NASA CR-
150996

FINAL REPORT

DEVELOPMENT OF AN INFLATABLE RADIATOR SYSTEM

NASA CONTRACT NAS9-13346

REPORT NO. 2-53002/6R-51338

28 MAY 1976

(NASA-CR-150996) DEVELOPMENT OF AN INFLATABLE RADIATOR SYSTEM Final Report (Vought Corp., Dallas, Tex.) 340 p HC $10.00 CSCL 20M G3/34 N76-33434 Unclas 05727

TO

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
HOUSTON, TEXAS

SUBMITTED BY

VOUGHT CORPORATION
systems division
Post Office Box 5907 • Dallas, Texas 75222
an LTV Company

FINAL REPORT

DEVELOPMENT OF AN INFLATABLE RADIATOR SYSTEM

NASA CONTRACT NAS9-13346

REPORT NO. 2-53002/6R-51338

28 MAY 1976

SUBMITTED BY

VOUGHT CORPORATION
SYSTEMS DIVISION
Dallas, Texas 75222

TO

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
HOUSTON, TEXAS

PREPARED BY:

J. W. Leach
J. W. Leach
Environmental Systems

REVIEWED BY:

J. A. Oren
J. A. Oren
Environmental Systems

APPROVED BY:

R L Cox
R. L. Cox
Project Engineer, ECS

J. C. Utterback
J. C. Utterback
Supervisor
Environmental Systems

TABLE OF CONTENTS

PAGE

TABLE OF CONTENTS (CONT'D)

APPENDICES

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

LIST OF FIGURES (CONT'D)

LIST OF TABLES

1.0 SUMMARY

This report describes work accomplished by the Vought Corporation Systems Division in developing an Inflatable Radiator System (IRS) for supplying short duration supplementary cooling of space vehicles. The program, which began in August 1973, was sponsored by NASA/JSC under contract NAS9-13346. It has resulted in conceptual designs of two flight articles, and fabrication and tests of two corresponding engineering model radiators. The designs have been supported by parametric trade studies, materials evaluation/selection studies, thermal and structural analyses, and numerous element tests. Fabrication techniques developed in constructing the engineering models and performance data from the model thermal vacuum tests will be used in refining the designs of the flight articles and in constructing a full scale prototype radiator.

One of the concepts evolved during the program uses soft (polyurethane, perfluoroelastomer, or Teflon) tubing and a thick-silvered Teflon flexible fin material. It deploys by unrolling like a party whistle, using a gas pressurant to inflate two tubes on either side of the flexible panel. Heavier deployment mechanisms such as a Storable Tubular Extension Member (STEM) may be substituted for the inflation tubes to obtain more positive control of the radiator displacement. The Teflon tubing-baseline design has three panels, each 40" wide by 25' long, with a combined 3-panel area of 250 sq.ft. and weight of 96 lb (including pumping power penalty but exclusive of fluid loop components). With polyurethane tubing the surface area and weight are increased by approximately 10%. The baseline design has a limited meteoroid lifetime (90% chance of surviving 2 days). A materials study task has been completed to extend the 90% survivability period to 30 days.

The second concept uses hard (aluminum) radiator tubes and Teflon coated silver wire mesh flexible fin material. The tubes are wound in a helical spring configuration, forming a cylinder covered by the fin material. It deploys by the inherent spring force, similar to a jack-in-the-box. The baseline design is a single cylinder 42" in diameter and 42' long, with a surface area of 463 sq.ft. and a weight of 233 lbs. The baseline design has a meteoroid lifetime of 30 days.

Engineering model test articles were fabricated and tested in the Vought twelve foot diameter vacuum chamber. The models have a reduced radiating surface area but are otherwise constructed to be as similar as possible to the flight articles so that fabrication techniques, materials evaluations, thermal performance data, and other information developed is useful for evaluating and improving the basic design. The soft tube model is 40" x 72" and the hard tube model is 28" dia x 45" length. The fin material and inflation tubing for the soft tube model were assembled at Vought using materials and manufacturing techniques expected to be employed on any subsequent prototype articles. Polyurethane tubing was bonded beween two sheets of the fin material with G.E. SR-585, a flexible adhesive. The fin material for the hard tube model was fabricated at Vought in rectangular sections of two square-foot area, and was attached to the helical tubing with nylon thread and SR-585 adhesive. Materials studies and fluid/tubing compatibility tests were conducted to determine the optimum soft tubing for fluid passages, and for selecting an appropriate transport fluid for the soft tube concept. As a result, polyurethane tubing with Coolanol 15 as the transport fluid was used in the soft tube model. Aluminum tubing with Freon 21 was selected for the hard tube model.

Each of the models was subjected to repeated deployment/retraction cycles to test their durability and tractability in adverse environments. Thermal vacuum tests were performed to evaluate the heat rejection capabilities of the radiators and to obtain data on operating temperature limits, flow distribution in parallel tubing networks, joint conductances at the fin/tube interfaces, and effective surface emissivities. Supporting element tests were conducted to determine material stiffness at ambient and low temperatures and to provide early thermal performance data during design development.

The tests results are very favorable, and give a strong indication that the IRS can be made to be superior in performance, cost and weight to conventional radiator systems. The thermal performance of the hard tube model was very near the expected level, and the radiator could be deployed and retracted in a cold vacuum environment without difficulty. The effective surface emissivity inferred from test data, which includes radiation transmitted through the surface but originating at other points on the radiator, is approximately 0.83. The average fin efficiency is 0.85 and the average heat rejection for a deep space environment is 87.6 BTU/hr-ft^2. The soft tube model also performed approximately as predicted. The surface emissivity of the soft tube model inferred from test data is 0.68, and the average fin efficiency is 0.72. The heat rejection for a deep space environment is 43.4 BTU/hr-ft^2. Some difficulties were experienced in attempting to re-deploy the radiator after it had been retracted in a cold environment, and the thermal performance was not as high as had been predicted. However, the radiator construction proved to be more flexible than had been anticipated, and the model showed very little wear or degradation in performance after more than fifty deployment/retraction cycles. The deployment difficulties were caused by gravity effects which were not accounted for in the test setup for simulating the retraction mechanism These difficulties can be corrected in the final design. The reduced thermal performance is apparently caused by out of tolerance variations in the thickness of the silver layers of the fin material, and may require modifications in the baseline design.

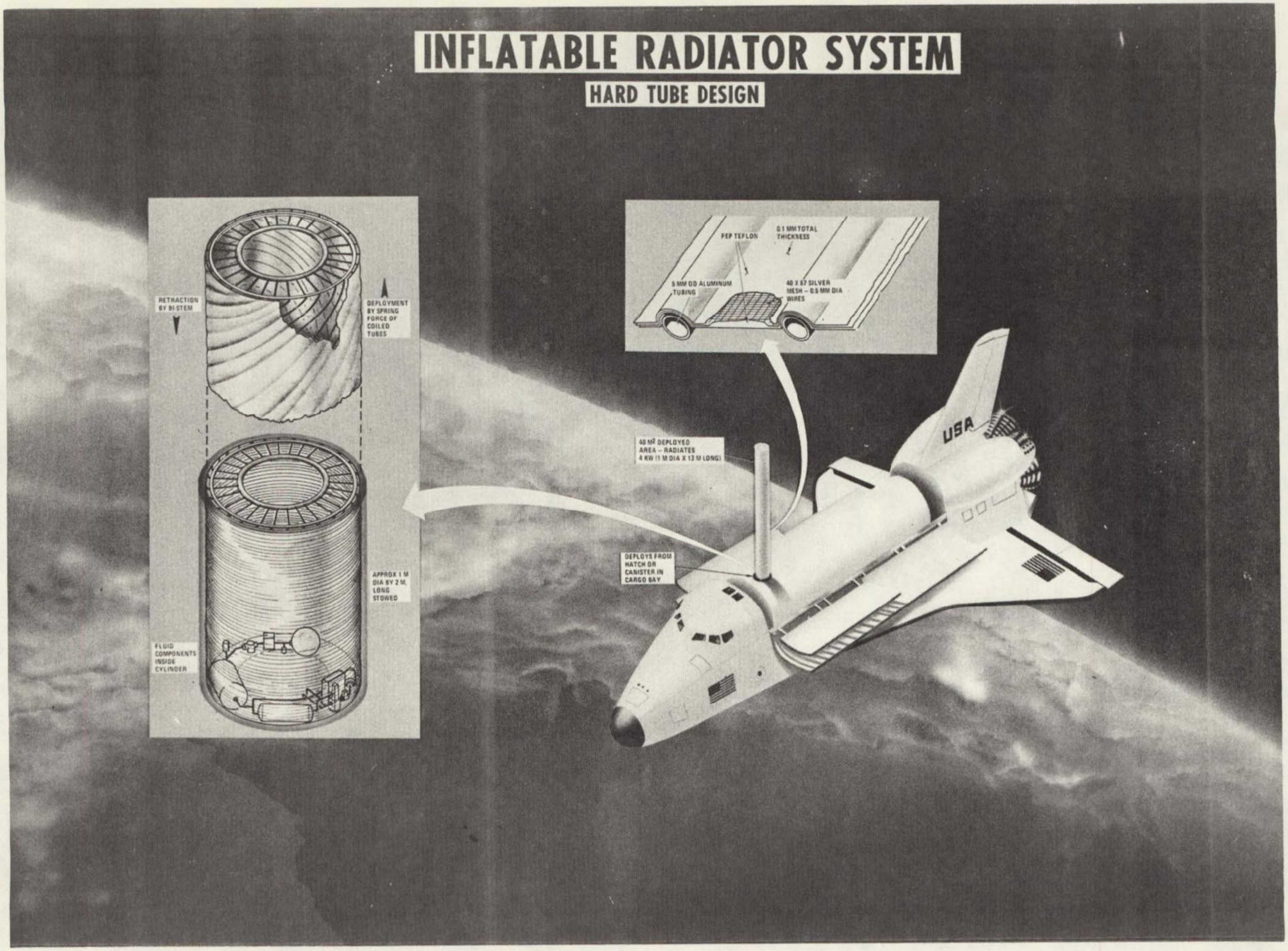
Several important facts relavent to the design and construction of a full scale IRS were established. The soft tube concept results in lighter system weight and consequently higher heat rejection per unit mass than the hard tube concept. The soft tube radiator is much easier to assemble from its components than the hard tube radiator. The quality of the silver wire mesh/Teflon fin material is much easier to control than that of the thick film silver backed Teflon material, and has slightly better thermal properties. The soft tube design with polyurethane tubing is very flexible, and it is likely that stiffer tubing with higher strength and capacity to withstand longer durations in a meteoroid environment are possible. Additional trade studies involving the stiffness of candidate tubing materials, fluid properties, and the weight of deployment mechanisms appear to be justifiable. The operating temperature range possible with Freon 21 as the transport fluid is approximately -125°F to +200°F. The corresponding ranges for Coolanol 15 is -10°F to +160°F.

2.0 INTRODUCTION

Conventional radiators, such as those of the Apollo and Gemini programs, are structurally integral with the vehicle skin, while the Space Shuttle Orbiter radiators line the interior of the cargo bay door. Experiments that exceed the capacity of the primary system require additional radiating surface area which cannot be readily provided with fixed radiators, and thus establish a requirement for a versatile auxiliary radiator system. The flexible deployable-retractable radiator concept permits the packaging of the radiator into a compact unit which can be attached to the vehicle structure or hatch prior to or after launch. On-orbit, the radiator may be deployed or retracted as shown in Figures 1 and 2 to provide the radiating surface area needed for a specific experiment. The unit may be independently developed and qualified as a heat rejection system which will then be ready for any spacecraft or experiment, and which will not require significant structural and systems accommodation.

The flexible radiator fin material should provide high thermal conductance and emittance, resistance to degradation caused by ultraviolet radiation, and strength and flexibility in a cold environment. Transport fluids and tubing materials should be selected for optimum thermal performance and pumping power requirements, operating temperature range, chemical compatibility, and survivability in a micrometeoroid environment. To satisfy these objectives a unique composite fin material has been developed, extensive materials evaluation studies have been performed to select transport fluids and tubing, and numerous tests have been conducted to evaluate radiator thermal performance, materials compatibility, packaging characteristics, techniques for deployment and retraction from a stowed volume, and methods for interfacing with spacecraft coolant hardware. Two feasibility demonstration flexible radiator articles representing alternate deployment concepts and radiator fin/transport fluid/tubing materials combinations have been fabricated and tested in a thermal vacuum environment.

The radiator fin material developed for the flexible radiator system has outer layers of FEP Teflon which provide structural strength and resistance to chemical attack, and increases the radiating surface emittance. The thickness of the layers is computed from effective surface



INFLATABLE RADIATOR SYSTEM

HARD TUBE DESIGN

FIGURE 1 METAL TUBE FLEXIBLE DEPLOYABLE RADIATOR CONCEPT

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

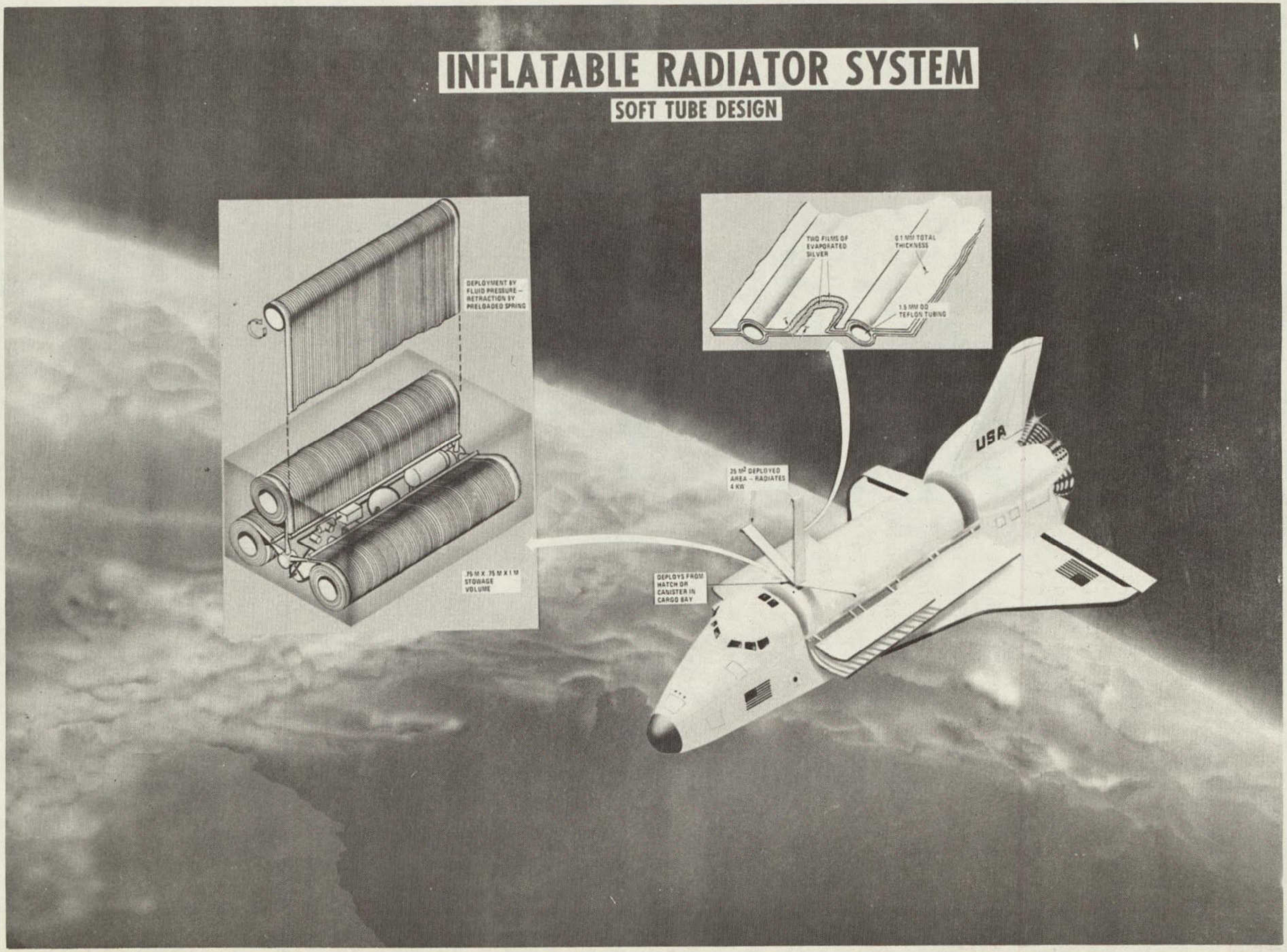


FIGURE 2 SOFT TUBE FLEXIBLE DEPLOYABLE RADIATOR CONCEPT

emittance data to optimize the performance and weight of the panel. Silver metal is vapor deposited on the interior surfaces of the Teflon to provide thermal conductance and to reflect incident solar radiation. The resulting composite surface has a very high ratio of emittance to solar absorptance, and protects the interior structure from damaging ultraviolet radiation. The thickness of the silver layer may be increased to give high thermal conductance. Alternately, high conductance can be effected through silver wire mesh which is fusion bonded to the interior surface of the Teflon. The transport fluid tubing diameter and spacing are selected to minimize the system weight including pumping power penalty and structural mass for protection from meteoroid penetration.

The basic purpose of transport tubing is to provide long operating lifetime in a meteoroid environment, a wide operating temperature range, pressure retention, and flexibility and strength consistent with the deployment/retraction system. The characteristics of transport fluids which influence fluid selection are: boiling point (or vapor pressure), fire point, pour point, toxicity, thermodynamic and transport properties, and compatibility with the tubing material. A materials evaluation study evaluated metal tubing and a great variety of flexible materials including fluoroelastomers, perfluoroelastomers, thermal and thermoplastic polyurethanes, polypropylenes, polyethylenes, polyester and silicone elastomers, and various types of rubber and fluorinated polymers. Fluids surveyed included fluorocarbons, silicate esters, and silicone fluids. The study identified three fluid and tubing combinations: Coolanol 15 with polyurethane tubing, Freon 21 with aluminum tubing, and Freon 21 with Teflon tubing which satisfy the flexible radiator design requirements. Screening tests consisting of chemical compatibility, flexibility, and long term thermal exposure testing were conducted for selected material combinations, and numerous thermal performance element tests were made to develop the radiator fin materials.

Two feasibility demonstration radiators were fabricated and tested in a vacuum environment to evaluate overall system thermal performance and deployment concepts. The test article shown in Figure 3 is constructed with

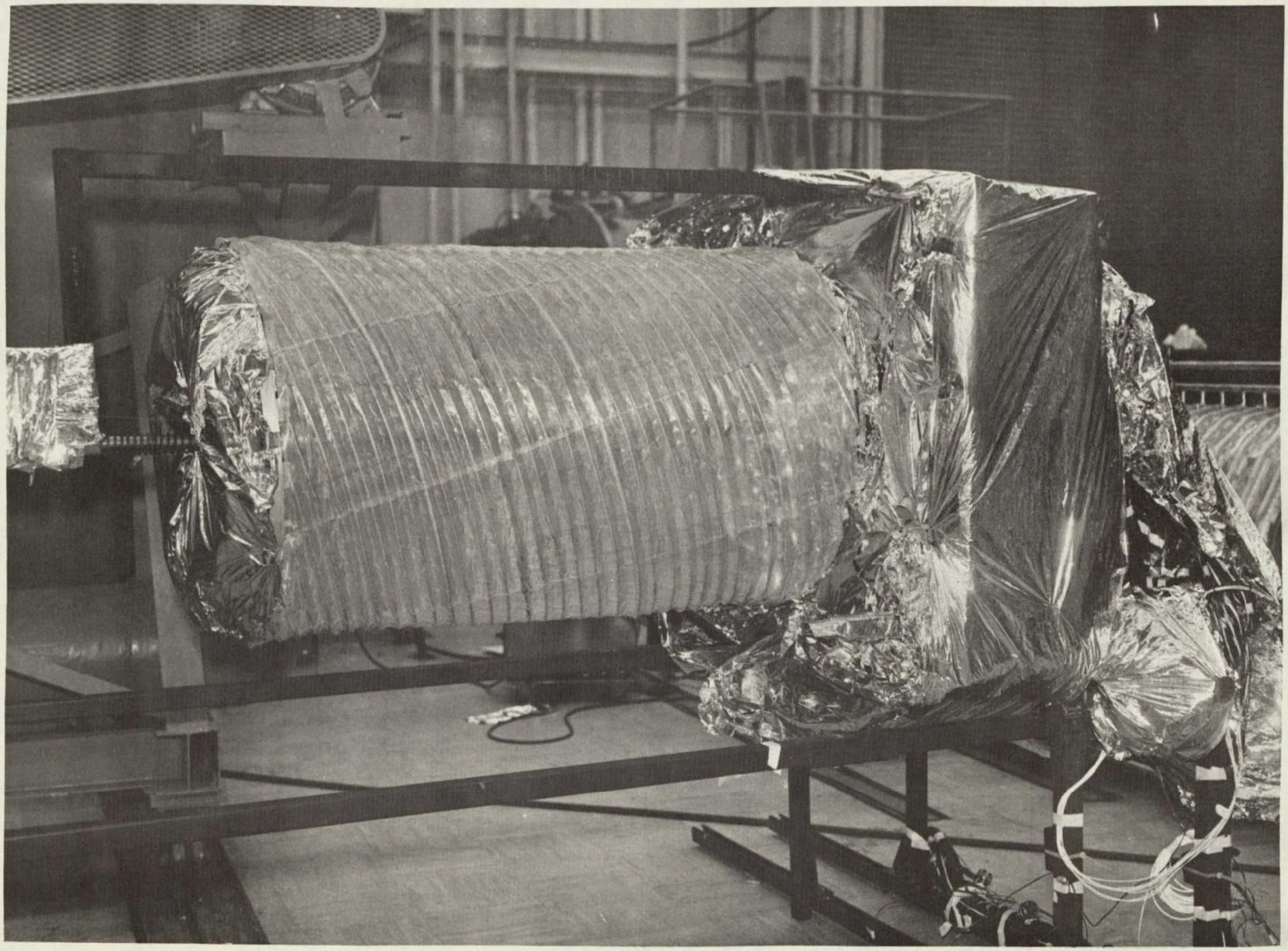


FIGURE 3 METAL TUBE FLEXIBLE RADIATOR TEST ARTICLE

aluminum fluid passage and deploys from the inherent spring force of the coiled tubing: a motor driven cable or boom compresses the coils to retract the radiator. The other test article, shown in Figure 4, has flexible tubing and is stored on a cylindrical drum. Deployment forces are supplied by a gas pressurant which inflates two tubes or either side of the flexible panel causing the radiator to unroll like a party whistle. Heavier deployment mechanisms such as Storable Tubular Extendible Member (STEM) may be substituted for inflation tubing in the flight design to obtain very precise control of the radiator displacements. Table I compares the construction and performance of the two feasibility demonstration articles. The results show that the metal tube concept has the widest operating range whereas the flexible tube concept has lighter weight.

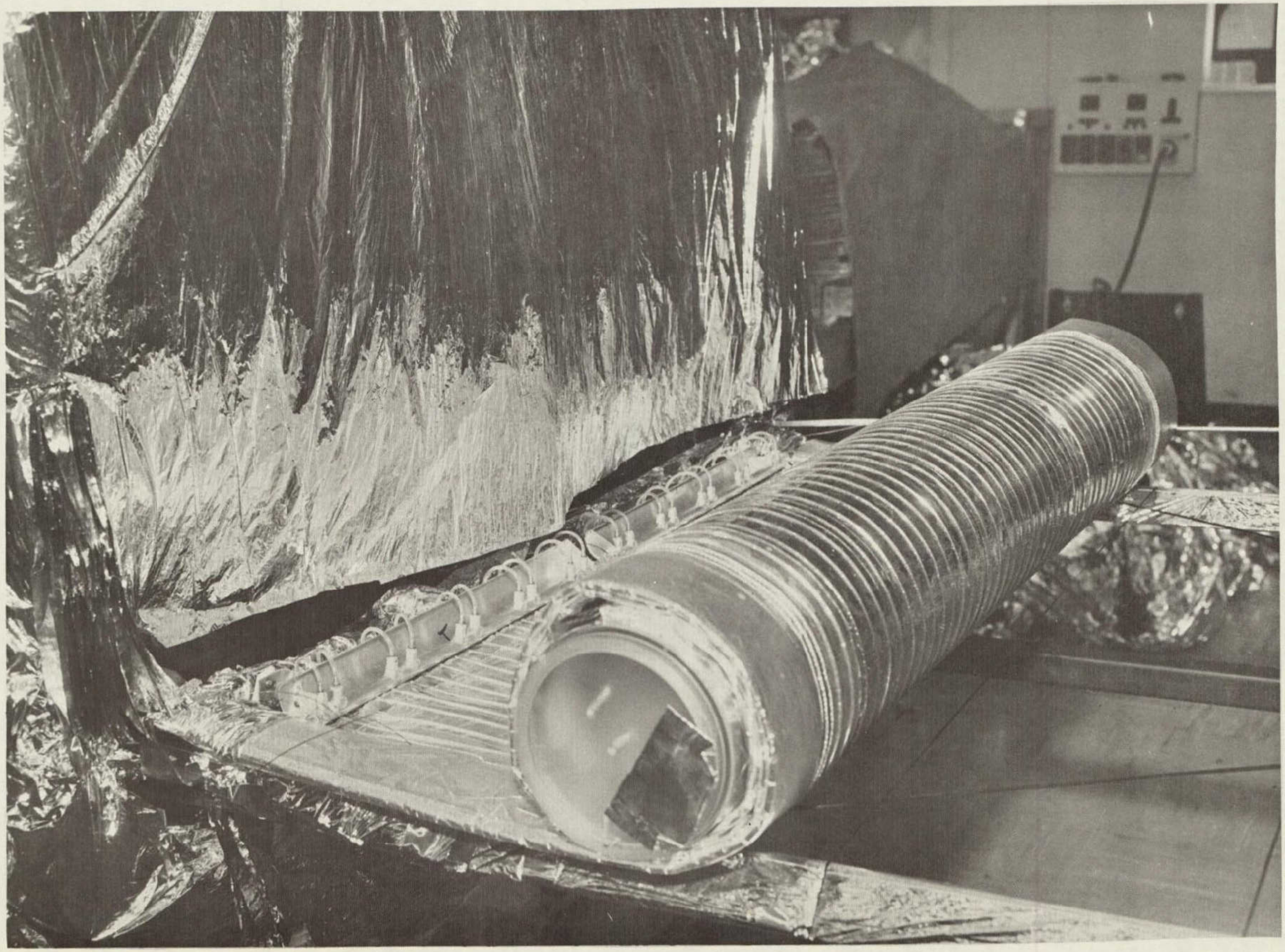


FIGURE 4 SOFT TUBE FLEXIBLE RADIATOR TEST ARTICLE

TABLE I COMPARISON OF FEASIBILITY DEMONSTRATION FLEXIBLE RADIATORS

	METAL TUBE RADIATOR	FLEXIBLE TUBE RADIATOR
TUBING MATERIAL	ALUMINUM	POLYURETHANE
TRANSPORT FLUID	FREON 21	COOLANOL 15
FIN MATERIAL	SILVER WIRE MESH/TEFLON	THICK LAYER SILVER/TEFLON
DEPLOYMENT FORCE	COILED TRANSPORT TUBING	INFLATION TUBING
MODEL DIMENSIONS	28" DIA X 45" (0.7M DIA X 1.14 M)	40" X 72" (1 m X 1.85m)
TUBE SPACING	1.5" (.038M)	1.0" (.025M)
RADIATOR FIN EFFICIENCY	0.85	0.72
EFFECTIVE SURFACE EMITTANCE	0.83	0.68
UPPER OPERATING TEMPERATURE LIMIT	300°F (450°K)	200°F (367°K)
LOWER OPERATING TEMPERATURE LIMIT	-140°F (178°K)	-20°F (245K)
WEIGHT	4.8 kg/m^2	1.9 kg/m^2

TABLE II

DESIGN REQUIREMENTS SUMMARY - FULL SCALE SPACE APPLICATION

THERMAL ENVIRONMENT	HOT: 55° X 100 N.MI. SUN ORIENTED COLD: FACING DEEP SPACE
MAXIMUM HEAT LOAD	4 KW
FLUID INLET TEMPERATURE	HIGH LOAD DESIGN POINT : 100°F HOT OPERATING LIMIT : 200°F
FLUID OUTLET TEMPERATURE	GOAL OF 40°F OR LOWER; 50°F MAX
VEHICLE PHYSICAL INTERFACE	ATTACHMENT TO AND DEPLOYMENT FROM MINIMUM VOLUME CANISTER. HEAT EXCHANGER INTERFACE. DESIRE POTENTIAL FOR DIRECT TIE-IN WITH VEHICLE LOOP.
ACCELERATIONS (DEPLOYED)	PER CURVE FOR 950-LB RCS STABILIZATION (MAX. 0.02-g END OF 50' IRS)
MINIMUM TEMPERATURE (MATERIALS)	-250°F
ATMOSPHERIC DRAG	— INCLUDE IN STRUCTURAL ANALYSIS

TABLE III

RADIATOR REQUIREMENTS FOR VARIOUS VEHICLES

VEHICLE	FLOWRATE/ FLUID	MAXIMUM HEAT LOAD(BTU/HR)	HEAT LOAD RANGE (BTU/HR)	RADIATOR INLET TEMP. °F	RADIATOR OUTLET TEMP. °F	ENVIRONMENT
Shuttle (Reference 18)	2200 Lb/Hr Freon 21	71,450	7550-71,450	164.0	40.0	100N.M.-270N.M. Orbits 0-90 Deg. Inc.
Space Station Prototype (Reference 19)	29,200 Lb/Hr Freon 21	155,000	Not Defined	56	34	255N.M. Orbit 55° Inc.
Modular Space Station (Reference 20)	Not Defined Probably Freon 21	27,425 Any One Module	Not Defined	Not Defined	40	270N.M. Earth Orbit
Spacelab (Reference 21)	Freon 21	46,250	Not Defined	Not Defined	40 For manned experiments; undefined for unmanned	Same as Shuttle

IRS was selected as the smallest of the potential envelopes of the docking hatch for the Modular Space Station, and airlock for the Spacelab and the docking module of the Shuttle Orbiter. By designing for the smallest envelope this insures the IRS could be integrated into the other potential locations. Capacity for deployment from the stowage compartment is a groundrule, and retractability is a likely mission requirement but was not considered necessary for initial feasibility demonstration.

The requirements summarized in Table II were established early in the development program to provide a starting point for designing the inflatable radiator system. Additional information on groundrule selection and mission requirements has evolved during the course of the program and should be incorporated into the designs of subsequent prototype programs. Of particular importance are constraints imposed by micrometeoroids and ultraviolet radiation. The effects of these environmental factors on the radiator design are discussed in separate sections below. Additional

3.2 Initial Concept Selection

The design requirements and groundrules of 3.1 provided a starting point for the generation of IRS concepts. The feasibility of these various concepts were then evaluated on the basis of screening criteria, which reflected the design requirements and performance evaluation considerations. This section describes the screening criteria and presents a series of concept formulations/evaluations for the two key aspects of an IRS design the radiator system itself and the associated packaging/deployment technique. The "radiator system" consists of the inflatable radiator panel(s), the transport fluid, and any associated pumps, valves, and heat exchangers. Finally, two concepts selected for development and testing are described

3.2.1 Screening Criteria

The screening criteria established for selecting IRS concepts is given in Table III-A. The criteria fall into three general categories, radiator system considerations, radiator panel design and fabrication considerations,

TABLE III-A
PROPOSED INFLATABLE RADIATOR SYSTEM CONCEPT
SCREENING CRITERIA

RADIATOR SYSTEM CONSIDERATIONS:	RADIATOR DESIGN & FABRICATION CONSIDERATIONS:	PACKAGING AND DEPLOYMENT CONSIDERATIONS:
o Thermal Performance	o State-of-the-art	o Radiator flexibility
o Operating Constraints	o Structural integrity	o Packaged volume of radiator
o Degradation in space environment	o Manifolding	o Packaged volume of other components
o Pressure drop/pumping power requirements	o Fluid compatibility	o Deployed dynamic stability
o Heat exchanger requirements	o Failure modes	o Deployment mechanism complexity
	o Cost	o Retraction capability
		o Packaged weight of system

and packaging and deployment considerations. Application of the criteria at a general level is demonstrated below for the selected concepts.

3.2.2 Radiator Concept Formulation and Evaluation

Elements to be considered in radiator concept formulation include transport fluids, transport tubing and radiator fin materials, and tube-fin geometric configurations. Documentation supporting the selection of materials for the IRS and detailed technical data on material properties are given in section 3.5. General information on materials requirements relevant to selection of an inflatable radiator concept are given below.

The major considerations in selecting a transport fluid are:

- Operating pressure (desired low for IRS structural simplicity)
- Freezing or pour point (condensation temperature for gases)
- Stability of composition
- Thermal performance
- Pressure Drop Performance
- Toxicity
- Compatibility
- Variation of properties over the design temperature range
- Availability
- Cost

These considerations reflect application of the general screening criteria (e.g., thermal performance, operating constraints) to the specific task of fluid screening.

Considering these characteristics, three liquids, Freon 21, Freon E-2, and Coolanol 15, were identified for use in design studies of the inflatable radiator. In addition, use of a gaseous transport fluid was considered and one gas (nitrogen) was selected for further evaluation.

Liquid Transport Fluid Screening

The operating pressure required to preclude fluid phase change is a predominant liquid transport fluid screening criterion for inflatable radiator applications, since to be flexible the radiator material must be thin and hence the burst pressure relatively low. Table 4 lists some typical liquid coolants and their vapor pressures at 200°F. This gives an indication of required operating pressure for a test heat source to provide 160°F inlet temperature.

The freezing point of the fluid is also important for radiator applications since it sets the lower limitation on heat load control, i.e., the lowest amount of heat rejection possible with the radiator still having the capability of recovering to high heat load. Radiator systems are generally sized to reject the maximum heat load under the worst thermal environment which could reasonably be expected for the mission. Heat loads and environments are not usually constant for an entire mission and thus under a lower heat load (lower inlet temperature) at a lower environment the radiator outlet temperature would fall below the design value. If the radiator system is used to cool a EC/LS water system for instance as is the case in the Shuttle, Space Station and Sortie Labs and the return temperature fell below 32°F, the water loop could be frozen and thermal control of the cabin lost. For this reason control of the amount of heat rejected by the radiator is required. The various ways of accomplishing heat load control through fluid system design are discussed in Reference (1), and the limitation of all these methods is the freezing point of the fluid. Since it would be desirable to have a wide heat load range for multiple mission capability, it is desirable to have a coolant with as low a freezing temperature as possible. Table 4 gives the freezing point of selected liquid coolants.

The combined requirement of low operating pressure and low freezing point is sufficient to screen the liquid coolants quite extensively. In general, liquids with a low freezing point have a high vapor pressure at design temperatures. Of the fluids listed in Table 4 , Freon E-2 and Coolanol 15 were identified as fluids which can be operated at 15 psia and have low freezing points. Freon 21 was also selected for further study although its operating pressure is relatively high (165 psia) for a

TABLE IV

LIQUID COOLANT CHARACTERISTICS

FLUID	VAPOR PRESSURE AT 200°F,PSIA	FREEZING OR POUR POINT °F	BOILING POINT AT 1 ATM. °F
Freon TF-DuPont	54	- 31	117.6
Freon E1-DuPont	73	-246	105.4
Freon E2-DuPont	10.3	-190	220.0
Freon E3-DuPont	2.1	-160	306.1
Freon E4-DuPont	.58	-138	380.8
Freon E5-DuPont	.185	-119	435.6
Coolanol 15	.155	-140	440.0
Coolanol 25	.0031	-120	590.0
Coolanol 35	.0031	-120	625.0
Coolanol 45	.0001	- 85	650.0
Therminal FR	.27	- 40	432.
Therminal FR-0	.026	- 15	570.
UCON HTF - L20	.0019	- 40	-
UCON HTF - 10	.0019	- 45	-
UCON HTF - 14	.0019	- 35	-
Freon 112	15	79	199
Freon 113	54	- 30	118
Freon 114B2	54	-167	117
Freon 11	103	-168	75
Freon 21	165	-211	48
Freon 114	180	-137	39
Freon C318	260	- 42	21.5
Freon 12	430	-252	-22
Freon 22	680	-256	-41
RS 89A	17	- 80	240
FC-25	1.9 @ 120	- 80	216
FC-43	5 @ 77°F	- 40	345
Oronite 8786	<1	-100	-
Oronite 7277	<1	- 35	-
Oronite 70	<1	-100	-
FC-77	2.3 @ 120°	-100	-

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

TABLE IV
LIQUID COOLANT CHARACTERISTICS (CONT'D)

FLUID	VAPOR PRESSURE AT 200°F, PSIA	FREEZING OR POUR POINT °F	BOILING POINT AT 1 ATM. °F
FC-78	<1 @ 77°F	-122	122
UC LB-165	<.1	- 50	-
SF-85	<.1	-120	-
F-50	Low	-100	-
L-45	Low	- 67	-
Oronite M-2	<.6	-110	-
Oronite 8200	<2.0	-100	-
DC 210	<2.5	- 85	-

flexible system. This selection was based on the use of Freon 21 in the Shuttle heat rejection system and its probable use in the Sortie Lab and Space Station Systems. The required operating pressure of F-21 is no problem for a "hard" system such as the Shuttle design and this fluid has significant other advantages which led to its selection for the Shuttle application. Freon 21 has a low freezing point (-211°F) and the viscosity is not sensitive to temperature as are many other low temperature freezing point fluids, including Coolanol 15 and Freon E-2. Freon 21 is compatible with most materials and, although somewhat toxic, is not highly lethal. In addition to these advantages Freon 21 was selected for further study since use of this fluid would make it possible to directly integrate the IRS with the primary fluid system of the Shuttle, Sortie Lab, or Space Station, thus eliminating the requirement for a IRS - primary coolant system heat exchanger.

The fluids selected have good thermal properties, and are not highly toxic, although they would be required to be isolated from inhabited areas. They have stable composition, are compatible with most materials and are available at reasonable cost.

Gas Transport Fluid Screening

Although not generally considered for conventional space radiator systems, gases are worthy of investigation as candidate transport fluids for an inflatable radiator system. Gas storage volume requirements are small, and a gas could act as both the inflation medium and a low pressure transport fluid in an IRS. A gas radiator obviously requires a heat exchanger interface with the spacecraft fluid system, but such an interface may well be a baseline IRS requirement. The primary disadvantage of gases is a potential large pumping power requirement. However, an inflatable gas radiator can potentially be configured with large, low pressure drop flow passages without incurring a severe penalty in radiator weight or transport fluid weight.

An important consideration in the evaluation of gases as inflatable radiator transport fluids is their condensation temperature. If the gas condenses in the operating temperature/pressure range of the radiator system, deflation of the radiator may result, with a coincident decrease in performance. As shown in Table 4 , the vapors of most transport fluids have one atmosphere boiling points in excess of 40°F and would condense under low-load radiator operating conditions. Thus the fluid selection is limited to substances which are normally called "gases", such as nitrogen, helium and hydrogen.

These gases can be evaluated from the standpoint of thermal and pressure drop performance in the same manner that liquid transport fluids have been evaluated in the past (Reference 11). Since large convective heat transfer coefficients will be required, it is the turbulent flow performance which is of interest. Values of turbulent flow pump power parameter (ψ_T) and turbulent conductance parameter (η_T) are shown in Figure 5 for nitrogen, helium and hydrogen at one atmosphere pressure and as a function of temperature. These parameters are dependent only upon fluid properties and are proportional to the pumping power and conductance, respectively. Low values of pumping power parameter are desirable, while high values of conductance parameter correspond to low fluid-to-wall temperature differences which are desirable. From a pumping power standpoint, nitrogen is seen to be somewhat worse than helium, while hydrogen is the best of the three. It is interesting to note that the pumping power requirement for gases increases with temperature as a result of the increase of gas viscosity with temperature. This effect is the opposite of that experienced in liquids, which require more pumping power as temperature decreases and viscosity increases. From a conductance standpoint, hydrogen and helium are seen to be somewhat better than nitrogen. However, the disadvantages of hydrogen (combustibility) and helium (leakage tendencies) tend to offset their pumping power and conductance advantages. The availability and reasonable performance characteristics of nitrogen make it the logical transport fluid for further design studies of a gas inflatable radiator.

IRS Tube-Fin Concept Screening

For a conventional radiator, the primary consideration in tube-fin configuration selection is the detail tradeoff involving radiator weight and pumping power penalty. However, inflatable radiator tube-fin concepts are first subject to a general screening on the basis of their

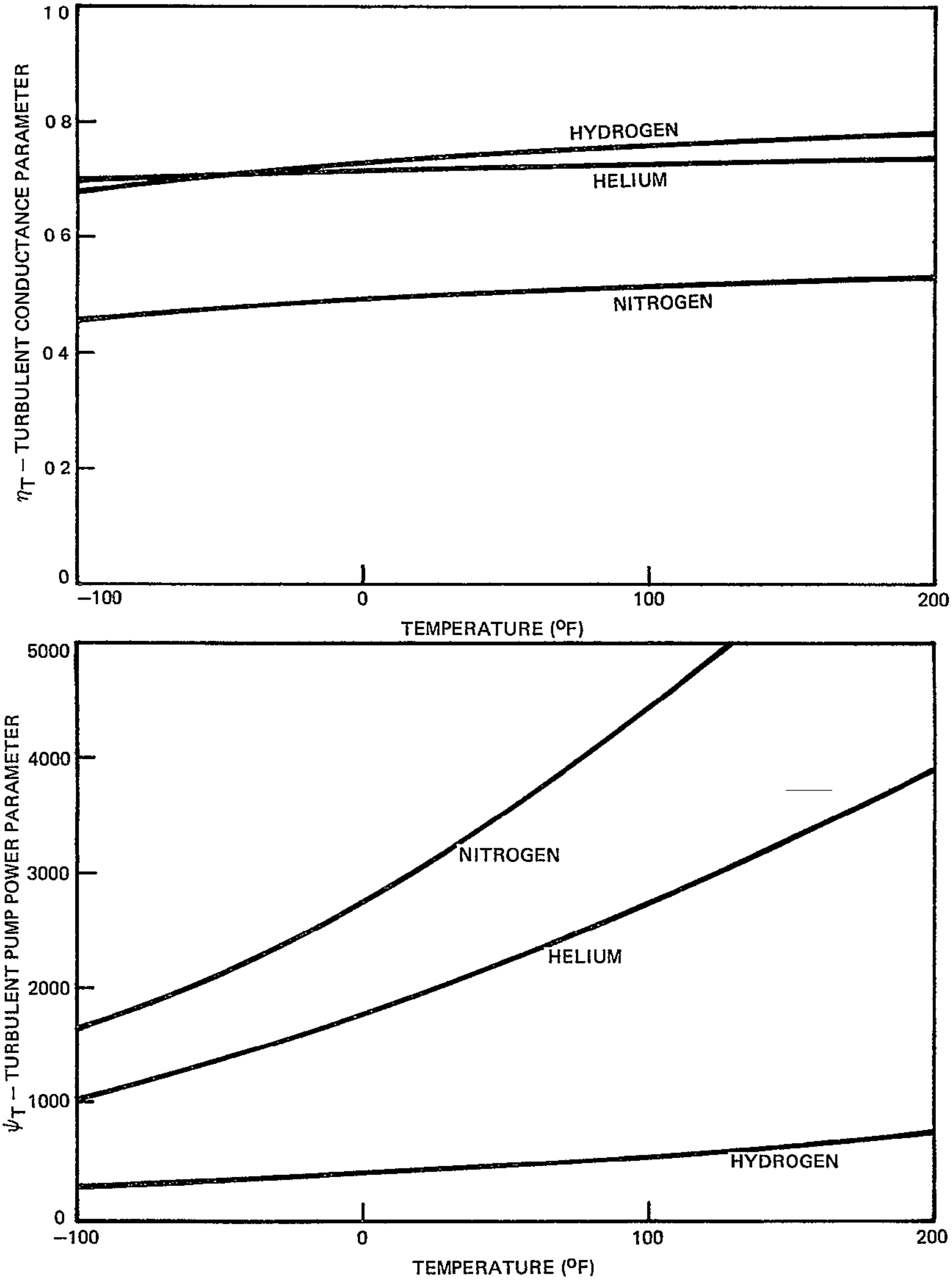


FIGURE 5 TURBULENT FLOW PUMP POWER AND CONDUCTANCE PARAMETERS FOR GASES

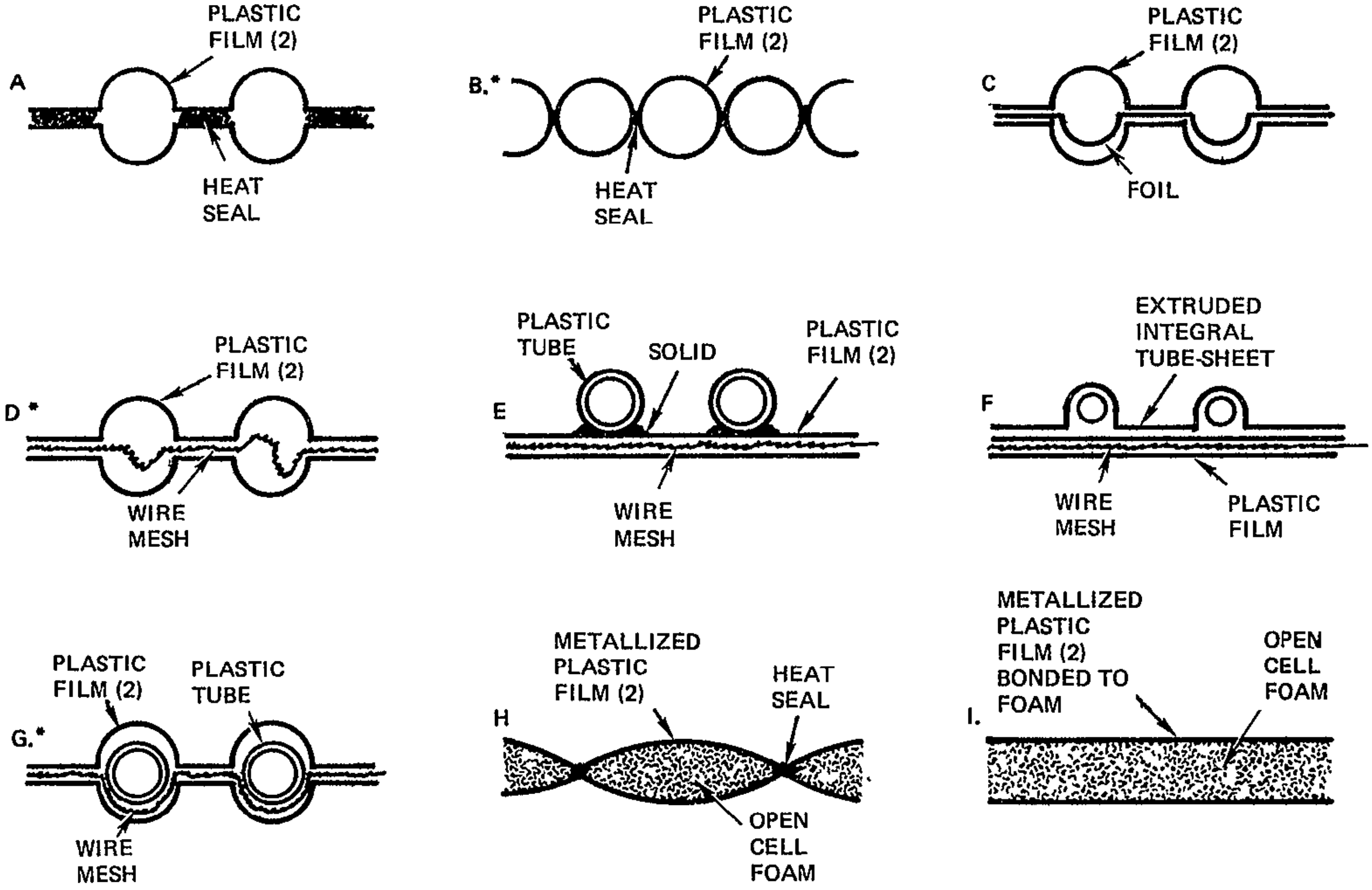
flexibility, fabricability, and structural integrity under the operating temperature and pressure condition of the associated transport fluid. A sequence of concept formulation is illustrated in Figure 6 and the results of the screening process are discussed below.

Concept A is formed by laminating two sheets of flexible material ("plastic") together in such a way as to form fins and flow passages upon inflation. The area which forms the tube walls may be metallized for use with the liquid transport fluids in order to reflect solar radiation. The fin area (and the tube area in the case of the gas transport fluid) requires no metallization since, in general, the materials utilized will be transparent to solar radiation. It is a very simple concept, but is unsuitable for use with the Freon 21 transport fluid because the high pressures involved are likely to cause delamination or a tearing failure at the flow passage. The configuration is also thermally unsuitable for the low pressure liquid (Freon E-2) and gas (Nitrogen) transport fluids because of the low thermal conductivity and correspondingly low fin effectiveness.

Concept B represents the logical extension of Concept A for the case of the gas transport fluid. Since the transport fluid mass is a small portion of the total mass in a gas radiator system, it is feasible to make the entire radiating area (except for inter-tube seals) tube area. Thus Concept B eliminates the fin effectiveness problem of Concept A by eliminating the fins. Concept B was selected as the baseline configuration for the gas transport fluid, and subsequent materials selection and system optimization studies for it are discussed in Section .

In an attempt to improve the thermal performance of Concept A for the case of the low pressure liquid transport fluid, Concept C was formulated. Here a metal foil is included in the lamination to improve fin effectiveness. The problem which immediately arises is fabrication of the laminate. With the foil in the interface, sealing is not possible. If a gap is left in the foil for heat sealing the resulting fin effectiveness is unacceptable.

This problem is overcome by Concept D, which employs a wire mesh in the laminate. This mesh allows the face materials to be laminated through



*SELECTED FOR FURTHER EVALUATION

FIGURE 6 SOME INFLATABLE RADIATOR TUBE-FIN CONCEPTS the mesh gaps. A mesh can be selected with high solar reflectivity, and can extend across the tube flow passage and tends to enhance convective heat transfer. Concept D was selected as the baseline tube-fin configuration for the low-pressure liquid transport fluid, and details of materials and system optimization studies for it are also presented in Section

Concept E represents a first attempt at a design for the high pressure transport fluid. It consists of flexible plastic tubes bonded to a plastic-wire-plastic laminate layup such as that of Concept D. This concept was deemed difficult to manufacture. In addition, the thermal performance and flexibility characteristics of the tube-fin bond were considered questionable.

Concept F resembles Concept E except that one sheet of the laminate includes integral extruded tubes. This eliminates the tube bonding problem, but feasibility of manufacturing the required extrusion (with the fin portion thin enough to be flexible) was investigated and found to be poor.

Concept G incorporates the flexible plastic tube of Concept E into the laminate itself. It is essentially the same as Concept D, with the tube inserted in the flow passage to provide structural integrity under the relatively high pressures of the Freon 21 system. This appeared to be a promising concept and was selected for further evaluation in the Design Studies Section.

To illustrate the variety of tube-fin concepts evaluated during this effort, Concepts H and I are presented. Concept H consists of an open cell form inserted in the flow passages of a concept such as B. The intent of this approach is to enhance heat transfer and maintain a favorable flow passage shape. Note that the laminate faces must be metallized for low solar absorptivity, since the foam would be expected to have a relatively high absorptivity. The difficulty with Concept H lies in the fact that the foam tends to deform as the radiator is inflated and the passage tries to assume a circular shape. Concept I represents an attempt to eliminate this problem by bonding facesheets to the open cell foam. Performance calculations showed that the flexibility and pressure drop characteristics are unacceptable, so they were screened out on that basis.

In the concept screening, consideration was also given to use of pyrolytic graphite with its high lateral thermal conductivity, for fin effectiveness enhancement. The various properties of pyrolytic graphite are discussed in Reference 12. In summary, pyrolytic graphite has a lateral thermal conductivity of 200 BTU/hr-ft-°F as compared with 217 BTU/hr-ft-°F for copper. However, its transverse thermal conductivity is some 200 times lower. It is relatively expensive and its attractive thermal transport properties are offset by a high solar absorptance, which would dictate use of a reflective coating. In addition, it requires a hot substrate (1900°F to 4400°F) for proper vapor phase deposition, thus precluding its use with polymer films. It is brittle, with a typical minimum bend radius of 1/8" for ribbon in the 0.0002" thickness range. This brittleness would make stowage/deployment of the inflatable radiator difficult. Thus pyrolytic graphite was eliminated from further consideration on the basis of this screening.

In summary, a series of tube-fin concepts have been evaluated. Concepts B, D, and G were selected as examples for detail design study for the gas transport fluid system and the low pressure and high pressure liquid transport fluid systems, respectively.

3.2.3 Deployment Concept Formulation and Evaluation

In this section several concepts for deploying the inflatable radiators are discussed and screened in order to select candidates for more detailed analysis in design studies. The screening criteria, as given specific definition for deployment concept evaluation, are

- Complexity
- State-of-the-art
- Volume
- Weight
- Power
- Stowability
- Installation Complexity
- Potential for Retractibility

Figures 6-A and 6-B show the concepts considered in this section.

Transport Fluid Inflatation - Figure 6-A shows several panel configurations which could be deployed by filling the fluid passages with

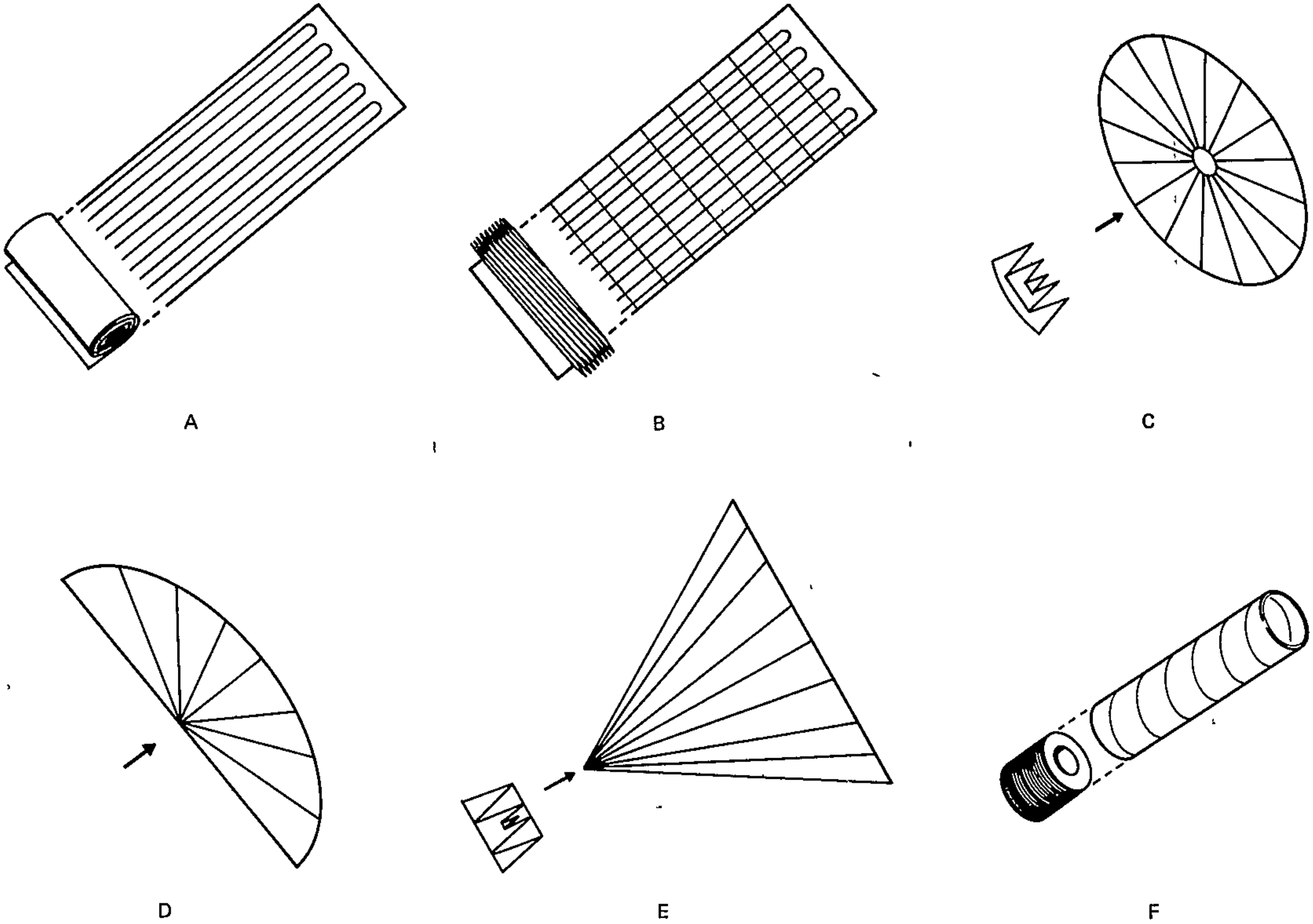


FIGURE 6-A TRANSPORT FLUID INFLATION DEPLOYMENT CONCEPTS

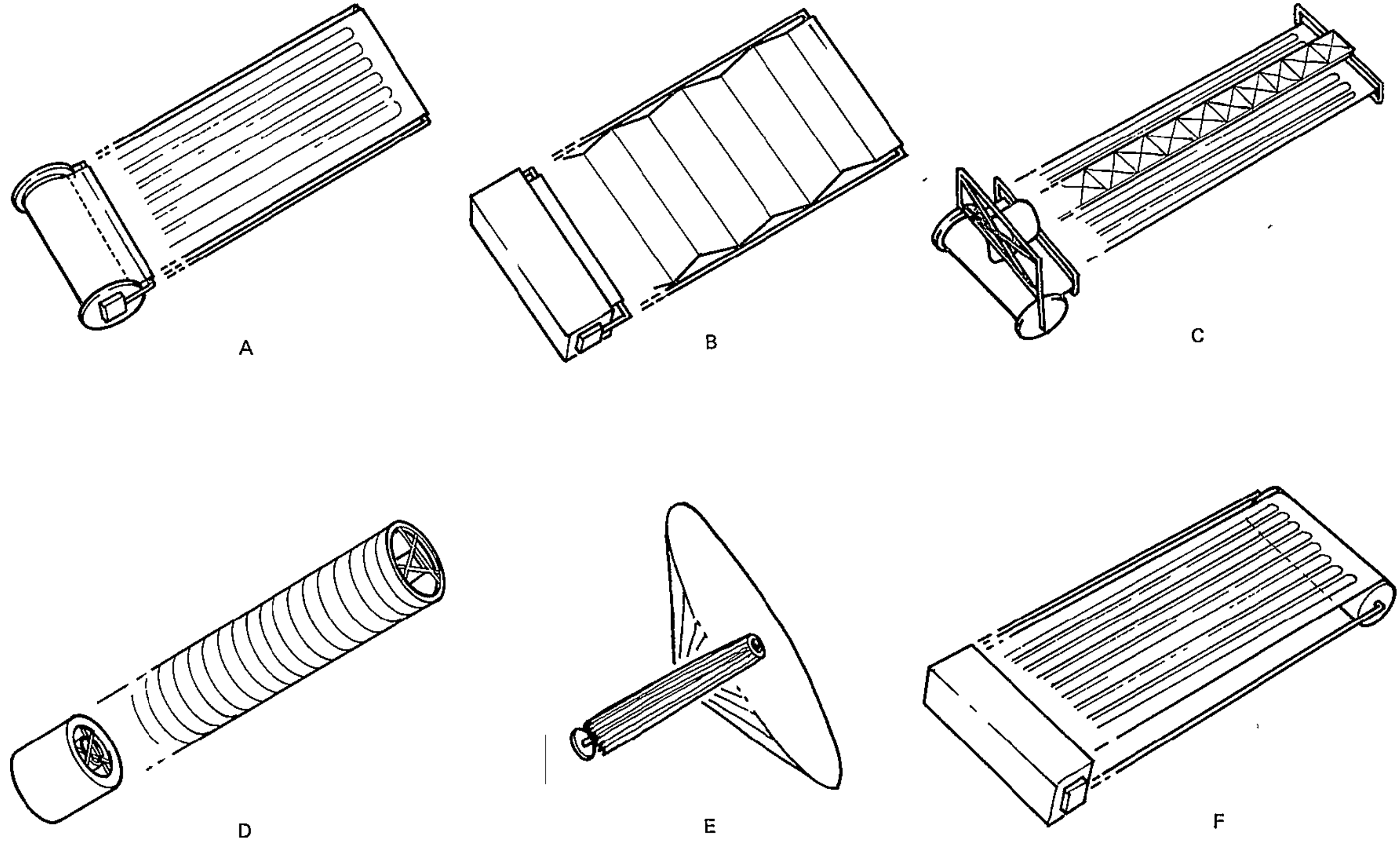


FIGURE 6-B MECHANICAL DEPLOYMENT CONCEPTS

transport fluid. Virtually any panel shape can be folded or rolled into a compact package and deployed in this manner. The package shape would be somewhat dependent upon the deployed panel shape. A means for retracting or stowing the panel after use would have to be provided separately. A simple retraction means for the rectangular panels would be a series of springs integrated into the panel such that when the transport fluid is relieved the panel will return to its stowed configuration. An example of this concept is the inflatable noisemaker seen at parties. There a rolled up paper tube is inflated by blowing on one end. When pressure is released a spring integrated into the tube rolls it up again. Retracting other shapes would probably be more complicated.

Separate Inflation Fluid - Should the filling of the fluid passages with the transport fluid fail to result in a panel rigid enough to withstand vehicle maneuvering accelerations, separate gas cavities could be provided which would make the panel rigid. The panel configuration shown in Figure 6-A would be deployed in this manner.

Mechanical Deployment - Figure 6-B shows several panel configurations which could be deployed mechanically. Particular shapes imply the use of certain types of mechanisms. STEM (Storable Tubular Extendable Member) devices and Astromasts are compactly packaged extension devices, having proven space applications, which are particularly of interest for this deployment application. Both these devices may be obtained for powered extension and retraction or can be spring loaded to the extended position. These devices are applicable for retraction of the panel as well as deployment if they are powered.

Flexible solar cell panels have been deployed in space using the concept shown in A, with parallel stem devices supporting each side of the panel. B is a variation using folded instead of rolled stowage.

C shows a panel rolled for stowage and extended using a single Astromast. This same arrangement could be used with a STEM device also.

The cylindrical panel shown in D uses an Astromast for deployment and retraction. The same arrangement could also be used with a STEM device.

A circular panel could be deployed like an umbrella, as shown in E, and retracted in the same manner.

F uses STEM devices in conjunction with a power drum to unroll and reroll the radiator panel. This would allow the varying of the radiator surface without complicating the transport fluid plumbing.

As an additional concept, the IRS deployment could utilize a recent development of Naval Ordinance Laboratory, 55-Nitinol alloy (Reference 13). This 55% nickel, 45% titanium alloy has a mechanical memory, i.e., it can be plastically deformed below the transition temperature range and given a permanent set. Application of sufficient heat to warm the alloy above the transition temperature range, (about +150°F) causes the deformed part to return to its original shape. Thermal deployment could be accomplished by electrical resistance heating of the metal itself, by solar heating, by separate heater, or by explosive squib. The resistance to metal fatigue, i.e., endurance limit, is quite good for the alloy, and the transition temperature range can be varied between 300°F and -300°F by changing the nickel to titanium ratio or by partial substitution of cobalt for the nickel. Self-erectable deployment structures of Nitinol alloy have been demonstrated for devices such as antennas, coil-uncoil tape devices, cylinders, extendable booms, mechanical actuators, radar reflectors, rectangular and circular grids, and solar cell arrays. Primary disadvantages of the material are close control requirements on alloy chemistry, and lack of available data on its performance when used on hardware deployed in space. In addition, its requirement for a controlled, external energy source is a significant disadvantage.

Initial Candidate Selection

Based on the screening criteria of Table III, three candidate deployment system concepts (Figure 6-A, Concepts B and F; Figure 6-A, Concept D) were initially selected for additional study and development. Later additional concepts which are able to survive long periods in a micrometeoroid environment were included in the list of candidates. These concepts are discussed in detail in Section 3.3.3, Selection of Concepts for Design Studies.

3.2.4 Radiator Material Evaluation

State-of-the-art plastic films, which are the prime candidate materials for the IRS panels, have been well established as either inflatable structures and/or thermal control surface materials. The plastic film serves both these functions in the IRS concept. It must act as the primary structure of the IRS itself, while retaining the transport fluid and maintaining a panel configuration which allows heat to be rejected as the fluid in circulated. In addition, the surface of the film must have optical properties which are stable and which allow the IRS to efficiently reject heat. A low solar absorptance and high emittance are thus required.

In any of the IRS concepts considered for system trades, a plastic film is required as the prime structural component. Any film considered as an IRS material must have the ability to meet these general and specific criteria

- Chemical compatibility with the heat exchange fluid
- Minimum degradation of mechanical and optical properties due to solar ultraviolet and other damaging irradiation
- Low solar absorptance
- High emittance
- Mechanical properties to retain shape and fluid pressure at the temperature extremes to be experienced by the IRS
- Formable by heat sealing to itself or heat bonding to metals or other polymers
- Flexibility to aid deployment by electromechanical, thermomechanical, or pneumatic techniques
- Adequate thermal conductivity to allow heat transfer across the film

Table 5 lists candidate film materials with key properties noted. Thermal effects or solar ultraviolet degradation disqualify most polymers except for the polyimides and fluorinated ethylenes and ethylene propylenes. The polyimide film, particularly the polyimide/fluorinated ethylene propylene (FEP) laminate, has attractive mechanical and thermal properties. Un-

TABLE 5 CANDIDATE IRS MATERIALS

MATERIAL	TRADE NAME	PRINCIPAL ADVANTAGE(S)	PRINCIPAL DISADVANTAGE(S)
Polyethylene	Bakelite	Ease of heat sealing	Brittle at low temperatures
Chloroprene	Neoprene	Flexibility at ambient temperatures	High solar absorptance; brittle at low temperatures
Polypropylene	Clysar	Mechanical strength	Brittle at low temperatures
Polycarbonate	Lexan	High impact strength	Tends to craze
Polyvinylidene fluoride	Kynar	Chemically inert	Limited uv degradation data
Polyvinyl flouride	Tedlar	Chemically inert	Loss of strength after thermal exposure
Polyester	Mylar	Mechanical strength	Loss of strength after thermal exposure
Polyimide	Kapton H	Mechanical strength	Not heat sealable, high solar absorptance
Polyimide/FEP laminate	Kapton HF	Heat sealable, mechanical strength	High solar absorptance
Ethylene tetrafluoro-ethylene copolymer	Tefzel	Mechanical strength reported good optical properties.	Limited solar ultraviolet (UV) degradation data
Fluorinated ethylene propylene	FEP Teflon	Low solar absorptance, High emittance, uv stable	Relatively low mechanical properties

fortunately, the yellow-gold tint inherent in the film raises the solar absorptance to unacceptable levels as the primary IRS material.

The ethylene-tetrafluoroethylene copolymer (ETFE) is a state of the art fluorocarbon film having mechanical ruggedness, tear resistance, impact resistance, and resistance to degradation by radiation as outstanding properties. The chemical and optical properties are similar to the more familiar FEP. It is considered as an inflatable radiator material since the yield strength in tension is about twice that of FEP. Other factors being equal, this allows a twofold margin of safety or a film thickness of one half that of FEP for a similar fluid operating pressure. In a number of other key properties, the ETFE is superior to FEP. The density is 20% lower. The impact strength is more than twice as large; tear strength is four to five times higher. Fabrication and heat sealing techniques are similar to those for FEP with sealing pressures being somewhat lower on ETFE. Resistance to radiation degradation is improved by a factor of three with little effect being noted on tensile properties of the ETFE after exposure. Unfortunately, little data exists on the effect of solar ultraviolet radiation on ETFE (Reference 14). Primarily for this reason, the ETFE will be considered an alternate material for radiator fabrication until the UV degradation limits are established.

The fluorinated ethylene propylene (FEP) film represents the most chemically inert polymer available as a heat sealable material. FEP film has a service temperature range from -400°F to +395°F. The resistance to tearing, abrasion, and impact is quite high at ambient temperature and remains useful in the cryogenic range. The FEP film resists degradation due to solar ultraviolet radiation better than alternate heat sealable films. (Reference 15). It has been highly successful as a substrate for thermal control coatings on numerous spacecraft and satellites. Flight hardware using FEP film in the thermal control systems includes SAS-A, SAS-B, ALSEP, Skylab, Mariner II, Mariner V, OSO-H, OGO-6, IMP-1, OAO-B, and OAO-C. The combination of low solar absorptance and high emittance found in FEP is more favorable than in other candidates for IRS use. This, couples with the resistance to solar radiation degradation and adequate mechanical properties, leads to selection of FEP film, type A, as the basic material of fabrication for the inflatable radiator system.

3.3 Concept Developments

Design requirements, groundrules and concepts established in the initial stages of the program served as a starting point for a more detailed development study, the purpose of which was to devise and design two inflatable radiator concepts and demonstrate their feasibility in a thermal vacuum test. This section documents the analysis, concept generation studies, screening studies, design studies, and element tests leading to the selection of the two concepts, and the optimization of their designs. A summary of the accomplishments and milestones of the concept development study is given below.

(1) Orientation briefing at NASA/JSC on 13 September 1973, at which time design requirements and groundrules were finalized.

(2) Concept generation studies, under which two basically new tube-fin approaches were added (hard tubes and thick-silvered Teflon fins)

(3) Concept screening studies, under which tube-fin concepts were evaluated along with potential manifolding schemes and deployment concepts to select five candidate tube-fin concepts for design studies.

(4) Design studies, under which meteoroid protection requirements have been evaluated, materials space radiation stability has been assessed, materials element tests have been conducted to determine fabricability and flexibility of concepts, and additional trade studies have been carried out leading to the selection of the two most promising concepts to support the Concepts Briefing.

(5) Concepts briefing at NASA/JSC on 20 November 1973, at which time agreement was obtained to pursue the following two concepts throughout the remainder of the design studies

    (a) Cylindrical hard tube concept with a silver wire mesh/Teflon film laminate fin material

(b) A roll-up soft tube concept with an evaporated thick silver/Teflon film fin material.

(6) Additional evaluation under Design Studies on the evaporated thick silver-Teflon film concept to determine an appropriate compromise between panel area and weight.

(7) Element tests during December 1973 to evaluate techniques for bonding the Teflon/wire mesh laminate to hard tubes.

(8) Additional analyses during January 1974 to study the effect of halving and doubling the silver thickness in the thick silver-Telfon film concept.

(9) Informal Review by NASA/JSC at Vought on 27 February 1974. Redirection by NASA at that time to relieve the meteoroid design requirement on the soft tube concept to the point that it does not control tube stiffness.

(10) Precursor thermal vacuum element test on 5" x 8" thick-silver test article on 27 March 1974. Verified Teflon tube wall and fin temperature drops.

(11) Receipt of partial order of silver wire mesh (12 ft^2) on 14 March 1974. Initiation of Spraylon coating trials with Lockheed Palo Alto Research Laboratory on 2 May 1974.

(12) Receipt of contract Mod No. 1 on 1 May 1974 to expand the program scope to include digital thermal analysis and fabrication and cold case thermal vacuum testing of a second inflatable radiator concept. Rescheduling during May of expanded program.

(13) Informal review by NASA/JSC at Vought on 22 May 1974 to review program progress, precursor thermal vacuum tests, preliminary Spraylon coated silver wire mesh elements, and materials for thick silver film test elements.

(14) Initiation of detailed preliminary design effort in May 1974, with supporting structural, environmental control, and materials analysis. Concept configurations finalized, including sizing of fluid loop components and deployment systems. Rehashed trade studies to incorporate revised meteoroid re-

quirements (per 27 February NASA redirection) and to incorporate subsystem level impacts for configurational options. Completion of preliminary design drawings in June 1974.

(15) Element tests during June 1974 for fabricability, flexibility, and mechanical integrity of 9 laminate samples formed of thick silvered Teflon of 3 silver and Teflon thicknesses.

(16) Notification by Newark Wire Cloth Co. on 11 June 1974 that the expected shipment date of the remaining GFE silver wire mesh has slid to 16 August 1974. Further notification on 23 August of another slide to 15 September.

(17) Formal Status Briefing at NASA/JSC on 21 June 1974, at which time the preliminary designs were presented, element tests were described, and a formal briefing document was delivered. Concurrence at and subsequent to the meeting was obtained on the preliminary designs.

(18) Initiation of Steady State Design Routine (SSDR) computer analysis of the preliminary designs in June 1974 to evaluate design parameters in more detail and greater fidelity than by hand.

(19) Request by NASA/JSC on 26 June 1974 to re-evaluate soft tube concept materials selection. Submission of matrix to NASA on 28 June comparing pertinent evaluation parameters for 19 candidate materials. FEP Teflon remains as choice for current program (per NASA direction).

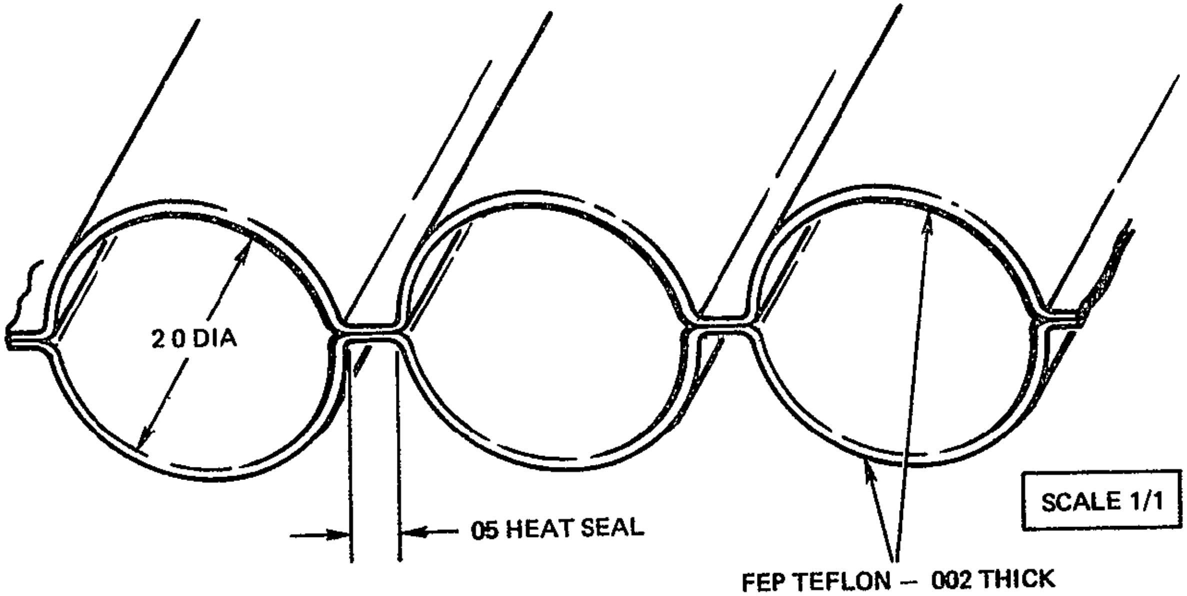
Details of the concept development study are given in References (2) and (3). The most significant results are summarized below.

3.3.1 Description and Screening of Candidate Concepts

This section describes the inflatable radiator concepts considered in the development study. Candidate designs include concepts formulated in the initial conceptual studies, NASA suggested concepts, and new concepts generated during the design studies.

Figure 7 shows a cross-section of a gas radiator concept. In the manufacture of an IRS for a moderate pressure, gaseous transport fluid, typically nitrogen at 15 psi, the gas flow passages are wide, ca. 2 inches. This IRS would be fabricated by heat sealing a series of parallel passages along the desired length of doubled FEP film or FEP tubing, as shown in Figure 7. Headers, manifolds and gas transfer passages as shown in Figure 8 are formed by heat sealing with thermal impulse equipment. Impulse sealers are now available for curves and irregular contours as well as more conventional linear seals (Reference 16). The structural limit of a heat sealed joint would be defined by tension in the film adjacent to the seal, rather than by peel within the heat seal itself, since the strength of FEP heat seals made using current impulse technology approach that of the film itself (Reference 14). Gas radiator deployment concepts considered in the design studies are shown in Figure 9.

Both moderate pressure, typically Freon E-2 at 15 psi, and high pressure, typically Freon 21 at 165 psi, transport fluids are considered in conceptual IRS designs. High lateral thermal conductivity is required in either of the systems using a liquid heat transfer fluid. The Freon E-2 transport fluid system is detailed in Figure 10. Note that a silver wire mesh is proposed as the high thermal conductivity material. Selection was based on the high thermal conductivity value intrinsic in the silver wires, the low solar absorptance of the silver, and the availability of 0.002" silver wire with adequate strength for weaving into the "open" mesh of 67 wires/inch in the warp direction and 40 wires/inch in the fill or shute direction was dictated by both thermal considerations and current metal weaving technology. The mesh would be laminated within the FEP film by either of two approaches. A hot roll, continuous laminating mill heats and compresses the FEP film to force a bond between and through the open areas of the silver mesh. The roll configuration is fixed so that a continuous pattern of unbonded fluid flow passages in either the transverse or longitudinal direction is produced from the laminating mill. Headers and manifolds are formed on the laminated sheet by configured, impulse sealing equipment. The result is a laminate of silver mesh within the FEP film. A wide strip impulse type heater designed to seal a long, narrow area, typically 2' x 0.25', could also be used to produce the desired



TWO-SIDED RADIATOR DESIGN (OPTIMIZED)

- TRANSPORT FLUID : N_2 @ 15 psia, 744 pph
- RADIATOR PANEL AREA : 310 ft^2
- PROJECTED TUBING AREA : 97.6%
- WEIGHTS : PANEL AND GAS - 16.5
  POWER PENALTY - 2.0
  18.5 LB.
- VEHICLE INTERFACE : GAS-TO-LIQ. HX

FEATURES

- SIMPLICITY
- FLEXIBILITY
- COST
- WEIGHT

FIGURE 7

GAS RADIATOR CONCEPT

PROPOSAL BASELINE

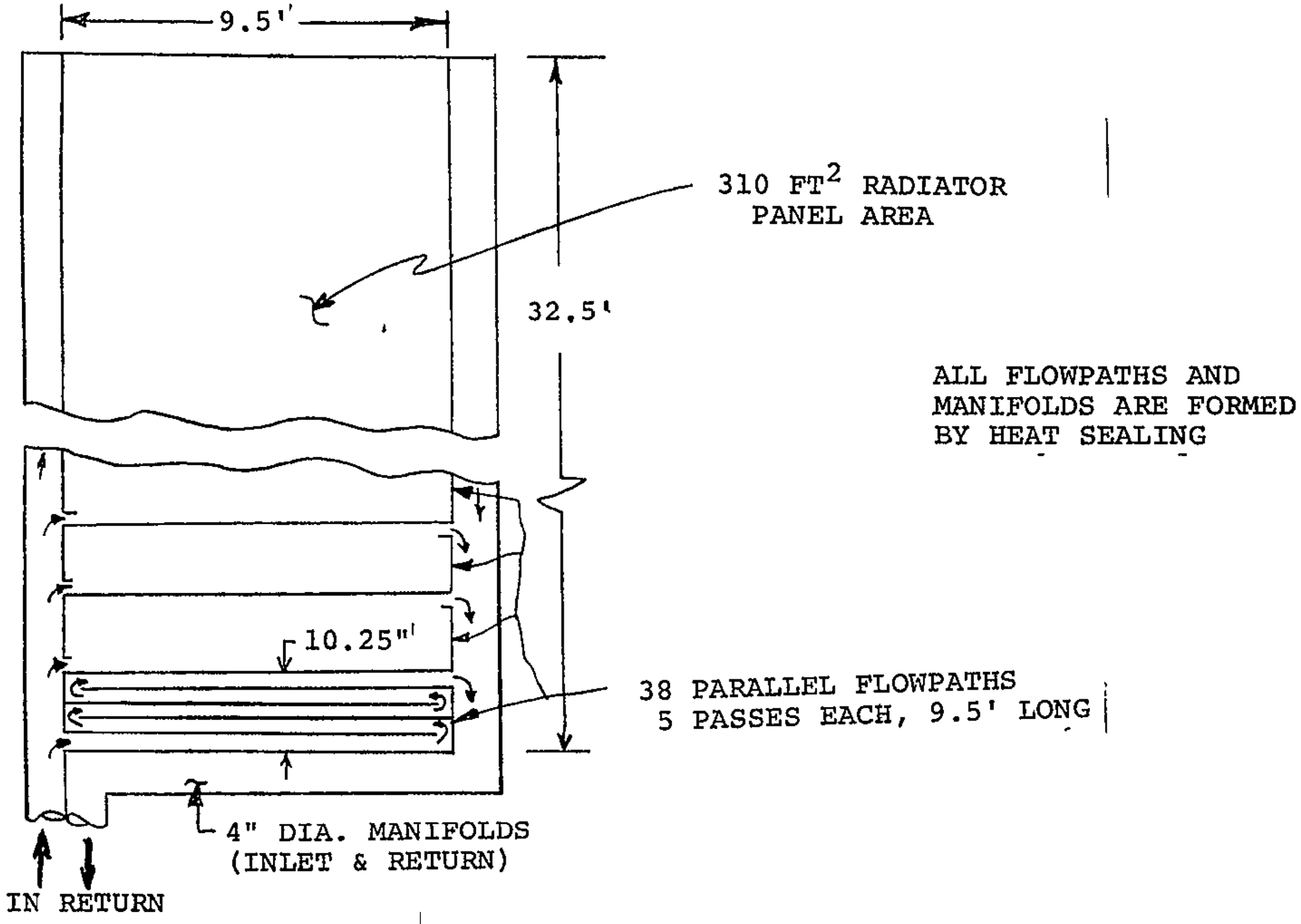
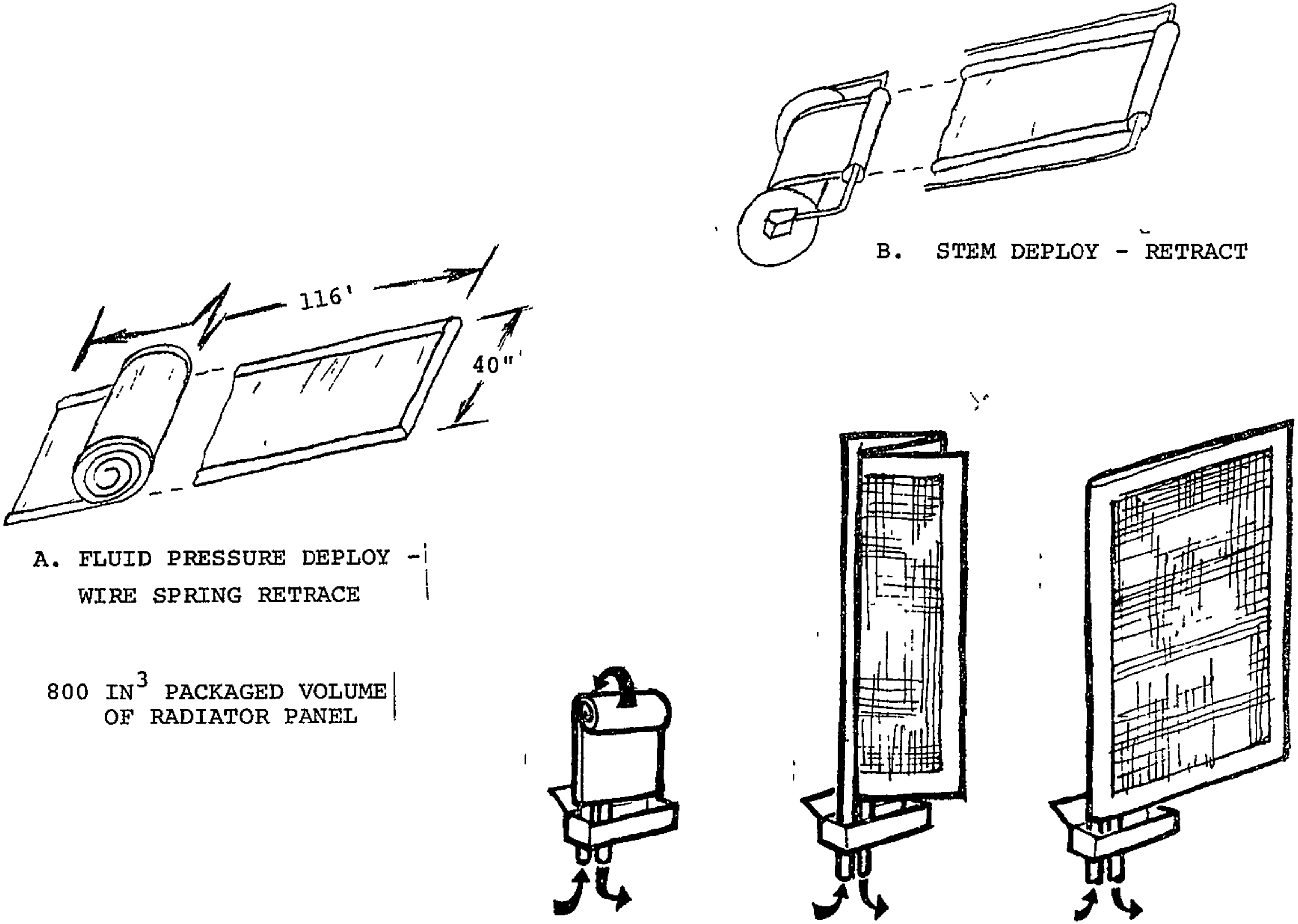


FIGURE 8 TYPICAL GAS RADIATOR MANIFOLDING



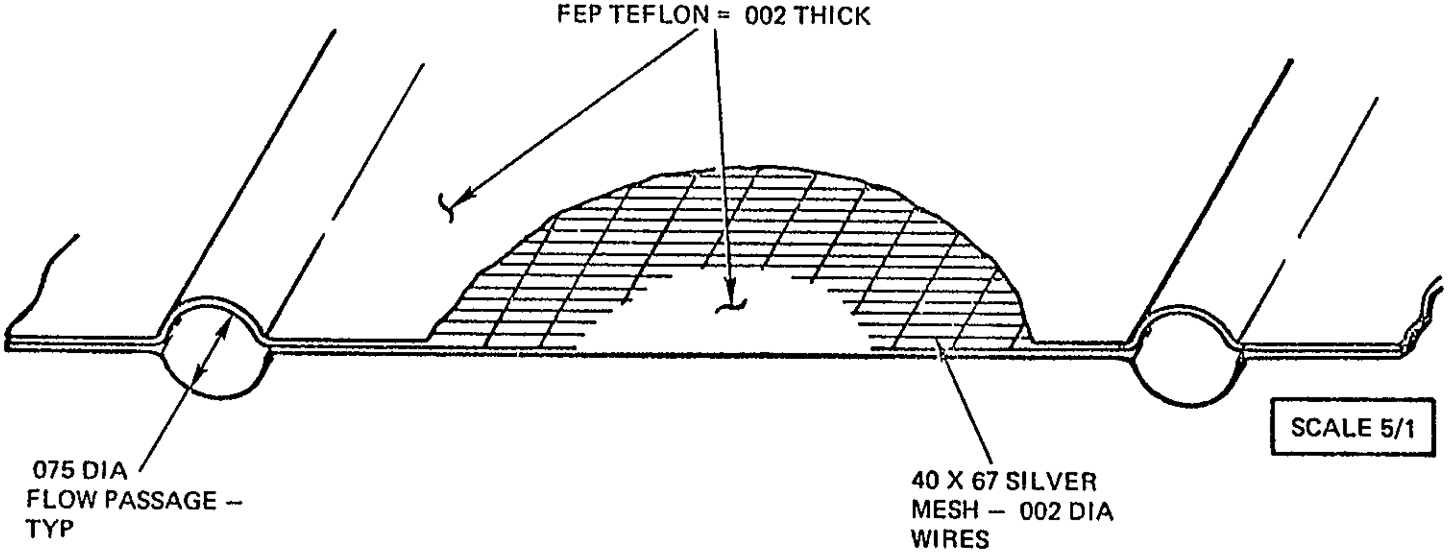
A. FLUID PRESSURE DEPLOY - WIRE SPRING RETRACE

800 IN^3 PACKAGED VOLUME OF RADIATOR PANEL

B. STEM DEPLOY - RETRACT

C. FLUID PRESSURE DEPLOY, NON-RETRACTABLE

FIGURE 9 TYPICAL GAS RADIATOR DEPLOYMENT CONCEPTS



TWO-SIDED RADIATOR DESIGN (OPTIMIZED)

- TRANSPORT FLUID : E-2 @ 10 psia, 899 pph
- RADIATOR PANEL AREA : 172 FT^2
- TUBE SPACING : 1 IN.
- PROJECTED TUBING AREA : 7.9%
- FLOWPATH : 13 TUBE PASSES, 39" LONG EACH
- WEIGHTS : PANEL + FLUID - 14.0
  POWER PENALTY - 14.5
  28.5 LB
- VEHICLE INTERFACE : LIQ.-TO-LIQ. HX

FEATURES

- INCREASED FLEXIBILITY OVER FREON 21 VERSION
- SIZE
- TUBING VULNERABLE AREA
- INTEGRAL FLOW PASSAGE
- COMPATIBLE WITH F-21 VERSION DEPLOYMENT CONCEPTS: POSSIBLY GAS RADIATOR CONCEPTS
- REDUCED STOWAGE VOLUME OVER F-21 VERSION

FIGURE 10

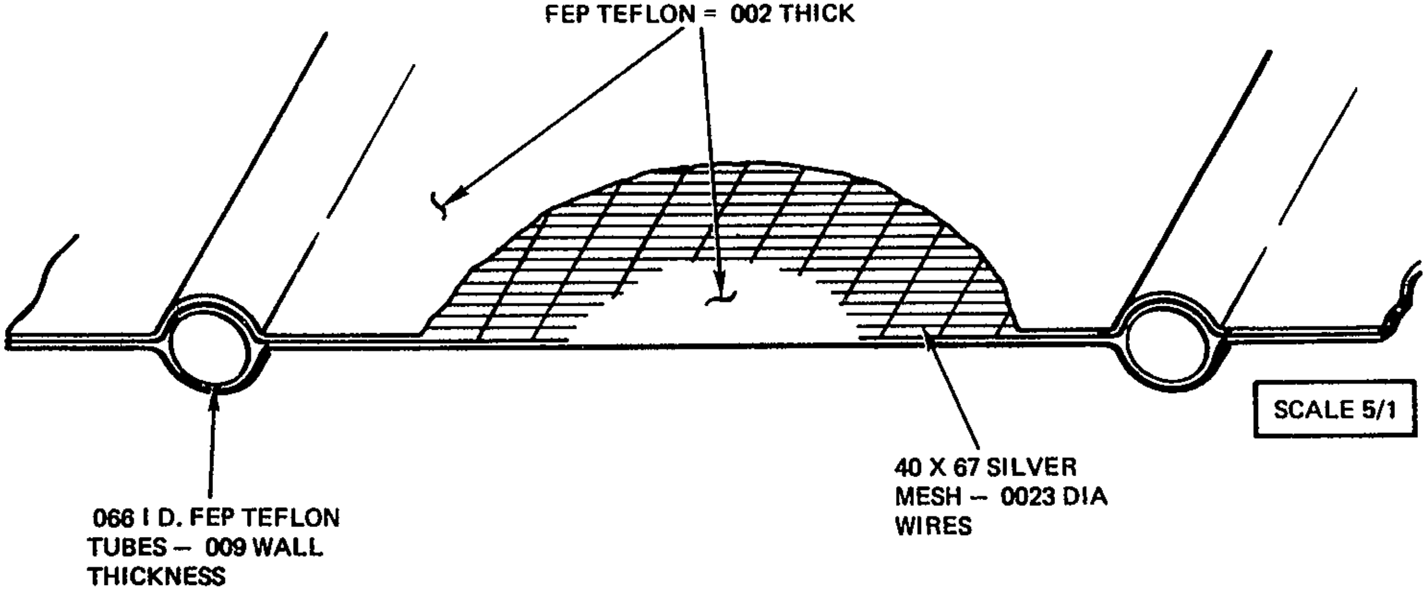
FREON E-2/WIRE MESH CONCEPT

SECOND PROPOSAL ALTERNATE LIQUID RADIATOR pattern of fins and tubes by step-sealing over the surface repetitively. This method allows more flexibility in design and fabrication than the hot roll, continuous laminating mill. The configured impulse sealer is again used to form headers and manifolds.

As shown in Figure 11, the IRS, based on Freon 21 transport fluid, requires a lined fluid flow passage to contain the higher pressure of this fluid. Tubes of several of the polymer candidates outlined in Table were considered. Polyimide composite tubes, consisting of polyimide film laminated between FEP film, are desirable from the strength and chemical compatibility standpoint. Wall thicknesses in the 0.0003" - 0.005" range are adequate to contain the high pressure refrigerant. The stiffness of these polyimide composite tubes presents a design problem in an inflatable, deployable system. Since the tubes would collapse and kink during rolling for deployment. Storage in the collapsed and kinked condition would quite possibly result in deterioration at these highly stressed areas. The polyimide tubing is limited to 3' lengths at present technology levels, a serious disadvantage.

A viable alternative is FEP tubing with wall thicknesses in the 0.009" - 0.016" range. It presents favorable optical properties and can be coiled into efficient, packed shapes during storage. It has the added advantage that connections to gas transfer passages, headers, and manifolds could be made by heat shrinking the FEP tubing onto these connectors. The burst strength of FEP tubing with 0.062" I.D. and 0.016" wall thickness is typically 500 psi at ambient temperature (Reference 17). Long lenghts are routinely available for serpentining through a deployable radiator. Heat seals with impulse equipment would be possible immediately adjacent to either side of the plastic tubing, or a continuous mill for encapsulating the FEP tubes in the FEP film/silver mesh laminate as it is formed could be developed with grooved, heated rolls. The grooves would accommodate the FEP tubes without crushing or flattening, while allowing the laminate bond to be made through the silver mesh. Typical manifolding and deployment concepts for the Freon 21 wire mesh radiator are shown in Figures 12 and 13.

Laminated plastic film concepts are shown in Figures 14 and 15. The tube spacing is reduced so that wire mesh is not required. This reduces



TWO-SIDED RADIATOR DESIGN (OPTIMIZED)

- TRANSPORT FLUID : F-21 @165 psia, 860 pph
- RADIATOR PANEL AREA : 172 FT^2
- TUBE SPACING : 1 IN.
- PROJECTED TUBING AREA : 8.4%
- SILVER WIRE MESH : 5% FIN CONDUCTION AREA
  23% PROJECTED RADIATING AREA
- WEIGHTS : PANEL + FLUID - 17.0
  POWER PENALTY - 9.5
  26.5 LB.
- VEHICLE INTERFACE : LIQ.-TO-LIQ. HX
  OR DIRECT TIE-IN

FEATURES

- SIZE
- TUBING VULNERABLE AREA
- DIRECT ORBITER TIE-IN COMPATIBILITY
- HEAT SEAL FEP THROUGH WIRE MESH

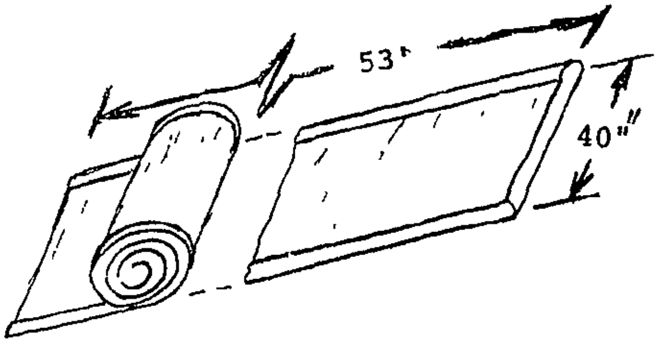
FIGURE-11

FREON 21/WIRE MESH CONCEPT

PROPOSAL ALTERNATE LIQUID RADIATOR

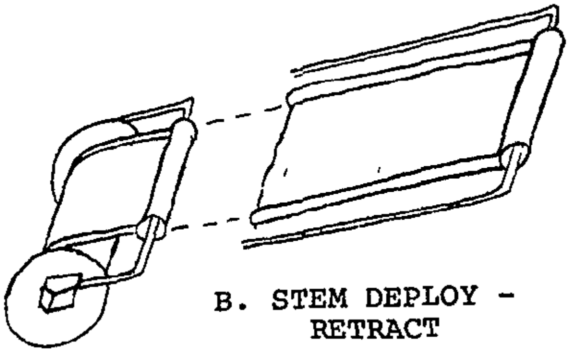
FIGURE 12

TYPICAL FREON 21/WIRE MESH RADIATOR MANIFOLDING AND DEPLOYMENT

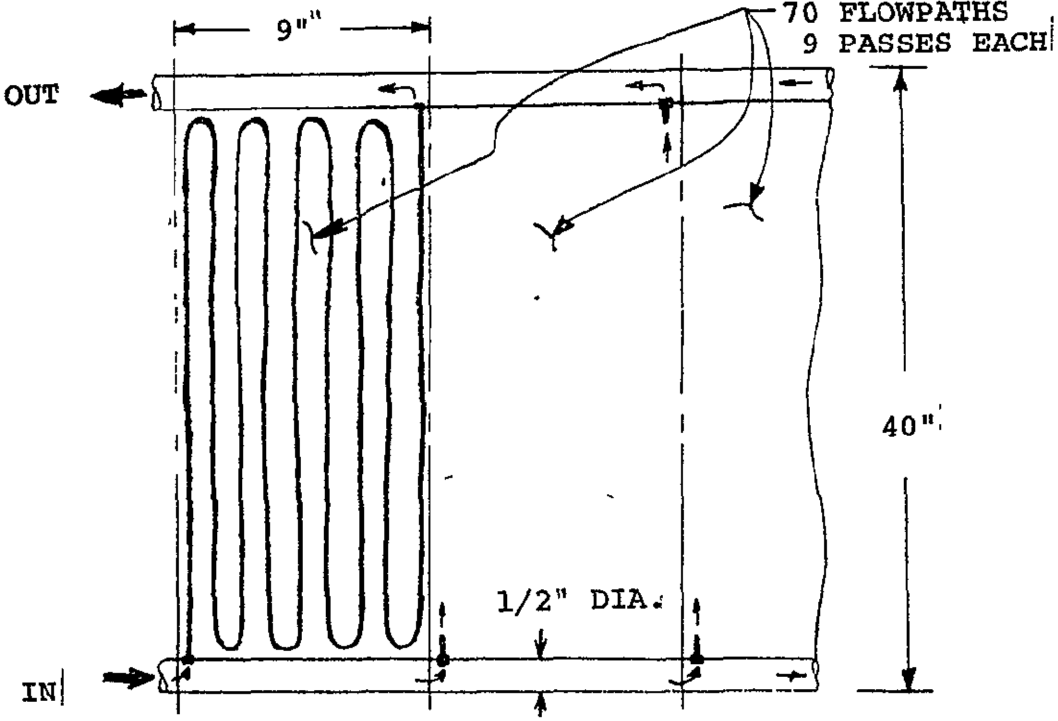


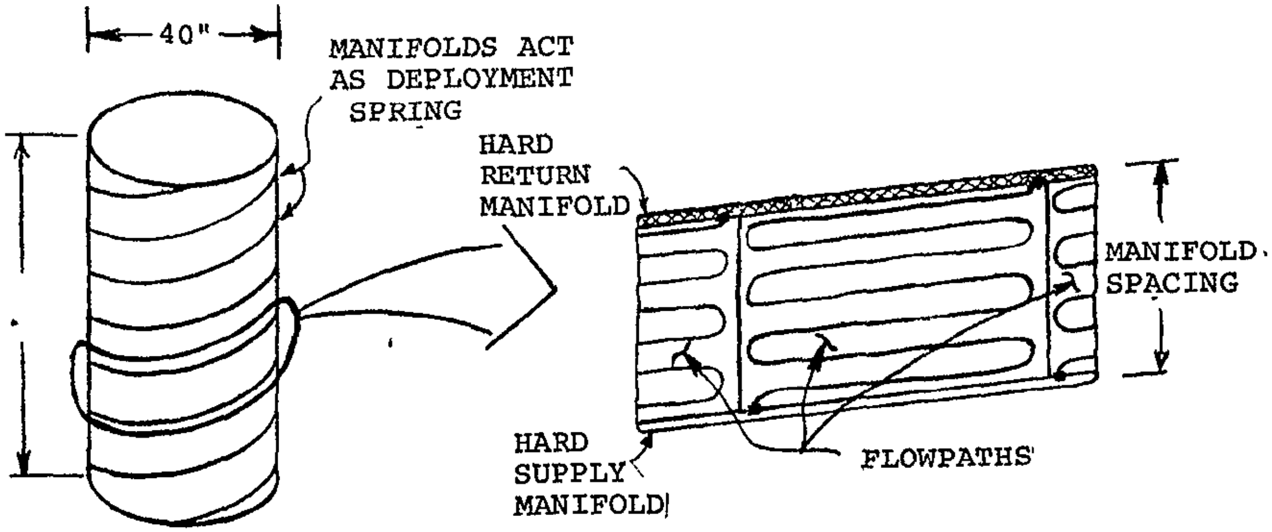
A. FLUID PRESSURE DEPLOY - WIRE SPRING RETRACT

3000 IN^3 PACKAGED VOLUME OF PANEL



B. STEM DEPLOY - RETRACT





FEATURES

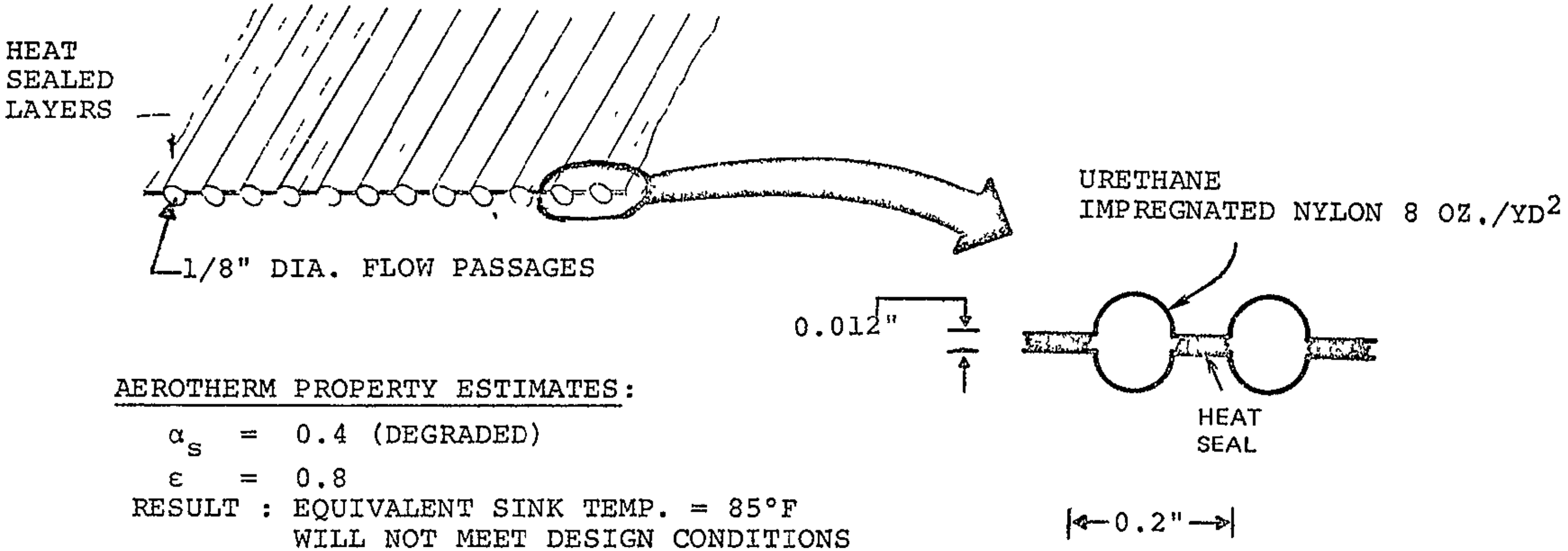
- ACCOMMODATES STIFF FIN/TUBE CONCEPTS
- SIMPLE DEPLOYMENT
- CAN BE RETRACTED
- RIGIDITY

TYPICAL FREON 21/WIRE MESH DESIGN

- AREA : 344 FT^2
- LENGTH : 33 FT
- TUBE SPACING : 1.4 IN.
- MANIFOLD SPACING : 19 IN.
- PROJECTED TUBING AREA : 6%
- FLOWPATH : 13 TUBE PASSES, 39" LONG EACH
- WEIGHTS : PANEL + FLUID - 29
  POWER PENALTY - 14
  43LB.

FIGURE 13 ONE-SIDED RADIATOR HARD MANIFOLD CONCEPT

AEROTHERM FLEXITHERM SUGGESTED BY NASA-JSC



AEROTHERM PROPERTY ESTIMATES:

α_s = 0.4 (DEGRADED)
ε = 0.8
RESULT : EQUIVALENT SINK TEMP. = 85°F
WILL NOT MEET DESIGN CONDITIONS

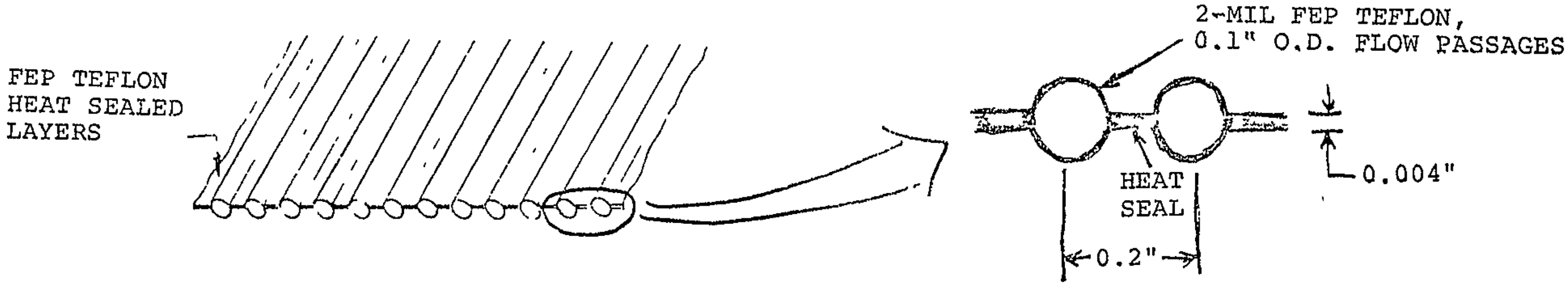
ESTIMATED BEST PROPERTIES

α_s = 0.25 (UNDEGRADED)
ε = 0.85
RESULT : EQUIVALENT SINK TEMP. = 35°F
TWO-SIDED RADIATOR PANEL AREA = 263 FT^2
PROJECTED TUBING AREA = 62.5%
WEIGHTS : PANEL + FLUID (E-2) - 65.9
POWER PENALTY - 50.0
115.9LB.

- MARGINAL AT BEST
- LARGE
- VULNERABLE
- HEAVY
- POTENTIAL FLUID INCOMPATIBILITY

- ELIMINATE BASIC FLEXITHERM
- CONSIDER ALTERNATE MATERIALS

FIGURE 14 LAMINATED PLASTIC FILM CONCEPT



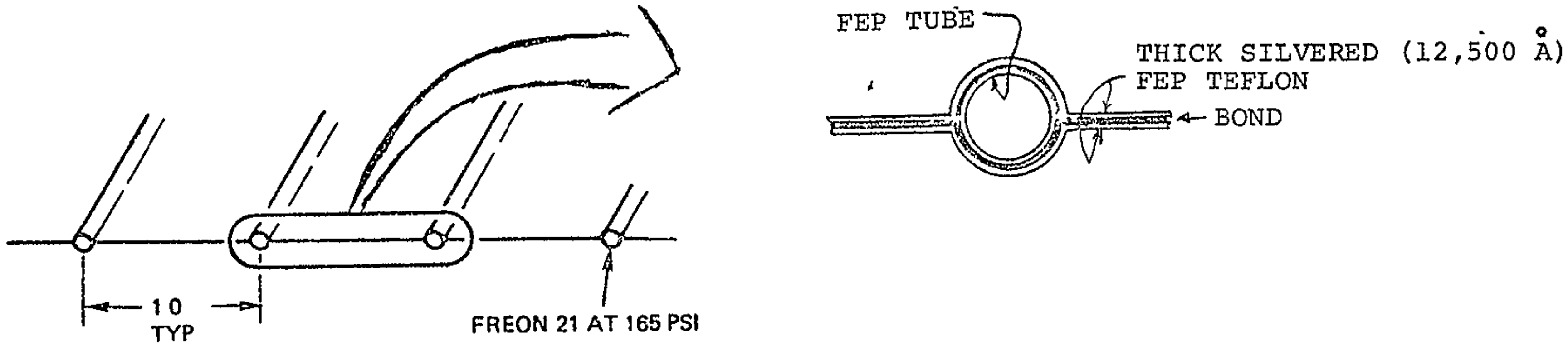
TYPICAL TWO-SIDED RADIATOR DESIGN

- TRANSPORT FLUID : E-2 @ 10 psia, 899 pph
- RADIATOR PANEL AREA : 154 FT^2
- TUBE SPACING : 0.2 IN.
- PROJECTED TUBING AREA : 50%
- WEIGHTS : PANEL + FLUID - 57
  POWER PENALTY - 25
  82LB
- VEHICLE INTERFACE : LIQ.-TO-LIQ. HX

FEATURES

- SIMPLICITY
- FLEXIBILITY
- COST
- SIZE
- DEPLOYMENT BY ANY OF PREVIOUS METHODS

FIGURE 15 ALTERNATE LAMINATED PLASTIC FILM CONCEPT



TYPICAL TWO-SIDED RADIATOR DESIGN

- TRANSPORT FLUID : FREON 21 @ 165 psia, 860 pph
- RADIATOR PANEL AREA : 203 FT^2
- TUBE SPACING : 1 IN.
- PROJECTED TUBING AREA : 8.4%
- TUBES : 0.066" I.D. FEP, 0.009" WALL
- FILM : 2-MIL FEP TEFLON EACH SIDE,
  12,500 Å SILVER EACH
- WEIGHTS :
  - PANEL + FLUID - 20
  - POWER PENALTY - 11
  - 31 LB
- VEHICLE INTERFACE : LIQ.-TO-LIQ. HX
  OR DIRECT TIE-IN
- DEPLOYMENT : ALL FREON 21/WIRE MESH CONCEPTS (EASIER)

FEATURES

- FLEXIBILITY
- EASE OF FABRICATION
- POTENTIAL BETTER WEIGHT THAN MOST WHEN OPTIMIZED
- REMOVE ONE SIDE FOR 1-SIDED RADIATOR
- DIRECT ORBITER TIE-IN COMPATIBILITY

FIGURE 16 LAMINATED SILVERED TEFLON FILM CONCEPT

NEW CONCEPT

cost and simplifies the processes required to manufacture the radiators but increases the weight of the panel. The surface properties of the Aerotherm film are not well suited for this application and will degrade to a point where the system will not meet the design requirements. The alternate construction shown in Figure 15 has better surface properties and lower weight than the Aerotherm material.

The laminated silver Teflon film concept, shown in Figure 16, is similar in principle to the Freon 21 radiator of Figure 11. Conductance is effected through two layers of silver metal which are vapor deposited on 2-mil Teflon films. The transport tubes are positioned at optimum spacing between the two films, and the assembly is bonded with a flexible adhesive.

The final concept considered in the development/optimization studies is shown in Figure 17. This system is unique because it retains the capacity for full deployment and retraction with metal transport tubing. The system is attractive because the deployment system is built into the radiator panel and thick metal tubes capable of surviving long periods in a micrometeoroid environment are used without penalty to the deployment/retraction system.

Table V-A compares the system characteristics of the candidate flexible radiator concepts.

3.3.2 Impact of Meteoroid Considerations

Calculations were made to determine the expected lifetime of the candidate inflatable radiator systems in a micrometeoroid environment. The near-earth meteoroid environment defined in NASA SP 8013, "Meteoroid Environment Model - 1969 (Near Earth to Lunar Surface)", was referenced to determine meteoroid flux. This model is groundruled for the Space Shuttle program, and is still considered to be applicable based on Skylab[1] and Meteoroid Technology Satellite[2] observations.

Meteoroid protection requirements are given by applying the ballistic thickness equation

---

[1] Telecon, R. L. Cox of Vought to R. J. Naumann of NASA-MSFC, April 1975

[2] Telecon, R. L. Cox of Vought to D. H. Humes of NASA-LaRC, April 1975

TABLE V-A

PRELIMINARY SCREENING OF IRS CONCEPTS

RADIATOR SYSTEM CONSIDERATIONS	GAS RADIATOR(5)	FREON 21/ SILVER WIRE MESH(5)	FREON E2/ SILVER WIRE MESH(5)	LAMINATED TEFLON FILM(5),(6)	LAMINATED SILVER TEFLON FILM(5) (6)	FREON 21 HARD TUBE(5) (6)
• THERMAL PERFORMANCE(1)	18 5 LB 310 FT^2	26 5 LB 172 FT^2	28 5 LB, 172 FT^2	82 LB 154 FT^2	31 LB 203 FT^2	46 LB 344 FT^2
• OPERATING CONSTRAINTS	NONE	NONE	NONE	NONE	NONE	NONE
• DEGRADATION IN SPACE ENVIRONMENT	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
• PRESSURE DROP/PUMPING POWER REQUIREMENTS	2 LB PENALTY	10 LB PENALTY	14 LB PENALTY	25 LB PENALTY	11 LB PENALTY	14 LB PENALTY
• HEAT EXCHANGER REQUIREMENTS	GAS TO LIQUID	NONE OR LIQ TO LIQ	LIQ TO LIQ	LIQ TO LIQ (E 2)	NONE OR LIQ TO LIQ	NONE OR LIQ TO LIQ
• LOW OUTGASSING	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
• MICROMETEOROID SUSCEPTIBILITY(2)	WORST	AMONG BEST	INTERMEDIATE	AMONG WORST	AMONG BEST	BEST
RADIATOR DESIGN & FABRICATION CONSIDERATIONS						
• STATE OF THE ART	AMONG BEST	WORST	AMONG WORST	AMONG BEST	GOOD	FAIR
• STRUCTURAL INTEGRITY	GOOD (15 PSI MAX)	GOOD (165 PSI)	FAIR (10 PSI)	GOOD (10 PSI)	GOOD (165 PSI)	BEST (165 PSI)
• MANIFOLDING	SIMPLE	FAIRLY SIMPLE	FAIRLY SIMPLE	SIMPLE	FAIRLY SIMPLE	SIMPLE
• FLUID COMPATIBILITY	EXCELLENT	EXCELLENT	OK TEFLON	OK TEFLON (E 2)	EXCELLENT	EXCELLENT
• FAILURE MODES	EXCELLENT	GOOD	GOOD	EXCELLENT	FAIR TO GOOD	GOOD
• COST	LOW	HIGHEST	HIGH	LOW	MEDIUM TO HIGH	HIGH
PACKAGING AND DEPLOYMENT CONSIDERATIONS						
• RADIATOR FLEXIBILITY	AMONG BEST	AMONG WORST	FAIR	AMONG BEST	FAIR	AMONG WORST
• PACKAGED VOLUME OF RADIATOR(3)	APPROX 800 IN^3	APPROX 3000 IN^3	APPROX 1500 IN^3	APPROX 400 IN^3	APPROX 3000 IN^3	APPROX 5500 IN^3 EXCEEDS CANISTER LENGTH
• PACKAGED VOLUME OF OTHER COMPONENTS	OK (WORST)	OK	OK	OK	OK	OK
• DEPLOYED DYNAMIC STABILITY(3)	GOOD	AMONG WORST	AMONG WORST	AMONG WORST	AMONG WORST	BEST
• DEPLOYMENT MECHANISM COMPLEXITY(3)	AMONG BEST	WORST	INTERMEDIATE	AMONG BEST	INTERMEDIATE	AMONG BEST
• RETRACTION CAPABILITY	GOOD	FAIR	FAIR GOOD	GOOD	FAIR	GOOD
• PACKAGED WEIGHT OF SYSTEM	VERY LOW	LOW	LOW	HIGH	LOW	MEDIUM LOW
• INTERFERENCE WITH EXPERIMENTS & SPACECRAFT RADIATORS/SYSTEMS	HIGH	LOW	LOW	LEAST	INTERMEDIATE	HIGH
• VEHICLE DRAG(7)	0 29 LB	0 17 LB	0 17 LB	0 15 LB	0 20 LB	0 11 LB
• ENVIRONMENTAL HEAT FLUX RELATIVE TO THAT ON SPACE CRAFT RADIATORS(4)	–	-	–	–	–	–

NOTES

(1) ALL CONCEPTS SHOWN MEET THERMAL PERFORMANCE REQT'S, THUS EVALUATION IS IN TERMS OF WEIGHT AND AREA WEIGHT INCLUDES TUBE FLUID FINS AND PUMP POWER PENALTY

(2) REQUIRES MORE DETAILED STUDY AT NEXT LEVEL, COULD DISQUALIFY SOME CONCEPTS

(3) BASED PRIMARILY ON TUBE/FIN CONSIDERATIONS AT THIS LEVEL OF SCREENING

(4) OPEN AT THIS LEVEL OF SCREENING, AS SEVERAL OPTIONS ARE AVAILABLE WITH EACH CONCEPT

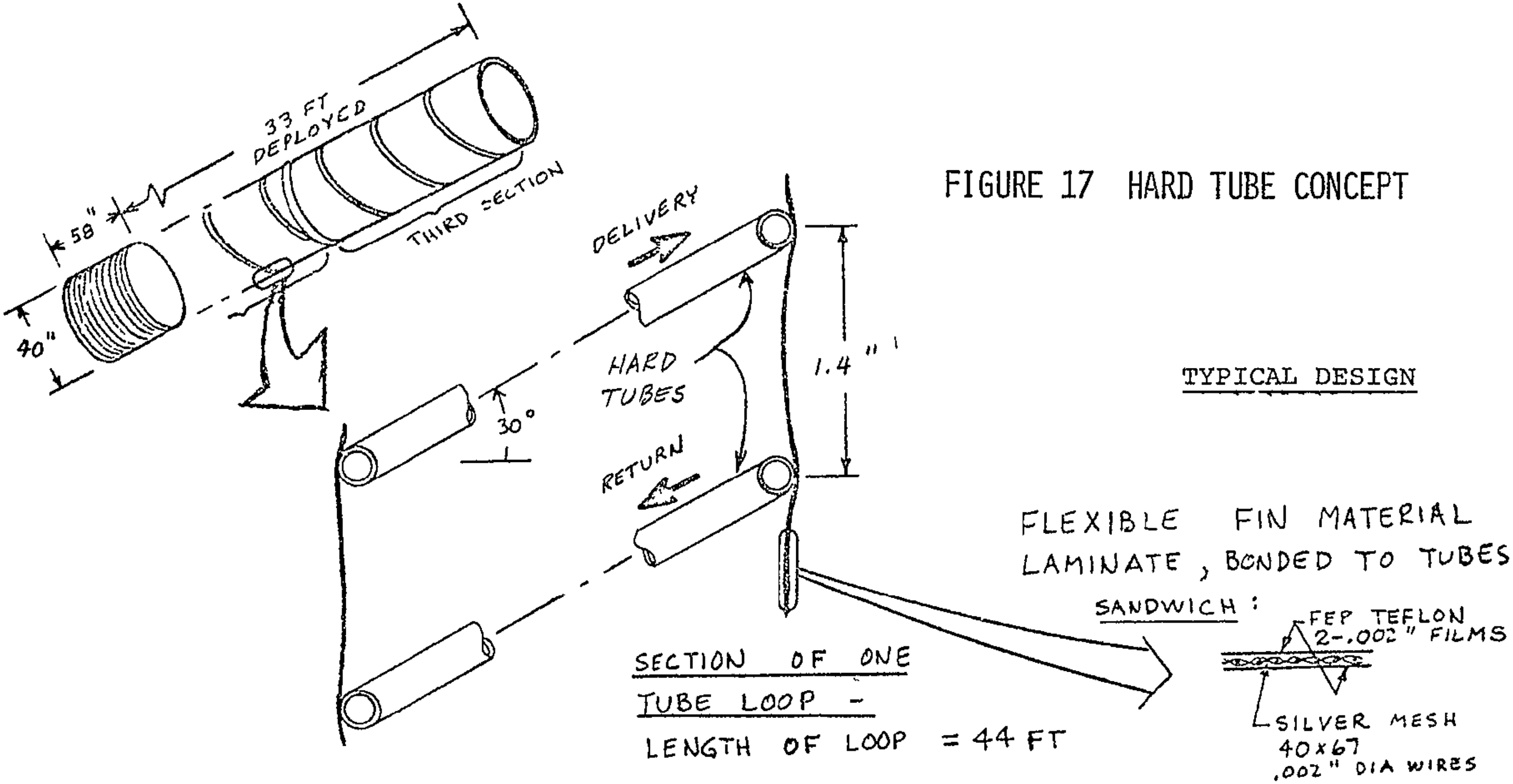
(5) ALL CONCEPTS ARE 2 SIDED EXCEPT HARD TUBE

(6) NOT OPTIMIZED

(7) AT 100 NMI ALTITUDE

FIGURE 17 HARD TUBE CONCEPT

TYPICAL DESIGN



TYPICAL ONE-SIDED RADIATOR DESIGN

- FREON 21, TRANSPORT FLUID, 860 pph
- 344 FT^2 RADIATING AREA
- 1.4 IN. TUBE SPACING
- ALUMINUM TUBES, .084" O.D., .009" WALL
- PROJECTED TUBE AREA : 11.9%
- WEIGHTS : PANEL & FLUID - 29
  POWER PENALTY - 17
  46 LB
- VEHICLE INTERFACE : LIQ.-TO-LIQ. HX
  OR DIRECT TIE-IN

FEATURES

- HARD TUBES (AL OR STEEL) DEPLOY BY SPRING FORCE
- POTENTIAL LOW METEOROID VULUNERABILITY
- RETRACTABILITY
- DIRECT ORBITER TIE-IN COMPATIBILITY
- CAN USE SILVERED TEFLON FILM FINS

$$t = K_1 \rho^{1/6} m^{.352} v^{.875}$$

where t is the thickness for threshold penetration of a plate (cm)

K_1 is a material constant

ρ is the meteoroid density (0.5 gm/cm^3)

m is the meteoroid mass (gm)

v is the normal impact velocity of the meteoroid (20 Km/sec)

along with the meteoroid flux curves of SP 8013 and the following survival probability equation:

$$P = e^{-NAT}$$

where P is the probability of no penetrations

N is the number of particles per unit time and area (from SP 8013)

A is the total vulnerable area

T is the mission time

While the ballistic equation was established for thin ductile metal plates it was determined by consulation with seven leading authorities in the field that it is the best available means of estimating meteoroid behavior of plastics. Similarly, the material constant for plastics is estimated to be proportional to the square root of density.

Table 6 summarizes the impact of meteoroid considerations on the designs of the candidate inflatable radiator systems discussed above. The table shows that micrometeoroid environments prohibit the use of gas radiators, and impact the flexibility and weight of the other systems. Studies documented in Reference (2) showed that meteoroid considerations force the optimum tube diameters to small values of about 0.04" to 0.05" I.D. and tube wall thickness in the 0.030" - 0.040" range. Weight is not impacted drastically compared to non-optimized weights without meteoroid protection. The weight increase for the hard tube concept is approximately 1.5 lb. and the increase for the two-sided silvered Teflon concept is about 3.0 lb.

3.3.3 Selection of Concepts for Design Studies

A concepts briefing was held at NASA/JSC on 20 November 1973, at which time agreement was obtained to pursue the following two concepts

TABLE 6 IMPACT OF METEOROID CONSIDERATIONS

CONCEPT(1), (2)	90% PROBABILITY LIFETIME(3)	TUBE WALL THICKNESSES REQUIRED				CONCLUSION
		30-DAY, 90%	30 DAY, 99%	5 DAY, 90%	5-DAY, 99%	
GAS RADIATOR	4 MINUTES	0 084″	0 153″	0 052″	0 096″	ELIMINATES CONCEPT
FREON 21/SILVER WIRE MESH	3 HOURS	0 037″	0 069″	0 024″	0 043″	IMPACTS FLEXIBILITY AND WEIGHT, CONCEPT SURVIVES WITH DOUBTS
FREON E 2/SILVER WIRE MESH	1½ HOURS	0 036″	0 068″	0 023″	0 042″	ELIMINATES CONCEPT
LAMINATED SILVER TEFLON FILM	2½ HOURS	0 039″	0 072″	0 025″	0 045″	IMPACTS FLEXIBILITY AND WEIGHT, CONCEPT SURVIVES
FREON 21/ALUMINUM HARD TUBE	3½ HOURS	0 038″	0 067″	0 023″	0 042″	PROVIDES WEIGHT IMPACT ONLY

NOTES

(1) ALL ARE 2 SIDED RADIATORS EXCEPT HARD TUBE
(2) ALL ARE TEFLON TUBES EXCEPT ALUMINUM HARD TUBE
(3) REFERS TO BASIC DESIGNS NOT CONSIDERING METEOROID REQUIREMENTS

throughout the remainder of the design studies.

(a) Cylindrical hard tube concept with a silver wire mesh/Teflon laminate fin material

(b) A roll-up soft tube concept with an evaporated thick silver/Teflon film fin material

Figures 17-A and 17-B list the advantages of the two concepts that led to their being selected for further development. The fin material for the two concepts are interchangeable and were not considered to be a fixed part of the designs. Also the tubing and fluids materials may be modified or changed as a result of additional studies and tests.

3.3.4 Design Studies

Analytical trades, system level studies, and numerous element tests were conducted for the two selected concepts. The design studies included analyses to study the effect of changing the thickness of the thick silver-Teflon film concept, consideration of steel tubes for the hard tube concept, tests of Spraylon coated silver wire mesh elements, flowpath optimization, manifolding/deployment/configuration/packaging studies, determination of effects of atmospheric drag and acceleration loads, materials evaluation studies, and element tests to establish fabrication techniques and thermal performance. A detailed account of the design studies is given in Reference (3). The more important aspects are summarized below.

3.3.4.1 Element Tests

Tube-Fin Bonding Tests:

During December 1973 element tests were conducted on specimens which simulated the wire mesh fin material to evaluate tube-fin bonding techniques. Materials on hand were used to permit tests at this time in order to gain early information on potential problems. Test elements were made to simulate the baseline fin material of a silver wire mesh/FEP Teflon film laminate and an alternate fin laminate. The most significant results obtained were:

(1) A satisfactory bond between the FEP Teflon fin surface and the metal tubing can be obtained using 6962 glue strips.

FIGURE 17-A

ADVANTAGES OF THE HARD TUBE CONCEPT

1. EXCELLENT PERFORMANCE :

   30-DAY DESIGN (ONE-SIDED)

   - 41 BTU/HR-FT^2, 284 BTU/HR-LB
   - 326 FT^2 RADIATING AREA, 47.5 LB
   - 0.05" I.D. ALUMINUM TUBING, 0.033" TUBE WALL, 1.43" SPACING
   - FEP TEFLON FILM/SILVER WIRE MESH LAMINATE FIN, 0.004" TOTAL THICKNESS

2. WORK TO DATE INDICATES FEASIBLE TO FABRICATE

3. POTENTIAL FOR EXTENDED MISSION DURATION, REDUNDANT FLUID LOOPS, DIRECT TIE-IN WITH ORBITER FREON LOOP.

4. POTENTIAL SIMPLE DEPLOY AND RETRACT (CYLINDRICAL SPRING - COULD USE STEEL TUBES WITHOUT PROHIBITIVE PENALTY)

5. INHERENT RIGIDITY OF CYLINDRICAL SPRING CONCEPT

6. BASELINE SILVER WIRE MESH/FEP TEFLON HEAT SEALED LAMINATE FIN

7. COMPATIBLE WITH SILVERED TEFLON FILM FINS IF FOUND TO OFFER PRACTICAL ADVANTAGE OR IF OPTIMIZES BETTER

1. EXCELLENT PERFORMANCE

   5-DAY DESIGN (2-SIDED)

   - 38 BTU/HR-FT^2 (PANEL AREA), 430 BTU/HR-LB
   - 345 FT^2 PANEL AREA, 30 LB
   - 0.05" ID TEFLON TUBING, 0.023" TUBE WALL, 1.43" SPACING
   - 0.002" TOTAL FIN THICKNESS

2. WORK TO DATE INDICATES FEASIBLE TO FABRICATE AND MORE FLEXIBLE THAN 2-SIDED SILVER MESH/TEFLON LAMINATE CONCEPTS

3. POTENTIAL FOR DIRECT TIE-IN WITH ORBITER FREON LOOP, REDUNDANT FLUID LOOPS.

4. POTENTIAL FOR SIMPLE ROLL-UP DEPLOY AND RETRACT

5. IDEAL FOR INTERMITTENT OR SHORT USE MISSIONS WHERE RETRACT CAPABILITY IS DESIRED

6. RECOMMEND 5-DAY BASELINE FOR THIS CONCEPT

FIGURE 17-B

ADVANTAGES OF THE SILVERED TEFLON FILM CONCEPT

(2) An alternate fin layup with silver-backed FEP Teflon film bonded to silver wire mesh, both bonded to the metal tubing, can be satisfactorily fabricated using either 6962 glue strips or SR585. The SR585 provides a much more flexible end product.

(3) Heat shrinkable Teflon tubing collapses during heat cure when bonded in similar layups as above.

In these tests a 100 x 100 weave nickel wire mesh with 2-mil wire was used to simulate the silver wire mesh. The resulting elements were quite stiff. The 40 x 67 weave silver wire mesh will exhibit much better flexibility due to both its lower weave density (40 per inch in bending crossection vs 100) and its lower modulus of elasticity (10.3 x 10^6 psi vs 30 x 10^6 psi). Calculations predict that the silver wire mesh would be 7 times as flexible. Also, the wire mesh test laminates ranged in thickness from 7 to 12 mils, as compared to the projected baseline layup thickness of 4 to 6 mils. Since stiffness varies as the cube of thickness this is also significant.

Precursor Thermal Vacuum Tests.

During March 1973 an opportunity arose to conduct an inexpensive thermal vacuum test using a test article fabricated from sample materials on an IR&D program, and using a test set-up which had been put together for another program. Although the test setup was not optimum for inflatable radiator heat transfer tests it was decided that a simple thermal vacuum test would still be worthwhile to obtain early data to verify fin and tube wall delta-T calculations.

The test article consisted of a 5" x 8" panel section with a single serpentine FEP Teflon tube (0.062" O.D. x 0.030" wall) flowpath. The panel was fabricated from 2 sheets of 5 mil FEP Teflon, each coated with 14,000 angstroms of silver (determined by electron photomicrograph - see June 1974 status briefing for pictures). The flowpath was sandwiched between the two sheets of silvered Teflon. The test element was mounted in a 24" dia. LN_2 shroud, evacuated, and supplied with heated Freon 21 as the transport fluid. Test article instrumentation consisted of 2 tube temperatures, 2 fin midpoint temperatures, and fluid inlet and outlet temperatures.

Facility instrumentation included fluid supply and return temperatures and pressures, flowrate, test vacuum, and LN_2 shroud coldwall temperatures. Tests were run at 133°F and 156°F fluid inlet temperatures, both at a 180 pph flowrate. Comparison of predicted and measured performance showed reasonably good agreement, with the test element performance slightly better than predicted. Comparison results at the 156°F inlet temperature are

	CALCULATED*	MEASURED*
Fin Midpoint Temp.	2°F & 18°F	16°F & 19°F
Tube Wall Plus Fluid ΔT	31°F & 30°F	27°F & 33°F
Total Heat Rejection	58 BTU/hr	21 BTU/hr - 62 BTU/hr
Pressure Drop	61 psi	50 psi

The test successfully demonstrated the validity of the thick silver film concept and established acceptable accuracy of the analytical model. The large test value of tube wall delta-T resulted from two circumstances unique to the test - the thick wall (0.30" vs 0.016" for the baseline design), and the severe combination of average fluid temperature/environment temperature (156°F/-310°F vs 65°F/0°F at the design point). The baseline design wall delta-T calculated at the design point using the same model is only 2.5°F.

Spraylon Tests.

A recent publication by Lockheed(1) described a new spray-on FEP Teflon formulation which was as good as or superior to FEP Teflon film in optical properties and space environment stability. It offered ease of

---

(1) L. A. Haslim, et.al., "A Highly Stable Clear Fluorocarbon Coating for Thermal Control Applications", AIAA Paper 74-117, presented at the 12th Aerospace Sciences Meeting, January 30 - Feb. 1, 1974.

---

* The dual values are at each of the two instrumentation locations, and reflect small differences in tube spacing.

application by spray, dip, or brush and requires only a low temperature cure. A purchase order was entered with Lockheed (P.O. #P-837895-AER) in May 1974 to coat 2 square feet of silver wire mesh material with Spraylon. The Spraylon would be used as an alternate to the sandwich of heat sealed FEP Teflon films on the wire mesh, and should insure intimate thermal contact between the Teflon and the wires as well as provide a potentially more producible design. Initial silver wire mesh material was delivered during a trip by R. L. Cox to Lockheed on 2 May. Small coupons were coated at that time. The coating on these coupons was very thin (estimated at 0.2 to 0.4 mil) and the composite had good flexibility. Emittance was measured to be 0.37 with a Gier-Dunkle DB-100 emissometer. Subsequent scanning electron photomicrographs (see June 1974 Status Briefing for examples) showed good intimate contact at the wire-Teflon interface and also at a Teflon-wire-stainless steel tube interface provided by weaving a section of tubing into the wire mesh.

Problems have been encountered in coating the 2 sq.ft. of wire mesh to the desired 1-3 mil thicknesses. Only about 1/2 mil of Spraylon was obtained. In addition, the specimens were damaged in shipment to Vought; thus a second 2 sq.ft. of silver wire mesh was sent to Lockheed on 31 May. The second set was coated and returned to Vought on 1 July. These specimens exhibited considerable wrinkling and were coated to only about 1/2 mil. Multiple coats have been unsuccessful due to solvent attack of the first coat.

Thick Silver Film Elements:

Nine small elements of thick silver coated FEP Teflon were fabricated. Each element was about 4" x 3" square and consisted of two identical layers of thick silvered Teflon film and sprayed-on SR585 silicone adhesive. The test elements were fabricated from 2-1/2 sq.ft. sections of 9 special thick silvered Teflon films ordered from G. T. Scheldahl Co. in nominal guages of 1-mil, 2-mil and 5-mil FEP Teflon, each metallized with 6000, 12,500 and 25,000 angstroms of evaporated silver. The tests demonstrated feasibility of spray application of SR585. Fabrication was somewhat difficult with the 1-mil film. Flexibility was essentially independent of silver thickness and was good on the 1-mil and 2-mil films laminates; the 5-mil film laminate was undesirably stiff. Mechanical integrity of the laminates, after boiling water/LN_2 shock, was good in all cases except the

5-mil Teflon/25,000 angstrom silver laminate, in which case slight delamination occurred. It is questionable that this element would have failed under more realistic environmental exposure conditions.

Gas Manifold Meteoroid Bumper Test:

Analysis of meteoroid protection requirements for the gas deployment manifold of the soft tube concept indicated 23 layers of 1/2-mil Teflon bumper wrapping will be required (for the baseline 1.7 day protection). Because of concern that the multilayers would make it difficult to roll up the manifold in the longitudinal direction, a simple test was run using materials on hand. Forty-six layers of 1/4-mil Mylar were wrapped into a 2-inch diameter tubular shape (simulating the 23 layers of 1/2-mil Teflon). The resulting layup was flexible and easy to roll, indicating that significantly more bumper protection could be added before seriously inhibiting the flexible radiator panel stiffness. This would make it feasible to significantly extend the protected lifetime. Since Mylar has a tensile modulus about 8 times that of FEP Teflon, the test simulation was estimated to be conservative by a factor of 2.

3.3.4.2 Concept Trade Studies

During the December-January 1974 time frame preliminary analytical trade studies were conducted to evaluate the effect of the evaporated silver thickness on the soft tube thick silver film concept. Subsequent trades were performed on both the soft tube and hard tube concepts in the May-June 1974 time period to support the configuration selection for the preliminary design and to refine and update earlier studies.

Silver Thickness Trades:

Silver film thickness of 6,250 angstroms and 25,000 angstroms were analyzed to complement the studies previously done at 12,500 angstroms. In all cases Teflon film thicknesses of 0.0005, 0.001 and 0.002 inches were analyzed. The model consisted of two thick-silver-backed Teflon films sandwiching FEP Teflon tubing of variable diameter and spacing. A glue layer of 0.0005 inch thickness was assumed. Tube wall thickness was determined to provide a 90% probability of a 30-day lifetime in the meteoroid environment. Area and weight were computed as a function of tube diameter and spacing. Calculated weights included tube, fluid and fin weights plus a pump power penalty based on 100% pump-motor efficiency.

Results show that minimum weight occurs for tube spacing in the 1 to 1-1/2 inch range and for tube inside diameters in the 0.04 to 0.05 inch range. Minimum weight was found to occur at the 25,000 angstrom silver thickness and 0.002 mil (each side) Teflon film thickness. The effect of Teflon film thickness is to minimize weight in the 0.001 to 0.002 inch single-film range. Area is independent of tube diameter, but decreases uniformly with decreasing tube spacing in all cases, with the effect being more pronounced at the thinner silver thicknesses. Area decreases with increasing silver and Teflon film thicknesses.

It was concluded from these studies that silver and Teflon film thicknesses in the range of these analyses are near the practical optimum and should be evaluated experimentally to determine fabricability, flexibility, and mechanical integrity. This led to the previously described element tests, as well as setting the range of variables for final configuration studies.

Soft Tube Concept Configuration Trades

The analysis carried out above was revised to alleviate meteoroid protection requirements (per NASA direction) and to refine studies to include estimated actual pump-motor efficiencies. Tube wall guage was determined as that required to retain fluid vapor pressure at the maximum system temperature of 200°F, using a design ultimate pressure of 4 x Maximum Expected Operating Pressure (MEOP). For Freon 21 and MEOP is 165 psi. From a correlation of data on existing space-qualified type pumps, and pump design conditions of 1.3 gpm and 12 psi delta-P, it was found the requirements fall between the vane and centrifugal pump ranges. Each type is poor in this range, but competitive with the other in efficiency. A canned AC motor centrifugal pump was chosen as typical, with a 13% overall pump-motor efficiency.

From these results a baseline design using 2-mil Teflon films with 12,500 angstroms silver on each film, 1-inch tube spacing, and

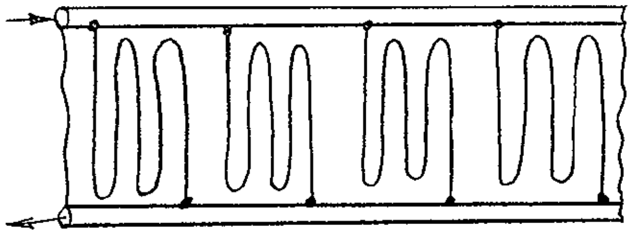
AWG #14 FEP Teflon tubing (0.069" I.D. x 0.016" wall) was chosen as the best compromise between optimum weight, minimum area, fabricability, expected flexibility, and expected mechanical integrity. The 0.016" tube wall guage provides 90% probability of meteoroid survival for 1.7 days, a 0.037" wall is required for 30-day protection. The previously described thick silver film laminate element tests and upcoming thermal vacuum element tests are designed to finalize the selection of film thickness and tube dimensions.

Flowpath arrangement trades were conducted on the two basically different configurations illustrated in Figure 18. In the "A" configuration the parallel flowpaths are arranged into serpentine sections with a feed manifold on one side and a return on the other. In the "B" configuration the parallel flowpaths are arranged into single flow loops, each fed from and returning into common manifolds at the base. Two basic arrangements were considered with each flowpath configuration - single panels and multiple panels. In the single-panel arrangement panel widths of 40" to 120" were allowed, while multiple panel widths of 40" to 60" were considered. In each case the previous panel tube diameter and spacing trades were extended to include manifold tube and fluid weights and pumping power penalty. Optimized results for single-panel and three-panel arrangements are given in Table 7. Two-panel arrangements are intermediate.

From the table it can be seen that the single-panel arrangement is not attractive in either configuration A or B for the narrow panels. In configuration A the manifold weight penalty is excessive. Also, the 3/8" ID, 0.083" wall, FEP Teflon manifold tubing presents an impractical stiffness level. In configuration B the weight is high due to a greatly increased pumping penalty for the long tubing run. The increased tube diameter of 0.087" ID with 0.019" wall, required to alleviate this condition, also inhibits flexibility. The wide panel arrangement offers considerable improvement, although configuration A still has a high manifold weight penalty and stiffness. Configuration B now looks practical, although the 120" width may be undesirable.

The three-panel arrangements are basically the wide single-panel arrangements, sliced into three individual panels and modified to accommodate

A. SIDE MANIFOLDS, SERPENTINE TUBES



B. BASE MANIFOLD, LONGITUDINAL TUBES

FIGURE 18 FLOWPATH AND MANIFOLD CONFIGURATIONS

TABLE 7

SOFT TUBE RADIATOR CONFIGURATION TRADE STUDIES

OPTIMIZED SINGLE-PANEL CONFIGURATIONS*

	A narrow	A wide	B narrow	B wide
Panel Length	65'	25'	55.2'	22.8'
Panel Width	42"	109"	40"	120"
Panel Area	228 ft^2	228 ft^2	184 ft^2	228 ft^2
Tube Spacing	1"	1"	1/2"	1"
Tube I.D.	065"	.065"	.087"	.065"
Tube Wall Guage	.014"	.014"	019"	.014"
Manifold I D.	.375"	.3125"	.472"Al.	.472"Al
Manifold Wall Guage	.083"	.069"	.014"Al.	.014"Al
Manifold Wt. Penalty	51.5#	29.8#	.9#	2.7#
Total Rad. Panel Wt.**	101.7#	80 0#	88.2#	52.9#

OPTIMIZED THREE-PANEL CONFIGURATIONS*

	A	B
Panel Length	21.7'	22.8'
Panel Width	42"	40"
Panel Area	76 ft^2	76 ft^2
Tube Spacing	1"	1"
Tube I.D.	.065"	.065"
Tube Wall Guage	.014"	.014"
Manifold I D.	.25"	.472"Al.
Manifold Wall Guage	.055"	014"Al.
Total Manifold Wt. Penalty (3 panels)	20#	2.7#
Total Rad. Panel Wt. (3 panels)**	70.2#	52 9#

---

*2-mil FEP Teflon films with 12,500 angstroms silver, two-sided

**Includes fin material, radiator panel and manifold tubing and Freon 21, and pump power penalty at 2.3 lb/psi.

physical constraints of the flowpath routing. Manifolding is re-optimized. Configuration A is again improved, but still retains the disadvantages of a high manifold penalty and stiff manifold tubing. Type A configurations are also expected to display increased fabrication problems, especially in the area of the tube-manifold junctions. Thus configuration B was selected. Further consideration was given to single vs multiple panels. The advantage of multiple panels is a more desirable width (for packaging), modularity (for greater flexibility in applications over a wide range of heat loads and for potential reliability improvement by panel isolation at failure), and ease of fabrication. The disadvantage is the likelihood of greater environmental heating due to radiant interchange. Three panels were selected for the soft tube concept baseline.

Hard Tube Concept Configuration Trades:

The silver wire mesh analysis for the hard tube concept, summarized in the November 1973 Concepts Briefing, was extended to include a 13% pump-motor efficiency and to add configurational considerations. Because of the inherent tubing stiffness desired in the hard tube concept for spring action, the metal tube wall guage was sized for 30-day meteoroid protection (at 90% survival probability) at no expected additional penalty. To limit studies to a reasonable scope, only a single cylinder diameter of about 40" was analyzed and only a single tubing "spring helix" angle of 20° was studied. Variables in the trades were tube diameter, spacing and material (aluminum vs steel), flowpath arrangement (all-parallel with a long return manifold vs each tube forming a complete flow loop), and Teflon thickness on the silver wire mesh fin material. Figure 19 illustrates the two arrangements analyzed. Reference (3) presents analysis conditions and selected results from the parametric analyses, which include tube, fluid and fin weights plus the pumping power penalty. Trades at the parametric level did not include manifold weight penalties.

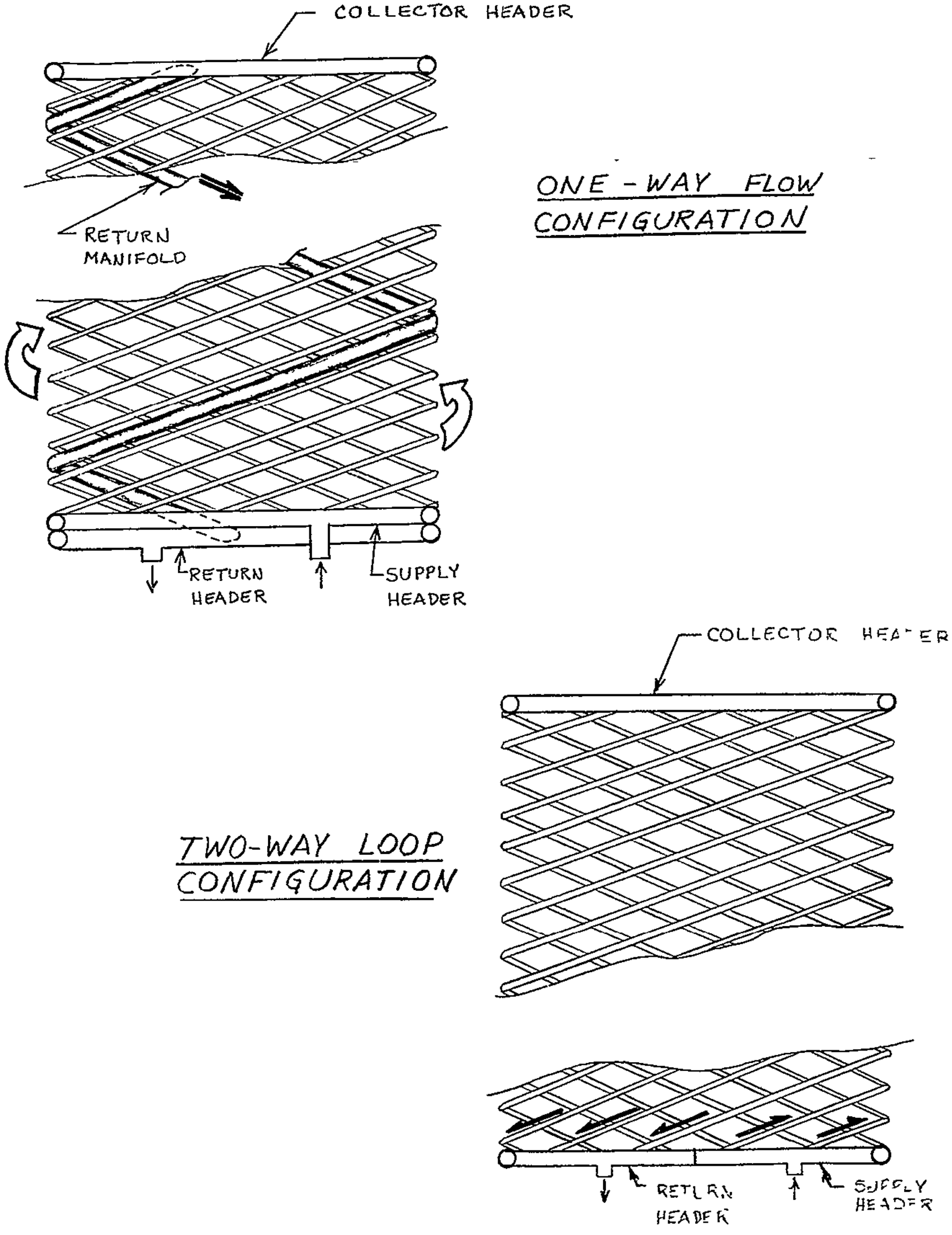


FIGURE 19 HARD TUBE CONCEPT FLOWPATH CONFIGURATIONS

A Teflon thickness of 4 mils was selected for the fin material, and a tube spacing of 1-1/2 inches was selected for the baseline. This spacing provides the minimum weight design and suffers only about a 10% area penalty compared to a 1-inch spacing. It is expected to be easier to fabricate and will package into about 20% less volume than the 1-inch spacing. The corresponding optimum tube ID was found to be 0.108" for one-way flow and 0.130" for a two-way loop.

Comparison of aluminum and steel tubing was made for equal meteoroid protection. Aluminum was found to offer a significant weight advantage (85 lb for the two-way flow loop). Stress analysis indicated acceptable spring stress levels will exist in either material and that usable spring forces can be obtained. Since no significantly different manufacturing problems were identified, aluminum was selected for the baseline.

Manifold penalties were added to the results of the parametric trades in order to make the selection between one-way flow and a two-way loop. In one-way flow this penalty is much larger because of the long return manifold. The return loop was optimized for the one-way flow arrangement and found to impress a penalty of 43 lb, including tube weight, fluid weight, and pumping power penalty for the 2-mil Teflon fin configuration. Since the return loop is arranged in a spiral spring configuration, it likewise experiences stresses due to spring compression. This stress (about 12,000 psi shear stress in aluminum) limits the manifold to 0.375"O.D. Three return manifold tubes were found to provide the minimum weight subject to this constraint. Adding the 43 lb return loop penalty to the one-way flow arrangement increases its weight to within 31 lbs of the two-way loop. The choice between the flow arrangements reduces itself to a trade between the weight advantage of the one-way arrangement and the greater fabrication simplicity of the two-way configuration. A baseline selection of one-way flow was made on the latter consideration.

3.3.5 Preliminary Design

3.3.5.1 Deployment System

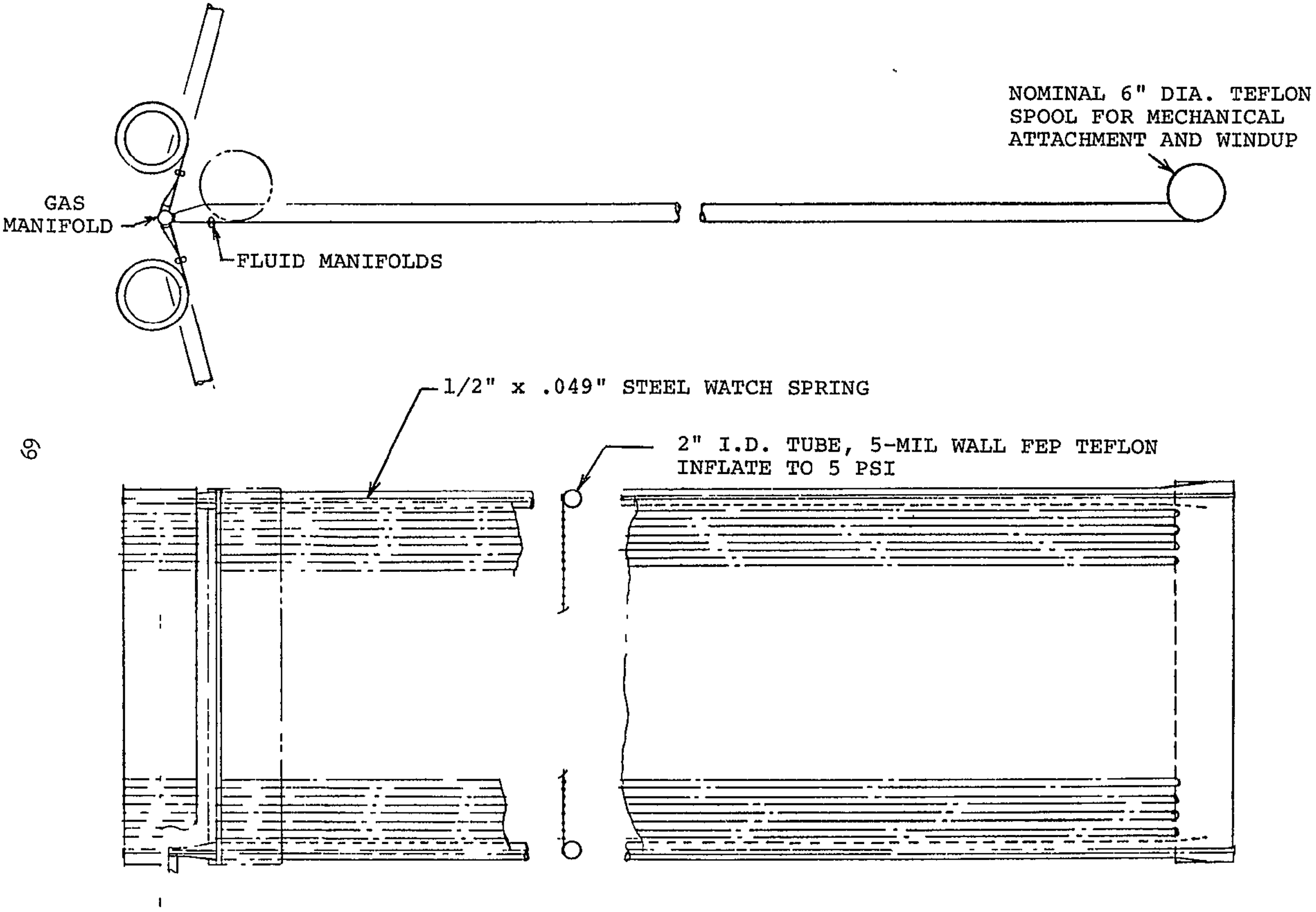
As groundruled at the 13 September 1973 Orientation Briefing, the flight article preliminary design studies defined a deployment system and established a feasible concept for retraction. (Feasibility demonstration tests, however, are only required to prove the deployment aspect.) Accordingly, studies supporting the flight article preliminary design considered both deployment and retraction.

Three concepts to "roll-out" the soft tube concept were evaluated. The first concept used Freon 21 fluid pressure. The second supplemented this by the addition of a larger diameter tube inflated by a gas pressurant. The third mechanically unrolled the panel using a Storable Tubular Extension Member (STEM). It was found that a 165 psi Freon 21 fluid pressure exerts an unrolling moment of only about 1 inch/lb, compared to 30 inch/lbs needed, thus the first concept is inadequate. Addition of two gas tubes, one to each side of the panel and both of 2-inch diameter, provides the needed 30 inch/lb if the tubes are inflated to 4.8 psi. Studies of meteoroid vulnerability showed that unprotected 5-mil nitrogen gas inflation tubes would incur a 20-35 lb/day makeup gas penalty. Thus this concept is feasible only if a meteoroid barrier is added. Penetration studies indicated that 23 layers of 1/2-mil Teflon wrapped around the 2-inch gas tubes would provide a 90% survival probability for about 2 days, consistent with the 1.7-day lifetime of the soft tube concept main radiator panel Freon 21 tubes. For 30-day survival 59 layers were calculated to be needed. Multilayer meteoroid barrier performance, especially on plastic materials, is poorly understood and based on sparse data(2). Tests are recommended to establish the protection required. It was calculated that two flat steel watchsprings (1/2" x .049") , one combined with each gas inflation tube, would be required to rewind the panels. Figures 19 and 20 show the integration of the gas inflation tube/watchspring deployment/retraction system with the panels.

---

(2) NASA TN D-6989, "Multimaterial Lamination as A Means of Retarding Penetration and Spallation Failures in Plates", by J.D. DiBattista and D. H. Humes, 1972.

FIGURE 19 GAS DEPLOYMENT SYSTEM FOR SOFT TUBE CONCEPT



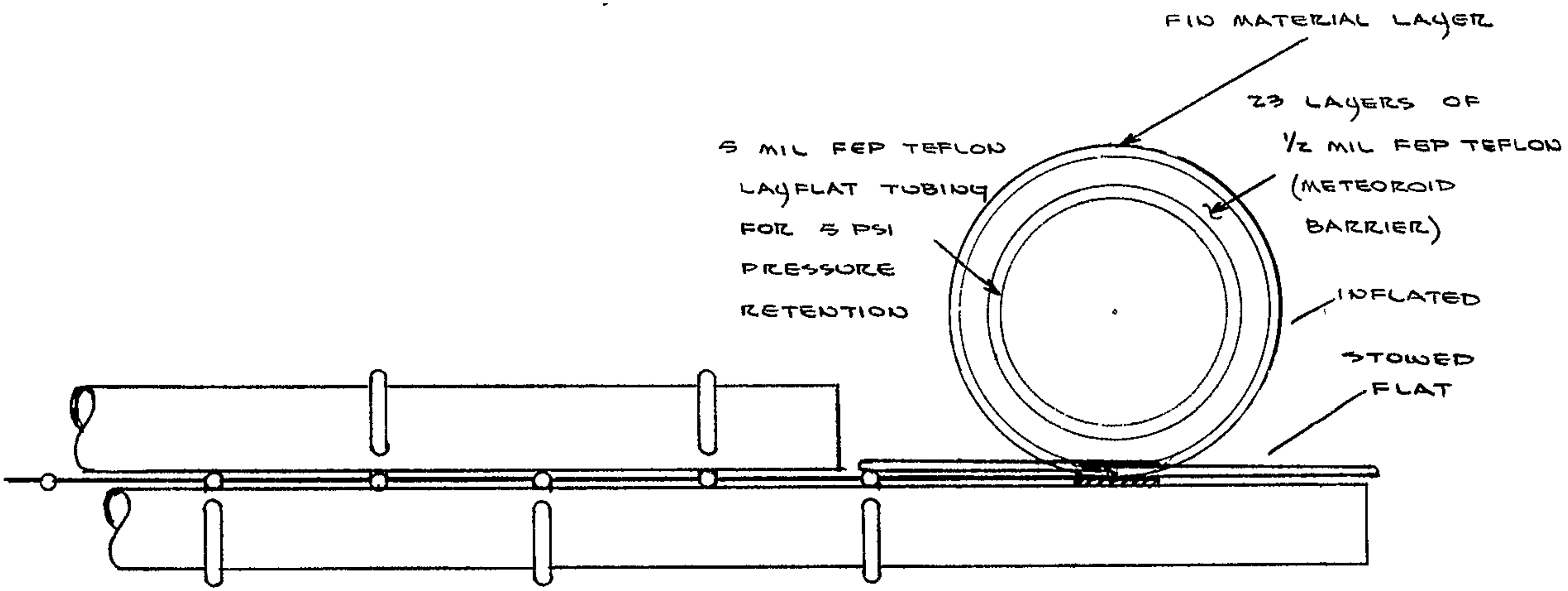


FIGURE 20 DEPLOYMENT GAS TUBING DETAIL

Evaluation of the STEM deployment system consisted of sizing the units based on data from SPAR Aerospace Products, Ltd. using calculated loads and integrating the STEM with the panels and a retraction system. A buckling load of 3 lbs was found to be required to overcome the roll-up spring force. Bending moments were calculated due to RCS firing (6.8 in-lb), air drag (9.9 in-lb), and the roll-up spring (30 in-lb). The buckling force controls. A model A-631 BI-STEM was selected as typical in performance. This unit weighs about 10 lbs,requires 20 watts, and withstands 10 lbs buckling force at an extension length of 25 ft. However, the packaging configuration of a slightly larger unit, model 5930 F1-1, was considered more representative. This unit weighs about 16 lbs, withstands 15-20 lbs of buckling force, and requires 60 watts. An intermediate design, weighing 13 lbs, packaged similar to the 5930 F1-1, and performing like the A-631 was assumed. Figure 21 illustrates the design, with a window shade type roll-up spring integrated into the wind-up spool Six BI-STEMS are required, one on each side of each panel. A net weight increase of 75.5 lbs was calculated, based on the removal of 30.5 lbs of gas inflation/watchspring retraction system parts and fluid loop components, and the addition of 108 lbs of BI-STEMS and rewind system. The gas inflation deployment system was selected as the baseline design, with the BI-STEM system as a feasible alternate.

A structural stress analysis was conducted to determine stresses in the tubing spring members and to estimate the deployment force exerted by the spring in the hard tube deployment concept. For the baseline design with the two-way flow and 30 tubes (0.25" O.D. x 0.049" wall, 10.6 turns each) was analyzed. This design has an extended length of 505 inches and a compressed length of about 81 inches. The compressed shear stress was calculated to be 6650 psi, and a retraction force of 25 lbs at the fully compressed condition is required. A BI-STEM retraction system, located inside the cylindrical radiator and attached to the upper rim by a harness, was selected as a representative feasible retraction system. The BI-STEM retraction system weight was estimated at 24 lbs. If necessary, the BI-STEM can also assist in deployment. Acceleration and air loads on the hard tube concept are negligible.

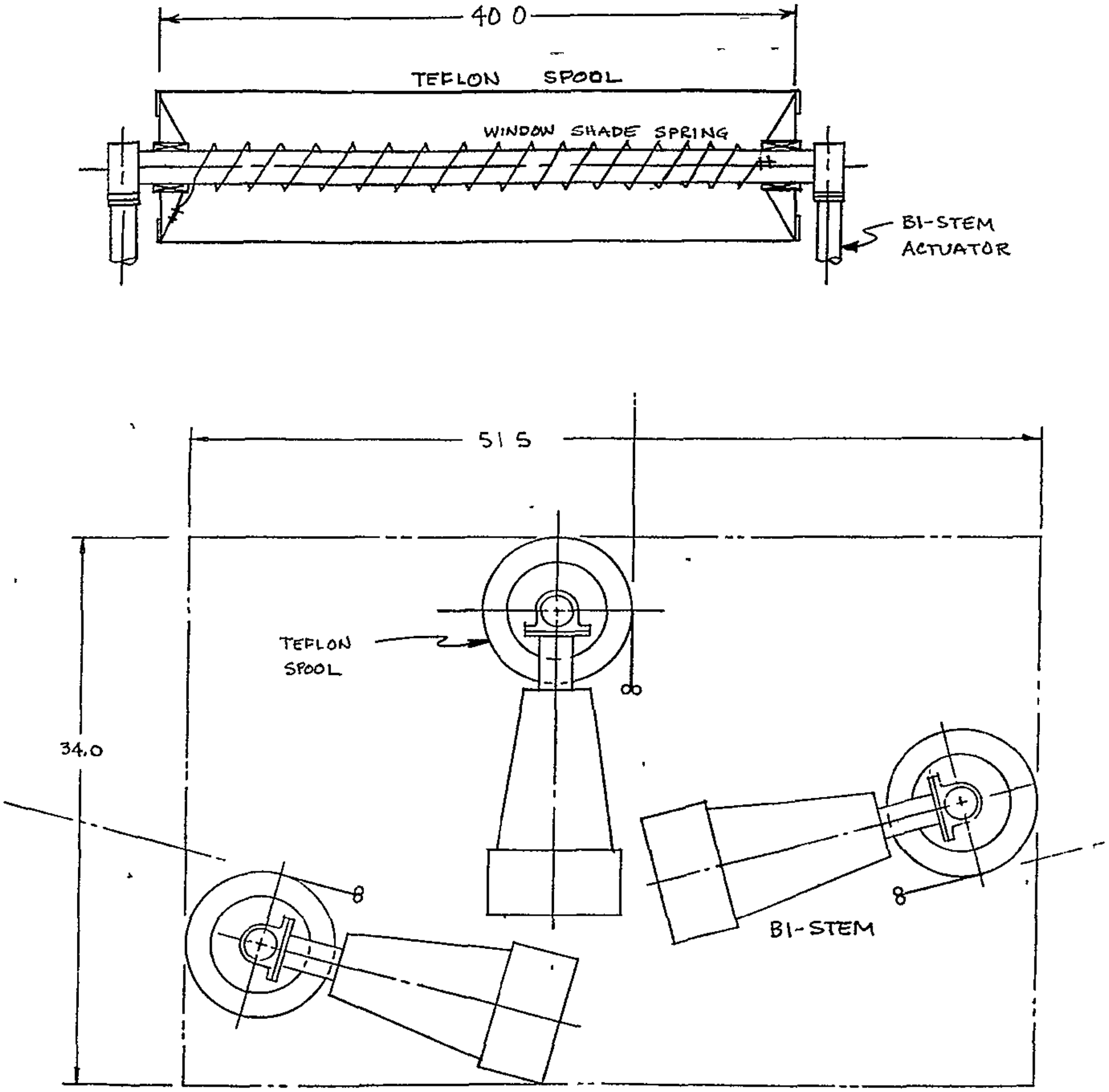


FIGURE 21 STEM ALTERNATE DEPLOYMENT SYSTEM FOR SOFT TUBE CONCEPT

3.3.5.2 Fluid Loop

Figures 22 and 23 show the respective fluid loop schematics for the soft tube (Party Whistle) and hard tube (Jack-In-The-Box) concepts. The two systems differ only in the addition of a regulator, valve, and plumbing for the Party Whistle concept inflation system, and in volumes of the Freon 21 and nitrogen gas reservoirs. As groundruled at the Orientation Briefing the Inflatable Radiator System concepts for the current feasibility demonstration program are presumed to always have a sufficient heat load applied to avoid Freon 21 transport fluid freezing in the radiator panels. This permits the simple bypass type fluid temperature control system illustrated in the figures.

The heat exchanger was sized assuming water as a representative vehicle side transport fluid. A minimum Freon inlet temperature of 35°F was defined to avoid possible water freeze-up when control tolerances are considered. Heat exchangers were sized for both 2°F and 5°F log mean temperature differences. Respective weights were found to be 32.8 lbs dry (47.2 lbs wet) vs 13.1 lbs dry (18.9 lbs wet) and envelope volumes of 529 in^3 vs 212 in^3. This heat exchanger weight savings was traded against radiator weight increases due to the lowered radiating temperature. The corresponding hard tube concept weight and area increases were found to be 8.2 lbs and 26 sq.ft., and the soft tube concept 3.4 lbs and 15 sq.ft. The 5°F heat exchanger design was selected as typical. Details are given in Figure 24.

The Freon reservoir was sized for the soft tube concept. Figure 25 shows the reservoir design and principle assumptions. The reference 30-day mission is indicated in that it affects the expendable nitrogen requirement, the reservoir design is independent of mission duration. The 30-day capability was chosen because of its small impact on the fluid loop. In the sizing analysis thermal expansion was computed for both the Freon and the radiator/fluid loop components; however, it was found that the Freon expansion/contraction is dominant.

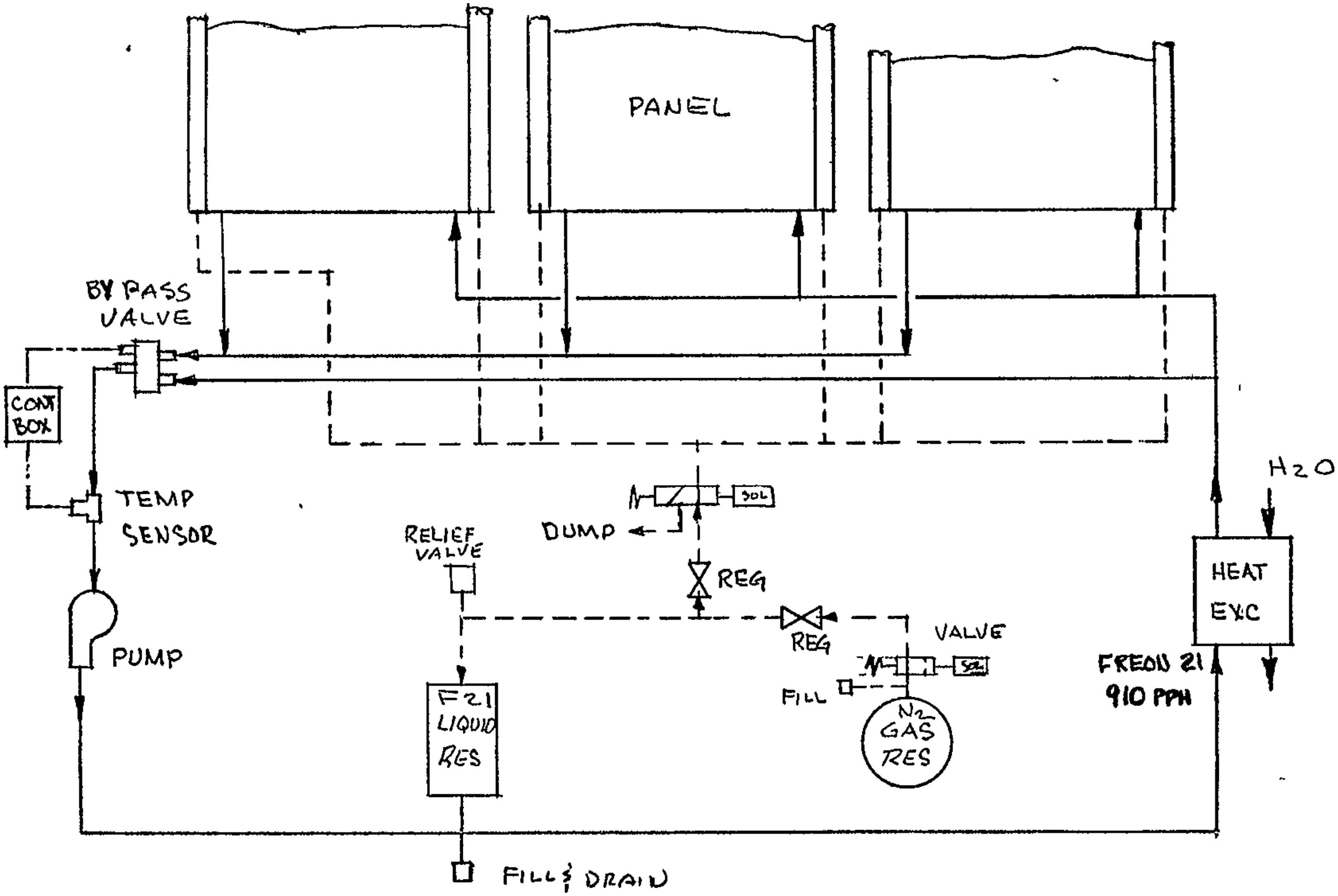


FIGURE 22 PARTY WHISTLE CONCEPT FLUID SCHEMATIC

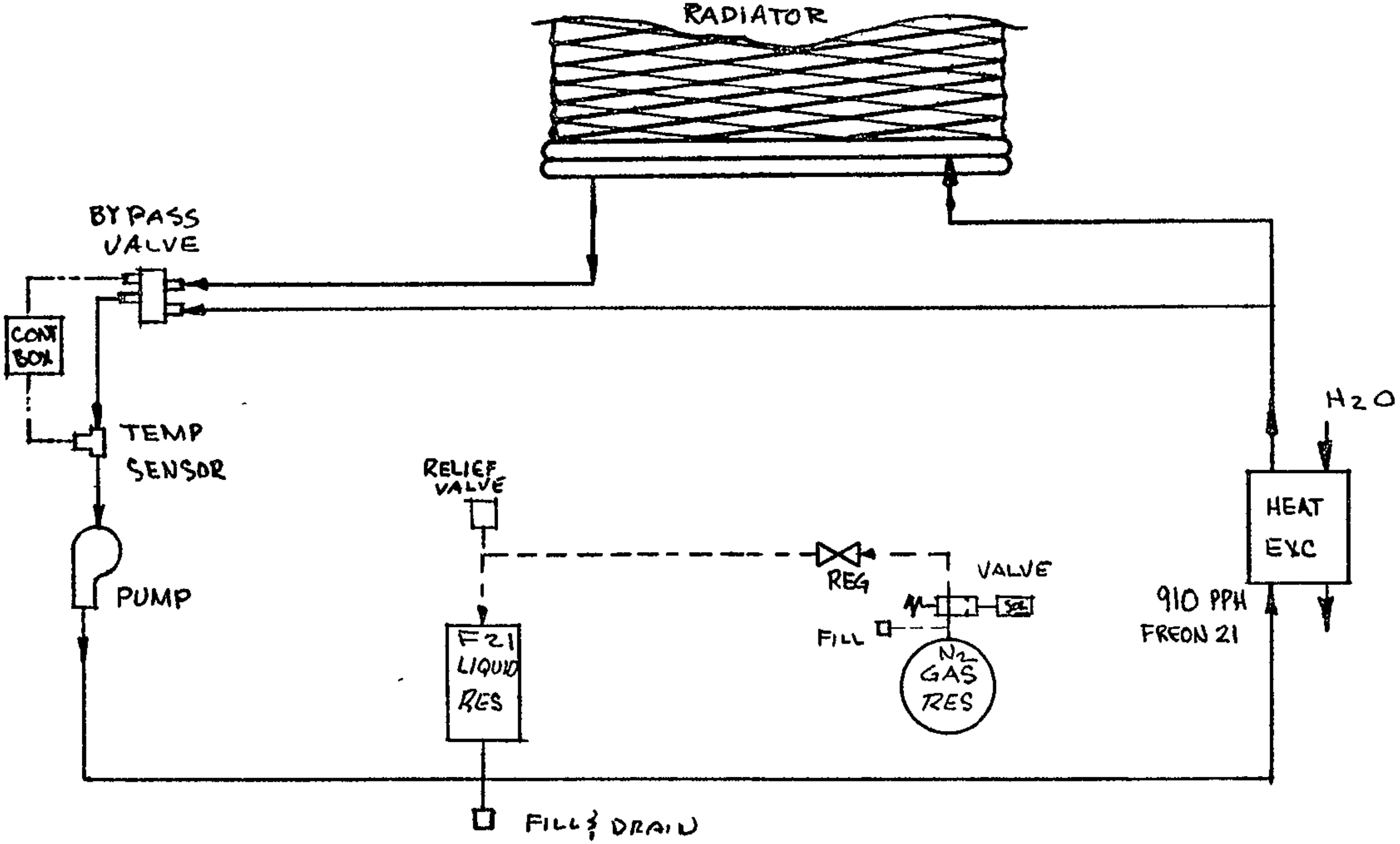


FIGURE 23 JACK-IN-THE-BOX CONCEPT FLUID SCHEMATIC

REQUIREMENTS:

IRS LOOP FLOW: 910 PPH FREON 21
HEAT TRANSFER: 4 KW
SECONDARY LOOP FLOW: 228 PPH WATER
SECONDARY LOOP TEMPS: 100°F IN, 40°F OUT
HEAT EXCHANGER LOG MEAN   T = 2°F TO 5°F
MINIMUM NOMINAL FREON TEMP: 35°F

CORES CONSIDERED:

AVCO EASY-WAY & HARD-WAY LANCE FIN
SHAH & LONDON LANCE FIN CORE

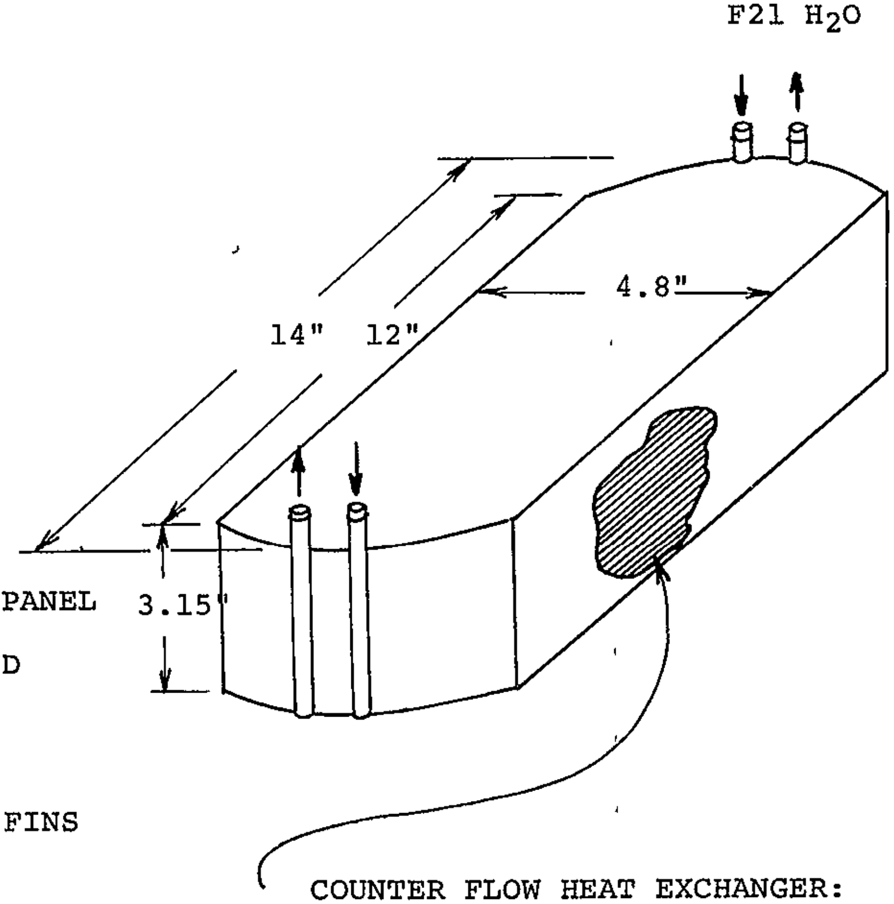
BASIS FOR SELECTION:

5°F LMTD	:	LOW SYSTEM WEIGHT TRADES FAVORABLY AGAINST PANEL WEIGHT
SHAH & LONDON:	:	MUCH SMALLER, LIGHTER, AND LOWER PRESSURE DROP

HEAT EXCHANGER DATA:

- MATERIALS: STAINLESS STEEL WITH NICKEL FINS
- DRY WEIGHT: 13.1 LBS
- WET WEIGHT: 18.9 LBS
- WATER SIDE   P = 0.0075 PSI*
  FREON SIDE   P = 0.0125 PSI*

*EXCLUSIVE OF MANIFOLD LOSSES



COUNTER FLOW HEAT EXCHANGER:

50 PARALLEL F21 PASSAGES
50 PARALLEL H_2O PASSAGES

FIGURE 24 HEAT EXCHANGER SIZING

REQUIREMENTS:

- MAINTAIN 165 PSI PRESSURE OF F21
- PREVENT OVER PRESSURIZATION OF F21 LOOP
- TEMPERATURE LEVELS

  + 70°F NOMINAL
  +200°F MAXIMUM
  -200°F MINIMUM RADIATOR RETURN
- ONE TEMP. CYCLE PER DAY, 30 DAYS

FLUID VOLUMES (F21):

- SUM OF 3 RADIATORS : 230 in^3
- HEAT EXCHANGER : 169 in^3
- LINES AND COMPONENTS : 53 in^3
- VOLUME INCREASE UPON INITIAL PRESSURIZATION: 4 in^3

RESERVIOR DATA:

- REGULATED GAS PRESSURIZATION SYSTEM
- BLADDER SEPARATION OF F21 AND N$_2$
- ALUMINUM TANK
- WEIGHTS: *

  DRY = 3.75 LBS
  AT LIFTOFF = 6.53 LBS
  FILLED TO MAX. CAPACITY = 12.1 LBS
- EXPENDABLE N$_2$ REQUIRED = 1.08 LBS

*Exclusive of Regulator & Relief Valve

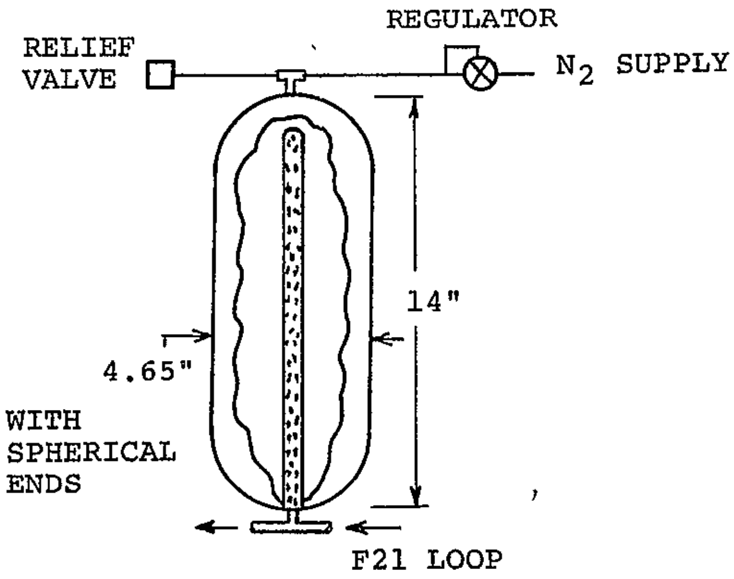


FIGURE 25 FLUID RESERVOIR SIZING FOR SOFT TUBE CONCEPT

The nitrogen gas bottle was sized for the soft tube concept using representative state-of-the-art construction materials and a 3000 psi pressure. Figure 26 gives details.

A typical Freon pump was sized based on the type and performance selected and discussed in paragraph 3.2.2, and by interpolation of weight and volume between two similar models in the Pneu Devices, Inc., catalog. Interpolation was between the Pneu Model 2114 pump (weighing 2.5 lbs with an envelope volume of 41.6 in^3 and rated 0.5 gpm at 15 psi) and their Model 2116 (weighing 4 lbs with an envelope volume of 62.3 in^3 and rated at 7 gpm at 20 psi). Using a semi-log interpolation of weight and volume with rated flowrate (Reference 9), the resulting design shown in Figure 27 was derived. The indicated pump should be representative for either the soft or hard tube concept.

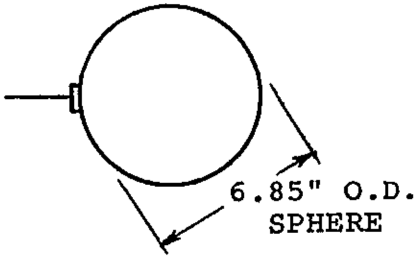
Other fluid loop components were sized based on the above-referenced Vought component study, current in-house electronic controller design studies, data on ECS components supplied by Vought on Apollo and Skylab programs, and recent information obtained from component manufacturers. A tabulation of weights and sketches of representative design envelopes are given in the preliminary design drawing of the soft tube concept.

3.3.6 Preliminary Design Drawings

Results from the Concept Selection Trade Studies, Deployment System Studies and Fluid Loop Studies were translated into scale preliminary design drawings. Drawing No. T-213-SK01, Inflatable Radiator System - Soft Tube Concept, 19 June 1974, was developed in 1/5 scale. Drawing No. T-213-SK02, Inflatable Radiator System - Hard Tube Concept, 20 June 1974, was done in 1/4 scale. Both drawings were transmitted to the NASA/JSC Technical Monitor, Mr. B. O. French. Figures 28 and 29, respectively, summarize the designs. During the current reporting period the hard tube drawing was not carried to the same level of completness as that of the soft tube concept.

REQUIREMENTS:

- PROVIDE N$_2$ GAS TO DEPLOYMENT SYSTEM
- PROVIDE EXPENDABLE N$_2$ TO F21 FLUID RESERVOIR
- PROVIDE ONE CYCLE PER DAY FROM MAXIMUM VOLUME TO MINIMUM VOLUME IN RESERVOIR FOR 30 DAYS



CONCEPT SELECTION:

- HIGH PRESSURE GAS SINCE SIMPLE AND PROVEN
- HIGH STRENGTH STEEL BOTTLE FOR LOW COST

N$_2$ BOTTLE DATA:

- PRESSURE: 3000 PSI
- MATERIAL: 4130 STEEL OR EQUIVALENT
- EXPENDABLE N$_2$: 1.2 LBS
  (0.08 LB FOR DEPLOYMENT SYSTEM)
- WEIGHTS:
  DRY - 2.8 LBS
  WET - 4.0 LBS

FIGURE 26 N$_2$ BOTTLE SIZING FOR SOFT TUBE CONCEPT

REQUIREMENTS:

- 907 #/HR FREON 21 (1.33 gpm)
- APPROX. 12 PSI PRESSURE RISE

PUMPS CONSIDERED:

- VANE AND CENTRIFUGAL
- REQT'S. FALL BETWEEN
- BOTH POOR EFFICIENCY REGION

CENTRIFUGAL CHOSEN AS TYPICAL:

- CANNED AC MOTOR
- 13% OVERALL PUMP-MOTOR EFFICIENCY TYPICAL

TYPICAL DESIGN INTERPOLATED
FROM DEVICES IN. CATALOG

WEIGHT = 3 LB

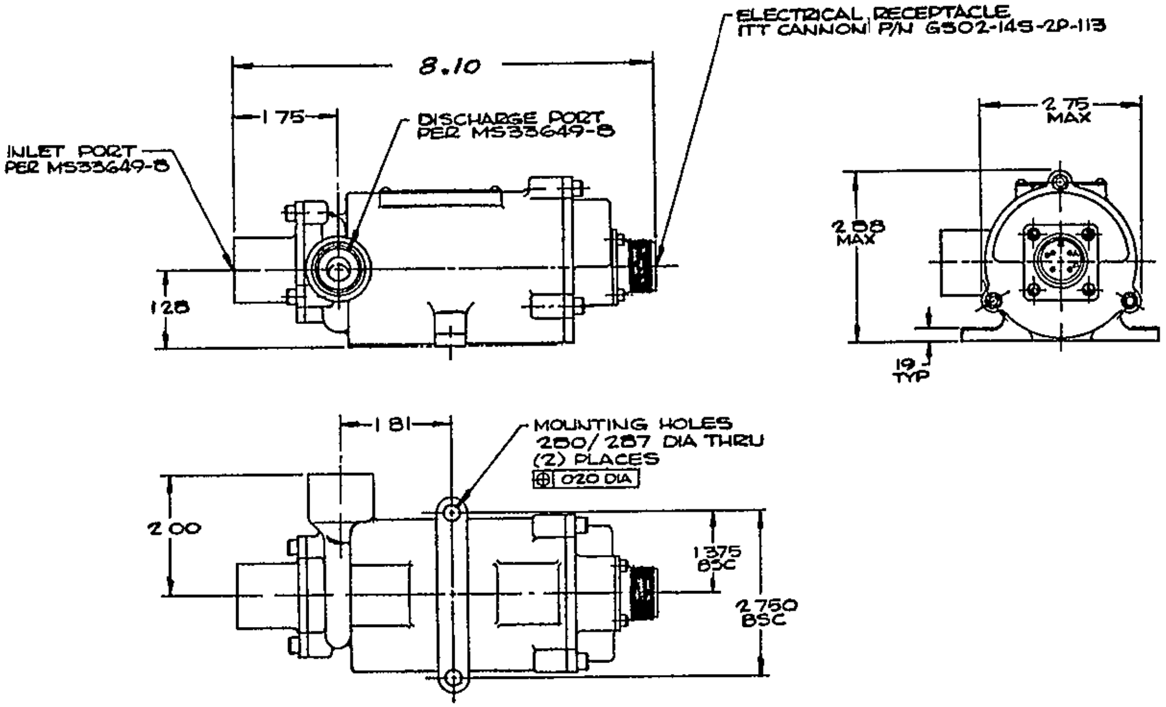
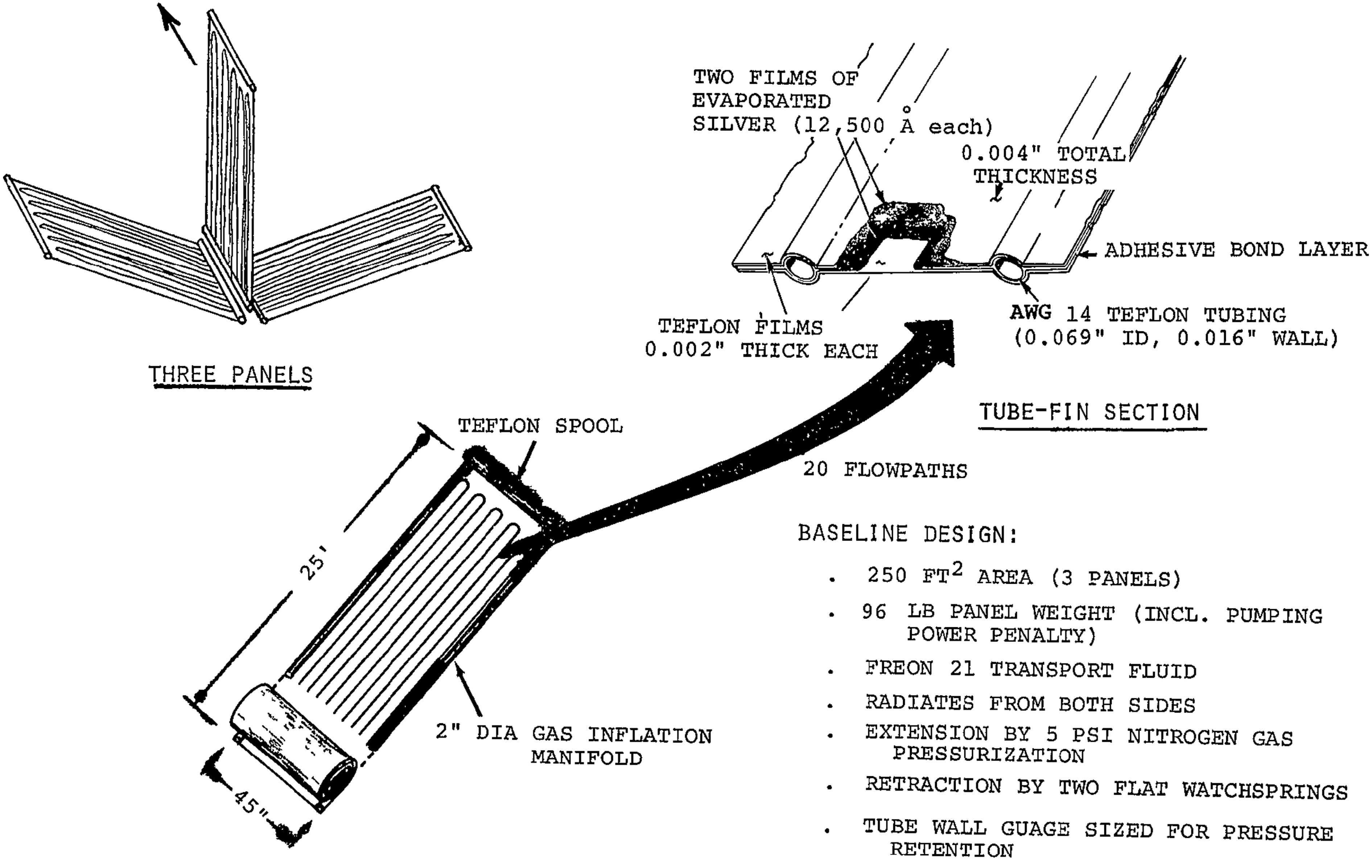


FIGURE 27 PUMP SIZING

DESCRIPTION OF PARTY WHISTLE CONCEPT PRELIMINARY DESIGN

FIGURE 28



THREE PANELS

TUBE-FIN SECTION

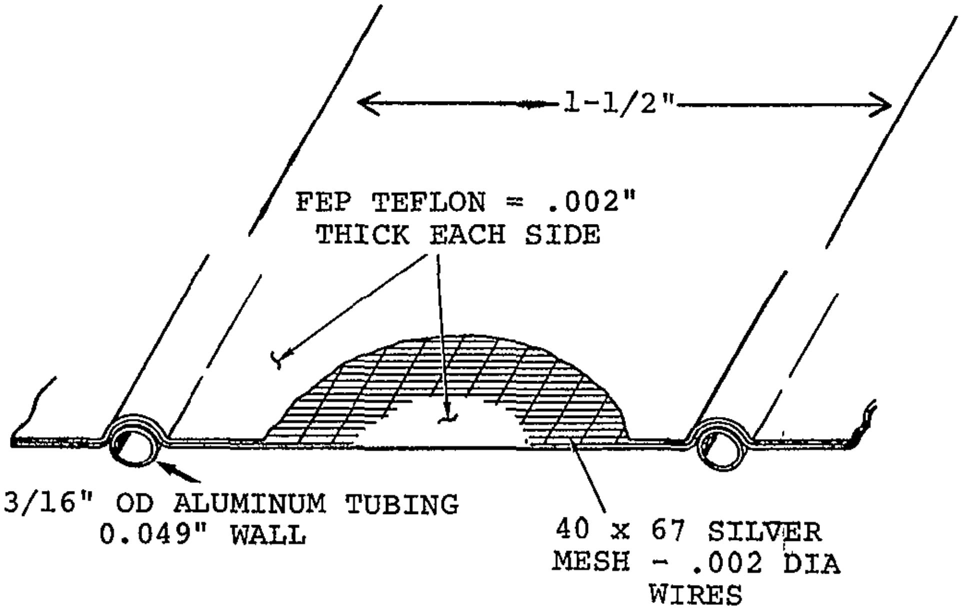
PANEL CONFIGURATION

BASELINE DESIGN:

- 250 FT^2 AREA (3 PANELS)
- 96 LB PANEL WEIGHT (INCL. PUMPING POWER PENALTY)
- FREON 21 TRANSPORT FLUID
- RADIATES FROM BOTH SIDES
- EXTENSION BY 5 PSI NITROGEN GAS PRESSURIZATION
- RETRACTION BY TWO FLAT WATCHSPRINGS
- TUBE WALL GUAGE SIZED FOR PRESSURE RETENTION

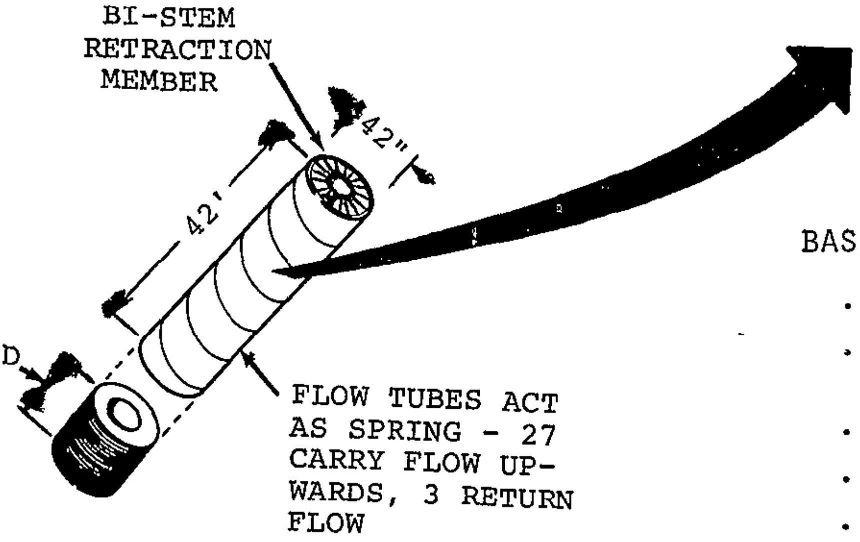
FIGURE 29

DESCRIPTION OF JACK-IN-THE-BOX PRELIMINARY DESIGN



TUBE-FIN SECTION

DEPLOYED CONFIGURATION



BASELINE DESIGN:

- 463 FT^2 AREA
- 233 LB WEIGHT (INCL. PUMPING POWER PENALTY)
- FREON 21 TRANSPORT FLUID
- RADIATES FROM ONE SIDE
- EXTENSION BY SPRING FORCE
- RETRACTION BY BI-STEM (ADDL. 24 LB.)
- 30-DAY METEOROID PROTECTION

3.4 Computer Analysis

Design studies were initiated in June 1974 using the Vought Steady State Design Routine (SSDR). The purpose of this work is to analyze the baseline configurations and perturbations of them to a higher level of fidelity than practical by hand. The principle objectives are to:

a) account for environmental influx in a more accurate and assymmetric way by using geometric models of the radiator system, and the vehicle (vs a 0°F environment sink temperature used in hand analyzes).

b) trade the soft tube concept relative panel angles including panel-to-panel and panel-to-vehicle radiant interchange effects.

c) account for the radiator longitudinal temperature distribution by breaking it into several nodes (vs one in hand analysis).

d) model the fluid-to-tube, tube-to-wall, and wall-to-fin thermal resistances in a more precise way than done in hand analysis

e) determine revised areas required for both radiator systems based on the above analytical refinements

3.4.1 Environment Model

A simplified shuttle orbiter geometric model was developed to include vehicle effects. Figure 30 shows the model geometry and Figure 31 is an isometric sketch showing the location of the soft tube concept relative to the vehicle, and giving vehicle properties. The hard tube concept geometric model is situated in the same location as the center panel of the soft tube concept.

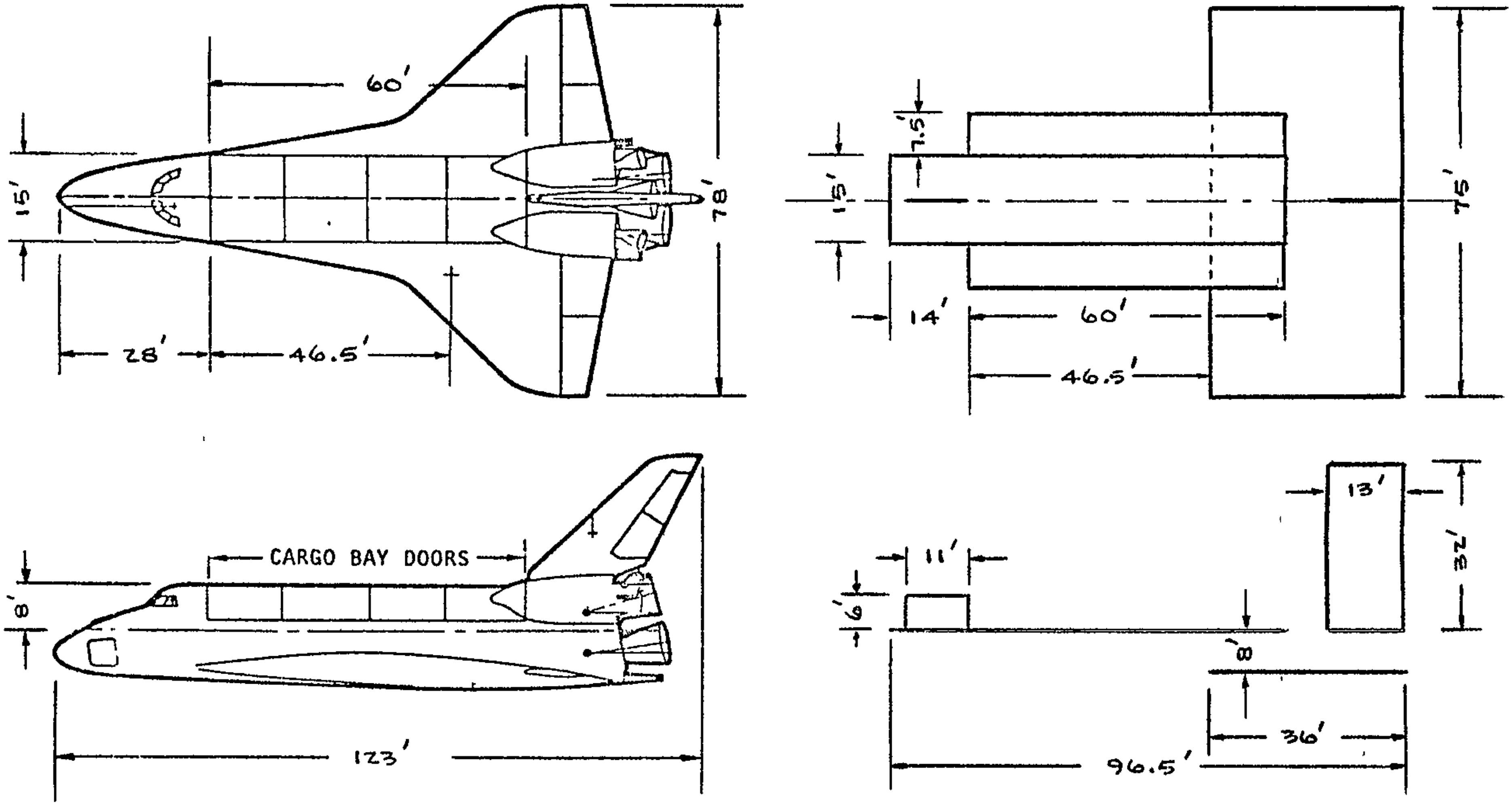


FIGURE 30 SHUTTLE ORBITER GEOMETRIC MODEL

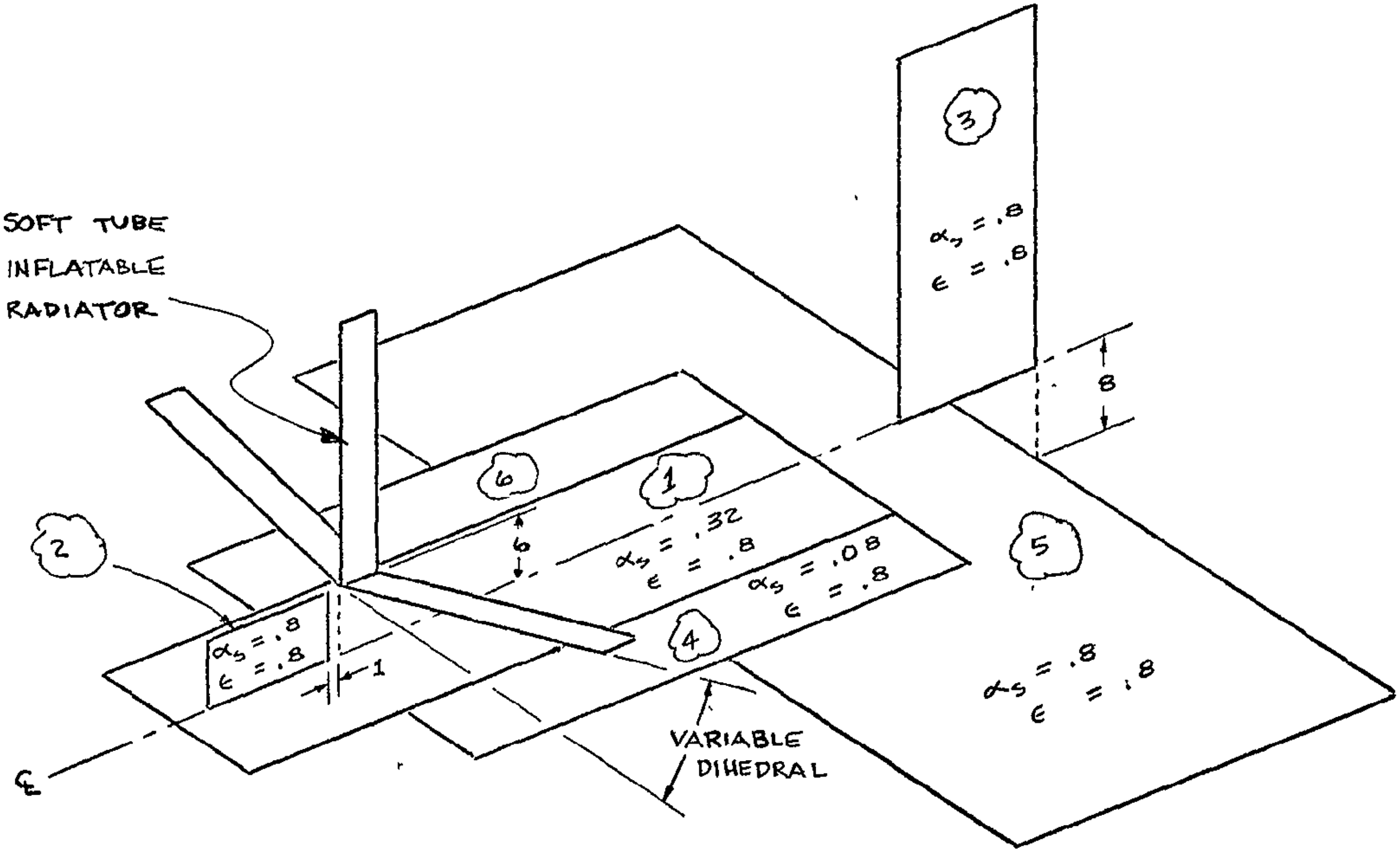


FIGURE 31 GEOMETRIC MODEL OF INFLATABLE RADIATOR ON SHUTTLE

View factors between the inflatable radiator surfaces and vehicle surfaces were calculated using the Martin Marietta Thermal Radiation Analyzer Program (MTRAP), and view factors between the earth and inflatable radiator and vehicle surfaces were obtained from graphs of published information. Direct incident flux on the inflatable surfaces and vehicle surfaces was calculated considering solar, earth emission, and earth albedo. Shadowing of one inflatable panel by another was included. A one-bounce analysis was conducted to obtain the component of each of these terms which is reflected from a vehicle or another inflatable panel surface onto an inflatable panel. Primary emission from vehicle radiator panels onto inflatable panels was calculated assuming a mean radiating temperature of 77°F and a fin effectiveness of 0.95. Emission from one inflatable panel onto another was computed (for the baseline soft tube concept) assuming a mean radiating temperature of 65°F, an emittance of 0.675, and a fin effectiveness of 0.77. Re-emission of absorbed flux on vehicle surfaces onto inflatable radiator panels was calculated by assuming adiabatic vehicle surfaces (other than for the vehicle radiator panels described above).

Hot case design orbital conditions were previously groundruled to be 55°, sun oriented, 100 n.mi. altitude, at the 13 September 1973 Orientation Briefing. Current studies determined the 180° orbital position (low side of orbit) to be most severe. Vehicle orientation with the cargo bay facing the sun and the vehicle broadside to the earth was found to approximate the most severe position.

3.4.2 Thermal Model

A radiator panel tube wall model was constructed consisting of a thermal resistance for radial tube wall conduction in series with the fluid-to-wall thermal resistance (already modeled in the SSDR as a function of flowrate). The model includes a glue line resistance, and both the glue line and tube wall thickness and properties may be varied. Peripheral temperature drop in the fin material around the circumference of the tube wall was modeled by assuming that all heat is added at the fin root located at the tube midpoint. The resulting model is somewhat conservative (i.e., computes a slightly larger radiator area requirement than an exact model would determine).

The SSDR accounts for fin temperature gradients by computing a fin effectiveness based on an assumed adiabatic fin condition midway between adjacent tubes. This case does not exist in the soft tube inflatable design near the manifolds, as the adjacent tubes may differ as much as 60°F in temperature.

Lengthwise temperature gradients in the panels were accounted for in the SSDR model by breaking each panel into 10 longitudinal nodes. This provides a much more accurate mean radiating temperature.

3.4.3 Environment Analysis

View factors and environmental fluxes were determined for the baseline soft tube concept at an outer panel dihedral value of 15°. View factors and fluxes for 30°, 45°, and 60° dihedrals were determined. The thermal model was incorporated into the SSDR for the baseline soft tube configuration. Checkout runs on the modified SSDR were made with the soft tube concept and comparison calculations with a 0°F equivalent environment sink temperature were made to check against hand analysis. Based on the results, a decision was made to ban the flexible radiator designs on a 0°F equivalent environment.

3.5 Materials Evaluation Study

3.5.1 Material Identification

The materials study initiated under the Inflatable Radiator Program has yielded primarily a summary of existing and development transport fluids and flexible tubing materials. Extensive information has been obtained from the suppliers listed in Table 8, and the current sampling is considered to be representative of state-of-the-art materials. A great variety of flexible tubing materials are currently in use, including fluoroelastomers, perfluoroelastomers, thermoset and thermoplastic polyurethanes, polypropylenes, polyethylenes, polyester elastomers and various types of rubber and fluorinated polymers. Specific flexible tubing materials evaluated by Vought in the current materials study are indicated in Table 9. Also included in

TABLE 8

MATERIALS MANUFACTURERS AND SUPPLIERS CONTACTED BY VOUGHT

Allied Chemical Division - New York
Moxness Products, Inc. - Racine, WI

Penntube Plastics Co., Inc. - Pa.

Uniroyal Chemical - Conn.
Union Carbide Chemicals Division - New York
E.I.duPont de Nemours and Co., Inc. - Wilmington, Pa.
   (Freon Products Group, Elastomer Chemicals Dept.)
Newage Industries, Inc. - Pa.

3-M Chemical Division - Minn.

Chevron-Oronite Division - Ca.
Raychem Corporation - Ca.
Pennwalt Corporation - Pa.
Chemplast, Inc. - New Jersey
Resistoflex Corporation - New Jersey
Thiokol Chemicals Division - New Jersey
Dow Corning Engineering Products Div. - Ca.
Firestone Central Research Laboratories - Ohio
Kirkhill Rubber Co. - Ca.
Rexnord Specialty Chemicals Division - Wisconsin
Phillips Petroleum Co., Chemicals Group - Oklahoma
U.S. Industrial Chemicals Co. - New York
B. F. Goodrich General Products Co. - Ohio
Cadillac Plastic and Chemical Co. - Michigan
Celanese Plastics Co. - New Jersey
Gates Rubber Company - Colorado
Monsanto Industrial Chemicals Co. - Houston
Hygienic Manufacturing Co. - Ohio
J.P. Stevens and Co., Inc. - Mass.

Norton Plastics and Synthetics Div. - Ohio

Table 9 are the tensile modulus, applicable temperature range and the more important thermophysical properties of each of the tubing materials. Detailed information concerning the physical properties, chemical resistance, etc. is provided in Appendix A.

The basic objective of the materials study has been to provide for increased meteoroid lifetime of the flexible radiator panel, by utilizing a tube material which is more flexible than the baseline FEP Teflon tubing. It had been previously determined (Ref. 10) that 14 AWG (.069 in. I.D., .016 in. wall) Teflon tubing with a 2-mil silver Teflon fin coating would yield a 90% probable lifetime in the meteoroid environment encountered in a 270 N.M., 78° solar-oriented orbit for only 1.7 days. From element tests conducted by Vought, the stiffness incurred using Teflon as the transport tubing was already severe, increasing the meteoroid lifetime to 30 days by increasing the tube wall would have yielded only a semi-flexible radiator. As indicated in Table 9, many materials have been identified with a tensile modulus less than that of Teflon. In the following paragraphs, the general characteristics of each of the flexible tubing materials listed in Table 9 will be considered. Probably the largest variety of elastomer materials available is manufactured by DuPont (i.e., Table 9).

Properties of Elastomers

Polyurethane elastomers (urethane rubber) encompass perhaps the largest range of hardness of any of the existing elastomers. Whereas the hardness range of rubber is generally considered to include Shore A durometer hardness of 20 - 90 and that of plastics to include Rockwell R hardness of 50 - 150, polyurethanes range in hardness from about 55 Shore A durometer to 90 Rockwell R. The hardness of polyurethane is governed by the molecular structure of the prepolymer, and not by the addition of plasticizers and fillers. The operating temperature range of polyurethane elastomers is usually considered to be -80°F to 225°F. Standard compositions normally do not become brittle at temperature below -80°F, although stiffening gradually increases as the temperature is reduced below 0°F

TABLE 9

ALTERNATE INFLATABLE RADIATOR TUBE MATERIAL CANDIDATES

MATERIAL	TRADE NAME	SPECIFIC GRAVITY	R T MODULUS (PSI)		UTS (PSI)	USEFULNESS OVER TEMP RANGE (-211° to 200°F)	COMPATIBILITY	AVAILABILITY IN TUBE	REMARKS
			TENSILE	FLEXURAL					
1 Fluorinated Ethylene Propylene	FEP Teflon	2 15	$50,000^T$	$80,000^T$	$2,000^T$	ok	ok	Yes	1 Excellent general inertness
2 Tetrafluoroethylene	TFE Teflon	2 17	$58,000^T$	$60,000^T$	$2,000^T$	ok	ok	Yes	2 Excellent gen inertness
3 Polyimide	Kapton H	1 42	$430,000^F$	-	$25,000^F$	ok	Unk (prob ok)	Limited	3 Spiral wound tubes only
4 Polyester	Mylar A	1 40	$550,000^F$	-	$25,000^F$	Prob ok	Unk (prob ok S T)	Custom, R&D	4 Good general inertness
5 Ethylene Tetrafluoroethylene Copolymer	Tefzel	1 70	$125,000^F$	$200,000^T$	6,500	ok	Unk (prob ok)	Yes	5 Excellent general inertness
6 Perfluoroalkoxy Fluorocarbon	PFA Teflon	2 15	-	$95,000^F$	$4,000^F$	Prob ok	Unk (prob ok)	Yes,Custom	6 New material, prob similar other Teflons
7 Polyvinylidene Fluoride	Kynar	1 77	$170,000^F$	$220,000^F$	$7,200^F$	"Brittle"@-4°F	Unk (prob Fair)	Custom, R&D	7 Good general chemical inertness
8 Polyvinyl Fluoride	Tedlar	1 38	$250,000^F$	-	$7,000^F$	Similar Tygon (Brittle)	Unk (prob ok S T)	Yes	8 Pliable (used for bagging), good inertness
9 Polyvinyl Chloride	Tygon(R2807)	1 20	400 - 3,000	-	1,800	"Brittle"@-68°F	Unk (prob Bad)	Yes	9 Common lab tubing, poor gen inertness
10 Polyethylene Terephthalate	Tenite 7DRO	1 39	$250,000^F$	-	$5,500^F$	Tested only to -40°F	Unk (prob ok S T	Custom, R&D	10 Good general inertness
11 Polyamide High Temp Nylon	K49	1 38	-	$520,000^F$	$17,000^F$	Questionable Cold	Unk (prob Fair)	R&D	11 New material (similar to Nomex)
12 Hexafluoropropylene-Vinylidene Fluoride	Viton B	1 40	$*225^F$	-	$1,400^F$	Stiff-30°F, stands LN_2	Bad	Yes,Custom	12 Elastomeric seal material, F21 Experience
13 Chloroprene	Neoprene W	1 25	$*150^F$	-	$1,250^F$	Flex to -40°F stands LN_2	OK (slight swell	Yes,Custom	13 Elastomeric F21 seal, Type GS common tubing
14 Polyethylene	Bakelite	92	$20,000^F$	-	$1,400^F$	"Brittle"(est -40°F)	Unk (prob Bad)	Yes	14 Readily available, fair general inertness
15 Polypropylene	Clysar	90	$160,000^F$	$170,000^F$	$4,800^F$	"Brittle"(est -40°F)	Unk (prob Bad)	Yes	15 Readily available, fair general inertness
16 Polycarbonate	Lexan	1 20	$340,000^F$	$310,000^F$	$8,000^F$	OK	Unk (prob Poor)	Custom	16 Poor general inertness
17 Silicone	RTV 560	1 42	300^F	-	800^F	Fair(Brittle -175°F)	Unk (prob ok S T)	Yes, Custom	17 Cryogenic exp shuttle TPS (Elastomer)
18 Fluorosilicone	DC 94009	1 85	similar silicone rubber		$1,000^F$	Similar silicone rubber (not as good)	Unk (prob ok S T)	Yes, Custom	18 Developed as adhesive, poor practical experience (Elastomer)
19 Trifluorochloroethylene	KEL-F	2 10	$190,000^F$	$200,000^F$	$4,600^F$	OK	Unk (prob OK)	Yes, Custom	19 Predecessor to FEP Teflon (similar)

S T - short term
T - evaluated in tube form
F - evaluated in film form
* - "100% Modulus" - stress @ 100% elongation

TABLE 9 (CONT'D)

	MATERIAL	TRADE NAME	SPECIFIC GRAVITY	R T MODULUS (PSI)		UTS (PSI)	TEMPERATURE RANGE (°F)		COMPATIBILITY WITH TRANSPORT FLUIDS	AVAILABILITY IN TUBE	REMARKS
				TENSILE	*FLEXURAL*		*Lo*	*Hi*			
20	Polyurethane	Hi-Tuff Tygothane Estane Vibrathane Elastothane Adiprene	1 03-1 4	750- 3000		6000 -8500	-80	225	No Phosphate Esters	yes	Polyether Urethanes have greater low temp flex than polyester urethanes Available in thermoset or thermoplastic, extruded tubing available in thermoplastics only
21	Perfluoroelastomer (Copolymer of Tetra-fluoroethylene, Perfluoro (Methyl vinyl ether) and Perfluorovinyl ether)	ECD-006	2 0	2650	-		-30	450	No Fluorinated Ethers	yes, custom	Standard formulations have carbon black as filling agent Low temp formulations available UV stability is unknown to manufacturer
22	Chlorosulfonated Polyethylene (*Synthetic Rubber*)	Hypalon	1 1-1 26	4000			-40	325	No Fluorinated Ethers	yes	No phosphates or diesters
23	Polyester	Hytrel Valox	1 1-1 3	5000	7000		-65	300		yes	Compatible with silicate and phosphate esters and most fluorocarbons Brittle at -90°F
24	Ethylene - Propylene Diene (EPDM)	Nordel Eplar Royalene	86	3000			-60 -70	250 400	No Fluoro-carbons	yes	Not compatible with diesters or Freons
25	Butadiene - Acrylonitrile (Nitrile Rubber)	Hycar Paracril	98	3000		5000	-40	200		yes	Very poor resistance to UV degradation, for use as mixture with solid nitrile rubber
26	Polyolefin Copolymer (Polyolefin Thermoplastic Rubber)	*TPR - 1600* - 1800 - 1900	88	*650F* 1400F 1850F	*1500F* 10,000F 35,000F		*-60*	250	Good in Silicate esters, Phosphate esters, & ethylene compounds	yes	No Aliphatic or aromatic solvents, or chlorinated Hydrocarbons
27	Ethylene Ethyl Acrylate Olefin Copolymer		93				-150	140	No Chlorinated Hydrocarbons	yes	
28	Ethylene Vinyl Acetate Olefin Copolymer		94				-140	140	No Chlorinated Hydrocarbons	yes	

Some compositions of polyurethane may be obtained that retain a small amount of flexibility at temperatures as low as -125°F. Although not flexible at extremely low temperatures, polyurethane elastomers have successfully been operated at cryogenic temperatures using non-oxidizing liquefied gases. Polyurethanes may be used continuously at 200-225°F and intermittently up to 250°F. Prolonged exposure to ultraviolet radiation usually darkens polyurethane and somewhat reduces the physical properties (i.e., the material may become brittle) due to polymer cross-linking. Ultraviolet screening agents and pigmentation are available in DuPont's Adiprene polyurethane elastomer.

Polyester elastomers range in hardness from about 85 durometer A to 70 durometer D (~80 Rockwell R). Polyester elastomers are thermoplastic, synthetic materials; the softer compositions of polyester elastomers resemble true elastomers more than plastics. The thermal service range of polyester elastomer is approximately -65°F to 300°F. The brittle point of polyester elastomers is about -100°F, but, as with other elastomeric materials, gradual stiffening occurs with decreasing temperatures. The degree to which polyester elastomers are degraded by ultraviolet radiation is a function of exposure time, but screening agents are available for this material.

Synthetic rubber is probably best known for its excellent ageing characteristics and chemical resistance (as compared to natural rubber). Use of synthetic rubber with a transport fluid is limited to nonaromatic hydrocarbons and it will not withstand chlorinated solvents. Acid and salt solutions of a highly oxidizing nature will cause surface deterioration and loss of strength in synthetic rubber. Synthetic rubber gives excellent service in contact with aliphatic hydrocarbons, aliphatic hydroxyl compounds and most fluorocarbon refrigerants. The practical high temperature range for continuous service is about 180 - 200°F. For intermittent use, specially compounded synthetic rubber products can operate at temperatures up to 250°F. Thermal exposure above these limits does not melt synthetic rubber, but it does cause hardening and loss of resilience. The brittle point of synthetic rubber is about -40°F, with gradual stiffening starting at 0°F. Again, specially formulated compositions permit service to about -70°F.

Fluoroelastomer compounds generally offer greater resistance to most fluids and have wider operating temperature characteristics than do most commercial rubber products. Fluoroelastomers (i.e., DuPont's Viton and Norton's Fluran) resist many aliphatic and aromatic hydrocarbons that act as solvents for other rubber compounds. Generally, fluoroelastomers may be used continuously at temperatures to 400°F, and up to 1000 hours at 500°F without affecting the mechanical properties or chemical resistance. Fluoroelastomers remain flexible at about 0°F, and with special compounding, as low as -65°F. They have successfully been used in static applications at cryogenic temperatures. Fluoroelastomers show excellent resistance to degradation via ultraviolet radiation and, under vacuum conditions, experience minimal outgassing.

Silicone rubber compounds consist of silicone polymers mixed with one or more suitable inorganic reinforcing fillers and a vulcanizing agent. While all silicone rubber compounds provide a number of outstanding characteristics, various fillers may be used to improve physical, thermal and electrical properties as well as chemical resistance. Silicone rubber is serviceable up to 500°F, with some formulations useful for limited service to 650°F. Continuous low temperature operation may be obtained to -70°F, with some grades remaining flexible at -150°F. The resistance to degradation by ultraviolet radiation is among the best of the available elastomers. Silicone rubber contains a low percentage of organic materials and contains no plasticizers.

There are several other types of plastic and elastomeric materials, and their physical, mechanical, electrical and thermal properties are tabulated in Appendix A. Included in Appendix A are the characteristics of various types of rubber, fluorocarbons, olefin polymers, polyesters and polyethylenes. A new development material offered by DuPont, ECD-006 perfluoroelastomer, is composed primarily of fluorine and carbon, and combines the properties of a fluoroelastomer (i.e., Viton) with those of a perfluorinated plastic (i.e, Teflon). ECD-006 perfluoroelastomer is based on the copolymerization of tetrafluoroethylene (TFE Teflon), perfluoro (methyl vinyl ether) and a third monomer (a perfluorovinyl ether grouping with an active cure site monomer). This material, when cross-linked, yields vulcanizates with outstanding chemical resistance and high temperature oxidative resistance. Perfluoroelastomers are chemically inert to most solvents, including polar solvents (ketones, ethers and esters), inorganic and organic acids and bases. Thus, perfluoroelastomers may be used with most transport fluids, excluding fluorocarbons. Generally, perfluoroelastomers are capable of providing continuous service at temperatures of 500 - 550°F and can operate at 600°F for short time durations.

Properties of Transport Fluids

Perhaps the most notable characteristic of the available transport fluids is their chemical variety. The transport fluids evaluated by Vought are listed in Table 10, together with their temperature range and typical thermophysical properties. Most of the transport fluid types represent a family of transport fluids, with a large variation of thermophysical and transport properties. Described in the following paragraphs are the major categories of fluid types evaluated during the materials study. More detailed information concerning a specific fluid is located in Table 10.

Fluorocarbons

Fluorocarbons are organic compounds containing one to four carbon atoms and fluorine. Chlorine, bromine and hydrogen atoms may also be present. Their physical characteristics include nonflammability, a low level of toxicity, excellent thermal and chemical stability, high density coupled with low boiling point and low viscosity and surface tension. The presence of fluorine atoms in the molecule is responsible for the stability of the compounds and, as a general rule, increased stability may be obtained for increased fluorine content. Toxicity levels of the fluorocarbon compounds are quite favorable for use and handling, with most of the fluorocarbons classified in groups 5 and 6 by the Underwriter's Laboratories. (Group 6 is

TABLE 10 INITIAL FLUID SCREENING

FLUID	TYPE	MFR	REF	VAPOR PRES 100F	VAPOR PRES 230F	FP @ 1 ATM	TOXICITY[3]	HI TEMP APPLICATION Pv < 1ATM	HI TEMP APPLICATION POUR PT < 40F	HI TEMP APPLICATION BOILING PT > 250F	LO TEMP APPLICATION Pv < 1ATM	LO TEMP APPLICATION POUR PT < -100F	LO TEMP APPLICATION BOILING PT > 100F	THERMOPHYSICAL PROPERTIES AT 77°F μ LBM/HR FT	cp BTU/LBM°F	k BTU/HR FT°F	SP GR
R 11	FLUOROCARBON	DUPONT	1	[illegible] 46	182 03	-168	GP 5A	×	✓	×	×	✓	×	92	208	050	1 476
R 12			1	131 86	[1]	-2[illegible]	GP 6	×	✓	×	×	✓	×	63	232	041	1 31
R 12B1			2	> 1 ATM	> 1 ATM	-2[illegible]7		×	✓	×	×	✓	×	73	186	057	1 83
R-12B2			2	> 1 ATM	> 1 ATM	-223		×	✓	×	×	✓	×	1 21	.151	067	2 275
R-13			1	[2]	[1]	-294		×	✓	×	×	✓	×	337	48	022	1 03
R-13B1			1	330	[1]	-270	GP 6	×	✓	×	×	✓	×	36	21	024	1 54
R-14			1	[2]	[1]	-299	GP 6	×	✓	×	×	✓	×	CRITICAL TEMP = -50 2°F			
R-21			1	40 5	240	-211	GP 4 5	×	✓	×	×	✓	×	80	25	063	1 37
R 22			1	210 6	[1]	-256	GP 5A	×	✓	×	×	✓	×	57	30	052	1 19
R 23			1	[2]	[1]	-247 4	GP 6	×		×	×	✓	×	36	1 33	008	.94
R 50 (METHANE)			3	[2]	[1]	-296 4		×	✓	×	×	✓	×	CRITICAL TEMP = -116 5°F			
R-112	FLUOROCARBON	DUPONT	1	1 75	34 6	79	GP 4-5	×	×	✓	✓	✓	✓	3 14	212	039	1 65
R-113			1	10 46	101 [illegible]	-31	GP 4 [illegible]	×	✓	✓	✓	✓	✓	1 60	218	038	1 56
R 114			1	46 5	312	-137	GP 6	×	✓	✓	×	✓	×	91	243	034	1 45
R-114B2			1	10 5	1[illegible]	-166 8	GP 5A	×	✓	✓	✓	✓	✓	1 74	166	027	2 16
R-115			1	182 7	[1]	-159	GP 6	×	✓	×	×	✓	×	6[illegible]	2[illegible]	026	1 34
R 116			3	[2]	[1]	-149 1	GP 6	×		×	×	✓	×	42		012	
R 112A			3	71 54	456 8	-204		×	✓	×	×	✓	×				1 11
R [illegible]A			4	124 6	[1]	-178 6		×	✓	×	×	✓	×				90
R 15[illegible]B			[illegible]	-16				✓		×	✓	✓	✓				
R 170 (ETHANE)			4	[2]	[1]	-2[illegible]	GP [illegible]B	×		×	×		×	—	—	—	33
R [illegible]	FLUOROCARBON	DUPONT	5	1	[illegible]10	-135		✓	✓	✓	✓	✓	✓	3 26	214	045	1 69
R [illegible]			3			-112						✓		2 25	218	.043	

1 CRITICAL [illegible]

FLUID	TYPE	MFR	REF	VAPOR PRES 100F	VAPOR PRES 235F	F P @ 1 ATM	TOXICITY[3]	HI TEMP APPLICATION Pv<1 ATM	HI TEMP APPLICATION POUR PT <40F	HI TEMP APPLICATION BOILING PT>235F		LO TEMP APPLICATION Pv<1 ATM	LO TEMP APPLICATION POUR PT <-100F	LO TEMP APPLICATION BOILING PT>100F	THERMOPHYSICAL PROPERTIES AT 77°F μ LBM/HR FT	Cp BTU/LBM°F	k BTU/HR FT°F	SP GR
R-216	FLUOROCARBON	DUPONT	3	15 8	139 2	-193 7	GP 6	X	✓	X		X	✓	X				1 56
R-C318			3	67 4	[1]	-42 5	GP 6	X	✓	X		X	✓	X	1 02	27	025	1.50
R-500	(AZEOTROPE OF R-12 & 152A)		3	153 9	(221)[1]	-284	GP 5A	X	✓	X		X		X	532	174	048	1 16
R 502	(AZEOTROPE OF R 22 & R-115)		3	230	HIGH	[4]	GP 5A	✓	✓	X		X	✓	X	58	—	057	1 24
R 503	(AZEOTROPE OF R-23 & R-13)		3	-	[1]	[4]	GP 6	X	✓	X		X	✓	X	CRITICAL TEMP = 67 1°F			
R-504	(AZEOTROPE OF R 32 & R 115)		3	376 4	[1]	[4]	GP 6	X	✓	X		X	✓	X				1 0
FREON-TF (SOLVENT)			4	10 8	>60	-31		X	✓	X		✓	X	✓	(1 679	213	043)‡	1 565
-E1	("E - SERIES" A FAMILY OF HOMOLOGY FLUIDS)		5	12 6	140	-246		X	✓	X		✓	✓	✓	1 21	24	036	1 54
-E2			5	1 1	24	-190		X	✓	X		✓	✓	✓	2 66	24	037	1 66
-E3			5	21	5 4	-160		✓	✓	✓		✓	✓	✓	5 3	24	.038	1 72
-E4			5	—	—	-138		✓	✓	✓		✓	✓	✓	9 92	24	039	1.76
-E5			5	—	—	-117		✓	✓	✓		✓	✓	✓	16 9	24	.039	1 79
DC-200-10	SILICONE FLUID	DOW CORNING	6			-148		✓	✓	✓	FLUID /GREASE	✓	✓	✓	≅ 200	.34	09	97
-210	(DIMETHYL POLYSILOXANE)		7	<10MM	<10MM	OIL		✓	✓	✓	"	✓	X	✓	≅ 230	34	09	97
-210H			7	<10MM	<10MM	OIL		✓	✓	✓	"	✓	X	✓	≅ 290	35	09	97
510			4	<100MM	<100MM	-70		✓	✓	✓		✓	X	✓	4500	—	035	985
-550			4	<100MM	<100MM	-50		✓	✓	✓			X	✓	850	35	085	1 065
-710			4	<100MM	<100MM	-0			✓	✓		✓	X	✓	41 0	32	0[illegible]5	1 08

[illegible]

‡ "FREON TF" PROPERTIES [illegible] AT 70 F

FLUID	TYPE	MFR	REF	VAPOR PRES		FP	TOXICITY[3]	HI TEMP APPLICATION				LO TEMP APPLICATION			THERMOPHYSICAL PROPERTIES AT 77°F			
				100F	250F	@1 ATM		Pv<1ATM	POUR PT <40F	BOILING PT>250F		Pv<1ATM	POUR PT <-100F	BOILING PT>100F	μ LBM/HR FT	cp BTU/LBM°F	k BTU/HR FT°F	SP GR
SF-96[5]	SILICONE FLUID	GEN ELECTRIC	8, 4			-58 TO -120			✓		NOTE 10		✓ X		[illegible]	.36	.067	.916
-97-20[3]	"	"	8,4			-85			✓		"		X		46.09	.36	.087	.953
-99	"	"	8,4			—[6]					"		7		23.5	.36	.087	.97
-81	"	"	8,4			-120			✓		"		✓		117.5	.36	.092	.972
-85 (20)	"	"	8,4	<10^{-3}	<10^{-2}	±120		✓	✓	✓	"	✓	✓	✓	—	.36		.96
-1017	"	"	8,4			-50			✓				X					
-1038 (50)	"	"	8,4			-100			✓				✓		~150			
-1053	"	"	8,4	<10^{-3}	<10^{-2}	-86		✓	✓	✓		✓	X	✓	~250	.33		.93
-1055	"	"	8,4			-67			✓				X					
F-44		"	8,4			-100		✓	✓	✓	NOTE 10	✓	✓	✓	177.7	.34	.087	1.09
F-50		"	8,4	< 1 MM	< 1 MM	-100		✓	✓	7	"	✓	✓	✓	107.6	.39	"	.89
COOLANOL 15	SILICATE ESTER	MONSANTO	9	02	43	<-140		✓	✓	✓		✓	✓	✓	3.74	.435	.065	.883
25	"	"	9	<10^{-3}	<10^{-2}	<-120		✓	✓	✓		✓	✓	✓	10.4	.443	.076	.892
35	"	"	9	<10^{-3}	<10^{-2}	<-170		✓	✓	✓		✓	✓	✓	11.7	.447	.077	.883
45	"	"	9	<10^{-3}	<10^{-2}	<-85		✓	✓	✓		✓	✓	✓	43.4	.447	.078	.896
THERMINOL FR[8]		"	4	05	60	-49		✓	✓	✓		✓	X	✓	21.5	.35	.062	1.44
44		"	13	<10^{-3}	7	-80		✓	✓	✓		✓	X	✓	19.5	.47	.087	.92
55		"	13	7	7	-40		✓	✓	✓		✓	X	✓	19	.46	.08	.89
60		"	13	7	7	-90		✓	✓	✓		✓	X	✓	33	.38	.0761	.99
66		"	13	7	7	-18		✓	✓	✓		✓	X	✓	345	.37	.0707	1.0
88		"	13	7	7	+293		✓	X	✓		✓	X	✓	MELTING POINT = 395°F			
VP-1	DIPHENYL OXIDE /BIPHENYL	"	13	<<1ATM	<1ATM	9		✓	X (?)	✓		✓	X (?)	✓				1.06
SANTOVAC 6		"	4			+60		✓	X	—	NOTE 10	✓	X	—				1.22

[7] Pv < 1 mm Hg @ 30 F

[8] NOT AVAILABLE

[9] CRYSTALLIZES @ 53°F

[10] PROPERTIES EVALUATED AT 80°F

				VAPOR PRES		F P		HI TEMP APPLICATION				LO TEMP APPLICATION			THERMOPHYSICAL PROPERTIE AT 77°F			
FLUID	TYPE	MFR	REF	100F	250F	@ 1 ATM	TOXICITY	Pv<1 ATM	POUR PT <40F	BOILING PT>250F		Pv<1 ATM	POUR PT <-100F	BOILING PT>100F	μ LBM/HR FT	c_p BTU/LBM°F	k BTU/HR FT °F	SP GR
PYDRAUL 90	PHOSPHATE ESTER BASE	MONSANTO	4	OK	<10	-25		✓	✓	✓		✓	X	✓	3150	.38	.072	1.15
135	"	"	4	OK	< 5	-12		✓	✓	✓	NOTE 10	✓	X	✓	~500	.33	.067	1.19
150	"	"	4	OK	<10	-55			✓	✓	"	✓	X	✓	2100	.40	.077	1.17
230	"	"	4	OK	$<10^2$	0		✓	✓	✓	"	✓	X	✓	167	.37	.068	1.15
540	"	"	4	OK	$<10^2$	0		✓	✓	✓	"	✓	X	✓	5000	.35	.069	1.14
PYRATEK 100		"	4	OK	"	-5		✓	✓	X	"	✓	X	X	~400	–	–	1.15
L-45	SILICONE FLUID	UNION CARBIDE	10	OK	OK	-45 to -160		✓	✓	X	FLUID /GREASE	✓	✓	✓	15.5	.35	.074-.09	.93-.97
-42	"	"	10	↓	↓	-83		✓	✓	–	OIL	✓	X	✓	498	–	–	1.03
-43	"	"	10	↓	↓	15		✓	✓	–	GREASE	✓	X	✓	3.7×10^4	–	–	1.08
-520	"	"	10	↓	↓	-34		✓	✓	–	OIL	✓	X	✓	2500	–	.092	1.05
-522	"	"	10	↓	↓	-56		✓	✓	–	"	✓	X	✓	240-365	–	.085	.99
-527	"	"	10	↓	↓	-56		✓	✓	–	"	✓	X	✓	240-365	–	.085	.99
-530	"	"	10	↓	↓	-25		✓	✓	–	OIL	✓	X	✓	4900	–	–	1.03
-531	"	"	10	↓	↓	29		✓	✓	–	"	✓	X	✓	340	–	–	1.06
-5510	"	"	10	↓	↓	90		✓	X	–	"	✓	X	✓	675	–	–	1.07
HTF-L20	SILICONE FLUID	UNION CARBIDE	4	↓	$<10^2$	-40		✓	✓	–	"	✓	X	✓	~300	.45	.10	.965
-10	"	"	4	↓	$<10^2$	-45		✓	✓	–	"	✓	X	✓	~425	.45	.11	1.02
-14	"	"	4	↓	$<10^2$	-36		✓	✓	–	"	✓	X	✓	~500	.45	.115	1.03
-30	"	"	4	$<10^{-2}$	$<10^{-1}$	0		✓	✓	✓	"	✓	X	✓	~350	.45	.13	1.05
UCON-50 HB-280			4	"	"	-35		✓	✓	✓	"	✓	X	✓	~450	.44	.11	1.03
-LB 300			4	"	"	40		✓	✓	✓	"	✓	X	✓	~450	.44	.095	.99
LB 550			4	$<10^{-1}$	<1	-25		✓	✓	✓	"	✓	X	✓	~850	.44	.086	.99

FLUID	TYPE	MFR	REF	VAPOR PRES. 100F	VAPOR PRES. 250F	F P @1 ATM	TOXICITY[3]	HI TEMP APPLICATION Pv<1ATM	HI TEMP APPLICATION POOR PT <40F	HI TEMP APPLICATION BOILING PT >250F		LO TEMP APPLICATION Pv<1ATM	LO TEMP APPLICATION POOR PT <-100F	LO TEMP APPLICATION BOILING PT >100F	THERMOPHYSICAL PROPERTIES AT 77°F μ LBM/HR FT	THERMOPHYSICAL PROPERTIES AT 77°F Cp BTU/LBM°F	THERMOPHYSICAL PROPERTIES AT 77°F k BTU/HR FT°F	SP GR
FC-88	FLUOROCARBON	3-M	11	720	(88°F)"	-150		X	✓	X		X	✓	X	1 6	25	032	1 64
-78	↓	↓	11	10 63	(122°F)	-100		X	✓	X		✓	✓	✓	1 8	24	036	1 70
-72			11	<1 ATM	(134°F)	-100		X	✓	X		✓	✓	✓	2 0	25	036	1 68
-77			11	1 93	(207°F)	-150		X	✓	X		✓	✓	✓	3 4	25	036	1 78
-104			11	<<1ATM	(214°F)	-100		X	✓	X		✓	✓	✓	3 9	25	037	1 75
-75			11	1 35	(216°F)	-135		X		X		✓	✓	✓	3 5	25	037	1 76
-40			11	12	4 5	-70		✓	✓	✓		✓	X	✓	10.9	27	.038	1 88
-43			11	<<1ATM	2 12	-58		✓	✓	✓		✓	X	✓	11.8	27	039	1 88
-48			11	12	3 58	-80		✓	✓	✓		✓	X	✓	13 7	24	04	1 93
-70			11	<<1ATM	<1ATM	-49		✓		✓		✓	X	✓	16 65	27	042	1 92
AQUEOUS ETHYLENE GLYCOL SOLUTION	HYDROXYL ETHER	UNION CARBIDE	12															
% BY WT 0	(WATER)	↓	12	95	29 64	32		X	✓	X		✓	X	✓	2.35	1.0	35	1 0
50			12	64	21 28	-32		X	✓	X		✓	X	✓	7 26	8	18	1 07
100			12	$<10^{2}$	86	10		✓	✓	✓		✓	X	✓	36.3	.56	.145	1 11
AQUEOUS DIETHYLENE GLYCOL SOLUTION																		
% BY WT 50			12	72	24 2	-17		X	✓	X		✓	X	✓	9 7	79	23	1 07
90			12	37	11 6	-15		✓		✓		✓	X	✓	38.7	6	.17	1 09
100			12	—	17	16		✓	✓	✓		✓	X	✓	67 8	54	14	1 10
AQUEOUS TRIETHYLENE GLYCOL SOLUTION																		
% BY WT 50			12	85	47 1	-7		X	✓	X		✓	X	✓	14 0	77	228	1 07
90			12	41	13 5	-7		✓	✓	✓		✓	X	✓	67 8	59	145	1 10
100	↓		12		63	23			✓	✓			X	✓	92	.50	135	1 12

" ( ) – BOILING PT AT 1 ATM

FLUID	TYPE	MFR	REF	VAPOR PRES 100 F	VAPOR PRES 250F	FP @1 ATM	TOXICITY[3]	HI TEMP APPLICATION Pv<1ATM	HI TEMP APPLICATION POUR PT <40F	HI TEMP APPLICATION BOILING PT>250F	LO TEMP APPLICATION Pv<1ATM	LO TEMP APPLICATION POUR PT <-100F	LO TEMP APPLICATION BOILING PT>100F	THERMOPHYSICAL PROPERTIES AT 77 °F μ LBM/HR FT	cp BTU/LBM°F	k BTU/HR FT°F	SP GR
AQUEOUS PROPYLENE GLYCOL SOLUTION	HYDROXYL ETHER	UNION CARBIDE	12														
% By wt 50	″	↓		77	23 2	-26		×	✓	×	✓	✓	✓	12 1	86	22	1 03
90	″	↓		28	53	-		✓	✓	✓	✓	×	✓	30 1	64	145	1 04
100	″	↓		<10^-	1 2	-		✓	✓	×	✓	×	✓	87 1	60	125	1 03
PYDRAUL 10-E	PHOSPHATE ESTER	MONSANTO	14	<10^-4	<10^4	-70		✓	✓	✓	✓	×	✓	42	42	047	1,09
29-E-LT	″	↓	14	<10^4	<10^4	-45		✓	✓	✓	✓	×	✓	136	39	076	1 10
30-E	″	↓	14	<10^4	<10^4	-15		✓	✓	✓	✓	×	✓	157	36	074	1 15
50-C	″	↓	14	<10^4	<10^4	-5		✓	✓	✓	✓	×	✓	278	37	073	1 15
65-E	″	↓	14	<10^-4	<10^3	0		✓	✓	✓	✓	×	✓	389	38	,073	1 15
115-E	″	↓	14	<10^-4	<10^7	10		✓	✓	✓	✓	×	✓	835	38	072	1 15
230-C	PHOSPHATE ESTER BASE	MONSANTO	14	<10^-2	<10^-1	-20		✓	✓	✓	✓	×	✓	208	41	076	1 09
312-C	″	↓	14	<10^2	<10^2	-10		✓	✓	✓	✓	×	✓	377.	41	076	1 04
540 C	″	↓	14	<10^2	<10^2	0		✓	✓	✓	✓	×	✓	654.	40	075	1 04
COOLANOL 20	SILICATE ESTER	↓		<1mm Hg	<1 0	<-100	GPS-6	✓	✓	✓	✓	✓	✓	5 1	45	069	88
COOLANOL 40	″	↓		<10^4	<10^-3	<-85	″	✓	✓	✓	✓	×	✓	20 7	46	080.	90

considered to be the least toxic of gases and vapors.) None of the fluorocarbons have been determined to be flammable or explosive at temperatures to about 210°F. The presence of fluorine in the molecule in many cases has an effect on the boiling point similar to that of hydrogen but at the same time providing a high molecular weight and non-flammability. This effect is even more pronounced when chlorine is also present. The high molecular weight of fluorocarbon compounds also contributes to low vapor specific heat values and fairly low latent heats of vaporization. Fluorocarbons do not conduct electricity and in general have excellent dielectric properties. Compatibility of the fluorocarbon compounds with elastomers is variable, due to chemical structure variations between fluorocarbons but, in general, at least one fluorocarbon compound may be found to be compatible with most elastomers. Obvious exceptions are elastomers for which all fluorocarbon compounds are strong solvents: i.e., some fluorinated elastomers. Homopolymers or copolymers with increasing polyvinyl alcohol compositions generally offer increasing compatibility with the fluorocarbon compounds. Variation in the thermodynamic and thermophysical properties of certain fluorocarbon compounds may be obtained by substituting (existing) higher homologs of the fundamental fluorocarbon. For example, a family of five (homolog) fluids, the "Freon E-series", is manufactured by DuPont, with higher homologs currently under development.

Silicate Esters

Monsanto's Coolanol transport fluid series is a family of silicate ester coolant/dielectric fluids. The Coolanol fluids are characterized by very small vapor pressure and high specific heat as compared to Freon fluorocarbons. These characteristics yield smaller elastomer tube wall thickness (for pressure retention) and excellent thermal performance, respectively. However, pumping power penalties are large for the Coolanol fluids due to their large viscosities. Maximum (recommended) bulk fluid temperatures range from 250°F for Coolanol 15 to 400°F for Coolanol 45. Low temperature operation may be extended to -140°F for Coolanol 15 and to -85°F for Coolanol 45. The Coolanol fluids are compatible with aluminum, iron, copper, copper alloys, silver alloys, brass, cadmium plated steels, solders and brazing materials. Several elastomers are compatible with the Coolanol fluids, including synthetic rubber, fluorocarbons, nitrile and some fluorosilicones. Compatibility of thermoplastic polyurethane, polyvinyl chloride (Tygon), fluoroelastomer (Viton) and perfluoroelastomer with Coolanol 15 has been demonstrated by Vought for 50-day duration ambient tests. In general, the Coolanol fluids are quite similar to the hydrocarbons in overall flammability characteristics. The products of combustion of silicate esters (i.e., Coolanol fluids) include silica (silicon dioxide), which is usually of small particle size and appears as smoke. Silicate esters are characterized by the tendency to hydrolize when in contact with water, thus requiring some protective measures to avoid water contamination. The Coolanol fluids are essentially nontoxic. Coolanol 15 is somewhat volatile (relative to the other Coolanol fluids), and at high temperatures, the vapor is moderately toxic. Chevron International is also a manufacturer of silicate ester fluids.

Hydroxyl Ethers (Glycols)

Glycols, also called diols, are characterized by two hydroxyl groups. The hydroxyl groups contribute water solubility and hygroscopicity and also provide reactive sites. The extent to which the hydroxyl groups influence the properties of the molecule depends upon the position of the hydroxyl groups, the length of the hydrocarbon chain, and the presence of branched chains and repeating ether linkages. In effect, the more closely the molecule resembles a hydrocarbon, the more it acts like a hydrocarbon. Repeating ether groups in "polyols" introduce hydrogen bonding, with its attendant influence on solubility. The ethylene series is completely water soluable at room temperature. Hygroscopicity does, however, decrease as the chain lengthens. The propylene series loses its water solubility as the chain lengthens. Aqueous glycol solutions exhibit minimum freezing points at about 60 - 65% glycol, by weight. Boiling points of aqueous glycol solutions are increased with increasing glycol composition and are greatly enhanced as the glycol composition increases above 80-90%, by weight. All of the pure glycol solutions have vapor pressures under 0.1 mm of mercury at 20°C (68°F). In order of decreasing vapor pressure, the glycols are grouped as: propylene glycol, hexylene glycol, ethylene glycol, dipropylene glycol, diethylene glycol, triethylene glycol and tetraethylene glycol.

Ethylene glycol is a colorless, practically odorless, low-volatile, hygroscopic liquid. It is completely miscible with water and many organic liquids. Ethylene glycol is the lowest molecular weight fluid of the glycol series, it is about 50% more hygroscopic than glycerol at normal room temperatures and humidities. The appearance and properties of diethylene glycol are similar to those of ethylene glycol. Diethylene glycol is considerably less volatile than ethylene glycol and it dissolves various resins and gums and many organic materials. Diethylene glycol may thus be a poor choice as a transport fluid in contact with elastomer materials. Triethylene glycol is a colorless liquid with a slight,sweet odor. Its properties closely resemble those of diethylene glycol, but has a higher boiling point. Tetraethylene, propylene, dipropylene and hexylene glycols are also similar in behavior to the simpler glycols. 2-Ethyl-1, 3-hexanediol (ethohexadiol U.S.P) differs from the aforementioned glycols by its longer hydrocarbon chain, thus yielding low volatility and limited water solubility. Its compatibility with elastomers is unknown, but is most likely limited. 1, 2, 6 - Hexanetriol is a stable, high-boiling liquid that is completely miscible with water. It differs from the other glycols by having three hydroxyl groups, thus characterizing it as a very strong solvent. Other glycols include polyethylene and polypropylene glycols, characterized by large viscosities, and would therefore be inferior transport fluids (at least from a pumping power and flow stability viewpoint). Elastomer compatibility of all of the glycol fluids would largely be a function of the hydroxyl group inertness with respect to the elastomer material.

Silicone Fluids

Chemically, silicone fluids are quite different from all other materials. Whereas organic hydrocarbon fluids have a basic structure of carbon-carbon atoms, silicone fluids have a basic structure of silicon-oxygen linkages similar to the Si-O linkages in other high temperature materials (quartz, glass and sand). It is this linkage that contributes to the outstanding high temperature characteristics and general inertness of silicone fluids. In addition, many organic hydrocarbon fluids contain some degree of unsaturation where carbon atoms are joined together by double bonds. The double bonds are the sites of attack by oxygen, particularly at high temperatures. Because most silicone fluids contain no double bonds, they are extremely resistant to oxygen attack - even at high temperatures over long periods of time. Several types of silicone fluids may be synthesized through the use of a variety of organic side groups along the polymer chain: methyl, ethyl, propyl, butyl, phenyl carboxyalkyl, hydroxyalkyl, cyanoalkyl and aminoalkyl. Of these, methyls and phenyls are used most frequently; consequently, the two most common (and most useful) silicone fluids are dimethyl polysiloxane polymer and methyl phenyl polysiloxane polymer.

Silicone fluids offer a relatively small viscosity change with temperature. (Petroleum oils and dibasic acid esters exhibit large changes of viscosity with temperature in relation to most silicone fluids.) Silicone fluids are also characterized by shear stability, excellent resistance to breakdown at high temperatures and low surface tension. Dimethyl polysiloxane fluids have pour points below -120°F and may be operated at temperatures up to 500°F. Methyl phenyl polysiloxane fluids may be used from about -80°F to 500°F. Extended storage of silicone fluids at low temperatures will produce no precipitation since no additives are present. When frozen solid for prolonged periods, silicone fluids do not deteriorate and when returned to operating temperatures will perform as effectively as before. Except for the very low viscosity products, the nominal specific gravity range for silicone fluids is 0.94 to 0.98. Incorporation of phenyl molecules in the polymer increases specific gravity. Dimethyl silicones have the lowest surface tension values and these are largely independent of viscosity. The surface tension of methyl phenyl fluids is somewhat greater than that of dimethyl fluids, but is still much lower than that of organic fluids. Silicone fluids, except for the low viscosity dimethyl materials ($\leq$ 20 centistokes), show exceptionally high flash points. The low viscosity dimethyl fluids, being short chain polymers, are more volatile. The self-extinguishing characteristics of non-volatile high molecular weight silicone fluids are due to the large temperature difference between the flash and fire points. Auto-ignition temperatures of both dimethyl and methyl phenyl silicone fluids are above 850°F.

The low molecular weight, low viscosity silicone fluids behave as solvents in the presence of plastics and resins.

3.5.2 Materials Screening

Fluid Selection Criteria

Selection of a transport fluid for the soft tube configuration of the Inflatable Radiator concept is based on several factors. Characteristics of the candidate transport fluids which have a major influence on fluid selection are: boiling point (or vapor pressure), flash point, pour point (freezing point), elastomer compatibility, thermodynamic and transport properties and toxicity. Essentially, all of the fluid characteristics are important in proper fluid selection, but a few minimum requirements must be met for the fluid to be a possible choice. Due to a concurrent requirement in selection of the most flexible elastomer available/possible (and consequently an elastomer of low strength), the criteria for vapor pressure has been defined as being under one atmosphere at 250°F (i.e., normal boiling point of the fluid must be greater than 250°F). Consequent to this restriction on the fluid's vapor pressure, tube wall thickness requirements for meteoroid protection will be inclusive of those for pressure retention. The fluid operating temperature range has been defined as -100°F to 250°F which is considered to be inclusive of high and low temperature applications for the Inflatable Radiator concept.

Selection of the proper fluid for low temperature operation is not entirely dependent upon pour point. The fluid viscosity at low temperatures dictates the minimum allowable return temperature for a given radiator inlet temperature. For heat rejection systems facing deep space, unstable operation of the radiator occurs if the return temperature drops below the minimum allowable temperature which, in most cases, is well above the fluid pour point. The resulting behavior of the radiator, when rejecting heat to an environment with equivalent temperature below the transport fluid pour point (i.e., a radiator facing deep space), has been observed to be freezing in one flow path with subsequent freezing in adjacent tubes, and eventual freezing of at least a large portion of the radiator. The subject of flow stability is addressed later in this report concerning the soft tube Inflatable

Radiator thermal vacuum test and feasibility demonstration and in Reference (8). The flow stability problem limits the choice of transport fluids to fluids other than those with moderate-to-high viscosity at lower temperatures (in addition to the increased pumping power penalty incurred by use of the higher viscosity fluids.)

The data available on toxicity is limited, with the only quantitative data indicated for the Freon fluorocarbons, Table 10. None of the fluids evaluated by Vought appear to be hazardous in handling, assuming normal handling procedures are observed. Table 10 lists the fluids evaluated on an initial screening basis. The fluids which warrant further evaluation are those for which sufficient data are available and which remain liquid at pressures under one atmosphere over the temperature range of -100°F to 250°F. Second level screening and final fluid selection are discussed in Section 3.5.3.

Screening Tests

Screening tests consisting of chemical compatibility, bonding, flexibility and thermal exposure testing have been performed using several of the tubing materials indicated in Table 9. Room ambient temperature chemical compatibility tests have been conducted at Vought using Freon E-2 and Coolanol 15 together with each of the tubing materials listed in Table 11. Also indicated in Table 11 are the results of 11-, 20-, and 30-day chemical compatibility tests. The chemical compatibility tests were conducted at room ambient temperature and pressure using typically a one-inch length of tubing material immersed in a small beaker containing the transport fluid. Chemical compatibility was determined by changes in physical appearance, weight change and swelling of the elastomer. Perhaps the most quantitative measure of chemical compatibility is the amount of elastomer swelling incurred when in contact with the fluid. Swelling of tubing materials is easily measureable and, in the absence of changes in surface appearance, is considered to be indicative of elastomer/fluid compatibility. The two fluids selected

TABLE 11 ROOM AMBIENT TEMPERATURE CHEMICAL COMPATIBILITY TESTS

% SWELLING $\frac{R_t - R_i}{R_i}$ X 100

	Freon E-2			Coolanol 15		
Exposure Time (Days)	11	20	30	11	20	30
Tubing Material						
MP-1485 Ester-Based Polyurethane	0	0	-2	0	1	1
MP-1280 Ether-Based Polyurethane	0	1	1	1	2 1/2	3
MP-1880 Ether-Based Polyurethane	0	0	0	0	0	0
8831-63A ECD-006 Perfluoroelastomer	(1)	-	-	0	0	0
8831-63B ECD-006 Perfluoroelastomer	12	27	28	0	0	0
Viton B Fluoroelastomer	0	1 1/2	1 1/2	0	0	0
SR-200 Silicone rubber	-	5	5	-	38	40
Neoprene W	1/2	1	1	(2)	1 1/2	1 1/2
TPR-1600 Thermoplastic Rubber (Polyolefin)	2	2	2	4	4	4
TPR-1900 Thermoplastic Rubber (Polyolefin)	1/2	1	1	7	7	8
Moxness Silicone Rubber	1 1/2	2	2	39	40	40
R-3603 Tygon Polyvinyl Chloride	1	2	2	0	-5	-8 1/2(3)

(1) 8831-63A ECD-006 (Standard grade of perfluoroelastomer) deteriorated in less than three days in the presence of Freon E-2, with complete collapse of the tubing structure.

(2) Neoprene W is apparently compatible with Coolanol 15, with very little swelling and no obvious loss of flexibility. However, the Coolanol solution became increasingly yellow, whereas Coolanol is normally clear.

(3) Immersion of Tygon (PVC) in Coolanol 15 caused shrinkage of the elastomer, as well as greatly decreased flexibility. Flexibility decreased to about that of teflon, at room ambient temperature.

with which to conduct the chemical compatibility tests, Freon E-2 and Coolanol 15, were chosen to be representative of the more applicable transport fluids, Table 10. As indicated in Table 11, the MP-1880 polyurethane, 8831-63A and -63B ECD-006 perfluoroelastomers and Viton B fluoroelastomer did not swell in the presence of Coolanol 15. Also, Coolanol 15 had a limited effect on the MP-1485 and MP-1280 polyurethanes and Neoprene W, although discoloration of the Coolanol solution was observed with Neoprene W. Substantial swelling of silicone rubber in Coolanol 15 was observed; whereas diameter reduction and significant loss of flexibility of polyvinyl chloride (Tygon) in Coolanol 15 was observed. Compatibility with Freon E-2 was indicated for MP-1880 polyurethane; and minor effects of E-2 on MP-1485 and MP-1280 polyurethanes, Viton B, Neoprene W, Tygon, one grade of silicone rubber and the polyolefin thermoplastics were noted. Substantial swelling of the low temperature formulation of perfluoroelastomer, 8831-63B, in E-2 was obtained; the standard grade of perfluoroelastomer, 8831-63A, completely deteriorated in the presence of E-2 in about three days. Of the tubing material/fluid combinations tested by Vought, the only resulting tubing material which lost its flexibility was Tygon (polyvinyl chloride) in Coolanol 15. This loss of flexibility is presumably due to loss of the plasticizer while in the presence of Coolanol.

Flexibility tests of the tubing materials listed in Table 11 were conducted at room ambient temperature, 220°F, -100°F and -320°F (LN_2 temperature). With little exception, the tubing materials were more flexible at 220°F than at room ambient temperature. For the high temperature tests, the tubing material samples were placed in individual aluminum containers located in an air-circulating oven maintained at 105°C (221°F). Since immediate provisions for maintaining the transport fluids at elevated and reduced temperatures were not available, the flexibility tests were conducted with the tubing materials in air at elevated temperature, and in air immediately subsequent to immersion in dry ice (solid CO_2)/Acetone and immersion in liquid nitrogen. Results of the flexibility tests are shown in Table 12. Direct comparison of the flexibility of each of the elastomers with that of

Table 12 Results of Elastomer Flexibility Tests

MATERIAL	ID X OD (Approx)	FLEXIBILITY			
		75°F	220°F	-100°F	-320°F
MP-1880 Polyurethane	1/16 X 1/8	Moderately Flexible	Increased Flexibility	Bending over 1/8" Mandrill w/moderate force (by hand)	No Flexibility
MP-1485 Polyurethane	1/8 X 1/4	Moderately Flexible	Permanent Longitudinal Curl; slightly yellowed.	(1/4" Mandrill)	No Flexibility
MP-1280 Polyurethane	1/16 X 1/8	Moderately Flexible	Increased Flexibility	(1/8" Mandrill)	No Flexibility
8831-63A Perfluoroelastomer	1/8 X 5/16	Moderately Flexible	Increased Flexibility	No Flexibility	No Flexibility
8831-63B Perfluoroelastomer	1/8 X 5/16	Moderately Flexible	Increased Flexibility	No Flexibility	No Flexibility
Viton B Fluoroelastomer	1/4 X 9/32	Flexible; Crinkles when bent	Increased Flexibility	No Flexibility Shattered when bent	Shattered when bent
SR-200 Silicone Rubber	1/16 X 5/32	Extremely Flexible	Increased Flexibility	Very Flexible at -80°F	Small Flexibility
Neoprene W	1/8 X 3/8	Moderately Flexible	Increased Flexibility	No Flexibility	No Flexibility
TPR-1600 Thermoplastic rubber	1/8 X 7/32	Flexible; crinkles when bent	Elongates permanently when stretched	No Flexibility; Permanent crinkle when bent	Brittle (Shattered)
TPR-1900 Thermoplastic rubber	3/16 X 9/32	Flexible; crinkles when bent	Elongates permanently when stretched	No Flexibility; permanent crinkle when bent	Brittle (Shattered)
Moxness Silicone Rubber	14 AWG (.069 X .101)	Extremely Flexible	No change from 75°F	Small loss in flexibility from 75°F	Small flexibility
R-3603 Tygon Polyvinyl Chloride	1/8 X 1/4	Moderately Flexible	Increased Flexibility	No Flexibility	No Flexibility

the other elastomers was difficult due to the variation of sizes encountered in obtaining samples. Qualitatively, the tubing materials may be ranked in order of increasing flexibility as: thermoplastic rubber, Neoprene W, Viton B, polyurethane, perfluoroelastomer and silicone rubber. Several other materials evaluated by Vought, Table 9, were either nonobtainable or unknown at the time of testing (EPDM, ethylene vinyl acetate, ethylene ethyl acrylate) or were judged to be too stiff to compete as alternate tubing materials (butadiene - acrylonitrile, polyester). As indicated earlier, it was recognized by Vought that a thorough screening of plastic, rubber and elastomer materials may still leave some existing materials unrecognized. It is believed, however, that some variation of most of the available flexible materials has been identified.

Elevated temperature chemical compatibility tests were possible for Coolanol 15 without reflux condensing, due to the low vapor pressure of the fluid, and were conducted using the materials listed in Table 11 for which zero elastomer swelling was observed (viz., perfluoroelastomer, Viton B and MP-1880 polyurethane). Three-day duration tests were performed with samples of Viton B and both grades of perfluoroelastomer immersed in Coolanol 15 at a temperature of 200 ± 10°F. The results of these tests were evaluated in terms of changes in physical appearance (i.e., swelling, color change, etc.). The perfluoroelastomer did not undergo any perceivable changes in surface appearance or size. Thus, at least from data indicated from the ambient immersion tests and the three-day elevated temperature tests, both the standard and low temperature formulations of perfluoroelastomer are quite compatible in Coolanol 15. The usual differences between members of a family of transport fluids (i.e., Collanols 15, 20, 25, 35, 40 and 45) are the transport and thermophysical properties; usually, the solubility of the fluid with other materials does not vary significantly between members of the same fluid family. Thus, it is expected that perfluoroelastomer would be compatible with any of the Coolanol silicate ester fluids. (Similar compatibility is expected of the Freon "E-series" fluids for elastomers which have been shown to be compatible with at least one of the "E-series" fluids.) Behavior of Viton B in Coolanol 15 at 200°F for three days showed a shrinkage of about 8% in diameter, with no apparent loss of flexibility.

Elevated temperature chemical compatibility tests were conducted with several samples of MP-1880 polyurethane immersed in Coolanol 15 for continuous exposure in excess of 500 hours (21 days) at temperature levels of approximately 140, 160 and 180°F. These tests were performed in support of the basic Inflatable Radiator program change to incorporate a more flexible tubing material (as compared to FEP Teflon) in the soft tube design scaled test article. As indicated above, MP-1880 polyurethane was found to be one of the most promising alternate tubing candidates, used in conjunction with Coolanol 15 as the transport fluid. Significant discoloration (yellowing) was observed in the 180°F MP-1880 samples. The 160°F samples were moderately discolored and the 140°F samples were only slightly discolored. It was also observed that longitudinal curling of the polyurethane samples increased with increasing temperature. Earlier hot case exposure test results for MP-1880 polyurethane/Coolanol 15 at 230°F for 72 hours indicated similar behavior in discoloration and curling. Pressure testing of the 230°F - 72 hour sample and the 160°F - 500 hour sample showed no apparent loss in strength, as these samples were capable of withstanding 300 psia burst pressure for approximately one-half hour (virtually equivalent results as for the MP-1880 sample which had undergone no chemical compatibility tests).

3.5.3 Materials Analysis and Selection

The transport fluids in Table 10 that may be considered after applying the fluid selection criteria of Section 3.5.2 are General Electric F-44 and F-50; Freons E-3, E-4 and E-5, and Coolanols 15 and 25. For a given environment heat load and radiator configuration that has tube wall thickness dictated by meteoroid protection (i.e., the tube wall thickness required for micrometeoroid protection is greater than that required for fluid pressure retention), the fluids may be compared directly by requiring equivalent fluid ΔT thru the radiator. This is tantamount to requiring equal heat removal capabilities for each fluid. Thus for each fluid, the mass flowrate is determined and, together with the fluid transport properties, pressure drop and pumping power penalty may be determined. Table 13 shows the results of this analysis, where the pumping power penalty is compared to the baseline fluid (R-21). Shown in Table 14 are tube wall thickness requirements for the elastomers that were compatible with either Freon E-2 or Coolanol 15 and their associated wall temperature drop.

The wall ΔT is essentially the same for all of the final tubing candidates. Table 13 indicates that from a pumping power requirement standpoint, Coolanol 15 is superior to the other fluids. Availability, cost, compatibility and extended testing has resulted in the choice of Coolanol 15 as the preferred transport fluid and MP-1880 polyether urethane as the preferred tubing material.

TABLE 13

FINAL SELECTION CRITERIA FOR TRANSPORT FLUID

FLUID	ΔP(PSI)	PUMP POWER(LBM)	$\frac{\text{PUMP POWER}}{(\text{PUMP POWER})_{R-21}}$
E-3	75.1	149.2	5.7
E-4	132.9	259.3	9.9
E-5	217.6	417.3	15.9
F-44	3044.	7038.	269.0
F-50	Insufficient property data (but similar to F-44)		
C-15	58.4	124.7	4.8
C-25	171.9	357.1	13.6

TABLE 14

TUBING WALL THICKNESS AND ΔT SUMMARY

			30-DAY	
TUBING	DENSITY (SP GR)	THERMAL CONDUCTIVITY (BTU/HR-FT-°F)	T (IN)	ΔT (°F)
FEP Teflon	2.15	.11	.037	4.05
MP-1485	1.04	.12	.053	4.56
MP-1280	1.04	.12	.053	4.56
MP-1880	1.04	.12	.053	4.56
ECD-006	2.0	∼ .11	.038	4.13
Viton B	1.4	∼ .11	.046	4.71

3.6 Engineering Model Inflatable Radiators

Engineering model test articles were fabricated and tested in the Vought Space Environment Simulator. Drawing No. T-213-SK03 - Inflatable Radiator Soft Tube Concept, and T-213-SK04 - Inflatable Radiator Hard Tube Concept give full scale details of the test articles. Both drawings have been transmitted to the NASA Technical Monitor. Figures 32-39 are photographs of the engineering models.

3.6.1 Soft Tube Test Article

The soft tube model is 37" wide x 72" long and contains twenty equally spaced transport tubes. The test article simulates one panel of the 3-panel flight configuration defined in Vought drawing T-213-SK01 and shown in Figure 2. The test article is smaller in size and does not have the watchspring retraction subsystem of the full scale system.

Figure 40 sketches the general overall test article configuration and its principal elements. The article was mounted horizontally in the test chamber, and rolls out on guides with deployment similar to a party whistle. The tubing is constructed from polyurethane and is arranged in U-shaped flowpaths which begin and end at adjacent manifolds located at the end of the panel nearest the deployment box. The tubing is bonded between two sheets of fin material with SR-585 adhesive. The fin material and inflation tubing were fabricated by Sheldahl Advanced Products Division. Each layer of the fin material consists of two mils of Teflon coated with 12,000 Å of silver. The inflation tubing was inserted into sleeves formed at the sides of the radiator, and the radiator was deployed from a 6" dia. spool by pressurizing the tubing with nitrogen gas at 15 psi. No watchspring retraction system is incorporated in the test article. Instead, the rewind moment applied by the watchspring is simulated by a cable which is wound around the 6" dia. spool and retracted by an electric motor.

The purpose of the deployment box is to permit simulation of deployment from a stowage compartment in the spacecraft into a cold space environment. The box simulates a 20°F stowage compartment and is pulled away from the radiator immediately following deployment so that the inflatable panel can be exposed to a well-defined chamber environment for thermal vacuum heat transfer measurements. A multilayer insulation curtain

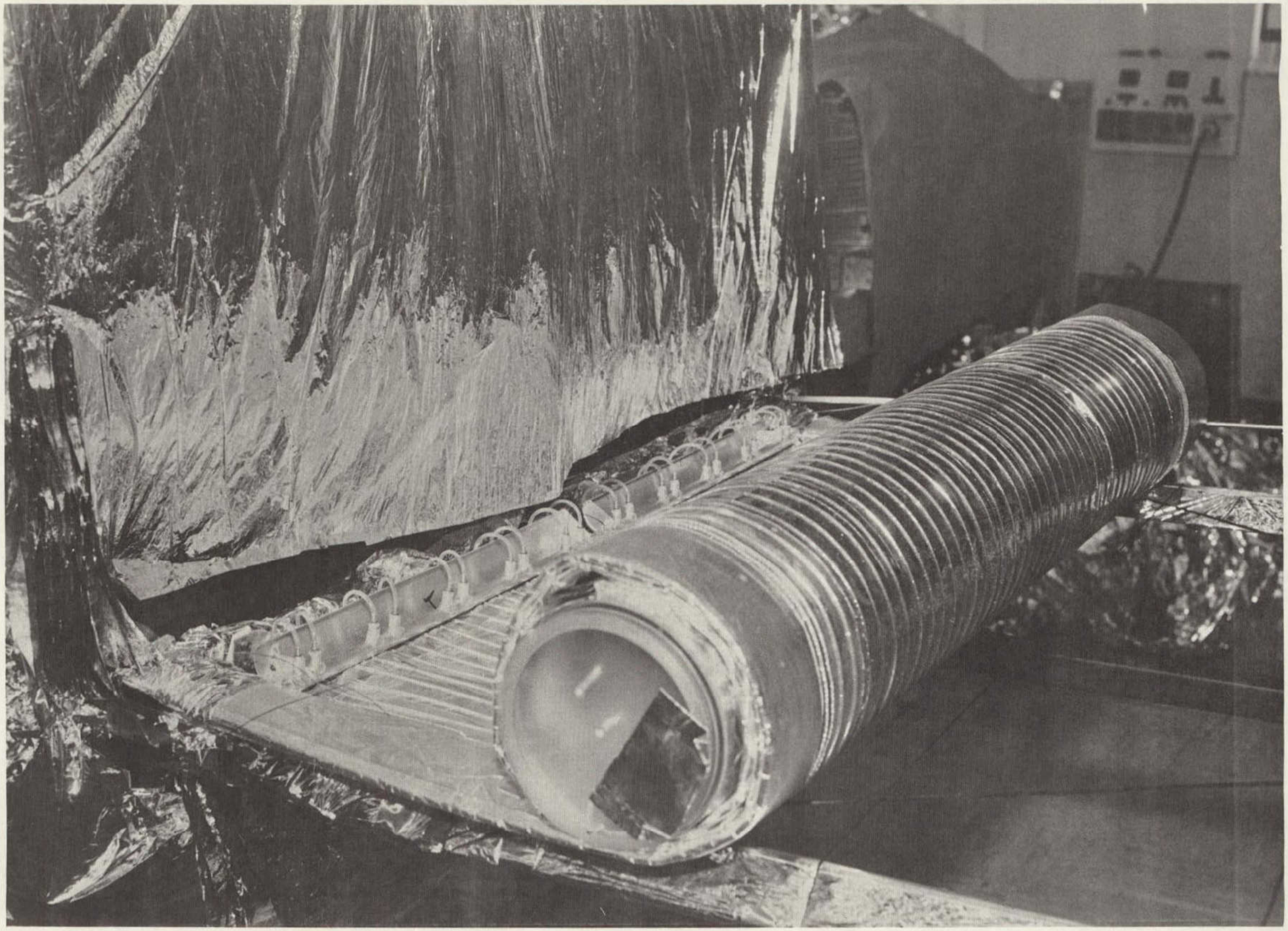


FIGURE 32 HARD TUBE FLEXIBLE RADIATOR TEST ARTICLE

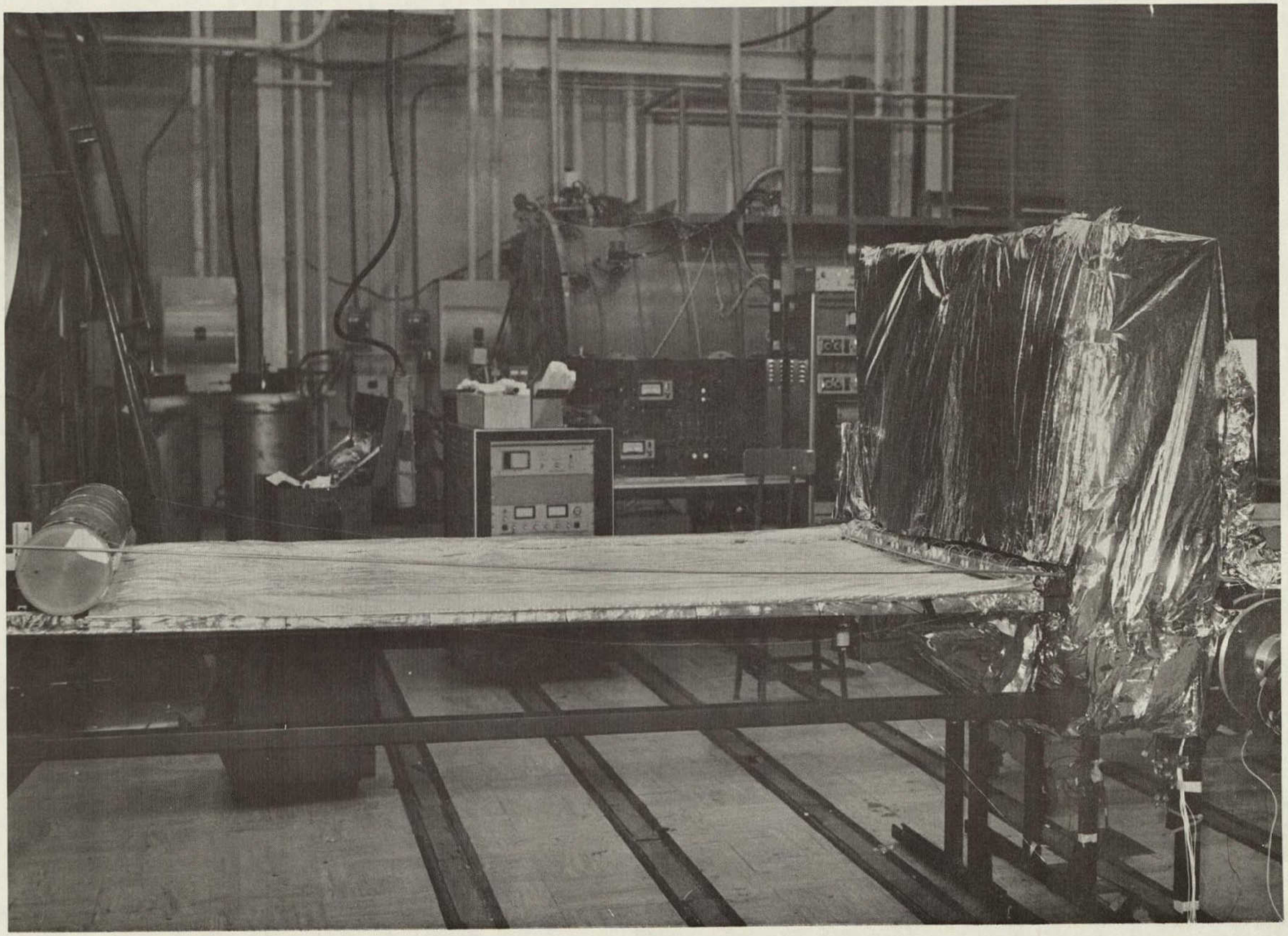


FIGURE 33 HARD TUBE FLEXIBLE RADIATOR TEST ARTICLE

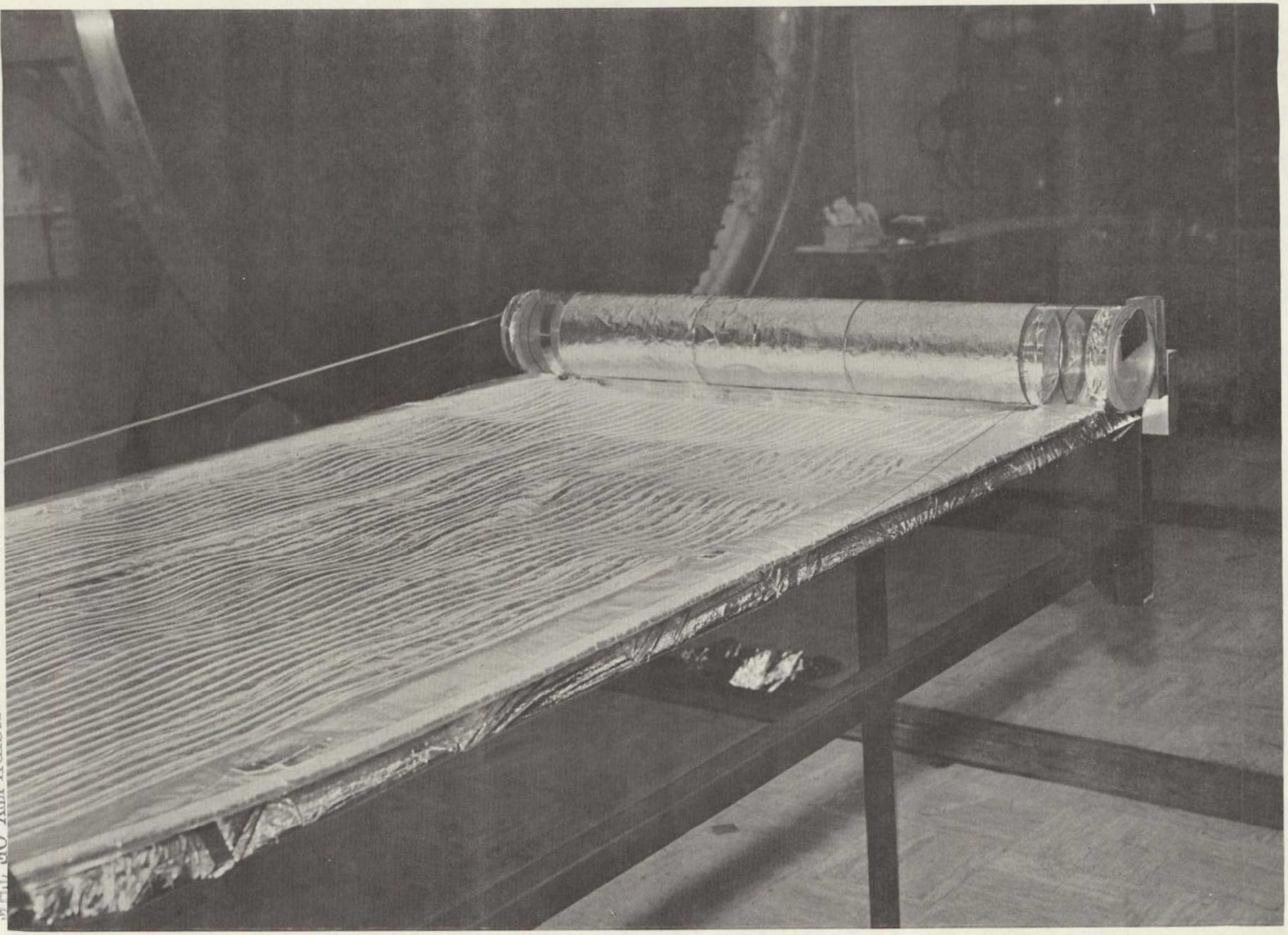


FIGURE 34 HARD TUBE FLEXIBLE RADIATOR TEST ARTICLE

FIGURE 35 HARD TUBE FLEXIBLE RADIATOR TEST ARTICLE

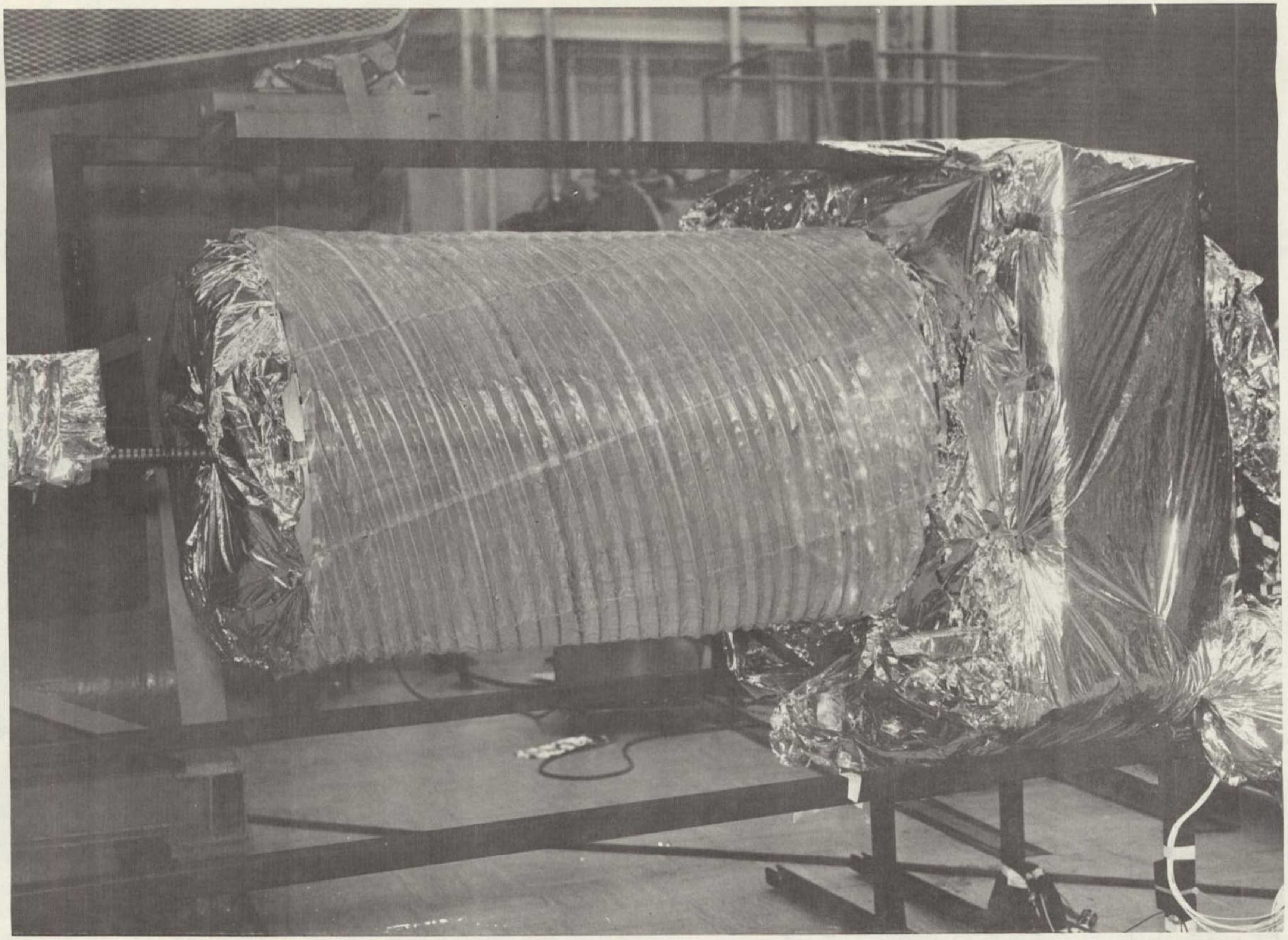


FIGURE 36 SOFT TUBE FLEXIBLE RADIATOR TEST ARTICLE

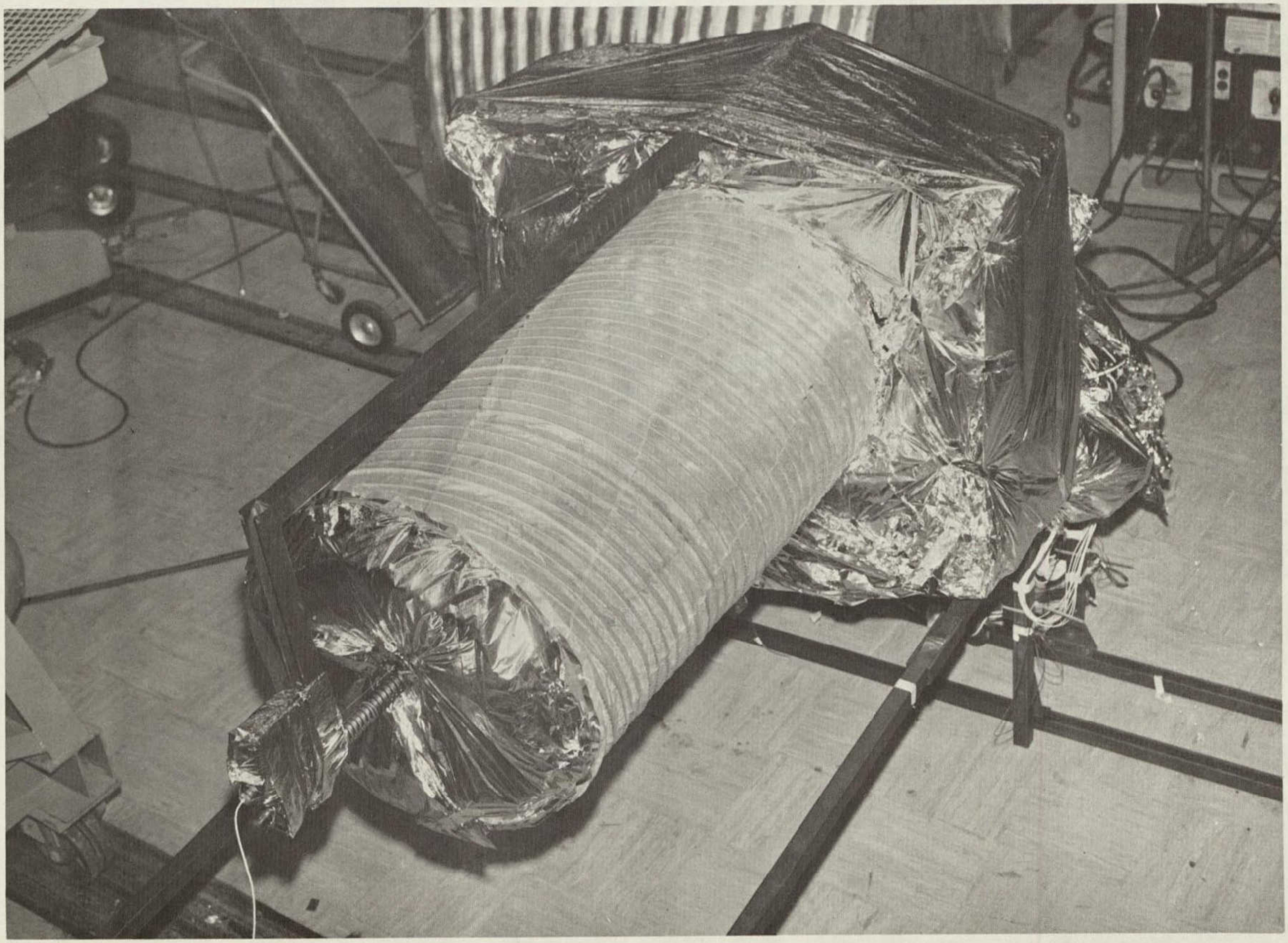


FIGURE 37 SOFT TUBE FLEXIBLE RADIATOR TEST ARTICLE

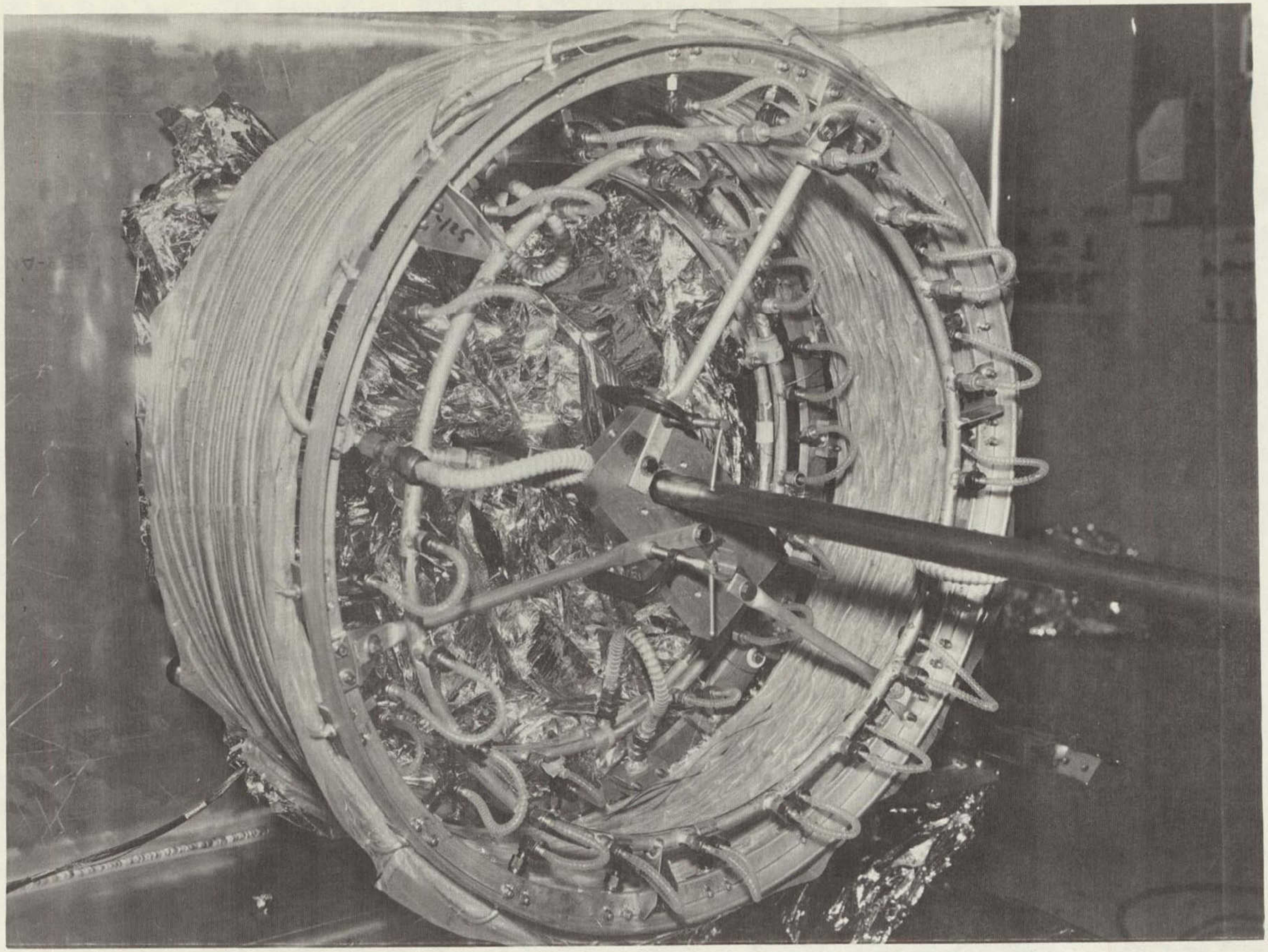


FIGURE 38 SOFT TUBE FLEXIBLE RADIATOR TEST ARTICLE

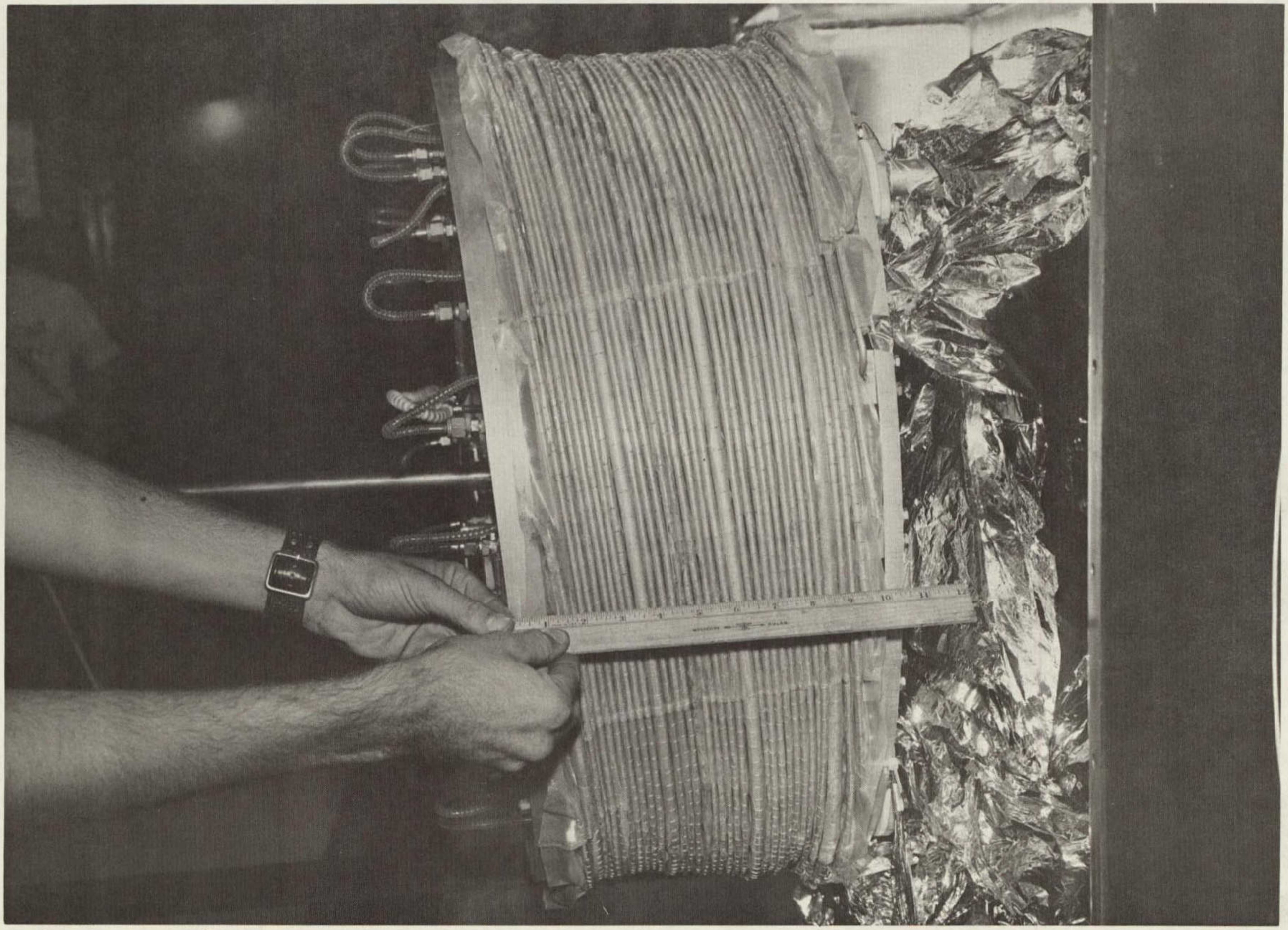


FIGURE 39 SOFT TUBE FLEXIBLE RADIATOR TEST ARTICLE

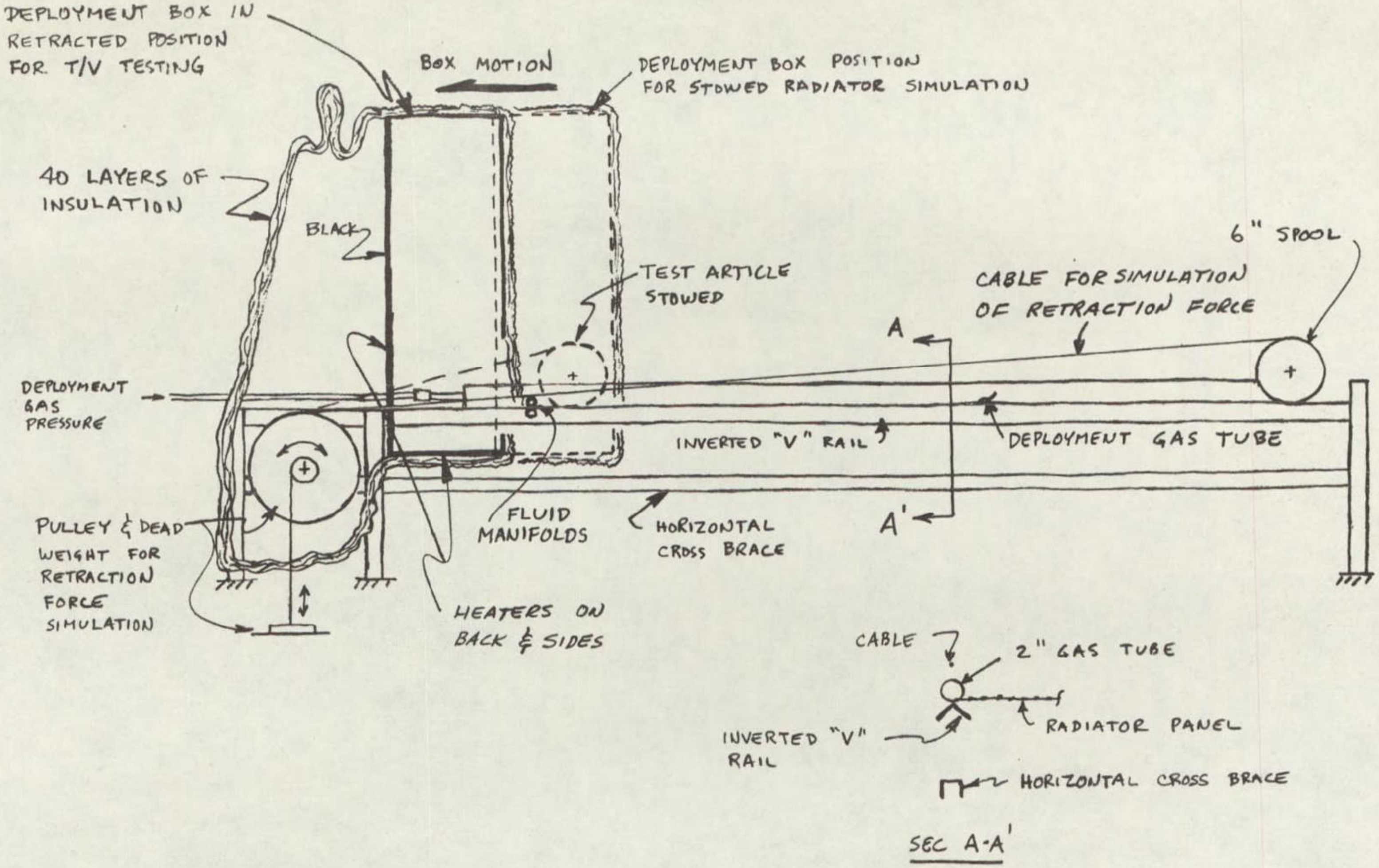


FIGURE 40 SOFT TUBE TEST ARTICLE CONFIGURATION

3. Demonstrate structural integrity over the range of expected nominal and limit case operational environments under steady state and transient conditions.
4. Obtain experimental data on tube and fin temperature drops and tube-to-tube and longitudinal gradients to evaluate test article integrity and analytical procedures.

Since the engineering models are not full scale it was not possible to test them at the correct flowrates while maintaining the fluid outlet temperatures at the value which would occur with a full scale system. Therefore, test sequences were executed with the flowrate adjusted to give the correct outlet temperature but incorrect Reynolds number, and with the correct Reynolds number but incorrect outlet temperature.

Table 15 summarizes the test sequence for the hard tube radiator. Test points 1-4 were conducted before the radiator was flexed as required in retraction and deployment to obtain baseline performance data for assessing possible damage which might occur in deployment/retraction. For test point 5 the radiator was subjected to several deployment/retraction cycles at ambient conditions to obtain spring force data and to observe how the radiator fin material reacts to the stress of deployment and retraction. Test points 6, 7, and 8 were designed to evaluate the radiator performance after repeated deployment and retraction in a cold vacuum environment.

Table 16 gives the test sequence for the soft tube engineering model. The test article was deployed and retracted approximately 50 times at room ambient conditions prior to thermal vacuum testing, and was deployed from a 70°F box in a -310°F vacuum environment at the beginning of the test. Test points 1, 2, 3, and 7-B were executed to establish the steady state performance characteristics of the fully deployed radiator, and test points 6-B and 6-C to determine the heat rejection at partial deployment. Test point 4 demonstrated that the system would function at the high temperature operating limit, and test point 2-A demonstrated that the system thermal performance had not degraded during the test.

TABLE 15 HARD TUBE INFLATABLE RADIATOR TEST OUTLINE

TEST POINT	TEST CONDITIONS	COMMENTS
1	-310°F Environment, Representative T_{in} and T_{out}	Performance prior to deployment
2	0°F Environment, Representative T_{in} and T_{out}	Performance prior to deployment
3	0°F Environment, Representative Flowrate	Design Re., 65°F avg. temp
4	0°F Environment, 160°F Inlet Temperature	Hot Limit Structural Integrity
5	Ambient Retraction/Deployment	Deployment Data
6	0°F Environment, Vacuum Deployment	Deployment Data
6-A	Same as Test Point 1	Effect of Deployment
6-B	Same as 6-A, But Radiator Half Retracted	Retraction/Deployment in Cold Envirn.
6-C	Same as 6-A, But Radiator Fully Retracted	Retraction/Deployment in Cold Envirn.
6-D	Same as 6-A	Retraction/Deployment in Cold Envirn.
7-B	-40°F Environment, Representative T_{in} and T_{out}	Intermediate Environment
8-A	Same as 7-B After 5 Retraction/Deployment Cycles	Intermediate Environment
8-B	Same as 7-B After 10 Retraction/Deployment Cycles	Intermediate Environment
7-A	-310°F Environment, Low Flow Cold Soak	Structural Integrity
7-C	Same as Test Point 1	Effects of Test

TABLE 16 SOFT TUBE INFLATABLE RADIATOR TEST OUTLINE

TEST POINT	TEST CONDITIONS	COMMENTS
A	Ambient Retraction/Deployment	Deployment Data
B	-310°F Environment, Vacuum Deployment	Deployment Data
1	-310°F Environment, Representative T_{in} and T_{out}	Steady State Performance
2	0°F Environment, Representative T_{in} and T_{out}	Steady State Performance
3	0°F Environment, Representative Flow Rate	Steady State Performance
7-B	-30°F Environment, Representative T_{in} and T_{out}	Steady State Performance
6-B	Same as 7-B, but Radiator Half Retracted	Steady State Performance
6-C	Same as 7-B, but Radiator Fully Retracted	Steady State Performance
4	0°F Environment, 160°F Inlet Temperature	Hot Operating Limit
2-A	Same as Test Point 2	Effects of Test

Several test points were planned which could not be completed. Test point 4 of Table 17 was designed to test the hot operating limit of the hard tube radiator. The system became inoperable when the flexible Teflon tubing connecting the aluminum tubing to the manifolds began to leak Freon into the vacuum chamber. The failure occurred when the fittings joining the Teflon and aluminum loosened because of cold flow of the Teflon at elevated temperature and pressure. Test points 7-a and 7-c were designed to demonstrate that performance would not degrade after the radiator had operated at extremely low temperatures. It was not possible to operate the radiator at the conditions of low flow scheduled for test point 7-a because an instability occurred which caused the flow to stagnate in most of the parallel flow passages. Post test analyses showed that the flow stability is predictable from the properties of the Coolanol 15 transport fluid. It was necessary to warm the environment simulation cold walls to allow the radiator to recover from the flow instability. Insufficient LN_2 remained to re-cool the shroud after the flow had been re-established. Therefore, test point 7-C could not be executed. Test point 2-A was scheduled in place of 7-C to determine the effects of the test on the radiator performance.

3.6.3.1 Test Set-Up

Figure 42 shows the arrangement of the test article and environment simulation shroud in the Vought 12' chamber.

Environment Simulation

Environment simulation was effected with a 6' isothermal shroud. The closed end of the 6' shroud was inserted toward the lamphouse. The back plate was installed so that the veiwing/illumination cutout (about 15-1/2" x 34-1/2") is on the lower half of the plate, and viewing of the test article was through the lower 2 rows of solar ports. (Deployment of the test article is toward the lamphouse). To make room for the test article, deployment box, deployment mechanism and deployment supports it was necessary to "stand off" the 6' shroud door plate several feet. The resulting ring-shaped gap in the 6' shroud cold wall was insulated with

TABLE 17 TEST POINTS NOT COMPLETED

TEST ARTICLE	TEST POINT	TEST CONDITIONS	COMMENTS
Hard Tube	4	0°F Environment, 160°F Inlet	Teflon Tubes Leaked
Soft Tube	7-A	-310°F Environment, Cold Soak	Flow Instability Occurred
Soft Tube	7-C	-310°F Environment, Repeat Test Point 1	Warmed Shroud to Recover Flow

covers the front of the box as shown in Figure 40. The radiator panel pushes the curtain out of the way as it unrolls, then the box is retracted from over the manifold area.

Test article instrumentation consists of thermocouples located on the tubes, fins, and manifold. The thermocouples are designed and fabricated as an integral part of the test article.

3.6.3 Hard Tube Test Article

The hard tube engineering model is 28" dia. x 45" long and contains twenty parallel flow 3/16" dia. aluminum transport tubes. The test article was fabricated as a joint effort of the Vought Materials Laboratory and Space Environment and Systems Test Laboratory. The test article simulates the flight configuration defined in Drawing T-213-SK02 and shown in Figure 1. The test article is smaller in size and does not have the STEM retraction subsystem or the fluid loop components of the full scale system.

Figure 41 sketches the general overall test article configuration and it's principal elements. The article was mounted horizontally in the test chamber to minimize gravity effects and was supported during deployment on a steel bar passing through the center of the radiator as shown in Figure 38. Loads are transmitted between the radiator and support bar through ball bearings which reduce friction forces during deployment.

The test article cylinder diameter and number of tubes is 2/3 scale relative to the flight article. The coil helix angle is 20° at the extended length of 45", and about 1.4 turns of each coil is required. The spring was wound at a free length of 48" (about 21° helix) in order to obtain a preload of about 1.8 lb at the extended length. Eighteen of the tubes are 3/16" O.D. 6061-T6 Aluminum, and the remaining two are 3/8" O.D. 6061-T6. The 18 small tubes carry the transport fluid from the supply manifold to a similar collection manifold at the opposite end of the radiator. The two large tubes pick up fluid at the collection manifold and deliver it to a return manifold at the bottom of the coil. The return tubes are spaced 180° apart. Centerline spacing of the tubes is 1.5" when the coil is extended. A support ring on each end of the cylinder is provided

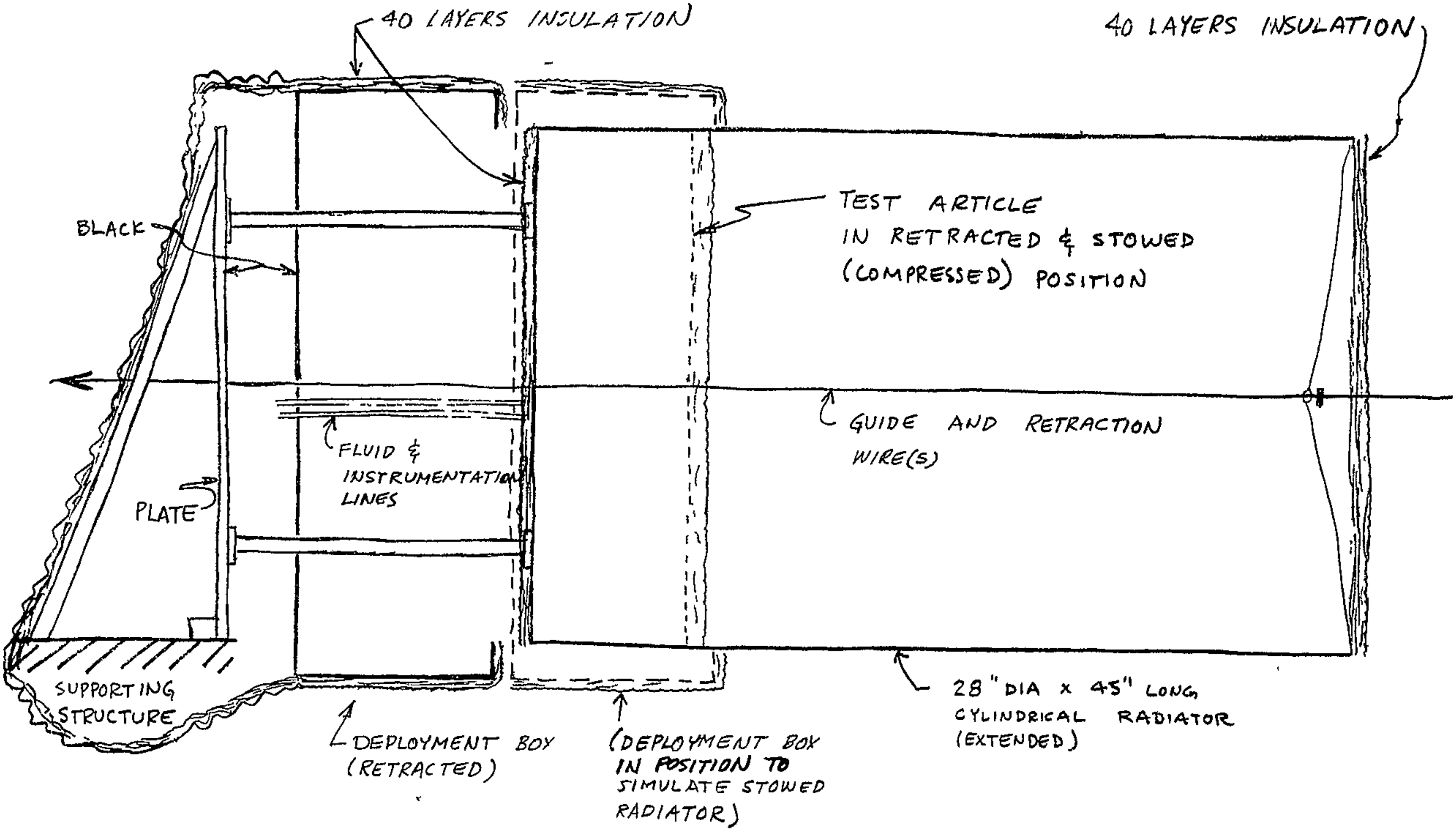


FIGURE 41 HARD TUBE TEST ARTICLE CONFIGURATION

40 layers of multilayer insulation. All coldwalls of the 6' shroud were also insulated with about 40 layers.

For cold case runs the 6' shroud and chamber cold trap were cooled with LN_2. (Cooling of the main chamber walls was not required.) For hot case (TP2, 3, and 4) and intermediate case (TP7B) tests the shroud was cooled to slightly below 0°F and -30°F, respectively, by flowing chilled GN_2 through the 6' shroud LN_2 passages. For transition from cold-to-hot conditions (TP1-to-2 and TP7B) and chamber warmup it was necessary to purge the LN_2 with GN_2.

The existing chamber GN_2 warmup system and blower were used for GN_2 cooling of the shroud, with LN_2 injection upstream of the heater to provide temperature depression.

A deployment box was used to simulate the Inflatable Radiator stowage compartment. For thermal vacuum deployment tests (TD3, TP5B) it was necessary to heat the box to about 70°F prior to deployment, then retract the box and shut-off its heater power after deployment to thermally remove the box from the test. A multilayer insulation blanket (40 layers) was applied to the front (test article face of box) and sides of the box (extending around the support structure as shown in Figures 40 and 41) to further isolate it from the Inflatable Radiator and the chamber. For the hard tube test article the front of the box was insulated only outside the area defined by the four test article support legs. To compensate an insulation blanket about 28 inches in diameter was applied to the bottom of the hard tube test article "cylinder". A similar blanket was applied to the top. For the soft tube test article the multilayer insulation was installed in such a way to allow the insulating blanket to re-cover the front of the box after deployment.

Deployment/Retraction Mechanism

The previously mentioned guide bar through the center of the hard tube test article was used in connection with appropriate actuators/releases to allow the radiator to deploy by itself from the deployment box. The actuators provided the capability for remotely retracting the radiator for testing in the vacuum environment. A retraction mechanism for the deployment box, which allows the box to be withdrawn

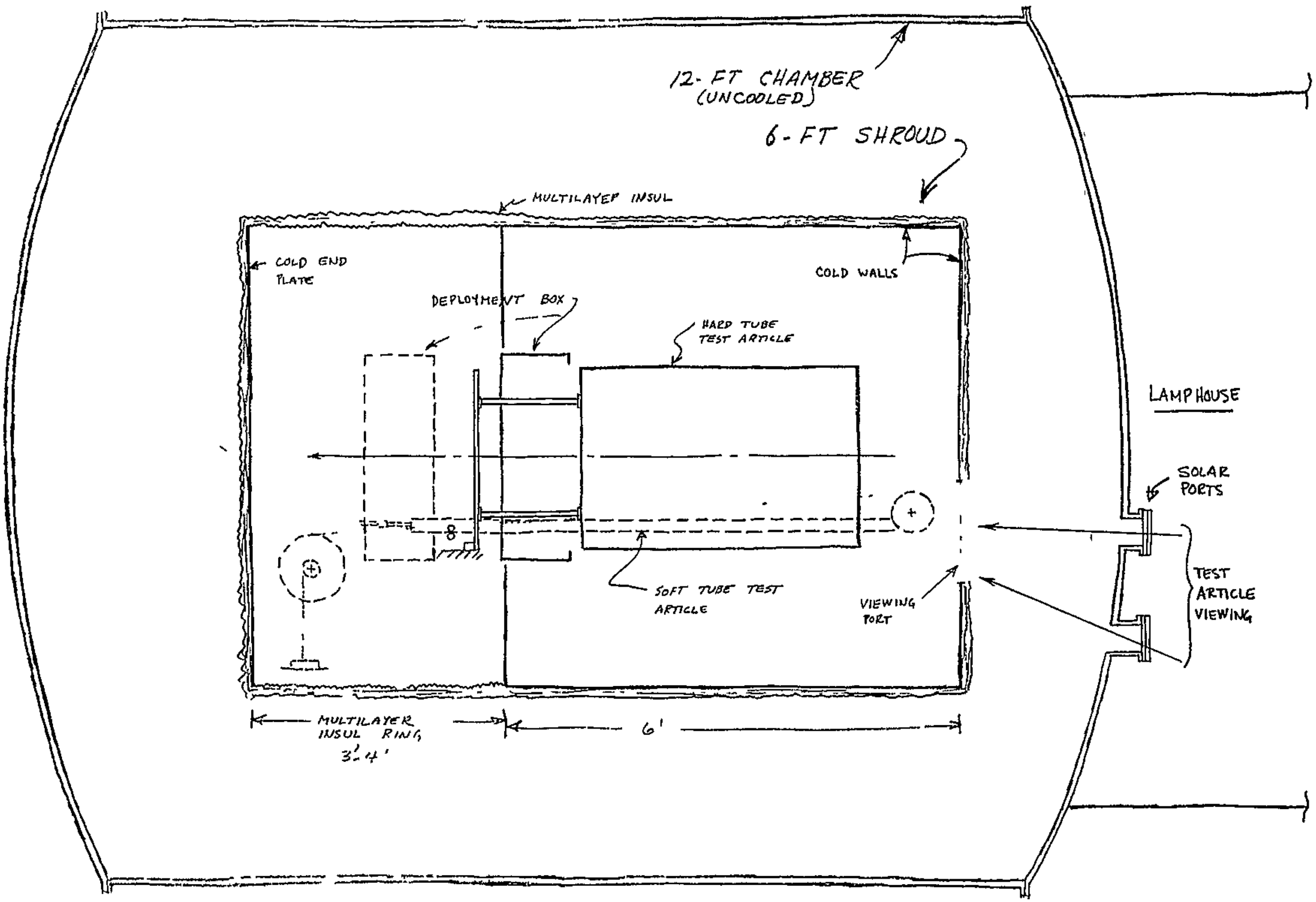


FIGURE 42 ARRANGEMENT IN CHAMBER

clear of the test article, was also provided. During ambient deployment tests (TP5A) the forces required to retract the hard tube radiator (about 30#) were measured with a scale. Forces for full extension to 45" were also measured at that time.

The deployment system and associated support and force measurement equipment for the soft tube test article are defined in the referenced drawings. A nitrogen bottle and regulator/indicator were provided which are capable of pressurizing the 2" gas inflation tubes to up to 30 psig. Weights for the pulley system used to simulate the flight retraction system restraint forces were supplied for calibrating purposes, and restraint forces vs inflation pressure were determined during ambient deployment tests. Actuators for retracting the soft tube radiator remotely were provided for thermal vacuum testing.

Viewing

Final positioning of the test articles and shroud in the chamber considered the necessity to observe the proper deployment during thermal vacuum testing. Lights (remotely switched on), mirrors, and a scale to verify extent of deployment were installed in the shroud in such a way as to provide minimum thermal interference. During ambient tests video-tape and still photography films of the deployment were recorded.

Flow Bench

The hard tube test article was tested with Freon 21 in the flow loop. Flow in the range from about 10 pph to 500 pph was required. System pressure was regulated to avoid damage to the test article. For protection of the Teflon flexlines, the test article inlet pressure was not operated above 100 psig (referenced to vacuum) for any test point except TP4. Test point 4 is a limit case, and pressure at the test article inlet was increased to 120 psig (referenced to vacuum) to avoid Freon 21 flashing.

The soft tube test article was tested with Coolanol 15 in the flow loop. Coolanol 15 is a very low vapor pressure fluid (10 mmHg @ 200°F) and, thus, system pressure was driven by flow pressure drop. Since Coolanol 15 is also highly viscous, large delta-p's occur. Maximum test article pressure drop at the highest flowrate of about 125 pph is approximately 20 psi. Flowbench changes and operating procedures to use Coolanol 15 avoided test article inlet pressures in excess of 70 psia (referenced to vacuum) to protect the Urethane 1880 tubes.

Hard Tube Test Article Instrumentation

Figure 43 and 44 show the approximate locations of the 50 thermocouples on the hard tube article. The thermocouples attached to the tubes, manifolds, and structure (#36 guage Cu-Cn) were spot-welded. The fin root and midpoint thermocouples (#40 guage Cu-Cn) were sewn into the fin material. Thermocouple leads were run parallel to the tube spirals.

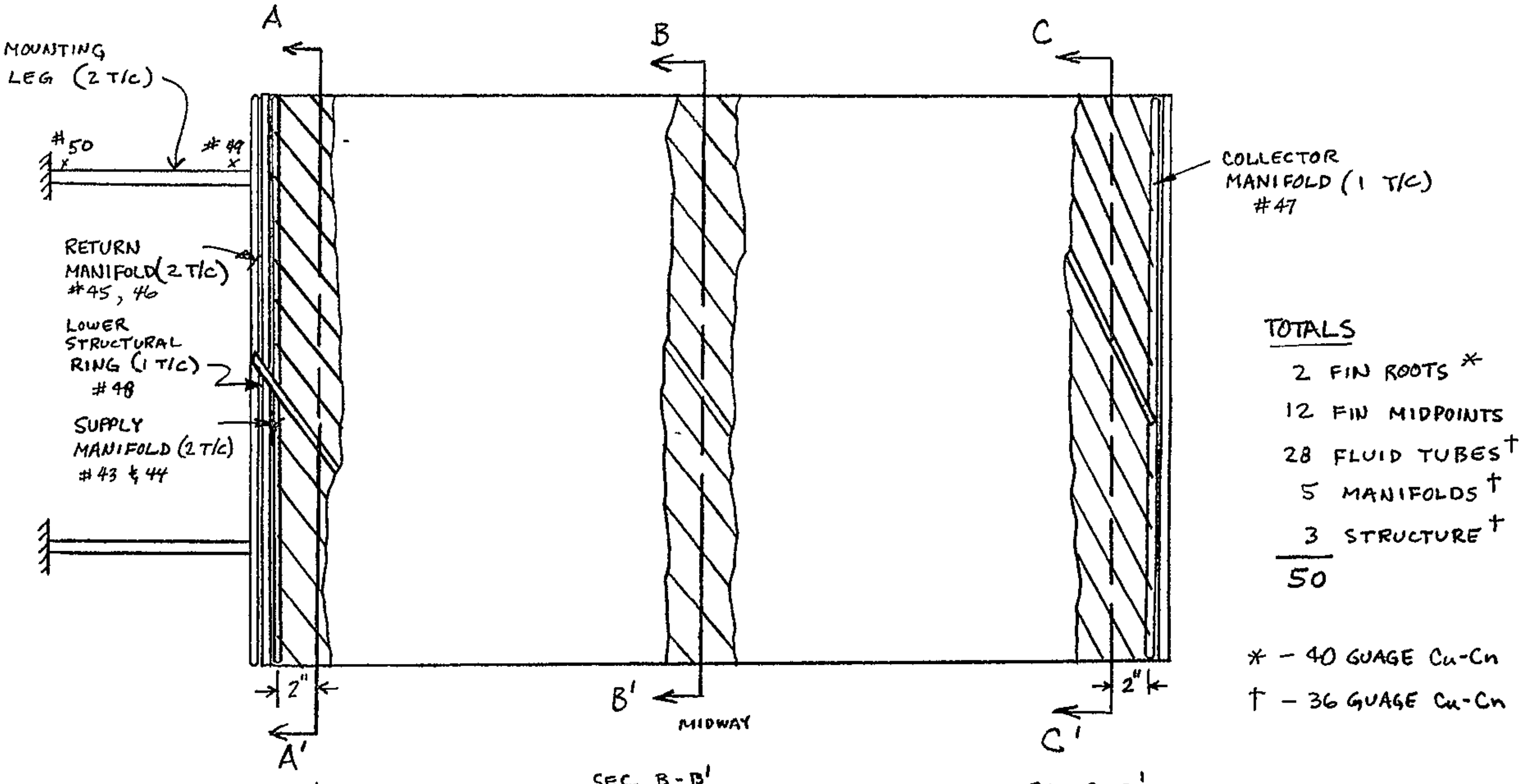
Other test article instrumentation included fluid inlet and outlet temperature and differential temperature, as specified in Figure 45 using the same instrumentation as previously used for element tests of Reference (7). Also, fluid inlet pressure and inlet-to-outlet delta-P should be measured at the test article fluid inlet/outlet.

Soft Tube Test Article Instrumentation

Figure 46 shows the 50 thermocouple locations on the soft tube article. The fin and tube thermocouples were laminated into the test article during fabrication, and are #40 guage Cu-Cn. The installation is like that of the square-foot soft tube test article, Reference (6). Thermocouple leads were made to run parallel to the tubes. Thermocouples attached to the manifolds and other metal structure were spot-welded and are #36 guage Cu-Cn. Fluid temperature and pressure instrumentation for the soft tube test article was the same as for the hard tube article.

Facility Instrumentation

The deployment box was instrumented with three thermocouples, one on the back (facing the supporting plate), one on the side, and one on the front (facing the test article). The existing shroud thermocouple instrumentation was used (17 T/C's). One thermocouple was attached to the structural supporting plate behind the deployment box which mounts the hard tube test article. For the soft tube tests a thermocouple was required on the -155 mounting bracket which attaches the test article manifold assembly to the support rails. In addition, one of the "inverted-V" deployment rails was instrumented about midway between the vertical cross braces.



TOTALS

2 FIN ROOTS *
12 FIN MIDPOINTS
28 FLUID TUBES †
5 MANIFOLDS †
3 STRUCTURE †
50

* – 40 GUAGE Cu-Cn
† – 36 GUAGE Cu-Cn

SEC A-A'

2 T/C ON 3/16" TUBES
2 T/C ON 3/8" TUBES
2 T/C ON FIN MIDPOINTS
2 T/C ON FINS NEAR ROOTS
8 T/C (#1 – #8)

SEC B-B'

6 T/C ON 3/16" TUBES
4 T/C ON FIN MIDPOINTS
10 T/C (#9 – #18)

SEC. C-C'

18 T/C ON 3/16" TUBES
6 T/C ON FIN MIDPOINTS
24 T/C (#19 – #42)

REF. DWG T213-SK04

FIGURE 43 HARD TUBE TEST ARTICLE INSTRUMENTATION SUMMARY

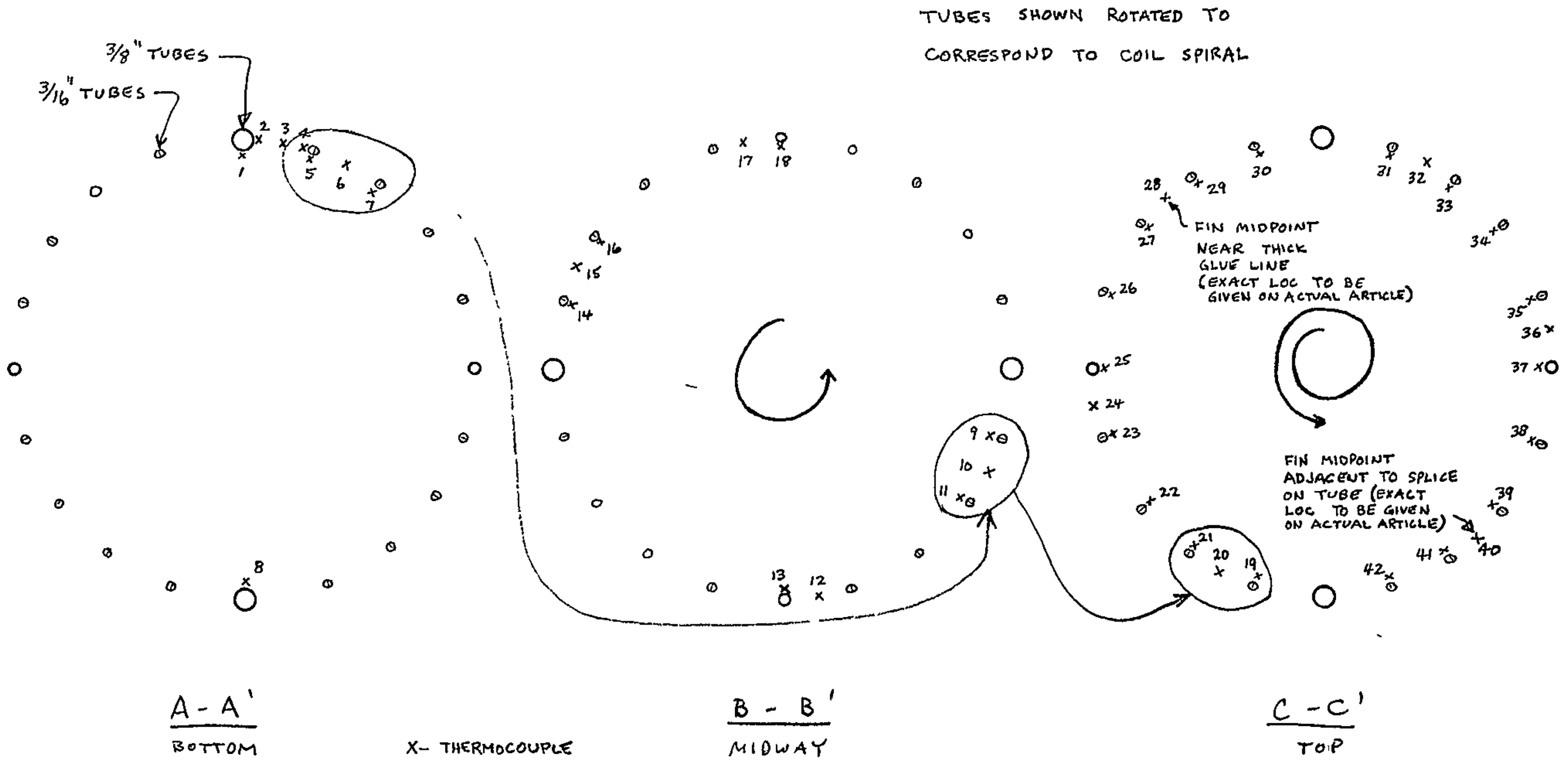


FIGURE 44 TUBE-FIN THERMOCOUPLE LOCATIONS

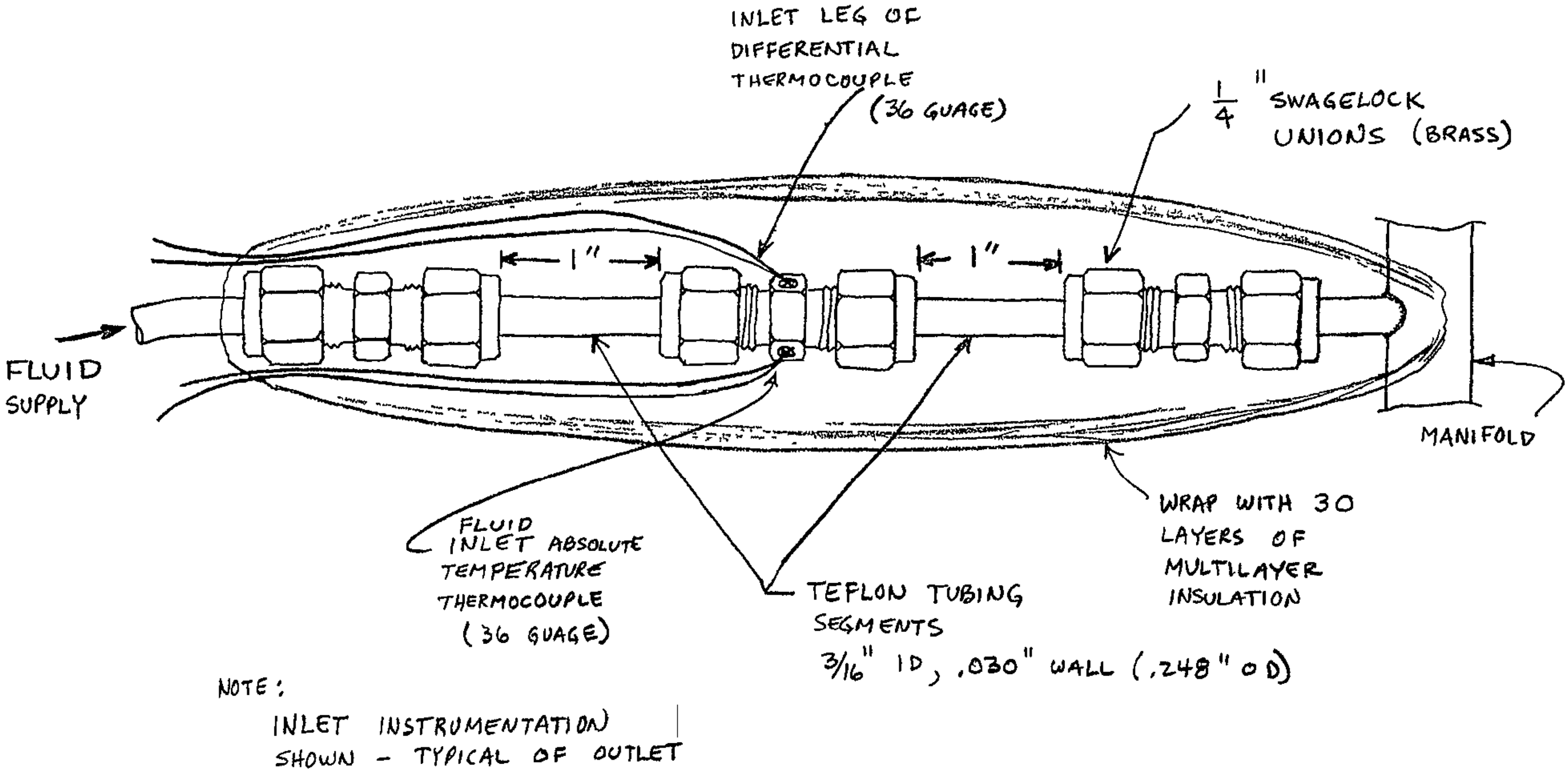


FIGURE 45 FLUID INLET AND OUTLET TEMPERATURE INSTRUMENTATION

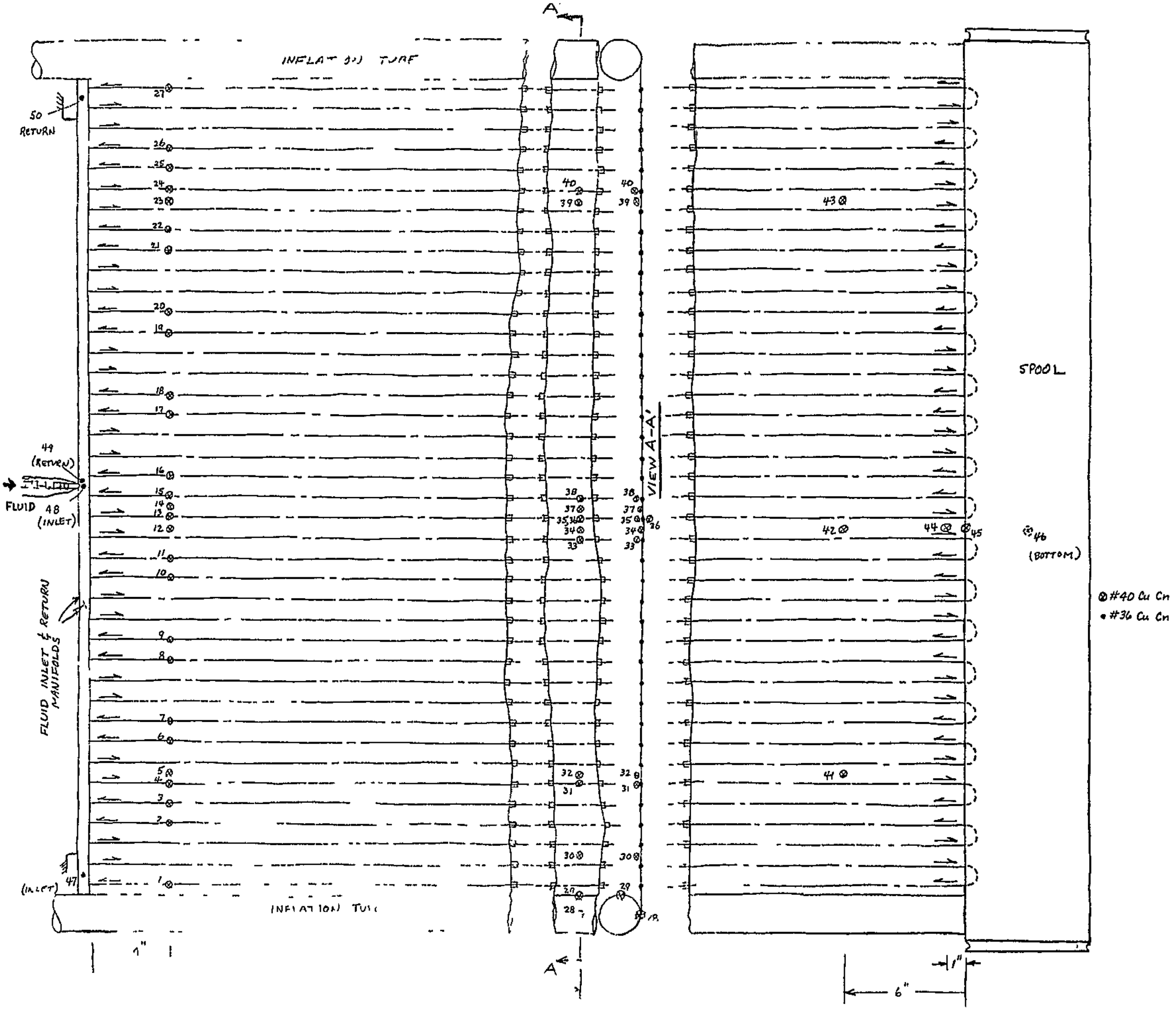


FIGURE 46 SOFT TUBE TEST ARTICLE INSTRUMENTATION

TABLE 18

DENSITY CORRECTION TO FLOWMETER READINGS

HARD TUBE RADIATOR

TEST POINT	TEMPERATURE AT FLOWMETER (°F)	FLUID DENSITY (lb/ft^3)	CORRECTION FACTOR ($\dot{W}$(ACTUAL) / $\dot{W}$(INDICATED))
1	106.6	83.0	0.967
2	113.6	82.4	0.960
3	50	87.5	1.020
6-A	92	84.1	0.980
6-B	91	84.2	0.981
6-C	91	84.2	0.981
6-D	91	84.2	0.981
7-B	99	83.5	0.973
8-A	106	82.9	0.966
8-B	112	82.5	0.960
7-A	123	81.5	0.949
7-C	87	84.4	0.983

SOFT TUBE RADIATOR

1	70.	55.6	1.00
2	72.	55.6	1.00
3	70	55.6	1.00
7-B	70	55.6	1.00
6-B	70	55.6	1.00
6-C	70	55.6	1.00
4	71	55.6	1.00
2-A	71	55.6	1.00

Existing facility instrumentation was used to measure the following.

Flowrate. 10-500 pph Freon 21 (Hard Tube)
15-125 pph Coolanol 15 (Soft Tube)
Fluid System Pressures
Fluid Delivery and Return Temperatures to Test Articles
Chamber Pressure
GN_2 Supply Temperature

Data Recording

Test article and facility data were recorded by hand on data sheets and selected data were relayed directly to a computerized data reduction system which stored the test data on magnetic tape and printed tabulated results at regular intervals. The printed output was relayed in real time by closed circuit television to a set at the flow bench. Fluid inlet and outlet absolute temperature and differential temperature using the thermally isolated Swagelock fitting arrangement were displayed on a digital voltmeter capable of reading to 0.001 mv. Both the test article and the fluid temperature indicators had a thermocouple running to an ice bath for a real-time check of accuracy. Flowmeter readings were corrected to account for fluid density variations with temperatures. Table 18 gives the correction factor for each test point.

Analysis of Test Environment

Figures 47 and 48 are approximate scale cross sections of the installations of the engineering model radiators in the test chamber. The figures show that the test environment consists of coldwalls, reflective aluminized mylar surfaces, and an open window. View factors from representative points on the two radiators to the environment surfaces are given in Figure 49. Analyses summarized in Figure 50 show that heat rejection is reduced by approximately 5% because of reflected radiation from the aluminized mylar and irradiation from the open window. Locally the heat rejection is reduced by about 9% near the base of the radiator, and by about 2% near the tip of the radiator.

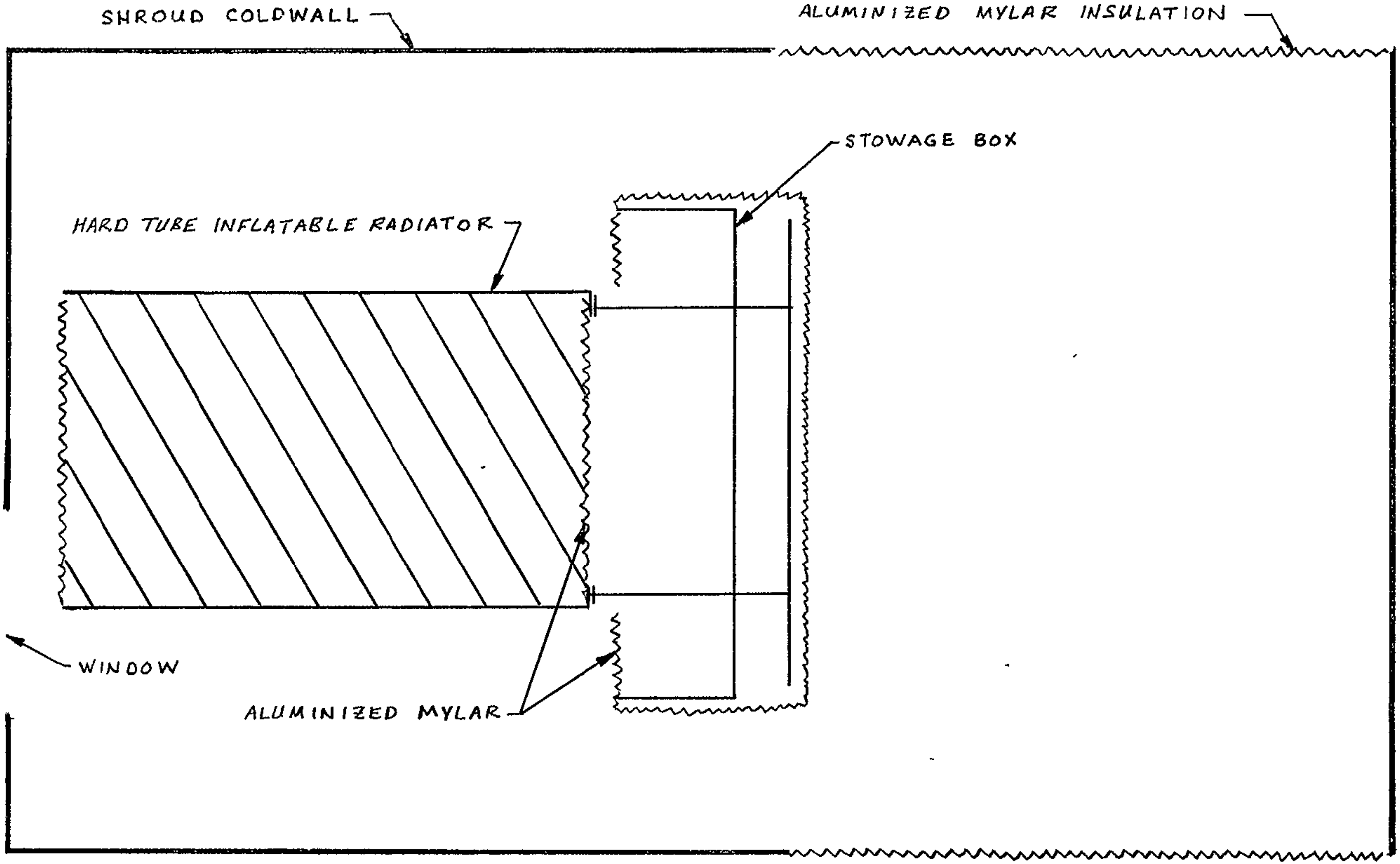


FIGURE 47

INSTALLATION OF HARD TUBE RADIATOR IN TEST CHAMBER

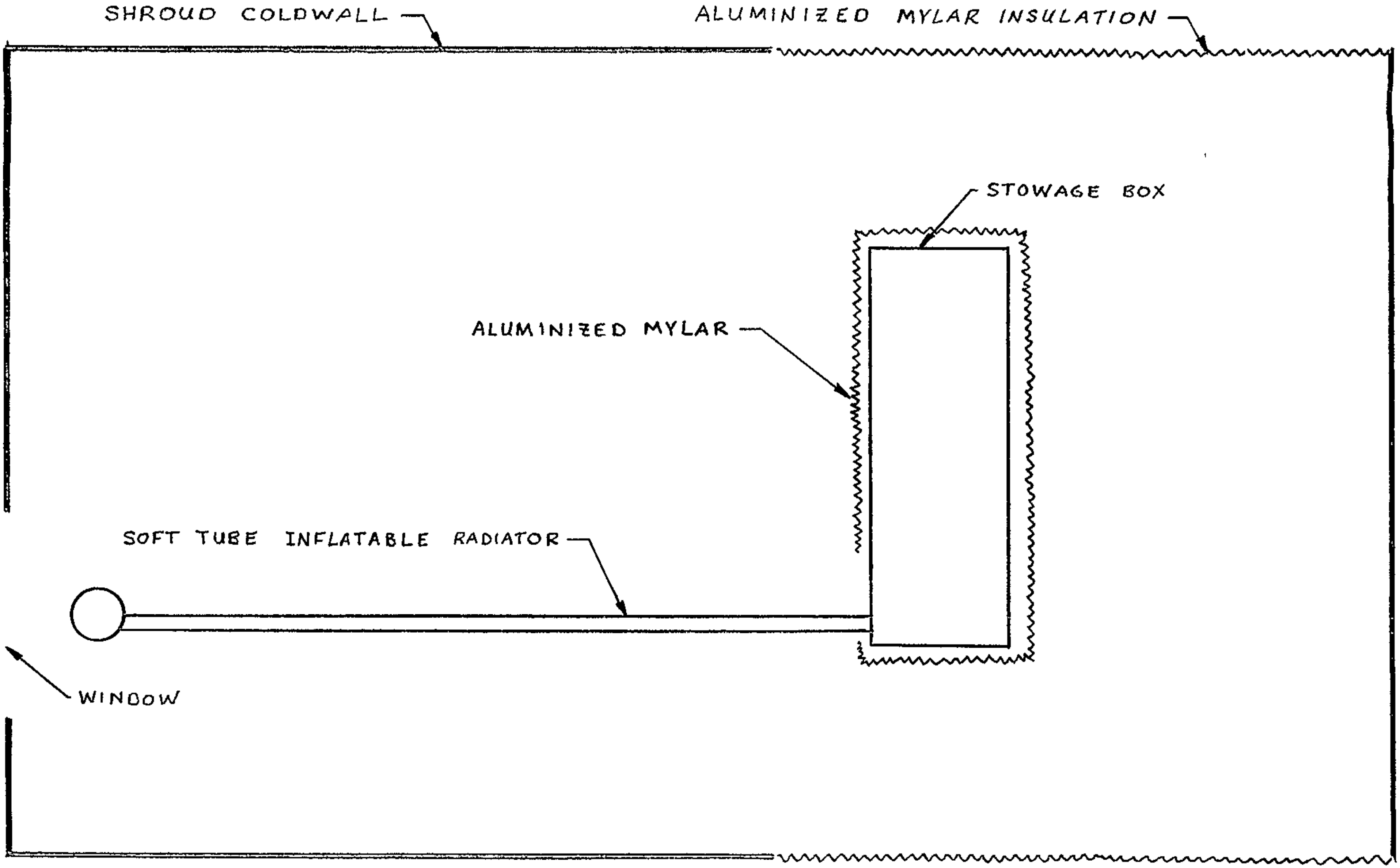
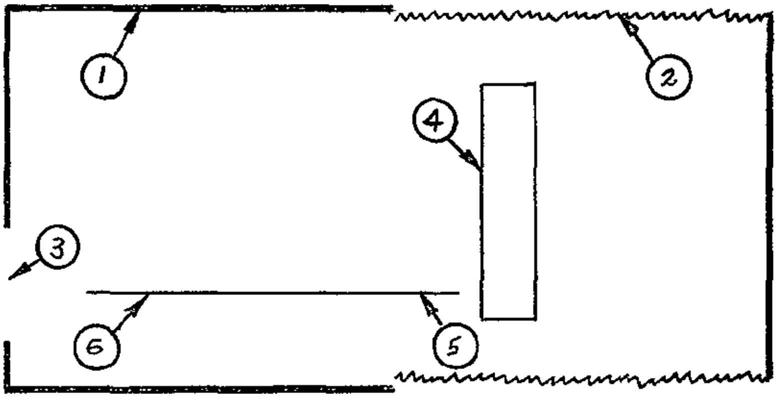


FIGURE 48

INSALLATION OF SOFT TUBE RADIATOR IN TEST CHAMBER



HARD TUBE RADIATOR	SOFT TUBE RADIATOR
$F_{5-4} = 0.182$	$F_{5-4} = 0.183$
$F_{5-3} = 0.020$	$F_{5-3} = 0.001$
$F_{5-2} = 0.079$	$F_{5-2} = 0.326$
$F_{5-1} = 0.719$	$F_{5-1} = 0.490$
$F_{6-4} = 0.090$	$F_{6-4} = 0.048$
$F_{6-3} = 0.061$	$F_{6-3} = 0.006$
$F_{6-2} = 0.076$	$F_{6-2} = 0.057$
$F_{6-1} = 0.774$	$F_{6-1} = 0.889$

FIGURE 49 SURFACE DEFINITION FOR TEST ENVIRONMENT ANALYSIS

FIGURE 50

ANALYSIS OF INFLATABLE RADIATOR TEST ENVIRONMENT

$$J_i = \epsilon_i E_{B_i} + \rho_i G_i$$

$$G_i = \Sigma F_{ij} J_j$$

$$(q/A)_i = J_i - G_i$$

$$(q/A)_R = \frac{\epsilon_R}{\epsilon_R + \rho_R (F_1 + F_3)} \left[E_{B_R} (F_1 + F_3) - F_1 E_{B_1} - F_3 E_{B_3} \right]$$

$$F_1 = F_{R-1} + \frac{F_{R-2} (F_{2-1} + F_{2-4} F_{4-1})}{1 - F_{2-2} - F_{2-4} F_{4-2}} \frac{+ F_{R-4} \left(F_{4-1} + \frac{F_{4-2} F_{2-1}}{1 - F_{2-2}} \right)}{1 - \frac{F_{4-2} F_{2-4}}{1 - F_{2-2}}}$$

$$F_3 = F_{R-3} + \frac{F_{R-2} (F_{2-3} + F_{2-4} F_{4-3})}{1 - F_{2-2} - F_{2-4} F_{4-2}} + \frac{F_{R-4} \left(F_{4-3} + \frac{F_{4-2} F_{2-3}}{1 - F_{2-2}} \right)}{1 - \frac{F_{4-2} F_{2-4}}{1 - F_{2-2}}}$$

$$E_{B_3} \approx E_{BR}$$

SOFT TUBE RADIATOR ($\epsilon \approx 0 67$)

Tip of radiator $\quad q/A = 0.976 \; \epsilon_R (E_{B_R} - E_{B_1})$

BASE of radiator $\quad q/A = 0.917 \; \epsilon_R (E_{B_R} - E_{B_1})$

HARD TUBE RADIATOR ($\epsilon \approx 0.84$)

TIP OF RADIATOR $\quad q/A = 0 98 \; \epsilon_R (E_{B_R} - E_{B_1})$

BASE OF RADIATOR $\quad q/A = 0 96 \; \epsilon_R (E_{B_R} - E_{B_1})$

Flow Calibration Tests

Prior to thermal vacuum testing the engineering model radiators were tested for uniformity of flow distribution by measuring the rate of flow in each individual tube. This was done by disconnecting the tubes from the outlet manifolds and flowing water through the radiator. The flowrates were determined by weighing the water collected during prescribed periods of time in glass beakers placed under each tube. The samples were collected simultaneously to eliminate the effects of small variations in total flow with time. Table 19 gives the percentage deviations from the mean flow per tube computed from data collected from several flow calibration tests of the two radiators. The results for the soft tube model show that tubes 1, 3, 7 and 13 have relatively low flow, and that tubes 4 and 16 have noticably higher flow than the remaining tubes. The low values of flow are probably caused by flow restrictions where the polyurethane tubing has been flattened or bent about a short radius. The two tubes with high flow apparently have fewer flow restrictions or larger diameters than the remaining tubes. Tubes 15 and 16 of the hard tube radiator have unusually high flow. This is believed to be a result of the diameters being slightly larger for these tubes than for the remaining tubes. There was no crimping of the aluminum which would create flow restrictions in the hard tube radiators,and the manifolds do not favor high flow in any of the tubes.

The flow distribution obtained for the models is sufficiently uniform for obtaining near optimum heat rejection. The nonuniformities that do occur in the engineering models are expected to be more severe than any which might occur in the full scale system. The reason is that the longer tubes of the prototype will induce frictional losses which are large in comparison to the more unpredictable minor losses associated with bends in the tubing.

Retraction Force For the Hard Tube Model

Force versus retraction distance. measurements were made for the hard tube engineering model to obtain data for sizing a retraction mechanism for future systems. The test article was supported by a rigid steel bar by means of a ball bearing, and was retracted horizontally to reduce friction and gravity forces. The data presented in Figure 51 shows a linear

TABLE 19

FLOW DISTRIBUTION TEST RESULTS

HARD TUBE RADIATOR

TUBE NO.	DEV FROM AVG FLOW (%)
1	-1.2
2	-1.4
3	-2.1
4	-0.5
5	0
6	-3.3
7	-2.3
8	0
9	-1.2
10	-3.7
11	-1.5
12	-0.1
13	1.1
14	-1.5
15	10.8
16	11.7
17	-2.7
18	0.3

RMS = 4.1

SOFT TUBE RADIATOR

TUBE NO.	DEV. FROM AVG FLOW (%)
1	-6.2
2	-2.4
3	-8.8
4	8.8
5	-0.2
6	2.8
7	-8 3
8	0 6
9	-0.2
10	-2 6
11	4.5
12	5.1
13	-9.0
14	3.8
15	-0.4
16	6.6
17	-0.9
18	2.8
19	2.8
20	1.7

RMS = 4.9

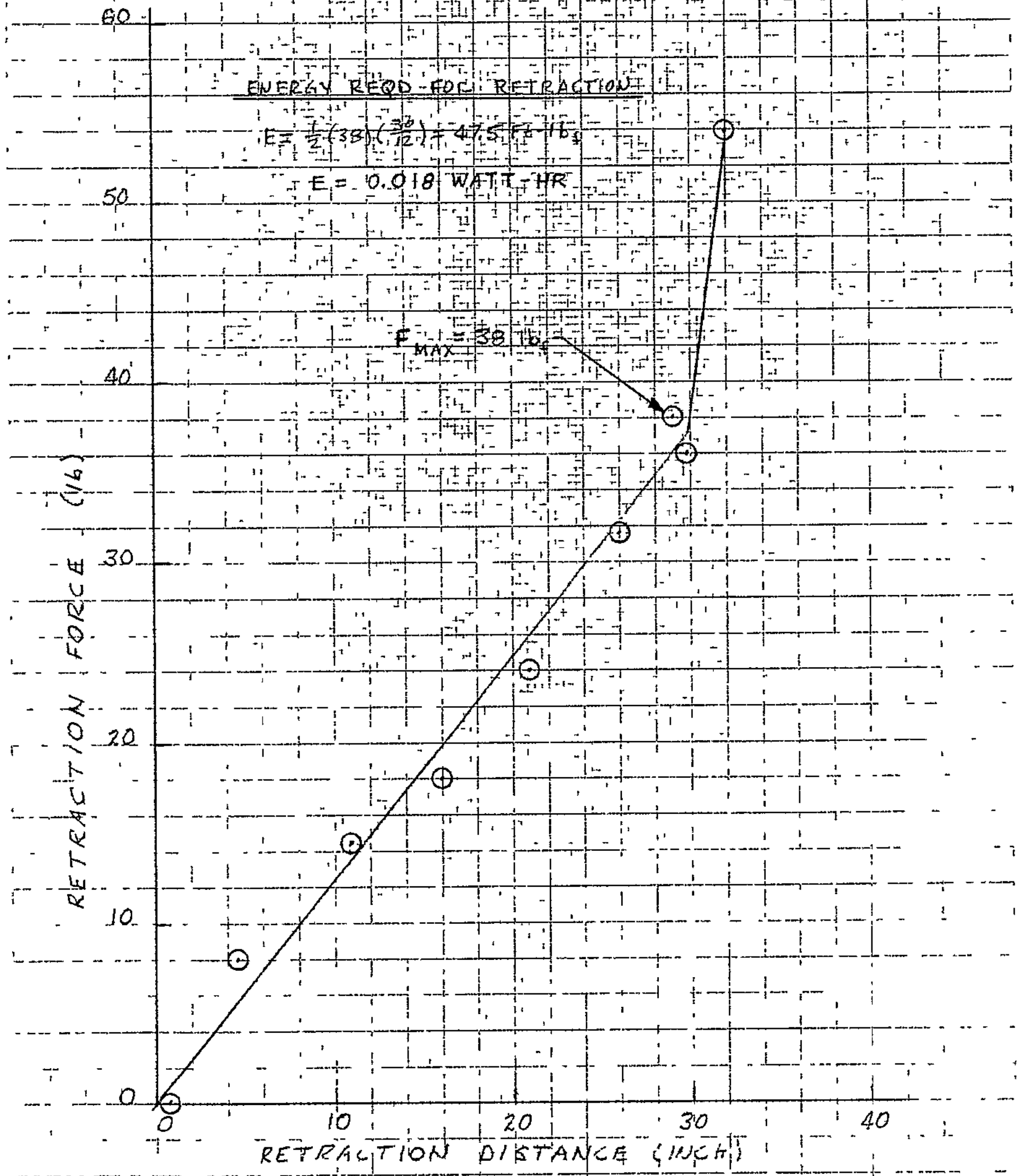


FIGURE 51

HARD TUBE INFLATABLE RADIATOR DEPLOYMENT DATA relationship between retraction force and displacement for the first 30 inches (67% of the radiator length). At this point the radiator fin material begins to interfer with the motion of the tubing and the force required for additional retraction increases rapidly. It is expected that some damage would occur to the fin material if the radiator were compressed far beyond the linear region.

3.6.4 Thermal Vacuum Test Results

Table 20 summarizes the test conditions and radiator performance in terms of heat rejection for the thermal vacuum test. More detailed information and analyses of the data are provided below. The heat rejection data in Table 20 shows that the radiator performance did not degrade as a result of the test. Test point 7-C for the hard tube radiator has nearly the same inlet temperature, ambient temperature, and flow rate as test point 1, but was executed at the end of the test whereas test point 1 occurred at the beginning of the test. The heat rejection for the two points is essentially the same. Also, test points 7-B, 8-A, and 8-B which show the effects of repeated deployment and retraction on radiator performance indicates no degradation in heat rejection. Similarly, test points 2 and 2-A for the soft tube radiator which were executed at the beginning and ending of the test respectively have approximately equal values of heat rejection.

Test points 6-A, 6-B, 6-C, and 6-D for the hard tube model, and test points 7-B, 6-B, and 6-C for the soft tube model give heat rejection for partially deployed radiator configurations. The results are plotted in Figures 51 and 52. The relationship between heat rejection and extent of deployment is not linear because the average radiator temperature decreases as the radiator is deployed at constant flowrate. Also the average radiator fin efficiency is a minimum when the panels are fully deployed.

Analysis of Hard Tube Model Test Results

SINDA computer models were constructed which account for all forms of thermal interactions between the various components of the engineering model and the walls of the environment simulation shroud. The computer model of the hard tube test article given in Appendix D predicts the radiator performance with great accuracy. Table 21 compares the experimental and

TABLE 20

SUMMARY OF THERMAL VACUUM TEST RESULTS

HARD TUBE RADIATOR

TEST POINT	T_{IN} (°F)	T_{OUT} (°F)	T_{∞} (°F)	$\dot{w}$ (lb/hr)	RADIATOR CONFIGURATION	q (BTU/hr)
1	96.3	37.6	-311	164.2	FULLY DEPLOYED	2410
2	946	34 8	-20	62.1	FULLY DEPLOYED	925
3	704	62 3	0	516.9	"	1047
4	160	~	~	~	"	~
6-A	94.1	37 1	-311	168.2	"	2397
6-B	94 1	51.8	-311	159.5	HALF DEPLOYED	1707
6-C	93.7	76 1	-311	167 8	FULLY RETRACTED	750
6-D	93 7	38 5	-311	161.5	FULLY DEPLOYED	2229
7-B	91 1	21 7	-40	60.6	"	1039
8-A	91 1	16.9	-40	59 5	"	1090
8-B	916	207	-40	61.0	"	1068
7-A	605	-104 2	-311	14 2	"	~
7-C	93.7	37 1	-311	175.0	"	2476

SOFT TUBE RADIATOR

TEST POINT	T_{IN} (°F)	T_{OUT} (°F)	T_{∞} (°F)	$\dot{w}$ (lb/hr)	RADIATOR CONFIGURATION	q (BTU/hr)
1-B	95.0	36.2	-311	63.2	FULLY DEPLOYED	1607
2	92.4	31.5	0	24 1	"	624
3	97 2	78 8	0	141 4	"	1147
7-B	90.7	10.2	-30	22 6	"	773
6-B	91.1	21 2	-30	23.2	HALF DEPLOYED	689
6-C	90.7	52 3	-30	23 3	FULLY RETRACTED	389
4	159.2	44.5	0	23.2	FULLY DEPLOYED	1184
2-A	95.0	30 6	0	23 8	"	659

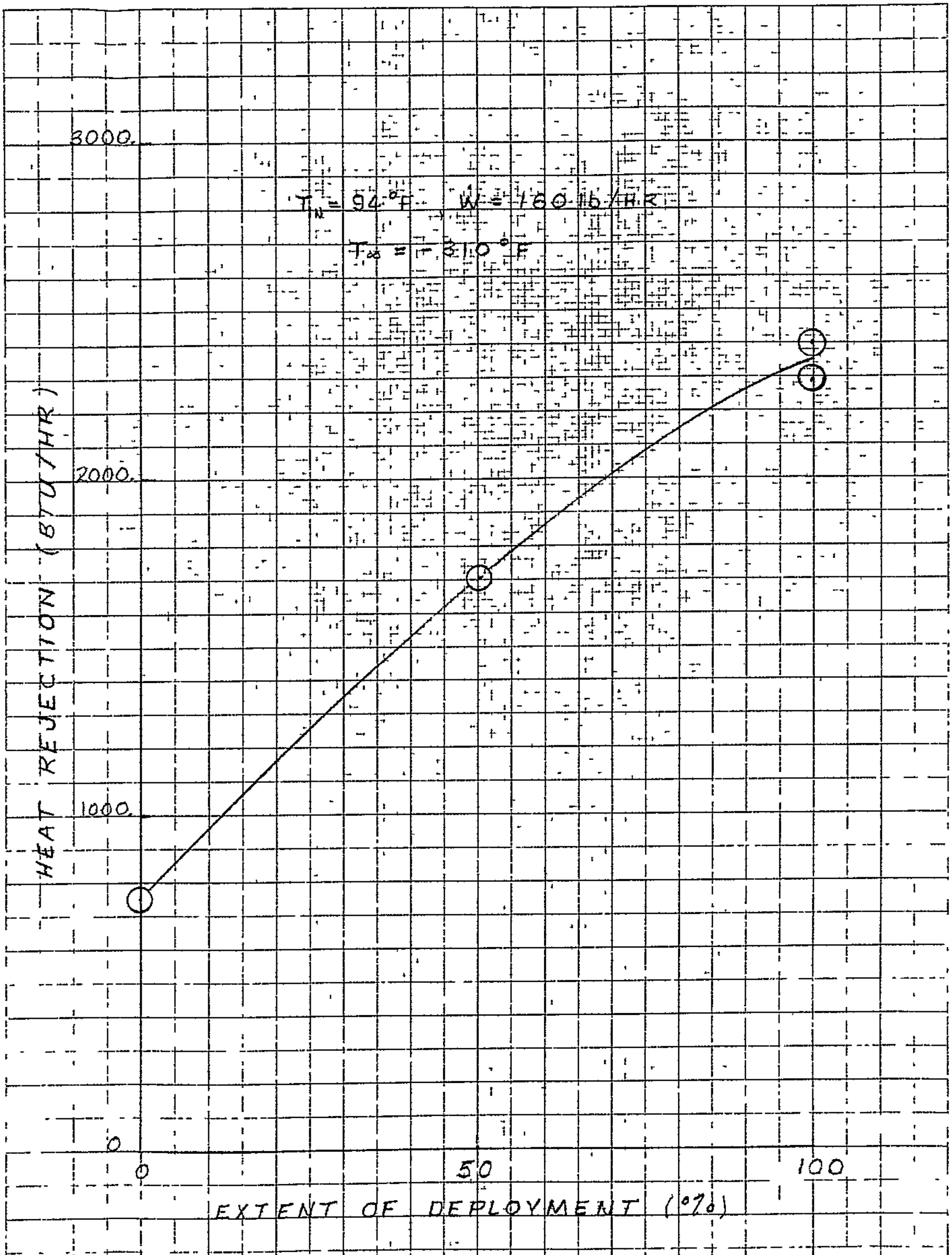


FIGURE 52 HEAT REJECTION FOR HARD TUBE MODEL

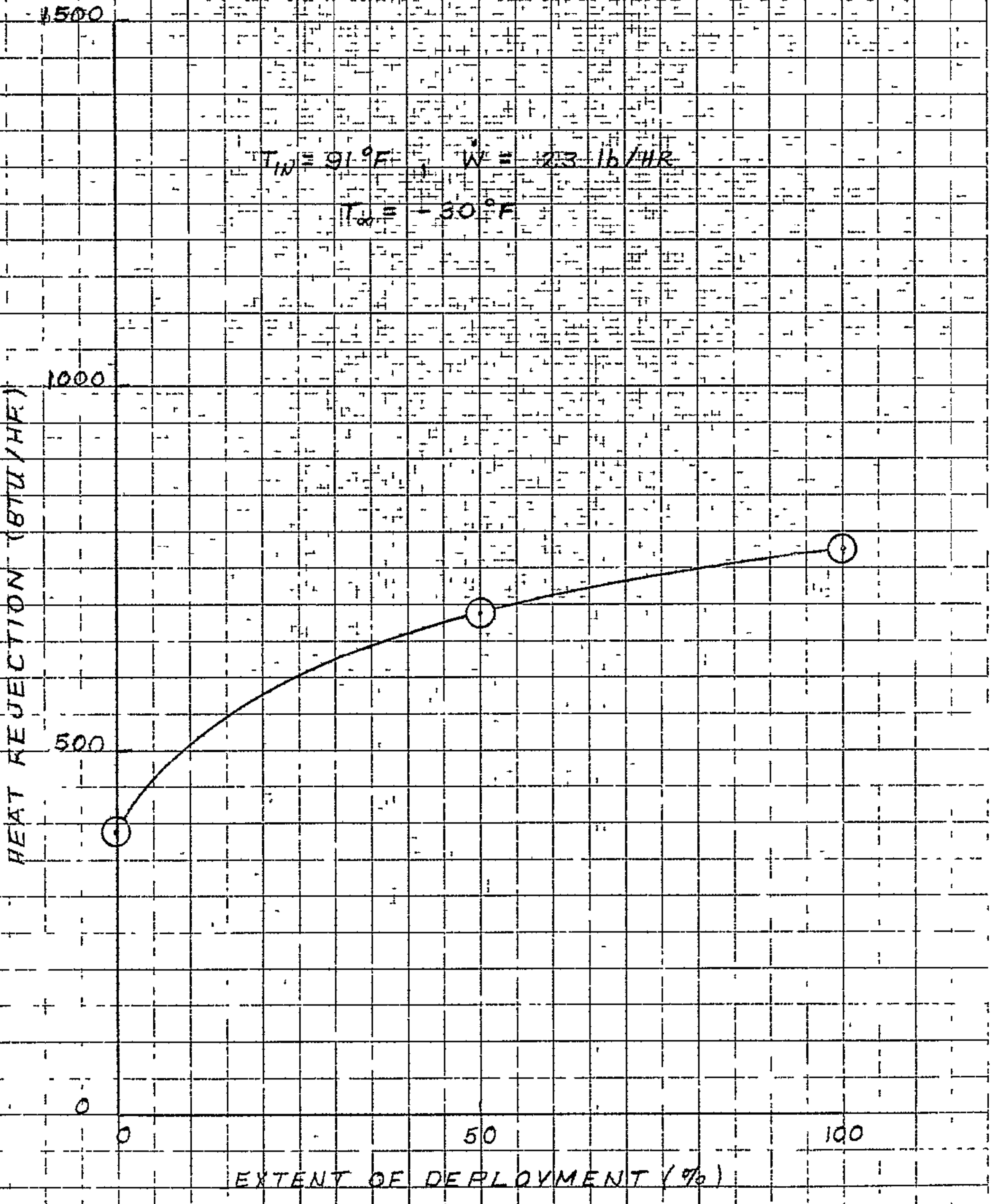


FIGURE 53. HEAT REJECTION FOR SOFT TUBE MODEL

predicted heat rejection and outlet temperatures for cold (-311°F) and warm (-20°F) environments. The results for the cold environment agree almost exactly, and the results for the warm environment agree within what is believed to be experimental error. The small discrepancy for the warm environment is probably caused by inconsistent control or modeling of the cold walls. It is difficult to maintain the environment walls at steady uniform temperatures. At the higher ambient temperatures small variations in the coldwall temperatures have a large effect on the heat rejection from the radiator. Thus any error in modeling or maintaining the environment would be reflected in the test results. For cold ambient temperatures errors in representing the environment have less impact on the radiator performance and the predicted performance depends more on the modeling of the radiator itself. The fact that the experimental and predicted performance agrees for this case indicates that the actual radiator construction and thermal properties are near the design values.

TABLE 21

COMPARISON OF EXPERIMENTAL AND PREDICTED THERMAL PERFORMANCE OF THE HARD TUBE TEST ARTICLE

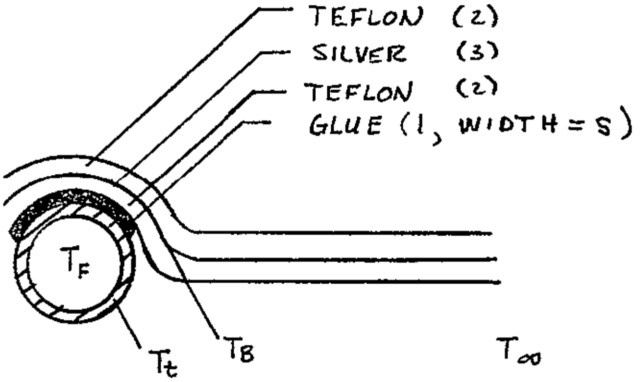
TEST POINT	T_{IN} (°F)	$\dot{W}$ (LB/HR)	T_∞ (°F)	T_{OUT}(EXP) (°F)	T_{OUT}(PRED) (°F)	Q(EXP) (BTU/HR)	Q(PRED) (BTU/HR)
1	96.3	164.2	-311	37.6	37.6	2410	2410
2	94.6	62.1	-20	34.8	28.6	925	1044

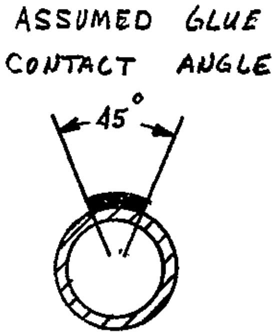
One area of uncertainty in the construction of the hard tube radiator concerns the thermal contact between the tubes and the radiator fins. The fins are glued to the tubes in such a way that it is difficult to predict the exact value of the joint conductance. Figure 54 shows that the contact resistance acts in series with a resistance associated with convection inside the tubing and a resistance associated with radiation from the fins. The values of the series connected resistors are plotted versus the temperature at the base of the radiator fin in Figure 55. For temperatures in the range of the thermal vacuum test the contact resistance

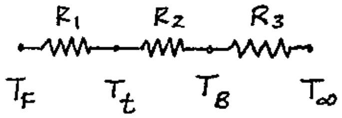
FIGURE 54

THERMAL RESISTANCE IN THE HARD TUBE

INFLATABLE RADIATOR







$$R_1 = \frac{2}{\pi K Nu} = \frac{2}{\pi(.059)(4)} = 2{,}696 \ \frac{\text{Ft-°F-HR}}{\text{BTU}}$$

$$R_2 = \frac{2}{\eta U S} = \frac{2}{(0.825)(4784)(\ 00412)} = 0.828 \ \frac{\text{Ft-°F-HR}}{\text{BTU}}$$

$$\eta = \frac{\tanh(m\frac{S}{2})}{(m\,S/2)}$$

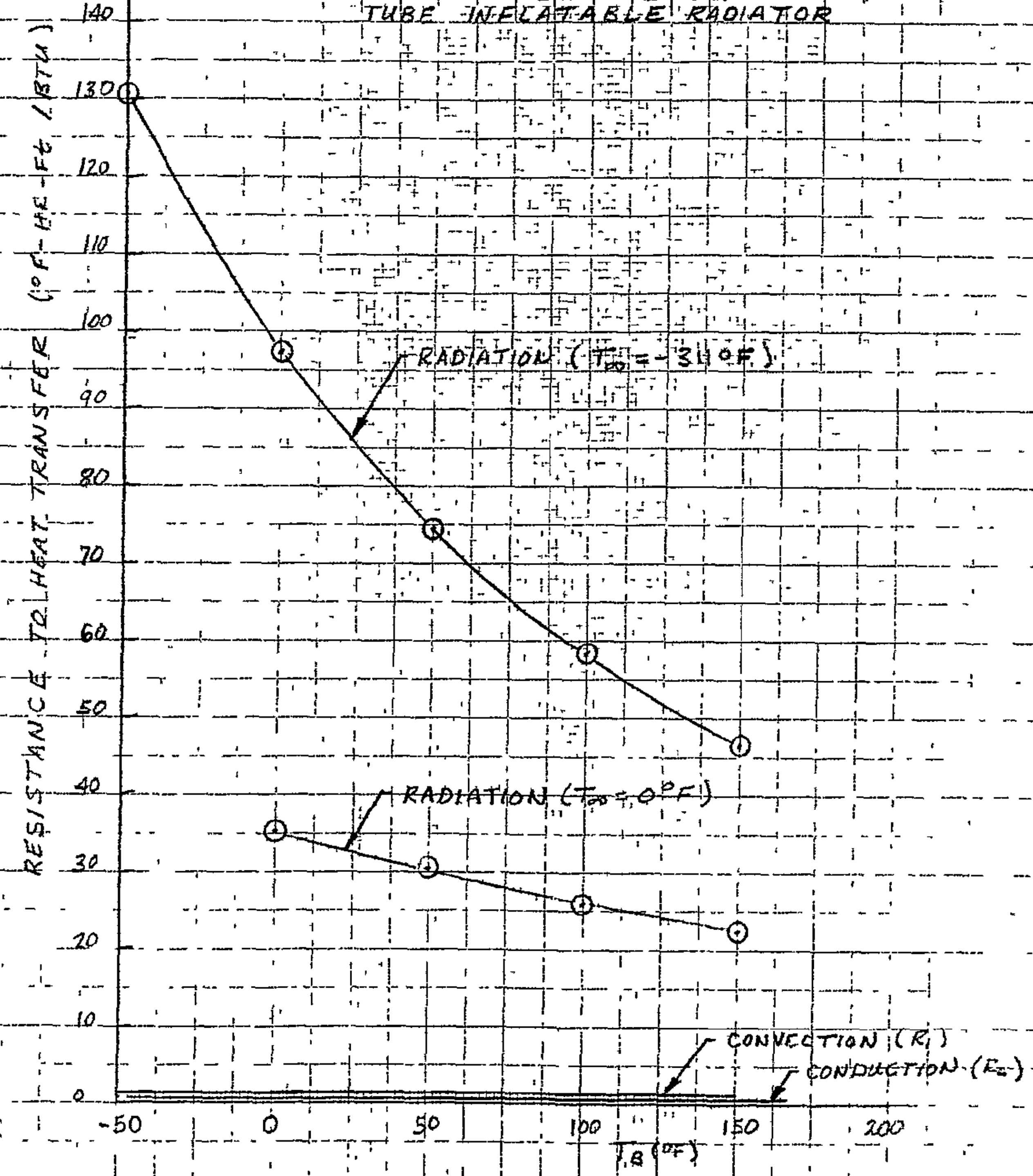
$$m\frac{S}{2} = \sqrt{\frac{S^2}{4(\delta_1/K_1 + \delta_2/K_2)(K_1\delta_1 + 2K_2\delta_2 + N K_3 \pi D^2/4)}}$$

$$U = 1./(\delta_1/K_1 + \delta_2/K_2)$$

$$R_3 = \frac{1}{\eta_f \epsilon \sigma \left(\frac{W}{2}\right)(T_B^2 + T_\infty^2)(T_B + T_\infty)}$$

FIGURE 55

THERMAL RESISTANCE IN THE HARD TUBE INFLATABLE RADIATOR



is a small part of the total so that it has a relatively small effect on the heat transfer from the radiator. Figure 56 shows that if the contact resistance is four times as large as expected the heat rejection is reduced by approximately 10%. Averaged values of the contact resistance determined from thermocouple readings for test points 1 and 2 are given in Figure 57. The results which are sensitive to experimental error indicate that the actual contact resistance is less than is predicted based on a glue contact angle of 45°, as shown in Figure 54. Typical comparisons between predicted and experimental temperatures for the hard tube test article are given in Figures 58 and 59.

Additional test data for the hard tube engineering model are given in Appendix E . All of the test results indicate that the test article performed almost exactly as had been expected.

Analysis of Soft Tube Model Test Results

The SINDA computer model for the soft tube test article is given in Appendix E. Unlike the hard tube model, the soft tube radiator did not reject heat at the predicted rate. Table 22 shows that the experimental heat rejection is approximately 25% lower than predicted.

TABLE 22

COMPARISON OF EXPERIMENTAL AND PREDICTED THERMAL PERFORMANCE OF THE SOFT TUBE TEST ARTICLE

TEST POINT	T_{IN} (°F)	T_{OUT} (°F)	T_∞ (°F)	$\dot{w}$(EXP) (LB/HR)	$\dot{w}$(PRED) (LB/HR)	Q(EXP) (BTU/HR)	Q(PRED) (BTU/HR)
1-B	95	36.2	-311	63.2	86.0	1607	2219
2	92.4	31.5	0	24.1	31.2	624	781

The low thermal performance of the soft tube test article is believed to be caused by nonuniformities in the thickness of the silver conducting layer in the radiator fin. Table 23 compares the expected and measured silver layer thickness of seven samples taken from the fin stock used to construct the soft tube test article.

FIGURE 56

SENSITIVITY OF HEAT TRANSFER TO THE JOINT CONDUCTANCE AT THE FIN-TUBE INTERFACE

$$q' = \eta \epsilon \sigma \frac{W}{2} (T_B^4 - T_\infty^4)$$

$$q'(R+\Delta R) = \eta \epsilon \sigma \frac{W}{2} \left[(T_B - \Delta T_B)^4 - T_\infty^4 \right]$$

$$\frac{\Delta q'}{q'} = \frac{(T_B - \Delta T_B)^4 - T_B^4}{T_B^4 - T_\infty^4}$$

$$\frac{\Delta T_B}{T_F - T_\infty} = \frac{\Delta R_2}{R_1 + R_2 + R_3}$$

$$\frac{\Delta q'}{q'} = \frac{\left[T_B - \frac{\Delta R_2}{R_1+R_2+R_3}(T_F - T_\infty) \right]^4 - T_B^4}{T_B^4 - T_\infty^4}$$

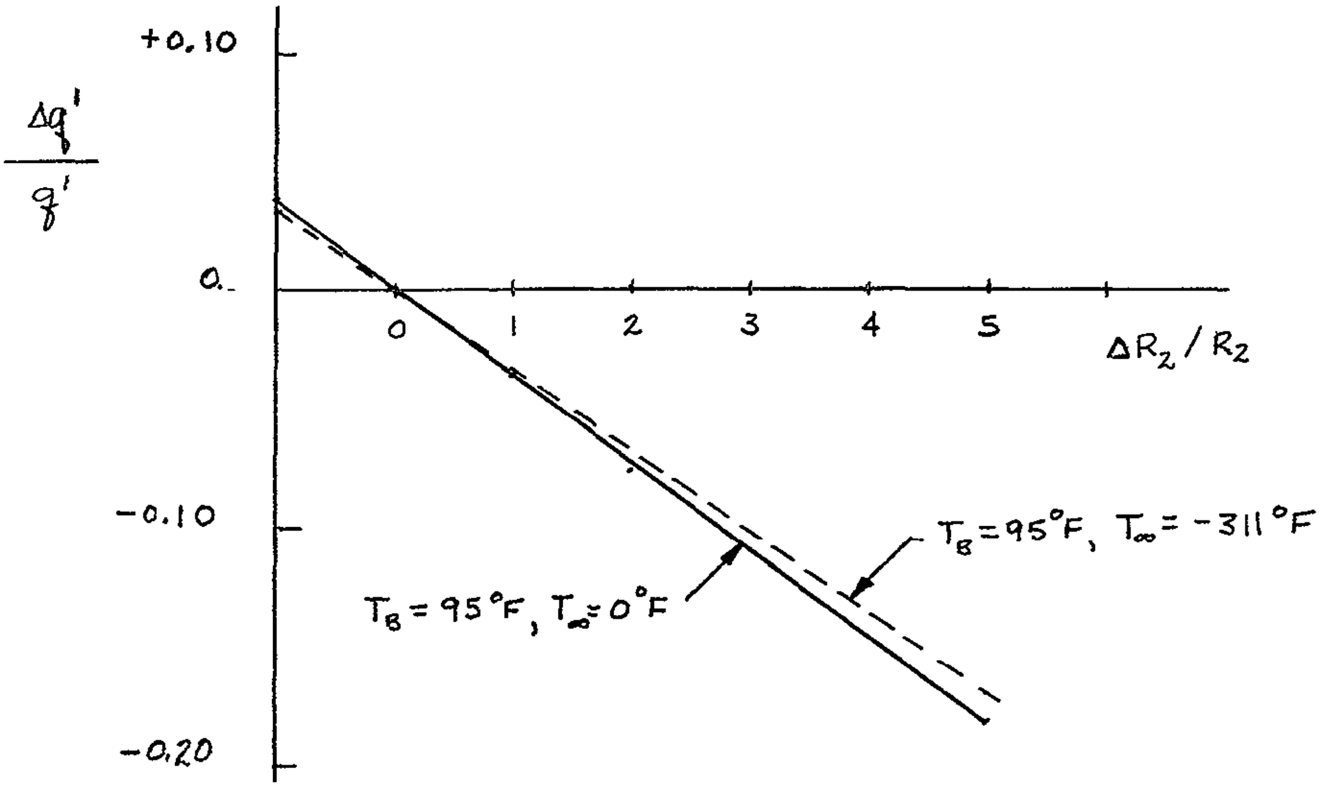


FIGURE 57

EXPERIMENTAL TUBE - FIN CONTACT CONDUCTANCE IN THE HARD TUBE INFLATABLE RADIATOR

$$R = \frac{q'}{T_{TUBE} - T_{BASE}} \sim \frac{\dot{m} c_p (T_{IN} - T_{OUT})}{\ell (T_{TUBE} - T_{BASE})}$$

$$-K\delta \left(\frac{\partial T}{\partial x} \right)_{BASE} = \int_0^{W/2} \epsilon \sigma (T^4 - T_\infty^4)\, dx$$

$$T \approx a + bx + cx^2 + \cdots$$

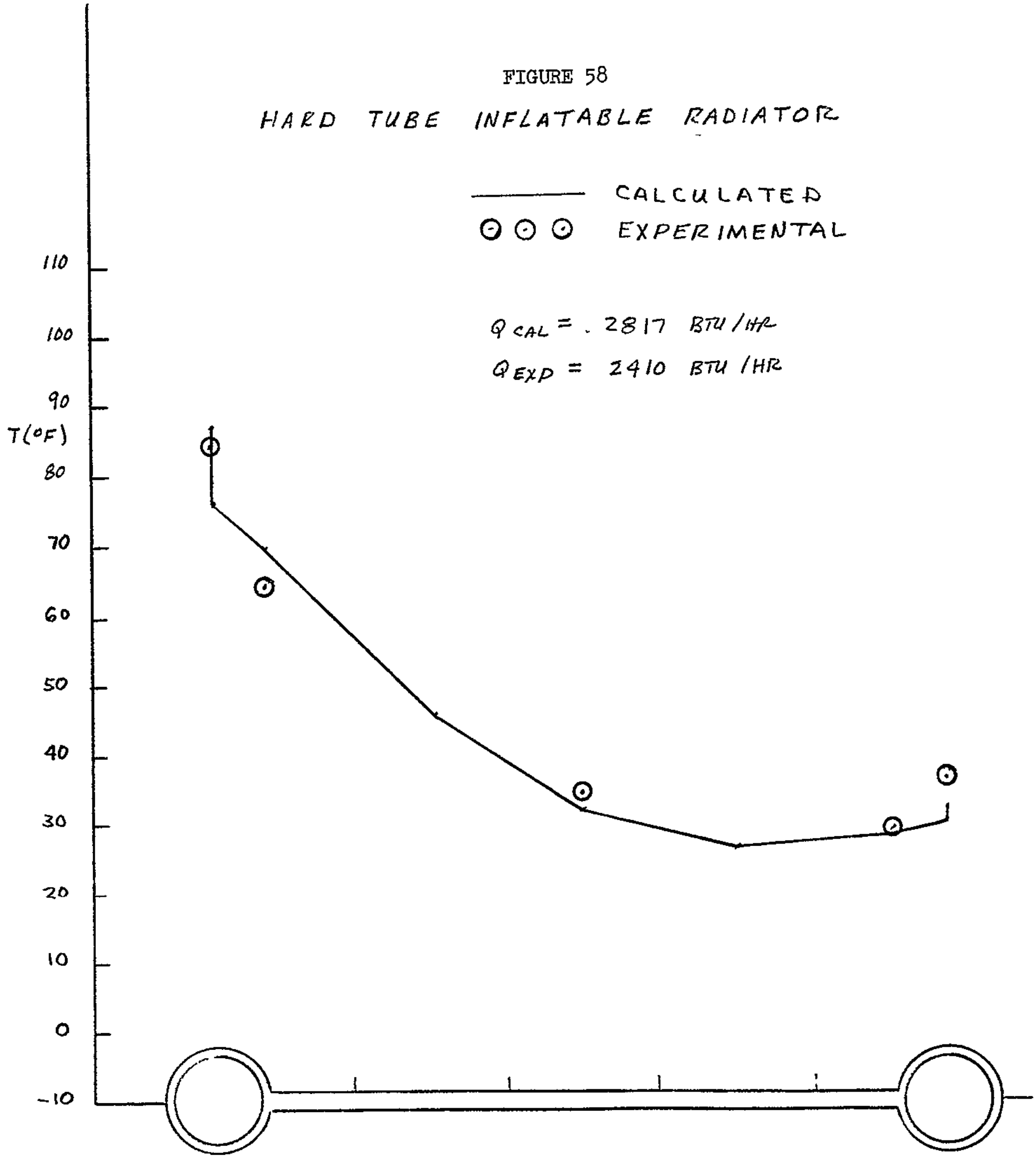
$$T_{BASE} = T_{\substack{MID\\POINT}} + \frac{(T_{MP}^4 - T_\infty^4)}{\frac{8K\delta}{\epsilon\sigma W^2} - \frac{4}{3} T_{M.P.}^3} + \cdots$$

THERMOCOUPLE PAIRS	TEST Pt 2, $q' = 4.7 \frac{BTU}{hr\text{-}Ft}$				TEST Pt 1, $q' = 12.1 \frac{BTU}{hr\text{-}Ft}$			
	T_{TUBE}	$T_{M,P}$	T_{BASE}	R_2	T_{TUBE}	T_{MP}	T_{BASE}	R_2
5-6	83.7	57.8	72	2.5	84.1	41.3	68	1.3
10-11	54.6	41.3	52	0.6	61.4	32.0	57	0.4
12-13	54.1	39.0	51	0.7	63.2	26.8	50	1.1
14-15	51.8	41.8	53.5	-0.4	65.0	39.5	63	.2
15-16	51.8	41.8	53.5	-0.4	61.4	39.5	68	-.3
17-18	49.1	40.9	53	-0.8	58.2	34.8	61	-.6
23-24	36.2	27.8	36	0.1	39.9	13.6	35	.4
24-25	36.7	27.8	36	0.2	40.4	13.6	35	.4
27-28	36.7	21.7	28	1.9	40.9	-6.3	12.5	2.4
28-29	34.8	21.7	28	1.5	39.0	-6.3	12.5	2.2
31-32	32.4	25.9	34	-0.3	39.9	16.5	37	.2
32-33	33.4	25.9	34	-0.1	39.9	16.5	37	.2
35-36	36.2	26.4	35	0.3	45.9	16.9	37.5	.7
36-37	32.4	26.4	35	-0.6	39.5	16.9	37.5	.2
39-40	32.9	24.5	32.5	0.1	39.9	12.1	31	.7
40-41	33.4	24.5	32.5	0.2	40.4	12.1	31	.8
				0.32 °F-Ft-HR/BTU				0.64 °F-Ft-Hr/BTU

PREDICTED = 0.83 °F-Ft-Hr/BTU

FIGURE 58

HARD TUBE INFLATABLE RADIATOR



Q_{CAL} = 2817 BTU/HR

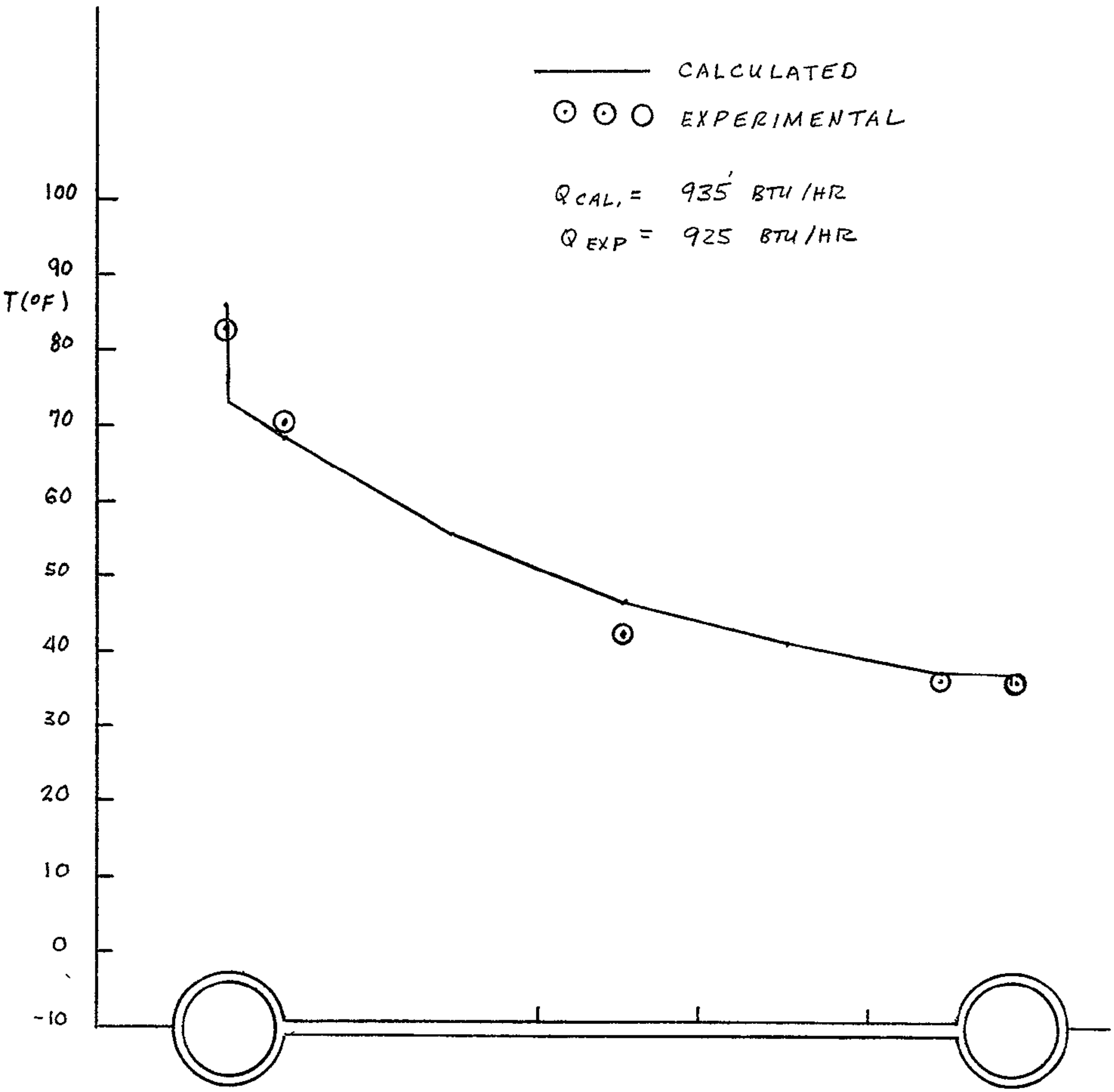
Q_{EXP} = 2410 BTU/HR

COMPARISON OF PREDICTED AND EXPERIMENTAL

TEMPERATURES FOR TEST POINT 1

FIGURE 59

HARD TUBE INFLATABLE RADIATOR



COMPARISON OF PREDICTED AND EXPERIMENTAL TEMPERATURES FOR TEST POINT 2

TABLE 23

SAMPLE-MEASUREMENTS OF SILVER LAYER THICKNESS FOR THE SOFT TUBE TEST ARTICLE

SAMPLE NO.	MEASURED THICKNESS (Å)	EXPECTED THICKNESS (Å)
2604	10,000	12,500
2613	10,000	12,500
2614	5,000	12,500
2610	5,000	12,500
2617	18,000	12,500
2591	9,000	12,500
2528C	11,000	12,500

The sample thicknesses were measured with a scanning electron microscope, and were selected randomly from the seven sheets of fin stock used to construct the soft tube test article. Since the measured thicknesses are much lower than they were designed to be, the radiator would not reject heat at the expected rates. Table 24 compares the fin efficiencies that would result from the silver film thicknesses of Table 23.

TABLE 24

APPROXIMATE FIN EFFICIENCY FOR MEASURED SOFT TUBE RADIATOR FILM THICKNESSES

FILM THICKNESS (Å)	FIN EFFICIENCY (%)
10,000	78
5,000	51
18,000	92
9,000	75
11,000	81

The average fin efficiency from Table 24 is 0.72. This is approximately 15% lower than the expected value of 0.85. The measured heat rejection in Table 22 is also low because the flow rate was lowered during the test to obtain the required outlet temperature. Because of the low flow, the temperatures are lower than predicted at the end of the radiator opposite to the inlet and outlet manifolds, and the emissive power of the radiator is reduced. Figure 60 compares the predicted and experimental temperatures at various locations on the panel for test point 1-B. The results show that the experimental temperatures agree with the theoretical temperatures near the inlet and outlet manifolds, but are about 15°F lower than predicted at the opposite end of the panel.

The radiator fin efficiency has the largest impact of any of the unknowns in the panel construction on heat rejection. Figures 61 and 62 show that the thermal resistance associated with radiation from the fin is much larger than the resistances from other sources. Thus it is likely that the cause of the reduced performance is reflected in this term. The two radiator fin properties which appear in R3 are the surface emissivity and the conductance of the fin material. Separate measurements made by NASA/JSC showed that the surface emissivity is actually slightly higher than expected. Therefore the thickness of the silver film is the most likely source of error.

Figures 63 and 64 compare predicted and experimental temperatures near the manifolds of the soft tube test article. The errors are not large, thus confirming that the thermal resistances are near the expected values.

The tubes of the soft tube radiator are raised so that the actual radiating area is 7.4% larger than the projected area of the panel. However, because the tubes block radiation from the fins and do not have a full view of the environment, the emissive power is not increased by this amount. Figure 62 summarizes an analysis of the non-planar surface which shows that the emitted radiation is increased by only 0.2%.

A flow instability occurred during the cold soak of the soft tube test article which has since been shown to be predictable from the viscosity versus temperature characteristics of Coolanol 15. Figure 66 shows a profile of the outlet temperatures measured during the cold soak. The figure shows

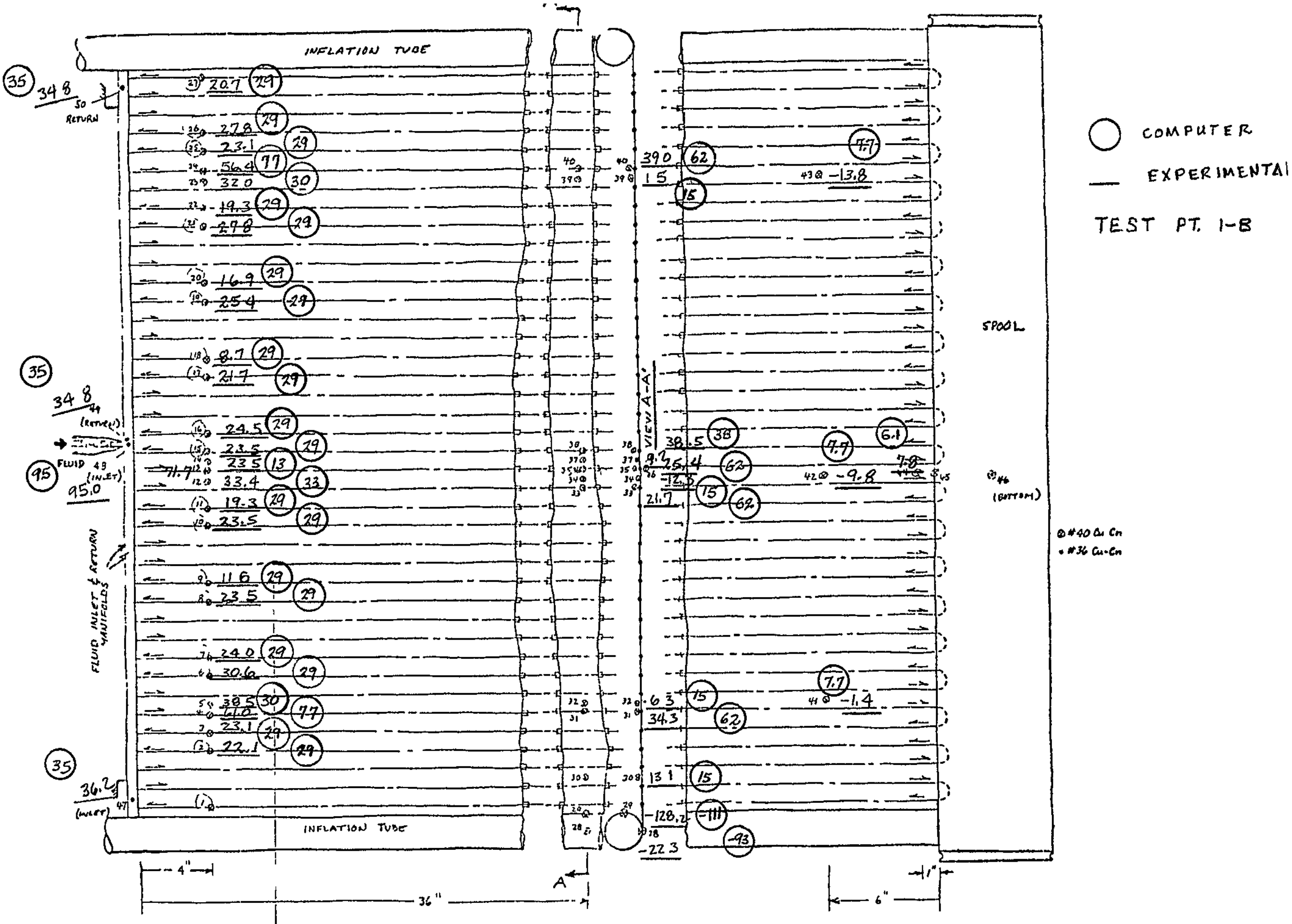
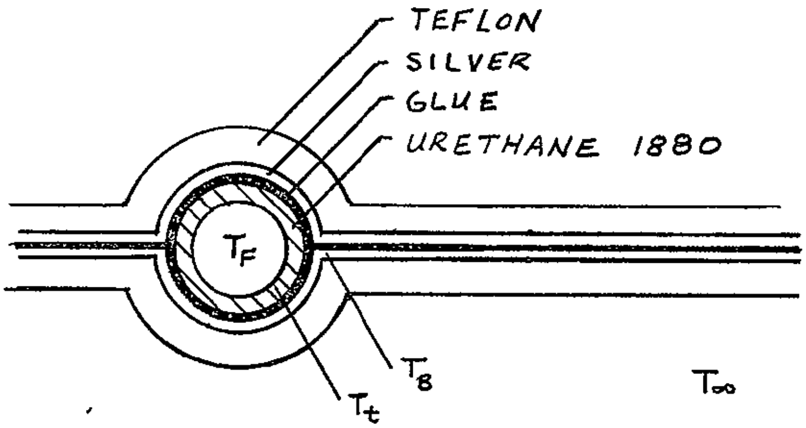
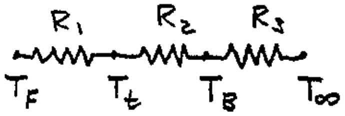


FIGURE 60 COMPARISON OF PREDICTED AND EXPERIMENTAL TEMPERATURES

FIGURE 61

THERMAL RESISTANCE IN THE SOFT TUBE INFLATABLE RADIATOR





$$R_1 = \frac{2}{\pi K N u} = \frac{2}{\pi(.065)(4)} = 2\ 449\ \frac{\text{Ft-°F-hr}}{\text{BTU}}$$

$$R_2 = \frac{2}{\pi D \eta u} = \frac{2}{\pi(.008442)(0.350)(6338)} = 3\ 40\ \frac{\text{Ft-°F-hr}}{\text{BTU}}$$

$$\eta = \frac{\tanh(m \pi D/4)}{(m \pi D/4)}$$

$$u = \frac{1/r_3}{\frac{1}{K_1} \ln(r_2/r_1) + \frac{1}{K_2} \ln(r_3/r_2)}$$

$$m = \sqrt{u/K_3 \delta_3}$$

$$R_3 = \frac{1}{\eta_f \, \epsilon \, \sigma \, (W/2)(T_B^2 + T_\infty^2)(T_B + T_\infty)}$$

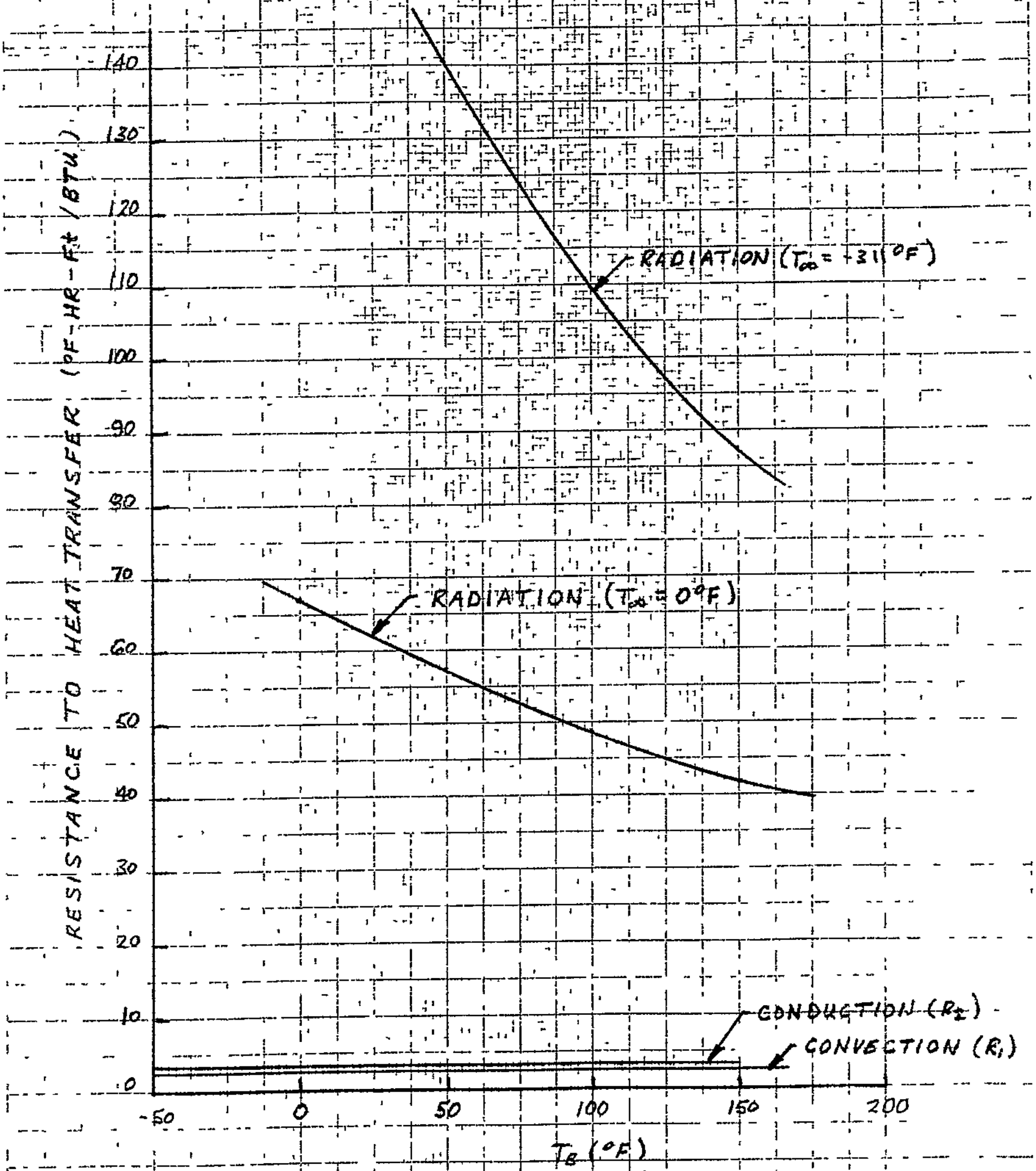


FIGURE 62

THERMAL RESISTANCE IN THE SOFT TUBE INFLATABLE RADIATOR

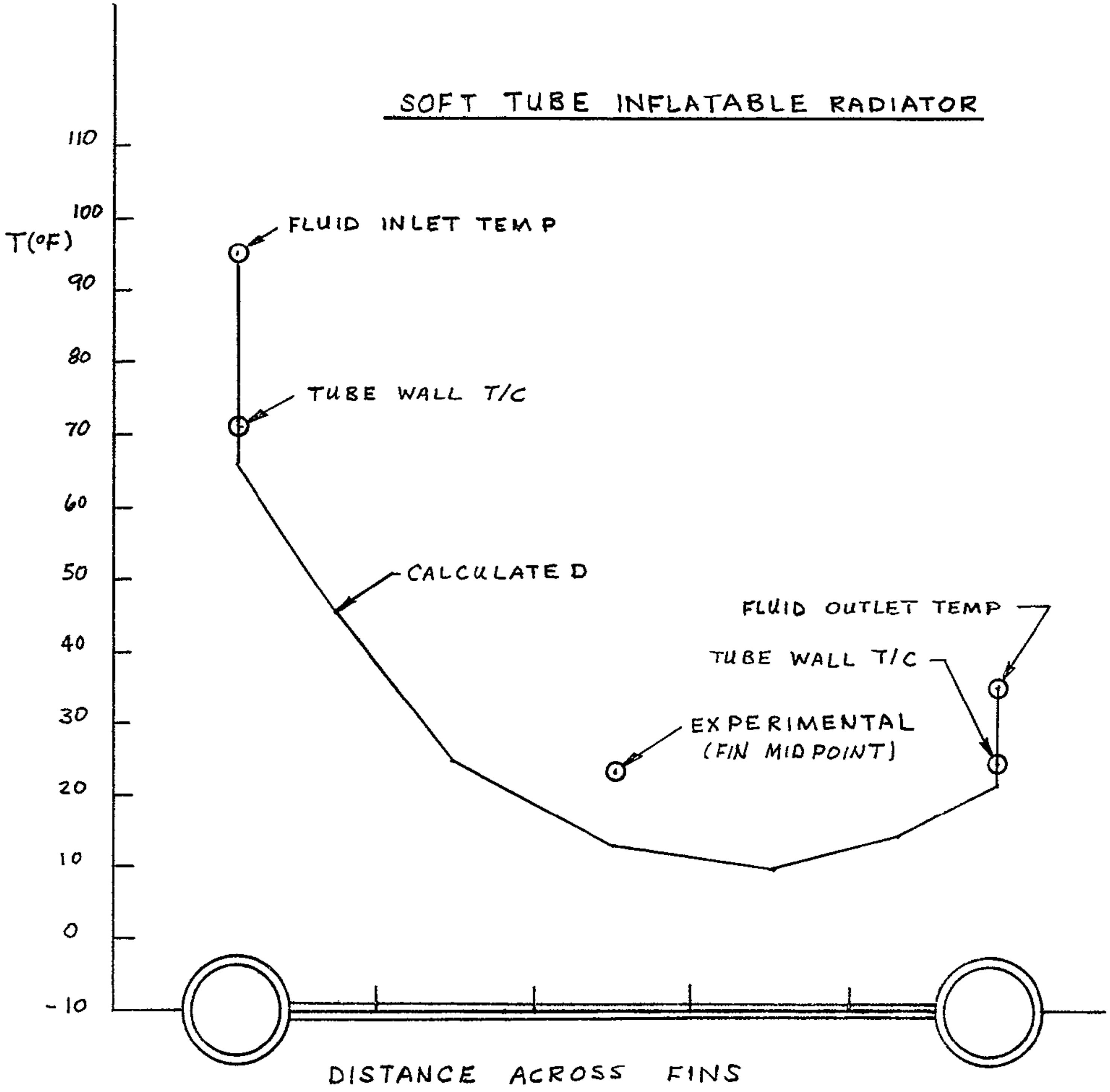


FIGURE 63

COMPARISON OF EXPERIMENTAL AND PREDICTED

TEMPERATURES FOR TEST POINT 1

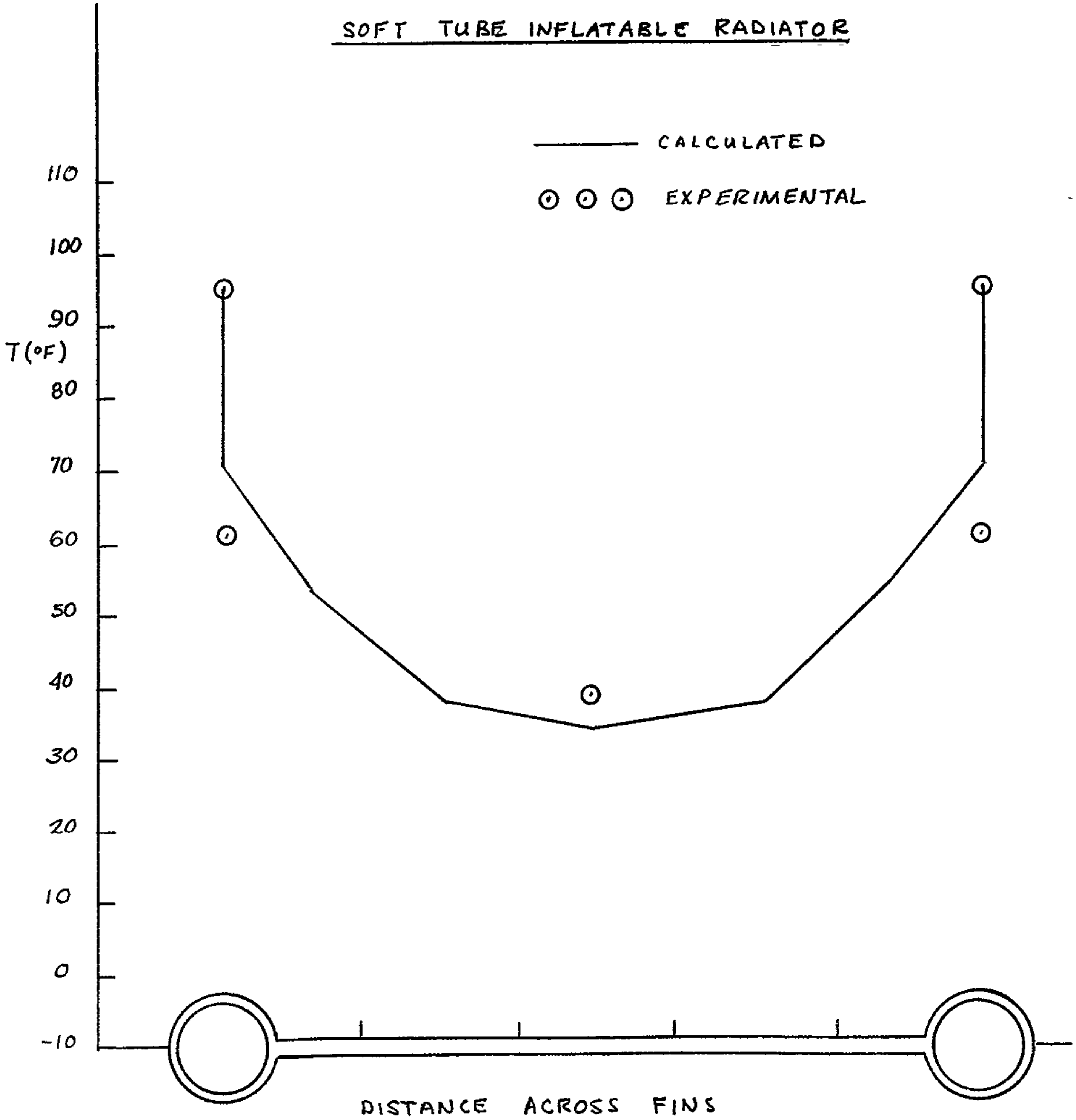
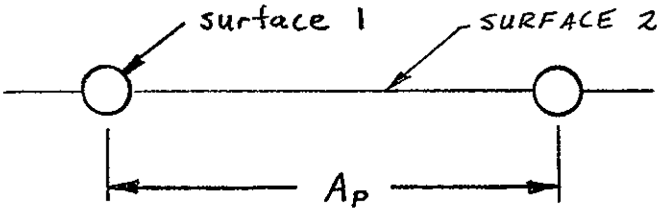


FIGURE 64
COMPARISON OF EXPERIMENTAL AND PREDICTED

TEMPERATURES FOR TEST POINT 1

FIGURE 65

EFFECT OF RAISED TUBES ON SURFACE EMITTANCE



$$A/A_p = 1 + (\pi - 2)r/W = 1 + (\pi - 2)\left(\frac{.065}{1}\right) = 1.074$$

$$J/A_p = \frac{\epsilon\sigma T^4}{1-\rho^2 F_{1-2}F_{2-1}}\left[\left(1-\epsilon F_{1-2}-\rho F_{1-2}F_{2-1}\right)\frac{A_1}{A_p} + \left(1-\epsilon F_{2-1}-\rho F_{1-2}F_{2-1}\right)\frac{A_2}{A_p}\right]$$

$F_{1-2} = 0.25$

$$F_{2-1} = \frac{\pi(.065)}{1-2(.065)}(0.25) = 0.0587$$

$\epsilon \approx 0.67$ $\qquad$ $\rho \approx 0.33$

$A_1 = 0\ 204\ A_p$ $\qquad$ $A_2 = 0.870\ A_p$

$$J/A_p = 1.002\,\epsilon\sigma T^4$$

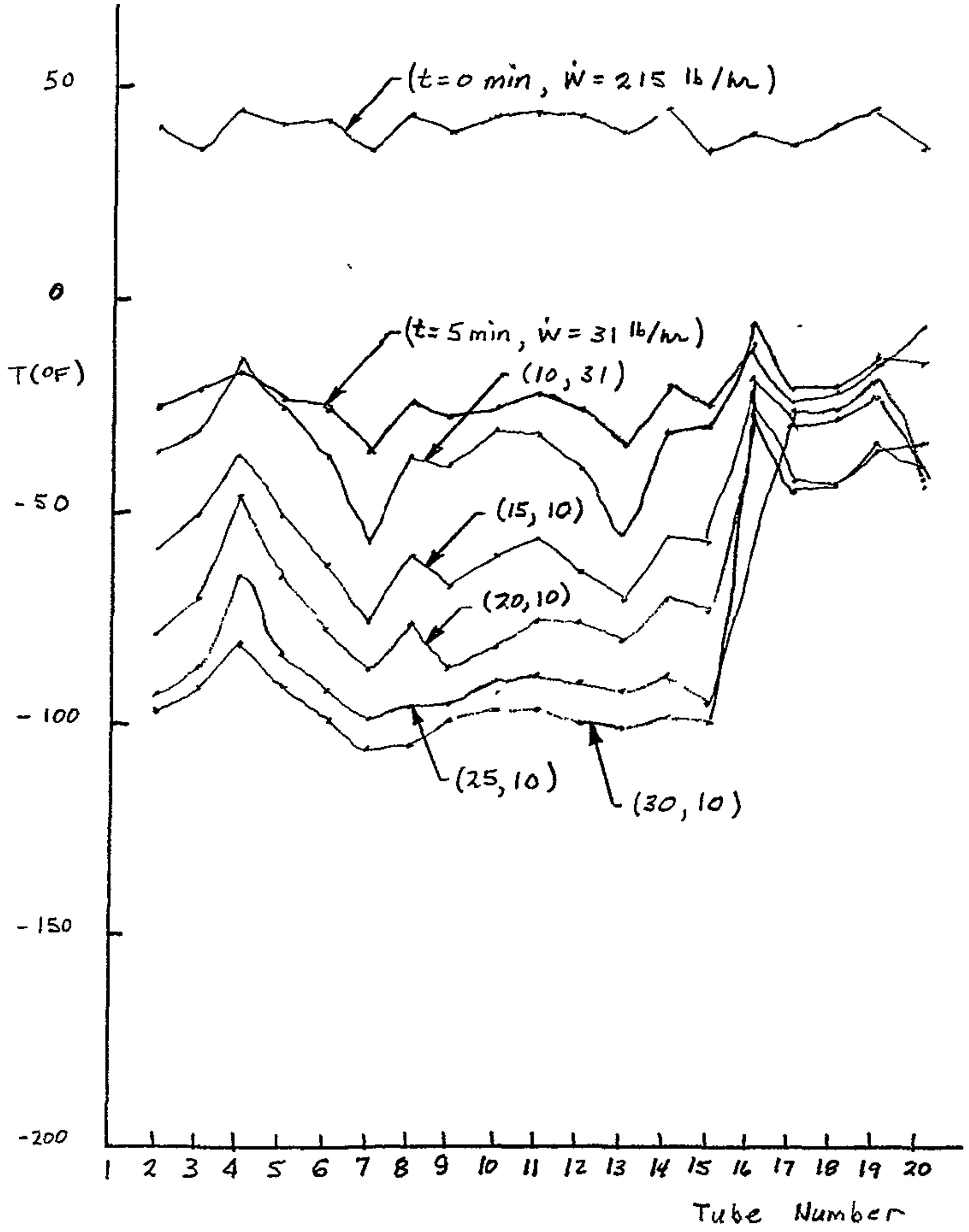


FIGURE 66

Outlet Tube Wall Temperatures During Cold Soak that at 10 minutes elapsed time with the flowrate at 31 lb/hr the outlet temperatures for tubes 7 and 12 had dropped below the temperatures of the remaining tubes. Eventually tubes 1 through 15 experienced uniformly low temperatures while 16 through 20 attained a uniform temperature level more than 50°F higher than the colder tubes. A study documented in Ref.(8) shows that this type of performance can be caused by a flow instability which allows the flow to stagnate in the tubes of parallel flow space radiators. Figure 67 defines the approximate limits of stable operation for Coolanol 15 computed from equations in Reference (8). For a 70°F inlet temperature flow instabilities are expected to occur when the outlet temperature drops below -50°F. Thus the operating conditions during the cold soak were well into the unstable region. Table 19 shows that tubes 9 and 13 normally have lower flows than the remaining tubes. Because of this the outlet temperatures of these tubes reached the unstable limit before the others. As the flow stagnated in tubes 7 and 13 the adjacent tubes were cooled and also entered into the unstable region. All of the tubes did not stagnate because the flow lost in the stagnated tubes accumulated in the remaining flowing tubes and kept the outlet temperature above the minimum stable limit.

The stable operating limit depends on the viscosity/temperature relationship of the transport fluid. Figure 68 compares the stability curves of three candidate flexible radiator transport fluids. The figure shows that the stable operating region is much narrower for Coolanol 15 than for the other fluids. This is a significant factor to be considered in selecting the transport fluid for future designs.

3.6.5 Computer Analysis of Engineering Model Inflatable Radiators

SINDA computer models were constructed to provide accurate theoretical predictions of the test articles transient thermal performance. The models account for all forms of heat transfer from the elements of the test articles to the environment simulation walls, and contain logic to determine the distribution of flow in the parallel passages of the radiators. Listings of the computer routines for the two test articles and example are

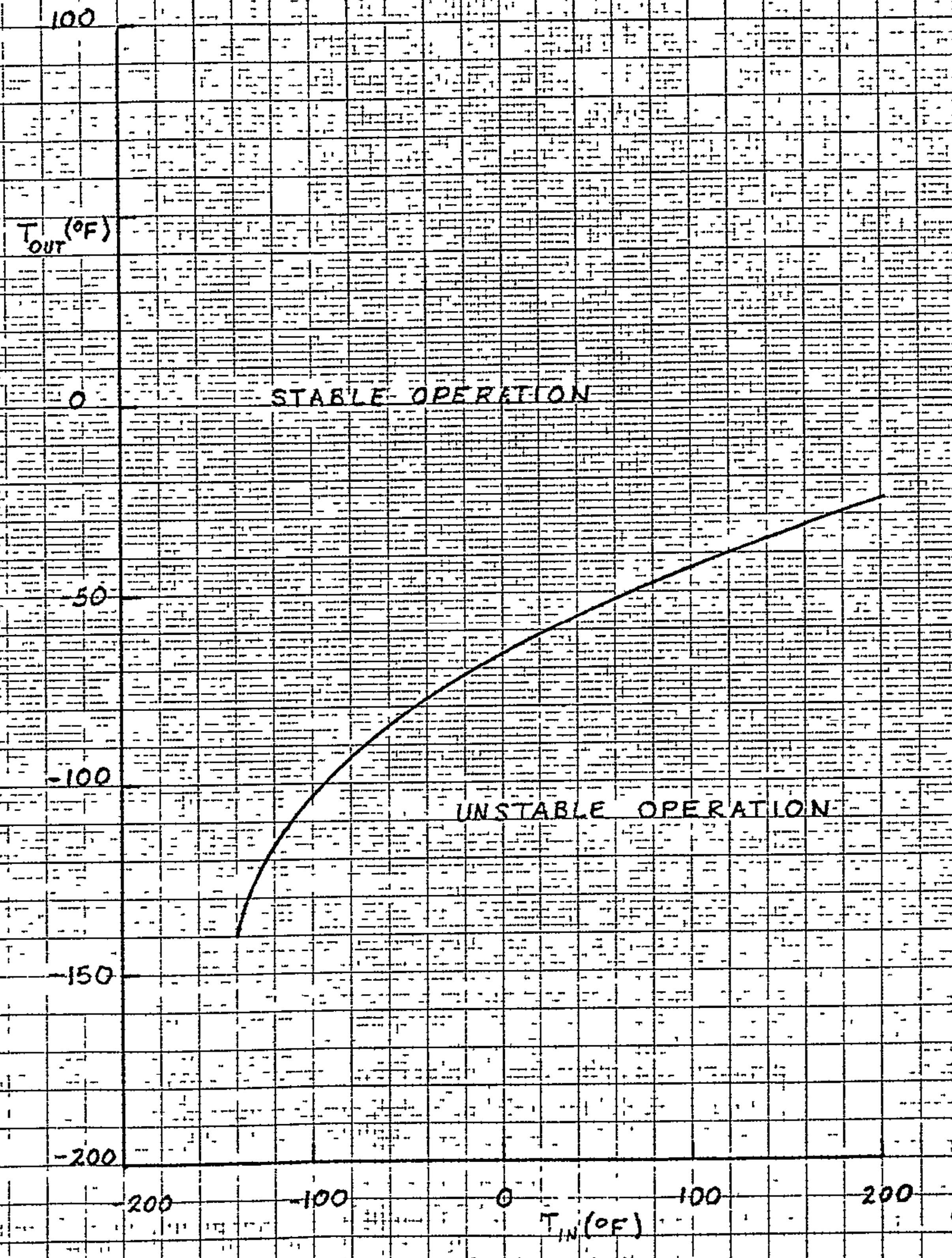
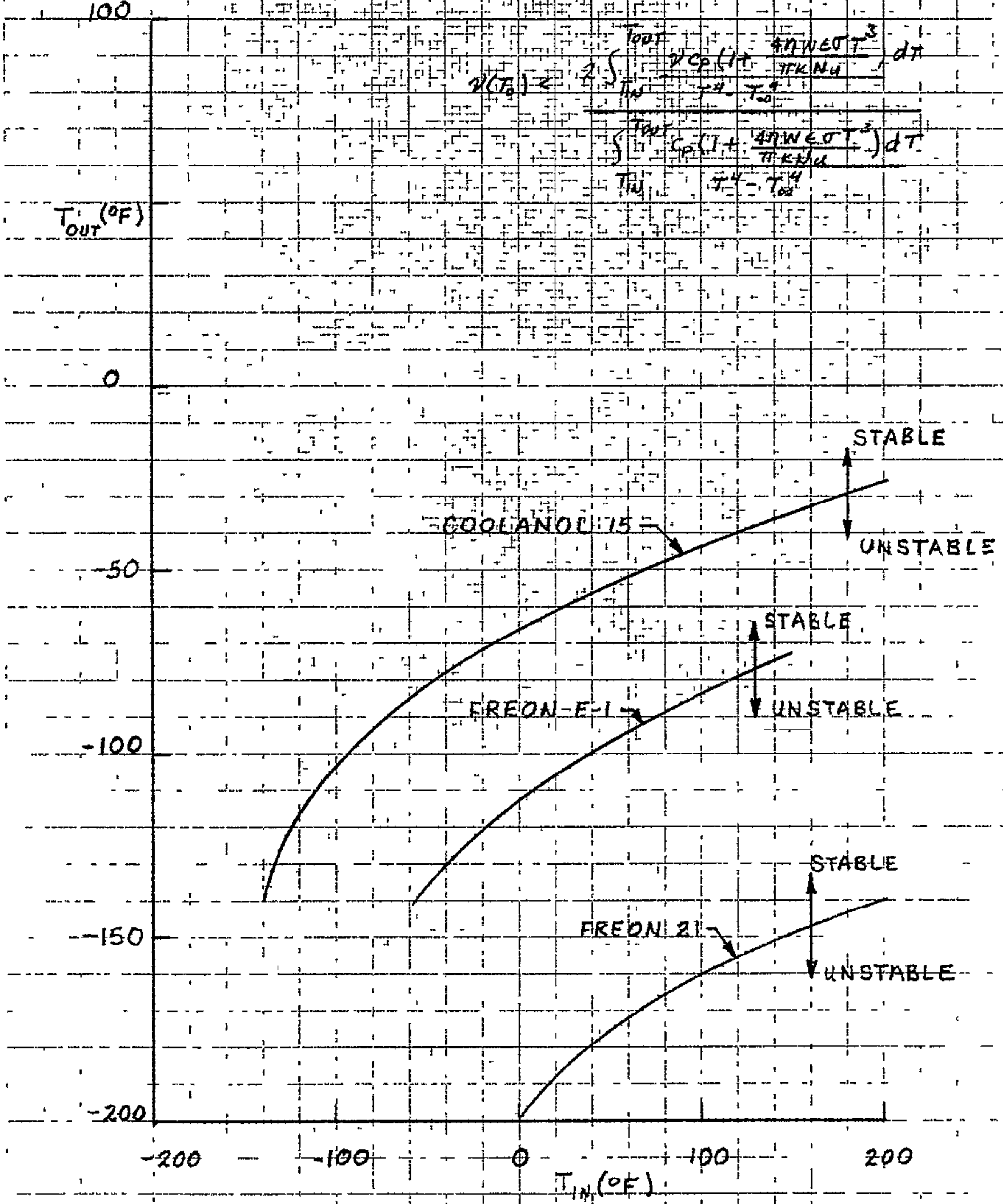


FIGURE 67

APPROXIMATE STABILITY CURVE FOR COOLANOL 15



$$\nu(T_0) < \frac{2\int_{T_{IN}}^{T_{OUT}} \frac{\nu c_p\left(1+\frac{4\eta W\epsilon\sigma T^3}{\pi K N_u}\right)}{T^4-T_\infty^4}\,dT}{\int_{T_{IN}}^{T_{OUT}} \frac{c_p\left(1+\frac{4\eta W\epsilon\sigma T^3}{\pi K N_u}\right)}{T^4-T_\infty^4}\,dT}$$

FIGURE 68

APPROXIMATE STABILITY CURVES FOR CANDIDATE INFLATABLE RADIATOR FLUIDS given in Appendices D and E. Details of the models are summarized below.

Hard Tube Test Article Computer Model

Because of the way that the manifolds and return lines are designed for the hard tube test article, there is symmetry of flow and temperature so that it is necessary to analyze only one fourth of the radiator. Thus the computer model contains only six tubes as shown in Figure 69. Each of the tubes was subdivided into twelve nodes and the fins connecting each pair of nodes on parallel tubes were divided into five nodes as shown in Figure 70. The numbering sequence for the fluid, tube and fin nodes is shown in Figure 71. Additional nodes defined for manifolds and support rings are identified in Appendix D . Radiation exchange between elements of the radiator which view each other across the interior of the cylindrical cavity is accounted for by defining three surfaces with averaged properties of the nodes contained by the surface, as shown in Figure 72, and employing SINDA subroutine RADIR. Conduction resistances computed from equations such as are outlined in Figure 54 are given in Appendix D .

Calculations showed that the pressure drop in the manifolds is less than 1% of the pressure drop in the small diameter radiator tubes. Therefore it was possible to simplify the flow model as shown in Figure 72 in the computer simulation. The flow in tube 6 is double the sum of the flows in tubes 1-5 because of symmetry built into the SINDA model.

Soft Tube Test Article Computer Model

The computer simulation of the soft tube test article also takes advantage of symmetry, and does not account for the effects of the manifold on flow distribution. This makes it possible to reduce the number of tubes in the computer model without sacrificing accuracy in the predictions. The model contains five tubes as shown in Figure 73 which represent five tubes on the test article located at the outside edge adjacent to the inflation tubing. Hand analyses showed that edge effects are not significant for the fifth tube so that no loss in accuracy results from assuming that the interior tubes are identical to the fifth tube of the computer model.

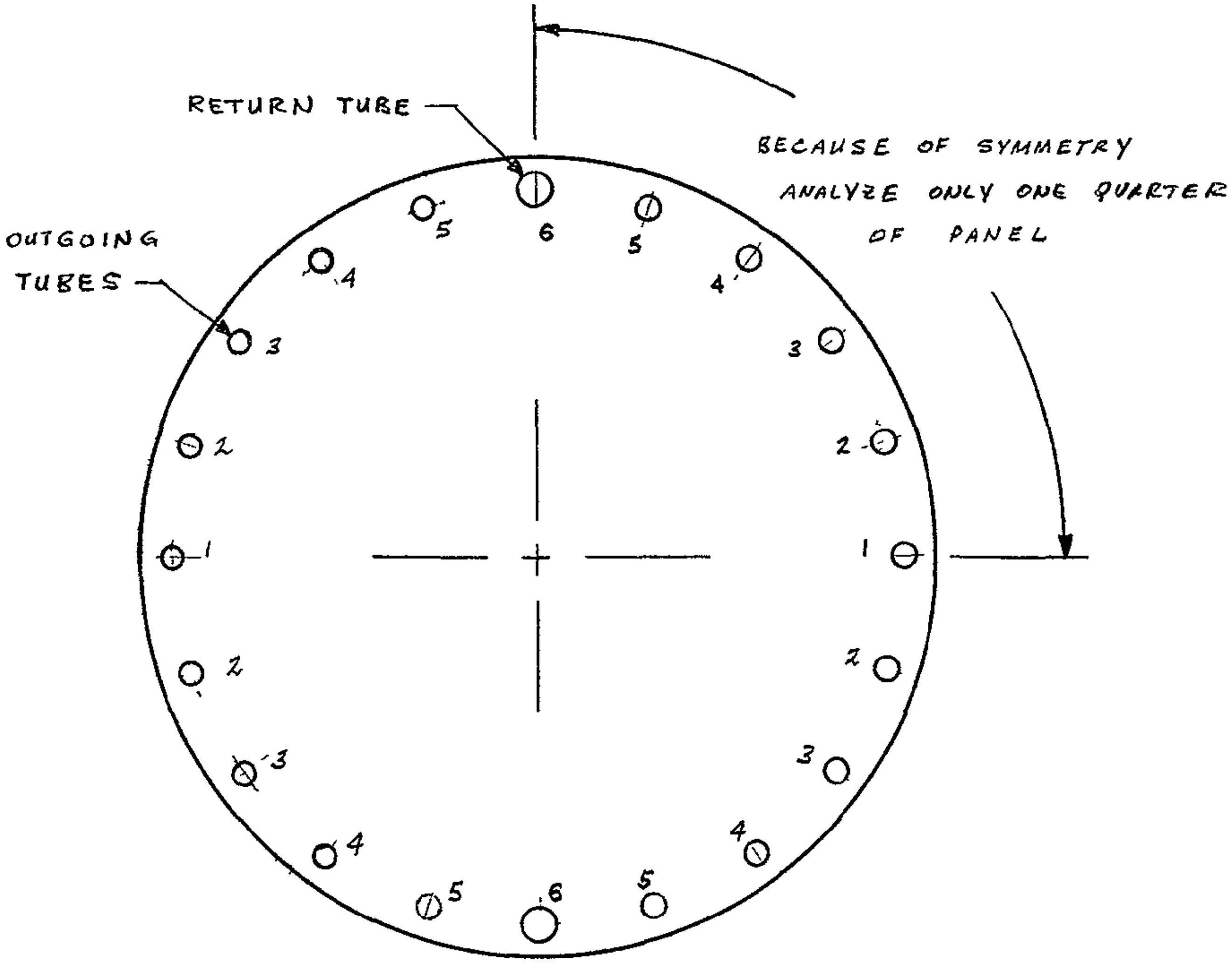
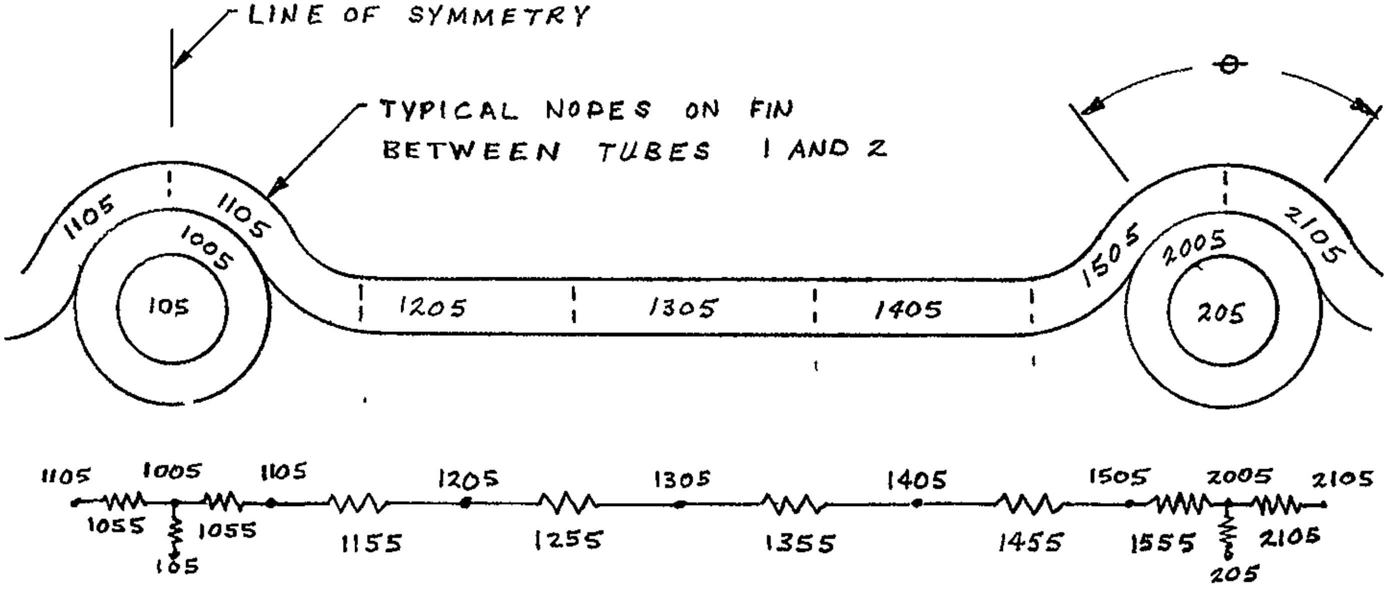


FIGURE 69 SYMMETRY IN THE HARD TUBE TEST ARTICLE



$$G(1055) = \eta_o h_c \left(\frac{\theta D_o}{4}\right) \Delta L$$

$$G(1155) = Kt\,\Delta L/\Delta X$$

$$G(1255) = Kt\,\Delta L/\Delta X$$

$$G(1355) = Kt\,\Delta L/\Delta X$$

$$G(1455) = Kt\,\Delta L/\Delta X$$

$$G(1555) = \eta_o h_c \left(\frac{\theta D_o}{4}\right) \Delta L$$

FIGURE 70 COMPUTER MODEL OF HARD TUBE TEST ARTICLE

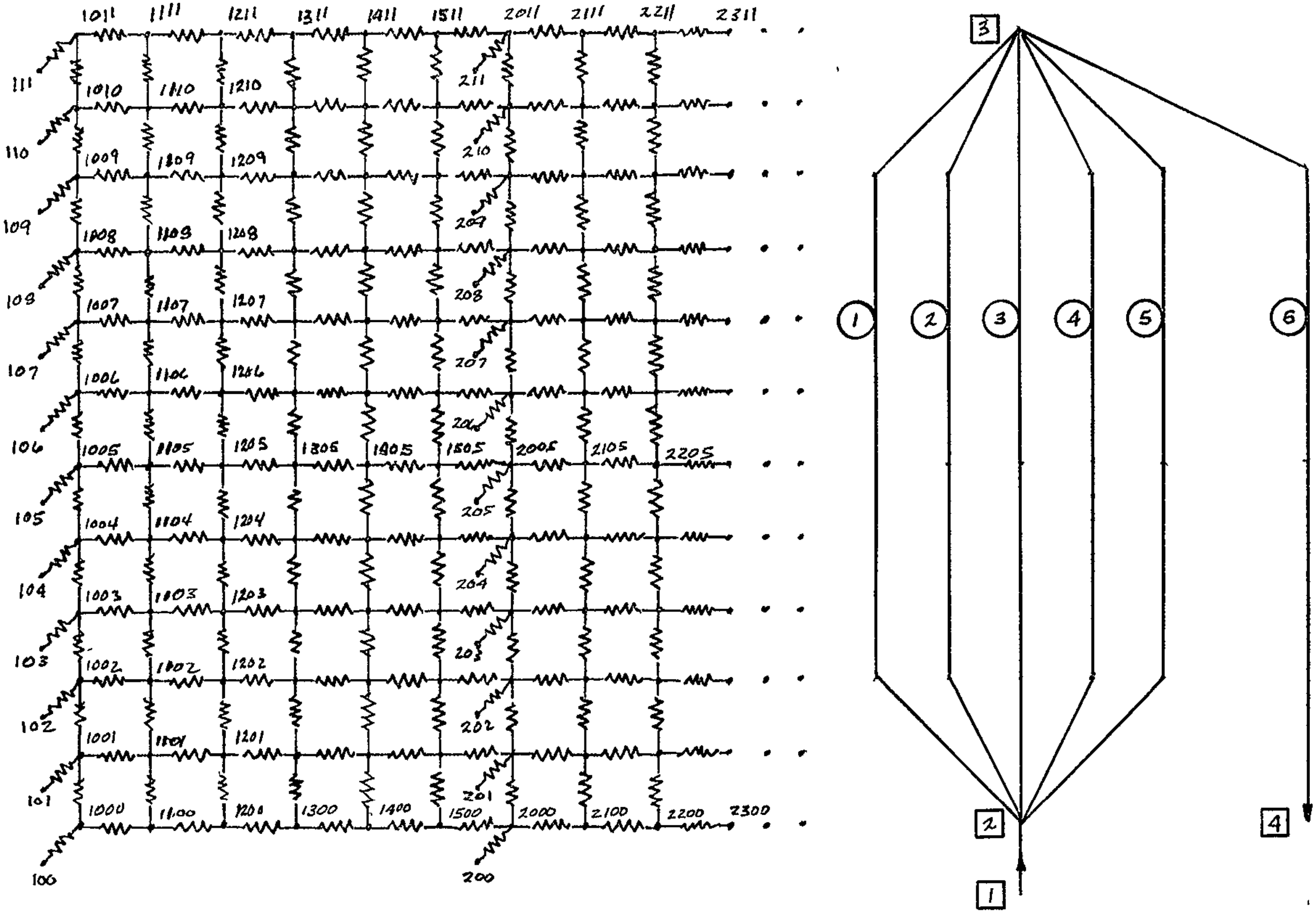


FIGURE 71 NODE IDENTIFICATION IN THE HARD TUBE COMPUTER MODEL

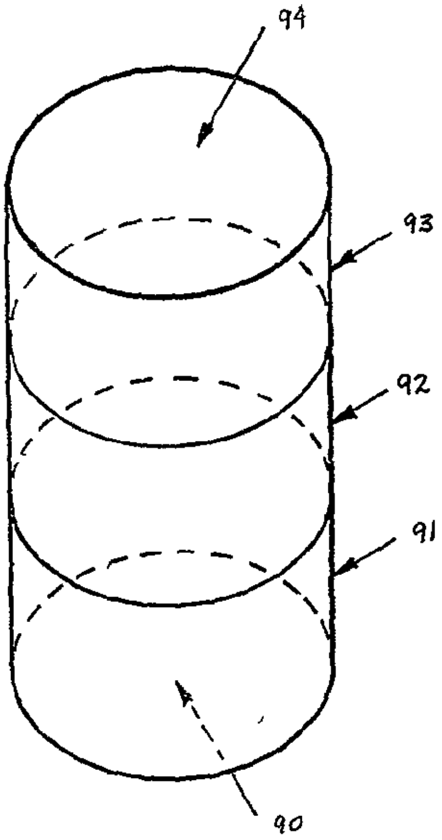
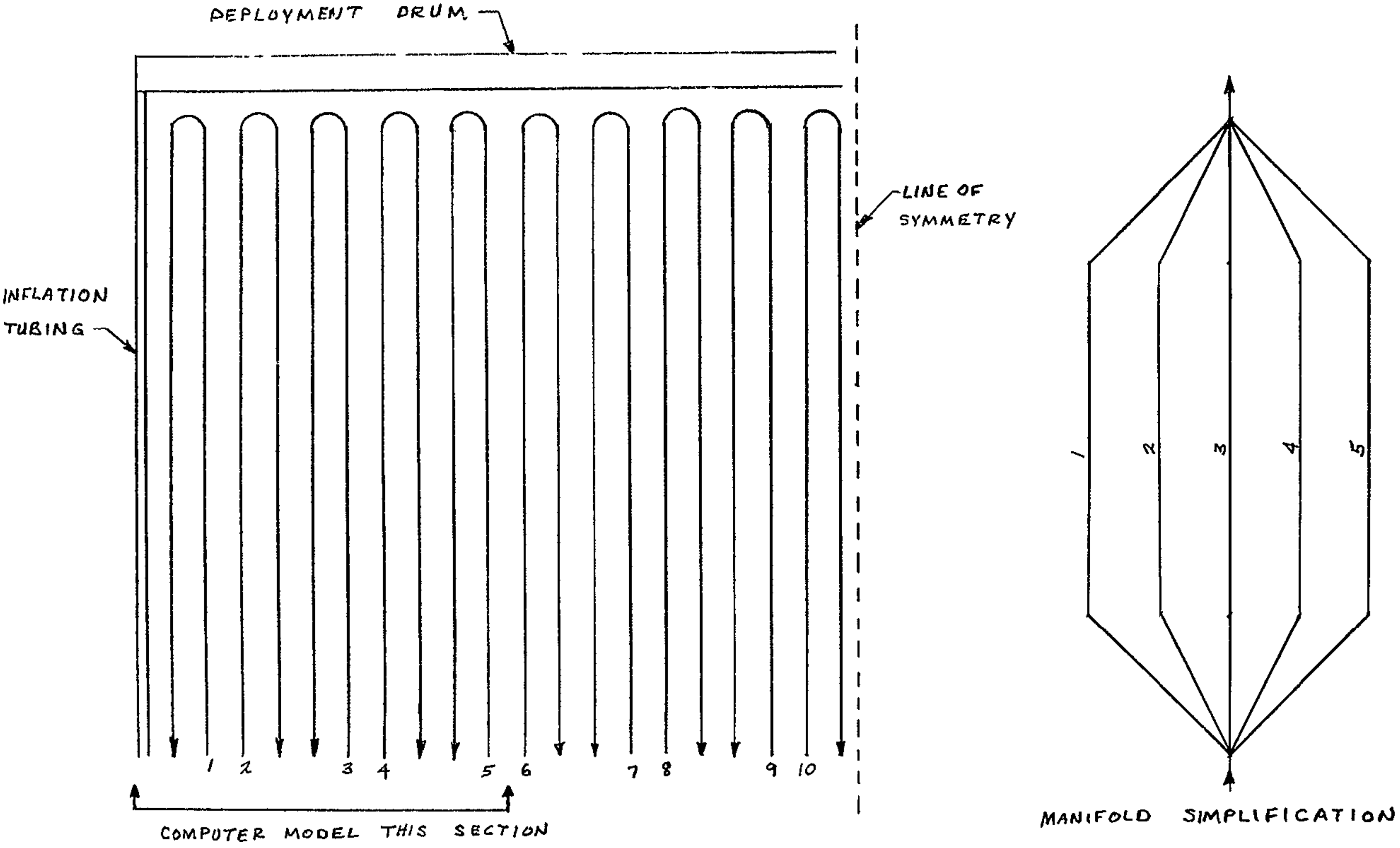


FIGURE 72 RADIATING SURFACE IDENTIFICATION IN THE HARD TUBE COMPUTER MODEL



MANIFOLD SIMPLIFICATION

FIGURE 73 FLOW ROUTING IN THE SOFT TUBE COMPUTER MODEL

Figure 74 identifies the nodes representing the inflation tubing, the outside transport tube, and the deployment drum. The figure shows that each transport tube is divided into 16 nodes. The fins connecting each pair of nodes on adjacent tubes are divided into five nodes as shown in Figure 75. The numbering sequence for the fluid, tube and fin nodes is shown in Figure 76. Radiation exchange between nodes on the radiator and the walls of the environment simulation chamber is accounted for by defining isothermal surfaces as shown in Figure 77 and employing subroutine RADIR of SINDA. Conduction resistances computed from equations such as are outlined in Figure 61 are given in Appendix E .

3.7 Computer Models of Flight Article Inflatable Radiators

SINDA computer models of the full scale system described in Figures 28 and 29 were developed to predict performance data for typical space environments. The computer models are similar to those developed for the engineering models except that dimensions, conductances, view factors, etc. have been changed to account for differences in size. Listings of the computer models and example runs with typical flowrates and inlet temperatures are given in Appendices F and G. Predicted performance data from the two models is given in Table 25.

TABLE 25

PREDICTED PERFORMANCE OF FULL SCALE INFLATABLE RADIATORS

TYPE OF RADIATOR	T_∞ (°F)	T_{IN} (°F)	T_{OUT} (°F)	$\dot{W}$ (LB/HR)	Q (BTU/HR)	Q (KW)
Hard Tube	0	95	38.6	1107	15,546	4.55
	-310	95	34	2970	45,111	13.21
Soft Tube	0	95	33	378	10,077	2.95
(Three Panels)*	-310	95	35	1152	29,722	8.71

* Analysis does not consider thermal interactions between panels

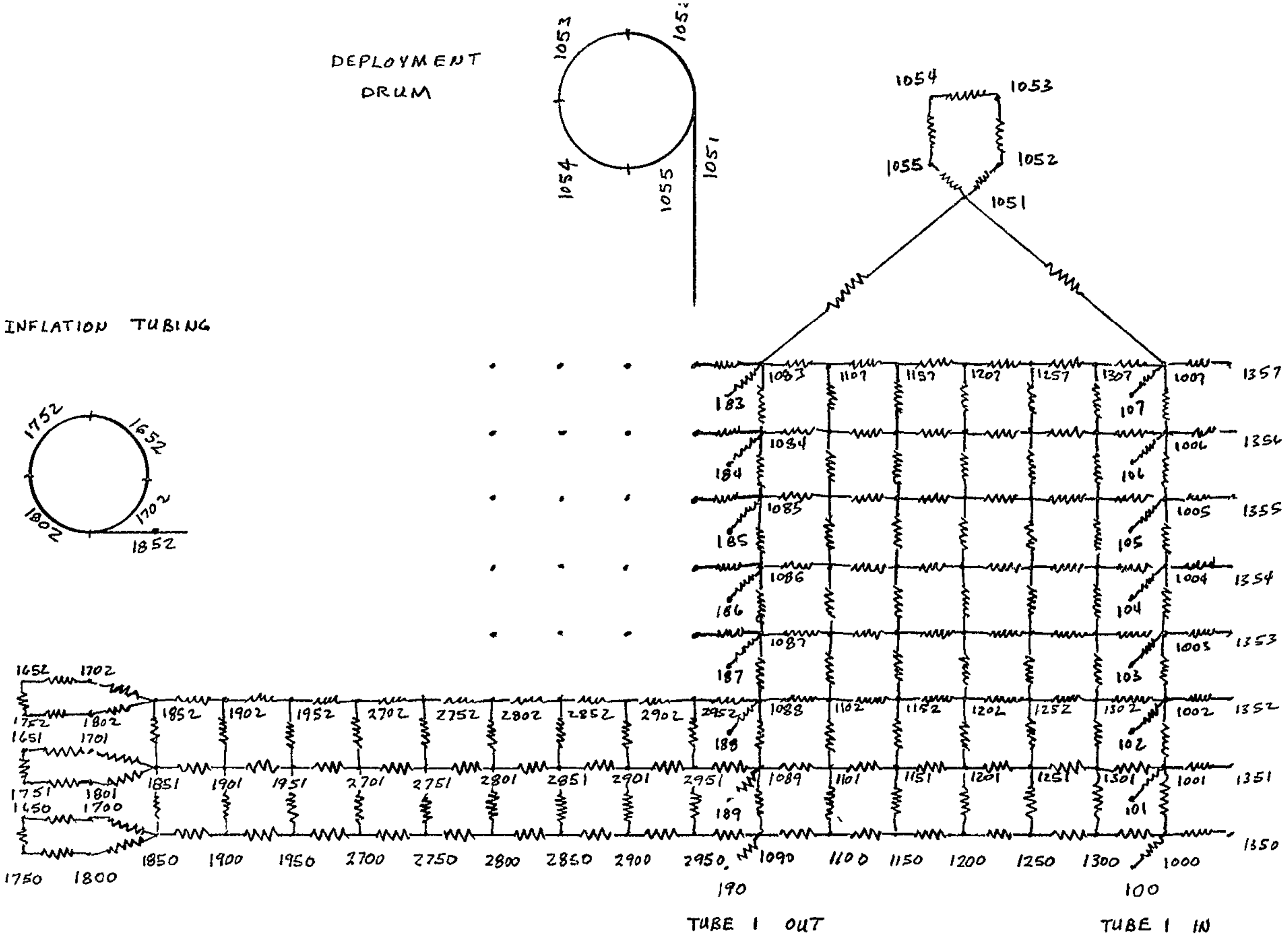


FIGURE 74 COMPUTER MODEL OF INFLATION TUBING AND DEPLOYMENT DRUM

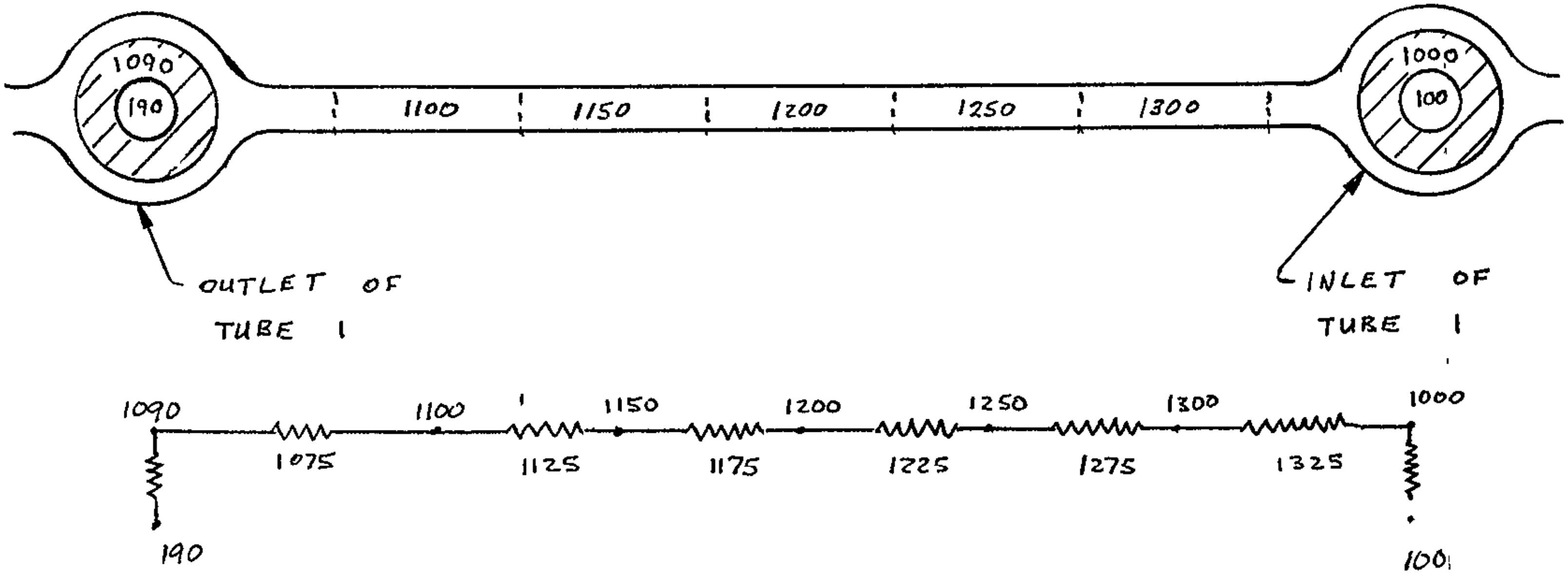


FIGURE 75 COMPUTER MODEL OF SOFT TUBE TEST ARTICLE

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

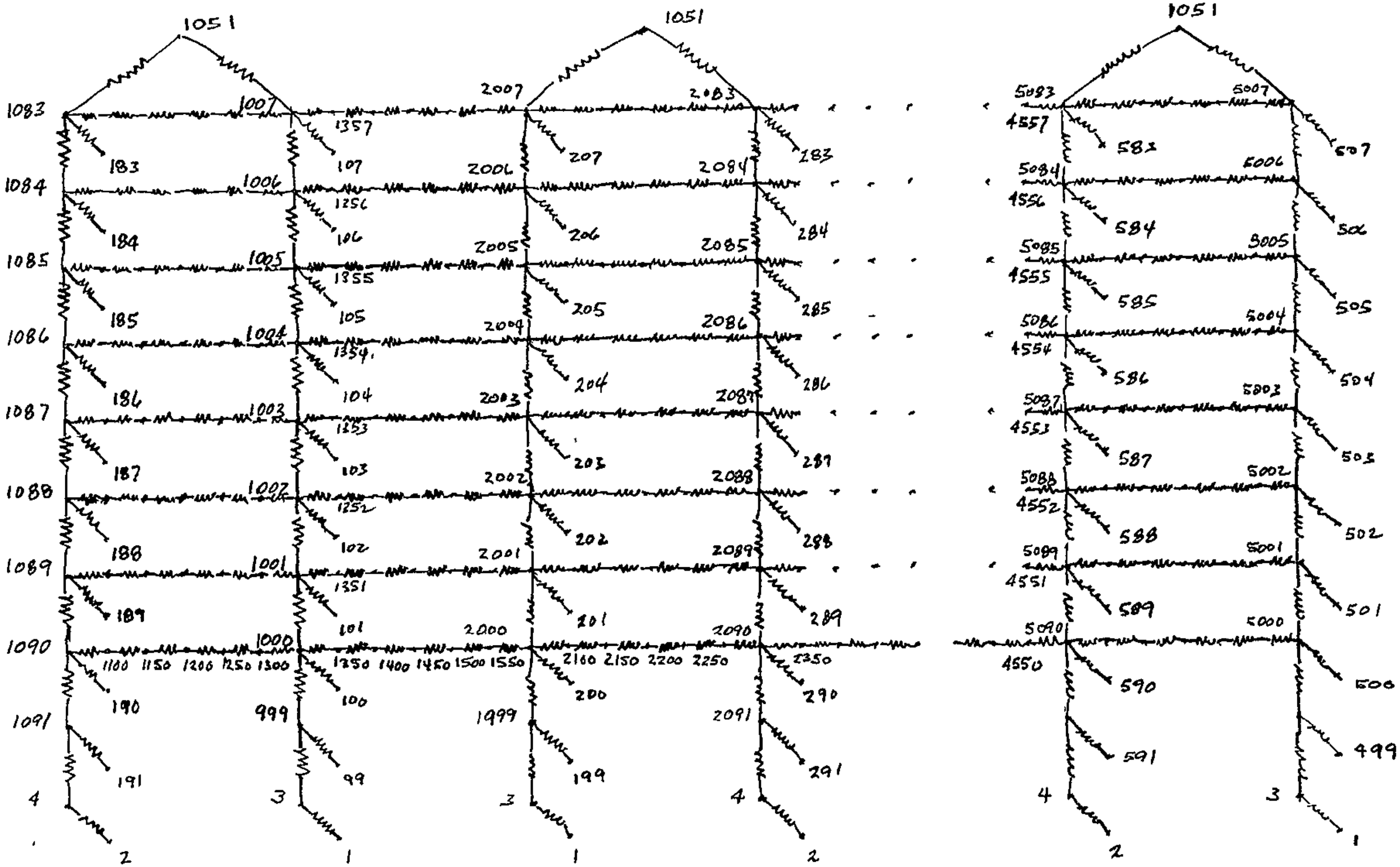


FIGURE 76 NODE IDENTIFICATION IN THE SOFT TUBE COMPUTER MODEL

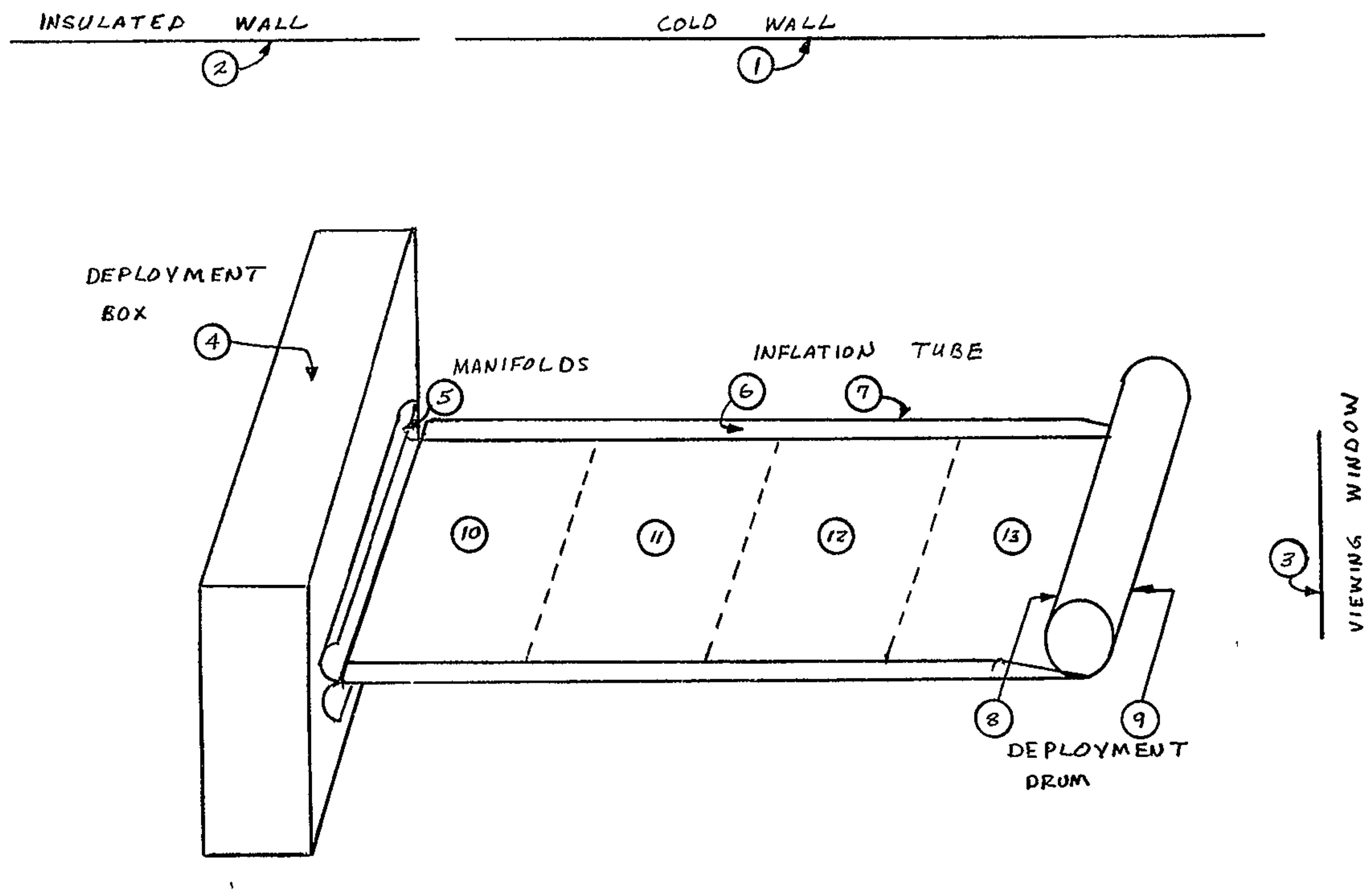


FIGURE 77 RADIATING SURFACE IDENTIFICATION IN THE SOFT TUBE COMPUTER MODEL

The results show that the hard tube model rejects more than had been estimated from earlier hand analysis (4 Kw at 0°F environment). The main difference between the hand analysis and the computer analysis is that the latter accounts for radiation emitted from the interior surfaces of the radiator which is transmitted through the fin material at other locations. This increases the heat rejection by about 10% as indicated in Table 25. The computer analysis for the soft tube prototype predicts that the heat rejection will be less than 4 Kw with a 0°F environment. The low performance results from cross conduction between the cold transport fluid in the return tubing and the warmer fluid in the adjacent outgoing tubing. Figure 78 shows that this causes the average fluid temperature to be low in sections of the radiator away from the manifolds and thus reduces the radiating capacity of the panel. Without regeneration the heat rejection is approximately what had been expected for Coolanol 15. Additional analyses are needed to study the effects of cross conduction and to evaluate possible alternate flow routing for increasing the performance of the soft tube radiator system.

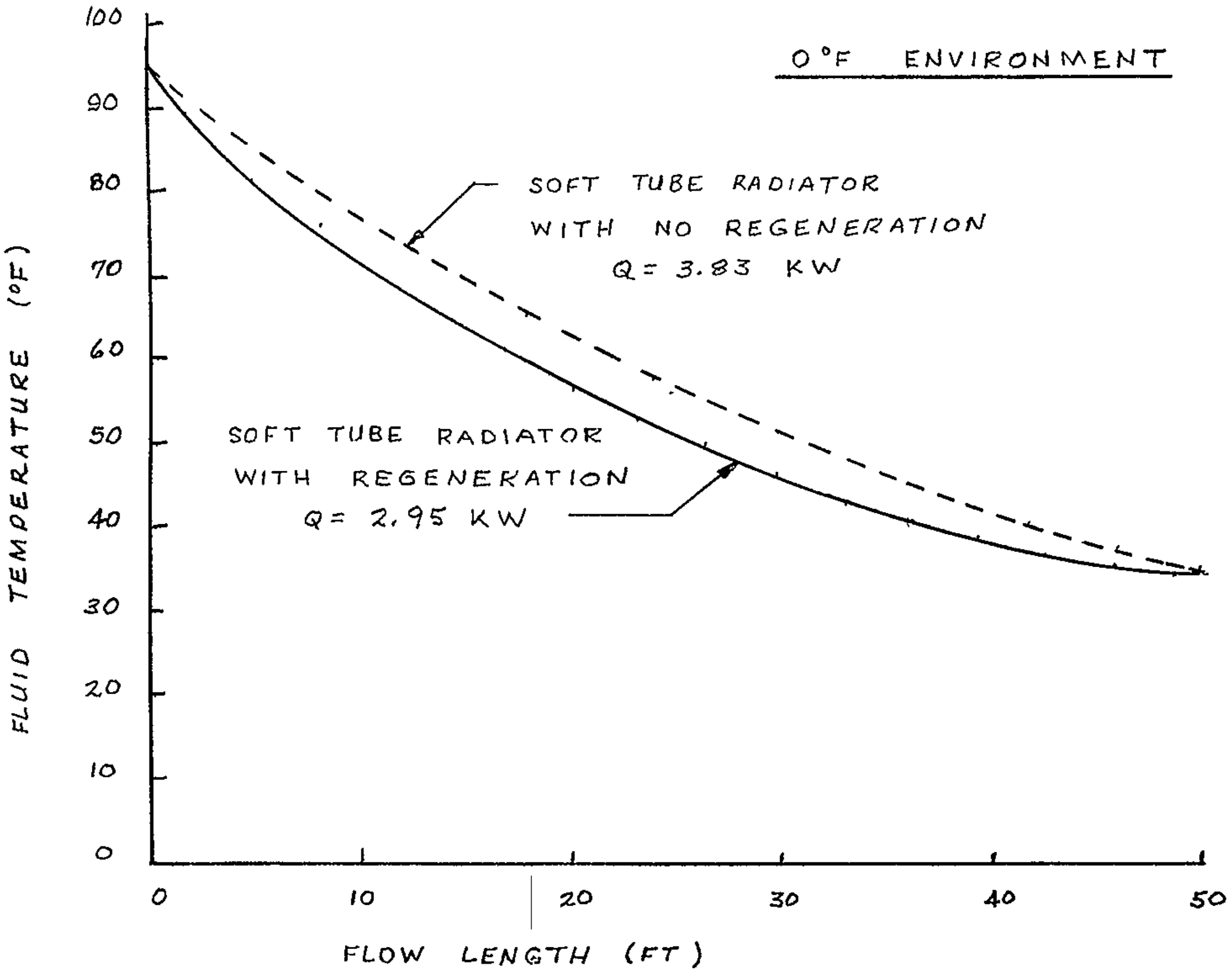


FIGURE 78 EFFECT OF CROSS CONDUCTION BETWEEN ADJACENT TUBES IN THE SOFT TUBE RADIATOR

4.0 TECHNOLOGY ASSESSMENT

Based on test results and experience gained during the inflatable radiator development program, the following assessment of flexible deployable/retractable radiator technology is given.

1) The soft tube radiator concept yields lower system weights and is much easier to fabricate than the hard tube concept. Therefore soft tube designs should be given first priority in future work on full scale prototypes.
2) Silver wire mesh/Teflon has more uniform and predictable thermal properties than thick silver backed Teflon and should be used as the fin material in future designs. Additional work is needed to develop methods for attaching tubing to the fin material and for constructing continuous strips of the material with the tubing bonded to the interior of the fin. Contacts with custom laminating vendors have established that it is probably possible with current technology to fusion bond silver mesh and Teflon on a roll-to-roll basis in four foot widths. The tubes could then be fusion bonded between the silver mesh/Teflon sheet and an opposing sheet of Teflon on a roll-to-roll basis in 6.5" widths. The risk involved in the second step are somewhat higher than is the first because cooling must be supplied locally at the tubes to prevent them from collapsing during the bonding process. Because of this it is recommended that in future work only the first step (fusion bonding of silver mesh and Teflon) be performed on a roll-to-roll basis. Thus tubing would then be bonded to the interior of the radiator with adhesive as shown in Figure 70. The second step of the process would then be the same as was used in constructing the soft tube test article and would have a high probability of success. In this case each half of the laminate would be coated with 1200 Å of vapor deposited silver to protect the adhesive and tubing from ultraviolet radiation.

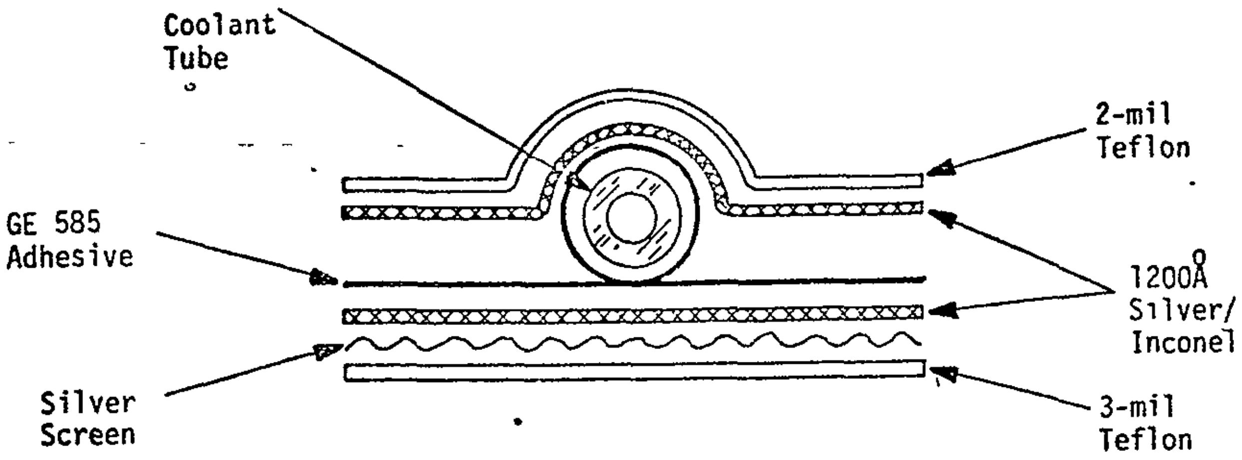


FIGURE 79 PROPOSED RADIATOR FIN CONSTRUCTION

Table 26 compares the predicted properties of the proposed fin laminate to those of the fin materials of the engineering model radiators. The data shows that the proposed laminate will combine desirable features from both of the previous designs but has a slight weight disadvantage. Overall, the effect on thermal performance is slightly positive and a significant increase in reliability is achieved.

TABLE 26 PROPERTIES OF RADIATOR FIN MATERIALS

FIN CONSTRUCTION	THERMAL CONDUCTANCE (BTU/HR-FT-°F)	AVERAGE EMISSIVITY	WEIGHT (LB/FT^2)
Thick Silver Backed Teflon	.0008 - .0028	0.67	.069
Silver Wire Mesh/Teflon	.0040	0.67	.072
Proposed Hybrid Design	.0042	0.71	.107

3) Polyurethane tubing should be selected as the baseline for designing the full scale radiator. However, additional tests and studies should be made to determine whether Teflon tubing can be used. Teflon tubing would permit the use of Freon 21 as the transport fluid and would extend the operating temperature range. Table 27 compares the tubing dimensions and

TABLE 27 COMPARISON OF ALTERNATE RADIATOR CONSTRUCTIONS

SYSTEM	FLUID LIMITS		TUBING LIMITS		SYSTEM VARIABLES						
	T_{MIN} (°F)	T_{MAX} (°F)	T_{MIN} (°F)	T_{MAX} (°F)	TUBE I.D. (IN.)	TUBE O.D. (IN.)	$\dot{W}$ (LB/HR)	Re NO.	ΔP (PSI)	RELATIVE STIFFNESS	RELATIVE AREA
Polyurethane/ Coolanol 15	-20(a)	185(b)	-100(d)	225	.090	.205(f)	529	358	7.3	1.0	1.0
FEP/Freon 21	-140(a)	350(c)	-140(d)	225(e)	.069	.143(f)	903	4278	11.2	1.5 - 2.0	0.94

(a) Limited By Flow Instabilities
(b) Fire Point of Fluid
(c) Critical Point
(d) Limited by Stiffness of Tubing
(e) Limited by Cold Flow of Tubing
(f) 30-Day Meteoroid Life

operating temperature ranges possible with polyurethane and Teflon for 30-day, 90% meteoroid survivability designs. Future studies should consider the impact of the tubing on the deployment mechanism and weight penalties required to accommodate the stiffness of tubing versus advantage of extended operating range.

4) Coolanol 15 has the most desirable transport properties of the fluids which are compatible with polyurethane. This fluid would permit stable operation in the temperature range from -20°F to 185°F and is only slightly inferior to Freon 21 in thermal conductance and pumping power requirements.

5) Additional work is needed to develop a deployment mechanism for the full scale soft tube inflatable radiator. Engineering model tests have demonstrated that inflation tubes will overcome the stiffness of the soft tube radiator construction, but did not demonstrate retraction or deployment against a spring force. Also fabrication techniques have not been demonstrated for obtaining sufficient straightness in inflation tubing to deploy a full scale radiator. Additional trade studies should consider alternate deployment concepts and account for weight penalties associated with each mechanism versus probability of success. Space deployable booms should be considered as an alternative to inflation tubing.

6) Cross conduction between outgoing and return tubes of the soft tube radiator apparently has a larger effect on radiator performance than had been initially estimated. Therefore, additional analyses are needed to study the effects of regeneration in the soft tube concept and to investigate alternate flow routing if required. Radiation interchange between adjacent radiators of the three panel system should be considered in establishing the temperature profiles on various sections of the radiator and in evaluating alternate flow routes. Also, a reoptimization of tube spacing with the proposed fin materials and flow routing will be required to minimize the overall dimensions of the system.

5.0 REFERENCES

(1) "Modular Radiator System Development for Shuttle and Advanced Spacecraft", J. B. Dietz, M. L. Fleming, R. J. Tufte and D. W. Morris, ASME Paper 72 ENAV-34, May 1972.

(2) "Development of An Inflatable Radiator System, Concepts Briefing", Vought Presentation at NASA/JSC, November 1973.

(3) "Development of An Inflatable Radiator System, Progress Report No. 4," Vought Report No. T213-RP-04, August 1974.

(4) "Inflatable Radiator System Materials Study", Vought Technical Proposal, Report No. 2-53002/4R-51101, December 1974.

(5) "Inflatable Radiator Quick Look Test Report", Vought Report No. T213-RP-07, August 1975.

(6) "Heat Transfer Element Tests of Soft Tube Inflatable Radiator System", Vought TR No. T-213-TR03, September 1974.

(7) "Heat Transfer Element Tests of Hard Tube Inflatable Radiator System", Vought TR No. T-213-TR06, September 1974.

(8) "Flow Instabilities in Spacecraft Radiators", Vought Report No. T169-56, November 1974.

(9) "Thermal Control System Component Weight and Volume Estimates", Vought Memorándum 2-52200/70IM-116, October 1970.

(10) "Development of An Inflatable Radiator System, Status Briefing", Vought Presentation at NASA/JSC, June 1974.

(11) "Basic Subsystem Module Space Radiator Study", Vought Report No. 00.977, August 1967.

(12) Private Communication, R. W. Froberg, Pfizer Chemical Co., Bethlehem, Pa., 1973.

(13) "Nitinol Characterization Study", F. J. Stimler et.al., NASA CR-1433, 1969.

(14) Private Communication, C. K. Nicholson, Plastics Dept., DuPont Co., Wilmington, Del., 1973.

(15) "Suitability of Metalized FEP Teflon as A Spacecraft Thermal Control Surface", James B. Heaney, NASA/Goddard, ASME Environmental Control Conference, July 1971.

References (Cont'd)

(16) "Design Feasibility of Sterile Insertion Techniques", J. C. Arnett, et.al., NASA Contract NASW-1621, 1967.

(17) Private Communication, H. W. Himbert, Fluoro-Plastics Inc., Philadelphia, Pa., 1973.

(18) "Specification for Orbiter Freon Coolant Loop", North American Rockwell Procurement Specification MC250-0001, 4 April 1973.

(19) "Space Station Prototype ETC/LSS Radiator and Solar Absorber Subsystems Final Preliminary Design Report", Vought Report No. 00.1380, 4 December 1970.

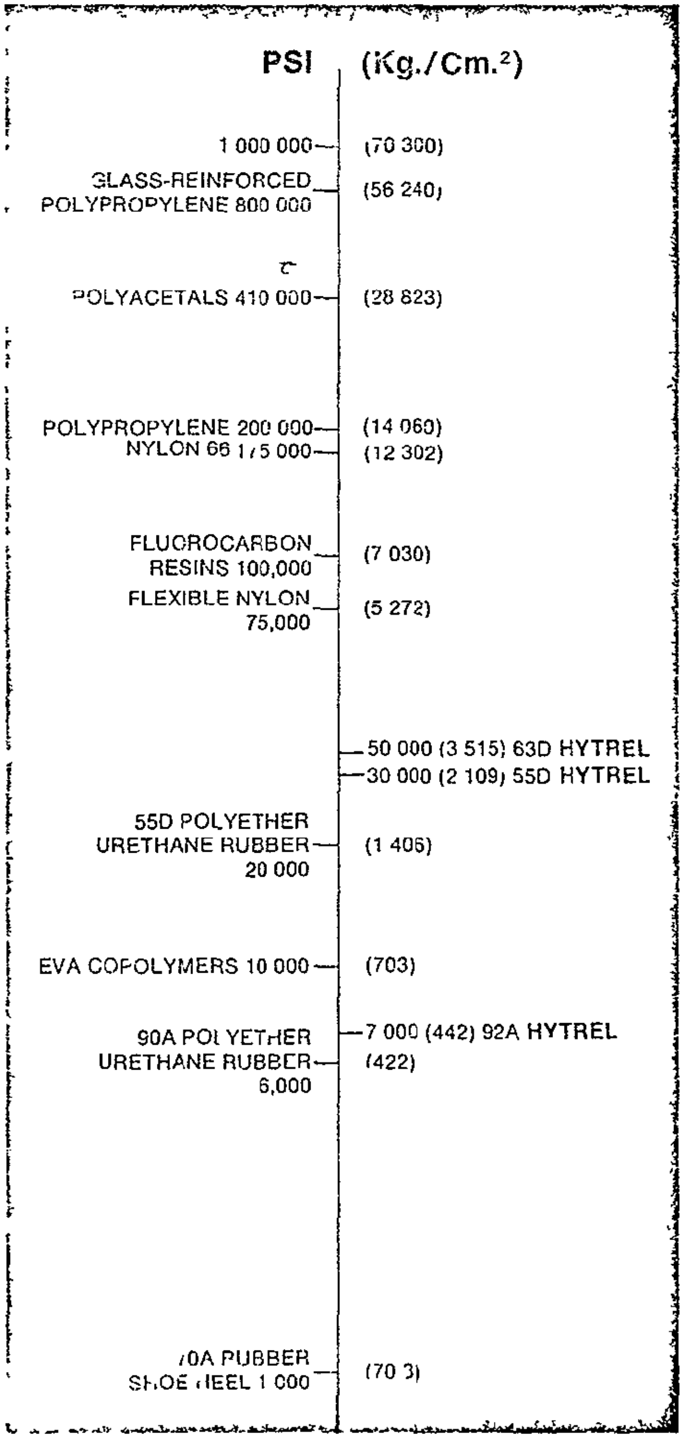
(20) "Modular Space Station Phase B Extension Preliminary Systems Design Vol. VI, Trades and Analyses", DRL No. MSC T-575 Line Item 68, North American Rockwell, January 1972.

(21) "Sortie Lab Program Review", NASA-MSFC, 16 November 1972.

APPENDIX A. PROPERTIES OF PLASTIC AND ELASTOMERIC MATERIALS[1]

---

[1] Data from "1975 Materials Selector", Issue Volume 80, No. 4, Materials Engineering, Reinhold Publishing Co., Inc., Connecticut, and "Engineering Guide to the DuPont Elastomers", E. I. DuPont de Nemours and Co., Inc., Delaware.



Flexural Modulus

comparative properties

of the Du Pont Elastomers and natural rubber

Properties	Natural Rubber	ADIPRENE polyurethane	HYPALON chloro sulfonated polyethylene	HYTREL polyester elastomer			NORDEL ethylene propylene diene polymer	Neoprene chloroprene	VITON co polymer of vinylidene fluoride and hexafluoro propylene
HARDNESS RANGE (durometer A & D)	30 90A	60 99 + A (up to 80 D)	40 95A	92A	55D	63D	40 90A	40 95A	60 95A
TENSILE STRENGTH (psi)									
Pure gum	Over 3000	Over 4000	Over 2500	5900	6400	5800	—	Over 3000	Over 2000
Black loaded stocks	Over 3000	—	Over 3000	—	—	—	Over 3000	Over 3000	Over 2000
SPECIFIC GRAVITY (Base Material)	0 93	1 06	1 12 1 28	1 17	1 20	1 22	0 86	1 23	1 85
VULCANIZING PROPERTIES	Excellent	Excellent	Excellent	Unnecessary to vulcanize			Excellent	Excellent	Good
ADHESION TO METALS	Excellent	Excellent	Excellent	Excel	Excel	Excel	Good to Excel	Excellent	Good to Excel
ADHESION TO FABRICS	Excellent	Excellent	Good	Good	Good	Good	Good	Excellent	Good to Excel
TEAR RESISTANCE	Good	Excellent	Fair	Excel	Outstng	Outstanding	Good	Good	Fair
ABRASION RESISTANCE	Excellent	Outstanding	Excellent	Outstng	Very Outstng	Very Outstanding	Excellent	Excellent	Good
COMPRESSION SET	Good	Fair	Fair	Fair	Fair	Poor	Good	Fair to Good	Fair to Good
REBOUND									
Cold	Excellent	Poor at V L. temp	Good	Very Good	Good	Fair	Very Good	Very Good	Good
Hot	Excellent	Good at R T	Good	Excel	Very Good	Good	Very Good	Very Good	Excellent
DIELECTRIC STRENGTH	Excellent	Excellent	Excellent	Fair to Good	Fair to Good	Fair to Good	Excellent	Good	Good
ELECTRICAL INSULATION	Good to Excellent	Fair to Good	Good	Fair to Good	Fair to Good	Fair to Good	Excellent	Fair to Good	Fair to Good
PERMEABILITY TO GASES	Fair	Fair	Low to V L	Fair	Fair	Fair	Fair	Low	Very low
ACID RESISTANCE									
Dilute	Fair to Good	Fair	Excellent	Fair	Fair	Fair	Excellent	Excellent	Excellent
Concentrated	Fair to Good	Poor	Very Good	Poor	Poor	Poor	Excellent	Good	Excellent
SOLVENT RESISTANCE									
Aliphatic hydrocarbons	Poor	Excellent	Good	Excel	Excel	Excel	Poor	Good	Excellent
Aromatic hydrocarbons	Poor	Fair to Good	Fair	Good	Good	Good	Poor	Fair	Excellent
Oxygenated (ketones, etc)	Fair to Good	Poor	Poor	Fair	Good	Good	Good	Poor	Poor
Lacquer solvents	Poor	Poor	Poor	Fair	Fair to Good	Good	Poor	Poor	Poor
RESISTANCE TO									
Swelling in lubricating oil	Poor	Excellent	Good to Excel	Good	Excel	Excel	Poor	Good	Excellent
Oil and gasoline	Poor	Excellent	Good	Very Good	Excel	Excel	Poor	Good	Excellent
Animal and vegetable oils	Poor to Good	Excellent	Good	Very Good	Excel	Excel	Good	Good	Excellent
Water absorption	Very Good	Good at R T Poor at 212° F	Very Good	Very Good up to 212° F	Very Good up to 212° F	Very Good up to 212° F	Very Good	Good	Very Good
Oxidation	Good	Excellent	Excellent	Excel	Excel	Excel	Excellent	Excellent	Outstanding
Ozone	Fair	Excellent	Outstanding	Excel	Excel	Excel	Outstanding	Excellent	Outstanding
Sunlight aging	Poor	Good	Outstanding	Very Good	Very Good	Very Good	Outstanding	Very Good	Very Good
Heat aging	Good	Good	Excellent	Good	Excel	Excel	Excellent	Excellent	Outstanding
Flame	Poor	Fair	Good	Will melt but can be made flame retardant			Poor	Good	Good
Heat	Good	Good	Excellent	Very Good	Excel	Excel	Excellent	Very Good	Outstanding
Cold	Excellent	Excellent	Good	Excel	Excel	Excel	Excellent	Good	Good

Comparison of Hi-TUFF polyurethane with natural and synthetic rubbers

FROM "HI-TUFF SOLID POLYURETHANE," J.P
STEVENS AND CO, INC, MASSACHUSETTS

PROPERTIES		NATURAL RUBBER	BUNA S butadiene styrene	BUTYL isobutylene isoprene	NITRILE (BUNA N) butadiene acrylonitrile	SILICONE polysiloxane polymer	NEOPRENE chloroprene	VITON co-polymer of vinylidene fluoride and hexafluoropropylene	HYPALON chlorosulfonated polyethylene	Hi-TUFF polyurethane
TENSILE STRENGTH (psi)	Pure gum	Over 3000	Below 1000	Over 1500	Below 1000	Below 1500	Over 3000	Over 2000	Over 2500	5000-8500
	Black loaded stocks	Over 3000	Over 2000	Over 2000	Over 2000		Over 3000	Over 2000	Over 3000	
HARDNESS RANGE (durometer A)		30 90	40 90	40 75	40 95	40 85	40 95	60 95	40 95	50 99+ (up to 75 durometer D)
SPECIFIC GRAVITY (Base Material)		0 93	0 94	0 92	1 00		1 23	1 85	1 12 1 28	1 10 to 1 24
VULCANIZING PROPERTIES		Excellent	Excellent	Good	Excellent		Excellent	Good	Excellent	Excellent
ADHESION TO METALS		Excellent	Excellent	Good	Excellent		Excellent	Good to excellent	Excellent	Excellent
ADHESION TO FABRICS		Excellent	Good	Good	Good		Excellent	Good to excellent	Good	Excellent
TEAR RESISTANCE		Good	Fair	Good	Fair	Poor	Good	Fair	Fair	Outstanding
ABRASION RESISTANCE		Excellent	Good to excellent	Good	Good	Poor	Excellent	Good	Excellent	Outstanding
COMPRESSION SET		Good	Good	Fair	Good	Fair	Fair to good	Very good	Fair	Good
REBOUND	Cold	Excellent	Good	Bad	Good	Excellent	Very good	Good	Good	Fair at low temp
	Hot	Excellent	Good	Very good	Good	Excellent	Very good	Excellent	Good	Good at room temp
DIELECTRIC STRENGTH		Excellent	Excellent	Excellent	Poor	Good	Good	Good	Excellent	Excellent
ELECTRICAL INSULATION		Good to excellent	Good to excellent	Good to excellent	Poor	Excellent	Fair to good	Fair to good	Good	Good
PERMEABILITY TO GASES		Fair	Fair	Very low	Fair	Fair	Low	Very low	Low to very low	Fair Good
ACID RESISTANCE	Dilute	Fair to good	Fair to good	Excellent	Good	Excellent	Excellent	Excellent	Excellent	Fair Good
	Concentrated	Fair to good	Fair to good	Excellent	Good	Fair	Good	Excellent	Very good	Poor
SOLVENT RESISTANCE	Aliphatic hydrocarbons	Poor	Poor	Poor	Excellent	Poor	Good	Excellent	Good	Excellent
	Aromatic hydrocarbons	Poor	Poor	Poor	Good	Poor	Fair	Excellent	Fair	Fair to good
	Oxygenated (ketones, etc)	Good	Good	Good	Poor	Fair	Poor	Poor	Poor	Poor
	Lacquer solvents	Poor	Poor	Poor	Fair	Poor	Poor	Poor	Poor	Poor
RESISTANCE TO	Swelling in lubricating oil	Poor	Poor	Poor	Very good	Fair	Good	Excellent	Good to excellent	Excellent
	Oil and gasoline	Poor	Poor	Poor	Excellent	Fair	Good	Excellent	Good	Excellent
	Animal and vegetable oils	Poor to good	Poor to good	Excellent	Excellent	Fair	Good	Excellent	Good	Excellent
	Water absorption	Very good	Good to excellent	Very good	Fair to good	Good	Good	Very good	Very good	Good at room temp Fair at 175°F
	Oxidation	Good	Good	Excellent	Good	Excellent	Excellent	Outstanding	Excellent	Outstanding
	Ozone	Fair	Fair	Excellent	Fair	Excellent	Excellent	Outstanding	Outstanding	Outstanding
	Sunlight aging	Poor	Poor	Very good	Poor	Excellent	Very good	Very good	Outstanding	Excellent
	Heat aging	Good	Very good	Excellent	Excellent	Outstanding	Excellent	Outstanding	Excellent	Good
	Flame	Poor	Poor	Poor	Poor	Fair	Good	Good	Good	Good
	Heat	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Good
	Cold	Excellent	Excellent	Good	Good	Excellent	Good	Good	Good	Excellent

chemical resistance

of the Du Pont elastomers

Du Pont elastomers are used widely and successfully in contact with a broad variety of chemicals To assist engineers in selecting the appropriate elastomer for the particular environment, the accompanying tabulation has been prepared We emphasize that it should be used as a guide only The tabulation is based on laboratory tests and records of actual service performance But an elastomer's degree of compatibility with a particular fluid also depends on such variables as temperature, aeration, velocity of flow, duration of exposure, stability of the fluid, degree of contact, etc Therefore, it is always advisable to test the material under actual service conditions before specification If this is not practical, tests should be devised that simulate service conditions as closely as possible

Chemical	ADIPRENE	HYPALON	HYTREL	Neoprene	NORDEL	VITON
Acetaldehyde	C	C	–	C	A	C
Acetic acid 20%	B	A	A	A	A	C
Acetic acid, 30%	C	A	A	A	A	C
Acetic acid glacial	C	A B	A	C	B	C
Acetic acid glacial	–	–	B(100°F)	–	–	–
Acetic anhydride	T	A	T	A	A	C
Acetone	C	B	B	B	A	C
Acetylene	–	B	A	B	A	A
Aluminum chloride solutions	T	A	T	A	A	A
Aluminum sulfate solutions	A	A(250 F)	T	A(158°F)	A	A
Ammonia, anhydrous	T	B	–	A	T	C
Ammonium chloride solutions	A	A	A	A	A	A
Ammonium hydroxide solutions	A	A(200°F)	T	A(158 F)	A	A
Ammonium sulfate solutions	A	A(200°F)	A	A(158°F)	A	A
Amyl acetate	C	C	B	C	A	C
Amyl alcohol	T	A(200°F)	A	A(158°F)	A	A(212°F)
Aniline	C	B	C	C	A	A B
Aniline	–	C(100 F)	–	–	–	B(158 F)
Aniline	–	–	–	–	–	C(300°F)
ASTM oil #1	A(158 F)	A	A(300°F)	A	C	A(300 F)
ASTM oil #3	B(158 F)	B(158 F)	A(300 F)	B(158°F)	C	A(350°F)
ASTM reference fuel A	A	A	A(158 F)	A	C	A
ASTM reference fuel B	B	C	A(158 F)	C	C	A
ASTM reference fuel C	C	C	A	C	C	A
ASTM reference fuel C	–	–	B(158°F)	–	–	A(258 F
Asphalt	–	B	T	B	X	A(400 F)
Barium hydroxide solutions	A	A(200°F)	T	A(158°F)	A	A
Beer	A	A	A	A	A	A
Benzaldehyde	–	C	–	C	A B	C
Benzene	C	C	B	C	C	B(158 F)
Benzoyl chloride	T	C	–	C	C	B
Borax solutions	A	A(200 F)	A	A(158 F)	A	A
Boric acid solutions	A	A(200 F)	A	A(158°F)	A	A
Bromine anhydrous liquid	X	B	X	C	C	A(212°F)
Butane	A	A	A	A	B	A
Butyl acetate	C	C	B	C	B	C
Butyraldehyde	T	B C	–	B C	B	C
Butyric acid	–	B C	T	C	X	T
Calcium bisulfite solutions	A	A(200 F)	–	A(158 F)	T	A
Calcium chloride solutions	A	A	A	A	A	A
Calcium hydroxide solutions	A	A(200°F)	T	A(158 F)	A	A
Calcium hypochlorite 5%	X	A	A	B	A	A
Calcium hypochlorite 20%	C	A(200°F)	–	B	A	B(158 F)
Carbon bisulfide	T	C	–	C	C	A
Carbon dioxide	A	A(200 F)	A	A	T	A
Carbon monoxide	A	A(200 F)	A	A	T	T
Carbon tetrachloride	C	C	B	C	C	A(158°F)
Castor oil	A	A(158°F)	B	A(158°F)	B	A
Chlorine gas dry	X	B	X	B	A	A(212°F)
Chlorine gas, wet	C	B	X	C	B	A
Chloroacetic acid	X	A	X	A	A	C
Chlorobenzene	X	X	X	X	X	A
Chloroform	C	C	C	C	C	A
Chlorosulfonic acid	C	C	C	C	C	C
Chromic acid, 10 50%	C	A(158°F)	X	C	C	A
Citric acid solutions	A	A	A	A	A	A
Copper chloride solutions	A	A	A	A	A	A
Copper sulfate solutions	A	A	A	A	A	A
Cottonseed oil	A	A	A	A	A B	A(300°F)
Creosote oil	T	C	–	C	C	A(212°F)
Cyclohexane	A	C	A	C	C	A
Dibutyl phthalate	C(158°F)	C	A	C	A	B
Diethyl sebacate	C	B	A	C	B	B
Dioctyl phthalate	C	C	A	C	B	B
DOWTHERM A	B	B	–	B	C	A(212°F)
DOWTHERM A	–	–	–	–	–	B(400 F)
Epichlorohydrin	–	T	X	–	B	C(122 F)
Ethyl acetate	C	C	B	C	A	C
Ethyl acetate	–	–	–	–	B(158°F)	–
Ethyl alcohol	C	A(200 F)	A	A(158 F)	A	A
Ethyl chloride	C	C	C	C	B	A
Ethyl ether	C	C	–	C	C	B
Ethylene dichloride	C(120°F)	C(120 F)	C	C(120 F)	B(120 F)	A B(120°F)
Ethylene glycol	B	A(200°F)	A	A(158 F)	A	A(250 F)
Ethylene oxide	T	X	A	X	X	C(158°F)
Exxon 2380 turbo oil (lubricant)	–	–	T	–	X	A(392 F)
Ferric chloride solutions	A	A(200°F)	T	A	A	A
Fluosilicic acid	T	A(250°F)	T	A(158 F)	T	T
Formaldehyde, 40%	C	A	B	A	A	A
Formaldehyde, 40%	–	C(158°F)	–	C(158 F)	–	–
Formic acid	C	A	B	A	A	C(158°F)
FREON*-11	B	A	T	A B	C	B
FREON 11	B(130°F)	T(130 F)	–	B(130 F)	–	T(130°F)
FREON-12	A	A	T	A	B	A B
FREON-12	A(130 F)	A(130 F)	–	A(130 F)	–	B(130°F)
FREON 22	C	A	–	A	C	C
FREON 22	C(130 F)	A(130 F)	–	A(130°F)	–	X(130°F)
FREON 113	A	A	A	A	C	A
FREON 113	T(130°F)	A(130 F)	A(130 F)	A(130 F)	–	T(130°F)
FREON 114	T	A	T	A	C	A
FREON-114	T(130°F)	T(130°F)	–	T(130°F)	–	–
Furfural	C	B	–	B	A	C(158 F)
Fyrquel 220 (hydraulic fluid)	–	–	T	–	–	A(212 F)
Gasoline	B	B	A	B	B C	A
Glue	A	A(200 F)	A	A(158°F)	A	A

*Freon is a registered trademark of E I du Pont de Nemours & Co (Inc)

Chemical	ADIPRENE	HYPALON	HYTREL	Neoprene	NORDEL	VITON
Glycerin	A	A(200 F)	A	A(158°F)	A	A(250 F)
n Hexane	B(122 F)	A	A	A	C	A
Hydrazine	—	—	C	—	A	C
Hydrochloric acid 20%	B	A	B	A	T	A
Hydrochloric acid 20%	—	A(158 F)	—	—	—	A(230 F)
Hydrochloric acid, 37%	C	A(122 F)	C	A	A	A(158 F)
Hydrochloric acid 37%	—	B(158 F)	—	—	—	—
Hydrochloric acid 37%	—	C(200 F)	—	C(200°F)	—	B(230 F)
Hydrocyanic acid	T	A	T	A	A	A
Hydrofluoric acid 48%	C	A(158 F)	X	A	B	A(212 F)
Hydrofluoric acid 75%	C	A	X	B	C	B(158 F)
Hydrofluoric acid anhydrous	C	A	X	B	C	A
Hydrogen	A	A	A	A	A	A
Hydrogen peroxide, 90%	T	A	—	B	T	A
Hydrogen peroxide 90%	—	—	—	—	—	C(270 F)
Hydrogen sulfide	T	A	A	A	A	B(270 F)
Isooctane	B(158°F)	A	A	A	X	A
Isopropyl alcohol	C	A(200 F)	A	A	T	A
Isopropyl ether	B	B	—	C	C	C
JP-4	B	C	A(100 F)	C	C	A(400 F)
JP 5	C	C	—	C	C	A(400 F)
JP 6	C	C	—	C	C	A(100 F)
JP 6	—	—	—	—	—	B(550 F)
Kerosene	B	B	T	C	C	A(158 F)
Kerosene	—	—	—	—	—	B(400 F)
Lacquer solvents	X	C	B	C	C	C
Lactic acid	T	A	T	A	A	A
Linseed oil	B	A	T	A	B	A
Lubricating oils	B	B(158 F)	A	B(158 F)	C	A(158 F)
Magnesium chloride solutions	A	A(220 F)	T	A(158°F)	A	A
Magnesium hydroxide solutions	A	A(200 F)	T	A(158°F)	A	A
Mercuric chloride solutions	—	A	T	A	A	A
Mercury	A	A	A	A	A	A
Methyl alcohol	C	A	A	A(158 F)	A	A B
Methyl ethyl ketone	C	C	A	C	A	C
Methylene chloride	C	C	C	C(100 F)	B	B(100 F)
Mineral oil	A	A	A	A	C	A
Mobil XRM 206A (aircraft eng lube)	—	—	T	—	—	A(350°F)
Naphtha	B	C	A	C	C	A(158 F)
Naphthalene	B	C	B	C(176 F)	C	A(176 F)
Nitric acid 10%	C	A	B C	B	B	A
Nitric acid 30%	C	A	C	C	B	A
Nitric acid, 30%	—	C(158 F)	—	—	C(158 F)	—
Nitric acid 60%	C	B	C	C	C	A
Nitric acid 70%	C	C	C	C	C	A
Nitric acid 70%	—	—	—	—	—	B(100 F)
Nitric acid red fuming	C	C	C	C	C	B
Nitric acid red fuming	—	—	—	—	—	C(158 F)
Nitrobenzene	C	C	C	C	A	B
Oleic acid	B	B	A	B	B	B
Oleum 20-25%	C	B	C	C	C	A
Palmitic acid	A	B	A	B(158 F)	B	A
Perchloroethylene	C	C	C	C	C	A(212 F)
Phenol	C	C	C	C	B	A(212 F)
Phenol	—	—	—	—	—	B(300 F)
Phosphoric acid 20%	A	A(200 F)	—	A	A	A
Phosphoric acid 60%	A	A(200 F)	X	A	A	A(212 F)
Phosphoric acid, 70%	A	A(200 F)	X	A	A	A
Phosphoric acid 85%	C	A(200 F)	X	A	A	A
Pickling solution (20% nitric acid, 4% HF)	C	A	X	C	C	A
Pickling solution (17% nitric acid 4% HF)	C	A(150 F)	X	C	C	A
Pickling solution (17% nitric acid, 4% HF)	—	—	—	—	—	C(225°F)

Chemical	ADIPRENE	HYPALON	HYTREL	Neoprene	NORDEL	VITON
Picric Acid	B	A	T	A	B	A
Potassium dichromate solutions	A	A(200°F)	T	A	A	A
Potassium hydroxide solutions	B	A(200°F)	A B	A(158°F)	A	A
Pydraul 312C	C	C	A	C	C	A
Pyridine	—	C	X	C	B	C
QFI 2023 (silicone brake fluid)	—	—	T	—	—	A(392°F)
SAE #10 oil	A(158°F)	C	A	C	C	A
Sea water	A	A	A	A	A	A
Shell turbine oil 307	—	T	T	T	X	B(392 F)
Silicone grease	A	A	A	A	A	A
SKYDROL 500	C(122 F)	C	A	C	A(250 F)	C
SKYLUBE 450	—	—	—	—	—	C(392 F)
Soap solutions	A	A(200 F)	A	A(158 F)	A(212 F)	A
Sodium chloride solutions	A	A	A	A	A	A
Sodium dichromate 20%	A	A(200 F)	T	B	A	A
Sodium hydroxide 20%	A	A(200°F)	A B	A	A	A
Sodium hydroxide 46½%	B	A	B	A	A	A
Sodium hydroxide 46½%	—	—	—	A(158°F)	—	C(100 F)
Sodium hydroxide 50%	C	A(285°F)	—	A	A	C
Sodium hydroxide 73%	C	A(280 F)	X	A	A	C
Sodium hypochlorite 5%	C	A	A	A	A	A
Sodium hypochlorite 20%	C	A(158 F)	T	B	A	B(158 F)
Sodium peroxide solutions	C	A(200 F)	—	A	A	A
Soybean oil	B	A	T	A	C	A(250 F)
Stannic chloride	—	B	—	B	—	A
Stannous chloride 15%	—	A(200 F)	T	A(158 F)	B	A
Steam (see water)	C	A	B(212 F)	A	A(350 F)	B(300 F)
Steam	—	—	C(230°F)	—	—	—
Stearic acid	A	B(158 F)	T	B(158 F)	B	T
Styrene	C	C	X	C	C	A
Sulfur molten	T	A	T	A	A	A(250 F)
Sulfur dioxide liquid	T	A	T	A	A	A
Sulfur dioxide gas	—	A	T	A	A	A
Sulfur trioxide	T	C	X	C	B	A
Sulfuric acid up to 5%	A	A	A	A	A	A
Sulfuric acid 5 10%	A	A	B	A	A	A
Sulfuric acid 10 50%	B C	A(250 F)	C	A(158 F)	B	A
Sulfuric acid 50 80%	C	A(158°F)	C	B C	C	A
Sulfuric acid 60%	C	A	C	B	C	A(250 F)
Sulfuric acid 90%	C	A	C	C	C	A(158 F)
Sulfuric acid, 95%	C	A B	C	C	B	A
Sulfuric acid 95%	—	B(122°F)	—	—	—	A(158 F)
Sulfuric acid fuming (20% oleum)	C	B C	C	C	C	A
Sulfurous acid	C	A(158 F)	B	C	C	A
Sunoco XS 820 (EP lubricant)	—	—	T	—	X	A(300 F)
Tannic acid 10%	A	A	A	A	A	A
Tartaric acid	A	A(200°F)	T	A(158 F)	B	A
Tetrahydrofuran	C	C	—	C	C	C
Toluene	C	C	B	C	C	B(100 F)
Tributyl phosphate	C	C	—	C	C	C(212 F)
Trichloroethylene	C	C	C	C	C	A
Trichloroethylene	—	—	—	—	—	B(158 F)
Tricresyl phosphate	B	C	—	C	A(212 F)	A(300 F)
Triethanolamine	C	A(158 F)	C	A(158 F)	A	C
Trisodium phosphate solutions	A	A	A	A	A	A
Tung oil	B	A	T	A	C	A
Turpentine	C	C	—	C	C	A(158 F)
Water	A(122 F)	A(158 F)	A(158 F)	A(158 F)	A(158 F)	A(158 F)
Water	C(212 F)	A(212 F)	B(212 F)	A(212 F)	A(212 F)	A(212 F)
Xylene	C	C	B	C	C	A
Xylene	—	—	—	—	—	B(158 F)
Zinc chloride solutions	A	A(200 F)	A	A	A	A

RATING KEY

A—Fluid has little or no effect
B—Fluid has minor to moderate effect
C—Fluid has severe effect

T—No data—likely to be compatible
X—No data—not likely to be compatible

Blanks indicate no evaluation has been attempted

Unless otherwise noted, concentrations of aqueous solutions are saturated All ratings are at room temperature unless specified

Acetals

Material →		Homopolymer[c]			Copolymer[d]		
		Standard	20% Glass Reinforced	22% TFE Filled	Standard	25% Glass Reinforced	High Flow
PHYSICAL PROPERTIES	ASTM						
Specific Gravity	D792	1 425	1 56	1 54	1 410	1 61	1 410
Ther Cond, Btu/hr/sq ft/°F/ft	—	0 13	—	—	0 16	—	1 6
Coef of Ther Exp, 10^5 per °F	D696	4 5	2 0 4 5	4 5	4 7	2 2 4 7	4 7
Specific Heat, Btu/lb/°F	—	0 35	—	—	0 35	—	0 35
Refractive Index, n_D	D542	Opaque	Opaque	Opaque	Opaque	Opaque	Opaque
Water Absorption (24 hr), %	D570	0 25	0 25	0 20	0 22	0 29	0 22
MECHANICAL PROPERTIES							
Tensile Strength, 1000 psi	D638						
Ultimate	—	10 0	8 5	6 9	8 8	18 5	8 8
Yield	—	10 0	—	—	8 8	18 5	8 8
Elongation, %	D638			12			
Ultimate	—	25	7	—	60 75	3	40
Yield	—	12	—	—	12	3	12
Mod of Elast in Ten, 10^5 psi	D638	5 2	—	—	4 1	12 5	4 13
Flex Strength, 1000 psi	D790	14 1	—	—	13	28	13
Mod of Elast in Flex, 10^5 psi	D790	4 1	8 8	4 0	3 75	11	3 75
Impact Str (Izod, notched), ft lb/in	D638	1 4	0 8	0 7	1 3	1 8	1 0
Compr Str (1%), 1000 psi	D695	5 2	5 2	4 5	4 5	—	4 5
Hardness (Rockwell)	D785	M94	M90	M78	M80	M79	M80
Coef of Static Frict (against steel)	—	0 1 0 3	0 1 0 3	0 05 0 15	0 15	0 15	0 15
Abr Res (Taber, CS 17), mg/1000 cyc	D1044	14 20	33	9	14	40	14
ELECTRICAL PROPERTIES							
Volume Resistivity, ohm cm	D257	1 x 10^{15}	5 x 10^{14}	—	1 x 10^{14}	1 2 x 10^{14}	1 0 x 10^{14}
Dielectric Str (short time), vpm	D149	500	500	—	500	580	500
Dielectric Constant	D150						
60 cycles	—	3 7	4 0	—	3 7 @ 100	3 9 @ 100	3 7 @ 100
10^6 cycles	—	3 7	4 0	—	3 7	3 9	3 7
Dissipation Factor	D150						
60 cycles	—	0 0048	0 0047	—	0 001 @ 100	0 003 @ 100	0 001 @ 100
10^6 cycles	—	0 0048	0 0036	—	0 006	0 006	0 006
Arc Resistance, sec	D495	129[b]	188	—	240	136	240
HEAT RESISTANCE							
Max Rec Service Temp, F	—	195	195	195	220	220	220
Deflection Temp, F	D648						
66 psi	—	338	345	329	316	331	316
264 psi	—	255	3 5	212	230	325	230
APPLICABLE PROCESSING METHODS		Injection molding, extrusion, rotational molding, blow molding			Injection molding, extrusion, rotational molding, blow molding		
CHEMICAL RESISTANCE		Excellent res to most organic solvents, including aliphatic and aromatic hydrocarbons Not rec for use with strong acids and alkalis	Same as standard homopolymer	Same as standard homopolymer	Excellent res to strong alkalis Most organic solvents including alcohols ketones, esters, aliphatic and aromatic hydrocarbons and glycols do not seriously alter properties Not recommended for use in strong mineral acids and oxidizing reagents		
USES		Appliance parts gears bushings aerosol bottles auto, plumbing textile, consumer uses	Same as homopolymer Where high stiffness and dimensional stability are required	Same as homopolymer Where low friction and high resistance to wear are required	Appliance parts, gears, bushings aerosol bottles, various automotive, plumbing, textile machinery and consumer products		

a 10% deformation b 15 mil specimen c ' Delrin is most common tradename d ' Celcon' is most common tradename

Acrylics

Type →		Cast Sheets, Rods		Moldings		
		General Purpose Type I[a]	General Purpose Type II[a]	Grades 5, 6, 8[b]	High Impact Grade	Modified (XT acrylic)
PHYSICAL PROPERTIES	ASTM					
Specific Gravity	D792	1 17 1 19	1 18-1 20	1 18 1 19	1 12 1 16	1 10 1 12
Ther Cond, Btu/hr/sq ft/°F/ft	[c]	0 12	0 12	0 12	0 12	0 13
Coef of Ther Exp, 10^{6} per °F	D696	4 5	4 5	3-4	4 6	4 4 4 5
Spec Ht, Btu/lb/°F	—	0 35	0 35	0 35	0 34	0 33
Refractive Index	D542	1 485 1 500	1 485 1 495	1 489 1 493	—	1 51
Transmittance (luminous, 0 125 in), %	D791	91 92	91 92	>92	—	86 88
Haze, %	D672	1 2	1 2	<3	—	—
Water Absorption (24 hr), %	D570	0 3 0 4	0 2 0 4	0 3 0 4	0 2 0 3	0 3
MECHANICAL PROPERTIES						
Mod of Elast in Tension, 10^5 psi	D638	3 5 4 5	4 0 5 0	3 5 5 0	2 3 3 3	3 7 4 3
Ten Str, 1000 psi	D638	6 9	8 10	9 5 10 5	5 5 8 0	7 0 8 0
Elong (in 2 in), %	D638	2 7	2-7	3 5	>25	12 30
Hardness (Rockwell)	D785	M80 90	M96 102	M80 103	L60 94	M45 68
Impact Str (Izod notched), ft lb/in	D256	0 4	0 4	0 2 0 4	0 8 2 3	1 2
Mod of Elast in Flex 10^5 psi	D790	3 5 4 5	4 0 5 0	3 5 5 0	2 8 3 6	3 5 4 0
Flex Str, 1000 psi	D790	12 14	15 17	15 16	8 7 12 0	11 13
Compr Yld Str (0 1% offset), 1000 psi	D695	12-14	14 18	14 5 17	7 3 12 0	9 5 11 5
ELECTRICAL PROPERTIES						
Vol Res ohm cm	D257	$>10^{15}$	$>10^{15}$	$>10^{14}$	$2 0 \times 10^{16}$	$>10^{16}$
Dielec Str (short time), v/mil	D149	450 530	450 500	400	400 500	400 500
Dielec Const						
60 Cycles	D150	3 5 4 5	3 5 4 5	3 5 3 9	3 5 3 9	—
10^6 Cycles	D150	2 7-3 2	2 7 3 2	2 7 2 9	2 5 3 0	2 78 2 86
Dissip Factor						
60 Cycles	D150	0 05 0 06	0 05 0 06	0 04 0 06	0 03 0 04	0 026 0 029
10^6 Cycles	D150	0 02 0 03	0 02 0 03	0 02 0 03	0 01 0 02	0 022 0 025
Arc Resistance, sec		No track	No track	No track	No track	No track
APPLICABLE PROCESSING METHODS		Thermoforming, casting		Injection molding, extrusion, thermoforming, blow molding		Injection molding, extrusion thermoforming, blow molding
HEAT RESISTANCE						
Max Recommended Svc Temp, F		140 160	180 200	155 190	—	160
Heat Dist Temp, F		150 180	190 225	166 250[d]	169 205	195 (264 ps)
CHEMICAL RESISTANCE		Resists weak alkalis, acids and aliphatic hydrocarbons Attacked by esters, ketones aromatic hydrocarbons, chlorinated hydrocarbons and concentrated acids				
USES		Transparent aircraft enclosures, radio and television parts lighting, drafting equipment, signs		Decorative and functional automotive parts, reflectors, protective goggle lenses, radio and television parts, appliances	Shoe heels, control knobs business machine and piano keys, pump parts, sprinkler heads, tool handles	Packaging lenses containers, shields

[a] ASTM D702 [b] Range includes typical values for Grades 5 6 and 8 and may be super or to minimum or maximum requirements for these grades as detailed in ASTM D788 [c] Cenco Fitch [d] D788 specified values for Grades 5 6 and 8 149 F, 162 F 183 F respectively

Alkyds and Thermoset Carbonate

Material →		Allyl Diglycol Carbonate	Alkyds			
			Putty (encapsulating)	Rope (general purpose)	Granular (high speed molding)	Glass Reinforced (heavy duty parts)
PHYSICAL PROPERTIES	ASTM					
Specific Gravity	D792	1 32	2 05–2 15	2 20–2 22	2 21–2 24	2 02–2 10
Ther Cond, Btu/hr/sq ft/°F/in	—	1 45	0 35–0 60	0 35–0 60	0 35–0 60	0 20–0 30
Coef of Ther Exp, per °F	D696	6×10^{-5}	$1\ 3 \times 10^{-5}$	$1\ 3 \times 10^{-5}$	$1\text{-}3 \times 10^{-5}$	$1\text{-}3 \times 10^{-5}$
Specific Heat, Btu/lb/°F	—	0 3	—	—	—	—
Water Absorption (24 hr), %	D570	0 20	0 10–0 15	0 05–0 08	0 08–0 12	0 07–0 10
Transparency (visible light), %	—	89–92	Opaque	Opaque	Opaque	Opaque
Refractive Index, n_D	D542	1 50	—	—	—	—
MECHANICAL PROPERTIES						
Tensile Strength, 1000 psi	D638	5–6	4–5	7–8	3–4	5–9
Tensile Mod, 10^5 psi	D638	3 0	20–27	19–20	24–29	20–25
Elongation, %	D638	—	—	—	—	—
Impact Str (Izod notched), ft lb/in	D256	0 2–0 4	0 25–0 35	2 2	0 30–0 35	8–12
Flex Strength, 1000 psi	D790	—	8–11	19–20	7–10	12–17
Mod of Elast in Flex, 10^5 psi	D790	2 5–3 3	—	22–27	22–27	22–28
Compr Strength, 1000 psi	D690	22 5	20–25	28	16–20	24–30
Hardness (Barcol)	D785	M95–M100 (Rockwell)	60–70	70–75	60–70	70–80
ELECTRICAL PROPERTIES						
Volume Resistivity, ohm cm	D257	4×10^{14}	10^{14}	10^{14}	$1 \times 10^{14}\text{–}1 \times 10^{15}$	10^{14}
Dielectric Str (step by step), v/mil	D149	290	300–350	290	300–350	300–350
Dielectric Constant	D150					
60 cycles		4 4	5 4–5 9	7 4	5 7–6 3	5 2–6 0
10^6 cycles		3 5 3 8	4 5–4 7	6 8	4 8–5 1	4 5–5 0
Dissipation Factor	D150					
60 cycles		0 03 0 04	0 030–0 045	0 019	0 030–0 040	0 02–0 03
10^6 cycles		0 1-0 2	0 016–0 020	0 023	0 017–0 020	0 015–0 022
Arc Resistance, sec	D495	185	180	180	180	180
APPLICABLE PROCESSING METHODS		Casting	Injection molding, compression molding, transfer molding			
HEAT RESISTANCE						
Max Rec Service Temp, F	—	212	250	300	300	300
Deflection Temp (264 psi), F	D648	—	350–400	>400	350–400	>400
CHEMICAL RESISTANCE		Resists nearly all solvents including acetone, benzene and gasoline, and practically all chemicals except highly oxiding acids	Resistant to weak acids, attacked by alkalis, practically unattacked by organic liquids such as alcohols, hydrocarbons and fatty acids			
USES		Aircraft windows, lenses, marine glazing, vending machine windows, slides, watch crystals, safety windows	Encapsulation of resistors, coils and small electronic parts	Molding of tube bases and sockets, connectors, tuning devices, electrical instrument parts, switches and relays Parts for transformers, motor controllers and automotive ignition systems		Heavy duty circuit breaker and switchgear, stand off insulators, electrical motor brush holders and end plates

Alloys—ABS/polycarbonate, ABS/PVC, Acrylic/PVC, ABS/Polysulfone, ABS/Polyurethane

Material →		ABS/ Polycarbonate	ABS/PVC (rigid)	Acrylic/ PVC	ABS/Poly-sulfone (Polyaryl ether)	ABS/Poly-urethane
PHYSICAL PROPERTIES	ASTM					
Specific Gravity	D792	1 19	1 21	1 28-1 35	1 14	1 04 1 07
Refractive Index, nD	D542	—	—	—	—	—
Transparency (visible light), %	D1003	Opaque	Opaque	Translucent to opaque	Opaque	Opaque
MECHANICAL PROPERTIES						
Tensile	D638					
Str (yield), 1,000 psi		8 0	6 0	6 5-7 0	7 5	3 7-4 5
Elong (ult), %		—	—	75 150	25 90	120 200
Modulus, 1,000 psi		370	330	335 370	320	160 220
Flexural	D790					
Str, 1,000 psi		13 7	10 2	10 7 11	11	5 3 7 1
Modulus, 1,000 psi		380	340	380 400	300	150 210
Compressive str, 1,000 psi (2% offset)	D695	—	7 4	8 4	—	3 6 4 8
Impact str						
Izod (notched), ft lb/in	D256	10 5	12 5	12 15	8 0 10 0	8 4 10 1
Gardner, lb/in		—	—	—	—	—
Hardness						
Rockwell	D785	R117	R102	R110 105	R117	R70 82
Shore	D785	—	—	—	—	—
Bending fatigue str (Woehler), 1,000 psi	D671	—	—	—	—	—
Abrasion res (Taber, CS 17 wheel, 1000g) mg/100 cycles	D1044	—	—	40	—	30 35
Coef of friction	D1894					
Against self		—	—	—	0 28	—
Against steel		—	—	—	0 31	—
ELECTRICAL PROPERTIES						
Vol res ohm cm	D257	10^{15} x 10^{16}	—	1 6 x 10^{15}	1 5 x 10^{16}	—
Dielec str, v/mil (dry)	D149					
Short time		1250 1550	600	430 670	430	—
Step by step		—	—	647	—	—
Dielec constant (dry)	D150					
60 Hz		3 08	—	3 33 3 86	3 14	—
10^6 Hz		3 2 3 6	—	3 06 3 44	3 10	—
Dissip factor (dry)	D150					
60 Hz		0 019 0 021	—	0 016	0 006	—
10^6 Hz		0 020	—	0 017	0 007	—
Arc res, sec	D495	—	—	42 80	180	—
THERMAL PROPERTIES						
Ther cond, Btu/hr/sq ft/°F/in	C177	0 95	—	1 01	2 07	—
Coef of ther exp, 10^{-5}/°F	D696	37	4 6	3 5 4 4	—	11 6 12 1
Specific heat, Btu/lb/°F		0.3	—	0 293	0 35	—
Heat deflection, °F	D648					
At 66 psi		238	—	177 205	320	214 216
At 264 psi		220	—	160 185	300	201 207
Brittleness temp, °F	D746	—	—	−46	—	—
Max temp for continuous use (no load), F	—	190 200	—	—	—	—
CHEMICAL AND ENVIRONMENTAL RESISTANCE						
Water absorption, %	D570					
In 24 hr		—	0 12	0 06 0 09	—	0 35 0 41
Saturation		—	—	—	—	—
Weathering		Slight effect	Slight effect	Resist	Embrittles	Slight effect
Acids						
Weak		Resist	Resist	Resist	Resist	Resist
Strong		Attack	Attack	Attack	Resist	Attack
Alkalis						
Weak		Resist	Resist	Resist	Resist	Resist
Strong		Resist	Resist	Resist	Resist	Resist
Organic solvents		Attack	Attack	Attack	Attack	Attack
Fuel		—	—	—	—	Attack
Oil and grease		—	—	—	—	—
METHODS OF PROCESSING		Inj mldg	Inj mldg, extrusion, thermoforming	Extrusion, thermoforming	Inj mldg extrusion	Inj mldg, extrusion, thermoforming

Cellulose Acetate

ASTM Grade[a] →		H6-1	H4-1	H2-1	MH-1, MH-2	MS-1, MS-2	S2-1
	ASTM						
PHYSICAL PROPERTIES							
Specific Gravity	D792		1 29–1 31	1 25–1 31	1 24–1 31	1 23–1.30	1 22–1 30
Ther Cond, Btu/hr/sq ft/°F/ft	C177	0 10–0 19	0 10–0 19	0 10–0 19	0 10–0 19	0 10–0 19	0 10–0 19
Coef of Ther Exp, 10^{-5} per °F	D696	4 4–9 0	4 4–9 0	4 4–9 0	4 4–9 0	4 4–9 0	4 4–9 0
Refractive Index	D542	1 46–1 50	1 46–1 50	1 46–1 50	1 46–1 50	1 46–1 50	1 46–1 50
Spec Ht, Btu/lb/°F	—	0 3–0 42	0 3–0 42	0 3–0 42	0 3–0 42	0 3–0 42	0 3–0 42
Luminous Transmittance, %	D791	75–90	75–90	80–90	80–90	80–90	80–95
Haze, %	D672	2–15	2–15	2–10	2–10	2–10	2–8
Water Absorption (24 hr), %	D570	—	1 7–2 7	1 7–2 7	1 8–4 0	2 1–4 0	2 3–4 0
Flammability, ipm[b]	D635	0 5–2 0	0 5–2 0	0 5–2 0	0 5–2 0	0 5–2 0	0 5–2 0
MECHANICAL PROPERTIES							
Ten St at Fracture, 1000 psi	D638	—	7–8	5 8–7 2	4 8–6 3	3 9–5 3	3 0–4 4
Hardness (Rockwell R)	D785	—	103–120	89–112	74–104	54–96	49–88
Impact Str (Izod), ft-lb/in of notch	D256	—	1 1–3 1	1 5–3 9	2 5–4 9	2 9–6 5	4 0–6 8
Modulus of Elast in Flex, 10^5 psi	D747	—	2 0–2 55	1 50–2 35	1 50–2 15	1 25–1 90	1 05–1 65
Flex Str at Yield, 1000 psi	D790	—	8 1–11 15	6 0–10 0	4 4–8 65	3 8–7 1	3 5–5 7
Compr Str at Yield, 1000 psi	D695	—	6 5–10 6	4 3–9 6	4 4–8 4	3 2–7 2	3 15–6 1
ELECTRICAL PROPERTIES							
Vol Res, ohm cm	D257	10^{10}–10^{13}	10^{10}–10^{13}	10^{10}–10^{13}	10^{10}–10^{13}	10^{10}–10^{13}	10^{10}–10^{13}
Dielec Str (short-time), v/mil	D149	250–600	250–600	250–600	250–600	250–600	250–600
Dielec Const							
60 Cycles	D150	3 5–7 5	3 5–7 5	3 5–7 5	3 5–7 5	3 5–7 5	3 5–7 5
10^6 Cycles	D150	3 2–7 0	3 2–7 0	3 2–7 0	3 2–7 0	3 2–7 0	3 2–7 0
Dissip Factor							
60 Cycles	D150	—	0 01–0 06	0 01–0 06	0 01–0 06	0 01–0 06	0 01–0 06
10^4 Cycles	D150	—	0 01–0 10	0 01–0 10	0 01–0 10	0 01–0 10	0 01–0 10
APPLICABLE PROCESSING METHODS		Injection molding, extrusion, thermoforming, rotational molding, blow molding foam					
HEAT RESISTANCE							
Heat Deflection Temp, F							
66 psi		—	172–203	145–188	145–170	136–153	132–141
264 psi		—	145–188	120–172	128–155	123–141	117–129
CHEMICAL RESISTANCE		Unattacked by water, salt water solutions, white gasoline, oleic acid, 5% acetic acid and dilute sulfuric acid Decomposed by 30% sulfuric, 10% nitric and 10% hydrochloric acids, sodium hydroxide, and 10% ammonium hydroxide Dissolved by acetone and ethyl acetate					
USES		Film, tape, blister packaging, appliance housings, optical parts, tool handles, brush handles, toys and novelties, toothbrushes, buttons, tags					

[a] According to ASTM D706–68 [b] Self-extinguishing compositions are available.

Cellulose Acetate Butyrate and Cellulose Acetate Propionate

ASTM Grade* →		Cellulose Acetate Butyrate			Cellulose Acetate Propionate		
		H4	MH	S2	1	3	6
PHYSICAL PROPERTIES	ASTM						
Specific Gravity	D792	1 22	1 18–1 20	1 15–1 18	1 22	1 20–1 21	1 19
Ther Cond, Btu/hr/sq ft/°F/ft	C177	0 10–0 19	0 10–0 19	0 10–0 19	0 10–0 19	0 10–0 19	0 10–0 19
Coef of Ther Exp, 10^{-5} per °F	D696	(6–9) x 10^{-5}	(6–9) x 10^{-5}	(6–9) x 10^{-5}	(6–9) x 10^{-5}	(6–9) x 10^{-5}	(6–9) x 10^{-5}
Refractive Index	D543	1 46–1 49	1 46–1 49	1 46–1 49	1 46–1 49	1 46–1 49	1 46–1 49
Spec Ht, Btu/lb/°F		0 3–0 4	0 3–0 4	0 3–0 4	0 3–0 4	0 3–0 4	0 3–0 4
Luminous Transmittance, %	D791	75–92	80–92	85–95	80–92	80–92	80–92
Haze, %	D672	2–5	2–5	2–5	2–5	2–5	2–5
Water Absorption (24 hr), %	D570	2 0	1 3–1 6	0 9–1 3	1 6–2 0	1 3–1 8	1 6
Flammability, ipm	D635	0 5–1 5	0 5–1 5	0 5–1 5	0 5–1 5	0 5–1 5	0 5–1 5
MECHANICAL PROPERTIES							
Ten Str at Fracture, 1000 psi	D638	6 9	5 0–6 0	3 0–4 0	5 9–6 5	5 1–5 9	4 0
Hardness (Rockwell R)	D785	114	80–100	23–42	100–109	92–96	57
Impact Str (Izod), ft-lb/in of notch	D256	3 0	4 4–6 9	7 5–10 0	1 7–2 7	3 5–5 6	9 4
Modulus of Elast in Flex, 10^5 psi	D747	1 80	1 20–1 40	0 70–0 90	1 7–1 8	1 45–1 55	1 1
Flex Str at Yield, 1000 psi	D790	9 0	5 6–6 7	2 5–3 95	6 8–7 9	5 6–6 2	—
Compr Str at Yield, 1000 psi	D695	8 8	5 3–7 1	2 6–4 3	6 2–7 3	4 9–5 8	—
ELECTRICAL PROPERTIES							
Vol Res, ohm cm	D257	10^{11}–10^{14}	10^{11}–10^{14}	10^{11}–10^{14}	10^{11}–10^{14}	10^{11}–10^{14}	10^{11}–10^{14}
Dielec Str (short time), v/mil	D149	250–400	250–400	250–400	300–450	300–450	300–450
Dielec Const							
60 Cycles	D150	3 5–6 4	3 5–6 4	3 5–6 4	3 7–4 0	3 7–4 0	3 7–4 0
10^6 Cycles	D150	3 2–6 2	3 2–6 2	3 2–6 2	3 4–3 7	3 4–3 7	3 7–3 4
Dissip Factor							
60 Cycles	D150	0 01–0 04	0 01–0 04	0 01–0 04	0 01–0 04	0 01–0 04	0 01–0 04
10^6 Cycles	D150	0 02–0 05	0 02–0 05	0 02–0 05	0 02–0 05	0 02–0 05	0 02–0 05
APPLICABLE PROCESSING METHODS		Injection molding, extrusion, thermoforming, rotational molding, blow molding			Injection molding, extrusion, thermoforming, rotational molding, blow molding		
HEAT RESISTANCE							
Heat Deflection Temp, °F							
66 psi		222	171–184	136–147	191–201	169–187	163
264 psi		196	146–160	118–130	163–173	141–157	129
CHEMICAL RESISTANCE		Unaffected by 3% sulfuric, 5% acetic, 10% hydrochloric and oleic acids, discolored by 10% nitric acid Unaffected by 1% sodium hydroxide and 2% sodium carbonate, slightly softened by 10% sodium hydroxide and discolored by 10% ammonium hydroxide, Unaffected by white gasoline, but swollen or dissolved by ethyl alcohol, acetone, ethyl acetate, ethylene dichloride, carbon tetrachloride and toluene Unaffected by water, salt water and 3% hydrogen peroxide					
USES		Vacuum-formed outdoor signs and molded letters, blister packaging, TV and radio knobs, handles, pipe, pens, optical parts, containers			Telephones, steering wheels, blister packaging, toothbrushes, pens, knobs, containers, optical parts		

*According to ASTM D707-63 and D1562-60, respectively

Diallyl Phthalates

Type ➔		Orlon-Filled	Dacron-Filled	Asbestos-Filled	Glass Fiber-Filled
PHYSICAL PROPERTIES	ASTM				
Specific Gravity	D792	1.31-1.35	1.40-1.65	1.50-1.96	1.55-1.85
Coef of Ther Exp, per °F	D696	5.0×10^{-5}	5.2×10^{-5}	4.0×10^{-5}	$2.2\text{-}2.6 \times 10^{-5}$
Water Abs (122 F 48 hr), %	–	0.2-0.5	0.2-0.5	0.4-0.7	0.2-0.4
MECHANICAL PROPERTIES					
Mod of Elast in Tension, psi[a]	D638	6×10^5	–	12×10^5	–
Ten Str, psi	D638	4500-6000	4600-5500	4000-6500	5500-9500
Hardness (Rockwell)	D785	M108	–	M107	M108
Impact Str (Izod notched), ft-lb/in.	D256	0.5-1.2	1.7-4.5	0.30-0.50	0.5-15.0
Flex Str, 1000 psi	D790	7.5-10.5	9-11.5	8-10	10-18
Compr Str, 1000 psi	D695	20-25	20-30	18-25	25
ELECTRICAL PROPERTIES					
Dielec Str, v/mil					
Short Time (dry)	D149	400	376-390	350-450	350-430
Short Time (wet[b])	D149	375	360-391	300-400	300-420
Step-by-Step (dry)	D149	350	350-374	300-400	300-420
Step-by-Step (wet[b])	D149	325	350-361	250-350	275-420
Dielec Breakdown, kv					
Short Time (dry)	–	65-75	65	55-80	63-70
Short Time (wet[b])	–	60-65	60	55	45-65
Step-by-Step (dry)	–	55-60	60	38-70	55-65
Step-by-Step (wet[b])	–	46-60	55	39-60	45-65
Dissip Factor[c]					
Dry	D150	0.023, 0.015	0.008, 0.015	0.05, 0.03	0.01, 0.015
Wet[d]	D150	0.045, 0.040	0.009, 0.017	0.154, 0.050	0.012, 0.020
Dielec Const[c]					
Dry	D150	3.9, 3.3	3.8, 3.6	5.2, 4.5	4.5, 4.2
Wet[d]	D150	4.1, 3.4	3.9, 3.7	6.5, 4.8	4.6, 4.4
Vol Res, megohm-cm[d]	D257	60,000-6,000,000	100-25,000	100-5000	10,000-50,000
Surface Res, megohms[d]	D257	25,000-2,500,000	500-25,000	100-5000	10,000-100,000
Arc Resistance, sec	D495	85-115	105-125	125-140	125-135
APPLICABLE PROCESSING METHODS		Injection molding, compression molding, transfer molding, layup molding			
HEAT RESISTANCE					
Max Recommended Svc Temp, F	–	300	300-370	350-450	400-450
Heat Dist Temp, F	D648	240-266	270-290	300-350	350-500
CHEMICAL RESISTANCE		Unaffected by weak acids and alkalis and organic solvents. Slightly affected by strong acids and alkalis			
USES		Molding compounds—connectors, potentiometers, plugboards, housings, appliance fixtures, resistors, insulators, etc Prepregs—radomes, aircraft leading edges, housings, nose cones, air ducts, etc Laminates—decorative sheets for surfacing real and grain-printed wood and fabrics, etc			

[a] Conditioned 48 hr at 122 F [b] Tested after 48-hr immersion in water at 122 F [c] Values given for frequencies of 1 kc and 1 mc, in that order [d] Conditioned 30 days at 100% RH and 158 F [e] Flame-resistant type is available [f] 480 hr, 257 F

Epoxies

Type →		Standard Epoxies (Diglycidyl Ether of Bisphenol A)					
		Cast Rigid[a]	Cast Flexible[b]	Molded[c]	Unidirectional Laminate	High Strength Laminate[e]	Filament Wound Composite[f]
PHYSICAL PROPERTIES	ASTM						
Specific Gravity	D792	1 15	1 14–1 18	1 80–2 0	1 8	1 84	2 18–2 17
Ther Cond, Btu/hr/sq ft/°F/ft	D325	0 1–0 3	—	0 1–0 5	—	2 35	—
Coef of Ther Exp, 10^{5} per °F	D696	3 3	3 5	1–2	3 3–4 8 x 10^{-6}	3 3–4 8 x 10^{-6}	2 6
Specific Heat, Btu/lb/°F	—	0 4–0 5	—	—	—	0 21	0 24
Water Absorp (24 hr), %	D570	0 1–0 2	0 4–1 0	0 3–0 8	0 05–0 07	0 05	0 05–0 07
Transparency (visible light), %	—	90	85	Opaque	Opaque	Opaque	Opaque
Refractive Index, n_D	D542	1 61	1 61	—	—	—	—
MECHANICAL PROPERTIES							
Tensile Str, 1000 psi	D638	9 5–11 5	1 4–7 6	8–11	50–58	160	230–240 (Hoop)
Tensile Mod, 10^{5} psi	D638	4 5	0 5–2 5	—	33–36	57–58	72–64
Elongation, %	D638	4 4	1 5–60	—	—	—	—
Impact Str (Izod notched), ft-lb/in	D256	0 2–0 5	0 3–2 0	0 4–0 5	12–15	60–61 (edgewise)	—
Flexural Str, 1000 psi	D790	14–18	1 2–12 7	19–22	80–90	165–177	180–170
Mod of Elast in Flex, 10^{5} psi	D790	4 5–5 4	0 36–3 9	15–25	36–39	53–55	69–75
Compr Strength, 1000 psi	D695	16 5–24	—	34–38	50–60	80–90 (edgewise)	—
Hardness (Rockwell)	D785	106M	50–100M	75–80 (Barcol)	115–117M	70–72 (Barcol)	98–120M
ELECTRICAL PROPERTIES							
Vol Resist, ohm cm	D257	6 1 x 10^{15}	9 1 x 10^{8}— 6 7 x 10^{9}	1–5 x 10^{15}	—	6 6 x 10^{7}–10^{9}	—
Dielectric Str (step by step), v/mil	D149	>400	400–410	360–400	450–550	650–750	—
Dielectric Constant	D150						
60 cycles		4 02	4 43–4 79	4 4–5 4	5 3–5 4	—	—
10^{6} cycles		3 42	2 78–3 52	4 1–4 6	4 7–4 8	4 8–5 2	—
Dissipation Factor	D150						
60 cycles		0 0074	0 0048–0 0380	0 011–0 018	0 004–0 006	—	—
10^{6} cycles		0 032	0 0369–0 0622	0 013–0 020	0 024–0 026	0 010–0 017	—
Arc Resistance, sec	D495	100	75–98	135–190	130–180	—	—
APPLICABLE PROCESSING METHODS		Casting	Casting	Injection, compression and transfer molding	Layup molding	Layup molding	Filament winding
HEAT RESISTANCE							
Max Rec Svc Temp, F	—	175–190	100–125	<400	250–350	250–350	250–350
Heat Deflection Temp (264 psi), F	D648	230	90–155	340–400	—	—	280–295
CHEMICAL RESISTANCE		Highly res to water and strong alkaline environments, less res to sulfuric and acetic acids, and oxidizing agents					
USES		Potting and encapsulation of electronic components, precision castings, tools and dies, patching compounds		Electrical moldings, such as condensers, switch plates, connector plugs, resistor bobbins and wirewound resistors, molded coils, relay assemblies	High strength parts, such as laminated tools for metal forming, aircraft structural parts, pipe, leaf or coil springs, high strength electrical or chemical resistant parts		Rocket motor cases, chemical tanks, pipe, pressure bottles, high strength tubing, shotgun barrels, missile bodies

---

[a] 13 phr of TETA curing agent [b] 30 80 phr of flexible curing agent [c] Mineral glass reinforced [d] 23 phr aromatic amine curing agent, 12 plies E-181 glass cloth with Volan A finish [e] 36% resin, 64% unidirectional nonwoven glass fiber reinforcement [f] NOL rings made with 12 end E HTS glass, 15 phr metaphenylenediamine curing agent

Epoxies

Type →		Epoxy Novolacs			High Performance Resins (Cycloaliphatic Diepoxides)	
		Cast, Rigid[g]	Molded[h]	Glass Cloth Laminate[i]	Cast, Rigid[j]	Glass Cloth Laminate[k]
PHYSICAL PROPERTIES	ASTM					
Specific Gravity	D792	1 24	1 7	1 97	1 22	1 97
Ther Cond, Btu/hr/sq ft/°f/ft	—	—	—	—	—	—
Coef of Ther Exp, per °F x 10^{6}	D696	—	1 7–2.2	—	1 6–3 0	—
Specific Heat	—	—	—	—	—	—
Water Absorption (24 hr), %	D570	—	0 11–0 2	0 04–0 06	0 1–0 7[l]	—
Transparency (visible light), %	—	—	Opaque	Opaque	—	Opaque
MECHANICAL PROPERTIES						
Tensile Strength, 1000 psi	D638	8–12	5 2–5 3	50–52	9 6–12 0	59 2
Tensile Modulus, 10^{5} psi	D638	4–5	—	32–33	4 8–5 0	27 5
Elongation, %	D638	2–5	—	—	2 2–4 8	—
Impact Str (Izod notched), ft-lb/in	D256	0 5	0 3–0 5	13–17	—	—
Flexural Strength, 1000 psi	D790	11–16	10–12	70–72	12–13	84–89
Mod of Elast in Flex, 10^{5} psi	D790	4–5	—	28–31	4 4–4 8	32–35
Compr Strength, 1000 psi	D695	17–19	22–26	67–71	30–50	48–57
Hardness (Rockwell)	D785	107–112[m]	94–96D[n]	75–80	—	—
ELECTRICAL PROPERTIES						
Volume Resistivity, ohm-cm	D257	2 10 x 10^{14}	1 4–5 5 x 10^{14}	—	$> 10^{16}$	—
Dielectric Str (step by-step), v/mil	D149	—	280–400	—	444 (short time)	—
Dielectric Constant	D150					
60 cycles		3 96–4 02	4 7–5 7	—	3 34–3 39	4 41–4 43
10^{6} cycles		3 53–3 58	4 3–4 8	5 1[m]	—	—
Dissipation Factor	D150					
60 cycles		0 0055–0 0074	0 0071–0 025	—	0 001–0 007	—
10^{6} cycles		0 029–0 028	—	0 015[m]	—	—
Arc Resistance, sec	D495	—	180–185	—	120	—
APPLICABLE PROCESSING METHODS		Casting	Injection molding, compression molding, transfer molding	Reinforced layup molding	Casting	Reinforced layup molding
HEAT RESISTANCE						
Max Rec Svc Temp, F	—	450	450–500	450–500	450–500	450–500
Heat Deflection Temp (264 psi), F	D648	300–400	300–425	—	300–525	—
CHEMICAL RESISTANCE		Res water and strong alkalis, more res to sulfuric and acetic acid and oxidizing agents than standard epoxy systems			Outstanding weather res compared to other epoxy systems Highly res to water, strong alkaline environments, less res to sulfuric and acetic acids, oxidizing agents	
USES		Impregnation and potting requiring high heat res, adhesives	Electrical and electronic encapsulation designed for high temp	High temp tooling, structural laminates, ablatives	Encapsulation, impregnation and potting req outstanding arc and tracking res	Electrical laminates req outstanding weather res

[g] 28 phr methylene dianiline, cure–16 hr at 130 F, 2 hr at 257 F, 2 hr at 347 F [h] Mineral-filled proprietary compounds [i] 12 plies glass cloth with Volan A finish, 26–27% resin, cure–20 min at 383 400 F and contact pressure, plus 24 min at 419 F post cure [j] 12 phr of hexahydrophthalic and anhydride, 12 phr sodium alcoholate accelerator, cure–24 phr at 250 F and post cure of 3 phr at 400 F [k] 100 phr resin, 85 parts anhydride curing agent, 181 Volan glass cloth, [l] 1 hr at 212 F [m] 1 mc [n] Durometer

Fluorocarbons

Type →		Polytrifluorochloroethylene (PTFCE)	Polytetrafluoroethylene (PTFE)	Ceramic-Reinforced (PTFE)	Fluorinated Ethylene Propylene (FEP)	Polyvinylidene fluoride (PVF₂)	ETFE & ECTFE		PFA
							Std	Glass reinf	
PHYSICAL PROPERTIES	ASTM								
Specific Gravity	D792	2 10 2 15	2 1 2 3	2 2 2 4	2 14 2 17	1 77	1 68	1 86	2 12 2 17
Ther Cond, Btu/hr/sq ft/°F/ft	•	0 145	0 14	—	0 12	0 14	—	—	—
Coef of Ther Exp, per °F x 10^{-5}	D696	3 88	5 5	1 7 2 0	8 3 10 5	8 5	14	1 7	6 7 11 1
Refractive Index	D542	1 43	1 35	—	1 34	1 42	1 44	—	—
Specific Heat, Btu/lb/°F		0 22	0 25	—	0 28	0 33	—	—	—
Transmittance (luminous) %	D791	80 92	—	—	—	—	0 7 0 8	—	—
Water Absorption (24 hr), %	D570	0 00	0 01	> 2	0 01	0 03	—	0 01	0 03
MECHANICAL PROPERTIES									
Mod of Elast in Compr, psi	D638	1 8 x 10	0 70 0 90 x 10^{5}	1 5 2 0 x 10^{5}	0 6 0 8 x 10^{5}	1 7 2 x 10^{5}	—	—	—
Mod of Elast in Tension, psi	D638	1 9 3 0 x 10^{5}	0 38 0 65 x 10^{5}	1 5 2 0 x 10	0 5 0 7 x 10^{5}	1 7 2 x 10^{5}	2 4 x 10^{5}	11 x 10^{5}	—
Ten Str, 1000 psi	D638	4 6 5 7	2 5 6 5	75 2 5	2 5 3 5	7 2 8 6	4 0 4 5	12 0	4 3
Elongation (in 2 in), %	D638	125 175	250 350	10 200	250 330	200 300	150 200WIA	9	200
Hardness (Rockwell)	D785	R110 115	52D	R35 55	58D	R110	R95	—	D60
Abrasion Res, gm/cycle	[d]	0 0080	—	—	—	0 0006 0 0012	0 005	—	—
Impact Str (Izod notched), ft lb/in	D256	3 50 3 62	2 5 4 0	—	No break	3 8	No break	7	—
Mod of Elast in Flexure, psi	D747	2 0 2 5 x 10^{5}	0 6 x 10^{5}	4 64 x 10^{5}	0 8 x 10^{5}	—	2 4 x 10^{5}	9 5 x 10^{5}	1 0 x 10^{5}
Flex Str (0 1% offset), 1000 psi	D790	3 5	—	—	—	2	—	15	—
Compr Str (0 1% offset), 1000 psi	D695	2 0	0 7-1 8	1 4 1 8	1 6	12 8 14 2	—	—	—
ELECTRICAL PROPERTIES									
Volume Resistivity ohm cm	D257	10^{18}	>10^{18}	10^{15}	>2 x 10^{18}	5 x 10^{14}	10^{16}	—	>10^{18}
Dielec Str (short time), v/mil	D149	530 600	400 500	300 400	500 600	260	490	—	2000
Dielectric Constant									
60 Cycles	D150	2 6 2 7	2 1	2 9 3 6	2 1	10 0	2 6	—	2 1
10^{6} Cycles	D150	2 30 2 37	2 1	2 9 3 6	2 1	7 5	2 5	—	2 1
Dissipation Factor									
60 Cycles	D150	0 02	0 0002	0005 0015	0 0003	0 050	0 0007	—	0 0002
10^{6} Cycles	D150	0 007 0 010	0 0002	0005 0015	0 0003	0 184	0 009	—	0 0003
Arc Resistance, sec		>360	>200	—	>165	50 60	135	—	—
APPLICABLE PROCESSING METHODS		Compression mldg, isotactic pressing	Compression molding, isostactic molding		Inject molding, extrus compres molding	Inject molding, extrus, compres molding	Inject, rotational, blow & transfer molding, extrus, thermoforming, foam		Injection mldg, extrusion, blow mldg
HEAT RESISTANCE									
Max Rec Svc Temp, F		380	550	450 500	400	340	300 355	—	500
Heat Dist Temp, F									
66 psi	D648	196 291	—	350 480	—	300	220 240	—	—
264 psi	D648	151 178	—	170 220	—	232	160 170	285	—
CHEMICAL RESISTANCE		High res to corrosive chemical & most organic solvent	Inert to most chemicals and solvents with exception of alkali metals Halogenated solvents at high temperatures and pressure have some effect			Res to most acids and bases except fuming sulfuric	Res to most acids & bases	Res to most acids & bases	Same as PTFE
USES		Chemical pipes pump parts, cables, tank linings, connectors, connector inserts, valve diaphragms, insulation	Chemical pipes valves and liners, gaskets, packings, pump bearings and impellers, electrical equip, anti adhesive coatings	Bearings, bushings, wear surfaces, elec insulators, gaskets packings, valve seats in corrosive conditions	Electronic instruments, valve linings, laminates, corrosion resistant and non adhesive coatings	Seals, chemical pipe and fittings gaskets, electrical jackets and primary insulation, finishes			PTFE uses req more ease of processing

[a] A proprietary material consisting of polytetrafluoroethylene and special constituents designed to improve TFE s mechanical and thermal properties while retaining its electrical and chemical characteristics [b] Range covers properties for compounds containing from 10-25% glass [c] Cenco Fitch [d] Federal Spec L P 406A No 1092 1
[e] From 73 to 500 F

Foams—Rigid (no surface skin)

Type→		ABS	Cellulose Acetate	Epoxy	Syntactic Epoxy[a]		Phenolic	Poly ethylene	Poly propylene
Density, pcf→		31	6 8	5-8	36	42	2-4	34	5
	ASTM								
Ther Cond, Btu/hr/sq ft/°F/in	177	0 58	0 31 0 32	0 24-0 28	4 56	—	0 20 0 22	0 92	0 27
Coef of Ther Exp, per °F x 10^{-5}	D696	9 7	2 5	2 3	4 5	—	0 5	4 18	—
Water Absorption, % vol	C272	0 6	13-17	—	—	1 5	<3	0 22	—
Dielectric Constant at 10^6 cps	—	1 59	1 10-1 12	2 0	1 55	—	—	1 48	—
Dissipation Factor at 10^6 cps	—	0 007	0 003	0 005	0 01	—	—	0 0003	—
Max Rec Service Temp, F	—	200	350	400 500	300	300	270	195	230
Tensile Str, psi	D1623	1400	170	50 200	3300	4600	20 55	1000	170
Ultimate Ten Elong, %	D1623	—	—	—	—	—	—	—	—
Mod of Elast in Tension, 1000 psi	D1623	2 4	—	—	—	610	—	—	—
Compr Str, psi (10%)	D1621	—	125 150	60 90	9600	13,400	20 90	800	55
Mod of Elast in Compr, 1000 psi	D1621	—	5 5 13	2 16 5	373	480	—	—	1 2
Flex Str, psi	D790	2 4	150	200 800	3800	6000	25 65	1900	230
Mod of Elast in Flex, 1000 psi	D790	9	5 5	2 5 6	—	—	—	88	9 6
Shear Str, psi	C273	—	140	—	3800	4400	15 30	—	—
Mod of Elast in Shear, 1000 psi	C273	—	—	—	—	—	0 4 0 75	—	—
Hardness (Shore D)	—	60	—	—	80 85	—	—	—	—

[a] Glass microsphere filled epoxy

Type→		Polyvinyl Chloride	Polystyrene (expanded)		Urea	Urethane		
Density, pcf→		3	2	6	0 8 1 2	2-3	4-7	18 25
	ASTM							
Ther Cond, Btu/hr/sq ft/°F/in	177	0 15-0 20	0 20 0 28	0 20-0 25	0 18 0 21	0 11 0 23	0 15 0 28	0 29 0 52
Coef of Ther Exp, per °F x 10^{-5}	D696	2	2 7-4	2 7-4	—	3-4	4	4
Water Absorption, % vol	C272	0 1	<0 1	<0 1	—	3 4	1 5 2	0 2
Dielectric Constant at 10^6 cps	—	—	1 02 1 24	—	—	—	—	—
Dissipation Factor at 10^6 cps	—	—	<0 0005	—	—	—	—	—
Max Rec Service Temp, F	—	180	175	175	120	200 250	250 300	300-400
Tensile Str, psi	D1623	100 200	50 55	120	—	20 70	90 250	700 1300
Ultimate Ten Elong, %	D1623	5 20	5	2	—	—	—	—
Mod of Elast in Tension, 1000 psi	D1623	3-4	740	6100	—	—	—	—
Compr Str psi (10%)	D1621	70 100	25 30	100 150	5	20 50	65 275	1200 2000
Mod of Elast in Compr 1000 psi	D1621	3-4	0 55 2	3 6	—	0 3 0 6	1 5 4 5	10 40
Flex Str, psi	D790	120 160	55 75	200 300	17	60 100	200 350	700 2000
Mod of Elast in Flex, 1000 psi	D790	3-4	1 3 3 8	5 15	0 7	0 8 0 9	0 8 15	12 100
Shear Str, psi	C273	60 80	35	150	—	20 30	60 130	7600
Mod of Elast in Shear, 1000 psi	C273	2 2 5	1 15 1 6	3	—	0 17 0 21	0 5 1 5	3 9

Plastics and Rubber Foams — Flexible

Type, Density[a]→	Polyethylene (cellular)			Silicone (foam in place)	Urethane (prefoamed)		Vinyl (open cell)
	2.2	33[b]	41[c]	10	1 5 2 0	4 0 5 0	4 and up
Max Rec Service Temp, F	160	—	—	500	—	—	—
Elec Res, microhm cm	1 5 x 10^{17}	—	—	3 8 x 10^{18}	—	—	—
Dielec Str (short time), v/mil	55	220	220	50	—	—	—
Dielec Const, 10^6 cycles	1 05[e]	1 5	1 84	1 17[d]	—	—	—
Dissip Factor, 10^6 cycles	0 0002[e]	0 0004	0 0006	0 001[d]	—	—	—
Tensile Strength, psi	20 30	600	2100	5	12-20	18 20	10 200
Elongation, %	60	300	350	40	150 250	100-125	75 300
Tear Strength, lb/in	6	—	—	—	2 0 3 0	1 0 2 0	—
Compression Set (22 hr at 158 F), %	15	—	—	4	4 8	2 9	15
Compression Deflection, psi							
Stress for 25% Defl	8 5[f]	—	—	1	0 35	0 9 2 2	3-500
Stress for 50% Defl	17 5	—	—	3	0 45	—	—

[a] Density in lb/cu ft [b] Based on low density polymer, typical expanded insulation (about 46% gas by vol) [c] Based on high density polymer typical expanded insulation (about 30% gas by vol) [d] 10^6 cycles [e] At 10^6 cps [f] Recovery at same temperature as compression

Foams—Rigid (structural, integral skin type)[a]

Type → Density, lb/ft^3 →		ABS 50	Polycarbonate 50	Polyethylene 37 5	Polypropylene 37 5	Noryl 50	Polystyrene 43 5
	ASTM						
Ther Cond, Btu/hr/sq ft/°F/in	177	—	—	—	—	—	—
Coef of Ther Exp, per °F x 10^{-5}	D696	—	—	6 7	5 2	—	5 0
Water Absorption, % vol	C272	—	—	—	—	—	—
Heat Deflection (264 psi), F	D648	180	270	94	132	205	176
Max Rec Service Temp, F	—	—	—	—	—	—	—
Tensile Str, psi	D1623	2700	5500	1300	2100	3300	1800
Ultimate Ten Elong, %	D1623	—	—	—	—	—	—
Mod of Elast in Tension, 1000 psi	D1623	—	—	—	—	—	—
Compr Str, psi (10%)	D1621	1000	7500	—	—	5500	—
Mod of Elast in Compr, 1000 psi	D1621	—	—	—	—	—	—
Flex Str, psi	D790	3700	10,000	2700	3200	6000	4500
Mod of Elast in Flex, 1000 psi	D790	125	300	120	120	240	210
Shear Str, psi	C273	—	—	—	—	—	—
Mod of Elast in Shear, 1000 psi	C273	—	—	—	—	—	—
Hardness (Shore D)	—	—	—	54	62	—	74
Impact Str (Izod, unnotched), ft lb	—	—	—	2 5	1 25	—	2 3

				Glass fiber reinforced types			
Type → Density, lb/ft^3 →		Polyurethane 34 5	Polyester 56	Polypropylene 45 5	Nylon 54	Polystyrene 52 5	ABS 52 5
	ASTM						
Ther Cond, Btu/hr/sq ft/°F/in	177	—	—	—	—	—	—
Coef of Ther Exp, per °F x 10^{-5}	D696	—	—	—	—	—	—
Water Absorption, % vol	C272	—	—	—	—	—	—
Heat Deflection (264 psi), F	D648	150	400 (66 psi)	162	390	190	210
Max Rec Service Temp, F	—	—	—	—	—	—	—
Tensile Str, psi	D1623	—	8550	3000	10,000	5000	7000
Ultimate Ten Elong, %	D1623	—	—	—	—	—	—
Mod of Elast in Tension, 1000 psi	D1623	—	—	—	—	—	—
Compr Str, psi (10%)	D1621	1600	9300	—	—	—	—
Mod of Elast in Compr, 1000 psi	D1621	—	—	—	—	—	—
Flex Str, psi	D790	4200	17,000	6000	16,000	8500	12,000
Mod of Elast in Flex, 1000 psi	D790	150	700	400	650	750	750
Shear Str, psi	C273	—	—	—	—	—	—
Mod of Elast in Shear, 1000 psi	C273	—	—	—	—	—	—
Hardness (Shore D)	—	70	—	—	—	—	—
Impact Str (Izod, unnotched), ft lb	—	—	—	3 5	3 2	1 5	3 5

---

[a] Also samples 0 25 in thick unless otherwise shown

Melamines

Filler and Type ➔		Unfilled	Cellülose Electrical	Glass Fiber	Alpha Cellulose and Mineral
PHYSICAL PROPERTIES	ASTM				
Specific Gravity	D792	1 48	1 43–1 50	1 9–2 0	1 49
Ther Cond, Btu hr sq ft/°F/ft		—	0 17–0 20	0 28	—
Coef of Ther Exp, per °F	D696	—	1 11–2 78 x 10^{-5}	0 82 x 10^{-5}	—
Transmittance (luminous), %		Good	Opaque	—	—
Water Absorption (24 hr), %	D570	0 2–0 5	0 27–0 80	0 09–0 60	0 5
Flammability		Self extinguishing	Self extinguishing	Self extinguishing	Self-extinguishing
Mechanical Properties					
Mod of Elast in Tension, psi	D638	—	10–11 x 10^5	—	—
Ten Str, 1000 psi	D638	—	5–9	5–10	5
Elong (in 2 in), %	D638	—	0 6	—	—
Hardness (Rockwell)	D785	E110	M115–125	—	—
Impact Str (Izod notched), ft-lb/in	D256	—	0 27–0 36	0 5–12 0	0 30
Mod of Elast in Flex, psi	D790	10–13 x 10^5	1 0–1 3 x 10^6	24 x 10^5	—
Compr Str, 1000 psi	D695	40–45	25–35	20–32	—
Flex Str, 1000 psi	D790	9 5–14	6–15	10–24	8
ELECTRICAL PROPERTIES					
Vol Res, ohm-cm	D257	—	10^{12}–10^{13}	1–7 x 10^{11}	10^{12}
Dielec Str (short time), v/mil	D149	—	350–400	250–300	375
Dielec Const					
60 Cycles	D150	7 9–11 0	6 2–7 7	7 0–11 1	—
10^6 Cycles	D150	6 3–7 3	5 2–6 0	6 9–7 9	6 4
Dissip Factor					
60 Cycles		0 048–0 162	0 026–0 192	0 14–0 23	—
10^6 Cycles		0 031–0 040	0 032–0 12	0 013–0 03	0 031
Arc Resistance, sec	D495	100–145	70–135	180–186	125
APPLICABLE PROCESSING METHODS		Compression molding transfer molding and, in some cases injection molding			
HEAT RESISTANCE					
Max Rec Svc Temp, F		210	250–280	300–400	275–325
Heat Dist Temp (264 psi), F	D648	293–298	265	400	300
CHEMICAL RESISTANCE		Resistant to weak acids, weak alkalis, organic solvents, greases and oils Attacked by strong acids and strong alkalis			
USES		Pearlescent buttons, moldings ornamental applications	General mechanical and electrical applications, particularly at elevated temperatures Applications requiring improved holding power for metallic inserts such as electrical and electronic parts	Applications requiring high shock resistance, good electrical properties, and high resistance to burning Switchgear, terminal strips, stand off insulators, coil forms	Primarily electrical applications requiring low after shrinkage, good dimensional stability and excellent molding characteristics

Type→		Type 6						Type 12	Transparent
		General Purpose[a]	Glass Fiber (30%) Reinforced[a]	Cast	Flexible[a] Copolymers	Type 8[b]	Type 11		
PHYSICAL PROPERTIES	ASTM								
Specific Gravity	D792	1 14	1 37	1 15	1 12 1 14	1 09	1 04	1 01	1 12
Ther Cond , Btu/hr/sq ft °F/in	—	1 2	1 2 1 7	1 2-1 7	—	—	1 5	1 7	—
Coef of Ther Exp , 10^{-5} per °F	D696	4 8	1 2	4 4	—	—	5 5	7 2	2 8
Specific Heat, Btu/lb/°F	—	0'4	—	0 4	—	0 4	0 58	0 28	—
Refractive Index, n_D	D542	—	—	—	—	—	—	—	1 566
Water Absorption (24 hr), %	D570	1 7-1 8	1 3	0 6	0 8 1 4	9 5	0 4	0 25	0 41
MECHANICAL PROPERTIES									
Tensile Strength (2 in /min)[d]	D638								
Ultimate		9 5 12 5	21 23	12 8	7 5 10 0	—	—	7 1 8 5	—
Yield		8 5 12 5	—	12 8	7 5 10 0	3 9	8 5	5 5 6 5	9 8
Elongation (2 in /min), %	D638								
Ultimate		30 220	2 4	20	200 320	400	100 120	120 350	130
Yield		—	—	5	—	—	—	5 8	—
Mod of Elast in Tension, 10 psi	D638	—	10 12	5 4	—	0 3	1 78 1 85	1 7 2 1	4 05
Flex Strength, 1000 psi	D790	Unbreak	26 34	16 5	3 4-16 4	—	—	—	13 26
Mod of Elast in Flex, 10^5 psi	D790	1 4 3 7	10 12	5 05	0 92 3 2	0 4	1 51	—	3 86
Impact Str (Izod notched), ft lb/in	D256	0 8 1 2	3 2 3	1 2	1 5 19	>16	3 3 3 6	1 2 4 2	—
Compr Strength (1% offset)[d]	D695	9 7	19 20	14	—	—	—	—	3 39
Hardness (Rockwell)	D785	R118 R120	R121	R116	R72 R119	—	R100 R108	R106	M93
Coef of Dyn Frict	—	—	—	0 32[c]	—	—	—	—	—
Abrasion Res (Taber, CS 17), mg/1000 cycles	D1044	5	—	2 7	—	—	—	—	21
ELECTRICAL PROPERTIES									
Volume Resistivity, ohm cm	D257	4 5 x 10^{14}	2 8 10^{11} to 1 5 x 10^{15}	2 6 x 10^{14}	—	1 5 x 10^{11}	2 x 10^{13}	10^{14}-10^{15}	>5 x 10^{15}
Dielectric Str (short time), v/mil	D149	385	400 450	380	440	340	425	840	670
Dielectric Constant	D150								
60 cycles		4 0 5 3	4 6 5 6	4 0	3 2 4 0	9 3	3 3(10^3cps)	3 6(10^3cps)	3 99
10^6 cycles		3 6 3 8	3 9 5 4	3 3	3 0 3 6	4 0	—	—	—
Dissipation Factor	D150								
60 cycles		0 06 0 014	0 022 0 008	0 015	0 007 0 010	0 19	0 03	0 04(10^3cps)	0 028
10^6 cycles		0 03 0 04	0 019 0 015	0 05	0 010 0 015	0 08	0 02	—	—
Arc Resistance, sec	D495	—	92 81	—	—	—	—	—	120
HEAT RESISTANCE									
Max Rec Service Temp, F	—	250 300[f]	250 300	250 300	175 200	—	212 250	175 230	—
Deflection Temp, F	D648								
66 psi		360	425 428	420	260 350	129	302	—	284
264 psi		155 160	420 419	410	115 130	—	131	—	256
APPLICABLE PROCESSING METHODS		Injection molding, extrusion, rotational molding, blow molding		Rotational molding	Extrusion, injection molding	Extrusion, injection molding		Extrusion, injection molding	Injection molding blow mold, extru compr molding
CHEMICAL RESISTANCE		Resists esters, ketones, alkalis, weak acids, alcohols and common solvents Not resistant to conc mineral acids		Res most organic chem, such as alcohols, ketones, hydrocarbons and chlor solv Att by str acids, phenols, str oxidizing agents	Res esters, ketones alkalis, weak acids, alcohols and common solvents Not res to conc mineral acids	Exc res to aqueous alkalis, aliphatic and aromatic hydrocarbons, ether and mineral oils, poor good res to dil min acids, alcohols, arom acids	Res alkalis petroleum products and common organic solvents Not res to phenols and conc acids and oxidants	Res alkalis petroleum products and common organic solvents Not res to phenols and conc acids and oxidants	Res weak acids alkali, strong alkali oil greases Attacked by strong acids alcohols and org solvents
USES		Bearings, gears bushings, coil forms, brush backs, rod, tubing tape	Gen purpose type 6 parts requiring greater stiffness and dimen stab	Bearings, wearplates, bushings, gears, rollers, stock shapes	Parts requiring high impact strength or flexibility	Molded parts requiring flexibility and chemical res	Elec insulation and other nylon uses where low mois absorp is needed	Filament, rod, tubing sheet moldings req dim stability and low moist absorp	Lenses, containers, gauges, fuel tanks

[a] Dry as molded properties [b] Non cross linked can be cross linked [c] Dynamic no lubrication nylon to steel 1000 psi [d] 0 4 self ext to slow burn [f] Heat stabilized

Nylons

Type →		6/6 Nylon				6/10 Nylon		6/12 Nylon	Mineral reinf nylon
		General Purpose Molding[a]	Glass Fiber Reinforced[b]	Glass Fiber, Molybdenum Disulfide Filled[c]	General Purpose Extrusion[a]	General Purpose[a]	Glass Fiber (30%) Reinforced[c]		
PHYSICAL PROPERTIES	ASTM								
Specific Gravity	D792	1 13–1 15,—	1 37, 1 47	1 37–1 41	1 13, 1 15	1 07–1 09, —	1 30	1 06–1 08	1 47
Ther Cond Btu/hr/sq ft/°F/in	—	1 7,—	1 5, 3 3	—	1 7, —	1 5	3 5	1 5	—
Coef of Ther Exp, 10^{-5} per °F	D696	4 5,—	2 1, 1 4	1 75	—	5	2 5	5 0	2 7–5 0
Specific Heat, Btu/lb/°F	—	0 3–0 5	—	—	0 3–0 5	0 3–0 5	—	0 3–0 5	—
Refractive Index, n_D	D542	Transluc	Opaque	Opaque	Opaque	Opaque	Opaque	Translucent	Opaque
Water Absorption (24 hr), %	D570	1 5,—	0 9, 0 8	0 5–0 7	1 5	0 4	0 2	0 4	0 5–0 8
Coef of Static Frict (against self)	—	0 04–0 13,—	—	—	—	—	—	—	0 23
MECHANICAL PROPERTIES									
Tensile Strength, 1000 psi	D638								
Ultimate		11 8, 11 2	25, 30	19–22	12 6, 8 6	8 5, 7 1	19	8 8, 8 8	—
Yield		11 8, 8 5	—	—	12 6, 8 6	8 5, 7 1	—	8 8, 7 4	9–10
Elongation, %	D638								
Ultimate		60, 300	1 8, 2 2	3	90, 240	85, 220	1 9	150, 340	10–25
Yield		5, 25	—	—	5, 30	5, 30	—	7, 40	—
Mod of Elast in Tension, 10^5 psi	D638	4 75, 3 85	14, 20	—	—	2 8–3 0, —	—	—	5 0
Flex Strength, 1000 psi	D790	Unbreak	26, 35	26–28	—	8	23	—	12–16
Mod of Elast in Flex, 10^3 psi	D790	410, 175	10, 18	11–13	4 1, 1 75	2 8, 1 6	8 5	2 9, 1 8	3 3–6 0
Impact Str (Izod notched), ft lb/in	D638	1 0, 2 0	2 5 3 4[e]	—	1 3, —	0 6, 1 6	3 4	1 0, 1 4	1 0–1 5
Compr Strength (1%), 1000 psi	D695	4 9,—	20, 24	—	4 9 (1%), —	3 0 (1%), —	18	2 4, —	—
Hardness (Rockwell)	D785	R118, R108	E60, E80	M95–100	R118–108	R111	E40–50	R114, —	R119–121
Abrasion Res (Taber CS 17, 1000g), mg/1000 cycles	D1044	3–5, 6–8	—	—	—, 3–5	—	—	—, 5 7	12–30
ELECTRICAL PROPERTIES									
Volume Resistivity, ohm cm	D257	10^{14} – 10^{15}	5 5 x 10^{15}, 2 6 x 10^{15},	—	10^{15}	10^{15}	—	10^{15}, 10^{12}	10^{16}
Dielectric Str (short time), v/mil	D149	385	400, 480	300–400	—	470	—	—	280–485
Dielectric Constant	D150								
60 cycles		4 0, —	4 0, 4 4	—	—	3 9, —	—	4 0, 6 0	—
10^6 cycles		3 6, —	3 5, 4 1	—	—	3 5, —	—	3 5, 4 0	—
Dissipation Factor	D150								
60 cycles		0 014, 0 04	0 018, 0 009	—	—	0 04, —	—	—	—
10^6 cycles		0 04, —	0 017, 0 018	—	—	—	—	0 02, 0 03	—
Arc Resistance, sec	D495	120	148, 100	135	120	120	—	—	115
HEAT RESISTANCE									
Max Rec Service Temp, F	—	250 300[d]	250–300[d]	250–300[d]	250 300[d]	225–300[d]	250–300[d]	350	—
Deflection Temp, F	D648								
66 psi		470	507, 509	—	470	300	430	330	400
264 psi		220	495, 500	—	220	135	420	180	300
CHEMICAL RESISTANCE		Inert to most organic chemicals such as esters ketones, alcohols and hydrocarbons Resist alkalis and salt solutions, but att by phenols, formic acid, strong mineral acids and strong oxidizing agents							
APPLICABLE PROCESSING METHODS		Injection molding			Extrusion	Injection molding		Injection molding, blow molding, extrusion	Injection molding
USES		Bearings, gears, bushings, coil forms, brush backs, rod, tubing		Mech parts where lubrication is undesirable or diff	Tubing, rod, pipe, sheeting, laminations	Jacketing for wire and cable special molded parts			Elec housings and mech parts

---

[a] Where two values are given first is for dry as molded material and second for moisture equilibrium in air single value pertains to dry material [b] First value for 30% glass fiber and second for 40% All values at moisture equilibrium [c] 30% glass fiber [d] Heat stabilized for max heat resistance [e] ¼ in

Phenolics

Type and Filler ➔		General—Woodflour and Flock	Shock—Paper, Flock or Pulp	High Shock—Chopped Fabric or Cord	Very High Shock—Glass Fiber	Arc Resistant—Mineral	Rubber Phenolic—Woodflour or Flock	Rubber Phenolic—Chopped Fabric	Rubber Phenolic—Asbestos
PHYSICAL PROPERTIES	ASTM								
Specific Gravity	D792	1 32-1 46	1 34 1 46	1 36 1 43	1 75-1 90	1 6 3 0	1 24 1 35	1 30 1 35	1 60 1 65
Ther Cond, Btu/hr/sq ft/°F/ft	C177	0 097 0 3	0 1 0 16	0 097 0 170	0 20	0 24 0 34	0 12	0 05	0 04
Coef of Ther Exp 10^{5} per °F	D696	1 66-2 50	1 6 2 3	1 60 2 22	0 88	—	0 83 2 20	1 7	2 2
Spec Ht, Btu/lb/°F		0 35 0 40	—	0 30 0 35	0 28 0 32	0 28 0 32	0 33	—	—
Water Absorption (24 hr), %	D570	0 3 0 8	0 4 1 5	0 4 1 75	0 1 1 0	0 2	0 5 2 0	0 5 2 0	0 10 0 50
MECHANICAL PROPERTIES									
Mod of Elast in Tension, 10^{5} psi	D638	8 13	8 12	9 14	30 33	10 30	4 6	3 5 6	5 9
Ten Str, 1000 psi	D638, D651	5 0 8 5	5 0 8 5	5 9	5-10	6	4 5 9	3 5	4
Elong (in 2 in), %	D638	0 4 0 8	—	0 37 0 57	0 2	—	0 75 2 25	—	—
Hardness (Rockwell)	D785	E85 100	E85 95	E80 90	E50 70	E80 90	M40 90	M57	M50
Impact Str (Izod notched), ft lb/in	D256	0 24 0 50	0 4 1 0	0 6 8 0	10 33	0 32	0 34-1 0	2 0 2 3	0 3 0 4
Mod of Elast in Flex, 10^{5} psi	D790	8 12	8 12	9 13	30 33	10 30	4 6	3 5	5 0
Flex Str, 1000 psi	D790	8 5 12	8 0 11 5	8 15	10 45	10	7 12	7	7
Compr Str, 1000 psi	D695	22 36	24 35	15 30	17 30	20	12 20	10 15	10 20
ELECTRICAL PROPERTIES									
Vol Res, ohm cm	D257	10^{9} 10^{13}	1 50 x 10^{11}	10^{10}	7 10 x 10^{12}	6 x 10^{13}	10^{8} 10^{11}	10^{11}	10^{11}
Dielec Str (short time), v/mil	D149	200 425	250 350	200 350	200 370	380	250 375	250	350
Dielec Const									
60 Cycles	D150	5 0 9 0	5 6 11 0	6 5 15 0	7 1-7 2	7 4	9 16	15	15
10^{6} Cycles	D150	4 0 7 0	4 5 7 0	4 5 7 0	4 6 6 6	5 0	5	5	5
Dissip Factor									
60 Cycles	D150	0 05 0 30	0 08 0 35	0 08 0 45	0 02 0 03	0 13 0 16	0 15 0 60	0 5	0 15
10^{6} Cycles	D150	0 03 0 07	0 03 0 07	0 03 0 09	0 02	0 10	0 1 0 2	0 09	0 13
Arc Resistance, sec	D495	5 60	5 60	5 60	60	180	7 20	10 20	5 20
APPLICABLE PROCESSING METHODS		Injection molding, compression molding, transfer molding				Injection molding, compression molding transfer molding, foam molding, reinforced layup molding, laminating			
HEAT RESISTANCE									
Max Rec Svc Temp, F		300 350	300	250 300	350-450	400	212 300	212-225	225 360
Deflection Temp, F	D648	260 360	290 340	250 340	600	335	220 270	220 280	250 300
CHEMICAL RESISTANCE		Severely attacked by strong acids and strong alkalis Effects of dilute acids, alkalis and organic solvents vary with the reagent Chemical resistance varies with the particular formulation and not all materials of a type are equally resistant							
USES		Mechanical applications include pulleys, wheels, motor housings, handles Electrical uses include coil forms, ignition parts, condenser housings, fuse blocks, instrument panels Thermal applications include handles, appliance connector plugs Chemical uses include photographic development tanks, rayon spinning buckets and parts, milking machine cups Decorative uses include radio and television cabinets, handles, knobs, buttons							

Phenylene Oxides, Polysulfones, Polyarylsulfone

Material →		Phenylene Oxides (Noryl)			Polysulfones		Polyaryl-sulfone
		SE-100	SE-1	Glass Fiber Reinforced[a]	Standard[c]	Glass Fiber Reinforced[b]	
PHYSICAL PROPERTIES	ASTM						
Specific Gravity	D792	1 10	1 06	1 21, 1 27	1 24	1 41, 1 55	1 36
Ther Cond, Btu/hr/sq ft/°F/in	C177	1 10	1 5	1 15, 1 1	1 8	—	1 1
Coef of Ther Exp, 10^{-5} per °F	D696	3 8	3 3	2 0, 1 4	3 1	1 6, 1 2	2 6
Specific Heat, Btu/lb/°F	—	—	—	—	0 24	—	—
Refractive Index, n_D	D542	Opaque	Opaque	Opaque	1 63	Opaque	—
Water Absorption (24 hr), %	D570	0 07	0 07	0 06	0 22	0 22, 0 18	1 8
MECHANICAL PROPERTIES							
Tensile Strength, 1000 psi	D638						
Ultimate		—	—	—	—	—	13
Yield		7 8	9 6	14 5, 17 0	10 2	17, 19	8
Elongation, %	—						
Ultimate		50	60	4 6	50 100	—	15 20
Yield		—	—	—	5 6	2, 1 6	13
Mod of Elast in Tension, 10^{5} psi	D638	3 8	3 55	9 25, 13 3	3 6	10 9, 14 9	3 7
Flex strength, 1000 psi	D790	12 8	13 5	20 5, 22	15 4	25, 28	17 2
Mod of Elast in Flex, 10^{5} psi	D790	3 6	3 6	7 4, 10 4	3 9	12, 15 5	4 0
Impact Str (Izod notched), ft lb/in	D638	5 0	5 0	2 3	1 3	1 8, 2 0	5 0
Compr Strength, 1000 psi	D695	12	16 4	17 6, 17 9	13 9	—	17 8
Hardness (Rockwell)	D785	R115	R119	L106, L108	R120	M84	M110
Coef of Static Frict (against self)	—	—	—	—	0 67	—	0 1 0 3
Abrasion Res (Taber, CS 17), mg/1000 cycles	—	100	20	35	20	—	40
ELECTRICAL PROPERTIES							
Volume Resistivity ohm cm	D257	10'	10^{17}	10^{17}	5×10^{16}	10^{17}	$3\ 2 \times 10^{16}$
Dielectric Str (short time), v mil	D149	400(⅛ in)	500(⅛ in)	1020(1/32 in)	425	480	350
Dielectric Constant	D150						
60 cycles		2 65	2 69	2 93	3 06	3 55	3 94
10^{6} cycles		2 64	2 68	2 92	3 03	3 41	3 7
Dissipation Factor	D150						
60 cycles		0 0007	0 0007	0 0009	0 0008	0 0019	0 003
10^{6} cycles		0 0024	0 0024	0 0015	0 0034	0 0049	0 012
Arc Resistance, sec	D495	75	75	120	122	114	67
HEAT RESISTANCE							
Max Rec Service Temp, F		—	212	—	340	350	500
Deflection Temp, F	D648						
66 psi		230	279	293, 317	358	389	—
264 psi		212	265	282, 310	345	365	525
APPLICABLE PROCESSING METHODS		Injection molding, extrusion, thermoforming, foam molding			Injection molding, extrusion, thermoforming		Injection molding
CHEMICAL RESISTANCE		Excellent res to aqueous media such as detergents and weak and strong acids and bases even at elevated temperatures Many halogenated and aromatic hydrocarbons will soften or partially dissolve these materials			Res to inorganic acids, alkalis and aliphatic hydrocarbons, partially soluble or swells in ketones and aromatic hydrocarbons, soluble in chlorinated hydrocarbons		Res to aqueous acids and bases, fuels, oils, fluorinated solvents Dissolves in highly polar solvents such as DMF, DMAC, NMP
USES		Automotive dashboards & electrical connectors, appliance & business machine housings, cabinets, consoles & covers, coffee brewers & dispensers, pump & plumbing parts, valves, tape cartridge platforms, coil assemblies, bus bar insulators, switch housings, terminal blocks, tuner bars, light fixtures			Coil bobbins, switches, terminal blocks, battery cases, connectors, circuit carriers, sockets tube bases, range hardware, coffee maker parts, sight glasses, auto parts, lamp bezels, aircraft ducts, housing and side wall panels, meter housings and components, projector transparencies		Molded parts requiring str and toughness at high temps Extrusions, coatings, filled compositions for bearing use

---

[a] Where two values are given first applies to 20% glass fiber and second to 30% otherwise same value applies to both [b] Where two values are given first applies to 30% glass fiber and second to 40% otherwise same value applies to both [c] 10% deformation

Polybutadienes, Polybutylenes, Polycarbonates and Polymethyl Pentenes

			Polybutylenes		Polycarbonates		
Materials and Type →		Polybutadienes	Copolymer	Homopolymer	Unfilled	40% gl reinf	Polymethyl pentenes
PHYSICAL PROPERTIES	ASTM						
Specific gravity	D792	1 6 2 0	0 894 0 910	0 910 0 915	1 19 1 25	1 52	0 83
Refractive Index, n_D	D542	—	—	150	1 586	—	1 465
Transparency (visible light), %	D1003	Opaque	Translucent	Translucent	87 89	Opaque	90
MECHANICAL PROPERTIES							
Tensile	D638						
Strength, 1000 psi (yld)		5 12	0 9 2 2	2 2 2 5	8 5 9 6	23 (ult)	4
Elongation % (ult)		—	400 500	300 400	10 115	3 5	15
Modulus, 1000 psi	D790	400 1200	12-34	34 36	340 450	1680	210
Flexural							
Strength, 1000 psi		7 21	—	—	12 15	27	—
Modulus, 1000 psi		700 1800	—	—	310 500	1400	140 200
Compressive str, 1000 psi (2% offset)	D695	11 20	—	—	10 14	21	—
Impact strength							
Izod (notched), lb/in	D256	1 10	—	—	4 16	2 5	0 8
Gardner ft lb/in		1 4	—	—	—	—	—
Hardness							
Rockwell	D785	E30 70	—	—	M68 85	M93	L67 74
Shore	D785	—	34 50D	53 60D	—	—	—
ELECTRICAL PROPERTIES							
Vol res, ohm cm	D257	1 5 x 10^{15}	—	—	2 5 8 2 x 10^{16}	4 x 10^{16}	10^{16}
Dielec str, v/mil (dry)	D149						
Short time		400 600	—	—	380 450	450	700
Dielec constant	D150						
60 Hz		3 3	2 18 2 25	2 25	3 10 3 17	3 53	2 12
10^6 Hz		3 3	2 18 2 25	2 25	2 96 3 05	3 48	2 12
Dissip factor	D150						
60 Hz		0 009	0 0002	0 0002	0 0009	0 0013	—
10^6 Hz		0 003	0 0002	0 0002	0 010 0 0091	0 0067	—
Arc res, sec (tungsten electrodes)	D495	—	—	—	120	120	—
THERMAL PROPERTIES							
Ther cond, Btu/hr/sq ft/°F/in	C177	—	—	1 5	1 35 1 41	1 53	—
Coef of therm exp 10^{-5}/°F	D696	—	—	7 1	1 79 3 75	0 93	—
Specific heat, Btu/lb/°F		—	—	—	0 30	—	—
Heat deflection temp, F	D648						
At 66 psi		—	—	215 235	180 295	310	—
At 264 psi		500	—	120 140	260 288	295	—
Brittleness temp, F	D746	—	−5 to −35	−5	−200	—	—
Max temp for cont use (no load), F	—	350 500	—	225	—	—	250 320
CHEMICAL AND ENVIRONMENTAL RES	D570						
Water absorption, %							
In 24 hr		0 10	0 01	0 01	0 12 0 19	0 12	0 01
Weathering		Discolors	—	Embrittles	Discolors	To none	None
Acids							
Weak		Resists	Resists	Resists	Resists	Resists	Attacks
Strong		Resists	—	Resists	Attacks	Attacks	Resists
Alkali							
Weak		Resists	Resists	Resists	Res attacks	Res attacks	Resists
Strong		Resists	Resists	Resists	Attacks	Attacks	Resists
Organic solvents		Resists	—	Slight swell	Attacks	Attacks	Attacks
Fuels		Resists	—	Slight swell	Attacks	Attacks	Resists
Oil and grease		Resists	—	Slight swell	Resists	Resists	Resists
METHODS OF PROCESSING		Calendering, casting extrusion compression, injection, rotational, transfer mldg	Extrusion casting thermoforming, injection, rotational, compression mldg	Extrusion, cast ing, thermoforming, injection, rotational, compression mldg	Blow, foam, injection, rotational mldg, extrusion, thermoforming	Injection mldg	Blow mldg, extrusion, injection mldg, thermoforming
USES		Wire and cable jackets, foot wear, floor tiles, gaskets, tires, sealants adhesive	Polymer additives and blends, hot melt adhesives	Water, gas chemical pipe and fittings, pressure vessels, drum liners, construction sheeting, packaging film	Electrical parts, portable tool housings, light globes, lenses, sports goods glazing sheet, impellers, automotive parts, body armor		Laboratory and medical ware light diffusers lenses reflectors vending machines parts packaging

Polyester—Thermoplastic

		Injection Moldings					
		Polybutylene Terephthalates			Polytetramethylene Terephthalate		
- Type →		General Purpose Grade	Glass-Reinforced Grades	Glass-Reinforced Flame Retardant	General Purpose Grade	Glass-Reinforced Grade	Asbestos-Filled Grade
PHYSICAL PROPERTIES	ASTM						
Specific Gravity	D792	1 31	1 52	1 58	1 31	1 45	1 46
Specific Heat, Btu/lb/°F	—	—	—	—	0 36 0 55	—	—
Ther Cond, Btu/hr/sq ft/°F/in	C177	1 1	1 3	1 3	—	—	—
Coef of Ther Exp, 10^{-5} in /in /°F	D696	5 3	2 7 3 3	3 5	4 9 13 0[a]	—	—
Volume Resistivity, 10^{16} ohm cm	D257	4	3 2 3 3	3 4	2 x 10^{15}	—	3 x 10^{14}
Dielectric Str (short time), v/mil	D149	590	560 750	750	420 540	—	580
Dielectric Constant	D150	3 1 3 3	3 7 4 2	3 7 3 8	3 16	—	3 5 4 2
Dissipation Factor (to 10^{3} Hz)	D150	0 002	0 002 0 003	0 002	0 023	—	0 015
Arc Resistance, sec	D495	190	130	80	125	—	108
Water Absorption (24 hr), %	D570	0 08	0 06 0 07	0 07	0 09	0 07	0 1
MECHANICAL PROPERTIES							
Tensile Str, 10^{3} psi	D638	8	17 17 3	17	8 2	14	12
212 F			7			—	—
302 F			5 5			—	—
Elongation, %	D638	300	1-5	5	250	<5	<5
Flexural Str, 10^{3} psi	D790	12 8	22 24	23	12	19	19
Flexural Modulus, 10^{5} psi	D790	0 34	1 2 1 5	1 2	3 3	8 7	9 0
212 F		—	0 63	—	—	—	—
302 F		—	0 53	—	—	—	—
Compressive Str, 10^{3} psi	D695	13	16 18	18	—	—	—
Shear Str, 10^{3} psi	D732	7 7	8 9	9	—	—	—
Impact Str (Izod), ft lb/in	D256						
Notched		1 2	1 3 2 2	1 8	1	1	0 5
Unnotched		—	4 2 15	15	—	7	6 0
Hardness, Rockwell	D785	R117	R118 M90	R119	R117	R117 M85	M85
Heat Deflection Temp, F	D648						
66 psi		310	420	420	302	—	—
264 psi		130	415 416	415	122	380	330
Endurance Limit (10 cyc), 10^{3} psi	D671	2 85	5	5	—	—	—
Creep %	D674	1 1 (1000 psi)	0 44 (4000 psi)	0 44 (4000 psi)	—	—	—
Abrasion Resistance[c], mg/10^{3} cyc	D1044	6 5	9 50	11	—	—	—
Coef of Friction	D1894						
Self		0 17	0 16	0 16	—	—	—
Steel		0 13	0 14	0 14	—	—	—

APPLICABLE PROCESSING METHODS	Injection molding, extrusion, thermoforming, foam molding
CHEMICAL RESISTANCE	Resistant to aliphatic hydrocarbons, gasoline, carbon tetrachloride, perchloroethylene, oils, fats, alcohols glycols, ethers, high molecular weight esters and ketones, dilute acids and bases, detergents, most aqueous salt sol, at ambient temp Attacked by strong acids and bases Resistant to potable water at ambient temp Prolonged use in water above 150 F not recommended Swollen by ethylene dichloride, low molecular weight ketones and substituted aromatic compounds
USES	Gears, bearings valves pump parts, fittings, rollers, cams, bushings, electronic parts, textile machinery parts, tape cassettes, fasteners

Properties shown are at approximately room temperature unless otherwise noted [a] For 32 302 F range [b] Underwriters' Lab spec [c] Taper abrasion CS 17 wheel 1000 g load

Polyesters—Thermosets

Type ➢		Cast Polyester		Reinforced Polyester Moldings			Pultrusions	
		Rigid	Flexible	High Strength (glass fibers)	Heat and Chemical Resistant (asbestos)	Sheet Molding Compounds, Genera Purpose	General purpose	High performance
PHYSICAL PROPERTIES	ASTM							
Specific Gravity	D792	1 12'1 46	1 06 1 25	1 8 12 0	1 5 1 75	1 65 1 80	1 61	1 94
Ther Cond, Btu/hr/sq ft/°F/in	—	0 10 0 12	—	1 32-1 68	—	—	4	5
Coef of Ther Exp, per °F	D696	3 9 5 6 x 10^{-6}	—	13 19 x 10^{-6}	—	—	5 x 10^{-6}	3 x 10^{-6}
Specific Heat, Btu/lb/°F	—	0 30 0 55	—	0 25 0 35	—	0 20 0 25	0 28	0 24
Water Absorption (24 hr), %	D570	0 20 0 60	0 12-2 5	0 5 0 75	0 25 0 50	0 15-0 25	0 75	0 75
Transparency (visible light), %	—	—	—	Opaque	Opaque	Opaque	Opaque	Opaque
Refractive Index, n_D	D542	1 53-1 58	1 50 1 57	—	—	—	—	—
MECHANICAL PROPERTIES								
Tensile Strength, 1000 psi	D638	4 10	1 8	5-10	4 6	15 17	20[a]	100[a]
Tensile Modulus, 10^{5} psi	D638	1 5 6 5	0 001 0 10	16 20	12 15	15 20	23[a]	60[a]
Elongation, %	D638	1 7 2 6	25 300	0 3 0 5	—	—	—	—
Impact Strength (Izod notched), ft/lb/in	D256	0 18 0 40	4 0	1-10	0 45-1 0	5-15	18[a]	18[a]
Flexural Strength, 1000 psi	D790	14 18	4 16	6 26	10 13	26 32	30[a]	—
Mod of Elast in Flex 10^5 psi	D790	1-9	0 001 0 39	15 25	—	15 18	20[a]	—
Compr Strength, 1000 psi	D690	12 37	1 17	20 26	20 25	22 36	—	—
Hardness (Barcol)	D785	35 50	6 40	60 80	40 70	45 60	50[a]	50[a]
ELECTRICAL PROPERTIES								
Volume Resistivity, ohm cm	D257	10^{13}	10^{12}	1 x 10^{12} 1 x 10^{13}	1 x 10^{12} 1 x 10^{13}	6 4 x 10^{15} 2 2 x 10^{16}	—	—
Dielectric Str (step by step), v/mil	D149	300 400	300 400	200 400	350	400 440	—	—
Dielectric Constant	D150							
60 cycles		2 8 4 4	3 18-7 0	—	—	4 62 5 0	4 5(1)	4 5(1)
10^6 cycles		2 8 4 4	3 7 6 1	—	—	4 55 4 75	—	—
Dissipation Factor	D150							
60 cycles		0 003 0 04	0 01 0 18	—	—	0 0087 0 04	0 03(1)	0 03(1)
10^6 cycles		0 006 0 04	0 02 0 06	—	—	0 0086 0 022	—	—
Arc Resistance, sec	D495	115 135	125 145	130 170	—	130 180	80	80
APPLICABLE PROCESSING METHODS		Casting		Layup molding, laminating, compression molding, transfer molding, injection molding		Matched metal die compression molding	Pultrusion	
HEAT RESISTANCE								
Max Rec Svc Temp, F	—	250 300	150 250	250 400	300	300	250 300	300
Heat Deflection Temp (264 psi), F	D648	120 400	—	400	375 400	375 400	400	400
CHEMICAL RESISTANCE		Slightly to heavily attacked by strong acids, attacked by strong alkalis, ketones and solvents		Good to exc res to weak acids, organic solvents, weak alkalis, good res to strong acids, poor to fair res to strong alkalis	Good to exc res to weak acids, or ganic sol vents and weak alkalis, good res to strong acids, air to good res to strong alkalis	Good to exc res to weak acids, or ganic sol vents and weak alkalis, good res to strong acids, poor to fair res to strong alkalis	Good to exc res to weak acids, organic solvents weak alkalies good res to strong acids, poor to fair res to strong alkalies	
USES		Electrical components, buttons, decorative architectural uses	Flooring, tooling encapsulants, buttons and shields	Chairs, housings, covers, trays molded panels, bezels, motor shrouds, electrical parts, fans, helmets			Elec components corrosion res construction, high str to wt mech parts	

[a] Longitudinal direction

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Polyethylenes

Type →		Type I—Lower Density (0 910-0 925)			Type II—Medium Density (0 926 0 940)	
		Melt Index 0 3-3 6	Melt Index 6 26	Melt Index 200	Melt Index 20	Melt Index 1 0-1.9
PHYSICAL PROPERTIES	ASTM					
Specific Gravity	D792	0 910=0 925	0˙918=0˙925	0˙910	0 930	0 930-0 940
Ther Cond, Btu/hr/sq ft/°F/ft	C177	0 19	0 19	0 19	0 19	0 19
Coef of Ther Exp, 10^{-5} per °F	D696	8 9-11 0	8 9-11 0	11 0	8 3-16 7	8 3-16 7
Refractive Index	D542	1 51	1 51	1 51	1 51	1 51
Spec Ht, Btu/lb/°F		0 53-0 55	0 53-0 55	0 53-0 55	0 53-0 55	0 53-0 55
Water Absorption (24 hr), %	D570	<0 01	<0 01	<0 01	<0 01	<0 01
MECHANICAL PROPERTIES						
Mod of Elast in Tension, 10^5 psi	D638	0 21-0 27	0 20-0 24	—	—	—
Ten Str, 1000 psi	D412	1 4-2 5	1 4-2 0	0 9-1 1	2 0	2 3-2 4
Elong, %	D412	500-725	125-675	80-100	200	200-425
Hardness (Shore)	D785	C73, D50-52	C73, D47-53	D45	D55	D55-D56
Impact Str (Izod), ft-lb/in notch	D256	—	—	—	—	—
Brittleness Temp, F		<−94	<−4	<14	<−148	<−148
Mod of Elast in Flex, 10^3 psi	D747	13-27	12-30	10	35 50	35-50
Shear Str, 1000 psi		1 6-1 85	1 4-1 7	1	—	—
ELECTRICAL PROPERTIES						
Vol Res, ohm-cm	D257	10^{17}-10^{19}	10^{17}-10^{19}	10^{17}-10^{19}	>10^{15}	>10^{15}
Dielec Str (short time), v/mil	D149	480	480	480	480	480
Dielec Const	D150	2 3	2 3	2 3	2 3	2 3
Dissip Factor	D150	<0 0005	<0 0005	<0 0005	<0 0005	<0 0005
APPLICABLE PROCESSING METHODS		Injection molding, extrusion, rotational molding, blow molding, foam molding			Injection molding, extrusion, thermoforming, rotational molding, blow molding	
HEAT RESISTANCE						
Vicat Softening Point, F		176-201	176-201	—	215 230	220-235
CHEMICAL RESISTANCE		Excellent resistance to acids and alkalis at normal temperature, except oxidizing acids such as nitric, chlorosulfonic and fuming sulfuric Below 122 F, insoluble in organic solvents, at higher temperatures, soluble to varying degrees in hydrocarbons and halogenated hydrocarbons, but insoluble in more polar liquids Generally, a higher melt index material has greater solubility				
USES		Injection moldings kitchen utilityware, toys, process tank liners,closures, packages, sealing rings, battery parts Blow moldings squeeze bottles for packaging, containers for drugs Film wrapping materials for food, clothes, other items Wire and cable high frequency insulation, jacketing. Pipe chemicals handling irrigation systems, natural gas transmission				

Type →		Type III—Higher Density (0.941-0 965)			High Molecular Weight
		Melt Index 0.2-0 9	Melt Index 0 1-12.0	Melt Index 1 5-15	
PHYSICAL PROPERTIES	ASTM				
Specific Gravity	D792	0 96	0 950 0 955	0 96	0 94
Ther Cond, Btu/hr/sq ft/°F/ft	C177	0 19	0 19	0 19	0 19
Coef of Ther Exp, 10^{-5} per°F	D696	8 3-16 7	8 3-16 7	8 3-16 7	—
Refractive Index	D542	1 54	1 54	1'54	—
Spec Ht , Btu/lb/°F		0 46-0 55	0 46-0 55	0 46-0 55	—
Water Absorption (24 hr), %	D570	<0 01	<0 01	<0 01	<0 01
Flammability, ipm	D635	1 0	1 0	1 0	1 0
MECHANICAL PROPERTIES					
Mod of Elast in Tension, 10^5 psi	D638	—	—	—	1 0
Ten Str 1000 psi	D412	4 4	2 9-4 0	4 4	5 4
Ultimate/Elongation,%	D412	700 1000	50 1000	100 700	400
Hardness (Shore)	D785	D68-70	D60-70	D68-70	60-65

Polyethylenes

Type →		Type III—Higher Density (0 941 0 965)			
		Melt Index 0.2 0 9	Melt Index 0 1 12 0	Melt Index 1 5 15	High Molecular Weight
MECHANICAL PROPERTIES (Cont'd)					
Impact Str (Izod), ft lb/in notch	D256	4 0–14	0 4–6 0	1 2–2 5	>20
Brittleness Temp, F		−106 to −180	<−76 to <−170	−100 to −180	<−100
Mod of Elast in Flex, 10^3 psi	D747	130–150	90–125	150	75
ELECTRICAL PROPERTIES					
Vol Res, ohm cm	D257	$>10^{15}$	$>10^{15}$	$>10^{15}$	$>10^{15}$
Dielec Str (short time), v/mil	D149	480	480	480	480
Dielec Const	D150	2 3	2 3	2 3	2 3
Dissip Factor	D150	<0 0005	<0 0005	<0 0005	<0 0005
APPLICABLE PROCESSING METHODS		Injection molding extrusion, thermoforming, rotational molding, blow molding, foam molding			Extrusion, compression molding, and special injection molding
HEAT RESISTANCE					
Vicat Softening Point, F		258 266	240 255	250 260	—
CHEMICAL RESISTANCE		Same basic chemical resistance as Types I and II, but better resistance to some specific chemicals			
USES		Refrigerator parts, packaging, structural housing panels, pipe, defroster and heater ducts sterilizable housewares and hospital equipment, hoops, battery parts, blow molded containers and parts, film wrapping materials, wire and cable insulation, and chemical resistant pipe			

[a] Powder [b] Flow molding

Olefin Copolymers

Type →		EEA (Ethylene Ethyl Acrylate)	EVA (Ethylene Vinyl Acetate)	Ethylene Butene	Propylene Ethylene	Ionomer	Poly allomer
PHYSICAL PROPERTIES	ASTM						
Specific Gravity	D792	0 93	0 94	0 95	0 91	0 94	0 898 0 904
Tensile Impact, ft lb/in	D1822	500	690	—	150	400	—
Tensile Str, 100 psi	D638	2 0	3 6	3 5	4	4	30 43
Izod Impact Str (notched), ft lb/in	D256	—	—	0 4	1 1	9 14	1 5
Hardness, Shore D	D785	35	36	65	—	60	—
Elongation (in 1 in), %	D638	650	650	20	—	450	300 400
Flexural Modulus, psi	D790	—	—	165	140	—	0 7 1 3 x 10'
ELECTRICAL PROPERTIES							
Vol Res, 10'' ohm cm	D257	2 4	0 15	—	—	10	>10''
Dielec Str (short time), v/mil	D149	550	525	—	—	1000	500 650
Dielec Const, 60 cps	D150	2 8	3 16	—	—	2 4	2 3
Dissip Factor, 60 cps	D150	0 001	0 003	—	—	0 003	>0 0005
THERMAL PROPERTIES							
Heat Deflection Temp (66 psi), F	D648	—	—	—	104	105	122 133[a]
Brittleness Temp, F	D746	−155	−148	−35	—	−160	—
Softening Point, Vicat	D1525	147	147	243	—	162	—
CHEMICAL RESISTANCE		Res most weak mineral acids, alkalis, att by chlorinated hydrocarbons, straight chain paraffinic solvents, benzene		Generally satisfactory res to chemicals, good res to stress corrosion		Res to organic solvents, att by oxidizing acids	Res to strong alk, weak acids organic solvents, att slowly by acid reagents
USES		Tubing, seals, bushings, dampening pads, rug backing, elec insulation, floor mats, other flexible items		Packaging, appliances, furniture, wire and cable insulation, rigid parts		Skin packaging, coated substrates, clear, flexible parts	Molded parts req toughness and good hinge properties

Polyimides, Poly (amide-imide)

Material ➢		Polyimides			Poly(amide imide)	
		Unreinforced	15% Graphite	Glass Reinf	High Modulus	High Impact
PHYSICAL PROPERTIES	ASTM					
Specific Gravity	D792	14 3	1 51	1 90	1 41	1 38
Ther Cond, Btu/hr/sq ft/°F/in	Cenco Fitch	2 5 6 8	6 0	3 59[b]	—	—
Coef of Ther Exp, per °F x 10^{-5}	D696	2 5 2 8	2 3	0 8	1 9	2 4
Specific Heat, Btu/lb/°F	—	0 27 0 31[b c]	—	0 27[b c]	—	—
Refractive Index, n_D	D542	Opaque	Opaque	Opaque	Opaque	Opaque
Water Absorption (24 hr), %	D570	0 24 0 47	0 19	0 2	—	—
Coef of Friction	—	—	—	—	—	—
MECHANICAL PROPERTIES						
Tensile Strength, 1000 psi	D638					
Ultimate		—	—	—	—	—
Yield		7 5 13	5 9	28	13 3	17 0
Elongation, %	D638					
Ultimate		<1 8	1 2 5	<1	5	15
Yield		—	—	—	—	—
Mod of Elast in Tension, 10^5 psi	D638	4 7 7 5	5 4 6	45	—	—
Flex Strength, 1000 psi	D790	11 17	6 6 15	56	23 4	27 4
Mod of Elast in Flex, 10^5 psi	D790	4 5 7 0	5 0 5 4	38 4	7 0	5 2
Impact Str (Izod notched), ft lb/in	D638	0 5[d]-1 0	0 5[d]	17[d]	1 0	3 0
Compr Strength, 1000 psi	D695	27 4 40	32	42	35	35
Hardness (Rockwell)	D785	97 99M	88M	114E	104E	78E
Abrasion Res (Taber, CS 10 wheel), mg/ 1000 cycles, gm loss	D1044	0 080[a]	—	20	—	—
ELECTRICAL PROPERTIES						
Volume Resistivity, ohm cm	D257	10^{15} 10^{16}	—	9 2 x 10^{15}	0 7 x 10^{15}	0 7 x 10^{15}
Dielectric Str (short time), v/mil	D149	310 560	—	300	430	440
Dielectric Constant	D150					
60 cycles		3 6 4 1	—	4 84	—	—
10^6 cycles		3 5 3 9	—	4 74	3 8	3 9
Dissipation Factor	D150					
60 cycles		0 002 0 003	—	0 0034	—	—
10^6 cycles		0 004 0 011	—	0 0055	0 001	0 009
Arc Resistance, sec	D495	152 230	—	50 180	—	—
HEAT RESISTANCE						
Max Rec Service Temp, F	—	500 800	800	500	—	—
Deflection Temp, F	D648					
66 psi		—	—	—	—	—
264 psi		582 680	680	660	545	520
APPLICABLE PROCESSING METHODS		Compression molding, laminating, filament winding, machining, sintering			Compression molding, laminating, injection molding, foam molding, transfer molding	
CHEMICAL RESISTANCE		Resist polar and nonpolar organic solvents, dilute acids and bases			Resists most acids, alkalis, oils, fuels, greases and alcohol, attacked by organic solvents	
USES		Bushings, valve seats and high temp mechanical parts		High temp bearing uses such as jet engine components	Bushings valve seats grinding wheels and other high temperature mechanical parts	

[a] Extruded sheet [b] G E test [c] Cal/gm/°C [d] ASTM D256 [e] In /1000 hr dry 10 000 PV [f] This grade is an electrical conductor

Polypropylene, Polyphenylene Sulfide, Polyether Sulfone

Material →		Polypropylene					Polyphenylene Sulfide		Poly ether sulfone
		General Purpose	High Impact	Asbestos Filled	Glass Reinforced	Flame Retardant	Standard	40% Glass Reinforced	
PHYSICAL PROPERTIES	ASTM								
Specific Gravity	D792	0 900 0 910	0 900 0 910	1 11 1 36	1 04-1 22	1 2	1.34	1 64	1 37
Ther Cond, Btu/hr/sq ft/°F/in	—	1 21 1 36	1 72	—	—	—	2 0	—	—
Coef of Ther Exp, 10^{-6} per °F	D696	3 8 5 8	4 0 5 9	2-3	1 6 2 4	—	3 0	2 2	—
Specific Heat, Btu/lb/°F	—	0 45	0 45 0 48	—	—	—	0 26	—	—
Refractive Index, n_D	D542	Transl op	Trans op	Opaque	Opaque	Opaque	Opaque	Opaque	Opaque
Water Ab (24 hr), %	D570	<0 01 0 03	<0 01 0 02	0 02 0 04	0 02 0 05	0 02 0 03	0 2	0 01	0 43
MECHANICAL PROPERTIES									
Tensile Strength, 1000 psi	D638, C								
Maximum		4 8 5 5	—	—	—	—	—	—	—
Yield		4 8 5 2	2 8 4 3	3 3 8 2	6 10	3 6 4 2	11	21	12 2
Elongation, %	—								
Break		30->200	30 >200	3 20	2 4	3 15	3	3 9	—
Yield		9-15	7 13	5	—	—	—	—	—
Mod of Elast in Tension, 10^5 psi	D638, B	1 6 2 2	1 3	—	812	1 5 2 4	4 8	11 2	3 54
Flex Yld Strength, 1000 psi	D790, B	6 7	4 1	7 5 9	8 11	—	20	37	18 65
Mod of Elast in Flex, 10^5 psi	D790, B	1 7-2 5	1 0 2 0	3 4 6 5	4 8 2	1 9 6 1	6 0	22 0	3 73
Impact Str (Izod notched), ft-lb/in	D256	0 4 2 2	1 5 12	0 5-1 5	0 5 2	2 2	3 0	6 0	1 6
Compr Yield Strength, 1000 psi	D695	5 5 6 5	4 4	7 0	6 5 7	—	16	21	—
Hardness (Rockwell)	D785	R80 R100	R28 95	R90 R110	R90 R115	R60 R105	R124	R123	M88
ELECTRICAL PROPERTIES									
Vol Res, ohm cm	D257	$>10^{17}$	10^{17}	1 5 x 10^{15}	1 7 x 10^{16}	4x10^{16} 10^{17}	10^{16}	10^{16}	10^{17}-10^{18}
Diel Str (short time), vpm	D149	650(125 mil)	450 650	450	317 475	485 700	595	490	—
Dielec Const	D150								
60 Cycles		2 20 2 28	2 20 2 28	2 75	2 3 2 5	2 46 2 79	3 11	3 79	3 5
10^6 Cycles		2 23 2 24	2 23 2 27	2 6 3 17	2 2 5	2 45 2 70	3 22	3 88	3 5
Dissip Factor	D150								
60 Cycles		0 0005 0 0007	<0 0016	0 007	0 002	0 0007 0 017	0 0004	0 0037	0 001
10^6 Cycles		0 0002 0 0003	0 0002 0 0003	0 002	0 003	0 0006 0 003	0 0007	0 0041	0 006
Arc Res, sec	D495	125 136	123 140	121 125	73 77	15 40	—	160	—
HEAT RESISTANCE									
Max Rec Svc Temp, F	—	230	—	250	250	205	500	500	—
Deflection Temp, F	D648								
66 psi		205 230	190 235	270 290	275 310	245 280	—	—	—
264 psi		135 140	120 140	170 220	250 300	155	278	425	400
APPLICABLE PROCESSING METHODS		Extrusion, injection mldg, thermoforming, rotational molding, blow mldg, coating, foam mldg					Injection mldg, coating, compression mldg		Injection mldg, extrusion
CHEMICAL RESISTANCE		Res to most acids, alkalis and saline solutions, even at higher temp, res to higher aliphatic solvents and polar substances Above 175 F, soluble in such aromatic substances as toluene and xylene, and chlorinated hydrocarbons					Exc res to org solv below 375 F Unaff by strong alkalis or aqueous inorg salt solns		Res most inorg reagents, org chem Att by conc oxid acids, some org solv, chlor hydrocarbons
USES		Hospital ware, housewares, appliances, radio and TV housings, film fibers	Luggage seating packaging, housings, automotive parts, containers wire coating	Housings, automobile fan shrouds, covers	Housings, shrouds, cases, panels and mechanical parts	Electrical uses to meet UL requirements, housings and shields	Corrosion resistant pump components, valves and pipe	Pump vanes, valve parts gaskets, fuel cells and auto parts req chem res at higher temps	Engine fittings, hi temp elec parts, appliance components

Polystyrenes

Type →		Polystyrenes				Styrene Acrylonitrile (SAN)	Glass Fiber (30%) Reinforced SAN
		General Purpose	Medium Impact	High Impact	Glass Fiber (30%) Reinf		
PHYSICAL PROPERTIES	ASTM						
Specific Gravity	D792	1 04	1 04 1 07	1 04-1 07	1 29	1 04 1 07	1 35
Ther Cond, Btu/hr/sq ft/°F/ft	—	0 058–0 090	0 024–0 090	0 024–0 090	0 117	—	—
Coef of Ther Exp, 10^5 per °F	D696	3 3–4 8	3 3–4 7	2 2–5 6	1 8	3 6–3 7	1 6
Specific Heat, Btu/lb/°F	—	0 30–0 35	0 30–0 35	0 30–0 35	0 256	0 33	—
Refractive Index, n_D	D542	1 60	Opaque	Opaque	Opaque	1 565–1 569	Opaque
Water Absorption (24 hr), %	D570	0 03 0 2	0 03-0 09	0 05 0 22	0 07	0 20 0 35	0 15
MECHANICAL PROPERTIES							
Tensile Strength, 1000 psi	D638						
Ultimate		5 0-10	6 0	3 3–5 1	14	9 5-12 0	18
Yield		5 0-10	6 0	2 8–5 3	14	—	18
Elongation, %	D638						
Ultimate		1 0 2 3	3 0-40	—	1 1	0 5 3 7	1 4
Yield		1 0 2 3	1 2–3 0	1 5 2 0	1 1	—	1 4
Mod of Elast in Tension, 10^5 psi	D638	4 6–5 0	3 9–4 7	1 50 3 80	12 1	4 0-5 0	17 5
Flex Strength, 1000 psi	D790	10-15	—	—	17	—	22
Mod of Elast in Flex, 10^5 psi	D790	4–5	3 5–5 0	2 3–4 0	12	—	14 5
Impact Str (Izod notched), ft lb/in	D638	0 2–0 4	0 5–0 7	0 8–1 8	2 5	0 30–0 45	3 0
Compr Strength, 1000 psi	D695	11 5–16 0	4–9	4–9	19	—	2 3
Hardness (Rockwell)	D785	M72	M47–65	M3–43	M85–95	M80 85	M90–100
Abrasion Res (Taber), mg/1000 cycles	—	—	—	—	164	—	—
ELECTRICAL PROPERTIES							
Volume Resistivity, ohm cm	D257	$>10^{16}$	$>10^{16}$	$>10^{16}$	3 6 x 10^{16}	$>10^{16}$	4 4 x 10^{16}
Dielectric Str (short time), v/mil	D149	>500	>425	300–650	396	400–500	515
Dielectric Constant	D150						
60 cycles		2 45–2 65	2 45–4 75	2 45–4 75	3 1	2 6–3 4	3 5
10^6 cycles		2 45–2 65	2 4–3 8	2 5–4 0	3 0	2 6–3 02	3 4
Dissipation Factor	D150						
60 cycles		0 0001–0 0003	0 0004–0 002	0 0004–0 002	0 005	>0 006	0 005
10^6 cycles		0 0001–0 0005	0 0004–0 002	0 0004–0 002	0 002	0 007-0 010	0 009
Arc Resistance, sec	D495	60 135	20 135	20–100	28	100–150	65
HEAT RESISTANCE							
Max Rec Service Temp, F	—	160–205	125–165	125–165	190–200	175–190	—
Deflection Temp, F	D648						
66 psi		—	—	—	230	—	230
264 psi		220 max	210 max	210 max	220	210–220	220
APPLICABLE PROCESSING METHODS		Injection molding, extrusion, thermoforming, rotational molding, blow molding, foam molding					
CHEMICAL RESISTANCE		Res alkalis, salts, low alcohols, glycols and water Fair res to mineral chemicals and vegetable oils Not res to aromatic and chlorinated hydrocarbons			No effect by weak acids, strong acids, att by oxid acids, no effect by weak alkalis, att slowly by str alkalis, soluble in aromatic and chlor hydrocarbons	Res to alkalis and acids, animal and vegetable oils, soaps, detergents and household chemicals	No effect by weak acids, alkalis, strong acids, att by oxid acids, str alkalis, soluble in ketones, esters, some chlor hydrocarbons
USES		Thin parts, long flow parts, toys, appliances, containers, film, mono filaments and housewares	Radio cabinets, toys, containers, packaging and closures	Containers, cups, lids, large thin wall parts, auto parts, TV cabinets, trays and appliance housings	Auto dash board skeletons, camera housings and frames, tape reels, fan blades	Kitchen ware, tumblers, broom bristles, ice buckets, closures, film, containers, lenses, battery cases	Camera housings and frames, auto bezels, electrical components, handles, auto panels

Polyvinyl Chloride and Copolymers

Type →		Polyvinyl Chloride, Polyvinyl Chloride Acetate			Vinylidene Chloride[a] Copolymer	Chlorinated Polyvinyl Chloride
		Nonrigid—General	Nonrigid—Electrical	Rigid—Normal Impact		
PHYSICAL PROPERTIES	ASTM					
Specific Gravity	D792	1 20 1 55	1 16 1 40	1 32 1 44	1 68 1 75	1 49 1 58
Ther Cond Btu/hr/sq ft/°F/ft	D325	0 07 0 10	0 07 0 10	0 07 0 10	0 053	—
Coef of Ther Exp, 10^{-5} per °F	D696	—	—	2 8 3 3	8 78	3 8
Refractive Index	D542	—	—	—	1 60 1 63	—
Spec Ht, Btu/lb/°F	—	—	—	—	0 32	—
Water Absorption (24 hr), %	D570	0 2-1 0	0 40 0 75	0 03 0 40	>0 1	0 02 0 15
MECHANICAL PROPERTIES						
Mod of Elast in Tension, 10^5 psi	D412	0 004 0 03	0 01 0 03	3 5 4 0[b]	0 7 2 0	—
Ten Str 1000 psi	D412	1 3 5	2 3 2	5 5 8	4 8, 15 40	—
Elong (in 2 in), %	D638	200 450	220 360	1-10	15 25, 20 30	—
Hardness (Rockwell)	D785	—	—	R110 120	M50 65	R117-122
Hardness (Shore)	D676	A50 100	A78 100	D70 85	>A95	—
Impact Str (Izod notched), ft lb/in	D256	Variable	Variable	0 5 10	2 8, 0 053	1 0 3 0
Mod of Elast in Flex, psi	D790	—	—	3 8 5 4 x 10^5	—	3 8 4 50
100% Modulus, psi	—	600 2800	600 2800	—	—	
Flex Str, 1000 psi	D790	—	—	11 16	15 17, flexible	14 5 17
Compr Str, 1000 psi	D695	—	—	11 12	—	—
Compr Yld Str, 1000 psi	D695	—	—	10 11	75 85	—
Cold Flex Temp, F	D1043	−70 to 0	−7 to +20	—	—	—
Cold Bend Temp, F	—	−40 to −4	−49 to −4	—	—	—
ELECTRICAL PROPERTIES						
Vol Res, ohm cm	D257	1 700 x 10^{12}	4 300 x 10^{11}	10^{14}->10^{16}	10^{14} 10^{16}	10^{15}
Dielec Str (short time), v/mil	D149	—	24 500	725 1400	—	1220 1500
Dielec Const (60 cycles)	D150	5 5 9 1	6 0 8 0	2 3 3 7	3 5	3 08
Dissip Factor (60 cycles)	D150	0 05 0 15	0 08 0 11	0 020 0 03	0 03 0 15	0 019 0 021
Loss Factor (60 cycles)	D150	—	1 0 1 2	0 030 0 072	—	—
APPLICABLE PROCESSING METHODS		Injection molding, extrusion, thermoforming, blow molding, foam molding, slush molding, calendering			Extrusion, calendering	Calendering, compression molding, extrusion, injection molding, thermoforming
HEAT RESISTANCE						
Max Rec Svc Temp, F	—	150 220	140 220	150 165	170 212	230
Heat Dist Temp, F						
66 psi	D648	—	—	170 185	190 210	215 247
264 psi	D648	—	—	140 170	130 150	202 234
CHEMICAL RESISTANCE		Generally resistant to alkalis and weak acids Moderately to not resist to strong acids Not resistant to keotones and esters, aromatic hydrocarbons produce swelling			Excellent to all acids and most common alkalis[c]	Res to acids, alkalis oil, grease and most organic solvents
USES		Parts made by molding high speed extrusion, calendering Blown extruded film Vacuum cleaner parts handlebar grips, doll parts, hair, curlers, safety goggle cups, grommets toy tires, garden hose, and protective garments	Parts made by calendering extrusion Insulation and jacketing for communication and low tension power wire and cable building wiring appliance and machine tool cords and switch board cable	Parts made by calendering laminating, molding, extrusion Fume hoods and ducts, storage tanks chemical piping, plating tanks phonograph records Sheets and shapes for decorative panels, other building uses	Extrusions gasket rods, valve seats, flexible chemical tubing and pipe, tape for wrapping joints chemical conveyor belts Moldings spray gun handles acid dippers, parts for rayon producing equipment	Hoods ducts exterior bldg components, pipe

---

[a] Where two values or ranges are given they represent unoriented and oriented forms respectively [b] Modulus of elasticity in compression [c] Unaffected by aliphatic and aromatic hydrocarbons alcohols esters etc [d] Barrel temperature [e] Stock temperature

Silicones

Type →		Glass Fiber Reinforced Silicones	Granular (Silica) Reinforced Silicones	Woven Glass Fabric/ Silicone Laminate
PHYSICAL PROPERTIES	ASTM			
Specific Gravity	D792	1 88	1 86–2 00	1 75–1 8
Ther-Cond, Btu/hr/sq-ft/°F/ft	—	0 18	0 25–0 5	0 075–0 125
Coef of Ther Exp, per °F x 10^5	D696	3 17–3 23	2 5–5 0	—
Specific Heat, Btu/lb/°F	—	—	—	0 246
Water Absorption (24 hr), %	D570	0 1–0 15	0 08–0 1	0 03–0 5
Transparency (visible light), %	—	Opaque	Opaque	Opaque
Refractive Index, n_D	D542	—	—	—
MECHANICAL PROPERTIES				
Tensile Strength, 1000 psi	D651	6 5	4–6	30–35
Tensile Modulus, 10^5 psi	D651	—	—	28
Elongation, %	D651	<3	<3	—
Impact Str (Izod notched), ft lb/in	D256	10	0 34	10–25
Flexural Strength, 1000 psi	D790	16–19	6–10	33–47
Mod of Elast in Flex, 10^5 psi	D790	25	14–17	26–32
Compr Strength, 1000 psi	D690	10–12 5	10 6–17 0	15–24
Hardness (Rockwell)	D785	M87	M71–95	75 (Barcol)
Abrasion Res (Taber)	—	—	—	—
ELECTRICAL PROPERTIES				
Volume Resistivity ohm cm (dry)	D257	9 x 10^{14}	5 x 10^{14}	2–5 x 10^{14}
Dielectric Str (short time), v/mil	D149	280 (in oil)	380 (in oil)	725
Dielectric Constant	D150			
60 cycles		4 34	4 1–4 5	3 9–4 2
10^6 cycles		4 28	3 4–4 3	3 8–3 97
Dissipation Factor	D150			
60 cycles		0 01	0 002–0 004	0 020
10^6 cycles		0 004	0 001–0 004	0 002
Arc Resistance, sec	D495	240	250–310	225–250
APPLICABLE PROCESSING METHODS		Compression molding, transfer molding and injection molding		Layup molding, laminating
TRANSFER MOLDING	—			
Pressure, 1000 psi		0 5–10	0 150–5	—
Temperature, F		350	310–350	—
Shrinkage, %		0 0005	0 004–0 006	—
HEAT RESISTANCE				
Max Rec Service Temp, F	—	>500	>500	450–500
Heat Deflection Temp (264 psi), F	D648	>900	520–>900	>900
CHEMICAL RESISTANCE		Resistant to aviation gasoline, lubricating oil, and sulphuric and hydrochloric acids Slightly softened and pitted by sodium hydroxide, except some mineral filled materials Should be tested if resistance to ketones, toluene, ethylenes, etc, is required		Satis res to aviation gas, lube oils, 40% sulfuric acid, 5% hydrochloric acid and freon 114 Slightly att by 5% hydrochloric acid Severely att by many organic solvents
USES		Connector plugs, and other structural electronic parts requiring heat resistance	Electronic component encapsulation such as transistors, diodes, resistors and capacitors	Special high temp struct or elect parts, such as aircraft radomes and ductwork, thermal and arc barriers, covers and cases for high freq equip

Rubber — Molded, Extruded

Type ➡		Natural Rubber (Cis-polyisoprene)	Butadiene-Styrene	Synthetic (Polyisoprene)	Butadiene-Acrylonitrile (Nitrile)	Chloroprene (Neoprene)	Butyl (Isobutylene-Isoprene)
PHYSICAL PROPERTIES	ASTM						
Specific Gravity	D792	0.93	0.94	0.93	0.98	1.25	0.90
Ther Cond, Btu/hr/sq ft/°F/ft	C177	0.082	0.143	0.082	0.143	0.112	0.053
Coef of Ther Exp (cubical), 10^{-5} per °F	D696	37	37	—	39	34	32
Electrical Insulation		Good	Good	Good	Fair	Fair	Good
Min Rec Svc Temp, F		-60	-60	-60	-60	-40	-50
Max Rec Svc Temp, F		180	180	180	300	240	300
MECHANICAL PROPERTIES							
Ten Str, psi							
Pure Gum	D412	2500–3500	200–300	2500–3500	500–900	3000–4000	2500–3000
Black	D412	3500–4500	2500–3500	3500–4500	3000–4500	3000–4000	2500–3000
Elongation, %							
Pure Gum	D412	750–850	400–600	—	300–700	800–900	750–950
Black	D412	550–650	500–600	300–700	300–650	500–600	650–850
Hardness (durometer)		A30–A90	A40–A90	A40–A80	A40–A95	A20–A95	A40–A90
Rebound							
Cold		Excellent	Good	Excellent	Good	Very good	Bad
Hot		Excellent	Good	Excellent	Good	Very good	Very good
Tear Resistance		Excellent	Fair	Excellent	Good	Fair to good	Good
Abrasion Resistance		Excellent	Good to excellent	Excellent	Good to excellent	Good	Good to excellent
CHEMICAL RESISTANCE							
Sunlight Aging		Poor	Poor	Fair	Poor	Very good	Very good
Oxidation		Good	Good	Excellent	Good	Excellent	Excellent
Heat Aging		Good	Very good	Good	Excellent	Excellent	Excellent
Solvents							
Aliphatic Hydrocarbons		Poor	Poor	Poor	Excellent	Good	Poor
Aromatic Hydrocarbons		Poor	Poor	Poor	Good	Fair	Poor
Oxygenated, Alcohols		Good	Good	Good	Good	Very good	Very good
Oil, Gasoline		Poor	Poor	Poor	Excellent	Good	Poor
Animal, Vegetable Oils		Poor to good	Poor to good	—	Excellent	Excellent	Excellent
Acids							
Dilute		Fair to good	Fair to good	Fair to good	Good	Excellent	Excellent
Concentrated		Fair to good	Fair to good	Fair to good	Good	Good	Excellent
Permeability to Gases		Low	Low	Low	Very low	Low	Very low
Water Swell Resistance		Fair	Excellent	Excellent	Excellent	Fair to excellent	Excellent
USES		Penumatic tires and tubes, power transmission belts and conveyor belts, gaskets, mountings, hose, chemical tank linings, printing press platens, sound or shock absorption, seals against air, moisture, sound and dirt		Same as natural rubber	Carburetor diaphragms, self-sealing fuel tanks, aircraft hose, gaskets, gasoline and oil hose, cables, machinery mountings, printing rolls	Wire and cable, belts, hose, extruded goods, coatings, molded and sheet goods, adhesives, automotive gaskets and seals, petroleum and chemical tank linings	Truck and automobile tire inner tubes, curing bags for tire vulcanization and molding, steam hose and diaphragms, flexible electrical insulation, shock, vibration absorption

Rubber — Molded, Extruded

Type ➜	Polysulfide	Silicone (Polysiloxane)	Urethane (Diisocyanate polyester)	Polyacrylate	Polybutadiene
PHYSICAL PROPERTIES					
Specific Gravity	1 35	1 1–1 6	1 25	1 09	0 91
Ther Cond, Btu/hr/sq ft/°F/ft	—	0 13	—	—	—
Coef of Ther Exp (cubical), 10^{-5} per °F	—	45	—	—	37 5
Electrical Insulation	Fair	Excellent	Fair	Fair	Good
Min Rec Svc Temp, F	−60	−178	−65	−20	−150[d]
Max Rec Svc Temp, F	250	600	240	350	200
MECHANICAL PROPERTIES					
Ten Str, psi					
Pure Gum	250 400	600–1300[a]	>5000	250–400	200–1000
Black	>1000	—	—	1000–2500	2000 3000
Elongation, %					
Pure Gum	450–650	100–500[a]	540–750	450–750	400–1000
Black	150-450	—	—	150–450	450–600
Hardness (durometer)	A40–85	A30–90	A35–100	A40–90	A40–90
Rebound					
Cold	Good	Very good	Bad	Fair	Excellent
Hot	Good	Very good	Good	Very good	Excellent
Tear Resistance	Poor	Fair	Good	Fair to good	Fair
Abrasion Resistance	Poor	Poor	Excellent	Good	Excellent
CHEMICAL RESISTANCE					
Sunlight Aging	Very good	Excellent	Excellent[b]	Excellent	Poor
Oxidation	Very good	Excellent	Very good	Excellent	Good
Heat Aging	Fair	Excellent	Excellent[b]	Excellent	Good
Solvents					
Aliphatic Hydrocarbons	Excellent	Fair	Excellent	Excellent	Poor
Aromatic Hydrocarbons	Excellent	Poor	Excellent[c]	Fair to good	Poor
Oxygenated, Alcohols	Very good	Excellent	Poor	Poor	—
Oil, Gasoline	Excellent	Poor	Excellent	Good to excellent	Poor
Animal, Vegetable Oils	Excellent	Excellent	Excellent	Very good	Poor to good
Acids					
Dilute	Good	Very good	Fair	Fair	—
Concentrated	Good	Good	Poor	Fair	—
Permeability to Gaes	Very low	High	Very low	Low	Low
Water Swell Resistance	Excellent	Excellent	Excellent	Poor to fair	Excellent
USES	Seals, gaskets, diaphragms, valve seat disks, flexible mountings, hose in contact with solvents, balloons, boats, life vests and rafts	High and low-temperature electrical insulation, seals, gaskets, diaphragms, ductwork, o-rings	Fork lift truck wheels, airplane tail wheels, backup wheels for turbine blade grinders, spinning cots for glass fiber, hydraulic accumulators, shoe heels	Oil hose, searchlight gaskets, white or pastel colored goods, and automotive gaskets and o-rings (especially for resistance to extreme pressure lubricants and oils containing sulfur)	Pneumatic tires, shoe heels and soles, gaskets and seals, belting, sponge stocks, often used in blends with other rubbers to impart better resilience abrasion resistance and low temperature properties

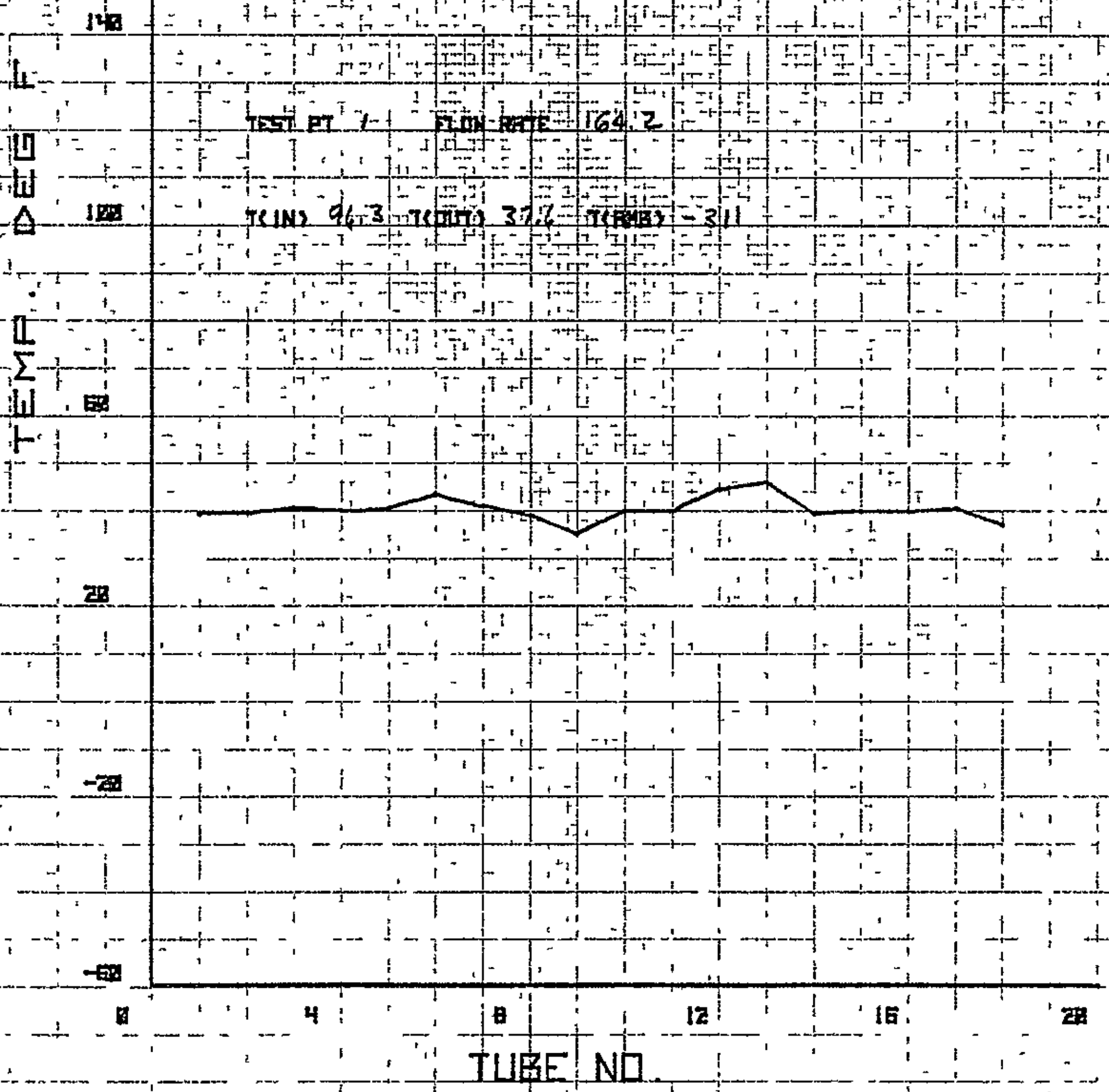
[a] Reinforced with high temperature non-organic fillers
[b] Discolors, but no change in properties
[c] For up to 80% aromatics
[d] Brittle point< −150 F may stiffen at higher temperatures

Rubber—Molded, Extruded

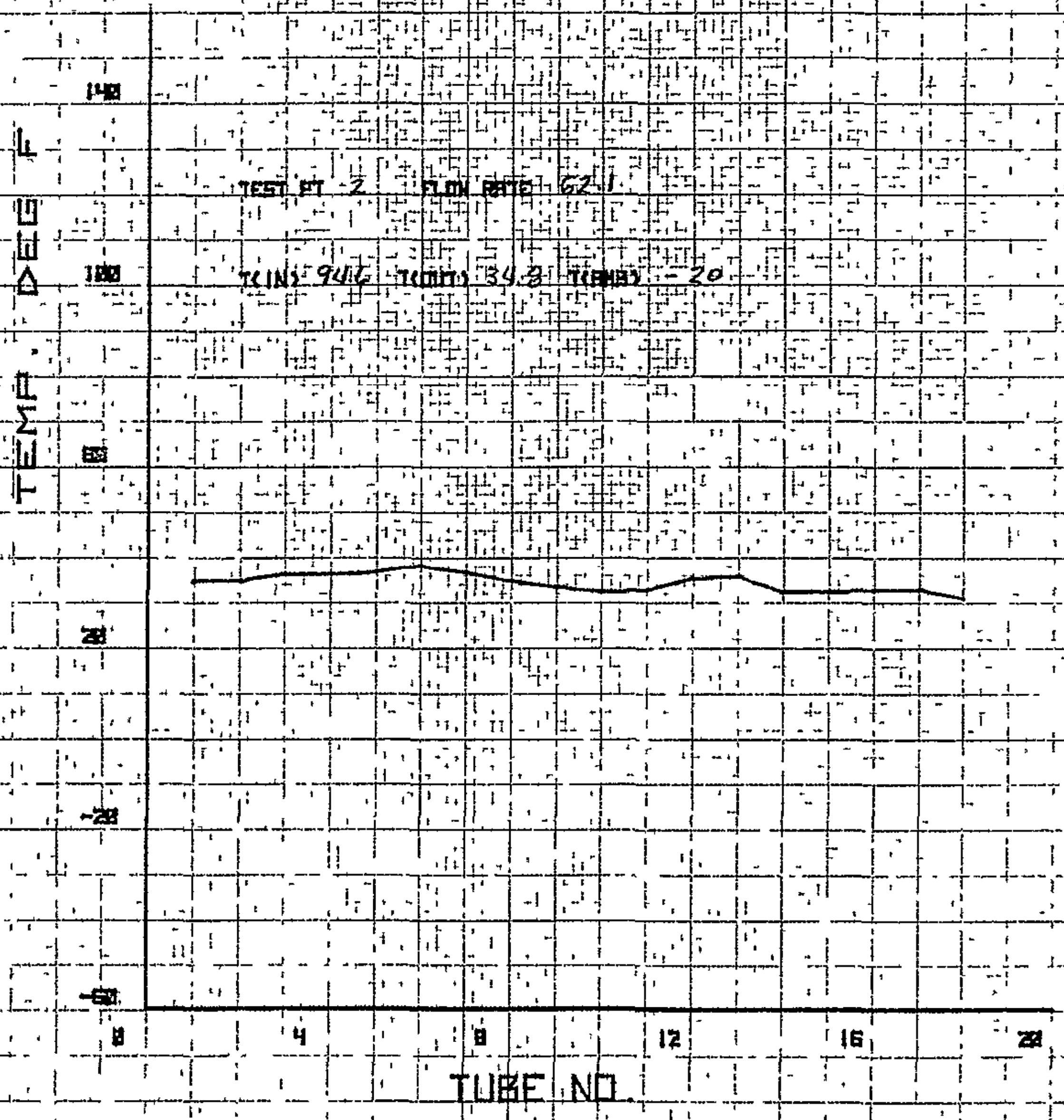
Type→	Epichlorohydrin Homopolymer & Copolymer	Fluorosilicone	Ethylene Propylene (EPDM)	Chloro sulfonated Polyethylene (Hypalon)	Fluorocarbon Elastomers	Propylene Oxides	Styrene Isoprene Styrene & Styrene Butadiene Styrene Block Polymers
PHYSICAL PROPERTIES							
Specific Gravity	1 32-1 49	1 4	0 86	1 11 1 26	1 4-1 95	1 02	0 94 1 15
Ther Cond[a]	—	0 13	—	0 065	0 13	—	0 087
Coef of Ther Exp, 10^{-5}/°F	—	45	—	27	8 8	—	7 5
Colorability	Good	Good	Excellent	Excellent	Good	Good	Good
MECHANICAL PROPERTIES							
Hardness (Shore A)	30-95	40 70	30 90	45 95	65 90	40-80	35 90
Tensile Strength, 1000 psi							
Pure Gum	—	1	<1	4	<2	>1	0 7-4 5
Reinforced	2-3	<2	0 8-3 2	1 5 2 5	1 5-3	>2	—
Elongation,%							
Reinforced	320 350	200 400	200-600	250 500	100 450	500 670	350 1350
Resilience	Poor Exc	Good Fair	Good	Good	Fair	Very Good	Good
Compression Set Res	Very Good	—	Good	Fair Good	Good Exc	Fair	—
Hysteresis Resistance	Good	Good	Good	Good	Good	Very Good	—
Flex Cracking Resistance	Very Good	Good	Good	Good	Good	Very Good	Good
Slow Rate	Very Good	Good	Good	Good	Good	Very Good	Good
Fast Rate	Good	Good	Good	Good	Good	Good	—
Tear Strength	Good	Fair	Poor Fair	Fair Good	Poor Fair	Excellent	Fair-Good
Abrasion Resistance	Fair Good	Poor	Good	Excellent	Good	Good	Good
ELECTRICAL PROPERTIES							
Dielectric Strength	Fair	Good	Excellent	Excellent	Good	—	Good
Electrical Insulation	Fair	Good	Very Good	Good	Fair Good	—	Good
THERMAL PROPERTIES							
Service Temperature, F							
Min for Cont Use	-15 to -80	−90	−60	−40	−10	−80	−60 to −80
Max for Cont Use	300	400	<350	<325	<500	<250	150
Low Temp Stiffening, F	15 to 80	<−100	20 to 60	−30 to −50	20 to −30	—	−60 to −80
CORROSION RESISTANCE							
Weather	Excellent	Excellent	Excellent	Excellent	Excellent	Very Good	Fair
Oxidation	Very Good	Excellent	Excellent	Excellent	Outstanding	Very Good	Good
Ozone	Good Exc	Excellent	Excellent	Excellent	Excellent	Very Good	Fair
Radiation	—	Good	Excellent	Fair Good	Fair-Good	—	Poor
Water	Good	Excellent	Good Exc	Good	Good	Excellent	Good
Acids	Good	Very Good Exc	Good Exc	Excellent	Good Exc	Good	Good
Alkalis	Good	Very Good	Good Exc	Excellent	Poor Good	Very Good Exc	Good
Aliphatic Hydrocarbons	Excellent	Excellent	Poor	Fair	Excellent	Poor Fair	Poor
Aromatic Hydrocarbons	Very Good	Excellent	Fair	Poor Fair	Excellent	Poor Fair	Poor
Halogenated Hydrocarbons	Good	—	Poor	Poor Fair	Good	Poor	Poor
Alcohol	Good	—	Good	Very good	Excellent	—	Good
Synthetic Lubricants (diester)	Fair Good	Excellent	Poor Fair	Poor	Fair Good	Fair Good	Poor
Hydraulic Fluids							
Silicates	Very Good	Excellent	Fair Good	Good	Good	—	—
Phosphates	Poor Fair	Excellent	Good Exc	Poor Fair	Poor	—	—
USES	Diaphragms, print rolls, belts, oil seals, molded mech goods, gaskets, hose for petroleum handling, low temperature parts	Parts requiring res to high temp solv or oils, seals, gaskets, O rings	Elec insul and jacketing, footwear, sponge, proofed fabrics, automotive weather stripping, hose, belts, auto, appliance parts parts req outstanding ozone res and heat res	Flex chemical and petroleum tube and hose rolls tank linings, high temp belts, wire and cable shoe soles and heels flooring building products, extruded and molded parts	O rings, brake seals, shaft seals, gaskets, hose and ducting, connectors, diaphragms carburetor needle tips, lined valves, packings, roll coverings	Electrical insulation, molded mechanical goods	Thermoplastic grades molded mechanical goods, packaging, sports equip, disposable pharmaceutical items Solution grades adhesives, coatings, caulking, sealants

[a] Btu/hr/sq ft/°F/ft

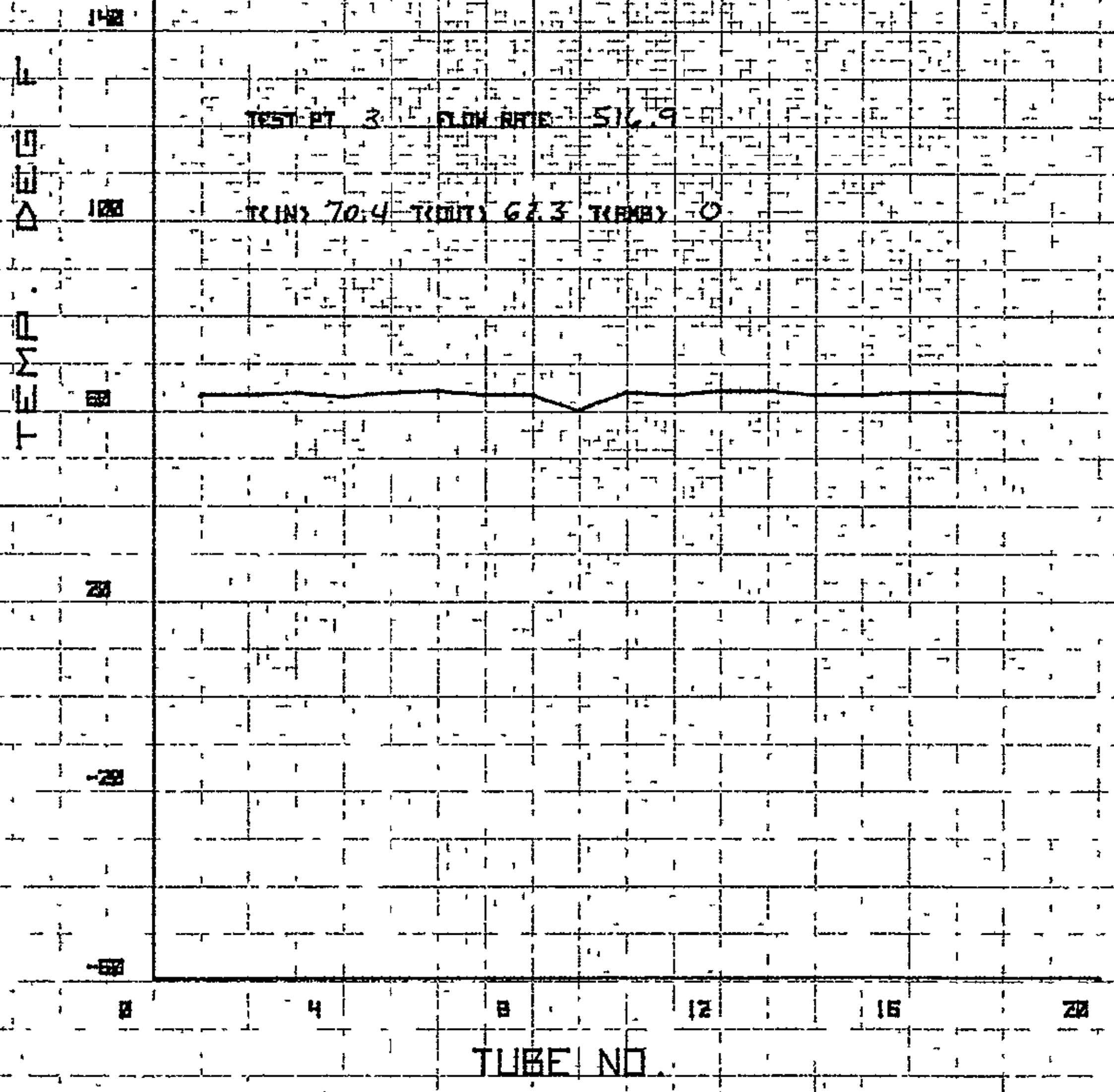
APPENDIX B. TEST DATA FOR THE HARD TUBE ENGINEERING MODEL RADIATOR (Outlet Temperature versus Tube Number and Map of Thermocouple Readings)



HARD TUBE RADIATOR

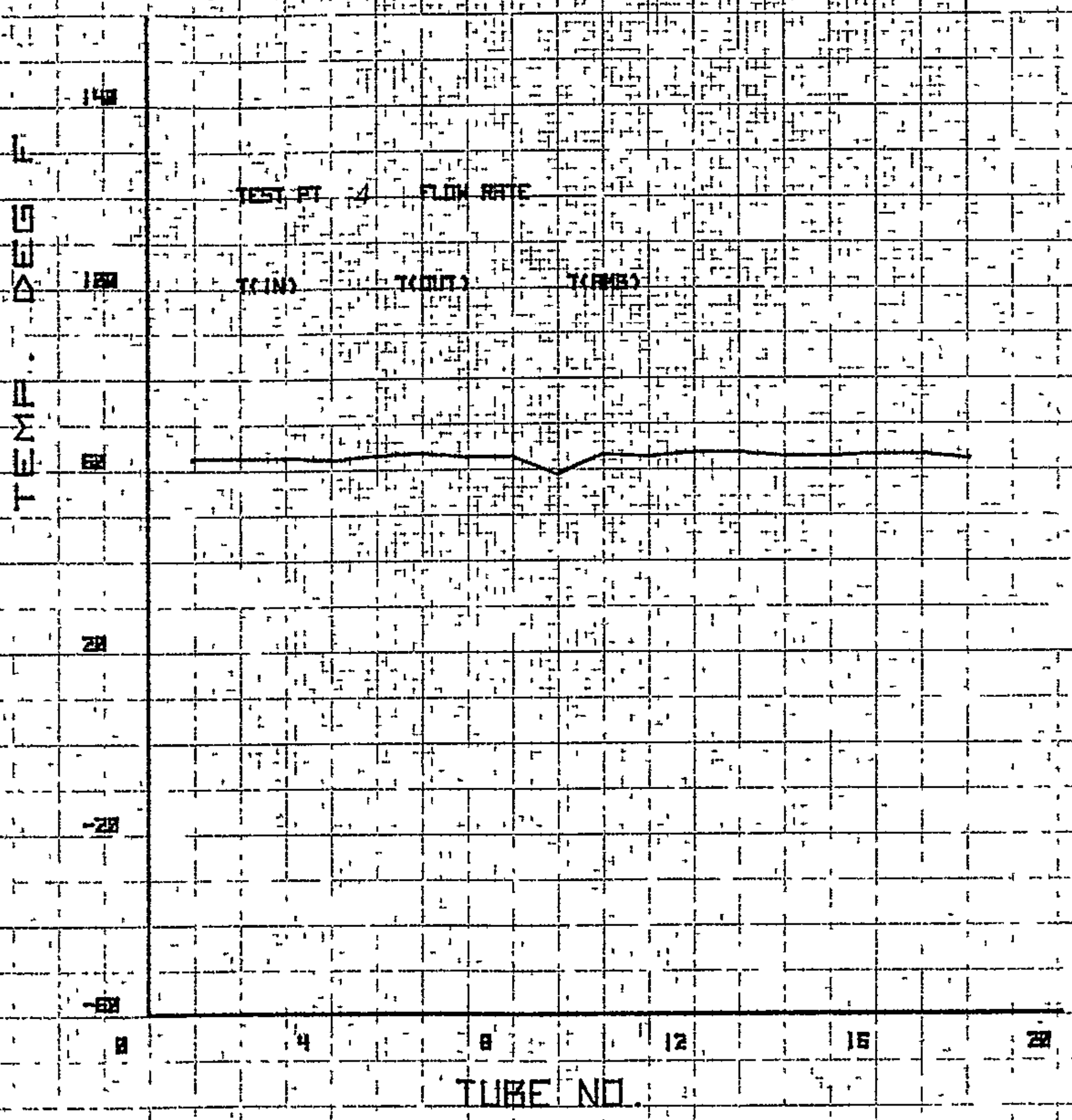


HARD TUBE RADIATOR

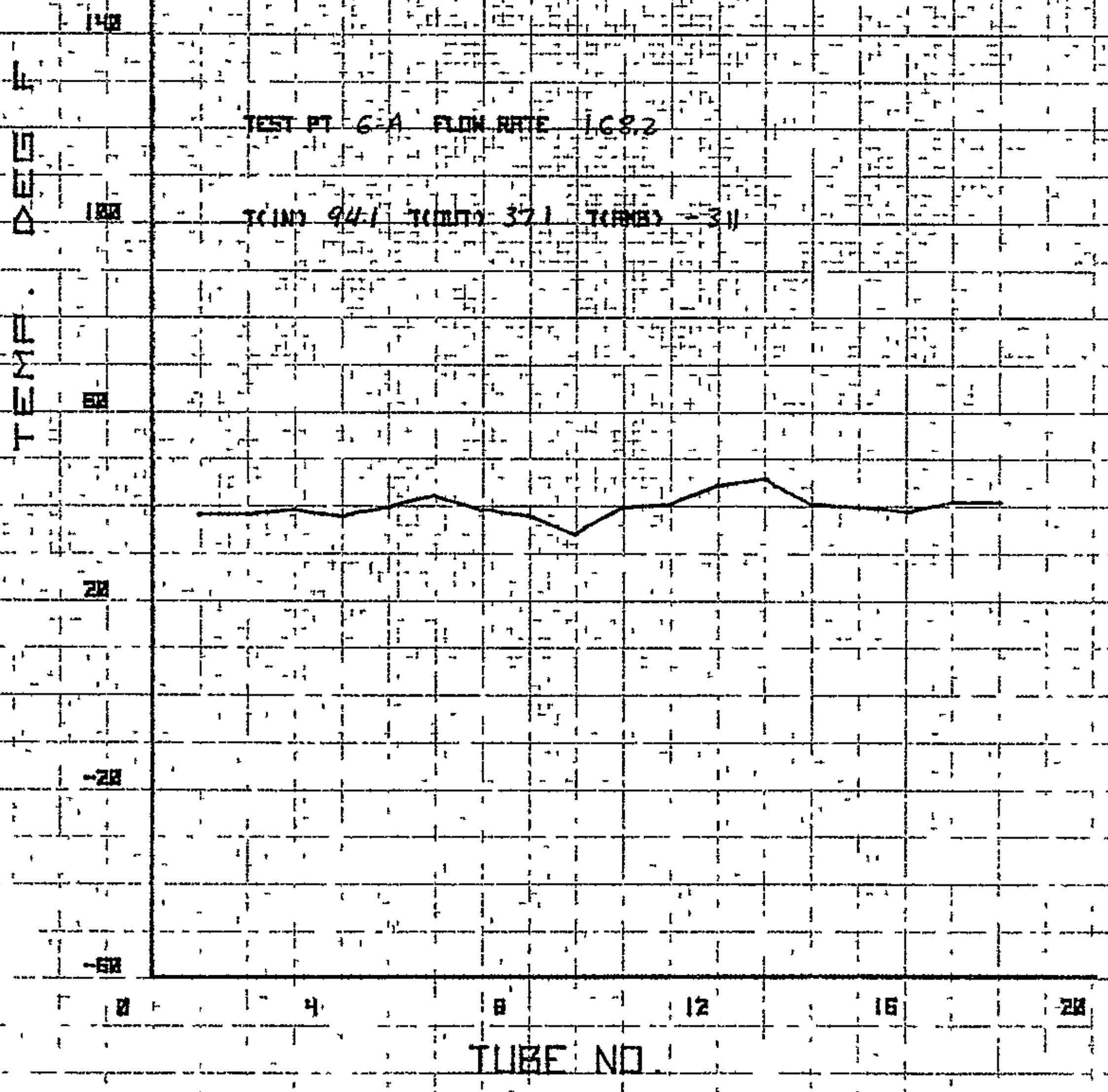


HARD TUBE RADIATOR

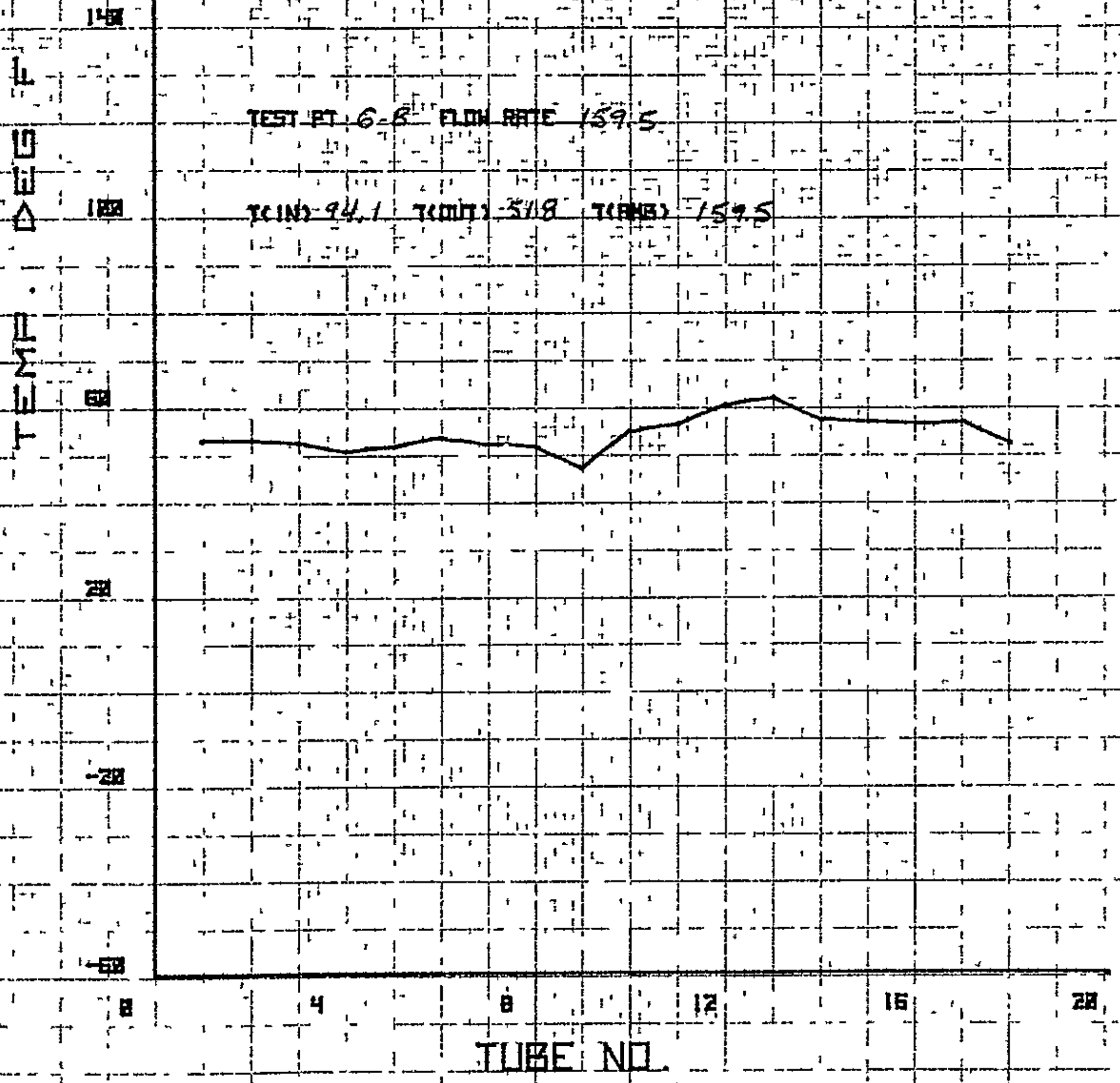
46 1320



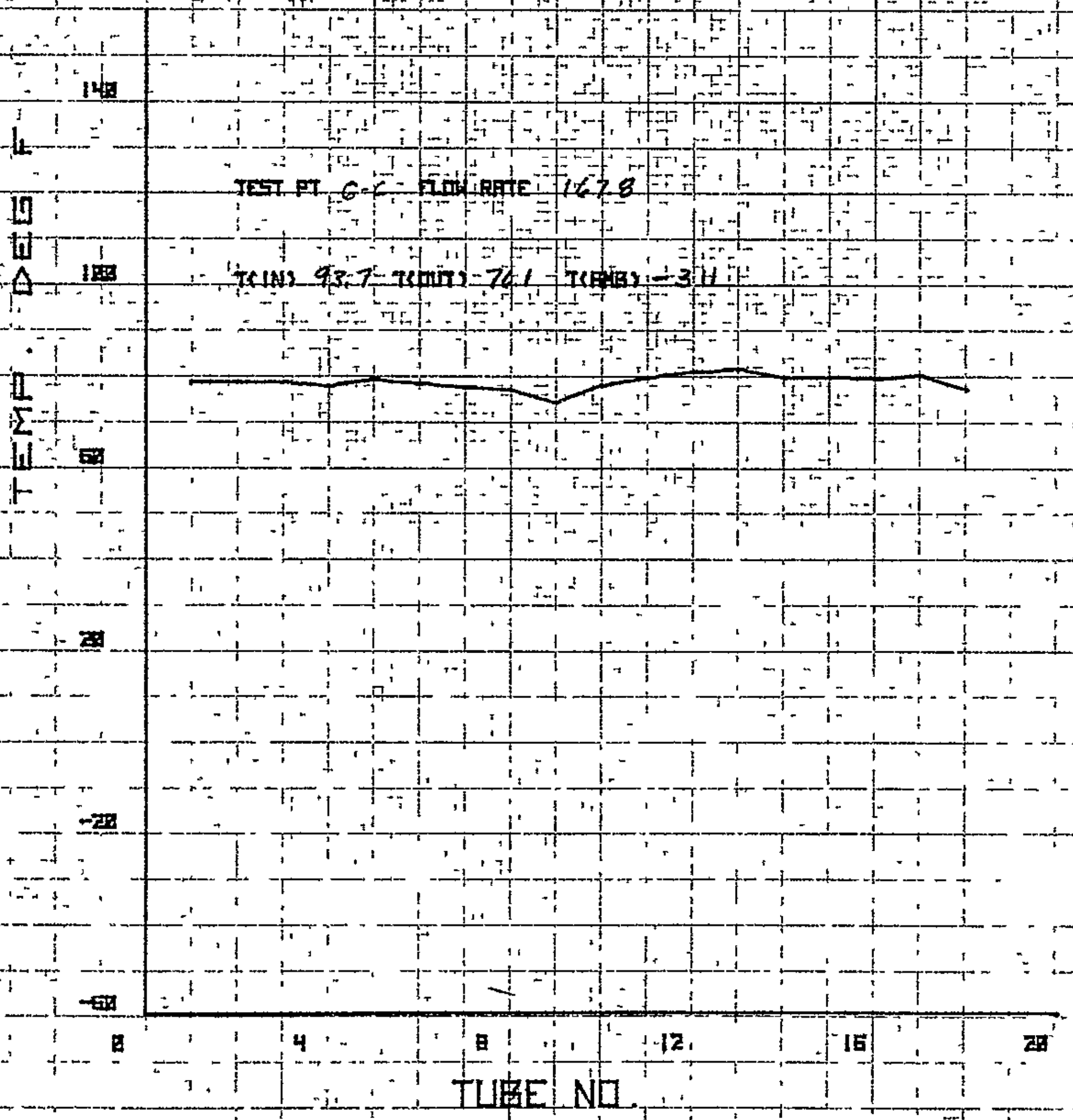
HARD TUBE RADIATOR



HARD TUBE RADIATOR



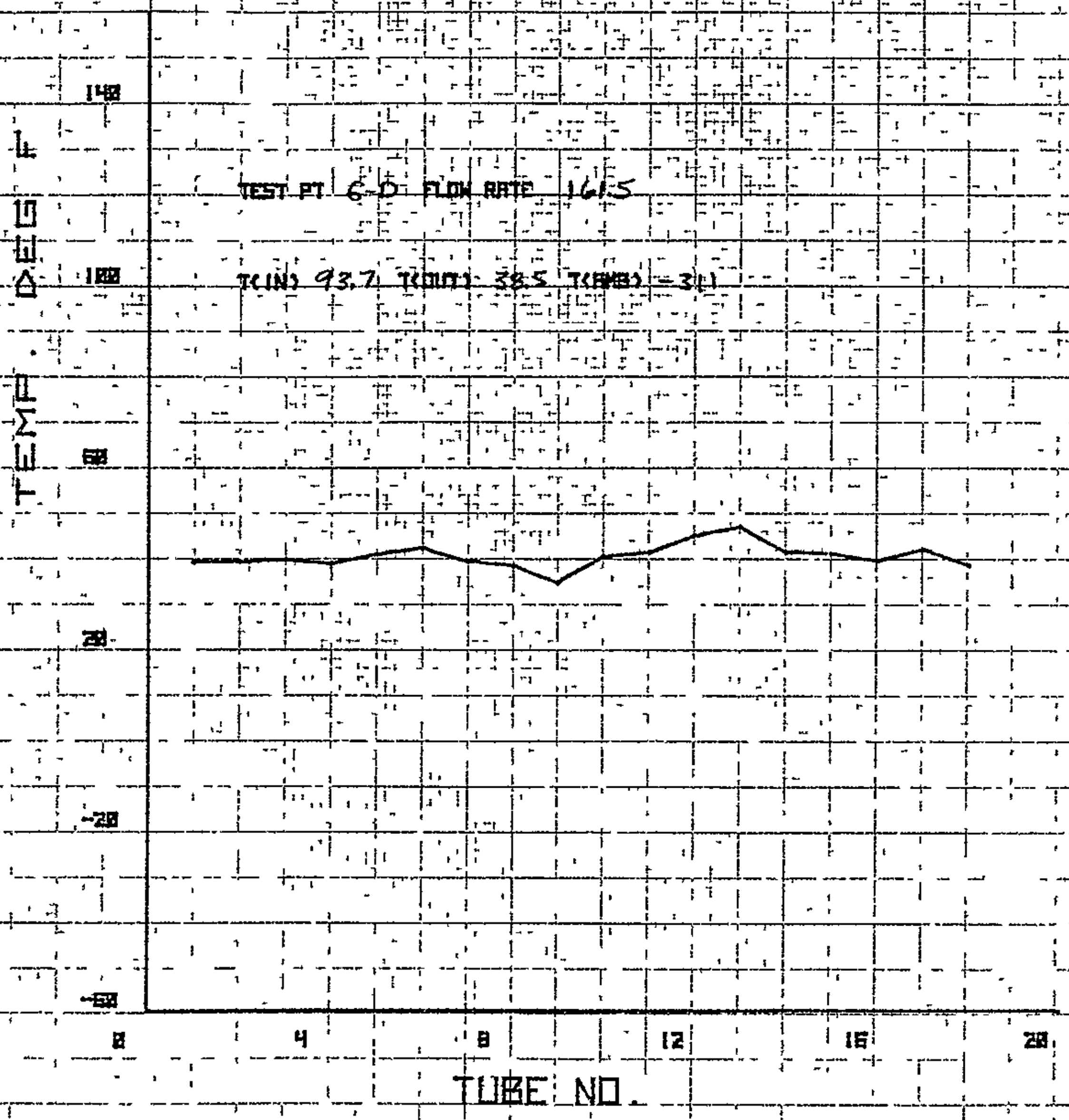
HARD TUBE RADIATOR



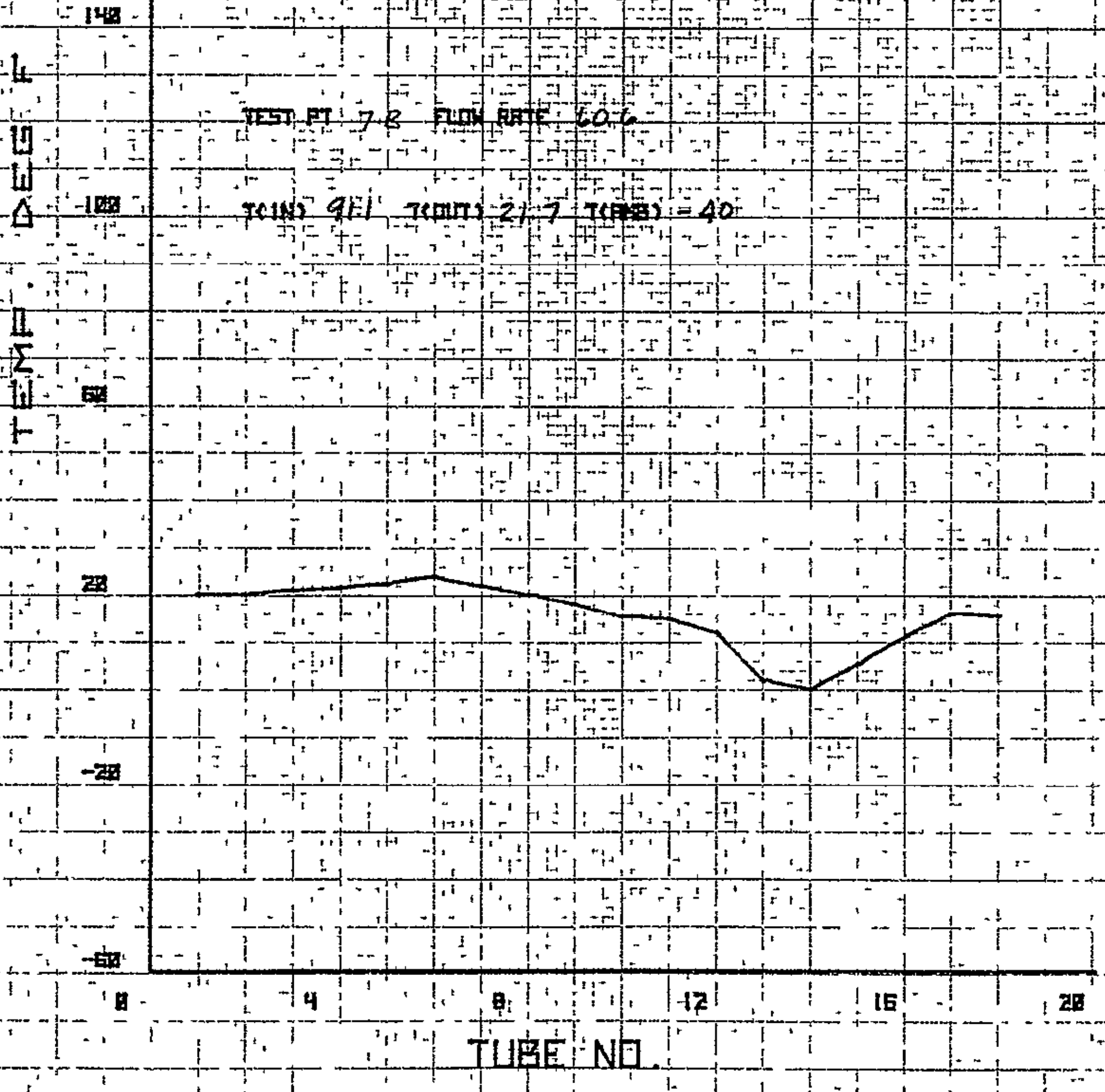
TEST PT 6-C FLOW RATE 1678

T(IN) 93.7 T(OUT) 76.1 T(AMB) -34

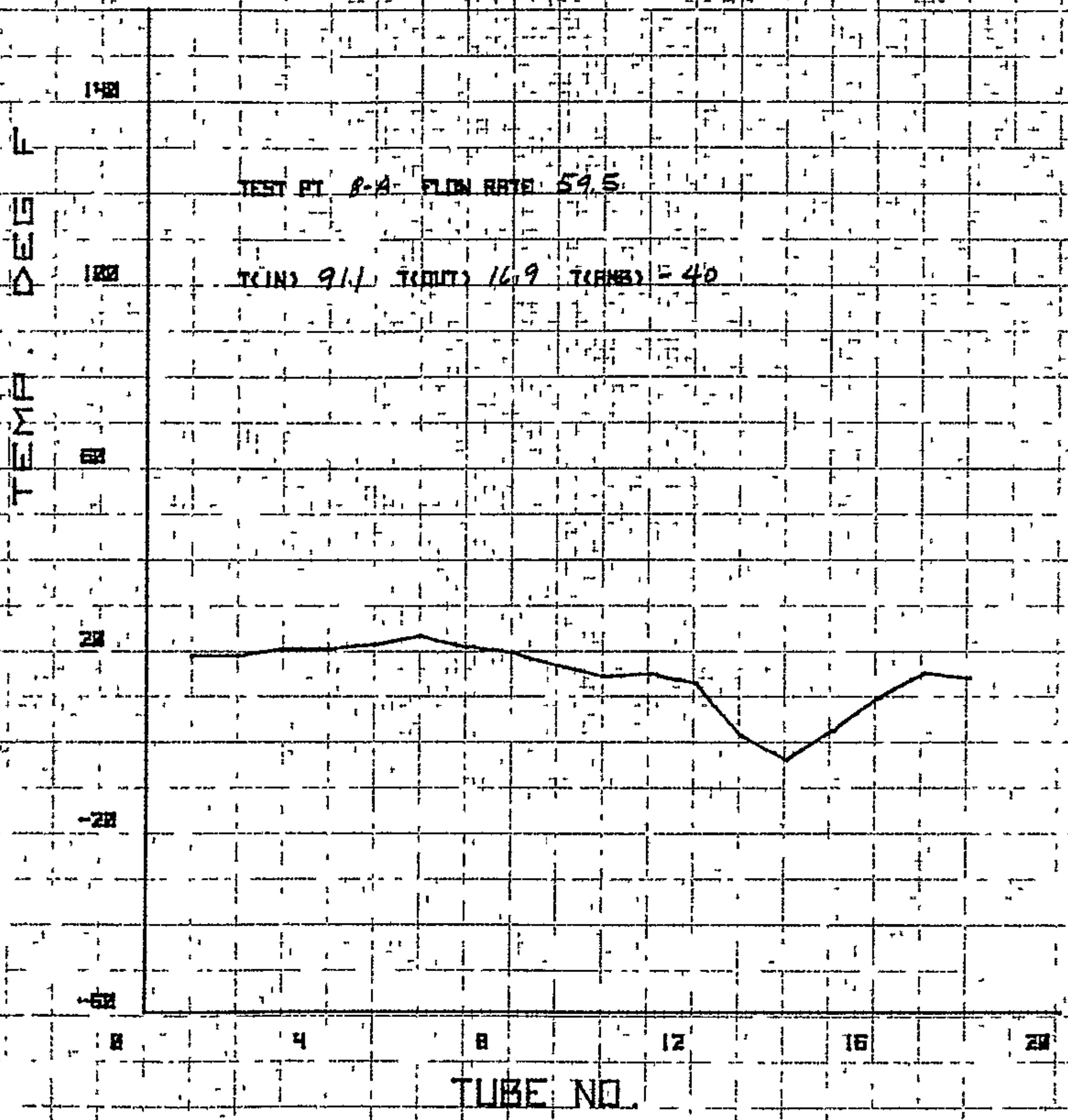
HARD TUBE RADIATOR



HARD TUBE RADIATOR



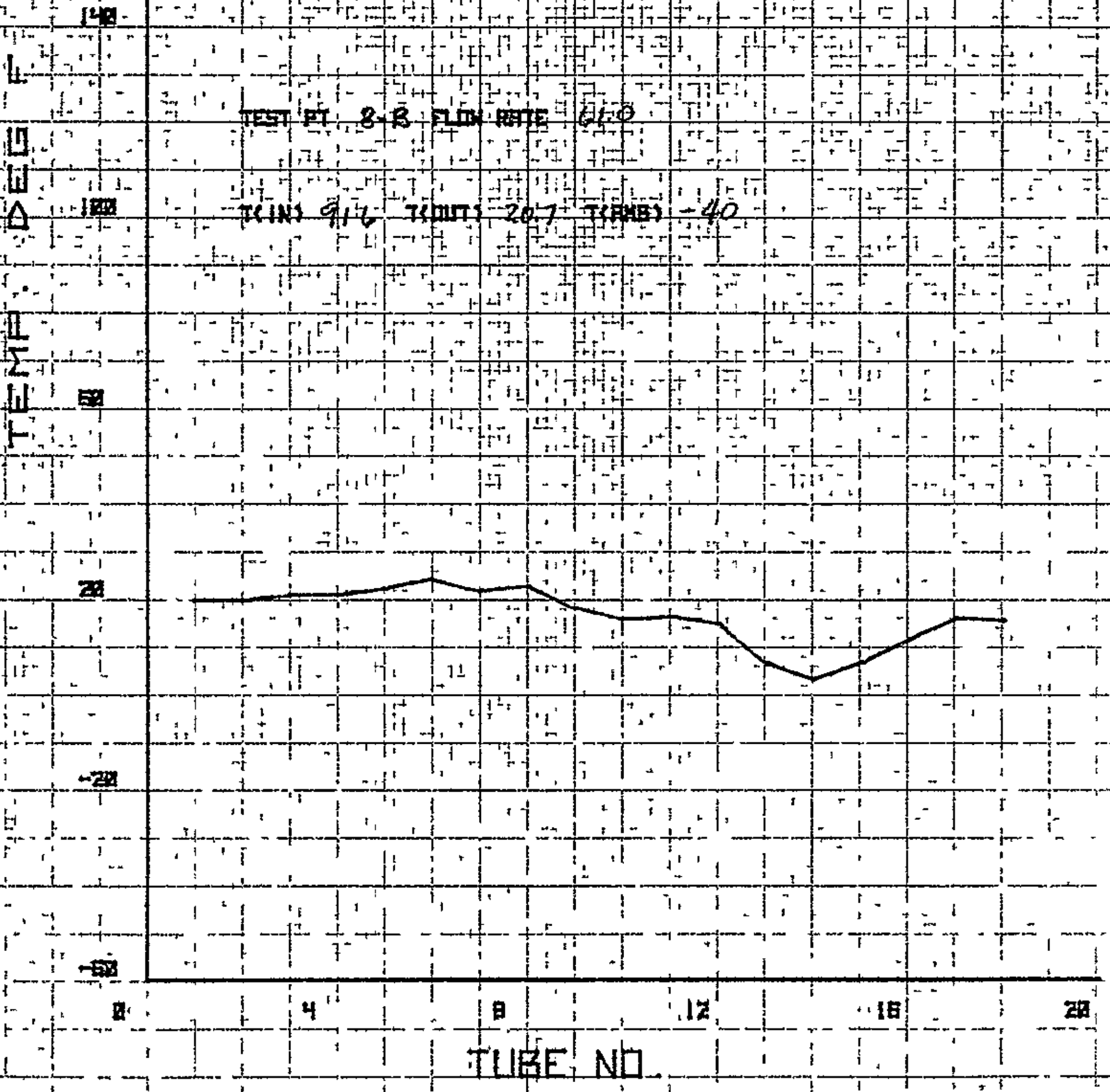
HARD TUBE RADIATOR



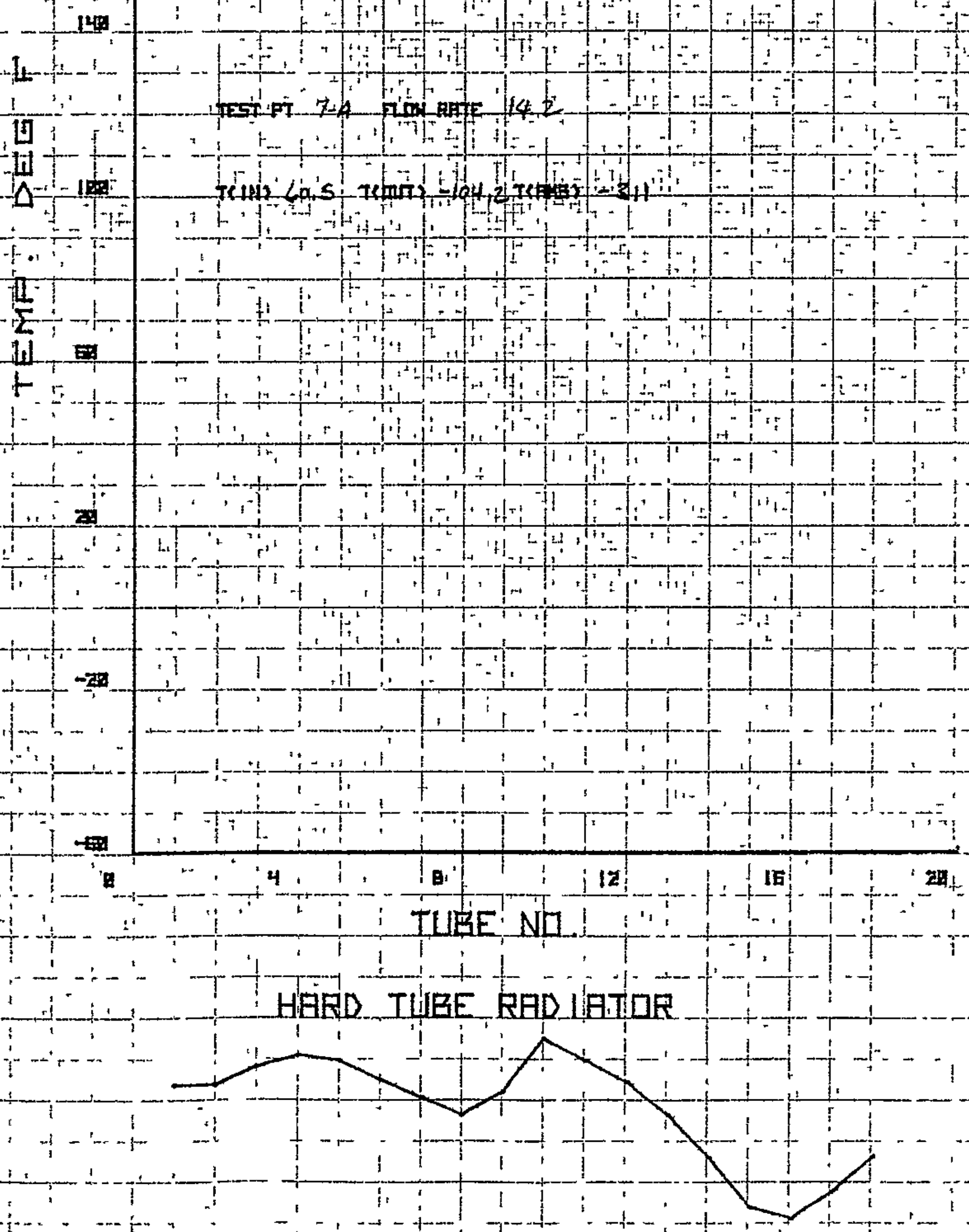
TEST PT 8-A FLOW RATE 59.5

T(IN) 91.1 T(OUT) 16.9 T(AMB) -40

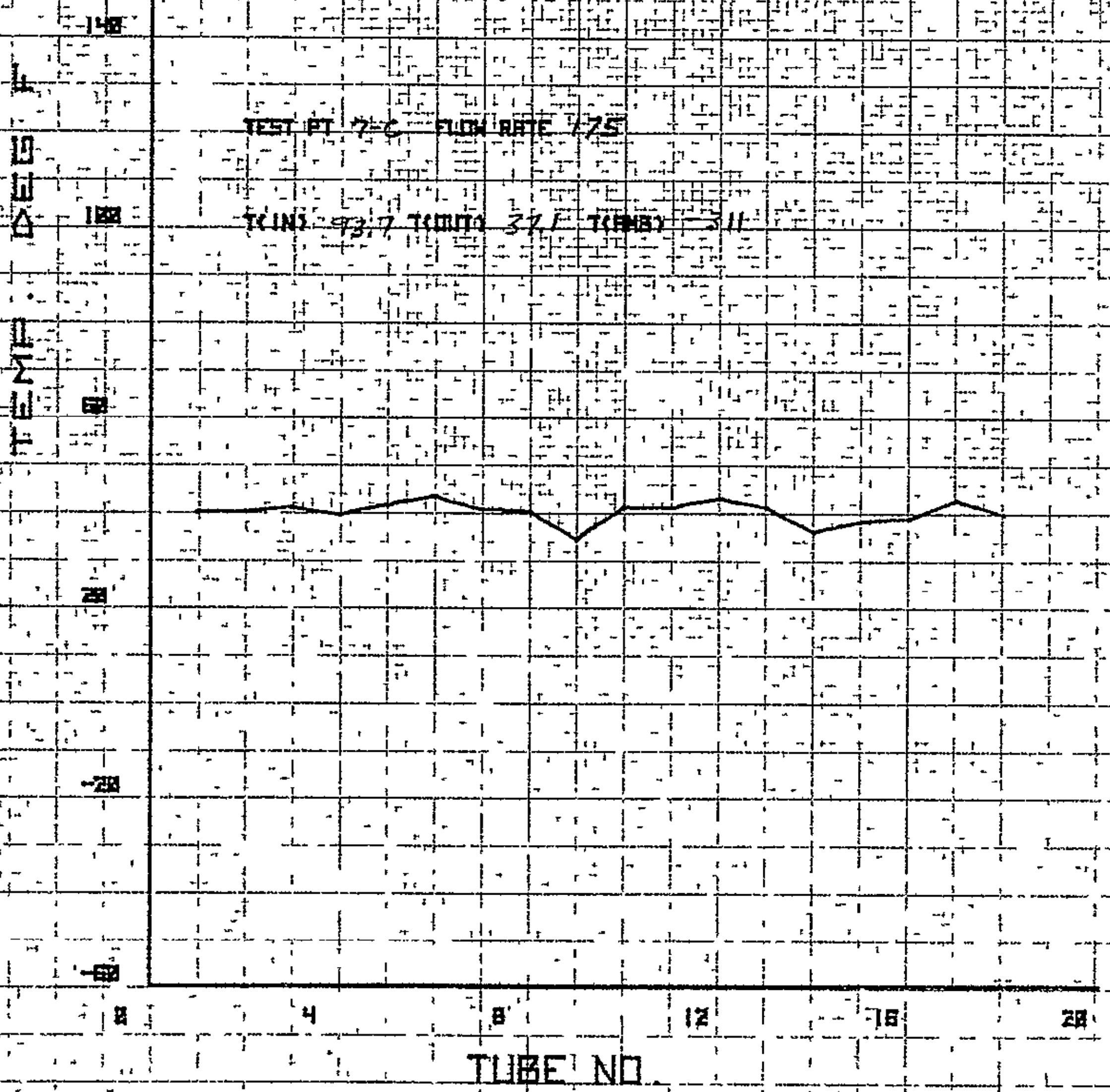
HARD TUBE RADIATOR



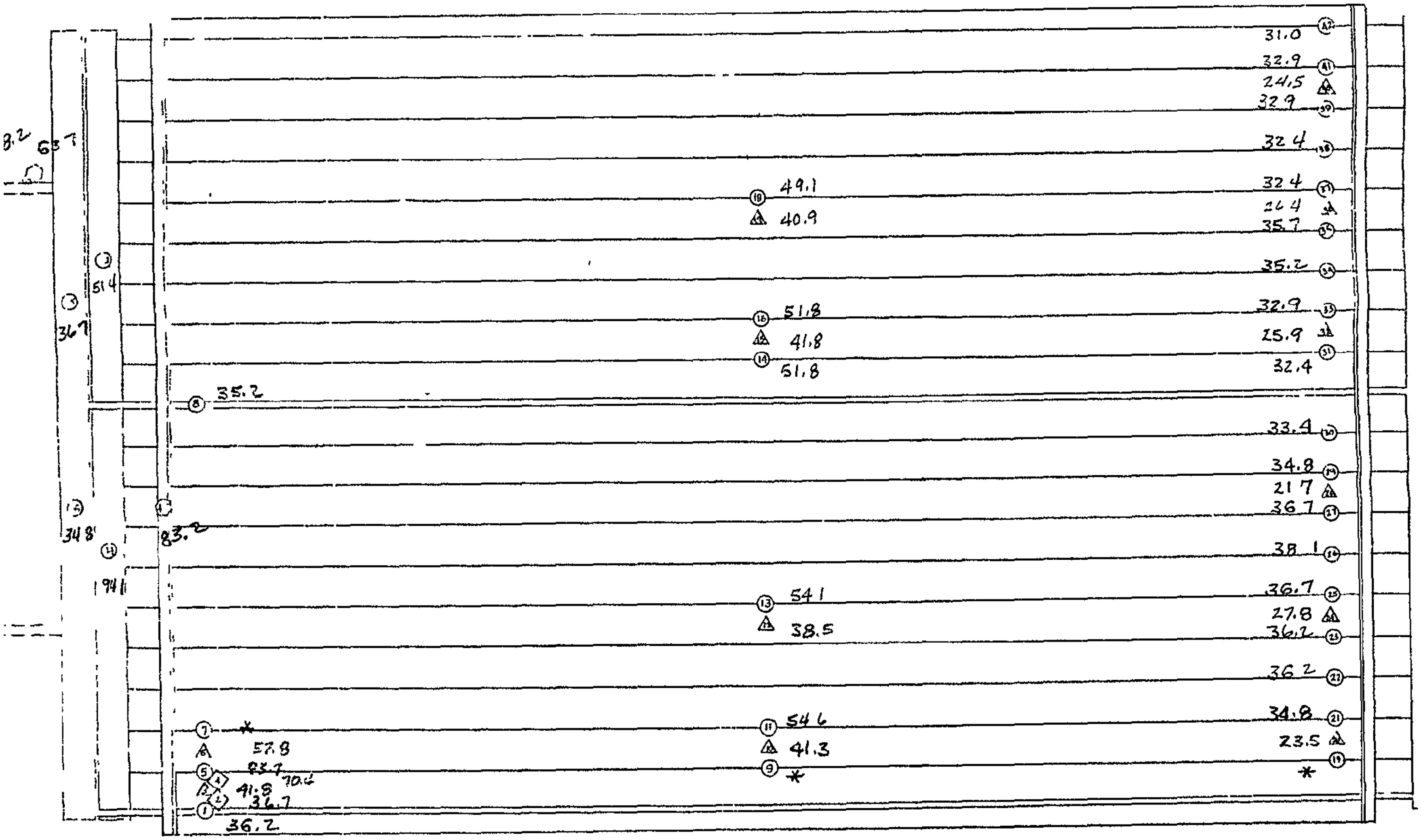
HARD TUBE RADIATOR



HARD TUBE RADIATOR

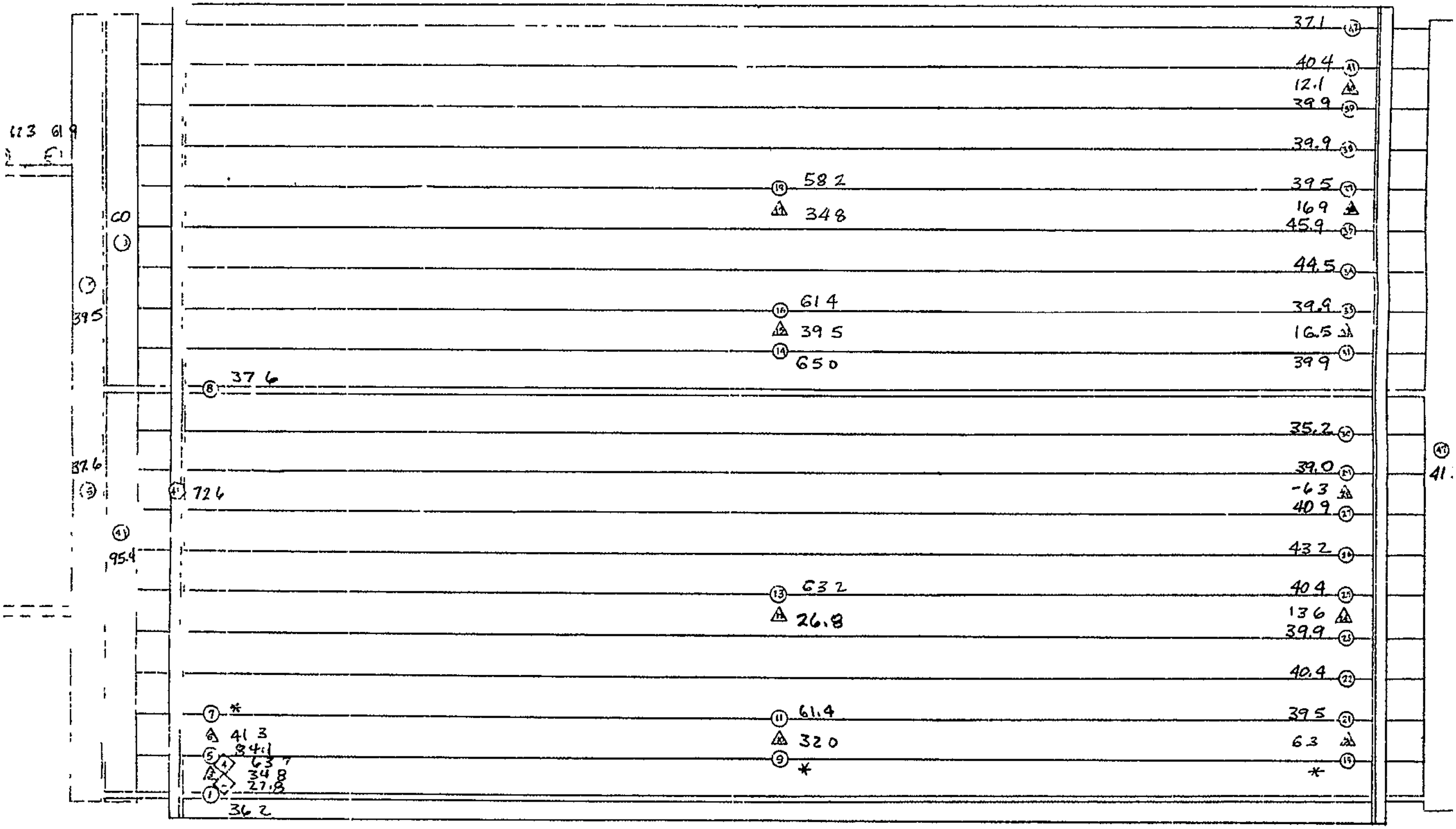


HARD TUBE RADIATOR



HARD TUBE INFLATABLE RADIATOR THERMOCOUPLE LOCATIONS

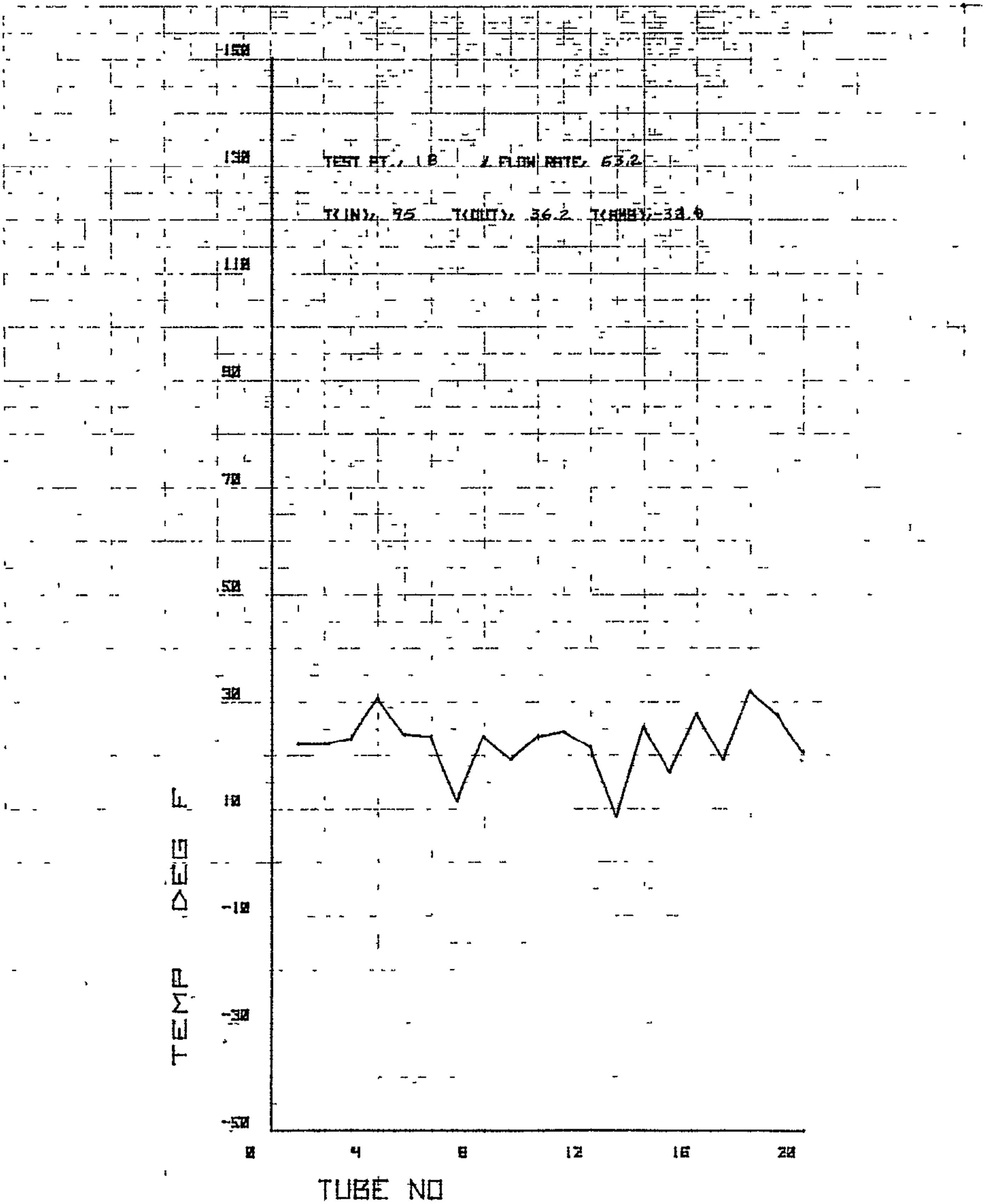
TEST POINT 1



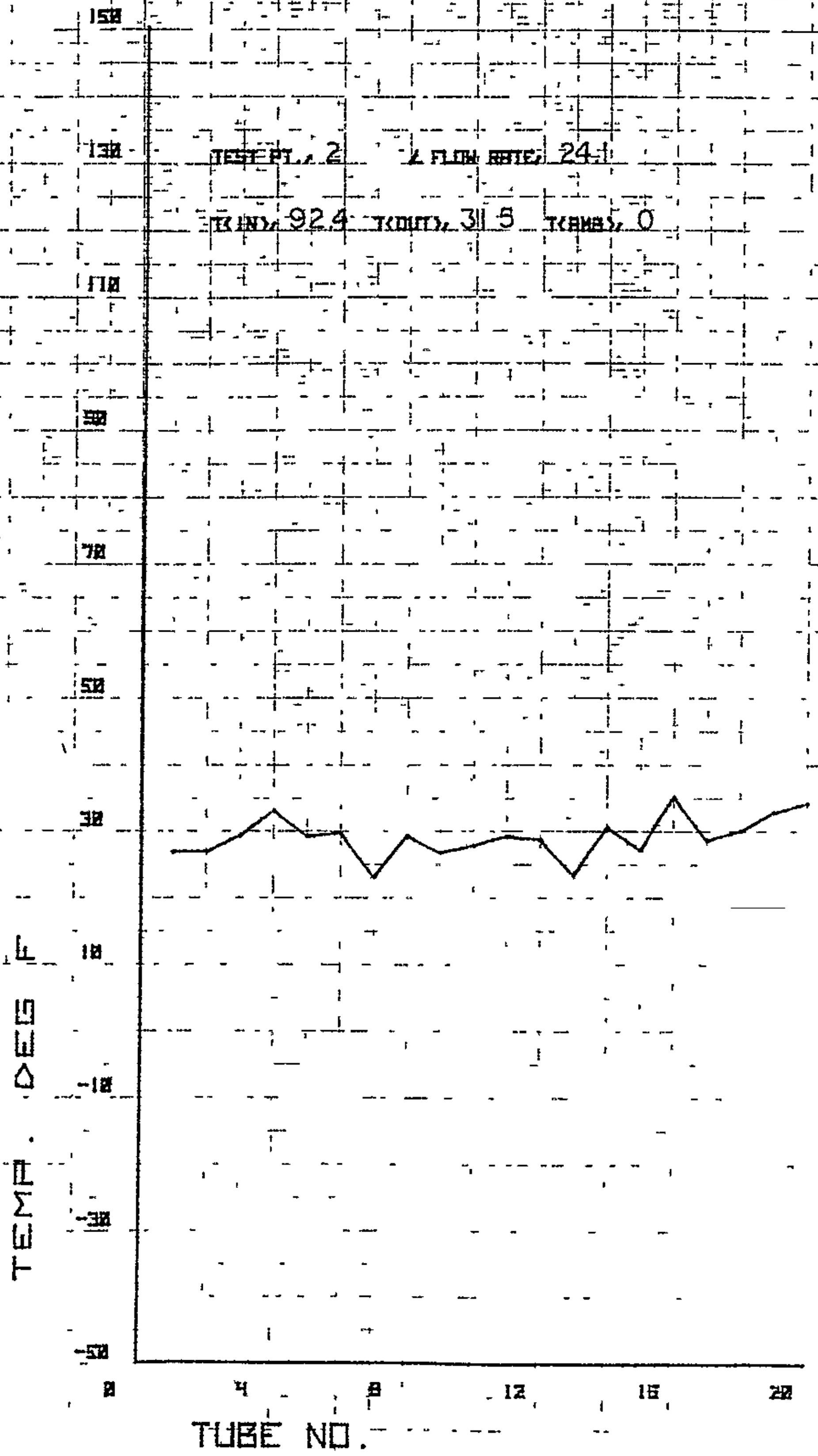
HARD TUBE INFLATABLE RADIATOR THERMOCOUPLE LOCATIONS

TEST POINT 2

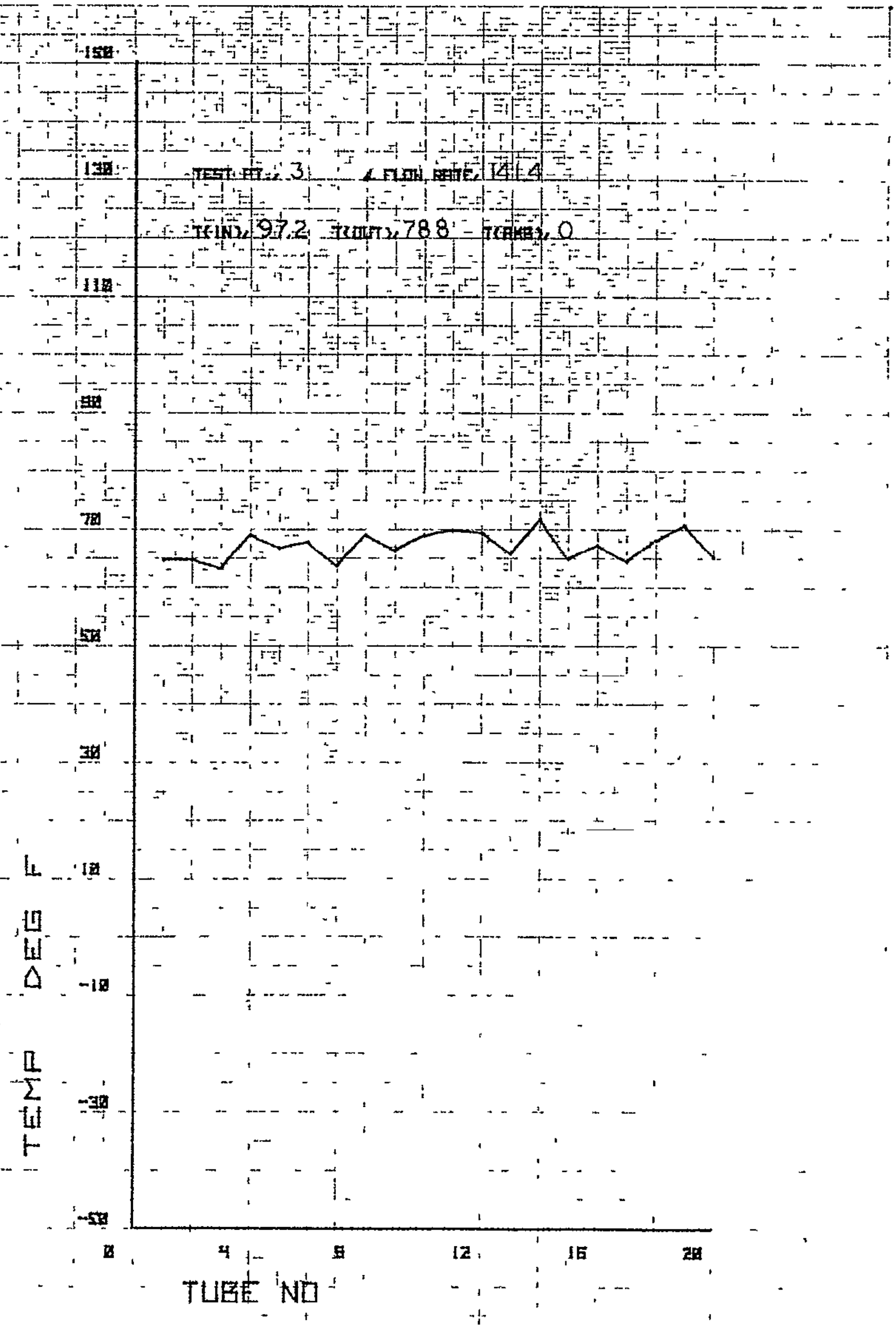
APPENDIX C. TEST DATA FOR THE SOFT TUBE ENGINEERING MODEL RADIATOR (Outlet Temperature versus Tube Number and Map of Thermocouple Readings)



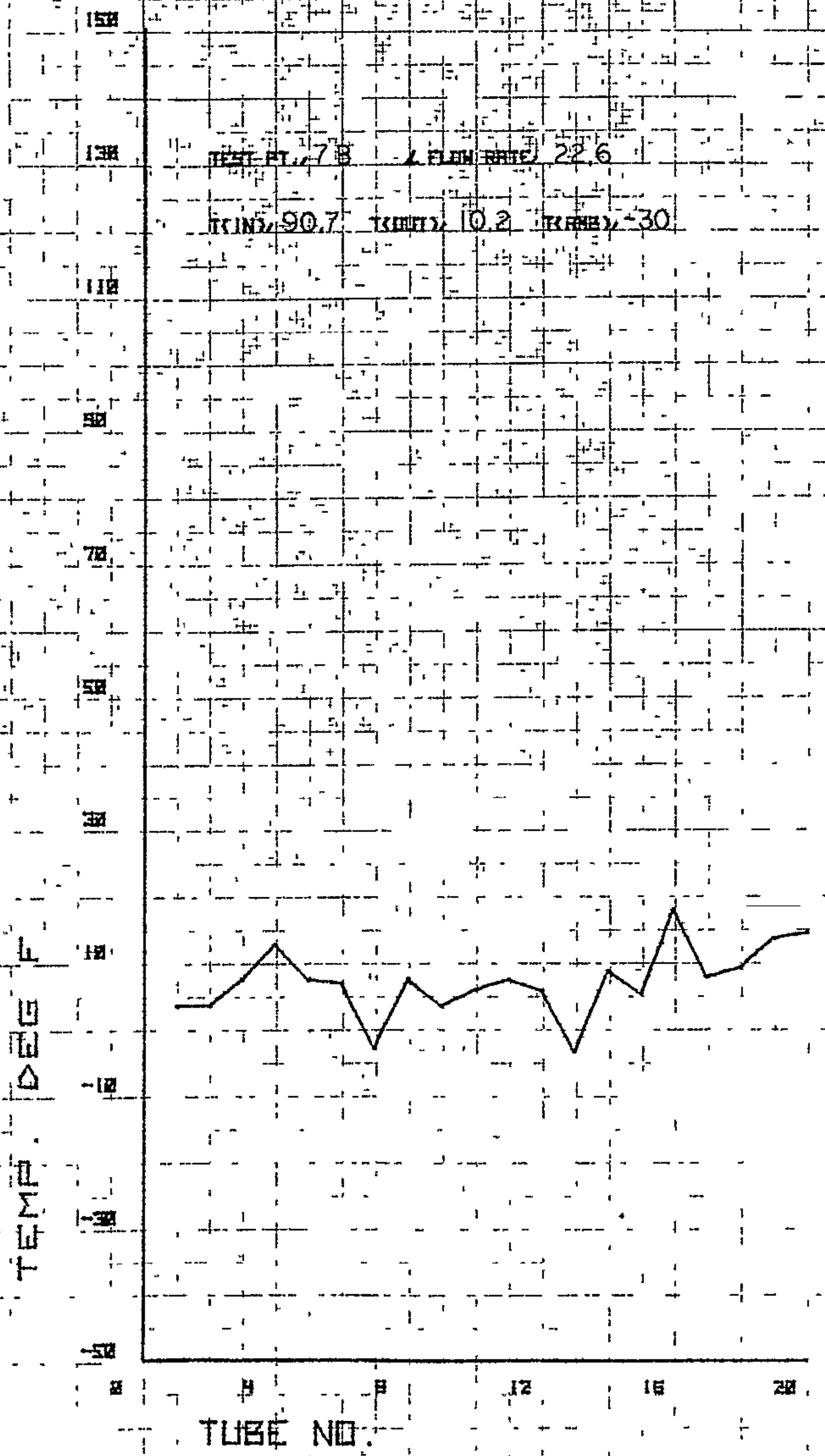
SOFT TUBE RADIATOR



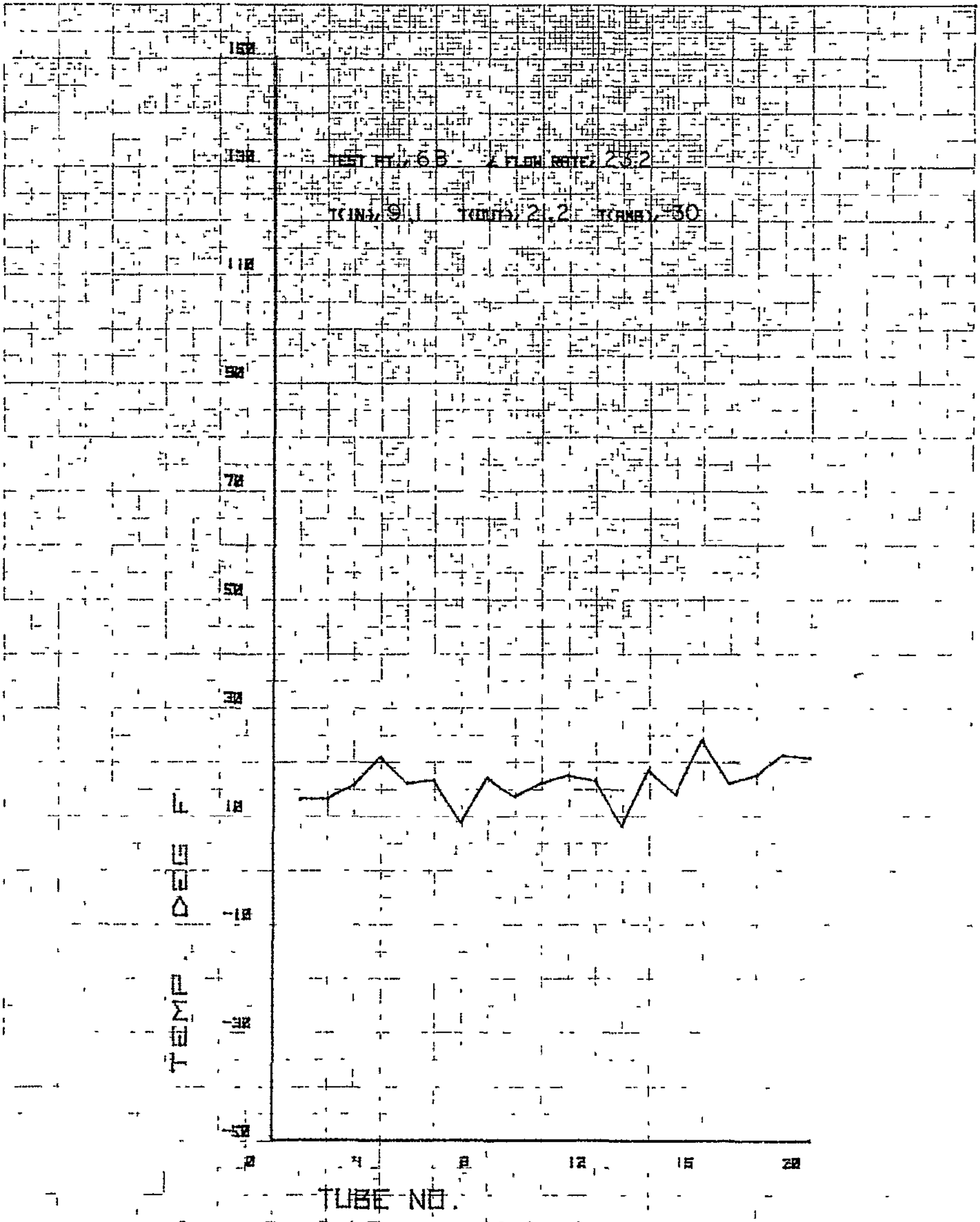
SOFT TUBE RADIATOR



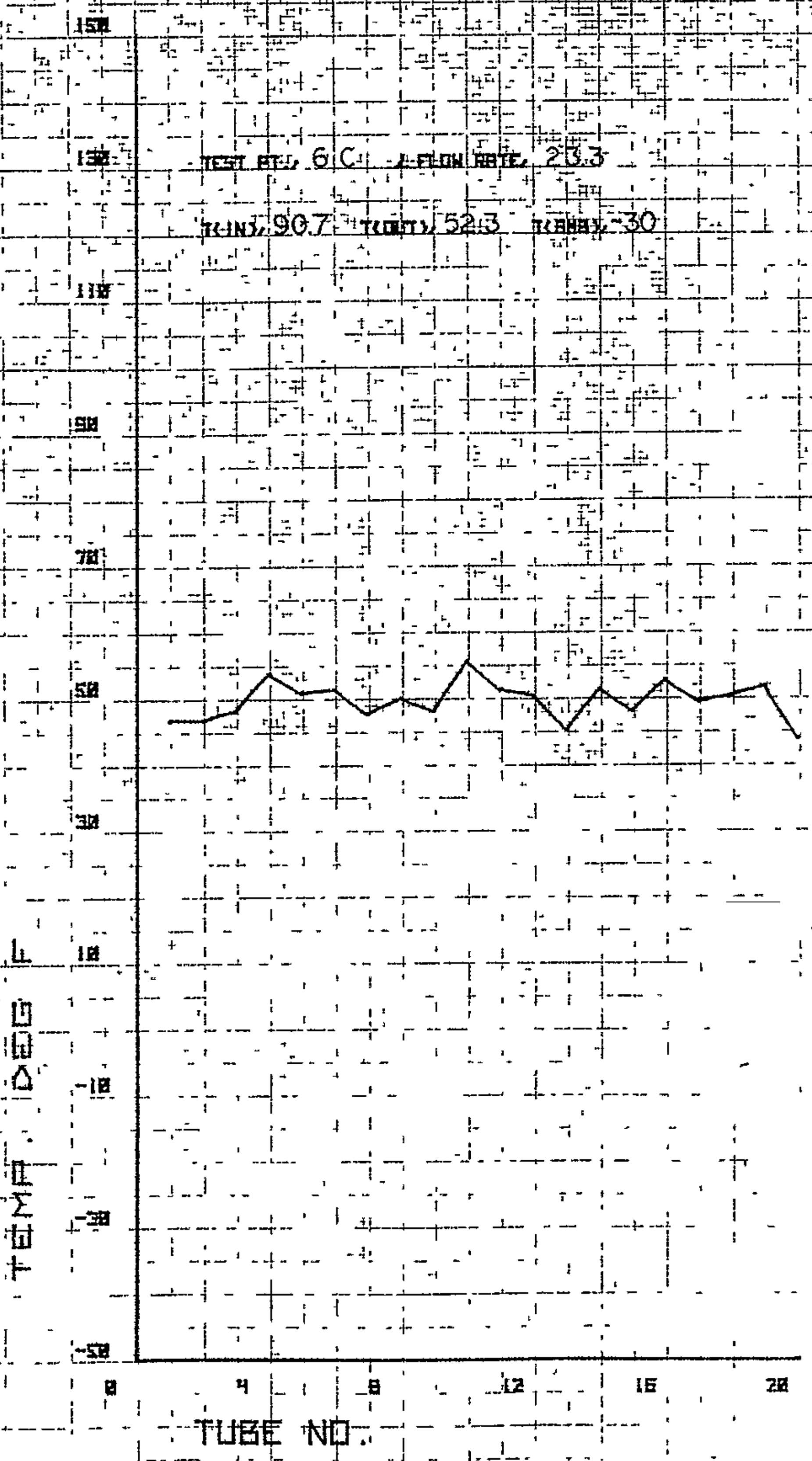
SOFT TUBE RADIATOR



SOFT TUBE RADIATOR

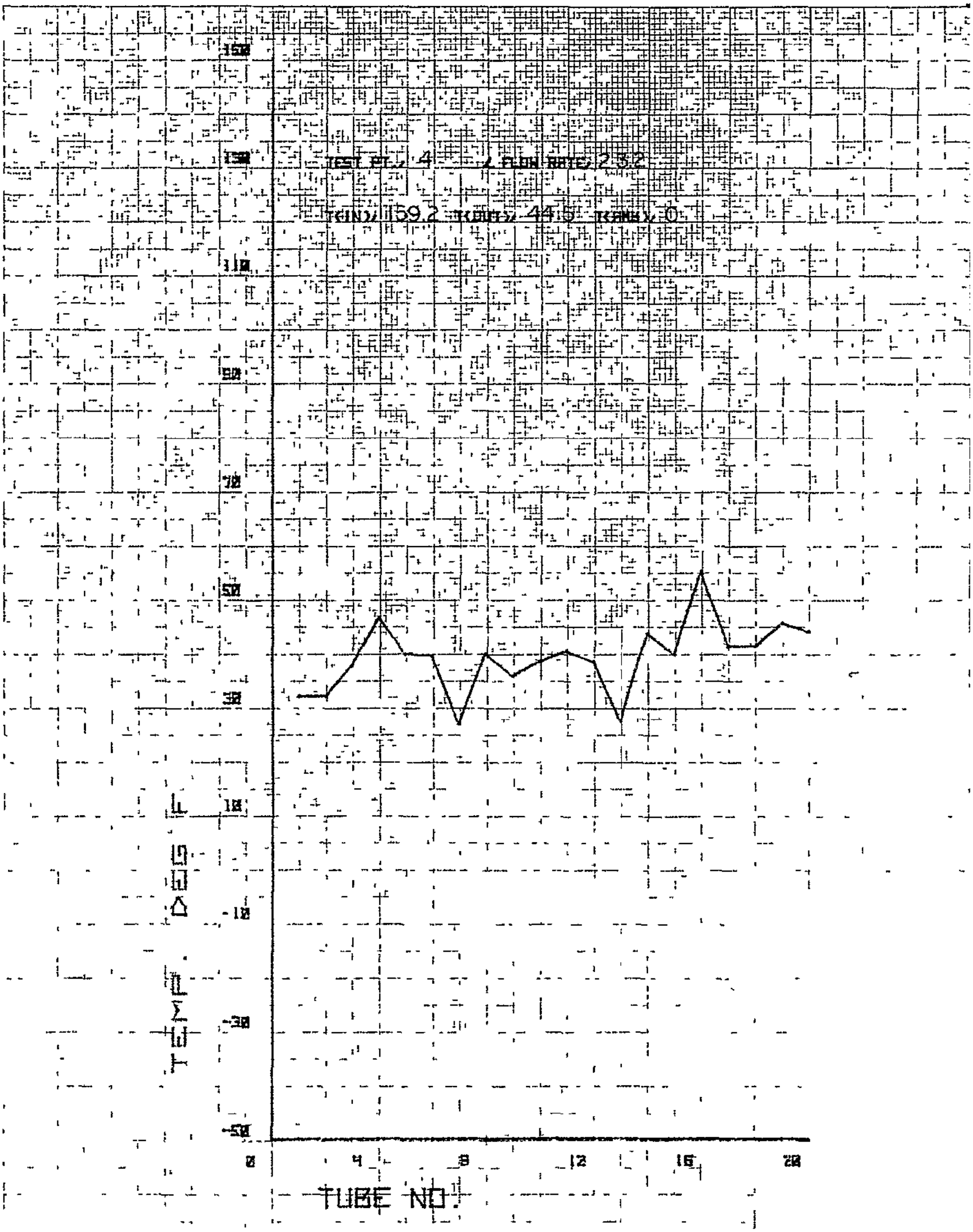


SOFT TUBE RADIATOR

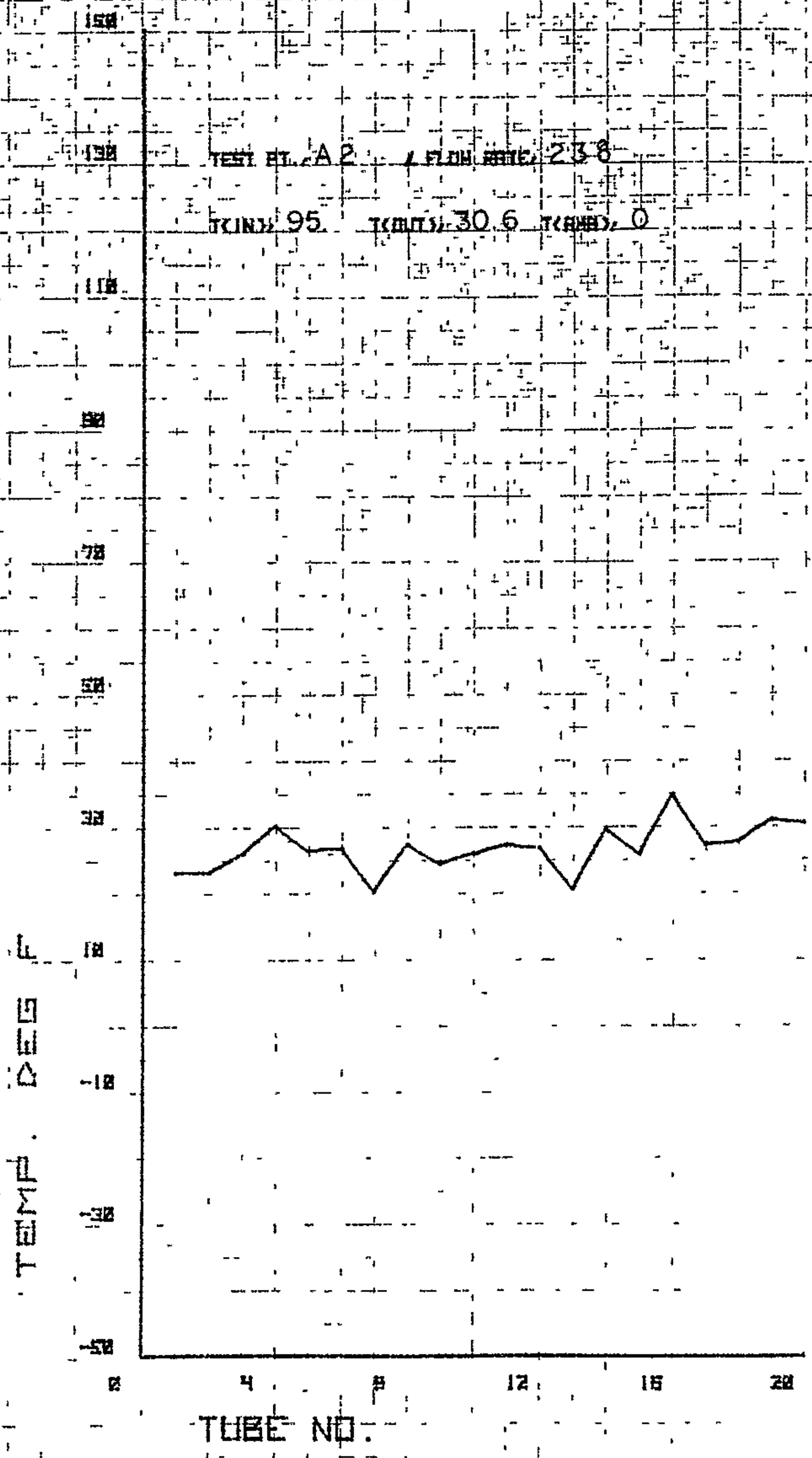


SOFT TUBE RADIATOR

46 1513



SOFT TUBE RADIATOR



SOFT TUBE RADIATOR

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

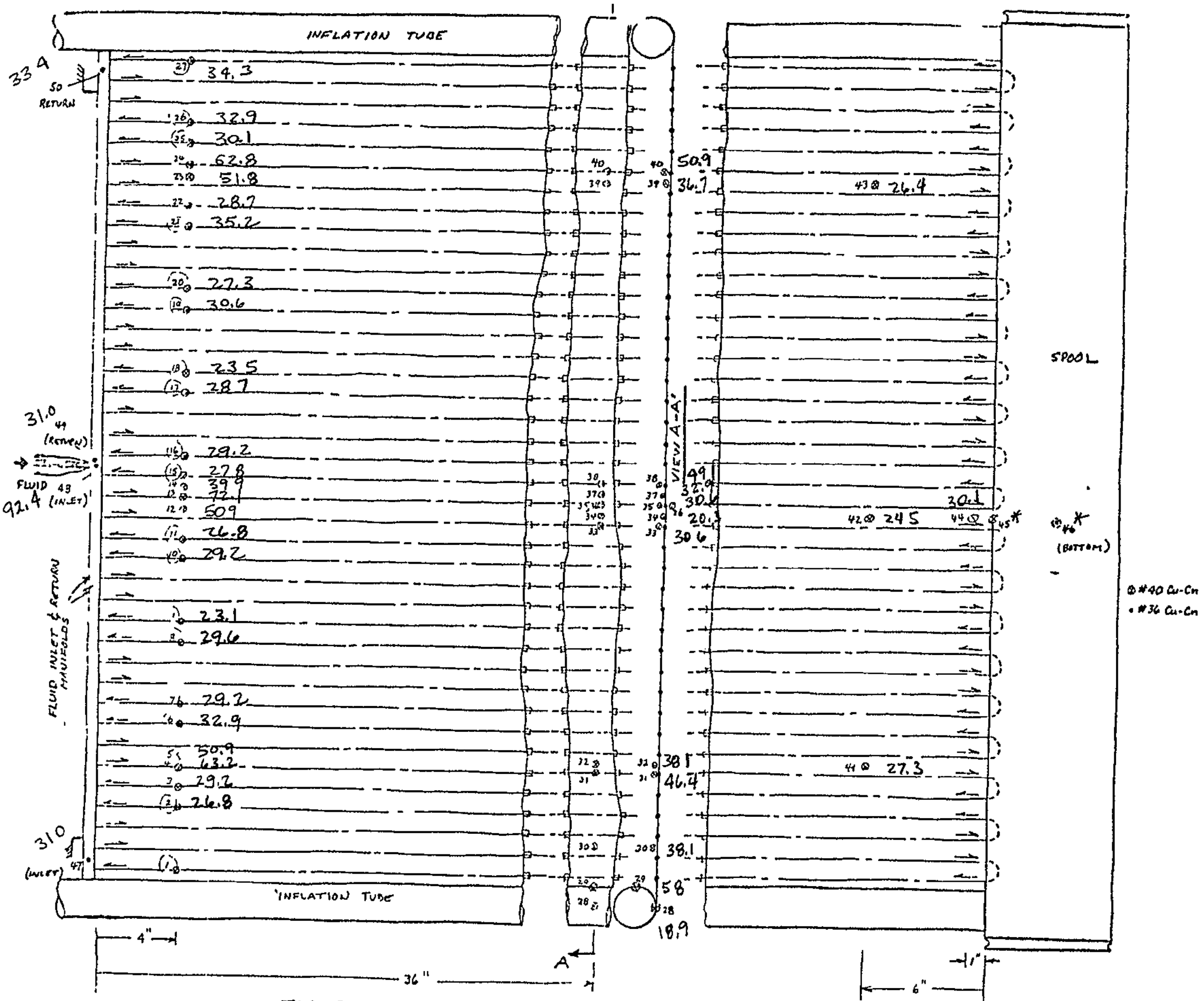


FIGURE 7 - SOFT TUBE TEST ARTICLE INSTRUMENTATION

TEST POINT 2

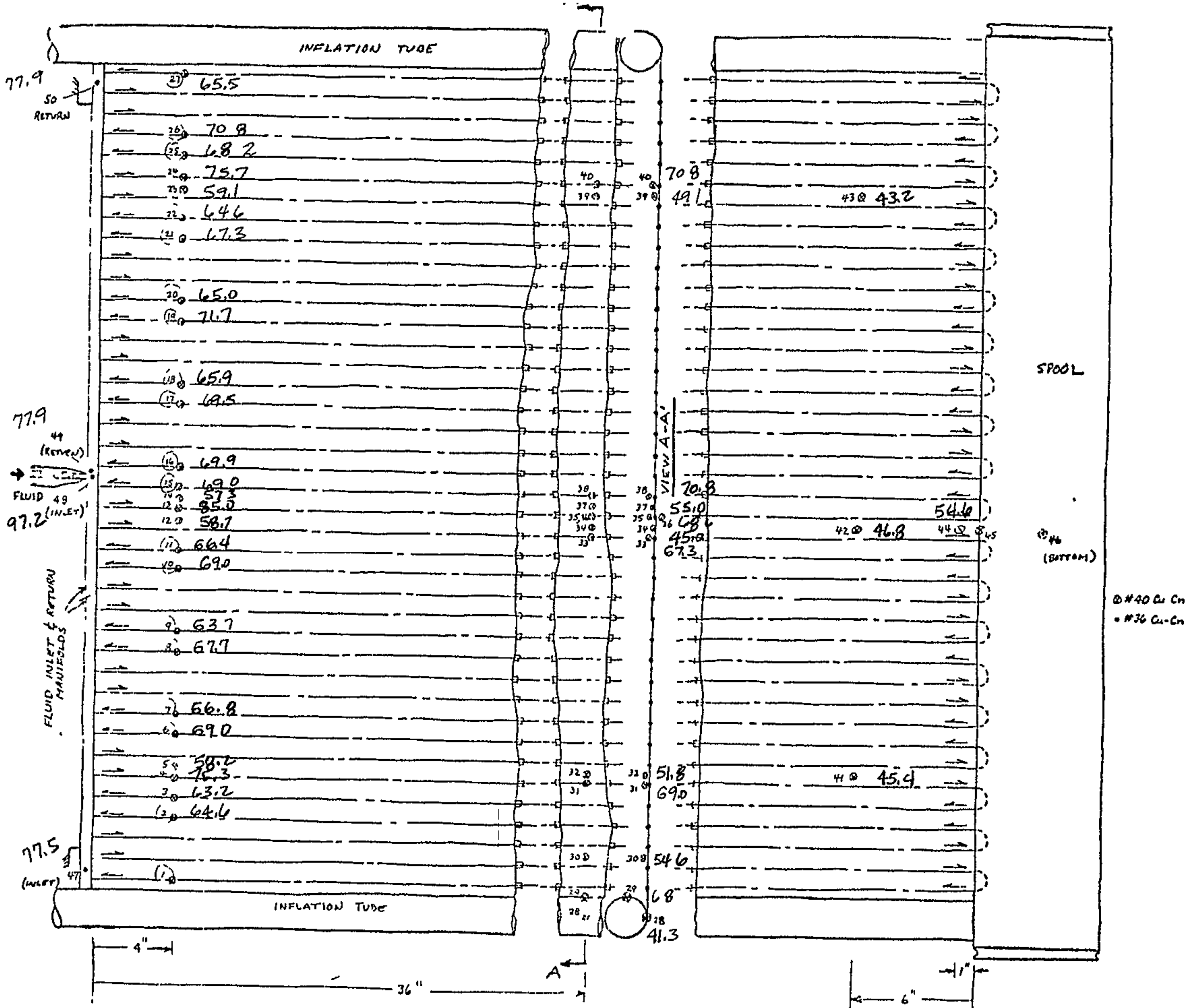


FIGURE 7 - SOFT TUBE TEST ARTICLE INSTRUMENTATION

TEST POINT 3

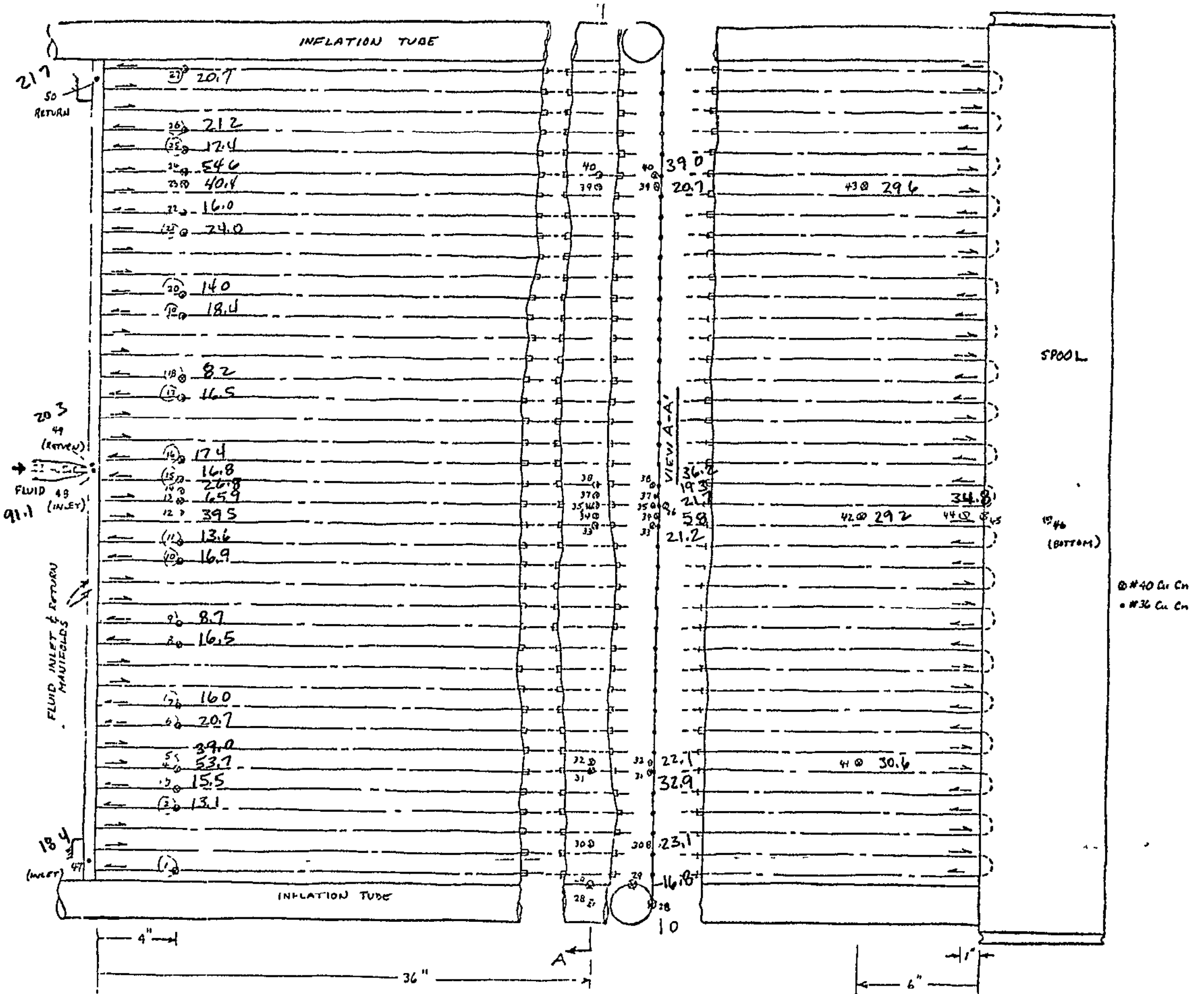


FIGURE 7 - SOFT TUBE TEST ARTICLE INSTRUMENTATION

TEST POINT 6-B

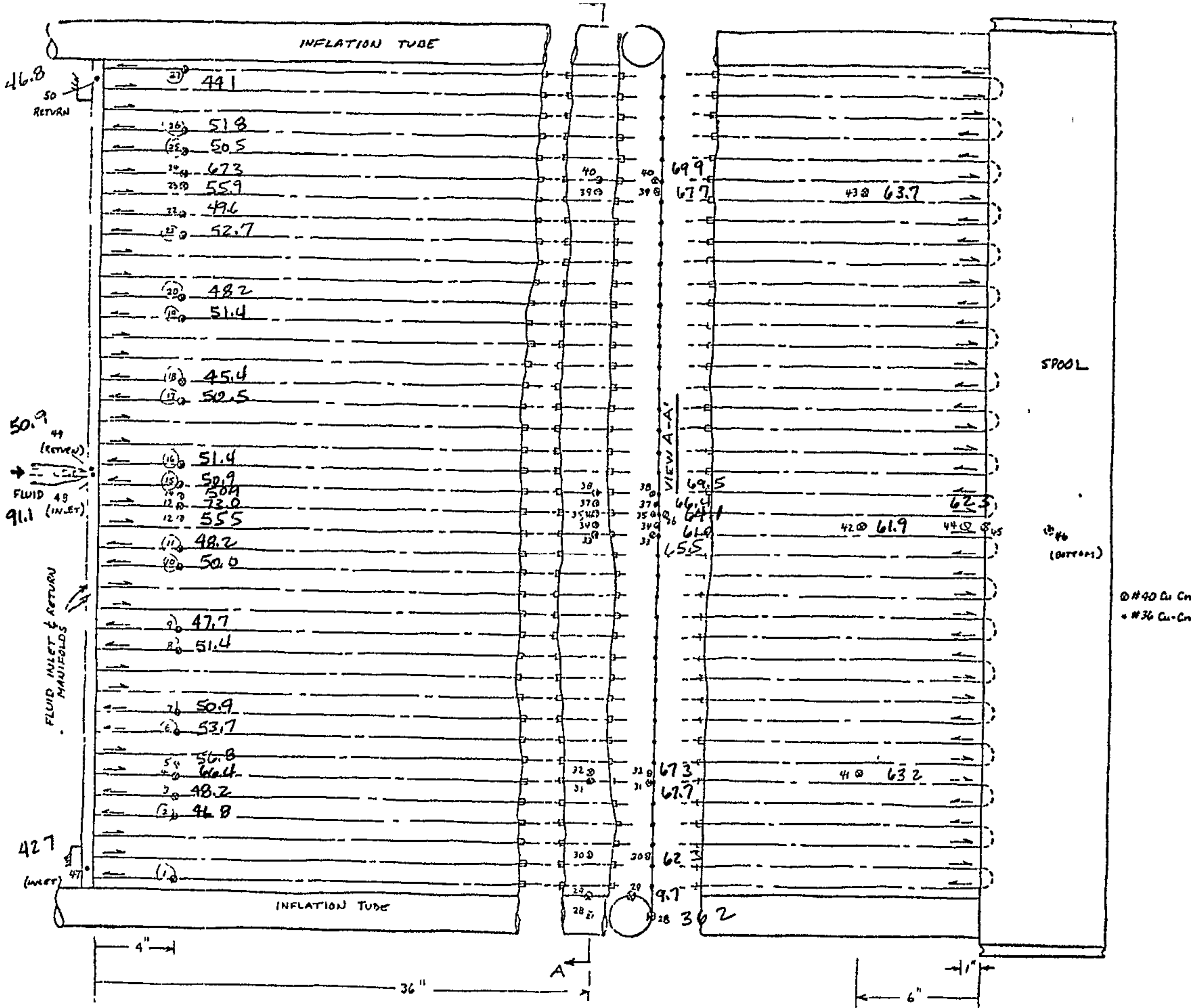


FIGURE 7 - SOFT TUBE TEST ARTICLE INSTRUMENTATION

TEST POINT 6-C

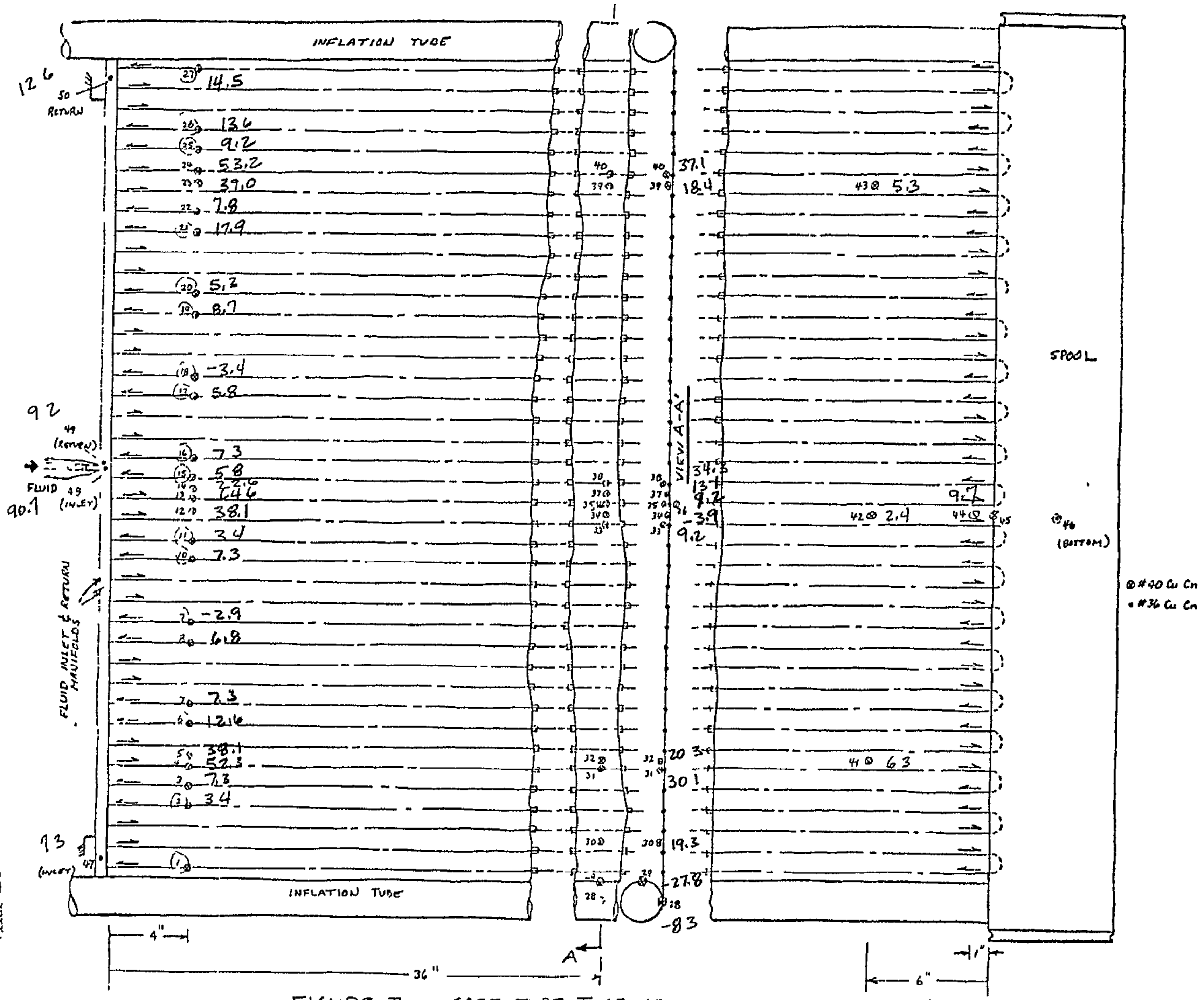


FIGURE 7 - SOFT TUBE TEST ARTICLE INSTRUMENTATION

TEST POINT 7-B

C-14

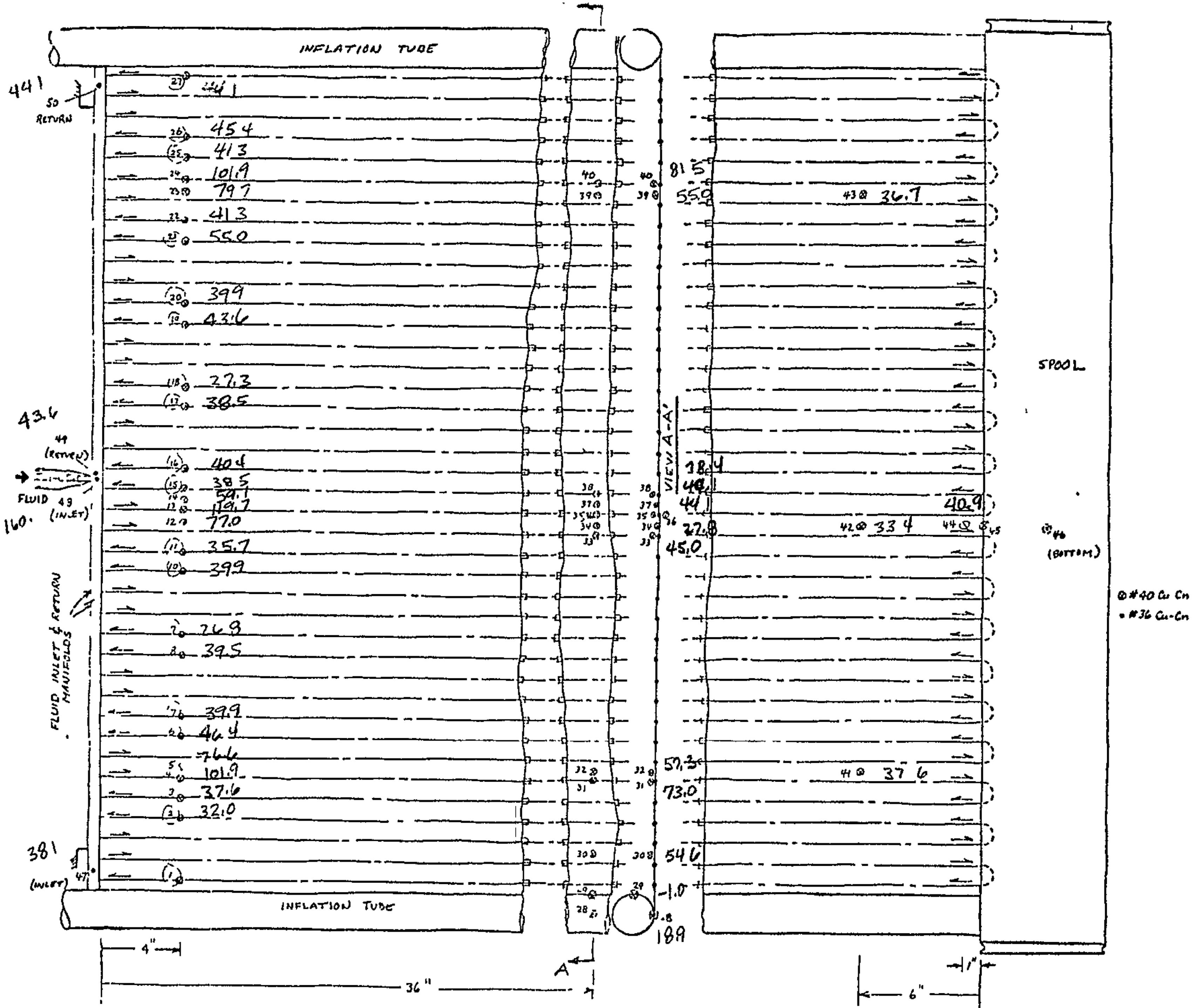


FIGURE 7 - SOFT TUBE TEST ARTICLE INSTRUMENTATION

TEST POINT 4

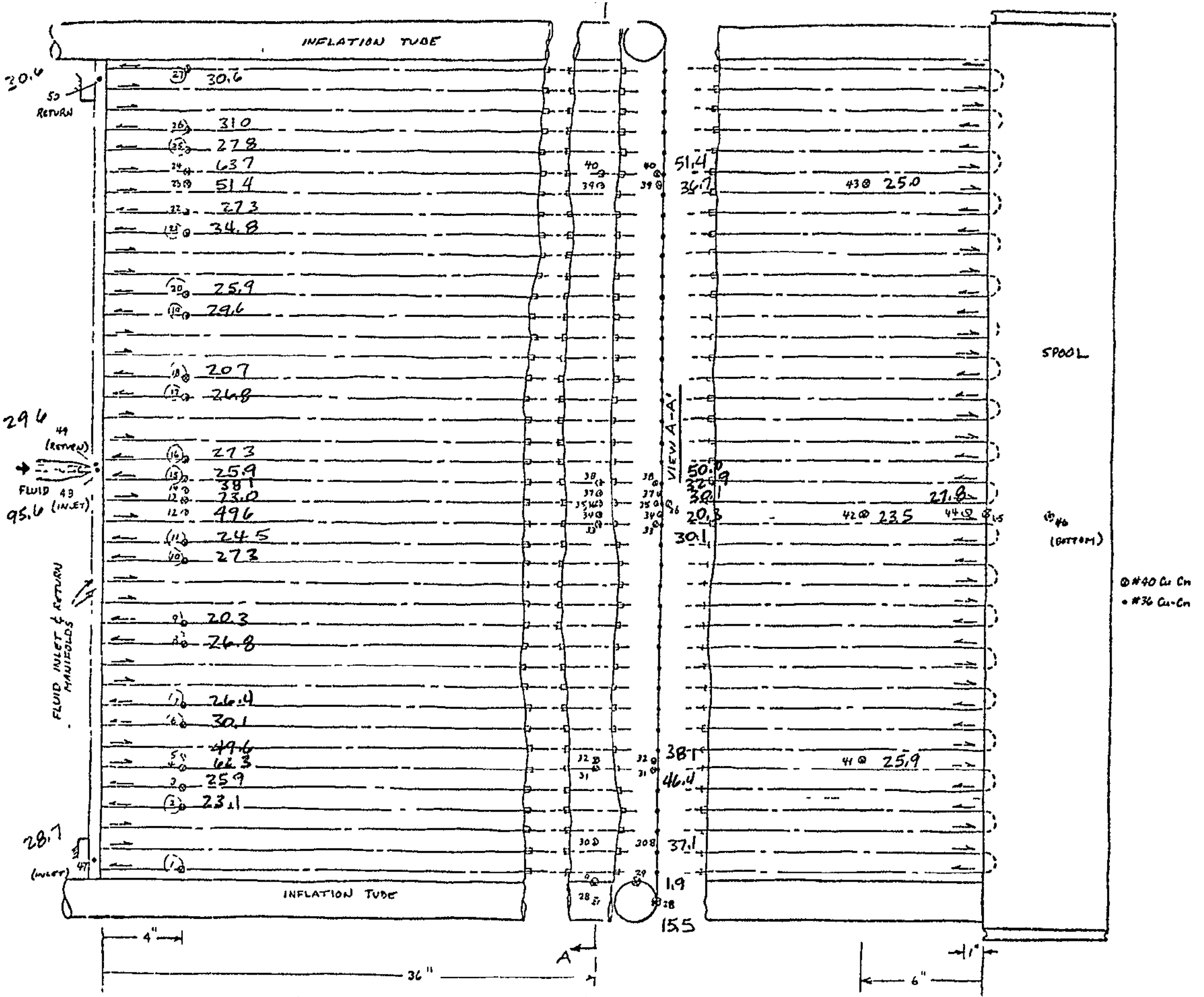


FIGURE 7 - SOFT TUBE TEST ARTICLE INSTRUMENTATION

TEST POINT 2-A

APPENDIX D. COMPUTER PROGRAM LISTING HARD TUBE TEST ARTICLE TEST POINT 1

```
          BCD 3THERMAL LPCS
          BCD 5HARD TUBE INFLATABLE RADIATOR
          END
          BCD 3NODE DATA
              -10000,-310.,1.            $ENVIRONMENT NODE
          GEN -90,5,1,70.,1.             $SURFACE NODES
          GEN 80,2,1,70.,.01             $END NODES
          GEN -1150,12,1,70.,1.           $SYMMETRICAL NODES
          GEN -6100,12,1,70.,1.          $SYMMETRICAL NODES
          GEN -2,2,1,70.,1.            $FLUID NODE
              -1,96.4,1.       $FLUID NODE
              -70,70.,1.       $FLUID NODE
              -71,70.,1.       $TUBE NODE
          GEN -10,6,10,70.,1.          $FLUID NODE
          GEN -15,6,10,70.,1.          $FLUID NODE
          GEN -100,12,1,70.,1.         $FLUID NODE
          GEN -200,12,1,70.,1.         $FLUID NODE
          GEN -300,12,1,70.,1.         $FLUID NODE
          GEN -400,12,1,70.,1.         $FLUID NODE
          GEN -500,12,1,70.,1.         $FLUID NODE
          GEN -600,12,1,70.,1.         $FLUID NODE
          GEN 5,2,1,70.,.0190          $TUBE NODE
              4,95.,.019     $TUBE NODE
          GEN 11,6,10,70.,.0025        $TUBE NODE
          GEN 16,6,10,70.,.0025        $TUBE NODE
          GEN 12,6,10,70.,.0544        $STRUCTURE NODE
          GEN 17,6,10,70.,.0224        $STRUCTURE NODE
          SIM 1000,12,1,70.,A2,K3 $TUBE NODE
          SIM 2000,12,1,70.,A2,K3 $TUBE NODE
          SIM 3000,12,1,70.,A2,K3 $TUBE NODE
          SIM 4000,12,1,70.,A2,K3 $TUBE NODE
          SIM 5000,12,1,70.,A2,K3 $TUBE NODE
          SIM 6000,12,1,70.,A2,K4 $TUBE NODE
          SIM 1100,12,1,70.,A3,K5 $FIN NODE
          SIM 1200,12,1,70.,A3,K5 $FIN NODE
          SIM 1300,12,1,70.,A3,K5 $FIN NODE
          SIM 1400,12,1,70.,A3,K5 $FIN NODE
          SIM 1500,12,1,70.,A3,K5 $FIN NODE
          SIM 2100,12,1,70.,A3,K5 $FIN NODE
          SIM 2200,12,1,70.,A3,K5 $FIN NODE
          SIM 2300,12,1,70.,A3,K5 $FIN NODE
          SIM 2400,12,1,70.,A3,K5 $FIN NODE
          SIM 2500,12,1,70.,A3,K5 $FIN NODE
          SIM 3100,12,1,70.,A3,K5 $FIN NODE
          SIM 3200,12,1,70.,A3,K5 $FIN NODE
          SIM 3300,12,1,70.,A3,K5 $FIN NODE
          SIM 3400,12,1,70.,A3,K5 $FIN NODE
          SIM 3500,12,1,70.,A3,K5 $FIN NODE
          SIM 4100,12,1,70.,A3,K5 $FIN NODE
          SIM 4200,12,1,70.,A3,K5 $FIN NODE
          SIM 4300,12,1,70.,A3,K5 $FIN NODE
          SIM 4400,12,1,70.,A3,K5 $FIN NODE
          SIM 4500,12,1,70.,A3,K5 $FIN NODE
          SIM 5100,12,1,70.,A3,K5 $FIN NODE
```

```
    SINDA/SINFLO PREPROCESSOR                                                                                DATE 100975        PAGE      4

               SIM 5200,12,1,70.,A3,K5 $FIN NODE
               SIM 5300,12,1,70.,A3,K5 $FIN NODE
               SIM 5400,12,1,70.,A3,K5 $FIN NODE
               SIM 5500,12,1,70.,A3,K5 $FIN NODE
               END

               RELATIVE NODE NUMBERS                           ACTUAL NODE NUMBERS

                 1   THRU     10            80       81        5        6        4       11       21       31       41       51
                11   THRU     20            61       16       26       36       46       56       66       12       22       32
                21   THRU     30            42       52       62       17       27       37       47       57       67     1000
                31   THRU     40          1001     1002     1003     1004     1005     1006     1007     1008     1009     1010
                41   THRU     50          1011     2000     2001     2002     2003     2004     2005     2006     2007     2008
                51   THRU     60          2009     2010     2011     3000     3001     3002     3003     3004     3005     3006
                61   THRU     70          3007     3008     3009     3010     3011     4000     4001     4002     4003     4004
                71   THRU     80          4005     4006     4007     4008     4009     4010     4011     5000     5001     5002
                81   THRU     90          5003     5004     5005     5006     5007     5008     5009     5010     5011     6000
                91   THRU    100          6001     6002     6003     6004     6005     6006     6007     6008     6009     6010
               101   THRU    110          6011     1100     1101     1102     1103     1104     1105     1106     1107     1108
               111   THRU    120          1109     1110     1111     1200     1201     1202     1203     1204     1205     1206
               121   THRU    130          1207     1208     1209     1210     1211     1300     1301     1302     1303     1304
               131   THRU    140          1305     1306     1307     1308     1309     1310     1311     1400     1401     1402
               141   THRU    150          1403     1404     1405     1406     1407     1408     1409     1410     1411     1500
               151   THRU    160          1501     1502     1503     1504     1505     1506     1507     1508     1509     1510
               161   THRU    170          1511     2100     2101     2102     2103     2104     2105     2106     2107     2108
               171   THRU    180          2109     2110     2111     2200     2201     2202     2203     2204     2205     2206
               181   THRU    190          2207     2208     2209     2210     2211     2300     2301     2302     2303     2304
               191   THRU    200          2305     2306     2307     2308     2309     2310     2311     2400     2401     2402
               201   THRU    210          2403     2404     2405     2406     2407     2408     2409     2410     2411     2500
               211   THRU    220          2501     2502     2503     2504     2505     2506     2507     2508     2509     2510
               221   THRU    230          2511     3100     3101     3102     3103     3104     3105     3106     3107     3108
               231   THRU    240          3109     3110     3111     3200     3201     3202     3203     3204     3205     3206
               241   THRU    250          3207     3208     3209     3210     3211     3300     3301     3302     3303     3304
               251   THRU    260          3305     3306     3307     3308     3309     3310     3311     3400     3401     3402
               261   THRU    270          3403     3404     3405     3406     3407     3408     3409     3410     3411     3500
               271   THRU    280          3501     3502     3503     3504     3505     3506     3507     3508     3509     3510
               281   THRU    290          3511     4100     4101     4102     4103     4104     4105     4106     4107     4108
               291   THRU    300          4109     4110     4111     4200     4201     4202     4203     4204     4205     4206
               301   THRU    310          4207     4208     4209     4210     4211     4300     4301     4302     4303     4304
               311   THRU    320          4305     4306     4307     4308     4309     4310     4311     4400     4401     4402
               321   THRU    330          4403     4404     4405     4406     4407     4408     4409     4410     4411     4500
               331   THRU    340          4501     4502     4503     4504     4505     4506     4507     4508     4509     4510
               341   THRU    350          4511     5100     5101     5102     5103     5104     5105     5106     5107     5108
               351   THRU    360          5109     5110     5111     5200     5201     5202     5203     5204     5205     5206
               361   THRU    370          5207     5208     5209     5210     5211     5300     5301     5302     5303     5304
               371   THRU    380          5305     5306     5307     5308     5309     5310     5311     5400     5401     5402
               381   THRU    390          5403     5404     5405     5406     5407     5408     5409     5410     5411     5500
               391   THRU    400          5501     5502     5503     5504     5505     5506     5507     5508     5509     5510
               401   THRU    410          5511    10000       90       91       92       93       94     1150     1151     1152
               411   THRU    420          1153     1154     1155     1156     1157     1158     1159     1160     1161     6100
               421   THRU    430          6101     6102     6103     6104     6105     6106     6107     6108     6109     6110
               431   THRU    440          6111        2        3        1       70       71       10       20       30       40
               441   THRU    450            50       60       15       25       35       45       55       65      100      101
               451   THRU    460           102      103      104      105      106      107      108      109      110      111
               461   THRU    470           200      201      202      203      204      205      206      207      208      209
               471   THRU    480           210      211      300      301      302      303      304      305      306      307
               481   THRU    490           308      309      310      311      400      401      402      403      404      405
```

```
                 491  THRU    500          406       407       408       409       410       411       500       501       502       503
                 501  THRU    510          504       505       506       507       508       509       510       511       600       601
                 511  THRU    520          602       603       604       605       606       607       608       609       610       611
        NODE ANALYSIS...  DIFFUSION =    401,  ARITHMETIC =      0,  BOUNDARY =    119,  TOTAL =    520

        BCD 3CONDUCTOR DATA
        GEN 11,6,10,11,10,12,10,.307        $COND STRUCTURE
        GEN 16,6,10,16,10,17,10,.307        $COND STRUCTURE
        GEN 12,5,10,12,10,22,10,.940        $COND STRUCTURE
        GEN 17,5,10,17,10,27,10,.235        $COND STRUCTURE
        GEN 950,12,1,1150,1,1000,1,1.22       $SYMMETRICAL G
        GEN 6050,12,1,6100,1,6000,1,1.22       $SYMMETRICAL G
        GEN 1000,11,1,1000,1,1001,1,.0111 $AXIAL  COND
        GEN 1100,11,1,1100,1,1101,1,.0001 $AXIAL  COND
        GEN 1200,11,1,1200,1,1201,1,.0001 $AXIAL  COND
        GEN 1300,11,1,1300,1,1301,1,.0001 $AXIAL  COND
        GEN 1400,11,1,1400,1,1401,1,.0001 $AXIAL  COND
        GEN 1500,11,1,1500,1,1501,1,.0001 $AXIAL  COND
        GEN 2000,11,1,2000,1,2001,1,.0111 $AXIAL  COND
        GEN 2100,11,1,2100,1,2101,1,.0001 $AXIAL  COND
        GEN 2200,11,1,2200,1,2201,1,.0001 $AXIAL  COND
        GEN 2300,11,1,2300,1,2301,1,.0001 $AXIAL  COND
        GEN 2400,11,1,2400,1,2401,1,.0001 $AXIAL  COND
        GEN 2500,11,1,2500,1,2501,1,.0001 $AXIAL  COND
        GEN 3000,11,1,3000,1,3001,1,.0111 $AXIAL  COND
        GEN 3100,11,1,3100,1,3101,1,.0001 $AXIAL  COND
        GEN 3200,11,1,3200,1,3201,1,.0001 $AXIAL  COND
        GEN 3300,11,1,3300,1,3301,1,.0001 $AXIAL  COND
        GEN 3400,11,1,3400,1,3401,1,.0001 $AXIAL  COND
        GEN 3500,11,1,3500,1,3501,1,.0001 $AXIAL  COND
        GEN 4000,11,1,4000,1,4001,1,.0111 $AXIAL  COND
        GEN 4100,11,1,4100,1,4101,1,.0001 $AXIAL  COND
        GEN 4200,11,1,4200,1,4201,1,.0001 $AXIAL  COND
        GEN 4300,11,1,4300,1,4301,1,.0001 $AXIAL  COND
        GEN 4400,11,1,4400,1,4401,1,.0001 $AXIAL  COND
        GEN 4500,11,1,4500,1,4501,1,.0001 $AXIAL  COND
        GEN 5000,11,1,5000,1,5001,1,.0111 $AXIAL  COND
        GEN 5100,11,1,5100,1,5101,1,.0001 $AXIAL  COND
        GEN 5200,11,1,5200,1,5201,1,.0001 $AXIAL  COND
        GEN 5300,11,1,5300,1,5301,1,.0001 $AXIAL  COND
        GEN 5400,11,1,5400,1,5401,1,.0001 $AXIAL  COND
        GEN 5500,11,1,5500,1,5501,1,.0001 $AXIAL  COND
        GEN 6000,11,1,6000,1,6001,1,.0304 $AXIAL  COND
        GEN 1050,12,1,1000,1,1100,1,1.22  $RADIAL  COND
        GEN 1550,12,1,1500,1,2000,1,1.22  $RADIAL  COND
        GEN 2050,12,1,2000,1,2100,1,1.22  $RADIAL  COND
        GEN 2550,12,1,2500,1,3000,1,1.22  $RADIAL  COND
        GEN 3050,12,1,3000,1,3100,1,1.22  $RADIAL  COND
        GEN 3550,12,1,3500,1,4000,1,1.22  $RADIAL  COND
        GEN 4050,12,1,4000,1,4100,1,1.22  $RADIAL  COND
        GEN 4550,12,1,4500,1,5000,1,1.22  $RADIAL  COND
        GEN 5050,12,1,5000,1,5100,1,1.22  $RADIAL  COND
        GEN 5550,12,1,5500,1,6000,1,1.22  $RADIAL  COND
        GEN 1150,12,1,1100,1,1200,1,.229  $RADIAL  COND
        GEN 1250,12,1,1200,1,1300,1,.229  $RADIAL  COND
        GEN 1350,12,1,1300,1,1400,1,.229  $RADIAL  COND
        GEN 1450,12,1,1400,1,1500,1,.229  $RADIAL  COND
```

```
          GEN 2150,12,1,2100,1,2200,1,.229  $RADIAL COND
          GEN 2250,12,1,2200,1,2300,1,.229  $RADIAL COND
          GEN 2350,12,1,2300,1,2400,1,.229  $RADIAL COND
          GEN 2450,12,1,2400,1,2500,1,.229  $RADIAL COND
          GEN 3150,12,1,3100,1,3200,1,.229  $RADIAL COND
          GEN 3250,12,1,3200,1,3300,1,.229  $RADIAL COND
          GEN 3350,12,1,3300,1,3400,1,.229  $RADIAL COND
          GEN 3450,12,1,3400,1,3500,1,.229  $RADIAL COND
          GEN 4150,12,1,4100,1,4200,1,.229  $RADIAL COND
          GEN 4250,12,1,4200,1,4300,1,.229  $RADIAL COND
          GEN 4350,12,1,4300,1,4400,1,.229  $RADIAL COND
          GEN 4450,12,1,4400,1,4500,1,.229  $RADIAL COND
          GEN 5150,12,1,5100,1,5200,1,.229  $RADIAL COND
          GEN 5250,12,1,5200,1,5300,1,.229  $RADIAL COND
          GEN 5350,12,1,5300,1,5400,1,.229  $RADIAL COND
          GEN 5450,12,1,5400,1,5500,1,.229  $RADIAL COND
          GEN -11100,12,1,1100,1,10000,0,3.62E-11  $RADIATION G
          GEN -11200,12,1,1200,1,10000,0,3.62E-11  $RADIATION G
          GEN -11300,12,1,1300,1,10000,0,3.62E-11  $RADIATION G
          GEN -11400,12,1,1400,1,10000,0,3.62E-11  $RADIATION G
          GEN -11500,12,1,1500,1,10000,0,3.62E-11  $RADIATION G
          GEN -12100,12,1,2100,1,10000,0,3.62E-11  $RADIATION G
          GEN -12200,12,1,2200,1,10000,0,3.62E-11  $RADIATION G
          GEN -12300,12,1,2300,1,10000,0,3.62E-11  $RADIATION G
          GEN -12400,12,1,2400,1,10000,0,3.62E-11  $RADIATION G
          GEN -12500,12,1,2500,1,10000,0,3.62E-11  $RADIATION G
          GEN -13100,12,1,3100,1,10000,0,3.62E-11  $RADIATION G
          GEN -13200,12,1,3200,1,10000,0,3.62E-11  $RADIATION G
          GEN -13300,12,1,3300,1,10000,0,3.62E-11  $RADIATION G
          GEN -13400,12,1,3400,1,10000,0,3.62E-11  $RADIATION G
          GEN -13500,12,1,3500,1,10000,0,3.62E-11  $RADIATION G
          GEN -14100,12,1,4100,1,10000,0,3.62E-11  $RADIATION G
          GEN -14200,12,1,4200,1,10000,0,3.62E-11  $RADIATION G
          GEN -14300,12,1,4300,1,10000,0,3.62E-11  $RADIATION G
          GEN -14400,12,1,4400,1,10000,0,3.62E-11  $RADIATION G
          GEN -14500,12,1,4500,1,10000,0,3.62E-11  $RADIATION G
          GEN -15100,12,1,5100,1,10000,0,3.62E-11  $RADIATION G
          GEN -15200,12,1,5200,1,10000,0,3.62E-11  $RADIATION G
          GEN -15300,12,1,5300,1,10000,0,3.62E-11  $RADIATION G
          GEN -15400,12,1,5400,1,10000,0,3.62E-11  $RADIATION G
          GEN -15500,12,1,5500,1,10000,0,3.62E-11  $RADIATION G
          END
          RELATIVE CONDUCTOR NUMBERS                                      ACTUAL CONDUCTOR NUMBERS

                1   THRU     10            11      21      31      41      51      61      16      26      36      46
               11   THRU     20            56      66      12      22      32      42      52      17      27      37
               21   THRU     30            47      57     950     951     952     953     954     955     956     957
               31   THRU     40           958     959     960     961    6050    6051    6052    6053    6054    6055
               41   THRU     50          6056    6057    6058    6059    6060    6061    1000    1001    1002    1003
               51   THRU     60          1004    1005    1006    1007    1008    1009    1010    1100    1101    1102
               61   THRU     70          1103    1104    1105    1106    1107    1108    1109    1110    1200    1201
               71   THRU     80          1202    1203    1204    1205    1206    1207    1208    1209    1210    1300
               81   THRU     90          1301    1302    1303    1304    1305    1306    1307    1308    1309    1310
               91   THRU    100          1400    1401    1402    1403    1404    1405    1406    1407    1408    1409
              101   THRU    110          1410    1500    1501    1502    1503    1504    1505    1506    1507    1508
              111   THRU    120          1509    1510    2000    2001    2002    2003    2004    2005    2006    2007
```

```
                   121   THRU    130          2008     2009     2010     2100     2101     2102     2103     2104     2105     2106
                   131   THRU    140          2107     2108     2109     2110     2200     2201     2202     2203     2204     2205
                   141   THRU    150          2206     2207     2208     2209     2210     2300     2301     2302     2303     2304
                   151   THRU    160          2305     2306     2307     2308     2309     2310     2400     2401     2402     2403
                   161   THRU    170          2404     2405     2406     2407     2408     2409     2410     2500     2501     2502
                   171   THRU    180          2503     2504     2505     2506     2507     2508     2509     2510     3000     3001
                   181   THRU    190          3002     3003     3004     3005     3006     3007     3008     3009     3010     3100
                   191   THRU    200          3101     3102     3103     3104     3105     3106     3107     3108     3109     3110
                   201   THRU    210          3200     3201     3202     3203     3204     3205     3206     3207     3208     3209
                   211   THRU    220          3210     3300     3301     3302     3303     3304     3305     3306     3307     3308
                   221   THRU    230          3309     3310     3400     3401     3402     3403     3404     3405     3406     3407
                   231   THRU    240          3408     3409     3410     3500     3501     3502     3503     3504     3505     3506
                   241   THRU    250          3507     3508     3509     3510     4000     4001     4002     4003     4004     4005
                   251   THRU    260          4006     4007     4008     4009     4010     4100     4101     4102     4103     4104
                   261   THRU    270          4105     4106     4107     4108     4109     4110     4200     4201     4202     4203
                   271   THRU    280          4204     4205     4206     4207     4208     4209     4210     4300     4301     4302
                   281   THRU    290          4303     4304     4305     4306     4307     4308     4309     4310     4400     4401
                   291   THRU    300          4402     4403     4404     4405     4406     4407     4408     4409     4410     4500
                   301   THRU    310          4501     4502     4503     4504     4505     4506     4507     4508     4509     4510
                   311   THRU    320          5000     5001     5002     5003     5004     5005     5006     5007     5008     5009
                   321   THRU    330          5010     5100     5101     5102     5103     5104     5105     5106     5107     5108
                   331   THRU    340          5109     5110     5200     5201     5202     5203     5204     5205     5206     5207
                   341   THRU    350          5208     5209     5210     5300     5301     5302     5303     5304     5305     5306
                   351   THRU    360          5307     5308     5309     5310     5400     5401     5402     5403     5404     5405
                   361   THRU    370          5406     5407     5408     5409     5410     5500     5501     5502     5503     5504
                   371   THRU    380          5505     5506     5507     5508     5509     5510     6000     6001     6002     6003
                   381   THRU    390          6004     6005     6006     6007     6008     6009     6010     1050     1051     1052
                   391   THRU    400          1053     1054     1055     1056     1057     1058     1059     1060     1061     1550
                   401   THRU    410          1551     1552     1553     1554     1555     1556     1557     1558     1559     1560
                   411   THRU    420          1561     2050     2051     2052     2053     2054     2055     2056     2057     2058
                   421   THRU    430          2059     2060     2061     2550     2551     2552     2553     2554     2555     2556
                   431   THRU    440          2557     2558     2559     2560     2561     3050     3051     3052     3053     3054
                   441   THRU    450          3055     3056     3057     3058     3059     3060     3061     3550     3551     3552
                   451   THRU    460          3553     3554     3555     3556     3557     3558     3559     3560     3561     4050
                   461   THRU    470          4051     4052     4053     4054     4055     4056     4057     4058     4059     4060
                   471   THRU    480          4061     4550     4551     4552     4553     4554     4555     4556     4557     4558
                   481   THRU    490          4559     4560     4561     5050     5051     5052     5053     5054     5055     5056
                   491   THRU    500          5057     5058     5059     5060     5061     5550     5551     5552     5553     5554
                   501   THRU    510          5555     5556     5557     5558     5559     5560     5561     1150     1151     1152
                   511   THRU    520          1153     1154     1155     1156     1157     1158     1159     1160     1161     1250
                   521   THRU    530          1251     1252     1253     1254     1255     1256     1257     1258     1259     1260
                   531   THRU    540          1261     1350     1351     1352     1353     1354     1355     1356     1357     1358
                   541   THRU    550          1359     1360     1361     1450     1451     1452     1453     1454     1455     1456
                   551   THRU    560          1457     1458     1459     1460     1461     2150     2151     2152     2153     2154
                   561   THRU    570          2155     2156     2157     2158     2159     2160     2161     2250     2251     2252
                   571   THRU    580          2253     2254     2255     2256     2257     2258     2259     2260     2261     2350
                   581   THRU    590          2351     2352     2353     2354     2355     2356     2357     2358     2359     2360
                   591   THRU    600          2361     2450     2451     2452     2453     2454     2455     2456     2457     2458
                   601   THRU    610          2459     2460     2461     3150     3151     3152     3153     3154     3155     3156
                   611   THRU    620          3157     3158     3159     3160     3161     3250     3251     3252     3253     3254
                   621   THRU    630          3255     3256     3257     3258     3259     3260     3261     3350     3351     3352
                   631   THRU    640          3353     3354     3355     3356     3357     3358     3359     3360     3361     3450
                   641   THRU    650          3451     3452     3453     3454     3455     3456     3457     3458     3459     3460
                   651   THRU    660          3461     4150     4151     4152     4153     4154     4155     4156     4157     4156
                   661   THRU    670          4159     4160     4161     4250     4251     4252     4253     4254     4255     4256
                   671   THRU    680          4257     4258     4259     4260     4261     4350     4351     4352     4353     4354
                   681   THRU    690          4355     4356     4357     4358     4359     4360     4361     4450     4451     4452
```

```
          SINDA/SINFLO PREPROCESSOR                                                                            DATE 100975          PAGE     8
          691  THRU   700          4453      4454      4455      4456      4457      4458      4459      4460      4461      5150
          701  THRU   710          5151      5152      5153      5154      5155      5156      5157      5158      5159      5160
          711  THRU   720          5161      5250      5251      5252      5253      5254      5255      5256      5257      5258
          721  THRU   730          5259      5260      5261      5350      5351      5352      5353      5354      5355      5356
          731  THRU   740          5357      5358      5359      5360      5361      5450      5451      5452      5453      5454
          741  THRU   750          5455      5456      5457      5458      5459      5460      5461     11100     11101     11102
          751  THRU   760         11103     11104     11105     11106     11107     11108     11109     11110     11111     11200
          761  THRU   770         11201     11202     11203     11204     11205     11206     11207     11208     11209     11210
          771  THRU   780         11211     11300     11301     11302     11303     11304     11305     11306     11307     11308
          781  THRU   790         11309     11310     11311     11400     11401     11402     11403     11404     11405     11406
          791  THRU   800         11407     11408     11409     11410     11411     11500     11501     11502     11503     11504
          801  THRU   810         11505     11506     11507     11508     11509     11510     11511     12100     12101     12102
          811  THRU   820         12103     12104     12105     12106     12107     12108     12109     12110     12111     12200
          821  THRU   830         12201     12202     12203     12204     12205     12206     12207     12208     12209     12210
          831  THRU   840         12211     12300     12301     12302     12303     12304     12305     12306     12307     12308
          841  THRU   850         12309     12310     12311     12400     12401     12402     12403     12404     12405     12406
          851  THRU   860         12407     12408     12409     12410     12411     12500     12501     12502     12503     12504
          861  THRU   870         12505     12506     12507     12508     12509     12510     12511     13100     13101     13102
          871  THRU   880         13103     13104     13105     13106     13107     13108     13109     13110     13111     13200
          881  THRU   890         13201     13202     13203     13204     13205     13206     13207     13208     13209     13210
          891  THRU   900         13211     13300     13301     13302     13303     13304     13305     13306     13307     13308
          901  THRU   910         13309     13310     13311     13400     13401     13402     13403     13404     13405     13406
          911  THRU   920         13407     13408     13409     13410     13411     13500     13501     13502     13503     13504
          921  THRU   930         13505     13506     13507     13508     13509     13510     13511     14100     14101     14102
          931  THRU   940         14103     14104     14105     14106     14107     14108     14109     14110     14111     14200
          941  THRU   950         14201     14202     14203     14204     14205     14206     14207     14208     14209     14210
          951  THRU   960         14211     14300     14301     14302     14303     14304     14305     14306     14307     14308
          961  THRU   970         14309     14310     14311     14400     14401     14402     14403     14404     14405     14406
          971  THRU   980         14407     14408     14409     14410     14411     14500     14501     14502     14503     14504
          981  THRU   990         14505     14506     14507     14508     14509     14510     14511     15100     15101     15102
          991  THRU  1000         15103     15104     15105     15106     15107     15108     15109     15110     15111     15200
         1001  THRU  1010         15201     15202     15203     15204     15205     15206     15207     15208     15209     15210
         1011  THRU  1020         15211     15300     15301     15302     15303     15304     15305     15306     15307     15308
         1021  THRU  1030         15309     15310     15311     15400     15401     15402     15403     15404     15405     15406
         1031  THRU  1040         15407     15408     15409     15410     15411     15500     15501     15502     15503     15504
         1041  THRU  1047         15505     15506     15507     15508     15509     15510     15511
      CONDUCTOR ANALYSIS...  LINEAR =    747,  RADIATION =   300,  TOTAL =  1047,  CONNECTIONS =  1047

      BCD 3FLOW DATA
      BCD 3NETWORK MAIN
              GC=6.0042E10,CP=A4,RO=A5,MU=A6,KT=A7,MPASS=1,H=A8
              TOL=.01,MXPASS=100,FRDX=.7,P(4)=0.,END
              1,2,3=10,11,(100,1000,111,1011),15,16,END
              2,2,3=20,21,(200,2000,211,2011),25,26,END
              3,2,3=30,31,(300,3000,311,3011),35,36,END
              4,2,3=40,41,(400,4000,411,4011),45,46,END
              5,2,3=50,51,(500,5000,511,5011),55,56,END
              6,3,4=2,5,65,66,(611,6011,600,6000,-1,-1),60,61,3,6,END
              7,1,2=1,-4,END
              8,5,3=70,-71,END
      END
      BCD 3FLUID LUMP DATA
              .001,.113,1.5,.340,0.,0,1.,1.,1.=1,2,3,END
              .000419,.0725,.96,.0696,0.,0,1.,1.,1.=(600,611),END
              .000419,.0725,.96,.0696,0.,0,1.,1.,1.=70,END
              .000194,.0492,.50,.0164,0.,0,1.,1.,1.=(10,60,10),(15,65,10),END
              .0000417,.0229,.96,.022,0.,0,1.,1.,1.=(100,111),(200,211)
```

```
                (300,311),(400,411),(500,511),END
        END
        BCD 3FLOW SOURCE DATA
            1,A1,END
            5,36.49,END
        END
        BCD 3END FLOW DATA
        BCD 3CONSTANTS DATA
            TIMEND,.5    $
            DTIMEI,.005    $
            NLOOP,100    $
            DRLXCA,.01   $
            ARLXCA,.01   $
            OUTPUT,.05     $
             1,10.      $
             3,.000143   $
             4,.000338   $
             5,4.19E-6       $
        END
        CONSTANTS ANALYSIS...  USER =      4,  ADDED =      0        0         0,  TOTAL =     4

        BCD 3ARRAY DATA
            1  $ FLOWRATE VS TIME
            0.,45.61,20.,95.61,END
            2  $ PCP AL
            -400.,15.6,-200.,25.8,0.,32.6,200.,36.4
            END
            3  $ PCP FIN
            -400.,34.3,400.,34.3
            END
            4  $ CP FREON 21
            -211.,.223,-160.,.224,-110.,.228,-60.,.231
            0.,.237,40.,.244,90.,.254,120.,.264,140.,.274
            180.,.295,246.,.315
            END
            5  $ P FREON 21
            -218.,110.,-211,110.,-160.,104.,-110.,99.3
            -60.,96.,0.,91.5,40.,88.5,90.,84.2,120.,81.8
            END
            6  $ VISCOSITY FREON 21
            -211.,19.1,-200.,13.7,-188.,10.1,-166.,6.36
            -154.,5.21,-142.,4.32,-130.,3.68,-118.,3.16
            -112.,2.81,-76.,2.02,-49.,1.62,0.,1.17,30.,.994
            60.,.870,100.,.726,160.,.561,260.,.396
            END
            7  $ CONDUCTIVITY FREON 21
            -300.,0.11,0.,.068,250.,.044,END
            8,SPACE,22,END $ ENTHALPY CURVE
            10,*A11,*A12,*A13,*A14,*A15,*A20,END
            11,5,*T90,1.07,1,*T91,2.510,100,*T92,2.510,100,*T93,2.510,100
            *T94,1.07,1,END
            12,.02,.68,.68,.68,.02,END
            13,.98,.32,.32,.32,.98,END
            14,*T90,*T91,.650,*T90,*T92,.205,*T90,*T93,.070,*T90,*T94,.075
            *T91,*T92,.196,*T91,*T93,.059,*T91,*T94,.031,*T92,*T93,.196
            *T92,*T94,.090,*T93,*T94,.285,END
            15,*T80,1.07,END
```

```
16,*T1100,.0251,*T1200,.0251,*T1300,.0251,*T1400,.0251,*T1500,.0251
*T2100,.0251,*T2200,.0251,*T2300,.0251,*T2400,.0251,*T2500,.0251
*T3100,.0251,*T3200,.0251,*T3300,.0251,*T3400,.0251,*T3500,.0251
*T4100,.0251,*T4200,.0251,*T4300,.0251,*T4400,.0251,*T4500,.0251
*T5100,.0251,*T5200,.0251,*T5300,.0251,*T5400,.0251,*T5500,.0251
*T1101,.0251,*T1201,.0251,*T1301,.0251,*T1401,.0251,*T1501,.0251
*T2101,.0251,*T2201,.0251,*T2301,.0251,*T2401,.0251,*T2501,.0251
*T3101,.0251,*T3201,.0251,*T3301,.0251,*T3401,.0251,*T3501,.0251
*T4101,.0251,*T4201,.0251,*T4301,.0251,*T4401,.0251,*T4501,.0251
*T5101,.0251,*T5201,.0251,*T5301,.0251,*T5401,.0251,*T5501,.0251
*T1102,.0251,*T1202,.0251,*T1302,.0251,*T1402,.0251,*T1502,.0251
*T2102,.0251,*T2202,.0251,*T2302,.0251,*T2402,.0251,*T2502,.0251
*T3102,.0251,*T3202,.0251,*T3302,.0251,*T3402,.0251,*T3502,.0251
*T4102,.0251,*T4202,.0251,*T4302,.0251,*T4402,.0251,*T4502,.0251
*T5102,.0251,*T5202,.0251,*T5302,.0251,*T5402,.0251,*T5502,.0251
*T1103,.0251,*T1203,.0251,*T1303,.0251,*T1403,.0251,*T1503,.0251
*T2103,.0251,*T2203,.0251,*T2303,.0251,*T2403,.0251,*T2503,.0251
*T3103,.0251,*T3203,.0251,*T3303,.0251,*T3403,.0251,*T3503,.0251
*T4103,.0251,*T4203,.0251,*T4303,.0251,*T4403,.0251,*T4503,.0251
*T5103,.0251,*T5203,.0251,*T5303,.0251,*T5403,.0251,*T5503,.0251,END
17,*T1104,.0251,*T1204,.0251,*T1304,.0251,*T1404,.0251,*T1504,.0251
*T2104,.0251,*T2204,.0251,*T2304,.0251,*T2404,.0251,*T2504,.0251
*T3104,.0251,*T3204,.0251,*T3304,.0251,*T3404,.0251,*T3504,.0251
*T4104,.0251,*T4204,.0251,*T4304,.0251,*T4404,.0251,*T4504,.0251
*T5104,.0251,*T5204,.0251,*T5304,.0251,*T5404,.0251,*T5504,.0251
*T1105,.0251,*T1205,.0251,*T1305,.0251,*T1405,.0251,*T1505,.0251
*T2105,.0251,*T2205,.0251,*T2305,.0251,*T2405,.0251,*T2505,.0251
*T3105,.0251,*T3205,.0251,*T3305,.0251,*T3405,.0251,*T3505,.0251
*T4105,.0251,*T4205,.0251,*T4305,.0251,*T4405,.0251,*T4505,.0251
*T5105,.0251,*T5205,.0251,*T5305,.0251,*T5405,.0251,*T5505,.0251
*T1106,.0251,*T1206,.0251,*T1306,.0251,*T1406,.0251,*T1506,.0251
*T2106,.0251,*T2206,.0251,*T2306,.0251,*T2406,.0251,*T2506,.0251
*T3106,.0251,*T3206,.0251,*T3306,.0251,*T3406,.0251,*T3506,.0251
*T4106,.0251,*T4206,.0251,*T4306,.0251,*T4406,.0251,*T4506,.0251
*T5106,.0251,*T5206,.0251,*T5306,.0251,*T5406,.0251,*T5506,.0251
*T1107,.0251,*T1207,.0251,*T1307,.0251,*T1407,.0251,*T1507,.0251
*T2107,.0251,*T2207,.0251,*T2307,.0251,*T2407,.0251,*T2507,.0251
*T3107,.0251,*T3207,.0251,*T3307,.0251,*T3407,.0251,*T3507,.0251
*T4107,.0251,*T4207,.0251,*T4307,.0251,*T4407,.0251,*T4507,.0251
*T5107,.0251,*T5207,.0251,*T5307,.0251,*T5407,.0251,*T5507,.0251,END
18,*T1108,.0251,*T1208,.0251,*T1308,.0251,*T1408,.0251,*T1508,.0251
*T2108,.0251,*T2208,.0251,*T2308,.0251,*T2408,.0251,*T2508,.0251
*T3108,.0251,*T3208,.0251,*T3308,.0251,*T3408,.0251,*T3508,.0251
*T4108,.0251,*T4208,.0251,*T4308,.0251,*T4408,.0251,*T4508,.0251
*T5108,.0251,*T5208,.0251,*T5308,.0251,*T5408,.0251,*T5508,.0251
*T1109,.0251,*T1209,.0251,*T1309,.0251,*T1409,.0251,*T1509,.0251
*T2109,.0251,*T2209,.0251,*T2309,.0251,*T2409,.0251,*T2509,.0251
*T3109,.0251,*T3209,.0251,*T3309,.0251,*T3409,.0251,*T3509,.0251
*T4109,.0251,*T4209,.0251,*T4309,.0251,*T4409,.0251,*T4509,.0251
*T5109,.0251,*T5209,.0251,*T5309,.0251,*T5409,.0251,*T5509,.0251
*T1110,.0251,*T1210,.0251,*T1310,.0251,*T1410,.0251,*T1510,.0251
*T2110,.0251,*T2210,.0251,*T2310,.0251,*T2410,.0251,*T2510,.0251
*T3110,.0251,*T3210,.0251,*T3310,.0251,*T3410,.0251,*T3510,.0251
*T4110,.0251,*T4210,.0251,*T4310,.0251,*T4410,.0251,*T4510,.0251
*T5110,.0251,*T5210,.0251,*T5310,.0251,*T5410,.0251,*T5510,.0251
*T1111,.0251,*T1211,.0251,*T1311,.0251,*T1411,.0251,*T1511,.0251
*T2111,.0251,*T2211,.0251,*T2311,.0251,*T2411,.0251,*T2511,.0251
```

```
SINDA/SINFLO PREPROCESSOR                                                                         DATE 100975         PAGE     1
           *T3111,.0251,*T3211,.0251,*T3311,.0251,*T3411,.0251,*T3511,.0251
           *T4111,.0251,*T4211,.0251,*T4311,.0251,*T4411,.0251,*T4511,.0251
           *T5111,.0251,*T5211,.0251,*T5311,.0251,*T5411,.0251,*T5511,.0251,END
           19,*T81,1.07,END
           20,SPACE,15,END
       END
       ARRAY ANALYSIS...  NUMBER OF ARRAYS =   19  TOTAL LENGTH =   818

 TUBE NUMBER LIST
         1           2           3           4           5           6            7           8                                    8

 PRESSURE NODE LIST
         1           2           3           4           5                                                                         5
       BCD 3EXECUTION
      DIMENSION X(10000)                                                            F
      NDIM=10000                                                                    F
      NTH=0                                                                         F
           RESET
           CRVINT(A4,A8)
           TOPLIN
           GENOUT(A8+1,1,A8,3H0A8)
           FLOSOL
      ITEST=0                                                                       F
           CSGOMP
      ITEST=1                                                                       F
           CNBACK
       END
       BCD 3VARIABLES 1
      IF(ITEST.EQ.1) CALL RADIR(A10,.1714E-8,-460.)                                 M
      T1150=T1100                                                                   M
      T1151=T1101                                                                   M
      T1152=T1102                                                                   M
      T1153=T1103                                                                   M
      T1154=T1104                                                                   M
      T1155=T1105                                                                   M
      T1156=T1106                                                                   M
      T1157=T1107                                                                   M
      T1158=T1108                                                                   M
      T1159=T1109                                                                   M
      T1160=T1110                                                                   M
      T1161=T1111                                                                   M
      T6100=T5500                                                                   M
      T6101=T5501                                                                   M
      T6102=T5502                                                                   M
      T6103=T5503                                                                   M
      T6104=T5504                                                                   M
      T6105=T5505                                                                   M
      T6106=T5506                                                                   M
      T6107=T5507                                                                   M
      T6108=T5508                                                                   M
      T6109=T5509                                                                   M
      T6110=T5510                                                                   M
      T6111=T5511                                                                   M
      T70=(T111+T211+T311+T411+T511)/5.                                             M
       END
       BCD 3VARIABLES 2
```

```
               FLOSOL
               TIMCHK(K1,0)
         END
         BCD 3OUTPUT CALLS
               TPRNT
               WPRINT(1,1,1,C)
               TIMCHK(K1,1)
         END
    @ADD,P EC02-V55008*SINFLO.PROC
```

```
        SYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER   - - -  SINDA  - - -   UNIVAC-1108 FORTRAN-V VERSION        PAGE    47
        HARD TUBE INFLATABLE RADIATOR
     IR CROSS RADIATION DATA

         SURFACE DATA
              NUMBER OF SURFACES =     5
              SURFACE NUMBER        SURFACE AREA        NUMBER OF NODES
                          90            1.07000                    1
                          91            2.51000                  100
                          92            2.51000                  100
                          93            2.51000                  100
                          94            1.07000                    1

         SURFACE EMISSIVITY DATA
                   .20000-01    .68000+00    .68000+00    .68000+00    .20000-01
         SURFACE REFLECTIVITY DATA
                   .98000+00    .32000+00    .32000+00    .32000+00    .98000+00

         SURFACE CONNECTION DATA
              FROM SURFACE         TO SURFACE          VIEW FACTOR
                          90                 91          .65000+00
                          90                 92          .20500+00
                          90                 93          .70000-01
                          90                 94          .75000-01
                          91                 92          .19600+00
                          91                 93          .59000-01
                          91                 94          .31000-01
                          92                 93          .19600+00
                          92                 94          .90000-01
                          93                 94          .28500+00

         NODE DATA
              SURFACE         NODE            AREA       NODE           AREA        NODE           AREA       NODE           AREA
                   90           80         1.07000
                   91         1100          .02510       1200          .02510       1300          .02510       1400          .02510
```

```
   1500        .02510      2100       .02510      2200       .02510      2300       .02510
   2400        .02510      2500       .02510      3100       .02510      3200       .02510
   3300        .02510      3400       .02510      3500       .02510      4100       .02510
   4200        .02510      4300       .02510      4400       .02510      4500       .02510
   5100        .02510      5200       .02510      5300       .02510      5400       .02510
   5500        .02510      1101       .02510      1201       .02510      1301       .02510
   1401        .02510      1501       .02510      2101       .02510      2201       .02510
   2301        .02510      2401       .02510      2501       .02510      3101       .02510
   3201        .02510      3301       .02510      3401       .02510      3501       .02510
   4101        .02510      4201       .02510      4301       .02510      4401       .02510
   4501        .02510      5101       .02510      5201       .02510      5301       .02510
   5401        .02510      5501       .02510      1102       .02510      1202       .02510
   1302        .02510      1402       .02510      1502       .02510      2102       .02510
```

```
HARD TUBE INFLATABLE RADIATOR
             2202      .02510      2302      .02510      2402      .02510      2502      .02510
             3102      .02510      3202      .02510      3302      .02510      3402      .02510
             3502      .02510      4102      .02510      4202      .02510      4302      .02510
             4402      .02510      4502      .02510      5102      .02510      5202      .02510
             5302      .02510      5402      .02510      5502      .02510      1103      .02510
             1203      .02510      1303      .02510      1403      .02510      1503      .02510
             2103      .02510      2203      .02510      2303      .02510      2403      .02510
             2503      .02510      3103      .02510      3203      .02510      3303      .02510
             3403      .02510      3503      .02510      4103      .02510      4203      .02510
             4303      .02510      4403      .02510      4503      .02510      5103      .02510
             5203      .02510      5303      .02510      5403      .02510      5503      .02510
       92    1104      .02510      1204      .02510      1304      .02510      1404      .02510
             1504      .02510      2104      .02510      2204      .02510      2304      .02510
             2404      .02510      2504      .02510      3104      .02510      3204      .02510
             3304      .02510      3404      .02510      3504      .02510      4104      .02510
             4204      .02510      4304      .02510      4404      .02510      4504      .02510
             5104      .02510      5204      .02510      5304      .02510      5404      .02510
             5504      .02510      1105      .02510      1205      .02510      1305      .02510
             1405      .02510      1505      .02510      2105      .02510      2205      .02510
             2305      .02510      2405      .02510      2505      .02510      3105      .02510
             3205      .02510      3305      .02510      3405      .02510      3505      .02510
             4105      .02510      4205      .02510      4305      .02510      4405      .02510
             4505      .02510      5105      .02510      5205      .02510      5305      .02510
             5405      .02510      5505      .02510      1106      .02510      1206      .02510
             1306      .02510      1406      .02510      1506      .02510      2106      .02510
             2206      .02510      2306      .02510      2406      .02510      2506      .02510
             3106      .02510      3206      .02510      3306      .02510      3406      .02510
             3506      .02510      4106      .02510      4206      .02510      4306      .02510
             4406      .02510      4506      .02510      5106      .02510      5206      .02510
             5306      .02510      5406      .02510      5506      .02510      1107      .02510
             1207      .02510      1307      .02510      1407      .02510      1507      .02510
             2107      .02510      2207      .02510      2307      .02510      2407      .02510
             2507      .02510      3107      .02510      3207      .02510      3307      .02510
             3407      .02510      3507      .02510      4107      .02510      4207      .02510
             4307      .02510      4407      .02510      4507      .02510      5107      .02510
             5207      .02510      5307      .02510      5407      .02510      5507      .02510
       93    1108      .02510      1208      .02510      1308      .02510      1408      .02510
             1508      .02510      2108      .02510      2208      .02510      2308      .02510
             2408      .02510      2508      .02510      3108      .02510      3208      .02510
             3308      .02510      3408      .02510      3508      .02510      4108      .02510
             4208      .02510      4308      .02510      4408      .02510      4508      .02510
             5108      .02510      5208      .02510      5308      .02510      5408      .02510
             5508      .02510      1109      .02510      1209      .02510      1309      .02510
             1409      .02510      1509      .02510      2109      .02510      2209      .02510
             2309      .02510      2409      .02510      2509      .02510      3109      .02510
             3209      .02510      3309      .02510      3409      .02510      3509      .02510
             4109      .02510      4209      .02510      4309      .02510      4409      .02510
```

```
                      4509       .02510      5109       .02510      5209       .02510      5309       .02510
                      5409       .02510      5509       .02510      1110       .02510      1210       .02510
                      1310       .02510      1410       .02510      1510       .02510      2110       .02510
                      2210       .02510      2310       .02510      2410       .02510      2510       .02510
                      3110       .02510      3210       .02510      3310       .02510      3410       .02510
                      3510       .02510      4110       .02510      4210       .02510      4310       .02510
                      4410       .02510      4510       .02510      5110       .02510      5210       .02510
                      5310       .02510      5410       .02510      5510       .02510      1111       .02510
                      1211       .02510      1311       .02510      1411       .02510      1511       .02510
                      2111       .02510      2211       .02510      2311       .02510      2411       .02510
                      2511       .02510      3111       .02510      3211       .02510      3311       .02510
                      3411       .02510      3511       .02510      4111       .02510      4211       .02510
                      4311       .02510      4411       .02510      4511       .02510      5111       .02510
                      5211       .02510      5311       .02510      5411       .02510      5511       .02510
            94          81      1.07000


   CONNECTION DATA

        FROM SURFACE      TO SURFACE       SCRIPT FA

                90              91         .18679-01
                90              92         .44075-02
                90              93         .26658-02
                90              94         .48731-04
                91              92         .34726+00
                91              93         .18021+00
                91              94         .26974-02
                92              93         .35189+00
                92              94         .45310-02
                93              94         .11019-01
```

```
        SYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER  - - -  SINDA  - - -   UNIVAC-1108 FORTRAN-V VERSION         PAGE    71
          HARD TUBE INFLATABLE RADIATOR

    T  5503=    29.082      T  5504=    29.283      T  5505=    29.404      T  5506=    29.554      T  5507=    29.757      T  5508=    30.004
    T  5509=    30.274      T  5510=    30.564      T  5511=    30.877      T  6000=    31.447      T  6001=    31.640      T  6002=    31.864
    T  6003=    32.120      T  6004=    32.439      T  6005=    32.743      T  6006=    33.072      T  6007=    33.432      T  6008=    33.820
    T  6009=    34.226      T  6010=    34.651      T  6011=    35.095      T  6100=    29.045      T  6101=    29.019      T  6102=    29.031
    T  6103=    29.083      T  6104=    29.284      T  6105=    29.406      T  6106=    29.555      T  6107=    29.758      T  6108=    30.005
    T  6109=    30.274      T  6110=    30.565      T  6111=    30.877      T 10000=   -310.00
    W          1= 9.1429    W          2= 9.1416    W          3= 9.1375    W          4= 9.1251    W          5= 9.0646
    W          6= 82.102    W          7= 45.609    W          8= 36.490

    DP         1= .26074    DP         2= .26074    DP         3= .26074    DP         4= .26074    DP         5= .26074
    DP         6= .10727    DP         7= .26115-03 DP         8= .90870-03
    P          1= .36827    P          2= .36801    P          3= .10727    P          4= .00000    P          5= .10818
    COMPUTER TIME =    1.515 MINUTES

    **********
    TIME=       .50000 DTIMEU=   2.50000-03 CSGMIN(   1100)=    9.86626-05 TEMPCC(     81)=   7.53021-02 RELXCC(     16)=   6.51550-03
    T     1=    96.400      T     2=    37.511      T     3=    32.963      T     4=    94.999      T     5=    37.511      T     6=    32.963
    T    10=    95.767      T    11=    90.724      T    12=    85.897      T    15=    38.139      T    16=    39.266      T    17=    40.115
    T    20=    95.708      T    21=    90.192      T    22=    84.904      T    25=    38.098      T    26=    39.170      T    27=    39.976
    T    30=    95.577      T    31=    89.022      T    32=    82.724      T    35=    37.961      T    36=    38.934      T    37=    39.663
    T    40=    95.351      T    41=    86.997      T    42=    78.954      T    45=    37.555      T    46=    38.456      T    47=    39.132
    T    50=    94.982      T    51=    83.752      T    52=    72.934      T    55=    36.067      T    56=    37.394      T    57=    38.427
    T    60=    32.962      T    61=    36.011      T    62=    63.673      T    65=    37.521      T    66=    37.589      T    67=    38.205
    T    70=    37.442      T    71=    70.000      T    80=    54.315      T    81=    47.395      T    90=    54.366      T    91=    49.671
    T    92=    32.881      T    93=    19.979      T    94=    47.470      T   100=    89.803      T   101=    83.931      T   102=    78.334
    T   103=    72.994      T   104=    67.926      T   105=    63.093      T   106=    58.481      T   107=    54.084      T   108=    49.872
    T   109=    45.802      T   110=    41.868      T   111=    38.012      T   200=    89.745      T   201=    83.876      T   202=    78.283
    T   203=    72.946      T   204=    67.881      T   205=    63.050      T   206=    58.440      T   207=    54.045      T   208=    49.835
    T   209=    45.766      T   210=    41.833      T   211=    37.977      T   300=    89.613      T   301=    83.747      T   302=    78.155
    T   303=    72.819      T   304=    67.755      T   305=    62.926      T   306=    58.317      T   307=    53.924      T   308=    49.713
    T   309=    45.644      T   310=    41.711      T   311=    37.851      T   400=    89.355      T   401=    83.465      T   402=    77.849
    T   403=    72.489      T   404=    67.405      T   405=    62.558      T   406=    57.937      T   407=    53.543      T   408=    49.324
    T   409=    45.252      T   410=    41.320      T   411=    37.453      T   500=    88.379      T   501=    82.034      T   502=    76.084
    T   503=    70.498      T   504=    65.290      T   505=    60.400      T   506=    55.815      T   507=    51.471      T   508=    47.332
    T   509=    43.387      T   510=    39.612      T   511=    35.916      T   600=    32.536      T   601=    32.830      T   602=    33.151
    T   603=    33.498      T   604=    33.870      T   605=    34.256      T   606=    34.665      T   607=    35.095      T   608=    35.545
    T   609=    36.011      T   610=    36.494      T   611=    36.999      T  1000=    77.981      T  1001=    71.967      T  1002=    66.158
    T  1003=    60.589      T  1004=    55.354      T  1005=    50.289      T  1006=    45.384      T  1007=    40.592      T  1008=    36.423
    T  1009=    32.858      T  1010=    29.411      T  1011=    26.071      T  1100=    72.231      T  1101=    66.490      T  1102=    60.938
    T  1103=    55.609      T  1104=    50.628      T  1105=    45.781      T  1106=    41.083      T  1107=    36.489      T  1108=    32.493
    T  1109=    29.062      T  1110=    25.742      T  1111=    22.524      T  1150=    72.229      T  1151=    66.489      T  1152=    60.936
    T  1153=    55.607      T  1154=    50.626      T  1155=    45.779      T  1156=    41.082      T  1157=    36.487      T  1158=    32.492
    T  1159=    29.061      T  1160=    25.741      T  1161=    22.523      T  1200=    55.134      T  1201=    50.172      T  1202=    45.353
    T  1203=    40.711      T  1204=    36.520      T  1205=    32.304      T  1206=    28.204      T  1207=    24.182      T  1208=    20.648
    T  1209=    17.607      T  1210=    14.660      T  1211=    11.798      T  1300=    49.622      T  1301=    44.917      T  1302=    40.319
```

```
HARD TUBE INFLATABLE RADIATOR
T  1303=   35.895   T  1304=   31.965   T  1305=   27.949   T  1306=   24.038   T  1307=   20.198   T  1308=   16.607
T  1309=   13.891   T  1310=   11.062   T  1311=   8.3138   T  1400=   55.108   T  1401=   50.146   T  1402=   45.329
T  1403=   40.688   T  1404=   36.499   T  1405=   32.283   T  1406=   28.183   T  1407=   24.162   T  1408=   20.634
T  1409=   17.594   T  1410=   14.647   T  1411=   11.785   T  1500=   72.177   T  1501=   66.438   T  1502=   60.668
T  1503=   55.561   T  1504=   50.582   T  1505=   45.737   T  1506=   41.040   T  1507=   36.447   T  1508=   32.465
T  1509=   29.035   T  1510=   25.716   T  1511=   22.497   T  2000=   77.920   T  2001=   71.908   T  2002=   66.102
T  2003=   60.536   T  2004=   55.303   T  2005=   50.239   T  2006=   45.335   T  2007=   40.544   T  2008=   36.392
T  2009=   32.828   T  2010=   29.382   T  2011=   26.041   T  2100=   72.170   T  2101=   66.432   T  2102=   60.881
T  2103=   55.554   T  2104=   50.575   T  2105=   45.730   T  2106=   41.033   T  2107=   36.447   T  2108=   32.461
T  2109=   29.030   T  2110=   25.711   T  2111=   22.492   T  2200=   55.065   T  2201=   50.105   T  2202=   45.286
T  2203=   40.645   T  2204=   36.456   T  2205=   32.240   T  2206=   28.139   T  2207=   24.117   T  2208=   20.604
T  2209=   17.564   T  2210=   14.617   T  2211=   11.754   T  2300=   49.539   T  2301=   44.824   T  2302=   40.236
T  2303=   35.811   T  2304=   31.883   T  2305=   27.866   T  2306=   23.952   T  2307=   20.112   T  2308=   16.747
T  2309=   13.832   T  2310=   11.003   T  2311=   8.2535   T  2400=   55.000   T  2401=   50.040   T  2402=   45.220
T  2403=   40.578   T  2404=   36.389   T  2405=   32.172   T  2406=   28.068   T  2407=   24.046   T  2408=   20.554
T  2409=   17.515   T  2410=   14.568   T  2411=   11.703   T  2500=   72.033   T  2501=   66.294   T  2502=   60.743
T  2503=   55.414   T  2504=   50.434   T  2505=   45.587   T  2506=   40.884   T  2507=   36.290   T  2508=   32.358
T  2509=   28.928   T  2510=   25.609   T  2511=   22.387   T  3000=   77.766   T  3001=   71.754   T  3002=   65.947
T  3003=   60.379   T  3004=   55.145   T  3005=   50.079   T  3006=   45.168   T  3007=   40.376   T  3008=   36.277
T  3009=   32.713   T  3010=   29.268   T  3011=   25.924   T  3100=   72.017   T  3101=   66.277   T  3102=   60.724
T  3103=   55.394   T  3104=   50.413   T  3105=   45.565   T  3106=   40.861   T  3107=   36.267   T  3108=   32.341
T  3109=   28.912   T  3110=   25.593   T  3111=   22.372   T  3200=   54.897   T  3201=   49.927   T  3202=   45.099
T  3203=   40.448   T  3204=   36.255   T  3205=   32.031   T  3206=   27.918   T  3207=   23.898   T  3208=   20.449
T  3209=   17.411   T  3210=   14.466   T  3211=   11.602   T  3300=   49.337   T  3301=   44.605   T  3302=   39.999
T  3303=   35.557   T  3304=   31.620   T  3305=   27.591   T  3306=   23.662   T  3307=   19.825   T  3308=   16.543
T  3309=   13.631   T  3310=   10.807   T  3311=   8.0581   T  3400=   54.744   T  3401=   49.756   T  3402=   44.910
T  3403=   40.243   T  3404=   36.039   T  3405=   31.805   T  3406=   27.679   T  3407=   23.664   T  3408=   20.283
T  3409=   17.249   T  3410=   14.310   T  3411=   11.448   T  3500=   71.694   T  3501=   65.917   T  3502=   60.327
T  3503=   54.963   T  3504=   49.961   T  3505=   45.090   T  3506=   40.359   T  3507=   35.777   T  3508=   31.995
T  3509=   28.575   T  3510=   25.267   T  3511=   22.051   T  4000=   77.404   T  4001=   71.351   T  4002=   65.503
T  4003=   59.897   T  4004=   54.638   T  4005=   49.547   T  4006=   44.607   T  4007=   39.829   T  4008=   35.898
T  4009=   32.338   T  4010=   28.904   T  4011=   25.567   T  4100=   71.607   T  4101=   65.817   T  4102=   60.218
T  4103=   54.849   T  4104=   49.846   T  4105=   44.979   T  4106=   40.250   T  4107=   35.691   T  4108=   31.929
T  4109=   28.518   T  4110=   25.220   T  4111=   22.013   T  4200=   54.184   T  4201=   49.114   T  4202=   44.210
T  4203=   39.509   T  4204=   35.314   T  4205=   31.089   T  4206=   26.979   T  4207=   23.113   T  4208=   19.859
T  4209=   16.884   T  4210=   14.006   T  4211=   11.205   T  4300=   48.244   T  4301=   43.352   T  4302=   38.636
T  4303=   34.130   T  4304=   30.207   T  4305=   26.198   T  4306=   22.303   T  4307=   18.756   T  4308=   15.725
T  4309=   12.925   T  4310=   10.220   T  4311=   7.5905   T  4400=   53.156   T  4401=   47.938   T  4402=   42.937
T  4403=   38.190   T  4404=   34.013   T  4405=   29.826   T  4406=   25.770   T  4407=   22.210   T  4408=   19.166
T  4409=   16.304   T  4410=   13.547   T  4411=   10.871   T  4500=   69.440   T  4501=   63.341   T  4502=   57.544
T  4503=   52.382   T  4504=   47.113   T  4505=   42.327   T  4506=   37.714   T  4507=   33.800   T  4508=   30.481
T  4509=   27.309   T  4510=   24.265   T  4511=   21.316   T  5000=   74.975   T  5001=   68.577   T  5002=   62.510
T  5003=   56.802   T  5004=   51.577   T  5005=   46.581   T  5006=   41.772   T  5007=   37.716   T  5008=   34.275
T  5009=   30.989   T  5010=   27.840   T  5011=   24.790   T  5100=   67.985   T  5101=   62.075   T  5102=   56.465
T  5103=   51.185   T  5104=   46.405   T  5105=   41.788   T  5106=   37.342   T  5107=   33.593   T  5108=   30.412
T  5109=   27.371   T  5110=   24.455   T  5111=   21.633   T  5200=   43.779   T  5201=   39.785   T  5202=   35.992
```

```
HARD TUBE INFLATABLE RADIATOR
T   5203=    32.423    T   5204=    29.455    T   5205=    26.359    T   5206=    23.379    T   5207=    20.877    T   5208=    18.725
T   5209=    16.703    T   5210=    14.769    T   5211=    12.962    T   5300=    29.965    T   5301=    27.484    T   5302=    25.136
T   5303=    22.937    T   5304=    21.342    T   5305=    19.463    T   5306=    17.662    T   5307=    16.172    T   5308=    14.874
T   5309=    13.695    T   5310=    12.577    T   5311=    11.507    T   5400=    25.196    T   5401=    23.996    T   5402=    22.878
T   5403=    21.851    T   5404=    21.282    T   5405=    20.443    T   5406=    19.654    T   5407=    19.039    T   5408=    18.524
T   5409=    18.088    T   5410=    17.693    T   5411=    17.330    T   5500=    29.033    T   5501=    29.006    T   5502=    29.019
T   5503=    29.071    T   5504=    29.272    T   5505=    29.394    T   5506=    29.543    T   5507=    29.747    T   5508=    29.993
T   5509=    30.263    T   5510=    30.553    T   5511=    30.866    T   6000=    31.435    T   6001=    31.628    T   6002=    31.852
T   6003=    32.108    T   6004=    32.427    T   6005=    32.731    T   6006=    33.060    T   6007=    33.421    T   6008=    33.808
T   6009=    34.215    T   6010=    34.639    T   6011=    35.084    T   6100=    29.034    T   6101=    29.007    T   6102=    29.020
T   6103=    29.072    T   6104=    29.273    T   6105=    29.395    T   6106=    29.544    T   6107=    29.747    T   6108=    29.994
T   6109=    30.263    T   6110=    30.554    T   6111=    30.866    T 10000=   -310.00

W          1= 9.1430   W          2= 9.1417   W          3= 9.1374   W          4= 9.1247   W          5= 9.0640
W          6= 82.101   W          7= 45.609   W          8= 36.498

DP         1= .26072   DP         2= .26072   DP         3= .26072   DP         4= .26072   DP         5= .26072
DP         6= .10727   DP         7= .26114-03 DP        8= .90865-03

P          1= .36825   P          2= .36799   P          3= .10727   P          4= .00000   P          5= .10818
COMPUTER TIME =    1.622 MINUTES
      END OF DATA
* *DIVIDE CHECK HAS OCCURRED* *

@PMD,E

@BRKPT PRINTS
```

APPENDIX E

COMPUTER PROGRAM LISTING

SOFT TUBE TEST ARTICLE

TEST POINT 1-B

```
BCD 3THERMAL LPCS
BCD 5SOFT TUBE INFLATABLE RADIATOR
END
BCD 3NODE DATA
GEN -51,13,1,70.,1. $SURFACE NODES
GEN 1000,8,1,70.,.0007  $TUBE NODE
GEN 2000,8,1,70.,.0007  $TUBE NODE
GEN 3000,8,1,70.,.0007  $TUBE NODE
GEN 4000,8,1,70.,.0007  $TUBE NODE
GEN 5000,8,1,70.,.0007  $TUBE NODE
GEN 1083,8,1,70.,.0007  $TUBE NODE
GEN 2083,8,1,70.,.0007  $TUBE NODE
GEN 3083,8,1,70.,.0007  $TUBE NODE
GEN 4083,8,1,70.,.0007  $TUBE NODE
GEN 5083,8,1,70.,.0007  $TUBE NODE
GEN 999,5,1000,70.,.0007$MANIFOLD TUBE
GEN 1091,5,1000,70.,.0007$MANIFOLD TUBE
GEN -1,2,1,95.,1.           $FLUID NODE
GEN -99,5,100,70.,1.        $FLUID NODE
GEN -191,5,100,70.,1.       $FLUID NODE
GEN -100,8,1,70.,1.         $FLUID NODE
GEN -200,8,1,70.,1.         $FLUID NODE
GEN -300,8,1,70.,1.         $FLUID NODE
GEN -400,8,1,70.,1.         $FLUID NODE
GEN -500,8,1,70.,1.         $FLUID NODF
GEN -183,8,1,70.,1.         $FLUID NODE
GEN -283,8,1,70.,1.         $FLUID NODE
GEN -383,8,1,70.,1.         $FLUID NODF
GEN -483,8,1,70.,1.         $FLUID NODE
GEN -583,8,1,70.,1.         $FLUID NODE
GEN 3,2,1,70.,.0007         $MANIFOLD NODE
GEN 1650,8,1,70.,.00144   $FIN NODE
GEN 1700,8,1,70.,.00144   $FIN NODE
GEN 1750,8,1,70.,.00144   $FIN NODE
GEN 1800,8,1,70.,.00144   $FIN NODE
GEN 1850,8,1,70.,.000117 $FIN NODE
GEN 1900,8,1,70.,.000117 $FIN NODE
GEN 1950,8,1,70.,.000117 $FIN NODE
GEN 2700,8,1,70.,.000117 $FIN NODE
GEN 2750,8,1,70.,.000117 $FIN NODE
GEN 2800,8,1,70.,.000117 $FIN NODE
GEN 2850,8,1,70.,.000117 $FIN NODE
GEN 2900,8,1,70.,.000117 $FIN NODE
GEN 2950,8,1,70.,.000117 $FIN NODE
GEN 1100,8,1,70.,.000117 $FIN NODE
GEN 1150,8,1,70.,.000117 $FIN NODE
GEN 1200,8,1,70.,.000117 $FIN NODE
GEN 1250,8,1,70.,.000117 $FIN NODE
GEN 1300,8,1,70.,.000117 $FIN NODE
GEN 1350,8,1,70.,.000117 $FIN NODE
GEN 1400,8,1,70.,.000117 $FIN NODE
GEN 1450,8,1,70.,.000117 $FIN NODE
GEN 1500,8,1,70.,.000117 $FIN NODE
GEN 1550,8,1,70.,.000117 $FIN NODE
```

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

```
  SINDA/SINFLO PREPROCESSOR                                                                    DATE 101775        PAGE      4
              GEN 2100,8,1,70.,.000117 $FIN NODE
              GEN 2150,8,1,70.,.000117 $FIN NODE
              GEN 2200,8,1,70.,.000117 $FIN NODE
              GEN 2250,8,1,70.,.000117 $FIN NODE
              GEN 2300,8,1,70.,.000117 $FIN NODE
              GEN 2350,8,1,70.,.000117 $FIN NODE
              GEN 2400,8,1,70.,.000117 $FIN NODE
              GEN 2450,8,1,70.,.000117 $FIN NODE
              GEN 2500,8,1,70.,.000117 $FIN NODE
              GEN 2550,8,1,70.,.000117 $FIN NODE
              GEN 3100,8,1,70.,.000117 $FIN NODE
              GEN 3150,8,1,70.,.000117 $FIN NODE
              GEN 3200,8,1,70.,.000117 $FIN NODE
              GEN 3250,8,1,70.,.000117 $FIN NODE
              GEN 3300,8,1,70.,.000117 $FIN NODE
              GEN 3350,8,1,70.,.000117 $FIN NODE
              GEN 3400,8,1,70.,.000117 $FIN NODE
              GEN 3450,8,1,70.,.000117 $FIN NODE
              GEN 3500,8,1,70.,.000117 $FIN NODE
              GEN 3550,8,1,70.,.000117 $FIN NODE
              GEN 4100,8,1,70.,.000117 $FIN NODE
              GEN 4150,8,1,70.,.000117 $FIN NODE
              GEN 4200,8,1,70.,.000117 $FIN NODE
              GEN 4250,8,1,70.,.000117 $FIN NODE
              GEN 4300,8,1,70.,.000117 $FIN NODE
              GEN 4350,8,1,70.,.000117 $FIN NODE
              GEN 4400,8,1,70.,.000117 $FIN NODE
              GEN 4450,8,1,70.,.000117 $FIN NODE
              GEN 4500,8,1,70.,.000117 $FIN NODE
              GEN 4550,8,1,70.,.000117 $FIN NODE
              GEN 5100,8,1,70.,.000117 $FIN NODE
              GEN 5150,8,1,70.,.000117 $FIN NODE
              GEN 5200,8,1,70.,.000117 $FIN NODE
              GEN 5250,8,1,70.,.000117 $FIN NODE
              GEN 5300,8,1,70.,.000117 $FIN NODE
              GEN -5350,8,1,70.,.000117$SYMMETRICAL NODL
              GEN 998,5,1000,70.,.0136 $MANIFOLD NODE
              GEN 1092,5,1001,70.,.0136$MANIFOLD NODE
              GEN 1052,4,1,70.,.110    $DRUM NODE
                  1051,70.,.00228      $END NODE
              GEN 9002,2,2,0.,0.05    $SURFACE NODE
                  9001,-310.,1000000.          $SURFACE NODE
                  9003,70.,1000000.            $SURFACE NODE
              END

              RELATIVE NODE NUMBERS                             ACTUAL NODE NUMBERS

                  1   THRU    10          1000     1001     1002     1003     1004     1005     1006     1007     2000     2001
                 11   THRU    20          2002     2003     2004     2005     2006     2007     3000     3001     3002     3003
                 21   THRU    30          3004     3005     3006     3007     4000     4001     4002     4003     4004     4005
                 31   THRU    40          4006     4007     5000     5001     5002     5003     5004     5005     5006     5007
                 41   THRU    50          1083     1084     1085     1086     1087     1088     1089     1090     2083     2084
                 51   THRU    60          2085     2086     2087     2088     2089     2090     3083     3084     3085     3086
                 61   THRU    70          3087     3088     3089     3090     4083     4084     4085     4086     4087     4088
                 71   THRU    80          4089     4090     5083     5084     5085     5086     5087     5088     5089     5090
                 81   THRU    90           999     1999     2999     3999     4999     1091     2091     3091     4091     5091
                 91   THRU   100             3        4     1650     1651     1652     1653     1654     1655     1656     1657
```

```
     SINDA/SINFLO PREPROCESSOR                                                                                DATE 101775        PAGE     5
              101   THRU    110            1700    1701    1702    1703    1704    1705    1706    1707    175     1751
              111   THRU    120            1752    1753    1754    1755    1756    1757    1800    1801    1802    1803
              121   THRU    130            1804    1805    1806    1807    1850    1851    1852    1853    1854    1855
              131   THRU    140            1856    1857    1900    1901    1902    1903    1904    1905    1906    1907
              141   THRU    150            1950    1951    1952    1953    1954    1955    1956    1957    2700    2701
              151   THRU    160            2702    2703    2704    2705    2706    2707    2750    2751    2752    2753
              161   THRU    170            2754    2755    2756    2757    2800    2801    2802    2803    2804    2805
              171   THRU    180            2806    2807    2850    2851    2852    2853    2854    2855    2856    2857
              181   THRU    190            2900    2901    2902    2903    2904    2905    2906    2907    2950    2951
              191   THRU    200            2952    2953    2954    2955    2956    2957    1100    1101    1102    1103
              201   THRU    210            1104    1105    1106    1107    1150    1151    1152    1153    1154    1155
              211   THRU    220            1156    1157    1200    1201    1202    1203    1204    1205    1206    1207
              221   THRU    230            1250    1251    1252    1253    1254    1255    1256    1257    1300    1301
              231   THRU    240            1302    1303    1304    1305    1306    1307    1350    1351    1352    1353
              241   THRU    250            1354    1355    1356    1357    1400    1401    1402    1403    1404    1405
              251   THRU    260            1406    1407    1450    1451    1452    1453    1454    1455    1456    1457
              261   THRU    270            1500    1501    1502    1503    1504    1505    1506    1507    1550    1551
              271   THRU    280            1552    1553    1554    1555    1556    1557    2100    2101    2102    2103
              281   THRU    290            2104    2105    2106    2107    2150    2151    2152    2153    2154    2155
              291   THRU    300            2156    2157    2200    2201    2202    2203    2204    2205    2206    2207
              301   THRU    310            2250    2251    2252    2253    2254    2255    2256    2257    2300    2301
              311   THRU    320            2302    2303    2304    2305    2306    2307    2350    2351    2352    2353
              321   THRU    330            2354    2355    2356    2357    2400    2401    2402    2403    2404    2405
              331   THRU    340            2406    2407    2450    2451    2452    2453    2454    2455    2456    2457
              341   THRU    350            2500    2501    2502    2503    2504    2505    2506    2507    2550    2551
              351   THRU    360            2552    2553    2554    2555    2556    2557    3100    3101    3102    3103
              361   THRU    370            3104    3105    3106    3107    3150    3151    3152    3153    3154    3155
              371   THRU    380            3156    3157    3200    3201    3202    3203    3204    3205    3206    3207
              381   THRU    390            3250    3251    3252    3253    3254    3255    3256    3257    3300    3301
              391   THRU    400            3302    3303    3304    3305    3306    3307    3350    3351    3352    3353
              401   THRU    410            3354    3355    3356    3357    3400    3401    3402    3403    3404    3405
              411   THRU    420            3406    3407    3450    3451    3452    3453    3454    3455    3456    3457
              421   THRU    430            3500    3501    3502    3503    3504    3505    3506    3507    3550    3551
              431   THRU    440            3552    3553    3554    3555    3556    3557    4100    4101    4102    4103
              441   THRU    450            4104    4105    4106    4107    4150    4151    4152    4153    4154    4155
              451   THRU    460            4156    4157    4200    4201    4202    4203    4204    4205    4206    4207
              461   THRU    470            4250    4251    4252    4253    4254    4255    4256    4257    4300    4301
              471   THRU    480            4302    4303    4304    4305    4306    4307    4350    4351    4352    4353
              481   THRU    490            4354    4355    4356    4357    4400    4401    4402    4403    4404    4405
              491   THRU    500            4406    4407    4450    4451    4452    4453    4454    4455    4456    4457
              501   THRU    510            4500    4501    4502    4503    4504    4505    4506    4507    4550    4551
              511   THRU    520            4552    4553    4554    4555    4556    4557    5100    5101    5102    5103
              521   THRU    530            5104    5105    5106    5107    5150    5151    5152    5153    5154    5155
              531   THRU    540            5156    5157    5200    5201    5202    5203    5204    5205    5206    5207
              541   THRU    550            5250    5251    5252    5253    5254    5255    5256    5257    5300    5301
              551   THRU    560            5302    5303    5304    5305    5306    5307     998    1998    2998    3998
              561   THRU    570            4998    1092    2092    3092    4092    5092    1052    1053    1054    1055
              571   THRU    580            1051    9002    9004    9001    9003      51      52      53      54      55
              581   THRU    590              56      57      58      59      60      61      62      63       1       2
              591   THRU    600              99     199     299     399     499     191     291     391     491     591
              601   THRU    610             100     101     102     103     104     105     106     107     200     201
              611   THRU    620             202     203     204     205     206     207     300     301     302     303
              621   THRU    630             304     305     306     307     400     401     402     403     404     405
              631   THRU    640             406     407     500     501     502     503     504     505     506     507
              641   THRU    650             183     184     185     186     187     188     189     190     283     284
              651   THRU    660             285     286     287     288     289     290     383     384     385     386
              661   THRU    670             387     388     389     390     483     484     485     486     487     488
```

```
          671  THRU    680                489     490     583     584     585     586     587     588     589     590
         ~~681  THRU    688~~                ~~5350    5351    5352    5353~~    ~~5354    5355    5356    5357~~
         NODE ANALYSIS...  DIFFUSION =    575,  ARITHMETIC =     0,  BOUNDARY =    113,  TOTAL =    688

         BCD 3CONDUCTOR DATA
         ~~GEN 350,7,1,1650,1,1651,1,16.3E-5$AXIAL COND~~
         GEN 400,7,1,1700,1,1701,1,16.3E-5$AXIAL COND
         GEN 450,7,1,1750,1,1751,1,16.3E-5$AXIAL COND
         GEN 500,7,1,1800,1,1801,1,16.3E-5$AXIAL COND
         ~~GEN 550,7,1,1850,1,1851,1,5.24E-5$AXIAL COND~~
         GEN 600,7,1,1900,1,1901,1,5.24E-5$AXIAL COND
         GEN 650,7,1,1950,1,1951,1,5.24E-5$AXIAL COND
         GEN 700,7,1,2700,1,2701,1,5.24E-5$AXIAL COND
         ~~GEN 750,7,1,2750,1,2751,1,5.24E-5$AXIAL COND~~
         GEN 800,7,1,2800,1,2801,1,5.24E-5$AXIAL COND
         GEN 850,7,1,2850,1,2851,1,5.24E-5$AXIAL COND
         GEN 900,7,1,2900,1,2901,1,5.24E-5$AXIAL COND
         ~~GEN 950,7,1,2950,1,2951,1,5.24E-5$AXIAL COND~~
         GEN 1100,7,1,1100,1,1101,1,5.24E-5 $AXIAL COND
         GEN 1150,7,1,1150,1,1151,1,5.24E-5 $AXIAL COND
         GEN 1200,7,1,1200,1,1201,1,5.24E-5 $AXIAL COND
         ~~GEN 1250,7,1,1250,1,1251,1,5.24E-5 $AXIAL COND~~
         GEN 1300,7,1,1300,1,1301,1,5.24E-5 $AXIAL COND
         GEN 1350,7,1,1350,1,1351,1,5.24E-5 $AXIAL COND
         GEN 1400,7,1,1400,1,1401,1,5.24E-5 $AXIAL COND
         ~~GEN 1450,7,1,1450,1,1451,1,5.24E-5 $AXIAL COND~~
         GEN 1500,7,1,1500,1,1501,1,5.24E-5 $AXIAL COND
         GEN 1550,7,1,1550,1,1551,1,5.24E-5 $AXIAL COND
         GEN 2100,7,1,2100,1,2101,1,5.24E-5 $AXIAL COND
         ~~GEN 2150,7,1,2150,1,2151,1,5.24E-5 $AXIAL COND~~
         GEN 2200,7,1,2200,1,2201,1,5.24E-5 $AXIAL COND
         GEN 2250,7,1,2250,1,2251,1,5.24E-5 $AXIAL COND
         GEN 2300,7,1,2300,1,2301,1,5.24E-5 $AXIAL COND
         ~~GEN 2350,7,1,2350,1,2351,1,5.24E-5 $AXIAL COND~~
         GEN 2400,7,1,2400,1,2451,1,5.24E-5 $AXIAL COND
         GEN 2450,7,1,2450,1,2451,1,5.24E-5 $AXIAL COND
         GEN 2500,7,1,2500,1,2501,1,5.24E-5 $AXIAL COND
         ~~GEN 2550,7,1,2550,1,2551,1,5.24E-5 $AXIAL COND~~
         GEN 3100,7,1,3100,1,3101,1,5.24E-5 $AXIAL COND
         GEN 3150,7,1,3150,1,3151,1,5.24E-5 $AXIAL COND
         GEN 3200,7,1,3200,1,3201,1,5.24E-5 $AXIAL COND
         ~~GEN 3250,7,1,3250,1,3251,1,5.24E-5 $AXIAL COND~~
         GEN 3300,7,1,3300,1,3301,1,5.24E-5 $AXIAL COND
         GEN 3350,7,1,3350,1,3351,1,5.24E-5 $AXIAL COND
         GEN 3400,7,1,3400,1,3401,1,5.24E-5 $AXIAL COND
         ~~GEN 3450,7,1,3450,1,3451,1,5.24E-5 $AXIAL COND~~
         GEN 3500,7,1,3500,1,3501,1,5.24E-5 $AXIAL COND
         GEN 3550,7,1,3550,1,3551,1,5.24E-5 $AXIAL COND
         GEN 4100,7,1,4100,1,4101,1,5.24E-5 $AXIAL COND
         ~~GEN 4150,7,1,4150,1,4151,1,5.24E-5 $AXIAL COND~~
         GEN 4200,7,1,4200,1,4201,1,5.24E-5 $AXIAL COND
         GEN 4250,7,1,4250,1,4251,1,5.24E-5 $AXIAL COND
         GEN 4300,7,1,4300,1,4301,1,5.24E-5 $AXIAL COND
         ~~GEN 4350,7,1,4350,1,4351,1,5.24E-5 $AXIAL COND~~
         GEN 4400,7,1,4400,1,4401,1,5.24E-5 $AXIAL COND
         GEN 4450,7,1,4450,1,4451,1,5.24E-5 $AXIAL COND
         GEN 4500,7,1,4500,1,4501,1,5.24E-5 $AXIAL COND
```

```
        GEN 4550,7,1,4550,1,4551,1,5.24E-5 $AXIAL COND
~~      GEN 5100,7,1,5100,1,5101,1,5.24E-5 $AXIAL COND~~
        GEN 5150,7,1,5150,1,5151,1,5.24E-5 $AXIAL COND
        GEN 5200,7,1,5200,1,5251,1,5.24E-5 $AXIAL COND
        GEN 5250,7,1,5250,1,5251,1,5.24E-5 $AXIAL COND
~~      GEN 5300,7,1,5300,1,5301,1,5.24E-5 $AXIAL COND~~
        GEN 1000,7,1,1000,1,1001,1,4.49E-6 $AXIAL COND
        GEN 2000,7,1,2000,1,2001,1,4.49E-6 $AXIAL COND
        GEN 3000,7,1,3000,1,3001,1,4.49E-6 $AXIAL COND
~~      GEN 4000,7,1,4000,1,4001,1,4.49E-6 $AXIAL COND~~
        GEN 5000,7,1,5000,1,5001,1,4.49E-6 $AXIAL COND
        GEN 1050,7,1,1083,1,1084,1,4.49E-6 $AXIAL COND
        GEN 2050,7,1,2083,1,2084,1,4.49E-6 $AXIAL COND
~~      GEN 3050,7,1,3083,1,3084,1,4.49E-6 $AXIAL COND~~
        GEN 4050,7,1,4083,1,4084,1,4.49E-6 $AXIAL COND
        GEN 5050,7,1,5083,1,5084,1,4.49E-6 $AXIAL COND
        GEN 1007,5,1000,1007,1000,1083,1000,4.49E-6 $AXIAL COND
~~      GEN 1049,5,1000,1007,1000,1051,0,0.003     $END COND~~
        GEN 1099,5,1000,1083,1000,1051,0,0.003     $END COND
        GEN 52,3,1,1052,1,1053,1,.00253              $DRUM COND
            51,1051,1052,.00134                      $DRUM COND
~~          55,1051,1055,.00134                      $DRUM COND~~
        GEN 325,8,1,1650,1,1750,1,.00539             $SIDE COND
        GEN 375,8,1,1650,1,1700,1,.00539             $SIDE COND
        GEN 425,8,1,1750,1,1800,1,.00539             $SIDE COND
~~      GEN 475,8,1,1700,1,1850,1,.0108              $SIDE COND~~
        GEN 525,8,1,1800,1,1850,1,.0108              $SIDE COND
        GEN 575,8,1,1850,1,1900,1,.152               $FIN COND
        GEN 625,8,1,1900,1,1950,1,.152               $FIN COND
~~      GEN 675,8,1,1950,1,2700,1,.152               $FIN COND~~
        GEN 725,8,1,2700,1,2750,1,.152               $FIN COND
        GEN 775,8,1,2750,1,2800,1,.152               $FIN COND
        GEN 825,8,1,2800,1,2850,1,.152               $FIN COND
~~      GEN 875,8,1,2850,1,2900,1,.152               $FIN COND~~
        GEN 925,8,1,2900,1,2950,1,.152               $FIN COND
        GEN 1125,8,1,1100,1,1150,1,.152              $FIN COND
        GEN 1175,8,1,1150,1,1200,1,.152              $FIN COND
~~      GEN 1225,8,1,1200,1,1250,1,.152              $FIN COND~~
        GEN 1275,8,1,1250,1,1300,1,.152              $FIN COND
        GEN 1375,8,1,1350,1,1400,1,.152              $FIN COND
        GEN 1425,8,1,1400,1,1450,1,.152              $FIN COND
~~      GEN 1475,8,1,1450,1,1500,1,.152              $FIN COND~~
        GEN 1525,8,1,1500,1,1550,1,.152              $FIN COND
        GEN 2125,8,1,2100,1,2150,1,.152              $FIN COND
        GEN 2175,8,1,2150,1,2200,1,.152              $FIN COND
~~      GEN 2225,8,1,2200,1,2250,1,.152              $FIN COND~~
        GEN 2275,8,1,2250,1,2300,1,.152              $FIN COND
        GEN 2375,8,1,2350,1,2400,1,.152              $FIN COND
        GEN 2425,8,1,2400,1,2450,1,.152              $FIN COND
~~      GEN 2475,8,1,2450,1,2500,1,.152              $FIN COND~~
        GEN 2525,8,1,2500,1,2550,1,.152              $FIN COND
        GEN 3125,8,1,3100,1,3150,1,.152              $FIN COND
        GEN 3175,8,1,3150,1,3200,1,.152              $FIN COND
~~      GEN 3225,8,1,3200,1,3250,1,.152              $FIN COND~~
        GEN 3275,8,1,3250,1,3300,1,.152              $FIN COND
        GEN 3375,8,1,3350,1,3400,1,.152              $FIN COND
        GEN 3425,8,1,3400,1,3450,1,.152              $FIN COND
```

```
SINDA/SINFLO PREPROCESSOR                                                                    DATE 101775          PAGE      8
          GEN 3475,8,1,3450,1,3500,1,.152                       $FIN COND
          GEN 3525,8,1,3500,1,3550,1,.152                       $FIN COND
          GEN 4125,8,1,4100,1,4150,1,.152                       $FIN COND
          GEN 4175,8,1,4150,1,4200,1,.152                       $FIN COND
          GEN 4225,8,1,4200,1,4250,1,.152                       $FIN COND
          GEN 4275,8,1,4250,1,4300,1,.152                       $FIN COND
          GEN 4375,8,1,4350,1,4400,1,.152                       $FIN COND
          GEN 4425,8,1,4400,1,4450,1,.152                       $FIN COND
          GEN 4475,8,1,4450,1,4500,1,.152                       $FIN COND
          GEN 4525,8,1,4500,1,4550,1,.152                       $FIN COND
          GEN 5125,8,1,5100,1,5150,1,.152                       $FIN COND
          GEN 5175,8,1,5150,1,5200,1,.152                       $FIN COND
          GEN 5225,8,1,5200,1,5250,1,.152                       $FIN COND
          GEN 5275,8,1,5250,1,5300,1,.152                       $FIN COND
          GEN 975,8,1,2950,1,1090,-1,.0950                       $TUBE COND
          GEN 1075,8,1,1100,1,1090,-1,.0950                      $TUBE COND
          GEN 1325,8,1,1300,1,1000,1,.0950                       $TUBE COND
          GEN 1025,8,1,1350,1,1000,1,.0950                       $TUBE COND
          GEN 1575,8,1,1550,1,2000,1,.0950                       $TUBE COND
          GEN 2025,8,1,2100,1,2000,1,.0950                       $TUBE COND
          GEN 2325,8,1,2300,1,2090,-1,.0950                      $TUBE COND
          GEN 2675,8,1,2350,1,2090,-1,.0950                      $TUBE COND
          GEN 2575,8,1,2550,1,3090,-1,.0950                      $TUBE COND
          GEN 3075,8,1,3100,1,3090,-1,.0950                      $TUBE COND
          GEN 3325,8,1,3300,1,3000,1,.0950                       $TUBE COND
          GEN 3025,8,1,3350,1,3000,1,.0950                       $TUBE COND
          GEN 3575,8,1,3550,1,4000,1,.0950                       $TUBE COND
          GEN 4025,8,1,4100,1,4000,1,.0950                       $TUBE COND
          GEN 4325,8,1,4300,1,4090,-1,.0950                      $TUBE COND
          GEN 4075,8,1,4350,1,4090,-1,.0950                      $TUBE COND
          GEN 4575,8,1,4550,1,5090,-1,.0950                      $TUBE COND
          GEN 5075,8,1,5100,1,5090,-1,.0950                      $TUBE COND
          GEN 5325,8,1,5300,1,5000,1,.0950                       $TUBE COND
          GEN 5025,8,1,5350,1,5000,1,.0950                       $TUBE COND
          GEN 799,5,1000,999,1000,998,1000,.300                 $MANIFOLD COND
          GEN 1399,5,1000,1091,1000,1092,1000,.300              $MANIFOLD COND
          GEN 899,5,1000,3,0,999,1000,9.E-6                     $MANIFOLD COND
          GEN 1299,5,1000,4,0,1091,1000,9.E-6                   $MANIFOLD COND
          GEN 999,5,1000,999,1000,1000,1000,4.49E-6             $MANIFOLD COND
          GEN 1199,5,1000,1091,1000,1090,1000,4.49E-6 $MANIFOLD COND
          END
          RELATIVE CONDUCTOR NUMBERS                                       ACTUAL CONDUCTOR NUMBERS

                1   THRU      10                 350      351      352      353      354      355      356      400      401      402
               11   THRU      20                 403      404      405      406      450      451      452      453      454      455
               21   THRU      30                 456      500      501      502      503      504      505      506      550      551
               31   THRU      40                 552      553      554      555      556      600      601      602      603      604
               41   THRU      50                 605      606      650      651      652      653      654      655      656      700
               51   THRU      60                 701      702      703      704      705      706      750      751      752      753
               61   THRU      70                 754      755      756      800      801      802      803      804      805      806
               71   THRU      80                 850      851      852      853      854      855      856      900      901      902
               81   THRU      90                 903      904      905      906      950      951      952      953      954      955
               91   THRU     100                 956     1100     1101     1102     1103     1104     1105     1106     1150     1151
              101   THRU     110                1152     1153     1154     1155     1156     1200     1201     1202     1203     1204
              111   THRU     120                1205     1206     1250     1251     1252     1253     1254     1255     1256     1300
              121   THRU     130                1301     1302     1303     1304     1305     1306     1350     1351     1352     1353
```

```
      SINDA/SINFLO PREPROCESSOR                                                                        DATE 101775       PAGE      9
             131   THRU      140              1354     1355     1356     1400     1401     1402     1403     1404     1405     1406
             141   THRU      150              1450     1451     1452     1453     1454     1455     1456     1500     1501     1502
             151   THRU      160              1503     1504     1505     1506     1550     1551     1552     1553     1554     1555
             161   THRU      170              1556     2100     2101     2102     2103     2104     2105     2106     2150     2151
             171   THRU      180              2152     2153     2154     2155     2156     2200     2201     2202     2203     2204
             181   THRU      190              2205     2206     2250     2251     2252     2253     2254     2255     2256     2300
             191   THRU      200              2301     2302     2303     2304     2305     2306     2350     2351     2352     2353
             201   THRU      210              2354     2355     2356     2400     2401     2402     2403     2404     2405     2406
             211   THRU      220              2450     2451     2452     2453     2454     2455     2456     2500     2501     2502
             221   THRU      230              2503     2504     2505     2506     2550     2551     2552     2553     2554     2555
             231   THRU      240              2556     3100     3101     3102     3103     3104     3105     3106     3150     3151
             241   THRU      250              3152     3153     3154     3155     3156     3200     3201     3202     3203     3204
             251   THRU      260              3205     3206     3250     3251     3252     3253     3254     3255     3256     3300
             261   THRU      270              3301     3302     3303     3304     3305     3306     3350     3351     3352     3353
             271   THRU      280              3354     3355     3356     3400     3401     3402     3403     3404     3405     3406
             281   THRU      290              3450     3451     3452     3453     3454     3455     3456     3500     3501     3502
             291   THRU      300              3503     3504     3505     3506     3550     3551     3552     3553     3554     3555
             301   THRU      310              3556     4100     4101     4102     4103     4104     4105     4106     4150     4151
             311   THRU      320              4152     4153     4154     4155     4156     4200     4201     4202     4203     4204
             321   THRU      330              4205     4206     4250     4251     4252     4253     4254     4255     4256     4300
             331   THRU      340              4301     4302     4303     4304     4305     4306     4350     4351     4352     4353
             341   THRU      350              4354     4355     4356     4400     4401     4402     4403     4404     4405     4406
             351   THRU      360              4450     4451     4452     4453     4454     4455     4456     4500     4501     4502
             361   THRU      370              4503     4504     4505     4506     4550     4551     4552     4553     4554     4555
             371   THRU      380              4556     5100     5101     5102     5103     5104     5105     5106     5150     5151
             381   THRU      390              5152     5153     5154     5155     5156     5200     5201     5202     5203     5204
             391   THRU      400              5205     5206     5250     5251     5252     5253     5254     5255     5256     5300
             401   THRU      410              5301     5302     5303     5304     5305     5306     1000     1001     1002     1003
             411   THRU      420              1004     1005     1006     2000     2001     2002     2003     2004     2005     2006
             421   THRU      430              3000     3001     3002     3003     3004     3005     3006     4000     4001     4002
             431   THRU      440              4003     4004     4005     4006     5000     5001     5002     5003     5004     5005
             441   THRU      450              5006     1050     1051     1052     1053     1054     1055     1056     2050     2051
             451   THRU      460              2052     2053     2054     2055     2056     3050     3051     3052     3053     3054
             461   THRU      470              3055     3056     4050     4051     4052     4053     4054     4055     4056     5050
             471   THRU      480              5051     5052     5053     5054     5055     5056     1007     2007     3007     4007
             481   THRU      490              5007     1049     2049     3049     4049     5049     1099     2099     3099     4099
             491   THRU      500              5099       52       53       54       51       55      325      326      327      328
             501   THRU      510               329      330      331      332      375      376      377      378      379      380
             511   THRU      520               381      382      425      426      427      428      429      430      431      432
             521   THRU      530               475      476      477      478      479      480      481      482      525      526
             531   THRU      540               527      528      529      530      531      532      575      576      577      578
             541   THRU      550               579      580      581      582      625      626      627      628      629      630
             551   THRU      560               631      632      675      676      677      678      679      680      681      682
             561   THRU      570               725      726      727      728      729      730      731      732      775      776
             571   THRU      580               777      778      779      780      781      782      825      826      827      828
             581   THRU      590               829      830      831      832      875      876      877      878      879      880
             591   THRU      600               881      882      925      926      927      928      929      930      931      932
             601   THRU      610              1125     1126     1127     1128     1129     1130     1131     1132     1175     1176
             611   THRU      620              1177     1178     1179     1180     1181     1182     1225     1226     1227     1228
             621   THRU      630              1229     1230     1231     1232     1275     1276     1277     1278     1279     1280
             631   THRU      640              1281     1282     1375     1376     1377     1378     1379     1380     1381     1382
             641   THRU      650              1425     1426     1427     1428     1429     1430     1431     1432     1475     1476
             651   THRU      660              1477     1478     1479     1480     1481     1482     1525     1526     1527     1528
             661   THRU      670              1529     1530     1531     1532     2125     2126     2127     2128     2129     2130
             671   THRU      680              2131     2132     2175     2176     2177     2178     2179     2180     2181     2182
             681   THRU      690              2225     2226     2227     2228     2229     2230     2231     2232     2275     2276
             691   THRU      700              2277     2278     2279     2280     2281     2282     2375     2376     2377     2378
```

```
    SINDA/SINFLO PREPROCESSOR                                                                              DATE 101775         PAGE    10
             701   THRU    710            2379     2380     2381     2382     2425     2426     2427     2428     2429     2430
             711   THRU    720            2431     2432     2475     2476     2477     2478     2479     2480     2481     2482
             721   THRU    730            2525     2526     2527     2528     2529     2530     2531     2532     3125     3126
             731   THRU    740            3127     3128     3129     3130     3131     3132     3175     3176     3177     3178
             741   THRU    750            3179     3180     3181     3182     3225     3226     3227     3228     3229     3230
             751   THRU    760            3231     3232     3275     3276     3277     3278     3279     3280     3281     3282
             761   THRU    770            3375     3376     3377     3378     3379     3380     3381     3382     3425     3426
             771   THRU    780            3427     3428     3429     3430     3431     3432     3475     3476     3477     3478
             781   THRU    790            3479     3480     3481     3482     3525     3526     3527     3528     3529     3530
             791   THRU    800            3531     3532     4125     4126     4127     4128     4129     4130     4131     4132
             801   THRU    810            4175     4176     4177     4178     4179     4180     4181     4182     4225     4226
             811   THRU    820            4227     4228     4229     4230     4231     4232     4275     4276     4277     4278
             821   THRU    830            4279     4280     4281     4282     4375     4376     4377     4378     4379     4380
             831   THRU    840            4381     4382     4425     4426     4427     4428     4429     4430     4431     4432
             841   THRU    850            4475     4476     4477     4478     4479     4480     4481     4482     4525     4526
             851   THRU    860            4527     4528     4529     4530     4531     4532     5125     5126     5127     5128
             861   THRU    870            5129     5130     5131     5132     5175     5176     5177     5178     5179     5180
             871   THRU    880            5181     5182     5225     5226     5227     5228     5229     5230     5231     5232
             881   THRU    890            5275     5276     5277     5278     5279     5280     5281     5282      975      976
             891   THRU    900             977      978      979      980      981      982     1075     1076     1077     1078
             901   THRU    910            1079     1080     1081     1082     1325     1326     1327     1328     1329     1330
             911   THRU    920            1331     1332     1025     1026     1027     1028     1029     1030     1031     1032
             921   THRU    930            1575     1576     1577     1578     1579     1580     1581     1582     2025     2026
             931   THRU    940            2027     2028     2029     2030     2031     2032     2325     2326     2327     2328
             941   THRU    950            2329     2330     2331     2332     2075     2076     2077     2078     2079     2080
             951   THRU    960            2081     2082     2575     2576     2577     2578     2579     2580     2581     2582
             961   THRU    970            3075     3076     3077     3078     3079     3080     3081     3082     3325     3326
             971   THRU    980            3327     3328     3329     3330     3331     3332     3025     3026     3027     3028
             981   THRU    990            3029     3030     3031     3032     3575     3576     3577     3578     3579     3580
             991   THRU   1000            3581     3582     4025     4026     4027     4028     4029     4030     4031     4032
            1001   THRU   1010            4325     4326     4327     4328     4329     4330     4331     4332     4075     4076
            1011   THRU   1020            4077     4078     4079     4080     4081     4082     4575     4576     4577     4578
            1021   THRU   1030            4579     4580     4581     4582     5075     5076     5077     5078     5079     5080
            1031   THRU   1040            5081     5082     5325     5326     5327     5328     5329     5330     5331     5332
            1041   THRU   1050            5025     5026     5027     5028     5029     5030     5031     5032      799     1799
            1051   THRU   1060            2799     3799     4799     1399     2399     3399     4399     5399      899     1899
            1061   THRU   1070            2899     3899     4899     1299     2299     3299     4299     5299      999     1999
            1071   THRU   1078            2999     3999     4999     1199     2199     3199     4199     5199
          CONDUCTOR ANALYSIS...  LINEAR =  1078,  RADIATION =      0,  TOTAL =  1078,  CONNECTIONS =  1078

          BCD 3FLOW DATA
          BCD 3NETWORK MAIN
              GC=6.0042E10,CP=A4,RO=A5,MU=A6,KT=A7,MPASS=1,H=A8
              TOL=.01,MXPASS=100,FRDX=.7,P(4)=0.,END
              1,2,3=(99,999,107,1007),(183,1083,191,1091),END
              2,2,3=(199,1999,207,2007),(283,2083,291,2091),END
              3,2,3=(299,2999,307,3007),(383,3083,391,3091),END
              4,2,3=(399,3999,407,4007),(483,4083,491,4091),END
              5,2,3=(499,4999,507,5007),(583,5083,591,5091),END
              6,1,2=1,-3,END
              7,3,4=2,4,END
          END
          BCD 3FLUID LUMP DATA
              2,1.31E-5,.01636,.75,.01227,0.,0.,1.,1.,1.=(99,107),(183,191)
              (199,207),(283,291),(299,307),(383,391),(399,407),(483,491)
              (499,507),(583,591),END
              .0001065,.03658,.0.,.01829,0.,0.,1.,1.,1.=1,2,END
```

```
    SINDA/SINFLO PREPROCESSOR                                                                  DATE 101775        PAGE    11

              END
              BCD 3FLOW SOURCE DATA
                  1,A1,END
              END
              BCD 3END FLOW DATA
              BCD 3CONSTANTS DATA
                  TIMEND,.5  $
                  DTIMEI,.005 $
                  NLOOP,100  $
                  DRLXCA,.01 $
                  ARLXCA,.01 $
                  OUTPUT,.05 $
                   1,10.    $
              END
              CONSTANTS ANALYSIS...  USER =     1,  ADDED =      0       0       0,  TOTAL =     1

              BCD 3ARRAY DATA
                  1 $ FLOWRATE VS TIME
                  0.,21.50,20.,21.50,END
                  4 $ CP COOLANOL 15
                  -150.,.343,-100.,.363,-50.,.385,0.,.405,50.,.424,100.,.444
                  150.,.465,200.,.483,END
                  5 $ RHO COOLANOL 15
                  -150.,63.4,-100.,62.3,-50.,60.2,0.,58.3,50.,56.5,100.,54.7
                  150.,52.9,200.,51.1,END
                  6 $ VISCOSITY COOLANOL 15
                  -150.,2500.,-100.,365.,-50.,30.,0.,10.4,50.,5.5,100.,3.7
                  150.,2.4,200.,1.9,END
                  7 $ CONDUCTIVITY COOLANOL 15
                  -150.,.065,200.,.065,END
                  8,SPACE,16,END $ ENTHALPY CURVE
                  10,*A11,*A12,*A13,*A14,*A15,*A28,END
                  11,13,*T51,33.76,1,*T52,17.57,1,*T53,2.674,1,*T54,2.649,1
                  *T55,0.153,5,*T56,0.345,16,*T57,0.345,16,*T58,0.719,2
                  *T59,0.719,2,*T60,2.495,126,*T61,2.495,126,*T62,2.495,126
                  *T63,2.728,127,END
                  12,.95,.02,1.0,.02,.10,.67,.67,.67,.67,.67,.67,.67,.67,END
                  13,.05,.98,0.0,.90,.90,.33,.33,.33,.33,.33,.33,.33,.33,END
                  14,*T63,*T62,0.,*T63,*T61,0.,*T63,*T60,0.,*T63,*T59,0.
                  *T63,*T58,.02,*T63,*T57,0.,*T63,*T56,.02,*T63,*T55,0.
                  *T63,*T54,.028,*T63,*T53,.006,*T63,*T52,.057,*T63,*T51,.869
                  *T62,*T61,0.,*T62,*T60,0.,*T62,*T59,0.,*T62,*T58,.003
                  *T62,*T57,0.,*T62,*T56,.02,*T62,*T55,0.,*T62,*T54,.028
                  *T62,*T53,.002,*T62,*T52,.057,*T62,*T51,.890,*T61,*T60,0.
                  *T61,*T59,0.,*T61,*T58,0.,*T61,*T57,0.,*T61,*T56,.02,*T61,*T55,0.
                  *T61,*T54,.043,*T61,*T53,.001,*T61,*T52,.088,*T61,*T51,.848
                  *T60,*T59,0.,*T60,*T58,0.,*T60,*T57,0.,*T60,*T56,.02,*T60,*T55,.03
                  *T60,*T54,.1325,*T60,*T53,0.,*T60,*T52,.3275,*T60,*T51,.49
                  *T59,*T58,0.,*T59,*T57,0.,*T59,*T56,0.,*T59,*T55,0.,*T59,*T54,0.
                  *T59,*T53,0.,*T59,*T52,0.,*T59,*T51,.5,*T58,*T57,0.,*T58,*T56,.02
                  *T58,*T55,0.,*T58,*T54,.05,*T58,*T53,0.,*T58,*T52,.05,*T58,*T51,.6
                  *T57,*T56,0.,*T57,*T55,0.,*T57,*T54,0.,*T57,*T53,.05,*T57,*T52,.2
                  *T57,*T51,.75,*T56,*T55,.01,*T56,*T54,.05,*T56,*T53,0.,*T56,*T52,.2
                  *T56,*T51,.6,*T55,*T54,.5,*T55,*T53,0.,*T55,*T52,0.,*T55,*T51,.5
                  *T54,*T53,.05,*T54,*T52,.05,*T54,*T51,.7,*T53,*T52,.2
                  *T53,*T51,.70,*T52,*T51,.70,END
                  15,*T9001,33.76,END
```

```
16,*T9002,17.57,END
~~17,*T9003,2.674,END~~
18,*T9004,2.649,END
19,*T998,.0306,*T1998,.0306,*T2998,.0306,*T3998,.0306
*T4998,.0306,END
~~20,*T1700,.02156,*T1701,.02156,*T1702,.02156,*T1703,.02156~~
*T1704,.02156,*T1705,.02156,*T1706,.02156,*T1707,.02156
*T1800,.02156,*T1801,.02156,*T1802,.02156,*T1803,.02156
*T1804,.02156,*T1805,.02156,*T1806,.02156,*T1807,.02160,END
~~21,*T1650,.02156,*T1651,.02156,*T1652,.02156,*T1653,.02156~~
*T1654,.02156,*T1655,.02156,*T1656,.02156,*T1657,.02156
*T1750,.02156,*T1751,.02156,*T1752,.02156,*T1753,.02156
*T1754,.02156,*T1755,.02156,*T1756,.02156,*T1757,.02156,END
~~22,*T1054,.3595,*T1055,.3595,END~~
23,*T1052,.3595,*T1053,.3595,END
24,*T1900,.0198,*T1901,.0198,*T1950,.0198,*T1951,.0198
*T2700,.0198,*T2701,.0198,*T2750,.0198,*T2751,.0198
~~*T2800,.0198,*T2801,.0198,*T2850,.0198,*T2851,.0199~~
*T2900,.0198,*T2901,.0198,*T2950,.0198,*T2951,.0198
*T1090,.0198,*T1089,.0198,*T1100,.0198,*T1101,.0198
*T1450,.0198,*T1451,.0198,*T1150,.0198,*T1151,.0198
~~*T1200,.0198,*T1201,.0198,*T1250,.0198,*T1251,.0198~~
*T1300,.0198,*T1301,.0198,*T1000,.0198,*T1001,.0198
*T1350,.0198,*T1351,.0198,*T1400,.0198,*T1401,.0198
*T1500,.0198,*T1501,.0198,*T1550,.0198,*T1551,.0198
~~*T2000,.0198,*T2001,.0198,*T2100,.0198,*T2101,.0198~~
*T2150,.0198,*T2151,.0198,*T2200,.0198,*T2201,.0198
*T2250,.0198,*T2251,.0198,*T2300,.0198,*T2301,.0198
*T2090,.0198,*T2089,.0198,*T2350,.0198,*T2351,.0198
~~*T2400,.0198,*T2401,.0198,*T2450,.0198,*T2451,.0198~~
*T2500,.0198,*T2501,.0198,*T2550,.0198,*T2551,.0198
*T3090,.0198,*T3089,.0198,*T3100,.0196,*T3101,.0198
*T3150,.0198,*T3151,.0198,*T3200,.0198,*T3201,.0198
~~*T3250,.0198,*T3251,.0198,*T3300,.0198,*T3301,.0198~~
*T3000,.0198,*T3001,.0198,*T3350,.0198,*T3351,.0198
*T3400,.0198,*T3401,.0198,*T3450,.0198,*T3451,.0198
*T3500,.0198,*T3501,.0198,*T3550,.0198,*T3551,.0198
~~*T4000,.0198,*T4001,.0198,*T4100,.0198,*T4101,.0198~~
*T4150,.0198,*T4151,.0198,*T4200,.0198,*T4201,.0198
*T4250,.0198,*T4251,.0198,*T4300,.0198,*T4301,.0198
*T4090,.0198,*T4089,.0198,*T4350,.0196,*T4351,.0198
~~*T4400,.0198,*T4401,.0198,*T4450,.0198,*T4451,.0198~~
*T4500,.0198,*T4501,.0198,*T4550,.0198,*T4551,.0198
*T5090,.0198,*T5089,.0198,*T5100,.0196,*T5101,.0198
*T5150,.0198,*T5151,.0198,*T5200,.0198,*T5201,.0198
~~*T5250,.0198,*T5251,.0198,*T5300,.0198,*T5301,.0198~~
*T5000,.0198,*T5001,.0198,END
25,*T1902,.0198,*T1903,.0198,*T1952,.0198,*T1953,.0198
*T1002,.0198,*T1003,.0198,*T1552,.0198,*T1553,.0198
~~*T2702,.0198,*T2703,.0198,*T2752,.0198,*T2753,.0198~~
*T2802,.0198,*T2803,.0198,*T2852,.0198,*T2853,.0198
*T2902,.0198,*T2903,.0198,*T2952,.0198,*T2953,.0198
*T1088,.0198,*T1087,.0198,*T1102,.0198,*T1103,.0198
~~*T1152,.0198,*T1153,.0198,*T1202,.0198,*T1203,.0198~~
*T1252,.0198,*T1253,.0198,*T1302,.0198,*T1303,.0198
*T1352,.0198,*T1353,.0198,*T1402,.0198,*T1403,.0198
*T1452,.0198,*T1453,.0198,*T1502,.0198,*T1503,.0198
```

```
                    *T2002,.0198,*T2003,.0198,*T2102,.0198,*T2103,.0198
                    *T2152,.0198,*T2153,.0198,*T2202,.0198,*T2203,.0198
                    *T2252,.0198,*T2253,.0198,*T2302,.0198,*T2303,.0198
                    *T2088,.0198,*T2087,.0198,*T2352,.0198,*T2353,.0198
                    *T2402,.0198,*T2403,.0198,*T2452,.0198,*T2453,.0198
                    *T2502,.0198,*T2503,.0198,*T2552,.0198,*T2553,.0198
                    *T3088,.0198,*T3087,.0198,*T3102,.0198,*T3103,.0198
                    *T3152,.0198,*T3153,.0198,*T3202,.0198,*T3203,.0198
                    *T3252,.0198,*T3253,.0198,*T3302,.0198,*T3303,.0198
                    *T3002,.0198,*T3003,.0198,*T3352,.0198,*T3353,.0198
                    *T3402,.0198,*T3403,.0198,*T3452,.0198,*T3453,.0198
                    *T3502,.0198,*T3503,.0198,*T3552,.0198,*T3553,.0198
                    *T4002,.0198,*T4003,.0198,*T4102,.0198,*T4103,.0198
                    *T4152,.0198,*T4153,.0198,*T4202,.0198,*T4203,.0198
                    *T4252,.0198,*T4253,.0198,*T4302,.0198,*T4303,.0198
                    *T4088,.0198,*T4087,.0198,*T4352,.0198,*T4353,.0198
                    *T4402,.0198,*T4403,.0198,*T4452,.0198,*T4453,.0198
                    *T4502,.0198,*T4503,.0198,*T4552,.0198,*T4553,.0198
                    *T5088,.0198,*T5087,.0198,*T5102,.0198,*T5103,.0198
                    *T5152,.0198,*T5153,.0198,*T5202,.0198,*T5203,.0198
                    *T5252,.0198,*T5253,.0198,*T5302,.0198,*T5303,.0198
                    *T5002,.0198,*T5003,.0198,END
                    26,*T1904,.0198,*T1905,.0198,*T1954,.0198,*T1955,.0198
                    *T1004,.0198,*T1005,.0198,*T1554,.0198,*T1555,.0198
                    *T2704,.0198,*T2705,.0198,*T2754,.0198,*T2755,.0198
                    *T2804,.0198,*T2805,.0198,*T2854,.0198,*T2855,.0198
                    *T2904,.0198,*T2905,.0198,*T2954,.0198,*T2955,.0198
                    *T1086,.0198,*T1085,.0198,*T1104,.0198,*T1105,.0198
                    *T1154,.0198,*T1155,.0198,*T1204,.0198,*T1205,.0198
                    *T1254,.0198,*T1255,.0198,*T1304,.0198,*T1305,.0198
                    *T1354,.0198,*T1355,.0198,*T1404,.0198,*T1405,.0198
                    *T1454,.0198,*T1455,.0198,*T1504,.0198,*T1505,.0198
                    *T2004,.0198,*T2005,.0198,*T2104,.0198,*T2105,.0198
                    *T2154,.0198,*T2155,.0198,*T2204,.0198,*T2205,.0198
                    *T2254,.0198,*T2255,.0198,*T2304,.0198,*T2305,.0198
                    *T2086,.0198,*T2085,.0198,*T2354,.0198,*T2355,.0198
                    *T2404,.0198,*T2405,.0198,*T2454,.0198,*T2455,.0198
                    *T2504,.0198,*T2505,.0198,*T2554,.0198,*T2555,.0198
                    *T3086,.0198,*T3085,.0198,*T3104,.0198,*T3105,.0198
                    *T3154,.0198,*T3155,.0198,*T3204,.0198,*T3205,.0198
                    *T3254,.0198,*T3255,.0198,*T3304,.0198,*T3305,.0198
                    *T3004,.0198,*T3005,.0198,*T3354,.0198,*T3355,.0198
                    *T3404,.0198,*T3405,.0198,*T3454,.0198,*T3455,.0198
                    *T3504,.0198,*T3505,.0198,*T3554,.0198,*T3555,.0198
                    *T4004,.0198,*T4005,.0198,*T4104,.0198,*T4105,.0198
                    *T4154,.0198,*T4155,.0198,*T4204,.0198,*T4205,.0198
                    *T4254,.0198,*T4255,.0198,*T4304,.0198,*T4305,.0198
                    *T4086,.0198,*T4085,.0198,*T4354,.0198,*T4355,.0198
                    *T4404,.0198,*T4405,.0198,*T4454,.0198,*T4455,.0198
                    *T4504,.0198,*T4505,.0198,*T4554,.0198,*T4555,.0198
                    *T5086,.0198,*T5085,.0198,*T5104,.0198,*T5105,.0198
                    *T5154,.0198,*T5155,.0198,*T5204,.0198,*T5205,.0198
                    *T5254,.0198,*T5255,.0198,*T5304,.0198,*T5305,.0198
                    *T5004,.0198,*T5005,.0198,END
                    27,*T1906,.0198,*T1907,.0198,*T1956,.0198,*T1957,.0198
                    *T1006,.0198,*T1007,.0198,*T1556,.0198,*T1557,.0198
                    *T2706,.0198,*T2707,.0198,*T2756,.0198,*T2757,.0198
```

```
              *T2806,.0198,*T2807,.0198,*T2856,.0198,*T2857,.0198
              *T2906,.0198,*T2907,.0198,*T2956,.0198,*T2957,.0198
              *T1084,.0198,*T1083,.0198,*T1106,.0198,*T1107,.0198
              *T1156,.0198,*T1157,.0198,*T1206,.0198,*T1207,.0198
              *T1256,.0198,*T1257,.0198,*T1306,.0198,*T1307,.0198
              *T1356,.0198,*T1357,.0198,*T1406,.0198,*T1407,.0198
              *T1456,.0198,*T1457,.0198,*T1506,.0198,*T1507,.0198
              *T2006,.0198,*T2007,.0198,*T2106,.0198,*T2107,.0198
              *T2156,.0198,*T2157,.0198,*T2206,.0198,*T2207,.0198
              *T2256,.0198,*T2257,.0198,*T2306,.0198,*T2307,.0198
              *T2084,.0198,*T2083,.0198,*T2356,.0198,*T2357,.0198
              *T2406,.0198,*T2407,.0198,*T2456,.0198,*T2457,.0198
              *T2506,.0198,*T2507,.0198,*T2556,.0198,*T2557,.0198
              *T3084,.0198,*T3083,.0198,*T3106,.0198,*T3107,.0198
              *T3156,.0198,*T3157,.0198,*T3206,.0198,*T3207,.0198
              *T3256,.0198,*T3257,.0198,*T3306,.0198,*T3307,.0198
              *T3006,.0198,*T3007,.0198,*T3356,.0198,*T3357,.0198
              *T3406,.0198,*T3407,.0198,*T3456,.0198,*T3457,.0198
              *T3506,.0198,*T3507,.0198,*T3556,.0198,*T3557,.0198
              *T4006,.0198,*T4007,.0198,*T4106,.0198,*T4107,.0198
              *T4156,.0198,*T4157,.0198,*T4206,.0198,*T4207,.0198
              *T4256,.0198,*T4257,.0198,*T4306,.0198,*T4307,.0198
              *T4084,.0198,*T4083,.0198,*T4356,.0198,*T4357,.0198
              *T4406,.0198,*T4407,.0198,*T4456,.0198,*T4457,.0198
              *T4506,.0198,*T4507,.0198,*T4556,.0198,*T4557,.0198
              *T5084,.0198,*T5083,.0198,*T5106,.0198,*T5107,.0198
              *T5156,.0198,*T5157,.0198,*T5206,.0198,*T5207,.0198
              *T5256,.0198,*T5257,.0198,*T5306,.0198,*T5307,.0198
              *T5006,.0198,*T5007,.0198,*T1051,.233,END
              28,SPACE,91,END
          END
          ARRAY ANALYSIS...  NUMBER OF ARRAYS =   25  TOTAL LENGTH =  1594

      TUBE NUMBER LIST
           1        2         3         4         5         6         7                              7

      PRESSURE NODE LIST
           1        2         3         4                                                          4
         BCD 3EXECUTION
         DIMENSION X(10000)                                        F
         NDIM=10000                                                F
         NTH=0                                                     F
              RESET
              CRVINT(A4,A8)
              TOPLIN
              GENOUT(A8+1,1,A8,3HOA8)
              FLOSOL
         ITEST=0                                                   F
              CSGDMP
         ITEST=1                                                   F
              CNBACK
          END
          BCD 3VARIABLES 1
         IF(ITEST.EQ.1) CALL RADIR(A10,.1714E-8,-460.)             M
         T5350=T3550                                               M
         T5351=T3551                                               M
```

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

```
SINDA/SINFLO PREPROCESSOR                                              DATE 101775        PAGE    15
          T5352=T3552                                                      M
          T5353=T3553                                                      M
          T5354=T3554                                                      M
          T5355=T3555                                                      M
          T5356=T3556                                                      M
          T5357=T3557                                                      M
          END
          BCD 3VARIABLES 2
               FLOSOL
               TIMCHK(K1,0)
          END
          BCD 3OUTPUT CALLS
               TPRNT
               WPRINT(1,1,1,0)
               TIMCHK(K1,1)
          END

@ADD,P EC02-V55008*SINFLO.PROC
```

```
       SOFT TUBE INFLATABLE RADIATOR
     IR CROSS RADIATION DATA

        * SURFACE DATA
              NUMBER OF SURFACES =    13
              SURFACE NUMBER        SURFACE AREA      NUMBER OF NODES

                          51             33.76300                  1
                          52             17.57000                  1
                          53              2.67400                  1
                          54              2.64900                  1
                          55               .15300                  5
                          56               .34500                 16
                          57               .34500                 16
                          58               .71900                  2
                          59               .71900                  2
                          60              2.49500                126
                          61              2.49500                126
                          62              2.49500                126
                          63              2.72800                127


       SURFACE EMISSIVITY DATA
                   .95000+00   .20000-01   .10000+01   .20000-01   .10000+00   .67000+00   .67000+00   .67000+00   .67000+00   .67000+00
                   .67000+00   .67000+00   .67000+00

       SURFACE REFLECTIVITY DATA
                   .50000-01   .98000+00   .00000      .98000+00   .90000+00   .33000+00   .33000+00   .33000+00   .33000+00   .33000+00
                   .33000+00   .33000+00   .33000+00

       SURFACE CONNECTION DATA
              FROM SURFACE          TO SURFACE        VIEW FACTOR
                    63                  62              .00000
                    63                  61              .00000
                    63                  60              .00000
                    63                  59              .00000
                    63                  58              .20000-01
                    63                  57              .00000
                    63                  56              .20000-01
                    63                  55              .00000
                    63                  54              .28000-01
                    63                  53              .60000-02
```

```
63      52      .57000-01
63      51      .86900+00
62      61      .00000
62      60      .00000
62      59      .00000
62      58      .30000-02
62      57      .00000
62      56      .20000-01
62      55      .00000
62      54      .28000-01
62      53      .20000-02
62      52      .57000-01
62      51      .89000+00
61      60      .00000
61      59      .00000
```

```
SOFT TUBE INFLATABLE RADIATOR
                     61                  58               .00000
                     61                  57               .00000
                     61                  56               .24700-01
                     61                  55               .00000
                     61                  54               .43000-01
                     61                  53               .10400-02
                     61                  52               .88000-01
                     61                  51               .84800+00
                     60                  59               .00000
                     60                  58               .00000
                     60                  57               .00000
                     60                  56               .20000-01
                     60                  55               .30000-01
                     60                  54               .13250+00
                     60                  53               .00000
                     60                  52               .32750+00
                     60                  51               .49000+00
                     59                  58               .00000
                     59                  57               .00000
                     59                  56               .00000
                     59                  55               .00000
                     59                  54               .00000
                     59                  53               .19900
                     59                  52               .10000
                     59                  51               .50000+00
                     58                  57               .00000
                     58                  56               .27000-01
                     58                  55               .00000
                     58                  54               .50000-01
                     58                  53               .00000
                     58                  52               .50000-01
                     58                  51               .60000+00
                     57                  56               .00000
                     57                  55               .00000
                     57                  54               .00000
                     57                  53               .50000-01
                     57                  52               .20000+00
                     57                  51               .75000+00
                     56                  55               .10000-01
                     56                  54               .50000-01
                     56                  53               .00000
                     56                  52               .20000+00
                     56                  51               .60000+00
                     55                  54               .50000+00
                     55                  53               .00000
                     55                  52               .00000
                     55                  51               .50000+00
```

```
SOFT TUBE INFLATABLE RADIATOR
                               54                  53                .50000-01
                               54                  52                .50000-01
                               54                  51                .70000+00
                               53                  52                .20000+00
                               53                  51                .70000+00
                               52                  51                .70000+00

 NODE DATA
         SURFACE        NODE           AREA     NODE          AREA     NODE          AREA     NODE          AREA

              51        9001       33.76000
              52        9002       17.57400
              53        9003        2.67400
              54        9004        2.64900
              55         998         .03060     1998        .03060     2998        .03060     3998        .03060
                        4998         .03060
              56        1700         .02156     1701        .02156     1702        .02156     1703        .02156
                        1704         .02156     1705        .02156     1706        .02156     1707        .02156
                        1800         .02156     1801        .02156     1802        .02156     1803        .02156
                        1804         .02156     1805        .02156     1806        .02156     1807        .02160
              57        1650         .02156     1651        .02156     1652        .02156     1653        .02156
                        1654         .02156     1655        .02156     1656        .02156     1657        .02156
                        1750         .02156     1751        .02156     1752        .02156     1753        .02156
                        1754         .02156     1755        .02156     1756        .02156     1757        .02156
              58        1054         .35950     1055        .35950
              59        1052         .35950     1053        .35950
              60        1900         .01980     1901        .01980     1950        .01980     1951        .01980
                        2700         .01980     2701        .01980     2750        .01980     2751        .01980
                        2800         .01980     2801        .01980     2850        .01980     2851        .01980
                        2900         .01980     2901        .01980     2950        .01980     2951        .01980
                        1090         .01980     1089        .01980     1100        .01980     1101        .01980
                        1450         .01980     1451        .01980     1150        .01980     1151        .01980
                        1200         .01980     1201        .01980     1250        .01980     1251        .01980
                        1300         .01980     1301        .01980     1000        .01980     1001        .01980
                        1350         .01980     1351        .01980     1400        .01980     1401        .01980
                        1500         .01980     1501        .01980     1550        .01980     1551        .01980
                        2000         .01980     2001        .01980     2100        .01980     2101        .01980
                        2150         .01980     2151        .01980     2200        .01980     2201        .01980
                        2250         .01980     2251        .01980     2300        .01980     2301        .01980
                        2090         .01980     2089        .01980     2350        .01980     2351        .01980
                        2400         .01980     2401        .01980     2450        .01980     2451        .01980
                        2500         .01990     2501        .01980     2550        .01980     2551        .01980
                        3090         .01980     3089        .01980     3100        .01980     3101        .01980
```

```
SOFT TUBE INFLATABLE RADIATOR
                    3150        .01980        3151        .01980        3200        .01980        3201        .01980
                    3250        .01980        3251        .01980        3300        .01980        3301        .01980
                    3000        .01980        3001        .01980        3350        .01980        3351        .01980
                    3400        .01980        3401        .01980        3450        .01980        3451        .01980
                    3500        .01980        3501        .01980        3550        .01980        3551        .01980
                    4000        .01980        4001        .01980        4100        .01980        4101        .01980
                    4150        .01980        4151        .01980        4200        .01980        4201        .01980
                    4250        .01980        4251        .01980        4300        .01980        4301        .01980
                    4090        .01980        4089        .01980        4350        .01980        4351        .01980
                    4400        .01980        4401        .01980        4450        .01980        4451        .01980
                    4500        .01980        4501        .01980        4550        .01980        4551        .01980
                    5090        .01980        5089        .01980        5100        .01980        5101        .01980
                    5150        .01980        5151        .01980        5200        .01980        5201        .01980
                    5250        .01980        5251        .01980        5300        .01980        5301        .01980
                    5000        .01980        5001        .01980
            61      1902        .01980        1903        .01980        1952        .01980        1953        .01980
                    1002        .01980        1003        .01980        1552        .01980        1553        .01980
                    2702        .01980        2703        .01980        2752        .01980        2753        .01980
                    2802        .01980        2803        .01980        2852        .01980        2853        .01980
                    2902        .01980        2903        .01980        2952        .01980        2953        .01980
                    1088        .01980        1087        .01980        1102        .01980        1103        .01980
                    1152        .01980        1153        .01980        1202        .01980        1203        .01980
                    1252        .01980        1253        .01980        1302        .01980        1303        .01980
                    1352        .01980        1353        .01980        1402        .01980        1403        .01980
                    1452        .01980        1453        .01980        1502        .01980        1503        .01980
                    2002        .01980        2003        .01980        2102        .01980        2103        .01980
                    2152        .01980        2153        .01980        2202        .01980        2203        .01980
                    2252        .01980        2253        .01980        2302        .01980        2303        .01980
                    2088        .01980        2087        .01980        2352        .01980        2353        .01980
                    2402        .01980        2403        .01980        2452        .01980        2453        .01980
                    2502        .01980        2503        .01980        2552        .01980        2553        .01980
                    3088        .01980        3087        .01980        3102        .01980        3103        .01980
                    3152        .01980        3153        .01980        3202        .01980        3203        .01980
                    3252        .01980        3253        .01980        3302        .01980        3303        .01980
                    3002        .01980        3003        .01980        3352        .01980        3353        .01980
                    3402        .01980        3403        .01980        3452        .01980        3453        .01980
                    3502        .01980        3503        .01980        3552        .01980        3553        .01980
                    4002        .01980        4003        .01980        4102        .01980        4103        .01980
                    4152        .01980        4153        .01980        4202        .01980        4203        .01980
                    4252        .01980        4253        .01980        4302        .01980        4303        .01980
                    4088        .01980        4087        .01980        4352        .01980        4353        .01980
                    4402        .01980        4403        .01980        4452        .01980        4453        .01980
                    4502        .01980        4503        .01980        4552        .01980        4553        .01980
                    5088        .01980        5087        .01980        5102        .01980        5103        .01980
                    5152        .01980        5153        .01980        5202        .01980        5203        .01980
                    5252        .01980        5253        .01980        5302        .01980        5303        .01980
                    5002        .01980        5003        .01980
```

```
SOFT TUBE INFLATABLE RADTATOR
         62      1904         .01980      1905         .01980      1954         .01980      1955         .01980
                 1004         .01980      1005         .01980      1554         .01980      1555         .01980
                 2704         .01980      2705         .01980      2754         .01980      2755         .01980
                 2804         .01980      2805         .01980      2854         .01980      2855         .01980
                 2904         .01980      2905         .01980      2954         .01980      2955         .01980
                 1086         .01980      1085         .01980      1104         .01980      1105         .01980
                 1154         .01980      1155         .01980      1204         .01980      1205         .01980
                 1254         .01980      1255         .01980      1304         .01980      1305         .01980
                 1354         .01980      1355         .01980      1404         .01980      1405         .01980
                 1454         .01980      1455         .01980      1504         .01980      1505         .01980
                 2004         .01980      2005         .01980      2104         .01980      2105         .01980
                 2154         .01980      2155         .01980      2204         .01980      2205         .01980
                 2254         .01980      2255         .01980      2304         .01980      2305         .01980
                 2086         .01980      2085         .01980      2354         .01980      2355         .01980
                 2404         .01980      2405         .01980      2454         .01980      2455         .01980
                 2504         .01980      2505         .01980      2554         .01980      2555         .01980
                 3086         .01980      3085         .01980      3104         .01980      3105         .01980
                 3154         .01980      3155         .01980      3204         .01980      3205         .01980
                 3254         .01980      3255         .01980      3304         .01980      3305         .01980
                 3004         .01980      3005         .01980      3354         .01980      3355         .01980
                 3404         .01980      3405         .01980      3454         .01980      3455         .01980
                 3504         .01980      3505         .01980      3554         .01980      3555         .01980
                 4004         .01980      4005         .01980      4104         .01980      4105         .01980
                 4154         .01980      4155         .01980      4204         .01980      4205         .01980
                 4254         .01980      4255         .01980      4304         .01980      4305         .01980
                 4086         .01980      4085         .01980      4354         .01980      4355         .01980
                 4404         .01980      4405         .01980      4454         .01980      4455         .01980
                 4504         .01980      4505         .01980      4554         .01980      4555         .01980
                 5086         .01980      5085         .01980      5104         .01980      5105         .01980
                 5154         .01980      5155         .01980      5204         .01980      5205         .01980
                 5254         .01980      5255         .01980      5304         .01980      5305         .01980
                 5004         .01980      5005         .01980
         63      1906         .01980      1907         .01980      1956         .01980      1957         .01980
                 1006         .01980      1007         .01980      1556         .01980      1557         .01980
                 2706         .01980      2707         .01980      2756         .01980      2757         .01980
                 2806         .01980      2807         .01980      2856         .01980      2857         .01980
                 2906         .01980      2907         .01980      2956         .01980      2957         .01980
                 1084         .01980      1083         .01980      1106         .01980      1107         .01980
                 1156         .01980      1157         .01980      1206         .01980      1207         .01980
                 1256         .01980      1257         .01980      1306         .01980      1307         .01980
                 1356         .01980      1357         .01980      1406         .01980      1407         .01980
                 1456         .01980      1457         .01980      1506         .01980      1507         .01980
                 2006         .01980      2007         .01980      2106         .01980      2107         .01980
                 2156         .01980      2157         .01980      2206         .01980      2207         .01980
                 2256         .01980      2257         .01980      2306         .01980      2307         .01980
                 2084         .01980      2083         .01980      2356         .01980      2357         .01980
                 2406         .01980      2407         .01980      2456         .01980      2457         .01980
```

```
SOFT TUBE INFLATABLE RADIATOR
                  2506        .01980       2507        .01980       2556        .01980       2557        .01980
                  3084        .01980       3083        .01980       3106        .01980       3107        .01980
                  3156        .01980       3157        .01980       3206        .01980       3207        .01980
                  3256        .01980       3257        .01980       3306        .01980       3307        .01980
                  3006        .01980       3007        .01980       3356        .01980       3357        .01980
                  3406        .01980       3407        .01980       3456        .01980       3457        .01980
                  3506        .01980       3507        .01980       3556        .01980       3557        .01980
                  4006        .01980       4007        .01980       4106        .01980       4107        .01980
                  4156        .01980       4157        .01980       4206        .01980       4207        .01980
                  4256        .01980       4257        .01980       4306        .01980       4307        .01980
                  4084        .01980       4083        .01980       4356        .01980       4357        .01980
                  4406        .01980       4407        .01980       4456        .01980       4457        .01980
                  4506        .01980       4507        .01980       4556        .01980       4557        .01980
                  5084        .01980       5083        .01980       5106        .01980       5107        .01980
                  5156        .01980       5157        .01980       5206        .01980       5207        .01980
                  5256        .01980       5257        .01980       5306        .01980       5307        .01980
                  5006        .01980       5007        .01980       1051        .23300

  CONNECTION DATA
       FROM SURFACE      TO SURFACE      SCRIPT FA

             62              63         .70285-02
             61              63         .77376-02
             60              63         .13443-01
             59              63         .62772-03
             58              63         .26396-01
             57              63         .82678-03
             56              63         .25932-01
             55              63         .22417-03
             54              63         .12126-02
             53              63         .23208-01
             52              63         .29084-02
             51              63         .16717+01
             61              62         .71212-02
             60              62         .12289-01
             59              62         .58446-03
             58              62         .51079-02
             57              62         .76366-03
             56              62         .23593-01
             55              62         .20415-03
             54              62         .11010-02
             53              62         .14600-01
             52              62         .26604-02
```

```
SOFT TUBE INFLATABLE RADIATOR
                    51             62        .15565+01
                    60             61        .16287-01
                    59             61        .57947-03
                    58             61        .20550-02
                    57             61        .89613-03
                    56             61        .23874-01
                    55             61        .28369-03
                    54             61        .16216-02
                    53             61        .15768-01
                    52             61        .37312-02
                    51             61        .15432+01
                    59             60        .52804-03
                    58             60        .42453-02
                    57             60        .19307-02
                    56             60        .26876-01
                    55             60        .58750-02
                    54             60        .52367-02
                    53             60        .34978-01
                    52             60        .12627-01
                    51             60        .14062+01
                    58             59        .12447-03
                    57             59        .75134-04
                    56             59        .82089-04
                    55             59        .58804-05
                    54             59        .16384-04
                    53             59        .86449-03
                    52             59        .93542-04
                    51             59        .23337+00
                    57             58        .17760-03
                    56             58        .69951-02
                    55             58        .89073-04
                    54             58        .53285-03
                    53             58        .33793-02
                    52             58        .68260-03
                    51             58        .33146+00
                    56             57        .21015-03
                    55             57        .86464-05
                    54             57        .23347-04
                    53             57        .13715-01
                    52             57        .10112-02
                    51             57        .20009+00
                    55             56        .32273-03
                    54             56        .34438-03
                    53             56        .33455-02
                    52             56        .11672-02
                    51             56        .22074+00
                    54             55        .16518-03
```

```
 SYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER   - - -  SINDA  - - -   UNIVAC-1108 FORTRAN-V VERSION        PAGE    65
 SOFT TUBE INFLATABLE RADIATOR
                            53                 55         .50267-03
                            52                 55         .34236-04
                            51                 55         .15660-01
                            53                 54         .29814-02
                            52                 54         .91296-04
                            51                 54         .42834-01
                            52                 53         .11908-01
                            51                 53         .23022+01
                            51                 52         .24911+00
```

```
         SOFT TUBE INFLATABLE RADIATOR
      T  5100=   13.819      T  5101=   14.729      T  5102=   13.125      T  5103=   14.353      T  5104=   15.438      T  5105=   16.816
      T  5106=   18.787      T  5107=   19.742      T  5150=   10.692      T  5151=   11.723      T  5152=   7.6643      T  5153=   8.0647
      T  5154=   8.2603      T  5155=   8.8149      T  5156=   10.104      T  5157=   10.269      T  5200=   13.495      T  5201=   12.836
      T  5202=   8.7635      T  5203=   8.3615      T  5204=   7.7362      T  5205=   7.5004      T  5206=   8.0551      T  5207=   7.4399
      T  5250=   22.664      T  5251=   21.167      T  5252=   16.487      T  5253=   15.259      T  5254=   13.833      T  5255=   12.793
      T  5256=   12.515      T  5257=   11.684      T  5300=   38.664      T  5301=   36.281      T  5302=   31.311      T  5303=   29.182
      T  5304=   26.926      T  5305=   23.517      T  5306=   23.758      T  5307=   21.421      T  5350=   45.579      T  5351=   42.248
      T  5352=   36.313      T  5353=   33.277      T  5354=   30.107      T  5355=   27.295      T  5356=   25.143      T  5357=   21.895
      T  9001=  -310.00      T  9002=  -88.921      T  9003=   69.999      T  9004=  -22.805

      W         1= 4.0721    W         2= 4.3540    W         3= 4.3579    W         4= 4.3580    W         5= 4.3581
      W         6= 21.500    W         7= 21.500

      DP        1= 5.3264    DP        2= 5.3264    DP        3= 5.3264    DP        4= 5.3264    DP        5= 5.3264
      DP        6= .31052-01 DP        7= .48220-01

      P         1= 5.4056    P         2= 5.3746    P         3= .48220-01 P         4= .00000

      COMPUTER TIME =   2.302 MINUTES

      **********
      TIME=   .50000 DTIMEU=  2.50000-03 CSGMIN(  2451)= -3.84669-04 TEMPCC(  1055)=  2.71160-01 RELXCC(  1856)=  6.47736-03
      T        1=   95.000   T        2=   35.353   T        3=   70.713   T        4=   35.354   T       51=  -310.00   T       52=  -93.896
      T       53=   69.999   T       54=  -24.863   T       55=   91.726   T       56=  -95.235   T       57=  -111.11   T       58=  -5.4578
      T       59=   13.182   T       60=   17.417   T       61=   13.418   T       62=   12.600   T       63=   6.5482   T       99=   94.661
      T      100=   89.926   T      101=   85.374   T      102=   65.735   T      103=   76.270   T      104=   71.950   T      105=   67.794
      T      106=   63.843   T      107=   59.839   T      183=   55.091   T      184=   50.715   T      185=   46.283   T      186=   41.998
      T      187=   37.913   T      188=   37.995   T      189=   30.523   T      190=   27.199   T      191=   27.227   T      199=   94.683
      T      200=   90.313   T      201=   86.096   T      202=   81.779   T      203=   77.610   T      204=   73.560   T      205=   69.647
      T      206=   65.911   T      207=   62.110   T      283=   58.457   T      284=   55.118   T      285=   51.851   T      286=   48.638
      T      287=   45.482   T      288=   42.444   T      289=   39.754   T      290=   37.158   T      291=   37.177   T      299=   94.684
      T      300=   90.321   T      301=   86.114   T      302=   81.818   T      303=   77.653   T      304=   73.613   T      305=   69.714
      T      306=   65.993   T      307=   62.226   T      383=   58.552   T      384=   55.214   T      385=   51.946   T      386=   48.737
      T      387=   45.580   T      388=   42.541   T      389=   39.850   T      390=   37.263   T      391=   37.271   T      399=   94.684
      T      400=   90.321   T      401=   86.114   T      402=   81.808   T      403=   77.651   T      404=   73.614   T      405=   69.715
      T      406=   65.994   T      407=   62.207   T      483=   58.555   T      484=   55.216   T      485=   51.949   T      486=   48.742
      T      487=   45.585   T      488=   42.546   T      489=   39.856   T      490=   37.269   T      491=   37.277   T      499=   94.684
      T      500=   90.321   T      501=   86.114   T      502=   81.809   T      503=   77.651   T      504=   73.614   T      505=   69.715
      T      506=   65.994   T      507=   62.207   T      583=   58.555   T      584=   55.217   T      585=   51.949   T      586=   48.742
      T      587=   45.585   T      588=   42.546   T      589=   39.856   T      590=   37.269   T      591=   37.278   T      998=   91.702
      T      999=   93.737   T     1000=   76.206   T     1001=   71.835   T     1002=   66.742   T     1003=   62.696   T     1004=   58.734
      T     1005=   55.023   T     1006=   51.665   T     1007=   47.468   T     1051=   85.947   T     1052=   12.726   T     1053=   13.183
      T     1054=  -5.4441   T     1055=  -6.0125   T     1056=   40.387   T     1084=   37.141   T     1085=   33.039   T     1086=   29.271
      T     1087=   25.766   T     1088=   22.338   T     1089=   20.183   T     1090=   17.290   T     1091=   27.311   T     1092=   27.465
      T     1100=   5.8193   T     1101=   7.1169   T     1102=   5.8950   T     1103=   7.5933   T     1104=   9.1792   T     1105=   11.154
      T     1106=   13.793   T     1107=   15.345   T     1150=   4.4921   T     1151=   4.8653   T     1152=   2.0750   T     1153=   2.7933
      T     1154=   3.3331   T     1155=   4.3069   T     1156=   6.0663   T     1157=   6.6554   T     1200=   8.9338   T     1201=   8.4056
      T     1202=   4.4897   T     1203=   4.2707   T     1204=   3.8521   T     1205=   3.8816   T     1206=   4.7377   T     1207=   4.3989
```

```
         SOFT TUBE INFLATABLE RADIATOR

  T  1250=    19.394     T  1251=    17.935     T  1252=    13.279     T  1253=    12.111     T  1254=      .766     T  1255=    9.8532
  T  1256=    9.7292     T  1257=    8.4422     T  1300=    36.488     T  1301=    34.012     T  1302=    28.970     T  1303=    26.783
  T  1304=    24.488     T  1305=    22.577     T  1306=    21.338     T  1307=    19.024     T  1350=    45.064     T  1351=    41.616
  T  1352=    35.506     T  1353=    32.302     T  1354=    28.974     T  1355=    26.021     T  1356=    23.730     T  1357=    20.364
  T  1400=    33.923     T  1401=    30.809     T  1402=    24.354     T  1403=    21.456     T  1404=    18.357     T  1405=    15.678
  T  1406=    13.772     T  1407=    10.706     T  1450=    30.340     T  1451=    27.356     T  1452=    20.810     T  1453=    18.029
  T  1454=    15.022     T  1455=    12.447     T  1456=    10.680     T  1457=    7.7215     T  1500=    34.080     T  1501=    31.032
  T  1502=    24.642     T  1503=    21.802     T  1504=    18.757     T  1505=    16.127     T  1506=    14.262     T  1507=    11.233
  T  1550=    45.388     T  1551=    42.077     T  1552=    36.101     T  1553=    33.018     T  1554=    29.800     T  1555=    26.946
  T  1556=    24.739     T  1557=    21.451     T  1650=   -110.91     T  1651=   -110.77     T  1652=   -112.03     T  1653=   -111.86
  T  1654=   -111.76     T  1655=   -111.52     T  1656=   -110.84     T  1657=   -110.65     T  1700=   -94.600     T  1701=   -94.268
  T  1702=   -96.904     T  1703=   -96.501     T  1704=   -96.291     T  1705=   -95.784     T  1706=   -94.384     T  1707=   -93.963
  T  1750=   -110.91     T  1751=   -110.77     T  1752=   -112.03     T  1753=   -111.86     T  1754=   -111.76     T  1755=   -111.52
  T  1756=   -110.84     T  1757=   -110.65     T  1800=   -94.600     T  1801=   -94.268     T  1802=   -96.903     T  1803=   -96.501
  T  1804=   -96.291     T  1805=   -95.784     T  1806=   -94.384     T  1807=   -93.968     T  1850=   -89.631     T  1851=   -88.913
  T  1852=   -94.112     T  1853=   -93.269     T  1854=   -92.853     T  1855=   -91.863     T  1856=   -89.150     T  1857=   -88.320
  T  1900=   -88.943     T  1901=   -88.168     T  1902=   -93.735     T  1903=   -92.817     T  1904=   -92.382     T  1905=   -91.324
  T  1906=   -88.424     T  1907=   -87.536     T  1950=   -86.301     T  1951=   -85.444     T  1952=   -91.144     T  1953=   -90.131
  T  1954=   -89.621     T  1955=   -88.464     T  1956=   -85.411     T  1957=   -84.438     T  1998=    91.732     T  1999=    93.760
  T  2000=    76.836     T  2001=    72.730     T  2002=    67.895     T  2003=    64.077     T  2004=    60.333     T  2005=    56.811
  T  2006=    53.614     T  2007=    49.563     T  2083=    46.372     T  2084=    44.054     T  2085=    41.007     T  2086=    38.168
  T  2087=    35.455     T  2088=    32.781     T  2089=    31.194     T  2090=    28.933     T  2091=    37.203     T  2092=    37.252
  T  2100=    38.619     T  2101=    36.228     T  2102=    31.254     T  2103=    29.114     T  2104=    26.845     T  2105=    24.925
  T  2106=    23.639     T  2107=    21.290     T  2150=    22.607     T  2151=    21.126     T  2152=    16.427     T  2153=    15.191
  T  2154=    13.754     T  2155=    12.706     T  2156=    12.401     T  2157=    10.960     T  2200=    13.426     T  2201=    12.764
  T  2202=    8.6966     T  2203=    8.2881     T  2204=    7.6544     T  2205=    7.4140     T  2206=    7.9425     T  2207=    7.3220
  T  2250=    10.523     T  2251=    10.643     T  2252=    7.5899     T  2253=    7.9857     T  2254=    8.1750     T  2255=    8.7277
  T  2256=    9.9942     T  2257=    10.156     T  2300=    13.730     T  2301=    14.639     T  2302=    13.041     T  2303=    14.266
  T  2304=    15.347     T  2305=    16.726     T  2306=    18.679     T  2307=    19.633     T  2350=    6.5784     T  2351=    8.4463
  T  2352=    7.8778     T  2353=    10.069     T  2354=    12.111     T  2355=    14.427     T  2356=    17.299     T  2357=    19.180
  T  2400=   -1.5083     T  2401=    .22108     T  2402=   -1.1121     T  2403=    .90807     T  2404=    2.7147     T  2405=    4.8474
  T  2406=    7.6624     T  2407=    9.3908     T  2450=   -4.1501     T  2451=   -2.4656     T  2452=   -4.0459     T  2453=   -2.0816
  T  2454=   -.35090     T  2455=    1.7222     T  2456=    4.5194     T  2457=    6.1982     T  2500=   -1.4869     T  2501=    .24257
  T  2502=   -1.0896     T  2503=   -.93011     T  2504=   -2.7371     T  2505=    4.8689     T  2506=   -7.6838     T  2507=    9.4116
  T  2550=    6.6216     T  2551=    8.4901     T  2552=    7.9227     T  2553=    10.113     T  2554=    12.156     T  2555=    14.471
  T  2556=    17.343     T  2557=    19.223     T  2700=   -81.627     T  2701=   -80.662     T  2702=   -86.262     T  2703=   -85.122
  T  2704=   -84.486     T  2705=   -83.195     T  2706=   -80.018     T  2707=   -78.931     T  2750=   -74.782     T  2751=   -73.676
  T  2752=   -78.941     T  2753=   -77.637     T  2754=   -76.819     T  2755=   -75.355     T  2756=   -72.073     T  2757=   -70.837
  T  2800=   -65.553     T  2801=   -64.269     T  2802=   -68.951     T  2803=   -67.438     T  2804=   -66.374     T  2805=   -64.688
  T  2806=   -61.313     T  2807=   -59.886     T  2850=   -53.639     T  2851=   -52.131     T  2852=   -55.956     T  2853=   -54.180
  T  2854=   -52.792     T  2855=   -50.824     T  2856=   -47.353     T  2857=   -45.683     T  2900=   -38.617     T  2901=   -36.825
  T  2902=   -39.480     T  2903=   -37.370     T  2904=   -35.561     T  2905=   -33.234     T  2906=   -29.650     T  2907=   -27.667
  T  2950=   -19.898     T  2951=   -17.746     T  2952=   -18.851     T  2953=   -16.313     T  2954=   -13.958     T  2955=   -11.167
  T  2956=   -7.4293     T  2957=   -5.0406     T  2998=    91.733     T  2999=    93.761     T  3000=    76.858     T  3001=    72.766
  T  3002=    67.947     T  3003=    64.145     T  3004=    60.417     T  3005=    56.911     T  3006=    53.731     T  3007=    49.696
  T  3083=    46.457     T  3084=    44.140     T  3085=    41.092     T  3086=    38.256     T  3087=    35.542     T  3088=    32.866
```

```
SOFT TUBE INFLATABLE RADIATOR
   T  3089=   31.277     T  3090=   29.016     T  3091=   37.296     T  3092=   37.344     T  3100=   17.789     T  3101=   14.701
   T  3102=   13.105     T  3103=   14.333     T  3104=   15.419     T  3105=   16.797     T  3106=   18.753     T  3107=   19.709
   T  3150=   10.570     T  3151=   10.694     T  3152=   7.6457     T  3153=   8.2455     T  3154=   6.2393     T  3155=   8.7945
   T  3156=   10.066     T  3157=   10.231     T  3200=   13.464     T  3201=   12.808     T  3202=   6.7459     T  3203=   8.3435
   T  3204=   7.7161     T  3205=   7.4806     T  3206=   8.0153     T  3207=   7.4029     T  3250=   22.638     T  3251=   21.165
   T  3252=   16.473     T  3253=   15.245     T  3254=   13.817     T  3255=   12.776     T  3256=   12.479     T  3257=   11.047
   T  3300=   38.645     T  3301=   36.264     T  3302=   31.307     T  3303=   29.171     T  3304=   26.913     T  3305=   25.003
   T  3306=   23.729     T  3307=   21.390     T  3350=   45.495     T  3351=   42.233     T  3352=   36.304     T  3353=   33.268
   T  3354=   30.095     T  3355=   27.283     T  3356=   25.114     T  3357=   21.863     T  3400=   34.246     T  3401=   31.274
   T  3402=   24.954     T  3403=   22.184     T  3404=   19.204     T  3405=   16.634     T  3406=   14.823     T  3407=   11.845
   T  3450=   30.577     T  3451=   27.697     T  3452=   21.251     T  3453=   18.567     T  3454=   15.649     T  3455=   13.157
   T  3456=   11.462     T  3457=   8.5722     T  3500=   34.246     T  3501=   31.273     T  3502=   24.954     T  3503=   22.184
   T  3504=   19.204     T  3505=   16.634     T  3506=   14.823     T  3507=   11.845     T  3550=   45.495     T  3551=   42.233
   T  3552=   36.304     T  3553=   33.268     T  3554=   30.095     T  3555=   27.283     T  3556=   25.115     T  3557=   21.863
   T  3998=   91.733     T  3999=   93.761     T  4000=   76.859     T  4001=   72.767     T  4002=   67.947     T  4003=   64.145
   T  4004=   60.418     T  4005=   56.912     T  4006=   53.732     T  4007=   49.697     T  4083=   46.461     T  4084=   44.144
   T  4085=   41.097     T  4086=   38.261     T  4087=   35.548     T  4088=   32.873     T  4089=   31.285     T  4090=   29.024
   T  4091=   37.303     T  4092=   37.350     T  4100=   38.647     T  4101=   36.266     T  4102=   31.302     T  4103=   29.173
   T  4104=   26.915     T  4105=   25.035     T  4106=   23.730     T  4107=   21.392     T  4150=   22.643     T  4151=   21.167
   T  4152=   16.475     T  4153=   15.247     T  4154=   13.819     T  4155=   12.778     T  4156=   12.481     T  4157=   11.049
   T  4200=   13.467     T  4201=   12.811     T  4202=   8.7487     T  4203=   8.3461     T  4204=   7.7186     T  4205=   7.4829
   T  4206=   8.0174     T  4207=   7.4027     T  4250=   10.574     T  4251=   10.698     T  4252=   7.6487     T  4253=   8.0487
   T  4254=   8.2423     T  4255=   8.7972     T  4256=   10.068     T  4257=   10.233     T  4300=   13.794     T  4301=   14.706
   T  4302=   13.110     T  4303=   14.337     T  4304=   15.421     T  4305=   16.800     T  4306=   18.756     T  4307=   19.711
   T  4350=   6.6414     T  4351=   8.5091     T  4352=   7.9410     T  4353=   8.131      T  4354=   12.174     T  4355=   14.487
   T  4356=   17.359     T  4357=  -19.239     T  4400=  -1.4587     T  4401=   .26983     T  4402=  -1.0632     T  4403=   .95665
   T  4404=   2.7634     T  4405=   4.8937     T  4406=   7.7084     T  4407=   9.4348     T  4450=  -4.1122     T  4451=  -2.4287
   T  4452=  -4.0100     T  4453=  -2.0452     T  4454=  -.31472     T  4455=   1.7565     T  4456=   4.5535     T  4457=   6.2305
   T  4500=  -1.4587     T  4501=   .76977     T  4502=  -1.0632     T  4503=   .95661     T  4504=   2.7633     T  4505=   4.8937
   T  4506=   7.7082     T  4507=   9.4346     T  4550=  -6.6415     T  4551=   8.5091     T  4552=   7.9410     T  4553=  -10.131
   T  4554=   12.174     T  4555=   14.487     T  4556=   17.359     T  4557=    9.238     T  4998=   91.733     T  4999=   93.761
   T  5000=   76.859     T  5001=   72.767     T  5002=   67.947     T  5003=   64.146     T  5004=   60.418     T  5005=   56.912
   T  5006=   53.733     T  5007=   49.698     T  5083=   46.461     T  5084=   44.144     T  5085=   41.097     T  5086=   38.262
   T  5087=   35.548     T  5088=   32.873     T  5089=   31.285     T  5090=   29.024     T  5091=   37.304     T  5092=   37.352
   T  5100=   13.796     T  5101=   14.707     T  5102=   13.110     T  5103=   14.338     T  5104=   15.422     T  5105=   16.801
   T  5106=   18.757     T  5107=   19.711     T  5150=   10.577     T  5151=   10.699     T  5152=   7.6491     T  5153=   8.0494
   T  5154=   8.2429     T  5155=   8.7977     T  5156=   10.069     T  5157=   10.233     T  5200=   13.471     T  5201=   12.812
   T  5202=   8.7490     T  5203=   8.3469     T  5204=   7.7192     T  5205=   7.4834     T  5206=   8.0180     T  5207=   7.4016
   T  5250=   22.643     T  5251=   21.166     T  5252=   16.474     T  5253=   15.246     T  5254=   13.818     T  5255=   12.777
   T  5256=   12.480     T  5257=   11.048     T  5300=   38.649     T  5301=   36.265     T  5302=   31.301     T  5303=   29.172
   T  5304=   26.914     T  5305=   25.004     T  5306=   23.730     T  5307=   21.391     T  5350=   45.495     T  5351=   42.234
   T  5352=   36.304     T  5353=   33.269     T  5354=   30.096     T  5355=   27.284     T  5356=   25.116     T  5357=   21.865
   T  9001=  -310.00     T  9002=  -94.145     T  9003=   69.999     T  9004=  -24.069

   W         1= 4.0706   W         2= 4.3544   W         3= 4.3582   W         4= 4.3584   W         5= 4.3584
   W         6= 21.500   W         7= 21.500

   DP        1= 5.3274   DP        2= 5.3274   DP        3= 5.3274   DP        4= 5.3274   DP        5= 5.3274
```

APPENDIX F

COMPUTER PROGRAM LISTING

HARD TUBE FULL SCALE RADIATOR

TEST POINT 1 CONDITIONS

```
BCD 3THERMAL LPCS
BCD 5HARD TUBE INFLATABLE RADIATOR
END
BCD 3NODE DATA
    -10000,-310.,1.          $ENVIRONMENT NODE
GEN -90,5,1,70.,1.           $SURFACE NODES
    80,70.,.01          $END NODES
    -81,-20.,.01          $END NODES
GEN -1150,12,1,70.,1.          $SYMMETRICAL NODES
GEN -6100,12,1,70.,1.          $SYMMETRICAL NODES
GEN -2,2,1,70.,1.        $FLUID NODE
    -1,95.,1.     $FLUID NODE
    -70,70.,1.     $FLUID NODE
    -71,70.,1.     $TUBE NODE
GEN -10,6,10,70.,1.      $FLUID NODE
GEN -15,6,10,70.,1.      $FLUID NODE
GEN -100,12,1,70.,1.     $FLUID NODE
GEN -200,12,1,70.,1.     $FLUID NODE
GEN -300,12,1,70.,1.     $FLUID NODE
GEN -400,12,1,70.,1.     $FLUID NODE
GEN -500,12,1,70.,1.     $FLUID NODE
GEN -600,12,1,70.,1.     $FLUID NODE
GEN 5,2,1,70.,.0190      $TUBE NODE
    4,95.,.019  $TUBE NODE
GEN 11,6,10,70.,.0025    $TUBE NODE
GEN 16,6,10,70.,.0025    $TUBE NODE
GEN 12,6,10,70.,.0544    $STRUCTURE NODE
GEN 17,6,10,70.,.0224    $STRUCTURE NODE
SIM 1000,12,1,70.,A2,K3 $TUBE NODE
SIM 2000,12,1,70.,A2,K3 $TUBE NODE
SIM 3000,12,1,70.,A2,K3 $TUBE NODE
SIM 4000,12,1,70.,A2,K3 $TUBE NODE
SIM 5000,12,1,70.,A2,K3 $TUBE NODE
SIM 6000,12,1,70.,A2,K4 $TUBE NODE
SIM 1100,12,1,70.,A3,K5 $FIN NODE
SIM 1200,12,1,70.,A3,K5 $FIN NODE
SIM 1300,12,1,70.,A3,K5 $FIN NODE
SIM 1400,12,1,70.,A3,K5 $FIN NODE
SIM 1500,12,1,70.,A3,K5 $FIN NODE
SIM 2100,12,1,70.,A3,K5 $FIN NODE
SIM 2200,12,1,70.,A3,K5 $FIN NODE
SIM 2300,12,1,70.,A3,K5 $FIN NODE
SIM 2400,12,1,70.,A3,K5 $FIN NODE
SIM 2500,12,1,70.,A3,K5 $FIN NODE
SIM 3100,12,1,70.,A3,K5 $FIN NODE
SIM 3200,12,1,70.,A3,K5 $FIN NODE
SIM 3300,12,1,70.,A3,K5 $FIN NODE
SIM 3400,12,1,70.,A3,K5 $FIN NODE
SIM 3500,12,1,70.,A3,K5 $FIN NODE
SIM 4100,12,1,70.,A3,K5 $FIN NODE
SIM 4200,12,1,70.,A3,K5 $FIN NODE
SIM 4300,12,1,70.,A3,K5 $FIN NODE
SIM 4400,12,1,70.,A3,K5 $FIN NODE
SIM 4500,12,1,70.,A3,K5 $FIN NODE
```

```
    SINDA/SINFLO PREPROCESSOR                                                                  DATE 103975        PAGE     4
            SIM 5100,12,1,70.,A3,K5 $FIN NODE
            SIM 5200,12,1,70.,A3,K5 $FIN NODE
            SIM 5300,12,1,70.,A3,K5 $FIN NODE
            SIM 5400,12,1,70.,A3,K5 $FIN NODE
            SIM 5500,12,1,70.,A3,K5 $FIN NODE
            END
            RELATIVE NODE NUMBERS                          ACTUAL NODE NUMBERS
              1  THRU    10              80      5      6      4     11     21     31     41     51     61
             11  THRU    20              16     26     36     46     56     66     12     22     32     42
             21  THRU    30              52     62     17     27     37     47     57     67   1000   1001
             31  THRU    40            1002   1003   1004   1005   1006   1007   1008   1009   1010   1011
             41  THRU    50            2000   2001   2002   2003   2004   2005   2006   2007   2008   2009
             51  THRU    60            2010   2011   3000   3001   3002   3003   3004   3005   3006   3007
             61  THRU    70            3008   3009   3010   3011   4000   4001   4002   4003   4004   4005
             71  THRU    80            4006   4007   4008   4009   4010   4011   5000   5001   5002   5003
             81  THRU    90            5004   5005   5006   5007   5008   5009   5010   5011   6000   6001
             91  THRU   100            6002   6003   6004   6005   6006   6007   6008   6009   6010   6011
            101  THRU   110            1100   1101   1102   1103   1104   1105   1106   1107   1108   1109
            111  THRU   120            1110   1111   1200   1201   1202   1203   1204   1205   1206   1207
            121  THRU   130            1208   1209   1210   1211   1300   1301   1302   1303   1304   1305
            131  THRU   140            1306   1307   1308   1309   1310   1311   1400   1401   1402   1403
            141  THRU   150            1404   1405   1406   1407   1408   1409   1410   1411   1500   1501
            151  THRU   160            1502   1503   1504   1505   1506   1507   1508   1509   1510   1511
            161  THRU   170            2100   2101   2102   2103   2104   2105   2106   2107   2108   2109
            171  THRU   180            2110   2111   2200   2201   2202   2203   2204   2205   2206   2207
            181  THRU   190            2208   2209   2210   2211   2300   2301   2302   2303   2304   2305
            191  THRU   200            2306   2307   2308   2309   2310   2311   2400   2401   2402   2403
            201  THRU   210            2404   2405   2406   2407   2408   2409   2410   2411   2500   2501
            211  THRU   220            2502   2503   2504   2505   2506   2507   2508   2509   2510   2511
            221  THRU   230            3100   3101   3102   3103   3104   3105   3106   3107   3108   3109
            231  THRU   240            3110   3111   3200   3201   3202   3203   3204   3205   3206   3207
            241  THRU   250            3208   3209   3210   3211   3300   3301   3302   3303   3304   3305
            251  THRU   260            3306   3307   3308   3309   3310   3311   3400   3401   3402   3403
            261  THRU   270            3404   3405   3406   3407   3408   3409   3410   3411   3500   3501
            271  THRU   280            3502   3503   3504   3505   3506   3507   3508   3509   3510   3511
            281  THRU   290            4100   4101   4102   4103   4104   4105   4106   4107   4108   4109
            291  THRU   300            4110   4111   4200   4201   4202   4203   4204   4205   4206   4207
            301  THRU   310            4208   4209   4210   4211   4300   4301   4302   4303   4304   4305
            311  THRU   320            4306   4307   4308   4309   4310   4311   4400   4401   4402   4403
            321  THRU   330            4404   4405   4406   4407   4408   4409   4410   4411   4500   4501
            331  THRU   340            4502   4503   4504   4505   4506   4507   4508   4509   4510   4511
            341  THRU   350            5100   5101   5102   5103   5104   5105   5106   5107   5108   5109
            351  THRU   360            5110   5111   5200   5201   5202   5203   5204   5205   5206   5207
            361  THRU   370            5208   5209   5210   5211   5300   5301   5302   5303   5304   5305
            371  THRU   380            5306   5307   5308   5309   5310   5311   5400   5401   5402   5403
            381  THRU   390            5404   5405   5406   5407   5408   5409   5410   5411   5500   5501
            391  THRU   400            5502   5503   5504   5505   5506   5507   5508   5509   5510   5511
            401  THRU   410           10000     90     91     92     93     94     81   1150   1151   1152
            411  THRU   420            1153   1154   1155   1156   1157   1158   1159   1160   1161   6100
            421  THRU   430            6101   6102   6103   6104   6105   6106   6107   6108   6109   6110
            431  THRU   440            6111      2      3      1     70     71     10     20     30     40
            441  THRU   450              50     60     15     25     35     45     55     65    100    101
            451  THRU   460             102    103    104    105    106    107    108    109    110    111
            461  THRU   470             200    201    202    203    204    205    206    207    208    209
            471  THRU   480             210    211    300    301    302    303    304    305    306    307
```

I

```
 SINDA/SINFLO PREPROCESSOR                                                                          DATE 130975        PAGE      5
             481   THRU    490                 308       309       310       311       400       401       402       403       404       405
             491   THRU    500                 406       407       408       409       410       411       500       501       502       503
             501   THRU    510                 504       505       506       507       508       509       510       511       600       601
             511   THRU    520                 602       603       604       605       606       607       608       609       610       611
           NODE ANALYSIS...   DIFFUSION =    400,  ARITHMETIC =     0,  BOUNDARY =   120,  TOTAL =    520

           BCD  CONDUCTOR DATA
           GEN 11,6,10,11,10,12,10,.307        $COND STRUCTURE
           GEN 16,6,10,16,10,17,10,.307        $COND STRUCTURE
           GEN 12,5,10,12,10,22,10,.940        $COND STRUCTURE
           GEN 17,5,10,17,10,27,10,.235        $COND STRUCTURE
           GEN   0,12,1,1150,1,1000,1,13.66      $SYMMETRICAL G
           GEN 6050,12,1,6100,1,6000,1,13.66       $SYMMETRICAL C
           GEN 1000,11,1,1000,1,1001,1,.0010 $AXIAL COND
           GEN 1100,11,1,1100,1,1101,1,.00001 $AXIAL COND
           GEN 1200,11,1,1200,1,1201,1,.00001 $AXIAL COND
           GEN 1300,11,1,1300,1,1301,1,.00001 $AXIAL COND
           GEN 1400,11,1,1400,1,1401,1,.00001 $AXIAL COND
           GEN 1500,11,1,1500,1,1501,1,.00001 $AXIAL COND
           GEN 2000,11,1,2000,1,2001,1,.0010 $AXIAL COND
           GEN 2100,11,1,2100,1,2101,1,.00001 $AXIAL COND
           GEN 2200,11,1,2200,1,2201,1,.00001 $AXIAL COND
           GEN 2300,11,1,2300,1,2301,1,.00001 $AXIAL COND
           GEN 2400,11,1,2400,1,2401,1,.00001 $AXIAL COND
           GEN 2500,11,1,2500,1,2501,1,.00001 $AXIAL COND
           GEN 3000,11,1,3000,1,3001,1,.0010 $AXIAL COND
           GEN 3100,11,1,3100,1,3101,1,.00001 $AXIAL COND
           GEN 3200,11,1,3200,1,3201,1,.00001 $AXIAL COND
           GEN 3300,11,1,3300,1,3301,1,.00001 $AXIAL COND
           GEN 3400,11,1,3400,1,3401,1,.00001 $AXIAL COND
           GEN 3500,11,1,3500,1,3501,1,.00001 $AXIAL COND
           GEN 4000,11,1,4000,1,4001,1,.0010 $AXIAL COND
           GEN 4100,11,1,4100,1,4101,1,.00001 $AXIAL COND
           GEN 4200,11,1,4200,1,4201,1,.00001 $AXIAL COND
           GEN 4300,11,1,4300,1,4301,1,.00001 $AXIAL COND
           GEN 4400,11,1,4400,1,4401,1,.00001 $AXIAL COND
           GEN 4500,11,1,4500,1,4501,1,.00001 $AXIAL COND
           GEN 5000,11,1,5000,1,5001,1,.0010 $AXIAL COND
           GEN 5100,11,1,5100,1,5101,1,.00001 $AXIAL COND
           GEN 5200,11,1,5200,1,5201,1,.00001 $AXIAL COND
           GEN 5300,11,1,5300,1,5301,1,.00001 $AXIAL COND
           GEN 5400,11,1,5400,1,5401,1,.00001 $AXIAL COND
           GEN 5500,11,1,5500,1,5501,1,.00001 $AXIAL COND
           GEN 6000,11,1,6000,1,6001,1,.00271 $AXIAL COND
           GEN 10  0,12,1,1000,1,1100,1,13.66   $RADIAL COND
           GEN 1   0,12,1,1500,1,2000,1,13.66   $RADIAL COND
           GEN     0,12,1,2000,1,2100,1,13.66   $RADIAL COND
           GEN     0,12,1,2500,1,3000,1,13.66   $RADIAL COND
           GEN     0,12,1,3000,1,3100,1,13.66   $RADIAL COND
           GEN     0,12,1,3500,1,4000,1,13.66   $RADIAL COND
           GEN 40  0,12,1,4000,1,4100,1,13.66   $RADIAL COND
           GEN     0,12,1,4500,1,5000,1,13.66   $RADIAL COND
           GEN     0,12,1,5000,1,5100,1,13.66   $RADIAL COND
           GEN     0,12,1,5500,1,6000,1,13.66   $RADIAL COND
           GEN  1  0,12,1,1100,1,1200,1,2.564   $RADIAL COND
           GEN  1  0,12,1,1200,1,1300,1,2.564   $RADIAL COND
           GEN  1  0,12,1,1300,1,1400,1,2.564   $RADIAL COND
```

```
GEN 1450,12,1,1400,1,1500,1,2.564   $RADIAL COND
GEN  150,12,1,2100,1,2200,1,2.564   $RADIAL COND
GEN  250,12,1,2200,1,2300,1,2.564   $RADIAL COND
GEN  350,12,1,2300,1,2400,1,2.564   $RADIAL COND
GEN  450,12,1,2400,1,2500,1,2.564   $RADIAL COND
GEN  150,12,1,3100,1,3200,1,2.564   $RADIAL COND
GEN  250,12,1,3200,1,3300,1,2.564   $RADIAL COND
GEN 3350,12,1,3300,1,3400,1,2.564   $RADIAL COND
GEN  450,12,1,3400,1,3500,1,2.564   $RADIAL COND
GEN 4150,12,1,4100,1,4200,1,2.564   $RADIAL COND
GEN 4250,12,1,4200,1,4300,1,2.564   $RADIAL COND
GEN 4350,12,1,4300,1,4400,1,2.564   $RADIAL COND
GEN 4450,12,1,4400,1,4500,1,2.564   $RADIAL COND
GEN  150,12,1,5100,1,5200,1,2.564   $RADIAL COND
GEN  250,12,1,5200,1,5300,1,2.564   $RADIAL COND
GEN  350,12,1,5300,1,5400,1,2.564   $RADIAL COND
GEN 5450,12,1,5400,1,5500,1,2.564   $RADIAL COND
GEN -11100,12,1,1100,1,10000,0,4.05E-10    $RADIATION G
GEN -11200,12,1,1200,1,10000,0,4.05E-10    $RADIATION G
GEN -11300,12,1,1300,1,10000,0,4.05E-10    $RADIATION G
GEN -11400,12,1,1400,1,10000,0,4.05E-10    $RADIATION G
GEN -11500,12,1,1500,1,10000,0,4.05E-10    $RADIATION G
GEN -12100,12,1,2100,1,10000,0,4.05E-10    $RADIATION G
GEN -12200,12,1,2200,1,10000,0,4.05E-10    $RADIATION G
GEN -12300,12,1,2300,1,10000,0,4.05E-10    $RADIATION G
GEN  12400,12,1,2400,1,10000,0,4.05E-10    $RADIATION G
GEN -12500,12,1,2500,1,10000,0,4.05E-10    $RADIATION G
GEN -13100,12,1,3100,1,10000,0,4.05E-10    $RADIATION G
GEN -13200,12,1,3200,1,10000,0,4.05E-10    $RADIATION G
GEN -13300,12,1,3300,1,10000,0,4.05E-10    $RADIATION G
GEN -13400,12,1,3400,1,10000,0,4.05E-10    $RADIATION G
GEN -13500,12,1,3500,1,10000,0,4.05E-10    $RADIATION G
GEN -14100,12,1,4100,1,10000,0,4.05E-10    $RADIATION G
GEN -14200,12,1,4200,1,10000,0,4.05E-10    $RADIATION G
GEN  14300,12,1,4300,1,10000,0,4.05E-10    $RADIATION G
GEN -14400,12,1,4400,1,10000,0,4.05E-10    $RADIATION G
GEN -14500,12,1,4500,1,10000,0,4.05E-10    $RADIATION G
GEN -15100,12,1,5100,1,10000,0,4.05E-10    $RADIATION G
GEN -15200,12,1,5200,1,10000,0,4.05E-10    $RADIATION G
GEN -15300,12,1,5300,1,10000,0,4.05E-10    $RADIATION G
GEN -15400,12,1,5400,1,10000,0,4.05E-10    $RADIATION G
GEN -15500,12,1,5500,1,10000,0,4.05E-10    $RADIATION G
END

RELATIVE CONDUCTOR NUMBERS                                        ACTUAL CONDUCTOR NUMBERS

   1  THRU   10          11     21     31     41     51     61     16     26     36     46
  11  THRU   20          56     66     12     22     32     42     52     17     27     37
  21  THRU   30          47     57    950    951    952    953    954    955    956    957
  31  THRU   40         958    959    960    961   6050   6051   6052   6053   6054   6055
  41  THRU   50        6056   6057   6058   6059   6060   6061   1000   1001   1002   1003
  51  THRU   60        1004   1005   1006   1007   1008   1009   1010   1100   1101   1102
  61  THRU   70        1103   1104   1105   1106   1107   1108   1109   1110   1200   1201
  71  THRU   80        1202   1203   1204   1205   1206   1207   1208   1209   1210   1300
  81  THRU   90        1301   1302   1303   1304   1305   1306   1307   1308   1309   1310
  91  THRU  100        1400   1401   1402   1403   1404   1405   1406   1407   1408   1409
 101  THRU  110        1410   1500   1501   1502   1503   1504   1505   1506   1507   1508
```

```
  SINDA/SINFLO PREPROCESSOR                                                                          DATE 1 J975        PAGE      7
            111   THRU   120              1509   1510   2000   2001   2002   2003   2004   2005   2006   2007
            121   THRU   130              2008   2009   2010   2100   2101   2102   2103   2104   2105   2106
            131   THRU   140              2107   2108   2109   2110   2200   2201   2202   2203   2204   2205
            141   THRU   150              2206   2207   2208   2209   2210   2300   2301   2302   2303   2304
            151   THRU   160              2305   2306   2307   2308   2309   2310   2400   2401   2402   2403
            161   THRU   170              2404   2405   2406   2407   2408   2409   2410   2500   2501   2502
            171   THRU   180              2503   2504   2505   2506   2507   2508   2509   2510   3000   3001
            181   THRU   190              3002   3003   3004   3005   3006   3007   3008   3009   3010   3100
            191   THRU   200              3101   3102   3103   3104   3105   3106   3107   3108   3109   3110
            201   THRU   210              3200   3201   3202   3203   3204   3205   3206   3207   3208   3209
            211   THRU   220              3210   3300   3301   3302   3303   3304   3305   3306   3307   3308
            221   THRU   230              3309   3310   3400   3401   3402   3403   3404   3405   3406   3407
            231   THRU   240              3408   3409   3410   3500   3501   3502   3503   3504   3505   3506
            241   THRU   250              3507   3508   3509   3510   4000   4001   4002   4003   4004   4005
            251   THRU   260              4006   4007   4008   4009   4010   4100   4101   4102   4103   4104
            261   THRU   270              4105   4106   4107   4108   4109   4110   4200   4201   4202   4203
            271   THRU   280              4204   4205   4206   4207   4208   4209   4210   4300   4301   4302
            281   THRU   290              4303   4304   4305   4306   4307   4308   4309   4310   4400   4401
            291   THRU   300              4402   4403   4404   4405   4406   4407   4408   4409   4410   4500
            301   THRU   310              4501   4502   4503   4504   4505   4506   4507   4508   4509   4510
            311   THRU   320              5000   5001   5002   5003   5004   5005   5006   5007   5008   5009
            321   THRU   330              5010   5100   5101   5102   5103   5104   5105   5106   5107   5108
            331   THRU   340              5109   5110   5200   5201   5202   5203   5204   5205   5206   5207
            341   THRU   350              5208   5209   5210   5300   5301   5302   5303   5304   5305   5306
            351   THRU   360              5307   5308   5309   5310   5400   5401   5402   5403   5404   5405
            361   THRU   370              5406   5407   5408   5409   5410   5500   5501   5502   5503   5504
            371   THRU   380              5505   5506   5507   5508   5509   5510   6000   6001   6002   6003
            381   THRU   390              6004   6005   6006   6007   6008   6009   6010   1050   1051   1052
            391   THRU   400              1053   1054   1055   1056   1057   1058   1059   1060   1061   1550
            401   THRU   410              1551   1552   1553   1554   1555   1556   1557   1558   1559   1560
            411   THRU   420              1561   2050   2051   2052   2053   2054   2055   2056   2057   2058
            421   THRU   430              2059   2060   2061   2550   2551   2552   2553   2554   2555   2556
            431   THRU   440              2557   2558   2559   2560   2561   3050   3051   3052   3053   3054
            441   THRU   450              3055   3056   3057   3058   3059   3060   3061   3550   3551   3552
            451   THRU   460              3553   3554   3555   3556   3557   3558   3559   3560   3561   4050
            461   THRU   470              4051   4052   4053   4054   4055   4056   4057   4058   4059   4060
            471   THRU   480              4061   4550   4551   4552   4553   4554   4555   4556   4557   4558
            481   THRU   490              4559   4560   4561   5050   5051   5052   5053   5054   5055   5056
            491   THRU   500              5057   5058   5059   5060   5061   5550   5551   5552   5553   5554
            501   THRU   510              5555   5556   5557   5558   5559   5560   5561   1150   1151   1152
            511   THRU   520              1153   1154   1155   1156   1157   1158   1159   1160   1161   1250
            521   THRU   530              1251   1252   1253   1254   1255   1256   1257   1258   1259   1260
            531   THRU   540              1261   1350   1351   1352   1353   1354   1355   1356   1357   1358
            541   THRU   550              1359   1360   1361   1450   1451   1452   1453   1454   1455   1456
            551   THRU   560              1457   1458   1459   1460   1461   2150   2151   2152   2153   2154
            561   THRU   570              2155   2156   2157   2158   2159   2160   2161   2250   2251   2252
            571   THRU   580              2253   2254   2255   2256   2257   2258   2259   2260   2261   2350
            581   THRU   590              2351   2352   2353   2354   2355   2356   2357   2358   2359   2360
            591   THRU   600              2361   2450   2451   2452   2453   2454   2455   2456   2457   2458
            601   THRU   610              2459   2460   2461   3150   3151   3152   3153   3154   3155   3156
            611   THRU   620              3157   3158   3159   3160   3161   3250   3251   3252   3253   3254
            621   THRU   630              3255   3256   3257   3258   3259   3260   3261   3350   3351   3352
            631   THRU   640              3353   3354   3355   3356   3357   3358   3359   3360   3361   3450
            641   THRU   650              3451   3452   3453   3454   3455   3456   3457   3458   3459   3460
            651   THRU   660              3461   4150   4151   4152   4153   4154   4155   4156   4157   4158
            661   THRU   670              4159   4160   4161   4250   4251   4252   4253   4254   4255   4256
            671   THRU   680              4257   4258   4259   4260   4261   4350   4351   4352   4353   4354
```

```
SINDA/SINFLO PREPROCESSOR                                                                                   DATE 100975        PAGE     8
                   681  THRU   690          4355    4356    4357    4358    4359    4360    4361    4450    4451    4452
                   691  THRU   700          4453    4454    4455    4456    4457    4458    4459    4460    4461    5150
                   701  THRU   710          5151    5152    5153    5154    5155    5156    5157    5158    5159    5160
                   711  THRU   720          5161    5250    5251    5252    5253    5254    5255    5256    5257    5258
                   721  THRU   730          5259    5260    5261    5350    5351    5352    5353    5354    5355    5356
                   731  THRU   740          5357    5358    5359    5360    5361    5450    5451    5452    5453    5454
                   741  THRU   750          5455    5456    5457    5458    5459    5460    5461   11100   11101   11102
                   751  THRU   760         11103   11104   11105   11106   11107   11108   11109   11110   11111   11200
                   761  THRU   770         11201   11202   11203   11204   11205   11206   11207   11208   11209   11210
                   771  THRU   780         11211   11300   11301   11302   11303   11304   11305   11306   11307   11308
                   781  THRU   790         11309   11310   11311   11400   11401   11402   11403   11404   11405   11406
                   791  THRU   800         11407   11408   11409   11410   11411   11500   11501   11502   11503   11504
                   801  THRU   810         11505   11506   11507   11508   11509   11510   11511   12100   12101   12102
                   811  THRU   820         12103   12104   12105   12106   12107   12108   12109   12110   12111   12200
                   821  THRU   830         12201   12202   12203   12204   12205   12206   12207   12208   12209   12210
                   831  THRU   840         12211   12300   12301   12302   12303   12304   12305   12306   12307   12308
                   841  THRU   850         12309   12310   12311   12400   12401   12402   12403   12404   12405   12406
                   851  THRU   860         12407   12408   12409   12410   12411   12500   12501   12502   12503   12504
                   861  THRU   870         12505   12506   12507   12508   12509   12510   12511   13100   13101   13102
                   871  THRU   880         13103   13104   13105   13106   13107   13108   13109   13110   13111   13200
                   881  THRU   890         13201   13202   13203   13204   13205   13206   13207   13208   13209   13210
                   891  THRU   900         13211   13300   13301   13302   13303   13304   13305   13306   13307   13308
                   901  THRU   910         13309   13310   13311   13400   13401   13402   13403   13404   13405   13406
                   911  THRU   920         13407   13408   13409   13410   13411   13500   13501   13502   13503   13504
                   921  THRU   930         13505   13506   13507   13508   13509   13510   13511   14100   14101   14102
                   931  THRU   940         14103   14104   14105   14106   14107   14108   14109   14110   14111   14200
                   941  THRU   950         14201   14202   14203   14204   14205   14206   14207   14208   14209   14210
                   951  THRU   960         14211   14300   14301   14302   14303   14304   14305   14306   14307   14308
                   961  THRU   970         14309   14310   14311   14400   14401   14402   14403   14404   14405   14406
                   971  THRU   980         14407   14408   14409   14410   14411   14500   14501   14502   14503   14504
                   981  THRU   990         14505   14506   14507   14508   14509   14510   14511   15100   15101   15102
                   991  THRU  1000         15103   15104   15105   15106   15107   15108   15109   15110   15111   15200
                  1001  THRU  1010         15201   15202   15203   15204   15205   15206   15207   15208   15209   15210
                  1011  THRU  1020         15211   15300   15301   15302   15303   15304   15305   15306   15307   15308
                  1021  THRU  1030         15309   15310   15311   15400   15401   15402   15403   15404   15405   15406
                  1031  THRU  1040         15407   15408   15409   15410   15411   15500   15501   15502   15503   15504
                  1041  THRU  1047         15505   15506   15507   15508   15509   15510   15511
            CONDUCTOR ANALYSIS...   LINEAR =    747,   RADIATION =    300,   TOTAL =   1047,   CONNECTIONS =  1047

            BCD 3FLOW DATA
            BCD 3NETWORK MAIN
                GC=6.0042E10,CP=A4,RO=A5,MU=A6,KT=A7,NPASS=1,H=A8
                TOL=.01,MXPASS=100,FRDX=.7,P(4)=0.,END
                1,2,3=10,11,(100,1000,111,1011),15,16,END
                2,2,3=20,21,(200,2000,211,2011),25,26,END
                3,2,3=30,31,(300,3000,311,3011),35,36,END
                4,2,3=40,41,(400,4000,411,4011),45,46,END
                5,2,3=50,51,(500,5000,511,5011),55,56,END
                6,3,4=2,5,65,66,( 611,6011,600,6000,-1,-1),60,61,3,6,END
                7,1,2=1,-4,END
                8,5,3=70,-71,END
            END
            BCD 3FLUID LUMP DATA
                .001,.113,1.5,.340,0.,0,1.,1.,1.=1,2,3,END
                .000419,.0725,10.75,.780,0.,0,1.,1.,1.=(600,611),END
                .000419,.0725,10.75,.780,0.,0,1.,1.,1.=70,END
                .000194,.0492,.50,.0164,0.,0,1.,1.,1.=(10,60,10),(15,65,10),END
```

```
              .0000417,.2469,10.75,.022,0.,0.,1.,1.,1.=(100,111),(200,211)
              (300,311),(400,411),(500,511),END
         END
         BCD 3FLOW SOURCE DATA
              1,A1,END
              5,440.,END
         END
         BCD 3END FLOW DATA
         BCD 3CONSTANTS DATA
              TIMEND,.5    $
              DTIMEI,.005      $
              NLOOP,100     $
              DRLXCA,.01    $
              ARLXCA,.01    $
              OUTPUT,.05     $
               1,10.     $
               3,.001602  $
               4,.00379   $
               5,4.69E-5        $
         END
         CONSTANTS ANALYSIS...  USER =      4,  ADDED =       0         0         0,  TOTAL =     4
         BCD 3ARRAY DATA
              1  $ FLOWRATE VS TIME
              0.,.550.,20.,550.,END
              2  $ PCP AL
              -400.,15.6,-200.,25.8,0.,32.6,200.,36.4
              END
              3  $ PCP FIN
              -400.,34.3,400.,34.3
              END
              4  $ CP FREON 21
              -211.,.223,-160.,.224,-110.,.228,-60.,.231
              0.,.237,40.,.244,90.,.254,120.,.264,140.,.274
              180.,.295,246.,.315
              END
              5  $ P FREON 21
              -218.,110.,-211,110.,-160.,104.,-110.,99.3
              -60.,96.,0.,91.5,40.,88.5,90.,84.2,120.,81.8
              END
              6  $ VISCOSITY FREON 21
              -211.,19.1,-200.,13.7,-188.,10.1,-166.,6.36
              -154.,5.21,-142.,4.32,-130.,3.68,-118.,3.16
              -112.,2.81,-76.,2.02,-49.,1.62,0.,1.17,30.,.994
              60.,.870,100.,.726,160.,.561,260.,.396
              END
              7  $ CONDUCTIVITY FREON 21
              -300.,0.11,0.,.068,250.,.044,END
              8,SPACE,22,END $ ENTHALPY CURVE
              10,*A11,*A12,*A13,*A14,*A15,*A20,END
              11,5,*T90,3.207,1,*T91,51.31,100,*T92,51.31,100,*T93,51.31,100
              *T94,3.207,1,END
              12,.02,.68,.68,.68,1.0,END
              13,.98,.32,.32,.32,0.0,END
              14,*T90,*T91,.984,*T90,*T92,.012,*T90,*T93,.002,*T90,*T94,.002
              *T91,*T92,.061,*T91,*T93,0.0,*T91,*T94,0.0,*T92,*T93,.061
              *T92,*T94,.002,*T93,*T94,.062,END
```

```
15,*T80,3.21,END
16,*T1100,.5131,*T1200,.5131,*T1300,.5131,*T1400,.5131,*T1500,.5131
*T2100,.5131,*T2200,.5131,*T2300,.5131,*T2400,.5131,*T2500,.5131
*T3100,.5131,*T3200,.5131,*T3300,.5131,*T3400,.5131,*T3500,.5131
*T4100,.5131,*T4200,.5131,*T4300,.5131,*T4400,.5131,*T4500,.5131
*T5100,.5131,*T5200,.5131,*T5300,.5131,*T5400,.5131,*T5500,.5131
*T1101,.5131,*T1201,.5131,*T1301,.5131,*T1401,.5131,*T1501,.5131
*T2101,.5131,*T2201,.5131,*T2301,.5131,*T2401,.5131,*T2501,.5131
*T3101,.5131,*T3201,.5131,*T3301,.5131,*T3401,.5131,*T3501,.5131
*T4101,.5131,*T4201,.5131,*T4301,.5131,*T4401,.5131,*T4501,.5131
*T5101,.5131,*T5201,.5131,*T5301,.5131,*T5401,.5131,*T5501,.5131
*T1102,.5131,*T1202,.5131,*T1302,.5131,*T1402,.5131,*T1502,.5131
*T2102,.5131,*T2202,.5131,*T2302,.5131,*T2402,.5131,*T2502,.5131
*T3102,.5131,*T3202,.5131,*T3302,.5131,*T3402,.5131,*T3502,.5131
*T4102,.5131,*T4202,.5131,*T4302,.5131,*T4402,.5131,*T4502,.5131
*T5102,.5131,*T5202,.5131,*T5302,.5131,*T5402,.5131,*T5502,.5131
*T1103,.5131,*T1203,.5131,*T1303,.5131,*T1403,.5131,*T1503,.5131
*T2103,.5131,*T2203,.5131,*T2303,.5131,*T2403,.5131,*T2503,.5131
*T3103,.5131,*T3203,.5131,*T3303,.5131,*T3403,.5131,*T3503,.5131
*T4103,.5131,*T4203,.5131,*T4303,.5131,*T4403,.5131,*T4503,.5131
*T5103,.5131,*T5203,.5131,*T5303,.5131,*T5403,.5131,*T5503,.5131,END
17,*T1104,.5131,*T1204,.5131,*T1304,.5131,*T1404,.5131,*T1504,.5131
*T2104,.5131,*T2204,.5131,*T2304,.5131,*T2404,.5131,*T2504,.5131
*T3104,.5131,*T3204,.5131,*T3304,.5131,*T3404,.5131,*T3504,.5131
*T4104,.5131,*T4204,.5131,*T4304,.5131,*T4404,.5131,*T4504,.5131
*T5104,.5131,*T5204,.5131,*T5304,.5131,*T5404,.5131,*T5504,.5131
*T1105,.5131,*T1205,.5131,*T1305,.5131,*T1405,.5131,*T1505,.5131
*T2105,.5131,*T2205,.5131,*T2305,.5131,*T2405,.5131,*T2505,.5131
*T3105,.5131,*T3205,.5131,*T3305,.5131,*T3405,.5131,*T3505,.5131
*T4105,.5131,*T4205,.5131,*T4305,.5131,*T4405,.5131,*T4505,.5131
*T5105,.5131,*T5205,.5131,*T5305,.5131,*T5405,.5131,*T5505,.5131
*T1106,.5131,*T1206,.5131,*T1306,.5131,*T1406,.5131,*T1506,.5131
*T2106,.5131,*T2206,.5131,*T2306,.5131,*T2406,.5131,*T2506,.5131
*T3106,.5131,*T3206,.5131,*T3306,.5131,*T3406,.5131,*T3506,.5131
*T4106,.5131,*T4206,.5131,*T4306,.5131,*T4406,.5131,*T4506,.5131
*T5106,.5131,*T5206,.5131,*T5306,.5131,*T5406,.5131,*T5506,.5131
*T1107,.5131,*T1207,.5131,*T1307,.5131,*T1407,.5131,*T1507,.5131
*T2107,.5131,*T2207,.5131,*T2307,.5131,*T2407,.5131,*T2507,.5131
*T3107,.5131,*T3207,.5131,*T3307,.5131,*T3407,.5131,*T3507,.5131
*T4107,.5131,*T4207,.5131,*T4307,.5131,*T4407,.5131,*T4507,.5131
*T5107,.5131,*T5207,.5131,*T5307,.5131,*T5407,.5131,*T5507,.5131,END
18,*T1108,.5131,*T1208,.5131,*T1308,.5131,*T1408,.5131,*T1508,.5131
*T2108,.5131,*T2208,.5131,*T2308,.5131,*T2408,.5131,*T2508,.5131
*T3108,.5131,*T3208,.5131,*T3308,.5131,*T3408,.5131,*T3508,.5131
*T4108,.5131,*T4208,.5131,*T4308,.5131,*T4408,.5131,*T4508,.5131
*T5108,.5131,*T5208,.5131,*T5308,.5131,*T5408,.5131,*T5508,.5131
*T1109,.5131,*T1209,.5131,*T1309,.5131,*T1409,.5131,*T1509,.5131
*T2109,.5131,*T2209,.5131,*T2309,.5131,*T2409,.5131,*T2509,.5131
*T3109,.5131,*T3209,.5131,*T3309,.5131,*T3409,.5131,*T3509,.5131
*T4109,.5131,*T4209,.5131,*T4309,.5131,*T4409,.5131,*T4509,.5131
*T5109,.5131,*T5209,.5131,*T5309,.5131,*T5409,.5131,*T5509,.5131
*T1110,.5131,*T1210,.5131,*T1310,.5131,*T1410,.5131,*T1510,.5131
*T2110,.5131,*T2210,.5131,*T2310,.5131,*T2410,.5131,*T2510,.5131
*T3110,.5131,*T3210,.5131,*T3310,.5131,*T3410,.5131,*T3510,.5131
*T4110,.5131,*T4210,.5131,*T4310,.5131,*T4410,.5131,*T4510,.5131
*T5110,.5131,*T5210,.5131,*T5310,.5131,*T5410,.5131,*T5510,.5131
*T1111,.5131,*T1211,.5131,*T1311,.5131,*T1411,.5131,*T1511,.5131
```

```
                 *T2111,.5131,*T2211,.5131,*T2311,.5131,*T2411,.5131,*T2511,.5131
                 *T3111,.5131,*T3211,.5131,*T3311,.5131,*T3411,.5131,*T3511,.5131
                 *T4111,.5131,*T4211,.5131,*T4311,.5131,*T4411,.5131,*T4511,.5131
                 *T5111,.5131,*T5211,.5131,*T5311,.5131,*T5411,.5131,*T5511,.5131,END
                 19,*T81,3.21,END
                 20,SPACE,15,END
             END
             ARRAY ANALYSIS... NUMBER OF ARRAYS =   19  TOTAL LENGTH =    818

       TUBE NUMBER LIST
               1           2           3           4           5           6           7           8                                    8

       PRESSURE NODE LIST
               1           2           3           4           5                                                                        5
             BCD 3EXECUTION
            DIMENSION X(10000)                                                        F
            NDIM=10000                                                                F
            NTH=0                                                                     F
                 RESET
                 CRVINT(A4,A8)
                 TOPLIN
                 GENOUT(A8+1,1,A8,3H0A8)
                 FLOSOL
            ITEST=0                                                                   F
                 CSGDMP
            ITEST=1                                                                   F
                 CNBACK
             END
             BCD 3VARIABLES 1
            IF(ITEST.EQ.1) CALL RADIR(A10,.1714E-8,-460.)                             M
            T1150=T1100                                                               M
            T1151=T1101                                                               M
            T1152=T1102                                                               M
            T1153=T1103                                                               M
            T1154=T1104                                                               M
            T1155=T1105                                                               M
            T1156=T1106                                                               M
            T1157=T1107                                                               M
            T1158=T1108                                                               M
            T1159=T1109                                                               M
            T1160=T1110                                                               M
            T1161=T1111                                                               M
            T6100=T5500                                                               M
            T6101=T5501                                                               M
            T6102=T5502                                                               M
            T6103=T5503                                                               M
            T6104=T5504                                                               M
            T6105=T5505                                                               M
            T6106=T5506                                                               M
            T6107=T5507                                                               M
            T6108=T5508                                                               M
            T6109=T5509                                                               M
            T6110=T5510                                                               M
            T6111=T5511                                                               M
            T70=(T111+T211+T311+T411+T511)/5.                                         M
             END
```

```
          BCD 3VARIABLES 2
              FLOSOL
              TIMCHK(K1,0)
          END
          BCD 3OUTPUT CALLS
              TPRNT
              WPRINT(1,1,1,0)
              TIMCHK(K1,1)
          END

  @ADD,P EC02-V55008*SINFLO.PROC
```

```
     HARD TUBE INFLATABLE RADIATOR
  IR CROSS RADIATION DATA
        SURFACE DATA
           NUMBER OF SURFACES =    5
           SURFACE NUMBER       SURFACE AREA      NUMBER OF NODES
                        90           3.20700                    1
                        91          51.31000                  100
                        92          51.31000                  100
                        93          51.31000                  100
                        94           3.20700                    1

        SURFACE EMISSIVITY DATA
               .20000-01    .68000+00    .68000+00    .68000+00    .10000+01

        SURFACE REFLECTIVITY DATA
               .98000+00    .32000+00    .32000+00    .32000+00    .00000

        SURFACE CONNECTION DATA
            FROM SURFACE         TO SURFACE         VIEW FACTOR
                      90                 91          .98460+00
                      90                 92          .12000-01
                      90                 93          .20000-02
                      90                 94          .20000-02
                      91                 92          .61000-01
                      91                 93          .00000
                      91                 94          .00000
                      92                 93          .61000-01
                      92                 94          .50000-03
                      93                 94          .62000-01

        NODE DATA
            SURFACE       NODE         AREA     NODE        AREA     NODE        AREA     NODE        AREA
                 90         80      3.21000
                 91       1100       .51310     1200      .51310     1300      .51310     1400      .51310
```

```
1500     .51310     2100     .51310     2200     .51310     2300     .5131
2400     .51310     2500     .51310     3100     .51310     3200     .51310
3300     .51310     3400     .51310     3500     .51310     4100     .51310
4200     .51310     4300     .51310     4400     .51310     4500     .51310
5100     .51310     5200     .51310     5300     .51310     5400     .51310
5500     .51310     1101     .51310     1201     .51310     1301     .51310
1401     .51310     1501     .51310     2101     .51310     2201     .51310
2301     .51310     2401     .51310     2501     .51310     3101     .51310
3201     .51310     3301     .51310     3401     .51310     3501     .51310
4101     .51310     4201     .51310     4301     .51310     4401     .51310
4501     .51310     5101     .51310     5201     .51310     5301     .51310
5401     .51310     5501     .51310     1102     .51310     1202     .51310
1302     .51310     1402     .51310     1502     .51310     2102     .51310
```

```
     SYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER   - - -  SINDA  - - -   UNIVAC-1108 FORTRAN-V VERSION       PAGE    48
     HARD TUBE INFLATABLE RADIATOR
                          2202          .51310          2302          .51310          2402          .51310          2502          .51310
                          3102          .51310          3202          .51310          3302          .51310          3402          .51310
                          3502          .51310          4102          .51310          4202          .51310          4302          .51310
                          4402          .51310          4502          .51310          5102          .51310          5202          .51310
                          5302          .51310          5402          .51310          5502          .51310          1103          .51310
                          1203          .51310          1303          .51310          1403          .51310          1503          .51310
                          2103          .51310          2203          .51310          2303          .51310          2403          .51310
                          2503          .51310          3103          .51310          3203          .51310          3303          .51310
                          3403          .51310          3503          .51310          4103          .51310          4203          .51310
                          4303          .51310          4403          .51310          4503          .51310          5103          .51310
                          5203          .51310          5303          .51310          5403          .51310          5503          .51310
                          1104          .51310          1204          .51310          1304          .51310          1404          .51310
                          1504          .51310          2104          .51310          2204          .51310          2304          .51310
                          2404          .51310          2504          .51310          3104          .51310          3204          .51310
                          3304          .51310          3404          .51310          3504          .51310          4104          .51310
                          4204          .51310          4304          .51310          4404          .51310          4504          .51310
                          5104          .51310          5204          .51310          5304          .51310          5404          .51310
                          5504          .51310          1105          .51310          1205          .51310          1305          .51310
                          1405          .51310          1505          .51310          2105          .51310          2205          .51310
                          2305          .51310          2405          .51310          2505          .51310          3105          .51310
                          3205          .51310          3305          .51310          3405          .51310          3505          .51310
                          4105          .51310          4205          .51310          4305          .51310          4405          .51310
                          4505          .51310          5105          .51310          5205          .51310          5305          .51310
                          5405          .51310          5505          .51310          1106          .51310          1206          .51310
                          1306          .51310          1406          .51310          1506          .51310          2106          .51310
                          2206          .51310          2306          .51310          2406          .51310          2506          .51310
                          3106          .51310          3206          .51310          3306          .51310          3406          .51310
                          3506          .51310          4106          .51310          4206          .51310          4306          .51310
                          4406          .51310          4506          .51310          5106          .51310          5206          .51310
                          5306          .51310          5406          .51310          5506          .51310          1107          .51310
                          1207          .51310          1307          .51310          1407          .51310          1507          .51310
                          2107          .51310          2207          .51310          2307          .51310          2407          .51310
                          2507          .51310          3107          .51310          3207          .51310          3307          .51310
                          3407          .51310          3507          .51310          4107          .51310          4207          .51310
                          4307          .51310          4407          .51310          4507          .51310          5107          .51310
                          5207          .51310          5307          .51310          5407          .51310          5507          .51310
                          1108          .51310          1208          .51310          1308          .51310          1408          .51310
                          1508          .51310          2108          .51310          2208          .51310          2308          .51310
                          2408          .51310          2508          .51310          3108          .51310          3208          .51310
                          3308          .51310          3408          .51310          3508          .51310          4108          .51310
                          4208          .51310          4308          .51310          4408          .51310          4508          .51310
                          5108          .51310          5208          .51310          5308          .51310          5408          .51310
                          5508          .51310          1109          .51310          1209          .51310          1309          .51310
                          1409          .51310          1509          .51310          2109          .51310          2209          .51310
                          2309          .51310          2409          .51310          2509          .51310          3109          .51310
                          3209          .51310          3309          .51310          3409          .51310          3509          .51310
                          4109          .51310          4209          .51310          4309          .51310          4409          .51310
```

```
HARD TUBE INFLATABLE RADIATOR
                        4509          .51310      5109        .51310      5209        .51310      5309        .51310
                        5409          .51310      5509        .51310      1110        .51310      1210        .51310
                        1310          .51310      1410        .51310      1510        .51310      2110        .51310
                        2210          .51310      2310        .51310      2410        .51310      2510        .51310
                        3110          .51310      3210        .51310      3310        .51310      3410        .51310
                        3510          .51310      4110        .51310      4210        .51310      4310        .51310
                        4410          .51310      4510        .51310      5110        .51310      5210        .51310
                        5310          .51310      5410        .51310      5510        .51310      1111        .51310
                        1211          .51310      1311        .51310      1411        .51310      1511        .51310
                        2111          .51310      2211        .51310      2311        .51310      2411        .51310
                        2511          .51310      3111        .51310      3211        .51310      3311        .51310
                        3411          .51310      3511        .51310      4111        .51310      4211        .51310
                        4311          .51310      4411        .51310      4511        .51310      5111        .51310
                        5211          .51310      5311        .51310      5411        .51310      5511        .51310
                  94      81         3.21000


           CONNECTION DATA
              FROM SURFACE     TO SURFACE     SCRIPT FA

                    90             91        .43776-01
                    90             92        .13903-02
                    90             93        .11606-03
                    90             94        .13448-03
                    91             92        .14940+01
                    91             93        .32080-01
                    91             94        .55775-02
                    92             93        .14485+01
                    92             94        .59857-01
                    93             94        .21644+01
```

```
    HARD TUBE INFLATABLE RADIATOR

 T  5503=    31.576     T  5504=    31.740      T  5505=    31.915      T  5506=    32.116      T  5507=    32.343      T  5508=    32.438
 T  5509=    32.727     T  5510=    33.040      T  5511=    33.381      T  6000=    33.740      T  6001=    34.033      T  6002=    34.290
 T  6003=    34.603     T  6004=    34.940      T  6005=    35.297      T  6006=    35.675      T  6007=    36.074      T  6008=    36.485
 T  6009=    36.939     T  6010=    37.413      T  6011=    37.914      T  6100=    31.332      T  6101=    31.380      T  6102=    31.461
 T  6103=    31.574     T  6104=    31.737      T  6105=    31.912      T  6106=    32.112      T  6107=    32.339      T  6108=    32.435
 T  6109=    32.723     T  6110=    33.034      T  6111=    33.368      T 10000=   -310.00

 W         1= 110.59    W          2= 110.55    W          3= 109.97    W          4= 110.48    W          5= 109.90
 W         6= 991.49    W          7= 549.29    W          8= 440.00
 DP        1= 4055.2    DP         2= 4055.2    DP         3= 4055.2    DP         4= 4055.2    DP         5= 4055.2
 DP        6= 63.136    DP         7= .31555-01 DP         8= 1.2072
 P         1= 4118.4    P          2= 4118.3    P          3= 63.136    P          4= .00000    P          5= 64.343

 COMPUTER TIME =    1.760 MINUTES

 ***********
 TIME=      .50000 DTIMEU=  2.50000-03 CSGMIN(  1100)=  9.86330-05 TEMPCC(     80)=  2.28424-02 RELXCC(     66)=  6.66428-03
 T     1=   95.000      T     2=   38.728       T     3=   33.949       T     4=   94.999       T     5=   38.726       T     6=   33.949
 T    10=   94.926      T    11=   94.386       T    12=   87.636       T    15=   39.587       T    16=   39.569       T    17=   39.413
 T    20=   94.907      T    21=   94.224       T    22=   85.692       T    25=   39.370       T    26=   39.348       T    27=   39.155
 T    30=   92.056      T    31=   70.017       T    32=   81.204       T    35=   38.019       T    36=   38.060       T    37=   38.589
 T    40=   94.856      T    41=   93.798       T    42=   80.587       T    45=   39.020       T    46=   38.987       T    47=   38.660
 T    50=   94.808      T    51=   93.395       T    52=   75.842       T    55=   37.647       T    56=   37.691       T    57=   38.253
 T    60=   33.950      T    61=   34.416       T    62=   65.528       T    65=   38.727       T    66=   38.723       T    67=   38.534
 T    70=   38.733      T    71=   70.000       T    80=   54.231       T    81=  -20.000       T    90=   54.374       T    91=   52.795
 T    92=   36.949      T    93=   22.444       T    94=  -19.897       T   100=   89.551       T   101=   64.190       T   102=   79.028
 T   103=   74.055      T   104=   69.245       T   105=   64.612       T   106=   60.145       T   107=   55.839       T   108=   51.562
 T   109=   47.435      T   110=   43.452       T   111=   39.597       T   200=   89.496       T   201=   84.105       T   202=   78.918
 T   203=   73.923      T   204=   69.095       T   205=   64.447       T   206=   59.967       T   207=   55.651       T   208=   51.366
 T   209=   47.233      T   210=   43.245       T   211=   39.373       T   300=   86.737       T   301=   81.534       T   302=   76.520
 T   303=   71.683      T   304=   67.003       T   305=   62.491       T   306=   58.139       T   307=   53.940       T   308=   49.764
 T   309=   45.734      T   310=   41.841       T   311=   38.014       T   400=   89.418       T   401=   83.996       T   402=   78.777
 T   403=   73.748      T   404=   68.888       T   405=   64.210       T   406=   59.702       T   407=   55.361       T   408=   51.056
 T   409=   46.909      T   410=   42.912       T   411=   39.025       T   500=   88.769       T   501=   82.870       T   502=   77.280
 T   503=   71.978      T   504=   66.941       T   505=   62.162       T   506=   57.628       T   507=   53.323       T   508=   49.120
 T   509=   45.126      T   510=   41.300       T   511=   37.642       T   600=   33.910       T   601=   34.188       T   602=   34.491
 T   603=   34.816      T   604=   35.164       T   605=   35.529       T   606=   35.914       T   607=   36.317       T   608=   36.738
 T   609=   37.196      T   610=   37.676       T   611=   38.187       T  1000=   80.593       T  1001=   75.171       T  1002=   69.944
 T  1003=   64.902      T  1004=   59.990       T  1005=   55.294       T  1006=   50.759       T  1007=   46.319       T  1008=   41.599
 T  1009=   37.306      T  1010=   33.145       T  1011=   29.092       T  1100=   74.969       T  1101=   69.761       T  1102=   64.737
 T  1103=   59.885      T  1104=   55.139       T  1105=   50.620       T  1106=   46.254       T  1107=   41.975       T  1108=   37.285
 T  1109=   33.144      T  1110=   29.127       T  1111=   25.211       T  1150=   74.977       T  1151=   69.769       T  1152=   64.744
 T  1153=   59.892      T  1154=   55.145       T  1155=   50.626       T  1156=   46.260       T  1157=   41.981       T  1158=   37.291
 T  1159=   33.150      T  1160=   29.133       T  1161=   25.217       T  1200=   58.078       T  1201=   53.485       T  1202=   49.042
 T  1203=   44.739      T  1204=   40.515       T  1205=   36.511       T  1206=   32.632       T  1207=   28.822       T  1208=   24.217
 T  1209=   20.520      T  1210=   16.925       T  1211=   13.410       T  1300=   52.599       T  1301=   48.198       T  1302=   43.936
```

```
HARD TUBE INFLATABLE RADIATOR
  T  1303=   39.805    T  1304=   35.751    T  1305=   31.909    T  1306=   28.184    T  1307=   24.521    T  1308=   19.943
  T  1309=   16.386    T  1310=   12.926    T  1311=   9.5371    T  1400=   58.027    T  1401=   53.423    T  1402=   48.969
  T  1403=   44.658    T  1404=   40.427    T  1405=   36.418    T  1406=   32.534    T  1407=   28.718    T  1408=   24.111
  T  1409=   20.410    T  1410=   16.813    T  1411=   13.294    T  1500=   74.860    T  1501=   69.628    T  1502=   64.583
  T  1503=   59.714    T  1504=   54.955    T  1505=   50.424    T  1506=   46.047    T  1507=   41.758    T  1508=   37.061
  T  1509=   32.915    T  1510=   28.894    T  1511=   24.968    T  2000=   80.472    T  2001=   75.023    T  2002=   69.773
  T  2003=   64.711    T  2004=   59.785    T  2005=   55.075    T  2006=   50.528    T  2007=   46.077    T  2008=   41.350
  T  2009=   37.051    T  2010=   32.886    T  2011=   28.821    T  2100=   74.769    T  2101=   69.542    T  2102=   64.500
  T  2103=   59.635    T  2104=   54.880    T  2105=   50.353    T  2106=   45.978    T  2107=   41.692    T  2108=   36.997
  T  2109=   32.853    T  2110=   28.835    T  2111=   24.909    T  2200=   57.439    T  2201=   52.863    T  2202=   48.435
  T  2203=   44.148    T  2204=   39.946    T  2205=   35.958    T  2206=   32.088    T  2207=   28.291    T  2208=   23.700
  T  2209=   20.015    T  2210=   16.432    T  2211=   12.916    T  2300=   51.462    T  2301=   47.115    T  2302=   42.904
  T  2303=   38.820    T  2304=   34.822    T  2305=   31.022    T  2306=   27.325    T  2307=   23.697    T  2308=   19.152
  T  2309=   15.625    T  2310=   12.193    T  2311=   8.8112    T  2400=   56.287    T  2401=   51.784    T  2402=   47.423
  T  2403=   43.197    T  2404=   39.057    T  2405=   35.121    T  2406=   31.289    T  2407=   27.535    T  2408=   22.982
  T  2409=   19.334    T  2410=   15.785    T  2411=   12.282    T  2500=   72.355    T  2501=   67.284    T  2502=   62.386
  T  2503=   57.651    T  2504=   53.022    T  2505=   48.605    T  2506=   44.310    T  2507=   40.117    T  2508=   35.501
  T  2509=   31.435    T  2510=   27.488    T  2511=   23.591    T  3000=   77.775    T  3001=   72.503    T  3002=   67.414
  T  3003=   62.498    T  3004=   57.711    T  3005=   53.126    T  3006=   48.670    T  3007=   44.323    T  3008=   39.683
  T  3009=   35.472    T  3010=   31.387    T  3011=   27.354    T  3100=   72.351    T  3101=   67.279    T  3102=   62.379
  T  3103=   57.642    T  3104=   53.012    T  3105=   48.594    T  3106=   44.298    T  3107=   40.104    T  3108=   35.488
  T  3109=   31.422    T  3110=   27.474    T  3111=   23.577    T  3200=   56.259    T  3201=   51.746    T  3202=   47.376
  T  3203=   43.141    T  3204=   38.994    T  3205=   35.050    T  3206=   31.211    T  3207=   27.451    T  3208=   22.894
  T  3209=   19.243    T  3210=   15.693    T  3211=   12.188    T  3300=   51.408    T  3301=   47.044    T  3302=   42.814
  T  3303=   38.713    T  3304=   34.701    T  3305=   30.886    T  3306=   27.175    T  3307=   23.536    T  3308=   18.982
  T  3309=   15.451    T  3310=   12.017    T  3311=   8.6324    T  3400=   57.355    T  3401=   52.751    T  3402=   48.295
  T  3403=   43.981    T  3404=   39.757    T  3405=   35.746    T  3406=   31.854    T  3407=   28.039    T  3408=   23.436
  T  3409=   19.744    T  3410=   16.160    T  3411=   12.638    T  3500=   74.646    T  3501=   69.378    T  3502=   64.297
  T  3503=   59.392    T  3504=   54.604    T  3505=   50.045    T  3506=   45.638    T  3507=   41.328    T  3508=   36.616
  T  3509=   32.463    T  3510=   28.442    T  3511=   24.510    T  4000=   80.339    T  4001=   74.847    T  4002=   69.554
  T  4003=   64.450    T  4004=   59.488    T  4005=   54.744    T  4006=   50.163    T  4007=   45.687    T  4008=   40.941
  T  4009=   36.632    T  4010=   32.465    T  4011=   28.394    T  4100=   74.673    T  4101=   69.386    T  4102=   64.290
  T  4103=   59.373    T  4104=   54.578    T  4105=   50.015    T  4106=   45.606    T  4107=   41.297    T  4108=   36.589
  T  4109=   32.442    T  4110=   28.431    T  4111=   24.510    T  4200=   57.527    T  4201=   52.801    T  4202=   48.247
  T  4203=   43.859    T  4204=   39.590    T  4205=   35.549    T  4206=   31.644    T  4207=   27.835    T  4208=   23.261
  T  4209=   19.611    T  4210=   16.085    T  4211=   12.634    T  4300=   51.743    T  4301=   47.140    T  4302=   42.722
  T  4303=   38.478    T  4304=   34.379    T  4305=   30.506    T  4306=   26.771    T  4307=   23.144    T  4308=   18.646
  T  4309=   15.196    T  4310=   11.874    T  4311=   8.6257    T  4400=   56.785    T  4401=   51.998    T  4402=   47.233
  T  4403=   42.775    T  4404=   38.489    T  4405=   34.456    T  4406=   30.579    T  4407=   26.840    T  4408=   22.368
  T  4409=   18.846    T  4410=   15.471    T  4411=   12.178    T  4500=   73.117    T  4501=   67.498    T  4502=   62.169
  T  4503=   57.111    T  4504=   52.277    T  4505=   47.732    T  4506=   43.385    T  4507=   39.223    T  4508=   34.730
  T  4509=   30.850    T  4510=   27.154    T  4511=   23.561    T  5000=   78.631    T  5001=   72.739    T  5002=   67.188
  T  5003=   61.927    T  5004=   56.921    T  5005=   52.199    T  5006=   47.688    T  5007=   43.376    T  5008=   38.870
  T  5009=   34.859    T  5010=   31.044    T  5011=   27.338    T  5100=   71.584    T  5101=   66.147    T  5102=   60.997
  T  5103=   56.115    T  5104=   51.465    T  5105=   47.086    T  5106=   42.902    T  5107=   38.901    T  5108=   34.582
  T  5109=   30.861    T  5110=   27.322    T  5111=   24.883    T  5200=   46.925    T  5201=   43.215    T  5202=   39.703
```

```
        HARD TUBE INFLATABLE RADIATOR

  T   5203=     36.375      T   5204=     33.270      T   5205=     33.306      T   5206=     27.477      T   5207=     24.776      T   5208=     21.414
  T   5209=     18.915      T   5210=     16.543      T   5211=     14.242      T   5300=     32.668      T   5301=     30.363      T   5302=     28.190
  T   5303=     26.141      T   5304=     24.303      T   5305=     22.503      T   5306=     20.794      T   5307=     19.171      T   5308=     16.809
  T   5309=     15.329      T   5310=     13.936      T   5311=     12.593      T   5400=     27.613      T   5401=     26.529      T   5402=     25.524
  T   5403=     24.593      T   5404=     23.820      T   5405=     23.038      T   5406=     22.312      T   5407=     21.639      T   5408=     20.396
  T   5409=     19.820      T   5410=     19.298      T   5411=     18.814      T   5500=     31.363      T   5501=     31.415      T   5502=     31.500
  T   5503=     31.616      T   5504=     31.781      T   5505=     31.955      T   5506=     32.153      T   5507=     32.375      T   5508=     32.465
  T   5509=     32.747      T   5510=     32.956      T   5511=     33.397      T   6000=     33.774      T   6001=     34.041      T   6002=     34.332
  T   6003=     34.646      T   6004=     34.984      T   6005=     35.340      T   6006=     35.715      T   6007=     36.108      T   6008=     36.512
  T   6009=     36.960      T   6010=     37.431      T   6011=     37.932      T   6100=     31.360      T   6101=     31.413      T   6102=     31.498
  T   6103=     31.615      T   6104=     31.780      T   6105=     31.955      T   6106=     32.155      T   6107=     32.378      T   6108=     32.467
  T   6109=     32.748      T   6110=     33.052      T   6111=     33.384      T  10000=    -310.00
  W          1= 110.50      W          2= 110.46      W          3= 109.87      W          4= 110.39      W          5= 109.80
  W          6= 991.03      W          7= 549.66      W          8= 440.00

  DP         1= 4050.9      DP         2= 4050.9      DP         3= 4050.9      DP         4= 4050.9      DP         5= 4050.9
  DP         6= 63.080      DP         7= .31555-01   DP         8= 1.2072

  P          1= 4114.0      P          2= 4114.0      P          3= 63.080      P          4= .00000      P          5= 64.287
  COMPUTER TIME =     1.864 MINUTES

         END OF DATA
  * *DIVIDE CHECK HAS OCCURRED* *

 @PMD,E

 @BRKPT PRINT$
```

APPENDIX G

COMPUTER PROGRAM LISTING

SOFT TUBE FULL SCALE RADIATOR

TEST POINT 1 CONDITIONS

```
      BCD 3THERMAL LPCS
      BCD 5SOFT TUBE INFLATABLE RADIATOR
      END
      BCD 3NODE DATA
      GEN -51,13,1,70.,1. $SURFACE NODES
      GEN 1000,8,1,70.,.002917  $TUBE NODE
      GEN 2000,8,1,70.,.002917  $TUBE NODE
      GEN 3000,8,1,70.,.002917  $TUBE NODE
      GEN 4000,8,1,70.,.002917  $TUBE NODE
      GEN 5000,8,1,70.,.002917  $TUBE NODE
      GEN 1083,8,1,70.,.002917  $TUBE NODE
      GEN 2083,8,1,70.,.002917  $TUBE NODE
      GEN 3083,8,1,70.,.002917  $TUBE NODE
      GEN 4083,8,1,70.,.002917  $TUBE NODE
      GEN 5083,8,1,70.,.002917  $TUBE NODE
      GEN 999,5,1000,70.,.002917$MANIFOLD TUBE
      GEN 1091,5,1000,70.,.002917$MANIFOLD TUBE
      GEN -1,2,1,95.,1.         $FLUID NODE
      GEN -99,5,100,70.,1.      $FLUID NODE
      GEN -191,5,100,70.,1.     $FLUID NODE
      GEN -100,8,1,70.,1.       $FLUID NODE
      GEN -200,8,1,70.,1.       $FLUID NODE
      GEN -300,8,1,70.,1.       $FLUID NODE
      GEN -400,8,1,70.,1.       $FLUID NODE
      GEN -500,8,1,70.,1.       $FLUID NODE
      GEN -183,8,1,70.,1.       $FLUID NODE
      GEN -283,8,1,70.,1.       $FLUID NODE
      GEN -383,8,1,70.,1.       $FLUID NODE
      GEN -483,8,1,70.,1.       $FLUID NODE
      GEN -583,8,1,70.,1.       $FLUID NODE
      GEN 3,2,1,70.,.002917       $MANIFOLD NODE
      GEN 1650,8,1,70.,.006   $FIN NODE
      GEN 1700,8,1,70.,.006   $FIN NODE
      GEN 1750,8,1,70.,.006   $FIN NODE
      GEN 1800,8,1,70.,.006   $FIN NODE
      GEN 1850,8,1,70.,.000488 $FIN NODE
      GEN 1900,8,1,70.,.000488 $FIN NODE
      GEN 1950,8,1,70.,.000488 $FIN NODE
      GEN 2700,8,1,70.,.000488 $FIN NODE
      GEN 2750,8,1,70.,.000488 $FIN NODE
      GEN 2800,8,1,70.,.000488 $FIN NODE
      GEN 2850,8,1,70.,.000488 $FIN NODE
      GEN 2900,8,1,70.,.000488 $FIN NODE
      GEN 2950,8,1,70.,.000488 $FIN NODE
      GEN 1100,8,1,70.,.000488 $FIN NODE
      GEN 1150,8,1,70.,.000488 $FIN NODE
      GEN 1200,8,1,70.,.000488 $FIN NODE
      GEN 1250,8,1,70.,.000488 $FIN NODE
      GEN 1300,8,1,70.,.000488 $FIN NODE
      GEN 1350,8,1,70.,.000488 $FIN NODE
      GEN 1400,8,1,70.,.000488 $FIN NODE
      GEN 1450,8,1,70.,.000488 $FIN NODE
      GEN 1500,8,1,70.,.000488 $FIN NODE
      GEN 1550,8,1,70.,.000488 $FIN NODE
```

```
          GEN 2100,8,1,70.,.000488 $FIN NODE
          GEN 2150,8,1,70.,.000488 $FIN NODE
          GEN 2200,8,1,70.,.000488 $FIN NODE
          GEN 2250,8,1,70.,.000488 $FIN NODE
          GEN 2300,8,1,70.,.000488 $FIN NODE
          GEN 2350,8,1,70.,.000488 $FIN NODE
          GEN 2400,8,1,70.,.000488 $FIN NODE
          GEN 2450,8,1,70.,.000488 $FIN NODE
          GEN 2500,8,1,70.,.000488 $FIN NODE
          GEN 2550,8,1,70.,.000488 $FIN NODE
          GEN 3100,8,1,70.,.000488 $FIN NODE
          GEN 3150,8,1,70.,.000488 $FIN NODE
          GEN 3200,8,1,70.,.000488 $FIN NODE
          GEN 3250,8,1,70.,.000488 $FIN NODE
          GEN 3300,8,1,70.,.000488 $FIN NODE
          GEN 3350,8,1,70.,.000488 $FIN NODE
          GEN 3400,8,1,70.,.000488 $FIN NODE
          GEN 3450,8,1,70.,.000488 $FIN NODE
          GEN 3500,8,1,70.,.000488 $FIN NODE
          GEN 3550,8,1,70.,.000488 $FIN NODE
          GEN 4100,8,1,70.,.000488 $FIN NODE
          GEN 4150,8,1,70.,.000488 $FIN NODE
          GEN 4200,8,1,70.,.000488 $FIN NODE
          GEN 4250,8,1,70.,.000488 $FIN NODE
          GEN 4300,8,1,70.,.000488 $FIN NODE
          GEN 4350,8,1,70.,.000488 $FIN NODE
          GEN 4400,8,1,70.,.000488 $FIN NODE
          GEN 4450,8,1,70.,.000488 $FIN NODE
          GEN 4500,8,1,70.,.000488 $FIN NODE
          GEN 4550,8,1,70.,.000488 $FIN NODE
          GEN 5100,8,1,70.,.000488 $FIN NODE
          GEN 5150,8,1,70.,.000488 $FIN NODE
          GEN 5200,8,1,70.,.000488 $FIN NODE
          GEN 5250,8,1,70.,.000488 $FIN NODE
          GEN 5300,8,1,70.,.000488 $FIN NODE
          GEN -5350,8,1,70.,.000488$SYMMETRICAL NODE
          GEN 998,5,1000,70.,.0136 $MANIFOLD NODE
          GEN 1092,5,1000,70.,.0136$MANIFOLD NODE
          GEN 1052,4,1,70.,.110    $DRUM NODE
              1051,70.,.00228      $END NODE
          GEN 9002,2,2,0.,0.50     $SURFACE NODE
              9001,-311.,1000000.            $SURFACE NODE
              9003,-311.,1000000.              $SURFACE NODE
          END

          RELATIVE NODE NUMBERS                              ACTUAL NODE NUMBERS

              1   THRU   10            1000   1001   1002   1003   1004   1005   1006   1007   2000   2001
             11   THRU   20            2002   2003   2004   2005   2006   2007   3000   3001   3002   3003
             21   THRU   30            3004   3005   3006   3007   4000   4001   4002   4003   4004   4005
             31   THRU   40            4006   4007   5000   5001   5002   5003   5004   5005   5006   5007
             41   THRU   50            1083   1084   1085   1086   1087   1088   1089   1090   2083   2084
             51   THRU   60            2085   2086   2087   2088   2089   2090   3083   3084   3085   3086
             61   THRU   70            3087   3088   3089   3090   4083   4084   4085   4086   4087   4088
             71   THRU   80            4089   4090   5083   5084   5085   5086   5087   5088   5089   5090
             81   THRU   90             999   1999   2999   3999   4999   1091   2091   3091   4091   5091
             91   THRU  100               3      4   1650   1651   1652   1653   1654   1655   1656   1657
```

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

```
SINDA/SINFLO PREPROCESSOR                                                                  DATE 120475        PAGE     5
          101  THRU   110            1700   1701   1702   1703   1704   1705   1706   1707   1750   1751
          111  THRU   120            1752   1753   1754   1755   1756   1757   1800   1801   1802   1803
          121  THRU   130            1804   1805   1806   1807   1850   1851   1852   1853   1854   1855
          131  THRU   140            1856   1857   1900   1901   1902   1903   1904   1905   1906   1907
          141  THRU   150            1950   1951   1952   1953   1954   1955   1956   1957   2700   2701
          151  THRU   160            2702   2703   2704   2705   2706   2707   2750   2751   2752   2753
          161  THRU   170            2754   2755   2756   2757   2800   2801   2802   2803   2804   2805
          171  THRU   180            2806   2807   2850   2851   2852   2853   2854   2855   2856   2857
          181  THRU   190            2900   2901   2902   2903   2904   2905   2906   2907   2950   2951
          191  THRU   200            2952   2953   2954   2955   2956   2957   1100   1101   1102   1103
          201  THRU   210            1104   1105   1106   1107   1150   1151   1152   1153   1154   1155
          211  THRU   220            1156   1157   1200   1201   1202   1203   1204   1205   1206   1207
          221  THRU   230            1250   1251   1252   1253   1254   1255   1256   1257   1300   1301
          231  THRU   240            1302   1303   1304   1305   1306   1307   1350   1351   1352   1353
          241  THRU   250            1354   1355   1356   1357   1400   1401   1402   1403   1404   1405
          251  THRU   260            1406   1407   1450   1451   1452   1453   1454   1455   1456   1457
          261  THRU   270            1500   1501   1502   1503   1504   1505   1506   1507   1550   1551
          271  THRU   280            1552   1553   1554   1555   1556   1557   2100   2101   2102   2103
          281  THRU   290            2104   2105   2106   2107   2150   2151   2152   2153   2154   2155
          291  THRU   300            2156   2157   2200   2201   2202   2203   2204   2205   2206   2207
          301  THRU   310            2250   2251   2252   2253   2254   2255   2256   2257   2300   2301
          311  THRU   320            2302   2303   2304   2305   2306   2307   2350   2351   2352   2353
          321  THRU   330            2354   2355   2356   2357   2400   2401   2402   2403   2404   2405
          331  THRU   340            2406   2407   2450   2451   2452   2453   2454   2455   2456   2457
          341  THRU   350            2500   2501   2502   2503   2504   2505   2506   2507   2550   2551
          351  THRU   360            2552   2553   2554   2555   2556   2557   3100   3101   3102   3103
          361  THRU   370            3104   3105   3106   3107   3150   3151   3152   3153   3154   3155
          371  THRU   380            3156   3157   3200   3201   3202   3203   3204   3205   3206   3207
          381  THRU   390            3250   3251   3252   3253   3254   3255   3256   3257   3300   3301
          391  THRU   400            3302   3303   3304   3305   3306   3307   3350   3351   3352   3353
          401  THRU   410            3354   3355   3356   3357   3400   3401   3402   3403   3404   3405
          411  THRU   420            3406   3407   3450   3451   3452   3453   3454   3455   3456   3457
          421  THRU   430            3500   3501   3502   3503   3504   3505   3506   3507   3550   3551
          431  THRU   440            3552   3553   3554   3555   3556   3557   4100   4101   4102   4103
          441  THRU   450            4104   4105   4106   4107   4150   4151   4152   4153   4154   4155
          451  THRU   460            4156   4157   4200   4201   4202   4203   4204   4205   4206   4207
          461  THRU   470            4250   4251   4252   4253   4254   4255   4256   4257   4300   4301
          471  THRU   480            4302   4303   4304   4305   4306   4307   4350   4351   4352   4353
          481  THRU   490            4354   4355   4356   4357   4400   4401   4402   4403   4404   4405
          491  THRU   500            4406   4407   4450   4451   4452   4453   4454   4455   4456   4457
          501  THRU   510            4500   4501   4502   4503   4504   4505   4506   4507   4550   4551
          511  THRU   520            4552   4553   4554   4555   4556   4557   5100   5101   5102   5103
          521  THRU   530            5104   5105   5106   5107   5150   5151   5152   5153   5154   5155
          531  THRU   540            5156   5157   5200   5201   5202   5203   5204   5205   5206   5207
          541  THRU   550            5250   5251   5252   5253   5254   5255   5256   5257   5300   5301
          551  THRU   560            5302   5303   5304   5305   5306   5307    998   1998   2998   3998
          561  THRU   570            4998   1092   2092   3092   4092   5092   1052   1053   1054   1055
          571  THRU   580            1051   9002   9004   9001   9003     51     52     53     54     55
          581  THRU   590              56     57     58     59     60     61     62     63      1      2
          591  THRU   600              99    199    299    399    499    191    291    391    491    591
          601  THRU   610             100    101    102    103    104    105    106    107    200    201
          611  THRU   620             202    203    204    205    206    207    300    301    302    303
          621  THRU   630             304    305    306    307    400    401    402    403    404    405
          631  THRU   640             406    407    500    501    502    503    504    505    506    507
          641  THRU   650             183    184    185    186    187    188    189    190    283    284
          651  THRU   660             285    286    287    288    289    290    383    384    385    386
          661  THRU   670             387    388    389    390    483    484    485    486    487    488
```

```
     671  THRU     680                 489      490      583      584      585      586      587      588      589      590
     681  THRU     688                5350     5351     5352     5353     5354     5355     5356     5357
   NODE ANALYSIS...  DIFFUSION =      575,  ARITHMETIC =       0,  BOUNDARY =     113,  TOTAL =    688

   BCD 3CONDUCTOR DATA
   GEN 350,7,1,1650,1,1651,1,3.912E-5$AXIAL COND
   GEN 400,7,1,1700,1,1701,1,3.912E-5$AXIAL COND
   GEN 450,7,1,1750,1,1751,1,3.912E-5$AXIAL COND
   GEN 500,7,1,1800,1,1801,1,3.912E-5$AXIAL COND
   GEN 550,7,1,1850,1,1851,1,1.258E-5$AXIAL COND
   GEN 600,7,1,1900,1,1901,1,1.258E-5$AXIAL COND
   GEN 650,7,1,1950,1,1951,1,1.258E-5$AXIAL COND
   GEN 700,7,1,2700,1,2701,1,1.258E-5$AXIAL COND
   GEN 750,7,1,2750,1,2751,1,1.258E-5$AXIAL COND
   GEN 800,7,1,2800,1,2801,1,1.258E-5$AXIAL COND
   GEN 850,7,1,2850,1,2851,1,1.258E-5$AXIAL COND
   GEN 900,7,1,2900,1,2901,1,1.258E-5$AXIAL COND
   GEN 950,7,1,2950,1,2951,1,1.258E-5$AXIAL COND
   GEN 1100,7,1,1100,1,1101,1,1.258E-5 $AXIAL COND
   GEN 1150,7,1,1150,1,1151,1,1.258E-5 $AXIAL COND
   GEN 1200,7,1,1200,1,1201,1,1.258E-5 $AXIAL COND
   GEN 1250,7,1,1250,1,1251,1,1.258E-5 $AXIAL COND
   GEN 1300,7,1,1300,1,1301,1,1.258E-5 $AXIAL COND
   GEN 1350,7,1,1350,1,1351,1,1.258E-5 $AXIAL COND
   GEN 1400,7,1,1400,1,1401,1,1.258E-5 $AXIAL COND
   GEN 1450,7,1,1450,1,1451,1,1.258E-5 $AXIAL COND
   GEN 1500,7,1,1500,1,1501,1,1.258E-5 $AXIAL COND
   GEN 1550,7,1,1550,1,1551,1,1.258E-5 $AXIAL COND
   GEN 2100,7,1,2100,1,2101,1,1.258E-5 $AXIAL COND
   GEN 2150,7,1,2150,1,2151,1,1.258E-5 $AXIAL COND
   GEN 2200,7,1,2200,1,2201,1,1.258E-5 $AXIAL COND
   GEN 2250,7,1,2250,1,2251,1,1.258E-5 $AXIAL COND
   GEN 2300,7,1,2300,1,2301,1,1.258E-5 $AXIAL COND
   GEN 2350,7,1,2350,1,2351,1,1.258E-5 $AXIAL COND
   GEN 2400,7,1,2400,1,2451,1,1.258E-5 $AXIAL COND
   GEN 2450,7,1,2450,1,2451,1,1.258E-5 $AXIAL COND
   GEN 2500,7,1,2500,1,2501,1,1.258E-5 $AXIAL COND
   GEN 2550,7,1,2550,1,2551,1,1.258E-5 $AXIAL COND
   GEN 3100,7,1,3100,1,3101,1,1.258E-5 $AXIAL COND
   GEN 3150,7,1,3150,1,3151,1,1.258E-5 $AXIAL COND
   GEN 3200,7,1,3200,1,3201,1,1.258E-5 $AXIAL COND
   GEN 3250,7,1,3250,1,3251,1,1.258E-5 $AXIAL COND
   GEN 3300,7,1,3300,1,3301,1,1.258E-5 $AXIAL COND
   GEN 3350,7,1,3350,1,3351,1,1.258E-5 $AXIAL COND
   GEN 3400,7,1,3400,1,3401,1,1.258E-5 $AXIAL COND
   GEN 3450,7,1,3450,1,3451,1,1.258E-5 $AXIAL COND
   GEN 3500,7,1,3500,1,3501,1,1.258E-5 $AXIAL COND
   GEN 3550,7,1,3550,1,3551,1,1.258E-5 $AXIAL COND
   GEN 4100,7,1,4100,1,4101,1,1.258E-5 $AXIAL COND
   GEN 4150,7,1,4150,1,4151,1,1.258E-5 $AXIAL COND
   GEN 4200,7,1,4200,1,4201,1,1.258E-5 $AXIAL COND
   GEN 4250,7,1,4250,1,4251,1,1.258E-5 $AXIAL COND
   GEN 4300,7,1,4300,1,4301,1,1.258E-5 $AXIAL COND
   GEN 4350,7,1,4350,1,4351,1,1.258E-5 $AXIAL COND
   GEN 4400,7,1,4400,1,4401,1,1.258E-5 $AXIAL COND
   GEN 4450,7,1,4450,1,4451,1,1.258E-5 $AXIAL COND
   GEN 4500,7,1,4500,1,4501,1,1.258E-5 $AXIAL COND
```

```
GEN 4550,7,1,4550,1,4551,1,1.258E-5 $AXIAL COND
GEN 5100,7,1,5100,1,5101,1,1.258E-5 $AXIAL COND
GEN 5150,7,1,5150,1,5151,1,1.258E-5 $AXIAL COND
GEN 5200,7,1,5200,1,5251,1,1.258E-5 $AXIAL COND
GEN 5250,7,1,5250,1,5251,1,1.258E-5 $AXIAL COND
GEN 5300,7,1,5300,1,5301,1,1.258E-5 $AXIAL COND
GEN 1000,7,1,1000,1,1001,1,1.078E-6 $AXIAL COND
GEN 2000,7,1,2000,1,2001,1,1.078E-6 $AXIAL COND
GEN 3000,7,1,3000,1,3001,1,1.078E-6 $AXIAL COND
GEN 4000,7,1,4000,1,4001,1,1.078E-6 $AXIAL COND
GEN 5000,7,1,5000,1,5001,1,1.078E-6 $AXIAL COND
GEN 1050,7,1,1083,1,1084,1,1.078E-6 $AXIAL COND
GEN 2050,7,1,2083,1,2084,1,1.078E-6 $AXIAL COND
GEN 3050,7,1,3083,1,3084,1,1.078E-6 $AXIAL COND
GEN 4050,7,1,4083,1,4084,1,1.078E-6 $AXIAL COND
GEN 5050,7,1,5083,1,5084,1,1.078E-6 $AXIAL COND
GEN 1007,5,1000,1007,1000,1083,1000,1.078E-6 $AXIAL COND
GEN 1049,5,1000,1007,1000,1051,0,.003   $END COND
GEN 1099,5,1000,1083,1000,1051,0,.003   $END COND
GEN 52,3,1,1052,1,1053,1,.00253            $DRUM COND
    51,1051,1052,.00134                    $DRUM COND
    55,1051,1055,.00134                    $DRUM COND
GEN 325,8,1,1650,1,1750,1,.02246           $SIDE COND
GEN 375,8,1,1650,1,1700,1,.02246           $SIDE COND
GEN 425,8,1,1750,1,1800,1,.02246           $SIDE COND
GEN 475,8,1,1700,1,1850,1,.045            $SIDE COND
GEN 525,8,1,1800,1,1850,1,.045            $SIDE COND
GEN 575,8,1,1850,1,1900,1,.633             $FIN COND
GEN 625,8,1,1900,1,1950,1,.633             $FIN COND
GEN 675,8,1,1950,1,2700,1,.633             $FIN COND
GEN 725,8,1,2700,1,2750,1,.633             $FIN COND
GEN 775,8,1,2750,1,2800,1,.633             $FIN COND
GEN 825,8,1,2800,1,2850,1,.633             $FIN COND
GEN 875,8,1,2850,1,2900,1,.633             $FIN COND
GEN 925,8,1,2900,1,2950,1,.633             $FIN COND
GEN 1125,8,1,1100,1,1150,1,.633            $FIN COND
GEN 1175,8,1,1150,1,1200,1,.633            $FIN COND
GEN 1225,8,1,1200,1,1250,1,.633            $FIN COND
GEN 1275,8,1,1250,1,1300,1,.633            $FIN COND
GEN 1375,8,1,1350,1,1400,1,.633            $FIN COND
GEN 1425,8,1,1400,1,1450,1,.633            $FIN COND
GEN 1475,8,1,1450,1,1500,1,.633            $FIN COND
GEN 1525,8,1,1500,1,1550,1,.633            $FIN COND
GEN 2125,8,1,2100,1,2150,1,.633            $FIN COND
GEN 2175,8,1,2150,1,2200,1,.633            $FIN COND
GEN 2225,8,1,2200,1,2250,1,.633            $FIN COND
GEN 2275,8,1,2250,1,2300,1,.633            $FIN COND
GEN 2375,8,1,2350,1,2400,1,.633            $FIN COND
GEN 2425,8,1,2400,1,2450,1,.633            $FIN COND
GEN 2475,8,1,2450,1,2500,1,.633            $FIN COND
GEN 2525,8,1,2500,1,2550,1,.633            $FIN COND
GEN 3125,8,1,3100,1,3150,1,.633            $FIN COND
GEN 3175,8,1,3150,1,3200,1,.633            $FIN COND
GEN 3225,8,1,3200,1,3250,1,.633            $FIN COND
GEN 3275,8,1,3250,1,3300,1,.633            $FIN COND
GEN 3375,8,1,3350,1,3400,1,.633            $FIN COND
GEN 3425,8,1,3400,1,3450,1,.633            $FIN COND
```

```
      GEN 3475,8,1,3450,1,3500,1,.633                  $FIN COND
      GEN 3525,8,1,3500,1,3550,1,.633                  $FIN COND
      GEN 4125,8,1,4100,1,4150,1,.633                  $FIN COND
      GEN 4175,8,1,4150,1,4200,1,.633                  $FIN COND
      GEN 4225,8,1,4200,1,4250,1,.633                  $FIN COND
      GEN 4275,8,1,4250,1,4300,1,.633                  $FIN COND
      GEN 4375,8,1,4350,1,4400,1,.633                  $FIN COND
      GEN 4425,8,1,4400,1,4450,1,.633                  $FIN COND
      GEN 4475,8,1,4450,1,4500,1,.633                  $FIN COND
      GEN 4525,8,1,4500,1,4550,1,.633                  $FIN COND
      GEN 5125,8,1,5100,1,5150,1,.633                  $FIN COND
      GEN 5175,8,1,5150,1,5200,1,.633                  $FIN COND
      GEN 5225,8,1,5200,1,5250,1,.633                  $FIN COND
      GEN 5275,8,1,5250,1,5300,1,.633                  $FIN COND
      GEN 975,8,1,2950,1,1090,-1,0.396                  $TUBE COND
      GEN 1075,8,1,1100,1,1090,-1,0.396                 $TUBE COND
      GEN 1325,8,1,1300,1,1000,1,0.396                  $TUBE COND
      GEN 1025,8,1,1350,1,1000,1,0.396                  $TUBE COND
      GEN 1575,8,1,1550,1,2000,1,0.396                  $TUBE COND
      GEN 2025,8,1,2100,1,2000,1,0.396                  $TUBE COND
      GEN 2325,8,1,2300,1,2090,-1,0.396                 $TUBE COND
      GEN 2075,8,1,2350,1,2090,-1,0.396                 $TUBE COND
      GEN 2575,8,1,2550,1,3090,-1,0.396                 $TUBE COND
      GEN 3075,8,1,3100,1,3090,-1,0.396                 $TUBE COND
      GEN 3325,8,1,3300,1,3000,1,0.396                  $TUBE COND
      GEN 3025,8,1,3350,1,3000,1,0.396                  $TUBE COND
      GEN 3575,8,1,3550,1,4000,1,0.396                  $TUBE COND
      GEN 4025,8,1,4100,1,4000,1,0.396                  $TUBE COND
      GEN 4325,8,1,4300,1,4090,-1,0.396                 $TUBE COND
      GEN 4075,8,1,4350,1,4090,-1,0.396                 $TUBE COND
      GEN 4575,8,1,4550,1,5090,-1,0.396                 $TUBE COND
      GEN 5075,8,1,5100,1,5090,-1,0.396                 $TUBE COND
      GEN 5325,8,1,5300,1,5000,1,0.396                  $TUBE COND
      GEN 5025,8,1,5350,1,5000,1,0.396                  $TUBE COND
      GEN 799,5,1000,999,1000,998,1000,.300            $MANIFOLD COND
      GEN 1399,5,1000,1091,1000,1092,1000,.300         $MANIFOLD COND
      GEN 899,5,1000,3,0,999,1000,9.E-6                $MANIFOLD COND
      GEN 1299,5,1000,4,0,1091,1000,9.E-6              $MANIFOLD COND
      GEN 999,5,1000,999,1000,1000,1000,1.078E-6        $MANIFOLD COND
      GEN 1199,5,1000,1091,1000,1090,1000,1.078E-6     $MANIFOLD COND
      END

      RELATIVE CONDUCTOR NUMBERS                                  ACTUAL CONDUCTOR NUMBERS

          1  THRU   10           350    351    352    353    354    355    356    400    401    402
         11  THRU   20           403    404    405    406    450    451    452    453    454    455
         21  THRU   30           456    500    501    502    503    504    505    506    550    551
         31  THRU   40           552    553    554    555    556    600    601    602    603    604
         41  THRU   50           605    606    650    651    652    653    654    655    656    700
         51  THRU   60           701    702    703    704    705    706    750    751    752    753
         61  THRU   70           754    755    756    800    801    802    803    804    805    806
         71  THRU   80           850    851    852    853    854    855    856    900    901    902
         81  THRU   90           903    904    905    906    950    951    952    953    954    955
         91  THRU  100           956   1100   1101   1102   1103   1104   1105   1106   1150   1151
        101  THRU  110          1152   1153   1154   1155   1156   1200   1201   1202   1203   1204
        111  THRU  120          1205   1206   1250   1251   1252   1253   1254   1255   1256   1300
        121  THRU  130          1301   1302   1303   1304   1305   1306   1350   1351   1352   1353
```

```
   131  THRU   140        1354   1355   1356   1400   1401   1402   1403   1404   1405   1406
   141  THRU   150        1450   1451   1452   1453   1454   1455   1456   1500   1501   1502
   151  THRU   160        1503   1504   1505   1506   1550   1551   1552   1553   1554   1555
   161  THRU   170        1556   2100   2101   2102   2103   2104   2105   2106   2150   2151
   171  THRU   180        2152   2153   2154   2155   2156   2200   2201   2202   2203   2204
   181  THRU   190        2205   2206   2250   2251   2252   2253   2254   2255   2256   2300
   191  THRU   200        2301   2302   2303   2304   2305   2306   2350   2351   2352   2353
   201  THRU   210        2354   2355   2356   2400   2401   2402   2403   2404   2405   2406
   211  THRU   220        2450   2451   2452   2453   2454   2455   2456   2500   2501   2502
   221  THRU   230        2503   2504   2505   2506   2550   2551   2552   2553   2554   2555
   231  THRU   240        2556   3100   3101   3102   3103   3104   3105   3106   3150   3151
   241  THRU   250        3152   3153   3154   3155   3156   3200   3201   3202   3203   3204
   251  THRU   260        3205   3206   3250   3251   3252   3253   3254   3255   3256   3300
   261  THRU   270        3301   3302   3303   3304   3305   3306   3350   3351   3352   3353
   271  THRU   280        3354   3355   3356   3400   3401   3402   3403   3404   3405   3406
   281  THRU   290        3450   3451   3452   3453   3454   3455   3456   3500   3501   3502
   291  THRU   300        3503   3504   3505   3506   3550   3551   3552   3553   3554   3555
   301  THRU   310        3556   4100   4101   4102   4103   4104   4105   4106   4150   4151
   311  THRU   320        4152   4153   4154   4155   4156   4200   4201   4202   4203   4204
   321  THRU   330        4205   4206   4250   4251   4252   4253   4254   4255   4256   4300
   331  THRU   340        4301   4302   4303   4304   4305   4306   4350   4351   4352   4353
   341  THRU   350        4354   4355   4356   4400   4401   4402   4403   4404   4405   4406
   351  THRU   360        4450   4451   4452   4453   4454   4455   4456   4500   4501   4502
   361  THRU   370        4503   4504   4505   4506   4550   4551   4552   4553   4554   4555
   371  THRU   380        4556   5100   5101   5102   5103   5104   5105   5106   5150   5151
   381  THRU   390        5152   5153   5154   5155   5156   5200   5201   5202   5203   5204
   391  THRU   400        5205   5206   5250   5251   5252   5253   5254   5255   5256   5300
   401  THRU   410        5301   5302   5303   5304   5305   5306   1000   1001   1002   1003
   411  THRU   420        1004   1005   1006   2000   2001   2002   2003   2004   2005   2006
   421  THRU   430        3000   3001   3002   3003   3004   3005   3006   4000   4001   4002
   431  THRU   440        4003   4004   4005   4006   5000   5001   5002   5003   5004   5005
   441  THRU   450        5006   1050   1051   1052   1053   1054   1055   1056   2050   2051
   451  THRU   460        2052   2053   2054   2055   2056   3050   3051   3052   3053   3054
   461  THRU   470        3055   3056   4050   4051   4052   4053   4054   4055   4056   5050
   471  THRU   480        5051   5052   5053   5054   5055   5056   1007   2007   3007   4007
   481  THRU   490        5007   1049   2049   3049   4049   5049   1099   2099   3099   4099
   491  THRU   500        5099     52     53     54     51     55    325    326    327    328
   501  THRU   510         329    330    331    332    375    376    377    378    379    380
   511  THRU   520         381    382    425    426    427    428    429    430    431    432
   521  THRU   530         475    476    477    478    479    480    481    482    525    526
   531  THRU   540         527    528    529    530    531    532    575    576    577    578
   541  THRU   550         579    580    581    582    625    626    627    628    629    630
   551  THRU   560         631    632    675    676    677    678    679    680    681    682
   561  THRU   570         725    726    727    728    729    730    731    732    775    776
   571  THRU   580         777    778    779    780    781    782    825    826    827    828
   581  THRU   590         829    830    831    832    875    876    877    878    879    880
   591  THRU   600         881    882    925    926    927    928    929    930    931    932
   601  THRU   610        1125   1126   1127   1128   1129   1130   1131   1132   1175   1176
   611  THRU   620        1177   1178   1179   1180   1181   1182   1225   1226   1227   1228
   621  THRU   630        1229   1230   1231   1232   1275   1276   1277   1278   1279   1280
   631  THRU   640        1281   1282   1375   1376   1377   1378   1379   1380   1381   1382
   641  THRU   650        1425   1426   1427   1428   1429   1430   1431   1432   1475   1476
   651  THRU   660        1477   1478   1479   1480   1481   1482   1525   1526   1527   1528
   661  THRU   670        1529   1530   1531   1532   2125   2126   2127   2128   2129   2130
   671  THRU   680        2131   2132   2175   2176   2177   2178   2179   2180   2181   2182
   681  THRU   690        2225   2226   2227   2228   2229   2230   2231   2232   2275   2276
   691  THRU   700        2277   2278   2279   2280   2281   2282   2375   2376   2377   2378
```

```
            701   THRU      710           2379      2380      2381      2382      2425      2426      2427      2428      2429      2430
            711   THRU      720           2431      2432      2475      2476      2477      2478      2479      2480      2481      2482
            721   THRU      730           2525      2526      2527      2528      2529      2530      2531      2532      3125      3126
            731   THRU      740           3127      3128      3129      3130      3131      3132      3175      3176      3177      3178
            741   THRU      750           3179      3180      3181      3182      3225      3226      3227      3228      3229      3230
            751   THRU      760           3231      3232      3275      3276      3277      3278      3279      3280      3281      3282
            761   THRU      770           3375      3376      3377      3378      3379      3380      3381      3382      3425      3426
            771   THRU      780           3427      3428      3429      3430      3431      3432      3475      3476      3477      3478
            781   THRU      790           3479      3480      3481      3482      3525      3526      3527      3528      3529      3530
            791   THRU      800           3531      3532      4125      4126      4127      4128      4129      4130      4131      4132
            801   THRU      810           4175      4176      4177      4178      4179      4180      4181      4182      4225      4226
            811   THRU      820           4227      4228      4229      4230      4231      4232      4275      4276      4277      4278
            821   THRU      830           4279      4280      4281      4282      4375      4376      4377      4378      4379      4380
            831   THRU      640           4381      4382      4425      4426      4427      4428      4429      4430      4431      4432
            841   THRU      850           4475      4476      4477      4478      4479      4480      4481      4482      4525      4526
            851   THRU      860           4527      4528      4529      4530      4531      4532      5125      5126      5127      5128
            861   THRU      870           5129      5130      5131      5132      5175      5176      5177      5178      5179      5180
            871   THRU      880           5181      5182      5225      5226      5227      5228      5229      5230      5231      5232
            881   THRU      690           5275      5276      5277      5278      5279      5280      5281      5282       975       976
            891   THRU      900            977       978       979       980       981       982      1075      1076      1077      1078
            901   THRU      910           1079      1080      1081      1082      1325      1326      1327      1328      1329      1330
            911   THRU      920           1331      1332      1025      1026      1027      1028      1029      1030      1031      1032
            921   THRU      930           1575      1576      1577      1578      1579      1580      1581      1582      2025      2026
            931   THRU      940           2027      2028      2029      2030      2031      2032      2325      2326      2327      2328
            941   THRU      950           2329      2330      2331      2332      2075      2076      7077      2078      2079      2080
            951   THRU      960           2081      2082      2575      2576      2577      2578      2579      2580      2581      2582
            961   THRU      970           3075      3076      3077      3078      3079      3080      3081      3082      3325      3326
            971   THRU      980           3327      3328      3329      3330      3331      3332      3025      3026      3027      3028
            981   THRU      990           3029      3030      3031      3032      3575      3576      3577      3578      3579      3580
            991   THRU     1000           3581      3582      4025      4026      4027      4028      4029      4030      4031      4032
           1001   THRU     1010           4325      4326      4327      4328      4329      4330      4331      4332      4075      4076
           1011   THRU     1020           4077      4078      4079      4080      4081      4082      4575      4576      4577      4578
           1021   THRU     1030           4579      4580      4581      4582      5075      5076      5077      5078      5079      5080
           1031   THRU     1040           5081      5082      5325      5326      5327      5328      5329      5330      5331      5332
           1041   THRU     1050           5025      5026      5027      5028      5029      5030      5031      5032       799      1799
           1051   THRU     1060           2799      3799      4799      1399      2399      3399      4399      5399       899      1899
           1061   THRU     1070           2899      3899      4899      1299      2299      3299      4299      5299       999      1999
           1071   THRU     1078           2999      3999      4999      1199      2199      3199      4199      5199
        CONDUCTOR ANALYSIS...  LINEAR =  1078,  RADIATION =     0,  TOTAL =  1078,  CONNECTIONS =  1078
        BCD 3FLOW DATA
        BCD 3NETWORK MAIN
            GC=6.0042E10,CP=A4,RO=A5,MU=A6,KT=A7,MPASS=1,H=A8
            TOL=.01,MXPASS=100,FRDX=.7,P(4)=0.,END
            1,2,3=(99,999,107,1007),(183,1083,191,1091),END
            2,2,3=(199,1999,207,2007),(283,2083,291,2091),END
            3,2,3=(299,2999,307,3007),(383,3083,391,3091),END
            4,2,3=(399,3999,407,4007),(483,4083,491,4091),END
            5,2,3=(499,4999,507,5007),(583,5083,591,5091),END
            6,1,2=1,-3,END
            7,3,4=2,4,END
        END
        BCD 3FLUID LUMP DATA
            2.131E-5,.01636,3.125,.0511,0.,0,1.,1.,1.=(99,107),(183,191)
            (199,207),(283,291),(299,307),(383,391),(399,407),(483,491)
            (499,507),(583,591),END
            .0001065,.03658,.50,.01829,0.,0,1.,1.,1.=1,2,END
```

```
END
BCD 3FLOW SOURCE DATA
    1,A1,END
END
BCD 3END FLOW DATA
BCD 3CONSTANTS DATA
    TIMEND,.5  $
    DTIMEI,.005 $
    NLOOP,100  $
    DRLXCA,.01 $
    ARLXCA,.01 $
    OUTPUT,.05 $
     1,10.   $
END
CONSTANTS ANALYSIS...  USER =     1,  ADDED =     0       0       0,  TOTAL =     1
BCD 3ARRAY DATA
    1 $ FLOWRATE VS TIME
    0.,96.0,20.,96.0,END
    4 $ CP COOLANOL 15
    -150.,.343,-100.,.363,-50.,.385,0.,.405,50.,.424,100.,.444
    150.,.465,200.,.483,END
    5 $ RHO COOLANOL 15
    -150.,63.4,-100.,62.3,-50.,60.2,0.,58.3,50.,56.5,100.,54.7
    150.,52.9,200.,51.1,END
    6 $ VISCOSITY COOLANOL 15
    -150.,2500.,-100.,365.,-50.,30.,0.,10.4,50.,5.5,100.,3.7
    150.,2.4,200.,1.9,END
    7 $ CONDUCTIVITY COOLANOL 15
    -150.,.065,200.,.065,END
    8,SPACE,16,END $ ENTHALPY CURVE
    10,*A11,*A12,*A13,*A14,*A15,*A28,END
    11,13,*T51,140.7,1,*T52,73.2,1,*T53,11.14,1,*T54,11.04,1
    *T55,0.638,5,*T56,1.438,16,*T57,1.438,16,*T58,2.996,2
    *T59,2.996,2,*T60,11.446,126,*T61,11.446,126,*T62,11.446,126
    *T63,12.417,127,END
    12,1.,1.0,1.0,.02,.10,.67,.67,.67,.67,.67,.67,.67,.67,END
    13,0.0,0.0,0.0,.98,.90,.33,.33,.33,.33,.33,.33,.33,.33,END
    14,*T63,*T62,0.,*T63,*T61,0.,*T63,*T60,0.,*T63,*T59,0.
    *T63,*T58,.004,*T63,*T57,0.,*T63,*T56,.02,*T63,*T55,0.
    *T63,*T54,.0016,*T63,*T53,.006,*T63,*T52,.057,*T63,*T51,.869
    *T62,*T61,0.,*T62,*T60,0.,*T62,*T59,0.,*T62,*T58,0.0
    *T62,*T57,0.,*T62,*T56,.02,*T62,*T55,0.,*T62,*T54,.0016
    *T62,*T53,.002,*T62,*T52,.057,*T62,*T51,.890,*T61,*T60,0.
    *T61,*T59,0.,*T61,*T58,0.,*T61,*T57,0.,*T61,*T56,.02,*T61,*T55,0.
    *T61,*T54,.0035,*T61,*T53,.001,*T61,*T52,.088,*T61,*T51,.848
    *T60,*T59,0.,*T60,*T58,0.,*T60,*T57,0.,*T60,*T56,.02,*T60,*T55,.03
    *T60,*T54,.010,*T60,*T53,0.,*T60,*T52,.3275,*T60,*T51,.49
    *T59,*T58,0.,*T59,*T57,0.,*T59,*T56,0.,*T59,*T55,0.,*T59,*T54,0.
    *T59,*T53,0.,*T59,*T52,0.,*T59,*T51,.5,*T58,*T57,0.,*T58,*T56,.02
    *T58,*T55,0.,*T58,*T54,.05,*T58,*T53,0.,*T58,*T52,.05,*T58,*T51,.6
    *T57,*T56,0.,*T57,*T55,0.,*T57,*T54,0.,*T57,*T53,.05,*T57,*T52,.2
    *T57,*T51,.75,*T56,*T55,.01,*T56,*T54,.05,*T56,*T53,0.,*T56,*T52,.2
    *T56,*T51,.6,*T55,*T54,.5,*T55,*T53,0.,*T55,*T52,0.,*T55,*T51,.5
    *T54,*T53,.05,*T54,*T52,.05,*T54,*T51,.7,*T53,*T52,.2
    *T53,*T51,.70,*T52,*T51,.70,END
    15,*T9001,140.7,END
```

```
16,*T9002,73.2,END
17,*T9003,11.14,END
18,*T9004,11.04,END
19,*T998,.1275,*T1998,.1275,*T2998,.1275,*T3998,.1275
*T4998,.1275,END
20,*T1700,.08983,*T1701,.08983,*T1702,.08983,*T1703,.08983
*T1704,.08983,*T1705,.08983,*T1706,.08983,*T1707,.08983
*T1800,.08983,*T1801,.08983,*T1802,.08983,*T1803,.08983
*T1804,.08983,*T1805,.08983,*T1806,.08983,*T1807,.08983,END
21,*T1650,.08983,*T1651,.08983,*T1652,.08983,*T1653,.08983
*T1654,.08983,*T1655,.08983,*T1656,.08983,*T1657,.08983
*T1750,.08983,*T1751,.08983,*T1752,.08983,*T1753,.08983
*T1754,.08983,*T1755,.08983,*T1756,.08983,*T1757,.08983,END
22,*T1054,1.4979,*T1055,1.4979,END
23,*T1052,1.4979,*T1053,1.4979,END
24,*T1900,.0908,*T1901,.0908,*T1950,.0908,*T1951,.0908
*T2700,.0908,*T2701,.0908,*T2750,.0908,*T2751,.0908
*T2800,.0908,*T2801,.0908,*T2850,.0908,*T2851,.0908
*T2900,.0908,*T2901,.0908,*T2950,.0908,*T2951,.0908
*T1090,.0908,*T1089,.0908,*T1100,.0908,*T1101,.0908
*T1450,.0908,*T1451,.0908,*T1150,.0908,*T1151,.0908
*T1200,.0908,*T1201,.0908,*T1250,.0908,*T1251,.0908
*T1300,.0908,*T1301,.0908,*T1000,.0908,*T1001,.0908
*T1350,.0908,*T1351,.0908,*T1400,.0908,*T1401,.0908
*T1500,.0908,*T1501,.0908,*T1550,.0908,*T1551,.0908
*T2000,.0908,*T2001,.0908,*T2100,.0908,*T2101,.0908
*T2150,.0908,*T2151,.0908,*T2200,.0908,*T2201,.0908
*T2250,.0908,*T2251,.0908,*T2300,.0908,*T2301,.0908
*T2090,.0908,*T2089,.0908,*T2350,.0908,*T2351,.0908
*T2400,.0908,*T2401,.0908,*T2450,.0908,*T2451,.0908
*T2500,.0908,*T2501,.0908,*T2550,.0908,*T2551,.0908
*T3090,.0908,*T3089,.0908,*T3100,.0908,*T3101,.0908
*T3150,.0908,*T3151,.0908,*T3200,.0908,*T3201,.0908
*T3250,.0908,*T3251,.0908,*T3300,.0908,*T3301,.0908
*T3000,.0908,*T3001,.0908,*T3350,.0908,*T3351,.0908
*T3400,.0908,*T3401,.0908,*T3450,.0908,*T3451,.0908
*T3500,.0908,*T3501,.0908,*T3550,.0908,*T3551,.0908
*T4000,.0908,*T4001,.0908,*T4100,.0908,*T4101,.0908
*T4150,.0908,*T4151,.0908,*T4200,.0908,*T4201,.0908
*T4250,.0908,*T4251,.0908,*T4300,.0908,*T4301,.0908
*T4090,.0908,*T4089,.0908,*T4350,.0908,*T4351,.0908
*T4400,.0908,*T4401,.0908,*T4450,.0908,*T4451,.0908
*T4500,.0908,*T4501,.0908,*T4550,.0908,*T4551,.0908
*T5090,.0908,*T5089,.0908,*T5100,.0908,*T5101,.0908
*T5150,.0908,*T5151,.0908,*T5200,.0908,*T5201,.0908
*T5250,.0908,*T5251,.0908,*T5300,.0908,*T5301,.0908
*T5000,.0908,*T5001,.0908,END
25,*T1902,.0908,*T1903,.0908,*T1952,.0908,*T1953,.0908
*T1002,.0908,*T1003,.0908,*T1552,.0908,*T1553,.0908
*T2702,.0908,*T2703,.0908,*T2752,.0908,*T2753,.0908
*T2802,.0908,*T2803,.0908,*T2852,.0908,*T2853,.0908
*T2902,.0908,*T2903,.0908,*T2952,.0908,*T2953,.0908
*T1088,.0908,*T1087,.0908,*T1102,.0908,*T1103,.0908
*T1152,.0908,*T1153,.0908,*T1202,.0908,*T1203,.0908
*T1252,.0908,*T1253,.0908,*T1302,.0908,*T1303,.0908
*T1352,.0908,*T1353,.0908,*T1402,.0908,*T1403,.0908
*T1452,.0908,*T1453,.0908,*T1502,.0908,*T1503,.0908
```

```
*T2002,.0908,*T2003,.0908,*T2102,.0908,*T2103,.0908
*T2152,.0908,*T2153,.0908,*T2202,.0908,*T2203,.0909
*T2252,.0908,*T2253,.0908,*T2302,.0908,*T2303,.0908
*T2088,.0908,*T2087,.0908,*T2352,.0908,*T2353,.0908
*T2402,.0908,*T2403,.0908,*T2452,.0908,*T2453,.0908
*T2502,.0908,*T2503,.0908,*T2552,.0908,*T2553,.0908
*T3088,.0908,*T3087,.0908,*T3102,.0908,*T3103,.0908
*T3152,.0908,*T3153,.0908,*T3202,.0908,*T3203,.0908
*T3252,.0908,*T3253,.0908,*T3302,.0908,*T3303,.0908
*T3002,.0908,*T3003,.0908,*T3352,.0908,*T3353,.0908
*T3402,.0908,*T3403,.0908,*T3452,.0908,*T3453,.0908
*T3502,.0906,*T3503,.0908,*T3552,.0908,*T3553,.0908
*T4002,.0908,*T4003,.0908,*T4102,.0908,*T4103,.0908
*T4152,.0908,*T4153,.0908,*T4202,.0908,*T4203,.0908
*T4252,.0908,*T4253,.0908,*T4302,.0908,*T4303,.0908
*T4088,.0908,*T4087,.0908,*T4352,.0908,*T4353,.0908
*T4402,.0908,*T4403,.0908,*T4452,.0908,*T4453,.0908
*T4502,.0908,*T4503,.0908,*T4552,.0908,*T4553,.0908
*T5088,.0908,*T5087,.0908,*T5102,.0908,*T5103,.0908
*T5152,.0908,*T5153,.0908,*T5202,.0908,*T5203,.0908
*T5252,.0908,*T5253,.0908,*T5302,.0908,*T5303,.0908
*T5002,.0908,*T5003,.0908,END
26,*T1904,.0908,*T1905,.0908,*T1954,.0908,*T1955,.0908
*T1004,.0908,*T1005,.0908,*T1554,.0908,*T1555,.0908
*T2704,.0908,*T2705,.0908,*T2754,.0908,*T2755,.0908
*T2804,.0908,*T2805,.0908,*T2854,.0908,*T2855,.0908
*T2904,.0908,*T2905,.0908,*T2954,.0908,*T2955,.0908
*T1086,.0908,*T1085,.0908,*T1104,.0908,*T1105,.0908
*T1154,.0908,*T1155,.0908,*T1204,.0908,*T1205,.0908
*T1254,.0908,*T1255,.0908,*T1304,.0908,*T1305,.0908
*T1354,.0908,*T1355,.0908,*T1404,.0908,*T1405,.0908
*T1454,.0908,*T1455,.0908,*T1504,.0908,*T1505,.0908
*T2004,.0908,*T2005,.0908,*T2104,.0908,*T2105,.0908
*T2154,.0908,*T2155,.0908,*T2204,.0908,*T2205,.0908
*T2254,.0906,*T2255,.0908,*T2304,.0908,*T2305,.0908
*T2086,.0908,*T2085,.0908,*T2354,.0908,*T2355,.0908
*T2404,.0908,*T2405,.0908,*T2454,.0908,*T2455,.0908
*T2504,.0908,*T2505,.0908,*T2554,.0908,*T2555,.0908
*T3086,.0908,*T3085,.0908,*T3104,.0908,*T3105,.0908
*T3154,.0908,*T3155,.0908,*T3204,.0908,*T3205,.0908
*T3254,.0906,*T3255,.0908,*T3304,.0908,*T3305,.0908
*T3004,.0908,*T3005,.0908,*T3354,.0908,*T3355,.0908
*T3404,.0908,*T3405,.0908,*T3454,.0908,*T3455,.0908
*T3504,.0908,*T3505,.0908,*T3554,.0908,*T3555,.0908
*T4004,.0906,*T4005,.0908,*T4104,.0908,*T4105,.0908
*T4154,.0908,*T4155,.0908,*T4204,.0908,*T4205,.0908
*T4254,.0908,*T4255,.0908,*T4304,.0908,*T4305,.0908
*T4086,.0908,*T4085,.0908,*T4354,.0908,*T4355,.0908
*T4404,.0906,*T4405,.0908,*T4454,.0908,*T4455,.0908
*T4504,.0908,*T4505,.0908,*T4554,.0908,*T4555,.0908
*T5086,.0908,*T5085,.0908,*T5104,.0908,*T5105,.0908
*T5154,.0906,*T5155,.0908,*T5204,.0908,*T5205,.0908
*T5254,.0908,*T5255,.0908,*T5304,.0908,*T5305,.0908
*T5004,.0908,*T5005,.0908,END
27,*T1906,.0908,*T1907,.0908,*T1956,.0908,*T1957,.0908
*T1006,.0908,*T1007,.0908,*T1556,.0908,*T1557,.0908
*T2706,.0908,*T2707,.0908,*T2756,.0908,*T2757,.0908
```

```
          *T2806,.0908,*T2807,.0908,*T2856,.0908,*T2857,.0908
          *T2906,.0908,*T2907,.0908,*T2956,.0908,*T2957,.0908
          *T1084,.0908,*T1083,.0908,*T1106,.0908,*T1107,.0908
          *T1156,.0908,*T1157,.0908,*T1206,.0908,*T1207,.0908
          *T1256,.0908,*T1257,.0908,*T1306,.0908,*T1307,.0908
          *T1356,.0908,*T1357,.0908,*T1406,.0908,*T1407,.0908
          *T1456,.0908,*T1457,.0908,*T1506,.0908,*T1507,.0908
          *T2006,.0908,*T2007,.0908,*T2106,.0908,*T2107,.0908
          *T2156,.0908,*T2157,.0908,*T2206,.0908,*T2207,.0908
          *T2256,.0908,*T2257,.0908,*T2306,.0908,*T2307,.0908
          *T2084,.0908,*T2083,.0908,*T2356,.0908,*T2357,.0908
          *T2406,.0908,*T2407,.0908,*T2456,.0908,*T2457,.0908
          *T2506,.0908,*T2507,.0908,*T2556,.0908,*T2557,.0908
          *T3084,.0908,*T3083,.0908,*T3106,.0908,*T3107,.0908
          *T3156,.0908,*T3157,.0908,*T3206,.0908,*T3207,.0908
          *T3256,.0908,*T3257,.0908,*T3306,.0908,*T3307,.0908
          *T3006,.0908,*T3007,.0908,*T3356,.0908,*T3357,.0908
          *T3406,.0908,*T3407,.0908,*T3456,.0908,*T3457,.0908
          *T3506,.0908,*T3507,.0908,*T3556,.0908,*T3557,.0908
          *T4006,.0908,*T4007,.0908,*T4106,.0908,*T4107,.0908
          *T4156,.0908,*T4157,.0908,*T4206,.0908,*T4207,.0908
          *T4256,.0908,*T4257,.0908,*T4306,.0908,*T4307,.0908
          *T4084,.0908,*T4083,.0908,*T4356,.0908,*T4357,.0908
          *T4406,.0908,*T4407,.0908,*T4456,.0908,*T4457,.0908
          *T4506,.0908,*T4507,.0908,*T4556,.0908,*T4557,.0908
          *T5084,.0908,*T5083,.0908,*T5106,.0908,*T5107,.0908
          *T5156,.0908,*T5157,.0908,*T5206,.0908,*T5207,.0908
          *T5256,.0908,*T5257,.0908,*T5306,.0908,*T5307,.0908
          *T5006,.0908,*T5007,.0908,*T1051,.9710,END
          28,SPACE,91,END
      END
      ARRAY ANALYSIS...  NUMBER OF ARRAYS =   25  TOTAL LENGTH =  1594

TUBE NUMBER LIST
        1           2           3           4           5           6           7                                                 7

PRESSURE NODE LIST
        1           2           3           4                                                                                     4
      BCD 3EXECUTION
     DIMENSION X(10000)                                                           F
     NDIM=10000                                                                   F
     NTH=0                                                                        F
          RESET
          CRVINT(A4,A8)
          TOPLIN
          GENOUT(A8+1,1,A8,3H0A8)
          FLOSOL
     ITEST=0                                                                      F
          CSGDMP
     ITEST=1                                                                      F
          CNBACK
      END
      BCD 3VARIABLES 1
     IF(ITEST.EQ.1) CALL RADIR(A10,.1714E-8,-460.)                                M
     T5355=T3555                                                                  M
     T5351=T3551                                                                  M
```

```
          T5352=T3552                                                         M
          T5353=T3553                                                         M
          T5354=T3554                                                         M
          T5355=T3555                                                         M
          T5356=T3556                                                         M
          T5357=T3557                                                         M
           END
           BCD 3VARIABLES 2
               FLOSOL
               TIMCHK(K1,0)
           END
           BCD 3OUTPUT CALLS
               TPRNT
               WPRINT(1,1,1,0)
               TIMCHK(K1,1)
           END

 @ADD,P ECD2-V55008*SINFLO.PROC
```

```
      SYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER   - - -  SINDA  - - -   UNIVAC-1108 FORTRAN-V VERSION        PAGE    58
      SOFT TUBE INFLATABLE RADIATOR
    IR CROSS RADIATION DATA

       SURFACE DATA
            NUMBER OF SURFACES =   13
            SURFACE NUMBER        SURFACE AREA      NUMBER OF NODES
                          51         140.70000                   1
                          52          73.20000                   1
                          53          11.14000                   1
                          54          11.04000                   1
                          55            .63800                   5
                          56           1.43800                  16
                          57           1.43800                  16
                          58           2.99600                   2
                          59           2.99600                   2
                          60          11.44600                 126
                          61          11.44600                 126
                          62          11.44600                 126
                          63          12.41700                 127

       SURFACE EMISSIVITY DATA
                 .10000+01   .10000+01   .10000+01   .20000-01   .10000+00   .67000+00   .67000+00   .67000+00   .67000+00   .67000+00
                 .67000+00   .67000+00   .67000+00

       SURFACE REFLECTIVITY DATA
                 .00000      .00000      .00000      .98000+00   .90000+00   .33000+00   .33000+00   .33000+00   .33000+00   .33000+00
                 .33000+00   .33000+00   .33000+00

       SURFACE CONNECTION DATA
            FROM SURFACE       TO SURFACE        VIEW FACTOR
                      63               62        .00000
                      63               61        .00000
                      63               60        .00000
                      63               59        .00000
                      63               58        .40000-02
                      63               57        .00000
                      63               56        .20000-01
                      63               55        .00000
                      63               54        .16000-02
                      63               53        .60000-02
```

```
                                    63                  52              .57000-01
                                    63                  51              .86900+00
                                    62                  61              .00000
                                    62                  60              .00000
                                    62                  59              .00000
                                    62                  58              .00000
                                    62                  57              .00000
                                    62                  56              .20000-01
                                    62                  55              .00000
                                    62                  54              .16000-02
                                    62                  53              .20000-02
                                    62                  52              .57000-01
                                    62                  51              .89000+00
                                    61                  60              .00000
                                    61                  59              .00000
```

```
SOFT TUBE INFLATABLE RADIATOR
                     61                 58            .00000
                     61                 57            .00000
                     61                 56            .20000-01
                     61                 55            .00000
                     61                 54            .35000-02
                     61                 53            .10000-02
                     61                 52            .86000-01
                     61                 51            .84800+00
                     60                 59            .00000
                     60                 58            .00000
                     60                 57            .00000
                     60                 56            .20000-01
                     60                 55            .30000-01
                     60                 54            .10000-01
                     60                 53            .00000
                     60                 52            .32750+00
                     60                 51            .49000+00
                     59                 58            .00000
                     59                 57            .00000
                     59                 56            .00000
                     59                 55            .00000
                     59                 54            .00000
                     59                 53            .00000
                     59                 52            .00000
                     59                 51            .50000+00
                     58                 57            .00000
                     58                 56            .20000-01
                     58                 55            .00000
                     58                 54            .50000-01
                     58                 53            .00000
                     58                 52            .50000-01
                     58                 51            .60000+00
                     57                 56            .00000
                     57                 55            .00000
                     57                 54            .00000
                     57                 53            .50000-01
                     57                 52            .20000+00
                     57                 51            .75000+00
                     56                 55            .10000-01
                     56                 54            .50000-01
                     56                 53            .00000
                     56                 52            .20000+00
                     56                 51            .60000+00
                     55                 54            .50000+00
                     55                 53            .00000
                     55                 52            .00000
                     55                 51            .50000+00
```

```
SOFT TUBE INFLATABLE RADIATOR
                   54             53          .50000-01
                   54             52          .50000-01
                   54             51          .70000+00
                   53             52          .20000+00
                   53             51          .70000+00
                   52             51          .70000+00


 NODE DATA

                SURFACE    NODE        AREA    NODE        AREA    NODE        AREA    NODE        AREA

                     51    9001   140.70000
                     52    9002    73.20000
                     53    9003    11.14000
                     54    9004    11.04000
                     55     998      .12750    1998      .12750    2998      .12750    3998      .12750
                           4998      .12750
                     56    1700      .08983    1701      .08983    1702      .08983    1703      .08983
                           1704      .08983    1705      .08983    1706      .08983    1707      .08983
                           1800      .08983    1801      .08983    1802      .08983    1803      .08983
                           1804      .08983    1805      .08983    1806      .08983    1807      .08983
                     57    1650      .08983    1651      .08983    1652      .08983    1653      .08983
                           1654      .08983    1655      .08983    1656      .08983    1657      .08983
                           1750      .08983    1751      .08983    1752      .08983    1753      .08983
                           1754      .08983    1755      .08983    1756      .08983    1757      .08983
                     58    1054     1.49790    1055     1.49790
                     59    1052     1.49790    1053     1.49790
                     60    1900      .09080    1901      .09080    1950      .09080    1951      .09080
                           2700      .09080    2701      .09080    2750      .09080    2751      .09080
                           2800      .09080    2801      .09080    2850      .09080    2851      .09080
                           2900      .09080    2901      .09080    2950      .09080    2951      .09080
                           1090      .09080    1089      .09080    1100      .09080    1101      .09080
                           1450      .09080    1451      .09080    1150      .09080    1151      .09080
                           1200      .09080    1201      .09080    1250      .09080    1251      .09080
                           1300      .09080    1301      .09080    1000      .09080    1001      .09080
                           1350      .09080    1351      .09080    1400      .09080    1401      .09080
                           1500      .09080    1501      .09080    1550      .09080    1551      .09080
                           2000      .09080    2001      .09080    2100      .09080    2101      .09080
                           2150      .09080    2151      .09080    2200      .09080    2201      .09080
                           2250      .09080    2251      .09080    2300      .09080    2301      .09080
                           2090      .09080    2089      .09080    2350      .09080    2351      .09080
                           2400      .09080    2401      .09080    2450      .09080    2451      .09080
                           2500      .09080    2501      .09080    2550      .09080    2551      .09080
                           3090      .09080    3089      .09080    3100      .09080    3101      .09080
```

```
SYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER   - - -  SINDA  - - -   UNIVAC-1108 FORTRAN-V VERSION        PAGE    61
SOFT TUBE INFLATABLE RADIATOR
                   3150        .09080        3151         .09080         3200        .09080        3201        .09080
                   3250        .09080        3251         .09080         3300        .09080        3301        .09080
                   3000        .09080        3001         .09080         3350        .09080        3351        .09080
                   3400        .09080        3401         .09080         3450        .09080        3451        .09080
                   3500        .09080        3501         .09080         3550        .09080        3551        .09080
                   4000        .09080        4001         .09080         4100        .09080        4101        .09080
                   4150        .09080        4151         .09090         4200        .09080        4201        .09080
                   4250        .09080        4251         .09080         4300        .09080        4301        .09080
                   4090        .09080        4089         .09080         4350        .09080        4351        .09080
                   4400        .09080        4401         .09080         4450        .09080        4451        .09080
                   4500        .09080        4501         .09080         4550        .09080        4551        .09080
                   5090        .09080        5089         .09080         5100        .09080        5101        .09080
                   5150        .09080        5151         .09080         5200        .09080        5201        .09080
                   5250        .09080        5251         .09080         5300        .09080        5301        .09080
                   5000        .09080        5001         .09080
          61       1902        .09080        1903         .09080         1952        .09080        1953        .09080
                   1002        .09080        1003         .09080         1552        .09080        1553        .09080
                   2702        .09080        2703         .09080         2752        .09080        2753        .09080
                   2802        .09080        2803         .09080         2852        .09080        2853        .09080
                   2902        .09080        2903         .09080         2952        .09080        2953        .09080
                   1088        .09080        1087         .09080         1102        .09080        1103        .09080
                   1152        .09080        1153         .09080         1202        .09080        1203        .09080
                   1252        .09080        1253         .09080         1302        .09080        1303        .09080
                   1352        .09080        1353         .09080         1402        .09080        1403        .09080
                   1452        .09080        1453         .09080         1502        .09080        1503        .09080
                   2002        .09080        2003         .09080         2102        .09080        2103        .09080
                   2152        .09080        2153         .09080         2202        .09080        2203        .09080
                   2252        .09080        2253         .09080         2302        .09080        2303        .09080
                   2088        .09080        2087         .09080         2352        .09080        2353        .09080
                   2402        .09080        2403         .09080         2452        .09080        2453        .09080
                   2502        .09080        2503         .09080         2552        .09080        2553        .09080
                   3088        .09080        3087         .09080         3102        .09080        3103        .09080
                   3152        .09080        3153         .09080         3202        .09080        3203        .09080
                   3252        .09080        3253         .09080         3302        .09080        3303        .09080
                   3002        .09080        3003         .09080         3352        .09080        3353        .09080
                   3402        .09080        3403         .09080         3452        .09080        3453        .09080
                   3502        .09080        3503         .09080         3552        .09080        3553        .09080
                   4002        .09080        4003         .09080         4102        .09080        4103        .09080
                   4152        .09080        4153         .09080         4202        .09080        4203        .09080
                   4252        .09080        4253         .09080         4302        .09080        4303        .09080
                   4088        .09080        4087         .09080         4352        .09080        4353        .09080
                   4402        .09080        4403         .09080         4452        .09080        4453        .09080
                   4502        .09080        4503         .09080         4552        .09080        4553        .09080
                   5088        .09080        5087         .09080         5102        .09080        5103        .09080
                   5152        .09080        5153         .09080         5202        .09080        5203        .09080
                   5252        .09080        5253         .09080         5302        .09080        5303        .09080
                   5002        .09080        5003         .09080
```

```
SOFT TUBE INFLATABLE RADIATOR
               62      1904        .09080       1905         .09080       1954        .09080       1955        .09080
                       1004        .09080       1005         .09080       1554        .09080       1555        .09080
                       2704        .09080       2705         .09080       2754        .09080       2755        .09080
                       2804        .09080       2805         .09080       2854        .09080       2855        .09080
                       2904        .09080       2905         .09080       2954        .09080       2955        .09080
                       1086        .09080       1085         .09080       1104        .09080       1105        .09080
                       1154        .09080       1155         .09080       1204        .09080       1205        .09080
                       1254        .09080       1255         .09080       1304        .09080       1305        .09080
                       1354        .09080       1355         .09080       1404        .09080       1405        .09080
                       1454        .09080       1455         .09080       1504        .09080       1505        .09080
                       2004        .09080       2005         .09080       2104        .09080       2105        .09080
                       2154        .09080       2155         .09080       2204        .09080       2205        .09080
                       2254        .09080       2255         .09080       2304        .09080       2305        .09080
                       2086        .09080       2085         .09080       2354        .09080       2355        .09080
                       2404        .09080       2405         .09080       2454        .09080       2455        .09080
                       2504        .09080       2505         .09080       2554        .09080       2555        .09080
                       3086        .09080       3085         .09080       3104        .09080       3105        .09080
                       3154        .09080       3155         .09080       3204        .09080       3205        .09080
                       3254        .09080       3255         .09080       3304        .09080       3305        .09080
                       3004        .09080       3005         .09080       3354        .09080       3355        .09080
                       3404        .09080       3405         .09080       3454        .09080       3455        .09080
                       3504        .09080       3505         .09080       3554        .09080       3555        .09080
                       4004        .09080       4005         .09080       4104        .09080       4105        .09080
                       4154        .09080       4155         .09080       4204        .09080       4205        .09080
                       4254        .09080       4255         .09080       4304        .09080       4305        .09080
                       4086        .09080       4085         .09080       4354        .09080       4355        .09080
                       4404        .09080       4405         .09080       4454        .09080       4455        .09080
                       4504        .09080       4505         .09080       4554        .09080       4555        .09080
                       5086        .09080       5085         .09080       5104        .09080       5105        .09080
                       5154        .09080       5155         .09080       5204        .09080       5205        .09080
                       5254        .09080       5255         .09080       5304        .09080       5305        .09080
                       5004        .09080       5005         .09080
               63      1906        .09080       1907         .09080       1956        .09080       1957        .09080
                       1006        .09080       1007         .09080       1556        .09080       1557        .09080
                       2706        .09080       2707         .09080       2756        .09080       2757        .09080
                       2806        .09080       2807         .09080       2856        .09080       2857        .09080
                       2906        .09080       2907         .09080       2956        .09080       2957        .09080
                       1084        .09080       1083         .09080       1106        .09080       1107        .09080
                       1156        .09080       1157         .09080       1206        .09080       1207        .09080
                       1256        .09080       1257         .09080       1306        .09080       1307        .09080
                       1356        .09080       1357         .09080       1406        .09080       1407        .09080
                       1456        .09080       1457         .09080       1506        .09080       1507        .09080
                       2006        .09080       2007         .09080       2106        .09080       2107        .09080
                       2156        .09080       2157         .09080       2206        .09080       2207        .09080
                       2256        .09080       2257         .09080       2306        .09080       2307        .09080
                       2084        .09080       2083         .09080       2356        .09080       2357        .09080
                       2406        .09080       2407         .09080       2456        .09080       2457        .09080
```

```
SOFT TUBE INFLATABLE RADIATOR
                    2506      .09080      2507      .09080      2556      .09080      2557      .09080
                    3084      .09080      3083      .09080      3106      .09080      3107      .09080
                    3156      .09080      3157      .09080      3206      .09080      3207      .09080
                    3256      .09080      3257      .09080      3306      .09080      3307      .09080
                    3006      .09080      3007      .09080      3356      .09080      3357      .09080
                    3406      .09080      3407      .09080      3456      .09060      3457      .09080
                    3506      .09080      3507      .09080      3556      .09080      3557      .09080
                    4006      .09080      4007      .09080      4106      .09080      4107      .09080
                    4156      .09080      4157      .09080      4206      .09080      4207      .09080
                    4256      .09080      4257      .09080      4306      .09080      4307      .09080
                    4084      .09080      4083      .09080      4356      .09080      4357      .09080
                    4406      .09080      4407      .09080      4456      .09080      4457      .09080
                    4506      .09080      4507      .09080      4556      .09080      4557      .09080
                    5084      .09080      5083      .09080      5106      .09080      5107      .09080
                    5156      .09080      5157      .09080      5206      .09080      5207      .09080
                    5256      .09080      5257      .09080      5306      .09080      5307      .09080
                    5006      .09080      5007      .09080      1051      .97100

 CONNECTION DATA

      FROM SURFACE     TO SURFACE     SCRIPT FA

               62             63     .59004-02
               61             63     .59225-02
               60             63     .63651-02
               59             63     .52012-06
               58             63     .23997-01
               57             63     .38952-06
               56             63     .11189+00
               55             63     .11330-03
               54             63     .34446-03
               53             63     .50792-01
               52             63     .48832+00
               51             63     .72914+01
               61             62     .54509-02
               60             62     .58515-02
               59             62     .49047-06
               58             62     .15616-02
               57             62     .36565-06
               56             62     .10300+00
               55             62     .10289-03
               54             62     .30718-03
               53             62     .16120-01
               52             62     .44958+00
```

```
SOFT TUBE INFLATABLE RADIATOR
          51             62          .68757+01
          60             61          .60928-02
          59             61          .46824-06
          58             61          .16941-02
          57             61          .35563-06
          56             61          .10307+00
          55             61          .14509-03
          54             61          .60252-03
          53             61          .91743-02
          52             61          .68808+00
          51             61          .65641+01
          59             60          .28913-06
          58             60          .31487-02
          57             60          .27556-06
          56             60          .10748+00
          55             60          .23712-01
          54             60          .37310-02
          53             60          .91715-02
          52             60          .25455+01
          51             60          .40531+01
          58             59          .92524-07
          57             59          .51545-07
          56             59          .56579-07
          55             59          .43662-08
          54             59          .11552-07
          53             59          .58808-06
          52             59          .37916-05
          51             59          .10037+01
          57             58          .69715-07
          56             58          .27588-01
          55             58          .30851-03
          54             58          .20501-02
          53             58          .50968-02
          52             58          .10944+00
          51             58          .12971+01
          56             57          .46777-07
          55             57          .33593-08
          54             57          .91168-08
          53             57          .48173-01
          52             57          .19269+00
          51             57          .72259+00
          55             56          .12813-02
          54             56          .11116-02
          53             56          .32067-02
          52             56          .22427+00
          51             56          .79315+00
          54             55          .65265-03
```

```
SYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER   - - -  SINDA  - - -   UNIVAC-1108 FORTRAN-V VERSION        PAGE    65
SOFT TUBE INFLATABLE RADIATOR
                  53                55       .15995-02
                  52                55       .55702-02
                  51                55       .61208-01
                  53                54       .11190-01
                  52                54       .11995-01
                  51                54       .16195+00
                  52                53       .22643+01
                  51                53       .82440+01
                  51                52       .53153+02
```

```
        SYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER   - - -   SINDA   - - -   UNIVAC-1108 FORTRAN-V VERSION        PAGE    93
        SOFT TUBE INFLATABLE RADIATOR
     T   5100=    12.059     T   5101=    12.446     T   5102=    10.058     T   5103=    11.327     T   5104=    12.281     T   5105=    13.677
     T   5106=    15.605     T   5107=    16.931     T   5150=    8.5246     T   5151=    7.7948     T   5152=    3.7429     T   5153=    4.1718
     T   5154=    4.1823     T   5155=    4.7432     T   5156=    5.9500     T   5157=    6.4542     T   5200=    11.621     T   5201=    9.7318
     T   5202=    4.5795     T   5203=    4.1959     T   5204=    3.3603     T   5205=    3.1223     T   5206=    3.5754     T   5207=    3.2901
     T   5250=    21.536     T   5251=    18.373     T   5252=    12.621     T   5253=    11.400     T   5254=    9.7624     T   5255=    8.7105
     T   5256=    8.3301     T   5257=    7.2375     T   5300=    38.893     T   5301=    34.253     T   5302=    28.392     T   5303=    26.254
     T   5304=    23.806     T   5305=    21.870     T   5306=    20.519     T   5307=    18.548     T   5350=    70.000     T   5351=    39.541
     T   5352=    32.663     T   5353=    29.630     T   5354=    26.273     T   5355=    23.451     T   5356=    21.223     T   5357=    18.359
     T   9001=   -311.00     T   9002=   -207.56     T   9003=   -311.00     T   9004=   -11.834

     W          1= 18.138    W          2= 19.399    W          3= 19.415    W          4= 19.424    W          5= 19.625
     W          6= 95.999    W          7= 96.002

     DP         1= 99.778    DP         2= 99.778    DP         3= 99.778    DP         4= 99.778    DP         5= 99.778
     DP         6= .15804    DP         7= .21680

     P          1= 100.15    P          2= 99.994    P          3= .21680    P          4= .00000

     COMPUTER TIME =    2.345 MINUTES
     **********
     TIME=        .50000 DTIMEU=   2.50000-03 CSGMIN(   2451)=   3.85454-04 TEMPCC(  1053)=   3.96748-01 RELXCC(  1850)=   7.50351-03
     T      1=    95.000     T      2=    34.856     T      3=    70.182     T      4=    34.857     T     51=   -311.00     T     52=   -207.82
     T     53=   -311.00     T     54=   -13.022     T     55=    85.651     T     56=   -108.45     T     57=   -131.74     T     58=   -106.11
     T     59=   -80.787     T     60=    14.445     T     61=    9.5898     T     62=    8.6223     T     63=    .90317     T     99=    94.697
     T    100=    89.996     T    101=    85.470     T    102=    80.780     T    103=    76.261     T    104=    71.868     T    105=    67.636
     T    106=    63.600     T    107=    59.637     T    183=    54.914     T    184=    50.434     T    185=    45.899     T    186=    41.519
     T    187=    37.346     T    188=    33.335     T    189=    29.807     T    190=    26.418     T    191=    26.423     T    199=    94.717
     T    200=    90.376     T    201=    86.182     T    202=    81.817     T    203=    77.596     T    204=    73.479     T    205=    69.496
     T    206=    65.683     T    207=    61.925     T    283=    58.303     T    284=    54.870     T    285=    51.512     T    286=    48.188
     T    287=    44.947     T    288=    41.820     T    289=    39.092     T    290=    36.463     T    291=    36.463     T    299=    94.717
     T    300=    90.384     T    301=    86.198     T    302=    81.843     T    303=    77.634     T    304=    73.528     T    305=    69.557
     T    306=    65.757     T    307=    62.013     T    383=    58.392     T    384=    54.959     T    385=    51.601     T    386=    48.281
     T    387=    45.039     T    388=    41.911     T    389=    39.182     T    390=    36.551     T    391=    36.552     T    399=    94.717
     T    400=    90.386     T    401=    86.203     T    402=    81.850     T    403=    77.642     T    404=    73.538     T    405=    69.570
     T    406=    65.771     T    407=    62.028     T    483=    58.414     T    484=    54.987     T    485=    51.636     T    486=    48.324
     T    487=    45.088     T    488=    41.966     T    489=    39.243     T    490=    36.619     T    491=    36.620     T    499=    94.720
     T    500=    91.410     T    501=    87.217     T    502=    82.857     T    503=    78.641     T    504=    74.528     T    505=    70.550
     T    506=    66.741     T    507=    62.988     T    583=    59.378     T    584=    55.953     T    585=    52.604     T    586=    49.337
     T    587=    46.099     T    588=    42.974     T    589=    40.245     T    590=    37.635     T    591=    37.635     T    998=    85.736
     T    999=    93.815     T   1000=    75.502     T   1001=    71.124     T   1002=    65.695     T   1003=    61.595     T   1004=    57.524
     T   1005=    53.751     T   1006=    50.314     T   1007=    46.557     T   1051=   -167.90     T   1052=   -81.334     T   1053=   -81.022
     T   1054=   -106.26     T   1055=   -106.74     T   1083=    39.294     T   1084=    35.589     T   1085=    31.461     T   1086=    27.617
     T   1087=    24.088     T   1088=    20.580     T   1089=    18.578     T   1090=    15.626     T   1091=    26.436     T   1092=    26.525
     T   1100=    2.6288     T   1101=    3.9676     T   1102=    2.0388     T   1103=    3.7826     T   1104=    5.2483     T   1105=    7.2569
     T   1106=    9.8309     T   1107=    11.746     T   1150=    .78466     T   1151=    1.1923     T   1152=   -2.5152     T   1153=   -1.7651
     T   1154=   -1.3992     T   1155=   -.40837     T   1156=    1.2499     T   1157=    2.1713     T   1200=    5.1222     T   1201=    4.6221
     T   1202=   -.30459     T   1203=   -.50240     T   1204=   -1.1206     T   1205=   -1.0861     T   1206=   -.34558     T   1207=   -.36028
```

```
     SOFT TUBE INFLATABLE RADIATOR
  T  1250=   15.892    T  1251=   14.455    T  1252=   8.8060    T  1253=   7.6482    T  1254=   6.1014    T  1255=   5.1818
  T  1256=   4.9461    T  1257=   3.9943    T  1300=   33.746    T  1301=   31.283    T  1302=   25.395    T  1303=   23.202
  T  1304=   20.725    T  1305=   18.792    T  1306=   17.456    T  1307=   15.507    T  1350=   42.348    T  1351=   38.915
  T  1352=   31.868    T  1353=   28.667    T  1354=   25.155    T  1355=   22.190    T  1356=   19.828    T  1357=   16.845
  T  1400=   30.492    T  1401=   27.401    T  1402=   19.808    T  1403=   16.929    T  1404=   13.623    T  1405=   10.948
  T  1406=   8.9669    T  1407=   6.2609    T  1450=   26.679    T  1451=   23.718    T  1452=   15.971    T  1453=   13.215
  T  1454=   9.9926    T  1455=   7.4267    T  1456=   5.5827    T  1457=   2.9790    T  1500=   30.649    T  1501=   27.623
  T  1502=   20.092    T  1503=   17.272    T  1504=   14.020    T  1505=   11.394    T  1506=   9.4571    T  1507=   6.7908
  T  1550=   42.673    T  1551=   39.375    T  1552=   32.457    T  1553=   29.377    T  1554=   25.977    T  1555=   23.113
  T  1556=   20.841    T  1557=   17.939    T  1650=  -131.28    T  1651=  -131.09    T  1652=  -132.69    T  1653=  -132.47
  T  1654=  -132.44    T  1655=  -132.20    T  1656=  -131.74    T  1657=  -131.51    T  1700=  -107.40    T  1701=  -106.99
  T  1702=  -110.05    T  1703=  -109.58    T  1704=  -109.49    T  1705=  -108.98    T  1706=  -108.07    T  1707=  -107.59
  T  1750=  -131.28    T  1751=  -131.09    T  1752=  -132.69    T  1753=  -132.47    T  1754=  -132.44    T  1755=  -132.20
  T  1756=  -131.74    T  1757=  -131.51    T  1800=  -107.40    T  1801=  -106.99    T  1802=  -110.05    T  1803=  -109.58
  T  1804=  -109.49    T  1805=  -108.98    T  1806=  -108.07    T  1807=  -107.59    T  1850=  -100.46    T  1851=  -99.656
  T  1852=  -105.42    T  1853=  -104.51    T  1854=  -104.30    T  1855=  -103.31    T  1856=  -101.56    T  1857=  -100.62
  T  1900=  -99.489    T  1901=  -98.634    T  1902=  -104.79    T  1903=  -103.80    T  1904=  -103.58    T  1905=  -102.52
  T  1906=  -100.65    T  1907=  -99.648    T  1950=  -96.452    T  1951=  -95.517    T  1952=  -101.62    T  1953=  -100.75
  T  1954=  -100.46    T  1955=  -99.298    T  1956=  -97.297    T  1957=  -96.196    T  1998=   85.762    T  1999=   93.842
  T  2000=   76.133    T  2001=   72.016    T  2002=   66.842    T  2003=   62.977    T  2004=   59.121    T  2005=   55.542
  T  2006=   52.275    T  2007=   48.673    T  2083=   45.505    T  2084=   42.712    T  2085=   39.605    T  2086=   36.673
  T  2087=   33.940    T  2088=   31.192    T  2089=   29.811    T  2090=   27.512    T  2091=   36.465    T  2092=   36.475
  T  2100=   35.890    T  2101=   33.507    T  2102=   27.656    T  2103=   25.512    T  2104=   23.060    T  2105=   21.126
  T  2106=   19.764    T  2107=   17.789    T  2150=   19.133    T  2151=   17.667    T  2152=   11.930    T  2153=   10.705
  T  2154=   9.0655    T  2155=   8.0213    T  2156=   7.6321    T  2157=   6.5371    T  2200=   9.6655    T  2201=   9.0237
  T  2202=   3.8883    T  2203=   3.5023    T  2204=   2.6671    T  2205=   2.4440    T  2206=   2.8902    T  2207=   2.6050
  T  2250=   6.9002    T  2251=   7.0439    T  2252=   3.0091    T  2253=   3.4374    T  2254=   3.4500    T  2255=   4.0338
  T  2256=   5.2365    T  2257=   5.7434    T  2300=   10.672    T  2301=   11.610    T  2302=   9.2368    T  2303=   10.506
  T  2304=   11.464    T  2305=   12.892    T  2306=   14.820    T  2307=   16.151    T  2350=   3.4949    T  2351=   5.3894
  T  2352=   4.1160    T  2353=   6.3464    T  2354=   8.2683    T  2355=   10.632    T  2356=   13.466    T  2357=   15.711
  T  2400=  -5.1921    T  2401=  -3.4400    T  2402=  -5.6456    T  2403=  -3.5963    T  2404=  -1.9579    T  2405=   .20731
  T  2406=   2.9445    T  2407=   4.9983    T  2450=  -8.0300    T  2451=  -6.3239    T  2452=  -8.8302    T  2453=  -6.8393
  T  2454=  -5.2921    T  2455=  -3.1910    T  2456=  -.48512    T  2457=   1.5072    T  2500=  -5.1725    T  2501=  -3.4202
  T  2502=  -5.6255    T  2503=  -3.5761    T  2504=  -1.9375    T  2505=   .22697    T  2506=   2.9642    T  2507=   5.0180
  T  2550=   3.5352    T  2551=   5.4303    T  2552=   4.1573    T  2553=   6.3882    T  2554=   8.3104    T  2555=   10.673
  T  2556=   13.507    T  2557=   15.752    T  2700=  -91.256    T  2701=  -90.214    T  2702=  -96.441    T  2703=  -95.244
  T  2704=  -94.827    T  2705=  -93.535    T  2706=  -91.386    T  2707=  -90.155    T  2750=  -83.751    T  2751=  -82.572
  T  2752=  -88.481    T  2753=  -87.122    T  2754=  -86.522    T  2755=  -85.054    T  2756=  -82.735    T  2757=  -81.336
  T  2800=  -73.709    T  2801=  -72.355    T  2802=  -77.689    T  2803=  -76.124    T  2804=  -75.268    T  2805=  -73.575
  T  2806=  -71.057    T  2807=  -69.442    T  2850=  -60.804    T  2851=  -59.230    T  2852=  -63.696    T  2853=  -61.869
  T  2854=  -60.671    T  2855=  -58.691    T  2856=  -55.937    T  2857=  -54.044    T  2900=  -44.561    T  2901=  -42.728
  T  2902=  -45.977    T  2903=  -43.816    T  2904=  -42.165    T  2905=  -39.818    T  2906=  -36.775    T  2907=  -34.527
  T  2950=  -24.402    T  2951=  -22.192    T  2952=  -23.783    T  2953=  -21.188    T  2954=  -18.940    T  2955=  -16.113
  T  2956=  -12.714    T  2957=  -10.000    T  2998=   85.762    T  2999=   93.843    T  3000=   76.155    T  3001=   72.051
  T  3002=   66.890    T  3003=   63.040    T  3004=   59.200    T  3005=   55.637    T  3006=   52.385    T  3007=   48.799
  T  3083=   45.584    T  3084=   42.791    T  3085=   39.683    T  3086=   36.755    T  3067=   34.020    T  3088=   31.271
```

```
         SYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER  - - -  SINDA  - - -  UNIVAC-1108 FORTRAN-V VERSION        PAGE    95

         SOFT TUBE INFLATABLE RADIATOR
     T   3089=   29.889      T   3090=   27.589      T   3091=   36.553      T   3092=   36.562      T   3100=   10.727      T   3101=   11.668
     T   3102=   9.2964      T   3103=   10.569      T   3104=   11.529      T   3105=   12.957      T   3106=   14.887      T   3107=   16.221
     T   3150=   6.9442      T   3151=   7.0918      T   3152=   3.0600      T   3153=   3.4923      T   3154=   3.5088      T   3155=   4.0950
     T   3156=   5.3020      T   3157=   5.8128      T   3200=   9.7011      T   3201=   9.0646      T   3202=   3.9336      T   3203=   3.5533
     T   3204=   2.7235      T   3205=   2.5050      T   3206=   2.9573      T   3207=   2.6780      T   3250=   19.162      T   3251=   17.704
     T   3252=   11.972      T   3253=   10.756      T   3254=   9.1233      T   3255=   8.0861      T   3256=   7.7052      T   3257=   6.6182
     T   3300=   35.916      T   3301=   33.541      T   3302=   27.699      T   3303=   25.565      T   3304=   23.123      T   3305=   21.199
     T   3306=   19.848      T   3307=   17.883      T   3350=   42.778      T   3351=   39.528      T   3352=   32.653      T   3353=   29.619
     T   3354=   26.262      T   3355=   23.439      T   3356=   21.207      T   3357=   18.342      T   3400=   30.814      T   3401=   27.860
     T   3402=   20.395      T   3403=   17.643      T   3404=   14.455      T   3405=   11.888      T   3406=   10.009      T   3407=   7.3952
     T   3450=   26.915      T   3451=   24.056      T   3452=   16.402      T   3453=   13.741      T   3454=   10.607      T   3455=   8.1229
     T   3456=   6.3565      T   3457=   3.8234      T   3500=   30.815      T   3501=   27.862      T   3502=   20.397      T   3503=   17.646
     T   3504=   14.457      T   3505=   11.891      T   3506=   10.012      T   3507=   7.3986      T   3550=   42.780      T   3551=   39.531
     T   3552=   32.657      T   3553=   29.623      T   3554=   26.267      T   3555=   23.445      T   3556=   21.213      T   3557=   18.349
     T   3998=   85.763      T   3999=   93.843      T   4000=   76.159      T   4001=   72.057      T   4002=   66.898      T   4003=   63.050
     T   4004=   59.211      T   4005=   55.648      T   4006=   52.398      T   4007=   48.813      T   4083=   45.624      T   4084=   42.837
     T   4085=   39.735      T   4086=   36.815      T   4087=   34.086      T   4088=   31.343      T   4089=   29.967      T   4090=   27.675
     T   4091=   36.621      T   4092=   36.630      T   4100=   35.931      T   4101=   33.557      T   4102=   27.715      T   4103=   25.581
     T   4104=   23.139      T   4105=   21.214      T   4106=   19.863      T   4107=   17.898      T   4150=   19.186      T   4151=   17.726
     T   4152=   11.994      T   4153=   10.776      T   4154=   9.1430      T   4155=   8.1043      T   4156=   7.7226      T   4157=   6.6347
     T   4200=   9.7338      T   4201=   9.0949      T   4202=   3.9618      T   4203=   3.5800      T   4204=   2.7486      T   4205=   2.5274
     T   4206=   2.9782      T   4207=   2.6971      T   4250=   6.9880      T   4251=   7.1321      T   4252=   3.0971      T   4253=   3.5269
     T   4254=   3.5408      T   4255=   4.1231      T   4256=   5.3276      T   4257=   5.8356      T   4300=   10.785      T   4301=   11.720
     T   4302=   9.3448      T   4303=   10.614      T   4304=   11.570      T   4305=   12.993      T   4306=   14.919      T   4307=   16.249
     T   4350=   3.7644      T   4351=   5.6399      T   4352=   4.3574      T   4353=   6.5834      T   4354=   8.4996      T   4355=   10.848
     T   4356=   13.677      T   4357=   15.916      T   4400=  -4.8404      T   4401=  -3.1160      T   4402=  -5.3324      T   4403=  -3.2876
     T   4404=  -1.6551      T   4405=   .49169      T   4406=   3.2241      T   4407=   5.2715      T   4450=  -7.5769      T   4451=  -5.9084
     T   4452=  -8.4267      T   4453=  -6.4402      T   4454=  -4.8991      T   4455=  -2.8206      T   4456=  -.11954      T   4457=  -1.8658
     T   4500=  -4.5936      T   4501=  -2.8906      T   4502=  -5.1080      T   4503=  -3.0629      T   4504=  -1.4306      T   4505=   .70614
     T   4506=   3.4382      T   4507=   5.4844      T   4550=   4.2716      T   4551=   6.1032      T   4552=   4.8196      T   4553=   7.0464
     T   4554=   8.9626      T   4555=   11.291      T   4556=   14.119      T   4557=   16.356      T   4998=   85.766      T   4999=   93.847
     T   5000=   80.434      T   5001=   72.903      T   5002=   67.732      T   5003=   63.875      T   5004=   60.027      T   5005=   56.456
     T   5006=   53.197      T   5007=   49.602      T   5083=   46.474      T   5084=   43.690      T   5085=   40.589      T   5086=   37.708
     T   5087=   34.978      T   5088=   32.233      T   5089=   30.854      T   5090=   28.646      T   5091=   37.637      T   5092=   37.645
     T   5100=   12.048      T   5101=   12.435      T   5102=   10.051      T   5103=   11.320      T   5104=   12.275      T   5105=   13.670
     T   5106=   15.596      T   5107=   16.922      T   5150=   8.5118      T   5151=   7.7818      T   5152=   3.7347      T   5153=   4.1637
     T   5154=   4.1748      T   5155=   4.7357      T   5156=   5.9391      T   5157=   6.4431      T   5200=   11.608      T   5201=   9.7184
     T   5202=   4.5711      T   5203=   4.1876      T   5204=   3.3525      T   5205=   3.1146      T   5206=   3.5639      T   5207=   3.2785
     T   5250=   21.524      T   5251=   18.360      T   5252=   12.613      T   5253=   11.393      T   5254=   9.7552      T   5255=   8.7033
     T   5256=   8.3194      T   5257=   7.2265      T   5300=   38.885      T   5301=   34.243      T   5302=   28.386      T   5303=   26.248
     T   5304=   23.800      T   5305=   21.865      T   5306=   20.510      T   5307=   18.539      T   5350=   70.000      T   5351=   39.531
     T   5352=   32.657      T   5353=   29.624      T   5354=   26.268      T   5355=   23.445      T   5356=   21.214      T   5357=   18.349
     T   9001=  -311.00      T   9002=  -207.84      T   9003=  -311.00      T   9004=  -13.084

     W         1= 18.131     W         2= 19.401     W         3= 19.417     W         4= 19.426     W         5= 19.627
     W         6= 95.999     W         7= 96.001

     DP        1= 99.789     DP        2= 99.789     DP        3= 99.789     DP        4= 99.789     DP        5= 99.789
```

```
SOFT TUBE INFLATABLE RADIATOR
DP       6= .15804      DP       7= .21684
P        1= 100.16      P        2= 100.01      P        3= .21684      P        4= .00000
COMPUTER TIME =     2.521 MINUTES
      END OF DATA
* *DIVIDE CHECK HAS OCCURRED* *

@PMD,E

@BRKPT PRINT$
```