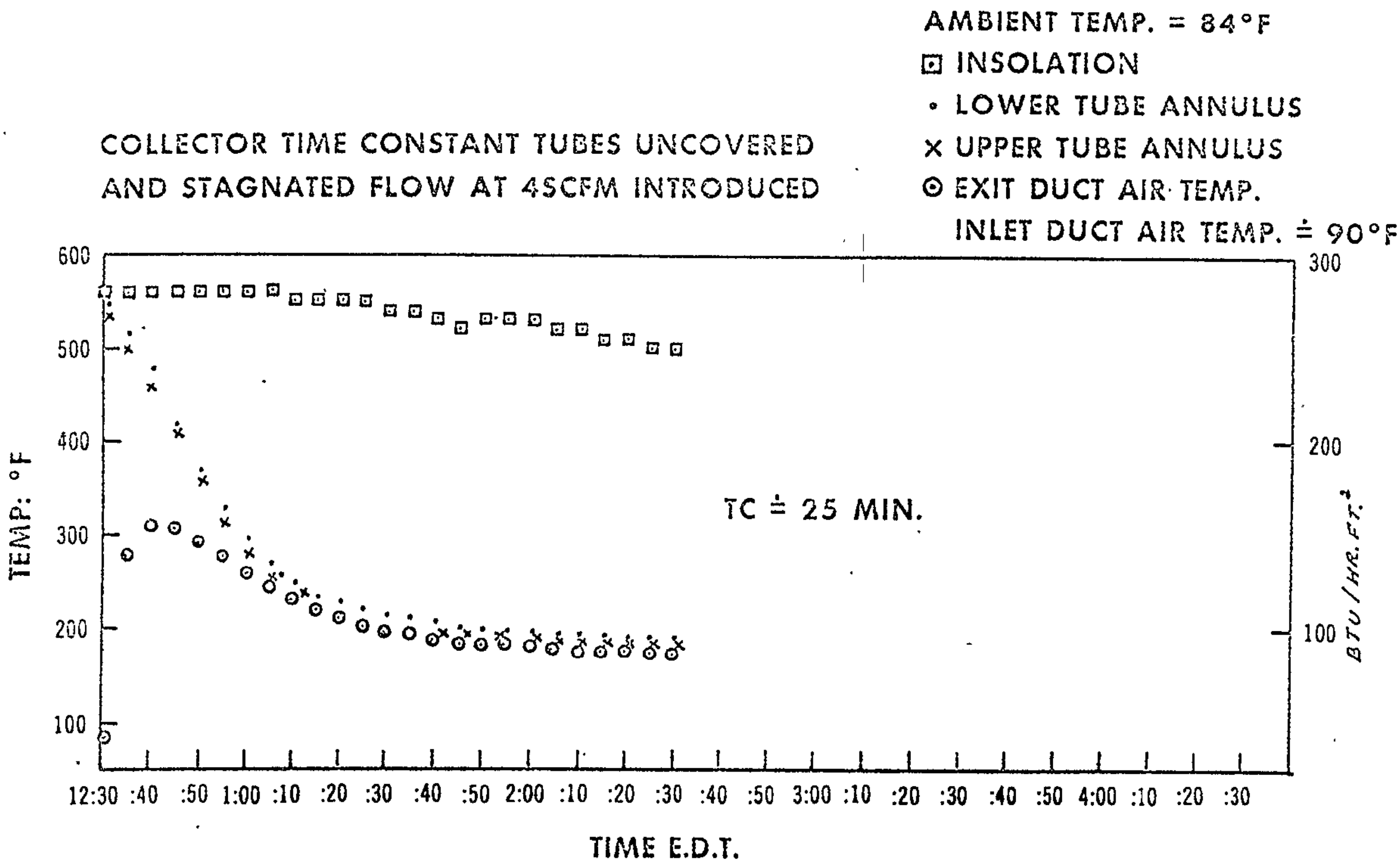
AMBIENT TEMP. = 84°F
INSOLATION
LOWER TUBE ANNULUS
UPPER TUBE ANNULUS
EXIT DUCT AIR TEMP.
INLET DUCT AIR TEMP. ≐ 90°F
COLLECTOR TIME CONSTANT TUBES UNCOVERED
AND STAGNATED FLOW AT 4SCFM INTRODUCED
TC ≐ 25 MIN.
TEMP: °F
BTU / HR. FT.²
600
500
400
300
200
100
300
200
100
12:30 :40 :50 1:00 :10 :20 :30 :40 :50 2:00 :10 :20 :30 :40 :50 3:00 :10 :20 :30 :40 :50 4:00 :10 :20 :30
TIME E.D.T.

FIGURE 4.2.1(c)

OWENS-ILLINOIS
Toledo, Ohio

Intra-Company

to K. Moan - Dev. Ctr.

cc: G. R. Mather - Dev. ctr.
F. H. Brown - Dev. Ctr.
B. R. Emch - Dev. Ctr.

subject Thermal Shock Testing of Sunpak™ Sunair Collector Tubes.

1. Introduction

Sunpak™ Sunair collector tubes can reach stagnation temperatures of 600 - 625°F under no-flow conditions. If air circulation is started in a stagnating system the inside surface of the absorber tube would be thermal shocked. The stresses generated in this type of thermal shock would be less than if water caused the thermal shock, due to the lower thermal mass of the air and the lower heat transfer film coefficient at the air/glass interface.

The purpose of this investigation was to develop an air thermal shock test for Sunpak™ Sunair collector tubes, and to assess the thermal shock strength under conditions of maximum expected shock and abuse.

2. Conclusions

2.1 Sunpak™ Sunair tubes can withstand the maximum possible thermal shock attainable (stagnation to room temperature air) even when severe defects are present in the glass.

3. Test Procedure

3.1 Thermal Shock

The collector tubes were heated with a calrod heating element enclosed in a one inch diameter aluminum tube. The calrod unit was placed inside the collector tube and the end sealed off with insulation. The tube temperature was measured and controlled by separate thermocouples placed at midpoint.

After the control temperature had been reached (about 45 minutes), the collector tube was removed from the heating fixture and placed in a verticle rack.

FIGURE 4.2.1(d).

Immediately an aluminum tube, identical to the feeder tube of a Sunpak™ Sunair air distribution system, was inserted into the tube. Nitrogen from a compressed tank was flowed through the feeder tube for five minutes. The temperature of the nitrogen was measured before the test and after the five minutes.

Test glass temperatures were varied from 625°F to 700°F. Nitrogen temperature was 70°F ± 2°F. Nitrogen flow rates of 120 CFH (Standard) and 360 CFH (3 times standard-more shock) were used.

3.2 Tube Scratching

In order to create a condition where the collector tubes are more likely to break under thermal shock, severe chatter checks were intoduced on the inside surface as follows:

A No. 14 hardened sheet metal screw was fastened through a flat steel strip so that the end of the screw extended through the strip. After sharpening the screw with a file, the tubes were scratched by running the tube over the screw at approximately 80% of the mid portion length of the tube. Six pairs of scratches were produced axially, approximately equidistant.

3.3 Pressure Testing

Hydrostatic destructive pressure testing was performed on the tubes of 3.2 after thermal shock tests had been completed. A hand operated piston pump was used at a load rate of about 100 psi per second.

4. Results

Table 1 summarizes the thermal shock test results. No breakage was encountered.

Pressure test of the five intentionally defected tubes, Nos. 4-8 gave an average failure pressure of 270 psi with a range of 250 - 300 psi.

Table 1. Thermal Shock Summary

Tube[1] #	Glass Temp. (°F)	Nitrogen Temp. (°F) Initial	Final	Thermal Shock ΔT (°F)	Nitrogen Flow (CFH)
1	700	68	208	632	120
2	700	68	256	632	120
3	700	71	230	619	120
1	700	68	116	632	360
2	700	71	117	629	360
3	700	71	115	629	360
4	700	71	243	629	120
5	660	71	258	589	120
6	700	69	247	631	120
7	625	70	245	555	120
8	620	69	263	551	120
4	700	68	142	632	360
5	660	70	151	590	360
6	700	69	143	631	360
7	625	69	155	556	360
8	620	68	152	552	360

Notes
(1) Tubes 1-3 standard tubes, no abuse
Tubes 4-8 defected tubes, see 3.2

4.3 Fire Safety.

4.3.1 Applicable Fire Standards.

Applicable sections of NFPA 89M, NFPA 90A and 90B, NFPA 30, NFPA 31, NFGC 54-1, NFPA 25b, NFPA 211 and ANSI/ASTM E-84 were reviewed for applicability to the Model SEC-601 collector. In addition, "HUD Intermediate Minimum Property Standards Supplement -- Solar Heating and Domestic Hot Water Systems, 1977 Edition" 4930.2 was reviewed for applicability. A review of the drawings and specifications of the Model SEC-601 collector was also completed. Experimental tests and evaluations were performed to evaluate qualitatively such factors as potential heat, rate of heat release, ease of ignition and smoke generation. The outside surfaces of the collector subsystem consist almost entirely of a metallic or glass material. All elements of the collector subsystem are mounted external to the roof (fire wall) of the building enclosure. The collector subsystem does not reduce the fire resistance rating of the roof assembly. A major or catastrophic fire condition would have to be reached before the collector components would reach ignition conditions. The heat transfer fluid is air and therefore does not contribute to a fire hazard condition.

4.6 Protection of Potable Water and Circulated Air.

4.6.4 Growth of Fungi.

Silicone base and zytel nylon materials, K633 glass and aluminum are the materials in contact with the air circulating in the Model SEC-601 collector. Attached Figure 4.6.4(a) and Figure 4.6.4(b)

4.6.4 (cont.d)

are design handback data on silicone and zytel nylon materials. The data indicates the resistance of the material to the growth of bacteria, fungi and termites.

Review of items 4.3, 4.3.1, 4.6, 4.6.4 successfully completed.

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Technical Manager
NASA Approval

At temperatures in excess of 150°F., however, certain specific lubricant additives may effect performance.

Test data on the behavior of "Zytel" exposed to these automotive fluids at elevated temperatures is essential to the success of the intended use. This matter is discussed in detail in an SAE Paper*.

Another approach designed to measure the suitability of "Zytel" in various environments involving exposure to automotive materials is discussed in a second portion of that same paper**. This describes how automotive parts were obtained and evaluated after extended in-use service. Copies of the SAE Paper can be obtained from your Engineering Plastics Sales office.

- *Gasolines.* "Zytel" nylons are outstanding in their resistance to conventional automotive fuels. "Zytel" shows an average weight increase of 0.57 percent and an average dimensional change of +0.009 percent after 270 days exposure at 73°F. (23°C.) to the following gasolines: Esso Regular, Esso Extra, Esso Golden Extra, Amoco High Test, Sunoco, Gulf Crest, Texaco, Mobile Premium.
- *Acids, Bases and Oxidizing Agents.* "Zytel" nylons are very resistant to alkalies even at high concentrations up to 40 percent. They are, however, rapidly attacked by strong mineral acids and/or oxidizing agents especially at high operating temperatures. Use in dilute solutions of acids or oxidizing agents under ambient conditions is often possible, but actual or simulated service tests should be conducted to ascertain the suitability of "Zytel" for the particular application.
- *Soaps and Detergents.* Tests conducted at 180°F. (82°C.) show that "Zytel" nylons have excellent resistance to standard detergent formulations such as "Tide", "Dreft", "Dash", "Oxydol", "Oakite", Calgon and Fels Naphtha soap.

CHEMICAL RESISTANCE OF GLASS-REINFORCED "ZYTEL"

The chemical resistance of glass-reinforced "Zytel" nylons is frequently superior to that of unmodified nylons. For a detailed discussion, see Section 11.

TABLE OF CHEMICAL RESISTANCE

Information on the resistance of "Zytel" to specific reagents is shown in Table 31. Ratings of excellent, satisfactory or unsatisfactory are based upon property retention for test bars exposed to the specified concentrations of the materials for the indicated time periods and temperatures. Chemical resistance information in Table 31 is based on appearance and on retention of physical properties normally after drying to remove residual moisture and reagents.

Du Pont also has accumulated a large bank of information on chemical resistance of "Zytel" to materials not shown in this Table and for many conditions not listed. Consult your Du Pont Engineering Plastics Sales office (see back cover) if additional chemical resistance information is needed.

Bacteria And Fungi: Soil And Underground Conditions

"Zytel" nylons have been found remarkably resistant to attack from bacteria, fungi and termites both in laboratory-type controlled tests and in burial tests.

Test specimens of "Zytel" 42 were buried at Landenberg, Pennsylvania for 3-1/2 years in termite-infested soil. Examination after burial showed no attack by termites nor any apparent deterioration from fungi, insects or other biological agencies. It was concluded that "Zytel" was neither attractive to termites nor readily utilized by fungi. Control specimens of pine wood showed heavy infestation with termites.

Two types of "Zytel" ("Zytel" 101 NC-10 and 211 NC-10) were tested microbiologically for their ability to support *Salmonella typhosa* growth, (food poisoning). The test proved that these samples would not support the growth of this bacteria.

Molded specimens of "Zytel" 101, 103, 105 and 63 were tested for resistance to fungi representatives of the following groups: (1) chaetomium globosum, (2) rhizopus nigricans, (3) aspergillis flavus, (4) penicillium luteum, and (5) momononiells echinata.

Test bars exposed for 28 days to active environments with respect to fungi showed no visual evidence of attack after cleaning and no loss in physical properties. Also, no changes occurred in molecular weight.

Irradiation

Among plastic materials, "Zytel" 101 is intermediate in its resistance to the heterogeneous radiation flux of an atomic pile†. Thus, "Zytel" 101 is more resistant than such materials as cellulose acetate and methyl methacrylate polymer, but less resistant that polyvinyl chloride acetate. During radiation, test bars of "Zytel" 101 initially show increased tensile strength with some loss in toughness. With progressive radiation, brittleness develops.

Furthermore, "Zytel" 101 is relatively resistant to the effects of gamma radiation††. Tests on nylon film (66 nylon) made after exposure to 6 megarads of gamma radiation indicate essentially no harm to the material. On the basis of the study, it was concluded that 66 nylon could be considered as packaging of food subject to perservation by high energy radiation.

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*"The Suitability of 66 Nylon Resins for Molded Parts Involving Long-Term Resistance to Heat, Gasoline and Salt", Society of Automotive Engineers, Mid-Year Meeting, Detroit, Michigan, May 18-22, 1970, Paper #700485.

**"Evaluating the Effect of Extended Service in Automobiles on Parts Made of 66 Nylon and Acetal Homopolymer", Society of Automotive Engineers, Mid-Year Meeting, Detroit, Michigan, May 18-22, 1970, Paper #700485.

†The United States Atomic Energy Commission ORNL-928, Sisman, O. and Bopp, C. D., June 29, 1951.

††Krasnansky, V. J., Achhammer, B. G., and Parker, M. S., SPE Transactions, July 1961 -- Effect of Gamma Radiation on Chemical Structure of Plastics.

FIGURE 4.6.4(a)

PART #5065
4-10-78

Inertness

An inert material, silicone rubber is oderless and tasteless. Because it is extremely stable and contains no sulfur or other acid producing chemicals, it does not cause staining, corrosion, or deterioration of other materials with which it comes in contact.

Fungus Resistance

Properly cured silicone rubber will not support the growth of fungus. Samples of silicone rubber have been successfully tested against the two major military specifications for fungus resistance: MIL-F-8261, Fungus, Resistance Tests, Aeronautical and Associated Materials, General Specification For; and MIL-E-5272A, Environmental Testing, Aeronautical and Associated Equipment, General Specification For. The fungi included in these tests were: Aspergillus Niger, Aspergillus Flavus, Trichoderma T-1, Chaetomium Globosum, Penicillium Luteum, Memnoniella Echinata.

Radiation Resistance

The ability of silicone rubber to resist radiation damage at normal temperatures is comparable to many other synthetic polymers. However, at temperature extremes, silicone rubber offers a combination of thermal, oxidation, and radiation resistance not available in any other polymer.

Its radiation resistance is normally defined by the ability of the silicone rubber to retain usable physical properties after exposure to high radiation dosage. Thus, silicone rubber reflects satisfactory resistance when exposed to 10^{8} roentgens. This radiation resistance far exceeds that of TFE resin and is comparable to, or superior to, fluroelastomers at room temperature. Available data, thus far, indicates a distinct radiation resistance advantage of silicone rubber over both TFE and fluroelastomers at elevated temperatures.

Release Characteristics

Silicone rubber provides better release from sticking than any other rubber. One example of an application utilizing these release properties is the use of silicone rubber for the rollers used in processing sticky materials such as hot polyethylene and adhesives.

Because silicone rubber rollers provide excellent release, they are used to handle sticky materials.

Bonding Properties

When properly applied, silicone rubber compounds will bond and have great usefulness as adhesives or sealants. Such bonds are tough and remain flexible at temperatures up to 500F and can be made to almost all metals, glass, ceramics, most rigid plastics, and, of course, silicone rubber itself.

The bond of silicone self-bonding rubbers exceeds the high tensile strength of the rubber itself. Notice the rubber yielding before the bonds.

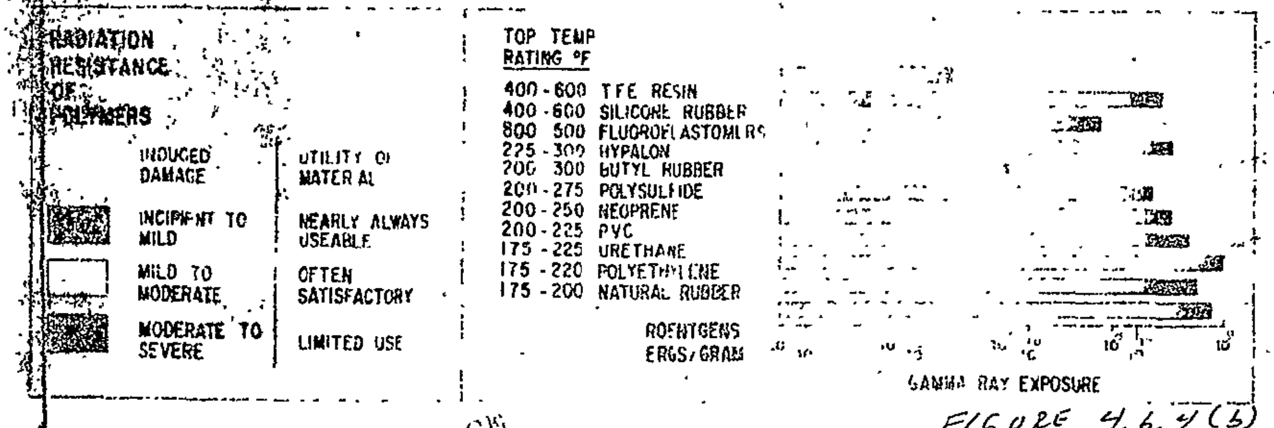


FIGURE 4.6.4(b)

ORIGINAL PAGE OF POOR QUALITY

PART #5065

This mount using silicone rubber bonded to steel provides excellent vibration damping characteristics.

Vibration Damping

Silicone rubber has the ability to absorb energy over a wide range of frequencies and over a wide temperature range. Its excellent elastic and dampening properties make it ideally suited for use in vibration control devices. The comparatively simple construction of vibration control mountings designed with silicone rubbers together with the proven durability of the rubber, assure the maximum in long term reliability.

The transmissibility and resonant frequency of mountings incorporating silicone rubber will remain virtually constant from -65 to 300F. The maximum magnification factor at resonance is generally 3.0 or less at 68F or lower temperatures, and 3.5 at 300F. The mounts also have linear load-deflection characteristics for constantly applied accelerations up to 5G in any direction. In addition normal variations in input amplitude will have little effect on isolation efficiency and cause no marked resonant frequency shift.

Spring rates are approximately equal in all directions and the highly damped characteristics yield a transmissibility curve that is smooth in the high frequency range. It is unbroken by spring surges or high frequency harmonics which might damage the mounted equipment.

Damping characteristics increase at an exponential rate and provide gentle bottoming under shock conditions. These mountings cushion a load gradually and are capable of large deflections with a non-linear spring rate. Repeated test shocks of 15G do not reduce isolation efficiency, and the mounts will withstand 30G shock pulses without failure

The series of impressions in this silicone rubber pad help assure uniform, predictable vibration deflection characteristics at temperatures from -65 to 300F.

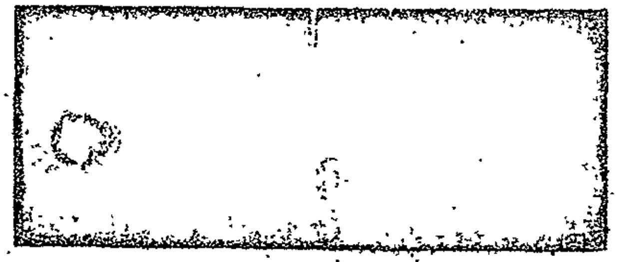
ORIGINAL PAGE OF POOR QUALITY

Ozone and Corona Resistance

The ozone resistance of silicone rubber approaches that of mica. Unlike fluoro-carbon materials, such as Polytetrafluoroethylene resins, which have good ozone-resistance but degrade rapidly when subjected to corona, silicone rubber also has excellent corona resistance.

To determine the resistance of silicone rubber to high-voltage gradients, samples of #20 AWG wire with a 3/64 inch wall of insulation have been subjected to a 10,000 volt potential for 100 hours at a temperature of 500F. There were no signs of stress cracking or corona erosion at the conclusion of this test Under the same conditions organic rubber insulations fail within a few minutes, even when the test is conducted at room temperature.

Tests also show that organic rubber is badly damaged after being subjected to a stress of 200 volts/mil for 30 minutes. Even after 12,000 hours silicone rubber insulated wire is unaffected by a stress of 200 volts/mil.



Silicone rubber is virtually unaffected by corona.

Resistance to Weathering

Silicone rubber resists the deteriorating effects of sunlight, ozone, and gases which cause weathering. Inherently water repellent, silicone rubber is not affected by most operating conditions. Very dry conditions and low humidity will not leach, dry out, or affect silicone rubber in any way, at any temperature extreme found in nature.

Silicone rubber also has good resistance to deteriorating agents found in rain water: chloride, sulfate, nitrate and hydrogen ions. Surface water which may have leeched minerals, acids, bases, and salts from the soil normally has no detrimental effect on silicone rubber. Silicone rubber will effectively resist the concentrations of such materials found in surface water.

SILICONE RUBBER RESISTANCE TO CHEMICALS COMMONLY FOUND IN SOIL

Chemical	Resistance
Acids	
Hydrochloric 3%	Good
Phosphoric 10%	Good
Sulfuric 10%	Good
Base	
Sodium Hydroxide 1%	Good
Potassium Hydroxide 1%	Good
Salts	
Calcium Carbonate	Good
Calcium Chloride	Good
Calcium Hydroxide	Good
Sodium Carbonate 2%	Good
Sodium Chloride 10%	Good

Part *5065

OZONE RESISTANCE

Silastic silicone rubber, when tested for resistance to ozone, shows excellent stability After both static and dynamic testing for periods of 2, 4, 6, and 8 hours, samples had no significant change in durometer hardness, tensile strength, or elongation. Under a magnification of 10, no cracking or checking was visible.

The tests followed procedures of ASTM D 518 and ASTM D 1149 with some modifications to match the outstanding properties of Silastic elastomers. As specified in ASTM D 518, specimens were stretched 20 percent. However, in addition to the static condition, a dynamic test elongated specimens 25 percent in a cycle of 60 stretches per minute. This cycling, if the rubber were affected by ozone, would result in the rapid propagation of any cracking As stated, no cracking or checking occurred.

Other test modifications concern test method ASTM D 1149 Part C under procedure, specifies a concentration of 25 parts of ozone per 100 million parts of air And for Silastic silicone rubber, this was increased to a concentration of 30,000 parts of ozone. Part D states that a temperature of 38 C may be used for elastomers with low resistance to ozone cracking and that 49 C is satisfactory for materials with good resistance Silastic rubber tested successfully at 74 C.

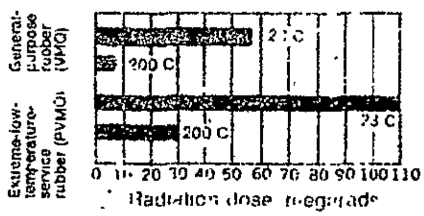
RADIATION RESISTANCE

Radiation causes changes in the properties of Silastic rubber similar to those caused by heat aging As the total radiation dose is increased, hardness of the rubber increases, tensile strength may increase at first, but later decreases sharply; elongation decreases

These direct effects of radiation are proportional to the total amount of radiation level--as long as the radiation level is low or moderate However with high radiation levels, the heating effects cause additional changes

Figure 15 shows the radiation dose that is required to reduce the elongation of two samples of Silastic rubber to an absolute level of 50 percent. Data is given for radiation exposure to a cobalt-60 source at room temperature and at 200 C The level of 50 percent elongation is arbitrarily used as the test endpoint because, for many applications, this is the minimum amount of rubberiness that an elastomer can have and still be useful Of course, static seals and similar products might remain serviceable at much lower levels of elongation

FIGURE 15. Radiation required to reduce elongation of two samples of Silastic silicone rubber to an absolute value of 50 percent



FUNGUS RESISTANCE

When rubber is used in any warm, damp environment, its properties must resist attack by mold or fungus. Although Silastic rubber is not antifungicidal it is not a nutrient for fungi nor is it adversely affected by fungus or mold.

With test procedures described in 005272B (USAF), several classes of Military Specification MIL-E-silicone rubber were exposed to chaetomium, globum, aspergillus niger, aspergillus terreus penicillium futem, and fusarium moniliforne None of these micro-organisms deteriorated the specimens

In another test, Silastic rubber samples were buried in 5 inches of warm (28 C) moist soil for 6 weeks with no evidence of microbial attack

In a third test, samples were sprayed with a mixed spore suspension of fungi and then placed in a tropical test chamber at 37 C 90/100 percent relative humidity. None was attacked by mildew

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Immersion Medium	ASTM Designation for Type of SILASTIC Rubber	Immersion Conditions	Hardness Change, points	Tensile Strength Change, percent	Elongation Change, percent	Volume Change, percent
[illegible]	MQ	14 days/20 psi	[illegible]	4[illegible]	40	+5
	VMQ		[illegible]	45	4[illegible]	+5
	PVMQ		5	20	-15	nil
	VMQ	1 day/50 psi	5	-25	-10	+5
		3 days/50 psi	5	-30	-5	+5
		5 days/50 psi	-5	-40	-25	+5
		7 days/50 psi	-5	-65	-30	+5
	VMQ	1 day/65 psi	-10	-30	-30	+5
		3 days/65 psi	-5	-50	-25	+5
		7 days/65 psi	-10	-65	-50	+5
		1 day/80 psi	10	-40	-10	+5
		3 days/80 psi	-10	-60	-40	+10
		7 days/80 psi	-10	-75	-45	+5
	MQ	16 hr/100 psi	-10	30	+25	nil
	MQ	1 day/100 psi	-10	-40	-10	+5
	VMQ		-5	-40	-15	nil
	PVMQ		-5	-25	+5	nil
	FVMQ		5	-20	+15	nil
	MQ	3 days/100 psi	10	-60	-20	+10
	VMQ		10	75	-55	+5
	PVMQ		-10	-35	-5	nil
	MQ	7 days/100 psi	-20	-30	-25	+5
	VMQ		-10	-85	-85	+5
	PVMQ		-20	-75	-75	nil
[illegible]						
[illegible] d (5%)	VMQ	7 days/24C (75F)	-5	...	..	+5
[illegible]	MQ	7 days/24C (75F)	-5	..	...	nil
	VMQ		5		..	+5
	PVMQ		-5	....	..	±5
	FVMQ	2 days/24C (75F)	..	.	..	+20
[illegible] Acid (5% [illegible] ethylene)	VMQ	1 day/100C (212F)	-30	.	..	+100
	FVMQ		-15	..	...	+10
[illegible] Acid (10%) HCl	MQ	7 days/24C (75F)	nil	.	...	nil
	VMQ		-5	.		nil
	PVMQ		nil	.	..	nil
	FVMQ		-5	-25	-15	nil
[illegible] chloric Acid (18%)	FVMQ	3 days/24C (75F)	nil	-20	-10	nil
		3 days/65C (150F)	nil	-35	-10	+10
Hydrochloric Acid (35% concentrated)	MQ	7 days/24C (75F)		poor		
	VMQ		-5	.	..	+5
	PVMQ			brittle		
	FVMQ		-5	-15	-30	+10
[illegible] Acid (40%)	PMQ	9 days/27C (80F)		deteriorated		
[illegible] Acid (10%) HNO_3	MQ	7 days/24C (75F)	nil		.	+10
	VMQ		nil		.	nil
	PVMQ		nil		.	nil
	FVMQ		nil	10	-5	nil

[illegible] MQ—(methyl groups only) • V—(vinyl groups) • P—(phenyl groups) • F—(fluorine-containing groups)

PART #5065

Immersion Medium	ASTM Designation for Type of SILASTIC Rubber	Immersion Conditions	Hardness Change, points	Tensile Strength Change, percent	Elongation Change, percent	Volume Change, percent
...ric Acid (50%)	FVMQ	3 days/24C (75F)	+5	15	−10	+5
		[illegible] days/65C (150F)	10	[illegible]	−30	−5
...ic Acid (...% concentrated)	MQ	[illegible] days/24C (75F)		poor		
	VMQ		+5			−10
	PVMQ			brittle		
	FVMQ		nil	40	−30	+5
...ic Acid (10%)	MQ	7 days/24C (75F)		unaffected		
	PMQ			unaffected		
	MQ	7 days/100C (212F)		unaffected		
	PMQ			unaffected		
...ric Acid (...% concentrated)	MQ	7 days/24C (75F)		unaffected		
	PMQ			unaffected		
	MQ	7 days/100C (212F)		dissolved		
	PMQ			dissolved		
...aric Acid	MQ	7 days/100C (212F)		unaffected		
	PMQ			unaffected		
...c Acid (20%) H2SO4	MQ	1 day/83C (180F)	nil	−10	−5	−5
		7 days/83C (180F)	nil	−25	−15	−10
...Acid (30%)	PVMQ	2 hr/93C (200F)	nil	20	−5	nil
...Acid (50%)	FVMQ	3 days/24C (75F)	nil	−5	−5	nil
		3 days/65C (150F)	+5	35	−15	nil
...ic Acid (...concentrated)	MQ	7 days/24C (75F		decomposed		
	VMQ			decomposed		
	FVMQ			decomposed		
	PVMQ			decomposed		
...ium Hydroxide (...ted)	MQ	7 days/24C (75F)	−5	.	...	nil
	VMQ		nil	..	...	nil
	PMQ			unaffected		
	PVMQ		nil		...	+5
	FVMQ		−5	−45	−5	+5
...Oxide (...saturated)	VMQ	1 day/149C (300F)	+5	15	−10	+5
...Hydroxide (2%)	VMQ	1 day/149C (300F)	nil	−25	−10	−5
...Hydroxide (5%)	VMQ	1 day/149C (300F)	−10	−70	nil	−35
...Hydroxide (...turated)	VMQ	1 day/149C (300F)		deteriorated		
...ium Hydroxide (10%)	VMQ	1 day/149C (300F)	+5	−20	−15	−5
...ium Hydroxide (25%)	MQ	7 days/83C (180F)	nil	.	...	+5
	PMQ		−5		.	nil
...ium Hydroxide (...)	VMQ	1 day/149C (300F)	20	−40	−10	−10
...ium Hydroxide (10%)	MQ	7 days/24C (75F)	5	.	..	nil
	VMQ		−5	..	...	nil
	PMQ		..	..		+5
	PVMQ		−5		...	nil
	FVMQ		−5	−45	−10	nil
...ium Hydroxide (25%)	MQ	7 days/83C (180F)	−5	..	..	nil
	PMQ		5	..	...	−10

MQ—(methyl groups only) • V—(vinyl groups) • P—(phenyl groups) • F—(fluorine-containing groups)

ORIGINAL PAGE OF POOR QUALITY

Immersion Medium	ASTM Designation for Type of SILASTIC Rubber	Immersion Conditions	Hardness Change, points	Tensile Strength Change, percent	Elongation Change, percent	Volume Change, percent
[illegible]rophenol ([illegible]thanol)	PMQ	7 days, 24C (75F)			...	+5
[illegible] (70%)	MQ	7 days/100C (212F)	-30			+5
[illegible] (85%)	MQ	7 days/24C (75F)	10		...	+10
[illegible] Anhydride	MQ	7 days/149C (300F)	+5	...	...	nil
[illegible]	MQ	1 day/200C (392F)	nil		...	nil
	VMQ	1 day/200C (392F)	nil	...	...	nil
	FVMQ	1 day/200C (392F)	nil		...	nil
	MQ	5 days/200C (392F)	-2		...	nil
	VMQ	5 days/200C (392F)	nil	...	...	nil
	FVMQ	5 days/200C (392F)	-2	...	...	+7
	MQ	7 days/200C (392F)	2		...	+2
	VMQ		nil	...	...	nil
	FVMQ		+2	...	...	+7
[illegible] (Dow 200)	VMQ	7 days/24C (75F)	-5	...	...	+5
	PVMQ		-5	...	...	+5
	MQ	7 days/121C (250F)	-5	...	...	+5
	VMQ		-10	...	...	+5
[illegible]	VMQ	7 days/24C (75F)	nil	+5	-10	nil
[illegible] Oxide	MQ	7 days/24C (75F)	-20		...	+150
[illegible]	VMQ	7 days/24C (75F)	-5		...	+10
	FVMQ		-5	...	...	+5
[illegible] (10% [illegible])	PMQ	7 days/24C (75F)	...		...	+5
[illegible] 141 [illegible]	VMQ	70 hr/150C (302F)		deteriorated		
	PVMQ			deteriorated		
	FVMQ			deteriorated		
[illegible]	PVMQ	1 hr/24C (75F)	-10	...	...	+55
		4 hr/100C (212F)	-20	...	...	+116
[illegible]	PMQ	7 days/121C (250F)		unchanged		
	VMQ	4 days/199C (390F)	-22	no strength or tear resistance		
[illegible] Dioxide (dry gas) SO_2	MQ	7 days/24C (75F)	nil	...	...	nil
	VMQ		-5	...	...	nil
	PVMQ		nil	...	...	nil
[illegible] Dioxide (liquid)	MQ	7 days/24C (75F)	nil	...	...	+5
[illegible]	VMQ	1 day/149C (300F)	nil	...	...	nil
	FVMQ		nil	...	...	nil
	VMQ	2 days/199C (390F)	nil		...	nil
	FVMQ		+5	...	...	nil
	VMQ	3 days/199C (390F)	nil	...	...	nil
	FVMQ		+5	...	...	nil
[illegible]	PMQ	7 days/100C (212F)	nil	...	...	+10
Te[illegible]hydrofuran ([illegible]methylene oxide)	VMQ	1 day/25C (77F)	...	...	...	+200
	FVMQ		...	...	...	+170
[illegible]chloroethylene	FVMQ	1 day/24C (75F)	-10	...	...	+25
	MQ	7 days/24C (75F)	-15		...	+35
	FVMQ	5 days/49C (120F)	10		...	+20
[illegible]	MQ	7 days/-58C (-65F)	-20	...	...	+100

M—(methyl groups only) • V—(vinyl groups) • P—(phenyl groups) • F—(fluorine-containing groups)

4.7. Excessive Surface Temperature.

4.7.1. Protection from heated components.

The Model SEC-601 collector was set up for thermal cycling tests. The air flow set up is shown schematically in Figure 4.7.1.(a). The collector was instrumented with temperature sensors as indicated in Figure 4.7.1.(b). The collector air flow path was into the exit air duct, through the manifold and tube elements and out through the inlet duct. The reverse air flow path simulates actual operating conditions where a positive temperature gain would be experienced from inlet to outlet.

A portion of a strip chart recorder indicating the sensed temperatures is contained in Figure 4.7.1.(c). A dual element electric heater was used to minimize the rate of change of the heated air flowing into the collector. Element 1 was activated at cycle time, t_0, the second after one hour into the cycle. Both elements were shut off after two hours into the cycle allowing ambient air to cool down the collector. The total cycle time was three hours. It will be noted in Figure 4.7.1.(c) that all temperatures were approaching steady state conditions and, in fact, extending the cycle time did not result in an appreciable change in the sensed temperatures.

It will be noted in Figure 4.7.1(c) that no exposed surface temperature exceeded 100°F at an inlet air flow temperature of 325°F. Couple No. 9 senses the temperature at the interface between the glass cover tube and the silicone rubber seal. This surface is not exposed during normal operating conditions. In addition, several of the personnel explored the collector surfaces by touch; no surface could be detected which was uncomfortable to the touch.

Review of Items 4.7. and 4.7.1. successfully completed.

Robert F. Romaker
O.I. Test Engineer

Kenneth L. Moan
P.E. (Ohio 5203)
O.I. Approval

David C. Miller, Ph.D.
SH&G Certification Officer

William C. Louie, V.P.
P.E. (Mi. 11084)
SH&G Certification Officer

John M. Caudle
Technical Manager
NASA Approval

THERMAL CYCLE TEST SCHEMATIC
FOR
SURFACE TEMPERATURE MEASUREMENTS

FIGURE 4.7.1(a)

COLLECTOR AIR AND SURFACE TEMPERATURE SENSOR LOCATIONS

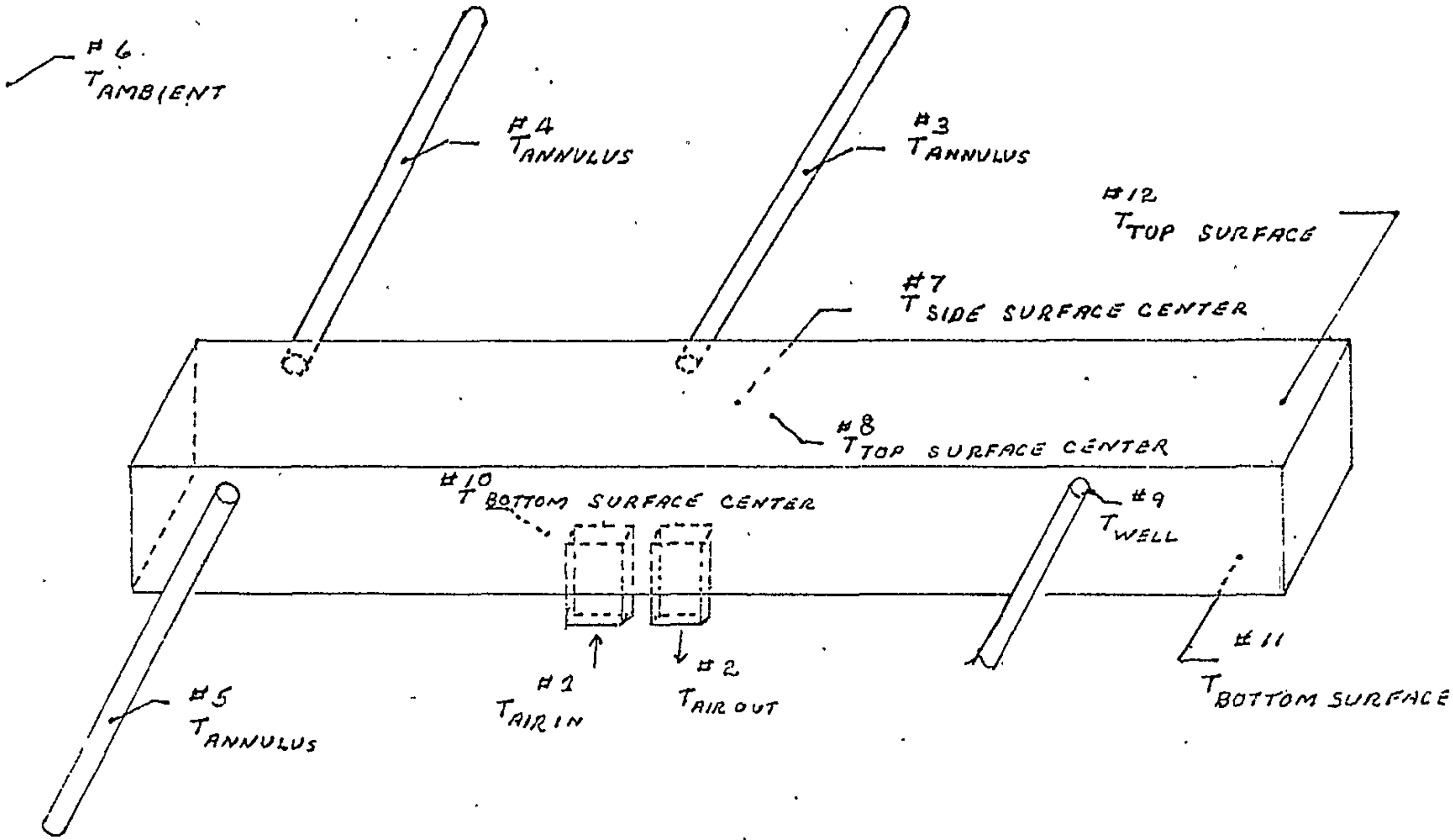

FIGURE 4.7.1 (b)

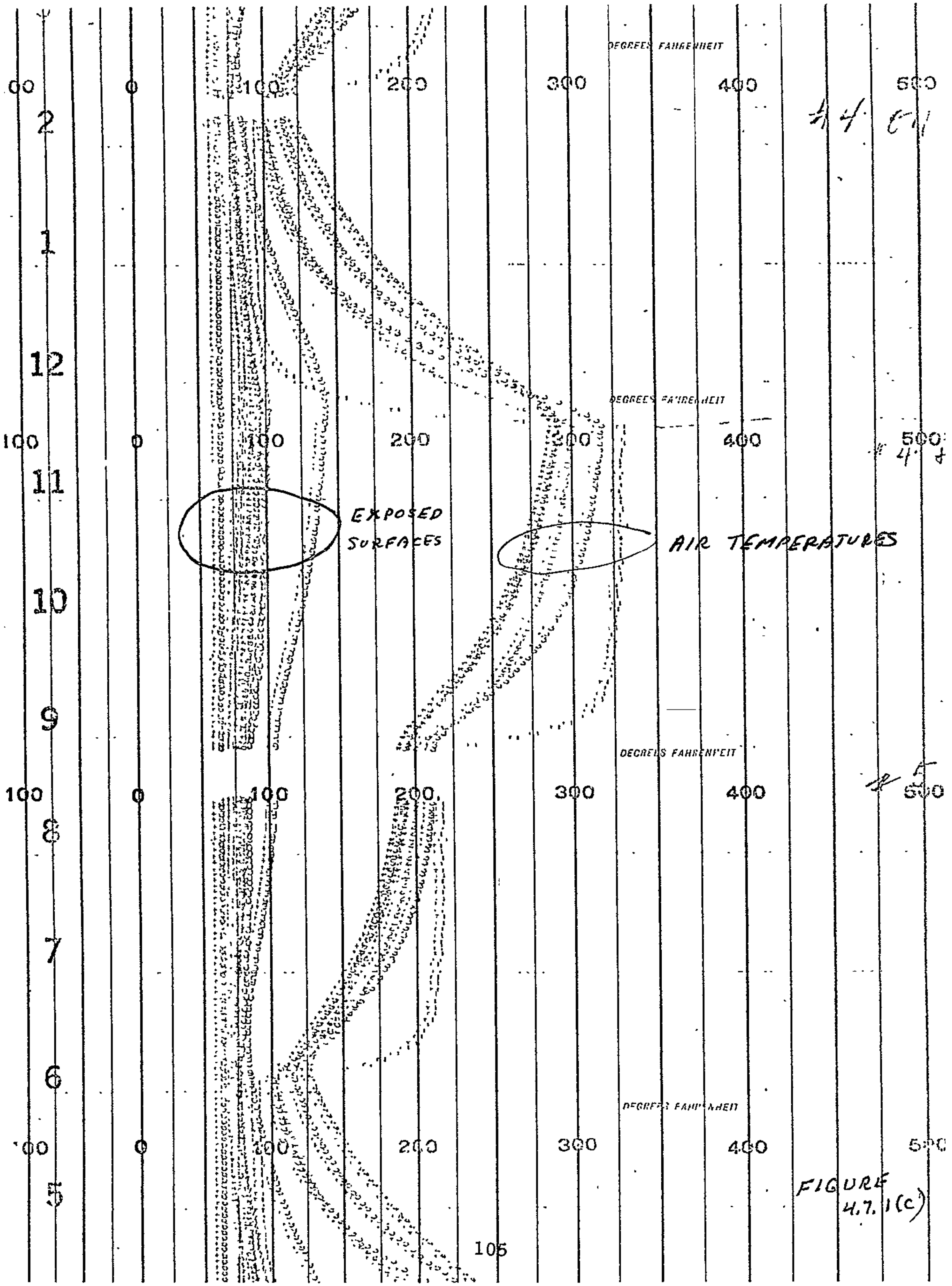
DEGREES FAHRENHEIT
100
0
100
200
300
400
500
2
1
12
11
10
9
8
7
6
5
EXPOSED SURFACES
AIR TEMPERATURES

FIGURE 4.7.1(c)

5.1 Effects of External Environment.

5.1.1 The capability of the Model SEC-601 collector cover material and wavelength selective coating to meet the solar degradation criterion have been evaluated by a combination of indoor accelerated life testing and long term outdoor exposure tests. The indoor accelerated life testing emphasized the evaluation of the long term stability of the wavelength selective coating and the vacuum. The tests and data have been reported under Section 4.2.1, previously submitted. The results of seventeen (17) months of outdoor exposure of the ERDA collector array are presented in Section 5.3. A review of this section verifies the capability of the collector components to withstand extended outdoor exposure without degradation which would adversely affect the capability of any component of the collector to perform its intended function.

As further evidence of the long term capability of the collector components to withstand outdoor exposure under stagnation conditions, collector components were subjected to outdoor exposure at the Desert Sunshine Exposure Tests, Inc. facility starting in August, 1976. Figure 5.1.1(a), sheet 1, contains a record of the stagnation temperature reached by a standard production liquid collector tube element in August, 1976. Figure 5.1.1(a), sheet 2, indicates the stagnation temperature reached as a function of solar time on June 24, 1978. An indication of the level of solar radiation is also given for each test day. Because of instrumentation difficulties, the solar radiation listed is not that existing in the tilt plane of the test rack. The test rack tilt angle was changed monthly to correspond roughly to the plane in which the solar radiation

5.1.1 (cont.d)

would be normal to the test rack during the month. A review of the data indicates no significant change in the stagnation temperature reached and therefore that no degradation to the wavelength selective coating or vacuum has occurred after essentially two years of continuous outdoor exposure to the maximum solar radiation condition with no cooling fluid flow through the collector element. The test requirements of Section 03 were exceeded by a factor of four with no evidence of deterioration in performance or change in characteristics of the wavelength selective coating. The production process for applying the wavelength selective coating, evacuation, tip off and getter material and flashing are identical for the liquid and air SUNPAK^{TM} collector tube elements. Therefore, the Model SEC-601 collector tube elements meet the criterion of this section by similarity. An extended outdoor exposure test has been initiated for the Model SEC-601 components. The first record of the stagnation temperature of each of the tubes is contained in Figure 5.1.1(b).

5.1.3 Airborne pollutants.

The capability of the components of the Model SEC-601 components to withstand exposure to airborne pollutants has been evaluated by similarity to the liquid SUNPAK^{TM} collector materials and moderate exposure testing of the Model SEC-601 components at Desert Sunshine Exposure Tests, Inc. Figure 5.3.1(a) contains a listing of the liquid SUNPAK^{TM} components with outdoor exposure test results from August 10, 1976 to June 27, 1978. Figure 5.1.3(b) contains a definition of the ranking applied to the physical inspection of the components. The rack on which the components are mounted is south facing. Its tilt angle is adjusted once a month in order to cause the solar radiation to be essentially normal to the rack during the month's test period.

Figure 5.1.3(c) contains the physical inspection ranking for the liquid SUNPAK™ components for June 27, 1978. Figure 5.1.3(d) contains the initial report for the Model SEC-601 collector components. The tube retainer component (panel item No. 3) of the Model SEC-601 collector uses the same material as the liquid SUNPAK™ component panel item No. 6 except that the polycarbonate source was changed from G.E. to Mobay. All other components of the liquid SUNPAK™ collector module demonstrate long term resistance to the attack of airborne pollutants under conditions of adverse severity to an extent that no significant impairment to the intended performance of the components during their design life would be expected.

The components of the Model SEC-601 collector are considered to meet the criterion of Section 5.1.3 by similarity. Further, a design review of the Model SEC-601 collector indicates that the only non-metallic parts subject to direct exposure to solar radiation are PN-SK-5103 (MS-1022) and PN-SK-5067 (MS-1021).

Review of items 5.1, 5.1.1, 5.1.3 successfully completed.

Robert F. Romaker
O.I. Test Engineer

Kenneth L. Moan
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O.I. Approval

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John M. Caudle
Technical Manager
NASA Approval

TABLE VII

DSET No. 16605S August 10, 1976

OWENS-ILLINOIS

Stagnation Temperatures - 45° South

Solar Time	Tube Temperatures (°C) #9	(°F)	#10	#11	#12	°C Ambient Temperature	(°F)	INSOLATION (BTU/ft.²hr)
1040	211.8	412	216.3	220.9	213.0	35.6	96	265
1100	251.8	485	261.2	258.3	257.1	36.1	97	281
1130	280.1	536	296.5	283.1	295.7	36.7	98	290
1200	289.7	553	305.3	290.0	312.1	36.9	98	292
1230	293.5	560	305.0	291.6	317.5	37.1	99	288
1300	296.7	566	303.6	292.0	318.4	36.9	98	281
1330	297.8	568	299.0	288.8	317.5	37.5	100	270
1400	297.8	568	295.2	286.0	312.3	37.3	99	248
1430	296.7	566	292.3	282.1	305.0	37.7	100	226
1500	293.7	561	288.1	276.5	296.6	39.4	103	199
1530	286.8	548	283.5	272.2	286.0	39.1	102	166
1600	277.8	532	276.1	266.4	271.1	38.5	101	131
1630	265.0	509	255.6	246.1	261.8	37.7	100	
1700	249.9	482	219.3	213.4	235.5	37.3	99	
1730	222.5	435	178.9	173.5	194.6	37.2	99	
1800	175.2	347	143.6	138.8	153.1	36.5	98	
1830	140.6	285	118.7	113.8	125.4	35.4	96	
1900	114.0	267	99.3	93.6	102.6	34.5	94	
1930	94.7	202	84.8	79.2	86.6	33.7	93	
2000	81.2	178	74.2	68.7	75.3	33.1	92	
2030	71.1	160	66.3	61.2	67.0	32.4	90	
2100	63.6	145	60.2	55.6	60.6	31.8	89	
2130	57.8	136	55.3	51.0	56.1	30.4	87	
2200	52.9	127	51.0	47.2	52.3	29.4	85	
2230	48.9	120	47.3	43.9	48.8	28.5	83	
2300	45.6	114	44.4	41.3	45.8	28.4	83	
2330	42.8	109	41.9	39.0	43.3	28.1	83	
0000	40.4	105	39.8	37.1	41.2	27.7	82	
August 11, 1976								
0030	38.4	101	38.1	35.5	39.5	27.8	82	
0100	36.7	98	36.5	34.1	38.0	27.9	82	
0130	35.2	95	35.1	32.9	36.7	27.1	81	
0200	33.8	93	33.8	31.7	35.4	26.5	80	
0230	32.6	91	32.6	30.7	34.2	25.9	79	
0300	31.5	89	31.6	29.8	33.1	25.4	78	
0330	30.4	87	30.5	28.9	32.1	25.3	78	
0400	29.4	85	29.6	27.9	31.1	25.1	77	
0430	28.7	84	28.8	27.4	30.4	25.2	77	
0500	27.9	82	28.0	26.6	29.5	24.8	77	
0530	28.5	85	28.6	27.4	30.1	25.5	78	
0600	33.8	93	33.7	33.2	35.8	26.1	79	

↑ STANDARD PRODUCTION

FIGURE 5.1.1(a)
SHEET 1.

WATER TUBE STAGNATION

OWENS-ILLINOIS

True Solar Time	Ch.#32 °F Tube 9	Ch. #33 °F Tube 10	Ch. #34 °F Tube 11	Ch.#35 °F Tube 12	Ambient °F	Insolation * (BUT/ft^2.hr)
JUNE 24, 1978						
0800	460.0	387.7	306.5	525.8	97.7	161.5
0830	494.0	409.1	322.5	569.7	99.8	190.2
0900	514.5	426.3	334.7	598.3	102.5	214.6
0930	529.6	439.6	341.7	616.6	104.3	238.9
1000	541.1	447.9	347.1	627.0	106.3	263.2
1030	549.1	454.5	353.3	637.4	106.0	280.9
1100	556.3	460.9	357.4	643.0	106.0	294.2
1130	561.7	465.1	358.6	645.4	107.6	303.1
1200	564.6	466.4	358.0	645.6	109.3	307.5
1230	566.9	467.5	358.9	645.5	107.7	305.3
1300	568.8	467.8	357.6	644.9	109.7	296.4
1330	569.4	465.3	354.0	642.6	108.9	287.6
1400	568.1	460.1	347.9	637.7	109.7	272.1
1430	564.9	455.1	343.0	629.2	108.8	250.0
1500	559.9	488.3	334.2	618.8	108.8	225.6
1530	552.5	439.3	324.1	606.1	110.1	199.1
1600	543.1	429.5	315.9	589.3	108.7	170.3
1630	507.6	402.4	294.4	559.2	108.0	139.4
1700	404.8	292.1	199.5	470.7	107.0	108.4
1730	391.1	273.2	201.1	450.8	106.2	75.2
1800	402.6	269.6	205.9	444.2	103.7	46.5
1830	380.5	237.2	176.6	406.8	103.0	22.1
1900	322.7	196.6	143.6	351.9	101.1	-0-
1930	270.6	164.2	120.8	301.8	99.3	-0-
2000	232.5	141.7	108.3	262.2	99.4	-0-
2030	204.1	126.9	102.0	231.5	97.2	-0-
2100	182.2	116.7	97.9	207.1	96.9	-0-
2130	164.5	108.8	94.9	187.1	95.3	-0-
2200	151.3	103.8	93.1	171.5	93.2	-0-
2230	139.5	98.8	90.1	158.3	90.1	-0-
2300	129.7	94.2	86.8	146.9	88.7	-0-
2330	121.8	91.0	85.0	137.2	88.4	-0-

↑ STANDARD PRODUCTION

* 0° Horizontal

FIGURE 5.1.1 (a)
SHEET 2

DESEI SUNSHINE EXPOSURE TESTS, INC.

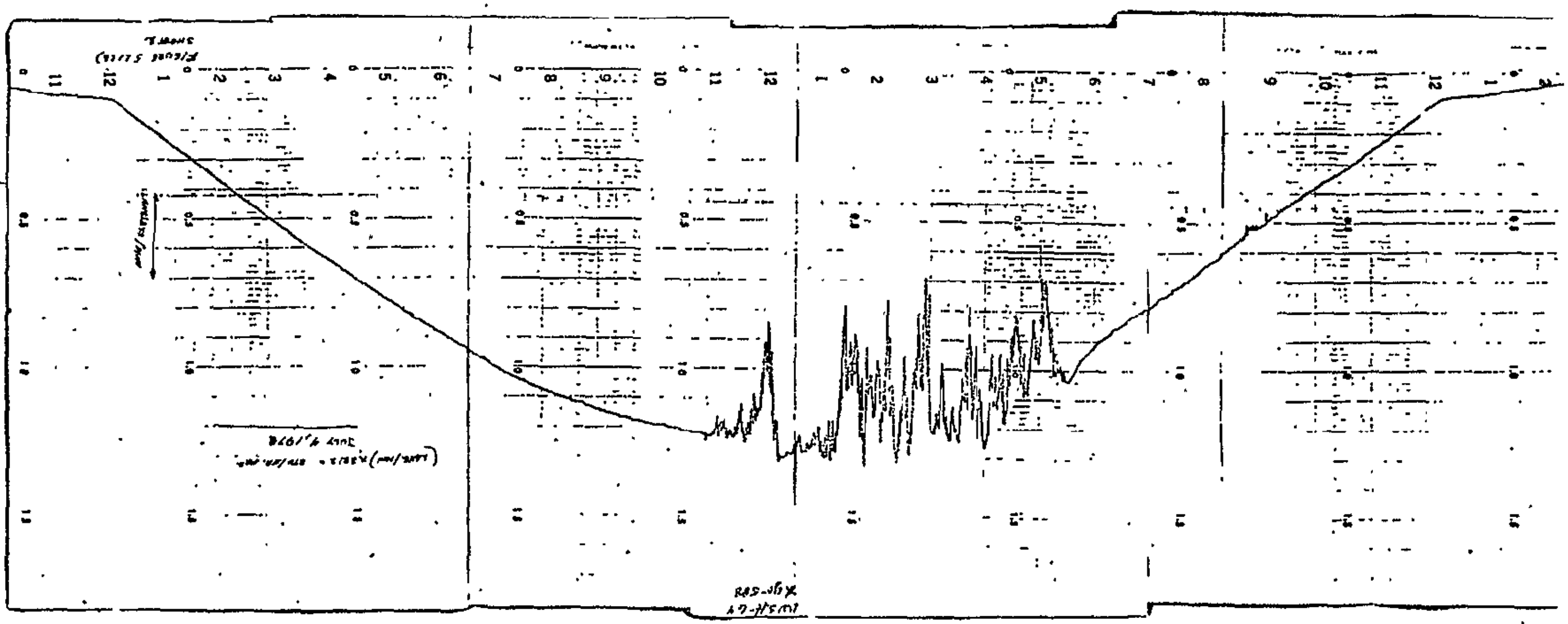
AIR TUBE STAGNATION

OWENS-ILLINOIS

True Solar Time	Ch. 24 0 °F Tube #1	Ch. 25 0 °F Tube #3	Ch. 21 Ambient Air 0 °F.
July 4, 1978			
8:29:01	469.8	460.3	88.8
9:00:07	504.5	495.2	91.1
9:28:37	524.3	515.7	93.3
10:00:00	538.2	530.9	94.0
10:30:00	544.5	538.8	94.2
10:59:52	548.6	545.7	94.8
11:30:00	555.6	553.8	98.0
12:00:00	557.9	555.8	97.6
12:30:00	558.8	558.7	98.8
13:03:54	556.1	556.2	96.9
13:28:57	557.1	556.8	98.9
14:00:34	559.7	559.4	98.7
14:35:33	550.4	548.5	99.4
14:59:15	547.2	546.4	100.4
15:30:34	540.4	539.9	100.0
16:02:42	526.9	526.8	98.4
16:28:00	508.8	517.6	100.4
17:00:00	411.2	458.3	98.3
17:30:00	372.2	408.9	98.9
18:00:00	379.5	403.2	97.1
18:30:00	376.4	383.4	94.9
19:00:00	340.4	330.9	92.2
19:30:00	286.9	277.9	90.3
20:00:00	246.5	238.3	88.1
20:30:00	215.6	208.0	85.9
21:00:00	191.4	184.3	82.9
21:30:00	171.7	165.1	81.2
22:00:00	155.6	149.6	78.8
22:30:00	142.1	136.6	77.7
23:00:00	131.0	125.8	77.3
23:30:00	121.6	117.0	75.3

FIGURE 5.1.1(b)

SHEET 1



COMPANY OWENS-ILLINOIS
P.O. M98-4442 dtd 7/19/76 PO 99-15423
OUR ORDER 16605S

INSPECTION REPORT

	PANEL NUMBER	GENERAL APPEARANCE	COLOR	GLOSS	DIRT RETENTION	CHALK	CHECK-CRAZE	CRACK	BLISTER	FLAKE	FIBER SHOW	DELAMINATION				REMARKS
1	1		10			10	10	10	10	10						Manifold with mounting bracket
2	2		10			10	10	10	10	10						Foam end cap
3	3		10			10	10	10	10	10						Joint covers
4	4		10			10	10	10	10	10						End bracket sections
5	5		10			10	10	10	10	10						Support straps
6	6		10			10	10	10	10	10						Original tube support cup, insert,
7																soft ring
8	7		10			10	10	10	10	10						Heavier support cup, insert, positive
9																restraint bolt
10	8		10			10	10	10	10	10						Heavy support cup, insert, stiff spring
11	9		10			NA	10	10	10	10				←		Tube, standard prod/flashed getter
12	10		10			NA	10	10	10	10						Tube, std. prod/old bake-out
13	11		10			NA	10	10	10	10						Tube, std. prod/new bake-out
14	12		10			NA	10	10	10	10						Tube, Airco coating/flashed getter
15																
16																
17																
18																
19																
20																
21																
22																
23																
24																

ORIGINAL PAGE IS OF POOR QUALITY

GENERAL REMARKS

TYPE EXPOSURE 45° south direct
EXPOSURE DATE: From: 8/10/76 To: 8/31/76
INSPECTED BY: Bill Dokos Date: 8/31/76

FIGURE 5.13

TABLE V

ORIGINAL PAGE IS OF POOR QUALITY

NUMBER AND DESCRIPTIVE RATINGS FOR WEATHERING TESTS

	FSPT		Other	
Number	Appearance	Failure (check, chalk, etc.)	Appearance	Failure (check, chalk, etc.)
10	as received	absent	as received	none
9			excellent	very slight
8	good	slight failure	good	slight
7			good to fair	slight to considerable
6			fair	considerable (marked)
5	intermediate	intermediate	fair to poor	considerable to severe (marked to very marked)
4			poor	severe (very marked)
3			poor to very poor	severe to very severe
2	poor	bad failure	very poor	almost complete
1			extremely poor	complete
0	poorest degree conceivable	complete failure		

Numerical readings of gloss will be made with the Gardner "Multiangle" Glossmeter.
Please specify:

(1) Angle
(2) Area of panel to be cleaned
(3) Manner in which panel is to be cleaned

DESERT SUNSHINE EXPOSURE TESTS, INC. - Phoenix, Arizona

FIGURE 5.1.3(b)

DESERT SUNSHINE EXPOSURE TESTS, INC.
BOX 185
BLACK CANYON STAGE
PHOENIX, ARIZONA 85020

COMPANY Owens Illinois
YOUR REF. Ref. M98-4442 PO 99-15423
DSET ORDER NO. 16605S Page 1 of 1

INSPECTION REPORT

	PANEL NUMBER	GENERAL APPEARANCE	COLOR	GLOSS	DIRT RETENTION	CHALK	CHECK-CRAZE	CRACK	BLISTER	FLAKE	FIBER SHOW	DELAMINATION					REMARKS
1	1		10			6	10	10	10								
2	2		10			8	10	10	10								
3	3		10			8	10	10	10								Adhesive retaining dirt
4	4		10			8	10	10	10								Rust developing along edges
5	5		10			10	10	10	10								Rust developing at ends
6	6		10			10	10	10	10								
7	7		8			8	7	9	6								Top cap has portion that has melted and left a hole.
8	8		10			10	10	10	10								
9	9		10			NA	10	10	10								
10	10		10			NA	10	10	10								
11	11		10			NA	10	10	10								
12	12		10			NA	10	10	10								
13																	
14																	
15																	
16																	
17																	
18																	
19																	
20																	
21																	
22																	
23																	
24																	
25																	

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GENERAL REMARKS Stagnation rack is readjusted once a month so the collector is normal incidence to the sun.

TYPE EXPOSURE 14° South direct - stagnation
EXPOSURE DATE: From 8/10/76 To 6/27/78
INSPECTED BY Herb Albert Date 6/27/78

FIGURE 5.1.3(c)

DESERT SUNSHINE EXPOSURE TESTS, INC.

BOX 185
BLACK CANYON STAGE
PHOENIX, ARIZONA 85020

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INSPECTION REPORT

COMPANY Owens Illinois
YOUR REF. Ref. M99-2952 PO 98-1101
DSET ORDER NO. 19174SA Page 1 of 1

	PANEL NUMBER	GENERAL APPEARANCE	COLOR	GLOSS	DIRT RETENTION	CHALK	CHECK-CRAZE	CRACK	BLISTER	FLAKE	FIBER SHOW	DELAMINATION					REMARKS
1	1		10			10	10	10	10								"O" Ring MS 1024
2	2		10			10	10	10	10								Seal Retainer MS 1021
3	3		10			10	10	10	10								Retainer - tube MS 1022
4	4		10			10	10	10	10								Cushion MS 1013
5	5		10			10	10	10	10								Support - outboard
6	6		10			10	10	10	10								Insulation - bottom MS 1027
7	7		10			10	10	10	10								Spacer Cup MS 1020
8	8		10			10	10	10	10								Retainer Cup
9	9		10			10	10	10	10								3/32" Alum. "Pop" Rivet
10	10		10			10	10	10	10								Red Silicone adhesive
11																	
12																	
13																	
14																	
15																	
16																	
17																	
18																	
19																	
20																	
21																	
22																	
23																	
24																	
25																	

GENERAL REMARKS Stagnation rack is readjusted once a month so the collector is normal incidence to the sun.

TYPE EXPOSURE Initial Inspection prior to Mounting
EXPOSURE DATE: From 5/19/78 To 5/19/78
INSPECTED BY Herb Albert Date 5/19/78

FIGURE 5.1.3(d)

5.1.4 Dirt Retention on Cover Plate Surface.

All tubes used in the ERDA air collector were rated by sun testing on November 1, 1976. The procedure used was the placement of sets of twenty two (22) tubes in a rack tilted at 45° from the horizontal. A white backing screen was provided consisting of outdoor marine plywood painted with flat white Dutch Boy paint. The rack was periodically relocated to face the sun. The test period was determined by the indicated temperatures reaching steady state. The tubes were retested on July 14, 1977 and again on March 28, 1978. A sample of the test data is in Figure 5.1.4(a). The tubes were washed only by the natural conditions of rain or melting snow over the seventeen (17) month test period. There is no significant deterioration in thermal performance due to dirt retention on the cover tube surface.

5.1.5 Abrasive Wear.

KG-33 borosilicate glass has the highest rating for the lasting quality of its surface of the commonly available glass compositions as indicated by the data of Figure 5.1.5(a).

5.1.6 Fluttering By Wind.

The only component of the Model SEC-601 collector subject to flutter induced vibration due to wind action is the collector tube element. Such vibrations are caused by vortices leaving the down stream side of the tube; this phenomena is known as Von Kármán vortex sheets. Figure 5.1.6(a) contains a discussion and a graph bearing on the subject. The information is taken from "Boundry Layer Theory," by Herman Schlichtrig, translated by Dr. J. Keston, Fourth Edition, McGraw Hill.

Figure 5.1.6(b) is derived by using the graph of Figure 5.1.6(a) and calculating Reynolds' Numbers for wind velocities from 0 to 120 MPH, with D = 53mm (.1739 Ft.) and $V = .180 \times 10^{-3}$ Ft.^{2}/Sec. The cross hatch area near the origin in Figure 5.1.6(b) shows the wind speed range in which regular vortex sheets are formed. Above this small wind speed regio[n] the wake is turbulent and regular vortex sheets are not formed; that is, no real flutter frequency is established. Also shown in Figure 5.1.6(b) is the location of the two resonant frequencies of the absorber tube measured by a scan of 0 to 300 Hz. on a vibration shake table. These are both far removed from the frequency range where the vortex sheets occur. The conclusion from this data is that wind induced flutter frequencies will not excite the resonant frequencies of the collector tube elements.

Review of items 5.1.4, 5.1.5 and 5.1.6 successfully completed.

Robert F. Romaker
O.I. Test Engineer

Kenneth L. Moan
P.E. (Ohio 5203)
O.I. Approval

David C. Miller, Ph.D.
SH&G Certification Officer

William C. Louie, V.P.
P.E. (Mi. 11084)
SH&G Certification Officer

John M. Caudle
Technical Manager
NASA Approval

OUTDOOR STAGNATION TESTS

TUBE No.	DATE 11/1/76	7/14/77	3/20/78		TUBE No.	DATE 11/1/76	7/14/77	3/20/78
(I_{TP})	275	270	280	BTU/FT.^{2} HR.		275	270	280
	TUBE DATA = STAGNATION TEMPERATURE °F							
111	513	508	502		128	507	570	502
112	490	526	520		129	537	560	530
113	523	530	515		132	558	575	550
114	530	525	525		136	558	565	540
117	515	518	510		137	554	560	542
118	556	570	545		139	575	560	560
119	508	516	505		140	553	560	555
120	515	518	505		143	570	535	560
122	515	518	502		147	548	560	530
123	550	556	545					
124	556	568	535					
126	536	545	535					
127	554	565	532					
			AVERAGE VALUE			537	546	529

FIGURE 5.1.4(a)

Chemical Durability is the lasting quality of a glass surface. It is frequently evaluated, after prolonged weathering or storing, in terms of chemical and physical changes in the glass surface or in terms of changes in the contents of a glass vessel. The glass which is best suited chemically in one situation is often inferior in another. This information book covers glassware intended for many different uses. For many of these, special tests or prolonged observation in service are required to establish excellence. Great differences exist in the chemical properties of glasses customarily used for these different purposes. The result obtained in an arbitrary test should therefore be interpreted with caution.

In this information book, typical values are given for several crushed-sample tests in order to indicate chemical durability broadly. A glass is handled in a specified manner to yield 10 g. of crushed grains that pass a No. 40 sieve and are retained by a No. 50. In ASTM Test P-W (ASTM Designation C225), this glass is exposed to the action of specially purified water at 121°C. for 30 minutes after which the alkaline material extracted is determined by titration. The result is expressed as "ml. 0.02 N H_2SO_4" (ml. N/50 H_2SO_4) used in the titration. This procedure is designated as the Powdered Glass Test by the United States Pharmacopeia (USP XVII, pp. 900-901) where it is the basis of the following container specifications.

Type	General Description	Limits
I	Highly resistant, borosilicate glass	1.0
III	Soda-lime glass	8.5
NP	General-purpose soda-lime glass	15.0

FIGURE 5.1.5(a)

G-1

The frequency with which vortices are shed in a Kármán vortex street behind a circular cylinder was first extensively measured by H. Blenk, D. Fuchs and L. Liebers [2]. A regular Kármán street is observed only in the range of Reynolds numbers VD/ν from about 60 to 5000. At lower Reynolds numbers the wake is laminar and has the form visible in the first two photographs of Fig. 1.6; at higher Reynolds numbers there is complete turbulent mixing. Measurements show that in the regular range given above, the dimensionless frequency,

$$\frac{nD}{V} = \mathsf{S}\,, \quad \text{(Strouhal number)}$$

also known as the Strouhal number [20], depends uniquely on the Reynolds number. This relationship is shown plotted in Fig. 2.9 which is based on the more recent measurements performed by A. Roshko [16]. The experimental points which were obtained with cylinders of different diameters D and at different velocities V arrange themselves well on a single curve. At the higher Reynolds numbers the Strouhal number remains approximately constant at $\mathsf{S} = 0{\cdot}21$. When the diameters of the cylinders are small and the velocities are moderate, the resulting frequencies lie in the acoustic range. For example, the familiar "aeolian tones" emitted by telegraph wires are the result of these phenomena. At a velocity of $V = 10$ m/sec (30·48 ft/sec) and a wire of 2 mm (0·079 in) in diameter, the frequency becomes $n = 0{\cdot}21\ (10/0{\cdot}002) = 1050\ \text{sec}^{-1}$, and the corresponding Reynolds number $\mathsf{R} \approx 1200$.

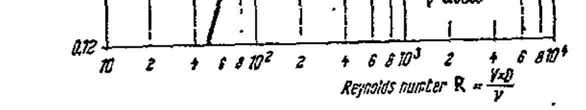

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FIGURE 5.1.6(a)

GRAPH PAPER GRAPHIC CONTROLS CORPORATION Buffalo New York
Printed in U.S.A.
SQUARE 10 X 10 TO THE CENTIMETER AS-8014-07

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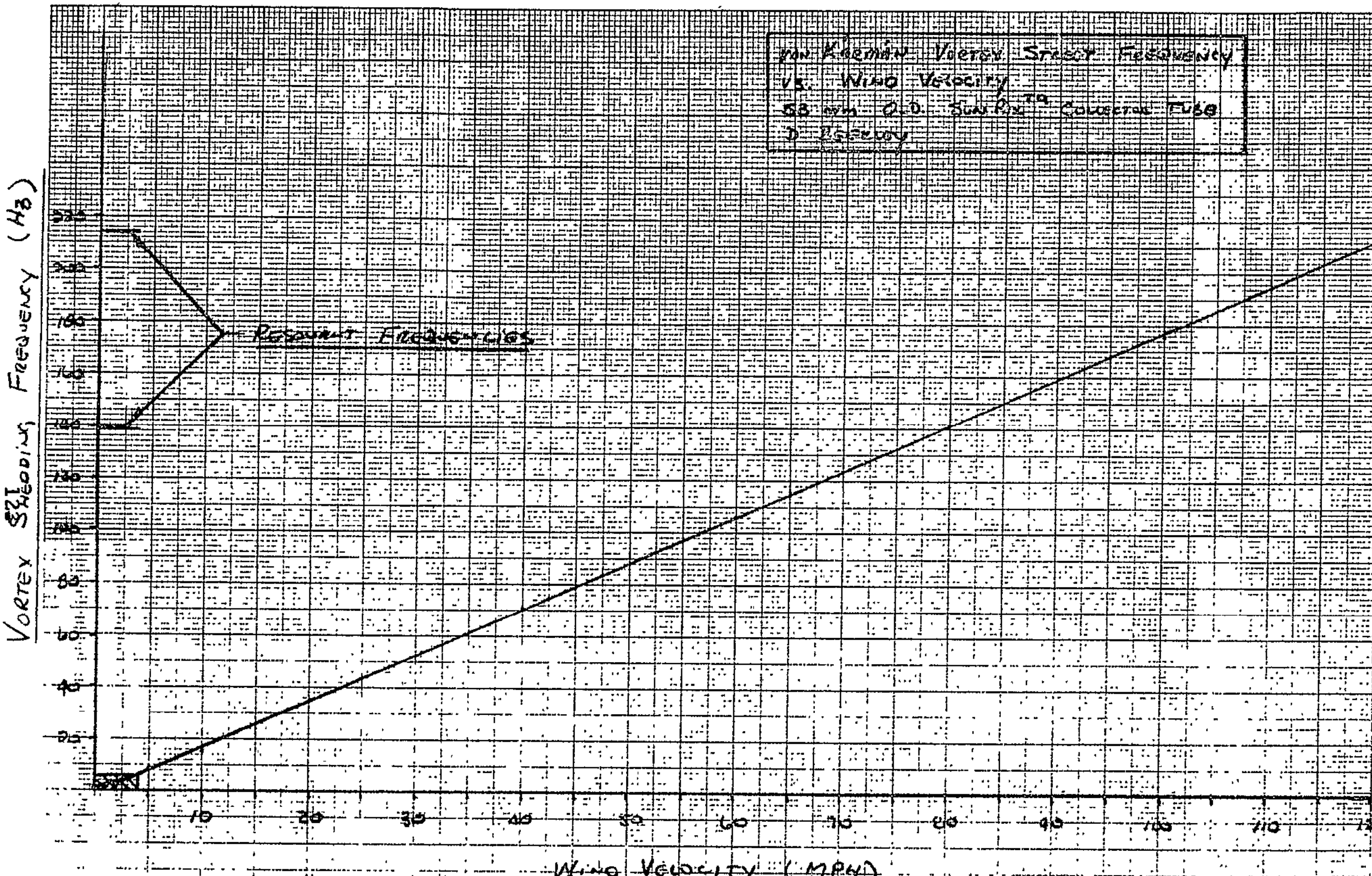

FIGURE 5.1.6 (b)

5.2 Temperature and Pressure Resistance.

5.2.4 Leakage. A thermal cycle test loop was built containing the elements indicated schematically in Figure 5.2.4(a). Ambient air is increased in pressure by the air fan. An electric heating element increases the air temperature to a preselected level. The high temperature air is introduced into the normally exit air duct. The air flows through the ducting internal to the manifold and the tube elements and out the normally inlet air duct. The reverse air flow path is used to simulate the temperature gain of the air as would exist under normal operating conditions. The air flow rate is monitored by the inclinometer which measures the pressure drop of the collector due to air flow. The flow rate used was in the range of that expected under normal operating conditions; viz. a flow rate which causes approximately 0.3 inches w.g. pressure drop.

Temperatures were monitored on a strip chart recorder with the sensors located as indicated in Figure 5.2.4(b). The three hour cycle to temperature and return to essentially ambient conditions as shown in Figure 5.2.4(c) was selected to allow a reasonable total elapsed time for the cycle testing and still allow all temperatures to reach essentially steady state conditions. After the accumulation of a selected number of cycles, the air supply was disconnected and the inlet and exit ducts taped closed. One tube was removed allowing the direct connection of a pressurized air supply to the air manifold. A rubber stopper, with two access holes was inserted into the manifold well in place of the tube and silicone seal. The second access hole was connected to an inclinometer of 5 inches w.g. total range for an accurate measurement of pressure. A precision air flow meter was used to measure the volume of leakage air flow.

The regulated air supply provided a precise control of manifold pressure from 0 to 5 inches w.g. The manifold pressure was set and allowed to stabilize. The volume of air flow required to maintain the selected manifold pressure is a measure of the leakage flow rate of the collector. Since time was required to make the change over, leakage air flow at the maximum temperature condition could not be accomplished. Therefore, a qualitative indication of leakage flow at maximum temperature was obtained by simply taping shut the exit flow duct. A smoke bomb was fired and the smoke ingested into the inlet to the fan. At no time could any evidence of leakage as indicated by a smoke pattern be detected.

The measured leakage flow rate after the accumulation of various numbers of thermal cycles is indicated in Figure 5.2.4(d). It will be noted that the high temperature condition was approached in steps as a precautionary measure. The principal features of the data are first the very low leakage flow rate measured at the order of 0.1% of operating flow and second the lack of any trend towards an increase in leakage flow rate. The scatter in the data indicates that the tightness with which the flow ducts were enclosed and with which the pressure source and inclinometer were attached to the manifold caused variations in the measured value of leakage flow rate as large as the leakage volume flow itself. Note that leakage flow was measured up to 5 inches w.g. which is a factor of 10 or more higher than the collector pressure drop itself.

Upon physical examination there was no sign of creep or embrittlement of the silicone seals.

5.2.5 Deterioration of Gaskets and Sealants.

The tests conducted and described in Section 5.2.4 are evidence of the capability of the gaskets and sealants to withstand operating service conditions. It is felt that the very low leakage evidenced at high temperature (smoke bomb tests) and near ambient conditions (direct leakage flow measurement) represent more demanding requirements than those of the approved Acceptance Test Procedure. The capability of the materials to operate satisfactorily after exposure to extreme cold conditions was evidenced during the extreme weather conditions of the Toledo winters of 1977 and 1978. Examination of the gaskets and sealants used in the ERDA collector array upon disassembly of a manifold after removal in March 1978 show no signs of creep, embrittlement, cracking or other deterioration. Testing of the assembled array just prior to removal from the roof showed no signs of loss of ability to perform the intended functions.

5.2.6 Transmission Losses Due to Outgasing.

This section is not applicable to the Model SEC-601 collector tube elements since the transmission path is a hard vacuum totally enclosed in hermetically sealed glass. However, this section is applicable in intent since a loss of vacuum due to outgasing of the glass and/or selective surface or a deterioration of the selective surface due to long term exposure to the high temperatures which can obtain under no flow conditions can cause a deterioration in performance.

To accumulate evidence that the collector tube elements have the requisite long term stability under exposure to normal operating conditions, all of the tube elements of the ERDA air collector were ranked by a standard outdoor sunshine test. The tube elements were tested first on 10/30 to 11/1, 1976. They were retested on 7/13/77 and a sample lot retested 3/20/78. The cover tubes were not cleaned at any time during the entire test period except by the natural processes of rain and melting snow. The level of insolation in the tilt plane of the outdoor test rack was noted for each day of test at the time the stagnation temperatures were measured. A suitable day for the stagnation tests was determined qualitatively as relatively "cloud clear" by the test operator.

The test data is shown in Figure 5.2.6(a). The change in the average value of stagnation temperature was of the order of 1.5%, well within the possible experimental error. The tubes were subjected to no flow stagnation conditions almost every weekend and over the holiday periods from 11/15/76 to 3/17/88, a period of 17 months.

Three major installations, GSA Building, Saginaw, Michigan; Terraset School, Reston, Virginia, and the Troy Library, Troy, Ohio represent a total of 12,672 tube elements installed and operating under field service conditions. Tube elements have been replaced for apparent loss of thermal performance under the O-I warranty agreement. The reason for failure has been investigated and in all cases was attributed to loss of vacuum due to a micro crack developing in one of the glass seal areas. No failure was attributed to outgassing or coating deterioration under field operating conditions.

Review of items 5.2.4, 5.2.5 and 5.2.6 successfully completed.

Robert F. Romaker
O.I. Test Engineer

Kenneth L. Moan
P.E. (Ohio 5203)
O.I. Approval

David C. Miller, Ph.D.
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SH&G Certification

John M. Caudle
Technical Manager
NASA Approval

THERMAL CYCLE AND LEAKAGE TEST SCHEMATIC

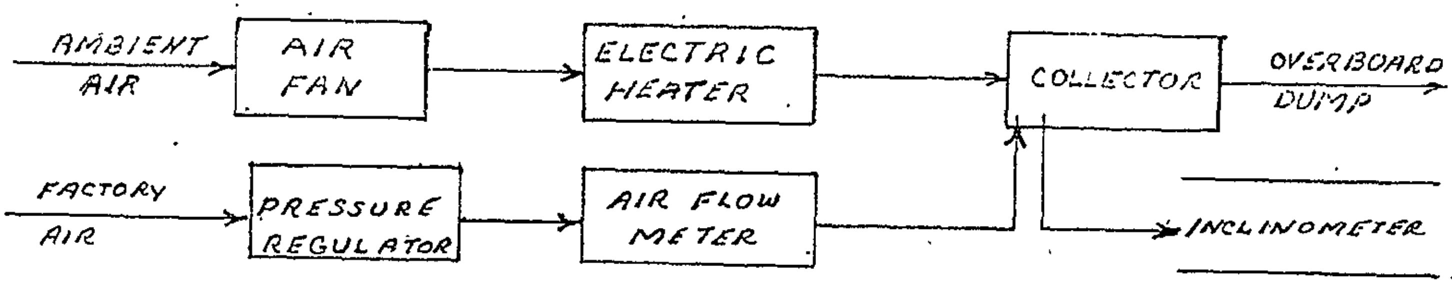

FIGURE 5.2.4(a)

COLLECTOR AIR AND SURFACE TEMPERATURE
SENSOR LOCATIONS

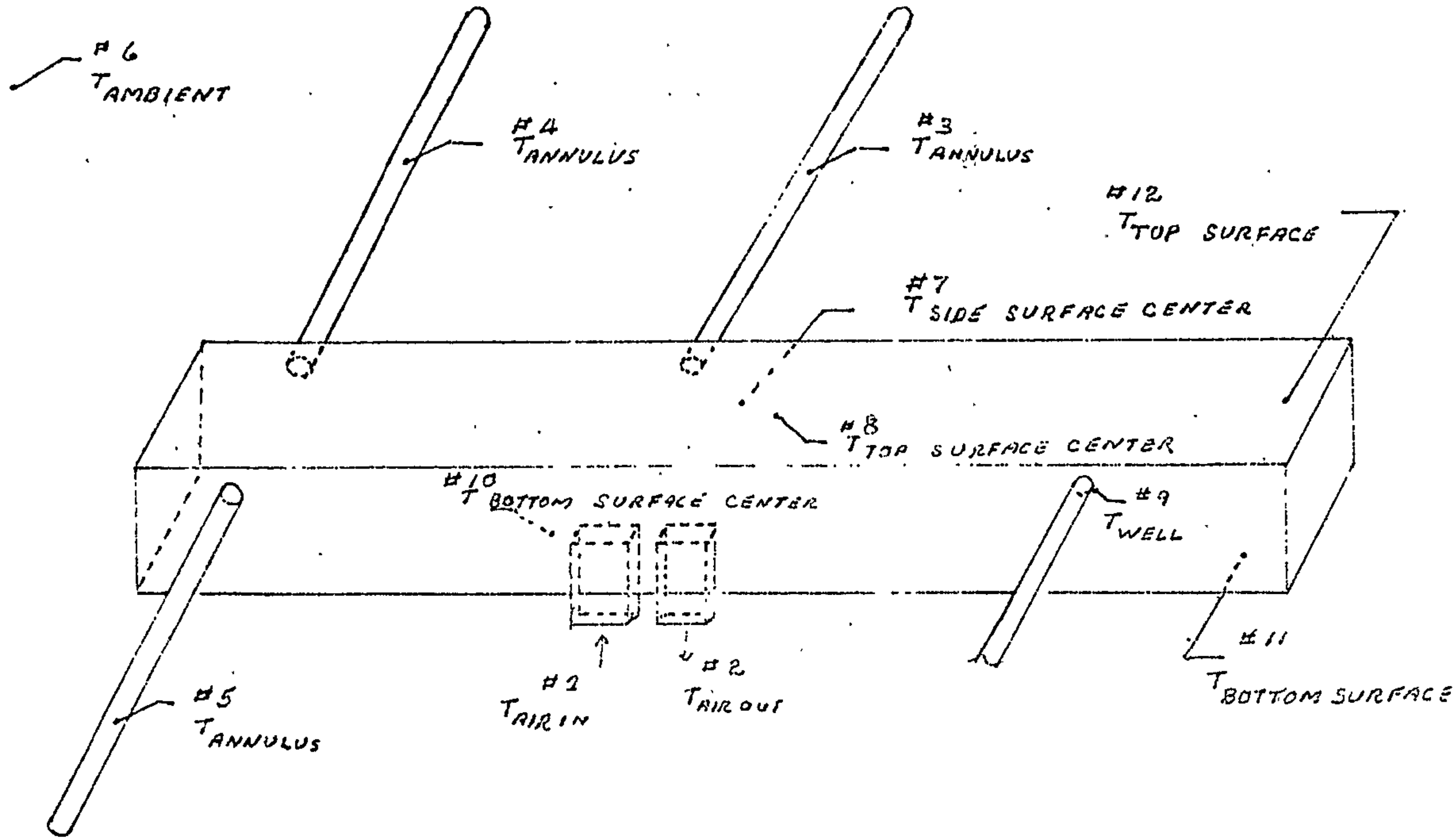

FIGURE 5.2.4(b)

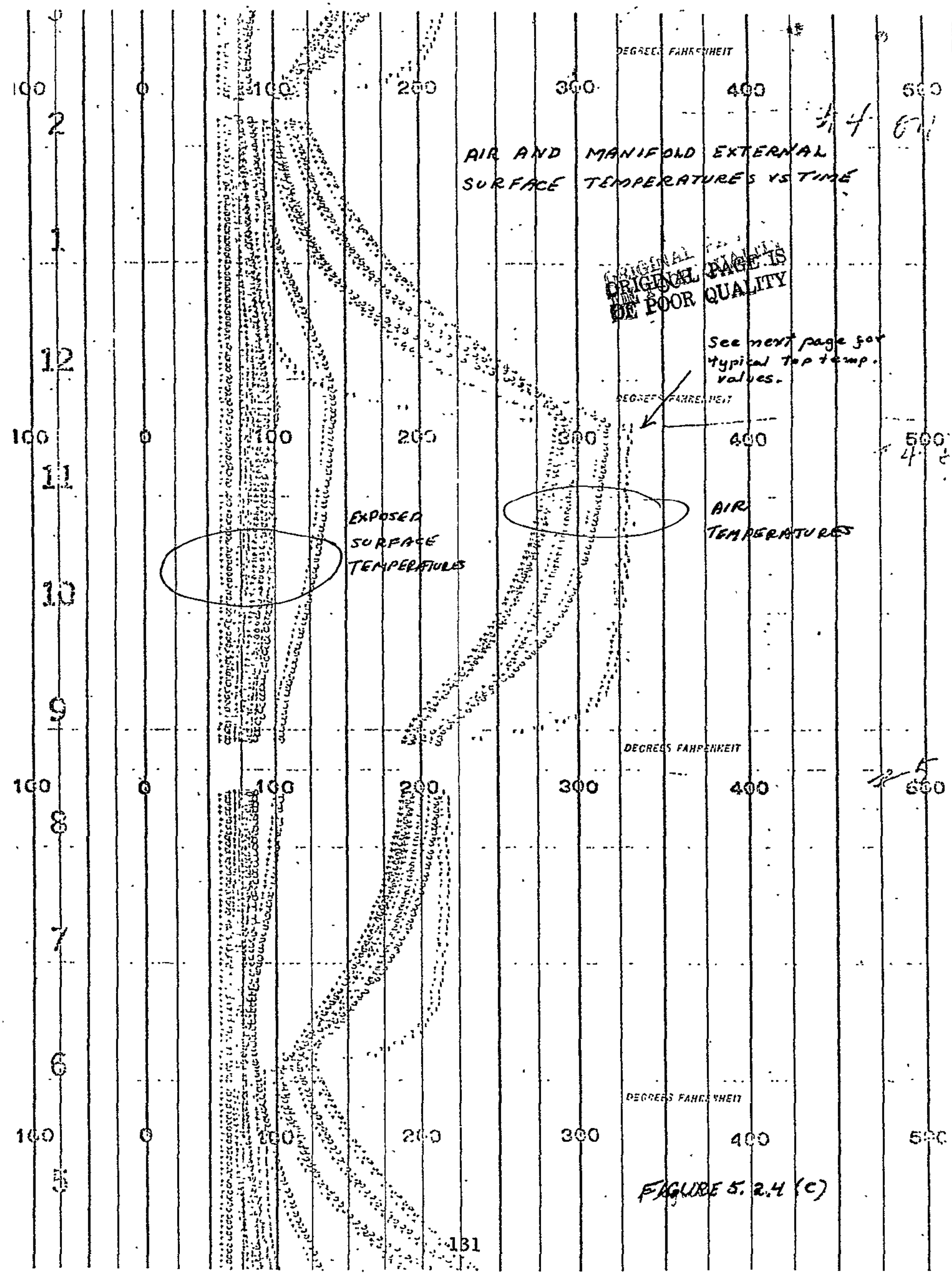

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FIGURE 5.2.4 (c)

Project 8721.003 Date MARCH 2 1978 129

Description NASA 32259 AIR LIQUID SYSTEM

1 CYCLE TO 300°F

MANIFOLD & TUBE TEMP.

TC	TEMP.	LOCATION
1	318°F	hot air inlet
2	305	" " outlet
3	322	tube annulus top center
4	302	" " " end.
5	302	" " bot. "
6	70	ambient, near recorder
7	95	man. surface, side near center
8	92	" " top " "
9	135	tube well betw. glass & silicone gasket
10	97	man. surface, bottom near center
11	82	" " " " end
12	85	" " top " "

3-3-78

LEAKAGE TEST
1 CYCLE TO 300°F

MANIFOLD PRESS.	SCALE AIR FLOW		CC/MIN	FT³/MIN
1.0" WC		11.5	4700	0.164
2.0	"	16.5	7300	0.258
3.0	"	20.5	9300	0.328
4.0	"	23.3	10900	0.385

3-6-78

2 CYCLES TO 300°F

3-7-78

2 CYCLES TO 300°F
LEAKAGE TEST USING SMOKE CANDLES
UNABLE TO DETECT ANY SMOKE LEAKAGE
BY VISUAL OBSERVATION

Pages ____ to ____ have been read and understood and Witnessed by ____ Signed Robert Romaker Date ____

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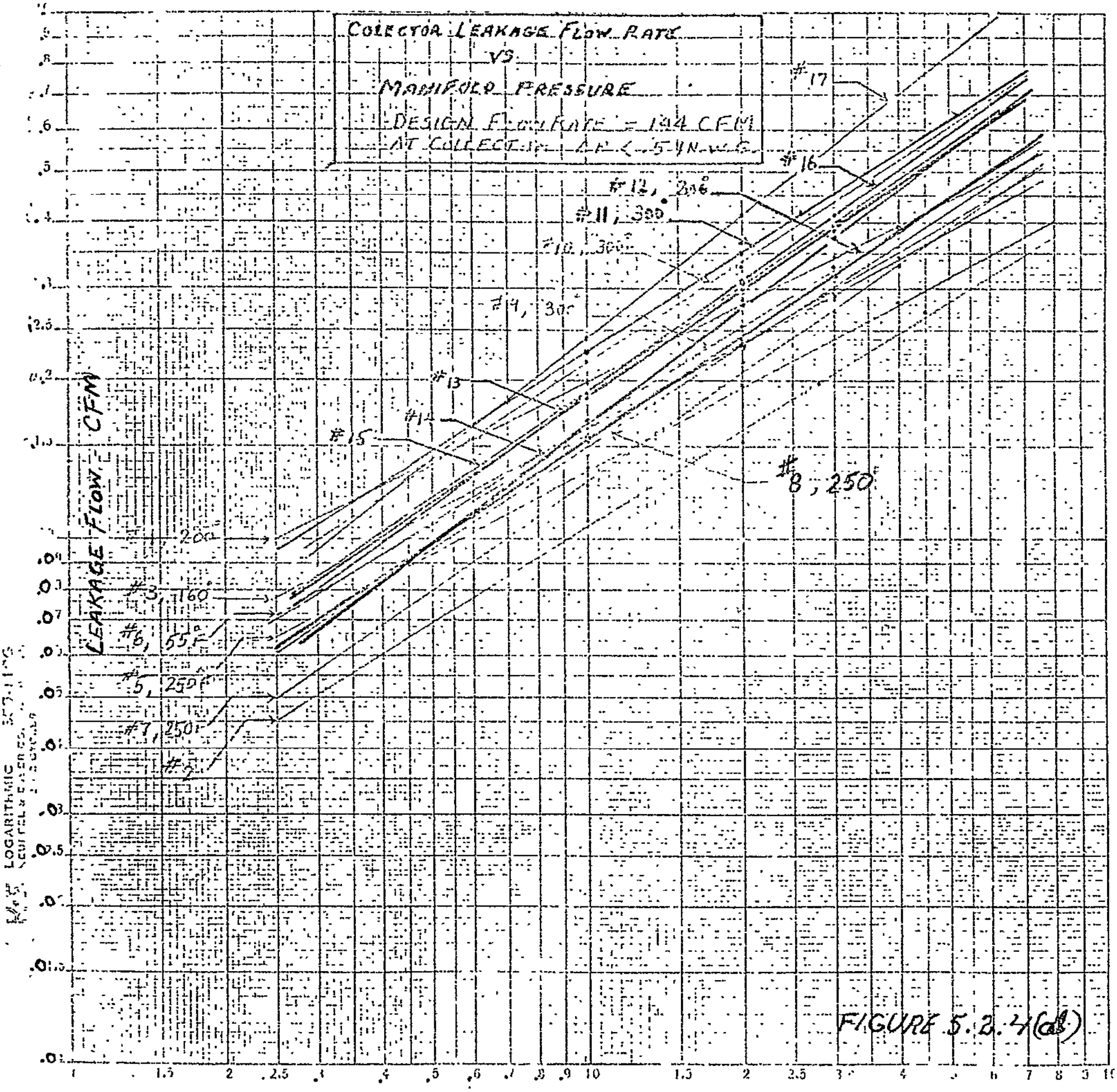

FIGURE 5.2.4(d)

MANIFOLD PRESSURE (in. of H_2O ABOVE AMBIENT)

DEFINITION OF TEST NUMBERS

#2.	FIRST CALIBRATED LEAKAGE FLOW TEST
#3	ONE CYCLE TO 160°F MAX. AIR TEMP.
#4	ONE CYCLE TO 200°F MAX. AIR TEMP.
#5	ONE CYCLE TO 250°F MAX. AIR TEMP.
#6	REPEAT AMBIENT AIR TEMP. LEAKAGE TEST
#7 + #8	REPEAT CYCLES AT 250°F MAX AIR TEMP.
#9	ONE CYCLE TO 325°F MAX. AIR TEMP.
#10	ONE CYCLE TO 325°F. MAX. AIR TEMP.
#11	TOTAL 11 CYCLES
#12	TOTAL 16 CYCLES.
#13	TOTAL 27 CYCLES
#14	TOTAL 43 CYCLES
#15	TOTAL 51 CYCLES
#16	TOTAL 70 CYCLES
#17	TOTAL 101 CYCLES

OUTDOOR STAGNATION TESTS

TUBE No.	DATE 11/1/76	7/14/77	3/20/78
(I_{TP})	275	270	280
111	513	508	502
112	490	526	520
113	523	530	515
114	530	525	525
117	515	518	510
118	556	570	545
119	508	516	505
120	515	518	505
122	515	518	502
123	550	556	545
124	556	568	535
126	536	545	535
127	554	565	532

(I_{TP} in BTU/FT.^{2} HR.)

TUBE DATA = STAGNATION TEMPERATURE °F

TUBE No.	DATE 11/1/76	7/14/77	3/20/78
(I_{TP})	275	270	280
128	507	570	502
129	537	560	530
132	558	575	550
136	558	565	540
137	554	560	542
139	575	560	560
140	553	560	555
143	570	535	560
147	548	560	530

AVERAGE VALUE 537 546 529

FIGURE 5.2.6 (a)

OWENS-ILLINOIS
Toledo Ohio
Solar Energy Products Group

December 12, 1977

Intra-Company

to G. R. Mather - Dev. Ctr.

subject

VACUUM LOSS IN SUNPAK(TM) TUBES AT GSA BUILDING, SAGINAW, MICHIGAN, 11/30/77

Seven tubes returned from the subject installation by Mr. E. G. J. LaBonte were examined to determine the cause of suspected vacuum degradation. The tubes had been selected out because they were warm to the touch.

A summary of the analysis is given in Table 1. Five of the seven tubes had a capillary channel in the tip-off. One tube had a pinhole in the tipoff tubulation seal to the cover tube. One tube had a crack in the cover tube due to external damage.

The above described tubes represent seven out of 1200 tubes in the first row or 0.58%.

Louis Spanoudis

LS/gs

Table 1.

Analysis of Sunpak(TM) Tubes With Suspected Poor Vacuum; Saginaw GSA Building; 11/30/77

Batch Number	Analysis
A-197	Tip Off Capillary
A-206	Tip Off Capillary
A-282	Tip Off Capillary
A-134	Tip Off Capillary
A-132	Tip Off Capillary
A-206	Pinhole in Tubulation--Cover Tube Seal
A-730	Crack Due to External Cover Tube Damage.

5.3 Chemical Compatibility of Components.

The design and material specifications for the ERDA and the Model SEC-601 collectors were reviewed and it was judged that similarity could be used for compliance to the criteria of Section 5.3. Since seventeen months of service experience has been accumulated, only data from the ERDA array will be used. One of the two ERDA manifolds was disassembled to allow complete inspection of all critical components by a representative of the certifying agency.

5.3.1 Materials/Transfer Fluid Compatibility.

No evidence of corrosion of the aluminum divider strip, the aluminum distributor tube or glass surfaces could be detected. In the Model SEC-601 collector, air flow is contained entirely within glass or aluminum materials.

5.3.2 Corrosion of Dissimilar Materials.

A review of the drawings and material specifications of the ERDA and Model SEC 601 collectors demonstrates that no non-dialectric materials are in contact one with the other within active collector flow path. The only dissimilar metals in contact with each other are 6061 Type aluminum with Type 340 stainless steel in the support structure. These are compatible materials for the application.

5.3.3 Corrosion by Leachable Substances.

Upon close inspection of the ERDA manifold, no evidence of corrosion by leachable substances occurred.

5.3.4 Effects of Decomposition Products.

A close inspection of the ERDA manifold and a review of performance data over the seventeen (17) month test period demonstrates no impairment in the ability of any of the components to perform their intended function.

Review of items 5.3, 5.3.1, 5.3.2, 5.3.3 and 5.3.4 successfully completed.

Robert F. Romaker
O.I. Test Engineer

Kenneth L. Moan
P.E. (Ohio 5203)
O.I. Approval

David C. Miller, Ph.D.
SH&G Certification Officer

William C. Louie, V.P.
P.E. (Mi. 11084)
SH&G Certification Officer

John M. Caudle
Technical Manager
NASA Approval

6.1 Accessibility for Maintenance and Servicing.

6.1.1 Access for system maintenance.

The Model SEC-601 collector subsystem has been designed for zero maintenance during its service life. However, the collector tube element could encounter service use failure due to natural causes such as unusual hail conditions or due to human factors such as vandalism or impact failure in handling. The need for replacement will be realized through visual observation of obvious glass breakage or by the detection of sub-par insulation properties of a collector tube element. The latter condition may be ascertained by physical hand contact with the glass cover tube and a sense of its being above ambient temperature; a lack of frost covering on the glass surface where most other tube covers are frosted; or by sophisticated techniques such as the use of infra red radiation detectors.

All of the collector elements required for the removal and replacement of a collector tube are easily accessible from above the plane of the collector. The system's designer/installer must ensure that suitable space is available for the mounting of a temporary support which can accommodate a workman for the removal and replacement activity. It is recommended that any collector tube replacement be accomplished in the early morning or late afternoon hours. If only a minor replacement effort (perhaps 10% of the tubes in a module or less) is required, no problem is introduced by collector tube change at any time of the day. Two precautions should be observed. First, the center air distributor tube could be very hot and could burn the skin if touched shortly after removal of the collector tube. Second, if the control thermocouples are in the annulus of the collector tube element being removed, an overtemperature condition could develop after the collector tube is replaced and prior to the time system activation is attempted. Proper control system functioning would prevent system start-up.

6.1.2 Access for system monitoring.

Thermocouples (two-copper-constanton, Type T) are provided to indicate the temperature of the air in the annulus of a collector tube element. These couples are intended for use in the control of the solar energy system. The collector inlet and exit air temperatures and air mass flow measurements are required to monitor the collector thermal performance. It is recommended that six element thermopiles be mounted in the transition ducting leading to and from the collector manifold if individual collector module monitoring is desired. If monitoring of the performance of a collector array is desired, suitable temperature and air flow sensing elements will have to be located in appropriate cross sections of the system main air ducting.

6.2 <u>Installation, Operation and Maintenance Manual</u>.

6.2.1 Installation instructions.

A section of the manual deals with the installation of a Model SEC-601 air collector subsystem. No special provisions are provided for interconnections between modules. The interconnection between collector modules is to be provided as a part of the dwelling/site installation

6.2.2 Maintenance and operation instructions.

Sections of the manual deal with the operating and the maintenance instructions for the collector subsystem.

6.2.3 Maintenance plan.

No routine maintenance plan has been developed for the Model SEC-601 collector. No component or subassembly has been designed or selected on the basis of limited life short of the design life (target, 20 years) of the collector subsystem.

6.2.4 Replacement parts.

No special tools or test equipment are required for service, repair or replacement of parts or components of the Model SEC-601 collector. Service, repair or replacement parts required by unforeseen in service conditions may be ordered from the collector manufacturer: attention, Field Service Engineering, Solar Energy Products Group, 1020 N. Westwood, Toledo, Ohio, 43666, (telephone (419) 247-9705).

6.3 Repair and Service Personnel.

6.3.1 and 6.3.2 Servicing of H, HC and HW Systems.

A review of the drawings, specifications, maintenance instructions and a typical installation demonstrates that an installed Model SEC-601 collector can be conveniently and simply serviced by a trained HVAC service technician using the Installation, Operation and Maintenance Manual.

11.2 Durability and Reliability of Dwelling and Site.

11.2.1 Chemical corrosion. Satisfactory completion of Criteria 5.3.3 and 5.3.4 (Chapter Five) satisfies the criterion of this section - 11.2.1.

11.2.2 Heat and moisture.

Physical and visual inspection of a Model SEC-601 collector subsystem installed and operating demonstrates that no heat or moisture build up can or will occur by a collector installation.

11.3 Durability and reliability of connections.

11.3.1 Satisfactory completion of Criterion 5.3.2 of Chapter Five constitutes satisfactory compliance with this criterion - 11.3.1.

Review of items 11.2, 11.2.1, 11.2.2, 11.3 and 11.3.1 successfully completed.

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O.I. Test Engineer

Kenneth L. Moan
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O.I. Approval

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Review of items 6.1, 6.1.1, 6.1.2, 6.2, 6.2.1, 6.2.2, 6.2.3, 6.2.4, 6.3, 6.3.1 and 6.3.2

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