DOE/NASA TECHNICAL MEMORANDUM

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DEVELOPMENT AND TESTING OF HEAT TRANSPORT FLUIDS FOR USE IN ACTIVE SOLAR HEATING AND COOLING SYSTEMS - Final Report

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Solar Energy

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TECHNICAL MEMORANDUM

DEVELOPMENT AND TESTING OF HEAT TRANSPORT FLUIDS FOR USE IN ACTIVE SOLAR HEATING AND COOLING SYSTEMS - FINAL REPORT

SUMMARY

The intended use for this report is to provide product development information as an aid to the solar heating and cooling systems manufacturing industry in their effort to determine the products suitability for use in active solar heating and/or cooling system for residential and commercial applications.

This report will also serve as a aid to those who desire to remain abreast of the state-of-the-art of solar energy heating and cooling projects.

In November of 1976, Houston Chemical Company, a division of PPG Industries Inc., entered into a contract with the National Aeronautics and Space Administration (NASA)/Marshall Space Flight Center (MSFC) for the development, testing and delivery of non-corrosive heat transport fluids that would be compatible with both metallic and non-metallic solar collectors and plumbing systems, or combinations of them, in closed loop solar system; and also to assure that the products could be classified as marketable and suitable for public use.

The deliverable end items under this contract was to be at least 100 gallons of each type of fluid recommended by the contractor.

At contract completion (over a 31-month period) Houston Chemical identified several solar transport fluids as being acceptable but only one fluid, Zerex Antifreeze, was recommended and delivered to NASA/MSFC as an end item. Zerex Antifreeze was selected based on failure free tests and no evidence that failure would occur with continued use; also Zerex was the only solar fluid tested which can be purchased off the shelf and is readily available.

INTRODUCTION

Program Background and Goals

Prior to dealing with the specific aspects of the Houston Chemical Heat Transport Fluids, a few background statements are pertinent. The problems of energy availability and increasing costs have led to a major national effort to develop alternate energy sources. One such source is the energy in solar radiation, which can be used for heating and cooling buildings, domestic hot water, and other applications. The National Energy Policy, as established in the Solar Heating and Cooling Demonstration Act of 1974 (PL93-409), is to provide for the demonstration within a 3-year period of the practical use of solar heating technology, and demonstration within a 5-year period of the practical use of combined heating and cooling technology. Responsibility for implementing the Demonstration Act was given to the Energy Research Development Administration (now the Department of Energy). NASA/MSFC manages a large part of this work.

Purpose of This Product Development and Testing Contract

The purpose of this contract was to provide funding to Houston Chemical to construct a test stand, equip it with aluminum, copper, steel and non-metallic solar collectors, associated components and copper plumbing, circulate various types of transport fluids through the systems and demonstrate, by frequent sampling, that the fluid or fluids will provide corrosion and freeze protection to all systems components. Also, at program completion examine the collectors and system components for corrosion and be able to recommend which fluids are suitable for use as transport fluids in active solar heating and cooling systems.

Contract performance period was from November 15, 1976 through June 15, 1979.

DESCRIPTION

Project Development Requirements and Criteria

During the development of the heat transport fluid, the contractor was required to:

A) Meet the applicable parts of the interim performance criteria, as stipulated in the contract.

B) Meet the subsystem performance specifications, as stipulated in the contract.

C) Provide test data/analyses to verify that the fluid meets the subsystem performance specifications.

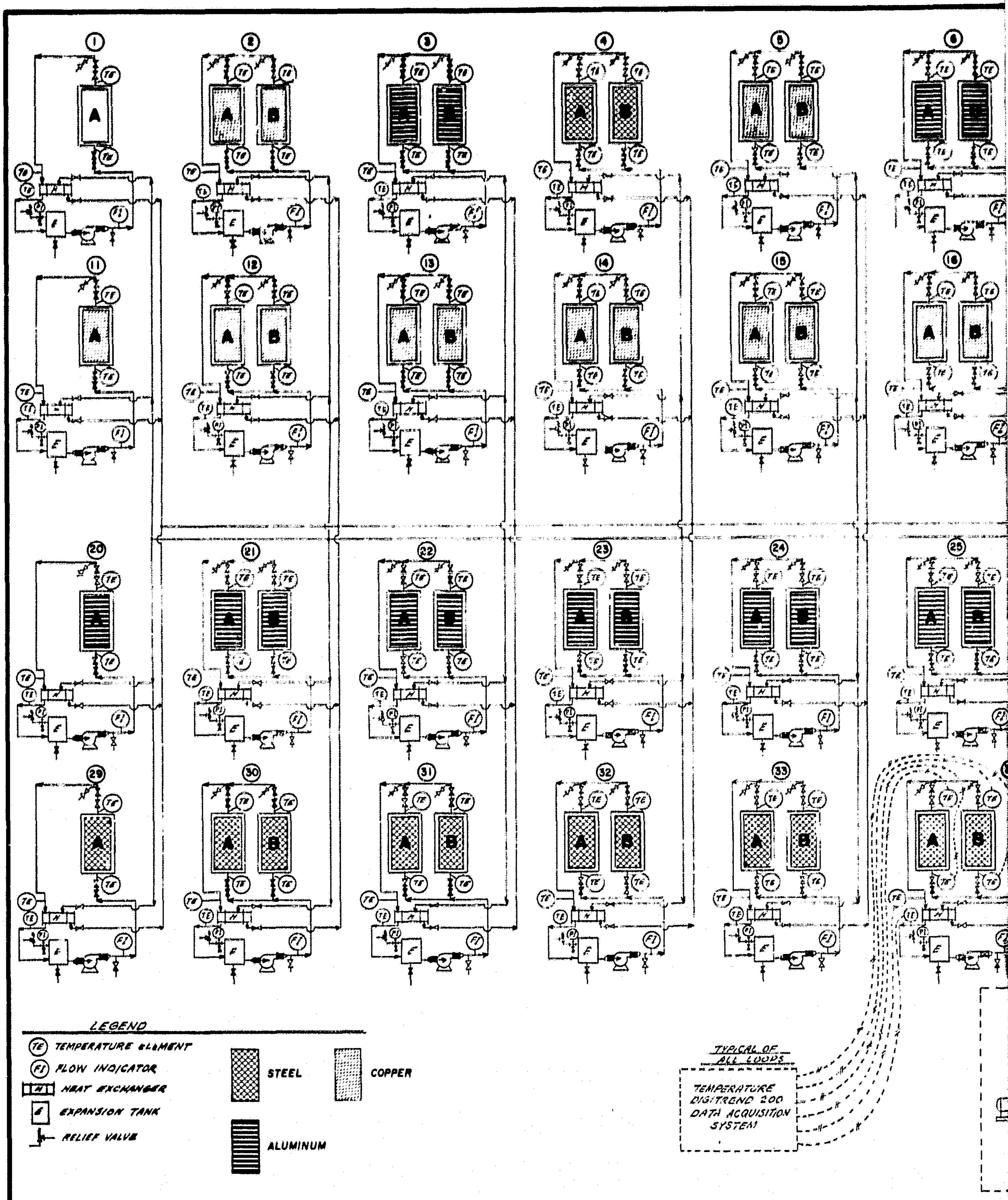
D) Provide documentation and specifications in sufficient detail to define the fluid and to ensure formulation repeatability.

E) Provide, if reasonably available, subsystem certification by independent test laboratory (such as Underwriters Laboratory and American Gas Association) to meet nationally recognized standards and codes (such as American Society of Heating, Refrigeration and Air Conditioning Engineers; American Society of Mechanical Engineers; American National Standards Institute and American Refrigeration Institute).

THE SOLAR TEST STAND AND OPERATION [1] [2]

The test stand structure was designed to the proper angle (25°) to maximize efficiency of the solar collector panels at a southern exposure. The location of the collector panels on the test stand allowed space for adequate accessibility for inspection, removal, and evaluation purposes. The structure was designed to carry the dead equipment load, live loads, and Gulf Coast wind loads. The structure framing was constructed of Wolmanized-treated lumber and the plywood deck was covered with asphalt shingles which also furnished skid protection. A layout of the solar collector panels and plumbing schematic is enclosed as Figure 1 and Figure 2.

The operation of the solar test stand was initiated on June 15, 1977, and its operation was monitored on a 24-hour basis. The operation of the solar stand was discontinued as of February 26, 1979, except for the non-metallic collector which was shut down on May 22, 1979. The final samples of the solar fluids were taken and were analyzed for pH, reserve alkalinity, appearance, ash content, foaming, and viscosity. The metallic solar collectors were tested for more than 20 months and the non-metallic collector for over 13 months.



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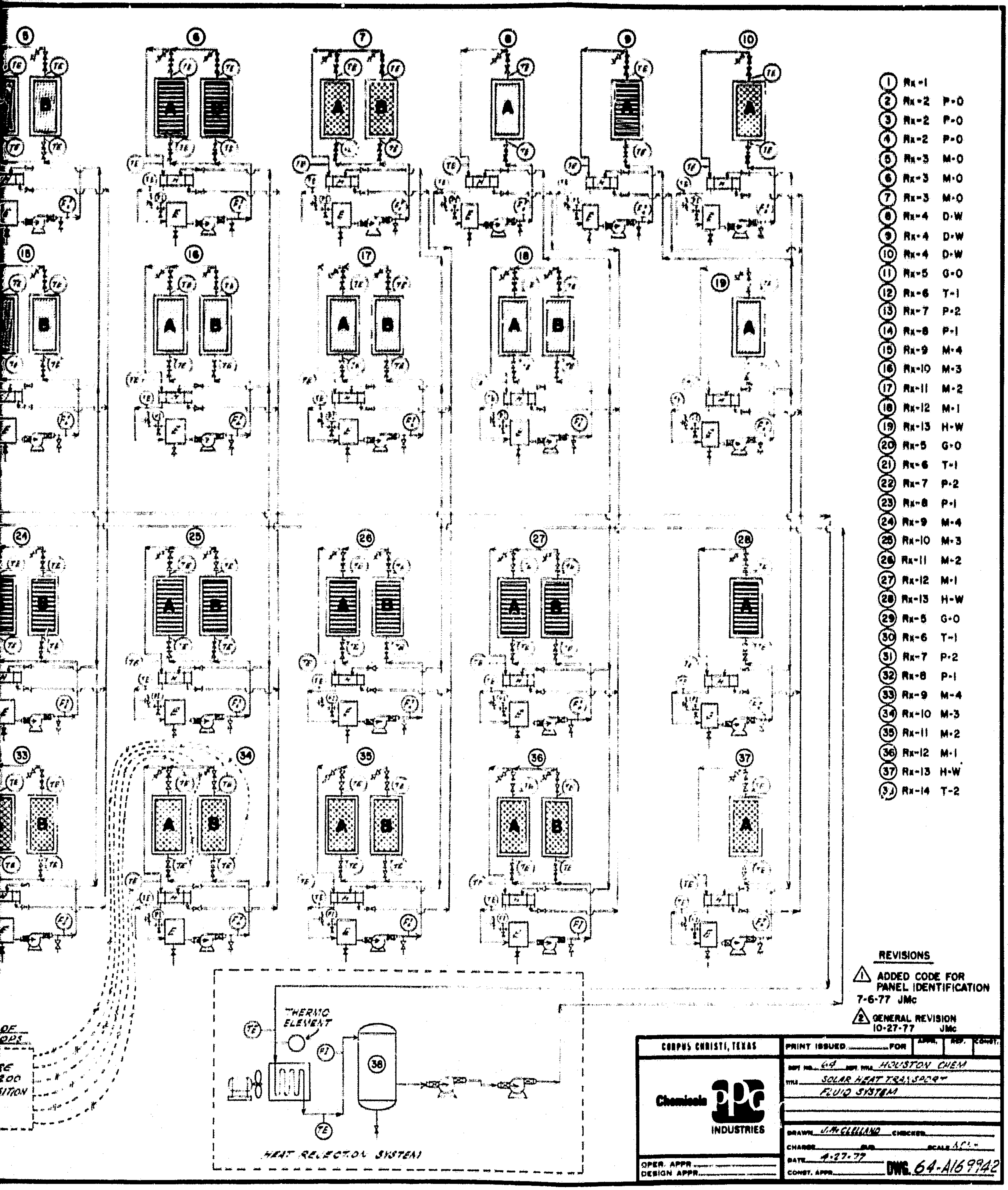

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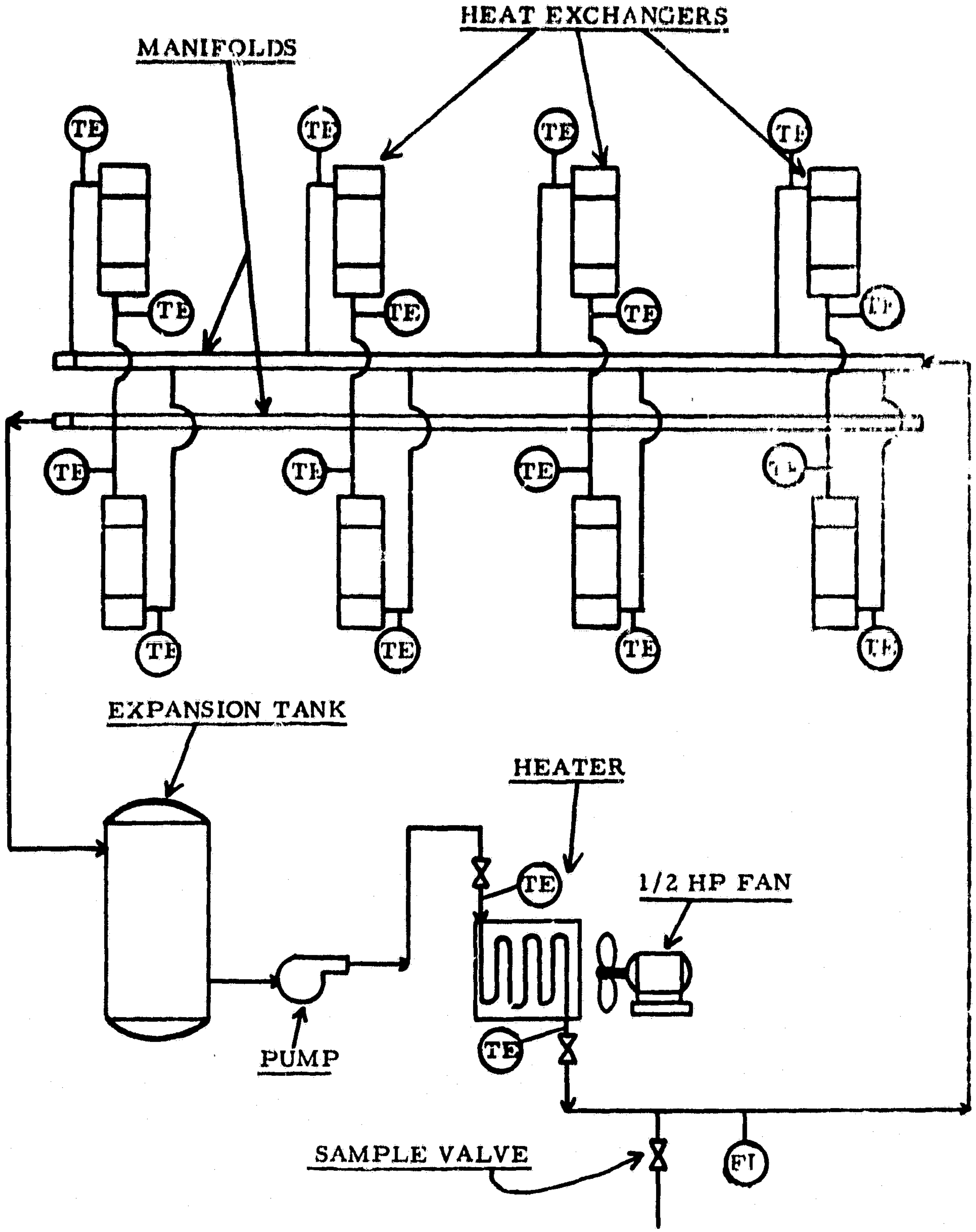
Figure 1



HEAT REJECTION SYSTEM

This drawing was redrawn for clarity.

Figure 2

SOLAR COLLECTOR PANELS

A study was conducted to have a representative sample of the market place; the solar collector plates materials selected were copper, aluminum, steel and one non-metallic (plastic) collector. The Roll-Bond and Tranter design was selected because it is more prone to crevice corrosion than the tube sheet type of construction. The metallic collector plates were ordered from their respective manufacturers and assembled by the PPG Glass Division and are as follows:

21 Aluminum solar collectors 34" x 76"; single glazed float glass; Duracron coated aluminum Roll-Bond panels with 6" fiberglass insulation and pans.

21 Steel solar collectors 34" x 76"; single glazed float glass; Duracron coated Tranter "Econocoil" steel panels with 6" fiberglass insulation and pans.

21 Copper solar collectors 34" x 76"; single glazed float glass; Duracron coated Roll-Bond panels with 6" fiberglass insulation and pans.

1 Non-metallic (plastic) solar collector 34" x 76"; single glazed reinforced plastic cover with fiberglass insulation and plastic framing.

The single glazed construction was selected for this project, because for this particular location, they perform more efficiently than double-glazed collectors. This conclusion was based on the analysis of a domestic hot water solar system for the Corpus Christi area.

The results of the FCHART computer analysis indicated that a PPG single glazed collector will supply 503,140 Btu/yr more than its double glazed counterpart, using the same collector area. Generally, this is true in warm climates such as in Corpus Christi.

Solar Heat Transport Fluid Description

P-0, Propylene Glycol	50% Deionized Water	
M-0, Monoethylene Glycol	50% Deionized Water	
G-0, Glycerine	60% Glycerine	
	40% Deionized Water	
D-W, Deionized Water		
H-W, Hard Water		
T-1, Triethylene Glycol	50% Deionized Water	
	DKP (50%) (Disotassium Phosphate)	2%
T-2, Triethylene Glycol	50% Deionized Water	
	DKP (50%) (Dipotassium Phosphate)	2.00%
	$NaNO_3$ (Sodium Nitrate)	0.20%
	Na_2SiO_3, .5 (Pentahydrate)	0.05%
	$NaNO_2$ (Sodium Nitrate)	0.05%
P-1, Propylene Glycol	50% Deionized Water	
	DKP (50%) (Dipotassium Phosphate)	2%
P-2, Propylene Glycol	50% Deionized Water	
	DKP (50%) (Dipotassium Phospate)	2%
	TOLY (50%) (Sodium Tolytriazole)	0.10%
M-1, Monoethylene Glycol	50% Deionized Water	
	Borax .5	0.584%
	NaOH (50%) (Sodium Hydroxide)	0.235%
	NaMBT (50%) (Sodium Mercaptobenzothiazole)	0.266%
	Na_2SiO_3, .5 (Pentahydrate)	0.050%
	$NaNO_3$ (Sodium Nitrate)	0.118%
	TSP (Trisodium Phospate)	0.102%
M-2, Monoethylene Glycol	50% Deionized Water	
	Borax .5	0.250%
	DKP (50%) (Dipotassium Phosphate)	2.50%
	NaOH (50%) (Sodium Hydroxide)	0.100%
	NaMBT (50%) (Sodium Mercaptobenzothiazole)	0.250%
M-3, Monoethylene Glycol	50% Deionized Water	
	DKP (50%) (Dipotassium Phosphate)	.735%
	DSP (50%) (Disodium Phosphate)	.515%
	NaMBT (50%) (Sodium Mercaptobenzothiazole)	.100%
M-4, Monoethylene Glycol	50% Deionized Water	
	DKP (50%) (Dipotassium Phosphate)	.735%
	DSP (Disodium Phosphate)	.515%
	NaMBT (50%) (Sodium Mercaptobenzothiazole)	.250%

Solar Heat Transport Fluid Description

M-5, Monoethylene Glycol	50% Deionized Water	
	Borax .5	0.584%
	NaOH (50%) (Sodium Hydroxide)	0.235%
	NaMBT (50%) (Sodium Mercaptobenzothiazole)	0.266%
	Na_2SiO_3, .5 (Pentahydrate)	0.050%
	$NaNO_3$ (Sodium Nitrate)	0.118%
	TSP (Trisodium Phosphate)	0.102%

Solar Heat Transport Solar Pump Description

Pump Identification	Grunfos UPS 20-24 1/20 H.P., 115 v. 60 H_2, 1 phase, 85 w, 0.85 a.
Test Conditions	190°F, 3-5 psig.

TESTING OF THE HEAT TRANSPORT FLUIDS

IN THE METALLIC COLLECTORS

The various types of solar transport fluids were circulated continously, on a 24 hour basis through the respective banks of collectors, and samples taken monthly and analyzed for appearance, pH, reserve alkalinity, ash content, foaming and viscosity. [3]

A listing of the various types of fluids [4] appears below:

Deionized Water

Hard Water

Monoethylene Glycol

Glycerine

Propylene Glycol

Triethylene Glycol

IN THE NON-METALLIC COLLECTORS [3]

A similar testing procedure was used.

An ethylene glycol with inhibitors and 50 percent deionized water was used at the solar heat transport fluid with this collector.

TESTING OF THE SOLAR PUMP

Solar pump failures are usually attributed to shaft and seal problems. Under this contract the contractor tested a 1/20 HP Grundfos pump untilizing a closed loop with applied heat, and off the shelf Zerex Antifreeze as a fluid (50-50 by volume aqueous), continously running at 190°F and 3-5 P.S.I. Routine visual inspections were performed over the period of the contract.

EVALUATION OF SOLAR FLUIDS, SOLAR COLLECTORS, AND SOLAR PUMPS [5]

1. SOLAR FLUIDS

Listed below are the fluid properties tested and the test method used.

TABLE	PROPERTIES	TEST METHOD	PAGE
Table VI	Color	Visual	27
Table XIII	Specific Gravity	ASTM D-1122	33
Table XI	Freeze Point	ASTM D-1177	32
Table IV	PH	ASTM D-1287	23
Table VII	ASH Content	ASTM D-1119	29
Table XII	Equilibrium Boiling Point	ASTM D-1120	32
Table V	Reserve Alkalinity	ASTM D-1121	25
Table IX	Foam Test	ASTM D-1881	30
Table VIII	Viscosities		29

All systems were charged with their individual solar fluid. The flow rates were set at 0.5 G.P.M. per solar collector. After monthly samplings and at test termination, their was either no change in fluid properties or insufficient change to eliminate the fluid as a candidate for use in the systems configurations tested.

2. SOLAR COLLECTORS

The following procedure was used to evaluate the collectors for corrosion:

1. Remove collector from the test stand.
2. Remove fittings, back pan, and insulation from collector.
3. Drain solar fluid.
4. Rinse collector flow passages with water.
5. Rinse collector flow passages with solvent.
6. Dry with nitrogen or other suitable gas.
7. Seal collector ports.

8. X-ray collector, see Figures 3 and 4.

9. Evaluate X-rays.

10. If corrosion is indicated, cut open collector and identify.

All of the metallic solar collector plates were evaluated in accordance with the above procedure. An independent institution, Southwest Research Institute, performed the X-ray inspections on site, and reported their findings (see Tables I, II and III). These findings indicated that after 20 months of testing, one small pit of corrosion was identified on an aluminum collector (see Figure 5) using a 60 percent mixture of glycerine and deionized water with no corrosion inhibitors. External corrosion occurred on the back side of one steel solar collector panel, (see Figure 6) it was evident that these surfaces were not properly prepared for painting.

Figure 7 is an X-ray of a copper collector plate, and shows no indication of interior or exterior corrosion.

Figure 8 is an X-ray of a portion of aluminum collector plate, and shows no indication of internal or external corrosion, but does show a washer like object in the corner and particles of debris in the bottom of the internal flow passages.

3. SOLAR PUMP

The 1/20 H.P. Grunfos pump completed 24 months of continuous running without failure.

PROBLEMS ENCOUNTERED AND THEIR SOLUTIONS:

Early in the program the procedure to evaluate the internal flow passages for corrosion was to cut open each flow passage with a band saw. This method left burrs along with metal shavings which required thorough cleaning before proper inspection of the area could start. In addition, the method was time consuming and expensive.

A radiographic application of X-ray inspection was investigated and found to be the solution to the problem. Southwest Research Institute was contracted by Houston Chemical to perform this work on site.

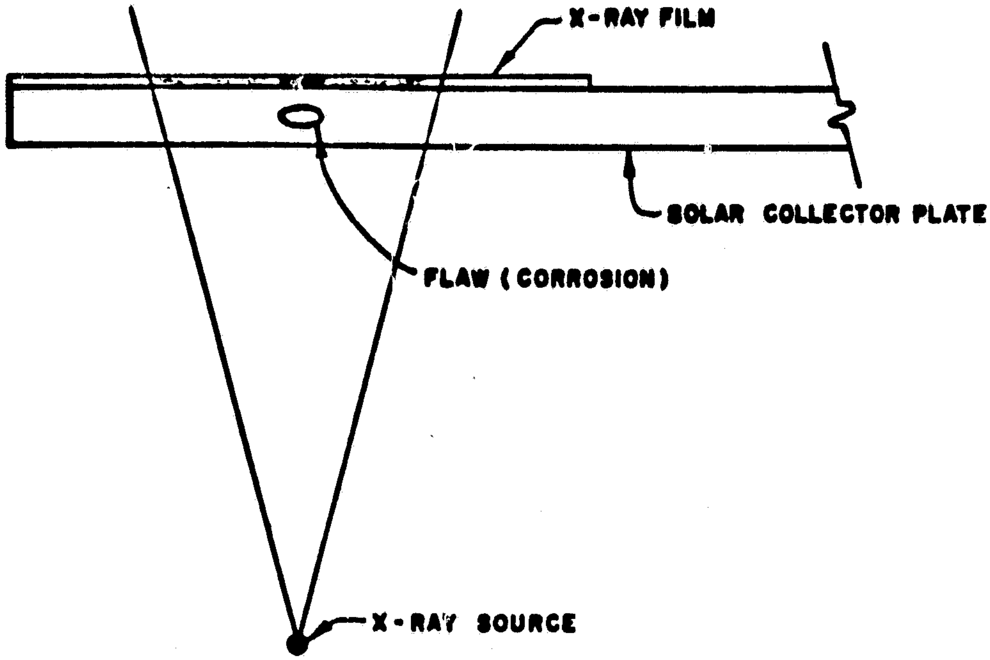


FIGURE 3 – SCHEMATIC OF FUNDAMENTAL X-RAY EXPOSURE

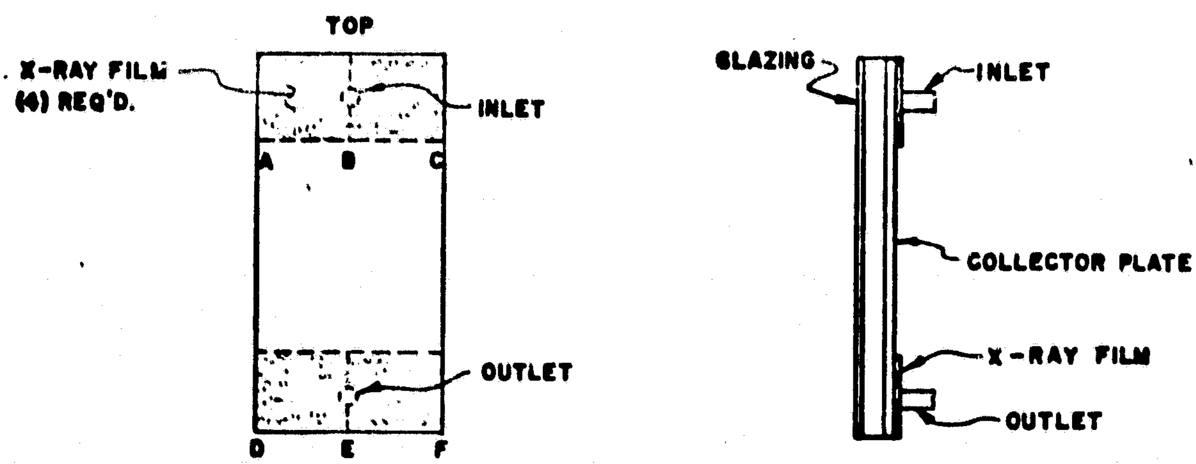


FIGURE 4 – DIAGRAM SHOWING LOCATION OF X-RAY FILM ON SOLAR COLLECTOR

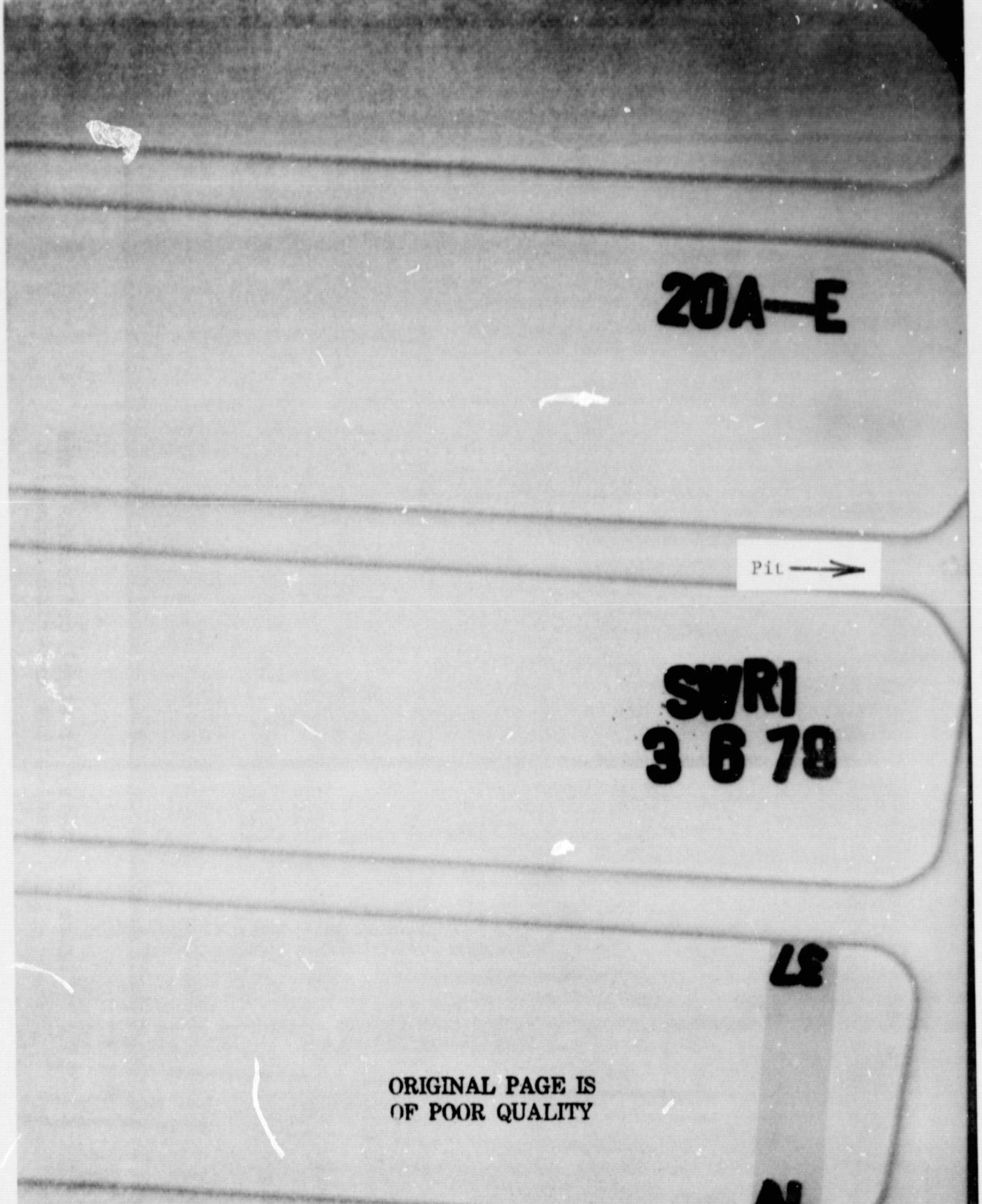


Figure 5 - X-ray of aluminum collector plate indicating corrosion pit

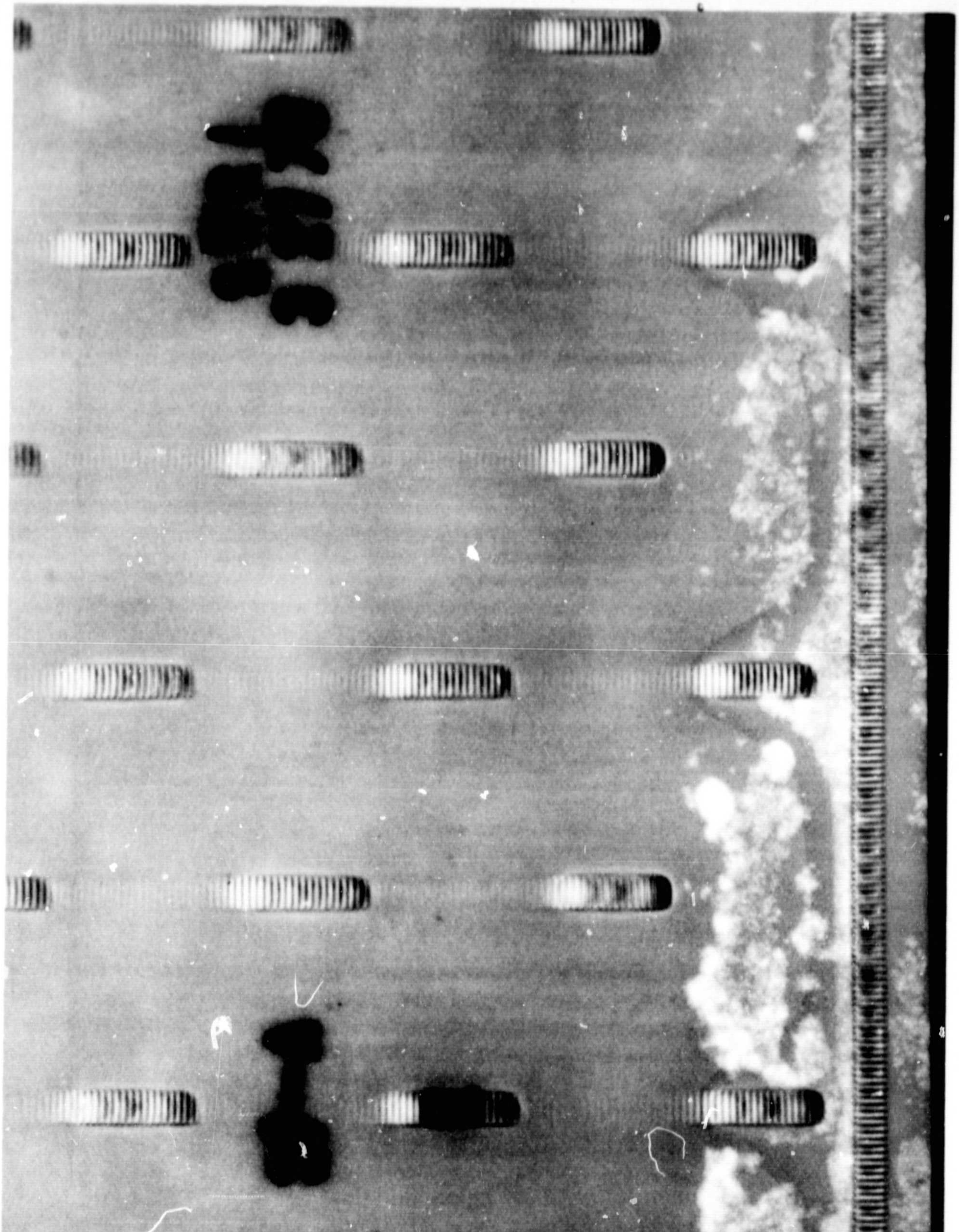


Figure 6 - X-ray of steel collector plate indicating exterior corrosion

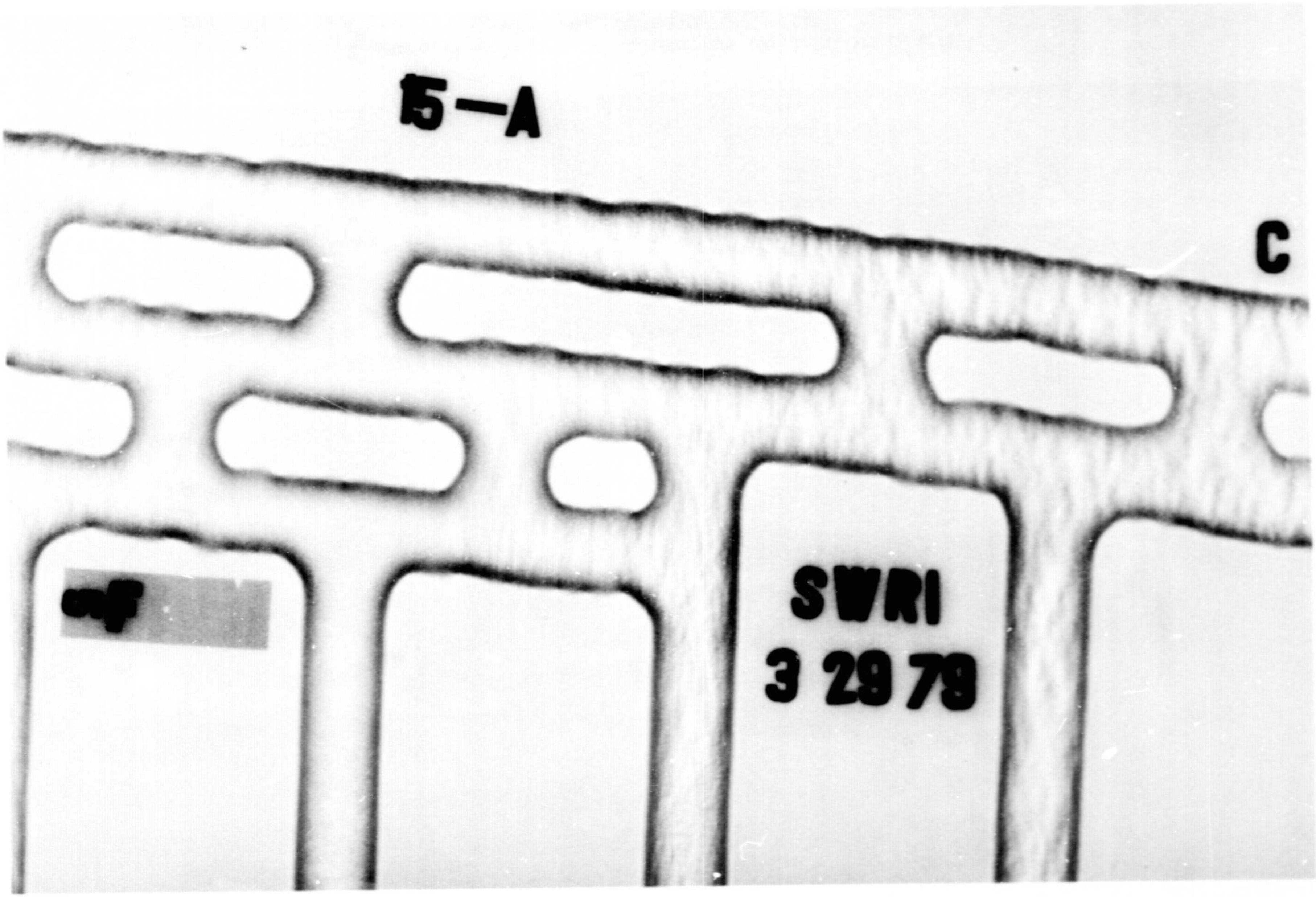


Figure 7 - X-ray of copper collector plate

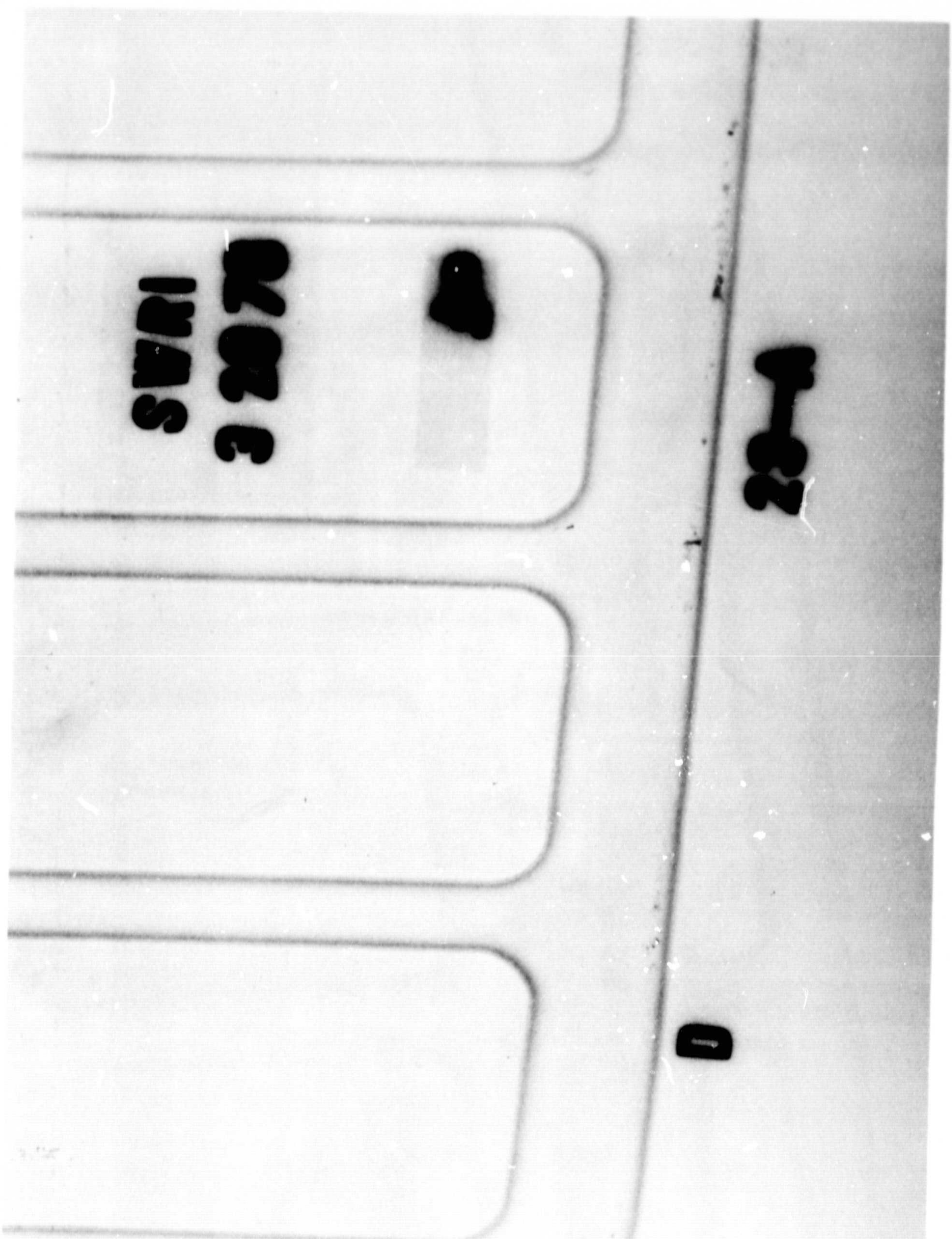


Figure 8 - X-ray of aluminum collector plate showing foreign objects

ORIGINAL PAGE IS OF POOR QUALITY

Solar Collector Panel
X-Ray Inspection

Table I

Panel Ident.	Panel Metal	Solar Fluid	Inhibited	Corrosion External	Corrosion Internal	Debris	Other
2A A-B	Copper	Propylene	No	N	N	N	
B-C		Glycol		N	N	N	
D-E		(P-0)		N	N	N	
E-F				N	N	N	
2B A-B	Copper	Propylene	No	N	N	N	
B-C		Glycol		N	N	N	
D-E		(P-0)		N	N	N	
E-F				N	N	F	
5A A-B	Copper	Monoethylene	No	N	N	N	
B-C		Glycol		N	N	N	
D-E		(M-0)		N	N	F	
E-F				N	N	N	
5B A-B	Copper	Monoethylene	No	N	N	N	
B-C		Glycol		N	N	N	
D-E		(M-0)		N	N	N	
E-F				N	N	N	
8A A-B	Copper	Deionized	No	N	N	N	
B-C		Water		N	N	N	
D-E		(D-W)		N	N	N	
E-F				N	N	N	
11A A	Copper	Glycerine	No	N	N	N	
B		(G-0)		N	N	N	
C				N	N	N	
D				N	N	N	
E				N	N	N	
F				N	N	N	
12A A-B	Copper	Triethylene	Yes	N	N	N	
B-C		Glycol		N	N	N	
D-E		(T-1)		N	N	N	
E-F				N	N	N	
12B A-B	Copper	Triethylene	Yes	N	N	N	
B-C		Glycol		N	N	N	
D-E		(T-1)		N	N	N	
E-F				N	N	F	
13A A-B	Copper	Propylene	Yes	N	N	N	
B-C		Glycol		N	N	N	
D-E		(P-2)		N	N	N	
E-F				N	N	F	
13B A-B	Copper	Propylene	Yes	N	N	N	
B-C		Glycol		N	N	N	
D-E		(P-2)		N	N	N	
E-F				N	N	N	

N = None
F = Few Particles
MF = More Than a Few Particles

Solar Collector Panel
X-Ray Inspection

Table I cont.

Panel Ident.		Panel Metal	Solar Fluid	Inhibited	Corrosion		Debris	Other
					External	Internal		
14A	A-B	Copper	Propylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(P-1)		N	N	N	
	E-F				N	N	N	
14B	A-B	Copper	Propylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(P-1)		N	N	N	
	E-F				N	N	N	
15A	A-B	Copper	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-4)		N	N	N	
	E-F				N	N	F	
15B	A-B	Copper	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-4)		N	N	F	
	E-F				N	N	N	
16A	A-B	Copper	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-3)		N	N	N	
	E-F				N	N	N	
16B	A-B	Copper	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-3)		N	N	F	
	E-F				N	N	F	
NA	A-B	Co-per	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-2)		N	N	F	
	E-F				N	N	N	
17B	A-B	Copper	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-2)		N	N	N	
	E-F				N	N	F	
18A	A-B	Copper	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-1)		N	N	N	
	E-F				N	N	N	
18B	A-B	Copper	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-1)		N	N	N	
	E-F				N	N	F	
19A	A-B	Copper	Hard Water	No	N	N	N	
	B-C		(H-W)		N	N	N	
	D-C				N	N	F	
	E-F				N	N	N	

N = None
F = Few Particles
MF = More Than a Few Particles

Solar Collector Panel
X-Ray Inspection

Table II

Panel Ident.		Panel Metal	Solar Fluid	Inhibited	Corrosion External	Corrosion Internal	Debris	Other
3A	A-B	Alum.	Propylene	No	N	N	F	
	B-C		Glycol		N	N	F	
	D-E		(P-O)		N	N	F	
	E-F				N	N	F	
3B	A-B	Alum.	Propylene	No	N	N	F	
	B-C		Glycol		N	N	N	
	D-E		(P-O)		N	N	N	
	E-F				N	N	N	
6A	A-B	Alum.	Monoethylene	No	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-O)		N	N	MF	
	E-F				N	N	MF	
6B	A-B	Alum.	Monoethylene	No	N	N	F	
	B-C		Glycol		N	N	F	
	D-E		(M-O)		N	N	MF	
	E-F				N	N	MF	
9A	A-B	Alum.	Deionized	No	N	N	F	
	B-C		(D-W)		N	N	F	Sight Deposit
	D-E				N	N	F	
	E-F				N	N	F	Sight Deposits
20A	A	Alum.	Glycerine	No	N	N	N	
	B		(G-O)		N	N	N	
	C				N	N	N	
	D				N	N	N	
	E				N	Yes	N	Pit Starting
	F				N	N	N	
21A	A-B	Alum.	Triethylene	Yes	N	N	MF	
	B-C		Glycol		N	N	MF	
	D-E		(T-1)		N	N	MF	
	E-F				N	N	MF	
21B	A-B	Alum.	Triethylene	Yes	N	N	F	
	B-C		Glycol		N	N	F	
	D-E		(T-1)		N	N	MF	
	E-F				N	N	MF	
22A	A-B	Alum.	Propylene	Yes	N	N	MF	
	B-C		Glycol		N	N	MF	
	D-E		(P-2)		N	N	MF	
	E-F				N	N	MF	
22B	A-B	Alum	Propylene	Yes	N	N	F	Deposits Noted
	B-C		Glycol		N	N	F	Deposits Noted
	D-E		(P-2)		N	N	MF	
	E-F				N	N	MF	

N = None
F = Few Particles
MF = More Than a Few Particles

Solar Collector Panel
X-Ray Inspection

Table II cont.

Panel Ident.		Panel Metal	Solar Fluid	Inhibited	Corrosion External	Corrosion Internal	Debris	Other
23A	A-B	Alum.	Propylene	Yes	N	N	MF	
	B-C		Glycol		N	N	F	
	D-E		(P-1)		N	N	MF	Circular Object Noted
	E-F				N	N	MF	
23B	A-B	Alum.	Propylene	Yes	N	N	F	
	B-C		Glycol		N	N	F	
	D-E		(P-1)		N	N	F	
	E-F				N	N	F	
24A	A-B	Alum.	Monoethylene	Yes	N	N	F	
	B-C		Glycol		N	N	F	
	D-E		(M-4)		N	N	F	
	E-F				N	N	F	
24B	A-B	Alum.	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-4)		N	N	N	
	E-F				N	N	N	
25A	A-B	Alum.	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-3)		N	N	N	
	E-F				N	N	N	
25B	A-B	Alum.	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-3)		N	N	N	
	E-F				N	N	N	
26A	A-B	Alum.	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	F	
	D-E		(M-2)		N	N	MF	
	E-F				N	N	MF	
26B	A-B	Alum.	Monoethylene	Yes	N	N	MF	
	B-C		Glycol		N	N	MF	
	D-E		(M-2)		N	N	MF	
	E-F				N	N	MF	
27A	A-B	Alum.	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-1)		N	N	N	
	E-F				N	N	N	
27B	A-B	Alum.	Monoethylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(M-1)		N	N	N	
	E-F				N	N	N	
28A	A-B	Alum.	Hard Water	No	N	N	MF	
	B-C		(H-W)		N	N	MF	
	D-E				N	N	MF	
	E-F				N	N	MF	

N = None
F = Few Particles
MF = More Than a Few Particles

Solar Collector Panel
X-Ray Inspection

Table III

Panel Ident.		Panel Metal	Solar Fluid	Inhibited	Corrosion External	Corrosion Internal	Debris	Other
4A	A-B	Steel	Propylene	No	SC	N	N	
	B-C		Glycol		SC	N	N	
	D-E		(P-0)		C	N	F	
	E-F				C	N	F	
4B	A-B	Steel	Propylene	No	SC	N	F	
	B-C		Glycol		SC	N	F	
	D-E		(P-0)		SC	N	F	
	E-F				SC	N	F	
7A	A-B	Steel	Monoethylene	No	SC	N	F	
	B-C		Glycol		SC	N	F	
	D-E		(M-0)		C	N	F	
	E-F				C	N	F	
7B	A-B	Steel	Monoethylene	No	C	N	F	
	B-C		Glycol		C	N	F	
	D-E		(M-0)		C	N	N	
	E-F				SC	N	F	
10A	A-B	Steel	Deionized	No	SC	N	F	
	B-C		Water		SC	N	F	
	D-E		(D-W)		SC	N	F	
	E-F				SC	N	F	
29A	A	Steel	Glycerine	No	SC	N	F	
	B		(G-0)		SC	N	N	
	C				SC	N	N	
	D				SC	N	F	
	E				SC	M	F	
	F				SC	N	F	
30A	A	Steel	Triethylene	Yes	C	N	N	
	B		Glycol		C	N	N	
	C		(T-1)		C	N	N	
	D				C	N	N	
	E				C	N	N	
	F				C	N	N	
30B	A-B	Steel	Triethylene	Yes	C	N	N	
	B-C		Glycol		C	N	N	
	D-E		(T-1		SC	N	N	
	E-F				SC	N	N	
31A	A-B	Steel	Propylene	Yes	C	N	N	
	B-C		Glycol		C	N	N	
	D-E		(P-2)		C	N	N	
	E-F				C	N	N	
31B	A-B	Steel	Propylene	Yes	N	N	N	
	B-C		Glycol		N	N	N	
	D-E		(P-2)		C	N	N	
	E-F				C	N	N	

N = None
F = Few Particles
MF = More Than a Few Particles

SC = Slight Corrosion
C = Corrosion

Solar Collector Panel
X-Ray Inspection

Table III cont.

Panel Ident.	Panel Metal	Solar Fluid	Inhibited	Corrosion External	Corrosion Internal	Debris	Other
32A A-B	Steel	Propylene	Yes	SC	N	F	
B-C		Glycol		C	N	F	
D-E		(P-1)		SC	N	F	
E-F				N	N	F	
32B A-B	Steel	Propylene	Yes	SC	N	N	
B-C		Glycol		SC	N	N	
D-E		(P-1)		SC	N	F	
E-F				N	N	N	
33A A-B	Steel	Monoethylene	Yes	SC	N	N	Small Weld Cracks
B-C		Glycol		SC	N	N	Noted
D-E		(M-4)		SC	N	N	
E-F				SC	N	N	
33B A-B	Steel	Monoethylene	Yes	SC	N	N	
B-C		Glycol		SC	N	N	
D-E		(M-4)		SC	N	N	
E-F				SC	N	N	
34A A-B	Steel	Monoethylene	Yes	SC	N	N	
B-C		Glycol		SC	N	N	
D-E		(M-3)		SC	N	N	
E-F				SC	N	N	
34B A-B	Steel	Monoethylene	Yes	SC	N	N	
B-C		Glycol		SC	N	N	
D-E		(M-3)		C	N	N	
E-F				C	N	N	
35A A-B	Steel	Monoethylene	Yes	C	N	N	
B-C		Glycol		C	N	N	
D-E		(M-2)		C	N	N	
E-F				C	N	N	
35B A-B	Steel	Monoethylene	Yes	C	N	N	
B-C		Glycol		C	N	N	
D-E		(M-2)		SC	N	N	
E-F				N	N	N	
36A A-B	Steel	Monoethylene	Yes	SC	N	N	
B-C		Glycol		SC	N	N	
D-E		(M-1)		C	N	N	
E-F				C	N	N	
36B A-B	Steel	Monoethylene	Yes	SC	N	N	
B-C		Glycol		C	N	N	
D-E		(M-1)		SC	N	N	
E-G				SC	N	N	
37A A-B	Steel	Hard Water	Yes	C	N	N	
B-C		(H-W)		C	N	N	
D-E				C	N	F	
E-F				C	N	F	

N = None
F = Few Particles
MF = More Than a Few Particles

SC = Slight Corrosion
C = Corrosion

Table IV

SOLAR HEAT TRANSPORT FLUIDS

NASA CONTRACT NAS8-32255

pH

System	Material	Fluid	Initial	1977 7/15	1977 8/15	1977 9/15	1977 10/15	1977 11/15	1977 12/15	1978 1/15	1978 2/15	1978 3/15	1978 4/15
1	EPDM	M-5	9.9										** 9.7
2	Cu	P-O	5.2	6.8	8.6	6.5	6.4	6.3	6.6	6.4	6.3	6.1	6.4
3	Al	P-O	5.2	5.5	4.9	4.9	5.0	5.2	5.0	5.3	5.6	5.6	4.7
4	Stl	P-O	5.2	5.9	5.1	4.9	5.1	5.1	5.0	5.3	5.8	5.7	4.9
5	Cu	M-O	7.0	5.9	5.4	5.1	5.1	5.2	5.1	5.2	5.6	5.6	5.0
6	Al	M-O	7.0	6.3	5.2	5.4	5.2	5.3	5.2	5.2	5.6	5.5	5.3
7	Stl	M-O	7.0	4.8	4.8	4.9	5.3	5.2	5.0	5.2	5.6	5.4	4.9
8	Cu	D-W	7.1	8.0	6.8	6.9	7.0	7.1	7.4	6.9	6.6	6.8	6.9
9	Al	D-W	7.1	8.0	7.6	7.7	7.2	7.1		*7.1	7.0	7.0	7.1
10	Stl	D-W	7.1	5.6	6.3	6.1	5.9	5.9	5.9	6.1	5.9	5.7	[illegible]
11	Cu	G-O	5.5	6.2	5.3	5.1	5.1	5.6	5.1	5.3	5.7	5.6	4.3
12	Cu	T-1	9.6	9.5	9.8	9.9	10.0	10.1	10.0	10.1	10.1	10.2	10.1
13	Cu	P-2	9.8	9.8	9.9	9.8	10.0	10.0	9.9	9.9	9.9	9.9	[illegible]
14	Cu	P-1	9.8	9.6	9.6	9.5	9.6	9.6	9.6	9.5	9.5	9.5	9.6
15	Cu	M-4	9.4	9.5	9.4	9.3	9.4	9.4	9.3	9.3	9.3	9.4	9.4
16	Cu	M-3	9.5	9.4	9.4	9.3	9.4	9.4	9.3	9.3	9.3	9.4	9.4
17	Cu	M-2	8.8	8.8	8.8	8.8	8.9	8.8	8.8	8.8	8.8	8.8	8.9
18	Cu	M-1	9.4	9.3	9.2	9.2	9.3	9.2	9.2	9.2	9.2	9.2	9.3
19	Cu	H-W	8.2	8.0	8.4	8.1	8.2	8.2	8.4	8.5	8.2	8.7	7.9
20	Al	G-O	5.5	6.1	6.2	7.2	5.3	5.4	6.0	6.0	5.8	5.8	5.7
21	Al	T-1	9.6	10.1	10.2	10.3	10.5	10.2	10.2	10.2	10.2	10.2	10.1
22	Al	P-2	9.8	10.2	10.3	10.3	10.4	10.3	10.3	10.3	10.4	10.4	10.3
23	Al	P-1	9.8	10.3	10.5	10.6	10.6	10.6	10.5	10.7	10.6	10.6	10.5
24	Al	M-4	9.4	9.4	9.4	9.5	9.5	9.4	9.4	9.4	9.4	9.4	9.4
25	Al	M-3	9.5	9.5	9.4	9.5	9.5	9.4	9.4	9.7	9.5	9.4	9.4
26	Al	M-2	8.8	9.1	9.1	9.3	9.3	9.2	9.2	9.3	9.3	9.3	9.3
27	Al	M-1	9.4	9.3	9.3	9.3	9.3	9.2	9.3	9.3	9.3	9.3	9.3
28	Al	H-W	8.2	7.8	8.5	8.0	8.5	8.4	9.2	8.4	8.9	8.8	7.7
29	Stl	G-O	5.5	5.9	5.2	6.6	6.5	5.3	5.2	5.7	5.5	5.5	5.2
30	Stl	T-1	9.6	9.5	9.8	9.9	10.2	10.2	10.3	10.3	10.4	10.4	10.4
31	Stl	P-2	9.8	9.8	9.8	9.9	9.9	9.9	9.9	10.0	10.1	10.0	10.0
32	Stl	P-1	9.8	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6
33	Stl	M-4	9.4	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
34	Stl	M-3	9.5	9.2	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.3	9.3
35	Stl	M-2	8.8	9.8	8.8	8.9	8.8	8.9	8.8	8.9	8.9	9.0	8.9
36	Stl	M-1	9.4	9.3	9.2	9.2	9.2	9.3	9.2	9.2	9.2	9.3	9.1
37	Stl	H-W	8.2	7.6	8.0	8.1	8.2	8.3	8.4	8.1	8.8	8.6	7.9
38	Mix	T-2	8.7	-	8.6	8.5	8.7	8.6	8.6	8.6		8.7	8.7

* New fluid installed

** Testing of plastic panel initiated

SOLAR HEAT TRANSPORT FLUIDS

NASA CONTRACT NAS8-32255

pH, continued

System	Material	Fluid	Initial	1978 5/15	1978 6/15	1978 7/15	1978 8/15	1978 9/15	1978 10/15	1978 11/15	1978 12/15	1979 1/15	1979 2/26
1	EPDM	M-5	9.9	9.7	9.6	9.7	9.6	9.5	9.5	9.5	9.5	9.5	9.5
2	Cu	P-0	5.2	6.3	6.5	6.3	6.1	6.1	6.0	7.1	6.9	6.7	6.0
3	Al	P-0	5.2	5.2	6.1	6.0	5.1	5.6	5.0	5.6	5.5	6.3	4.9
4	Stl	P-0	5.2	5.2	6.2	6.2	4.9	5.7	4.9	5.6	5.5	6.4	4.9
5	Cu	M-0	7.0	5.4	6.0	6.0	5.0	5.6	5.1	5.4	5.4	6.5	4.8
6	Al	M-0	7.0	5.6	6.2	6.0	5.2	5.6	5.3	6.0	5.9	6.4	5.2
7	Stl	M-0	7.0	5.4	6.2	6.2	6.2	5.7	4.9	5.7	5.4	6.4	5.1
8	Cu	D-W	7.1	7.1	6.8	6.8	6.8	6.6	6.9	7.3	7.2	7.2	7.0
9	Al	D-W	7.1	7.1	8.7	8.3	8.2	8.2	7.0	7.3	7.1	7.3	8.4
10	Stl	D-W	7.1	6.3	5.8	5.8	5.7	5.6	5.7	6.8	6.6	6.3	5.5
11	Cu	G-0	5.5	5.2	5.9	6.0	5.4	5.5	4.9	5.4	5.4	6.2	5.9
12	Cu	T-1	9.6	10.1	10.2	10.3	10.0	10.1	10.1	10.0	10.1	10.1	10.1
13	Cu	P-2	9.8	9.9	10.0	10.0	9.8	9.9	9.9	9.8	9.9	9.9	9.9
14	Cu	P-1	9.8	9.6	9.6	9.6	9.5	9.5	9.5	9.4	9.4	9.5	9.5
15	Cu	M-4	9.4	9.3	9.4	9.4	9.3	9.3	9.4	9.3	9.3	9.4	9.4
16	Cu	M-3	9.5	9.4	9.4	9.5	9.3	9.4	9.4	9.4	9.5	9.5	9.4
17	Cu	M-2	8.8	8.8	8.9	8.9	8.9	8.8	8.8	8.8	8.8	8.8	8.8
18	Cu	M-1	9.4	9.2	9.3	9.4	9.2	9.3	9.3	9.3	9.2	9.2	9.2
19	Cu	H-W	8.2	8.2	8.3	8.8	8.2	6.3	7.8	8.0	8.8	8.8	8.8
20	Al	G-0	5.5	7.2	6.1	6.2	5.4	5.5	5.3	5.3	5.4	6.7	6.3
21	Al	T-1	9.6	10.2	10.3	10.2	10.0	10.1	10.1	10.1	10.1	10.2	10.1
22	Al	P-2	9.8	10.3	10.4	10.5	10.3	10.4	10.3	10.3	10.4	10.5	10.5
23	Al	P-1	9.8	10.6	10.6	10.6	10.4	10.5	10.5	10.5	10.5	10.5	10.5
24	Al	M-4	9.4	9.4	9.4	9.5	9.3	9.4	9.4	9.4	9.4	9.5	9.4
25	Al	M-3	9.5	9.4	9.4	9.5	9.5	9.4	9.3	9.4	9.4	9.4	9.4
26	Al	M-2	8.8	9.3	9.3	9.4	9.4	9.0	9.3	9.3	9.3	9.4	9.4
27	Al	M-1	9.4	9.2	9.2	9.4	9.3	9.3	9.3	9.2	9.2	9.3	9.2
28	Al	H-W	8.2	8.6	8.3	8.8	8.6	8.7	7.6	7.7	7.7	8.8	8.4
29	Stl	G-0	5.5	5.0	5.5	5.4	5.1	6.2	5.1	5.2	5.2	6.3	6.2
30	Stl	T-1	9.6	10.5	10.5	10.6	10.6	10.6	10.6	10.6	10.6	10.7	10.7
31	Stl	P-2	9.8	10.0	10.1	10.2	10.2	10.2	10.1	10.1	10.2	10.2	10.2
32	Stl	P-1	9.8	9.6	9.6	9.6	9.6	9.6	9.5	9.6	9.5	9.6	9.6
33	Stl	M-4	9.4	9.2	9.3	9.4	9.3	9.3	9.4	9.3	9.2	9.3	9.3
34	Stl	M-3	9.5	9.2	9.2	9.3	9.3	9.2	9.2	9.2	9.2	9.3	9.3
35	Stl	M-2	8.8	8.9	9.0	9.1	9.1	9.4	9.0	9.0	9.0	9.1	9.1
36	Stl	M-1	9.4	9.2	9.2	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2
37	Stl	H-W	8.2	8.0	8.3	8.8	8.4	8.6	8.5	7.7	8.7	8.7	8.6
38	Mix	T-2	8.7	8.6	8.6	8.7	8.6	9.0	8.9		8.8		

Table V

SOLAR HEAT TRANSPORT FLUIDS

NASA CONTRACT NAS8-32255

RESERVE ALKALINITY

System	Material	Fluid	Initial	1977 7/15	8/15	9/15	10/15	11/15	12/15	1978 1/15	2/15	3/15	4/15
1	EPDM	M-5	10.75										*10.83
2	Cu	P-0											
3	Al	P-0											
4	Stl	P-0											
5	Cu	M-0											
6	Al	M-0											
7	Stl	M-0											
8	Cu	D-W											
9	Al	D-W											
10	Stl	D-W											
11	Cu	G-0											
12	Cu	T-1	6.10	6.10	6.10	5.90	6.05	5.90	6.00	6.00	6.00	6.00	5.95
13	Cu	P-2	6.25	6.30	6.20	6.10	6.15	6.10	6.20	6.10	6.10	6.10	6.08
14	Cu	P-1	6.00	5.95	5.90	5.80	5.90	5.80	5.90	6.00	5.80	5.80	5.80
15	Cu	M-4	6.65	6.50	6.50	6.50	6.50	6.40	6.50	6.50	6.50	6.50	6.43
16	Cu	M-3	6.65	6.45	6.50	6.50	6.50	6.40	6.50	6.50	6.40	6.50	6.40
17	Cu	M-2	11.45	11.30	11.40	11.30	11.35	11.20	11.40	11.30	11.30	11.30	11.33
18	Cu	M-1	9.90	9.50	9.10	9.10	9.20	9.00	9.10	9.10	9.00	9.90	9.00
19	Cu	H-W				0.12							
20	Al	G-0											
21	Al	T-1	6.10	6.00	6.00	6.00	6.00	5.90	6.00	6.00	5.80	5.80	5.88
22	Al	P-2	6.25	6.20	6.25	6.20	6.23	6.20	6.40	6.30	6.20	6.20	6.13
23	Al	P-1	6.00	5.90	5.95	5.90	5.90	5.90	5.95	5.90	5.80	5.90	5.80
24	Al	M-4	6.55	6.60	6.65	6.60	6.70	6.55	6.70	6.60	6.60	6.60	6.53
25	Al	M-3	6.55	6.60	6.60	6.70	6.65	6.50	6.60	6.60	6.60	6.60	6.48
26	Al	M-2	11.45	11.50	11.50	11.40	11.50	11.30	11.40	11.50	11.40	11.40	11.35
27	Al	M-1	9.90	9.90	10.00	9.95	9.90	9.80	9.90	9.90	9.80	9.80	9.78
28	Al	H-W											
29	Stl	G-0											
30	Stl	T-1	6.10	6.10	6.05	6.10	6.05	5.90	6.10	6.00	6.00	6.00	5.95
31	Stl	P-2	6.25	6.20	6.21	6.30	6.15	6.10	6.30	6.20	6.20	6.20	6.13
32	Stl	P-1	6.00	5.90	5.90	6.10	5.90	6.00	6.00	5.90	5.90	5.90	5.83
33	Stl	M-4	6.65	6.60	6.63	6.70	6.65	6.50	6.60	6.60	6.60	6.60	5.55
34	Stl	M-3	6.65	6.60	6.58	6.60	6.60	6.50	6.60	6.60	6.60	6.60	6.53
35	Stl	M-2	11.45	11.40	11.24	11.50	11.40	11.25	11.40	11.40	11.30	11.40	11.40
36	Stl	M-1	9.90	9.90	9.84	9.80	9.85	9.70	9.90	9.90	9.80	9.80	9.70
37	Stl	H-W											
38	Mix	T-2	10.6	--	3.23	3.30	3.45	3.10	3.20	3.30		3.20	3.05

* Testing of plastic panel initiated.

NOTE: All blank spaces are <0.100

Table V

SOLAR HEAT TRANSPORT FLUIDS

NASA CONTRACT NAS8-32255

RESERVE ALKALINITY, Continued

				1978								1979	
System	Material	Fluid	Initial	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	1/15	2/26
1	EPDM	M-5	10.75	10.73	10.90	10.80	10.73	10.80	10.80	10.80	10.80	10.80	10.80
2	Cu	P-O											
3	Al	P-O											
4	Stl	P-O											
5	Cu	M-O											
6	Al	M-O											
7	Stl	M-O											
8	Cu	D-W											
9	Al	D-W											
10	Stl	D-W											
11	Cu	G-O											
12	Cu	T-1	6.10	5.93	6.00	6.00	5.88	6.00	6.00	6.00	6.00	6.00	6.00
13	Cu	P-2	6.25	6.08	6.08	6.20	6.08	6.20	6.20	6.15	6.20	6.10	6.30
14	Cu	P-1	6.00	5.80	5.85	6.00	5.78	5.90	5.90	5.85	5.80	5.80	6.00
15	Cu	M-4	6.65	6.43	6.45	6.50	6.40	6.50	6.50	6.55	6.50	6.40	6.50
16	Cu	M-3	6.65	6.40	6.50	6.50	6.43	6.50	6.50	6.50	6.50	6.50	6.50
17	Cu	M-2	11.45	11.38	11.35	11.40	11.28	11.30	11.40	11.35	11.20	11.30	11.30
18	Cu	M-1	9.90	9.00	9.10	9.10	9.00	9.10	9.10	9.10	9.10	9.10	9.10
19	Cu	H-W											
20	Al	G-O											
21	Al	T-1	6.10	5.83	5.80	5.90	5.90	6.00	6.00	5.90	5.90	6.00	6.00
22	Al	P-2	6.25	10.10	6.15	6.30	6.18	6.20	6.20	6.25	6.20	6.20	6.30
23	Al	P-1	6.00	5.80	5.88	5.90	5.85	5.90	5.90	5.95	6.00	6.00	5.90
24	Al	M-4	6.55	6.55	6.60	6.70	6.58	6.60	6.60	6.60	6.60	6.60	6.60
25	Al	M-3	6.55	6.50	6.55	6.60	6.70	6.60	6.60	6.55	6.50	6.60	6.60
26	Al	M-2	11.45	11.35	11.45	11.60	11.40	11.40	12.50	11.45	11.40	11.40	11.50
27	Al	M-1	9.90	9.75	9.90	9.90	9.75	9.90	9.80	9.85	9.80	9.90	9.90
28	Al	H-W											
29	Stl	G-O											
30	Stl	T-1	6.10	5.93	6.00	6.00	5.95	6.10	6.00	6.05	5.60	6.10	6.10
31	Stl	P-2	6.25	6.10	6.15	6.20	6.10	6.20	6.20	6.15	6.10	6.20	6.20
32	Stl	P-1	6.00	5.85	5.85	5.90	5.83	5.90	6.00	5.90	5.80	5.90	5.90
33	Stl	M-4	6.65	6.50	6.65	6.70	6.58	6.60	6.70	6.00	6.50	6.60	6.60
34	Stl	M-3	6.65	6.48	6.55	6.60	6.50	6.60	6.60	6.55	6.60	6.70	6.60
35	Stl	M-2	11.45	11.30	11.40	11.40	11.33	11.50	11.40	11.40	11.40	11.40	11.40
36	Stl	M-1	9.90	9.70	9.75	9.80	9.73	9.80	9.80	9.80	9.80	9.80	9.80
37	Stl	H-W											
38	Mix	T-2	10.6	3.03	3.05	3.10	2.93	4.10	4.00		4.00		

NOTE: All blank spaces are <0.100

Table VI

SOLAR HEAT TRANSPORT FLUID

NASA CONTRACT NAS8-32255

VISUAL APPEARANCE TEST

			1977						1978			
System	Fluid	Material	7/15	8/15	9/15	10/15	11/15	12/15	1/15	2/15	3/15	4/15
1	M-5	EPDM										*100-250
2	P-0	Cu	50-100	50-100	50-100	100-250	0-050	0-050	100-250	100-250	100-250	100-250
3	P-0	Al	250-500	250-500	100-250	500 +	250-500	500 +	500 +	250-500	250-500	250-500
4	P-0	Stl	250-500	250-500	250-500	250-500	250-500	250-500	250-500	100-250	100-250	500 +
5	M-0	Cu	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	250-500
6	M-0	Al	250-500	100-250	250-500	250-500	500 +	500 +	500 +	500 +	500 +	500 +
7	M-0	Stl	100-250	250-500	250-500	250-500	250-500	250-500	250-500	100-250	100-250	250-500
8	D-W	Cu	50-100	100-250	50-100	0-050	0-050	0-050	0-050	0-050	0-050	0-050
9	D-W	Al	0-050	50-100	0-050	50-100	0-050	-	50-100	100-250	100-250	050-100
10	D-W	Stl	100-250	100-250	100-250	50-100	50-100	50-100	0-050	0-050	100-250	100-250
11	G-0	Cu	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	050-100	250-500
12	T-1	Cu	100-250	100-250	100-250	100-250	250-500	250-500	500 +	500 +	250-500	500 +
13	P-2	Cu	50-100	50-100	0-050	0-050	0-050	0-050	0-050	050-100	050-100	050-100
14	P-1	Cu	100-250	50-100	0-050	0-050	0-050	0-050	0-050	0-050	050-100	050-100
15	M-4	Cu	50-100	50-100	50-100	50-100	0-050	0-050	0-050	050-100	050-100	100-250
16	M-3	Cu	50-100	50-100	50-100	0-050	50-100	0-050	0-050	050-100	050-100	050-100
17	M-2	Cu	50-100	50-100	50-100	50-100	0-050	0-050	0-050	050-100	050-100	050-100
18	M-1	Cu	50-100	50-100	50-100	50-100	0-050	0-050	0-050	050-100	050-100	050-100
19	H-W	Cu	50-100	50-100	50-100	50-100	0-050	0-050	0-050	050-100	050-100	050-100
20	G-0	Al	100-250	100-250	100-250	100-250	100-250	100-250	100-250	050-100	100-250	250-500
21	T-1	Al	100-250	100-250	100-240	100-250	250-500	250-500	500 +	500 +	500 +	500 +
22	P-2	Al	50-100	50-100	50-100	50-100	0-050	0-050	0-050	0-050	0-050	050-100
23	P-1	Al	0-050	0-050	50-100	0-050	0-050	0-050	0-050	0-050	0-050	050-100
24	M-4	Al	50-100	50-100	50-100	50-100	50-100	50-100	0-050	050-100	050-100	050-100
25	M-3	Al	50-100	50-100	50-100	0-050	50-100	0-050	0-050	050-100	050-100	050-100
26	M-2	Al	50-100	50-100	50-100	0-050	0-050	0-050	0-050	050-100	050-100	050-100
27	M-1	Al	50-100	50-100	50-100	0-050	0-050	0-050	0-050	050-100	050-100	050-100
28	H-W	Al	0-050	50-100	0-050	50-100	0-050	0-050	0-050	0-050	0-050	050-100
29	G-0	Stl	100-250	100-250	100-250	100-250	100-250	100-250	100-250	050-100	100-250	250-500
30	T-1	Stl	50-100	100-250	100-250	100-250	250-500	250-500	500 +	500 +	500+	500 +
31	P-2	Stl	50-100	50-100	50-100	50-100	50-100	50-100	50-100	100-250	100-250	100-250
32	P-1	Stl	50-100	50-100	50-100	50-100	50-100	50-100	50-100	050-100	050-100	050-100
33	M-4	Stl	50-100	50-100	50-100	100-250	50-100	50-100	50-100	100-250	100-250	100-250
34	M-3	Stl	100-250	100-250	100-250	50-100	100-250	50-100	100-250	100-250	100-250	100-250
35	M-2	Stl	100-250	100-250	100-250	100-250	250-500	100-250	100-250	100-250	100-250	100-250
36	M-1	Stl	100-250	100-250	50-100	50-100	50-100	100-250	100-250	100-250	100-250	250-500
37	H-W	Stl	50-100	0-050	50-100	0-050	0-050	0-050	0-050	050-100	100-250	0-050
38	T-2	Mix	-	100-250	100-250	100-250	100-250	100-250	100-250		250-500	250-500

* Testing of plastic panel initiated

Table VI

SOLAR HEAT TRANSPORT FLUID

NASA CONTRACT NAS8-32255

VISUAL APPEARANCE TEST, continued

System	Fluid	Material	1978								1979	
			5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	1/15	2/26
1	M-5	EPDM	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	050-100
2	P-0	Cu	100-250	050-100	100-250	100-250	100-250	100-250	100-250	100-250	100-250	250-500
3	P-0	Al	250-500	250-500	250-500	500 +	500 +	500 +	500 +	500 +	500 +	500 +
4	P-0	Stl	250-500	100-250	100-250	250-500	250-500	250-500	250-500	250-500	100-250	250-500
5	M-0	Cu	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	250-500
6	M-0	Al	500 +	500 +	500 +	500 +	500 +	500 +	500 +	500 +	500 +	500 +
7	M-0	Stl	250-500	100-250	100-250	250-500	250-500	250-500	100-250	250-500	100-250	250-500
8	D-W	Cu	050-100	050-100	050-100	100-250	000-050	000-050	000-050	000-050	000-050	000-050
9	D-W	Al	000-050	000-050	000-050	000-050	000-050	000-050	000-050	000-050	000-050	000-050
10	D-W	Stl	100-250	100-250	050-100	100-250	100-250	050-100	000-050	000-050	050-100	050-100
11	G-0	Cu	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	250-500
12	T-1	Cu	500 +	500 +	500 +	500 +	500 +	500 +	500 +	500 +	500 +	500 +
13	P-2	Cu	050-100	050-100	050-100	050-100	050-100	000-050	050-100	050-100	000-050	050-100
14	P-1	Cu	050-100	000-050	000-050	050-100	000-050	000-050	000-050	000-050	000-050	050-100
15	M-4	Cu	100-250	050-100	050-100	050-100	050-100	050-100	050-100	050-100	050-100	050-100
16	M-3	Cu	100-250	050-100	050-100	100-250	050-100	050-100	100-250	050-100	050-100	050-100
17	M-2	Cu	100-250	050-100	050-100	050-100	050-100	050-100	050-100	050-100	000-050	050-100
18	M-1	Cu	050-100	050-100	050-100	050-100	050-100	000-050	050-100	050-100	000-050	050-100
19	H-W	Cu	000-050	050-100	050-100	050-100	000-050	000-050	050-100	050-100	000-050	000-050
20	G-0	Al	100-250	100-250	100-250	100-250	250-500	100-250	100-250	100-250	050-100	100-250
21	T-1	Al	500 +	500 +	500 +	250-500	500 +	500 +	500 +	500 +	500 +	500 +
22	P-2	Al	050-100	000-050	000-050	050-100	000-050	000-050	000-050	000-050	000-050	000-050
23	P-1	Al	000-050	000-050	000-050	050-100	000-050	000-050	000-050	000-050	000-050	000-050
24	M-4	Al	050-100	050-100	050-100	050-100	050-100	050-100	050-100	050-100	050-100	050-100
25	M-3	Al	050-100	050-100	050-100	050-100	050-100	050-100	050-100	050-100	050-100	050-100
26	M-2	Al	050-100	050-100	050-100	050-100	100-250	050-100	050-100	050-100	050-100	050-100
27	M-1	Al	050-100	050-100	050-100	050-100	050-100	050-100	000-050	000-050	050-100	050-100
28	H-W	Al	000-050	000-050	000-050	050-100	000-050	000-050	000-050	000-050	000-050	000-050
29	G-0	Stl	100-250	100-250	100-250	100-250	100-250	050-100	100-250	100-250	050-100	250-500
30	T-1	Stl	500 +	500 +	500 +	500 +	500 +	500 +	500 +	500 +	500 +	500 +
31	P-2	Stl	050-100	050-100	050-100	100-250	050-100	050-100	050-100	050-100	050-100	050-100
32	P-1	Stl	050-100	050-100	050-100	050-100	050-100	050-100	050-100	050-100	050-100	050-100
33	M-4	Stl	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	050-100
34	M-3	Stl	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250
35	M-2	Stl	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250
36	M-1	Stl	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250	100-250
37	H-W	Stl	000-050	000-050	000-050	050-100	000-050	000-050	000-050	000-050	000-050	000-050
38	T-2	Mix	250-500	250-500	250-500	250-500	250-500	250-500		250-500		

Table VII

Ash Test
Weight %

System	Initial	Final	System	Initial	Final
1	.72	.69	19	Hard Water	
2	Nil	.02	20	Nil	nil
3	Nil	.01	21	.968	.92
4	Nil	.01	22	.978	.95
5	Nil	.01	23	.943	.80
6	Nil	.01	24	.86	.87
7	Nil	.004	25	.872	.93
8	Deionized Water		26	1.30	1.33
9	Deionized Water		27	.61	.62
10	Deionized Water		28	Hard Water	
11	Nil	.004	29	Nil	Nil
12	.968	.93	30	.968	.91
13	.978	.83	31	.978	.95
14	.943	.96	32	.943	.91
15	.86	.87	33	.86	.88
16	.872	.90	34	.872	.92
17	1.30	1.35	35	1.30	1.41
18	.61	.59	36	.61	.66
			37	Hard Water	

Table VIII

Viscosities
Centistokes

System	Initial	Final	System	Initial	Final
1	3.74	3.95	19	Hard Water	
2	6.26	5.27	20	8.62	9.48
3	6.26	6.31	21	6.60	5.86
4	6.26	6.25	22	6.52	6.24
5	3.40	3.69	23	6.58	6.44
6	3.40	3.55	24	3.72	3.94
7	3.40	3.67	25	3.69	3.57
8	Deionized Water		26	3.78	3.67
9	Deionized Water		27	3.68	3.60
10	Deionized Water		28	Hard Water	
11	8.62	8.59	29	8.62	8.88
12	6.60	6.03	30	6.60	5.87
13	6.52	6.24	31	6.52	5.91
14	6.58	6.18	52	6.58	6.10
15	3.72	3.58	33	3.72	3.55
16	3.69	3.72	34	3.69	3.81
17	3.78	4.01	35	3.78	4.00
18	3.68	3.28	36	3.68	4.00
			37	Hard Water	

Table IX

Foam Test

System	Foam Volume, ml Initial	Foam Volume, ml Final	Break Time, sec. Initial	Break Time, sec. Final
1	63	275	3.7	11.9
2	> 350	> 350	19	18.5*
3	> 350	> 350	19	20.4*
4	> 350	> 350	19	22.0*
5	45	> 350	4	15.0
6	45	32	4	4.4
7	45	341	4	11.4
8		Deionized Water		
9		Deionized Water		
10		Deionized Water		
11	55	220	1.3	9.8
12	85	> 350	10	18.1
13	> 350	> 350	15.4	21.9*
14	> 350	> 350	20	19.6*
15	45	106	2	4.1
16	40	116	3	5.6
17	50	287	3.2	11.0
18	45	130	1.0	5.1
19		Hard Water		
20	55	90	1.3	4.5
21	85	330	10	11.0
22	> 350	> 350	15.4	21.1*
23	> 350	> 350	20	20.5*
24	45	123	2	5.5
25	40	135	3	6.0
26	50	115	3.2	5.3
27	45	135	1.0	6.1
28		Hard Water		
29	55	230	1.3	11.7
30	85	227	10	6.7
31	> 350	> 350	15.4	21.8*
32	> 350	> 350	20	18.7*
33	45	65	2	1.7
34	40	89	3	2.0
35	50	92	3.2	1.9
36	45	85	1.0	1.9
37		Hard Water		

*Foamed in <5 minutes

TABLE X

Solar Heat Transport Fluid Description

See Pages 7 and 8.

Table XI

Freezing Point

System	°F	System	°F
1	-36	19	+32
2	-33	20	-37
3	-33	21	-13
4	-33	22	-34.5
5	-36	23	-36.5
6	-36	24	-35.3
7	-36	25	-35.8
8	+32	26	-36.7
9	+32	27	-35.3
10	+32	28	+32
11	-37	29	-37
12	-13	30	-13
13	-34.5	31	-34.5
14	-36.5	32	-36.5
15	-35.3	33	-35.3
16	-35.8	34	-35.8
17	-36.7	35	-36.7
18	-35.3	36	-35.3
		37	+32

Table XII

Equilibrium Boiling Point

System	°C	System	°C
1	105.8	19	100
2	110	20	108
3	110	21	104
4	110	22	105
5	107	23	105
6	107	24	108
7	107	25	107
8	100	26	108
9	100	27	107
10	100	28	100
11	108	29	108
12	104	30	104
13	105	31	105
14	105	32	105
15	108	33	108
16	107	34	107
17	108	35	108
18	107	36	107
		37	100

Table XIII

Specific Gravity

System	@ 60°F	System	@ 60°F
1	1.067	19	1.00
2	1.036	20	1.057
3	1.036	21	1.087
4	1.036	22	1.049
5	1.064	23	1.041
6	1.064	24	1.077
7	1.064	25	1.077
8	1.00	26	1.076
9	1.00	27	1.066
10	1.00	28	1.00
11	1.057	29	1.057
12	1.087	30	1.087
13	1.049	31	1.049
14	1.041	32	1.041
15	1.077	33	1.077
16	1.077	34	1.077
17	1.076	35	1.076
18	1.066	36	1.066
		37	1.00

CONCLUSIONS

1. SOLAR HEAT TRANSPORT FLUIDS

The information generated during this test period indicated that most aqueous glycol mixtures with properly designed corrosion inhibitor packages which include monethylene glycol, propylene glycol and triethylene glycol can give adequate corrosion, freeze protection, and extended boiling point in closed loop solar systems fabricated using either copper, aluminum, steel or plastic collector plates and all copper plumbing, or any combinations of them.

2. SOLAR COLLECTOR PANELS

Collector panels fabricated from steel or copper are better candidates for long life against corrosion than aluminum panels. Copper is the preferred material to resist corrosion.

In the case of the aluminum collector plate that evidouced a small pit upon X-ray inspection, it was impossible to determine when the collector plate might fail in its closed system environment. Further, one panel with one small pit out of a total of 21 panels tested and inspected by X-ray indicates the possibility that this local corrosion pit may have had its origin prior to the beginning of testing.

RECOMMENDATIONS

Zerex, a monoethylene glycol, is the recommended transport fluid. Further, it was the only solar fluid tested which can be purchased over the counter and is readily available.

Regardless of the type of solar heat transport fluid used in a closed loop active solar heating and cooling system and regardless of the combinations of hardware items that go to make up the system, every effort should be exercised to reduce to a minimum the length of time any portion of the system must be open to the atmosphere, such as during servicing and maintenance; because the flow passages of any system, exposed to the atmosphere increases the possibility of corrosion, especially in systems having parts fabricated from aluminum.

GENERAL

The reference documents indicated by [ ] throughout the text are extensions of this final report and are recommended reading to provide a more detailed understanding of the development effort under this contract. They may be obtained through DOE, Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830 or purchased from National Technical Information Service, Springfield, Virginia 22151.

REFERENCES

1. Preliminary Design Package for Non-corrosive Fluid Subsystems, Solar Heating and Cooling. DOE/NASA CR-150698, Houston Chemical Company, Pittsburgh, Pennsylvania, contract NAS8-32255, May 1978.

2. Solar Heat Transport Fluids for Solar Energy Collection Systems (a collection of Quarterly Reports) DOE/NASA CR-150560, Houston Chemical Company, Pittsburgh, Pennsylvania, contract NAS8-32255, January 1978.

3. Solar Heat Transport Fluid (a Quarterly Report) DOE/NASA CR-150612, Houston Chemical Company, Pittsburgh Pennsylvania, contract NAS8-32255, February 1978.

4. Solar Heat Transport Fluid (a Quarterly Report) DOE/NASA CR-150704, Houston Chemical Company, Pittsburgh, Pennsylvania, contract NAS8-32255, June 1978.

5. Solar Heat Transport Fluid (a Quarterly Report) DOE/NASA CR-150806, Houston Chemical Company, Pittsburgh Pennsylvania, contract NAS8-32255, September 1978.

APPROVAL

DEVELOPMENT AND TESTING OF THE HOUSTON CHEMICAL COMPANY HEAT TRANSPORT FLUID FINAL REPORT

By John C. Parker

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety has been determined to be unclassified.

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