DOE/SF/10535-1/2

ALTERNATE CENTRAL RECEIVER POWER SYSTEM PROGRAM
PHASE II

Midterm Technical Report. Volume 2—Sodium Test Receiver Experiment

By
J. C. Amos
A. V. Curinga
J. A. Elsner
E. E. Gerrels
C. C. Hussey
D. J. Muller
H. P. Offer
C. Oganowski
E. Olich
B. D. Pomeroy
P. J. Ring
S. I. Schwartz

July 1980

Work Performed Under Contract No. AC03-79SF10535

General Electric Company
Energy Systems Programs Department
Schenectady, New York

U.S. Department of Energy

Solar Energy

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Printed Copy A15
Microfiche A01

DOE/SF/10535-1/2
Distribution Category UC-62

MIDTERM TECHNICAL REPORT
VOLUME II - SODIUM TEST RECEIVER EXPERIMENT

ALTERNATE CENTRAL RECEIVER POWER SYSTEM PROGRAM PHASE II

July 1980

PREPARED FOR
UNITED STATES DEPARTMENT OF ENERGY
(CONTRACT NO. DE-AC03-79SF10535)

GENERAL ELECTRIC COMPANY
ENERGY SYSTEMS PROGRAMS DEPARTMENT
SCHENECTADY, NEW YORK

GENERAL ELECTRIC

VOLUME II

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

VOLUME II

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

VOLUME II

LIST OF TABLES

LIST OF TABLES (Cont'd)

PHASE II PROGRAM OVERVIEW

This Midterm Technical Report documents progress during the first year of the Alternate Central Receiver Power System Program Phase II (DoE Contract No. DE-AC03-79SF10535). The report consists of the following three volumes:

- Volume I - Commercial Plant Design Refinement
- Volume II - Sodium Test Receiver Experiment
- Volume III - Materials Experiments

BACKGROUND

The Phase II program is a follow-on program to the completed Conceptual Design of Advanced Central Receiver Power Systems - Phase I (DoE Contract No. DE-AC03-78ET20500) led by General Electric Corporate Research and Development.

During Phase I, parametric analyses were performed to select the preferred commercial scale (100 MWe) sodium cooled central receiver power plant. The reference concept selected utilizes an external cylindrical receiver with a surrounding field of heliostats. The plant loop schematic is shown in Figure 1 and an artist's concept of the plant in Figure 2. There are approximately three hours of storage, ground level steam generators, and a high efficiency reheat steam power conversion cycle.

A conceptual design was prepared for the reference plant concept and detailed cost estimates were calculated. A number of potential improvements to be examined during Phase II were identified, as were a number of Subsystem Research Experiments (SRE's). The SRE's were selected as those technical steps necessary for advancement of the sodium central receiver technology towards commercialization and addressed critical technical uncertainties.

The Phase II program is a logical extension of the Phase I effort and has as its objective "the near term application of sodium solar central receiver power plants for low cost electric power generation." The specific Phase II activities, shown graphically on Figure 3, include the following efforts:

- Performance of a receiver panel test at the Central Receiver Test Facility (CRTF)

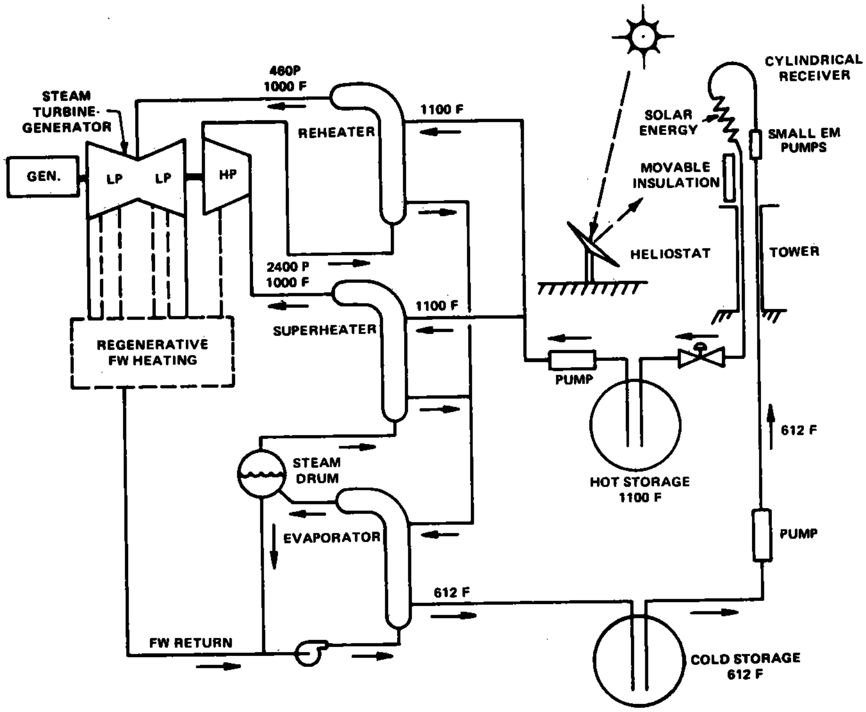


Figure 1. Plant Schematic

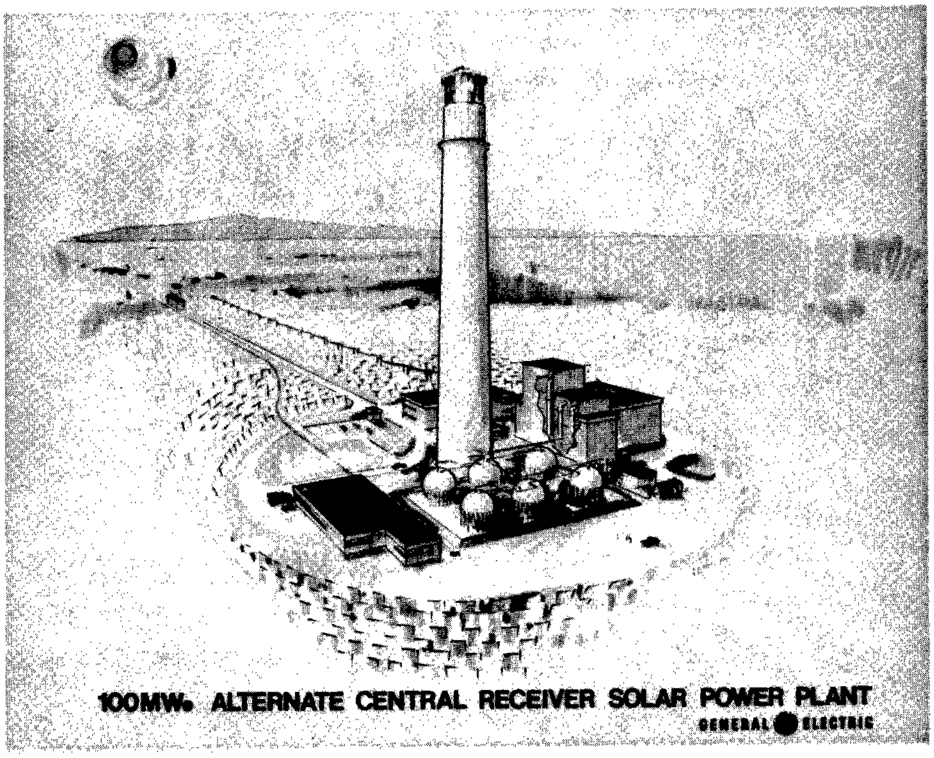
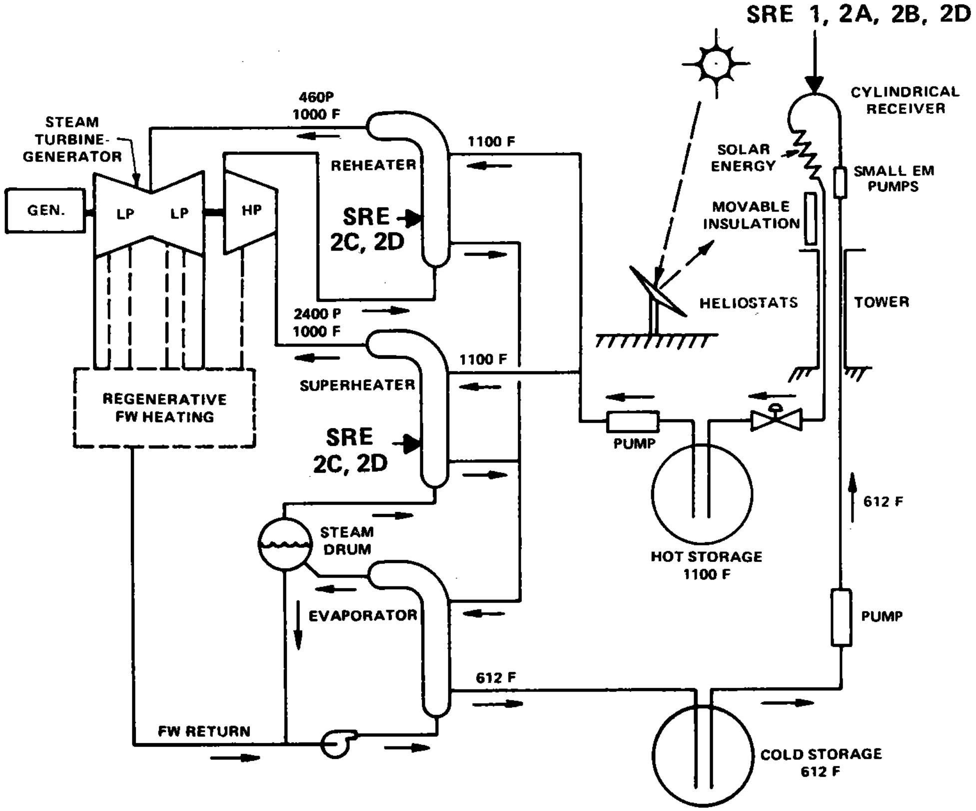


Figure 2. Plant Arrangement

SYSTEM ENGINEERING AND ANALYSIS



SUBSYSTEM RESEARCH EXPERIMENTS (SRE'S)

• SRE 1	ABSORBER PANEL TEST
• SRE 2	MATERIALS SRE'S
SRE 2A	PANEL FABRICATION DEVELOPMENT
SRE 2B	PANEL INSPECTION AND EVALUATION
SRE 2C	STRESS CORROSION AND FATIGUE
SRE 2D	FATIGUE CRACK GROWTH AND FRACTURE TOUGHNESS

Figure 3. Major Phase II Activities

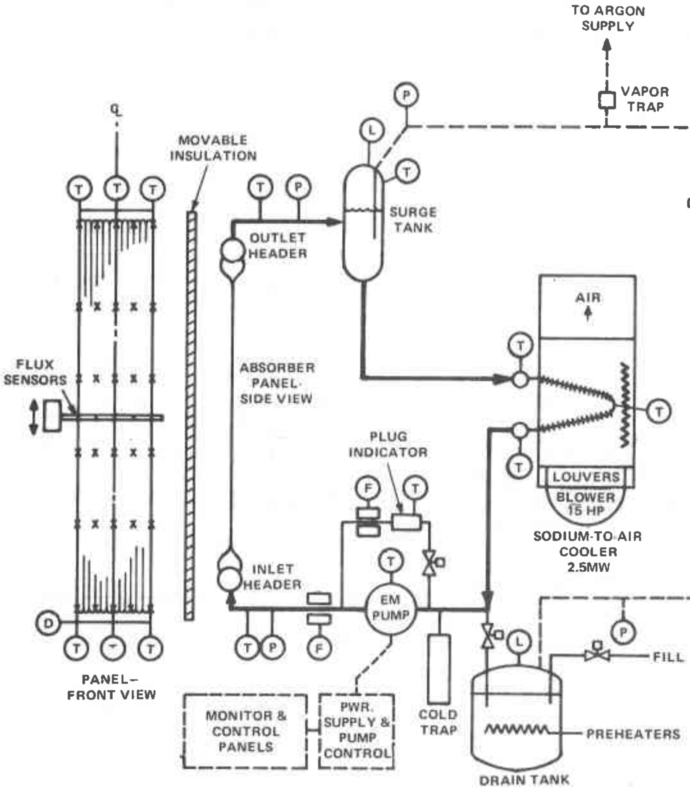
- Performance of materials experiments and panel fabrication development
- Commercial plant design updates
- Development planning.

PROGRAM WORK PLAN

The Phase II program consists of the five tasks described below that extend over two years.

- Task 1 - Subsystem Research Experiments (SRE's)
  Perform the necessary hardware development efforts to move sodium central receiver technology from conceptual design status to commercial demonstration status. Key efforts are design, fabrication, and testing of a Sodium Receiver Test Assembly (SRTA) shown in Figure 4 and the conduct of critical materials experiments.
- Task 2 - Commercial Plant Design
  Perform a revivification of the conceptual design, based on improvements identified during Phase I. Near the end of the program, update the design to reflect knowledge gained during Phase II.
- Task 3 - Critical Module Design
  Define the next step in plant commercial plant development by conceptualizing a large scale critical module configuration. Update the critical module concept near the end of the program to reflect knowledge gained during Phase II.
- Task 4 - Development Planning
  Prepare an update of the Phase I development plan for solar sodium receiver technology near the end of Phase II to reflect the knowledge gained during Phase II.
- Task 5 - Program Management
  Perform appropriate program management.

The work flow for accomplishing these tasks is shown on Figure 5 and the related schedule shown on Figure 6.



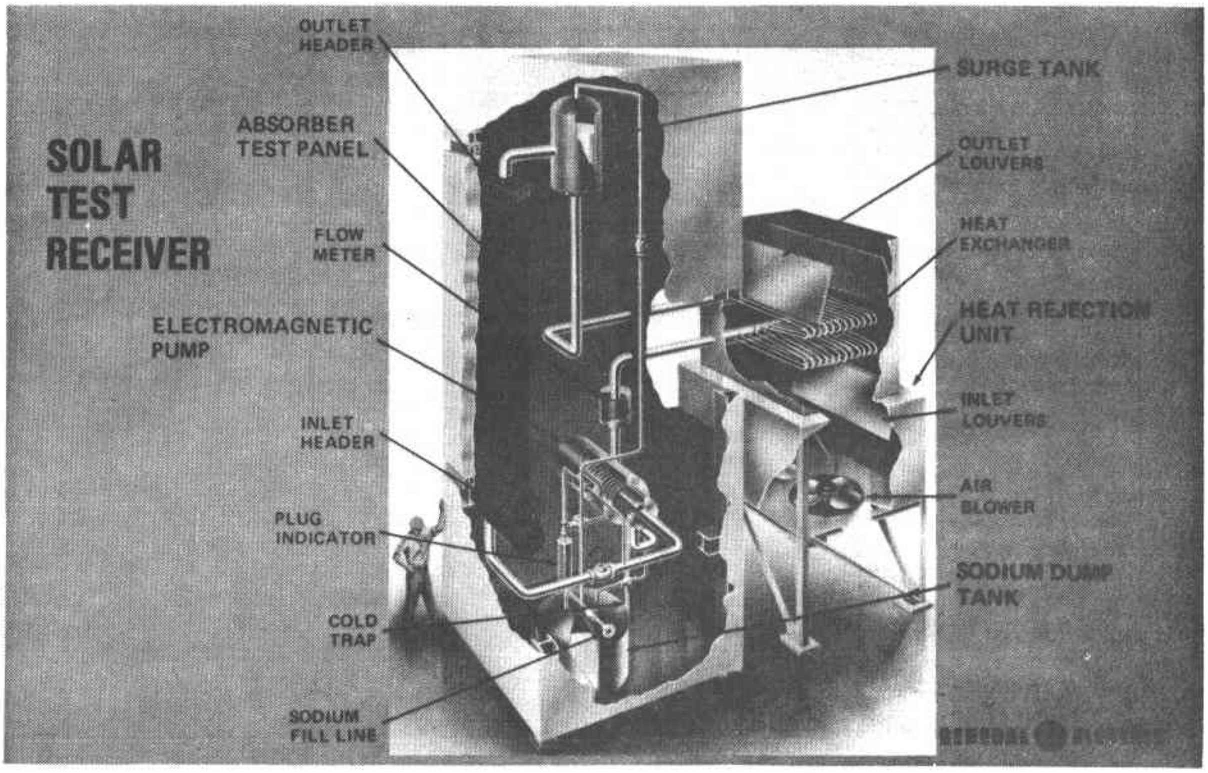


Figure 4. SRTA Schematic and Artist's Concept

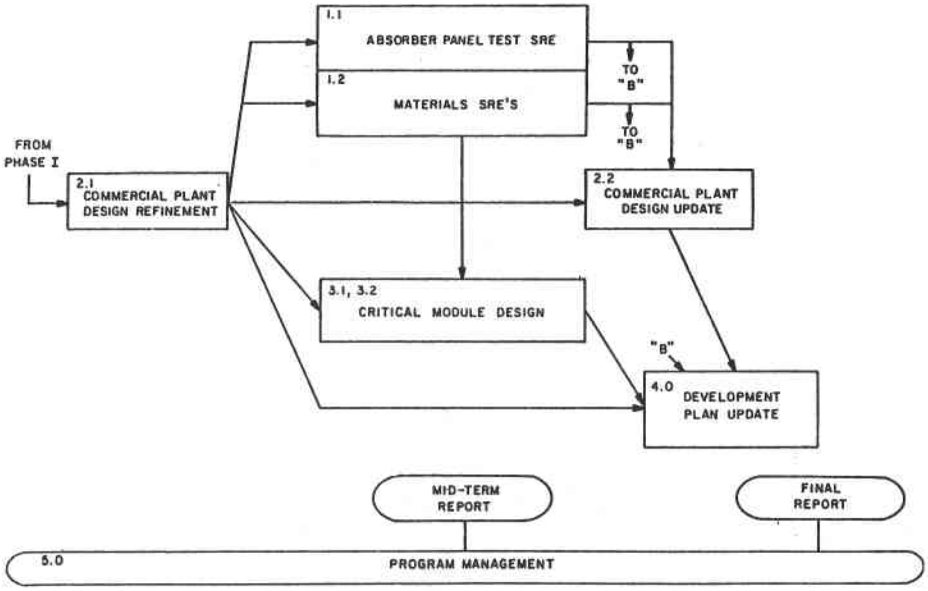


Figure 5. Phase II Work Flow Diagram

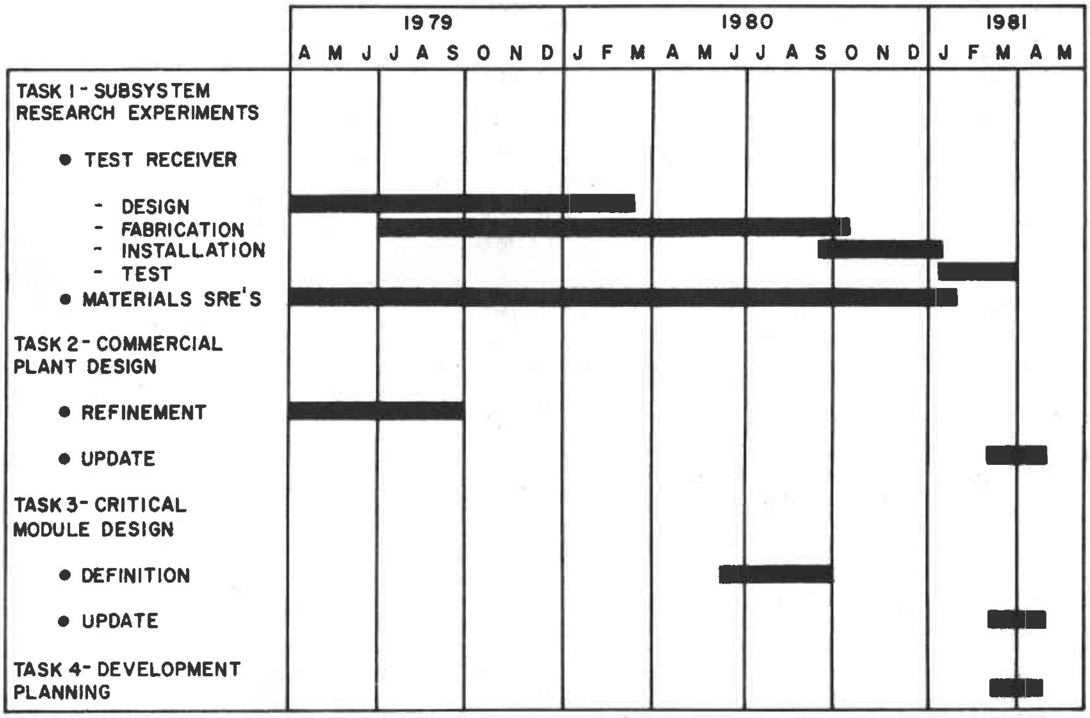


Figure 6. Phase II Program Schedule

ORGANIZATION

The Phase II program is being led by the General Electric Energy Systems Programs Department (ESPD). The transition of leadership from Corporate Research and Development (CRD) to ESPD is a normal activity for General Electric and represents the logical transition of a primarily R&D program into a primarily hardware and commercial application program. CRD played a major role in the plant design refinement task and ensured that a sound technical transition occurred. Kaiser Engineers, Incorporated of Oakland, CA was the Architect Engineer during Phase I and performed the storage tank design refinement described in Volume I of this report. The current organization is shown in Table 1.

TABLE 1

PROGRAM ORGANIZATION

- GENERAL ELECTRIC COMPANY
  - ENERGY SYSTEMS PROGRAMS DEPARTMENT (ESPD)

    Program Management
    Systems Engineering
    Plant Integration
  - ADVANCED REACTOR SYSTEMS DEPARTMENT (ARSD)

    Liquid Metal Engineering
    Sodium Components
    Brazing Development
- FOSTER WHEELER DEVELOPMENT CORPORATION (FWDC)
  - Absorber Test Panel Fabrication
- PYROMET INDUSTRIES, INC.
  - Test Panel Brazing
  - Temporary Brazing Furnace

PROGRAM STATUS

As of April 1980, the Phase II program is focused on fabrication of the 2.5 MWth Sodium Receiver Test Assembly (SRTA). The design refinement of the 100MWe commercial plant was completed in October 1979 and the analysis and results are detailed in Volume I of this report.

The SRTA design has been completed and fabrication of the components are underway. The panel fabrication scheme (horizontal furnace braze) has been selected and fabrication of a large temporary brazing furnace is well underway.

The design and fabrication status of the SRTA is reported in Volume II.

Significant progress has been made in the development of the panel fabrication techniques and several materials test efforts are underway. The materials experiments are discussed in Volume III.

SECTION 1

INTRODUCTION AND OBJECTIVES

The design, fabrication, installation and testing of a test sodium-cooled receiver comprise the largest effort of the Phase II Program. This volume of the Midterm Technical Report describes the design status, analysis results, and fabrication status of the 2.5 MWth Sodium Receiver Test Assembly (SRTA).

1. 1 EXPERIMENT OBJECTIVES

This Subsystem Research Experiment (SRE #1) has seven principal objectives which will be discussed below:

- Manufacturability

  The SRTA absorber test panel has the thin-walled Incoloy 800 constuction selected for the commercial scale (100 MWe) receiver absorber panels. It is being fabricated using tube-to-tube brazing techniques developed in the Panel Fabrication Subsystem Research Experiment (SRE) described in Volume III of this report. Thus, the absorber test panel forms the first demonstration of this thin-walled, brazed construction.

- Panel Structural Integrity

  The SRTA absorber test panel will be installed and tested at the Central Receiver Test Facility (CRTF) at power levels up to 2.5 MWth and be subjected to a number of transients. This testing will enable verification of structural integrity during operation.

- Control Stability

  The control system being designed for this SRTA must demonstrate control characteristics and stability during actual testing at the CRTF for sodium cooled central receivers.

- Panel Performance

  Testing at CRTF will provide a measure of panel efficiency for typical operating modes as well as specific data for radiative, connective and reflective losses.

- Sodium System Reliability/Safety

  Over thirty years of experience exists for liquid metal-cooled systems;

however, questions on sodium hardware reliability/safety in solar plants need demonstration. The three-month operation of this SRTA at CRTF will provide a visible opportunity for DOE and industry to examine sodium system operating and safety characteristics.

- High Flux Operation
  The excellent heat transfer properties of liquid sodium allow receiver operation at relatively high heat flux levels. These higher fluxes result in smaller, more efficient receivers. The SRTA will therefore operate at fluxes up to approximately 1.5 MW/M^2.

- Cost Data
  The construction of actual sodium hardware for solar applications, particularly the absorber test panel, will allow more confident calculation of commercial plant receivers.

1.2 SRTA DESCRIPTION

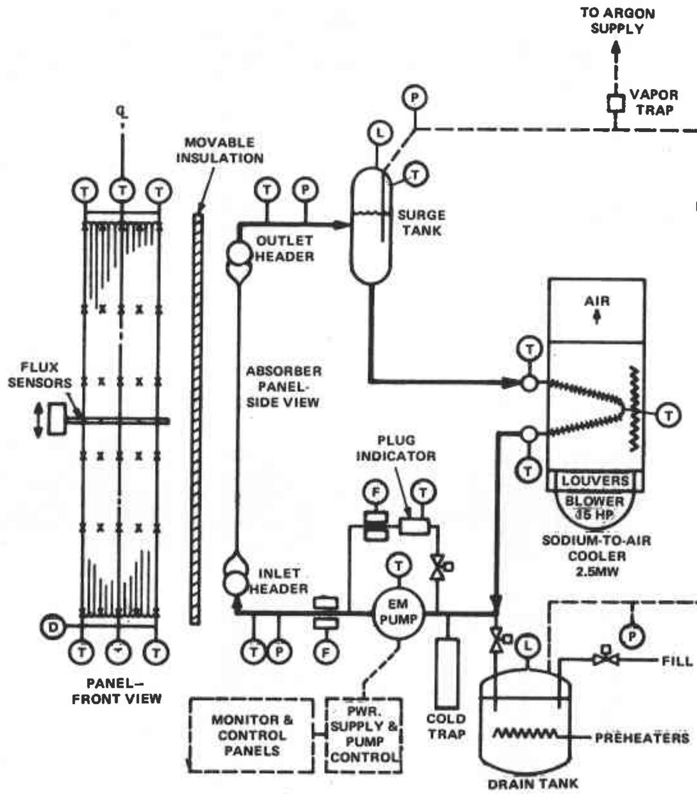
The 2.5 MW (thermal) sodium cooled test receiver has a nominal outlet temperature of 1100^{o}F and a cold leg return temperature of 600^{o}F, typical of the reference 100 MWe commercial scale plant.

The Solar Receiver Test Assembly (SRTA) shown in Figure 1-1, is scheduled to be tested at the Central Receiver Test Facility (CRTF) during the winter of 1980/81. It consists of a sodium fluid circulation loop powered by a helical electromagnetic pump. The loop schematic indicates that there are six major SRTA components: the absorber test panel, a surge tank, a dump (drain) tank, and electromagnetic (EM) pump, sodium-to-air heat dump, and control and instrumentation.

The fluid circulation module has an overall height of about 40 feet. The heat dump has a height of about eighteen feet. Therefore, the SRTA will be installed on top of the CRTF tower, in lieu of a test bay. The CRTF tower is shown in Figure 1-2 and an artist's concept of the installed SRTA is shown in Figure 1-3.

1.3 SRE WORK FLOW

The design and fabrication of the SRTA is controlled through the careful preparation and adherence to specifications. Once the test objectives and test panel configuration were selected during the commercial plant design refinement task (see Volume I), a top level system specification was prepared. The current issue system specification, provided as Appendix A, forms the baseline for all design and fabrication efforts. All lower level specifications must track the requirements of the system specification in order to ensure the SRTA meets all test objectives. Figure 1-4 shows the specification work flow. Note that specifications were prepared for



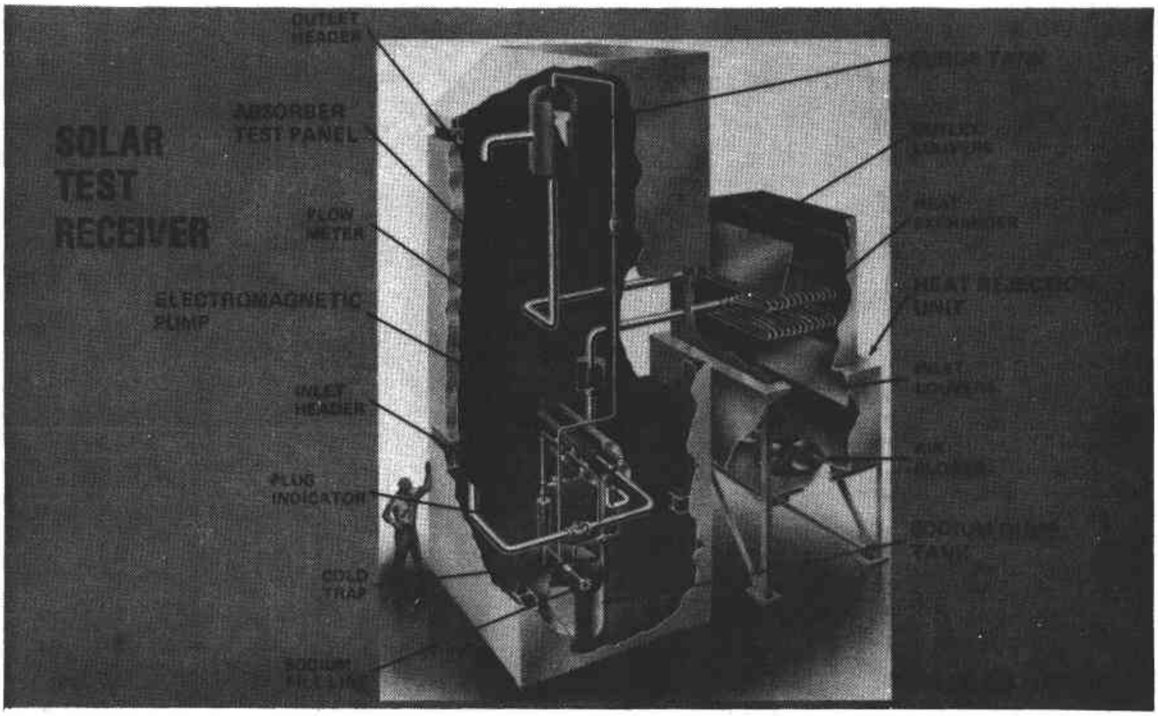


Figure 1-1. SRTA Loop Schematic and Artist's Concept

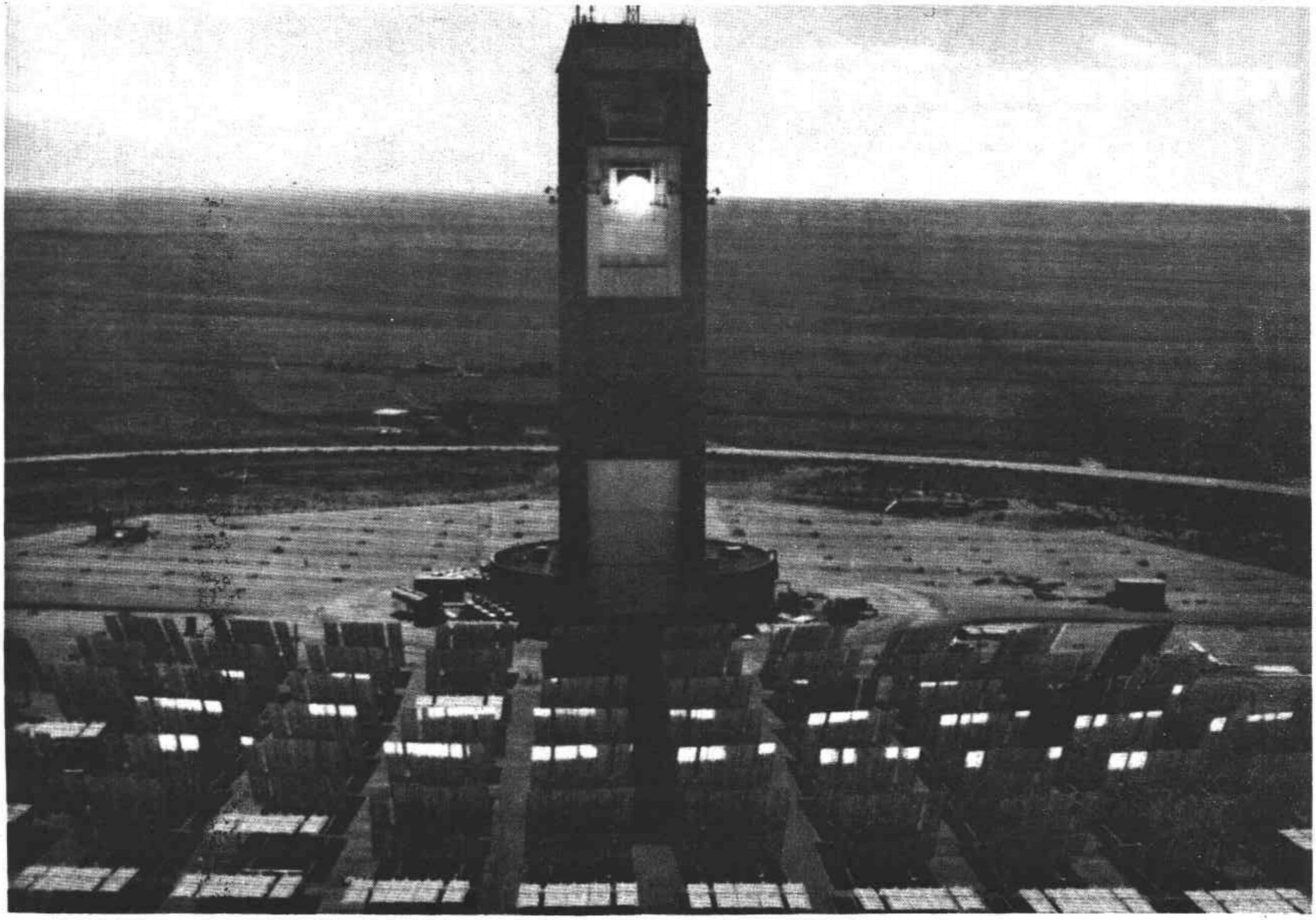


Figure 1-2. Central Receiver Test Facility (CRTF)

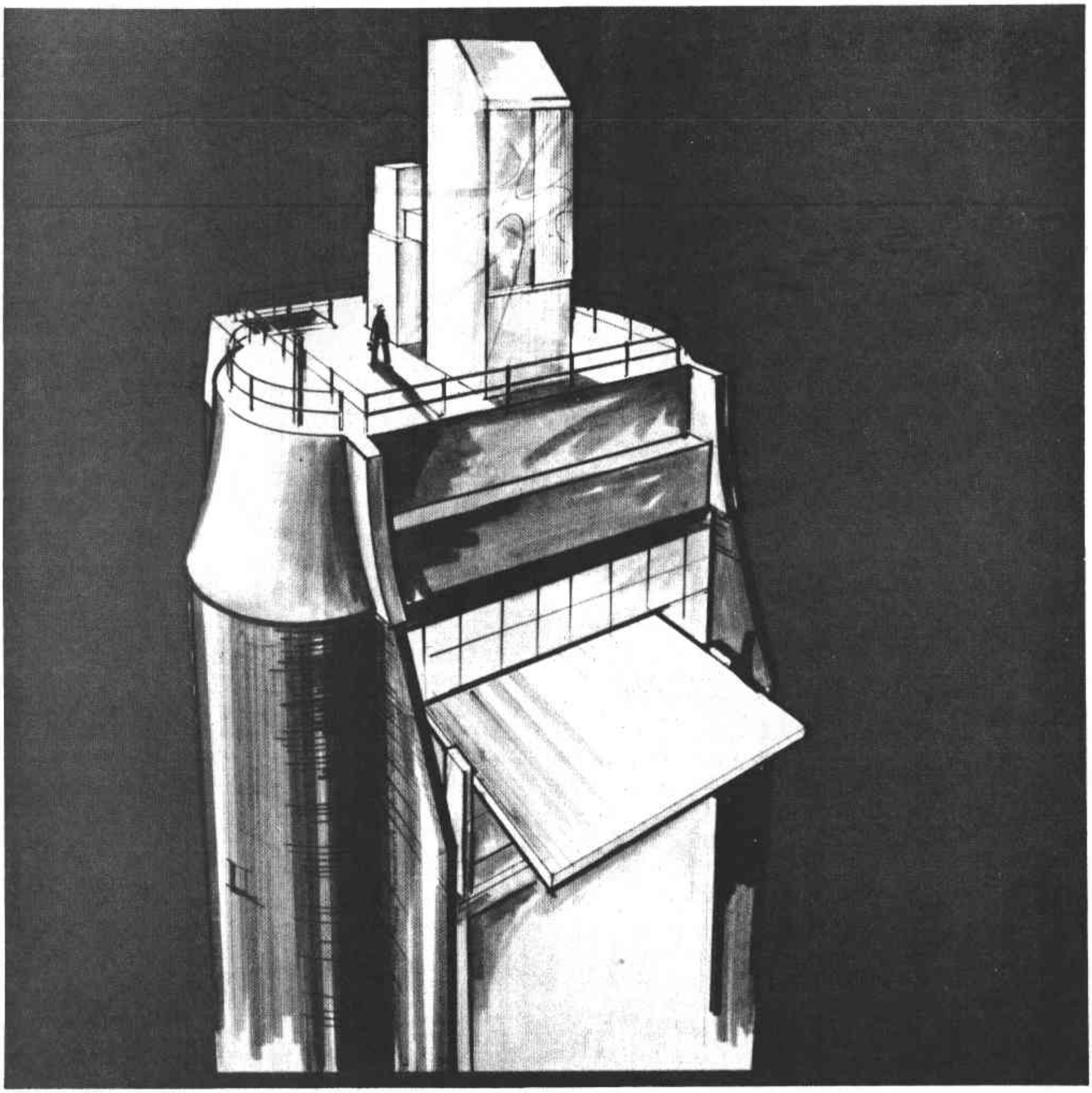


Figure 1-3. Artist's Concept of SRTA Installed on the CRTF Tower

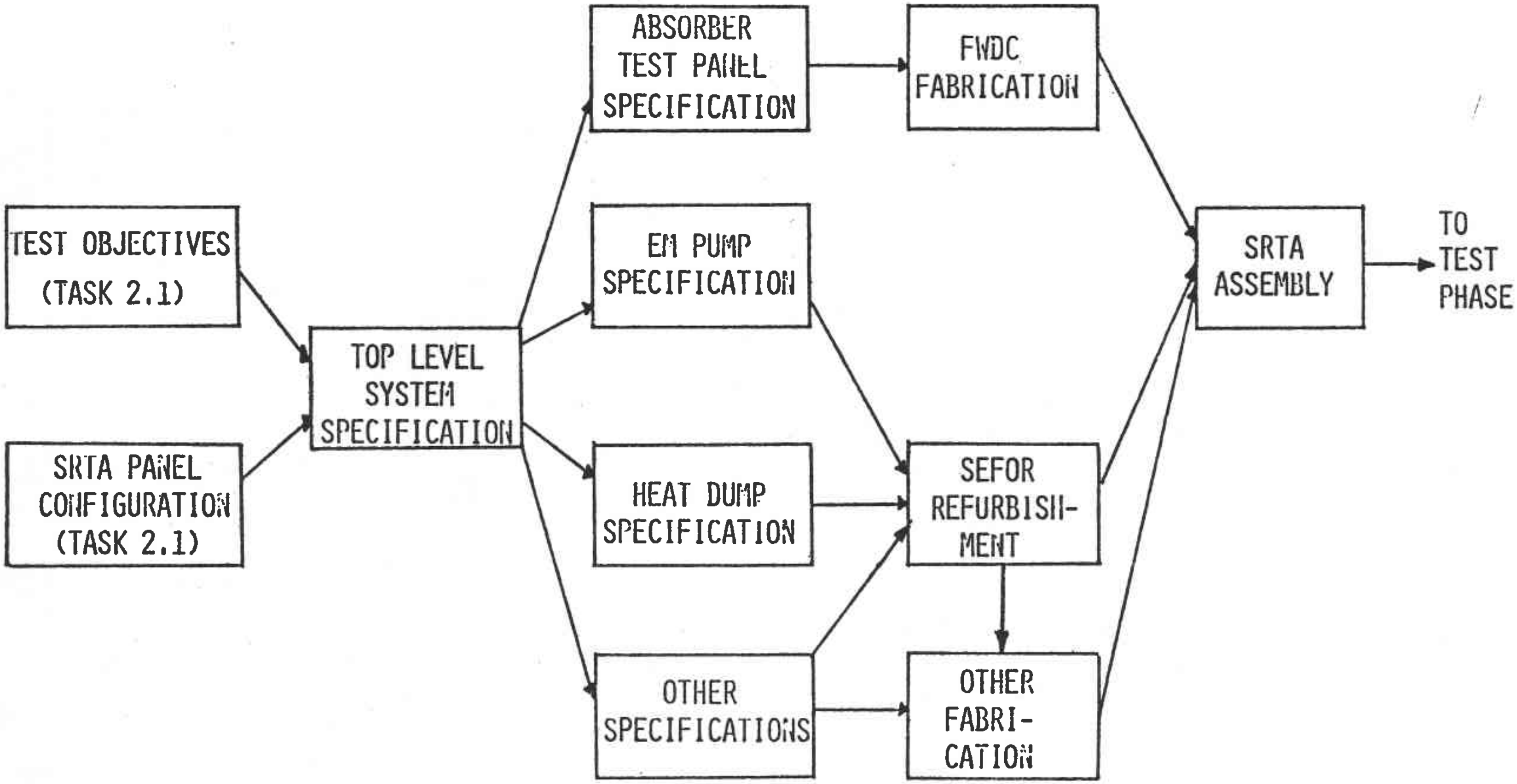


Figure 1-4. Summary Work Flow

all major components, including the refurbished SEFOR hardware.

Once The SRTA has been completely fabricated, it will be shipped to the CTRF in Albuquerque, N.M. The sodium loop will be erected first and then the absorber test panel will be installed. Finally the entire SRTA will be raised to the top of the tower after initial sodium fill. Testing will take place during the first quarter of 1981, as shown in the summary schedule on Figure 1-5.

1.4 SRTA DESIGN AND FABRICATION OVERVIEW

The design of the Sodium Receiver Test Assembly (SRTA) is based on a specification developed to define the requirements, characteristics, design and construction features and performance verification criteria for the unit. This specification, number 295A4725, is included as Appendix A.

The key component of the SRTA is the absorber test panel which has been designed to be prototypical of a commercial scale receiver. Panel dimensions of approximately 1 meter in width and 5 meters long were selected to give a total of 2.5 MW of incident energy at a uniform flux level of 0.5 MW/M^2. This flux level was selected to be consistent with commercial peak average flux levels. As indicated in Section 2.0 of Volume I, the peak flux for commercial operation is anticipated to be approximately 1.2 MW/M^2. Accordingly, tests at that peak flux value have been planned. The test matrix also includes operation at flux levels 130% of the expected peak 1.2 MW/M^2 value. These 1.55 MW/M^2 tests will be scheduled as the last test. The total power at all operating conditions is limited to 2.5 MW by the size of the sodium-to-air heat exchanger selected for use.

A schematic of the SRTA test loop was shown in Figure 1-1 that identified the major components. A factor in the design of the components was the opportunity to utilize hardware from a non-radioactive sodium loop of the decomissioned Southwest Experimental Fast Oxide Reactor (SEFOR) located near Fayetteville, Arkansas. SEFOR components used in the SRTA include the electromagnetic (EM) pump, surge and drain tanks, valves, flow meters, and the sodium-to-air heat exchanger (heat dump). The surge and drain tanks and air cooler have required substantial work to modify and refurbish for SRTA use. The tank volumes have been changed to meet the test requirements. The heat dump heat exchanger coil is being replaced because of external corrosion in the original exchanger.

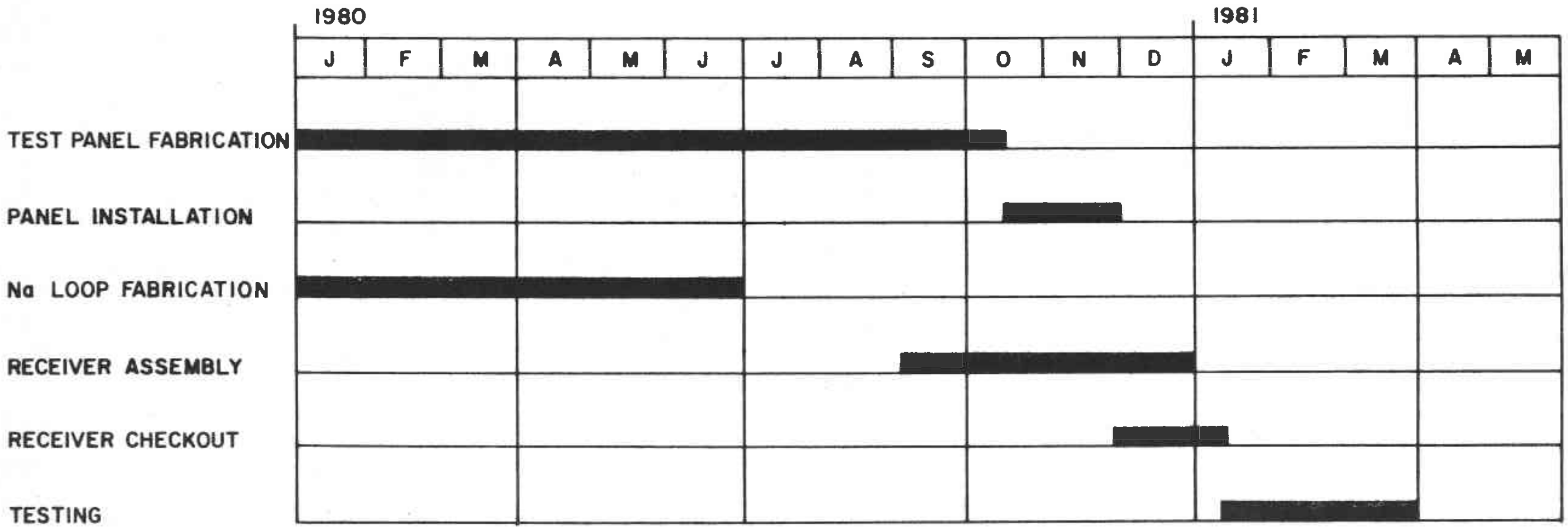


Figure 1-5. SRTA Schedule

The status of the principal components is described below.

1.4.1 ABSORBER TEST PANEL

The principal purpose of the SRTA effort is to successfully fabricate and test a prototype sodium cooled absorber based upon the General Electric thin-walled, brazed construction scheme. Key design parameters are listed in Table 1-1.

Table 1-1

ABSORBER TEST PANEL DESIGN DATA

Incident Power	2.5 MW
Peak Solar Flux	~1.5 MW/M^2
Inlet Temperature	500^o-700^oF
Outlet Temperature	1100^oF
Design Cyclic Life	30 Years
Material	Incoloy 800
No. Tubes	50
Tube O.D.	.75 inches
Tube Wall Thickness	.05 inches
Active Length	15 feet
Peak Na Velocity	2.3 fps
Width	~3.26 feet

The manufacturing approach for the test panel has undergone some changes from that initially considered as a result of the Phase I study. The initial approach was to braze a 51 tube 15 foot long panel with the tubes tangent to each other with braze alloy introduced between the tubes. This was subsequently modified with the addition of "hour glass" shaped filler strips between the tubes to increase the braze joint strength and aid fixturing of the panel tubes. Simple joint tensile tests show that the filler strip increases the strength by about a factor of 2. Brazing tests have indicated that best results were obtained not with the panel in the vertical position during brazing but with the panel horizontal and tilted at 45^o to 60^o from flat. After an extensive search of U.S. furnaces, it was found that a temporary hydrogen atmosphere brazing furnace needed to be built. A furnace was designed of sufficient size to braze a full length segment of a panel up to 20 tubes wide and it was planned to join several segments into the full panel width. This joining resulted in significant additional development effort and risk and the the decision was made to build a larger furnace of sufficient size to accommodate a full width panel of 50 tubes. The design and procurement of this brazing furnace is the critical path item in the panel manufacturing schedule. The details of the brazing development program are provided in Section 2 of Volume III.

In order to provide an interface between the test panel and the other components of the sodium loop, an intermediate structure is provided. This structure, to be supplied by the panel manufacturer (Foster Wheeler), is bolted to the structure that supports the pump, piping and tankage. The panel support structure also serves as a strong back during shipping and handling of the panel. The panel is attached to the structure by a constant load hanger at the top. Thermal expansion downward is accommodated by pivoted links between the panel and structure which also provide support against wind loading on the panel. Wind loading and seismic forces constitute the major structural forces. The general configuration of the test panel is shown in Figure 1-6.

1.4.2 SODIUM LOOP COMPONENTS

Fabrication of the SRTA is well under way with most components in San Jose, California in preparation for assembly. The characteristics and status of some principal components are summarized below:

Structure: The structure for the fluid circulation module has been fabricated and erected and ladders, platforms, tanks, piping, etc. are currently being installed (Figure 1-7). Prior to shipment to the CRTF, the lower twelve feet will be unbolted from the top. This lower section, containing the dump tank, EM pump, and other large equipment will be shipped in a vertical orientation, while the top 28 feet will be shipped horizontally. The two parts will be welded together and provided with an enclosure in Albuquerque.

Tanks: The surge tank and drain tank were purchased from the Southwest Experimental Fast Oxide Reactor (SEFOR) in the summer of 1979 and have been refurbished for use in the SRTA. The surge tank is the high point in the loop and acts as an expansion and surge control volume. The drain tank is the low point in the loop and is used for sodium storage or for emergency dumping of the loop. Under normal operation and at night the loop will contain the sodium at elevated temperatures ($\sim 600^{\circ}F$) through the use of trace heaters. Principal tank parameters are listed in Table 1-2.

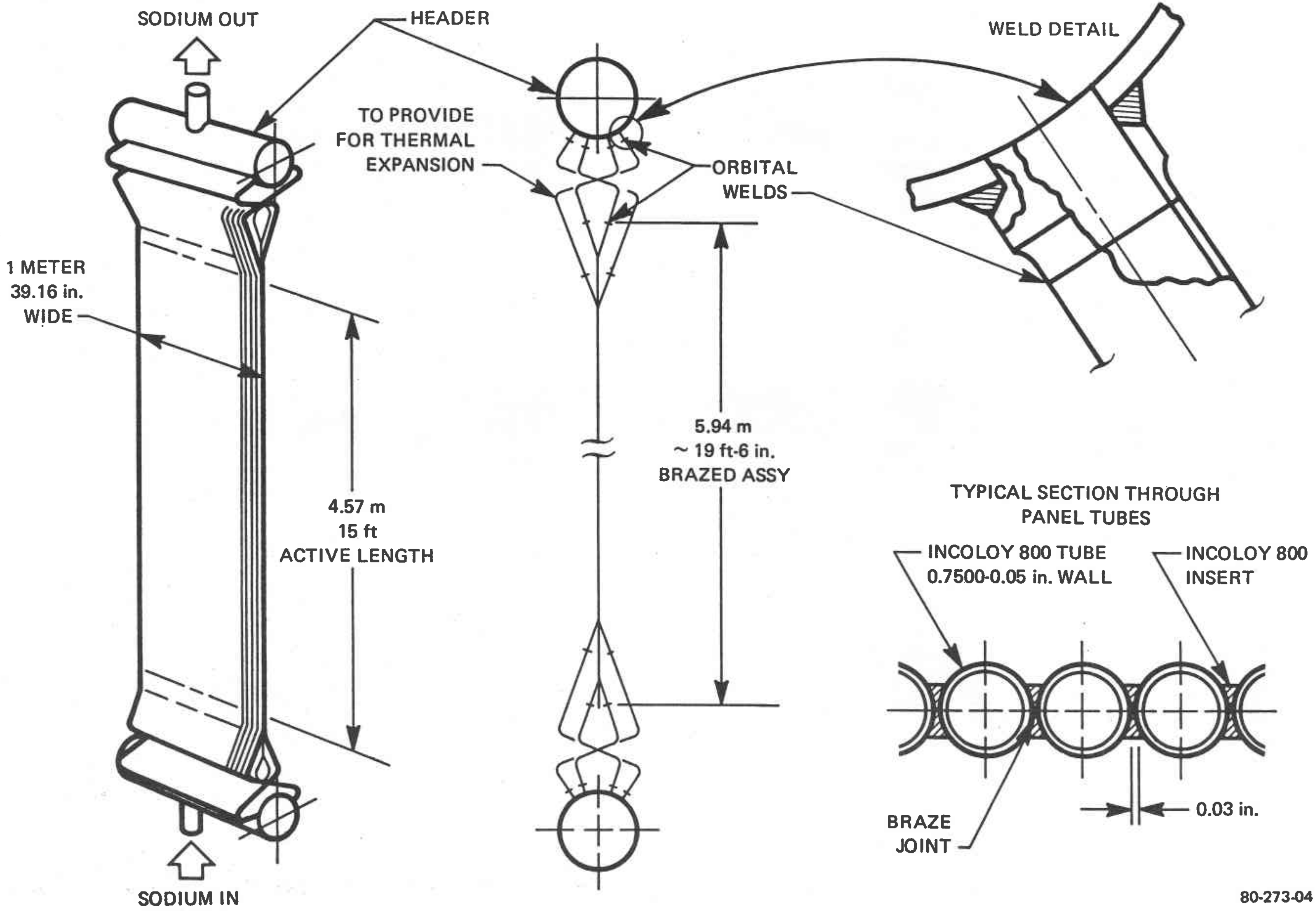


Figure 1-6. Absorber Test Panel Configuration

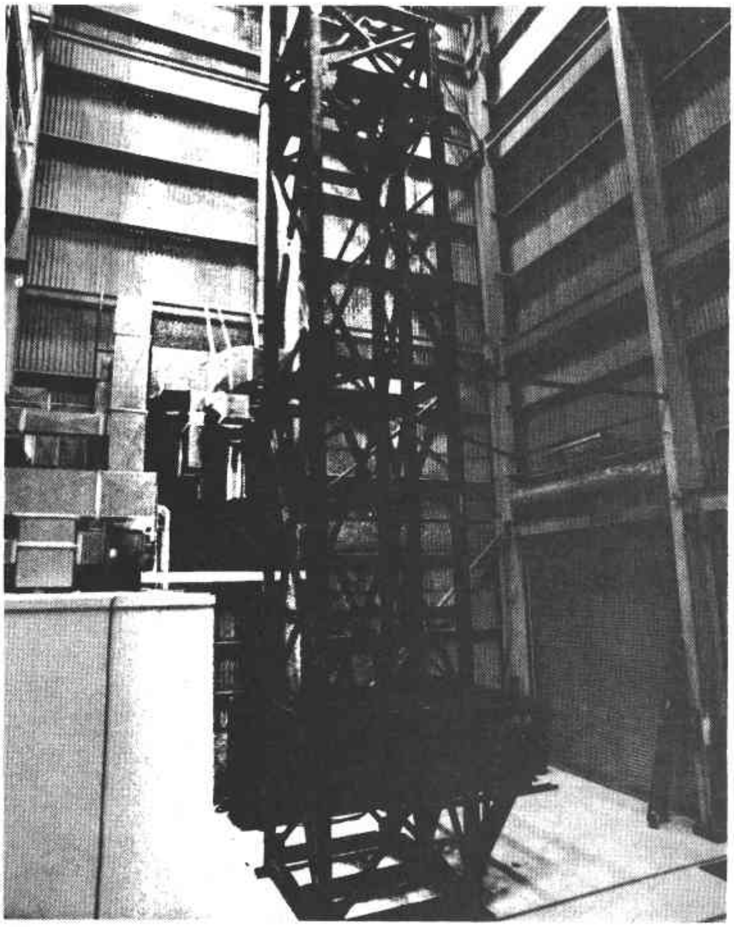


Figure 1-7. SRTA Structure

Table 1-2

SRTA TANK DATA

Material	304 Stainless Steel
Design Pressure	50 psig
Design Temperature	1150°F
Drain Tank Volume	240 gal.
Surge Tank Volume	75 gal.

EM Pump: The pump for the SRTA is also refurbished SEFOR hardware. The pump will be an important part of the control scheme by changing the flow as needed to maintain a nominal test panel outlet temperature of 1100°F. Principal data is listed below (Table 1-3):

Table 1-3

EM PUMP DATA

Design Flow	175 gpm
Design Head	30 psi
Design Temperature	1150^{o}F
Design Suction Pressure	5 psia
Power Input	33.6 kW
Power Factor	.327
Line Voltage	475 volts

Heat Dump: The sodium-to-air heat exchanger, also refurbished SEFOR equipment, is rated at 2.5 MW thermal. Unlike the other SEFOR equipment purchased last year, a portion of the heat dump required replacement. The W-shaped heater coil was found to have reduced contact between the coil piping and the mechanically connected fins. A replacement coil is being procured to ensure sufficient heat rejection capacity. SRTA control will utilize the variable speed fans and the outlet doors to match the test panel heat input after an appropriate time delay for hot leg loop transit. Photographs of the heat dump base and the coil/windscreen portions are shown below.

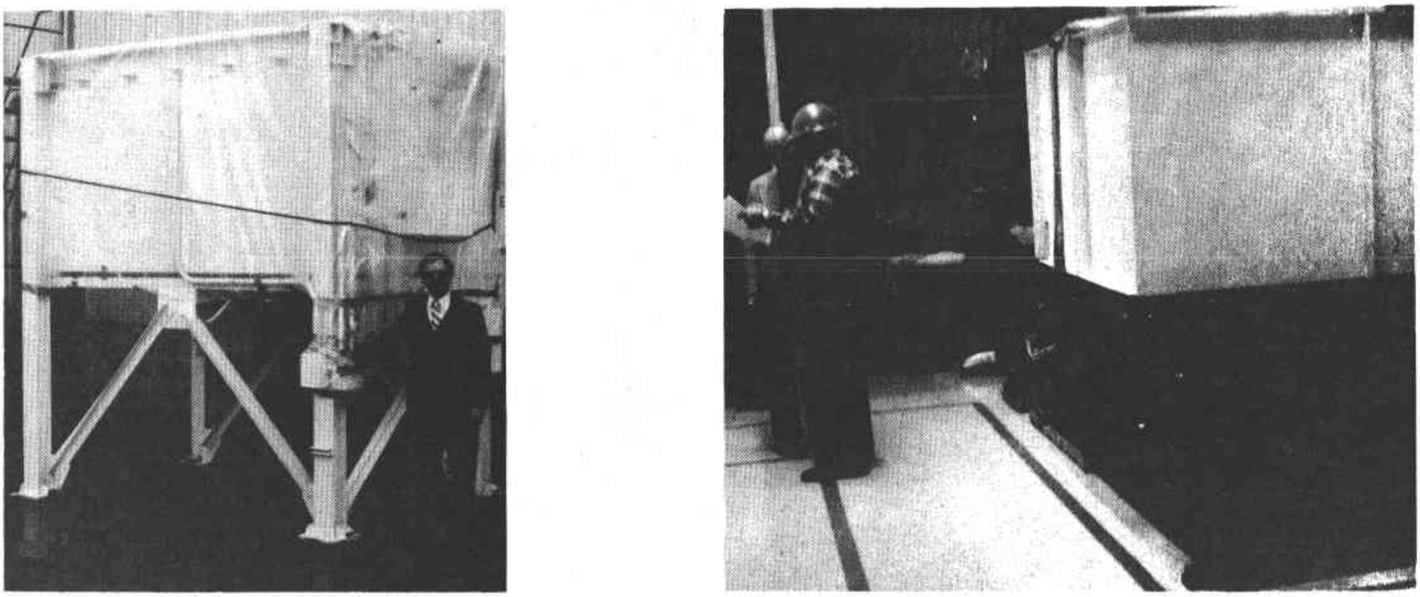


Figure 1-8. Disassembled Heat Dump

The following sections of Volume II of Midterm Technical Report detail the engineering design, analysis, and fabrication status of the SRTA.

SECTION 2

ABSORBER TEST PANEL DESIGN

As described in the overview and Section 1, the absorber test panel configuration is based on the system design engineering performed for a 100 MWe commercial scale plant during the Phase I program and revised during the early part of Phase II. This section describes the specification, design, engineering, and analysis for the test panel.

2.1 ABSORBER TEST PANEL SPECIFICATION

The basic technical requirements for the SRTA are contained in the "Development Specification for Sodium Receiver Test Assembly (SRTA)." The current revision of this specification (No. 295A4725) is provided as Appendix A.

2.1.1 TEST PANEL REQUIREMENTS

The system requirements of the SRTA Development Specification were expanded into specific requirements for the test panel through preparation and issuance of an "Equipment Specification for Absorber Panel." This equipment specification became the technical benchmark for Foster Wheeler in the design and fabrication of the absorber test panel. The current revision of the panel specification (No. 295A4724) is provided as Appendix B. Key requirements are listed on Table 2-1 and are summarized below.

2.1.1.1 Performance Requirements

As indicated in Table 2-1 the test panel is designed for a total incident power level of 2.5 MW. Three general flux profiles were planned for the CRTF test, including: a uniform flux of .5 MW/m^2 (representative of the average commercial panel), an intermediate profile with a peak of 1.2 MW/m^2 (representative of the peak commercial panel), and a high flux profile of approximately 1.5 MW/m^2 (representative of an upset condition on the commercial receiver).

To be consistent with the commercial plant operating modes, a constant outlet temperature of 593°C (1100°F) is planned. A thirty year design life has been imposed on the panel to ensure that the resultant panel design has fatigue endurance sufficient for commercial application. Note that the rest of the SRTA is only

Table 2-1

ABSORBER TEST PANEL REQUIREMENTS

Performance

- 2.5 MW Total Incident Power with "Uniform" Flux ∿ .5 MW/m^2, Peak Flux ∿ 1.5 MW/m^2
- Inlet Temperature 500°F-700°F
- Constant Outlet Temperature 1100°F
- 30 Year Cyclic Design Life
- Operating Modes
- Operating/Survival Requirements
- Truck Transportation
- Minimum Field Labor/Welding
- Cleanliness

Design and Construction

- ASME Boiler & Pressure Vessel Code Section VIII Division 1
- AISC Structure
- Incoloy 800

Design Documentation

Testing

- Hydrostatic or Pneumatic Pressure
- Helium Leak Test

Insulation/Trace Heating

Quality Assurance

Shipping

- Purged

designed for a 5,000 hour life.

The panel operating modes are the same as those for the SRTA system.

- Normal Operation - automatic mode
- Hot Hold - panel insulating door closed, trace heaters on auto at 600°F
- Preheat - ambient to hot hold
- Startup - hot hold to operation
- Shutdown - operation to hot hold
- Emergency Dump - rapid Na drain, inert gas
- Calibration - 600°F to 1100°F isothermal, surge tank level gages

2.1.1.2 Design and Construction Requirements

The absorber test panel is designed to meet the intent of Section VIII of the ASME code, but is not required to have a code stamp. Some additional requirements appropriate for sodium systems, such as a helium leak check, have been imposed in the specification (Appendix B). As indicated in Section 1, the test panel will utilize brazed construction over the active length with Incoloy 800 inserts between the tubes.

2.1.1.3 Other Requirements

As indicated on Table 2-1, the panel is required to have appropriate design documentation, quality assurance, and nitrogen purged shipment in order to assure a satisfactory product for the CRTF test. Appendix B should be consulted for details.

2.1.1.4 Interface Control

The test panel has a number of direct mechanical interfaces with the rest of the SRTA. The more obvious interfaces are between the panel structure and the SRTA structure, between the panel inlet/outlet headers and the SRTA piping, and between the panel boundary and the solar shield. The details of the SRTA portion of the interfaces are described in Section 4.

Mechanical interface control is performed by preparation and careful updating of an Interface Control Drawing. The current revision of the Panel Interface Control Drawing is shown on Figure 2-1.

2.1.2 SOLAR FLUX CONSIDERATIONS

A basic input required for test panel detailed design is the flux profiles for the three general distributions described in Section 2.1.1 (uniform, 1.2 MW/m^2 peak, and 1.5 MW/m^2 peak).

2.1.2.1 Flux Profiles

As indicated in Section 1, the general configuration of the active portion of the absorber test panel is a flat plate about 1 meter wide and 5 meters tall. The three general panel distributions were provided to CRTF personnel, who then utilized the HELIOS code to generate flux profiles for the test panel when installed on the CRTF tower. Figures 2-2 and 2-3 are graphical representations of the HELIOS output for the "uniform" and maximum peak (1.5 MW/m^2) distributions. Examination of Figure 2-2 shows that the narrowness of the test panel has made achievement of a truly uniform distribution impossible; in fact, there is a peak-to-average ratio of about 1.5/1. This uneven flux distribution causes uneven vertical thermal expansion that made panel detailed design much more complicated than anticipated. Note that the maximum flux profile is non-symmetric in the vertical direction. This condition was necessary to avoid negative efficiencies near the panel top.

The flux data from CRTF was used as input to the General Electric Absorber Loss Code developed during the Phase I program. That code calculates thermal data for the panel (e.g. tube temperatures, sodium temperatures, flows, etc.). The Phase I code had to be modified to more accurately perform calculations for the test panel (Table 2-2). Detailed outputs are provided in Table 3-4 of Appendix A.

2.1.2.2 Flux Blockage

The incident solar flux beam geometry at the test panel surface is determined by the location of the CRTF heliostats, the height of the panel above the ground, and the east-west position of the SRTA on the tower top.

Analysis of these parameters resulted in the incident beam distribution shown in Figure 2-4. This information was provided to both the panel and SRTA structural designers with the requirement that no structures of the SRTA shall intercept the beam prior to its impingement on the test panel active surface.

2.1.3 CORRELATION OF TEST AND COMMERCIAL PANELS

The purpose of the SRTA experiment is to obtain data for use in the design and fabrication of commercial scale absorber panels. Table 2-3 shows a comparison of principal parameters for the absorber test panel, the commercial scale (100 MWe) stand alone plant absorber panel, and the repowering plant (60 MWe) absorber panel. It can be seen that the construction method, tube geometry, temperatures and fluxes of the SRTA panel are well correlated with the larger panels.

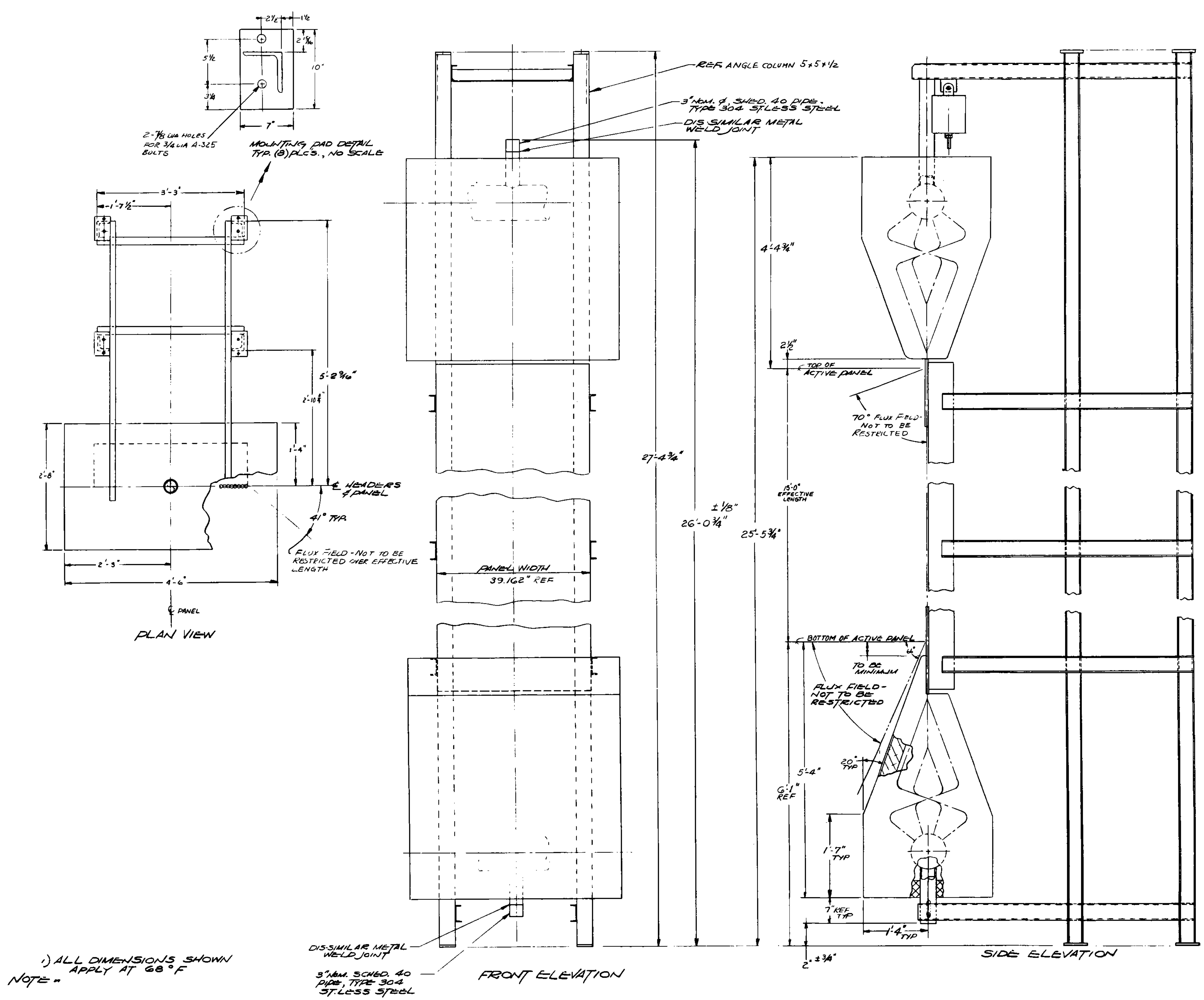


Figure 2-1. Absorber Test Panel Interface Control Drawing

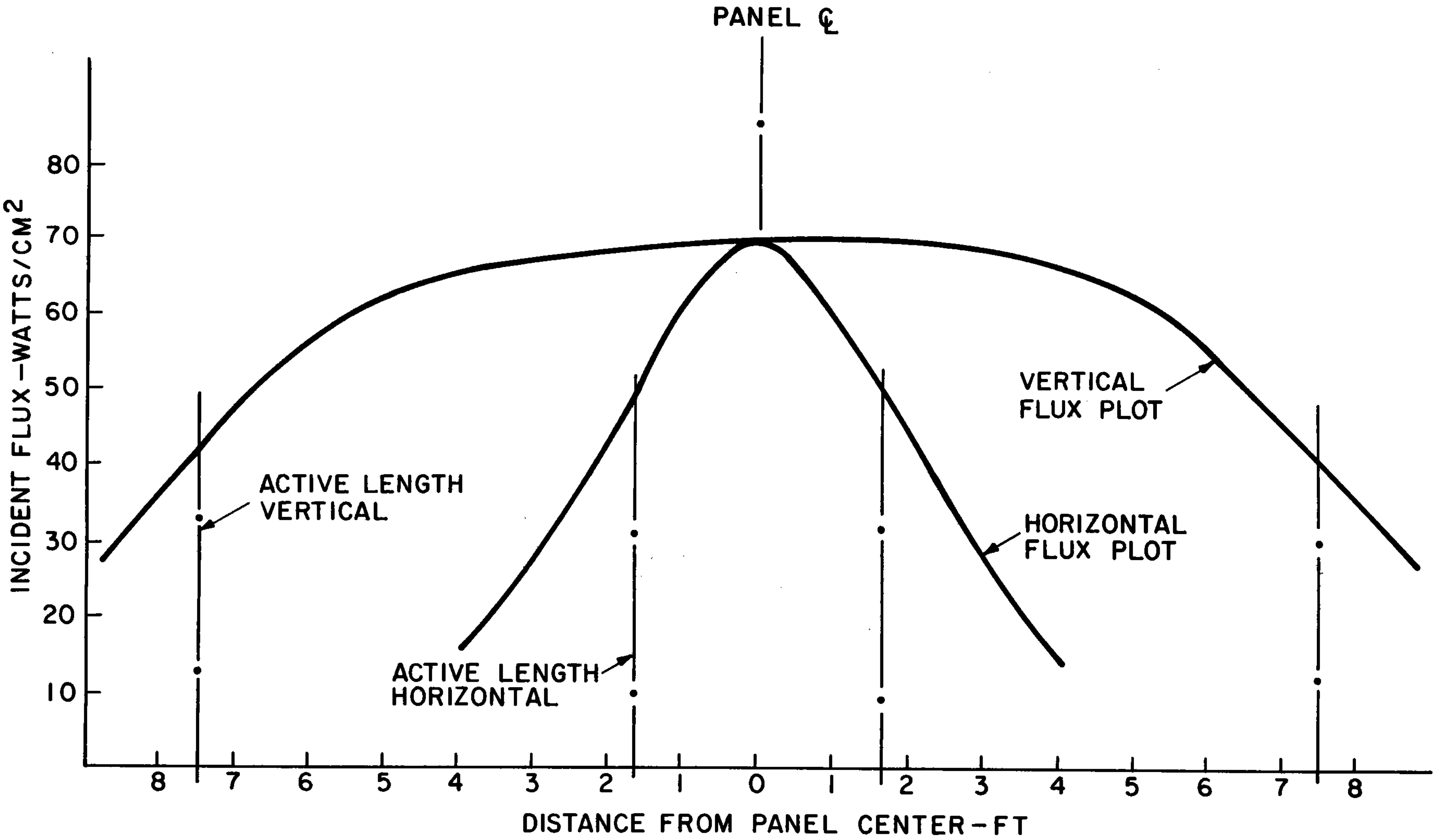


Figure 2-2. Test Panel "Uniform" Flux Profile

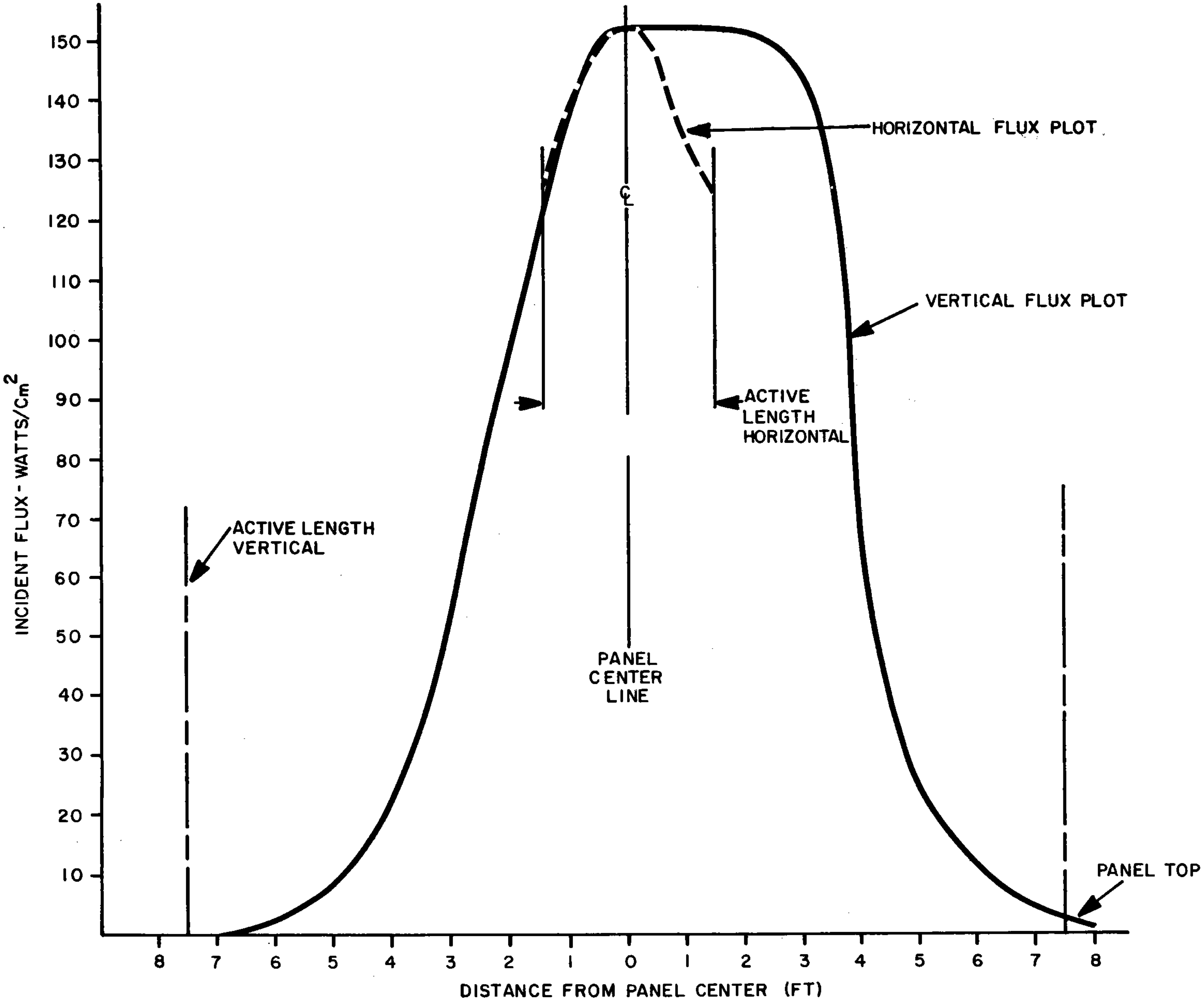


Figure 2-3. Test Panel Peak Flux Profile

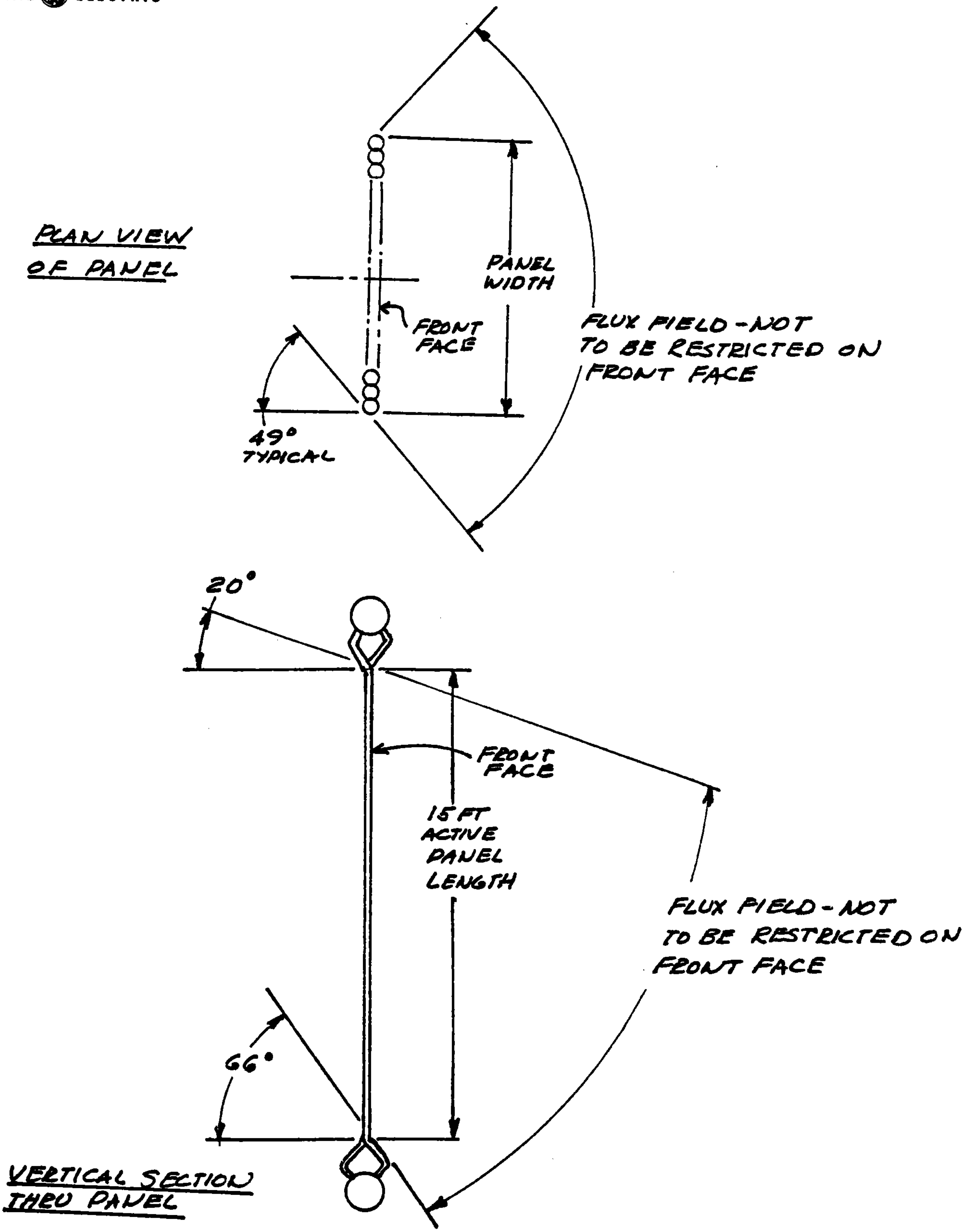


Figure 2-4. Panel Flux Field Restrictions

Table 2-2

ABSORBER LOSS PROGRAM MODIFICATIONS

- Expansion of data arrays to accommodate 121 data points from HELIOS.
- Changing panel physical description to conform to the test panel.
- Changing panel operating characteristics (Sodium inlet/outlet temps.)
- Changing basic panel geometry from three header center feed to two header bottom inlet, top outlet.
- Changing from Lyons to Lubarsky-Kaufman correlation for calculating Nusselt number (more realistic for test panel operating range).
- Addition of print out for absorbed flux.
- Changing flow calculation from a per horizontal mode basis to a total panel basis.

Table 2-3

SRTA/COMMERCIAL PANEL COMPARISON

Parameter Physical Characteristics	SRTA		Commercial (100 MWe)	Repowering (60 MWe)
Width, M (ft.)	1 (3.31)		2.09 (6.87)	1.52 (5.0
Length, M (ft.)	4.57 (15.0)		16 (52.48)	12 (39.3
Tube Diam. CM (in.)	1.905 (.75)		1.905 (.75)	1.905 (.7
Tube Wall, CM (in.)	.127 (.05)		.127 (.05)	.127 (.0
Number of Tubes	51		108	80
Material	I800		I800	I800
Flow Driver	EM Pump		EM Pump	EM Pump
Tube-To-Tube Joints	Brazed		Brazed	Brazed
Tube-To-Header Joints	Welded		Welded	Welded
Performance Characteristics	**Uniform Profile**	**Peak Profile**		
Peak Flux, (MW/M^2)	0.64	1.55	1.2	1.1
Inlet Temp., °C (°F)	323 (613)	323 (613)	323 (613)	293 (56
Outlet Temp., °C (°F)	593 (1100)	593 (1100)	593 (1100)	593 (110
Sodium Velocity (Max.) M/sec (ft/sec)	.70 (2.3)	.70 (2.3)	3.1 (10.2)	1.9 (6.
Max. Wall Temperature Rise °C (°F)	52 (90.5)	105 (189)	86 (155)	78 (14

2.2 PANEL FATIGUE LIFE ANALYSIS

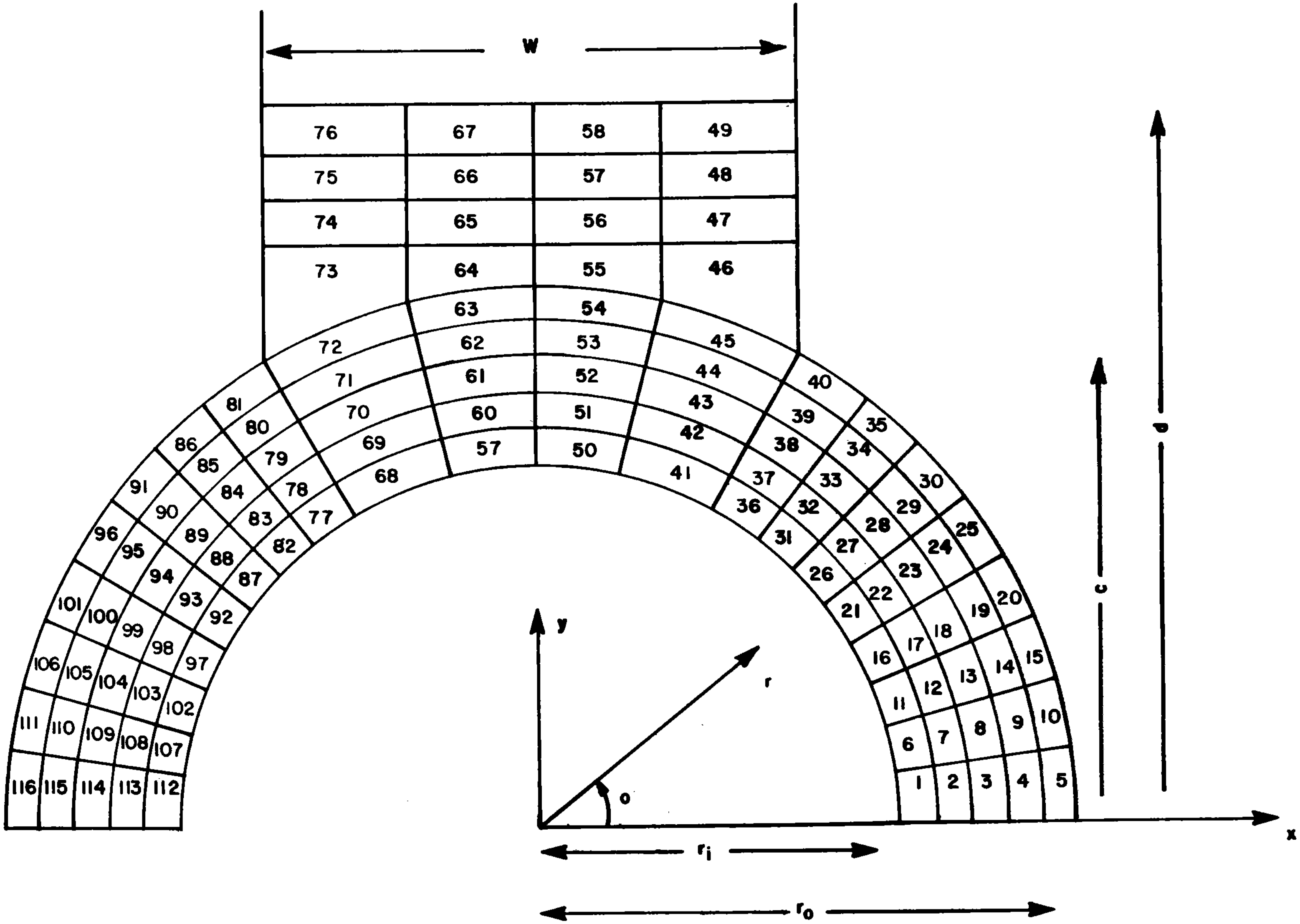
The absorber test panel will be operated at most a few thousand hours and fatigue does not appear to be a concern; however, it is very desirable that the design and fabrication be appropriate for a commercial scale plant with a thirty year life. Volume I Section 2 describes in detail the fatigue life calculations used by General Electric to evaluate the commercial panel. As described in Volume III Section 2 and in Section 1 of this volume, the test panel will be brazed with hourglass inserts between the tubes. Foster Wheeler and General Electric have conducted preliminary analysis of the fatigue life of a panel with inserts. The final analysis results will be included in the program final design report; however, the preliminary Foster Wheeler analysis for the current configuration is summarized below.

2.2.1 ANALYSIS METHOD

The steady-state temperature distribution analysis and thermal stress analysis of the commercial absorber panel were done using the finite element computer program ANSYS (Ref. 1). It should be noted that this analysis took into account only those stresses that were induced by the front-to-back thermal gradient, as opposed to those that were caused by temperature differentials at different points in the plane of the panel.

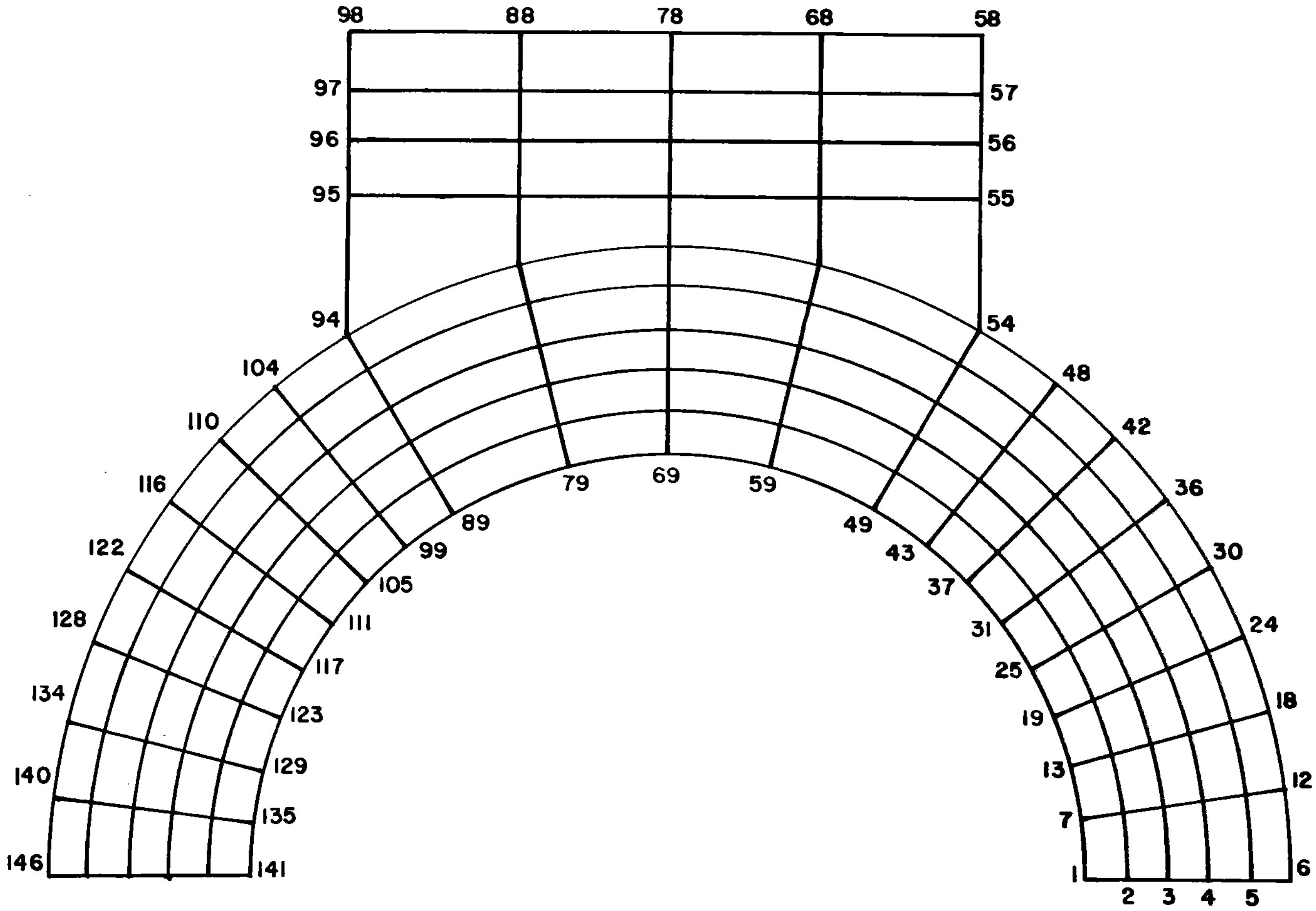
The finite element model used is shown in Figures 2-5 and 2-6. Because of symmetry, only one-half of the 19.05 mm (.75 inches) x 1.27 mm (.05 inches) mean wall tube and its 9.525 mm (.315 inches) x .762 mm (.030 inches) hourglass-shaped spacer strip was considered. The tube was divided into 100 isoparametric elements whereas the strip was simulated by a coarser, 12-element mesh because the critical area, in terms of stress, was expected to be the front of the tube. The boundary conditions for the thermal analysis are given in Table 2-4.

Generalized plane strain conditions were assumed for the stress analysis along with the stress boundary conditions shown in Table 2-4. Because of the intermediate and end supports and the axial variations of flux, the problem is of a three-dimensional nature. A study conducted by J. Jones of Sandia Livermore (Ref. 2) however, has demonstrated that the two-dimensional generalized plane strain model reflects the state of stress and strain accurately. The generalized plane strain analysis was accomplished by first performing a plane strain analysis and then relaxing the axial forces at the ends. A postprocessor computer program was written for this purpose. The postprocessor can also calculate the bending stresses and peak stress in the tube.



NOTE: (1) ELEMENT NUMBERS ARE SHOWN
(2) NOT TO SCALE

Figure 2-5. Finite Element Model Node Locations



NOTE: (1) NODE NUMBERS ARE SHOWN
(2) NOT TO SCALE

Figure 2-6. Finite Element Model

Table 2-4

BOUNDARY CONDITIONS FOR RECEIVER PANEL ANALYSIS

Boundary	Thermal	Stress
$r = r$ $0 \leq \theta \leq \pi/2 - \phi$	$k\ \partial T/\partial r = -q''_o \cos\theta$	$\sigma_{rr} = 0$ $\tau_{r\theta} = 0$
$r = r_o$ $\pi/2 + \phi \leq \theta < \pi$	$\partial T/\partial r = 0$	
$r = r_i$ $0 \leq \theta \leq \pi$	$k\ \partial T/\partial r = h_i\ (T - T_f)$	$\sigma_{rr} = -p$ $\tau_{r\theta} = 0$
$r_i \leq r \leq r_o$ $\theta = 0$	$\partial T/\partial \theta = 0$	$V = 0$ $\tau_{r\theta} = 0$
$r_i \leq r \leq r_o$ $0 = \pi$		
$z = 0$	$\partial T/\partial z = 0$	$W = \text{constant}$ $\int_A \sigma_{zz}\, da = 0$
$z = 1$		
$x = w/2$ $c \leq y \leq d$	$k\ \partial T/\partial x = -q''_o$	$\sigma_{xx} = 0$ $\tau_{xy} = 0$
$x = -w/2$ $c \leq y \leq d$	$\partial T/\partial x = 0$	
$-w/2 \leq x \leq w/2$ $y = d$	$\partial T/\partial y = 0$	$V = \text{constant}$ $\tau_{xy} = 0$

Note: U, V, W are the displacements in the x, y and z directions, respectively.

Based on Figures 2-7 through 2-9 of Panel Specification 295 A4724 (See Appendix B), it was expected that the panel's peak metal temperature would be experienced at a point located 6 m below the top of the panel. As a result, this elevation was chosen for analysis and the following parameters were determined to exist at this point:

- Flux q_o = 1.01MW/m^2 = 320,700 Btu/h·ft^2
- Film coefficient h_i = 7,625 Btu/h·ft^2°F
- Bulk temperature T_f = 518°C (965°F)
- Thermal conductivity k = 0.9416 Btu/in.h°F
- Modulus of elasticity E = 22.4 x 10^6psi
- Coefficient of thermal expansion α = 9.6 x 10^{-6}in./in.
- Poisson's ratio ν = 0.372

The temperatures and axial stresses were calculated at this elevation for each element of the model. The temperatures and stresses that exist at the inner and outermost elements of the tube and spacer strip are shown in Figures 2-7 and 2-8. From these data it can be seen that element #5, which corresponds to the crown of the tube exposed to the solar flux, experiences the worst combination of stress and temperature.

2.2.2 CREEP/FATIGUE EVALUATION

Although a complete evaluation of the creep-fatigue life of the panel can be done only after the transient analysis is completed, some insight can be gained by analyzing the steady-state results.

There is no consensus as to what is a reasonable approach or criteria to evaluate creep-fatigue life of solar receiver components. ASME Boiler and Pressure Vessel Code Sections I and VIII have no criteria for creep-fatigue evaluation. Code Case N-47 has criteria for creep-fatigue evaluation, but these criteria are deemed too conservative and may result in severe economic penalties if used for solar applications.

In this analysis, four approaches were considered. They are as follows:

I <u>Modified Coffin-Manson Approach</u>: This is a fatigue correlation suggested earlier by GE, but is not "frequency modified" as more recently proposed by GE and documented in Volume I, Section 2.

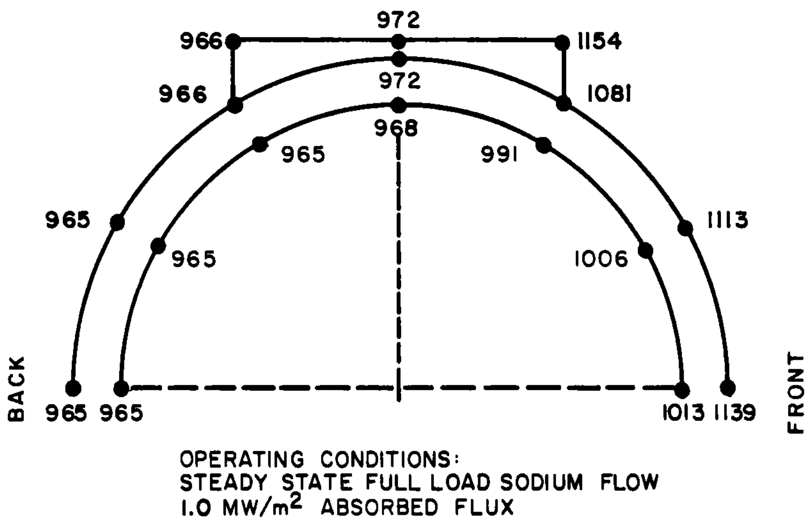


Figure 2-7. Panel Front to Back Temperature Distribution (°F) 6 Meters Below Top of Panel

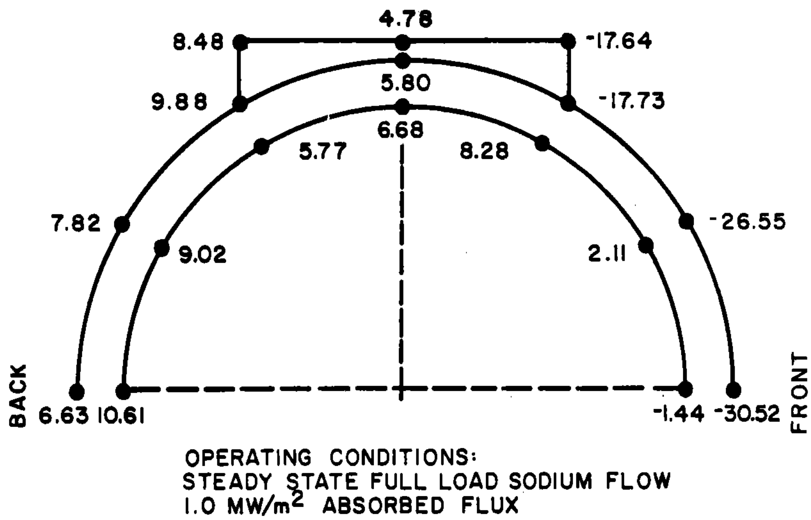


Figure 2-8. Panel Front to Back Axial Stress Distribution (KSi) 6 Meters Below Top of Panel

II <u>Modified Nuclear Approach</u>: This approach was suggested in Reference 3 and was used by Foster Wheeler in Phase I of this program. In this approach, the inelastic fatigue curves of Code Case N-47 are used. Creep damage due to compressive hold times is ignored.

III <u>Interim Structural Design Standard Approach</u>: A detailed description of this approach may be found in Reference 4. This is also a modification of the nuclear approach. In this approach, creep-fatigue damage is evaluated according to the linear damage equation:

$$\sum_{j=1}^{p} \left(\frac{n}{N_d}\right)_j + \sum_{k=1}^{q} \left(\frac{t}{T_d}\right)_k \leq D$$

where:

D = Total allowable creep fatigue damage (=1 for Incoloy 800).

n = Number of applied cycles of loading condition j.

N_d = Number of design allowable cycles for loading conditions j. N_d is obtained from Figure T-1420-1C of Code Case N-47.

This is a departure from the nuclear approach which requires the use of Figure T-1430-1C in conjnction with elastic analysis.

t = Time duration of load condition k.

T_d = Allowable creep rupture time at a given stress from load, k. In this analysis, T_d is obtained from the creep-rupture time curves given in Code Case N-47. The stress value used is 1.25 S_{yk}, where S_{yk} is the yield stress. This is also a departure from nuclear approach which requires the use of 1.25 $S_{yk}/0.9$.

IV <u>Nuclear Approach</u>: For comparison purposes, the nuclear approach is also considered.

Using the "Hold at Full Flux" time and cycle data given in Figure 3-2 of this panel specification the creep-fatigue life of Element #5 was calculated by all four of the above approaches and the results are summarized in Table 2-5. The effective stress and strain (elastic) for this element was calculated to be 27.018 ksi and 1.0887×10^{-3}, respectively.

The design approaches proposed by GE and FW both indicate that the commercial panel's full flux operating condition will result in creep-fatigue life in excess of 30 years. As expected, approaches III and IV predict much lower creep-life, but it is noted that there could be a considerable improvement through an elastic-plastic-creep analysis.

Table 2-5

CREEP-FATIGUE LIFE OF THE COMMERCIAL PANEL†††

Approach	Fatigue Life (Cycles)	Creep Life (hours)	Creep-Fatigue (years)
Coffin-Manson	$>10^6$		>30
Code Case 1592 Figure 1420-1C No hold time	$>10^6$		>30
Interim Structural Design Standard	$>10^6$	20,000	=6.5*
Nuclear (Elastic Analysis)	1,000	6,500	=1**

* This analysis ignores the reduction in stresses due to creep relaxation. If an inelastic analysis is done, it can be shown that the life would be considerably higher.

** This is very unrealistic. By doing an inelastic analysis, the creep-fatigue life can be shown to be increased at least up to 5 to 10 years.

††† Results shown are for steady-state (full flux) conditions only; effect of transient conditions will be included at a later date.

2.3 PANEL THERMAL ANALYSIS

The calculation of the "uniform" flux distribution to be absorbed by the brazed test panel when operated in a no wind, 70°F ambient condition was discussed in Section 2.1.2 (Figure 2-2). This distribution results in 2.26 MW of absorbed flux over the panel's face. Under this design condition, the flux distribution (shown in Table 2-6) is observed to be approximately symmetrical about the panel's horizontal and vertical centerlines with flux extremes ranging from 24.3 to 63.8 W/cm^2. For analysis purposes, the panel was subdivided into an 11 x 11 element matrix with each element approximately .885 cm (3.5 inches) wide x 4.1593 cm (16.375 inches) high. The sodium and average outside metal temperatures that will exist at the center of each element of the panel are given in Tables 2-7 and 2-8. Because the incident flux possesses significant nonuniformity, it is observed that the sodium outlet temperatures (topmost elements) will range from 548°C (1019°F) at the ends of the panel to 613°C (1136°F) at the center of the panel. Upon combining in the outlet pipe header, the sodium will exit thepanel at an average mix temperature of 593°C (1100°F), despite this 48°C (118°F) end-to-center element temperature difference. The average metal temperature of the end and center element flow streams will, however, be 470°C (878°F) and 513°C (955°F), respectively. Tables 2-9 through 2-11 tabulate similar data for the minimum load condition during which the sodium flow and absorbed solar flux will be reduced to 0.37 MW and 3786 kg/h (8,347 lb/h), respectively, while still yielding a 593°C (1100°F) outlet temperature.

Although uniform flux aiming will be the panel's design condition, an analysis was also made to determine the fluxes and temperatures that will exist if a "single point" aiming strategy was used (Figure 2-8). In this approach, the mirrors will be focused at a point slightly above the panel's horizontal centerline to minimize flux spillage off the bottom and top of the panel. Tables 2-12 through 2-14 present flux and temperature data for this condition. From these tabulations, it is observed that the flux will vary from extremes of 0.1 to 145 W/cm^2 and average outside metal temperatures will vary from 454°C (849°F) at the ends to 487°C (908°F) at the center. Although the average metal temperature differentials will be much lower than experienced with uniform flux aiming 14°C versus 25°C (57°F versus 77°F), the maximum absorbed flux will be approximately 2.3 times higher and result in substantially higher local tube metal temperatures.

Table 2-6

PANEL ABSORBED FLUX DISTRIBUTION (W/cm^2) @ MAXIMUM LOAD AND UNIFORM FLUX OPERATION

22.7	24.7	26.5	27.8	28.6	28.9	28.8	28.0	26.8	25.1	23.1
37.4	40.9	44.0	46.2	47.5	48.1	47.5	46.2	44.0	41.0	37.5
46.1	50.5	54.0	56.7	58.3	58.9	58.3	56.6	53.8	50.2	45.8
49.1	53.6	57.5	60.2	61.8	62.6	61.8	60.1	57.3	53.4	48.9
49.9	54.5	58.2	61.1	62.9	63.4	62.7	61.0	58.0	54.2	49.6
50.0	54.7	58.6	61.3	63.1	63.8	63.0	61.2	58.5	54.5	49.9
50.0	54.7	58.5	61.4	63.2	63.8	63.2	61.4	58.5	54.6	49.9
49.2	53.8	57.6	60.4	62.1	62.8	62.0	60.2	57.5	53.6	49.0
46.2	50.5	54.2	56.8	58.5	59.0	58.4	56.7	53.9	50.2	45.7
37.9	41.6	44.7	47.0	48.5	49.1	48.5	47.1	44.8	41.8	38.0
24.3	26.6	28.5	30.0	31.0	31.3	31.1	30.2	28.9	27.0	24.7

Table 2-7

PANEL NODE SODIUM TEMPERATURES (°F) @ MAXIMUM LOAD AND UNIFORM FLUX OPERATION

1019.4	1058.5	1091.4	1115.5	1130.6	1136.3	1130.4	1115.3	1091.0	1057.8	1018.7
991.5	1028.0	1058.7	1081.2	1095.3	1100.5	1095.0	1080.8	1058.1	1027.1	990.6
952.7	985.6	1013.1	1033.4	1046.1	1050.8	1045.8	1033.1	1012.7	984.8	951.9
908.5	937.2	961.3	979.1	990.3	994.4	990.0	978.9	961.1	936.7	907.9
862.5	887.1	907.6	922.8	932.4	935.9	932.2	922.6	907.5	886.7	862.1
816.1	836.4	853.4	865.9	873.9	876.7	873.7	865.9	853.4	836.3	815.9
769.7	785.6	799.0	808.9	815.2	817.5	815.1	808.9	799.1	785.6	769.5
723.6	735.2	745.1	752.4	757.0	758.7	757.0	752.5	745.2	735.4	723.6
679.3	686.8	693.2	697.9	701.0	702.1	701.0	698.2	693.5	687.2	679.5
640.2	644.0	647.3	649.7	651.3	651.9	651.4	650.0	647.7	644.5	640.6
611.3	612.3	613.2	614.0	614.4	614.5	614.4	614.0	613.4	612.5	611.5

Table 2-8

PANEL AVERAGE OUTSIDE TUBE METAL TEMPERATURE (°F) @ MAXIMUM LOAD AND UNIFORM FLUX OPERATION

1052.1	1094.0	1129.3	1155.2	1171.3	1177.5	1171.4	1155.2	1129.3	1094.0	1052.1
1045.6	1086.9	1121.8	1147.2	1163.0	1169.1	1162.7	1146.8	1121.2	1086.2	1044.9
1019.6	1058.5	1090.9	1114.8	1129.7	1135.2	1129.4	1114.3	1090.1	1057.3	1018.4
980.1	1015.1	1044.5	1066.0	1079.4	1084.6	1079.1	1065.6	1044.0	1014.2	979.2
935.7	966.8	992.5	1011.6	1023.7	1027.9	1023.3	1011.3	992.1	966.0	935.1
890.1	916.9	939.4	955.8	966.3	970.1	966.0	955.6	939.3	916.5	889.7
844.2	866.7	885.6	899.6	908.4	911.5	908.3	899.6	885.6	866.6	843.9
797.4	815.7	831.1	842.4	849.5	852.2	849.3	842.2	831.1	815.5	797.1
749.0	763.0	774.8	783.4	789.0	790.8	788.8	783.4	774.6	763.0	748.7
698.0	707.3	715.3	721.1	725.0	726.4	725.0	721.5	715.9	708.1	698.6
648.7	653.2	657.0	660.1	661.9	662.5	662.1	660.5	657.8	654.0	649.5

GENERAL ELECTRIC

Table 2-9

PANEL ABSORBED FLUX DISTRIBUTION (W/cm^2) @ MINIMUM
LOAD AND UNIFORM FLUX CONDITIONS

2.2	2.4	2.5	2.6	2.7	2.7	2.7	2.6	2.6	2.5	2.3
5.2	5.7	6.1	6.4	6.5	6.6	6.6	6.4	6.1	5.7	5.3
7.1	7.8	8.3	8.7	9.0	9.1	9.0	8.7	8.3	7.7	7.1
7.9	8.6	9.3	9.7	10.0	10.1	10.0	9.7	9.2	8.6	7.9
8.3	9.1	9.7	10.2	10.5	10.6	10.5	10.2	9.7	9.0	8.2
8.5	9.3	10.0	10.5	10.8	10.9	10.8	10.5	10.0	9.3	8.5
8.7	9.5	10.2	10.8	11.1	11.2	11.1	10.8	10.2	9.5	8.7
8.7	9.5	10.3	10.8	11.1	11.3	11.1	10.8	10.2	9.5	8.7
8.2	9.1	9.8	10.3	10.6	10.7	10.6	10.3	9.7	9.0	8.1
6.7	7.4	8.0	8.5	8.8	8.9	8.8	8.5	8.1	7.5	6.7
4.1	4.5	4.9	5.2	5.4	5.5	5.4	5.3	5.0	4.6	4.2

Table 2-10

PANEL NODE SODIUM TEMPERATURES (°F) @ MINIMUM
LOAD AND UNIFORM FLUX CONDITIONS

1021.3	1062.5	1097.0	1122.0	1137.5	1143.5	1137.3	1121.7	1096.5	1061.8	1020.6
1000.4	1039.8	1072.6	1096.6	1111.5	1117.1	1111.2	1096.2	1071.9	1038.7	999.3
965.4	1001.6	1031.8	1053.9	1067.7	1072.8	1067.3	1053.5	1031.2	1000.6	964.5
922.9	955.1	982.0	1001.7	1014.1	1018.7	1013.8	1001.4	981.6	954.4	922.2
877.2	905.1	928.3	945.5	956.3	960.2	956.1	945.3	928.2	904.6	876.7
829.8	853.0	872.6	887.0	896.2	899.4	896.0	886.9	872.6	852.9	829.5
781.2	799.7	815.4	826.9	834.2	836.9	834.1	826.9	815.5	799.8	781.0
732.1	745.8	757.4	766.0	771.5	773.4	771.4	766.1	757.6	746.0	732.1
684.3	693.2	700.8	706.4	710.1	711.4	710.1	706.7	701.2	693.7	684.6
642.0	646.6	650.5	653.4	655.3	656.0	655.4	653.7	651.0	647.1	642.5
611.5	612.8	613.9	614.7	615.2	615.4	615.3	614.8	614.1	613.0	611.8

Table 2-11

PANEL AVERAGE OUTSIDE TUBE METAL TEMPERATURES (°F) @ MINIMUM
LOAD AND UNIFORM FLUX CONDITIONS

1026.1	1067.6	1102.4	1127.6	1143.2	1149.3	1143.1	1127.4	1102.0	1067.1	1025.6
1011.6	1052.0	1085.8	1110.3	1125.6	1131.4	1125.3	1109.9	1085.1	1051.0	1010.6
980.8	1018.4	1049.7	1072.6	1086.9	1092.2	1086.6	1072.2	1049.0	1017.3	979.7
940.0	973.8	1002.0	1022.6	1035.6	1040.4	1035.2	1022.3	1001.5	973.0	939.2
895.0	924.6	949.2	967.4	978.9	983.0	978.6	967.2	949.0	924.1	894.5
848.1	873.2	894.2	909.7	919.5	923.0	919.3	909.6	894.2	873.0	847.8
800.0	820.4	837.5	850.2	858.2	861.1	858.1	850.2	837.6	820.3	799.8
750.9	766.5	779.7	789.4	795.6	797.8	795.4	789.4	779.8	766.6	750.8
702.1	712.9	722.0	728.7	733.1	734.6	733.1	729.0	722.3	713.2	702.3
656.7	662.7	668.0	671.9	674.4	675.3	674.5	672.2	668.5	663.4	657.2
620.5	622.7	624.6	626.1	627.0	627.3	627.1	626.3	625.0	623.1	620.9

Table 2-12

PANEL ABSORBED FLUX DISTRIBUTION (W/cm^2) @ MAXIMUM
LOAD AND SINGLE POINT AIMING CONDITIONS

1.8	1.7	1.4	1.3	2.1	1.9	2.1	1.3	1.4	1.7	1.8
12.6	13.4	14.1	14.9	14.7	15.6	14.7	14.9	14.1	13.4	12.6
51.7	54.5	55.2	57.0	57.8	59.6	57.8	57.0	55.2	54.5	51.7
111.6	118.3	128.7	133.5	139.1	142.9	139.1	133.5	128.7	118.3	111.6
115.3	120.1	130.7	136.4	144.1	144.1	144.1	136.4	130.7	120.1	115.3
113.0	119.7	130.4	135.3	141.1	145.0	141.1	135.3	130.4	119.7	113.0
53.7	56.6	57.6	59.6	60.5	62.5	60.5	59.6	57.6	56.6	53.7
14.7	15.7	16.7	17.6	17.6	18.6	17.6	17.6	16.7	15.7	14.7
4.0	4.0	4.0	4.0	5.0	5.0	5.0	4.0	4.0	4.0	4.0
2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table 2-13

PANEL NODE SODIUM TEMPERATURES (°F) @ MAXIMUM
LOAD AND SINGLE POINT AIMING CONDITIONS

1043.8	1067.5	1099.9	1119.1	1139.6	1151.8	1139.6	1119.1	1099.9	1067.5	1043.8
1037.1	1060.5	1092.7	1111.6	1131.8	1143.7	1131.8	1111.6	1092.7	1060.5	1037.1
1007.3	1029.1	1060.6	1078.4	1098.3	1108.9	1098.3	1078.4	1060.6	1029.1	1007.3
931.8	949.2	975.5	990.3	1007.2	1015.2	1007.2	990.3	975.5	949.2	931.8
826.8	838.9	855.5	865.4	876.1	882.4	876.1	865.4	855.5	838.9	826.8
721.2	728.0	734.7	739.7	744.2	748.7	744.2	739.7	734.7	728.0	721.2
644.1	646.4	647.7	649.5	650.9	652.7	650.9	649.5	647.7	646.4	644.1
612.4	612.9	613.3	613.8	614.7	615.1	614.7	613.8	613.3	612.9	612.4
603.8	603.8	603.8	603.8	604.2	604.2	604.2	603.8	603.8	603.8	603.8
601.0	601.0	601.0	601.0	601.0	601.0	601.0	601.0	601.0	601.0	601.0
600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0

PAUSE

Table 2-14

PANEL AVERAGE OUTSIDE TUBE METAL TEMPERATURE (°F) @ MAXIMUM
LOAD AND SINGLE POINT AIMING CONDITIONS

1047.9	1071.2	1103.0	1121.9	1144.2	1156.2	1144.2	1121.9	1103.0	1071.2	1047.9
1065.6	1090.8	1124.4	1145.1	1164.9	1178.7	1164.9	1145.1	1124.4	1090.8	1065.6
1124.3	1151.9	1184.5	1206.0	1227.4	1242.0	1227.4	1206.0	1184.5	1151.9	1124.3
1184.2	1215.8	1264.4	1289.0	1317.7	1333.8	1317.7	1289.0	1264.4	1215.8	1184.2
1090.9	1113.3	1153.0	1175.2	1202.6	1208.5	1202.6	1175.2	1153.0	1113.3	1090.9
984.1	1006.0	1036.7	1052.3	1069.7	1082.7	1069.7	1052.3	1036.7	1006.0	984.1
772.2	781.3	784.9	791.2	794.8	801.2	794.8	791.2	784.9	781.3	772.2
648.0	650.8	653.6	656.4	657.3	660.1	657.3	656.4	653.6	650.8	648.0
613.4	613.4	613.4	613.4	616.3	616.3	616.3	613.4	613.4	613.4	613.4
605.9	605.9	605.9	605.9	605.9	605.9	605.9	605.9	605.9	605.9	605.9
600.2	600.2	600.2	600.2	600.2	600.2	600.2	600.2	600.2	600.2	600.2

CONTINUE ITERATION?(YES=1,NO=0)?0

The sodium temperatures to be experienced at the end and center element stream tubes are plotted in Figure 2-9 versus panel length for both uniform and single point aiming conditions. These data reveal that the uniform aiming condition results in the largest tube-to-tube temperature differentials both within and above the active solar region of the panel. Figure 2-9 indicates that temperature differentials of approximately 58°C (136°F) and 62°C (143°F) will exist between the end and center tubes at the outlet of the brazed panel section during full load and minimum conditions, respectively.

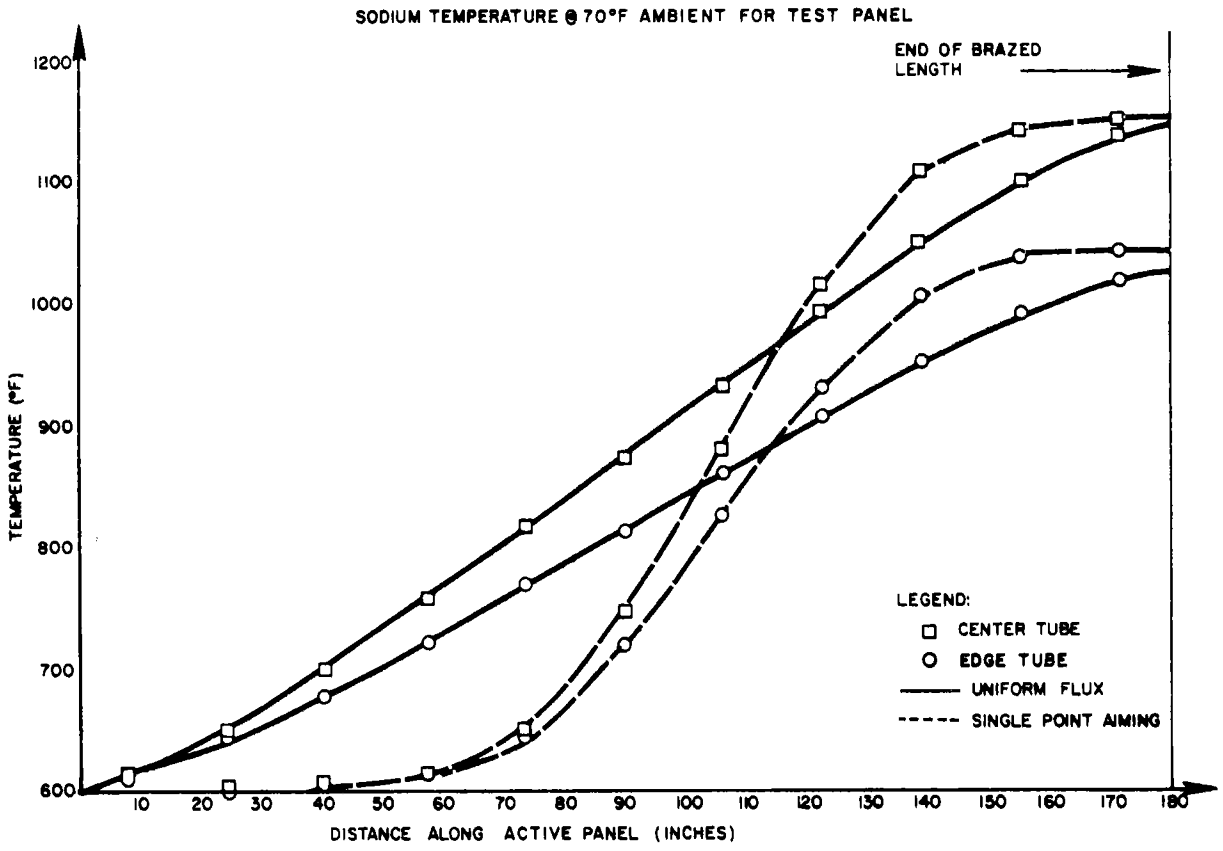
This large panel center-to-edge temperature gradient causes uneven thermal expansion. Since the active panel is brazed rapidly, there will be stresses generated in the tube-to-tube braze. A further design implication is that the rigid panel must be joined to the rigid header by curved "jumper tubes" that accommodate the uneven expansion and resultant stresses. Figure 2-10 shows the evolution of the current crossed jumper tube configuration.

This panel has been designed to operate with temperature differentials of 66°C (150°F) in the jumper tube region and 27°C (80°F) within the brazed section. With regard to the latter requirement, it is conventional practice to weld boiler panel tubes tangent-to-tangent with up to 38°C (100°F) difference in temperature between the tubes. Since the brazed panel's end-to-center tube differential is only 27°C (80°F) and since it is spread over 25 tubes rather than 2 tubes (differential is only about 3°F to 4°F between adjoining tubes), this differential will cause no problem provided the braze material strength is comparable to that of the Incoloy 800 tubes and spacer strips.

2.4 ABSORBER TEST PANEL DETAILED DESIGN

2.4.1 GENERAL ARRANGEMENT

The solar test panel's thermal performance has been discussed from the standpoint of a 51-tube assembly, based upon preliminary configuration specification during the Phase I program. The actual test panel has been designed to contain 50 tubes, 46 spacer strips, and 3 instrumentation strips. The latter are identical to the hourglass-shaped spacer strips except that their thickness has been increased to 2.38 mm (.09375 inch) at their minimum point to enable them to accept six thermocouples for measurement of the front face temperature of the panel. The panel's



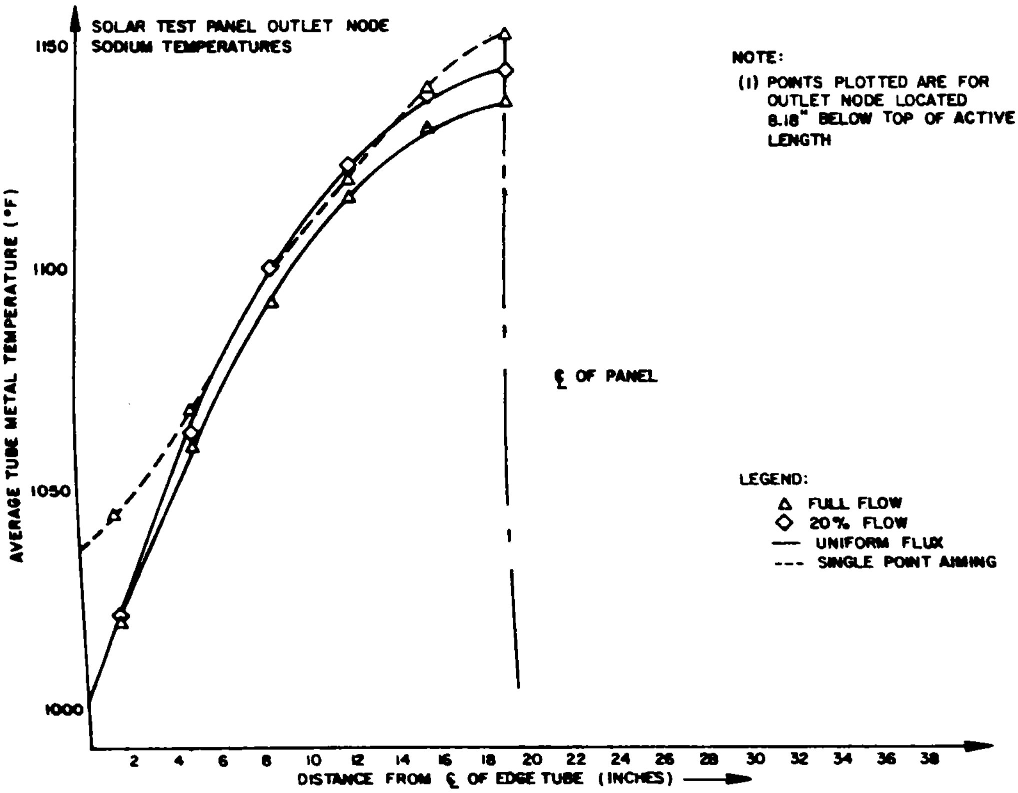


Figure 2-9. Absorber Test Panel Sodium Temperature Profiles

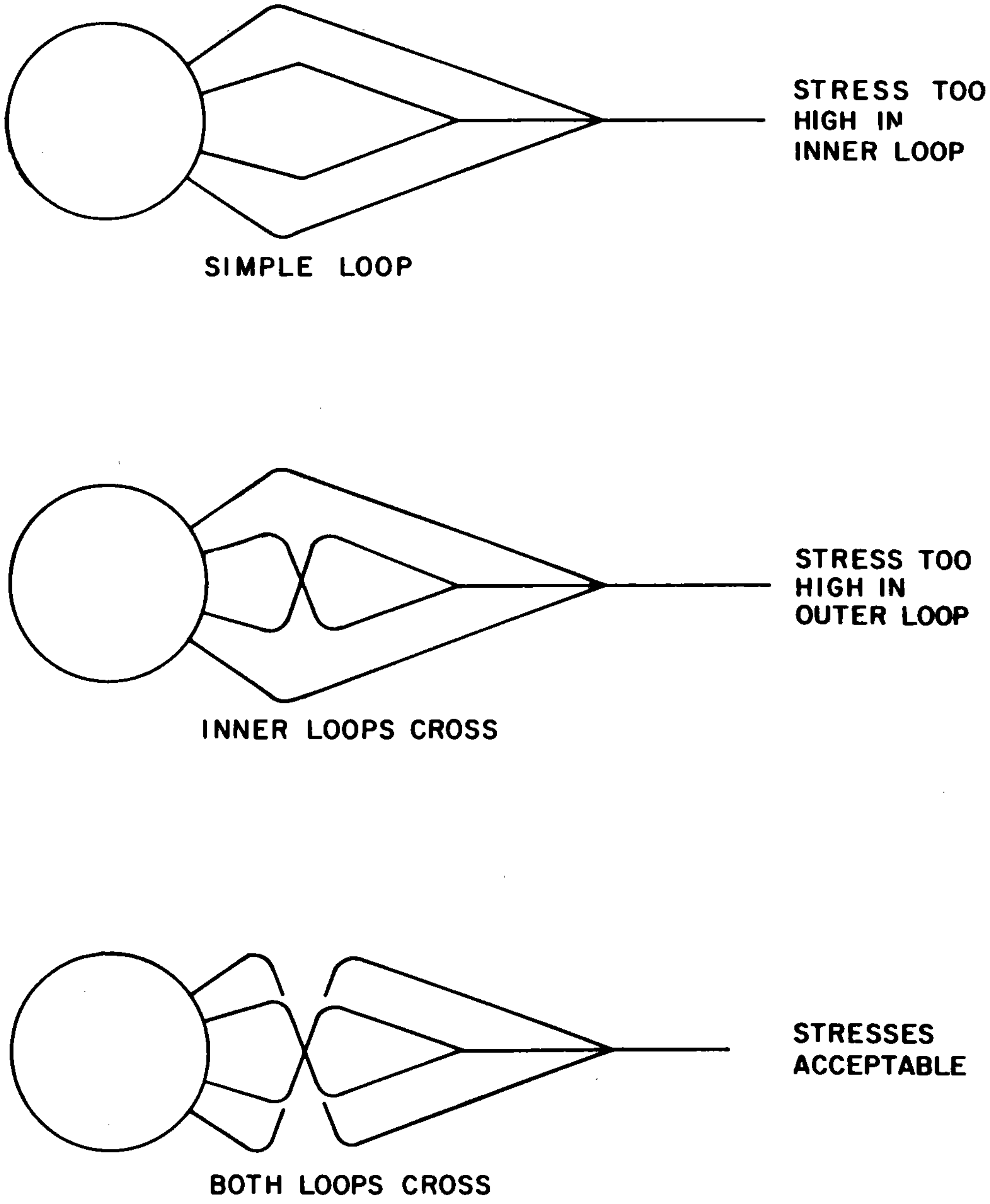


Figure 2-10. Jumper Tube Evolution

tube count was reduced to an even number to permit an instrumentation strip to be placed on the panel's centerline, the point of flux symmetry. The two remaining strips are located between the second and third tubes in from each end of the panel. As a result, the panel will be 994.569 mm (39.15625 inches) wide (excluding nickel plating) and will be mounted vertically, as shown in General Arrangement Drawing 67-3581-5-20 (Figure 2-11). Sodium will enter the panel via a 76.2 mm (3-inch) Schedule 40 nozzle provided on the centerline of the panel's bottom headers 203.2 mm (8-inch) Schedule 40 pipe and exit via a similar arrangement at the top. To minimize heat loss, the backside of the panel and the pipe headers will be covered by insulation jackets/boxes. The panel's top header will be anchored via cantilevered beams that protrude from the four post-type support structure detailed in Figures 2-12 and 2-13. The bottom header will be left free to grow downward. A support linkage is attached to this header to enable it to withstand 226 kg (500-lb) 2033.7 Newton-meter forces and (1500-ft/lb) moments in any direction. The jumper tubes will be attached to the headers by butt welding to stubs. These stubs will be machined from rod material and welded to the headers. The rod will then be bored out to remove the root notch. Dye penetrant checks will be used to ensure weld quality. The tube-to-stub-to-header connection arrangement is shown in Figure 2-14.

As indicated in Table 2-15, the panel will weigh approximately 1905 kg (4,200 lb) dry and 2041 kg (4,500 lb) when filled with sodium; the support structure will weigh approximately 1814 kg (4,000 lb) thus yielding an overall operating assembly weight of approximately 3856 kg (8,500 lb).

2.4.2 THERMAL EXPANSION

The test panel's top-to-bottom header height is 22 ft-10-3/4 in. After installation in the SRTA at CRTF, the panel will be operated isothermally with 593.3°C (1100°F) sodium being pumped through the unit. Under this condition and with the top header anchored, the panel will expand and the bottom header translate approximately 63.5 mm (2.5 inch) downward. To accommodate and guide this movement, a series of linkages are attached to the backside of the panel, as shown in Figure 2-15. The top and bottom linkages center the panel relative to the structure, whereas the interior linkages accommodate the axial expansion and serve as wind braces for the panel. Linkages were chosen for the panel after consideration of alternatives such as

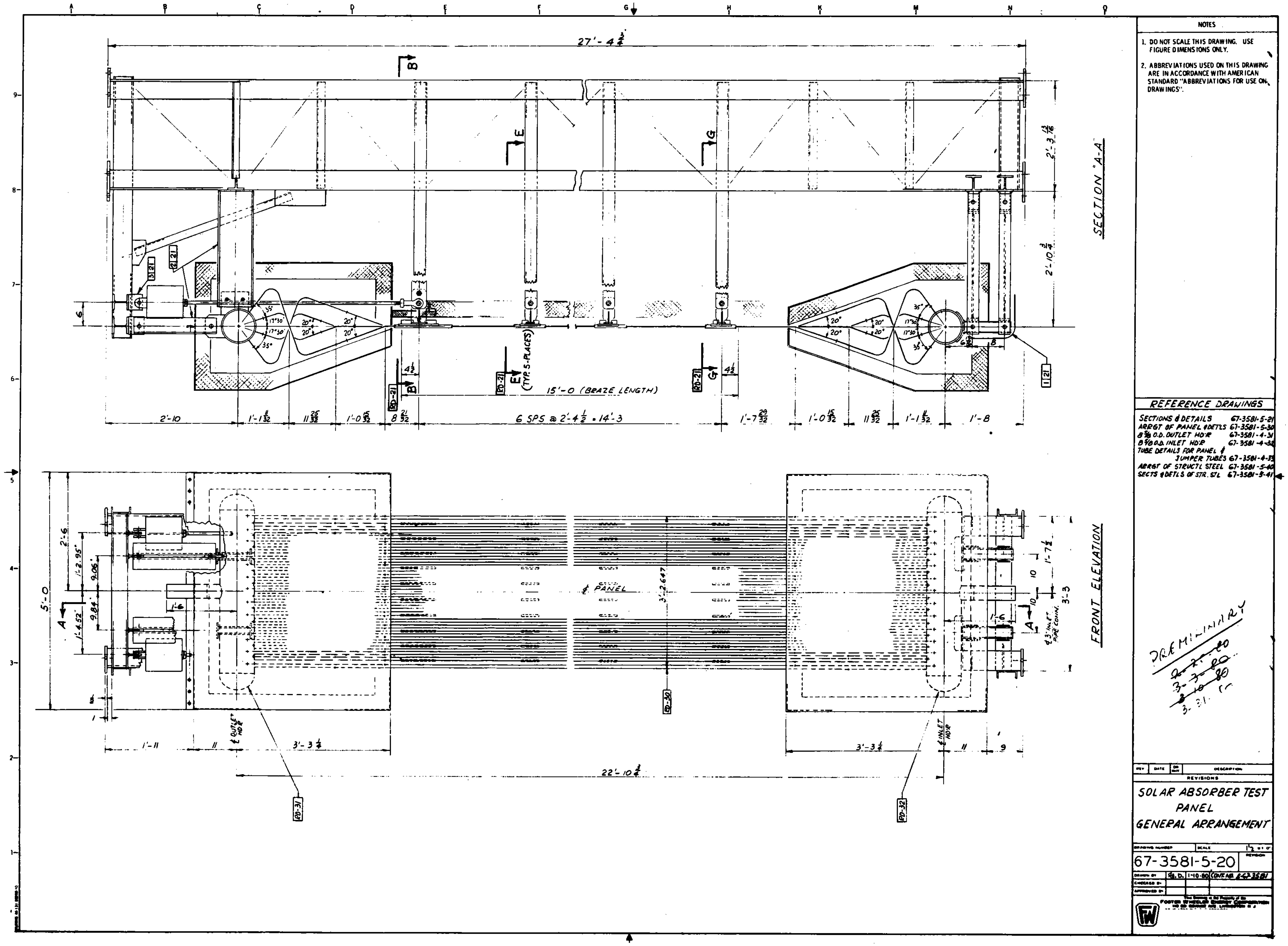


Figure 2-11. Absorber Test Panel General Arrangement

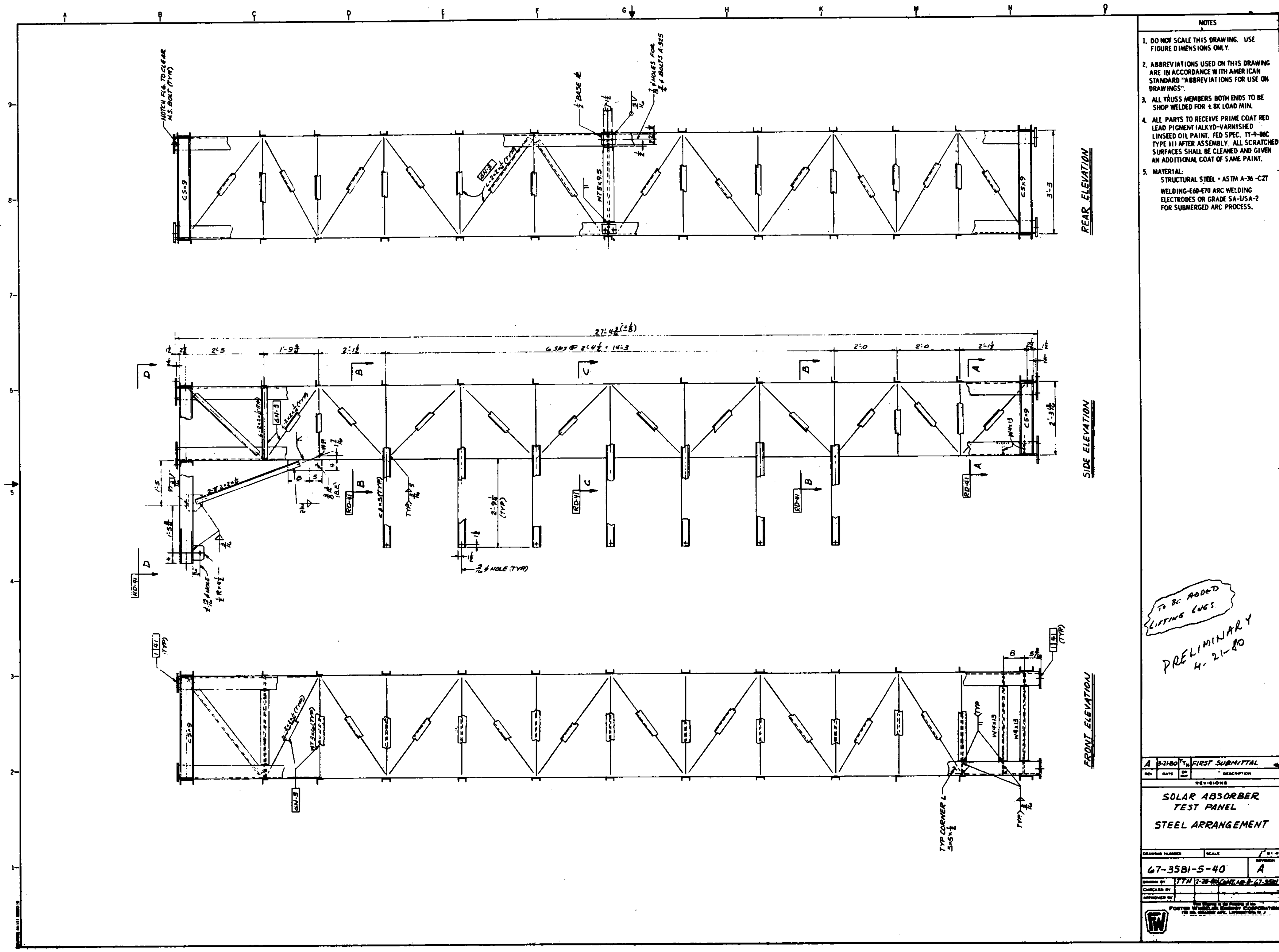


Figure 2-12. Absorber Test Panel Structure (Sheet 1)

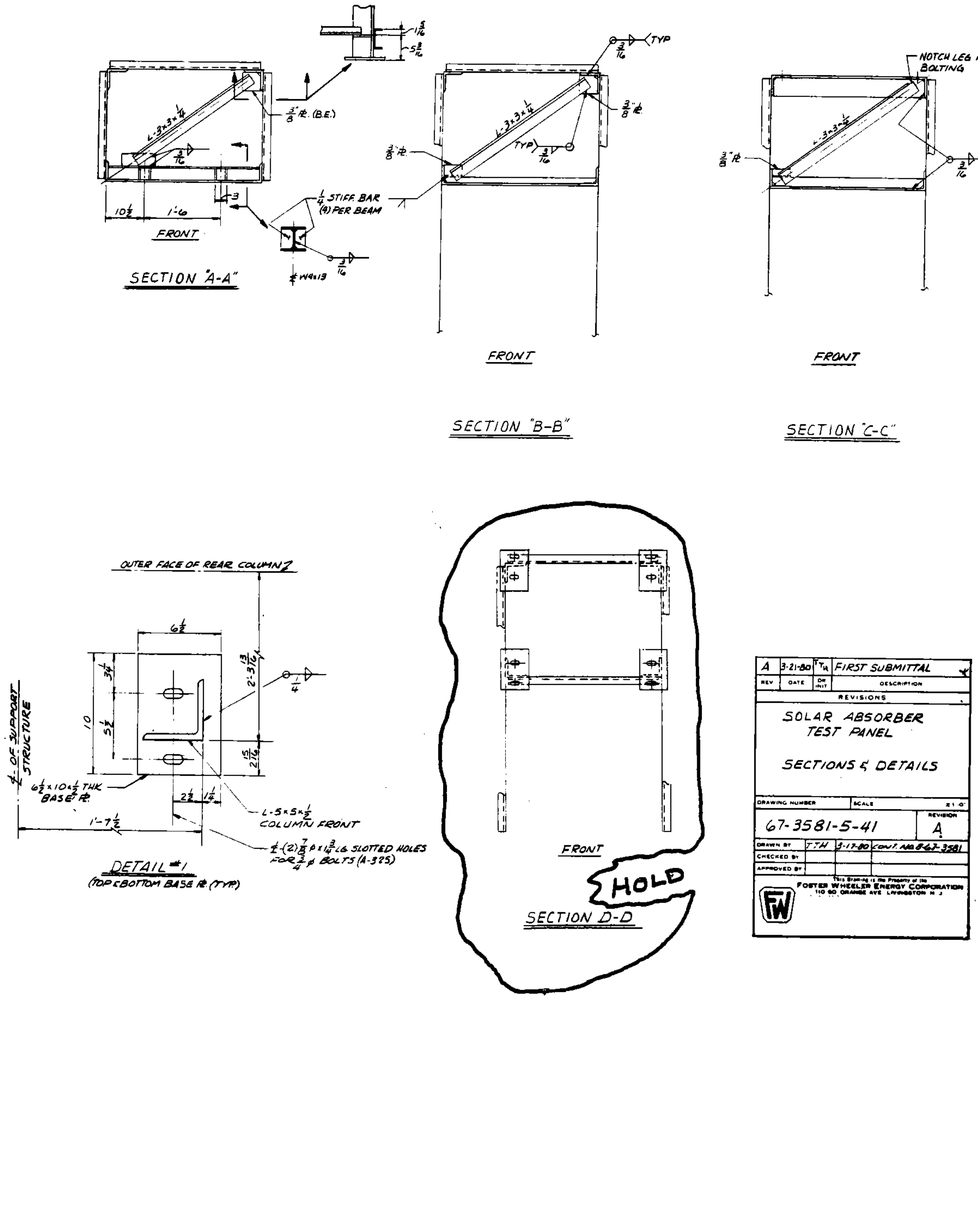


Figure 2-13. Absorber Test Panel Structure (Sheet 2)

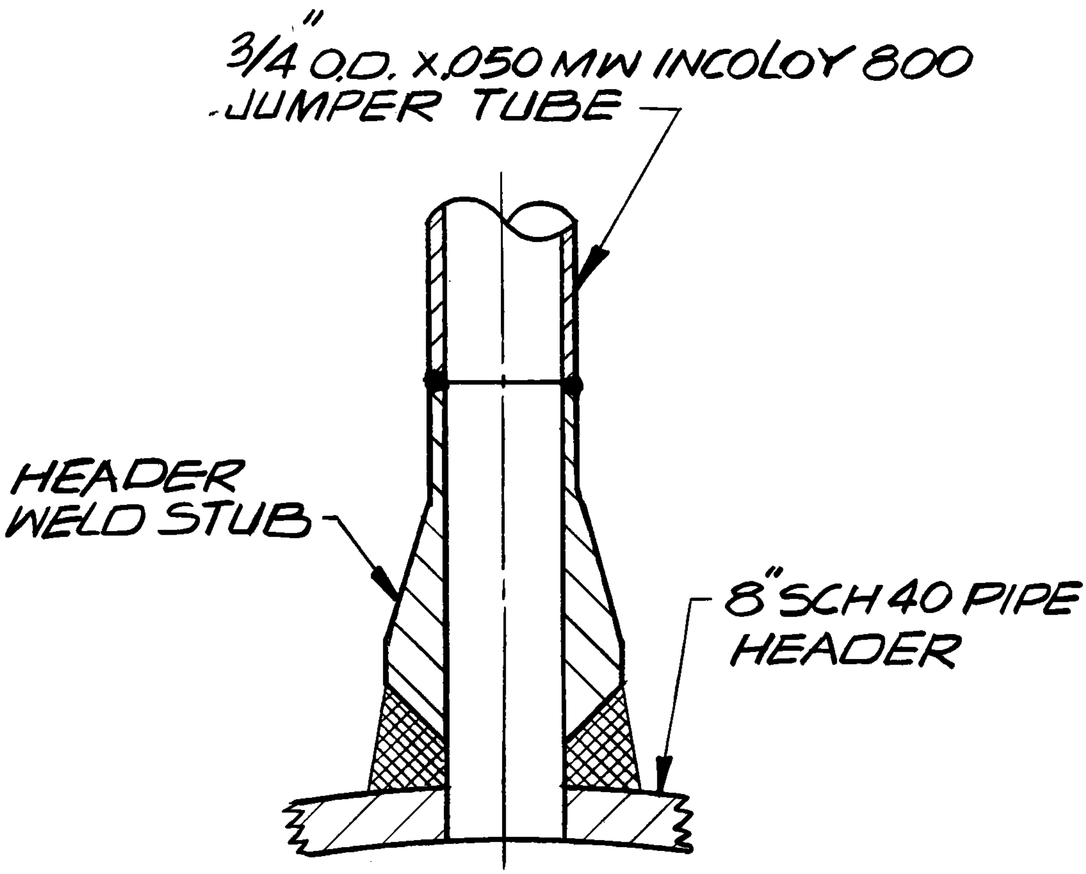


Figure 2-14. Tube-Header Stub Design Arrangement

Table 2-15

ABSORBER TEST PANEL DRY WEIGHTS

Item	Weight kg (lbs)		
Test Panel			
Headers	159	(350)	
Brazed Panel	200	(440)	
Jumper Tubes	50	(110)	
Header Boxes	907	(2000)	
Linkages	256	(565)	
Back Insulation Boxes	317	(700)	
	1889		(4165)
Steel Structure	1814		(4000)
Total	3703		(8165)

slip joints and roller-ball bearing slides. The former were ruled out as they operate with the risk of binding whereas any misalignment between the panel and guide tracks would cause the latter arrangement to bind.

As discussed above, to accommodate a 65°C (150°F) design temperature differential between center and end tubes at the top of the panel, two expansion bends are provided in each jumper tube between the end of the solar active portion of the panel and the top header. For ease of fabrication (symmetry), the jumper tube arrangement provided at the top of the panel is also provided at the bottom. Since the jumper tubes have been designed to be relatively flexible, calculations have shown that the top jumpers will undergo excessive creep due to the weight of the panel. Consequently, the top jumpers are isolated from the hanging weight of the panel via the spring support arrangement shown in Figure 2-11.

2.4.3 ACTIVE PANEL SUBASSEMBLY

The 50-tube panel will be brazed together as a 1000.918 mm (39.406-inch) wide x 5929.312 mm (19.453-ft) long subassembly (Figures 2-15 and 2-16). Prior to brazing, each item will be nickle-plated in accordance with AMS 2424 to a thickness of .0177 mm $\pm$ 0.00762 mm (0.0007 inch - 0.0003 inch) to enhance brazing characteristics. Although the tubes could be furnished with jumper-type expansion loops on each end, the tubes have been shortened to minimize braze furnace length requirements The tube-to-tube butt welds will be performed using a miniature orbital welder (described in Section 3). In order to facilitate the orbital weld operation, the panel's tube ends will bend off in multiples of four with approximately a 317.5 mm (12.5 inch) spacing between bends to provide clearances and accessibility.

The braze zone of the panel will be 4.572 m (15 feet) long and end approximately 11.112 mm (15.437 inch) and 104.775 mm (4.125 inch), respectively, from the working point of the innermost tube bends. The clearance provided at the bottom of the panel is much larger than that provided at the top because the former corresponds to the shadow cast on the tube panel by the bottom header's insulation box.

In an attempt to reduce the braze furnace's width requirement, it was originally proposed to weld together three 16-tube brazed subassemblies to form a 48-tube test panel. An investigation of the work that would be involved in developing welding procedures and tooling/fixturing to control distortion during welding revealed that

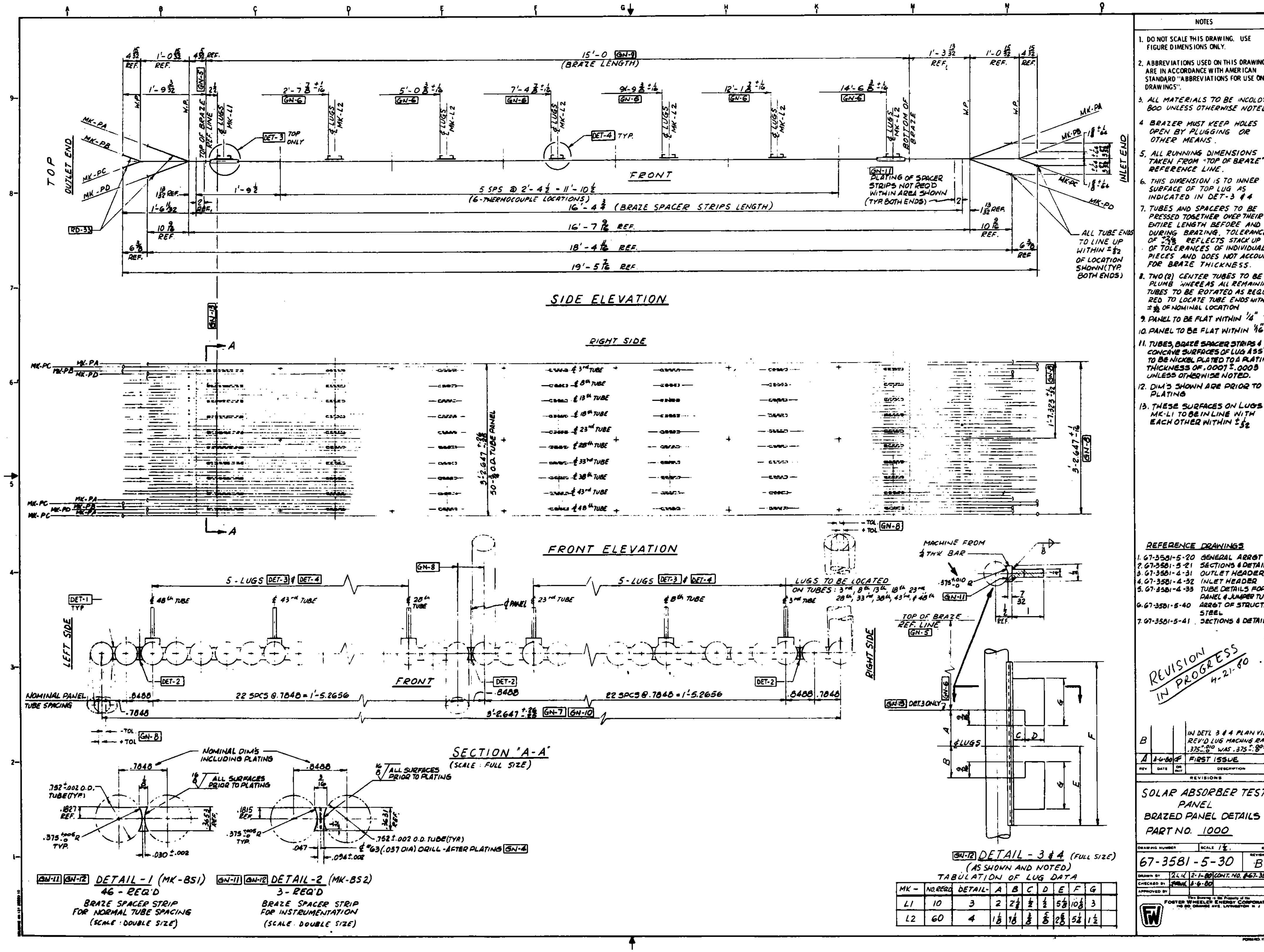


Figure 2-15. Absorber Test Panel Brazing Details

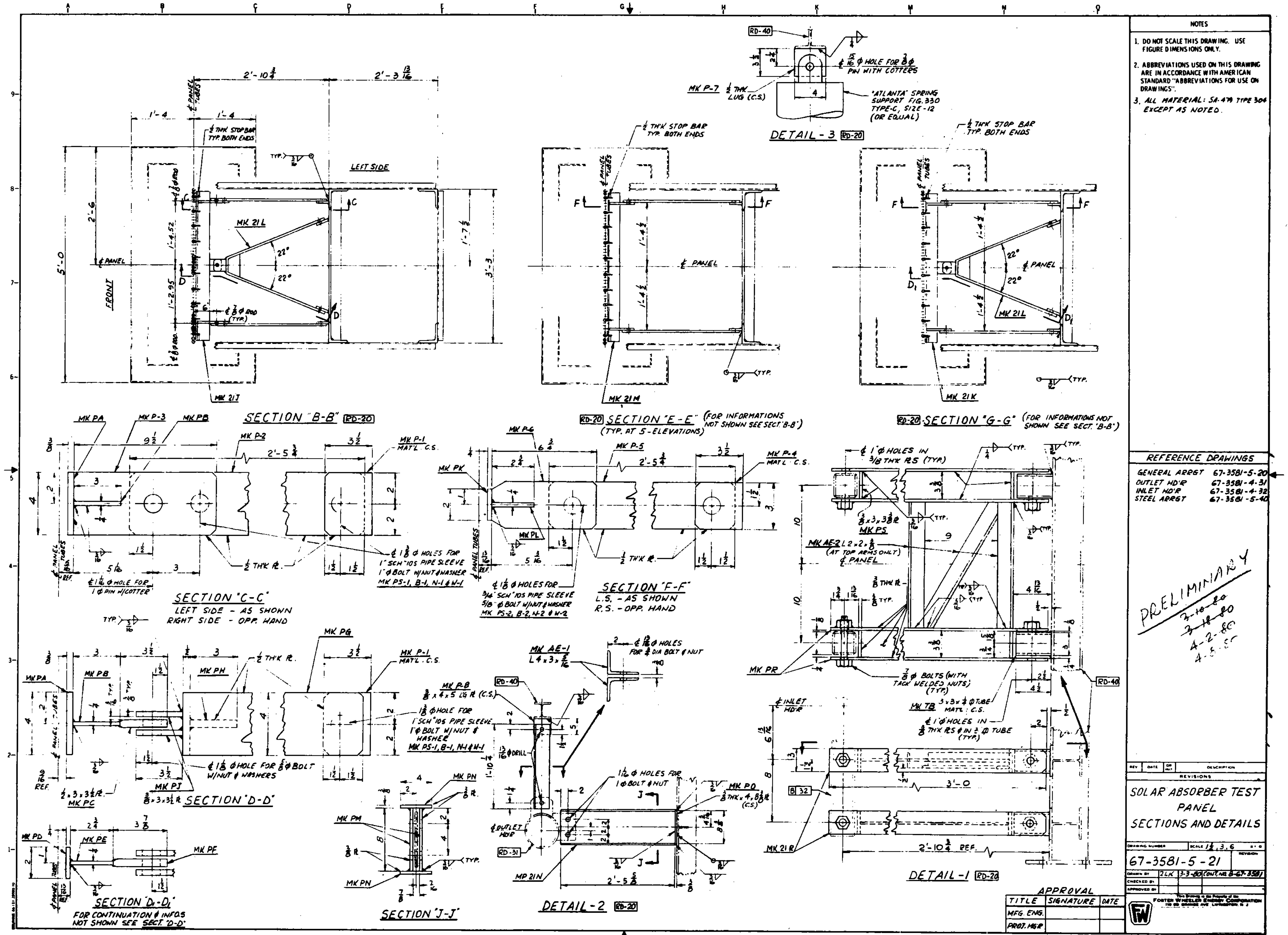


Figure 2-16. Absorber Test Panel Sections and Details

it would be both expensive and risky. Since it would be cheaper to build a wider braze furnace, it was decided to go with the referenced 50-tube brazed subassembly. Prior to brazing the full panel, the brazing vendor will be required to braze together a full-length 12-tube minipanel to test vendor's procedures.

2.4.4 TRACE HEATING

Before sodium can be admitted into the test panel, the unit must be heated from ambient to 316°C (600°F) via electrical heaters. The heaters will be 12.7 mm (.5 inch) in diameter and possess Incoloy 800 sheaths. Since the pipe headers will be approximately 7.9 mm (.31 inch) thick, lugs can be welded to the headers that will enable the heaters to be clamped directly to the headers. Because the tubes will be only 1.27 to 1.524 mm (0.050 to 0.060 inch) thick, it will not be possible to weld heater mounting lugs to the panel.

The heaters to be provided on the backside of the panel will thus have to be attached to the insulation boxes. Although the details of the heat tracing system have not yet been defined, the panel will contain three independently operable heating zones on its backside and one zone on each header.

2.4.5 ABSORBER PANEL STRESS ANALYSIS

The test panel has been designed to safely withstand the thermal stresses that will be induced by the nonuniformity of incident solar flux as well as mechanical stresses caused by 160 kilometers/hour (100 mph) winds and 1-1/2 g seismic accelerations. The wind and seismic forces will be transmitted into the panel's support structure via the buckstay-linkage arrangement provided on the backside of the panel and detailed in Figure 2-13.

The metal temperature distributions given in Tables 2-8 and 2-11 reveal that the panel's center tube will be approximately 25°C (77°F) hotter than the end tubes. This temperature distribution will place the panel's center tubes in compression and, because of the panel's high length-to-radius of gyration ratio, the panel will tend to buckle. As a result, the panel's buckstay spacing has been set by buckling considerations rather than by seismic or wind conditions; the buckstays will be provided on 723.9 mm (28.5 inch) centers (unsupported tube span length) and will keep the panel from bowing/buckling. The tube bending stress induced by the wind was calculated to be 5.516 x 10^6 Newton/meters (800 psi) whereas the seismic load was found to be negligible.

During the minimum load, uniform flux operating condition, a 62°C (143°F) difference in temperature will develop between the center and end jumper tubes. The stresses induced in the jumper tubes by this difference in temperature, assuming a 66°C (150°F) differential as a worst-case analysis, were determined via a FW piping stress computer program that considered both in-plane and out-of-plane (lateral) deflections. As a worst-case analysis, the jumper tube lateral deflection was calculated assuming the header to be at 593°C (1100°F) and the panel at 510°C (950°F). In-plane axial deflections were calculated assuming one jumper (end) at 538°C (1000°F) and another (center) at 621°C (1150°F), and that all jumper-to-panel connecting points remained in a straight line (panel expanded as a rigid body). Superposition of these in-plane and out-of-plane deflections revealed that the inner jumper would experience the highest stress and that this would occur at the bend nearest to the header. The maximum stress was calculated to be 5.7918 x 10^7 Newton/meter^2 (8400 psi) which is well below the 1.83407 x 10^8 Newton/meter^2 (26,600 psi) thermal stress limit permitted by the power piping code (1-1/4 x cold allowable + 1/4 x hot allowable stress).

The thermal shear forces that will be induced in the brazed portion of the panel by the nonuniformity of the solar flux distribution were determined via the use of a STRUDL model. Because the solar flux distribution is approximately symmetrical about the panel's centerline, the model took into consideration only one side (half) of the panel. The model consisted of six vertical members, each of which corresponded to the column element matrix used to generate the Table 2-11 data. The eleven temperatures given for each column of elements in Table 2-11 were entered for each of the six vertical members. The vertical members were assumed to be interconnected at a total of 12 elevations; the topmost and bottommost elevations were assumed to be rigid members, whereas the 10 interior connections were assumed to be pinned joints. This joint arrangement was used, as testing of steam generator waterwall panels has shown that the vertical shear forces that develop in these panels do not distribute uniformly but instead are carried primarily at the ends of the panel. The topmost horizontal member was fixed in space and the bottommost member was left free to grow downward. This STRUDL analysis indicates that the shear forces that will exist between the six vertical members, starting from the end column and working to the center of the panel, will be 1995.8 kg (4.4 kips), 2857.68 kg (6.3 kips), 2721.6 kg (6.0 kips), 1950.48 kg (4.3 kips) and 680.4 kg (1.5 kips).

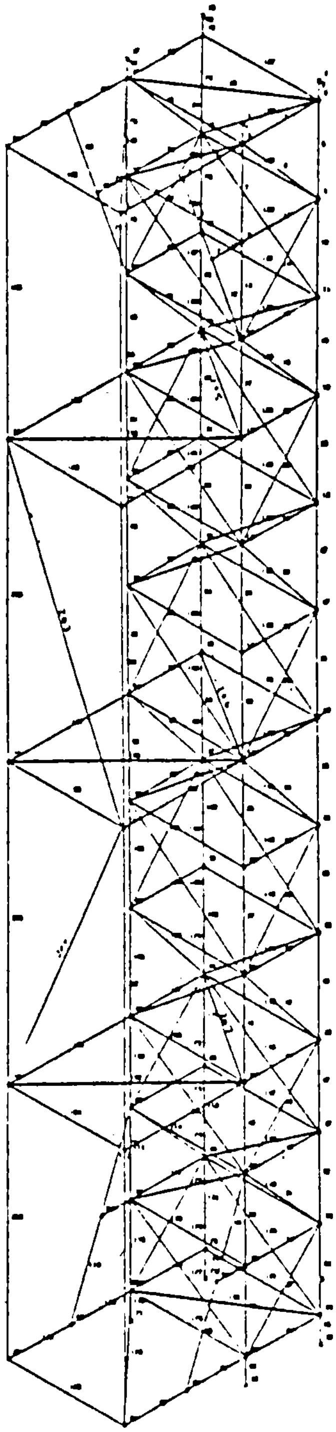


Figure 2-17. Support Structure Natural Frequency Model

The seismic data for the CRTF site indicated that a 1-1/2 g acceleration can be assumed for all panel and structure elements possessing a natural frequency of 10 hertz or higher. Although panel natural frequencies could be determined relatively easily, a Macuto STRUDL program had to be developed for the support structure. The model used is shown in Figure 2-17; calculations revealed it would possess a minimum natural frequency of 7.5 hertz. Calculations also showed that, by providing an intermediate support for the structure (midpoint elevation), its natural frequency would be increased to 16.6 hertz.

2.5 REFERENCES

1. ANSYS Engineering Analysis System User's Manual. Swanson Analysis Systems, Incorporated, 1974.
2. J. Jones, "Absence of Bending Effects on Solar-Receiver-Tube Fatigue." Journal of Energy, AIAA, Volume 3, No. 3, May-June 1979.
3. T. V. Narayanan, et al, "Structural Design of a Superheater for a Central Receiver." Transactions of ASME, Journal of Pressure Vessel Technology. Volume 101, February 1979.
4. I. Berman, et al, "An Interim Structural Design Standard for Solar Energy Applications." Report No. SAND79-8183, Sandia Laboratories, Livermore, California, April 1979.

SECTION 3

ABSORBER TEST PANEL FABRICATION

The fabrication effort includes all production stages required to take the panel from design to delivery at the Central Receiver Test Facility near Albuquerque, New Mexico. Principal fabrication activities include material procurement, material inspection and testing, process qualification, manufacturing operations, acceptance testing, and shipment. This section describes the panel fabrication plan and status through April 1980.

3.1 PANEL MANUFACTURING PLAN

The absorber test panel manufacturing plan defines all activities required to construct the panel. A summary flow chart of principal activities is shown on Figure 3-1. As described in earlier sections, the absorber test panel is comprised of the following major parts:

- 50 Incoloy 800 tube active panel; brazed into a rigid structure approximately 5 meters long; tubes to be separated by hourglass-shaped Incoloy 800 inserts
- Bottom Inlet Header
- Top Outlet Header
- 100 Incoloy 800 Jumper tubes to connect the ends of the active panel to the headers
- Structure to support the panel
- Insulation
- Trace Heaters

3.1.1 MANUFACTURING PROCESS

The manufacturing process was initiated during the design effort by identifying and planning the following four specific development efforts required prior to the final manufacturing of the absorber test panel:

- Braze Qualification
- Temporary Braze Furnace Construction
- Weld Qualification
- Mockup of Header/Jumper/Panel.

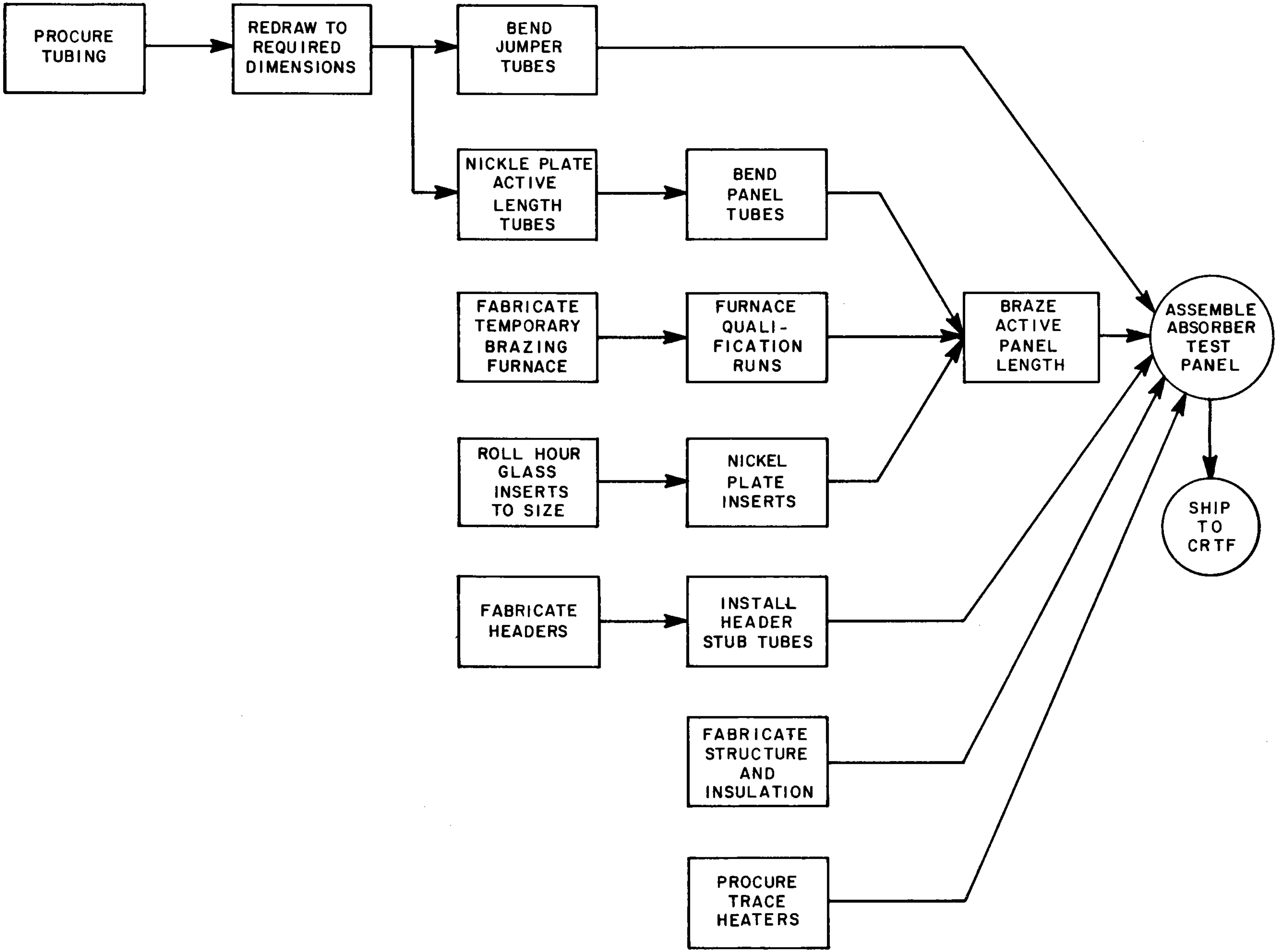


Figure 3-1. Summary Test Panel Manufacturing Work Flow

These development efforts are discussed in Sections 3.2 through 3.5.

The manufacturing process for the absorber panel is separated into the following elements: panel tubing, panel spacer (hourglass) inserts, brazing, header assembly, panel assembly, panel support structure and preparation for shipment. In order to expedite delivery of the panel tubing, available standard size Incoloy 800 tubes were purchased. The tubing was redrawn from its original 1.5 inch O.D. (.125" wall thickness) condition down to the required .750 inch O.D. and .050 inch wall thickness. This process required annealing to bring the Incoloy tubing back to its initial metallurigical properties. The tubing was ground on the outside diameter and vapor blasted on the inside diameter to obtain the required surface finish.

The redrawn tubing will be separated into jumper tubes and panel tubes. The jumper tubes will be cut to length and bent to the required shape completing pre-assembly efforts on the jumper tubes. The panel tubes will be nickel plated using an electroplating process to a thickness of .0004-.0016 inches, then bent at the ends to the required shape.

Concurrently with the tubing operations, the panel hourglass inserts are currently being rolled to shape from Incoloy 800 flat stock. The rolled hourglass shape must form a close fit with the panel tubing necessitating careful production controls. The inserts will then be nickel plated using an electroplating process.

The plated panel tubing and plated inserts will be shipped to the brazing vendor (Pyromet Industries, Inc.) and assembled together for the brazing operation. Figure 3-2 shows a typical pre-base prototype tubing and insert. The brazing process development and resulting braze procedure is described in detail in Volume III, Section 2. The panel braze requires a fixture to hold the tubing and inserts securely together in a diagonal orientation while in the furnace. In addition, the fixture accurately locates the panel tube ends. This is a critical item since alignment of the active panel tube ends and the jumper tubes is of great importance during the panel assembly operation. Figure 3-3 shows a typical twelve tube section of the panel. The braze material will then be applied to the tube/insert assembly and then the entire panel active portion will be placed in the hydrogen controlled atmosphere of the temporary brazing furnace. Figure 3-4 shows a typical post-braze micrograph from the braze development program.

Two cylindrical header assemblies are being fabricated from Incoloy 800. Stubs will be welded into the header pipes at the proper locations as described in

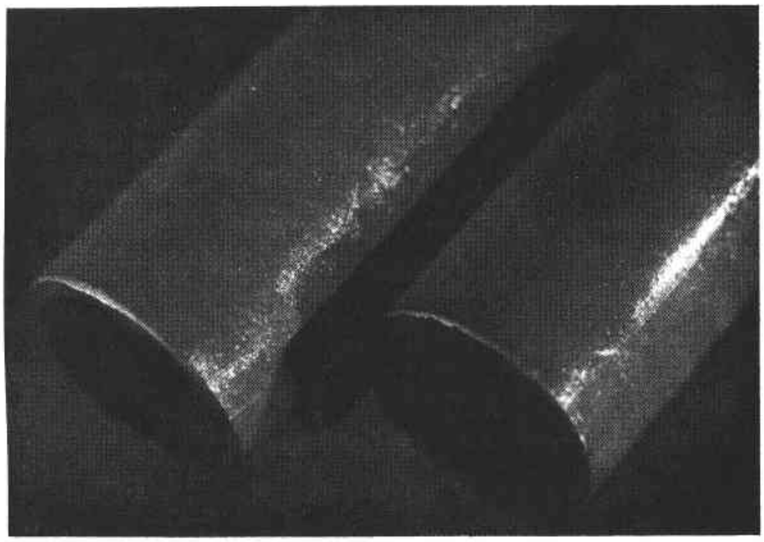


Figure 3-2. Prototype Pre-Braze Panel

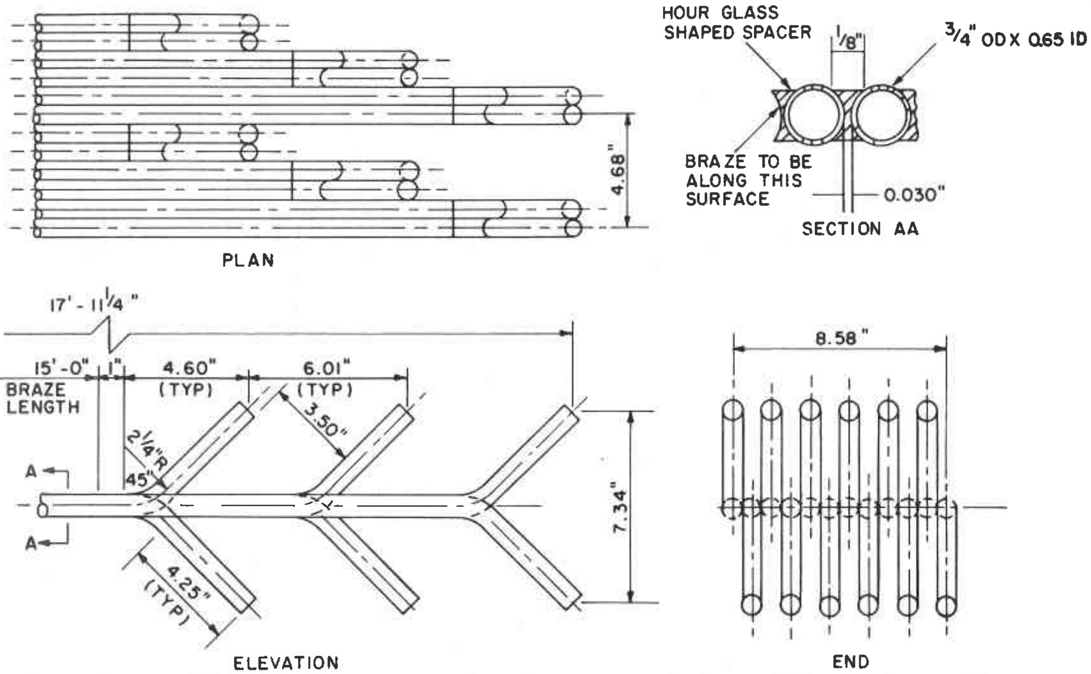


Figure 3-3. Test Panel Typical Twelve Tube Section

Section 2. The plugs will then be bored out to remove the root notch as shown in Figure 2-14. The weld preparation added to the ends of the stubs will make the headers ready for butt welding to the jumper tubes.

The panel subassembly parts will then be accumulated at Foster Wheeler for the panel assembly operation. The brazed panel will be placed in a large fixture and the two headers accurately located at each end. The next operation is to cut and fit each jumper tube between the header plug and its corresponding panel tube. As shown in Figure 3-5, the tubes are then welded together using a miniature orbital welder developed by Foster Wheeler. The completed panel subassembly will then be pressure tested and helium mass-spectrometer leak checked.

The panel subassembly is now ready to be mated with the panel support structure, which contains the support linkages, insulation boxes and trace heaters. After assembly, the entire absorber test panel will be packaged for shipment to the Central Receiver Test Facility (CRTF).

3.1.2 PANEL MANUFACTURING SCHEDULE

The panel manufacturing schedule is shown in Figure 3-6. Each element of the plan is continuously monitored in order to identify problem areas and control the critical path.

3.2 PANEL BRAZING DESCRIPTION

The unique characteristic of the General Electric sodium cooled receiver is its thin walled tube construction and resulting high efficiency. The thin tube walls prompted selection of brazing for tube-to-tube joining during the Phase I program. As reported in Volume III, Section 2, significant efforts were expended during Phase II in panel fabrication development. The result was somewhat of a change in the braze procedure suggested during Phase I; specifically, the tubes will be horizontal instead of vertical and hourglass inserts will be installed between the tubes. These changes, when compounded with the need to braze a full two header panel instead of two one-half panels for the three header geometry (see Volume II, Section 2), required that a large horizontal hydrogen furnace be found. After an exhausted search, it was concluded that a temporary brazing furnace be fabricated.

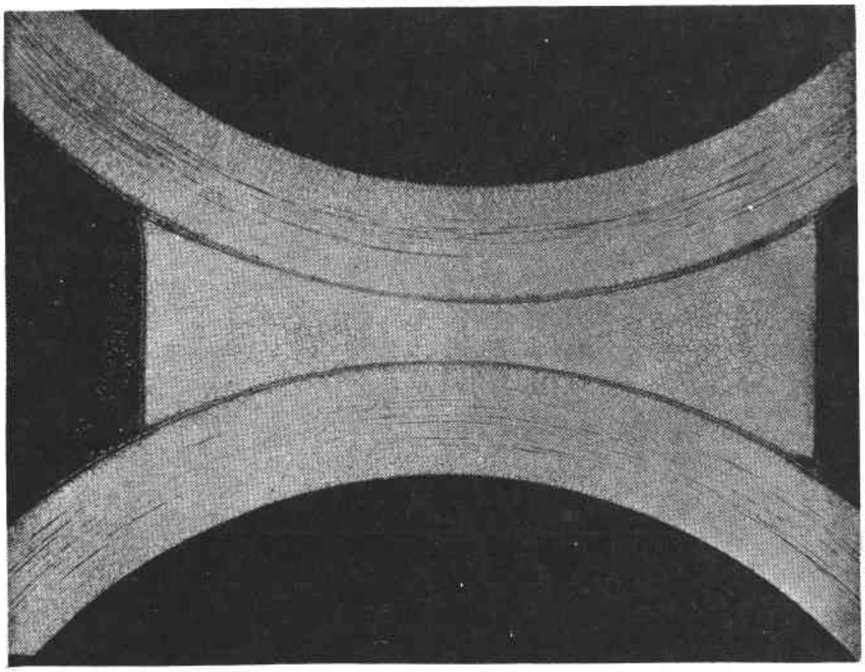


Figure 3-4. Prototype Post-Braze Micrograph

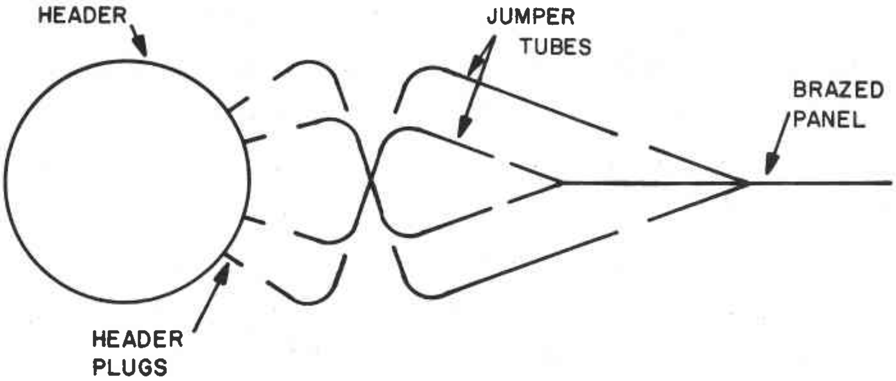


Figure 3-5. Panel Subassembly Schematic

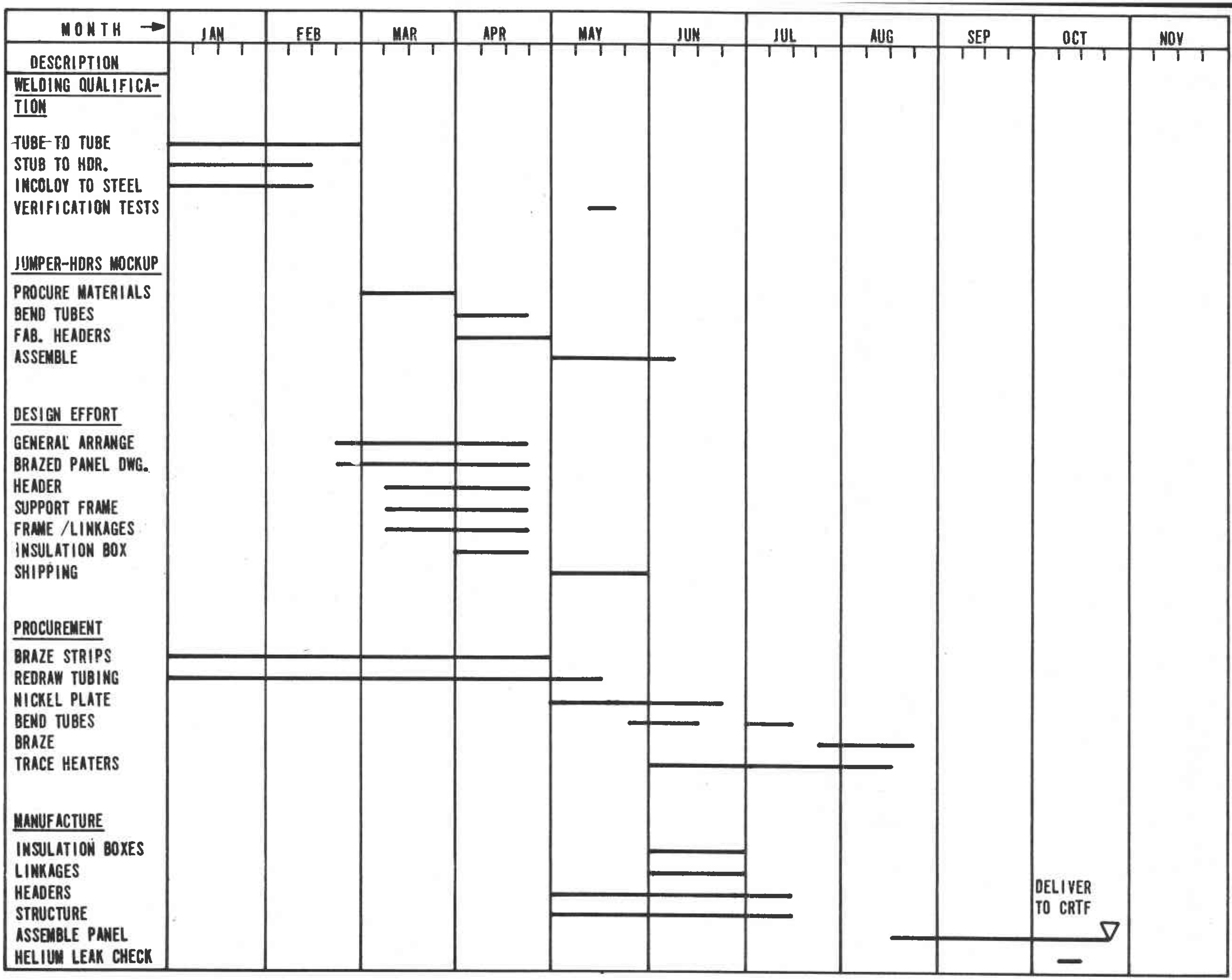


Figure 3-6. Panel Manufacturing Schedule

3.2.1 BRAZING PROCEDURE

The details of panel brazing is provided in Volume III, Section 2; however, the required materials and fixtures are shown on Table 3-1 and the general procedure is listed on Table 3-2.

Table 3-1

MATERIALS AND FIXTURES FOR FURNACE BRAZE

- Tube - I800 19.05mm OD (.75 in) ASTM B407
- Filler Strip - I800 Hourglass Extruded or Machined
- Plating - Nickel Electroplate ~ 2.7 mil Thickness, Dull Finish
- Braze Alloy - Amdry 939, Metal Powder ~140 mesh
- Stop-Off-Compound - Nicrobraz Green
- Platers Tape
- Furnace - Horizontal with Hydrogen DP of $<$-62°C (-80°F)
- Fixtures - Flat Metal Hearth, Clamps and Weights

3.2.2 TEMPORARY BRAZING FURNACE DESCRIPTION

Pyromet Industries, Inc. has designed and is currently fabricating a temporary brazing furnace to accommodate the absorber test panel. The furnace has been designed to braze one 50 tube panel (approximately 20' long, by 34" wide, by 9" high) horizontally, with the width in a diagonal orientation. The modular design and low weight insulating brick make this furnace and, with fabrication of other modules, flexible for use with longer panels. It can be transported to another site, if required, on future solar programs.

The furnace has a simple fabricated steel construction as shown in Figure 3-7. The insulation is a combination of Kaowool and Pyroblock lined with refractory brick. The furnace is electrically heated to maintain at least 1900°F within the retort, a seal welded vessel used to contain the hydrogen atmosphere required by the brazing process. The furnace was designed so that the inlet dew point can be maintained at -80°F or lower. The absorber test panel and the necessary assembly fixture will be placed inside the retort for the brazing operation. The temperature will be monitored during heating, hold, and cooling portions of the furnace cycle.

3.2.3 FURNACE INSTALLATION SCHEDULE

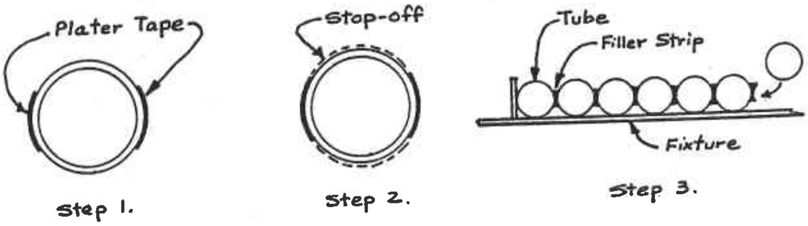
The furnace installation is currently on schedule (Figure 3-8) and should be completed the week of June 13, 1980. A qualification run is scheduled for the week of June 20, 1980. The design has been completed and all materials are on order or have arrived at Pyromet for furnace and retort fabrication. Furnace fabrication has started and the steel structure is scheduled to be completed in mid-May.

Table 3-2

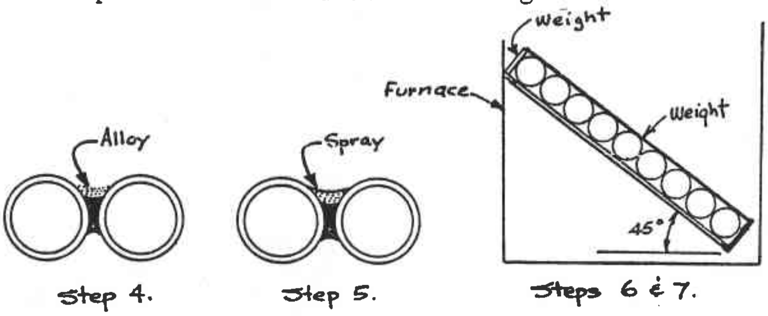
GENERALIZED BRAZING PROCEDURE

APPLICATION

Step 1.	Apply Plater Tape on Alloyed Portion of Tube
Step 2.	Apply Stop-Off Compound to Tubes and Fixtures
Step 3.	Assembly Tubes and Filler Strips on Flat Fixture



Step 4.	Apply Braze Alloy in Continuous Fillet
Step 5.	Apply Acrylic Enamel Spray to Braze Alloy
Step 6.	Install Tubes in Fixture on 45° Angled Hearth in Furnace
Step 7.	Prepare Fixture Guides and Weight



Step 8.	Purge Furnace Muffle
Step 9.	Heat Panel Segment to ~900°C (1650°F) - Hold
Step 10.	Heat Rapidly to ~1025°C (1880°F) - Hold 12 Min.
Step 11.	Cool Rapidly to Below 904°C (1660°F)
Step 12.	Cool to Room Temperature
Step 13.	Remove and Clean as Necessary
Step 14.	Inspect

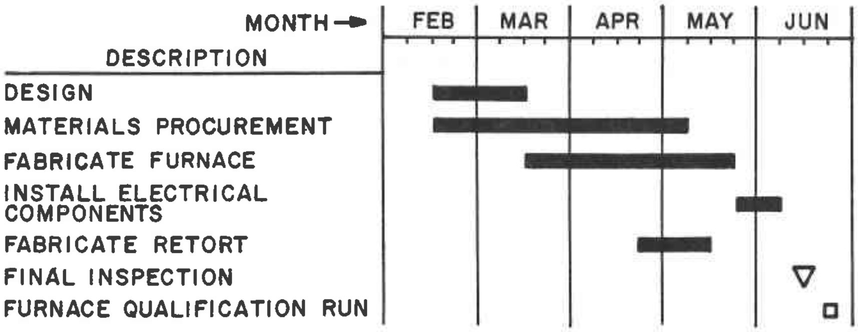


Figure 3-8. Furnace Installation Schedule

3.3 WELD DEVELOPMENT/MOCKUPS

The panel tube-to-jumper tube and jumper tube-to-header stub orbital welds will be accomplished via the miniature welding torch shown in Figures 3-9 and 3-10. Using this torch, development work has been conducted at Foster Wheeler to establish the parameters and develop the techniques for accomplishing these welds via the Gas Tungsten Arc Process. The welds will be performed in the horizontal position with argon purge gas and, in order to minimize wall thinning, tests have shown that it will be necessary to use the Inco 82 consumable inserts shown in Figure 3-11. The inserts will be tack-welded to the tube at the 3 and 9 o'clock positions. Welding will commence at the 8 o'clock position, and after completing 360° of rotation, tailoff will start at about 9 o'clock and terminate at approximately 2 o'clock.

All welding work performed to date has been with 1/16 in. average wall, commercial grade, Incoloy 800 tubing since test panel thin-walled tubing has not yet been available from the tube mill. Once test panel tubing is available, additional weld tests will be performed to finalize welding parameters. Testing to date indicates that to insure satisfactory weld quality, tube-to-tube fit up must be limited to lateral and angular misalignments of 0.015 in. and 1°, respectively. These tolerances are quite tight and, since good fit up is essential to the production of a satisfactory weld, a mockup of the panel jumper tube and header region is being made to permit a checkout of both the weld procedures and the tools/fixtures that have been designed for the fit up operation. The mockup is shown in Figure 3-12

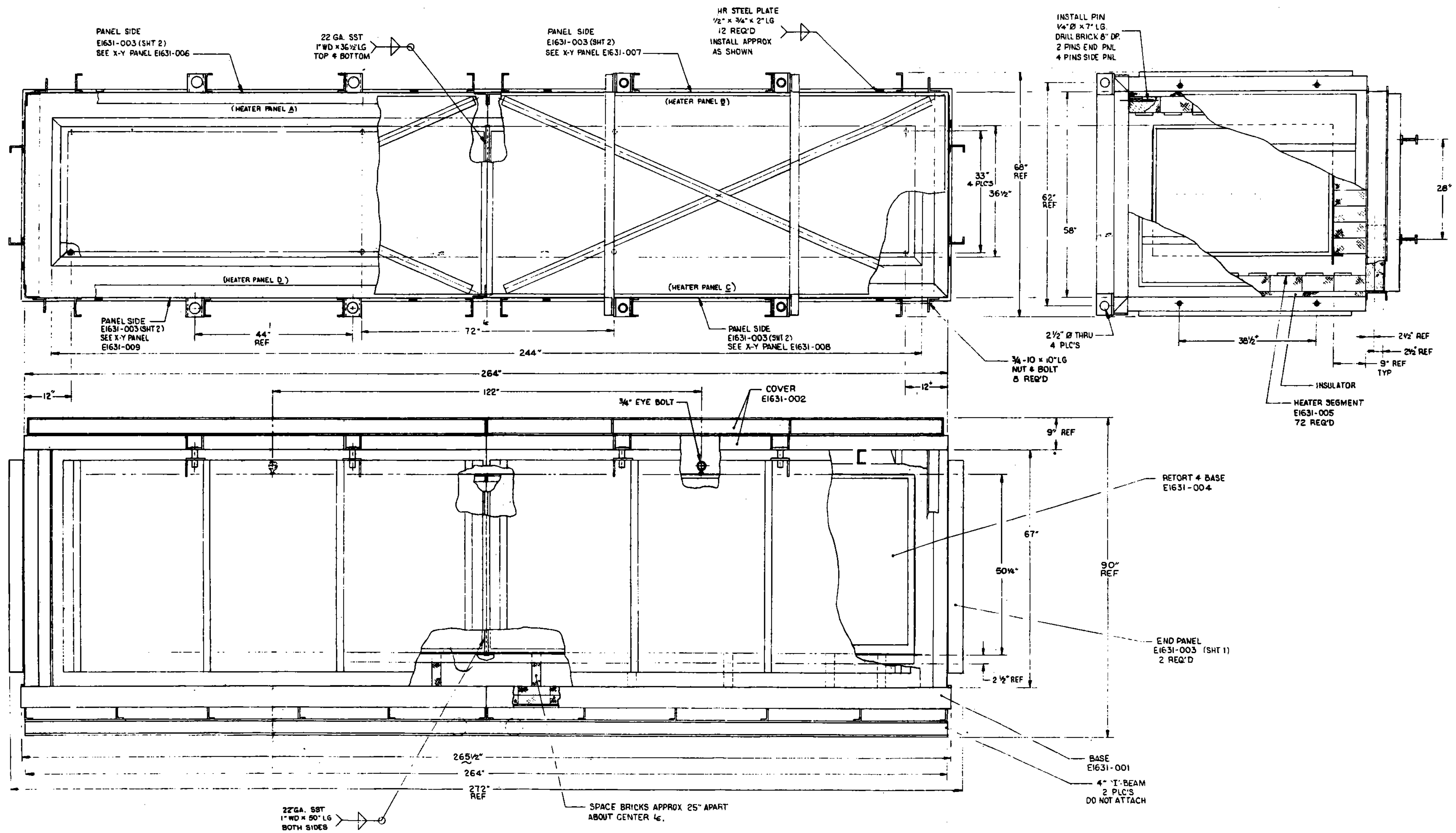


Figure 3-7. Temporary Brazing Furnace

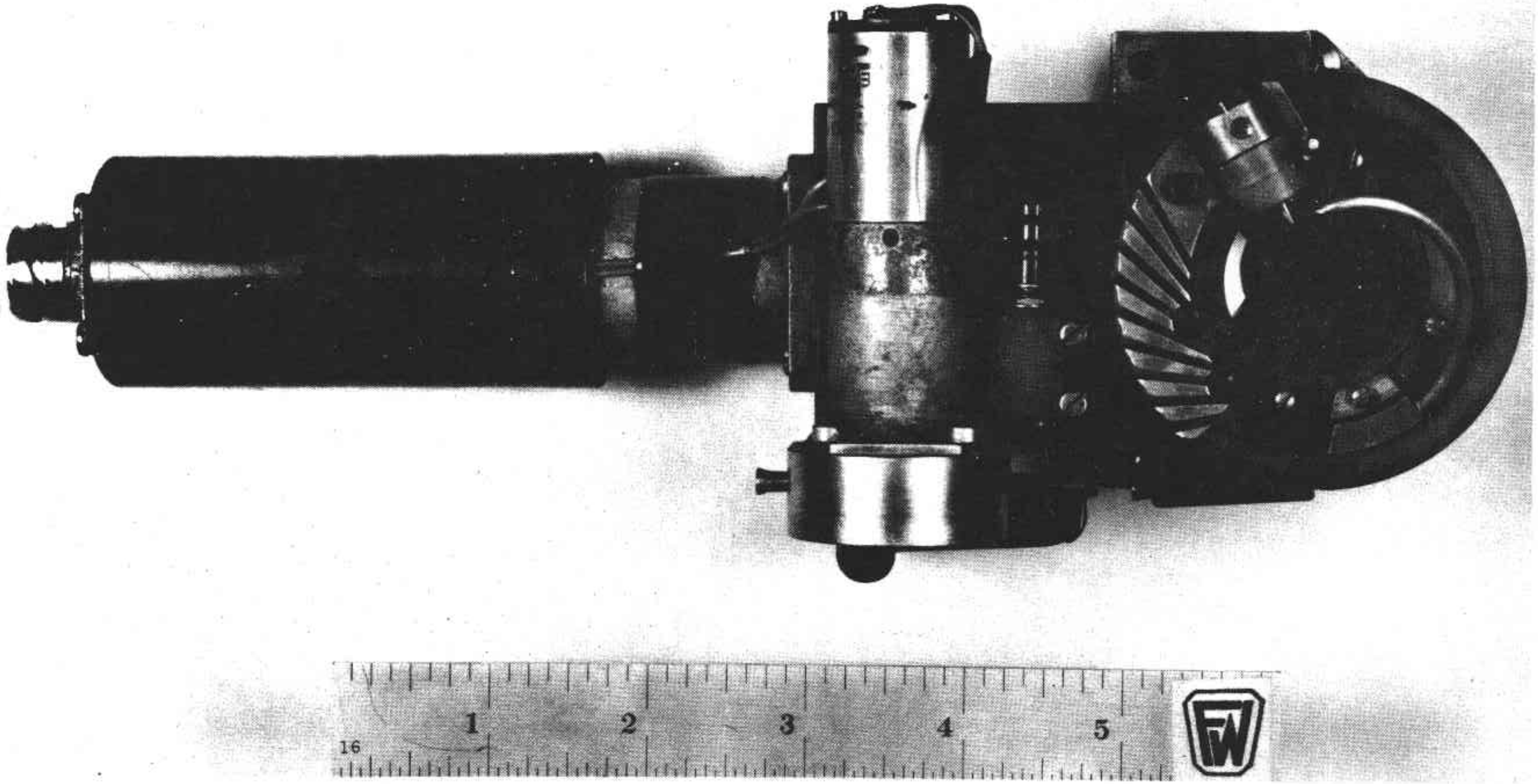


Figure 3-9. Plan View of Miniature Tube Orbital Welding Torch

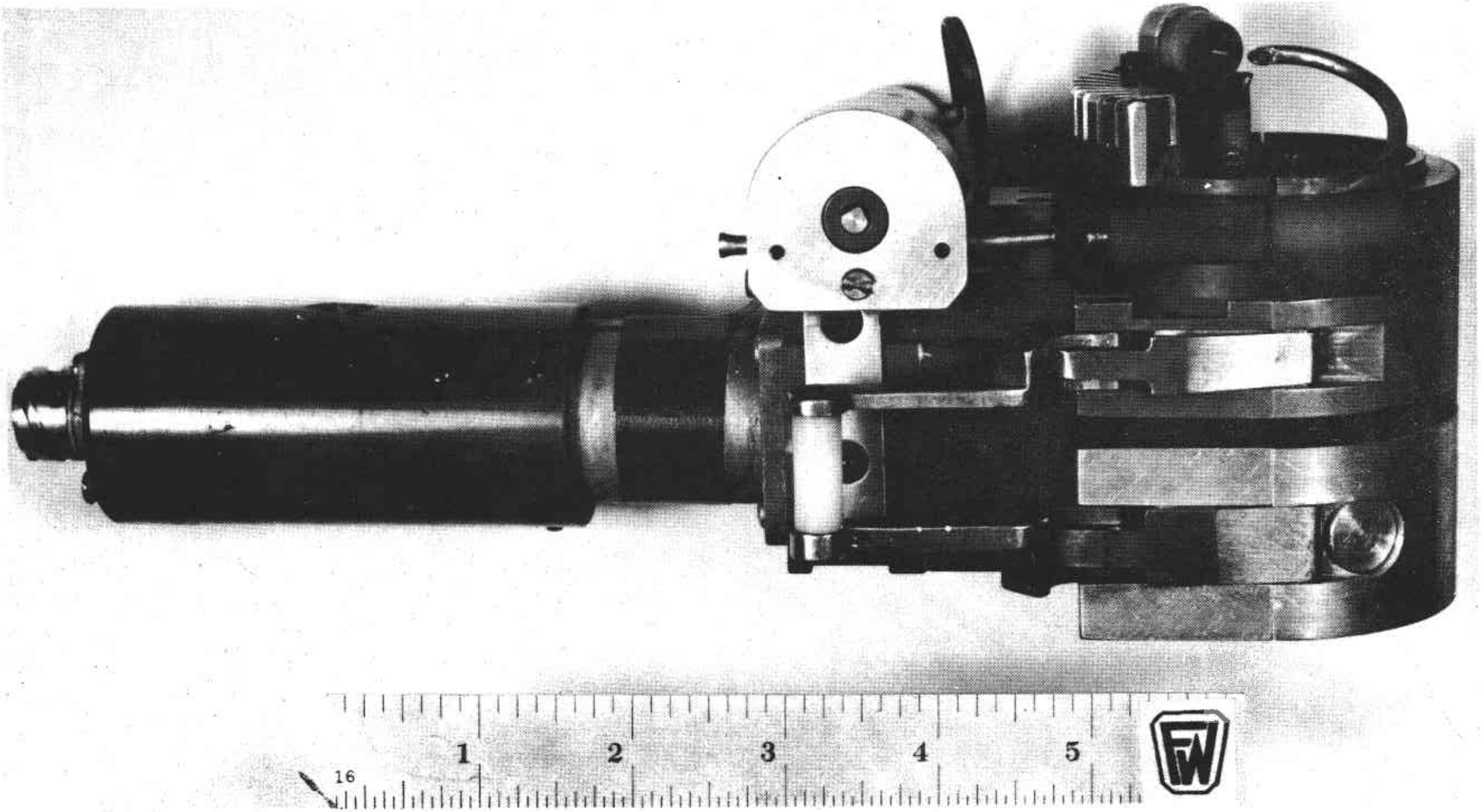


Figure 3-10. Side View of Miniature Tube Orbital Welding Torch

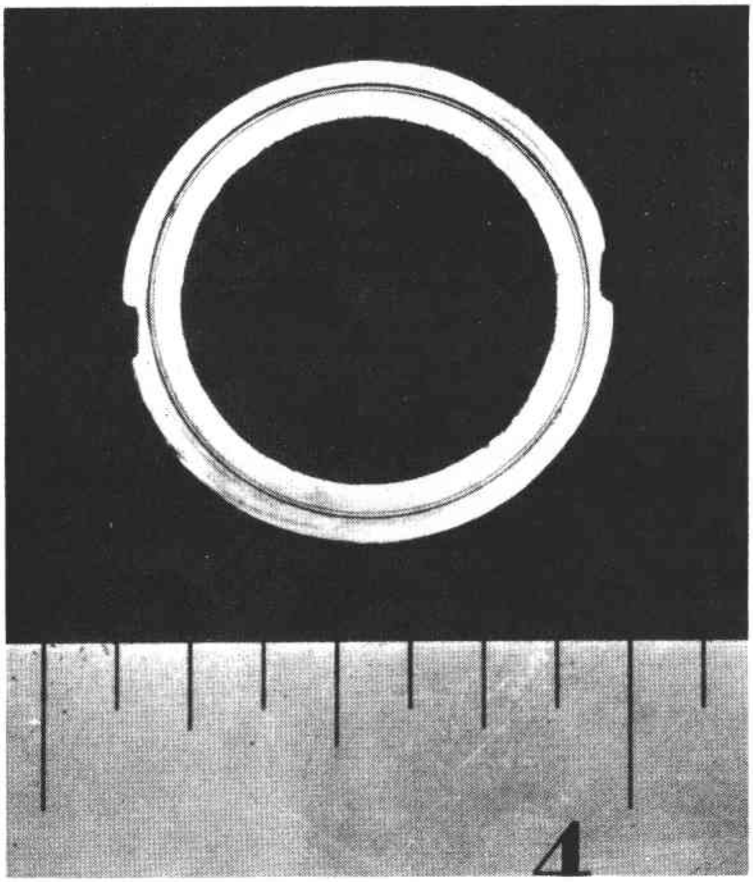


Figure 3-11. Consumable Insert for Tube Orbital Welds

and it will have the capability of accommodating 23 jumper tubes. Header fabrication and tube bending operations have commenced on the mockup and fit up/assembly is expected to commence in early May 1980.

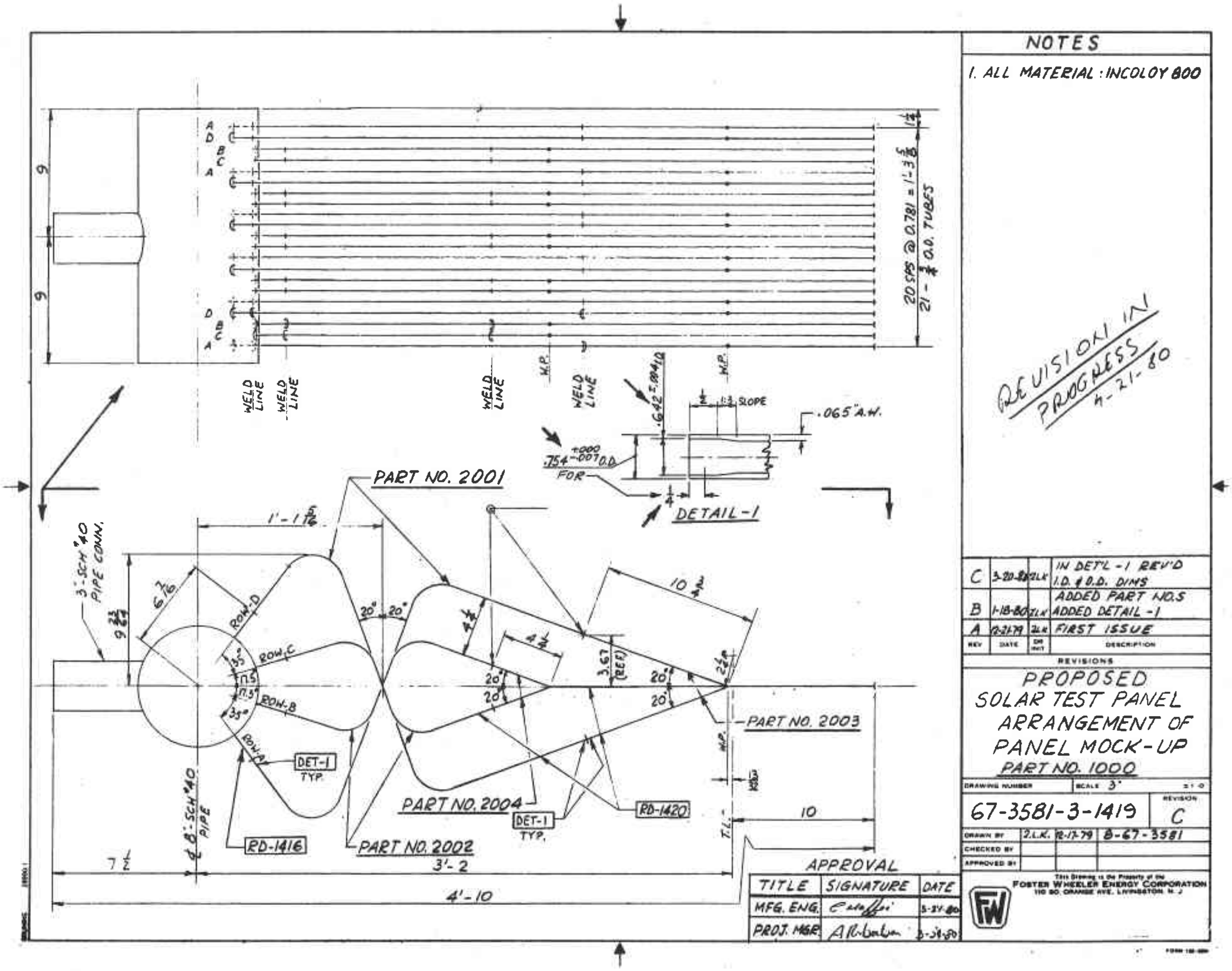


Figure 3-12. Test Panel Weld Mockup Assembly

SECTION 4

SODIUM LOOP DESIGN

The absorber test panel described in Sections 2 and 3 will be installed into a sodium fluid circulation loop at the Central Receiver Test Facility. This section describes the design of the heat transfer loop and the principal components.

4.1 SUMMARY DESCRIPTION

The SRTA system, as delineated by the Piping and Instrumentation (P&ID) Drawing (Figure 4-1) and the General Arrangement Drawing, Sheets 1 and 2 (Figures 4-2 and 4-3), provides the sodium heat transfer loop for the absorber test panel. The panel includes a support structure which attaches to the SRTA support structure. The SRTA also houses the components and piping which make up the fluid circulation equipment including an electromagnetic (EM) sodium pump, sodium valves, cold trap, surge and drain tanks and sodium flow, pressure, temperature, and oxygen level sensors. The interconnecting piping is 3-inch Schedule 40 Type 304 stainless steel, with the exception of the drain line which is 2" Schedule 40 pipe and the equalizer line which is 1" Schedule 40 pipe. All sodium piping is electrically trace heated and insulated to allow preheat to 600°F ± 50° with the sodium drained and to maintain this temperature with sodium flowing in the system. Drip pans are provided under the SRTA structure and siding supported by the structure totally encloses the sodium system. Exceptions to this are the sodium heat dump, which is mounted separately on its own support structure and is separately enclosed, and the front of the absorber panel which is not covered during solar operation. The front of the absorber panel is covered by a movable insulating door when the system is not in the solar operating mode. The absorber panel is surrounded by a solar heat shield constructed with alumina and zirconia high temperature insulating tiles to protect the SRTA from solar spillage.

The SRTA structure and the heat dump will be mounted on separate sleeper beams to distribute their weight on the CRTF elevator module. The sleeper beams will be bolted to the elevator roof main support members to accommodate the design seismic and wind loads for the 200 ft. tower level. The SRTA sodium system is designed for a maximum operating temperature of 1150°F at a maximum pressure of 50 psig, with a maximum sodium flow rate of 175 gpm, and an operating life of 5000 hours.

The SRTA local control panel is designed for location in the elevating module computer room and includes all local instrumentation and control equipment required for startup, operating, and shutdown of the SRTA. This panel also provides interfacing connections to the CRTF data acquisition system to provide data display and remote control from the experimenter's console in the CRTF master control room. SRTA instrumentation provided for test data only and not required for system operation will be connected directly to the CRTF interfacing connectors or signal conditioning equipment and will not pass through the local control panel. The SRTA emergency heliostat "cut" (rapid heliostat defocus) will be hardwired to redundant cable pairs connected to the CRTF heliostat control system.

The SRTA is equipped with an argon inert gas supply and vent system for controlled surge tank and drain tank cover gas pressure, that can be controlled either automatically or manually. This system will be connected to an argon supply bottle header provided by the CRTF and located in the elevator module machine shop level.

4.2 HEAT DUMP

This assembly can be described as a high temperature sodium to ambient air heat exchanger complete with forced draft air delivery system. Included are the structure, heat exchanger section, dampers and operator, fans, fan drives, heaters and controls. Air operated isolation doors mounted on the top and bottom of the heat exchanger are included as part of the structure. The arrangement of these components is shown in Figure 4-4.

The function of the heat dump is to transfer the heat from the high temperature sodium stream to the surrounding atmosphere. This is accomplished by passing the hot sodium through the tubes and cooling it by ambient air passed over the outside finned surface of the tubes. The sodium enters the inlet manifold (header) at the top of the heat exchanger, flows through one layer of tubes in four (4) cross counter-flow passes, and leaves through the outlet manifold at the bottom of the heat exchanger. The cooler ambient air enters the plenum chamber below the heat exchanger, flows vertically upward through the damper and the finned tube bundle, and then passes back into the atmosphere.

The heat dump is a refurbished auxiliary air blast cooler which was removed from the Southwest Experimental Fast Oxide (SEFOR) nuclear reactor. The major refurbishment items are summarized below and described in more detail in Section 5.

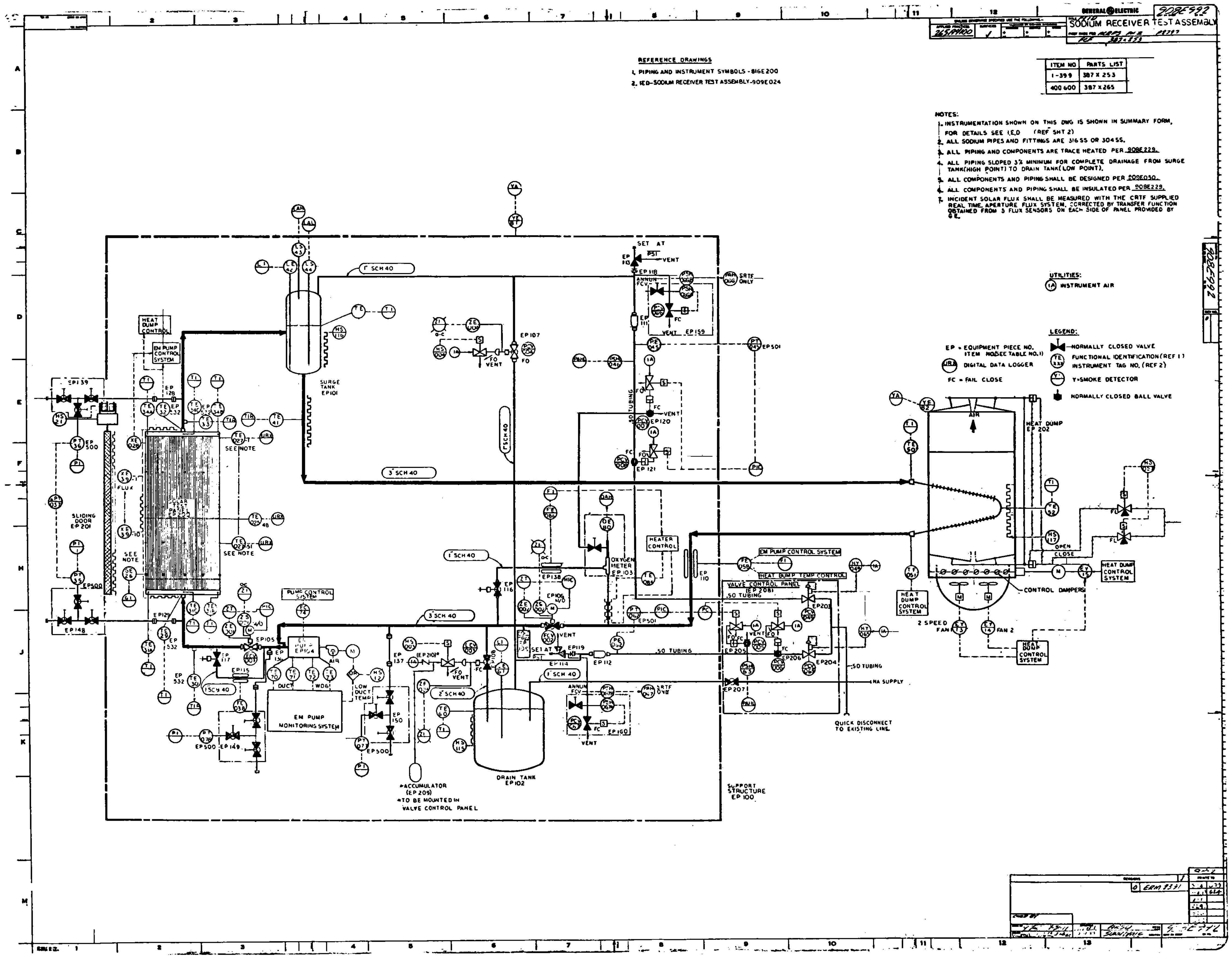
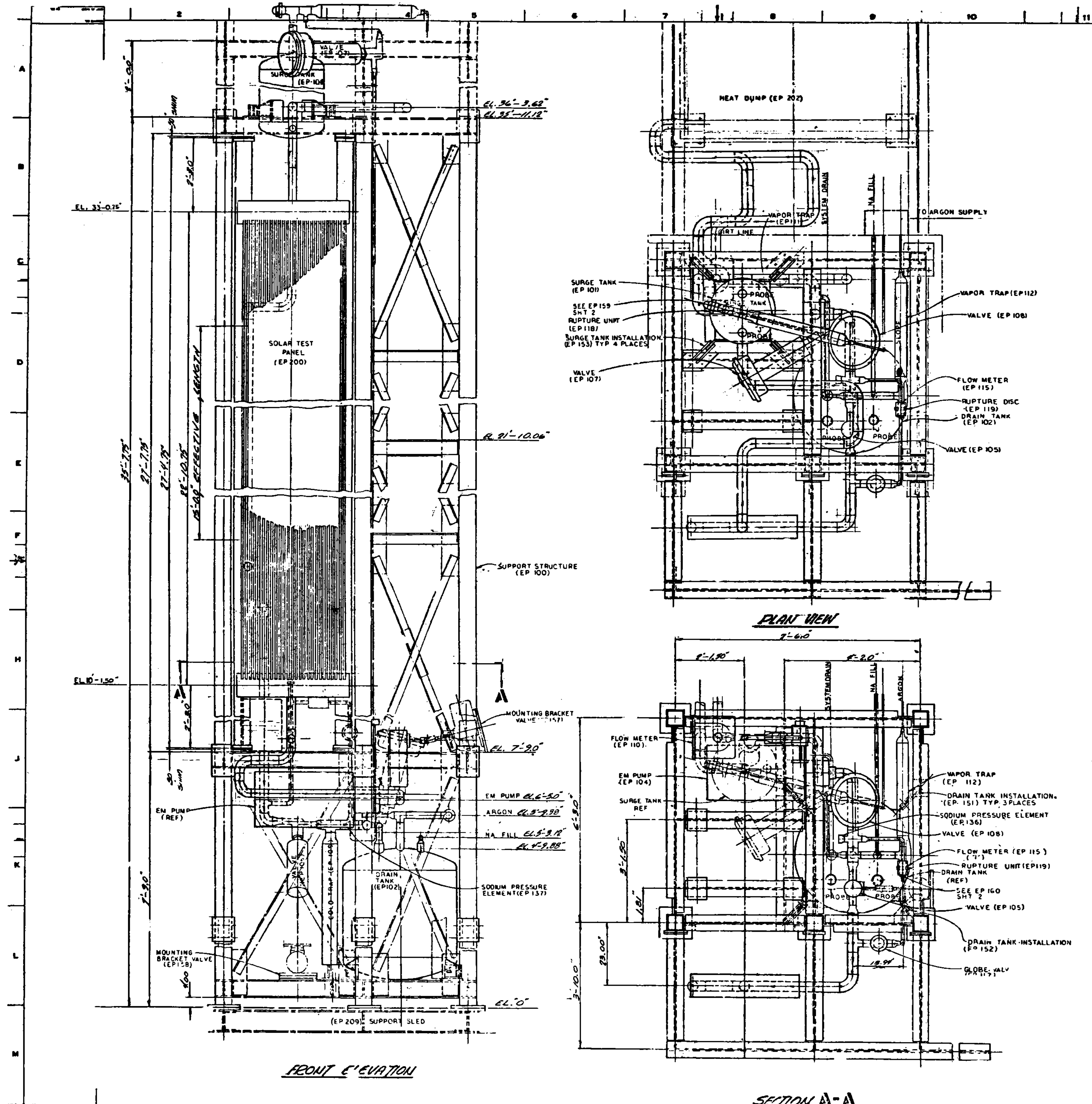


Figure 4-1. Piping and Instrumentation Drawing



GENERAL ELECTRIC 908E982

SODIUM RECEIVER TEST ASSEMBLY

265A4100

NOTES:

1. ALL SODIUM PIPES AND FITTINGS ARE 316SS OR 304SS
2. ALL PIPING AND COMPONENTS ARE TRACE HEATED PER 908E229.
3. ALL PIPING SLOPED 3° MINIMUM FOR COMPLETE DRAINAGE FROM SURGE TANK (HIGH POINT) TO DRAIN TANK (LOW POINT).
5. ALL COMPONENTS AND PIPING SHALL BE DESIGNED PER 909E050.
6. ALL COMPONENTS AND PIPING SHALL BE INSULATED PER 908E229.
7. LOCATE VALVE PANELS AT ASSEMBLY.

REFERENCE DRGS

SODIUM RECEIVER TEST ASSEMBLY P&ID	908E992
TEST SUPPORT STRUCTURE - STRUCTURAL	908E983
TEST SUPPORT STRUCTURE FRAMING	908E984
TEST FACILITY TOWER - LAYOUT	908E993
SODIUM RECEIVER TEST LOOP	909E050

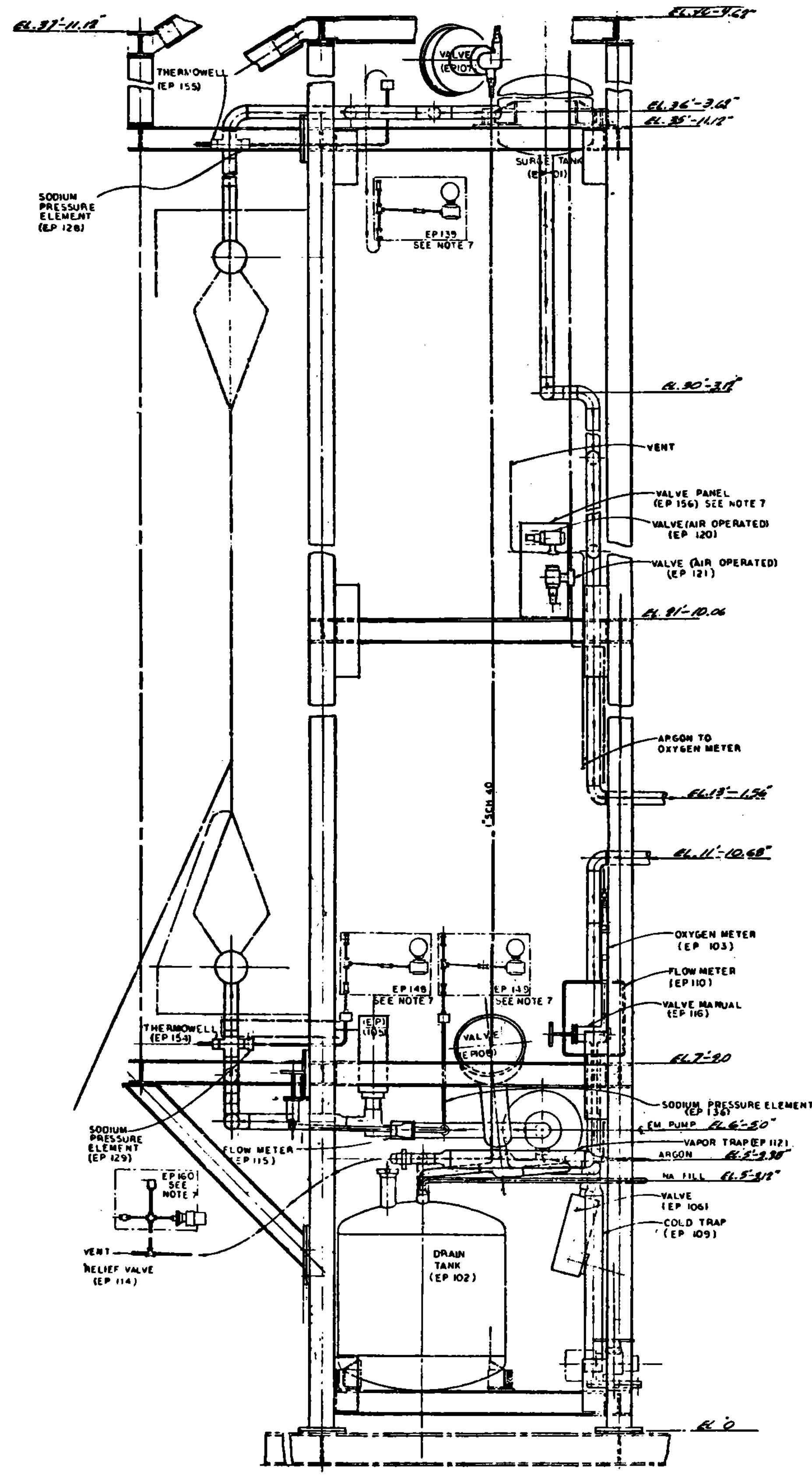
REFERENCE PARTS LIST FOR COMPONENTS IN STRUCTURE

	E.P. NO	DESCRIPTION	DRWG. NO.
	100	SUPPORT STRUCTURE	908E983
	101	SURGE TANK	908E999
	102	DRAIN TANK	13401931
	103	ELECTRO CHEMICAL OXYGEN METER	GE MODEL NO.18 EME 11A01X
	104	EM PUMP	134D1856
	105	VALVE (2") MOTOR OPERATED	179C5264 PT 2
	106	VALVE (2") MOTOR OPERATED	179C5262 PT 1
	107	VALVE (2")	179C5262 PT 1
	108	VALVE (2")	179C5264 PT 2
	109	COLD TRAP	145D6361
	110	FLOW METER (3" VERTICAL)	134D1875
	111	VAPOR TRAP	179C5261
	112	VAPOR TRAP	179C5382
	113	VALVE RELIEF	PI-789-1 CIRCLE SEAL
	114	VALVE RELIEF	PI-789-1 CIRCLE SEAL
	115	FLOW METER (1")	LATER
	116	GLOBE VALVE (2" MANNUAL)	179C5263 PT
	117	GLOBE VALVE (2" MANNUAL)	179C5263 PT
	118	RUPTURE UNIT	179C5259
	119	RUPTURE UNIT	179C5259
	120	BALL VALVE WORCHESTER CONTROLS	B38SHM224DS MARK III PNEUMATIC 25-46 NSWO ACTUATOR
	121	BALL VALVE WORCHESTER CONTROLS	B38SHM224DS MARK III PNEUMATIC 50-416 NSWO ACTUATOR
★	122	PRIMARY RETURN LOOP	145D6374 G1
★	123	-	- G2
★	124	-	- G3
★	125	PRIMARY INLET LOOP	145D6373 G1
★	126	-	- G2
★	127	-	- G3
	128	SODIUM PRESSURE ELEMENT	145D6380
	129	SODIUM PRESSURE ELEMENT	145D6380
★	130	PRIMARY INLET LOOP	145D6373 G4
★	131	-	- G5
★	132	-	- G6
★	133	-	- G7
★	134	-	- G8
★	135	PRIMARY INLET LOOP	145D6373 G9
	136	SODIUM PRESSURE ELEMENT	145D6380
	137	SODIUM PRESSURE ELEMENT	145D6380
	138	FLOW METER (1")	LATER
	139	VALVE PANEL-PRESSURE ELEMENT	134D1932 G1
★	140	PUMP OUTLET LOOP	145D6375 G1
★	141	-	- G2
★	142	-	- G3
★	143	PUMP OUTLET LOOP	145D6375 G4
★	144	SURGE TANK INLET LOOP	145D6375 G1
★	145	-	- G2
★	146	-	- G3
★	147	SURGE TANK INLET LOOP	145D6375 G4
	148	VALVE PANEL-PRESSURE ELEMENT	134D1932 G1
	149	VALVE PANEL- -	134D1932 G1
	150	VALVE PANEL-PRESSURE ELEMENT	134D1932 G1

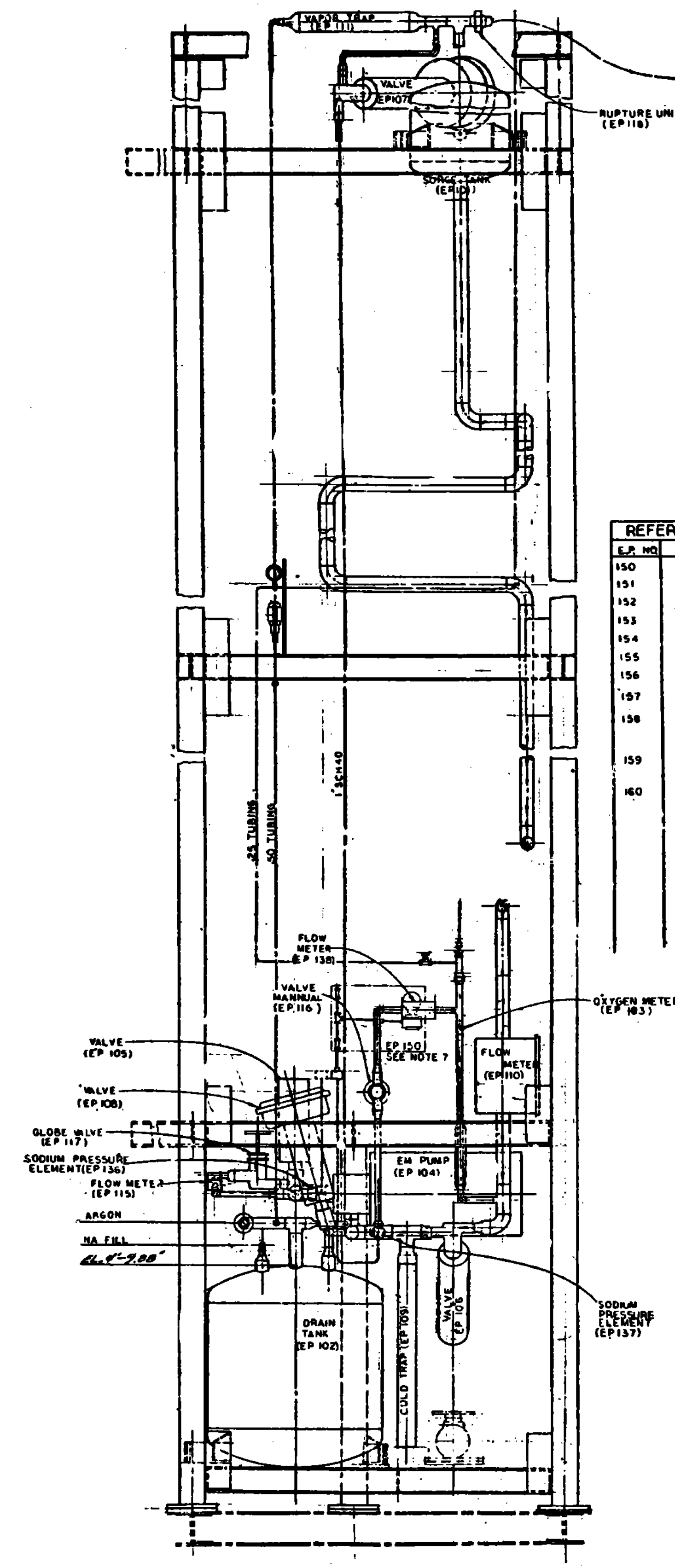
★ SEE SODIUM RECEIVER TEST LOOP 909E050 (ISOMETRIC)

908E982

Figure 4-2. SRTA Arrangement Drawing (Sheet 1)



SIDE ELEVATION



REAR ELEVATION

REFERENCE PARTS LIST FOR COMPONENTS IN STRUCTURE		
E.P. NO.	DESCRIPTION	DRWG NO.
150	VALVE PANEL-PRESSURE ELEMENT	134D1932 G1
151	DRAIN TANK INSTALLATION	145D6381 G1
152	" " " " " "	145D6381 G2
153	SURGE TANK INSTALLATION	145D6361 G1
154	THERMOWELL	179C5377
155	THERMOWELL	179C5377
156	VALVE PANEL-MOUNTING	179C5378
157	MOUNTING BRACKET-VALVE	179C5379
158	MOUNTING BRACKET-VALVE	179C5388
159	VALVE PANEL-RUPTURE DISC LEAK DETECTION	179C5383
160	VALVE PANEL RUPTURE DISC LEAK/DETECTION	179C5383

Figure 4-3. SRTA Arrangement Drawing (Sheet 2)

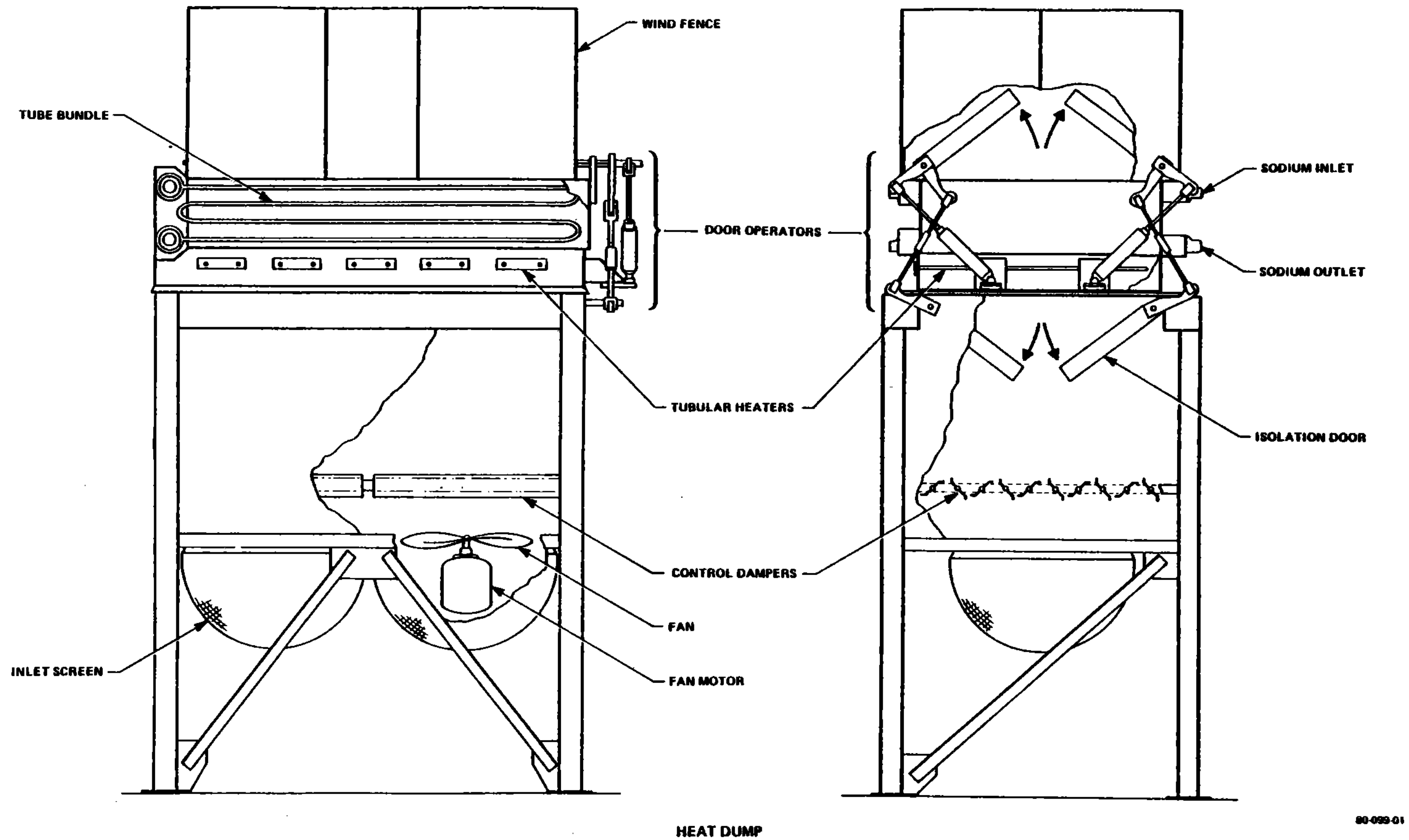


Figure 4-4. SRTA Heat Dump Arrangement

Heat Dump Part	Action
Tube Bundle Section	Replaced
Isolation Doors and Operators	Rebuilt
Tubular Heaters	Replaced/higher rating
Damper Operating Motor	Replaced
Fan Motors	1 Rebuilt, 1 Replaced
Assembly	Clean, Inspect, Paint, Checked Out

4.2.1 STRUCTURE

The heat dump structure is composed of the welded bed, support columns, grating, and isolating doors. The welded bed is essentially a plenum with double fan rings below and is bolted to four (4) vertical columns which support the bed, heat exchanger, etc. Angles are included for reinforcing the structure against side loads. Two expanded metal type fan guards are included to protect personnel from the fan blades. A grating is mounted above the heat exchanger for protection against "flying objects". The pneumatically operated upper doors are mounted above the grating and are opened and closed together. The doors are used to isolate the heat exchanger during hot hold operations in order to retain heat within the heat exchanger and keep the sodium in the tubes from freezing.

4.2.2 HEAT EXCHANGER SECTION

The heat exchanger or tube bundle section is composed of manifolds, finned tubes, thermocouples and the structure.

The manifolds or headers are made from seamless type 304 stainless steel pipe. The tube sheet has specially machined nipples to which the tubes are welded. With this design a crevice-free tube-to-tube sheet joint is obtained. The manifolds are closed at one end with standard welding cap and with eccentric reducers on the other end for attachment to the SRTA piping.

The tubes are 1" outside diameter with .072" thick seamless wall of type 304 stainless steel. Each tube is finned in the heat transfer region (approximately 88") with 5/8" high x .030" thick helically wound carbon steel fins at a pitch of 7 fins per inch. The carbon steel fins are nickel braze bonded to the tubes. The complete tube assembly from inlet to outlet manifold includes one shepherd crook 'U' tube and one 'U' tube butt welded together. Figure 4-5 shows the original SEFOR coil that is being replaced.

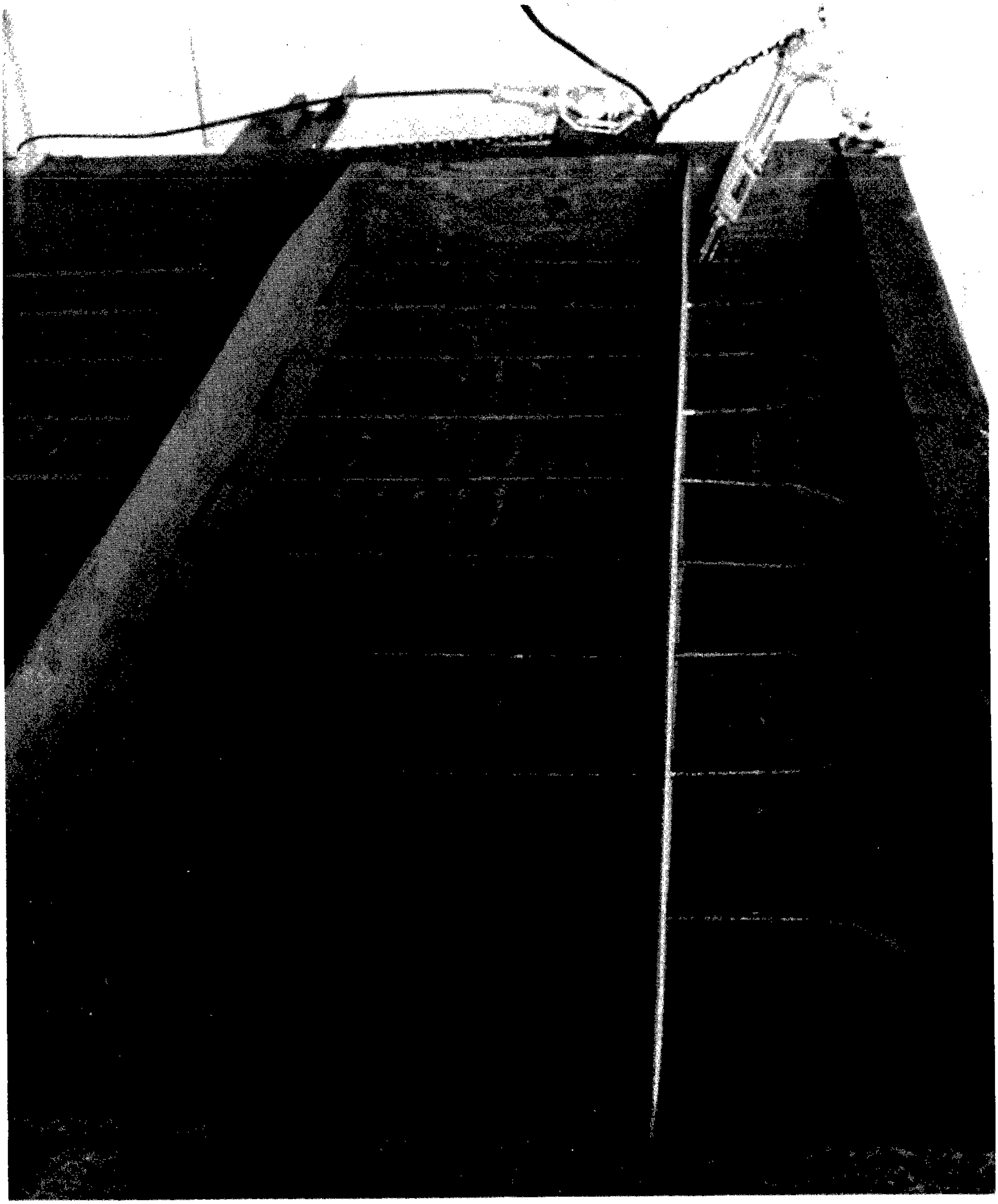


Figure 4-5. Sefor Heat Dump Coil

This tube and manifold support structure is composed of tube and manifold support plates welded to carbon steel side channels. Tube support plates support the O.D. of the tube at areas where no fins have been placed on the tube. In supporting the manifolds and tubes connecting to the manifolds, there is a provision for horizontal thermal expansion of both manifolds and tubes. A special thermal sleeve is used to connect the stainless steel manifolds to the carbon steel support plate at the fixed end. The tube return bends, manifolds and manifold caps are enclosed by sheet metal covers.

4.2.3 DAMPERS

The damper assembly was manufactured by Honeywell and includes two (2) sets of opposed steel blades mounted in a steel frame. An electrically operated positioning motor is supplied for operating the dampers. The motor can be controlled remotely and used with blade position indicator.

4.2.4 FANS

The cooling air is supplied by two (2) six-bladed aluminum fixed pitch propeller type fans manufactured by Hartzell Propeller Fan Company. Each fan is driven by a two-speed 5 HP totally enclosed, fan-cooled motor. Motor speeds are 1140 or 860 rpm.

4.2.5 HEATERS

The heaters are 'U' tube, .496 O.D. electric "Calrod" tubular heaters. They are mounted below the heat exchanger and can be used in the preheating or hot hold operations.

4.2.6 HEAT DUMP THERMAL ANALYSIS

A detailed component specification was prepared and a summary comparison of SRTA requirements to SEFOR requirements follows in Table 4-1. Several thermal analyses were made to investigate the capability of the refurbished SEFOR auxiliary air blast cooler to transfer the specified 2500 KW of heat under SRTA conditions.

Table 4-1

COMPARISON OF SRTA AND SEFOR THERMAL DUTY

- Heat Transfer Rate Unchanged

  2.5 MW = $8.5 \times 10^6 \ \frac{Btu}{Hr}$

- Sodium Side

	SEFOR	SRTA
Inlet Temp	850^oF	1100^oF
Outlet Temp	550^oF	$500-700^oF$
Flow	$92000 \ \frac{lb}{hr}$	$47000 \ \frac{lb}{hr}$

- Air Side

Inlet Temp	90^oF	120^oF

Particular attention was given to themal contact resistance between the 304 stainless steel tube and the mechanically attached (grooved) carbon steel helical fin. At one location about four carbon steel fins were cut and peeled away from the groove in the stainless tube for visual inspection. Subjective evaluation of these indicated the following:

- The bottom edge of the fin base did not seat into the bottom of the groove; there was an air gap.
- Mechanical contact existed on the sides of the fin base through an overlap which varied from about 0.02 inches on a side to zero.
- There was a definite rust film over the fin base area through which the heat must flow.
- In the cold condition, contact pressure on the sides of the sides of the fin base was slight.

The effect on heat transfer resulting from imperfect contact is treated in the GE Heat Transfer Databook; data which is applicable to the fin/tube is included. The original heat transfer calculations for the SEFOR auxiliary air blast cooler were used as a data source and guide for new calculations except that provision was made to add a thermal contact resistance. As a verification of the analysis method, a "THTD" computer model was made to determine temperature distribution and overall conductance. Some of the salient conclusions from the analytical studies are:

- Convection on the air side is controlling when no contact resistance is assumed.
- Most all the heat passes through the fin surface or conversely, the bare tube area is not significant in the overall performance.

- If contact between fin and tube is perfect, the unit would have about 20% excess area for its 2500 kW rating (see Table 4-2).
- The contact resistance is estimated to be .0048. Thermal analysis indicated a capability of about 1600 kW. It must be emphasized that confidence in the contact resistance estimate is low. An order of magnitude lower contact resistance would be required to achieve 2500 kW.

Table 4-2

EFFECT OF SRTA CONDITIONS ON SEFOR HEAT TRANSFER CALCULATIONS

- "H_T" Convection Inside Tubes Drops

  $4500 \frac{Btu}{Hr\ ft^2 {}^oF}$ — 3300

- "LMTD" Increases

  430^oF — 500

- Required Surface Area Drops

  $2560\ Ft^2$ — 2250

  (Available Area = $2730\ Ft^2$)

CONCLUSION: Acceptable for SRTA, however, consideration of contact resistance between imbedded carbon steel fin and stainless tube led to recommendation to replace with a new brazed fin tube bundle.

No analytical solution appeared likely, such as justifying an order of magnitude reduction in contact resistance. Hardware solutions considered were:

- Replace the tube bundle section.
- Increase air flow to get a higher log mean temperature difference and higher air side convection coefficient.
- Test to determine contact resistance then select alternate one or two unless the required order of magnitude reduction in contact resistance is verified.

Replacement of the tube bundle was implemented. The replacement tube bundle design is nearly identical to the original except that the carbon steel fins are to be attached with a nickel alloy braze thus eliminating the concern for contact resistance.

Alternate two was studied analytically (using the estimated contact resistance); it appeared that about three times the original air flow would be required. To get this air flow would mean replacement of the two five HP fans with two 70 HP vane arial fans. Also, it is expected that the present louvers would have to be replaced with inlet control dampers. A considerable extrapolation of available heat transfer correlation data (of a similar but not identical geometry) was used to estimate the air side convection at such a high Reynolds number (17000).

Testing was judged not to be a solution; it might have provided a more acceptable confidence in contact resistance to make alternate two more technically viable. Removing one of 23 tubes would have been necessary to make a practical test.

4.2.7 STRUCTURAL ANALYSIS

Calculations were made in accordance with the requirements of ASME B&PV Code Section VIII, Division 1, to justify the design of the heat dump tube assembly for a 50 psig design pressure at a design temperature of 1150°F. Also a finite element model of a tube was used to verify that the tube flexibility and support are adequate for an 1100°F to 600°F temperature distribution. Finally, a structural analysis was performed of the heat dump support structure for specified wind and seismic loadings.

4.3 SODIUM PUMP

EM Pump Model 5KY416PH1 is a helical induction electromagnetic pump with the characteristics listed in Table 4-3. Calculated performance is shown on Figure 4-6. The pump is hermetically sealed, has no moving parts, and has no direct electrical connections to the liquid metal carrying components. Pressure is developed by the interaction of the magnetic field and current which flows as a result of the voltage induced in the liquid metal contained in the dump duct. Flow may be controlled by variation of the voltage supplied to the pump windings. Power input and developed pressure at a particular flow vary approximately as the square of the applied voltage.

The pump consists of two major sub-assemblies: the stator assembly and the pump duct assembly.

Table 4-3

GENERAL INFORMATION

PUMP RATING	
Fluid	Sodium 700°F
Flow	175 gpm
Developed Pressure	30 psi
Power Supply	480 volts, 3 phase, 60 cycle
Power Input	33.6 kW
Efficiency	6.8%
Power Factor	32.7
COOLANT REQUIREMENTS	
Coolant	Air
Coolant Flow	1500 cfm
Coolant Inlet Temperature	50°C, Max
DESIGN CHARACTERISTICS	
Pressure	75 psig at 1150°F
Number of Poles	4
Duty Rating	Continuous
Hot Spot Temperature (Insulation)	200°C
Weight, Less Duct	1487 lbs

4.3.1 STATOR ASSEMBLY

The stator winding is of form wound construction. The winding insulation system is Class H, suitable for operation at temperatures up to 200°C. After the coils are inserted in the slots and connected, the wound stator is treated with several applications of silicone resin. When supplied with three phase 60 Hz power, the stator winding produces a 4-pole magnetic field revolving at 30 revolutions per second in the stator bore. The stator is air cooled, utilizing a through ventilation pattern in which cooling air is supplied to one end shield, is directed around the end turns at one end, through axial passages between the frame and the outside of the stator laminations, around the end turns at the other end, and out of the pump by way of the end shield ventilation opening. Chromel-Alumel thermocouples are located in the end windings to provide a means of monitoring pump winding temperature during operation. A small fraction of the ventilating air flows axially between the stator bore and the pump duct.

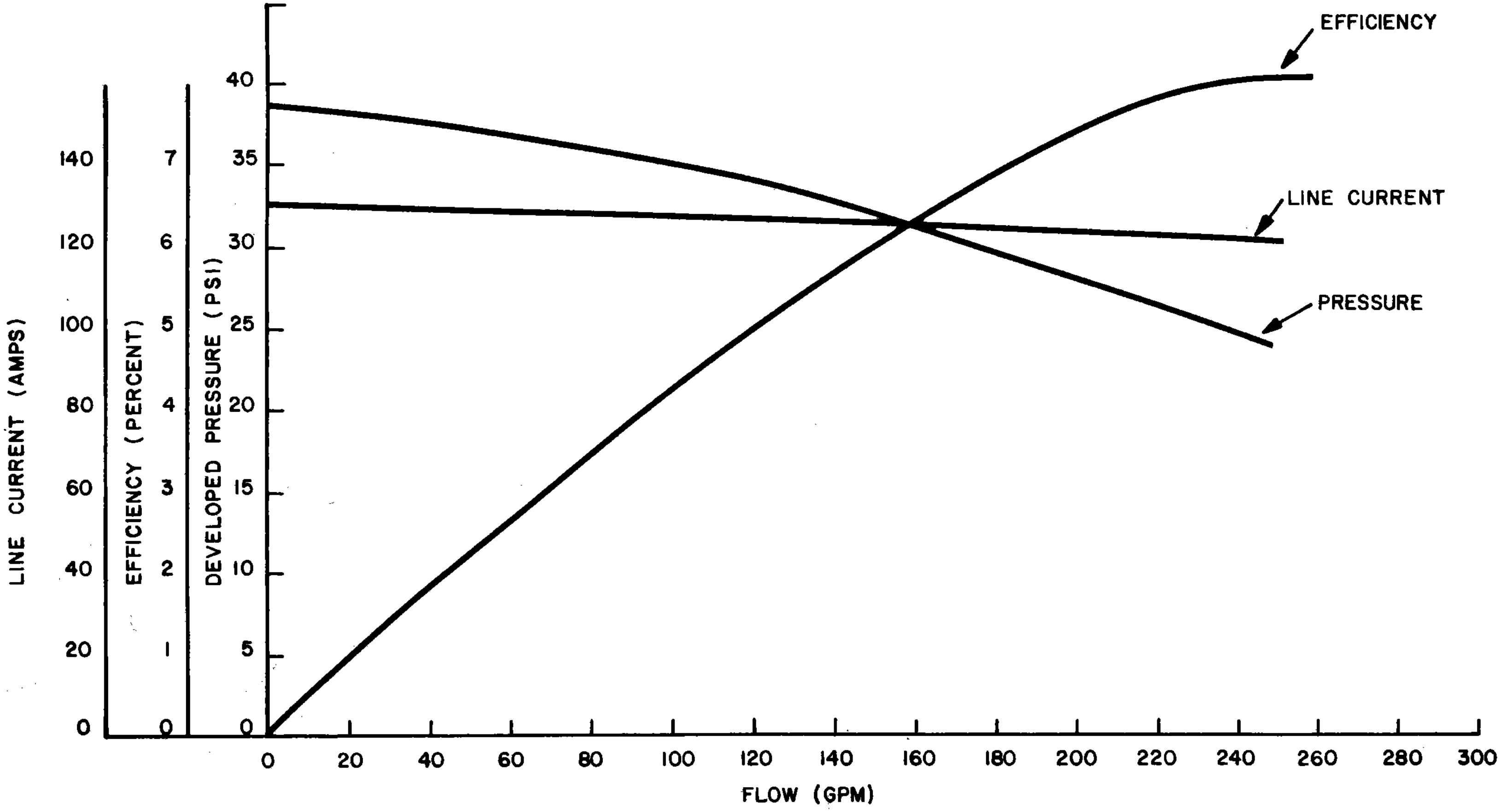


Figure 4-6. EM Pump Performance Curves

4.3.2 PUMP DUCT ASSEMBLY

The pump duct is made of Type 304 stainless steel. Entrance and exit connections to the duct are perpendicular to each other at the same end of the duct. Therefore, the pump duct can expand freely without giving rise to stress. The principal parts of the pump duct assembly are the outer tube and the inner tube. The inner tube includes machined helical passages such that, in the duct assembly, fluid passing through the pump is constrained to flow in a spiral path so that the tangential force on the fluid is converted into a developed pressure. The pump will operate satisfactorily in either direction, but it is designed for fluid entry through the annulus and exit through the central passage in the inner tube. The inner tube is shrunk onto the outer tube to minimize leakage between passages. The pump duct is entirely self-supporting and is insulated from the stator by a blanket of refractory fiber felt insulation. The insulation is applied directly on the duct forming one complete assembly. The approximately 1/4 inch of radial space between the inner sleeve and outer envelope is filled with refractory fiber felt applied as a blanket and secured with a covering of glass tape. Two Chromel-Alumel thermocouples are installed in channels which extend from the dead end of the thermal insulation assembly to the approximate center of the assembly. They lie on the outer surface of the duct, hence thermocouples inserted in these channels indicate duct temperature.

4.4 <u>SODIUM TANKS</u>

The drain tank is used for the initial filling of the SRTA loop and to allow for complete draining. The nominal volume of the drain tank is 234 gallons. A required 226 gallon drain tank volume is justified in Table 4-4. Nozzles are provided on the drain tank for: argon cover gas connections, filling and draining, connection to the circulating loop (through a normally closed valve), and level probes. Dip tubes (vertical pipes internal to the tank) are provided for the fill-and-drain nozzle and the circulating loop connection to allow sodium to be forced either into the circulating loop or out of the tank to shippers for decommissioning by the use of cover gas pressure. The drain tank is a modified expansion tank from the SEFOR plant.

The 75-gallon surge tank is normally filled with about 60 gallons of sodium. It is the highest elevation sodium containing SRTA component. Thus, the surge tank provides an argon space above the circulating sodium for thermal expansion, transient pressures surges and allows for the measurement of the loop sodium inventory (level in surge tank). Nozzles are provided on the surge tank for: argon cover gas connections, sodium loop connections, and level probes. The surge tank is a modified expansion tank from the SEFOR plant.

Requirements for both the drain tank and the surge tank were defined in a component Specification; the more significant requirements applicable to both tanks are:

- Compliance with ASME B&PV Code Section VIII, Division 1 (except for stamping)
- Design pressure 50 psig at 1150^{O}F
- Butt welds 100 percent radiographed
- Helium mass spectrometer leak test

Table 4-4

REQUIRED DUMP TANK VOLUME

Heat Dump	32 Gal
Solar Panel	42
Piping	37
Surge Tank (Na)	60
	171 Gal
20% Miscellaneous Components or Overfill of Surge Tank	+34
	205

Allowance of 10% for free argon and heel results in a required dump tank volume of 226 gallons.

4.5 SUPPORT STRUCTURE

The support structure is a steel assemblage of square tubular columns, wide flange beams and double angle bracing, configured to provide a support for the SRTA that could be truck transported without violating overload/oversize highway limitations.

Standard structural steels were utilized for the framing. The horizontal beams are attached to the welded column gussets with two A307 bolts at each end. The flanges were coped locally to provide a simple shear connection. Lateral stiffness and strength is provided by the back-to-back double angle cross bracing. It was assumed that the siding would not provide any additional stiffness.

The final support structure assembly is comprised of five major components:

- The base frame
- The upper frame
- The door support frame cantilevered from the roof
- The door support frame cantilevered from the base
- The tower elevator sleeper beams

After these subassemblies are connected, horizontal Z purlins will be attached to the columns and the corrugated asbestos siding installed. The structure for the fluid circulation equipment is shown on Figures 4-7 and 4-8.

4.6 INSTRUMENTATION

The instrumentation for the SRTA loop and associated components was shown in summary form on Figure 4-1 and is detailed on Figure 4-9. It consists of the following measurement functions, plus an alarm system:

- Temperature
- Pressure
- Flow
- Level
- Solar Flux
- Displacement
- Strain
- Oxygen
- Smoke

4.6.1 TEMPERATURE

Temperature is measured at the absorber panel inlet and outlet with Resistance Temperature Detectors to obtain high accuracy for the loop heat balance, and for use in the flow control system. Thermocouples (Chromel-Alumel) are applied at the Heat Dump inlet and outlet for control of the Heat Dump and to monitor Heat Dump performance. Chromel-Alumel thermocouples are applied throughout the sodium loop structure and the absorber panel headers and rear surface for trace heat monitoring and control and absorber panel performance monitoring. Some temperatures are indicated on the local control panel, located in the tower elevating module, on meters and on data acquisition units. All temperatures except trace heating are recorded in the CRTF data system. Trace heat temperatures are indicated on a data acquisition (microprocessor) unit which also has provision for paper tape recording.

4.6.2 PRESSURE

Sodium pressure is measured at the absorber panel inlet and outlet and at the pump suction and discharge. A transducer using Sodium-Potassium (NaK) eutectic alloy, contained between two slack diaphragms, transfers pressure from the sodium

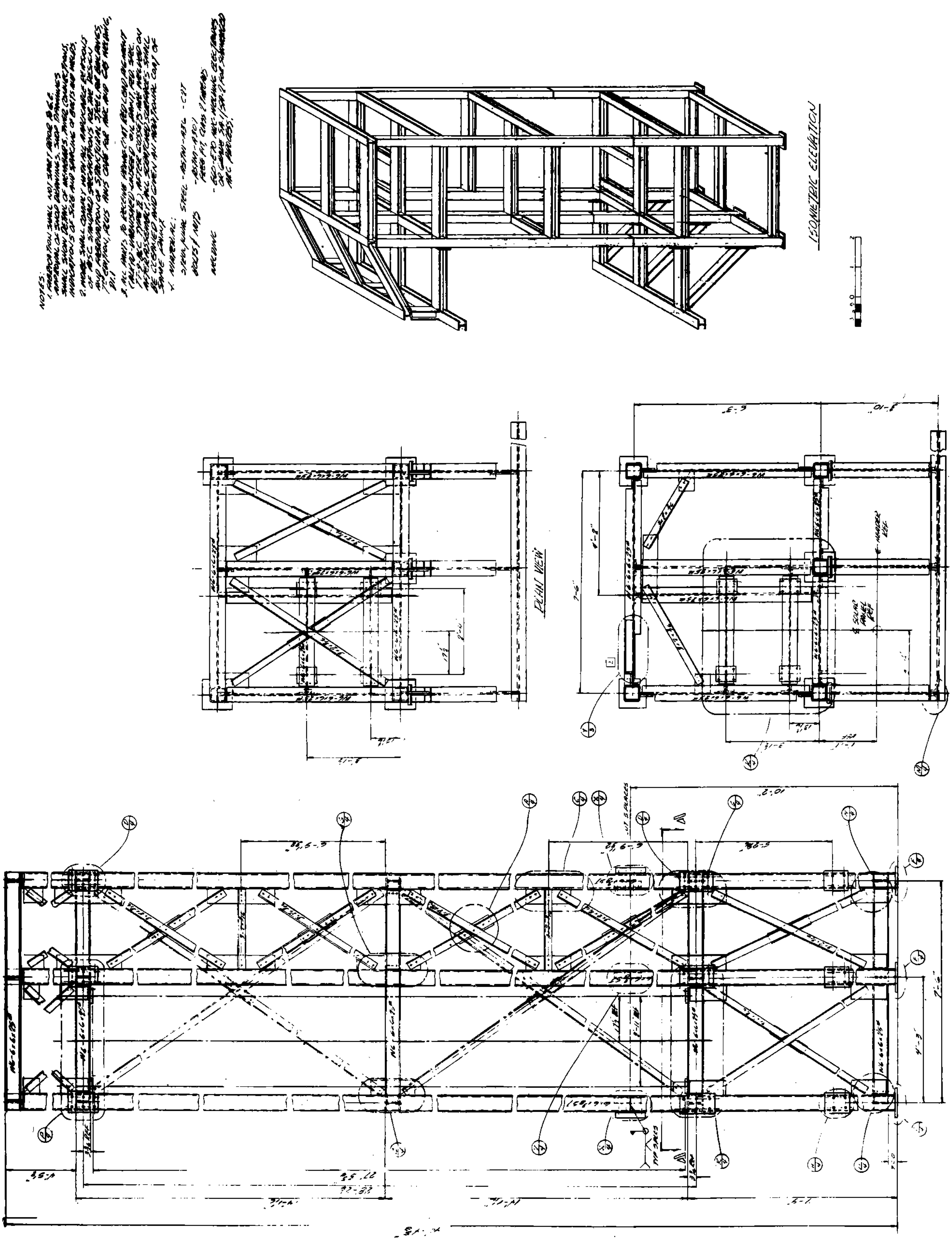


Figure 4-7. SRTA Support Structure (Sheet 1)

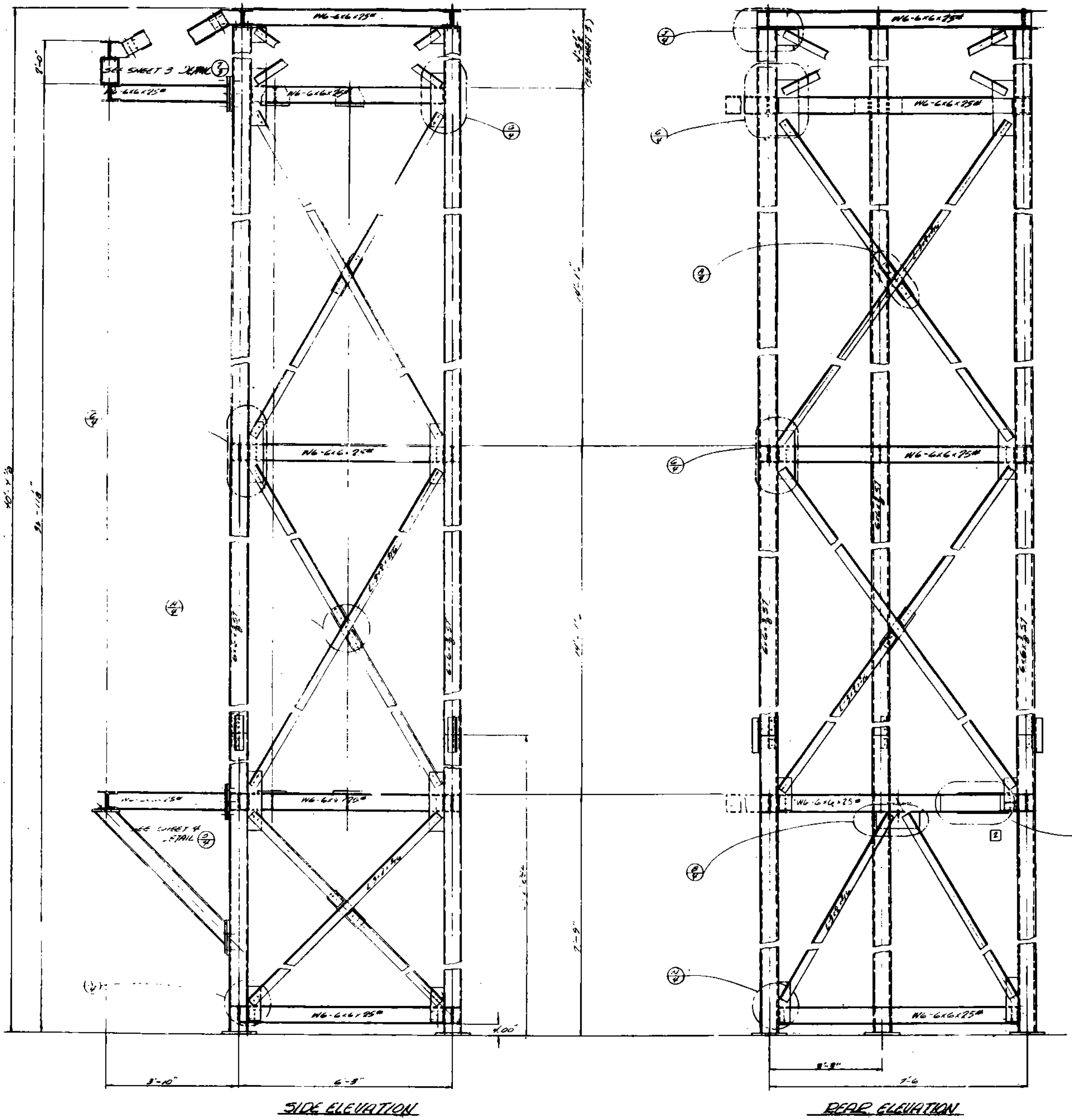


Figure 4-8. SRTA Support Structure (Sheet 2)

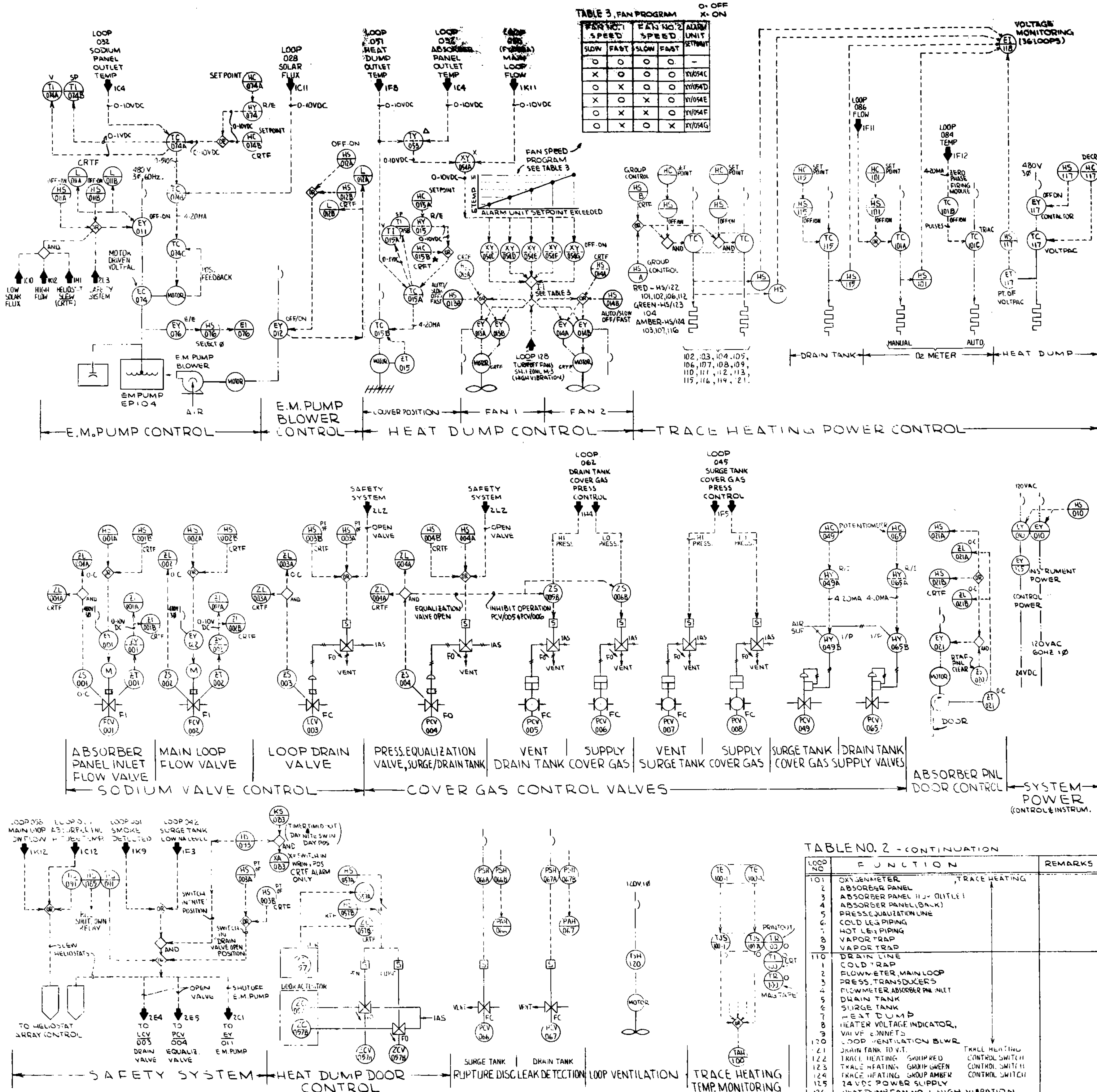


TABLE 3, FAN PROGRAM

O- OFF
X- ON

FAN NO. 1 SPEED		FAN NO. 2 SPEED		ALARM UNIT SETPOINT
SLOW	FAST	SLOW	FAST	
O	O	O	O	-
X	O	O	O	XY/054C
O	X	O	O	XY/054D
X	O	X	O	XY/054E
O	X	X	O	XY/054F
O	X	O	X	XY/054G

TABLE NO. 2

LOOP NO.	FUNCTION	REMARKS
001	FLOW CONTROL VALVE, ABSORBER PANEL INLET	
2	FLOW CONTROL VALVE, MAIN LOOP FLOW	
3	LOOP DRAIN VALVE	
4	PRESS.EQUALIZATION VALVE, SURGE/DRAIN TANK	
5	VENT VALVE } DRAIN TANK COVER GAS	
6	SUPPLY VALVE } DRAIN TANK COVER GAS	
7	VENT VALVE } SURGE TANK COVER GAS	
8	SUPPLY VALVE } SURGE TANK COVER GAS	
009		
010	CONTROL & INSTRUMENT POWER, HANDSWITCH	
11	EM PUMP POWER	
12	EM PUMP BLOWER MOTOR POWER	
13	HEAT DUMP FAN #1 MOTOR POWER	
14	HEAT DUMP FAN #2 MOTOR POWER	
15	HEAT DUMP LOUVER MOTOR POWER	
16		
17		
18		
019		
020	RTAF INTERLOCK (RTAF OPEN)	
1	ABSORBER PANEL DOOR CONTROL	
2		
3		
4	ABSORBER PANEL DISPLACEMENT	
5	ABSORBER PANEL TEMP PROFILE	
6	ABSORBER PANEL STRESS	
7	ABSORBER PANEL TUBE TEMP.	
8	SOLAR FLUX, ABSORBER PANEL	
9	INLET TEMP.	
030	INLET TEMP	
1	INLET MANIFOLD TEMP	
2	OUTLET TEMP.	
3	OUTLET TEMP.	
4	OUTLET MANIFOLD TEMP.	
5	INLET PRESS	
6	OUTLET PRESS.	
7	DIFFERENTIAL PRESS	
8	INLET FLOW	
9	SOLAR FLUX PROFILE, ABSORBER PANEL	
040	TEMPERATURE, SURGE TANK	
1	OUTLET TEMP.	
2	SODIUM LEVEL, ANALOG	
3	SODIUM LEVEL, HIGH	
4	SODIUM LEVEL, LOW	
5	COVER GAS PRESS., CONTROL	
6	COVER GAS PRESS., ALARM	
7	LEVEL PROBE POWER SUPPLY,	
8	COVER GAS SUPPLY PRESS,	
9	COVER GAS SUPPLY PRESS. CONTROL, SURGE TANK	
050	INLET TEMP, HEAT DUMP	
1	OUTLET TEMP	
2		
3	HEAT DUMP OUTLET, ABS PNL INET, ΔT	
4	TEMP/FLOW MULTIPLIER	
5		
6		
7	DOOR CONTROL, HEAT DUMP	
8	MAIN LOOP FLOW	
9		
060	TEMP. (CONTROL TEMP), DRAIN TANK	
1	SODIUM LEVEL	
2	COVER GAS PRESS. (CONTROL)	
5	COVER GAS PRESS. (ALARM),	
4	COVER GAS SUPPLY PRESS.	
5	COVER GAS SUPPLY PRESS CONTROL, DRAIN TANK	
6	RUPTURE DISC LEAK DETECTION, SURGE TANK	
7	RUPTURE DISC LEAK DETECTION, DRAIN TANK	
8		
9		
070	DUCT TEMP, E.M. PUMP	
1	DUCT TEMP	
2	WINDING TEMP	
3	WINDING TEMP.	
4	CONTROL SYSTEM	
5	TEMP OFF NORMAL (ALARM)	
6	VOLTAGE MONITORING	
7	INLET PRESSURE	
8	OUTLET PRESSURE, E.M. PUMP	
9		
080	OXYGENMETER OUTPUT	
1	SMOKE DETECTION, LOOP STRUCTURE	
2	SMOKE DETECTION, HEAT DUMP	
3	DAY - NITE CONTROL SWITCH	
4	OXYGENMETER TEMP.	
5	ANNUNCIATOR SYS.	
6	OXYGENMETER FLOW	
7		
8		
9		
090	HELIOSTAT SLEW SIGNAL	
2		
3		
4		
5		
6		
7		
8		
9		
100	TRACE HEATING TEMP MONITORING	

SEE CONTINUATION

TABLE NO. 2 - CONTINUATION

LOOP NO.	FUNCTION	REMARKS
101	OXYGENMETER, TRACE HEATING	
2	ABSORBER PANEL	
3	ABSORBER PANEL (HDR OUTLET)	
4	ABSORBER PANEL (BACK)	
5	PRESS.EQUALIZATION LINE	
6	COLD LEG PIPING	
7	HOT LEG PIPING	
8	VAPOR TRAP	
9	VAPOR TRAP	
110	DRAIN LINE	
1	COLD TRAP	
2	FLOWMETER, MAIN LOOP	
3	PRESS. TRANSDUCERS	
4	FLOWMETER, ABSORBER PNL INLET	
5	DRAIN TANK	
6	SURGE TANK	
7	HEAT DUMP	
8	HEATER VOLTAGE INDICATOR,	
9	VALVE BONNETS	
120	LOOP VENTILATION BLWR.	
121	DRAIN TANK TO V.T., TRACE HEATING	
122	TRACE HEATING GROUP RED CONTROL SWITCH	
123	TRACE HEATING GROUP GREEN CONTROL SWITCH	
124	TRACE HEATING GROUP AMBER CONTROL SWITCH	
125	24 VDC POWER SUPPLY	
126	HEAT DUMP FAN NO. 1 HIGH VIBRATION	
127	HEAT DUMP FAN NO. 2 HIGH VIBRATION	
128	HEAT DUMP HIGH VIBRATION ALARM	

Figure 4-9. SRTA Instrumentation Diagram

to a third fluid (silicon oil) where a conventional pressure transmitter measures the sodium pressures and differential pressure (across the panel and the pump). Argon cover gas pressure is measured for the surge tank and drain tank at the cold side of the vapor traps for these two tanks. Argon supply pressures are also measured with conventional pressure transmitters. All pressures are indicated on the central control panel and sodium pressures are recorded in the CRTF data system.

4.6.3 FLOW

Sodium flow is measured with permanent magnet (PM) flow meters at three places in the loop. Main loop flow is measured in the cold leg piping (3 inch) between the Heat Dump and the pump suction control valve. By-pass flows in the oxygen meter loop and the low flow loop are measured with small PM flowmeters. All three flows are indicated on the central control panel and are recorded by the CRTF data system.

4.6.4 LEVEL

Level is measured in the surge tank and in the dump tank continuously over fixed ranges, and discretely in the surge tank at two points, one high and one low, for the purpose of calibrating the 3-inch flowmeter. The level probes use resistant types, both "I" (discrete) and "J" (continuous analog), based on the principle that stainless steel has significant electrical resistance and that sodium is a good electrical conductor which "shorts out" stainless steel electrical circuits. Level is indicated on the central control panel and recorded in the CRTF data system.

4.6.5 SOLAR FLUX

Solar flux is measured just off the edge of the absorber panel at ten discrete points using water cooled circular foil calorimeter sensors. One of the solar flux signals is used as a feed forward signal in the control system for the pump flow control. All ten signals are recorded in the CRTF data system.

4.6.6 DISPLACEMENT

The absorber panel expansion is measured with an LVDT (linear voltage displacement transducer) mounted at the bottom of the solar panel. A range of about 3 inches is provided and the signal is recorded in the CRTF data system.

4.6.7 STRAIN

Fifteen high temperature strain gauges are mounted on the back of the absorber panel. The strain signal is conditioned by an amplifier provided by CRTF and the signals are recorded in the CRTF data system.

4.6.8 OXYGEN

The oxygen level in the sodium is measured with an electrochemical oxygen meter probe. The probe is located in a separate small loop that by-passes the pump suction control valve. This loop is heated to provide sodium at 1000°F to the probe. The oxygen level is indicated on the measuring instrument located in the central control panel and is recorded in the CRTF data system.

4.6.9 SMOKE

Sodium "smoke" detectors are located at the ventilation outlet of the structure and over the heat dump to indicate a sodium leak in the system. These detectors provide an alarm at the central control panel and in the CRTF data system.

4.6.10 ALARM SYSTEM

An anunciator is located at the central control panel which provides audible and visual indication of process conditions "out of normal". These alarm signals are also transmitted to the CRTF data system to be recorded there. The alarm signals are listed in Table 4-5.

Table 4-5

SRTA ALARM SIGNALS

- Surge Tank, High or Low Level
- Surge Tank, High or Low Pressure
- Drain Tank, High or Low Pressure
- Surge Tank, Rupture Disk Leak
- Drain Tank, Rupture Disk Leak
- Loop Structure, Smoke Detection
- Heat Dump, Smoke Detection
- Oxygen Meter, High O_2 Content
- Absorber Panel, High Outlet Temperature
- E.M. Pump, High or Low Duct or Winding Temperatures
- Trace Heating, High Temperature
- Main Loop, Low Flow
- Absorber Panel, High Temperature
- Safety System, Trip

4.7 CONTROL SYSTEM

Control of the sub-systems of the loop are done from the local control panel, or for the key sub-systems, control can be taken over from the master control center. Controls are shown on Figure 4-10 and summarized below:

- E.M. Pump (Loop Flow Rate) *
- Heat Dump *
- Trace Heating **
- Sodium Valves *
- Cover Gas Valves **

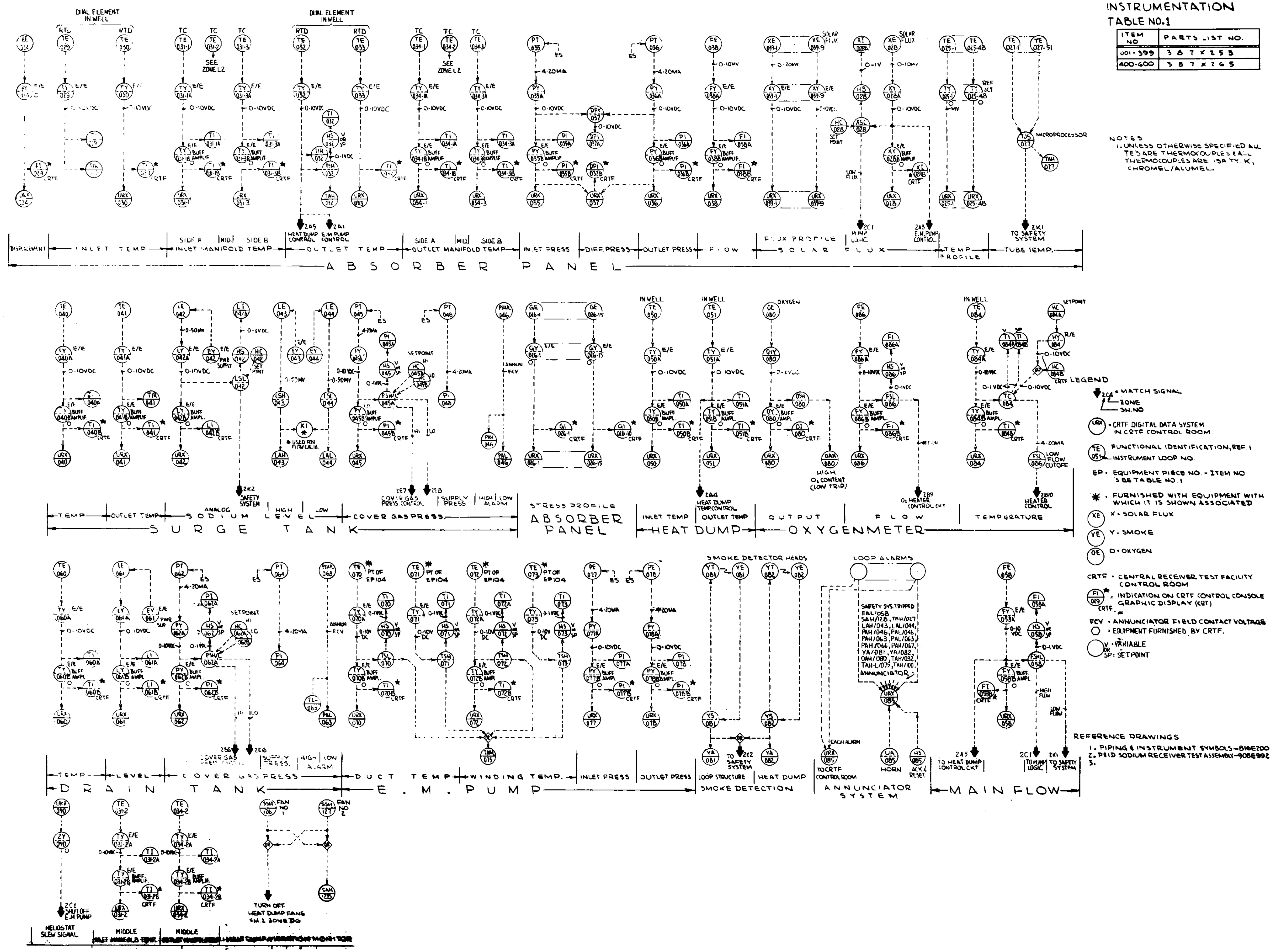


Figure 4-10. SRTA Control Diagram

- Absorber Panel Door *

  * Control at both Local Control Panel and Master Control Center
  ** Control at Local Control Panel Only

4.7.1 EM PUMP CONTROL

The EM pump is controlled automatically by absorber panel outlet temperature and solar-heat flux. Solar heat flux provides a feed forward signal that the control system responds to instantaneously and the outlet temperature provides the slower trimming control. Three mode control functions are provided for each control signal.

The pump can be manually tripped from the central local panel or automatically from low solar flux/high flow/heliostat slew combination or from the safety system. The pump cooling blower is manually controlled on-off only.

4.7.2 HEAT DUMP CONTROL

The heat dump is controlled by off, slow, and fast speeds of two blower motors and by louver positions. The blower controls are programmed based on panel power calculated from loop flow multiplied by absorber panel differential temperature. A preset matrix logic of fan speed combinations controls the primary air volume and velocity. The louvers are controlled from the heat dump outlet temperature and provide the trimming action for exact outlet temperature. All controllers have three mode adjustments (proportional band, reset, and rate action).

A bank of heaters in the cooling area can provide additional trimming of the outlet temperature controls, particularly at very low cooling rates where the fan/louver combination tends to overcool. The heaters are controlled manually from the local control panel and can provide heating from near zero to their full power rating of 40 kW.

For shutdown operation the bottom and top doors are closed. These doors can be controlled from the local control panel or the master control center.

4.7.3 TRACE HEATING CONTROL

Trace heating control is done manually from the local control panel. Most of the heater banks are controlled by phase firing triacs, operating either in the 220 volt region or in the 120 volt region. Control is by adjustment of a potentiometer in the trace heating control module which is located in the local control panel. The voltage output of the triac is read by meter at the control module.

Switches provide for individual bank on-off control as well as multiple bank control which can also be made from the master control center. The multiple bank controls are:

- Drain tank
- Hot leg piping, including the surge tank and absorber panel outlet header
- Absorber panel back
- Cold leg piping and absorber panel inlet header

The balance of the controls are individual on-off controlled locally only.

Trace heating temperature monitoring consists of a thermocouple for each heater being monitored by a digital data processor located on the local control panel. Flexible controls on this data acquisition unit provide for overall scanning as well as bank or individual thermocouple monitoring. Paper tape recording and cathode ray tube viewing is available.

4.7.4 SODIUM VALVES

Two types of sodium valve control are used. For open-close operation a pneumatic operator controlled by electromagnetic solenoid(s) provides for either full open or full closed control. The loop drain valve and the gas pressure equalizing valve are controlled in this manner.

For position at any point between open and closed, an electric motor operated valve is provided. Controls on the local control panel drive the valve in the open or shut direction, and the stopping point is determined by the operator. All sodium valves are controlled from either the local control panel in the tower or the master control center.

4.7.5 COVER GAS VALVES

Control of the cover gas source pressure is done at the central control panel by an electronic-to-pneumatic control transducer for each of the two sodium vessels. The final control pressure is done by feed/bleed solenoid valves controlled from a pressure control system. In this manner a significant dead band can be set where both valves are closed in order to minimize usage of argon gas. Small fluctuations in the cover gas pressure are not important for most phases of operation.

4.7.6 ABSORBER PANEL DOOR

When the solar flux is not focused on the absorber panel, a door is provided to cover the panel to reduce heat loss. This panel is electric motor operated from full open to full shut by controls at either the local control panel or the master control center. Interlocks are provided so as not to interfere with the real time aperture flux measuring device which occupies the same space at the front of the panel. Open/shut stops and indicator lights are provided.

4.8 AUXILIARY EQUIPMENT

SRTA auxiliary equipment includes 480 volt electrical power supplies, breakers, switches, and cabling for the heat dump blowers, EM pump cooling blower and trace heating control equipment. The control center is shown in Figure 4-11. In addition, the EM pump will be supplied from a 90 ampere motor operated auto-transformer and will have 50 KVAR of power factor (PF) correcting capacitors.

4.9 SRTA SYSTEM ANALYSIS

One objective of the SRTA experiment is the demonstration of sodium absorber controlability during solar plant transient operation. In order to assure proper SRTA control and component acceptability, transient analyses are being performed.

4.9.1 LOOP ANALYSIS

The SRTA control loop is being evaluated to determine its tolerance to transient events. This evaluation utilizes a software simulation program that addresses loop regulation, response and controlability. The simulation assumes the loop to consist of two parts which may be considered somewhat independent of each other: the absorber panel and its control and the heat dump and its control. Although flow through both these components is controlled by a common pump, the transport time through the loop is sufficiently long that any control interaction between these two components will not be severe. The most critical control problem involves regulation/control of the solar panel.

The evaluation of loop regulation/control must consider the following characteristics:

- One control parameter (flow) controls the behavior of exit sodium temperature and maximum tube metal temperature.
- The panel consists of 50 tubes, ∿ 15 ft. long, with jumper tubes and inlet/outlet headers. The active panel area is subjected to nonuniform time varying insolation.
- At rated flow (120 GPM), it takes ∿ 20 seconds for sodium entering the panel to reach the outlet header. At 15% flow, the time is 120 seconds. The effect of the header (volume and thermal mass) is to mask the effect of incoming changes, such that a sodium temperature measurement at this point is likely to be ineffective for use in responsive closed loop regulation and control.

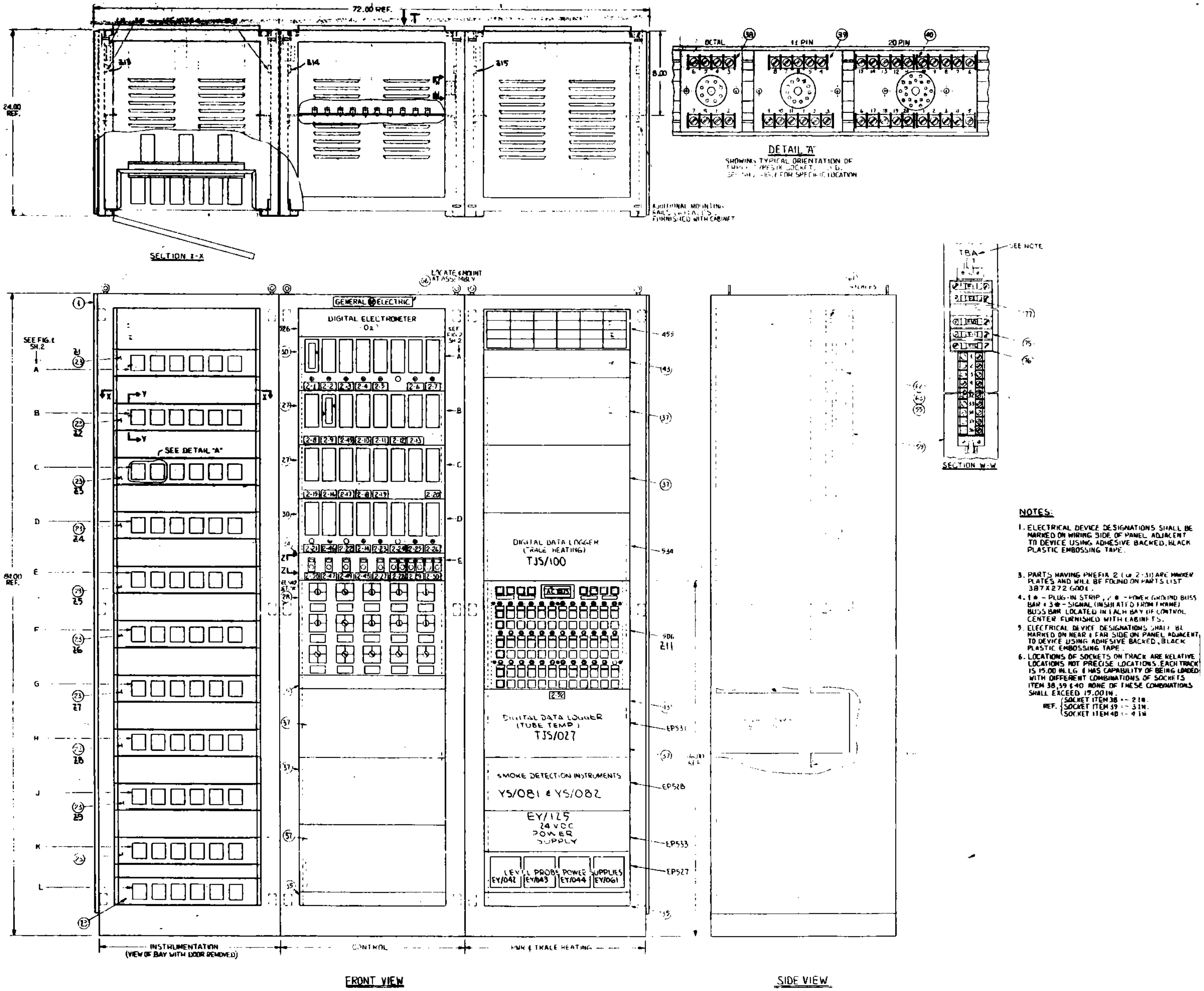


Figure 4-11. SRTA Control Center

- The major system disturbance anticipated during normal operation will be insolation transient on the panel due to passing clouds. An accurate method must be developed to measure insolation flux changes and derive a programmed flow signal from them.

The procedure being used for control system evaluation consists of: identification of candidate control algorithms, control simulation development and choice of preferred approvals, choice of system gains and stabilization valves, verification of preferred approval by simulation and analysis and evaluation of control system flexibility. For a complex, nonlinear development loop such as the SRTA, conventional linear control response and stability analysis procedures (Bode, Nyquist, etc.) are not applicable. System simulation of the loop and closed loop control is required in order to develop confidence in the control approach.

Results to Date

The original method of controlling flow does not appear adequate. This concept used a single flux sensor off to one side of the panel to indicate increasing or decreasing flux and then driving the pump up or down relative to the indication. Panel outlet header exit temperature was then used to fine tune the pump flow to maintain Na outlet temperature at 593°C (1100°F). The inability of this scheme to maintain the desired loop conditions is shown in Figures 4-12 through 4-14. Figure 4-12 is a plot of flux and flow versus time for a 120 second down transient; the flow tracking shown assumes an idealized case. Figure 4-13 shows that the average sodium exit temperature peaks 40 seconds after the conclusion of the transient. The high outlet temperature would signal the pump to increase flow, when in fact flow should be reduced to compensate for reduced insolation. The effects of flux and flow changes on panel center tube metal temperatures are shown on Figure 4-14.

The sensitivity of this scheme to loop flow rates is shown on Figures 4-15 through 4-17. These plots are based on 5% decrease of the initial insolation in 5 seconds. The control acts to restore the steady state temperature back to 1100°F; however, the response time is slow, almost 120 seconds at rated flow (Figure 4-15), some overshoot appears at 48% flow (Figure 4-16), and the response is unacceptably lightly damped at 16.8% flow (Figure 4-17).

Conclusion

Outlet header temperatures are not acceptable as a flow control parameter. Panel flux level changes must be incorporated as the primary flow control parameter. A fast and accurate method of measuring the flux changes must be incorporated into

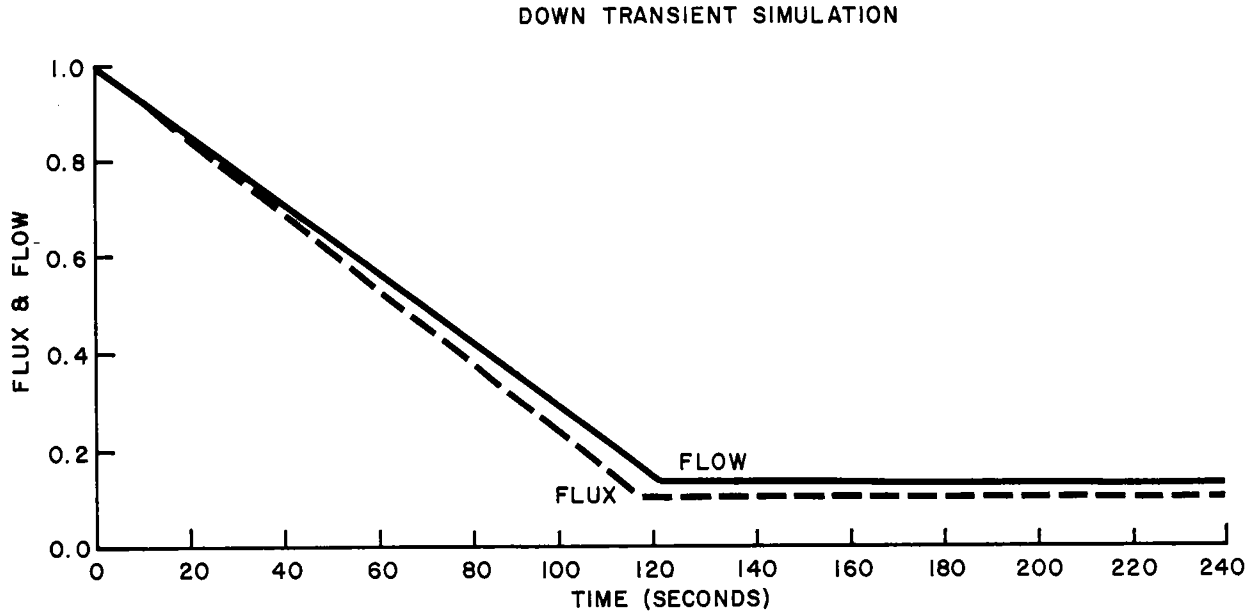


Figure 4-12. Flux Down Transient

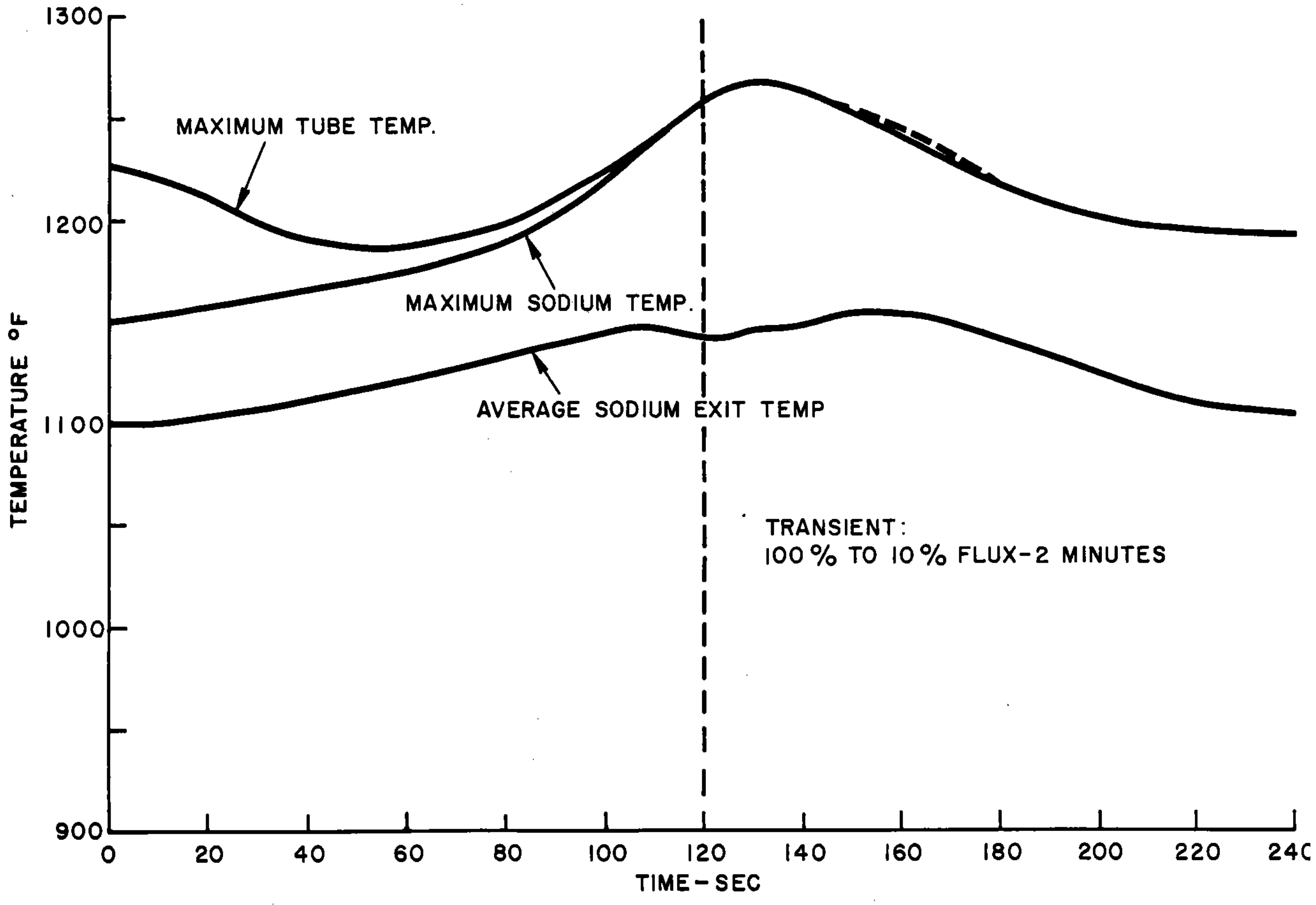


Figure 4-13. Power Down Transient Operation

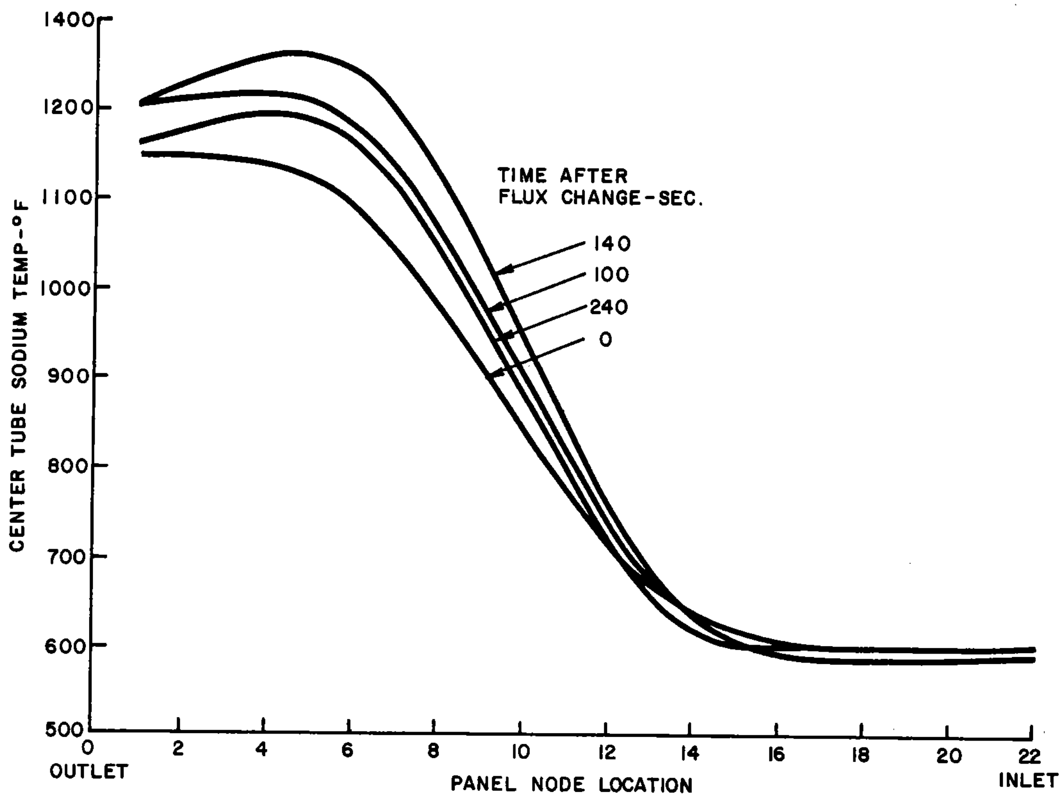


Figure 4-14. Power Down Transient Operation

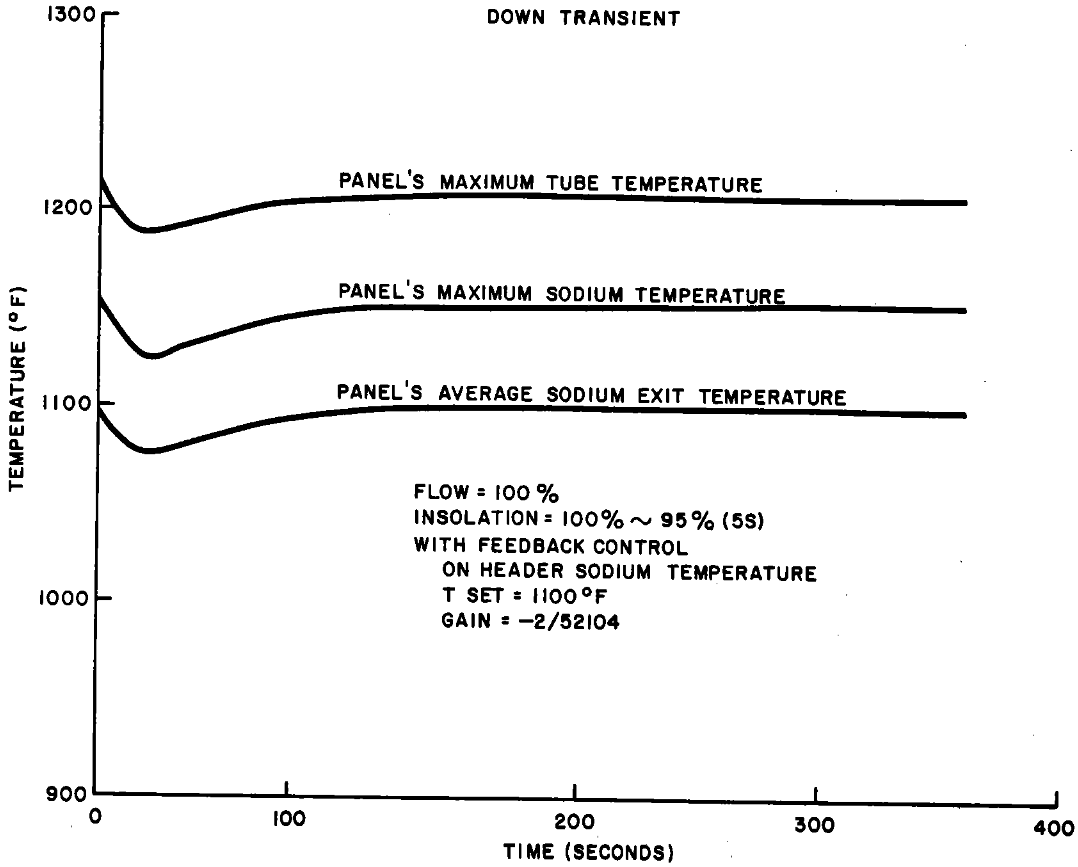


Figure 4-15. Full Flow Response to 5%, 5 Sec. Transient

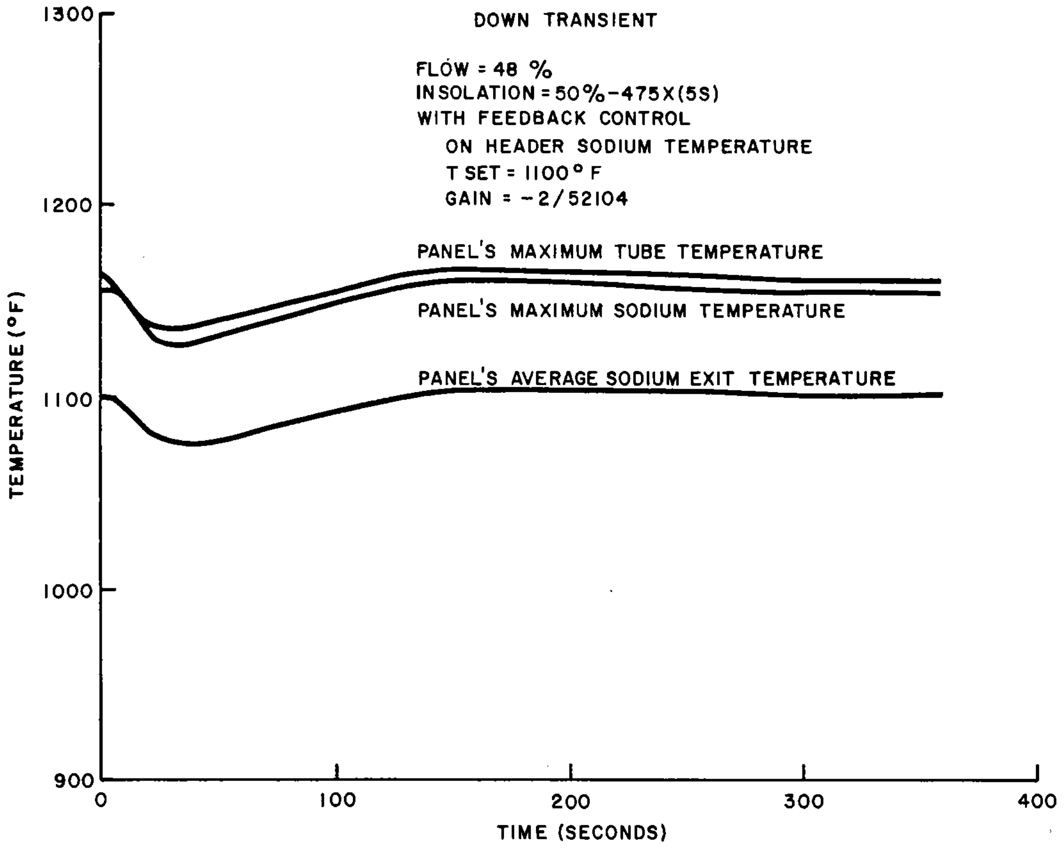


Figure 4-16. 48% Flow Response to 5%, 5 Sec. Transient

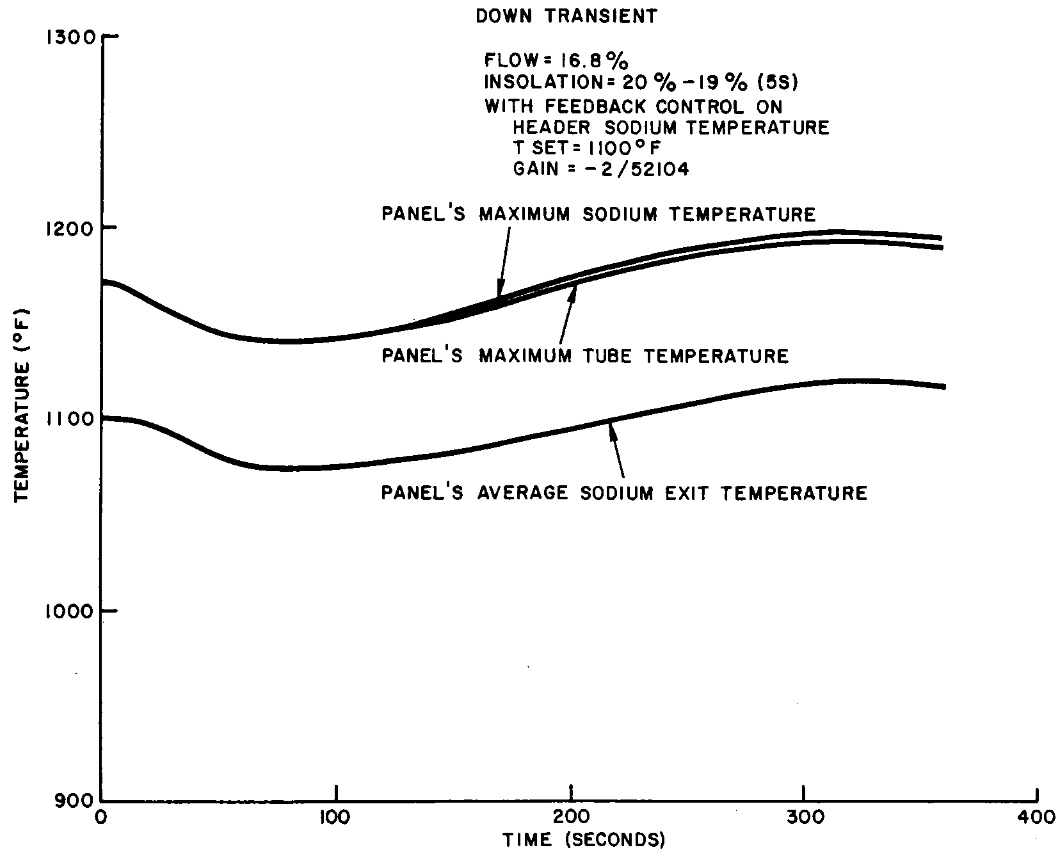


Figure 4-17. 16.8% Flow Response to 5%, 5 Sec. Transient

- Absorber Panel Door *

  * Control at both Local Control Panel and Master Control Center
  ** Control at Local Control Panel Only

4.7.1 EM PUMP CONTROL

The EM pump is controlled automatically by absorber panel outlet temperature and solar-heat flux. Solar heat flux provides a feed forward signal that the control system responds to instantaneously and the outlet temperature provides the slower trimming control. Three mode control functions are provided for each control signal.

The pump can be manually tripped from the central local panel or automatically from low solar flux/high flow/heliostat slew combination or from the safety system. The pump cooling blower is manually controlled on-off only.

4.7.2 HEAT DUMP CONTROL

The heat dump is controlled by off, slow, and fast speeds of two blower motors and by louver positions. The blower controls are programmed based on panel power calculated from loop flow multiplied by absorber panel differential temperature. A preset matrix logic of fan speed combinations controls the primary air volume and velocity. The louvers are controlled from the heat dump outlet temperature and provide the trimming action for exact outlet temperature. All controllers have three mode adjustments (proportional band, reset, and rate action).

A bank of heaters in the cooling area can provide additional trimming of the outlet temperature controls, particularly at very low cooling rates where the fan/louver combination tends to overcool. The heaters are controlled manually from the local control panel and can provide heating from near zero to their full power rating of 40 kW.

For shutdown operation the bottom and top doors are closed. These doors can be controlled from the local control panel or the master control center.

4.7.3 TRACE HEATING CONTROL

Trace heating control is done manually from the local control panel. Most of the heater banks are controlled by phase firing triacs, operating either in the 220 volt region or in the 120 volt region. Control is by adjustment of a potentiometer in the trace heating control module which is located in the local control panel. The voltage output of the triac is read by meter at the control module.

Switches provide for individual bank on-off control as well as multiple bank control which can also be made from the master control center. The multiple bank controls are:

- Drain tank
- Hot leg piping, including the surge tank and absorber panel outlet header
- Absorber panel back
- Cold leg piping and absorber panel inlet header

The balance of the controls are individual on-off controlled locally only.

Trace heating temperature monitoring consists of a thermocouple for each heater being monitored by a digital data processor located on the local control panel. Flexible controls on this data acquisition unit provide for overall scanning as well as bank or individual thermocouple monitoring. Paper tape recording and cathode ray tube viewing is available.

4.7.4 SODIUM VALVES

Two types of sodium valve control are used. For open-close operation a pneumatic operator controlled by electromagnetic solenoid(s) provides for either full open or full closed control. The loop drain valve and the gas pressure equalizing valve are controlled in this manner.

For position at any point between open and closed, an electric motor operated valve is provided. Controls on the local control panel drive the valve in the open or shut direction, and the stopping point is determined by the operator. All sodium valves are controlled from either the local control panel in the tower or the master control center.

4.7.5 COVER GAS VALVES

Control of the cover gas source pressure is done at the central control panel by an electronic-to-pneumatic control transducer for each of the two sodium vessels. The final control pressure is done by feed/bleed solenoid valves controlled from a pressure control system. In this manner a significant dead band can be set where both valves are closed in order to minimize usage of argon gas. Small fluctuations in the cover gas pressure are not important for most phases of operation.

4.7.6 ABSORBER PANEL DOOR

When the solar flux is not focused on the absorber panel, a door is provided to cover the panel to reduce heat loss. This panel is electric motor operated from full open to full shut by controls at either the local control panel or the master control center. Interlocks are provided so as not to interfere with the real time aperture flux measuring device which occupies the same space at the front of the panel. Open/shut stops and indicator lights are provided.

4.8 AUXILIARY EQUIPMENT

SRTA auxiliary equipment includes 480 volt electrical power supplies, breakers, switches, and cabling for the heat dump blowers, EM pump cooling blower and trace heating control equipment. The control center is shown in Figure 4-11. In addition, the EM pump will be supplied from a 90 ampere motor operated auto-transformer and will have 50 KVAR of power factor (PF) correcting capacitors.

4.9 SRTA SYSTEM ANALYSIS

One objective of the SRTA experiment is the demonstration of sodium absorber controlability during solar plant transient operation. In order to assure proper SRTA control and component acceptability, transient analyses are being performed.

4.9.1 LOOP ANALYSIS

The SRTA control loop is being evaluated to determine its tolerance to transient events. This evaluation utilizes a software simulation program that addresses loop regulation, response and controlability. The simulation assumes the loop to consist of two parts which may be considered somewhat independent of each other: the absorber panel and its control and the heat dump and its control. Although flow through both these components is controlled by a common pump, the transport time through the loop is sufficiently long that any control interaction between these two components will not be severe. The most critical control problem involves regulation/control of the solar panel.

The evaluation of loop regulation/control must consider the following characteristics:

- One control parameter (flow) controls the behavior of exit sodium temperature and maximum tube metal temperature.
- The panel consists of 50 tubes, ∿ 15 ft. long, with jumper tubes and inlet/outlet headers. The active panel area is subjected to nonuniform time varying insolation.
- At rated flow (120 GPM), it takes ∿ 20 seconds for sodium entering the panel to reach the outlet header. At 15% flow, the time is 120 seconds. The effect of the header (volume and thermal mass) is to mask the effect of incoming changes, such that a sodium temperature measurement at this point is likely to be ineffective for use in responsive closed loop regulation and control.

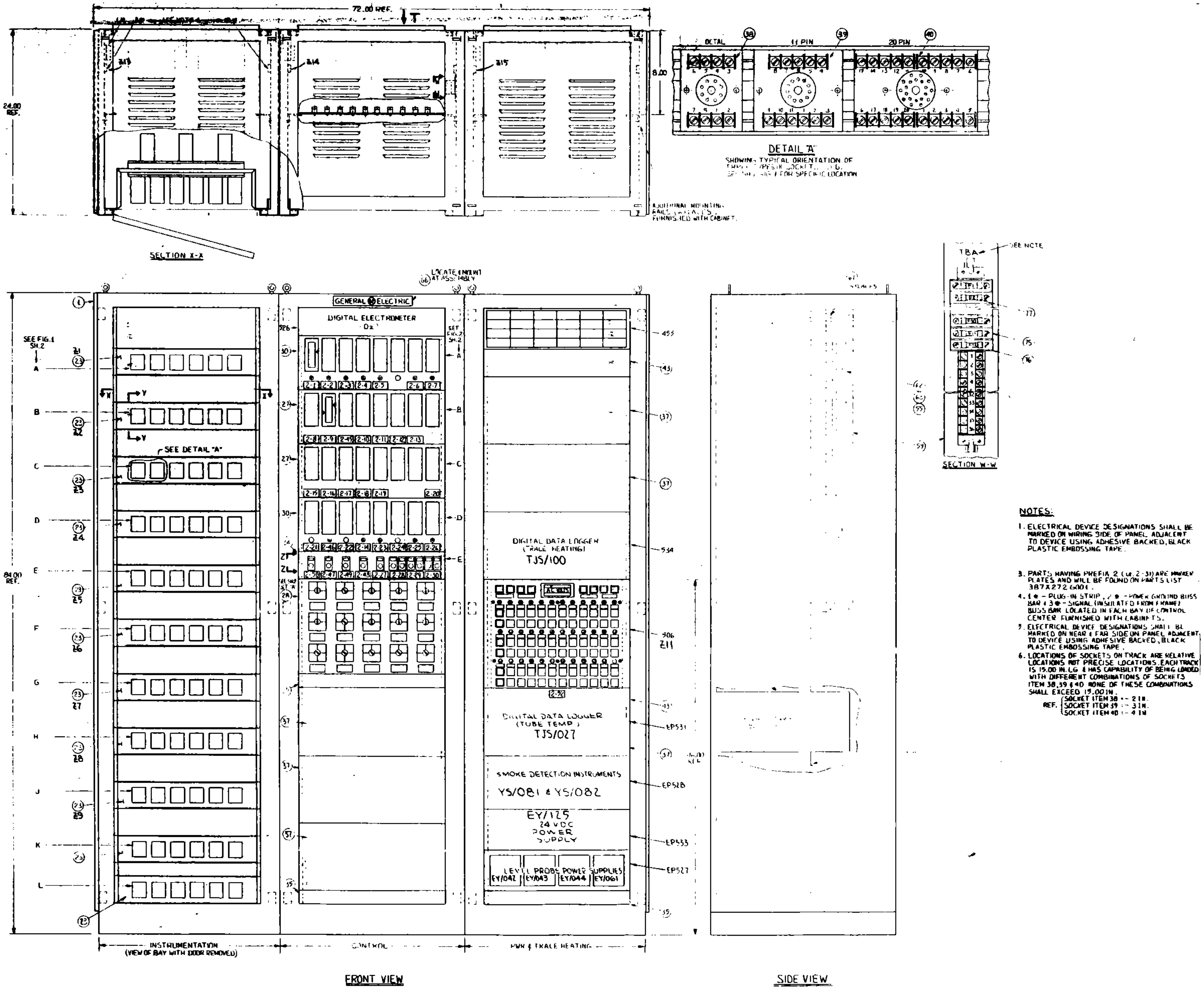


Figure 4-11. SRTA Control Center

- The major system disturbance anticipated during normal operation will be insolation transient on the panel due to passing clouds. An accurate method must be developed to measure insolation flux changes and derive a programmed flow signal from them.

The procedure being used for control system evaluation consists of: identification of candidate control algorithms, control simulation development and choice of preferred approvals, choice of system gains and stabilization valves, verification of preferred approval by simulation and analysis and evaluation of control system flexibility. For a complex, nonlinear development loop such as the SRTA, conventional linear control response and stability analysis procedures (Bode, Nyquist, etc.) are not applicable. System simulation of the loop and closed loop control is required in order to develop confidence in the control approach.

Results to Date

The original method of controlling flow does not appear adequate. This concept used a single flux sensor off to one side of the panel to indicate increasing or decreasing flux and then driving the pump up or down relative to the indication. Panel outlet header exit temperature was then used to fine tune the pump flow to maintain Na outlet temperature at 593°C (1100°F). The inability of this scheme to maintain the desired loop conditions is shown in Figures 4-12 through 4-14. Figure 4-12 is a plot of flux and flow versus time for a 120 second down transient; the flow tracking shown assumes an idealized case. Figure 4-13 shows that the average sodium exit temperature peaks 40 seconds after the conclusion of the transient. The high outlet temperature would signal the pump to increase flow, when in fact flow should be reduced to compensate for reduced insolation. The effects of flux and flow changes on panel center tube metal temperatures are shown on Figure 4-14.

The sensitivity of this scheme to loop flow rates is shown on Figures 4-15 through 4-17. These plots are based on 5% decrease of the initial insolation in 5 seconds. The control acts to restore the steady state temperature back to 1100°F: however, the response time is slow, almost 120 seconds at rated flow (Figure 4-15), some overshoot appears at 48% flow (Figure 4-16), and the response is unacceptably lightly damped at 16.8% flow (Figure 4-17).

Conclusion

Outlet header temperatures are not acceptable as a flow control parameter. Panel flux level changes must be incorporated as the primary flow control parameter. A fast and accurate method of measuring the flux changes must be incorporated into

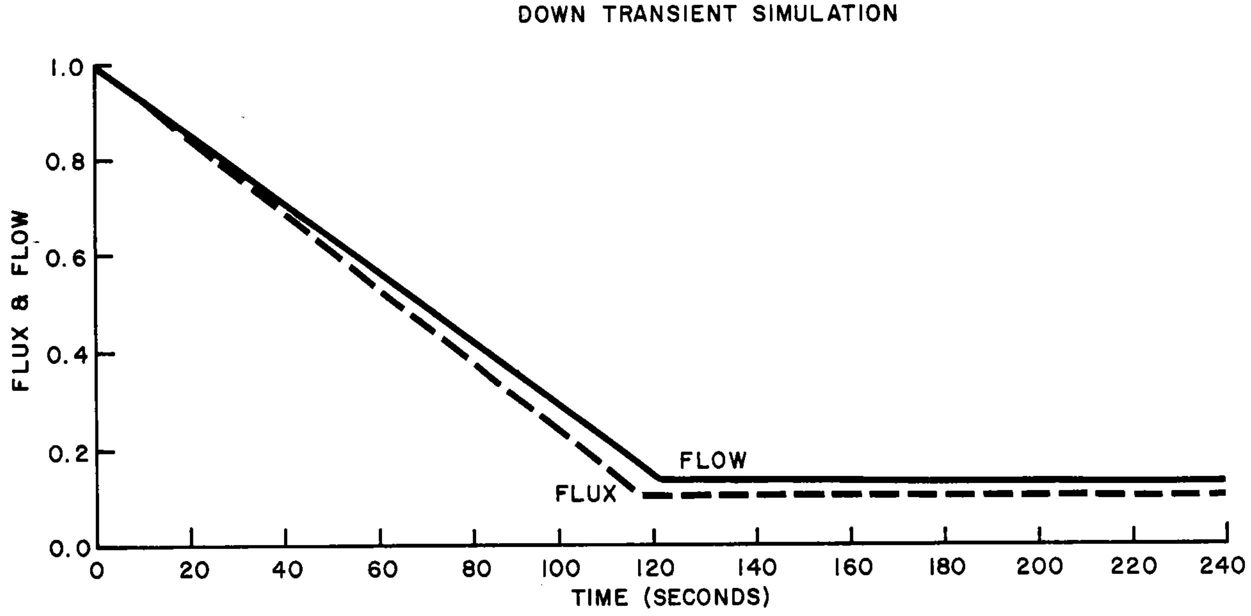


Figure 4-12. Flux Down Transient

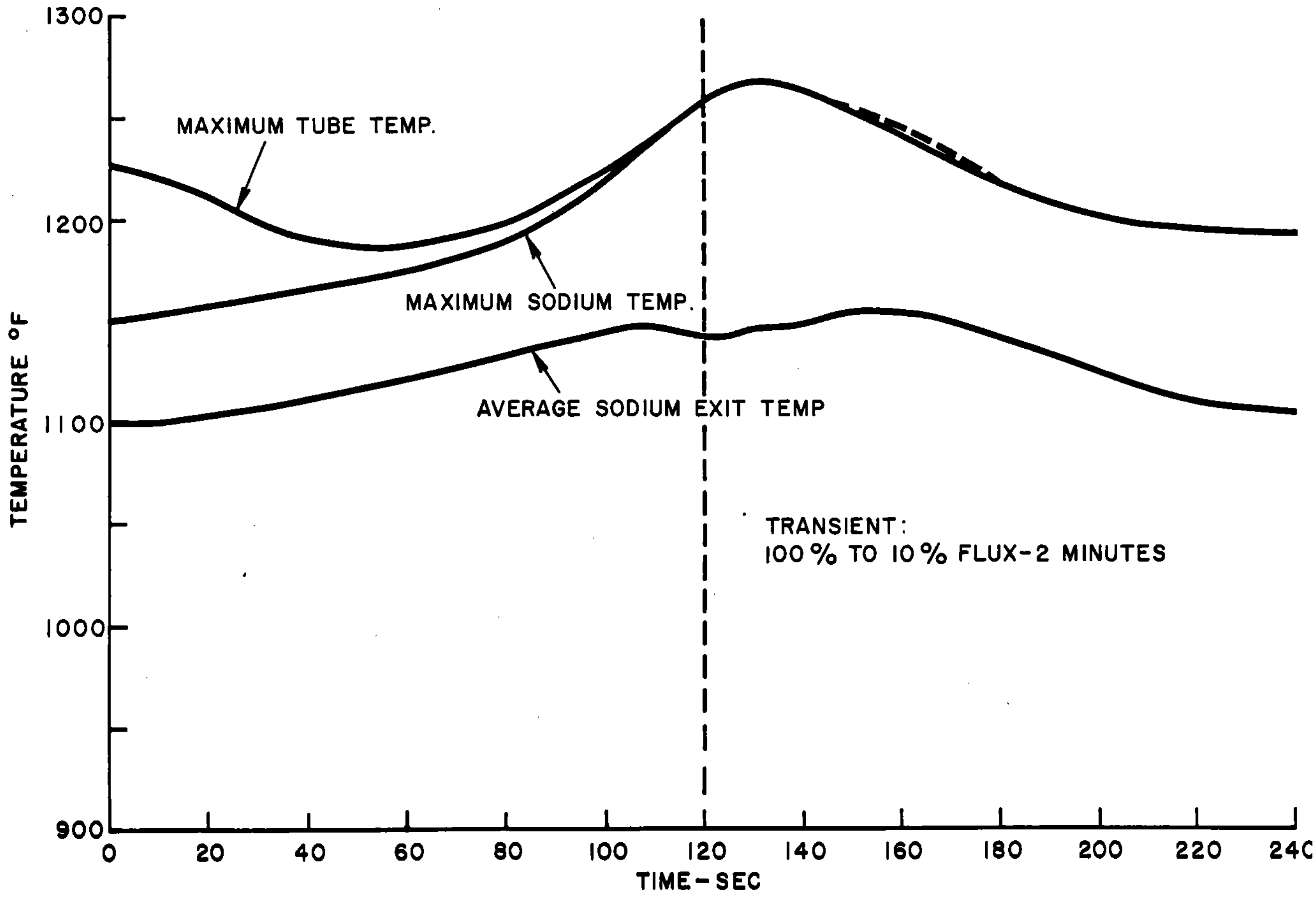


Figure 4-13. Power Down Transient Operation

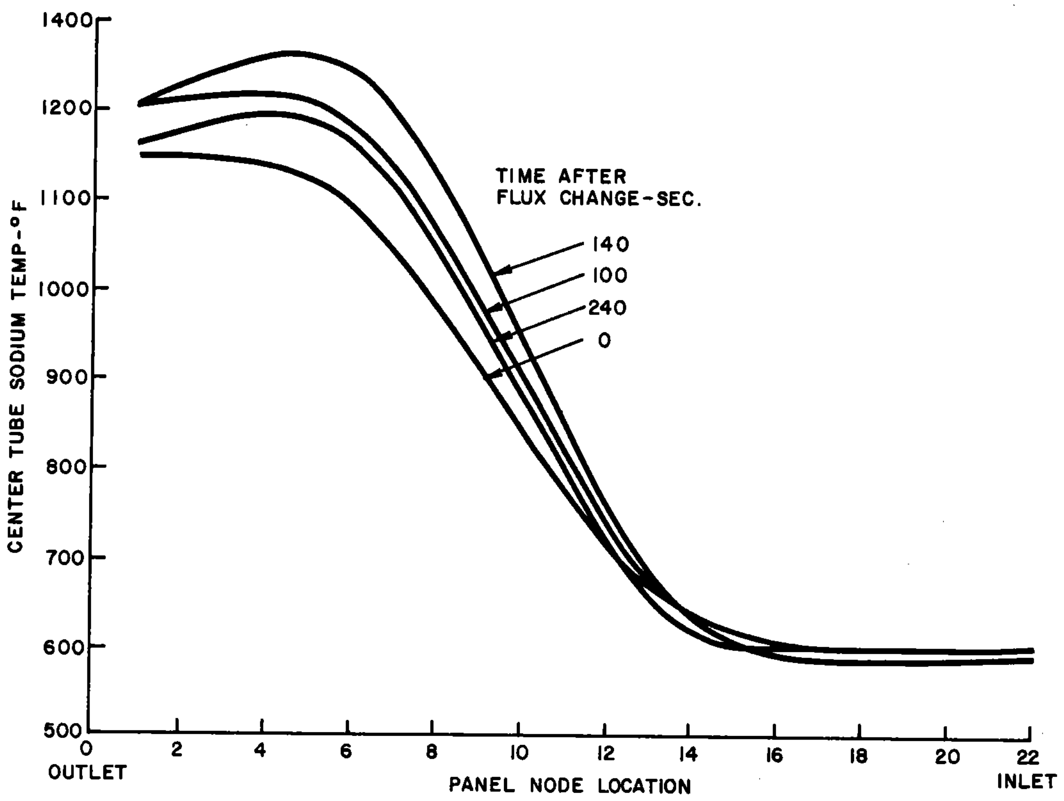


Figure 4-14. Power Down Transient Operation

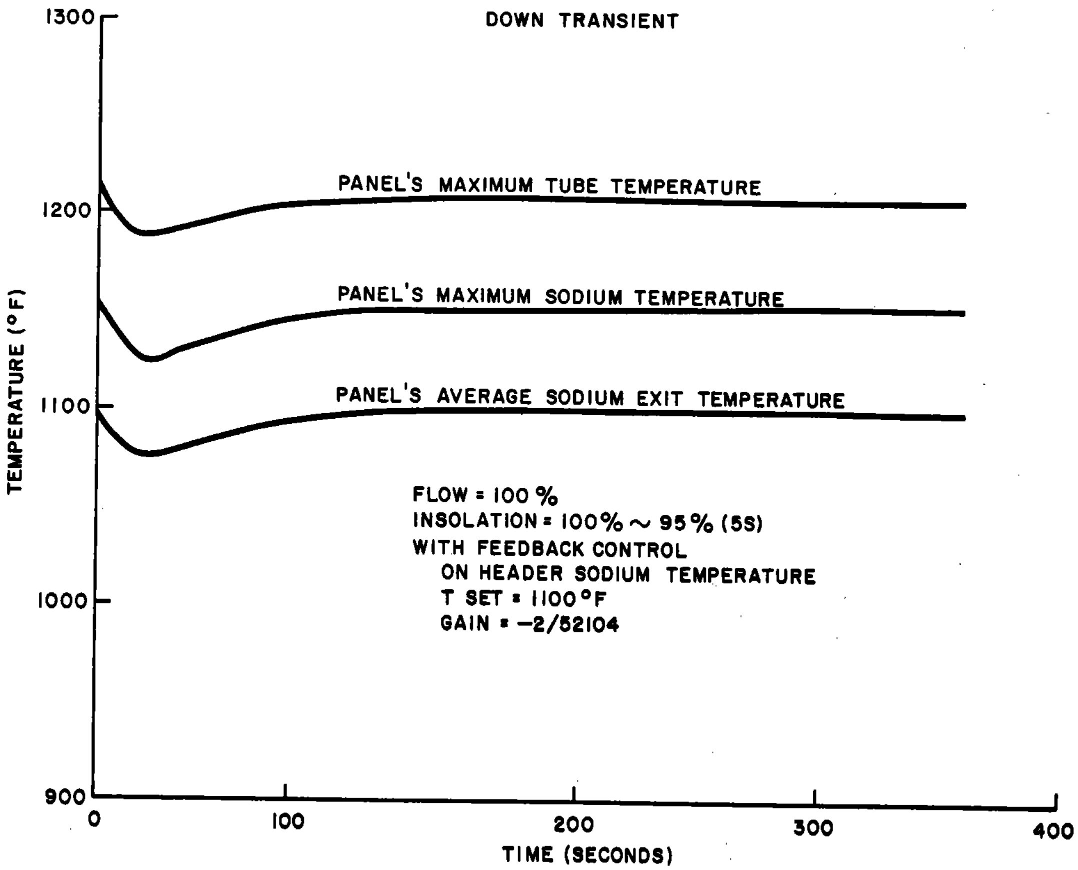


Figure 4-15. Full Flow Response to 5%, 5 Sec. Transient

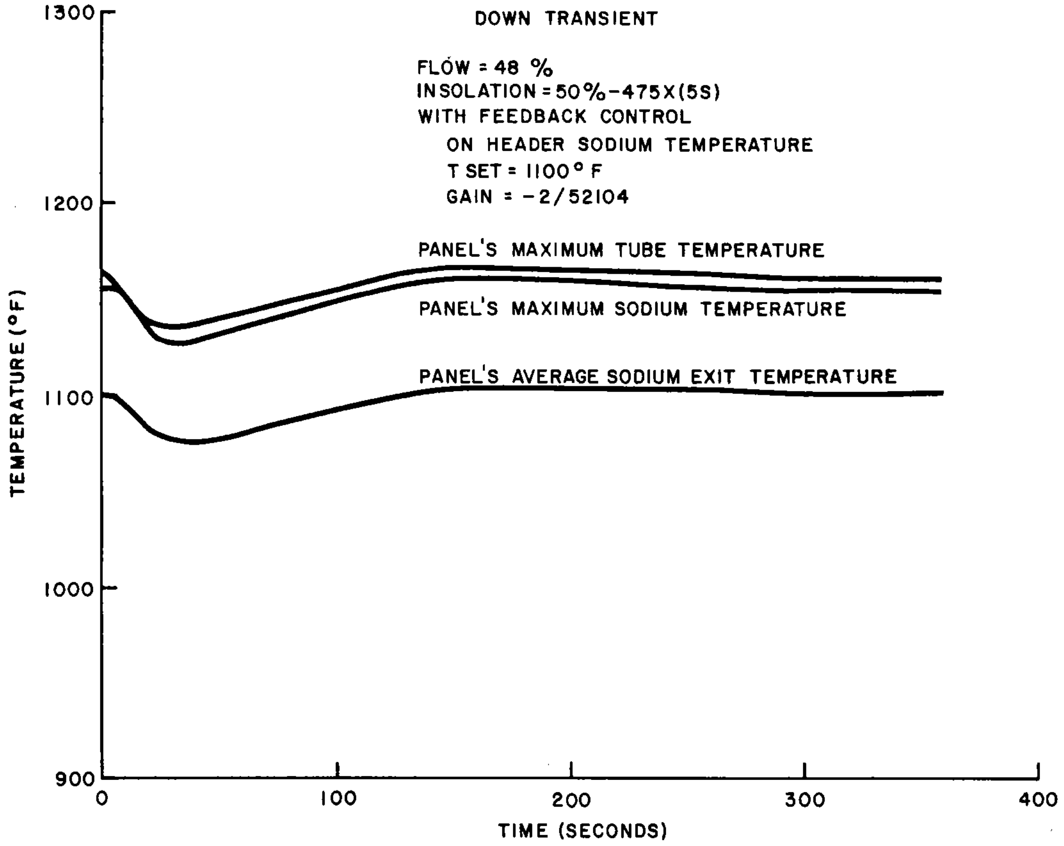


Figure 4-16. 48% Flow Response to 5%, 5 Sec. Transient

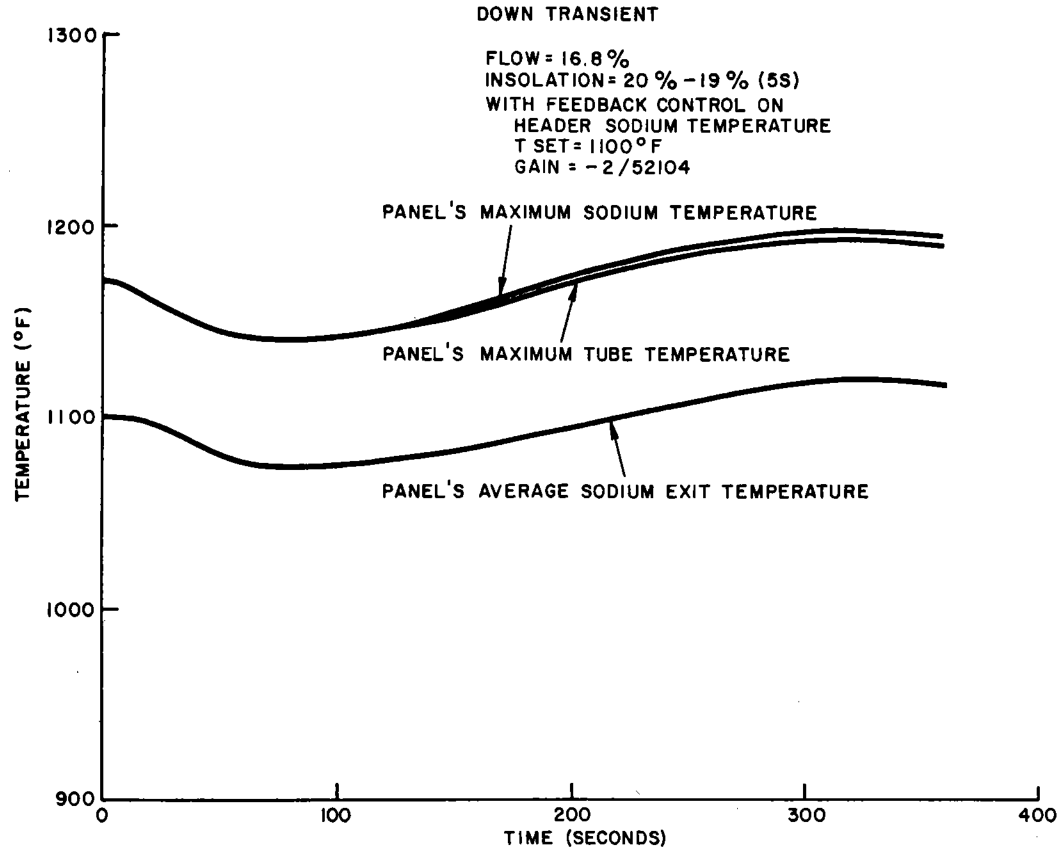


Figure 4-17. 16.8% Flow Response to 5%, 5 Sec. Transient

the control scheme. A single flux sensor provides only quantitative data relative to the flux level on the panel and in fact could conceivably give erroneous reading due to its location in the outer edge of the solar beam.

The use of the 18 thermocouples embedded in the panel tube spacer strips to provide fast and accurate data on flux changes is being investigated. Preliminary results indicate that a workable control scheme can be implemented using this approach.

4.9.2 COMPONENT TRANSIENT RESPONSE

To study the severity of the thermal transient on sodium components, a simple analytical model was constructed as shown schematically in Figure 4-18. The General Electric code GENCON was used in this analysis.

GENCON is a FORTRAN computer code which calculates transient temperatures and flows in a liquid metal heat transfer system, such as in a Liquid Metal Fast Breeder Reactor (LMFBR). The code is particularly suited to the analysis of an LMFBR after reactor shutdown when flow is produced mainly by natural convection.

Operation of GENCON is through a timesharing system, with detailed printout available on the batch system. Data is read from a simple input file, with the capability of accommodating relatively complicated piping systems, including brached flow. The following simplifying assumptions are made in the analysis in order to keep the input file simple and to minimize the calculation cost.

- Flow resistance is defined as a constant for each section of the system rather than for individual components that make up the section, with friction pressure drop proportional to flow squared.
- Average liquid density, thermal expansion coefficient, and heat capacity are assumed to be independent of temperature.
- Heat capacities of pipes and other components are accounted for, but with no time lag.
- Flow inertia is neglected (normally negligible at very low flow rates).

The following events have been studied to date:

- Cuts of heliostats from an initial full power equilibrium condition.
  - a) With normal EM pump rundown to minimum flow
  - b) With a trip of the EM pump
  - c) With various panel losses
- Loss of EM pump and failure of the heliostats to cut off
- Studies of a realistic large rapidly moving cloud.
- Studies of the 1 MW/min transient specified in Appendix A.

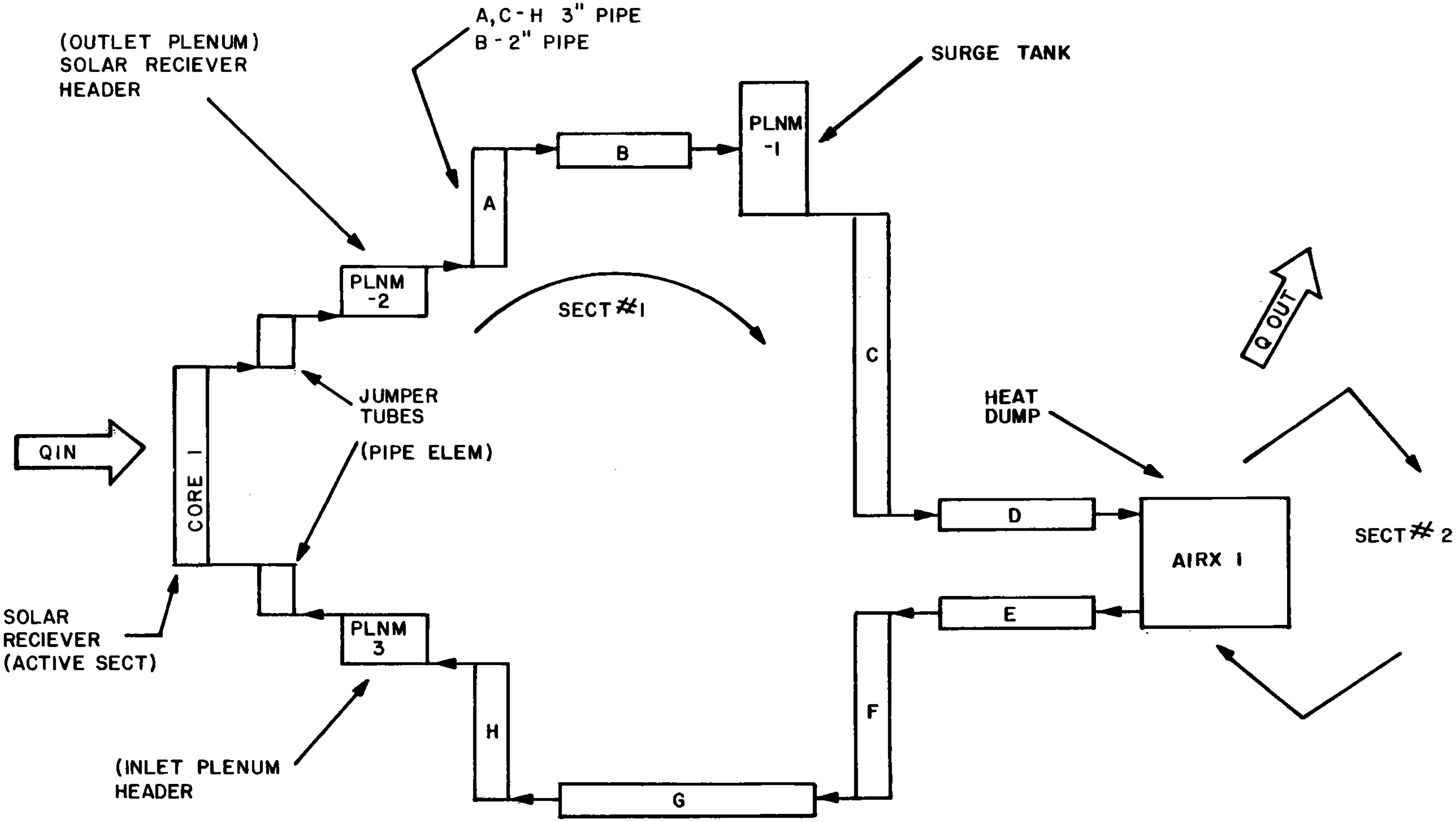


Figure 4-18. Loop Analysis Model

The preliminary analysis indicates that anticipated transients will not adversely affect the sodium loop components. As indicated in Section 4.9.1, the test panel transient response is still under investigation.

4.10 SODIUM TANKS

Calculations were made in accordance with the requirements of ASME B&PV Code Section VIII, Division 1, to justify the design of the drain tank and the surge tank for a 50 psig design pressure at a design temperature of 1150°F. In addition to the basic code calculations, design calculations were made for tank mounting and overpressure protection.

SECTION 5

SODIUM LOOP FABRICATION

This section describes the fabrication status and assembly plan for the sodium loop equipment including the procurement and refurbishment of the SEFOR hardware.

5.1 BACKGROUND

In early April 1979 the General Electric Company, along with other organizations, was notified by the University of Arkansas of the intent to sell certain sodium loop equipment formerly used during operation of the Southwest Experimental Fast Oxide Reactor (SEFOR) experimental liquid metal breeder plant. The equipment was designed to the appropriate ASME Codes and fabricated from 304 SS. The General Electric Company had first-hand knowledge of this equipment since the Company was the prime contractor and plant operator in the late 1960's and early 1970's. It was immediately apparent by a review of the equipment list that much of the equipment associated with SEFOR secondary sodium system was of use in the Sodium Receiver Test Assembly (SRTA).

GE engineers visited the facility in April 1979 and examined the items of equipment that the University offered for sale. The result of the examination indicated that most of the equipment was in excellent condition and several key components were of the size and performance rating required of the SRTA. A subsequent evaluation of cost savings and risk was performed to arrive at a justifiable and realistic bid price. The equipment was subsequently purchased. The components purchased are identified in Table 5-1 and will be used as shown on the loop schematic shown in Figure 5-1.

The purchase of the equipment was made at the SEFOR site in July. Removal of equipment was initiated in mid-July 1979. All major sodium components were cut out of the loop and set on pallets. A hydraulic crane was used to pick up and separate the three major sections of the heat dump and remove sodium tanks and the EM pump stator from the inside of the building. The equipment was delivered to the GE San Jose, CA site in September 1979.

Table 5-1

SEFOR EQUIPMENT LIST

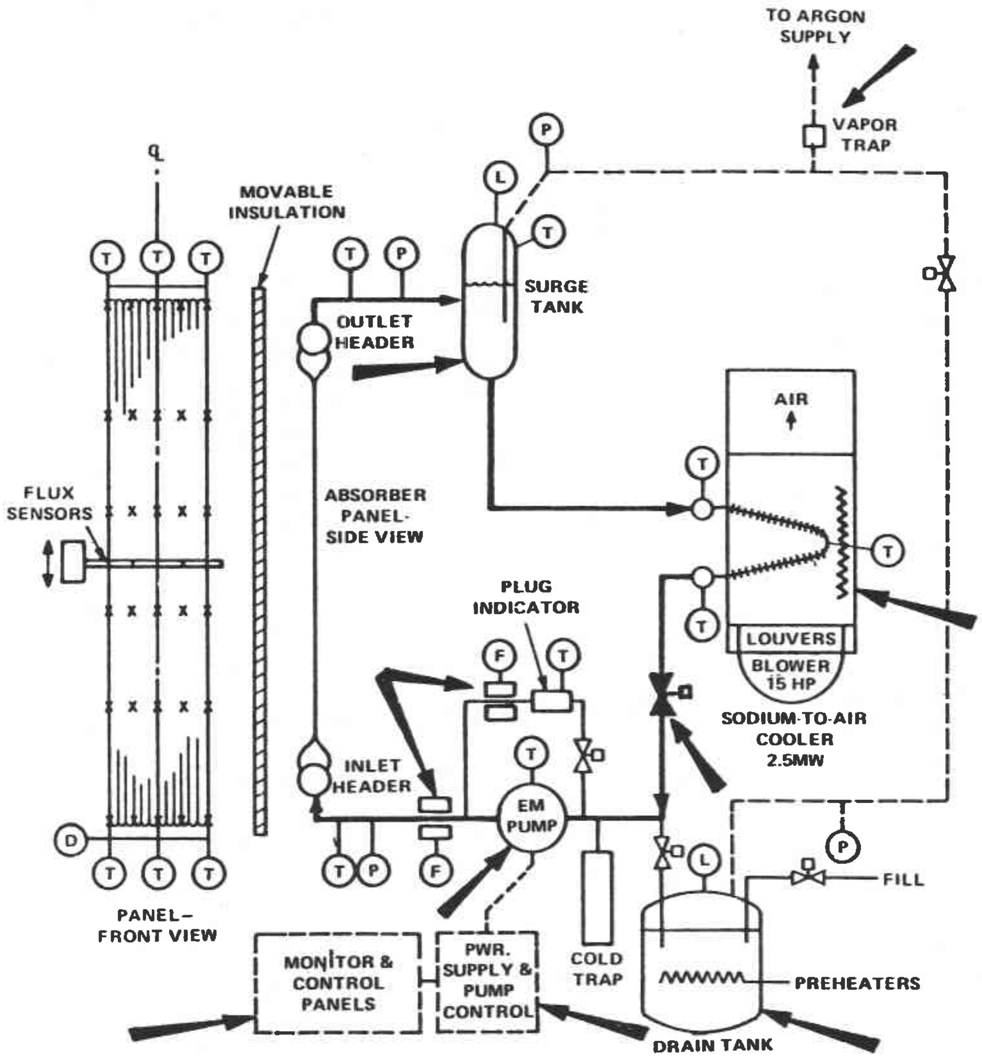
Item	Quantity
2.5 MW_t Heat Dump	1
250 gpm Electromagnetic Pump	1
EM Pump Blower	1
EM Pump Controller/Capacitors	1
EM Flowmeter 3"-250 gpm	2
3" 304 SS Pipe	80'
75 Gal. Sodium Storage Tank	1
450 Gal. Sodium Storage Tank	1
Trace Heater Power Supplies & Controllers	-
Piping Hangers and Snubbers	-
2" Pneumatic & Motor Operated Valves	5
2" Manually Operated Valves	2
1" Sodium Valves	2
Vapor Trap	1

A brief description of the equipment and refurbishment performed in contained in the following paragraphs.

5.2 HEAT DUMP

The auxiliary air blast cooler (heat dump) was stationed outside the SEFOR building, the only piece of equipment not under cover. Photographs of the heat dump SEFOR removal process are provided in Figure 5-2.

The heat dump consists of a finned tube heat exchanger, support structure, controlled dampers, two fans, trace heaters, air operated isolation doors and controls. The unit was removed and the coil successfully cleaned and hydrotested at the site. The structure was wire brushed, cleaned, and repainted with Rustoleum primer and top coat. After arrival at San Jose the actuators and louvers were refurbished. The isolation doors were badly rusted and the insulation within the doors had deteriorated. The doors were completely refurbished with new metal plate and insulation. The heat dump controls were checked and a new louver operating motor was installed.



MAJOR COMPONENTS

PANEL (FW)
STRUCTURE
DOOR
- PIPING LOOP/SUPPORTS
- DRAIN TANK
- SURGE TANK
- EM PUMP
- FLOW METERS
- Na VALVES

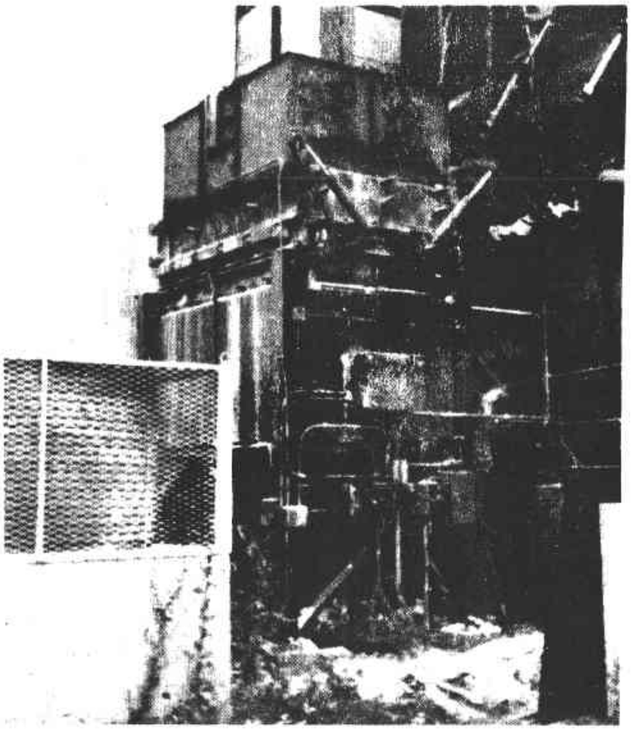
COLD TRAP
PLUGGING IND
- VAPOR TRAP

ARGON SUPPLY
- HEAT DUMP

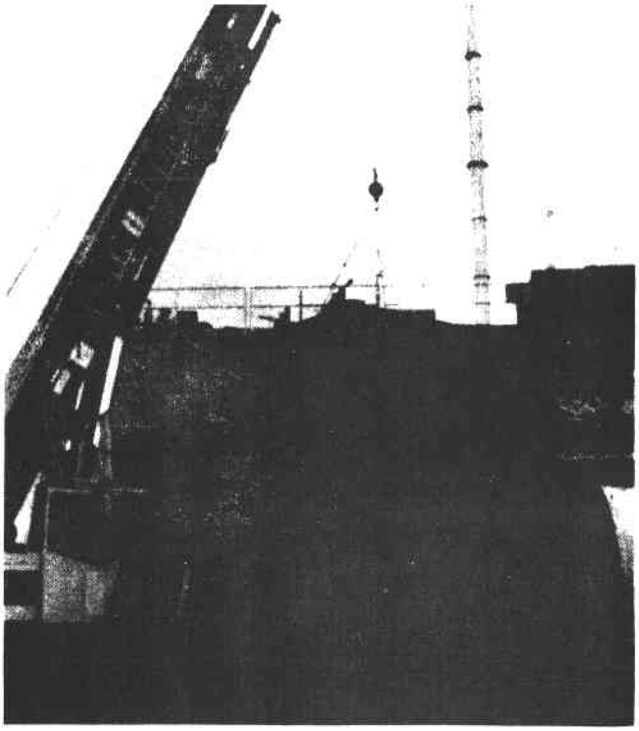
INSTRUMENTATION
ELECTRICAL
- TRACE HEATING - CONTROLS

SAFETY SYSTEM

Figure 5-1. SRTA Schematic Shwoing SEFOR Equipment

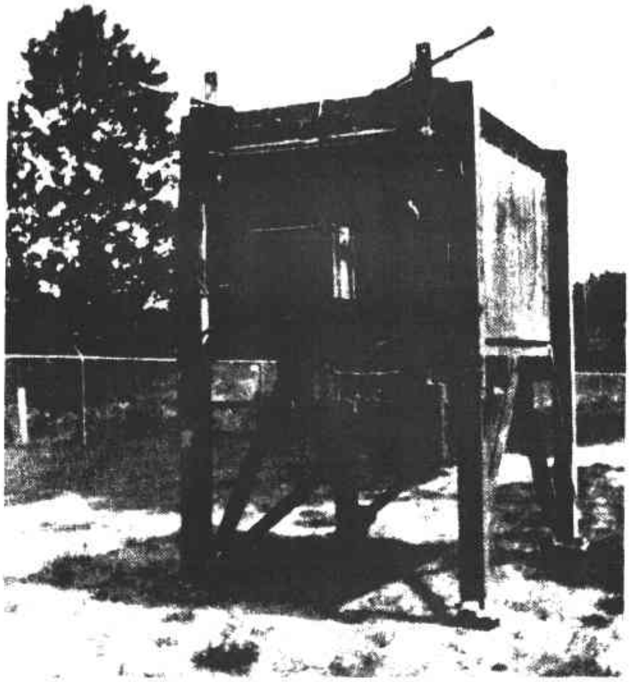


Heat Dump Being Disassembled



45 ton Crane Removing Lower Section of Heat Dump

Heat Dump Coil and Isolation Doors



Lower Section, Blowers and Louvers

Figure 5-2. Heat Dump Disassembly at the SEFOR Site

The heat dump coil was helium mass spectrometer leak checked at the San Jose facility. Five very small leaks were detected in the header welds. The size of the leaks were determined to be not greater than 3 cc's of helium a year. The leaks were repaired by weld buildup and a subsequent helium leak test was performed.

Concern existed with respect to the heat transfer performance of the finned tube heat dump coil since considerable rust existed on the carbon steel fins. As discussed in Section 4, the coil is being replaced after analysis results indicated an unacceptable heat transfer capacity. A new coil has been ordered from Voss Finned Tube Products, Medina, Ohio. A modification in the design has been made to provide a brazed fin/tube to prevent rusting of the heat transfer path from the fin to the tube. Larger trace heaters will also be installed.

A photo of the disassembled refurbished heat dump exclusive of the coil was shown in Figure 1-8.

5.3 ELECTROMAGNETIC PUMP & SUPPORT EQUIPMENT

The auxiliary secondary EM pump acquired from SEFOR is a helical induction pump designed and built by General Electric. The pump was located inside the SEFOR building and had been inerted since SEFOR plant closedown. The stator, duct, and pump support equipment were shipped to San Jose after cleaning of the pump duct at the site. The pump duct upon arrival at San Jose was successfully hydrotested to 225 psi. The stator was given an electrical check, baked out, and is considered in excellent condition. The cooling blower and controllers were also checked out satisfactorily. A 60 and 90 KVA power supply was obtained from the SEFOR site. The 90 KVA supply is to be used in the SRTA. Photographs of the EM pump duct and stator are shown in Figures 5-3 and 5-4.

5.3.1 EM FLOWMETERS

Two General Electric designed 250 gpm, 7.5 cm, (3 inch) electromagnetic flowmeters were obtained. No significant refurbishment was required.

5.3.2 PIPING

24 meters (80 ft.) of 7.5 cm (3 inch) piping was cut out of the SEFOR loop and alcohol/water cleaned prior to shipment to San Jose; however, new piping is being used in most areas of the SRTA loop, with the SEFOR piping retained as spare supplies. A typical piping isometric is shown in Figure 5-5.

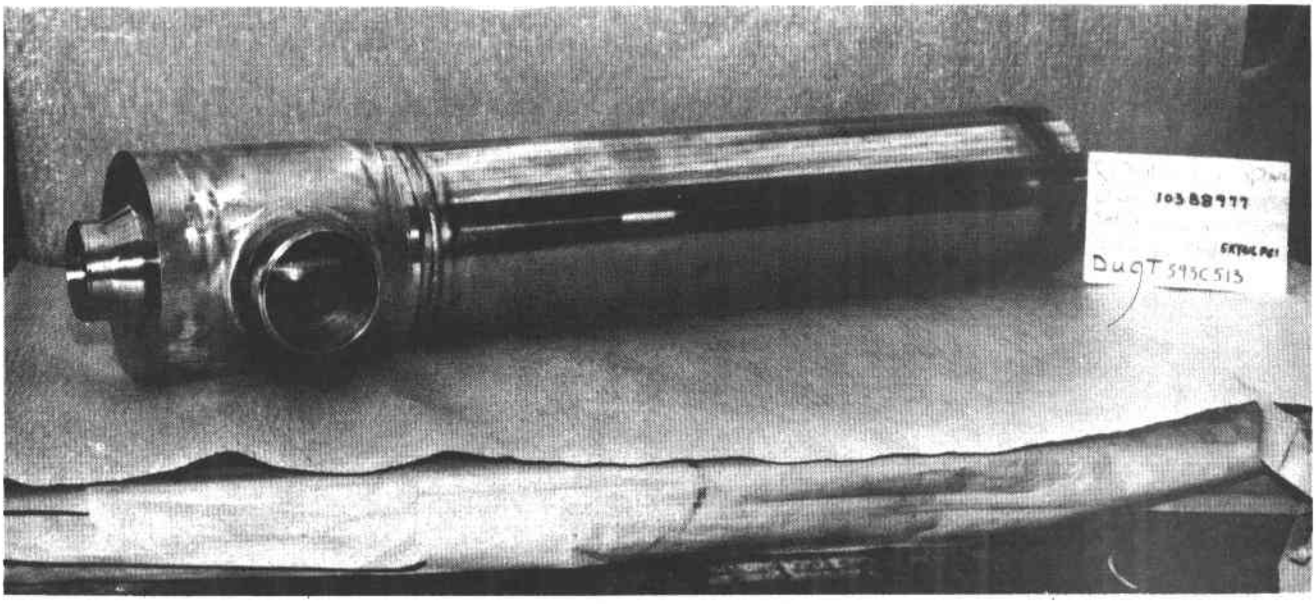


Figure 5-3. EM Pump Duct

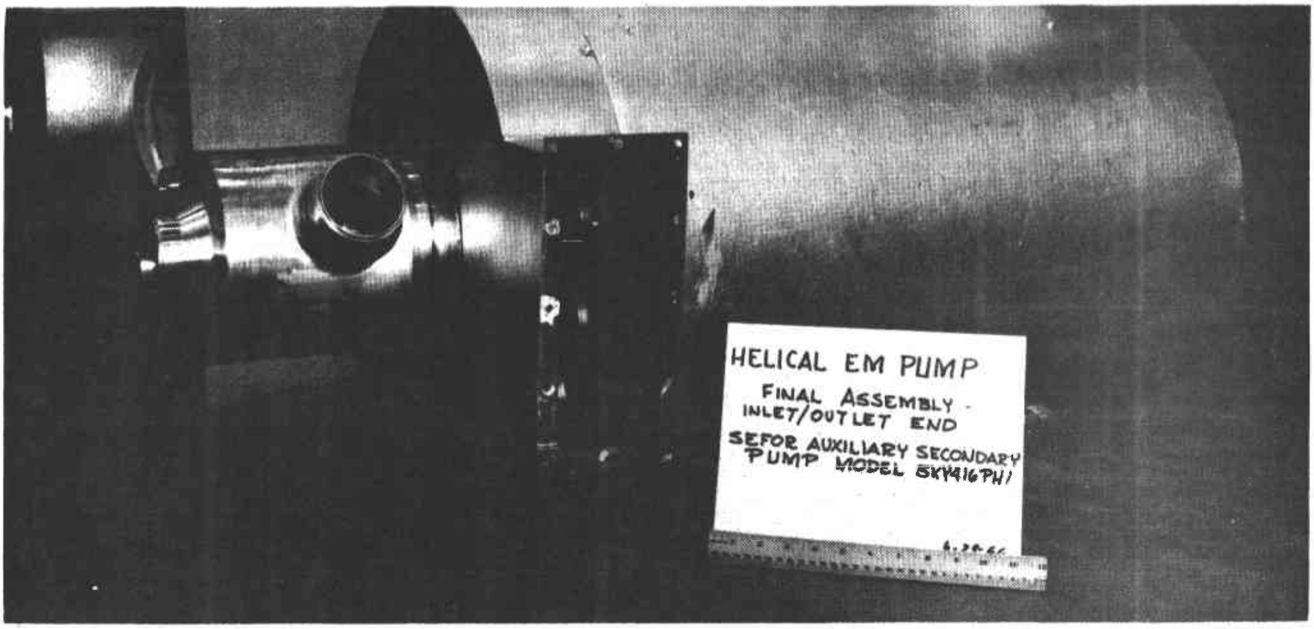


Figure 5-4. EM Pump Stator with Duct Inside

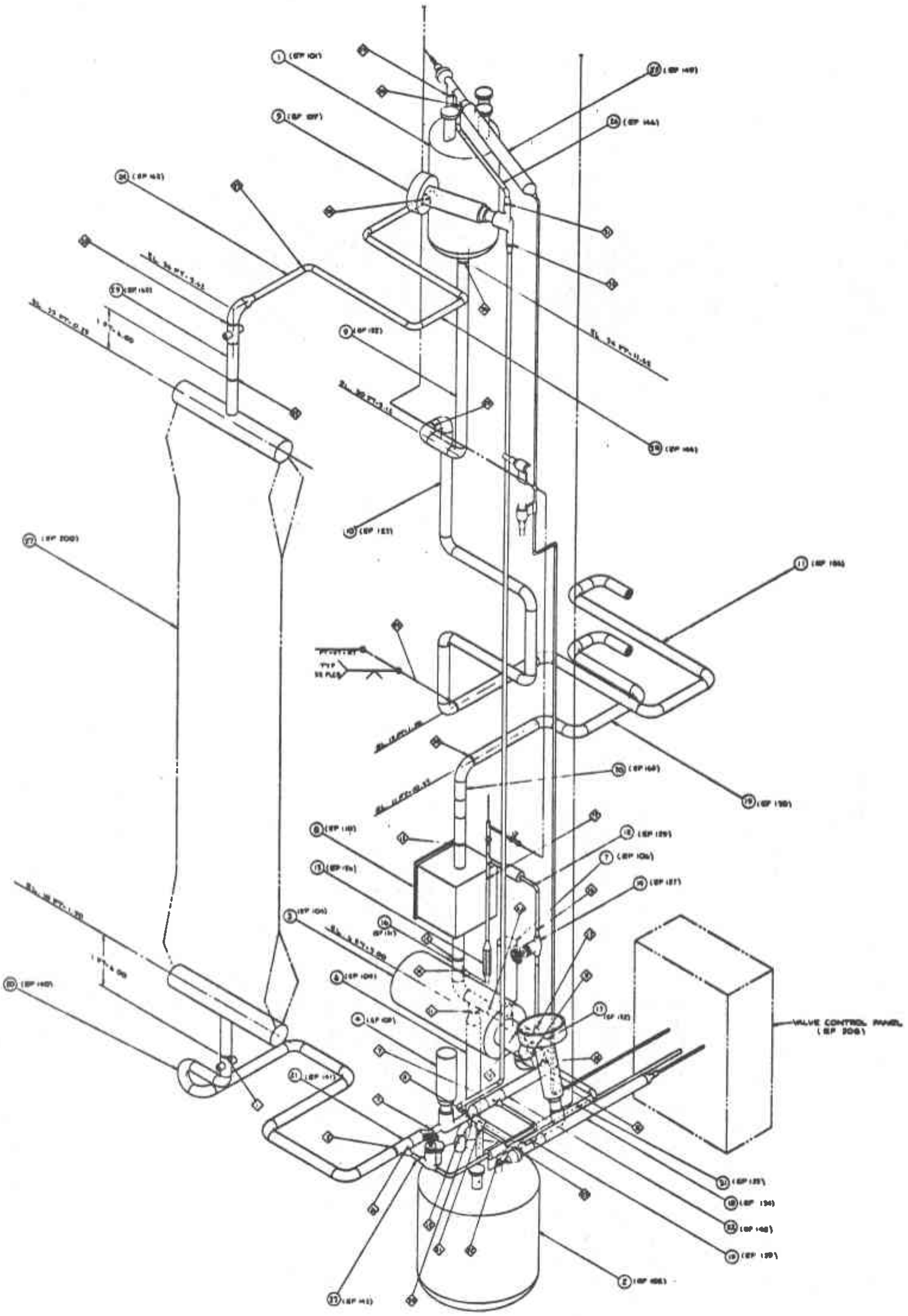


Figure 5-5. Piping Isometric

5.4 SODIUM TANKS

A 285 liter (75 gallon) auxiliary expansion tank and a 1640 liter (450 gallon) main secondary expansion tank were made available for the SRTA from SEFOR. The 75 gallon 304 SS tank, designed to Section VIII of the ASME Code, is 0.6 m (2 ft.) in diameter and 1.1 m (3 ft.-8 in.) high. The vessel has nozzles for cover gas sampling and level indicators in the upper head. This vessel was drained and has been kept inerted since SEFOR operation. Prior to shipment to San Jose, it was alcohol/water cleaned and hydrotested at 210 psi.

The smaller tank is being used as the surge tank at the top of the SRTA loop. Modifications have been completed which included (1) removal of two 1-inch nozzles and replacement with 3-inch nozzles for tank inlet and outlet, (2) dye check and repair of all welds, (3) modification of support legs, and (4) modification of level probes. After these modifications the tank closing seam weld was made, and a leak test and hydrostatic test performed.

The larger tank will be used as the sodium drain tank. This tank was cut open and 0.95m (38 inches) was removed from the shell to reduce the volume from 450 gallons to 234 gallons. Minor modifications were made to the nozzles and the level probes were shortened. A dip tube was installed to be used in sodium filling. The legs were shortened. Weld dye checks and repairs were made, where required. The tank was cleaned and hydrotested after the closing seam was made and radiographed.

5.5 TRACE HEATER EQUIPMENT

The SEFOR auxiliary secondary loop was provided with electrical tubular-type resistance heaters on all piping and components containing sodium. Each functional circuit was provided with a preheater system which could be turned on or off as required. Manual controllers with auto-transformers (volt packs) were used. This equipment was all enclosed and in good working order and was removed and shipped to San Jose for use on SRTA.

5.6 PIPING HANGERS AND SNUBBERS

A number of pipe hangers and snubbers were on the SEFOR auxiliary secondary loop. This hardware was removed and shipped to San Jose and is being selectively used in the assembly of the SRTA loop piping components.

5.7 SODIUM VALVES

Several 2-inch and 1-inch sodium globe valves were available at SEFOR. The valves removed from the site included the following:

2 - 2-inch manual operated sodium valves
3 - 2-inch pneumatic operated sodium valves
2 - 2-inch motor operated sodium valves
2 - 1-inch manual operated sodium valves

These valves have stellite seats and forged 304 SS bodies. A bellows stem seal with a back-up braided asbestos packing provides sodium isolation.

Alcohol/water cleaning was done at the site and again at the San Jose facility. Cleaning was followed by a test of the bellows stem seal per manufacturer's instructions and a helium mass spectrometer leak test of the bellows-to-stem seal and valve closure. A photograph of one of the 2-inch penumatic operated valves is shown in Figure 5-6.

5.8 SRTA MANUFACTURING & ASSEMBLY

The Sodium Receiver Test Assembly (SRTA) sodium loop and structure is being fabricated and assembled at General Electric's facilities in San Jose, CA. As shown in Figure 5-7, the present assembly plan specifies a delivery of the SRTA (exclusive of the absorber panel assembly) to the CRTF site in September 1980.

The 40-foot high structure was fabricated by a local structural steel vendor in December. The structure was cut in two parts to simplify erection in the high bay assembly area and provide a better transportation configuration for shipment to the CRTF. The erected structure, prior to component installation, was shown in Figure 1-7.

Platforms and ladders have been fabricated and installed on the structure to provide access to the loop during assembly and for maintenance and operation at the CRTF. As noted on the schedule, the final enclosure is made at the CRTF.

The surge and drain tanks have been installed in the structure. The loop piping consists of over 20 separate spool pieces that interconnect components and the panel. These spool pieces (3, 2, and 1-inch 304 SS piping and fittings) are presently being fabricated in the General Electric San Jose shop and are being assembled in a pre-established sequence in the structure. An isometric of the EM pump outlet piping was shown in Figure 5-5. All sodium contained welds are being radiographed and dye penetrant inspected. Due to the sequence of assembly, some

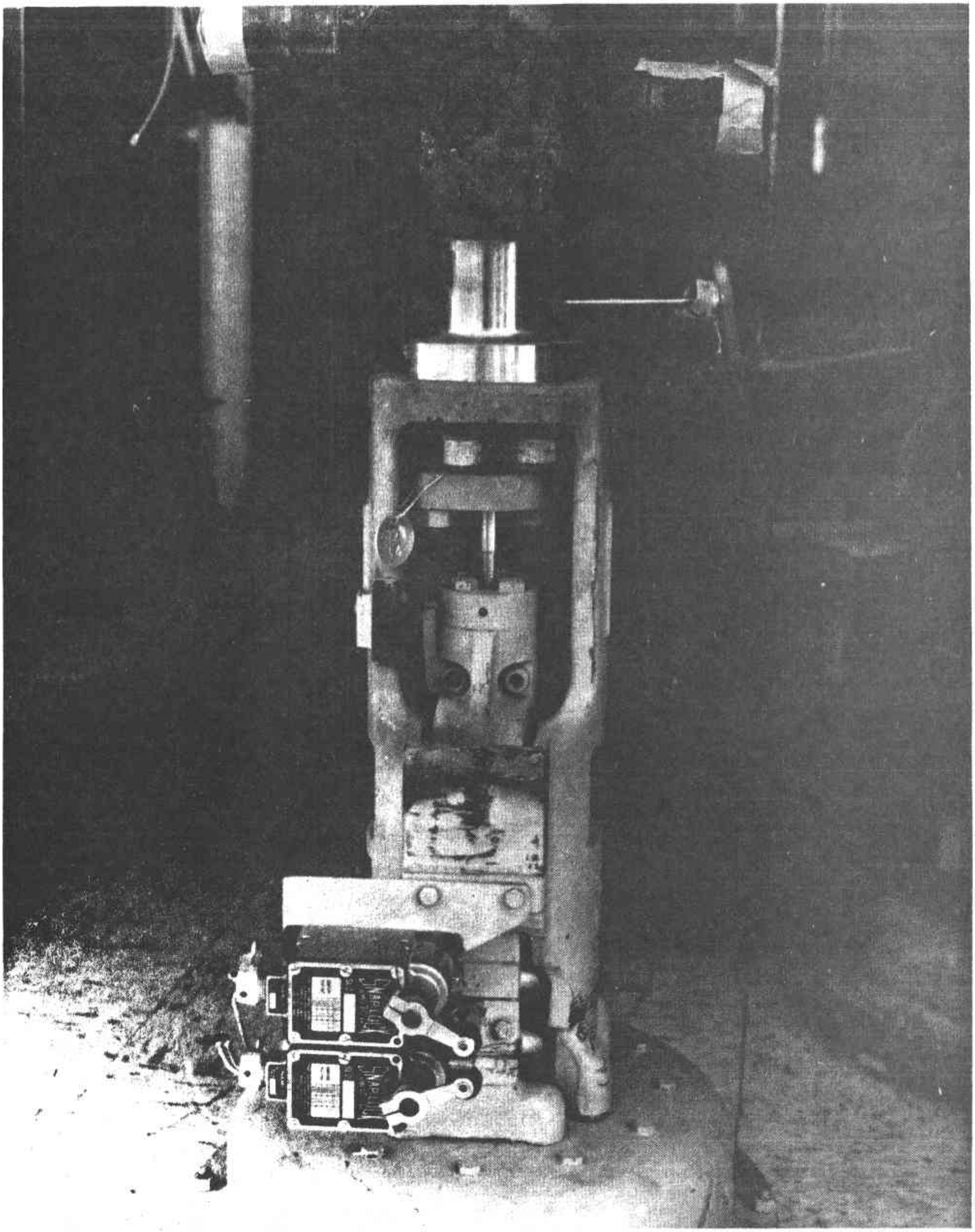


Figure 5-6. 2-Inch Pneumatic Operated Valve

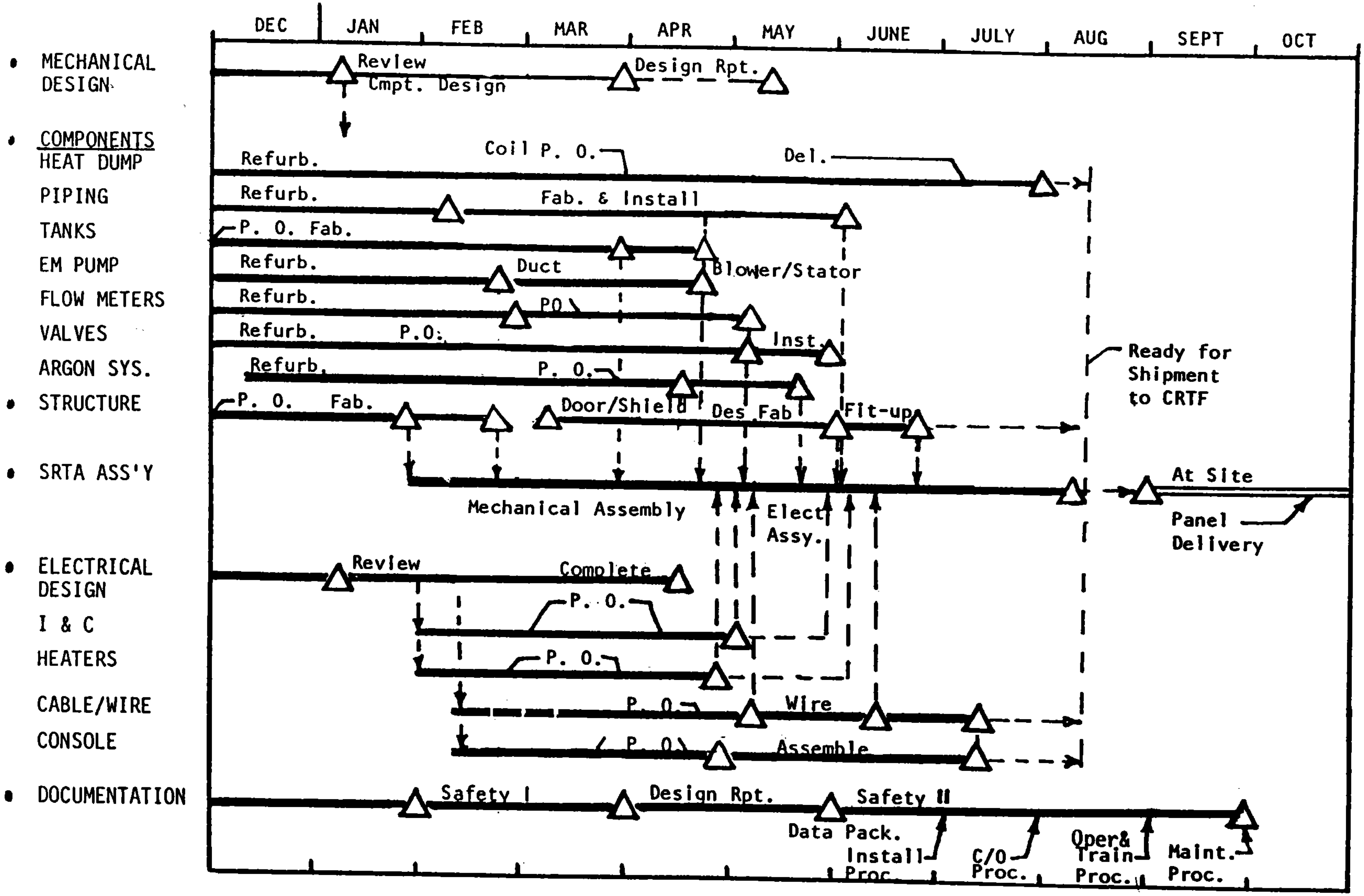


Figure 5-7. SRTA Assembly Schedule

interconnecting welds will be made at CRTF (e.g., connections to the absorber panel, heat dump, and the two sections of the structure).

Additional loop components to be fabricated include a cold trap, vapor trap, sodium pressure gages, and the argon cover gas/relief system. These components are scheduled for fabrication in May 1980.

After assembly of piping and components, trace heaters will be installed on the entire loop. Loop instrumentation will be installed followed by insulation of the loop and components. This activity is scheduled for the months of May and June. Loop wiring will be accomplished after the insulation has been installed.

During the assembly of the loop, appropriate component and piping hangers and snubbers are being attached to maintain allowable pipe stresses as supported by a piping analysis.

Assembly of a 3 bay electrical control console is being initiated and is planned for completion in mid-summer. All of the electrical components for the console have been ordered.

Several components are scheduled for fabrication in May and June but will not be permanently assembled to the structure in San Jose, but will be shipped separately to the CRTF for assembly there. In some instances (i.e., door and hangers) fit up checks will be made in San Jose but the components will be removed from the assembly for separate shipment.

The SRTA structure and assembled loop will be shipped in two major sections to facilitate handling and shipping. The lower structure contains the bulk of the loop components including the drain tank, cold trap, EM pump, flowmeters, oxygen meters, and most valving. It is designed for shipment in the vertical position to reduce the donnage and special fixturing required. The oxygen meters and level probes will be removed from the unit for separate shipment due to their fragility.

The longer upper SRTA structure will be shipped horizontally. It contains the surge tank, a vapor trap, the pressure relief system, door drive unit, and considerable loop piping. The level probes will be removed from the surge tank for separate shipment.

Several mechanical components are scheduled for installation at the CRTF. The sleeper beams for both the SRTA structure and the heat dump and their respective sodium catch pans will be fabricated by a structural steel contractor for delivery to the CRTF in September 1980.

Initial activity at CRTF will begin sometime after September 1, 1980. The work will be performed on a lift platform inside the tower. The major tasks will be unloading and inspection of SRTA subassemblies, assembly of SRTA structure on the sleeper beams, installation of connecting piping, preheaters and insulation as appropriate, installation of pipe hangers, and connection of power cabling. The SRTA assembly will then be moved out of the tower to allow for lowering and removal of the Martin Marietta receiver. Framework for the solar shield will be provided for mounting of the insulation by CRTF personnel.

The absorber panel will arrive in October 1980. After receiving inspection it will be instrumented and readied for integration into the SRTA.

The GE local control panel will be moved into the computer level of the module and the elevating module lowered to allow for installation of equipment on the elevator module top. The heat dump, electrical power supply and SRTA structural assembly will then be mounted to the module top. The absorber panel will be mounted to the structure and the final welding and inspection of the sodium piping will be completed. Following this, the remaining preheaters and loop insulation will be installed. The installation of the solar shield, insulating door, cabling and SRTA siding will complete this activity.

SECTION 6

PRELIMINARY TEST PLAN

The general objectives of the SRTA experiment were described in Section 1. They formed the fundamental basis for preparation of a plan for the testing at the Central Receiver Test Facility (CRTF). The Preliminary Test Plan issued in February 1980 will be summarized in this section.

6.1 TEST OVERVIEW

The general objectives discussed in Section 1 were used to specify what items the SRTA experiment must demonstrate or verify and what measurements are required, specifically:

Demonstrate

- Manufacturability of Panel
- Safety and Reliability of Sodium Systems

Verify

- SRTA Compliance with Development Specification

Measure

- Panel Efficiency
- Radiation and Convective Losses
- Reflective Losses
- Thermally Induced Strains

The satisfactory completion of the test program will demonstrate the manufacturability of the absorber panel and the safety/reliability of sodium systems.

The test program will provide the necessary data for verification of performance requirements defined in Paragraph 4.3 of the SRTA development specification (Appendix A) and also provide measurement of panel efficiency, losses, and thermally induced strains. The synthesis of these data requirements into a minimum number of tests is shown on the following page:

SRTA Requirement	Tests
• Flux Handling • Inlet Temperature Control • Outlet Temperature Control • Startup/Operation/Shutdown Emergency Dump	• Startup/Shutdown & Transient Characterization
• Heat Dissipation • Piping Pressure Drop	• Normal Operation
• EM Pump Control • Heat Dump Control	• High Flux
• Panel Loss Characterization	• Radiation & Convection Loss
• Thermally Induced Strains	• Reflection Loss

The resultant five tests constitute the performance testing of the SRTA. Instrumentation to be provided in the SRTA was described in detail in earlier sections. Table 6-1 provides a tabulation of instrumentation used for test data acquisition.

Table 6-1

SRTA TEST DATA ACQUISITION

PARAMETER	INSTRUMENTATION	ACCURACY
Incident Flux	RTAF	4%
Front Surface Panel Temperature	Thermocouple	TBD
Back Surface Panel Temperature	Thermocouple	1%
Sodium ΔT	Platnium RTD	1%
Sodium Flow	Flow Meter	1.5%
Panel Strain	BLH Strain Gauge	TBD
Panel Expansion	Linear Variable Differential Transformer	2%
Ambient Temperatures	CRTF Weather Station	1%
Wind Speed	CRTF Weather Station	2%

6.2 DESCRIPTIONS OF MAJOR TESTS

This section provides descriptions of the general characteristics of SRTA test matrices and discusses each of the five major tests.

GENERALIZED TEST MATRIX

Each test matrix includes a tabulation of the test conditions required for each run of the test. The following nine columns are used to group the requirements.

- Total Time - Estimated time for startup, data taking, and shutdown of the test for scheduling purposes.
- Flux Distribution - Figure 6-1 shows the three flux distributions used for the test program, the number in this column selects one of the three. If no flux is required, a zero is entered in the column.
- Flux Ramp - Figure 6-2 shows the nine startup and shutdown ramps used for the test program. The number in this column identifies which ramp is to be used for this test. If the test requires no flux, a zero is entered in the column.
- % Heliostats - This defines the portion of the field to be utilized during testing.
- Inlet Temperature ^{o}F - Sodium temperature at the absorber panel inlet header.
- Outlet Temperature ^{o}F - Sodium temperature at the absorber panel outlet header.
- % Flow - EM pump flow rate; this is only controlled in test #2. For all other tests, flow is controlled by panel outlet temperature and flux change sensing.
- Wind Speed - Defines wind conditions compatible with test objectives.
- Air Temperature - Defines air temperature compatible with test objectives.

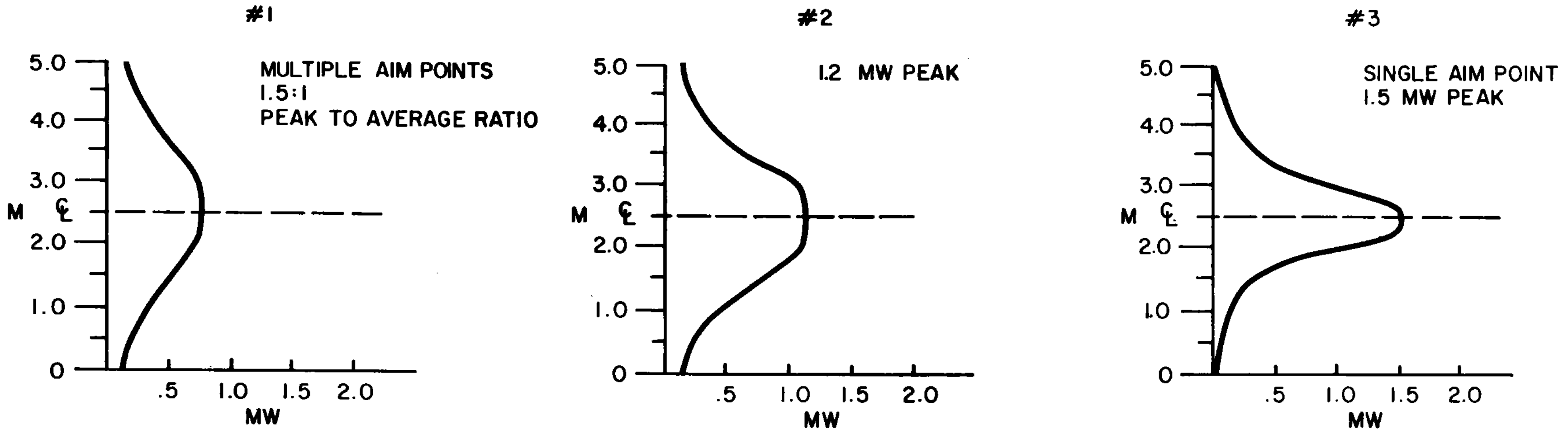
The data requirements and sampling times are also listed in each matrix. The data interval is total time over which the data will be sampled and recorded on magnetic tape, disc or other appropriate storage medium. The data system will sample and record the identified parameters at the stated interval. The data will be reduced and analyzed after completion of the test.

6.2.2 TEST #1 - RADIATION AND CONVECTIVE LOSS

The objective of this test is to measure the radiation and convection losses of the absorber panel. The test will be performed by heating the loop to an isothermal condition and then, with no flux present, open the absorber panel insulating door and take data on panel ΔT and sodium flow. The test conditions and data requirements for this test are shown on Table 6.2.

The data acquired from Test #1 will be used to estimate the emissivity (ε) of the panel surface and the airside convective coefficient (H_T). A family of curves will be generated by varying H_T and ε in the following equations:

$$Q_R = \sigma \varepsilon A \ (T_N + 460)^4 - (T_A + 460)^4 \qquad (6\text{-}1)$$



FLUX DISTRIBUTIONS
CANNOT EXCEED 2.5 MW TOTAL

Figure 6-1. SRTA Test Flux Profiles

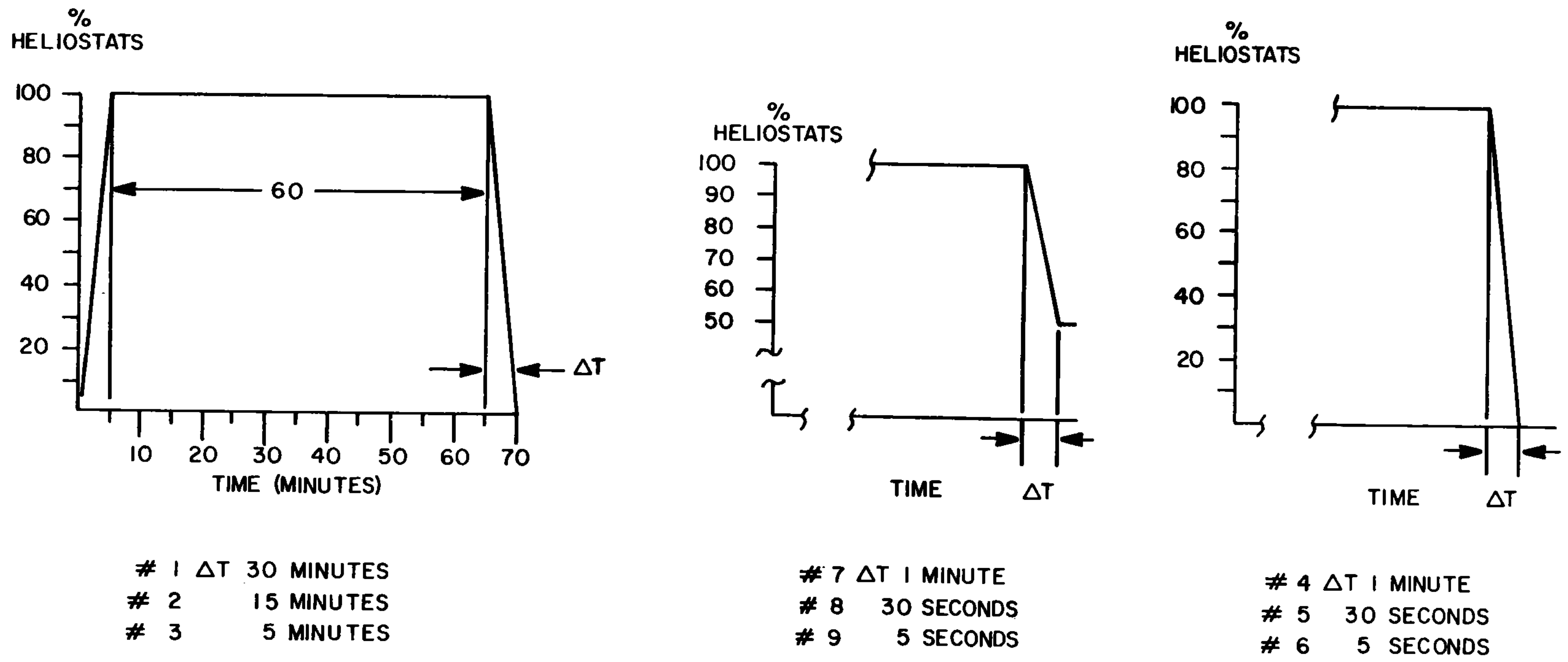


Figure 6-2. SRTA Flux Ramps

Table 6-2

TEST #1 RADIATION AND CONVECTIVE LOSS TEST CONDITIONS

RUN #	TOTAL TIME	FLUX DISTRIBUTION	FLUX RAMP	% HELIOSTATS	INLET TEMP °F	OUTLET TEMP °F	% FLOW	WIND SPEED	AIR TEMP
1.1	4	0	0	0	350	300	As Rqd.	Note 1	Note 1
1.2	4	0	0	0	450	400	As Rqd.	Note 1	Note 1
1.3	4	0	0	0	600	550	As Rqd.	Note 1	Note 1
1.4	4	0	0	0	850	800	As Rqd.	Note 1	Note 1
1.5	4	0	0	0	1100	1050	As Rqd.	Note 1	Note 1

DATA

RUN #	DATA INTERVAL	FLOW	ΔT	PANEL T/C	STRAIN GUAGE	RTAF	WIND SPEED	AIR TEMP
1.1	10 min.	5 sec	5 sec	5 sec	NA	NA	30 sec	30 sec
1.2	"	"	"	"	"	"	"	"
1.3	"	"	"	"	"	"	"	"
1.4	"	"	"	"	"	"	"	"
1.5	"	"	"	"	"	"	"	"

Notes: 1. These conditions should be constant over the data recording interval of the test.

$$Q_C = H_T A \, (T_N - T_A) \qquad (6\text{-}2)$$

where: Q_R = Radiative Loss

Q_C = Convective Loss

A = Panel Surface Area

T_N = Average Panel Sodium Temperature

T_A = Ambient Temperature

σ = Stephan Boltzman Constant

The actual heat loss will be calculated using measured panel parameters in the following equation:

$$THL = WCp \, \Delta T_N = Q_R + Q_C \qquad (6\text{-}3)$$

where: THL = Total Panel Heat Loss

W = Panel Sodium Flow Rate

Cp = Sodium Average Specific Heat

ΔT_N = Sodium Average Panel Temperature Rise

The actual THL will be compared with the family of curves ($Q_R + Q_C$) to estimate the actual values of ε and H_T for the test panel. Figure 6-3 shows an example family of curves.

6.2.3 TEST #2 STARTUP/SHUTDOWN AND TRANSIENT CHARACTERIZATION

This test will determine the startup/shutdown flux ramp and flow conditions for subsequent tests as well as evaluating the SRTA tolerance to transients. The test conditions and data requirements for this test are shown on Table 6-3.

Test runs 2.1 through 2.12 will provide the startup/shutdown evaluation. For constant flux distributions and ramp conditions the initial flow rate will be held at 40, 30, 20 and 10 percent of normal flow until the 1100°F outlet temperature is reached. This will be updated for two additional flux ramps and an analysis of the data will determine the optimum startup/shutdown scenario. A sample plot of the data is shown on Figure 6-4.

Test runs 2-13 through 2-18 will evaluate the tolerance of the SRTA to transients. The transients will be introduced by steering off heliostats. Starting from normal operating conditions, three different ramps will be used to vary the flux from 100 to 50 percent, the ramps will be repeated varying the flux from 100 percent to zero.

The data will be analyzed to determine operational limits of the SRTA as a function of transient conditions.

APPENDIX A

DEVELOPMENT SPECIFICATION FOR SODIUM RECEIVER TEST ASSEMBLY

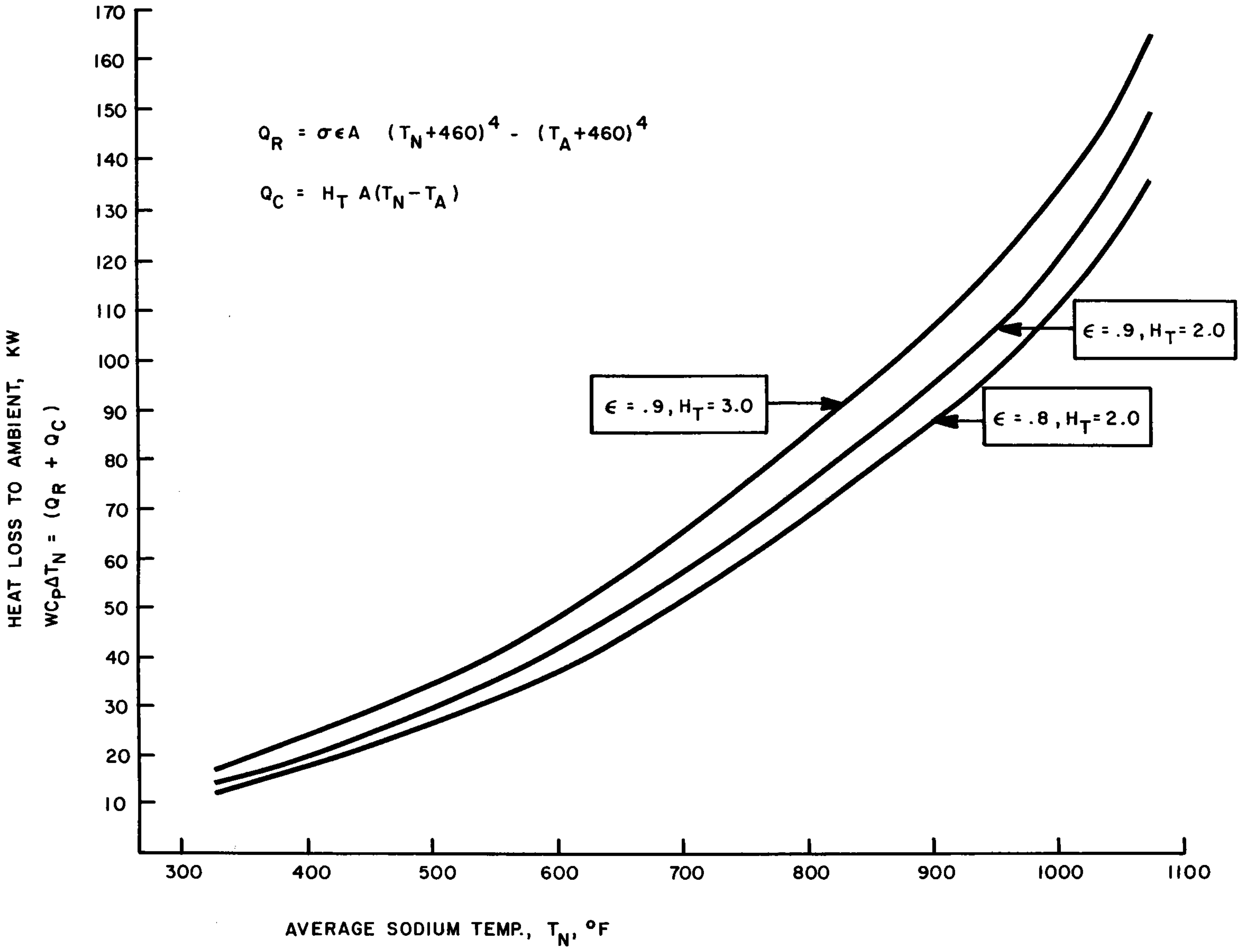


Figure 6-3. Curve Fit Determination of ε and H_T

Table 6-3

TEST #2 STARTUP/SHUTDOWN AND TRANSIENT CHARACTERIZATION TEST CONDITIONS

RUN #	TOTAL TIME	FLUX DISTRIBUTION	FLUX RAMP	HELIOSTATS	INLET TEMP °F	OUTLET TEMP °F	% FLOW	WIND SPEED	AIR TEMP
2.1	6	1	1	0-100-0	600 ↑	600-1100-600 ↑	Initial 40	Note 2 ↑	Note 2 ↑
2.2	6	1	1	0-100-0			Initial 30		
2.3	6	1	1	0-100-0			Initial 20		
2.4	6	1	1	0-100-0			Initial 10		
2.5	6	1	2	0-100-0			Initial 40		
2.6	6	1	2	0-100-0			Initial 30		
2.7	6	1	2	0-100-0			Initial 30		
2.8	6	1	2	0-100-0			Initial 10		
2.9	6	1	3	0-100-0			Initial 40		
2.10	6	1	3	0-100-0			Initial 30		
2.11	6	1	3	0-100-0		↓	Initial 20		
2.12	6	1	3	0-100-0		600-1100-600	Initial 10		
2.13	4	1	4	100-0		1100-600	As Rqd.		
2.14	4	1	5	100-0		1100-600	As Rqd.		
2.15	4	1	6	100-0		1100-600	As Rqd.		
2.16	4	1	7	100-50		1100-	As Rqd.		
2.17	4	1	8	100-50	↓	1100-	As Rqd.	↓	↓
2.18	4	1	9	100-50	600	1100-	As Rqd.	Note 2	Note 2

RUN #	DATA INTERVAL	FLOW	ΔT	PANEL T/C	STRAIN GUAGE	RTAF	WIND SPEED	AIR TEMP
2.1	2 hours	5 sec ↑	5 sec ↑	T/C on center & edge tubes and those associated with strain gauges every 5 sec ↑	5 sec ↑	↑	5 min. ↑	5 min. ↑
2.2	2 hours							
2.3	2 hours							
2.4	2 hours							
2.5	1½ hours							
2.6	1½ hours							
2.7	1½ hours							
2.8	1½ hours							
2.9	1 hour, 10 min.							
2.10	1 hour, 10 min.							
2.11	1 hour, 10 min.					↓	↓	↓
2.12	1 hour, 10 min.					5 min.	5 min.	5 min.
2.13	3 min.					Start & end of data interval ↑	Start & end of data interval ↑	↑
2.14	3 min.							
2.15	3 min.			↓				
2.16	3 min.			T/C on center & edge tubes and those associated with strain gauges every 5 seconds				
2.17	3 min.	↓	↓		↓	↓	↓	↓
2.18	3 min.	5 sec	5 sec		5 sec		Start & end of data interval	

Notes: 2. These values are accepted as is; there are no preset values required for this test.

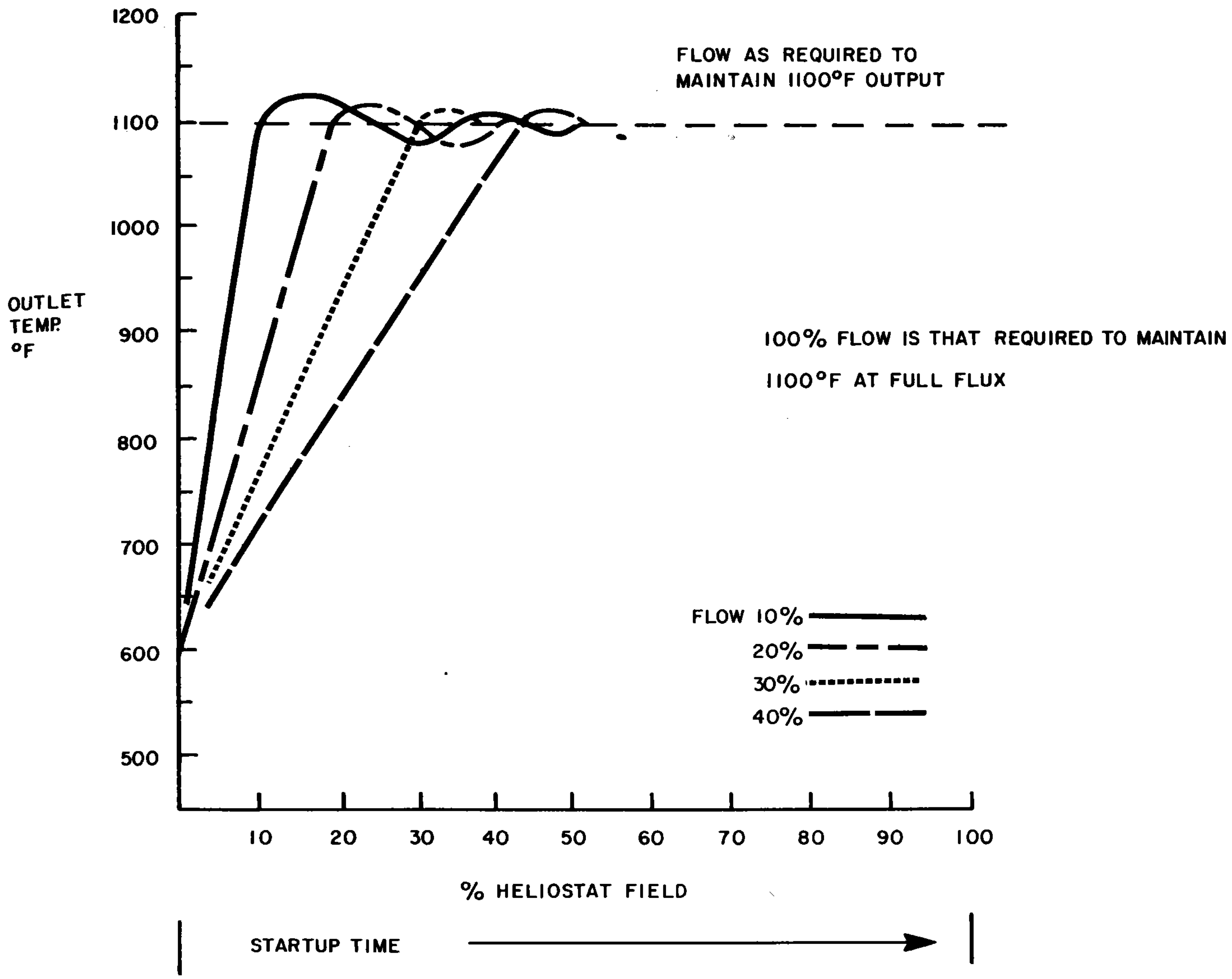


Figure 6-4. Sample Data Plot for Test Runs 2.1 Through 2.12

6.2.4 TEST #3 NORMAL OPERATION

The objective of this test is to acquire data on the panel under normal operating conditions. The data will be used to evaluate panel efficiency and correlate the loss predictions made in Tests 1 and 4.

The test conditions and requirements are identified on Table 6-4. The SRTA will be operated with 1.5:1 peak to average flux distribution for 100, 60 and 20 percent of heliostat field capacity. Three test runs (3.4, 3.5, 3.6) will be made at the 1.2 MW/m^2 level to evaluate receiver performance for this condition.

6.2.5 TEST #4 REFLECTIVE LOSS TEST

The objective of this test is to measure the effective solar absorptivity of the panel coating.

The test conditions and data requirements are currently under revision. A current method under consideration would measure reflectivity directly by comparing the brightness of the panel reflected beam to the brightness of a standard reflector.

Figure 6-5 shows a schematic of this apparatus. The standard reflector is a white Barium Sulfate coated coupon (Kodak paint, catalog number 6090, or powder #6091) with a reflectance of 99.7%. The sensing apparatus consists of a simple tube (black inside) for colimating the incoming beam, a filter to eliminate the infrared interference from heat coming off the hot panel and a detector such as a photomultiplier tube or a thermopile.

To measure the panel reflectance, the colimator tube is aimed at the standard reflector and then at a nearby part of the panel. The ratio of the brightness is directly related to the ratio of the reflectivities of the two surfaces. Since the barium sulfate standard has a high reflectance its brightness is essentially that of the incident solar beam.

6.2.6 TEST #5 HIGH FLUX TEST

The objective of this test is to demonstrate the ability of the sodium cooled absorber panel to tolerate high flux levels. The test conditions and data requirements are shown on Table 6-5.

The procedure will be to operate the panel at $\sim$ 1.5 MW/m^2 peak flux while maintaining 600°F inlet, 1100°F outlet. The data will be evaluated to determine the effects on the absorber panel of operating at this peak flux level.

Table 6-4

TEST #3 NORMAL OPERATION TEST CONDITIONS

RUN #	TOTAL TIME	FLUX DISTRIBUTION	FLUX RAMP	% HELIOSTATS	INLET TEMP °F	OUTLET TEMP °F	% FLOW	WIND SPEED	AIR TEMP
3.1	6 hrs.	1	Note 3	100	600	1100	As Rqd.	Note 2	Note 2
3.2	6 hrs.	1	↑	100	↑	↑	↑	↑	↑
3.3	6 hrs.	1		100					
3.4	4 hrs.	2		100					
3.5	4 hrs.	2		100					
3.6	4 hrs.	2		100					
3.7	4 hrs.	1		60					
3.8	4 hrs.	1		60					
3.9	4 hrs.	1	↓	20	↓	↓	↓	↓	↓
3.10	4 hrs.	1	Note 3	20	600	1100	As Rqd.	Note 2	Note 2

DATA

RUN #	DATA INTERVAL	FLOW	ΔT	PANEL T/C	STRAIN GUAGE	RTAF	WIND SPEED	AIR TEMP
3.1	∿ 5 hrs.	5 sec.	12 continuous samples every 15 seconds at 15 minute intervals	15 minutes	15 minutes	15 min.	15 min.	15 min.
3.2	∿ 5 hrs.	↑		↑	↑	↑	↑	↑
3.3	∿ 5 hrs.							
3.4	∿ 2 hrs.							
3.5	∿ 2 hrs.		↑					
3.6	∿ 2 hrs.							
3.7	∿ 2 hrs.							
3.8	∿ 2 hrs.							
3.9	∿ 2 hrs.	↓	↓	↓	↓	↓	↓	↓
3.10	∿ 2 hrs.	5 sec	—	15 minutes	15 minutes	—	15 min.	15 min.

Notes: 2. These values are accepted as is; there are not preset values required for this test.

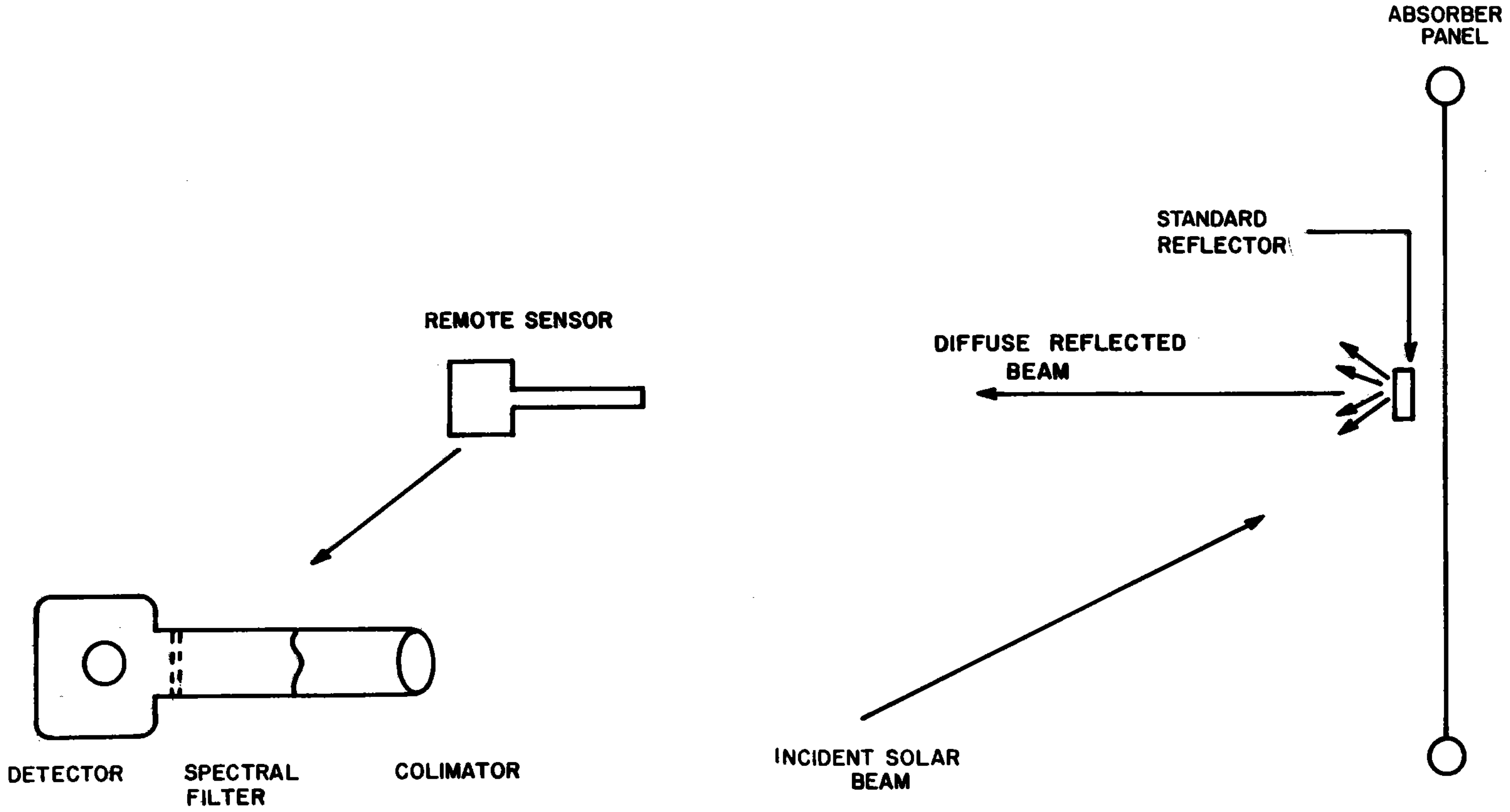


Figure 6-5. Candidate Approach for Test #4

Table 6-5

TEST #5 HIGH FLUX TEST CONDITIONS

RUN #	TOTAL TIME	FLUX DISTRIBUTION	FLUX RAMP	% HELIOSTATS	INLET TEMP °F	OUTLET TEMP °F	% FLOW	WIND SPEED	AIR TEMP
5.1	6 hrs.	3	Note 3	As Rqd.	600	1100	As Rqd.	Note 2	Note 2
5.2	6 hrs.	3	Note 3	As Rqd.	600	1100	As Rqd.	Note 2	Note 2
5.3	6 hrs.	3	Note 3	As Rqd.	600	1100	As Rqd.	Note 2	Note 2

DATA

RUN #	DATA INTERVAL	FLOW	ΔT	PANEL T/C	STRAIN GUAGE	RTAF	WIND SPEED	AIR TEMP
5.1	15 minutes	5 sec	5 sec	5 sec	5 sec	3 min.	1 min.	1 min.
5.2	15 minutes	5 sec	5 sec	5 sec	5 sec	3 min.	1 min.	1 min.
5.3	15 minutes	5 sec	5 sec	5 sec	5 sec	3 min.	1 min.	1 min.

Notes: 2. These values are accepted as is; there are no preset values required for this test.

3. The appropriate flux rays will be determined in Test 2.

6.3 TEST PROGRAM SCHEDULE

Initial activity at CRTF will be performed on a lift platform inside the tower. The major tasks will be unloading and inspection of SRTA subassemblies, assembly of SRTA structure on sleeper beams, installation of piping, preheaters and insulation as appropriate, installation of pipe hangers, installation of pump stator, blower and capacitor, and connection of the pump power cabling. The SRTA assembly will then be moved out of the tower to allow for lowering and removal of the molten salt test receiver. Framework for the solar shield shall be provided for mounting of the insulation by CRTF personnel.

The absorber panel after a receiving inspection, will be instrumented and ready for integration into the SRTA.

The installation and checkout schedule is shown on Figure 6-6. The GE local control panel will be moved into the computer level of the module and the elevating module lowered to allow for installation of equipment on the module top. The heat dump, electrical power supply and SRTA structural assembly will then be mounted to the module top. The absorber panel will be mounted to the structure and the welding and inspection of the sodium piping will be completed. Following this the remaining preheaters will be installed and the loop will be insulated. The installation of the solar shield, insulating door, and cabling and SRTA siding will complete this activity.

Prior to the initiation of any performance testing a demonstration of solar startup, automatic control and safety circuits functioning and shutdown of the SRTA will be completed. The general test schedule is also shown on Figure 6-6.

6.4 CRTF SUPPORT SERVICES

The CRTF will supply the following equipment and services in support of SRTA installation and testing.

RTAF - A real time aperature flux system will be required to measure the amplitude and distribution of the incident flux impinging on the panel.

DATA SYSTEM - The hardware and software necessary to operate the SRTA from the MCS and record the data.

FLUX DISTRIBUTION - The required flux distribution and startup/shutdown ramps will be provided by CRTF control of the heliostat field.

DATA LOGGER - CRTF will provide an in-tower data logger to support SRTA operation and testing.

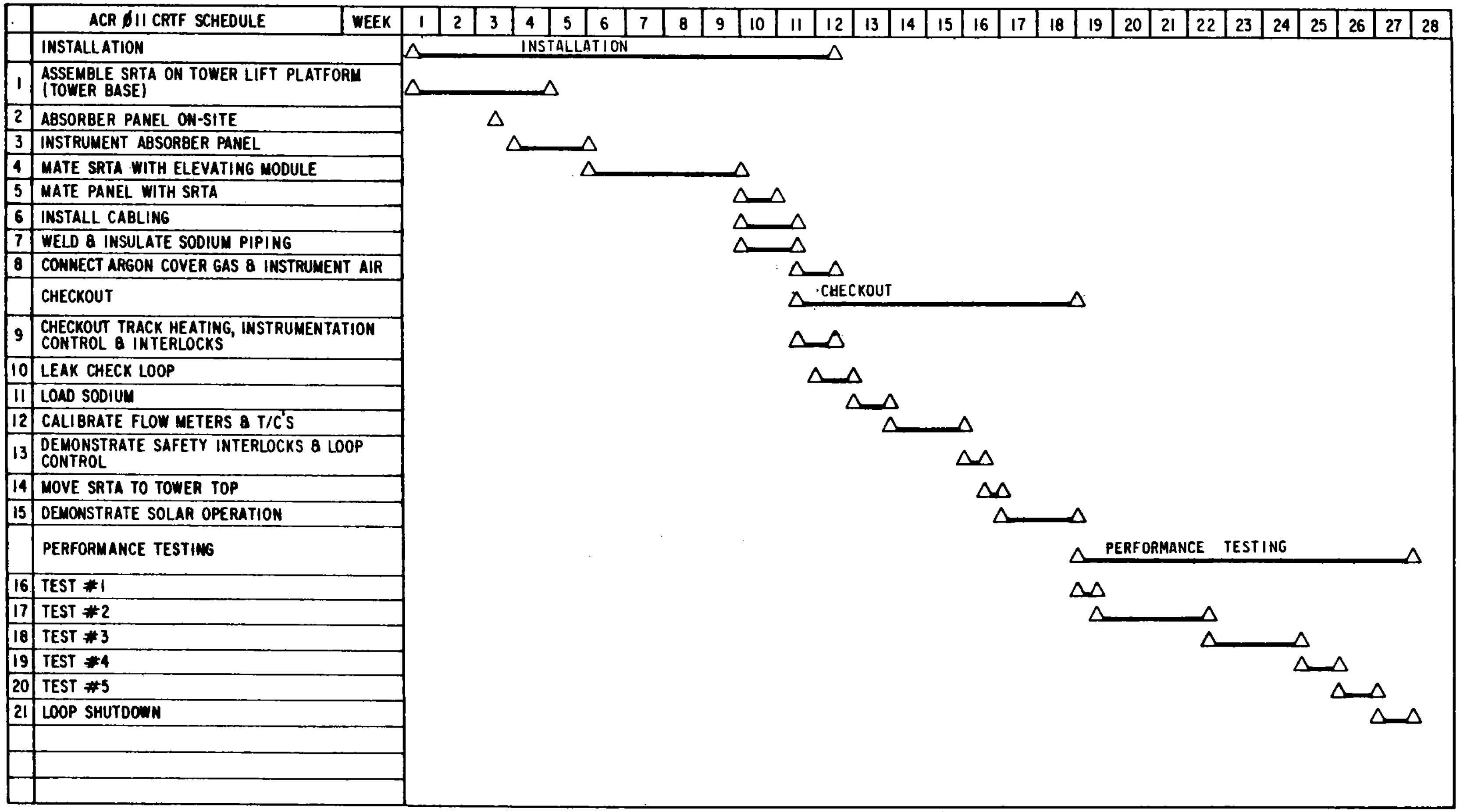


Figure 6-6. SRTA Test Schedule

HIGH TEMPERATURE INSULATION - CRTF will install the solar shield insulation. CRTF will provide the zirconia and alumina (3000 board) shielding for the high spillage flux regions of the shield.

RIGGING SUPPORT - CRTF will provide the rigging necessary to support the off-loading of SRTA components from trucks, assembly of SRTA assembly and movement of SRTA components and/or assembly on and off the elevating module.

WELDER - CRTF will provide a heliarc welding machine.

STORAGE AREA - Space to accumulate components required for assembly and installation.

- Space will be required for storage of tools, special equipment and repair parts.

ASSEMBLY & REPAIR FACILITIES - Space and equipment required for assembly, repair and maintenance of mechanical, electrical and electronic equipment.

OFFICE SPACE - Space for on-site organization of seven people.

COMPUTER TERMINAL - Space for a computer terminal of the GE terminet 1232 variety.

The CRTF will provide utility support for the SRTA electrical, air, argon gas system.

Section 7

PRELIMINARY SAFETY EVALUATION

The preliminary safety evaluation of the Sodium Receiver Test Assembly (SRTA) described in this section includes an examination of the major SRTA components and operating modes to evaluate the design safety features and to identify any needed safety improvements. The evaluation indicates that the SRTA system is designed to minimize hazards. Operation of the SRTA is not a significant hazard to the general public and presents only a minimum hazard to operating personnel and equipment. The preliminary safety evaluation performed consists of a preliminary failure mode and effects analysis of the SRTA components.

7.1 SODIUM SAFETY OVERVIEW

General Electric and a number of other industrial and governmental organizations in the US and foreign countries have over twenty-five years experience in the handling and operation of large liquid sodium loops in power plants and test facilities. Proof that liquid sodium can be handled and utilized safely has been demonstrated. This experience provides the basis for the design and operating and maintenance procedures to be used on the SRTA. The key factors leading to good safety records are proper design and rigorous adherence to established operating and maintenance procedures. Where necessary, a degree of redundancy is provided to assure high reliability. Equipment is included to detect leaks should they occur, and equipment and procedures will be included to handle leaks and spills, thereby minimizing their impact on other equipment and the environment.

7.1.1 SODIUM CHARACTERISTICS

Sodium in its solid state is a silvery white metal which can be cut easily with a knife. Sodium oxidized in air turns to a dull gray. Pure sodium melts at approximately 208°F (96°C), and when liquid, combines or reacts quite readily and violently with water. Liquid sodium exposed to air when temperatures are approximately 260°F (126°C) or above will often ignite. It gives off clouds of dense white caustic smoke which is very noticeable and is quite irritating to the skin, nose, and throat. The temperature rapidly increases to over 1200°F (650°C). In this condition, burning liquid sodium spalls concrete and reacts with common materials such as asbestos, firebrick, and even glass.

Burning sodium is characterized by a very small or nonexistent flame depending on the oxygen content of surrounding materials. Elimination or suppression of free oxygen will extinguish or drastically reduce the combustion process. Common fire extinguishing agents such as water cannot be used because of sodium's violent reaction with water:

$$2Na + 2H_2O \rightarrow 2NaOH + H_2 + \text{heat}$$

The liberated hydrogen is then free to combine with oxygen which can result in an explosion. Table 7-1 provides a summary of reactions of sodium with various materials.

7.1.2 PERSONNEL HAZARDS

Direct skin contact with sodium can cause severe thermal and chemical burns. Sodium hydroxide penetrates the tissues and must be neutralized before effective healing can be accomplished. Sodium burns are self-cauterizing and are rarely accompanied by bleeding.

The reaction between sodium and the eyes, throat, and lungs is generally limited to contact with sodium oxide smoke from a fire or caustic mist from a sodium/water reaction. Prolonged contact is unlikely, as the resulting irritation and coughing are sufficient warning of danger. There is no recognized local or systemic form of acute or chronic toxicity resulting from sodium or sodium oxide smoke.

The many years of General Electric experience with operation of sodium systems will be used to develop operating procedures for the SRTA that adequately consider sodium hazards.

7.2 SRTA SAFETY FEATURES

As described in previous sections, the SRTA is designed to accept a maximum steady state incident solar power of 2.5MW. The absorber panel inlet temperature

Table 7-1

SODIUM REACTIONS

Material	Reaction	No Reaction
Water	X	
Alcohol	X	
Acids (all)	X	
Halogenated Hydrocarbons (methylbromine, methylchroide, etc.)	X	
Polyhalogenated Hydrocarbons (freon, carbon tetrachloride, etc.)	X	
Calcium Carbonate		X
Sodium Chloride (dry)	X	
Graphite		X
Dry Sand (below 300°F)		X
Met-L-X Compound (fire extinguisher)		X
Dry Soda Ash		X
Glass (below 300°F)		X
Oxygen	X	
Argon		X
Dry Nitrogen		X
Helium		X
Carbon Dioxide	X	
Stainless Steel		X
Carbon Steel		X

will be maintained between 260°C (500°F) and 371°C (700°F) and the outlet temperature at 593°C (1100°F) under all steady state solar insolation conditions. The operating modes form the boundary conditions for the safety analysis, and include:

- Operation - EM pump and heat dump under automatic control responding to variations in the solar heat input.
- Hot Hold - Hot shutdown condition with the absorber panel movable insulation closed. Trace heaters maintain the loop temperature at approximately 315°C (600°F).
- Preheat - Transition mode from cold ambient temperature condition to hot hold.
- Startup - Transition mode from hot hold to operation.
- Shutdown - Transition mode from operation to hot hold.
- Emergency Dump - In this mode, all sodium is drained rapidly (less than one minute) out of the loop into the dump tank and the loop is filled with inert gas.
- Calibration Maneuvers - Possible calibration modes include sodium flowmeter calibration using the surge tank level gages, and thermocouple calibration over a range of isothermal temperatures from 315°C to 593°C (600°F to 1100°F).

The SRTA includes two safety systems, shown schematically in Figure 7-1. System #1 provides automatic heliostat cutoff to remove the solar heat input from the absorber panel in the event of a panel high temperature condition or sodium-low flow condition. High panel temperature is sensed by one thermocouple on each tube located on the back of the panel near the vertical center in the maximum heat flux region of the panel. These thermocouples detect the temperature rise due to reduction or loss of flow in any one or more of the panel tubes. System #2 provides for manual or automatic emergency sodium drain in the event of a sodium leak. Emergency drain is accomplished by simultaneous cutoff of the heliostats, an open signal to the normally open equalizer valve, shutoff of the EM pump, and opening of the drain valve. Complete sodium drain has been calculated to occur in approximately forty seconds. Since visual verfication of a leak on the panel surface during attended operation can be performed rapidly and effectively, manual draining may be used under most attended operating conditions. Smoke detection in either the SRTA enclosure or the heat dump air exhaust ducts and low surge tank level will activate a drain during automatic operation or will provide an annunciator alarm only when manual dumping is selected. Additional safety features include a

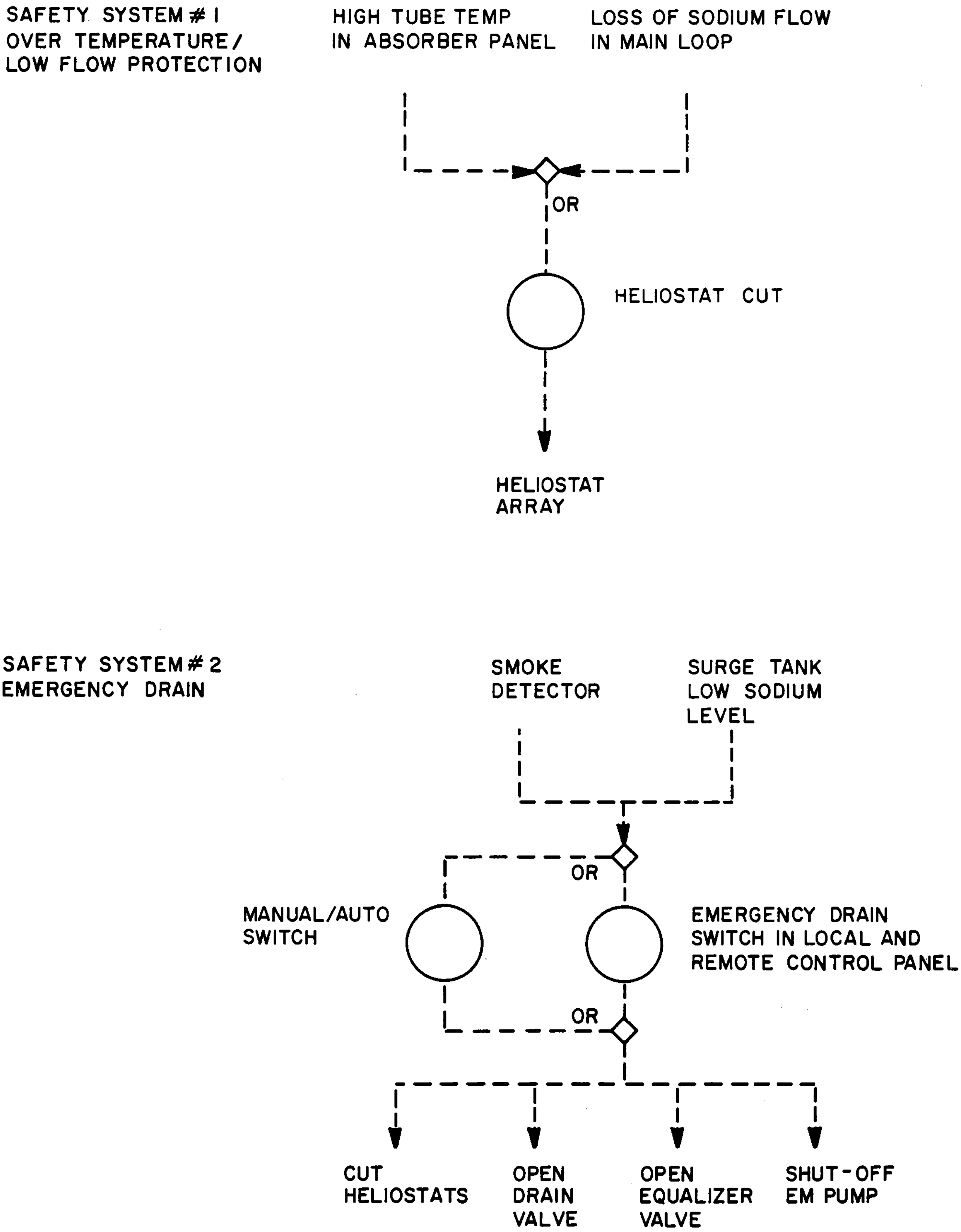


Figure 7-1. SRTA Safety Systems

combination rupture disc/pressure relief valve for over pressure protection in the surge tank and the drain tank. The rupture disc provides a leak-tight seal until activated. After activation the relief valve will reclose when pressure is reduced below the set pressure to maintain a positive inert gas pressure on the tanks. An automatic bleed is provided between the rupture disc and relief valve to assure that a pressure buildup does not occur in this region. Pressure buildup downstream could prevent proper rupture of the disc. The SRTA is equipped with drip/catch pans under the fluid circulation module and the heat dump capable of containing the total system sodium inventory.

Facility safety procedures will preclude access to the test elevation during solar operation to ensure personnel safety. When it is necessary to enter the SRTA enclosure for maintenance, it will be done only during hot standby or system drain conditions. Safety clothing will be worn any time the enclosure is entered when sodium is in the loop. The safety clothing will include face shield, fire resistant coat or coveralls, shoe scuffs and gloves.

When the SRTA is unattended, an annunciator provides an alarm and identification of out-of-limit conditions, including smoke detection. A set of contacts is provided to indicate at a remote location (i.e., guard shack) that an annunciation has occurred.

The SRTA is completely enclosed with fire retardant siding except during solar operation during which time the front side of the absorber panel is exposed. Since the drip pan for the heat dump will be exposed to the weather, it is equipped with a drain to remove any rain water collected in the pan. In the event of a large leak on the front of the panel, the system pressure will rapidly decay and the molten sodium will run down the panel into the pan. If the leak is small, sodium may spray out away from the panel. However, the sodium will form a fine oxide smoke which will be dispersed by the ambient air. The following section summarizes recent work on sodium releases to the atmosphere.

7.3 SODIUM RELEASE TO THE ATMOSPHERE

A condition that could result from a SRTA sodium leak is the burning of sodium in air and the resultant release of combustion product to the atmosphere. Recent experimental studies have been conducted by Rockwell Energy Systems Group under DOE contract at the Air Research Laboratory in Idaho. Releases 22 kg to 75 kg (50-160 lbs) of sodium were made. The amounts of sodium used in these experiments is far in excess of the maximum credible release of the SRTA.

A total of 7 atmosphere sodium release tests were conducted with the first 5 tests at release elevations ranging from ground level to 30 meters under Pasquill Type A and Type D meteorological conditions. The last two tests were conducted under very stable (Pasquill E and G) conditions where the natural humidity content was high (47 to 96%).

Detailed description of the tests and results are contained in References 1 and 2. In general, it was found that sodium releases result in rapid local fallout under all conditions. This rapid fallout is attributed to rapid agglomeration of particles in the plume near the release point. Analysis of particles collected closer than 200 meters downwind were predominantly sodium oxide with traces of sodium carbonate (without the presence of sodium hydroxide). The conversion from the hydroxide or hydroxide-hydrate is suspected to be rapid. Airborne concentrations measured beyond 200 meters were near or below the NIOSH inhalation limit for sodium hydroxide.

As indicated above, these experiments used very large quantities of sodium for the releases, yet the ground level damage was not significant. These tests will be analyzed and extrapolated to the smaller release levels postulated for the SRTA as part of the final safety evaluation; however, preliminary analysis indicates even under the worst SRTA accident that damage to heliostats will not be severe.

7.4 FAILURE MODE AND EFFECTS ANALYSIS

The failure mode and effects analysis was performed by postulating a potential event and its possible causes and failure effects. The analysis identifies the system failure detection modes and lists the safety design features. The potential hazards as the result of the event are also identified. The analysis was performed on the absorber panel, SRTA loop, instrumentation and controls, and cover gas pressure system. The major events postulated were (1) sodium leaks in the absorber panel and loop, (2) electrical malfunctions in the instrumentation and controls, and (3) gas leaks in the cover gas pressure system. The system failure detection modes are listed in the order in which the safety design features may respond to the failure.

7.4.1 ABSORBER PANEL FAILURE

The failure mode and effects analysis for sodium leaks in the absorber panel is tabulated in Tables 7-2 through 7-5. Small sodium leaks (< 1 kg) are postulated in Tables 7-2, 7-3, and 7-4 and a large guillotine tube failure (> 1 kg) in Table 7-5. The event title is stated in the "failure mode" column.

Table 7-2 shows that during operation, TV surveillance is the most effective device for detection of leaks on the panel front surface. (See "system failure detection" and "safety design features" columns). A front surface panel leak is postulated to occur from a failed tube due to defects, stress, burn-out or exterior damage such as a rifle bullet. A sodium fire can result as the sodium exits and runs down the tube. The dense white caustic smoke directly in front of the panel may be masked by the glowing panel; however, two TV cameras with different camera angles should overcome this shortcoming. In addition, burning sodium on the panel surface will cause a temperature rise detectable by the panel thermocouples. Upon detection, the system will be shut down and the sodium inventory rapidly drained.

Table 7-3 discusses the postulated events assuming no immediate detection with the TV camera, as may be the case for a leak inside the enclosed surfaces of the panel. The fire will burn within the absorber panel insulation and smoke will flow into the structure where smoke detectors are placed. Thus, the smoke may be detected faster with smoke detectors than with the TV cameras. Eventually the white smoke will exit at the SRTA air outlet louvers at the top of the structure. The key to proper operation of the smoke detectors is an adequate bake-out of insulating materials to prevent false detector signals.

The events postulated in Table 7-4 occur during a hot hold operation mode where test personnel may not be present. The door is closed and the automatic dump is activated in this mode. The smoke generated from the fire will travel within the structure where the smoke will be sensed by the smoke detectors. The loop will then be automatically drained and the alarm at the guard shack will be simultaneously actuated. If a leak causes loss of level in the surge tank before smoke detector activation, the level probe in the surge tank can be the actuation signal

Table 7-2

SMALL ABSORBER PANEL LEAK ON FRONT SURFACE DURING OPERATION

Failure Mode	Possible Cause	Failure Effects	System Failure Detection	Safety Design Features	Hazards
1. Small sodium leak from a tube. Leak on the front surface of the panel at full power operation.	1. Plugged tube/burnout 2. Tube defect 3. Panel defect 4. Stress failure 5. Projectile	1. Sodium exits tube from panel front surface. 2. Sodium dribbles down tube. A stream is not considered probable. 3. Sodium fire and smoke 4. Caustic contamination of panel and adjacent structure 5. Corrosion of tube surface	1.a) Small sodium leak may not be detected immediately until smoke becomes visible. b) Smoke will be detected by TV camera as leak rate increases gradually. 2.a) The temperature of the faulted tube will increase gradually until the high temperature set point is reached. b) The alarm in the local and Master Control System panel will be actuated as the temperature goes beyond its set point. 3.a) Absorber Panel temperature will start to increase - the rate of temperature increase depends on leak size. b) EM Pump and Heat Dump Control will be activated as soon as the Absorber Panel outlet temperature reaches its set point. c) Alarm actuated from high Absorber Panel outlet temperature. 4. Sodium smoke visible on TV. a) Emergency drain switch manually actuated. 5. Pressure and flow measurements will not be affected by a small sodium leak.	1. TV surveillance 2. Thermocouple installed in each tube to monitor temperature. Thermocouples are located at the middle of each tube. 3. Annunciator system 4. Thermocouples to monitor absorber panel temperatures. 5. The heliostat control will slew the heliostats in less than 4 sec. 6. Loop drain in 40 seconds by emergency control. Pump stop is immediate.	1. No personnel hazard will occur because test area is "off limits" during loop operation. 2. No equipment damage will occur other than localized caustic contamination. 3. Minor impact on local environment.

Table 7-3

SMALL LEAK ABSORBER PANEL ON BACK (ENCLOSED) SURFACE DURING OPERATION

Failure Mode	Possible Cause	Failure Effects	System Failure Detection	Safety Design Features	Hazards
2. Small sodium leak from a tube on the back surface of the panel at full power operation.	1. Plugged tube/ burnout 2. Tube defect 3. Panel defect 4. Stress failure	1. Sodium exits tube from panel back surface. 2. Sodium runs down back side of panel. 3. Sodium fire and smoke. 4. Caustic contamination of panel and adjacent structure. 5. Corrosion of tube surface.	1.a) Small sodium leak may not be detected immediately. TV monitor not effective unless observed exiting top of structure. 2.a) Smoke will collect in SRTA support structure where smoke detectors are placed. b) Smoke sensed by smoke detector. c) Alarm actuated 3.a) The temperature of the faulted tube will increase until thermocouple set point is reached. b) Alarm actuated. 4.a) Absorber Panel temperature will increase slowly. b) Alarm actuated on high Absorber Panel outlet temperature. 5. Sodium smoke visible at top and surrounding structure - TV monitoring.	1. TV surveillance partially effective. 2. Tube thermocouples monitor tube temperatures. 3. Annunciators active 4. Thermocouples monitor absorber panel temperatures. 5. Heliostat controls slew heliostats in less than 4 sec. 6. Loop drain in 40 seconds. Pump stopped immediately.	1. No personnel hazard will occur because test area is "off limits" during loop operation. 2. No equipment damage will occur other than localized caustic contamination. 3. Minor impact on local environment

Table 7-4

SMALL ABSORBER PANEL LEAK DURING HOT HOLD WITH DOORS CLOSED

Failure Mode	Possible Cause	Failure Effects	System Failure Detection	Safety Design Features	Hazards
3. Small sodium leak from a tube. Leak occurs on front or back surface of the panel during hot hold operation.	1. Tube defect 2. Panel defect 3. Stress/fatigue /failure	1. Sodium exits tube 2. Sodium runs down tube 3. Sodium fire and smoke 4. Caustic contamination of panel and adjacent structure 5. Corrosion of tube surface	1. Small sodium leak may be detected with TV camera. However, detection may not occur due to: a) Insufficient light to operate camera. b) Smoke may be masked by door. c) Camera not operating	1. Annunciator at guard shack. 2. Automatic system drain.	1. No personnel hazard will occur because test area is "off limits" during loop operation. 2. No equipment damage will occur other than localized caustic contamination. 3. Minor impact on local environment.

for the emergency drain.

The potential worst case accident that may occur in the absorber panel is postulated in Table 8-5. This event is a guillotine rupture of one or more tubes. The emergency drain will be actuated manually during power operation or automatically by smoke detectors or surge tank level during hot hold operation. The loop will drain in forty seconds and the heliostats cut in less than four seconds once the emergency control switch is actuated. The catch pan at the base of the structure will restrain the spilled sodium from damaging the CRTF tower and associated equipment. The catch pan will contain the total sodium volume of the loop and drain tank. The fire from the sodium pool in the catch pan may be allowed to burn out or it can be suppressed with Met-L-X fire extinguisher.

7.4.2 SRTA LOOP FAILURES

The failure mode and effects analysis for events within the SRTA loop include sodium leaks in piping and components (Tables 7-6, 7-7, and 7-8) and overfill of the loop (Table 7-9).

The SRTA structure is designed to contain all leaks in the loop. The structure is completely enclosed with fireproof siding and roofing and a catch pan is located at the bottom of the structure to catch and confine any sodium. Draining of the loop stops the leak and sodium that remains in the insulation or in the catch pan would burn until self-extinguished or extinguished with an oxygen inhibitor such as Met-L-X powder. Smoke generated would fill the inside of the structure and escape out the upper vent. Although caustic, the dispersion of the smoke at the top of the tower will not constitute a hazard to personnel since the immediate area is cleared of personnel during testing. Small sodium leaks in SRTA loop piping or components are presented in the failure mode and effects analysis of Table 7-6. Small sodium leaks generally would result in a slow burning of sodium in the insulation causing an accumulation of the typical dense white caustic smoke. Based on sodium leak experiments in air, the growth rate of small leaks are slow unless the leak size is increased by external forces such as stress. It is anticipated that smoke would be detected prior to any accumulation of sodium outside the insulation and in the catch pans. The smoke detectors, the most responsive early warning feature incorporated in the SRTA design, will sense the smoke and actuate the alarm. Secondary

Table 7-5

LARGE ABSORBER PANEL LEAK DURING OPERATION

Failure Mode	Possible Cause	Failure Effects	System Failure Detection	Safety Design Features	Hazards
4. Large guillotine tube failure at either top or bottom tube-to-panel joint	1. Stress failure 2. Fatigue 3. Projectile	1. Sodium outburst from tube. 2. Sodium runs down the tubes and the SRTA structure. 3. Significant fire and smoke. 4. Significant caustic contamination around SRTA. 5. Corrosion of absorber panel. 6. Some caustic released to air at 200' level.	1. Fire and smoke detected by visual observation, TV or with smoke detectors. 2. Tube temperature will rise rapidly and be sensed by the tube thermocouples. 3. Absorber panel temperatures will gradually increase until set point is reached. a) Emergency Dump 4. Excessive smoke will actuate smoke detectors inside of structure. 5. Loss of sodium flow will be sensed and an emergency drain will take place. 6. Sodium surge tank low level will be reached and an emergency drain will take place. 7. Sodium spill will be stopped by catch pan at the base of the structure.	1. TV surveillance 2. T/Cs installed on panel are located at the middle of each tube. 3. Annunciator system 4. T/Cs to monitor absorber panel temperatures 5. Heliostat slew in less than 4 seconds. 6. Loop emergency drain in 40 sec. EM pump shutoff 7. Sodium catch pan in bottom of SRTA. 8. Met-L-X fire extinguishing material	1. No personnel hazard will occur because test area is "off limits" during loop operation. 2. Damage to absorber panel/tubing would be extensive. Field repair considered impractical. 3. Some damage could occur to SRTA insulation, instrumentation, structure and loop equipment. 4. No damage should occur to CRTF equipment due to enclosure and catch pans. Some caustic ash may go in environment and fall to ground. Low density of ash is not expected to cause equipment damage.

Table 7-6

SMALL LEAK IN PIPING OF COMPONENTS DURING OPERATION

Failure Mode	Possible Cause	Failure Effects	System Failure Detection	Safety Design Features	Hazards
1. Small sodium leak from pipe/component at full power operation.	1. Weld crack in piping 2. Weld/fatigue crack in nozzle 3. Leak in valve bellows	1. Sodium burns through insulation and sodium fire. 2. Caustic contamination constrained inside structure by enclosure. 3. Pipe/metal corrosion	1. Smoke generated from fire will be sensed by smoke detectors. a) Alarm actuated b) Emergency drain actuated 2. Smoke circulated through and out the structure. a) Smoke visually observed with TV camera 3. Leak size may continue to grow and sodium flow may start to decrease. a) Absorber panel outlet temperature increases gradually. b) Alarm actuated when temperature reaches high set point. 4. Any sodium spill will be restrained by catch pan. 5. Surge tank level will decrease gradually. a) Alarm actuated when surge tank low level set point reached. b) Emergency drain activated	1. Smoke detectors 2. Annunciator system 3. Catch pan 4. TV surveillance of structure 5. Met-L-X fire extinguisher 6. Emergency drain in 40 seconds 7. Protective enclosure 8. Slew heliostats	1. No personnel hazard will occur because test area is "off limits" during loop operation. 2. No equipment damage will occur other than localized caustic contamination. 3. Minor impact on local environment

detection is provided by the smoke circulating through the structure and becoming visible as it exits the upper vent. Detection of smoke (visual or by TV) would probably occur prior to detection in a change in loop characteristics. Once a leak is verified, the emergency drain will be actuated.

The chances of a large leak are considered very low, but should one occur, large amounts of smoke would result and the pump would be stopped and emergency drain would be activated (See Table 7-7). The smoke detectors and surge tank level would provide indications for the annunciator system. The damage from a large leak would be confined to within the SRTA structure. Sodium spilled would be caught by the catch pan at the base of the structure. Normal procedure would call for letting what fire was initiated to burn out and self-extinguish. Met-L-X application would be available for use if needed. Since the test area is off limits during loop operation, no personnel hazards would occur.

A leak in the piping between the SRTA and the heat dump would be contained by a protective enclosure/catch trough which will drain excessive sodium into the catch pan of the SRTA.

7.4.3 HEAT DUMP FAILURES

A sodium leak in the coil of the heat dump is postulated and described in Table 7-8. A smoke detector is located at the outlet of this unit and would be a primary detector. A catch pan is also provided at the base of the unit. Detection of a leak in this unit is followed by a shutdown of the entire loop and an emergency drain of the sodium into the drain tank. Inert Argon cover gas immediately fills the entire loop piping and prevents oxygen/air from entering the loop. Equipment damage caused by a leak would be confined to the heat dump.

A loop overfill failure is postulated in Table 7-9. This event may be caused if the high level probe in the surge tank fails, too high a pressure is used in the drain tank, or the drain valve leaks across the seat when closed. The sodium level in the surge tank is monitored with an analog level probe. If the loop is overfilled, the pressure in the cover gas system may increase and the pressure alarm will be actuated. A loop overfill can be prevented by using the proper drain tank cover gas pressure coupled with a properly set cover gas pressure relief system. The SRTA is designed with vapor traps, relief valve and a rupture disc to prevent

Table 7-7

LARGE LEAK IN HIGH PRESSURE ZONE OF PIPING DURING OPERATION

Failure Mode	Possible Cause	Failure Effects	System Failure Detection	Safety Design Features	Hazards
2. Large sodium pipe leak in high pressure zone below absorber panel inlet nozzle at full power operation	1. Pipe break due to stress	1. Sodium burns in insulation 2. Sodium fire and smoke 3. Sodium spill 4. Caustic contamination around leak site. 5. Damage of equipment under spill 6. Corrosion	1. Smoke generated from fire will be sensed by smoke detectors. a) Alarm actuated b) Emergency drain actuated 2. Smoke circulated through and out the structure. a) Smoke visually observed with TV camera 3. Any sodium spill will be restrained by catch pan. 4. Surge tank level will decrease a) Alarm actuated when surge tank low level set point reached. b) Emergency drain activated	1. Smoke detectors 2. Annunciator system 3. Catch pan 4. TV surveillance of structure 5. Met-L-X fire extinguisher 6. Emergency drain in 40 seconds 7. Protective enclosure 8. Slew heliostats	1. No personnel hazard should occur. Test area is "off limits" during loop operation. 2. Damage to equipment in lower portion of SRTA will result. Some damage could occur to SRTA structure and instrumentation. 3. No damage should occur to CRTF equipment due to enclosure and catch pan restraints. Some caustic smoke/ash will go into the environment but concentration on ground should be within tolerance to prevent damage to ground equipment. 4. If personnel were required to inspect area and assist in fire suppression, protective clothing would be used.

Table 7-8

SODIUM LEAK IN HEAT DUMP COIL

Failure Mode	Possible Cause	Failure Effects	System Failure Detection	Safety Design Features	Hazards
3. Sodium leak in heat dump coil during operation or in standby	1. Stress failure 2. Weld joint failure	1. Sodium leaks/spills from coil tube/header area and fire and smoke result 2. Caustic contamination and corrosion in tube bundle and louvers can result. 3. Some sodium could fall to drip pan 4. Some caustic release to the air at the 200' level.	1. Smoke generated from fire will be sensed by smoke detectors. a) Alarm actuated b) Emergency drain actuated 2. Smoke circulated through and out the top of heat dump. a) Smoke visually observed with TV camera (operation) 3. Leak size may continue to grow and sodium flow may start to decrease. a)* Absorber panel outlet temperature increases gradually. b)* Alarm actuated when temperature reaches high set point. 4. Any sodium spill will be restrained by catch pan. 5. Surge tank level will decrease gradually. a) Alarm actuated when surge tank low level set point reached. b) Emergency drain acivated	1. Smoke detector 2. Catch pan 3. Met-L-X fire extinguisher 4. Annunciator system 5. Heliostat slew in less than 4 seconds 6. Loop emergency drain in 40 seconds.	1. No personnel hazard will occur. Test area is "off limits" during loop operation. 2. No equipment damage will occur other than localized caustic contamination/corrosion of heat dump surfaces. 3. Minor impact on local environment

* During operation only

Table 7-9

LOOP - OVERFILL

Failure Mode	Possible Cause	Failure Effects	System Failure Detection	Safety Design Features	Hazards
4. Loop overfill	1. Surge tank high level sensor fails	1. Cover gas pressure system plugged	1. Pressure increase in cover gas system a) Pressure alarm actuated b) Cover gas pressure valve control activated c) Monitor sodium level 2. Excessive pressure released a) Pressure relief valve b) Rupture disc	1. Annunciator system 2. Rupture disc in series with mech-amoca; pressure relief valve 3. Analog level probe 4. SRTA loop fill procedures	1. No personnel hazard

gas overpressure. Recovery from an overfill is a normal system drain followed by inspection/maintenance to assure that the surge tank gas supply is not plugged.

7.4.4 INSTRUMENTATION AND CONTROL FAILURES

The failure mode and effects analysis for the SRTA instrumentation and controls is tabulated in Table 7-10. The major event postulated is an electrical malfunction. The principal effects due to this event is the loss of sodium flow, heat dump air flow and loop control. The CRTF will provide the power to the SRTA system. Heliostat cutoff must take place to prevent damage to equipment and burnout of absorber panel tubes. The CRTF heliostat power supply should be equipped with automatic transfer from M-G set power to utility power.

The SRTA system and the CRTF heliostats will always be operated from separate power supplies with the backup power system available when solar operation is performed, since simultaneous loss of heliostat control power and SRTA sodium pump power for a period of approximately one minute during high flux operation would cause meltdown of the absorber panel. Simultaneous loss of two independent power supplies plus the utility system backup power source is not considered a creditable event.

7.4.5 COVER GAS PRESSURE SYSTEM

The failure mode and effects analysis for the cover gas pressure system is tabulated in Table 7-11. A failure in the cover gas system has the potential for contamination of the loop and sodium with air/oxygen. The cover gas pressure system is protected with a vapor trap to avoid hot sodium from coming in contact with the cover gas pressure piping, vent and supply solenoid valves. A rupture disc is in series with a mechanical pressure relief valve which allows gas to flow only in one direction and prevents overpressure. The annunciator system will be actuated when the pressure reaches its low set point.

The SRTA sodium system is equipped with an oxygen meter which monitors the oxygen level in the sodium. If the oxygen level reaches a level equivalent to a plugging indicator temperature above 450°F, the annunciator in the SRTA will be actuated. Procedures will require discontinuing solar operation until the cause of high oxygen level has been determined and corrected.

Table 7-10

ELECTRICAL MALFUNCTION/POWER LOSS

Failure Mode	Possible Cause	Failure Effects	System Failure Detection	Safety Design Features	Hazards
1. Electrical malfunction to pump and/or other SRTA components	1. Wiring failure 2. Device malfunction 3. Loss of electrical power	1. Indicator device(s) may overrange 2. Loss of data 3. Electrical fire 4. Equipment damage 5. Loss of sodium flow 6. Loss of heat dump blower/cooling	1. Annunciator activated. 2. Faulted indicator device output compared with other measurements 3. Emergency control power supply activated	1. Annunciators 2. System control from local and CRTF panels 3. Emergency control power supply 4. Low sodium flow or rise in panel temperature will result in annunciation and automatic or manual heliostat cutoff	1. Damage to measurement devices and equipment
2. Simultaneous failure of SRTA pump power and CRTF heliostat control power	a. Two simultaneous electrical power failures	1. Transfer to alternate power supply 2. Temporary loss or interruption of data	1. Annunciation 2. Loss of normal lighting	1. Alternate power supply for both systems 2. Procedure prohibits solar operation except on normal power with alternate as backup	1. Loss of data or interruption 2. No equipment damage unless complete loss of power to heliostats with no heliostat cut

Table 7-11

COVER GAS PRESSURE SYSTEM FAILURE

Failure Mode	Possible Cause	Failure Effects	System Failure Detection	Safety Design Features	Hazards
1. Gas leak	1. Valve failure 2. Tube ruptures 3. Joint failure 4. I&C failure	1. Potential for oxygen/ air contamination of sodium	1. Low pressure set point will be reached as gas pressure decreases a) Alarm actuated b) Cover gas control valves actuated 2. Oxygen level in SRTA sodium loop exceeded a) Alarm actuated	1. Annunciator 2. Cover gas pressure control valves 3. Oxygen meter 4. Two cover gas supply systems are provided (surge tank and drain tank); only one is required for normal operation.	1. None

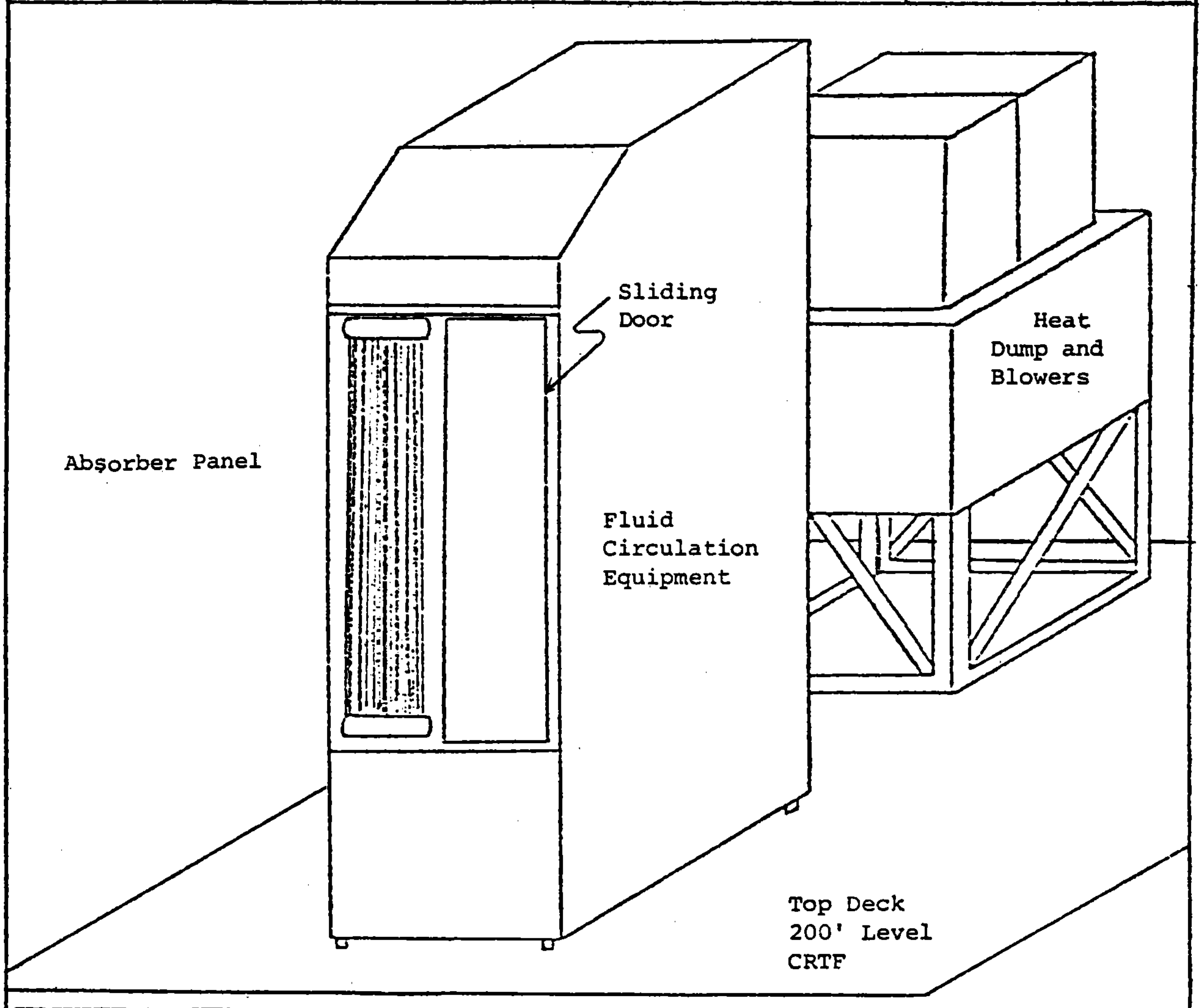
7.5 PRELIMINARY ASSESSMENT

The preliminary safety evaluation indicates that the safety design features of the SRTA - catch pan, smoke detectors, and TV cameras - in conjunction with the proven sodium loop design and operating features of the SRTA will provide safe operation with no significant hazard to personnel and minimum hazard to local equipment. Further work will refine the analysis of airborne releases with particular emphasis on hazards to the heliostat field.

7.6 REFERENCES

1. N707TR130028, "Interim Test Report for the Characterization of Released Particle Tests Conducted at INEL During FY1979, dated 2/8/79.
2. N607TR130025, "Test Report for the Characterization of Released Particle Tests Conducted at INEL during FY1978, dated 9/23/78.

ENERGY SYSTEMS PROGRAMS DEPARTMENT / GENERAL ELECTRIC	ENGINEERING SPECIFICATION	SPECIFICATION NUMBER 295A4725
	TITLE Development Specification for Sodium Receiver Test Assembly (SRTA)	ORIGINAL ISSUE DATE 25 May 1979
	CLASSIFICATION B1	



DESIGN P.E. — DATE 5/29/79	
INTEGRATION ENG. — DATE	
TEST P.E. — DATE 29 May 79	PROGRAM MGR. — DATE May 29, 1979
	DATE
MAT'LS — DATE 5/31/79	
PREPARED BY: BDP, AVC, CCH	ISSUED BY: ADVANCED ENERGY SYSTEMS

REVISION NUMBER	REVISION DATE	SUPERSEDES	
3	1 April 80		PAGE 1 OF 58

ES3-003 (5-73)

GENERAL ELECTRIC

ENERGY SYSTEMS PROGRAM DEPARTMENT

REVISION CONTROL SHEET

No. 295A4725

Rev 02

Cont. on Sh ______ Sh ______

TITLE

REVISION AUTHORIZATION		g.v. C[signature]	g.v. C[signature]	g.v. C[signature]
REV. NO.	0	1	2	3
SH. NO.	LATEST REVISION NUMBER			
1		X	X	X
2			X	
3			X	
4				
5				
6			X	
7				X
8				
9				X
10				
11		X		X
12				X
13			X	X
14			X	X
15			X	
16			X	X
17			X	
18			X	X
19				
20				
21				
22				X
23				
24			X	X
24A			X	
25				
26				X
27			X	
28			X	
29			X	
30			X	

Prepared by ______ Date ______

Document Status

Project

Config. Control Cl.:

Functional Cl.:

Proprietary CL.:

Issued by [signature] Issue Date 8/30/79

No. Rev. No.

ES-3-004 (5-78)

GENERAL ELECTRIC

ENERGY SYSTEMS PROGRAM DEPARTMENT

REVISION CONTROL SHEET

No. 295A4725

Rev 0 2a

Cont. on Sh ______ Sh ______

TITLE

REVISION AUTHORIZATION			G.F.	G.F.														
REV. NO.	0	1	2	3														
SH. NO.	LATEST REVISION NUMBER																	
31				X														
32			X	X														
32 A			X															
33			X	X														
33A			X															
34			X	X														
35																		
36																		
37			X	X														
38				X														
39																		
40																		
41																		
42																		
43																		
44																		
45																		
46																		
47			X	X														
48																		
49																		
50																		
51				X														
52				X														
53																		
54																		
55																		
56																		
57			X	X														
57A			X															
58																		

Prepared by / Date	Document Status	Project
Config. Control Cl.:		Functional Cl.: Proprietary CL.:
Issued by / Issue Date		No. / Rev. No.

ES-3-004 (5-78)

TABLE OF CONTENTS

ENERGY SYSTEMS PROGRAMS DEPARTMENT GENERAL ELECTRIC	ENGINEERING SPECIFICATION	SPECIFICATION NUMBER 295A4725
	TITLE	ORIGINAL ISSUE DATE MAY 2 5 1979
	CLASSIFICATION	

REVISION NUMBER	REVISION DATE	SUPERSEDES	PAGE 3 OF 58
2	24 AUG 79		

ES3-005 (5-78)

1.0 SCOPE

This specification describes the design parameters and required operating characteristics of the sodium receiver test assembly. The design parameters include a description of the absorber panel and the manufacturing processes to be used wherever these are unique. The operating characteristics describe the operating modes, thermal performance and control function requirements for the absorber panel and its associated equipment.

2.0 APPLICABLE DOCUMENTS

The following documents of the issue in effect 25 May 1979 form a part of this specification to the extent specified herein.

2.1 Conceptual Design of Advanced Central Receiver Power Systems, General Electric Company Final Report (Draft), U.S. Dept. of Energy Contract No. EM-78-C-03-1725, March 5, 1979.

2.2 Alternate (Advanced) Central Receiver Power System Program Phase II Technical Proposal, General Electric Co., U.S. Dept. of Energy RFP No. EG-77-R-03-1483, January 19, 1979.

2.3 Advanced Central Receiver Program Requirements, L.N. Tallerico, C.F. Lundbom, Sandia Laboratories, Issue B, March 16, 1978.

2.4 Central Receiver Test Facility Interface Specification, A.V. Curinga.

2.5 ASME Section I, II, V, and VIII Division 1, Boiler and Pressure Vessel Code.

2.6 ANSI Power Piping Code B31.1.

2.7 Manual of Steel Construction, 8th Edition 1974, American Institute of Steel Construction.

2.8 National Electric Code, NFPA 70-1978.

2.9 OSHA Standards.

2.10 National Electrical Manufacturers Association (NEMA) Standards.

2.11 Uniform Building Code - 1976 Edition, Vol. 1 (Earthquake Criteria).

3.0 REQUIREMENTS

The sodium receiver test assembly construction and operation requirements are described in this section.

3.1 ITEM DEFINITION

3.1.1 DIAGRAMS

The following diagrams are included with this specification:

Figure 3-1 Sodium Receiver Test Assembly (SRTA) Schematic

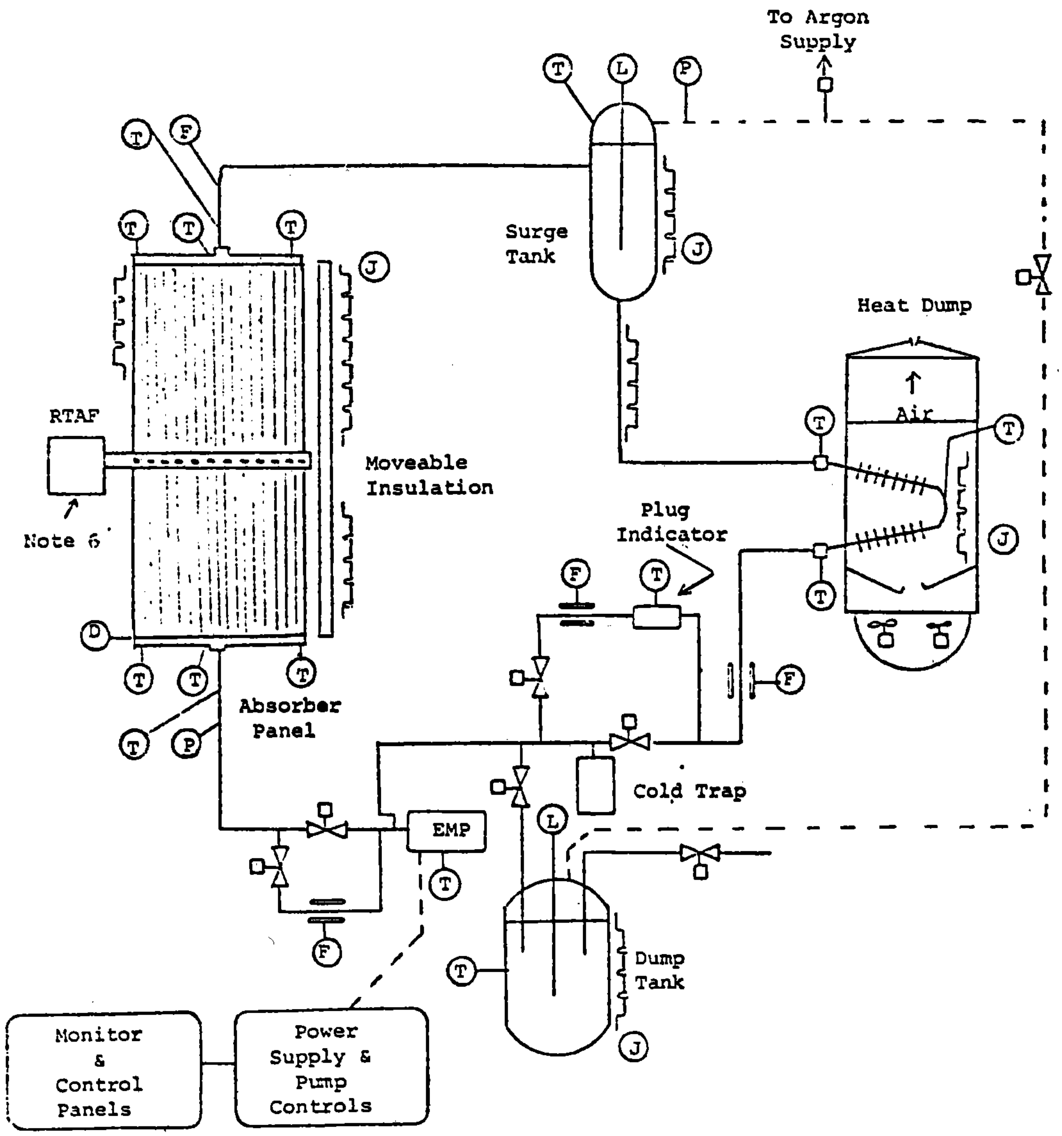


FIGURE 3-1 LEGEND & NOTES

1. ALL SODIUM PIPE & FITTINGS ARE 316 SS AND (OR) 304 SS
2. ALL PIPING & COMPONENTS ARE TRACE HEATED PER THE REQUIREMENTS OF PARAGRAPH 3.7.3.3.
3. ALL PIPING IS SLOPED 3% MINIMUM FOR COMPLETE DRAINAGE FROM THE SURGE TANK (HIGH POINT) TO THE DUMP TANK (LOW POINT).
4. ALL COMPONENTS AND PIPING SHALL BE DESIGNED PER THE CODES SPECIFIED IN PARAGRAPHS 3.7.3.11.
5. ALL COMPONENTS AND PIPING SHALL BE INSULATED PER PARAGRAPH 3.7.3.12.
6. INCIDENT SOLAR FLUX SHALL BE MEASURED WITH THE CRTF SUPPLIED REAL TIME APERTURE FLUX SYSTEM.

(T) THERMOCOUPLE

× THERMOCOUPLE PAIR ON ABSORBER TUBE PLUS STRAIN GAGE (SEE FIGURE 3-3)

• SOLAR HEAT FLUX SENSOR

(P) PRESSURE SENSOR

(L) LIQUID LEVEL SENSOR

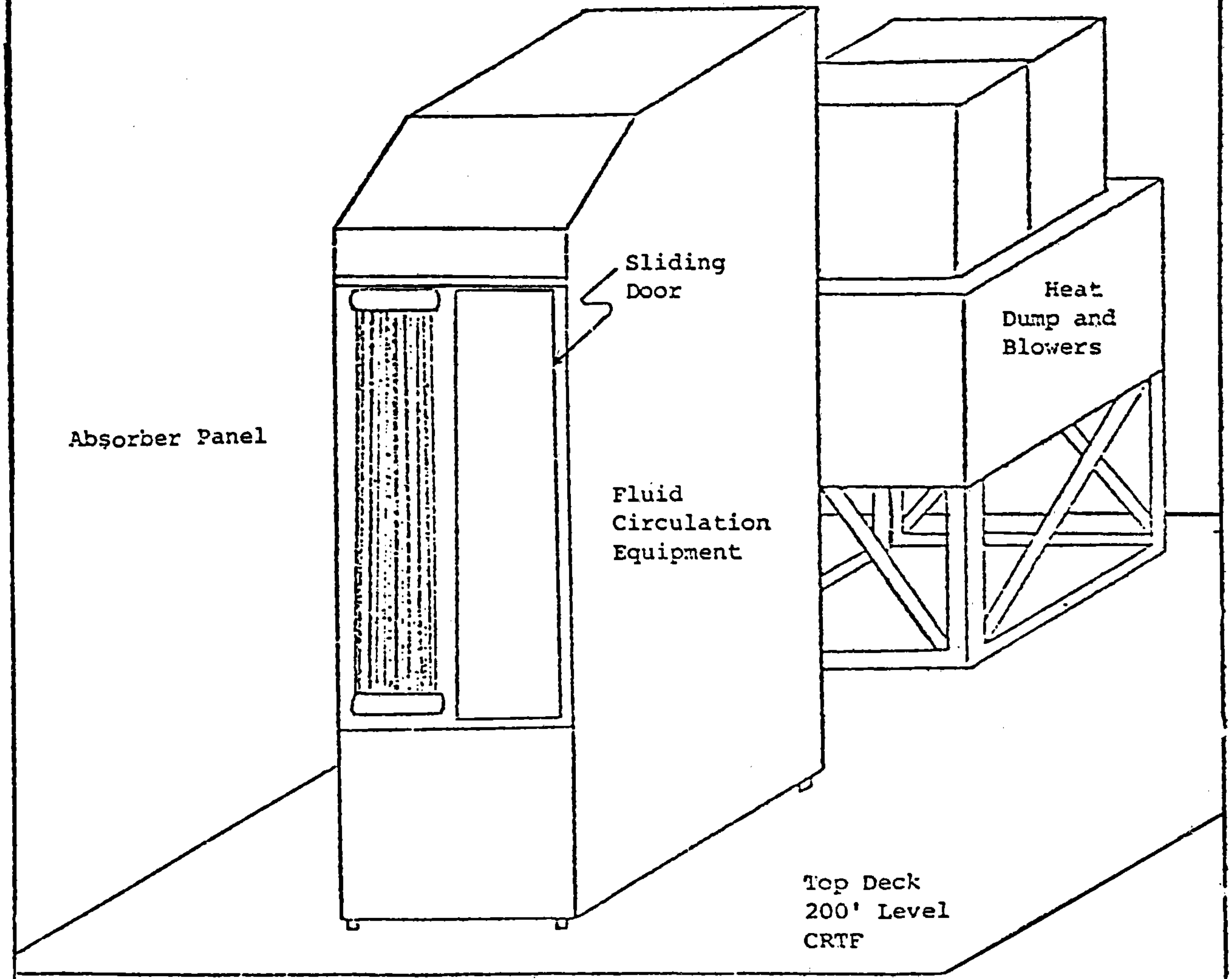
(J) TRACE HEATING JACKET WITH TEMPERATURE SENSOR

(F) FLOWRATE SENSOR

REMOTE CONTROL VALVE

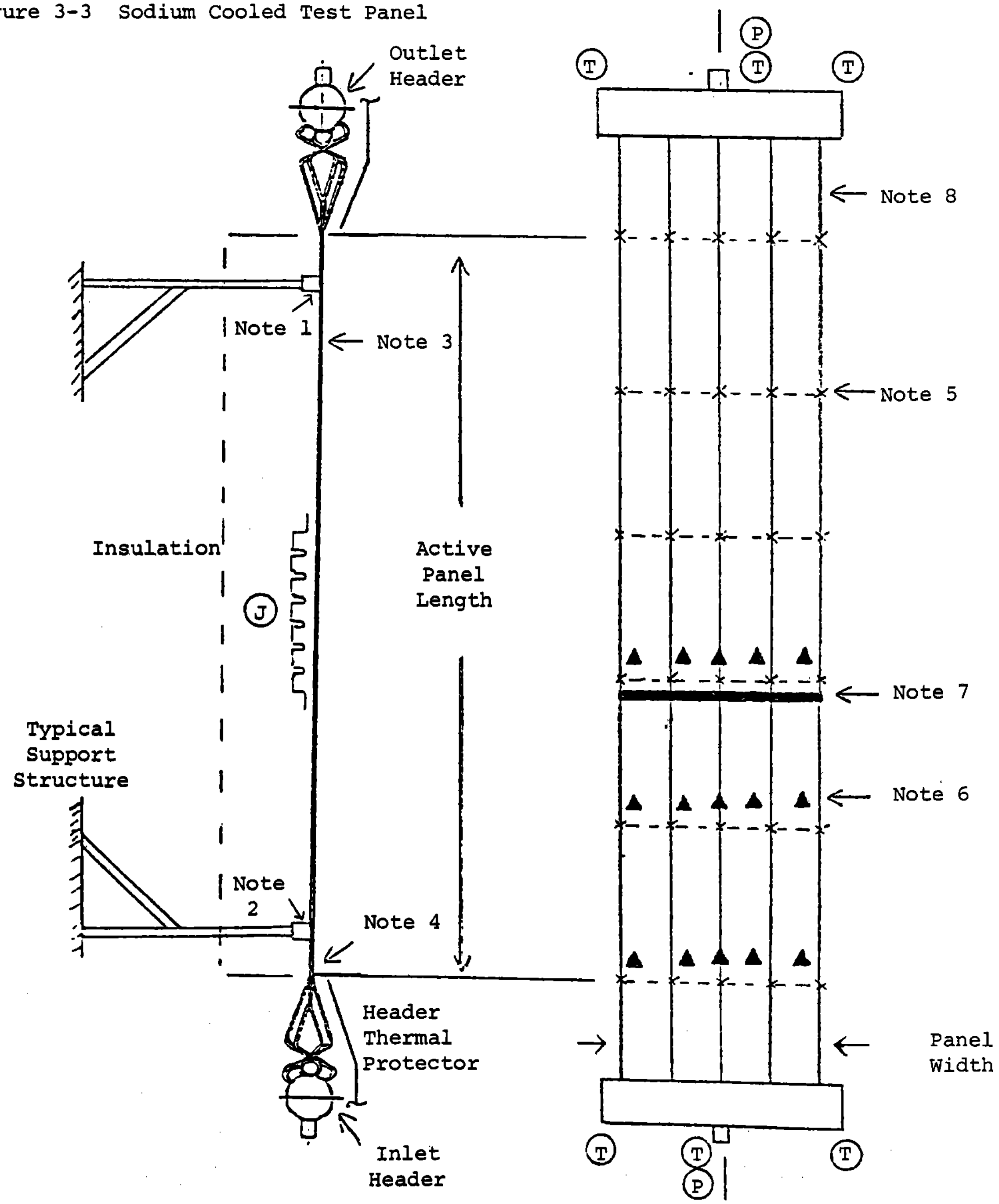
(D) DISPLACEMENT SENSOR (PANEL EXPANSION)

Figure 3-2 Sodium Receiver Test Assembly General Arrangement



ENERGY SYSTEMS PROGRAMS DEPARTMENT GENERAL ELECTRIC	ENGINEERING SPECIFICATION	SPECIFICATION NUMBER 295A4725
	TITLE	ORIGINAL ISSUE DATE MAY 2 5 1979
	CLASSIFICATION	

Figure 3-3 Sodium Cooled Test Panel



REVISION NUMBER	REVISION DATE	SUPERSEDES	
3	1 April 80		PAGE 12 OF 58

FIGURE 3-3 LEGEND & NOTES

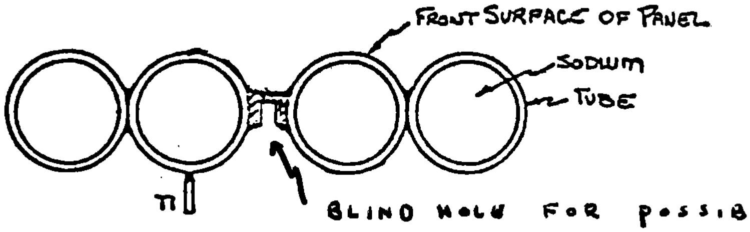
1. TUBE BUNDLE SHALL BE ATTACHED TO A STRUCTURE WHICH SUPPORTS THE WEIGHT OF THE BUNDLE.

2. THE SUPPORT STRUCTURE SHALL MAINTAIN FLATNESS OF THE TUBE BUNDLE WHILE ALLOWING THERMAL EXPANSION.

3. TUBE BUNDLE CONTAINS ~ 51 TUBES.
TUBES ARE INCOLOY 800, 0.75 IN. O.D. × 0.05 IN. WALL.
TUBES ARE JOINED TOGETHER AXIALLY BY BRAZING.
OUTER SURFACE OF TUBES IS COATED WITH A SOLAR ABSORPTIVE MATERIAL.

4. HEADERS MUST BE PROTECTED FROM DIRECT EXPOSURE TO THE FOCUSSED SOLAR BEAM.

5. CANDIDATE LOCATIONS OF TUBE SURFACE TEMPERATURE SENSORS ARE INDICATED BY (X) AND DESCRIBED IN PARAGRAPH 3.7.1.6. AN EXAMPLE OF HOW THESE SENSORS MIGHT BE MOUNTED IS SHOWN BELOW:



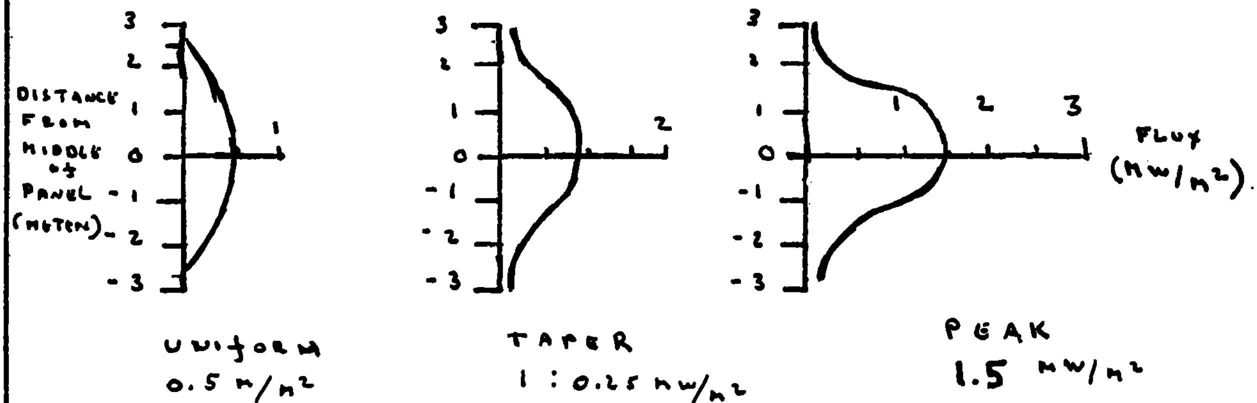
T1 MEASURES BACKSIDE TUBE WALL TEMPERATURE, AND MAY BE SPOT WELDED IN PLACE
MEASURES FRONTSIDE TUBE WALL TEMPERATURE

THERMOCOUPLES ARE SHEATHED IN STAINLESS STEEL (~ 0.032" O.D. SHEATH) WITH OPEN TIPS; THE WIRES ARE CHROMEL-ALUMEL.

6. STRAIN GAGES MOUNTED ON BACK SURFACE OF TUBES ARE INDICATED BY (A), REF. PARAGRAPH 3.7.1.6.

7. THERMOCOUPLES MOUNTED ON BACK SURFACE OF EVERY TUBE ACROSS WIDTH OF PANEL ARE INDICATED BY (—), REF. PARAGRAPH 3.7.1.6.

8. ACTIVE HEAT EXCHANGE SURFACE IS INDICATED BY (- - -) AND SHALL HAVE A LENGTH AND WIDTH AS SPECIFIED IN PARAGRAPH 3.2.2.1. FLUX DISTRIBUTIONS ON THIS SURFACE SHALL BE SYMMETRICAL ABOUT THE VERTICAL CENTERLINE, AND MAY VARY BETWEEN THE EXTREMES OF IDEAL VERTICAL DISTRIBUTIONS SHOWN BELOW.



Ⓣ THERMOCOUPLE
Ⓟ PRESSURE SENSOR
Ⓓ DISPLACEMENT SENSOR
Ⓙ TRACE HEATING

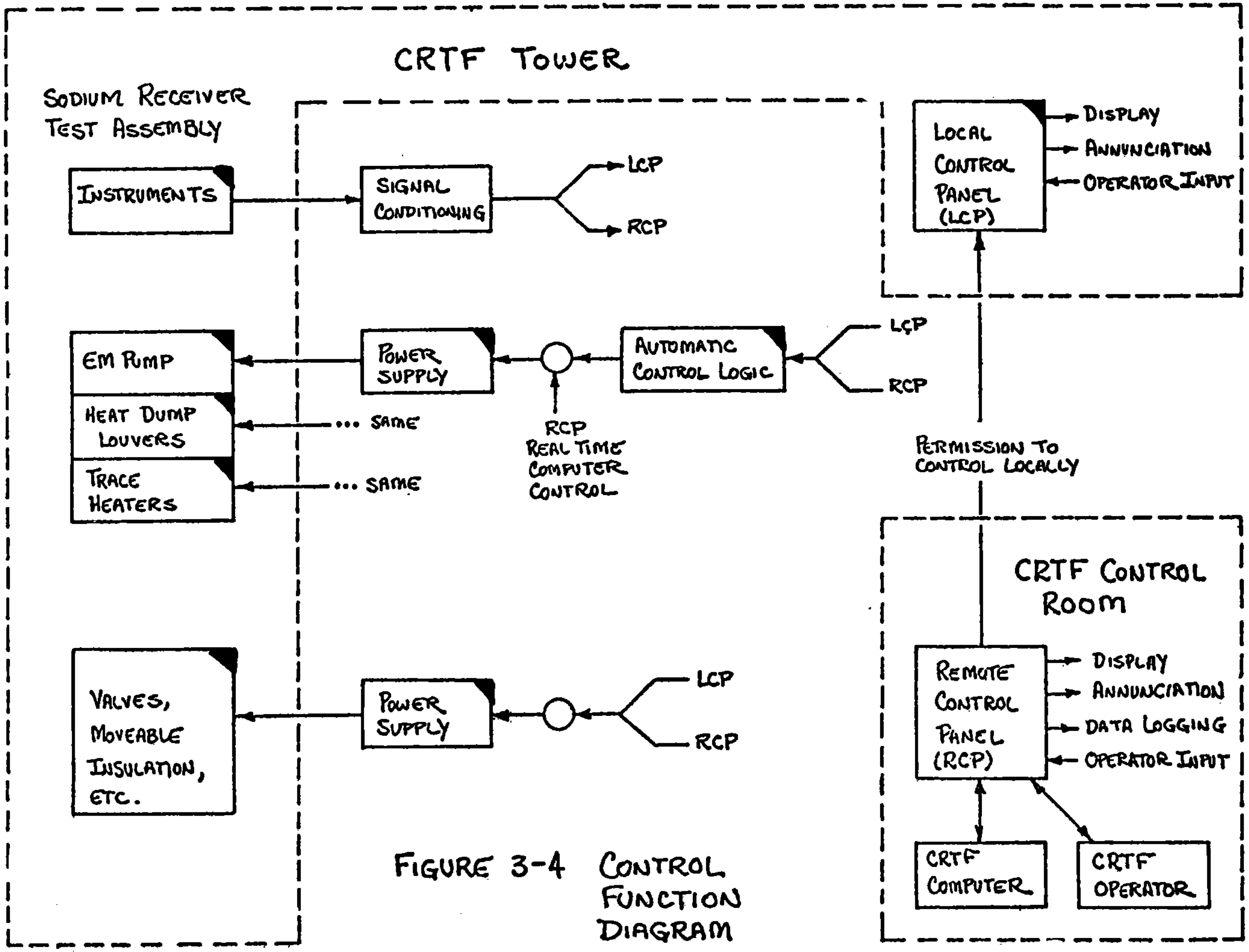
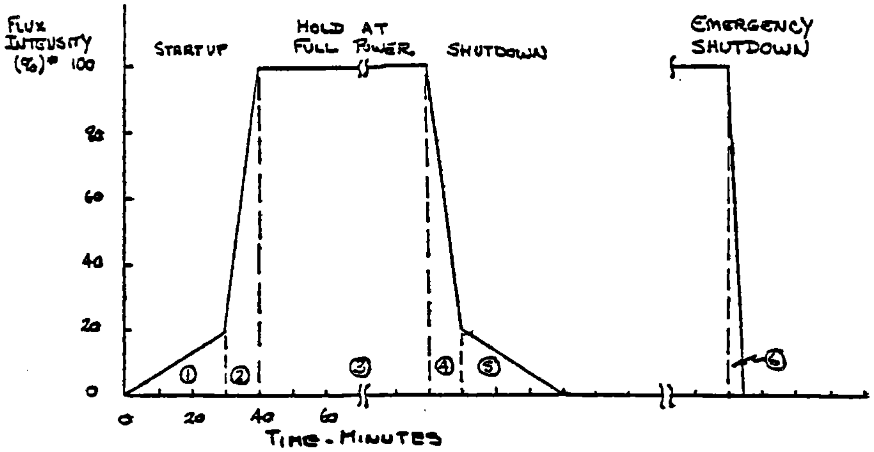


FIGURE 3-4 CONTROL FUNCTION DIAGRAM

INDICATES G.E. SUPPLIED

FIGURE 3-5 ABSORBER PANEL THERMAL CYCLING HISTOGRAM



TYPE OF CYCLE	NUMBER OF CYCLES	DURATION (MINUTES)
① RAMP TO FULL TEMPERATURE	18,000	30
② RAMP TO FULL FLUX	18,000	10
③ HOLD AT FULL FLUX CLEAR DAYS HALF CLOUDY DAYS PARTLY CLOUDY DAYS	 7,000 2,500 8,500	 600 300 60
④ RAMP TO MINIMUM FLOW	9,500	10
⑤ RAMP TO UNIFORM TEMPERATURE	9,500	30
⑥ EMERGENCY SHUTDOWN	8,500	5 SECONDS

* PERCENT OF FULL POWER FLUX INTENSITY

3.1.2 INTERFACE DEFINITION

The SRTA shall have several types of interfaces with the CRTF as described below. The details of the interfaces described in the following paragraphs will be defined in the Central Receiver Test Facility interface specification (Ref. 2.4).

3.1.2.1 Structural Interfaces

- Compatibility with CRTF supplied real time aperature flux system.
- Attachment of test support structure to the 200' level deck in the CRTF tower.
- Mounting in the tower of the EM Pump power supply and capacitors, the heat dump power supply, the preheater voltage controllers, and a control cabinet with display panel.
- Mounting of the local control cabinet in the computer room of the CRTF tower elevating module.

3.1.2.2 Utility Interface - Electrical

- EM Pump
- Heat Dump BLower
- Sodium Preheaters
- Miscellaneous service for power tools, heat dump, flux sensor drive, insulating panel drive

3.1.2.3 Utility Interface - Fluids

- Argon Supply
- Instrument Air Supply

3.1.2.4 Instrumentation Interfaces

All instrument signals (except RTAF and meteorological) shall be available for display at both the local (GE) and remote (CRTF) control panels. Selected signals will be identified for data recording.

- Signal Conditioning Equipment
- Thermocouples
- Strain Gages
- Flux Meters

- Sodium Flowmeters
- Sodium Pressure Gages
- Sodium Liquid Level Gages
- Inert Gas Pressure Gages
- Linear Displacement Sensor on Absorber Panel
- Smoke Detectors
- Real Time Aperature Flux System } No Local Readout Required
- Meteorological System }

All SRTA instrumentation signal leads shall be terminated in connectors and/or terminals compatible with the CRTF data system signal conditioning, multiplexing and other terminating equipment located in the computer room level of the tower elevator.

3.1.2.5 Control Interfaces

All control functions shall be connected to both a local control (GE) panel (in the CRTF tower) and a remote control (CRTF) panel (in the CRTF Master Control Room). The items listed below are the major control points requiring connections to these two panels.

- EM Pump automatic controls and manual override
- Heat Dump automatic louver controls and manual override
- Preheater automatic control and manual override
- Open/close control on absorber panel insulating door
- Sodium valve controls
- Inert gas valve controls

3.1.2.6 Solar Interface

The SRTA testing will require the following mutally independent incident solar beam characteristics:

- A flux distribution which is nearly uniform with an intensity of 0.5 MW/M^2 over the active panel heat exchanger area.
- A flux distribution which provides a peak intensity of 1.5 MW/M^2 near the center of the panel.
- The ability to vary the incident solar power from 0 MW to 2.5 MW and back to 0 MW in less than 10 minutes.

3.1.3 MAJOR COMPONENT LIST

The Sodium Receiver Test Assembly equipment can be organized into the following five categories:

3.1.3.1 Absorber Panel

This category includes the tube bundle and headers, support structure, insulation and associated instrumentation and heat tracing.

3.1.3.2 Heat Dump

This category includes the sodium-to-air heat exchanger, blower, louvers, support structure and associated instrumentation and heat tracing.

3.1.3.3 Fluid Circulation Equipment

This category includes the sodium piping, tanks, EM pump, purification system, valves, heat tracing, insulation, support structure, inert gas system, moveable insulation and associated instrumentation.

3.1.3.4 Monitor and Control Equipment

This category includes a local control panel (in CRTF tower), a remote control and display console (in CRTF control room), and automatic control logics for the EM pump and heat dump louvers and annunciation systems.

3.1.3.5 Auxiliary Equipment

This category includes the power supplies for the EM pump and other motors, sodium fire fighting equipment, and sodium system maintenance equipment.

3.2 CHARACTERISTICS

3.2.1 PERFORMANCE CHARACTERISTICS

The SRTA shall be desinged to provide the following performance characteristics:

3.2.1.1 Incident Solar Beam Acceptance

The SRTA shall accept a maximum steady state incident solar power of 2.5 MW on the absorber panel active heat exchanger surface. The panel shall be able to accept this power level in any distribution which is symmetric about the vertical centerline of the panel, between the extremes of uniform flux and single point aiming flux (see Figure 3-3, note 8). The SRTA shall be designed to accept transients in the solar power level of up to 1 MW/minute and hold times at full power (2.5 MW incident) of up to 10 hours.

3.2.1.2 Absorber Panel Inlet Temperature

The absorber panel inlet temperature (measured at the inlet pipe on the panel inlet header) shall be maintained at a set point between 500°F and 700°F (± 5°F) under all incident solar power levels between 0.25 MW and 2.5 MW including transient as well as steady state condition. This specification shall be met under all operating environmental conditions listed in 3.2.5.1.

3.2.1.3 Absorber Panel Outlet Temperature

The absorber panel outlet temperature (measured at the outlet pipe on the panel outlet header) shall be maintained at 1100°F ± 5°F under all steady state and transient insolation conditions from 0.25 MW to 2.5 incident power under all operating environments as defined in 3.2.5.1.

3.2.1.4 Design Life Requirements

The SRTA equipment shall be designed to operate for at least 5000 hours without significant deterioration in performance or planned replacement of major components. In addition the absorber panel shall be designed to provide 30 year life with respect to corrosion and thermal cycling damage of the metallic parts. For corrosion, 30 year life shall be defined as 131,000 hours of exposure to full load operating temperatures and environments. For thermal cycling damage, 30 year life shall be defined as in Figure 3.5.

3.2.1.5 Design Operating Modes

The SRTA shall be capable of performing in the following modes:

- Operation - In this mode the sodium pump and the heat dump are under an automatic control which responds to variations in the solar heat input to maintain the absorber panel inlet/outlet temperatures at approximately 600°F/1100°F respectively.

- Hot Hold - This is a hot shutdown condition in which the panel moveable insulation is closed and the trace heaters function under automatic control to maintain the loop temperature at approximately 600°F.

- Preheat - This is the transition from a cold ambient temperature condition to hot hold.

- Startup - This is the transition from hot hold to operation.

- Shutdown - This is the transition from operation to hot hold.

- Emergency Dump - In this mode all of the sodium is drained rapidly out of the loop into the dump tank and the loop is filled with inert gas.

- Calibration Maneuvers - Calibration modes shall be provided as required, for instance the sodium flowmeter calibration using the surge tank level gages. T/C calibration may be run over a range of isothermal temperatures from 600°F to 1100°F.

3.2.2 PHYSICAL CHARACTERISTICS

3.2.2.1 Absorber Panel Surface Area

The Sodium Receiver Test Assembly shall have an active solar heat exchange area which has a vertical dimension of ∿ 15 feet and a horizontal dimension of approximately 3.28 feet.

3.2.2.2 Surface Orientation

The heat exchange active surface shall be oriented to face towards the CRTF heliostat field (north) and be mounted in the CRTF tower at an elevation of approximately 200 feet.

3.2.2.3 Surface Obstructions

This surface shall be located in such a manner that no structural feature of the CRTF or the test assembly will obstruct the optical path between the heat exchanger and any heliostat in the field.

3.2.3 RELIABILITY - NA

3.2.4 MAINTAINABILITY

The Sodium Receiver Test Assembly shall be designed and constructed to provide free access for maintenance operations. In particular the design should minimize the necessity to cut the sodium loop or move large components requiring a crane in order to calibrate, repair or replace instrumentation, trace heaters, or electrical control and power connections.

The instrumentation and control equipment shall be designed to function over the range of operating conditions for a minimum period of six months with little or no maintenance required after initial calibration.

3.2.5 ENVIRONMENTAL CHARACTERISTICS

3.2.5.1 Operating Requirements

The Sodium Receiver Test Assembly (SRTA) shall be designed to operate under the following environmental conditions:

Temperature (Dry Bulb):	-20 to 120°F
Wind Speed:	0 to 14 M/S (30 mph)

3.2.5.2 Survival Requirements

The SRTA shall be capable of surviving without damage appropriate combinations of the environments specified below:

Wind Speed:	45 M/S gusts from any direction (100 mph)
Snow:	5 lb/ft^2 snow deposition
Lightning:	Direct hit
Rain:	3 inches in 24 hours
Ice:	2 inch thick deposit
Earthquake: (at top of tower)	.5 g lateral (no spectrum requirement)
Hail	1 inch diameter 0.9 specific gravity 75 fps

Realignment prior to returning to operations after surviving these conditions is allowable.

3.2.6 TRANSPORTABILITY

The Sodium Receiver Test Assembly shall be constructed in modular form, and all of the modules shall be of a size which may be shipped by truck. In addition all of the modules which are to be placed in the CRTF tower must be of such a size and weight that they can be lifted into place with CRTF supplied elevators and cranes.

3.2.7 INSTALLATION

The SRTA assemblies shall be designed and constructed to minimize field installation labor with particular emphasis on minimizing field welding and instrumentation attachments.

3.2.8 CLEANLINESS

Fabrication, assembly and shop testing operations shall be conducted to facilitate cleaning, inspection for cleanliness and to minimize contamination during these operations. The SRTA equipment delivered to the CRTF shall be sutiable for installation without additional cleaning. Cleaning and cleanliness control shall be implemented according to approved procedures.

ENERGY SYSTEMS PROGRAMS DEPARTMENT GENERAL ELECTRIC	ENGINEERING SPECIFICATION TITLE CLASSIFICATION	SPECIFICATION NUMBER 295A4725 ORIGINAL ISSUE DATE MAY 25 1979

3.3 DESIGN & CONSTRUCTION

As a minimum the loop components in contact with sodium shall be designed to meet ASME Section VIII Division requirements (Ref. 2.5) and the sodium piping shall comply with ANSI power piping code B31.1 (Ref. 2.6), however code stamp is not required. Additional requirements may be imposed as needed, for instance 100% x-ray inspection of butt welded absorber panel tube header welds. The structure elements of the test assembly shall comply with accepted design standards (Ref. 2.7) and all electrical power distribution equipment and electrical components shall be designed to the National Electric Code (Ref. 2.8) and National Electrical Manufacturers Association Standards (2.10).

All lifting attachements to be used for assembly or handling shall be designed for 3g in all directions. Load testing of all integral lifting lugs shall be provided. Loads encountered during shipping shall be provided for in the item design or with suitable shipping only structure. Shipping loads shall be 2g vertical and lateral and 5g in direction of travel.

The completed assembly shall be inspected for leak tightness by subjecting it to a helium leak test per ASME Section V by approved procedures.

3.3.1 MATERIALS PROCESSES AND PARTS

The absorber panel materials shall meet the appropriate ASME requirements, tubes and headers shall be constructed from a commercially available grade of Incoloy 800. The tubes shall be welded to the headers in such a way as to maximize radiographic inspection of all tube-header welds, and this inspection shall be performed. The tubes shall be joined together longitudinally by brazing. The remainder of the loop components in contact with sodium shall be constructed from stainless steel (type 304 and/or 316). All welded joints within the inlet header and between the panel outlet header and the surge tank shall be designed to be radiographed and this inspection shall be performed.

All non-corrosion resistant materials used in the structure and enclosure shall be painted with a rust preventative to protect it from the environment.

All surfaces (with the exception of the active zone panel tubing) subjected to the concentrated solar insolation from the heliostats shall be insulated to protect from thermal damage. Insulative covering shall be compatible with the environment.

REVISION NUMBER	REVISION DATE	SUPERSEDES	
3	1 April 80		PAGE 24 OF 58

3.3.2 ELECTROMAGNETIC RADIATION - NA

3.3.3 NAMEPLATE AND PRODUCT MARKINGS

The absorber panel shall bear a nameplate which lists the following information (as a minimum):

Name of manufacturer:
Material of construction:

Design temperature and pressure:
Weights: Dry, Wet
Code:

The surge tank and dump tank shall bear nameplates which specify:

Name of Manufacturer:
Material:
Volume:
Design temperature and pressure:
Weights: Dry, Wet

The electromagnetic pump shall bear a nameplate which specifies:

Name of manufacturer:
Maximum Head:
Maximum Flow:
Maximum Temperature and Pressure:
Electrical Circuits Required: volts, kVA
Weights: Dry, Wet

The heat dump shall bear a nameplat which specifies:

Name of manufacturer:
Maximum Thermal Dissipation:
Weights: Dry, Wet
Electrical Circuits Required: volts, kVA

All other components or assemblies to be lifted at CRTF shall be marked with weights; dry, wet and appropriate location of center of gravity.

3.3.4 WORKMANSHIP

Unless otherwise specified workmanship shall be that commensurate with normal commercial practice. Nuclear service, codes, and practices are not required.

3.3.5 INTERCHANGEABILITY - NA

3.3.6 SAFETY

The test assembly shall be desinged to meet applicable government safety standards for industrial equipment (Reference 2.9). In addition, the apparatus shall be designed to prevent exposure of personnel to solar spillage flux or reflected flux with intensitites greater than 1 KW/M^2. Smoke detectors and sodium low pressure sensors shall be included in the apparatus to warn of large scale leaks. Equipment and procedures shall be provided to minimize damage and contain where possible liquid sodium in the event of a leak.

3.3.7 HUMAN ENGINEERING - NA

3.4 DOCUMENTATION

3.4.1 DESIGN DOCUMENTATION

Documents required with the delivery of vendor supplied and internally (GE) manufactured components shall include pertiment design analysis to show code and specification adherence, performance characteristics, manufacturing quality resutls, load test results, as-built drawings and information required for safe handling, packaging and unpacking. The following items shall be supplied when specified in the purchase request. Other items may be added as appropriate:

1) Quality Records

- Material Certification and Properties
- Load Test Conditions and Results
- Dimensional Inspection Results
- Welding Records

2) As Built Dimensions and Drawings

3) Design Analysis

4) Component Operating Characteristics

5) Packing, Packaging and Unpacking Instructions

6) Special Handling/Shipping Requirements

3.4.2 INSTALLATION PLAN

The installation plan shall define the schedule and procedures required to install and checkout the SRTA at the CRTF. Typically procedures shall be written for:

- SRTA site assembly prior to installation
- Installation of SRTA on the elevating module
- Helium Leak Test
- CRTF interface connections
- Instrumentation Checkout (Local Control)
- Heater System Checkout
- Sodium Loading
- Instrumentation Checkout (Remote Control & Readout)
- Pre-solar checkout (minimum insolation on receiver to verify operation prior to full scale testing)

The contents of these procedures are described in paragraph 4.1.3.1.2.

3.4.3 OPERATIONS AND MAINTENANCE (O&M) PLAN

This plan shall describe the procedures necessary for the safe operation and maintenance of the SRTA at the CRTF. As a minimum the plan shall include:

- Maintenance schedule
- Functional flow diagrams of the control circuits and narrative descriptions of their operation (Ref. 3.1.3.4)
- Procedures for each of the operating modes:
  - Operaton
  - Hot Hold
  - Preheat
  - Startup
  - Shutdown
  - Emergency Dump
  - Calibration checks of instrumentation
- Pre-test and post-test evaluation of equipment operation
- Safety monitoring as required
- Support services and manpower required to operate and maintain the SRTA
- Documentation scheme to record O&M data and corrective actions as required
- Procedures for the removal and replacement of items that are field repairable.

3.4.4 TEST PLAN

The contents of the test plan are described in paragraph 4.1.1 & 4.1.3.1.

3.4.5 SAFETY ANALYSIS

A safety analysis of SRTA will be performed and a report of the results shall be available prior to the design review at the end of month 9. The safety analysis will include a first level failure mode and effects evaluation but not a statistical failure probability analysis. Design and procedural features will be identified to accommodate failure modes.

3.5 LOGISTICS

3.5.1 MAINTENANCE

To maximum extent practical the SRTA instrumentation auxiliary and control equipment shall be field replaceable. The basic design of the SRTA should allow for the replacement of these items in a reasonable amount of time.

The SRTA enclousre and support structure shall provide personnel access and design features (i.e. ladders) to facilitate maintenance.

3.5.2 SUPPLY

On site spare parts required to support the CRTF testing will be identified and available at the CRTF prior to checkout.

3.5.3 FACILITIES (CRTF ONLY)

The CRTF facility shall be capable of providing the interfaces generally described in paragraph 3.1.2 and more specifically defined in the CRTF Interface Specification (Ref. 2.4). The CRTF shall also provide space for accumulation and maintenance of the SRTA assemblies. Space shall be provided for the storage of spare parts. Office space shall be provided for the resident and transient G.E. personnel. Material handling equipment for large assemblies shall also be provided by the CRTF.

3.6 PERSONNEL AND TRAINING

Trained technicians and engineering support will be required to install, checkout and operate the test apparatus at the CRTF.

3.7 MAJOR COMPONENT CHARACTERISTICS

3.7.1 ABSORBER PANEL

3.7.1.1 Description

The absorber panel is shown schematically in Figure 3-3. It shall consist of a tube bundle having 51 tubes, each 0.75 inch O.D. (nominal) by 0.05 inch wall (nominal). These tubes shall be brazed together longitudinally to form a flat panel with a header at either end. The tube-header joints shall be formed by welding. The tube bundle shall form an active heat exchange surface which is ∿ 15 feet long.

3.7.1.2 Mounting

The absorber panel tube bundle shall be connected to a support structure which supports the weight of the panel when mounted vertically.

3.7.1.3 Flatness

The panel support structure shall maintain flatness of the tube bundle to within ± 1 inch while allowing movement for thermal expansion, under all the operating conditions defined in Figure 3.3, note 8 and paragraph 3.2.1.5 except for the preheat and emergency dump modes. The displacement sensor (Ref. Fig. 3-1) shall be capable of measuring and reporting displacement to within ± 0.05 inches.

3.7.1.4 Assembly

The panel support structure shall mate with and be easily fastened to the fluid circulation equipment support structure.

3.7.1.5 Insulation

The back side of the tube bundle shall be insulated. The maximum back side surface temperature of this insulation shall be 150°F under all operating conditions.

3.7.1.6 Instrumentation (Surface Temperature & Strain Measurements)

The tube bundle shall be instrumented on the active heat exchange surface as shown in Figure 3-3. This instrumentation shall include front surface temperature sensors, seventy seven back surface temperature sensors and fifteen strain gages mounted on the back surface. The temperature measurement shall have an accuracy of at a minimum ± 5°F.

3.7.1.7 Instrumentation (Sodium Temperature)

The absorber panel inlet and outlet header temperatures shall be measured at a minimum of 3 locations each to an accuracy of ± 4°F. The absorber panel inlet/outlet ΔT shall be measured to an accuracy of ± 1°F. In addition a sodium pressure sensor shall be located at the inlet/outlet of each header, the accuracy of these sensors shall be ± 1 psi.

3.7.1.8 Trace Heating

The panel tube bundle shall have trace heaters on the back side to maintain a hot hold temperature of 600°F ± 50°F with the moveable insulation in place.

3.7.1.9 Absorptive Coating

The front surface of the tube bundle shall be coated with a material which has the following properties at 600-1200°F

Solar absorptivity:	0.95 (minimum)
Infrared emissivity:	0.90 (maximum)
Life:	5000 hours (minimum)

In addition the thermal conductivity and thickness of the coating shall be such that the temperature rise across the coating layer is less than 50°F at an absorbed flux of 1.5 MW/M^2.

3.7.2 HEAT DUMP

3.7.2.1 Description

The heat dump shall consist of a sodium-to-air heat exchanger, an air blower, support and ducting structure, and a system for air flow control. The sodium/air heat exchanger shall be instrumented at the sodium inlet and outlet to measure sodium temperature, and shall have trace heating for preheating the exchanger prior to sodium fill.

3.7.2.2 Heat Dissipation

The heat dump shall dissipate a minimum of 2.5 MW of thermal power (measured across the sodium inlet and outlet) in all of the operating environments specified in 3.2.5.1.

3.7.2.3 Instrumentation

Thermocouples used on the heat exchanger inlet and outlet shall have an accuracy of ± 4.0°F.

3.7.3 FLUID CIRCULATION EQUIPMENT

3.7.3.1 Description

The fluid circulation equipment are described in Figure 3-1. These equipment shall consist of: sodium piping to form a closed loop with includes the panel and the heat dump, sodium inventory to fill the loop to the required level for full power operation, surge tank, dump tank, electromagnetic pump, cold trap, sodium valves, sodium flowmeters, thermocouples to measure sodium temperature, plug indicator, preheaters for dump tank, sodium liquid level indicators for tanks, heat tracing and thermocouples as required to preheat sodium piping and valves, thermal insulation for all components, insulating doors to cover panel during shutdown and to intercept spillage flux, inert gas pressurization system, structure to support all equipment and to mate with panel structure, smoke detectors, drip pans for sodium spills, and interface connections to CRTF utilities. All piping shall have a minimum of 3" of insulation with a K factor of .5 BTU in/hr/ft^2 ^{o}F at 600^{o}F. All components shall have a minimum of 4" of insulation with a K factor of .5 BTU in/hr/ft^2 ^{o}F at 600^{o}F.

3.7.3.2 Surge Tank (Location & Capacity)

The surge tank shall be mounted at the highest point in the system and shall be large enough to provide for calibrating the sodium flow meters.

3.7.3.3 Trace Heating (except drain tank)

The loop trace heating shall be sized and distributed so as to provide preheat from 70^{o}F to 600^{o}F in six hours and to maintain 600^{o}F ± 50^{o}F during shutdown and hold (shutdown and hold modes are with panel moveable insulation in place).

3.7.3.4 Loop Operating Temperature & Pressure

The entire loop shall be designed to operate at 1100^{o}F and 50 psig minimum. All sodium piping shall be designed for a maximum temperature of 1150^{o}F and a maximum pressure of 75 psig.

3.7.3.5 EM Pump (Flow Rate)

The electromagnetic pump shall provide a maximum sodium flowrate of 150 gpm at a head of 30 psi at a maximum sodium temperature of 1150^{o}F and pressure of 75 psig.

3.7.3.6 Sodium Piping (Pressure Drop)

The sodium piping shall be designed to provide a loop pressure drop (including the panel and heat dump) of less than 30 psi at 150 gpm of sodium (measured at EM pump when cold leg temperature is 600°F).

3.7.3.7 Dump Tank (Location & Capacity)

The dump tank shall be large enough to contain the entire loop inventory of sodium. The tank shall be located at the lowest point in the loop and shall be equipped with preheaters sized to heat the tank and sodium inventory from 70°F to 600°F in 24 hours and hold at 600°F ± 50°F. The dump/drain tank shall be equipped with a fill line & shut off valve for sodium transfer to and from shipping containers.

3.7.3.8 Loop Flowmeters

The flowmeters shall measure the sodium flowrate to ±1.5% of the reading within the range from 15 gpm to 150 gpm at 600°F.

3.7.3.9 Sodium Level Gages

The surge tank and dump tank shall be fitted with sodium liquid level gages. These gages shall have accuracies as follows:

Surge tank: ± 0.1%
Dump tank: ± 5.0%

3.7.3.10 Thermocouples

Thermocouples used in the fluid circulation equipment shall have an accuracy of ± 4°F or better.

3.7.3.11 Codes

Piping shall be in compliance with ANSI B31.1 (Ref. 2.6), the pressure components shall be designed to be in compliance with Section VIII Division 1 (Ref. 2.5).

3.7.3.12 Insulation (Loop)

Loop components shall be insulated with a material that is compatible with the piping material and which is protected against contamination by moisture.

3.7.3.13 Loop Impurity Monitoring

The SRTA shall be equipped with oxygen monitoring equipment for continuous monitoring of the oxygen impurity in the sodium.

3.7.3.14 Inert Gas System

The SRTA shall include an inert gas system complete with vapor traps, supply, equalizer and vent valves for maintaining the sodium system under an inert gas blanket and to provide differential pressure for loading the sodium into the system. Piping shall provide an automatic gravity drain into the drain tank in the event of an emergency condition. All inert gas piping between the sodium system and the vapor traps shall be preheated. The inert gas system shall be designed for a maximum pressure of 100 psig.

3.7.4 MONITOR & CONTROL EQUIPMENT

3.7.4.1 Operating Modes

The monitor and control equipment shall be capable of supporting the operating modes defined in paragraph 3.2.1.5:

- Operation
- Hot Hold
- Preheat
- Startup
- Shutdown
- Emergency Dump
- Calibration Maneuvers

3.7.4.2 Description

The monitor and control equipment (Ref: Figure 3-4) shall consist of a local control panel, in the CRTF tower elevating module, a remote control and display console center, the real time aperture flux system (supplied by CRTF), automatic control for EM pump to maintain panel outlet temperature, automatic control for heat dump louvers to maintain panel inlet temperature and annunciator systems.

3.7.4.3 Local & Remote Panels

All instrumentation* readout and control functions shall be available at both the local (GE) and remote (CRTF) control panels; however, the remote panel shall have precedence in all control decisions and shall be able to lock out the local panel control functions to insure the precedence.

* RTAF and meteorological not required at local panel.

3.7.4.4 EM Pump Control Logic

A control logic shall be built into the electromagnetic pump controls to automatically adjust the sodium flowrate to maintain a temperature of 1100°F ± 5°F at the absorber panel outlet for the range of solar incident power from .25 MW to 2.5 MW. This logic shall be prototypical of that which would be used in a commercial solar power plant. These control circuits shall also include the option of bypassing the built-in logic to control the EM pump through the CRTF computer.

3.7.4.5 Heat Dump Control Logic

A control logic shall be built into the heat dump louver controls to automatically maintain a sodium temperature setpoint between 500°F and 700°F (± 5°F) at the absorber panel inlet for the range of duty from 0.25 MW to 2.5 MW of reject heat. These control circuits shall include the option of bypassing the built-in logic to control the louvers through the CRTF computer.

3.7.5 AUXILIARY EQUIPMENT

3.7.5.1 Description

The auxiliary equipment shall consist of the motor controls and power supplies for the insulating panels and flux sensor drives, capacitors, and power supply for EM pump, power supply for heat dump motors, fire fighting equipment for sodium fires, maintenance equipment for working with sodium, cables and signal conditioning equipment for instrumentation and controls interconnection.

3.8 PRECEDENCE

In the event of conflict between this document and the reference documents, the contents of this specification shall be the superseding requirement.

4.0 PERFORMANCE VERIFICATION

This section establishes the test methods for verification of the design and performance requirements specified in Section 3.0 of this document.

4.1 GENERAL

The verification philosophy applicable to this specification is as follows:

a. The verification approach shall provide high confidence, consistent with economy of implementation, that each characteristic of the equipment meets its specified requirement.

b. Operational and safety tests to largest scale practical (within cost and schedule constraints) shall be performed prior to shipment of the equipment to the Central Receiver Test Facility (CRTF).

c. Verification of performance shall make full use of data available at the component level to assure performance at the total assembly level.

d. All test, operations and maintenance data for the various components/assemblies acquired throughout the life of the test program will be utilized to support and or reliability, maintainability, and availability projections.

Testing will be performed at three primary locations; vendors facilities (components), ARSD - San Jose test facilities (component/assemblies) and Department of Energy (DOE) - Central Receiver Test Facility (CRTF) (total assembly).

4.1.1 RESPONSIBILITIES

All testing shall be performed in accordance with approved test plans/procedures. The test plan shall address the following areas for each of the test locations listed in 4.1;

- test organization
- definition of areas of responsibility between interfacing organizations
- sequence and scheduling of testing
- facility test support requirements
- special test equipment (not off the shelf)

- test software and off line data reduction (OLDR) requirements
- technical details of each test
- safety considerations of each test

The results of the testing as well as any corrective action or retest required shall be documented in test reports.

The General Electric (GE) Company will be responsible for conducting the testing at the San Jose and CRTF locations. All CRTF test procedures shall be approved by CRTF and GE.

Vendor component tests will be performed by the vendor at their facilities according to procedures developed by them and approved by GE. Witnessing of vendor tests by GE will be determined on a case by case basis.

CRTF facility interface verification tests will be performed by CRTF personnel according to procedures developed by them and agreed to by GE. These tests will be witnessed by GE.

4.1.2 SPECIAL TESTS & EXAMINATIONS

4.1.2.1 ABSORBER PANEL (Major Component 3.1.3.1)

The tubes shall be welded to the header in a manner that allows for radiographic inspection of each weld.

4.1.2.2 FLUID CIRCULATION EQUIPMENT (Major Component 3.1.3.3)

All sodium piping shall be welded in a manner that allows for radiographic inspection of each weld.

4.1.3 DATA REQUIREMENTS

4.1.3.1 TEST PLANNING

General Electric shall provide a test plan and test procedures that will be used to verify the performance requirements of Section 3.0 of this specification. The test plan shall address the area's identified in paragraph 4.1.1, and be responsive to the verification matrix.

4.1.3.1.1 Facility Acceptance (CRTF Testing Only)

The test plan shall define the facility acceptance criteria and the method of acceptance. The interface specification will define the facility requirements (Ref. 2.4).

4.1.3.1.2 Installation & Checkout (CRTF Testing Only)

The test plan shall include the detailed installation and checkout procedures. These procedures as a minimum shall define:

- Prerequisites
- Support Equipment
- Special Tools
- Manpower
- Hardware
- Drawing References
- Pass/Fail Criteria

4.1.3.1.3 Safety Analysis

A safety analysis will be performed for each unique test configuration (grouping of SRTA components).

4.1.3.2 TEST PROCEDURES

Test procedures will be written to verify the performance of those characteristics requiring verification by test (Ref. 4.3). As a minimum the test procedure shall include:

- Equipment/Software Requirements
- Test Equipment
- Test Prerequisites
- Test Restrictions
- Safety Considerations
- Test Procedure
- Test Set Up and Instrumentation Block Diagrams
- Data Sheets
- Data Reduction and Analysis
- Pass/Fail Criteria

4.1.3.3 TEST REPORTS

Reports shall be provided for each test performed at the CRTF. (Ref: Test plan for sodium receiver test assembly testing at CRTF). These reports will consist of data acquired during the performance of the testing, test configuration, environmental conditions and data analysis (as required) to assess performance of the equipment under test.

4.2 VERIFICATION DEFINITIONS

Each performance requirement in Section 3 of this specification shall be verified using the following evaluation methods.

4.2.1 INSPECTION (I)

Verification by determination of physical characteristics.

4.2.2 SIMILARITY (S)

Similarity is a procedure used to show that an article is comparable with, or identical in design and manufacturing processes to, another article previously qualified to equivalent or more stringent criteria.

4.2.3 ANALYSIS (A)

Verification by examination of technical data, mathematical derivations, or analytical combination of measured data and/or other technical data of component units.

4.2.4 DEMONSTRATION (D)

Verification by operation of any item or by performance of any function without a requirement for analysis of quantitative data that might result from instrumentation of recorded observations during the verification.

4.2.5 TEST (T)

Verification by operation of any device or performance of any function that requires analysis of quantitative data that results from required instrumentation or from recorded observations during the verification.

4.3 VERIFICATION MATRIX

The verification matrix shows the classification and methods of evaluation for all Section 3 requirements. Verification of performance and design requirements shall be based on evaluation by inspection, similarity, analysis, demonstration, and/or test. Inspection shall be used to check adequacy of design documentation to applicable specifications and conformance of hardware to design documentation and applicable standards. Similarity shall be used in verifying the performance of a component that has been proven in another application.

Analysis shall be used in lieu of, or to supplement, test data. Demonstration is used when quantitative measurements are not required for verification. Tests shall be conducted when an acceptable level of confidence cannot be established by other methods or when testing can be shown to be most cost-effective method.

The Section 3 paragraphs for which verification is not applicable are indicated in the table as N/A, on the basis of the following criteria:

a. The paragraph contains the title only.

b. The paragraph is descriptive and no requirement is stated.

c. The paragraph is introductory and the requirements are stated in subsequent subparagraphs.

VERIFICATION MATRIX SECTION 3.0

REQUIREMENT REFERENCE		N/A	VERIFICATION METHOD I	S	A	D	T		COMMENTS
3.0	REQUIREMENTS	X							
3.1	ITEM DEFINITION	X							
3.1.1	DIAGRAMS		X						
3.1.2	INTERFACE DEFINITION	X							
3.1.2.1	STRUCTURAL		X		X				
3.1.2.2	UTILITY (ELECTRICAL)		X				X		Test at CRTF
3.1.2.3	UTILITY (FLUID)		X				X		Test at CRTF
3.1.2.4	INSTRUMENTATION		X				X		Test at CRTF
3.1.2.5	CONTROL		X				X		Test at CRTF
3.1.2.6	SOLAR		X		X				
3.1.3	MAJOR COMPONENTS	X							
3.1.3.1	ABSORBER PANEL		X						
3.1.3.2	HEAT DUMP		X						
3.1.3.3	FLUID CIRCULATION EQUIPMENT		X						
3.1.3.4	MONITOR AND CONTROL EQUIPMENT		X						
3.1.3.5	AUXILIARY EQUIPMENT		X						

GENERAL ELECTRIC

ENERGY SYSTEMS PROGRAMS DEPARTMENT

ENGINEERING SPECIFICATION

TITLE

CLASSIFICATION

SPECIFICATION NUMBER 295A4725

ORIGINAL ISSUE DATE MAY 25 1979

REVISION NUMBER 2

REVISION DATE

SUPERSEDES

VERIFICATION MATRIX SECTION 3.0 REQUIREMENT REFERENCE	N/A	VERIFICATION METHOD I	S	A	D	T		COMMENTS
3.2 CHARACTERISTICS	X							
3.2.1 PERFORMANCE CHARACTERISTICS	X							
3.2.1.1 INCIDENT SOLAR BEAM ACCEPTANCE				X		X		Test at CRTF
3.2.1.2 ABSORBER PANEL INLET TEMPERATURE				X		X		Test at CRTF
3.2.1.3 ABSORBER PANEL OUTLET TEMPERATURE				X		X		Test at CRTF
3.2.1.4 DESIGN LIFE REQUIREMENTS				X				
3.2.1.5 DESIGN OPERATING MODES		X		X		X		Test at CRTF
3.2.2 PHYSICAL CHARACTERISTICS	X							
3.2.2.1 ABSORBER PANEL SURFACE AREA		X						
3.2.2.2 SURFACE ORIENTATION		X						
3.2.2.3 SURFACE OBSTRUCTIONS		X						

VERIFICATION MATRIX SECTION 3.0 REQUIREMENT REFERENCE	N/A	VERIFICATION METHOD I	S	A	D	T		COMMENTS
3.2.3 RELIABILITY	X							
3.2.4 MAINTAINABILITY		X	X		X			Demonstration at CRTF
3.2.5 ENVIRONMENTAL CHARACTERISTICS	X							
3.2.5.1 OPERATING REQUIREMENTS				X				
3.2.5.2 SURVIVAL REQUIREMENTS				X				

GENERAL ELECTRIC — ENERGY SYSTEMS PROGRAMS DEPARTMENT

ENGINEERING SPECIFICATION

TITLE

CLASSIFICATION

SPECIFICATION NUMBER 295A4725

ORIGINAL ISSUE DATE MAY 25 1979

REVISION NUMBER 2

REVISION DATE

SUPERSEDES

VERIFICATION MATRIX SECTION 3.0 REQUIREMENT REFERENCE		N/A	VERIFICATION METHOD I	S	A	D	T		COMMENTS
3.2.6	TRANSPORTABILITY		X			X			
3.2.7	INSTALLATION		X			X			Demonstration at CRTF
3.2.8	CLEANLINESS		X			X			Demonstration at CRTF
3.3	DESIGN & CONSTRUCTION		X		X	X	X		See 4.2.27
3.3.1	MATERIALS, PROCESSES AND PARTS		X						
3.3.2	ELECTROMAGNETIC RADIATION	X							
3.3.3	NAMEPLATE & PRODUCT MARKINGS		X						
3.3.4	WORKMANSHIP		X						
3.3.5	INTERCHANGEABILITY	X							
3.3.6	SAFETY		X		X		X		
3.3.7	HUMAN ENGINEERING	X							

VERIFICATION MATRIX SECTION 3.0 REQUIREMENT REFERENCE		N/A	VERIFICATION METHOD I	S	A	D	T		COMMENTS
3.4	DOCUMENTATION	X							
3.4.1	DESIGN DOCUMENTATION		X						
3.4.2	INSTALLATION PLAN		X						
3.4.3	OPERATIONS & MAINTENANCE PLAN		X						
3.4.4	TEST PLAN		X						
3.4.5	SAFETY ANALYSIS		X						
3.5	LOGISTICS	X							
3.5.1	MAINTENANCE		X						
3.5.2	SUPPLY		X						
3.5.3	FACILITIES		X						
3.6	PERSONNEL & TRAINING		X						
3.7	MAJOR COMPONENTS CHARACTERISTICS	X							
3.7.1	ABSORBER PANEL	X							
3.7.1.1	DESCRIPTION		X						
3.7.1.2	MOUNTING		X		X	X			Demonstration at CRTF

GENERAL ELECTRIC
ENERGY SYSTEMS PROGRAMS DEPARTMENT

ENGINEERING SPECIFICATION

TITLE

CLASSIFICATION

ORIGINAL ISSUE DATE: MAY 25 1979

SPECIFICATION NUMBER: 295A4725

REVISION NUMBER: 2

REVISION DATE

SUPERSEDES

ES3 005 .5 78.

VERIFICATION MATRIX SECTION 3.0 REQUIREMENT REFERENCE	N/A	VERIFICATION METHOD I	S	A	D	T		COMMENTS
3.7.1.3 FLATNESS		X		X		X		Test at CRTF
3.7.1.4 ASSEMBLY		X						
3.7.1.5 INSULATION		X		X				
3.7.1.6 INSTRUMENTATION (SURFACE TEMPERATURE & STRAIN MEASUREMENT)		X	X	X				
3.7.1.7 INSTRUMENTATION (SODIUM TEMPERATURE)		X	X					
3.7.1.8 TRACE HEATING		X		X		X		Test at CRTF
3.7.1.9 ABSORPTIVE COATING		X	X					
3.7.2 HEAT DUMP	X							
3.7.2.1 DESCRIPTION		X						
3.7.2.2 HEAT DISSIPATION				X		X		Test at CRTF
3.7.2.3 INSTRUMENTATION		X	X					
3.7.3 FLUID CIRCULATION EQUIPMENT	X							
3.7.3.1 DESCRIPTION		X						
3.7.3.2 SURGE TANK (LOCATION & CAPACITY)		X		X				
3.7.3.3 TRACE HEATING		X		X		X		Test at CRTF

VERIFICATION MATRIX SECTION 3.0

REQUIREMENT REFERENCE	N/A	I	S	A	D	T		COMMENTS
3.7.3.4 LOOP OPERATING TEMPERATURE & PRESSURE		X						
3.7.3.5 EM PUMP (FLOW RATE)		X	X					
3.7.3.6 SODIUM PIPING (PRESSURE DROP)				X		X		Test at CRTF
3.7.3.7 DUMP TANK (LOCATION & CAPACITY)		X		X		X		Test at CRTF
3.7.3.8 LOOP FLOW METERS		X				X		Test at CRTF
3.7.3.9 SODIUM LEVEL GAUGES		X	X					
3.7.3.10 THERMOCOUPLES		X	X					
3.7.3.11 CODES		X						
3.7.3.12 INSULATION		X						
3.7.3.13 LOOP IMPURITY MONITORING		X						
3.7.3.14 INERT GAS SYSTEM		X						
3.7.4 MONITOR & CONTROL EQUIPMENT	X							
3.7.4.1 OPERATING MODES		X		X	X			Demonstration at CRTF
3.7.4.2 DESCRIPTION		X						
3.7.4.3 LOCAL & REMOTE PANELS		X			X			Demonstration at CRTF
3.7.4.4 EM PUMP CONTROL LOGIC		X		X		X		Test at CRTF
3.7.4.5 HEAT DUMP CONTROL LOGIC		X		X		X		Test at CRTF
3.7.5 AUXILIARY EQUIPMENT	X							
3.7.5.1 DESCRIPTION		X						

VERIFICATION MATRIX
SECTION 3.0

REQUIREMENT REFERENCE	N/A	VERIFICATION METHOD I	S	A	D	T	COMMENTS
3.8 PRECEDENCE	X						

4.4 VERIFICATION METHODS

This section establishes the test verification methods and concepts that shall be used to verify the requirements of section 3.0. The verification matrix (Ref. 4.3) includes a cross reference to the appropriate section 3.0 Requirement paragraph and verification method.

Tests may be combined or rearranged in order to accommodate a more cost effective program or to maintain the program schedule.

In the following paragraphs the number in the parenthesis referes to the appropriate section 3.0 paragraph.

4.4.1 DIAGRAMS (3.1.1)

An inspection of the drawings and hardware of the SRTA shall be done to assure the equipment delineated in Figures 3-1, 3-2, 3-3 is present.

4.4.2 STRUCTURAL INTERFACES (3.1.2.1)

An inspection of the drawings and mounting structures will assure the physical compatibility of the interface.

An analysis will be performed to verify the ability of the structure to support the SRTA over the full range of its operating environments and modes.

4.4.3 UTILITY (ELECTRICAL) (3.1.2.2)

An inspection of the drawing and equipment shall verify the availability and distribution of the specified interface.

Testing to the maximum extent practical shall be performed to verify the functioning and regulation of the interface to within the specified tolerances.

4.4.4 UTILITY (FLUID) (3.1.2.3)

Same as Paragraph 4.3.3.

4.4.5 INSTRUMENTATION (3.1.2.4)

Same as Paragraph 4.3.3.

4.4.6 CONTROL (3.1.2.5)

Same as Paragraph 4.3.3.

4.4.7 SOLAR (3.1.2.6)

An inspection of flux plots shall verify the ability of the CRTF to provide the required solar interface.

An analysis of the facility control fucntions will verify its ability to vary the flux over the required range within the required time frame.

4.4.8 ABSORBER PANEL (3.1.3.1)

An inspection of the drawings and hardware shall verify conformance with the paragraph description and requirements.

4.4.9 HEAT DUMP (3.1.3.2)

Same as Paragraph 4.4.8.

4.4.10 FLUID CIRCULATION EQUIPMENT (3.1.3.3)

Same as Paragraph 4.4.8.

4.4.11 MONITOR AND CONTROL EQUIPMENT (3.1.3.4)

Same as Paragraph 4.4.8.

4.4.12 AUXILIARY EQUIPMENT (3.1.3.5)

Same as Paragraph 4.4.8.

4.4.13 INCIDENT SOLAR BEAM ACCEPTANCE (3.2.1.1)

An analysis of the design shall substantiate its ability to accept the flux levels, distributions and transients associated with actual operation.

Testing of the SRTA under the specified conditions will verify performance of the unit, cooroborate the analysis and characterize the actual performance of the receiver.

4.4.14 ABSORBER PANEL INLET TEMPERATURE (3.2.1.2)

An analysis of the SRTA design and control loop functions over its range of operating modes and environmental conditions will substantiate the ability of the unit to satisfy its requirements.
Testing of the SRTA under the specified conditions will verify performance of the unit, corroborate the analysis and characterize the actual performance of the test assembly.

4.4.15 ABSORBER PANEL OUTLET TEMPERATURE (3.2.1.3)

Same as Paragraph 4.4.14.

4.4.16 DESIGN LIFE REQUIREMENTS (3.2.1.4)

An analysis of the ATP design shall verify the 30 year requirement under the specified corrosion and thermal cycling conditions.

4.4.17 DESIGN OPERATING MODES (3.2.1.5)

An inspection of the drawings and hardware will identify the equipment necessary to support the operating modes.

Analysis of the design will substantiate its ability to satisfy the specification requirements.

Testing at CRTF will verify compliance with the requirements and corroborate the analysis.

4.4.18 ABSORBER PANEL SURFACE AREA (3.2.2.1)

Same as Pragraph 4.4.8.

4.4.19 SURFACE ORIENTATION (3.2.2.2)

Same as Pragraph 4.4.8.

4.4.20 SURFACE OBSTRUCTIONS (3.2.2.3)

Same as Paragraph 4.4.8.

4.4.21 MAINTAINABILITY (3.2.4)

An inspection of the drawings and equipment will substantiate the ease of maintenance requirement. The ability of the equipment to support the 6 month operational requirement will be verified by data from use in similar applications. Verification of this requirement will be demonstrated by the maintenance activities performed at CRTF.

4.4.22 OPERATING REQUIREMENTS (3.2.5.1)

An analysis of the SRTA design shall verify ability to operate in the specified environment.

4.4.23 SURVIVAL REQUIREMENTS (3.2.5.2)

An analysis of the SRTA design shall verify its ability to survive the specified environment.

4.4.24 TRANSPORTABILITY (3.2.6)

An inspection of drawings and hardware shall substantiate the ability of the equipment to meet these requirements. Actual compliance will be demonstrated by shipping the equipment to the CRTF via truck and having the SRTA equipment placed on the test tower.

4.4.25 INSTALLATION (3.2.7)

An inspection of the drawings and hardware shall substantiate the ability of the equipment to meet these requirements. Actual compliance will be demonstrated by installation at CRTF.

4.4.26 CLEANLINESS (3.2.8)

An inspection of the facilities and procedures used for the fabrication and assembly of the equipment will substantiate compliance with requirement. The ability to assemble the SRTA on site (CRTF) without additional cleaning will demonstrate compliance with this requirement.

4.4.27 DESIGN & CONSTRUCTION (3.3)

Paragraph 3.3 has essentially four specific verification requirements:

Code Compliance - Inspection of the documentation required in paragraph 3.4.1 will verify compliance with the codes and standards requirements.

Lifting Lug Load Tests - An analysis of the design will substantiate the ability of the lifting lugs to satisfy the requirements. Tests will be performed to verify compliance with this requirement.

Shipping Loads - An analysis of the design of the unit and/or the shipping structure will substantiate its ability to withstand the required shipping loads.

Periodic inspections of the equipment during transport and final inspection on arrival at site (CRTF) will demonstate compliance with this requirement.

Leak Tests — Tests will be performed on the assembled SRTA to verify compliance with the leak requirements. This test will be performed at CRTF after completion of the field welds.

4.4.28 MATERIALS, PROCESSES AND PARTS (3.3.1)

Inspection of documentation required in paragraph 3.4.1 will verify compliance with codes and standards requirements.

4.4.29 NAMEPLATE AND PRODUCT MARKING (3.3.3)

Same as Paragraph 4.4.8.

4.4.30 WORKMANSHIP (3.3.4)

Same as Paragraph 4.4.28.

4.4.31 SAFETY (3.3.6)

Inspection of SRTA drawings and equipment will verify the presence of required safety equipment. An analysis of system design and operations will verify that it is compliant with the specified safety requirements. Tests will be performed to verify operation of the safety monitoring equipment.

4.4.32 DESIGN DOCUMENTATION (3.4.1)

An inspection of the documentation shall verify this requirement.

4.4.33 INSTALLATION PLAN (3.4.2)

Same as Paragraph 4.4.32.

4.4.34 OPERATIONS AND MAINTENANCE PLAN (3.4.3)

Same as Paragraph 4.4.32.

4.4.35 TEST PLAN (3.4.4)

Same as Paragraph 4.4.32.

4.4.36 SAFETY ANALYSIS (3.4.5)

Same as Paragraph 4.4.32.

4.4.37 MAINTENANCE (3.5.1)

Same as Paragraph 4.4.8.

4.4.38 SUPPLY (3.5.2)

Inspection of documentation, order forms and bills of lading shall verify conformance with this requirement.

4.4.39 FACILITIES (3.5.3)

Inspection of drawing and designated facilities shall verify conformance with this requirement.

4.4.40 PERSONNEL AND TRAINING (3.6)

Inspection of documentation supplied in 3.4.4 (test plan) shall verify this requirement. The test plan will contain a description of the test organization (GE personnel) required to install, checkout, test and O&M.

4.4.41 DESCRIPTION (3.7.1.1)

Same as Paragraph 4.4.8.

4.4.42 MOUNTING (3.7.1.2)

An inspection of the drawing and equipment will verify compliance with the equipment description. The ability of the support structure to support the absorber panel will be substantiated by analysis and verified by demonstration at CRTF.

4.4.43 FLATNESS (3.7.1.3)

An inspection of the drawings and equipment will identify the method of allowing movement for thermal expansion. An analysis of the design will substantiate the ability of the equipment to maintain the flatness tolerance.

Testing of the equipment at CRTF under the specified conditions of operation will verify design compliance with the requirement, corroborate the analysis, and characterize the actual performance of the unit.

4.4.44 ASSEMBLY (3.7.1.4)

Same as Paragraph 4.4.8.

4.4.45 INSULATION (3.7.1.5)

An inspection of the drawing and equipment will verify that the back side of the tube bundle is insulated. An analysis of the design shall substantiate the ability of the insulation to maintain the 150° degree temperature over the range of operating modes and environments.

4.4.46 INSTRUMENTATION (SURFACE TEMPERATURE AND STRAIN MEASUREMENT (3.7.1.6)

An inspection of drawing and equipment will verify the quantity and location of the specified instrumentation. Calibration data on similar instrumentation in similar temperature regimes and analysis of SRTA geometry will verify compliance of the accuracy tolerance.

4.4.47 INSTRUMENTATION (SODIUM TEMPERATURE) (3.7.1.7)

An inspection of the drawings and equipment will verify the quantity and location of the specified instrumentation.

Calibration data on similar instrumentation in similar temperature regimes will verify compliance of the accuracy tolerance.

4.4.48 TRACE HEATING (3.7.1.8)

Inspection of the drawing and equipment shall verify the presence of the trace heating units. An analysis of the design will substantiate its ability to maintain the required temperature under the specified conditions. Testing at CRTF under these conditions will verify compliance with the design and corroborate the analysis.

4.4.49 ABSORPTIVE COATING (3.7.1.9)

An inspeciton of the drawings and equipment will verify the presence and quality of an absorptive coating. The ability of the coating to comply with the requirements will be verified by data from use in similar applications.

4.4.50 DESCRIPTION (3.7.2.1)

Same as Paragraph 4.4.8.

4.4.51 HEAT DISSIPATION (3.7.2.2)

An analysis of the deisgn shall substantiate its ability to satisfy the heat dissipation requirements over the range of operating modes and environmental conditions.

Testing at CRTF over the range of operating modes and available environmental conditions will verify compliance with this requirment, corroborate the analysis and provide data for the overall characterization of SRTA.

4.4.52 INSTRUMENTATION (3.7.2.3)

Same as Paragraph 4.4.47.

4.4.53 DESCRIPTION (3.7.3.1)

Same as 4.4.8.

4.4.54 SURGE TANK (LOCATION AND CAPACITY) (3.7.3.2)

An inspection of the drawings and equipment shall verify that the surge tank is at the highest point in the system. An analysis of the system design and surge tank capacity will verify that it is large enough to support calibrating of the sodium flow meters.

4.4.55 TRACE HEATING (3.7.3.3)

Same as Paragraph 4.4.48.

4.4.56 LOOP OPERATING TEMPERATURES & PRESSURE (3.7.3.4)

An inspection of the drawing and equipment will verify that the selection of materials is compatible with the temperature and pressure criteria.

4.4.57 EM PUMP FLOW RATE (3.7.3.5)

Inspection of the drawing and equipment shall substantiate the ability of the equipment design to satisfy specification requirements. Operating data on similar equipment under similar operating conditions shall verify the compliance with the requirements.

4.4.58 SODIUM PIPING (PRESSURE DROP) (3.7.3.6)

An analysis of the design shall substantiate its ability to satisfy the requirement.

Testing at CRTF under the stated conditions will verify compliance with the requirements, corroborate the analysis and contribute data to the overall characterization of SRTA performance.

4.4.59 DUMP TANK (LOCATION AND CAPACITY) (3.7.3.7)

An inspection of the drawing and equipment shall show compliance with the paragraph description and verify that it is in the lowest point in the loop. An analysis of the design will substantiate the tank capacity. Testing at CRTF will verify compliance with the preheater requirements.

4.4.60 LOOP FLOWMETERS (3.7.3.8)

An inspection of the drawings and equipment will verify the inclusion of the specified instrumentation. Calibration tests will verify compliance with the accuracy requirement.

4.4.61 SODIUM LEVEL GAUGES (3.7.3.9)

Same as Paragraph 4.4.57.

4.4.62 THERMOCOUPLES (3.7.3.10)

Same as Paragraph 4.4.47.

4.4.63 CODES (3.7.3.11)

Inspection of the documentation required in paragraph 3.4.1 will verify compliance with this requirement.

4.4.64 INSULATION (3.7.3.12)

Inspection of drawings and equipment will verify the presence of the required insulation.

4.4.64a LOOP IMPURITY MONITORING (3.7.3.13)

Same as paragraph 4.4.8.

4.4.64b INERT GAS SYSTEM (3.7.3.14)

Same as paragraph 4.4.8.

4.4.65 OPERATING MODES (3.7.4.1)

An inspection of the drawing and equipment will indicate the ability of the monitoring and control equipment to support the specified operating modes.

An analysis of the design will substantiate this and verification will be demonstated at CRTF.

4.4.66 DESCRIPTION (3.7.4.2)

Same as Paragraph 4.4.8.

4.4.67 LOCAL AND REMOTE PANELS (3.7.4.3)

The ability of the control panels to readout the required date and the precedence of the remote panel shall be substantiated by inspection of drawing and equipment and verified by demonstration at the CRTF.

4.4.68 EM PUMP CONTROL LOGIC (3.7.4.4)

An inspection of the drawing and equipment shall verify conformance with the equipment description. An analysis of the design shall substantiate its compliance with the specified requirements. Testing at CRTF will verify compliance with the requirements, corroborate the analysis and provide data for SRTA performance characterization.

4.4.69 HEAT DUMP CONTROL LOGIC (3.7.4.5)

Same as 4.4.68

4.4.70 DESCRIPTION (3.7.5.1)

Same as Paragraph 4.4.8.

5.0 PREPARATION FOR DELIVERY

Preparation for delivery of the equipment will be the responsibility of the appropriate vendor according to accepted standards for the equipment involved. Acceptance of equipment at CRTF by GE will preclude accepting equipment sustaining visual damage.

6.0 NOTES - NA

APPENDIX B

EQUIPMENT SPECIFICATION FOR ABSORBER PANEL

ENERGY SYSTEMS PROGRAMS DEPARTMENT GENERAL ELECTRIC	ENGINEERING SPECIFICATION	SPECIFICATION NUMBER 295A4724
	TITLE EQUIPMENT SPECIFICATION FOR ABSORBER PANEL	ORIGINAL ISSUE DATE AUG 8, 1979
	CLASSIFICATION C1	

ENGR. [signature] DATE 8/14/79	
MFG. DATE	PROGRAM MGR. [signature] DATE 8/13/79
	QA DATE
MAT'LS DATE	
PREPARED BY [signature] DATE 8/14/79	ISSUED BY [signature] DATE 8/14/70

REVISION NUMBER	REVISION DATE	SUPERSEDES	PAGE
1	4·9·80	ORIGINAL ISSUE	PAGE 1 OF 39

ES3-003 (5-78)

GENERAL ELECTRIC

ENERGY SYSTEMS PROGRAM DEPARTMENT

REVISION CONTROL SHEET

No. 295A4724
Rev 1
Cont. on Sh 2A Sh 2 of 39

TITLE

REVISION AUTHORIZATION

REV. NO.	0	1
SH. NO.	LATEST REVISION NUMBER	
1		X
2		X
3		
4		
5		
6		
7		X
8		X
9		X
10		X
11		X
12		X
13		
14		X
15		X
16		X
17		X
18		X
19		
20		
21		
22		X
23		
24		
25		X
26		
27		
28		
29		
30		
31		

Prepared by Date

Document Status

Project

Config. Control Cl.:

Functional Cl.:

Proprietary CL.:

Issued by Issue Date 8/14/76

No. 295A4724 Rev. No. 1

ES-3-004 (5-78)

GENERAL ELECTRIC

ENERGY SYSTEMS PROGRAM DEPARTMENT

REVISION CONTROL SHEET

Rev 1

Cont. on Sh — Sh 2A OF 39

TITLE

REVISION AUTHORIZATION

REV. NO.	0	1																
SH. NO.	LATEST REVISION NUMBER																	
32																		
33																		
34																		
35		X																
36																		
37																		
38		X																
39		X																

Prepared by / Date	Document Status	Project
Config. Control Cl.:		Functional Cl.: / Proprietary CL.:
Issued by [signature] Issue Date 8/14/76		No. 295A4724 Rev. No. 1

ES-3-004 (5-78)

ENERGY SYSTEMS PROGRAMS DEPARTMENT

GENERAL ELECTRIC

ENGINEERING SPECIFICATION

TITLE

CLASSIFICATION

SPECIFICATION NUMBER 295A4724

ORIGINAL ISSUE DATE AUG 8, 1979

TABLE OF CONTENTS

REVISION NUMBER	REVISION DATE	SUPERSEDES	PAGE 3 OF 39

1.0 SCOPE

This specification establishes the requirements for the design, fabrication, testing and delivery of an Absorber Panel. The Vendor shall be responsible that all work and/or material provided by him or his subcontractors meets the requirements of this specification.

2.0 APPLICABLE DOCUMENTS

The following listed documents form a part of this specification to the extent specified herein. The requirements of this document shall govern if conflicts exist in the contents of the documents. Unless otherwise indicated that issue in effect on 25 May 1979 shall apply.

2.1 ASME Boiler & Pressure Vessel Code

Section II, Materials

Section V, Non-Destructive Examination

Section VIII, Division 1

2.2 American Institute of Steel Construction Manual

2.3 Interface Control Drawing E-017.

2.4 Deleted.

2.5 National Electric Code, NFPA 70-1978

2.6 National Electrical Manufacturers Associations (NEMA) Standards

2.8 Deleted.

3.0 REQUIREMENTS

The absorber panel assembly design, construction and performance requirements are described this section.

3.1 ITEM DEFINITION

The following items are covered by this specification and will be provided by the panel manufacturer unless specified "to be supplied by others". The absorber panel consists of a flat panel assembly of Incoloy 800 seamless tubes welded to an inlet header and single connecting pipe at one end and an outlet header and single connecting pipe at the other end. The tubes are metalluriGically joined together by brazing. The panel assembly shall be mounted to a panel support structure with appropriate attachments to accommodate differential thermal expansion encountered during any operating conditions. Heating elements are provided on the back side of the panel assembly to maintain a hot hold condition. Measuring instrumentation and lead outs are to be supplied by others and shall be attached to the panel by others to monitor temperatures and strain conditions during operation. Thermal insulation shall be provided between the heating elements and supporting structure and on the inlet/outlet headers and pipes. A high absorptivity coating shall be applied to the tubes on the panel side exposed to solar readiation. All attachements, clips and mountings required for the above other than measuring instrumentation shall be provided. A solar shield, to be supplied by others, will surround the active panel to protect the support structure and limit incident flux to the active panel region.

3.1.1 ITEM DIAGRAMS

The following diagrams are a part of this specification.

Figure 3-1 Sodium Receiver Test Assembly - Schematic
Figure 3-2 Absorber Panel Thermal Cycling
Figure 3-3 Absorber Panel Dimensional Limits
Figure 3-4 Panel Flux Distribution
Figure 3-5 Flux Distribution for Cyclic Life

3.1.2 INTERFACE DEFINITION

The absorber panel, as defined in 3.1, shall interface with other portions of a Sodium Receiver Test Assembly (SRTA) as shown schematically in Figure 3-1 and the general dimensional limits of Figure 3-3. Specific interfaces are as defined below and in reference 2.3.

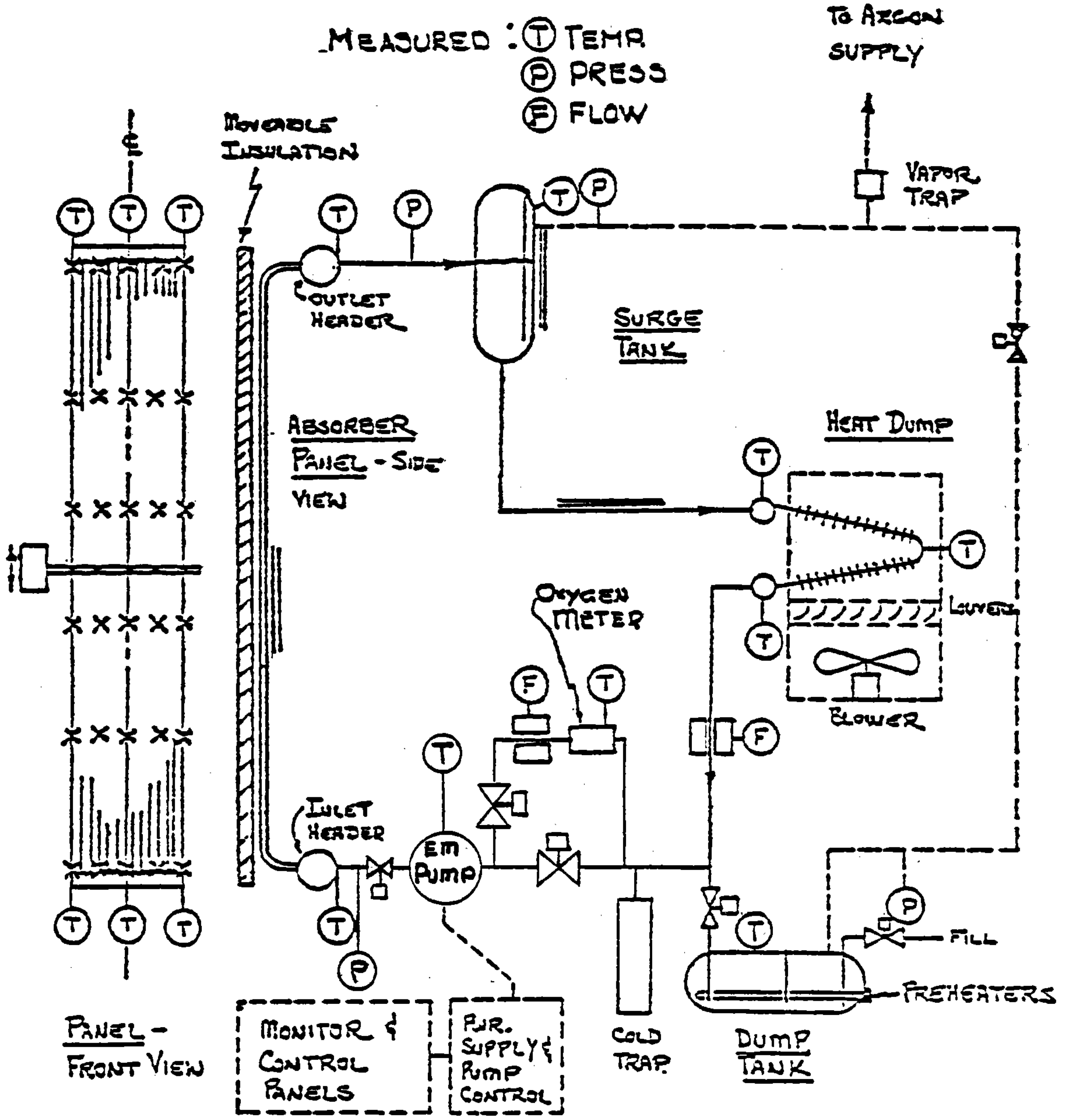
3.1.2.1 Structural Interfaces

- Absorber panel support structure to the fluid circulation equipment structure.
- Inlet/outlet header piping with loop piping. Pipe mechanical loads are as shown in Figure 3-3.
- Solar shield as shown in Figure 3-3 and Reference 2.3.

3.1.2.2 Fluid Interface

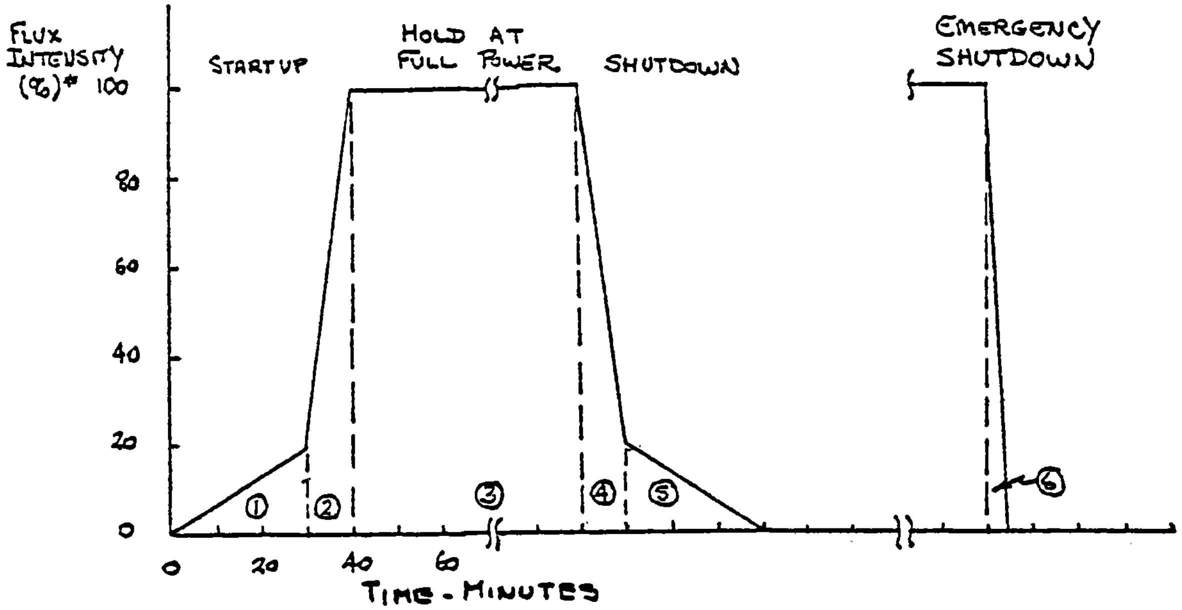
- Inlet/outlet header piping with loop piping.

FIGURE 3-1 SODIUM RECEIVER TEST ASSEMBLY (SRTA) SCHEMATIC



ABSORBER PANEL THERMAL CYCLING HISTOGRAM - FIGURE 3-2

Nov 5, 1979



TYPE OF CYCLE	NUMBER OF CYCLES	DURATION (MINUTES)
① RAMP TO FULL TEMPERATURE	18,000	30
② RAMP TO FULL FLUX	18,000	10
③ HOLD AT FULL FLUX		
CLEAR DAYS	7,000	600
HALF CLOUDY DAYS	2,500	300
PARTLY CLOUDY DAYS	8,500	60
④ RAMP TO MINIMUM FLOW	9,500	10
⑤ RAMP TO UNIFORM TEMPERATURE	9,500	30
⑥ EMERGENCY SHUTDOWN	8,500	5 SECONDS

* PERCENT OF FULL POWER FLUX INTENSITY

PAGE 10 OF 39
REVISION 1
4-9-80

SYSTEMS PROGRAMS DEPARTMENT GENERAL ELECTRIC	ENGINEERING SPECIFICATION	NUMBER 295A 4724
	TITLE	ORIGINAL ISSUE DATE AUG 8, 1979
	CLASSIFICATION	

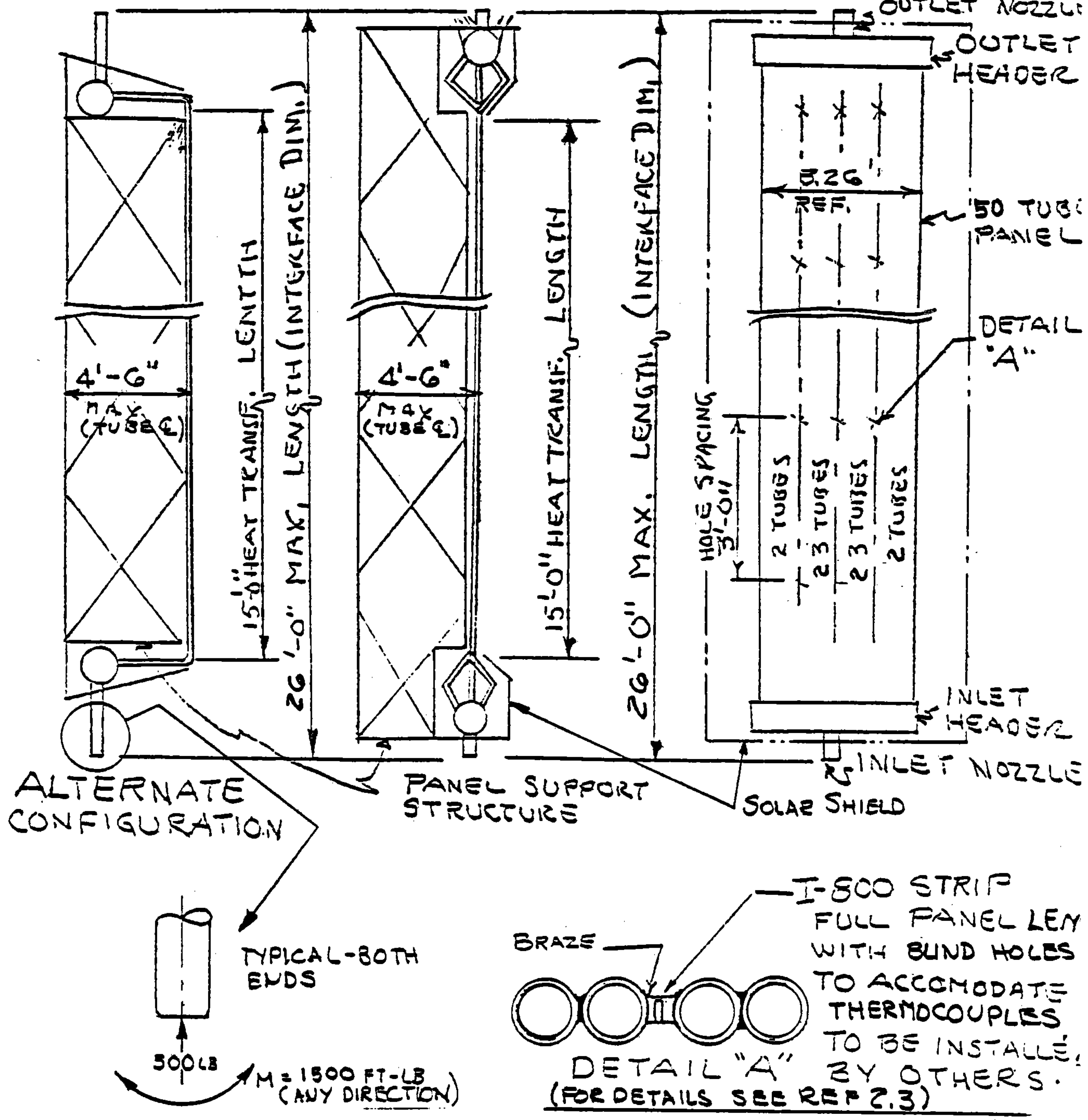


FIGURE 3-3, ABSORBER PANEL DIMENSIONAL LIMITS

Table 3-4

Table 3-4 provides solar test panel flux and thermodynamic characteristics for the following operating conditions.

A - "Uniform" flux with a total incident flux on the panel of 2.5 MW and an ambient temperature of 70°F used to calculate losses.

B, C - Same as A but with ambient temperatures of -20°F and 120°F respectively.

D - "Uniform" flux but reduced to a value consistent with a pump minimum flow of 20 GPM and an ambient temperature of 70°F.

E, F - Same as D but with ambient temperatures of -20°F and 120°F respectively.

G - "Peak" flux with a total incident flux on the panel of 2.5 MW and an ambient temperature of 70°F used to calcaulate losses.

A Uniform Flux, 70°F Ambient

ATPFW 11:19EDT 09/05/79

AIR TEMP.,CONV. COEFF.,C1?70.,2.0,.6366

FLUX PLOT FILENAME?FLUXTF

FULL PRINT(YES=1,NO=0)?1

RECEIVER SUMMARY

FLOW	=	50798.LB/HR
INCIDENT	=	2495438.W
RAD. LOSS	=	86998.W
CONV. LOSS	=	24845.W
REFL. LOSS	=	124772.W
EFFICIENCY	=	0.9052

TUBE GROUP	FLOW LB/HR	INCIDENT W	RADIATION W	CONVECTION W	EFFICIENCY
1	4618.	195242.	6783.	2139.	0.9043
2	4618.	213277.	7397.	2208.	0.9050
3	4618.	228505.	7946.	2265.	0.9053
4	4618.	239689.	8369.	2307.	0.9055
5	4618.	246663.	8644.	2333.	0.9055
6	4618.	249346.	8748.	2343.	0.9055
7	4618.	246622.	8640.	2333.	0.9055
8	4618.	239606.	8366.	2307.	0.9055
9	4618.	228381.	7941.	2265.	0.9053
10	4618.	213071.	7388.	2207.	0.9050
11	4618.	195036.	6775.	2139.	0.9043

OUTSIDE TUBE TEMPERATURES(DEG. F)

1052.1	1094.0	1129.3	1155.2	1171.3	1177.5	1171.4	1155.2	1129.3	1094.0	1052.1
1045.6	1086.9	1121.8	1147.2	1163.0	1169.1	1162.7	1146.8	1121.2	1086.2	1044.9
1019.6	1058.5	1090.9	1114.8	1129.7	1135.2	1129.4	1114.3	1090.1	1057.3	1018.4
980.1	1015.1	1044.5	1066.0	1079.4	1084.6	1079.1	1065.6	1044.0	1014.2	979.2
935.7	966.8	992.5	1011.6	1023.7	1027.9	1023.3	1011.3	992.1	966.0	935.1
890.1	916.9	939.4	955.8	966.3	970.1	966.0	955.6	939.3	916.5	889.7
844.2	866.7	885.6	899.6	908.4	911.5	908.3	899.6	885.6	866.6	843.9
797.4	815.7	831.1	842.4	849.5	852.2	849.3	842.2	831.1	815.5	797.1
749.0	763.0	774.8	783.4	789.0	790.8	788.8	783.4	774.6	763.0	748.7
698.0	707.3	715.3	721.1	725.0	726.4	725.0	721.5	715.9	708.1	698.6
648.7	653.2	657.0	660.1	661.9	662.5	662.1	660.5	657.8	654.0	649.5

NODE EFFICIENCIES(P.U.)

0.835	0.834	0.833	0.832	0.831	0.831	0.831	0.832	0.834	0.835	0.837
0.878	0.877	0.877	0.876	0.876	0.876	0.876	0.876	0.877	0.878	0.878
0.894	0.894	0.893	0.893	0.893	0.893	0.893	0.893	0.893	0.894	0.894
0.902	0.902	0.902	0.902	0.901	0.901	0.901	0.902	0.902	0.902	0.902
0.907	0.908	0.908	0.908	0.908	0.908	0.908	0.908	0.908	0.907	0.907
0.912	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.912	0.912
0.916	0.917	0.918	0.918	0.918	0.918	0.918	0.918	0.917	0.917	0.916
0.919	0.921	0.921	0.922	0.922	0.922	0.922	0.922	0.921	0.920	0.919
0.921	0.923	0.924	0.924	0.925	0.925	0.925	0.924	0.924	0.923	0.921
0.920	0.922	0.923	0.924	0.925	0.925	0.925	0.924	0.923	0.922	0.920
0.910	0.913	0.915	0.916	0.917	0.917	0.917	0.917	0.915	0.913	0.911

PAUSE

LINE CALLING-ROUTINE

980 ATPFW

INCIDENT FLUX(W/SQ.CM)

27.2	29.6	31.8	33.4	34.4	34.8	34.6	33.6	32.1	30.1	27.6
42.6	46.6	50.2	52.7	54.2	55.0	54.2	52.7	50.2	46.7	42.7
51.6	56.5	60.5	63.5	65.3	66.0	65.3	63.4	60.3	56.1	51.3
54.4	59.4	63.7	66.7	68.6	69.4	68.6	66.6	63.5	59.2	54.2
55.0	60.0	64.1	67.3	69.2	69.9	69.1	67.2	63.9	59.7	54.7
54.8	59.9	64.1	67.2	69.1	69.9	69.0	67.1	64.0	59.7	54.7
54.6	59.6	63.7	66.9	68.8	69.4	68.8	66.9	63.7	59.5	54.5
53.5	58.4	62.5	65.6	67.4	68.2	67.3	65.3	62.4	58.2	53.3
50.1	54.7	58.6	61.4	63.3	63.8	63.2	61.3	58.3	54.4	49.7
41.2	45.1	48.5	50.8	52.5	53.1	52.5	51.0	48.6	45.3	41.3
26.7	29.1	31.2	32.8	33.8	34.1	33.9	33.0	31.6	29.5	27.2

ABSORBED FLUX(W/SQ.CM)

22.7	24.7	26.5	27.8	28.6	28.9	28.8	28.0	26.8	25.1	23.1
37.4	40.9	44.0	46.2	47.5	48.1	47.5	46.2	44.0	41.0	37.5
46.1	50.5	54.0	56.7	58.3	58.9	58.3	56.6	53.8	50.2	45.8
49.1	53.6	57.5	60.2	61.8	62.6	61.8	60.1	57.3	53.4	48.9
49.9	54.5	58.2	61.1	62.9	63.4	62.7	61.0	58.0	54.2	49.6
50.0	54.7	58.6	61.3	63.1	63.8	63.0	61.2	58.5	54.5	49.9
50.0	54.7	58.5	61.4	63.2	63.8	63.2	61.4	58.5	54.6	49.9
49.2	53.8	57.6	60.4	62.1	62.8	62.0	60.2	57.5	53.6	49.0
46.2	50.5	54.2	56.8	58.5	59.0	58.4	56.7	53.9	50.2	45.7
37.9	41.6	44.7	47.0	48.5	49.1	48.5	47.1	44.8	41.8	38.0
24.3	26.6	28.5	30.0	31.0	31.3	31.1	30.2	28.9	27.0	24.7

RADIATION LOSS(W)

955.7	1067.7	1169.5	1248.6	1299.6	1319.9	1300.0	1248.6	1169.6	1067.6	955.6
939.0	1048.0	1147.1	1223.6	1273.0	1292.8	1272.1	1222.4	1145.5	1046.0	937.2
875.0	972.1	1059.0	1126.8	1170.6	1187.0	1169.8	1125.4	1057.0	968.9	872.0
783.6	864.0	936.3	991.8	1027.7	1041.7	1026.9	990.8	934.9	862.0	781.7
689.7	754.5	811.5	855.8	884.6	895.0	883.7	855.1	810.6	752.8	688.4
602.0	652.5	697.1	731.1	753.4	761.6	752.8	730.7	696.9	651.7	601.3
522.3	560.3	593.7	619.5	636.2	642.1	636.0	619.5	593.9	560.1	521.8
449.3	476.8	501.1	519.4	531.2	535.6	530.8	519.1	501.0	476.7	448.9
381.9	400.6	416.8	428.9	437.0	439.6	436.8	429.0	416.6	400.5	381.5
319.1	330.0	339.5	346.5	351.3	353.1	351.4	347.0	340.2	330.9	319.8
265.8	270.3	274.3	277.5	279.4	280.0	279.6	277.9	275.1	271.2	266.6

CONVECTION LOSS(W)

236.3	246.4	254.9	261.1	265.0	266.5	265.0	261.1	254.9	246.4	236.3
234.8	244.7	253.1	259.2	263.0	264.5	262.9	259.1	252.9	244.5	234.6
228.5	237.9	245.7	251.4	255.0	256.3	254.9	251.3	245.5	237.6	228.2
219.0	227.4	234.5	239.7	242.9	244.1	242.8	239.6	234.4	227.2	218.8
208.3	215.8	222.0	226.6	229.5	230.5	229.4	226.5	221.9	215.6	208.2
197.3	203.8	209.2	213.2	215.7	216.6	215.6	213.1	209.2	203.7	197.2
186.3	191.7	196.2	199.6	201.7	202.5	201.7	199.6	196.3	191.7	186.2
175.0	179.4	183.1	185.9	187.6	188.2	187.5	185.8	183.1	179.4	175.0
163.4	166.8	169.6	171.7	173.0	173.4	173.0	171.7	169.6	166.7	163.3
151.1	153.4	155.3	156.7	157.6	158.0	157.6	156.8	155.4	153.5	151.3
139.2	140.3	141.3	142.0	142.4	142.6	142.5	142.1	141.4	140.5	139.4

12C

NODE SODIUM TEMPERATURES(DEG. F)

1019.4	1058.5	1091.4	1115.5	1130.6	1136.3	1130.4	1115.3	1091.0	1057.8	1018.7
991.5	1028.0	1058.7	1081.2	1095.3	1100.5	1095.0	1080.8	1058.1	1027.1	990.6
952.7	985.6	1013.1	1033.4	1046.1	1050.8	1045.8	1033.1	1012.7	984.8	951.9
908.5	937.2	961.3	979.1	990.3	994.4	990.0	978.9	961.1	936.7	907.9
862.5	887.1	907.6	922.8	932.4	935.9	932.2	922.6	907.5	886.7	862.1
816.1	836.4	853.4	865.9	873.9	876.7	873.7	865.9	853.4	836.3	815.9
769.7	785.6	799.0	808.9	815.2	817.5	815.1	808.9	799.1	785.6	769.5
723.6	735.2	745.1	752.4	757.0	758.7	757.0	752.5	745.2	735.4	723.6
679.3	686.8	693.2	697.9	701.0	702.1	701.0	698.2	693.5	687.2	679.5
640.2	644.0	647.3	649.7	651.3	651.9	651.4	650.0	647.7	644.5	640.6
611.3	612.3	613.2	614.0	614.4	614.5	614.4	614.0	613.4	612.5	611.5

PAUSE

LINE CALLING-ROUTINE

1120 ATPFW

SODIUM HEAT TRANSFER COEFFICIENTS(BTU/HR*F*FT**2)

3502.1	3474.8	3452.5	3436.6	3426.7	3423.0	3426.9	3436.7	3452.8	3475.3	3502.6
3522.1	3496.0	3474.7	3459.4	3450.0	3446.4	3450.1	3459.6	3475.1	3496.6	3522.8
3550.8	3526.4	3506.5	3492.2	3483.3	3480.1	3483.5	3492.4	3506.9	3527.0	3551.4
3584.7	3562.4	3544.3	3531.1	3523.0	3520.0	3523.2	3531.3	3544.5	3562.9	3585.1
3621.5	3601.6	3585.3	3573.5	3566.1	3563.5	3566.3	3573.6	3585.4	3601.9	3621.8
3660.4	3643.2	3629.0	3618.7	3612.2	3609.9	3612.3	3618.7	3629.0	3643.3	3660.6
3701.4	3687.1	3675.2	3666.6	3661.2	3659.2	3661.2	3666.6	3675.2	3687.1	3701.5
3744.2	3733.2	3723.9	3717.2	3712.9	3711.4	3712.9	3717.1	3723.8	3733.0	3744.2
3787.7	3780.2	3773.7	3769.1	3766.1	3765.0	3766.0	3768.8	3773.4	3779.7	3787.4
3828.2	3824.1	3820.7	3818.1	3816.5	3815.9	3816.4	3817.9	3820.2	3823.6	3827.7
3859.5	3858.4	3857.4	3856.6	3856.1	3856.0	3856.1	3856.5	3857.2	3858.2	3859.3

TUBE CONDUCTANCE(BTU/HR*F*FT**2)

1396.9	1404.1	1410.0	1414.2	1416.8	1417.7	1416.8	1414.2	1410.0	1404.1	1396.9
1395.2	1402.4	1408.2	1412.4	1415.0	1416.0	1414.9	1412.4	1408.2	1402.3	1395.1
1390.2	1397.1	1402.7	1406.7	1409.2	1410.1	1409.1	1406.6	1402.6	1396.9	1390.0
1382.7	1389.1	1394.4	1398.1	1400.4	1401.3	1400.4	1398.0	1394.3	1389.0	1382.6
1374.1	1380.0	1384.7	1388.2	1390.3	1391.1	1390.3	1388.1	1384.6	1379.8	1374.0
1365.0	1370.2	1374.5	1377.6	1379.5	1380.2	1379.5	1377.5	1374.4	1370.1	1364.9
1355.4	1359.9	1363.6	1366.4	1368.1	1368.7	1368.0	1366.4	1363.6	1359.9	1355.4
1345.4	1349.1	1352.2	1354.5	1355.9	1356.5	1355.9	1354.5	1352.3	1349.1	1345.4
1334.8	1337.7	1340.1	1341.9	1343.0	1343.4	1343.0	1341.9	1340.1	1337.7	1334.8
1323.6	1325.6	1327.2	1328.4	1329.2	1329.5	1329.2	1328.5	1327.3	1325.7	1323.8
1312.9	1313.8	1314.6	1315.2	1315.6	1315.7	1315.6	1315.3	1314.7	1313.9	1313.0

TUBE WALL CONDUCTIVITY(BTU/HR*F*FT)

11.6	11.8	11.9	12.0	12.1	12.1	12.1	12.0	11.9	11.8	11.6
11.5	11.7	11.8	11.9	12.0	12.0	12.0	11.9	11.8	11.7	11.5
11.3	11.5	11.6	11.8	11.8	11.8	11.8	11.8	11.6	11.5	11.3
11.1	11.3	11.4	11.5	11.6	11.6	11.6	11.5	11.4	11.3	11.1
10.9	11.1	11.2	11.3	11.3	11.3	11.3	11.2	11.2	11.1	10.9
10.7	10.8	10.9	11.0	11.0	11.0	11.0	11.0	10.9	10.8	10.7
10.5	10.6	10.7	10.7	10.8	10.8	10.8	10.7	10.7	10.6	10.5
10.3	10.3	10.4	10.5	10.5	10.5	10.5	10.5	10.4	10.3	10.3
10.1	10.1	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.1	10.1
9.8	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9
9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7

PEAK TUBE TEMPERATURE (DEG. F)

1070.8	1114.3	1151.0	1177.9	1194.5	1201.0	1194.8	1178.0	1151.2	1114.6	1071.1
1076.5	1120.5	1157.8	1184.8	1201.6	1208.3	1201.3	1184.4	1157.2	1119.9	1075.9
1057.9	1100.1	1135.3	1161.2	1177.4	1183.3	1177.1	1160.7	1134.3	1098.7	1056.4
1021.0	1059.5	1092.0	1115.6	1130.3	1136.1	1130.0	1115.1	1091.3	1058.5	1020.0
977.5	1012.3	1041.0	1062.3	1075.7	1080.5	1075.3	1061.9	1040.4	1011.3	976.7
932.3	962.9	988.5	1007.1	1019.0	1023.4	1018.6	1006.8	988.3	962.3	931.8
886.7	913.0	935.0	951.3	961.6	965.2	961.5	951.3	935.0	912.8	886.3
839.6	861.6	880.2	893.8	902.4	905.6	902.1	893.4	880.1	861.3	839.1
788.9	806.5	821.4	832.1	839.2	841.4	839.0	832.1	821.0	806.2	788.2
731.0	743.5	754.2	761.9	767.0	769.0	767.1	762.3	754.8	744.4	731.7
670.0	676.5	682.0	686.4	689.0	689.9	689.3	687.0	683.2	677.6	671.2

CONTINUE ITERATION?(YES=1,NO=0)?0

B UNIFORM FLUX, -20°F AMBIENT

ATPFW   13:04EDT   09/05/79

AIR TEMP.,CONV. COEFF.,CI?-20.,2.0,.6366

FLUX PLOT FILENAME?FLUXTF

FULL PRINT(YES=1,NO=0)?1

RECEIVER SUMMARY

FLOW	=	50719.LB/HR
INCIDENT	=	2495438.W
RAD. LOSS	=	87908.W
CONV. LOSS	=	27463.W
REFL. LOSS	=	124772.W
EFFICIENCY	=	0.9038

TUBE GROUP	FLOW LB/HR	INCIDENT W	RADIATION W	CONVECTION W	EFFICIENCY
1	4611.	195242.	6865.	2377.	0.9027
2	4611.	213277.	7479.	2445.	0.9035
3	4611.	228505.	8029.	2503.	0.9039
4	4611.	239689.	8453.	2545.	0.9041
5	4611.	246663.	8727.	2571.	0.9042
6	4611.	249346.	8832.	2581.	0.9042
7	4611.	246622.	8724.	2571.	0.9042
8	4611.	239606.	8449.	2545.	0.9041
9	4611.	228381.	8024.	2503.	0.9039
10	4611.	213071.	7471.	2445.	0.9035
11	4611.	195036.	6856.	2376.	0.9027

12F

OUTSIDE TUBE TEMPERATURES(DEG. F)

1051.9	1093.9	1129.2	1155.2	1171.3	1177.5	1171.4	1155.2	1129.3	1093.8	1051.9
1045.4	1086.8	1121.7	1147.1	1163.0	1169.2	1162.7	1146.8	1121.2	1086.1	1044.7
1019.5	1058.4	1090.8	1114.8	1129.7	1135.2	1129.4	1114.3	1090.1	1057.2	1018.3
979.9	1015.0	1044.5	1066.0	1079.4	1084.6	1079.1	1065.6	1043.9	1014.1	979.1
935.6	966.7	992.4	1011.6	1023.6	1027.9	1023.2	1011.3	992.0	965.9	934.9
889.9	916.8	939.3	955.8	966.2	970.0	965.9	955.6	939.2	916.4	889.6
844.0	866.6	885.5	899.5	908.4	911.5	908.3	899.5	885.5	866.5	843.7
797.3	815.5	831.0	842.3	849.5	852.1	849.3	842.1	831.0	815.4	797.0
748.9	762.9	774.7	783.2	788.8	790.7	788.7	783.3	774.5	762.8	748.6
697.9	707.2	715.2	721.0	724.8	726.3	724.9	721.4	715.8	708.0	698.5
648.6	653.0	656.9	659.9	661.8	662.4	662.0	660.3	657.7	653.8	649.4

NODE EFFICIENCIES(P.U.)

0.832	0.831	0.830	0.829	0.829	0.828	0.829	0.830	0.831	0.833	0.834
0.876	0.876	0.875	0.875	0.874	0.874	0.874	0.875	0.875	0.876	0.876
0.892	0.892	0.892	0.892	0.892	0.891	0.892	0.892	0.892	0.892	0.892
0.900	0.901	0.901	0.900	0.900	0.900	0.900	0.900	0.901	0.900	0.900
0.906	0.906	0.907	0.907	0.907	0.907	0.907	0.907	0.906	0.906	0.906
0.910	0.911	0.912	0.912	0.912	0.912	0.912	0.912	0.912	0.911	0.910
0.915	0.916	0.916	0.917	0.917	0.917	0.917	0.917	0.916	0.916	0.915
0.918	0.919	0.920	0.921	0.921	0.921	0.921	0.921	0.920	0.919	0.918
0.920	0.921	0.922	0.923	0.924	0.924	0.923	0.923	0.922	0.921	0.920
0.918	0.920	0.922	0.923	0.923	0.923	0.923	0.923	0.922	0.920	0.918
0.907	0.910	0.913	0.914	0.915	0.915	0.915	0.914	0.913	0.911	0.908

PAUSE

LINE CALLING-ROUTINE

980 ATPFW

INCIDENT FLUX(W/SQ.CM)

27.2	29.6	31.8	33.4	34.4	34.8	34.6	33.6	32.1	30.1	27.6
42.6	46.6	50.2	52.7	54.2	55.0	54.2	52.7	50.2	46.7	42.7
51.6	56.5	60.5	63.5	65.3	66.0	65.3	63.4	60.3	56.1	51.3
54.4	59.4	63.7	66.7	68.6	69.4	68.6	66.6	63.5	59.2	54.2
55.0	60.0	64.1	67.3	69.2	69.9	69.1	67.2	63.9	59.7	54.7
54.8	59.9	64.1	67.2	69.1	69.9	69.0	67.1	64.0	59.7	54.7
54.6	59.6	63.7	66.9	68.8	69.4	68.8	66.9	63.7	59.5	54.5
53.5	58.4	62.5	65.6	67.4	68.2	67.3	65.3	62.4	58.2	53.3
50.1	54.7	58.6	61.4	63.3	63.8	63.2	61.3	58.3	54.4	49.7
41.2	45.1	48.5	50.8	52.5	53.1	52.5	51.0	48.6	45.3	41.3
26.7	29.1	31.2	32.8	33.8	34.1	33.9	33.0	31.6	29.5	27.2

ABSORBED FLUX(W/SQ.CM)

22.6	24.6	26.4	27.7	28.5	28.9	28.7	27.9	26.7	25.0	23.0
37.3	40.8	43.9	46.1	47.4	48.0	47.4	46.1	43.9	40.9	37.4
46.1	50.4	53.9	56.6	58.3	58.8	58.3	56.5	53.8	50.1	45.8
49.0	53.5	57.4	60.1	61.7	62.5	61.7	60.0	57.2	53.3	48.8
49.8	54.4	58.2	61.0	62.8	63.4	62.7	60.9	58.0	54.1	49.6
49.9	54.6	58.5	61.3	63.1	63.7	62.9	61.2	58.4	54.4	49.8
50.0	54.6	58.4	61.3	63.1	63.7	63.1	61.3	58.4	54.5	49.9
49.2	53.7	57.5	60.4	62.1	62.8	62.0	60.1	57.4	53.5	49.0
46.1	50.4	54.1	56.7	58.4	58.9	58.3	56.6	53.8	50.1	45.7
37.8	41.5	44.7	46.9	48.4	49.0	48.4	47.0	44.8	41.7	37.9
24.2	26.5	28.4	30.0	30.9	31.2	31.0	30.2	28.8	26.9	24.7

RADIATION LOSS(W)

962.9	1075.1	1177.0	1256.2	1307.3	1327.5	1307.6	1256.2	1177.0	1074.9	962.8
946.3	1055.4	1154.7	1231.2	1280.7	1300.5	1279.9	1230.1	1153.1	1053.4	944.5
882.3	979.6	1066.6	1134.4	1178.3	1194.7	1177.5	1133.1	1064.5	976.4	879.4
790.9	871.5	943.9	999.4	1035.3	1049.4	1034.6	998.4	942.4	869.5	789.1
697.1	761.9	819.0	863.4	892.3	902.6	891.3	862.7	818.1	760.3	695.8
609.4	659.9	704.6	738.7	760.9	769.2	760.3	738.3	704.4	659.2	608.7
529.7	567.8	601.2	627.1	643.7	649.7	643.6	627.1	601.4	567.6	529.3
456.8	484.3	508.6	526.9	538.7	543.2	538.4	526.6	508.6	484.1	456.3
389.4	408.1	424.3	436.4	444.5	447.1	444.3	436.6	424.1	408.0	389.0
326.7	337.5	347.0	354.1	358.8	360.6	358.9	354.6	347.7	338.4	327.3
273.3	277.9	281.9	285.0	286.9	287.6	287.1	285.4	282.7	278.7	274.2

CONVECTION LOSS(W)

257.9	268.0	276.5	282.8	286.7	288.2	286.7	282.8	276.5	268.0	257.9
256.4	266.3	274.7	280.8	284.7	286.1	284.6	280.8	274.6	266.1	256.2
250.1	259.5	267.3	273.1	276.6	278.0	276.6	272.9	267.1	259.2	249.8
240.6	249.0	256.1	261.3	264.5	265.8	264.5	261.2	256.0	248.8	240.4
229.9	237.4	243.6	248.2	251.1	252.1	251.0	248.2	243.5	237.2	229.8
219.0	225.4	230.8	234.8	237.3	238.2	237.2	234.7	230.8	225.3	218.9
207.9	213.3	217.9	221.3	223.4	224.1	223.4	221.3	217.9	213.3	207.8
196.7	201.1	204.8	207.5	209.2	209.9	209.2	207.4	204.8	201.0	196.6
185.0	188.4	191.2	193.3	194.6	195.1	194.6	193.3	191.2	188.4	184.9
172.7	175.0	176.9	178.3	179.2	179.6	179.2	178.4	177.0	175.2	172.9
160.9	162.0	162.9	163.6	164.1	164.2	164.1	163.7	163.1	162.1	161.1

NODE SODIUM TEMPERATURES(DEG. F)

1019.3	1058.4	1091.4	1115.6	1130.6	1136.4	1130.5	1115.3	1091.0	1057.8	1018.6
991.4	1028.0	1058.7	1081.3	1095.3	1100.6	1095.1	1080.9	1058.1	1027.1	990.5
952.6	985.6	1013.2	1033.5	1046.2	1050.9	1045.9	1033.1	1012.7	984.8	951.8
908.4	937.2	961.4	979.2	990.4	994.5	990.1	978.9	961.1	936.7	907.8
862.5	887.0	907.6	922.8	932.5	935.9	932.2	922.7	907.5	886.7	862.1
816.1	836.3	853.4	866.0	873.9	876.8	873.8	865.9	853.4	836.2	815.8
769.6	785.5	799.0	808.9	815.3	817.5	815.2	808.9	799.1	785.6	769.5
723.5	735.2	745.1	752.4	757.0	758.7	757.0	752.5	745.2	735.4	723.5
679.2	686.7	693.2	697.9	701.0	702.1	701.0	698.1	693.5	687.2	679.5
640.2	644.0	647.2	649.7	651.3	651.8	651.4	649.9	647.7	644.4	640.6
611.3	612.3	613.2	613.9	614.4	614.5	614.4	614.0	613.4	612.5	611.5

PAUSE

LINE CALLING-ROUTINE

1120 ATPFW

SODIUM HEAT TRANSFER COEFFICIENTS(BTU/HR*F*FT**2)

3500.0	3472.7	3450.4	3434.4	3424.6	3420.8	3424.7	3434.5	3450.6	3473.1	3500.4
3520.0	3493.8	3472.5	3457.2	3447.7	3444.2	3447.9	3457.4	3472.9	3494.4	3520.6
3548.6	3524.2	3504.3	3490.0	3481.1	3477.8	3481.3	3490.2	3504.6	3524.8	3549.2
3582.5	3560.2	3542.0	3528.9	3520.7	3517.7	3520.9	3529.1	3542.2	3560.6	3582.9
3619.2	3599.4	3583.1	3571.3	3563.9	3561.2	3564.0	3571.4	3583.2	3599.6	3619.6
3658.1	3640.9	3626.7	3616.4	3609.9	3607.6	3610.0	3616.4	3626.7	3641.0	3658.3
3699.1	3684.8	3672.9	3664.3	3658.9	3656.9	3658.9	3664.3	3672.9	3684.8	3699.2
3741.9	3730.9	3721.6	3714.8	3710.5	3709.0	3710.6	3714.8	3721.5	3730.7	3741.9
3785.4	3777.8	3771.4	3766.7	3763.7	3762.7	3763.7	3766.5	3771.1	3777.4	3785.1
3825.8	3821.8	3818.3	3815.7	3814.1	3813.5	3814.0	3815.5	3817.9	3821.3	3825.4
3857.1	3856.0	3855.0	3854.2	3853.7	3853.6	3853.7	3854.1	3854.8	3855.8	3856.9

TUBE CONDUCTANCE(BTU/HR*F*FT**2)

1396.5	1403.7	1409.6	1413.8	1416.3	1417.3	1416.4	1413.8	1409.5	1403.6	1396.4
1394.8	1402.0	1407.8	1412.0	1414.6	1415.6	1414.5	1411.9	1407.7	1401.8	1394.7
1389.8	1396.7	1402.3	1406.3	1408.8	1409.7	1408.7	1406.2	1402.1	1396.5	1389.6
1382.3	1388.7	1394.0	1397.7	1400.0	1400.9	1400.0	1397.6	1393.9	1388.6	1382.2
1373.7	1379.6	1384.3	1387.8	1390.0	1390.7	1389.9	1387.7	1384.2	1379.4	1373.6
1364.6	1369.8	1374.1	1377.2	1379.1	1379.8	1379.1	1377.1	1374.0	1369.7	1364.5
1355.0	1359.5	1363.2	1366.0	1367.7	1368.3	1367.7	1366.0	1363.3	1359.5	1355.0
1345.0	1348.8	1351.9	1354.1	1355.6	1356.1	1355.5	1354.1	1351.9	1348.7	1345.0
1334.5	1337.4	1339.8	1341.5	1342.7	1343.0	1342.6	1341.6	1339.8	1337.4	1334.4
1323.3	1325.2	1326.9	1328.1	1328.8	1329.1	1328.9	1328.1	1327.0	1325.4	1323.4
1312.5	1313.4	1314.2	1314.8	1315.2	1315.3	1315.3	1314.9	1314.4	1313.6	1312.7

TUBE WALL CONDUCTIVITY(BTU/HR*F*FT)

11.6	11.8	11.9	12.0	12.1	12.1	12.1	12.0	11.9	11.8	11.6
11.5	11.7	11.8	11.9	12.0	12.0	12.0	11.9	11.8	11.7	11.5
11.3	11.5	11.6	11.8	11.8	11.8	11.8	11.8	11.6	11.5	11.3
11.1	11.3	11.4	11.5	11.6	11.6	11.6	11.5	11.4	11.3	11.1
10.9	11.1	11.2	11.3	11.3	11.3	11.3	11.2	11.2	11.1	10.9
10.7	10.8	10.9	11.0	11.0	11.0	11.0	11.0	10.9	10.8	10.7
10.5	10.6	10.7	10.7	10.8	10.8	10.8	10.7	10.7	10.6	10.5
10.3	10.3	10.4	10.5	10.5	10.5	10.5	10.5	10.4	10.3	10.3
10.1	10.1	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.1	10.1
9.8	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9
9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7

PEAK TUBE TEMPERATURE (DEG. F)

1070.6	1114.1	1150.8	1177.8	1194.5	1201.0	1194.7	1177.9	1151.1	1114.4	1070.9
1076.3	1120.3	1157.7	1184.7	1201.6	1208.3	1201.3	1184.4	1157.1	1119.7	1075.6
1057.7	1100.0	1135.2	1161.2	1177.3	1183.3	1177.1	1160.6	1134.3	1098.5	1056.2
1020.8	1059.4	1091.9	1115.5	1130.2	1136.0	1130.0	1115.1	1091.2	1058.3	1019.8
977.4	1012.1	1040.8	1062.2	1075.7	1080.4	1075.2	1061.9	1040.3	1011.1	976.5
932.1	962.7	988.3	1007.0	1018.9	1023.3	1018.5	1006.7	988.2	962.2	931.6
886.5	912.8	934.8	951.2	961.5	965.1	961.4	951.2	934.9	912.6	886.1
839.4	861.4	880.0	893.7	902.2	905.5	901.9	893.3	879.9	861.1	838.9
788.7	806.3	821.2	832.0	839.0	841.2	838.8	832.0	820.8	806.0	788.0
730.8	743.3	754.0	761.7	766.8	768.8	766.9	762.2	754.6	744.2	731.5
669.9	676.3	681.8	686.2	688.8	689.7	689.1	686.8	683.0	677.4	671.0

CONTINUE ITERATION?(YES=1,NO=0)?0

C UNIFORM FLUX, 120°F AMBIENT

ATPFW 13:08EDT 09/05/79

AIR TEMP.,CONV. COEFF.,CI?120.,2.0,.6366

FLUX PLOT FILENAME?FLUXTF

FULL PRINT(YES=1,NO=0)?1

RECEIVER SUMMARY

FLOW	=	50848.LB/HR
INCIDENT	=	2495438.W
RAD. LOSS	=	86241.W
CONV. LOSS	=	23391.W
REFL. LOSS	=	124772.W
EFFICIENCY	=	0.9061

TUBE GROUP	FLOW LB/HR	INCIDENT W	RADIATION W	CONVECTION W	EFFICIENCY
1	4623.	195242.	6715.	2007.	0.9053
2	4623.	213277.	7328.	2075.	0.9059
3	4623.	228505.	7877.	2133.	0.9062
4	4623.	239689.	8300.	2175.	0.9063
5	4623.	246663.	8574.	2201.	0.9063
6	4623.	249346.	8679.	2211.	0.9063
7	4623.	246622.	8571.	2201.	0.9063
8	4623.	239606.	8296.	2174.	0.9063
9	4623.	228381.	7872.	2132.	0.9062
10	4623.	213071.	7320.	2075.	0.9059
11	4623.	195036.	6707.	2006.	0.9053

12K

OUTSIDE TUBE TEMPERATURES(DEG. F)

1052.2	1094.1	1129.4	1155.2	1171.3	1177.5	1171.4	1155.2	1129.4	1094.0	1052.2
1045.7	1086.9	1121.8	1147.2	1163.0	1169.1	1162.7	1146.8	1121.2	1086.2	1045.0
1019.7	1058.5	1090.9	1114.8	1129.7	1135.1	1129.4	1114.3	1090.2	1057.3	1018.5
980.2	1015.1	1044.6	1066.0	1079.4	1084.6	1079.2	1065.6	1044.0	1014.3	979.3
935.8	966.8	992.5	1011.6	1023.7	1027.9	1023.3	1011.4	992.2	966.1	935.2
890.2	917.0	939.4	955.9	966.3	970.1	966.0	955.7	939.3	916.6	889.8
844.3	866.8	885.6	899.6	908.5	911.6	908.4	899.6	885.7	866.7	844.0
797.5	815.7	831.2	842.5	849.6	852.3	849.4	842.3	831.2	815.6	797.2
749.1	763.1	774.9	783.4	789.0	790.8	788.9	783.5	774.7	763.0	748.8
698.1	707.4	715.4	721.2	725.0	726.5	725.1	721.6	716.0	708.2	698.7
648.8	653.2	657.1	660.1	662.0	662.6	662.2	660.5	657.9	654.0	649.6

NODE EFFICIENCIES(P.U.)

0.837	0.835	0.834	0.833	0.832	0.832	0.833	0.834	0.835	0.837	0.838
0.879	0.878	0.878	0.877	0.877	0.877	0.877	0.877	0.878	0.879	0.879
0.895	0.895	0.894	0.894	0.894	0.893	0.894	0.894	0.894	0.895	0.895
0.903	0.903	0.903	0.902	0.902	0.902	0.902	0.902	0.902	0.903	0.902
0.908	0.908	0.909	0.909	0.909	0.908	0.908	0.909	0.908	0.908	0.908
0.913	0.913	0.914	0.914	0.914	0.914	0.914	0.914	0.914	0.913	0.913
0.917	0.918	0.918	0.919	0.919	0.919	0.919	0.919	0.918	0.918	0.917
0.920	0.921	0.922	0.923	0.923	0.923	0.923	0.922	0.922	0.921	0.920
0.922	0.924	0.925	0.925	0.925	0.926	0.925	0.925	0.924	0.924	0.922
0.921	0.923	0.924	0.925	0.925	0.926	0.925	0.925	0.924	0.923	0.921
0.912	0.915	0.917	0.918	0.919	0.919	0.919	0.918	0.917	0.915	0.913

PAUSE

LINE CALLING-ROUTINE

980 ATPFW

INCIDENT FLUX(W/SQ.CM)

27.2	29.6	31.8	33.4	34.4	34.8	34.6	33.6	32.1	30.1	27.6
42.6	46.6	50.2	52.7	54.2	55.0	54.2	52.7	50.2	46.7	42.7
51.6	56.5	60.5	63.5	65.3	66.0	65.3	63.4	60.3	56.1	51.3
54.4	59.4	63.7	66.7	68.6	69.4	68.6	66.6	63.5	59.2	54.2
55.0	60.0	64.1	67.3	69.2	69.9	69.1	67.2	63.9	59.7	54.7
54.8	59.9	64.1	67.2	69.1	69.9	69.0	67.1	64.0	59.7	54.7
54.6	59.6	63.7	66.9	68.8	69.4	68.8	66.9	63.7	59.5	54.5
53.5	58.4	62.5	65.6	67.4	68.2	67.3	65.3	62.4	58.2	53.3
50.1	54.7	58.6	61.4	63.3	63.8	63.2	61.3	58.3	54.4	49.7
41.2	45.1	48.5	50.8	52.5	53.1	52.5	51.0	48.6	45.3	41.3
26.7	29.1	31.2	32.8	33.8	34.1	33.9	33.0	31.6	29.5	27.2

ABSORBED FLUX(W/SQ.CM)

22.7	24.8	26.5	27.8	28.6	29.0	28.8	28.1	26.8	25.2	23.1
37.5	41.0	44.1	46.2	47.5	48.2	47.5	46.2	44.1	41.1	37.6
46.2	50.5	54.1	56.8	58.4	59.0	58.4	56.7	53.9	50.2	45.9
49.1	53.6	57.5	60.2	61.9	62.7	61.9	60.1	57.3	53.4	48.9
49.9	54.5	58.3	61.1	62.9	63.5	62.8	61.0	58.1	54.2	49.7
50.1	54.7	58.6	61.4	63.2	63.9	63.1	61.3	58.5	54.5	50.0
50.1	54.7	58.5	61.4	63.2	63.8	63.2	61.4	58.5	54.6	50.0
49.3	53.8	57.7	60.5	62.2	62.9	62.1	60.3	57.6	53.6	49.1
46.2	50.6	54.2	56.8	58.6	59.1	58.5	56.7	53.9	50.3	45.8
38.0	41.6	44.8	47.0	48.6	49.2	48.6	47.1	44.9	41.8	38.1
24.4	26.6	28.6	30.1	31.0	31.3	31.1	30.3	29.0	27.0	24.8

RADIATION LOSS(W)

949.6	1061.6	1163.3	1242.3	1293.3	1313.5	1293.7	1242.4	1163.4	1061.4	949.5
932.9	1041.8	1140.9	1217.2	1266.6	1286.4	1265.8	1216.1	1139.2	1039.8	931.1
868.8	965.9	1052.8	1120.4	1164.2	1180.6	1163.4	1119.1	1050.7	962.7	865.9
777.4	857.8	930.1	985.5	1021.3	1035.4	1020.6	984.5	928.6	855.8	775.5
683.5	748.2	805.2	849.5	878.3	888.7	877.4	848.8	804.3	746.6	682.2
595.8	646.2	690.8	724.8	747.1	755.3	746.5	724.4	690.6	645.5	595.1
516.1	554.1	587.5	613.3	629.9	635.8	629.7	613.2	587.6	553.9	515.6
443.1	470.6	494.8	513.1	524.9	529.4	524.6	512.8	494.8	470.4	442.7
375.7	394.3	410.6	422.7	430.7	433.3	430.5	422.8	410.4	394.3	375.3
312.9	323.7	333.2	340.3	345.0	346.8	345.1	340.8	333.9	324.6	313.5
259.5	264.0	268.0	271.2	273.1	273.7	273.3	271.6	268.9	264.9	260.3

CONVECTION LOSS(W)

224.3	234.4	242.9	249.1	253.0	254.5	253.0	249.1	242.9	234.4	224.3
222.7	232.7	241.1	247.2	251.0	252.5	250.9	247.1	240.9	232.5	222.6
216.5	225.8	233.6	239.4	243.0	244.3	242.9	239.3	233.4	225.5	216.2
207.0	215.4	222.5	227.6	230.9	232.1	230.8	227.5	222.3	215.2	206.8
196.3	203.8	210.0	214.6	217.4	218.5	217.4	214.5	209.9	203.6	196.2
185.3	191.8	197.2	201.1	203.6	204.6	203.6	201.1	197.2	191.7	185.2
174.3	179.7	184.2	187.6	189.7	190.5	189.7	187.6	184.2	179.7	174.2
163.0	167.4	171.1	173.8	175.6	176.2	175.5	173.8	171.1	167.4	163.0
151.4	154.7	157.6	159.6	161.0	161.4	161.0	159.7	157.5	154.7	151.3
139.1	141.3	143.3	144.7	145.6	145.9	145.6	144.8	143.4	141.5	139.3
127.2	128.3	129.2	130.0	130.4	130.6	130.5	130.1	129.4	128.5	127.4

lam

NODE SODIUM TEMPERATURES(DEG. F)

1019.4	1058.5	1091.4	1115.5	1130.5	1136.3	1130.3	1115.2	1091.0	1057.8	1018.8
991.5	1028.0	1058.6	1081.1	1095.2	1100.5	1094.9	1080.8	1058.1	1027.1	990.6
952.7	985.6	1013.1	1033.4	1046.1	1050.8	1045.8	1033.0	1012.6	984.8	951.9
908.5	937.2	961.3	979.1	990.3	994.3	990.0	978.8	961.0	936.7	907.9
862.5	887.1	907.6	922.8	932.4	935.8	932.1	922.6	907.5	886.7	862.2
816.2	836.4	853.4	865.9	873.9	876.7	873.7	865.9	853.4	836.3	815.9
769.7	785.6	799.0	808.9	815.2	817.5	815.1	808.9	799.1	785.6	769.6
723.6	735.2	745.1	752.4	757.0	758.7	757.0	752.5	745.3	735.4	723.6
679.3	686.8	693.2	697.9	701.0	702.1	701.1	698.2	693.5	687.2	679.6
640.2	644.0	647.3	649.7	651.3	651.9	651.4	650.0	647.7	644.5	640.7
611.3	612.3	613.2	614.0	614.4	614.5	614.4	614.1	613.4	612.5	611.5

PAUSE

LINE CALLING-ROUTINE

1120 ATPFW

SODIUM HEAT TRANSFER COEFFICIENTS(BTU/HR*F*FT**2)

3503.4	3476.2	3453.9	3437.9	3428.1	3424.4	3428.2	3438.1	3454.2	3476.6	3503.9
3523.5	3497.4	3476.1	3460.8	3451.3	3447.8	3451.5	3461.0	3476.5	3498.0	3524.1
3552.1	3527.8	3507.9	3493.6	3484.8	3481.5	3484.9	3493.8	3508.3	3528.4	3552.7
3586.1	3563.8	3545.7	3532.5	3524.4	3521.4	3524.6	3532.7	3545.9	3564.3	3586.5
3622.9	3603.0	3586.7	3574.9	3567.6	3564.9	3567.7	3575.1	3586.8	3603.3	3623.2
3661.8	3644.6	3630.4	3620.1	3613.6	3611.3	3613.7	3620.1	3630.4	3644.7	3662.0
3702.8	3688.5	3676.7	3668.0	3662.6	3660.7	3662.7	3668.0	3676.6	3688.5	3702.9
3745.6	3734.6	3725.3	3718.6	3714.3	3712.8	3714.4	3718.5	3725.2	3734.4	3745.6
3789.2	3781.6	3775.2	3770.5	3767.5	3766.5	3767.5	3770.3	3774.9	3781.2	3788.9
3829.6	3825.6	3822.2	3819.6	3817.9	3817.3	3817.8	3819.3	3821.7	3825.1	3829.2
3861.0	3859.9	3858.9	3858.1	3857.6	3857.5	3857.6	3858.0	3858.7	3859.7	3860.8

TUBE CONDUCTANCE(BTU/HR*F*FT**2)

1397.2	1404.4	1410.2	1414.5	1417.0	1418.0	1417.0	1414.5	1410.2	1404.3	1397.1
1395.5	1402.6	1408.5	1412.7	1415.2	1416.2	1415.2	1412.6	1408.4	1402.5	1395.4
1390.5	1397.4	1402.9	1407.0	1409.4	1410.4	1409.4	1406.9	1402.8	1397.1	1390.3
1383.0	1389.4	1394.6	1398.4	1400.7	1401.6	1400.6	1398.3	1394.5	1389.2	1382.8
1374.4	1380.2	1385.0	1388.4	1390.6	1391.4	1390.5	1388.4	1384.9	1380.1	1374.2
1365.2	1370.4	1374.7	1377.8	1379.7	1380.5	1379.7	1377.8	1374.7	1370.3	1365.1
1355.7	1360.2	1363.9	1366.6	1368.3	1368.9	1368.3	1366.6	1363.9	1360.1	1355.6
1345.7	1349.4	1352.5	1354.7	1356.2	1356.7	1356.1	1354.7	1352.5	1349.4	1345.6
1335.1	1338.0	1340.4	1342.1	1343.3	1343.6	1343.2	1342.1	1340.4	1338.0	1335.0
1323.9	1325.8	1327.4	1328.6	1329.4	1329.7	1329.4	1328.7	1327.6	1326.0	1324.0
1313.1	1314.0	1314.8	1315.4	1315.8	1315.9	1315.8	1315.5	1315.0	1314.2	1313.3

N21

TUBE WALL CONDUCTIVITY(BTU/HR*F*FT)

11.6	11.8	11.9	12.0	12.1	12.1	12.1	12.0	11.9	11.8	11.6
11.5	11.7	11.8	11.9	12.0	12.0	12.0	11.9	11.8	11.7	11.5
11.3	11.5	11.6	11.8	11.8	11.8	11.8	11.8	11.6	11.5	11.3
11.1	11.3	11.4	11.5	11.6	11.6	11.6	11.5	11.4	11.3	11.1
10.9	11.1	11.2	11.3	11.3	11.3	11.3	11.2	11.2	11.1	10.9
10.7	10.8	10.9	11.0	11.0	11.0	11.0	11.0	10.9	10.8	10.7
10.5	10.6	10.7	10.7	10.8	10.8	10.8	10.7	10.7	10.6	10.5
10.3	10.3	10.4	10.5	10.5	10.5	10.5	10.5	10.4	10.3	10.3
10.1	10.1	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.1	10.1
9.8	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9
9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7

PEAK TUBE TEMPERATURE (DEG. F)

1071.0	1114.4	1151.0	1177.9	1194.6	1201.1	1194.9	1178.1	1151.3	1114.7	1071.3
1076.6	1120.6	1157.8	1184.9	1201.6	1208.3	1201.4	1184.5	1157.3	1119.9	1076.0
1058.0	1100.2	1135.3	1161.3	1177.4	1183.3	1177.1	1160.7	1134.4	1098.7	1056.5
1021.1	1059.6	1092.1	1115.6	1130.3	1136.1	1130.1	1115.2	1091.3	1058.6	1020.1
977.7	1012.4	1041.0	1062.4	1075.8	1080.5	1075.3	1062.0	1040.5	1011.3	976.8
932.4	963.0	988.6	1007.2	1019.1	1023.4	1018.7	1006.9	988.4	962.4	932.0
886.8	913.1	935.0	951.4	961.7	965.3	961.6	951.4	935.1	912.9	886.5
839.7	861.7	880.3	893.9	902.4	905.7	902.2	893.5	880.2	861.4	839.2
789.0	806.6	821.5	832.2	839.3	841.5	839.1	832.2	821.1	806.3	788.3
731.2	743.6	754.3	762.0	767.1	769.1	767.2	762.5	754.9	744.5	731.8
670.2	676.6	682.1	686.5	689.1	690.0	689.4	687.1	683.3	677.7	671.3

CONTINUE ITERATION?(YES=1,NO=0)?0

D UNIFORM FLUX, 20 GPM FLOW, 70°F AMBIENT

ATPFW 13:42EDT 09/05/79

AIR TEMP.,CONV. COEFF.,C??70.,2.0,.6366

FLUX PLOT FILENAME?FLUXTF
FULL PRINT(YES=1,NO=0)?1

RECEIVER SUMMARY

FLOW = 8347.LB/HR
INCIDENT = 496896.W
RAD. LOSS = 77250.W
CONV. LOSS = 23612.W
REFL. LOSS = 24845.W
EFFICIENCY = 0.7470

TUBE GROUP	FLOW LB/HR	INCIDENT W	RADIATION W	CONVECTION W	EFFICIENCY
1	759.	38877.	6043.	2036.	0.7422
2	759.	42468.	6579.	2099.	0.7456
3	759.	45500.	7057.	2152.	0.7476
4	759.	47727.	7424.	2191.	0.7485
5	759.	49116.	7661.	2216.	0.7489
6	759.	49650.	7751.	2225.	0.7491
7	759.	49108.	7657.	2215.	0.7490
8	759.	47711.	7420.	2191.	0.7486
9	759.	45476.	7052.	2152.	0.7476
10	759.	42427.	6571.	2099.	0.7457
11	759.	38836.	6035.	2035.	0.7422

OUTSIDE TUBE TEMPERATURES(DEG. F)

1026.1	1067.6	1102.4	1127.6	1143.2	1149.3	1143.1	1127.4	1102.0	1067.1	1025.6
1011.6	1052.0	1085.8	1110.3	1125.6	1131.4	1125.3	1109.9	1085.1	1051.0	1010.6
980.8	1018.4	1049.7	1072.6	1086.9	1092.2	1086.6	1072.2	1049.0	1017.3	979.7
940.0	973.8	1002.0	1022.6	1035.6	1040.4	1035.2	1022.3	1001.5	973.0	939.2
895.0	924.6	949.2	967.4	978.9	983.0	978.6	967.2	949.0	924.1	894.5
848.1	873.2	894.2	909.7	919.5	923.0	919.3	909.6	894.2	873.0	847.8
800.0	820.4	837.5	850.2	858.2	861.1	858.1	850.2	837.6	820.3	799.8
750.9	766.5	779.7	789.4	795.6	797.8	795.4	789.4	779.8	766.6	750.8
702.1	712.9	722.0	728.7	733.1	734.6	733.1	729.0	722.3	713.2	702.3
656.7	662.7	668.0	671.9	674.4	675.3	674.5	672.2	668.5	663.4	657.2
620.5	622.7	624.6	626.1	627.0	627.3	627.1	626.3	625.0	623.1	620.9

NODE EFFICIENCIES(P.U.)

0.407	0.401	0.396	0.391	0.388	0.387	0.391	0.395	0.402	0.410	0.416
0.616	0.614	0.612	0.609	0.607	0.607	0.607	0.609	0.612	0.615	0.617
0.694	0.694	0.692	0.691	0.690	0.689	0.690	0.691	0.691	0.693	0.693
0.730	0.731	0.732	0.731	0.730	0.730	0.730	0.731	0.731	0.731	0.730
0.756	0.759	0.759	0.760	0.760	0.760	0.760	0.760	0.759	0.758	0.756
0.778	0.782	0.784	0.785	0.786	0.786	0.786	0.785	0.784	0.781	0.778
0.798	0.803	0.806	0.808	0.809	0.810	0.809	0.808	0.806	0.803	0.798
0.815	0.821	0.825	0.827	0.829	0.829	0.829	0.827	0.825	0.820	0.815
0.825	0.832	0.837	0.840	0.842	0.842	0.841	0.840	0.836	0.831	0.824
0.817	0.827	0.833	0.837	0.840	0.841	0.840	0.838	0.833	0.827	0.818
0.767	0.781	0.791	0.798	0.802	0.804	0.803	0.799	0.793	0.783	0.770

PAUSE

LINE CALLING-ROUTINE

980 ATPFW

INCIDENT FLUX(W/SQ.CM)

5.4	5.9	6.3	6.7	6.8	6.9	6.9	6.7	6.4	6.0	5.5
8.5	9.3	10.0	10.5	10.8	10.9	10.8	10.5	10.0	9.3	8.5
10.3	11.2	12.0	12.6	13.0	13.1	13.0	12.6	12.0	11.2	10.2
10.8	11.8	12.7	13.3	13.7	13.8	13.7	13.3	12.6	11.8	10.8
10.9	12.0	12.8	13.4	13.8	13.9	13.8	13.4	12.7	11.9	10.9
10.9	11.9	12.8	13.4	13.8	13.9	13.7	13.4	12.8	11.9	10.9
10.9	11.9	12.7	13.3	13.7	13.8	13.7	13.3	12.7	11.8	10.9
10.7	11.6	12.5	13.1	13.4	13.6	13.4	13.0	12.4	11.6	10.6
10.0	10.9	11.7	12.2	12.6	12.7	12.6	12.2	11.6	10.8	9.9
8.2	9.0	9.6	10.1	10.4	10.6	10.4	10.1	9.7	9.0	8.2
5.3	5.8	6.2	6.5	6.7	6.8	6.7	6.6	6.3	5.9	5.4

ABSORBED FLUX(W/SQ.CM)

2.2	2.4	2.5	2.6	2.7	2.7	2.7	2.6	2.6	2.5	2.3
5.2	5.7	6.1	6.4	6.5	6.6	6.6	6.4	6.1	5.7	5.3
7.1	7.8	8.3	8.7	9.0	9.1	9.0	8.7	8.3	7.7	7.1
7.9	8.6	9.3	9.7	10.0	10.1	10.0	9.7	9.2	8.6	7.9
8.3	9.1	9.7	10.2	10.5	10.6	10.5	10.2	9.7	9.0	8.2
8.5	9.3	10.0	10.5	10.8	10.9	10.8	10.5	10.0	9.3	8.5
8.7	9.5	10.2	10.8	11.1	11.2	11.1	10.8	10.2	9.5	8.7
8.7	9.5	10.3	10.8	11.1	11.3	11.1	10.8	10.2	9.5	8.7
8.2	9.1	9.8	10.3	10.6	10.7	10.6	10.3	9.7	9.0	8.1
6.7	7.4	8.0	8.5	8.8	8.9	8.8	8.5	8.1	7.5	6.7
4.1	4.5	4.9	5.2	5.4	5.5	5.4	5.3	5.0	4.6	4.2

RADIATION LOSS(W)

890.5	996.1	1091.2	1164.4	1211.5	1230.1	1211.2	1163.8	1090.2	994.7	889.3
855.8	955.4	1044.9	1113.9	1158.5	1175.8	1157.6	1112.7	1043.1	952.9	853.5
785.1	872.0	949.5	1009.4	1048.2	1062.8	1047.3	1008.2	947.8	869.4	782.8
698.3	769.6	833.2	882.1	913.9	925.9	913.1	881.3	832.2	767.9	696.8
611.0	667.5	717.4	755.9	781.0	790.1	780.2	755.4	716.9	666.4	610.0
528.8	571.7	609.6	638.6	657.5	664.4	657.0	638.3	609.5	571.3	528.3
453.1	484.1	511.4	532.2	545.8	550.6	545.6	532.2	511.5	484.1	452.8
384.4	405.3	423.7	437.6	446.6	449.9	446.4	437.6	423.9	405.5	384.3
323.9	336.6	347.7	356.0	361.4	363.3	361.4	356.2	348.0	337.0	324.1
273.9	280.3	285.8	290.0	292.7	293.7	292.8	290.3	286.4	280.9	274.5
238.3	240.4	242.2	243.6	244.5	244.8	244.6	243.8	242.6	240.7	238.7

CONVECTION LOSS(W)

230.1	240.1	248.4	254.5	258.2	259.7	258.2	254.4	248.3	239.9	229.9
226.6	236.3	244.4	250.3	254.0	255.4	253.9	250.2	244.3	236.1	226.3
219.2	228.2	235.7	241.3	244.7	246.0	244.6	241.2	235.6	228.0	218.9
209.3	217.5	224.3	229.2	232.3	233.5	232.3	229.1	224.1	217.3	209.2
198.5	205.6	211.6	215.9	218.7	219.7	218.6	215.9	211.5	205.5	198.4
187.2	193.3	198.3	202.1	204.4	205.3	204.4	202.0	198.3	193.2	187.2
175.7	180.6	184.7	187.7	189.7	190.3	189.6	187.7	184.7	180.6	175.6
163.9	167.6	170.8	173.1	174.6	175.1	174.6	173.1	170.8	167.6	163.8
152.1	154.7	156.9	158.5	159.6	159.9	159.6	158.6	157.0	154.8	152.1
141.2	142.6	143.9	144.8	145.4	145.7	145.5	144.9	144.0	142.8	141.3
132.5	133.0	133.4	133.8	134.0	134.1	134.1	133.9	133.5	133.1	132.6

NODE SODIUM TEMPERATURES(DEG. F)

1021.3	1062.5	1097.0	1122.0	1137.5	1143.5	1137.3	1121.7	1096.5	1061.8	1020.6
1000.4	1039.8	1072.6	1096.6	1111.5	1117.1	1111.2	1096.2	1071.9	1038.7	999.3
965.4	1001.6	1031.8	1053.9	1067.7	1072.8	1067.3	1053.5	1031.2	1000.6	964.5
922.9	955.1	982.0	1001.7	1014.1	1018.7	1013.8	1001.4	981.6	954.4	922.2
877.2	905.1	928.3	945.5	956.3	960.2	956.1	945.3	928.2	904.6	876.7
829.8	853.0	872.6	887.0	896.2	899.4	896.0	886.9	872.6	852.9	829.5
781.2	799.7	815.4	826.9	834.2	836.9	834.1	826.9	815.5	799.8	781.0
732.1	745.8	757.4	766.0	771.5	773.4	771.4	766.1	757.6	746.0	732.1
684.3	693.2	700.8	706.4	710.1	711.4	710.1	706.7	701.2	693.7	684.6
642.0	646.6	650.5	653.4	655.3	656.0	655.4	653.7	651.0	647.1	642.5
611.5	612.8	613.9	614.7	615.2	615.4	615.3	614.8	614.1	613.0	611.8

PAUSE

LINE CALLING-ROUTINE

1120 ATPFW

SODIUM HEAT TRANSFER COEFFICIENTS(BTU/HR*F*FT**2)

1700.0	1686.0	1674.8	1666.7	1661.9	1660.0	1661.9	1666.8	1674.9	1686.3	1700.2
1707.2	1693.7	1682.7	1674.9	1670.1	1668.3	1670.2	1675.0	1682.9	1694.0	1707.6
1719.6	1706.8	1696.4	1688.9	1684.3	1682.7	1684.4	1689.1	1696.6	1707.1	1720.0
1735.3	1723.4	1713.7	1706.8	1702.4	1700.9	1702.6	1706.9	1713.8	1723.6	1735.5
1752.8	1742.0	1733.2	1726.9	1722.9	1721.5	1723.0	1727.0	1733.3	1742.2	1753.0
1771.9	1762.4	1754.6	1749.0	1745.4	1744.2	1745.5	1749.0	1754.6	1762.5	1772.0
1792.4	1784.4	1777.8	1773.0	1770.0	1768.9	1770.1	1773.0	1777.8	1784.4	1792.5
1814.3	1808.0	1802.8	1799.0	1796.6	1795.8	1796.6	1799.0	1802.7	1807.9	1814.3
1836.9	1832.6	1828.9	1826.2	1824.5	1823.9	1824.5	1826.1	1828.7	1832.3	1836.7
1858.0	1855.7	1853.7	1852.2	1851.3	1850.9	1851.2	1852.1	1853.5	1855.4	1857.8
1874.1	1873.4	1872.8	1872.4	1872.1	1872.0	1872.1	1872.3	1872.7	1873.3	1874.0

TUBE CONDUCTANCE(BTU/HR*F*FT**2)

937.2	937.9	938.5	938.8	939.0	939.1	939.0	938.8	938.5	937.9	937.2
937.2	938.0	938.6	939.0	939.2	939.3	939.2	939.0	938.6	938.0	937.2
936.8	937.6	938.3	938.7	938.9	939.0	938.9	938.7	938.3	937.6	936.8
935.9	936.8	937.5	937.9	938.2	938.3	938.2	937.9	937.5	936.8	935.9
934.8	935.7	936.3	936.8	937.1	937.2	937.1	936.8	936.3	935.7	934.8
933.5	934.3	935.0	935.5	935.7	935.8	935.7	935.5	935.0	934.3	933.5
932.0	932.8	933.4	933.8	934.1	934.2	934.1	933.8	933.4	932.8	932.0
930.3	931.0	931.5	931.9	932.1	932.2	932.1	931.9	931.5	931.0	930.3
928.4	929.0	929.4	929.7	929.9	930.0	929.9	929.7	929.4	929.0	928.4
926.4	926.8	927.0	927.3	927.4	927.4	927.4	927.3	927.1	926.8	926.5
924.6	924.7	924.8	924.9	925.0	925.0	925.0	925.0	924.9	924.7	924.6

TUBE WALL CONDUCTIVITY(BTU/HR*F*FT)

11.5	11.7	11.9	12.0	12.1	12.1	12.1	12.0	11.9	11.7	11.5
11.4	11.6	11.8	11.9	12.0	12.0	12.0	11.9	11.8	11.6	11.4
11.3	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.6	11.4	11.3
11.1	11.2	11.4	11.5	11.5	11.5	11.5	11.5	11.4	11.2	11.1
10.9	11.0	11.1	11.2	11.3	11.3	11.3	11.2	11.1	11.0	10.9
10.6	10.8	10.9	10.9	11.0	11.0	11.0	10.9	10.9	10.8	10.6
10.4	10.5	10.6	10.6	10.7	10.7	10.7	10.6	10.6	10.5	10.4
10.2	10.3	10.3	10.4	10.4	10.4	10.4	10.4	10.3	10.3	10.2
10.0	10.0	10.0	10.1	10.1	10.1	10.1	10.1	10.0	10.0	10.0
9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6

PEAK TUBE TEMPERATURE (DEG. F)

1028.8	1070.5	1105.4	1130.8	1146.5	1152.5	1146.4	1130.6	1105.2	1070.1	1028.4
1018.0	1059.0	1093.3	1118.2	1133.6	1139.6	1133.3	1117.7	1092.6	1058.1	1017.1
989.6	1028.0	1059.9	1083.4	1097.9	1103.3	1097.6	1082.9	1059.2	1026.8	988.4
949.7	984.4	1013.4	1034.6	1047.8	1052.8	1047.5	1034.2	1012.9	983.6	948.9
905.2	935.8	961.2	979.9	991.8	996.0	991.4	979.7	960.9	935.2	904.6
858.6	884.7	906.6	922.6	932.8	936.5	932.6	922.5	906.5	884.4	858.3
810.7	832.1	850.1	863.5	871.9	874.9	871.8	863.4	850.2	832.1	810.5
761.7	778.3	792.4	802.7	809.3	811.7	809.2	802.7	792.5	778.4	761.5
712.3	724.1	734.1	741.5	746.2	747.8	746.2	741.7	734.3	724.4	712.4
665.0	672.0	678.0	682.4	685.3	686.4	685.4	682.8	678.5	672.7	665.6
625.5	628.3	630.7	632.6	633.7	634.1	633.9	632.8	631.2	628.8	626.0

CONTINUE ITERATION?(YES=1,NO=0)?0

E UNIFORM FLUX, ~20GPH FLOW, -20°F AMBIENT

ATPFW 13:45EDT 09/05/79

AIR TEMP.,CONV. COEFF.,CI?-20.,2.0,.623__366

FLUX PLOT FILENAME?FLUXTF

FULL PRINT(YES=1,NO=0)?1

RECEIVER SUMMARY

FLOW	=	8267.LB/HR
INCIDENT	=	496896.W
RAD. LOSS	=	78202.W
CONV. LOSS	=	26233.W
REFL. LOSS	=	24845.W
EFFICIENCY	=	0.7398

TUBE GROUP	FLOW LB/HR	INCIDENT W	RADIATION W	CONVECTION W	EFFICIENCY
1	752.	38877.	6122.	2274.	0.7341
2	752.	42468.	6662.	2337.	0.7381
3	752.	45500.	7143.	2391.	0.7405
4	752.	47727.	7514.	2430.	0.7417
5	752.	49116.	7753.	2455.	0.7422
6	752.	49650.	7844.	2464.	0.7424
7	752.	49108.	7749.	2454.	0.7422
8	752.	47711.	7510.	2430.	0.7417
9	752.	45476.	7139.	2391.	0.7405
10	752.	42427.	6654.	2337.	0.7381
11	752.	38836.	6113.	2273.	0.7341

2 of 5

OUTSIDE TUBE TEMPERATURES(DEG. F)

1025.5	1067.4	1102.4	1127.8	1143.6	1149.6	1143.5	1127.6	1102.0	1066.9	1025.0
1011.3	1052.0	1086.0	1110.8	1126.2	1132.0	1125.9	1110.3	1085.3	1051.0	1010.3
980.6	1018.5	1050.0	1073.1	1087.6	1092.9	1087.2	1072.7	1049.3	1017.4	979.5
939.8	973.8	1002.3	1023.1	1036.1	1041.0	1035.8	1022.7	1001.8	973.0	939.0
894.8	924.6	949.5	967.8	979.4	983.5	979.1	967.6	949.2	924.1	894.2
847.9	873.2	894.4	910.0	919.8	923.4	919.6	909.8	894.3	872.9	847.5
799.7	820.2	837.5	850.3	858.4	861.3	858.3	850.3	837.6	820.2	799.5
750.6	766.3	779.6	789.4	795.6	797.8	795.5	789.4	779.7	766.4	750.5
701.8	712.6	721.8	728.6	733.0	734.5	733.0	728.8	722.1	712.9	701.9
656.3	662.4	667.7	671.6	674.2	675.1	674.3	671.9	668.2	663.1	656.8
620.2	622.4	624.4	625.9	626.8	627.1	626.9	626.1	624.8	622.8	620.6

NODE EFFICIENCIES(P.U.)

0.393	0.388	0.383	0.379	0.376	0.375	0.380	0.383	0.389	0.397	0.403
0.607	0.605	0.604	0.601	0.599	0.600	0.600	0.602	0.604	0.607	0.609
0.686	0.687	0.685	0.684	0.683	0.683	0.683	0.684	0.685	0.686	0.685
0.723	0.725	0.725	0.725	0.724	0.724	0.724	0.725	0.725	0.724	0.723
0.749	0.752	0.753	0.754	0.754	0.754	0.754	0.754	0.753	0.751	0.749
0.771	0.776	0.778	0.779	0.780	0.780	0.780	0.779	0.778	0.775	0.771
0.792	0.797	0.800	0.802	0.804	0.804	0.804	0.802	0.800	0.797	0.791
0.808	0.814	0.819	0.821	0.823	0.824	0.823	0.821	0.818	0.814	0.808
0.817	0.825	0.830	0.834	0.836	0.836	0.835	0.833	0.829	0.824	0.816
0.808	0.818	0.825	0.830	0.833	0.834	0.833	0.830	0.825	0.819	0.808
0.753	0.768	0.779	0.787	0.791	0.792	0.791	0.788	0.781	0.770	0.756

PAUSE

LINE CALLING-ROUTINE

980 ATPFW

INCIDENT FLUX(W/SQ.CM)

5.4	5.9	6.3	6.7	6.8	6.9	6.9	6.7	6.4	6.0	5.5
8.5	9.3	10.0	10.5	10.8	10.9	10.8	10.5	10.0	9.3	8.5
10.3	11.2	12.0	12.6	13.0	13.1	13.0	12.6	12.0	11.2	10.2
10.8	11.8	12.7	13.3	13.7	13.8	13.7	13.3	12.6	11.8	10.8
10.9	12.0	12.8	13.4	13.8	13.9	13.8	13.4	12.7	11.9	10.9
10.9	11.9	12.8	13.4	13.8	13.9	13.7	13.4	12.8	11.9	10.9
10.9	11.9	12.7	13.3	13.7	13.8	13.7	13.3	12.7	11.8	10.9
10.7	11.6	12.5	13.1	13.4	13.6	13.4	13.0	12.4	11.6	10.6
10.0	10.9	11.7	12.2	12.6	12.7	12.6	12.2	11.6	10.8	9.9
8.2	9.0	9.6	10.1	10.4	10.6	10.4	10.1	9.7	9.0	8.2
5.3	5.8	6.2	6.5	6.7	6.8	6.7	6.6	6.3	5.9	5.4

ABSORBED FLUX(W/SQ.CM)

2.1	2.3	2.4	2.5	2.6	2.6	2.6	2.6	2.5	2.4	2.2
5.2	5.6	6.0	6.3	6.5	6.6	6.5	6.3	6.0	5.6	5.2
7.1	7.7	8.3	8.7	8.9	9.0	8.9	8.6	8.2	7.7	7.0
7.8	8.6	9.2	9.6	9.9	10.0	9.9	9.6	9.2	8.5	7.8
8.2	9.0	9.6	10.1	10.4	10.5	10.4	10.1	9.6	8.9	8.2
8.4	9.3	9.9	10.4	10.7	10.9	10.7	10.4	9.9	9.2	8.4
8.6	9.5	10.2	10.7	11.0	11.1	11.0	10.7	10.2	9.4	8.6
8.6	9.5	10.2	10.7	11.0	11.2	11.0	10.7	10.2	9.4	8.6
8.2	9.0	9.7	10.2	10.5	10.6	10.5	10.2	9.6	8.9	8.1
6.6	7.3	8.0	8.4	8.7	8.8	8.7	8.4	8.0	7.4	6.7
4.0	4.4	4.8	5.1	5.3	5.4	5.3	5.2	4.9	4.5	4.1

RADIATION LOSS(W)

896.8	1003.2	1099.0	1172.8	1220.3	1239.0	1220.0	1172.1	1098.0	1001.7	895.6
862.7	963.1	1053.3	1122.9	1167.8	1185.3	1166.9	1121.7	1051.5	960.5	860.4
792.3	879.8	958.0	1018.5	1057.6	1072.3	1056.7	1017.3	956.3	877.2	789.9
705.5	777.5	841.6	891.0	923.0	935.1	922.2	890.1	840.5	775.7	704.0
618.3	675.2	725.5	764.4	789.7	798.9	789.0	763.9	725.0	674.1	617.3
536.1	579.3	617.5	646.8	665.8	672.8	665.4	646.5	617.5	578.9	535.5
460.4	491.6	519.1	540.1	553.8	558.7	553.6	540.1	519.2	491.6	460.0
391.7	412.7	431.3	445.2	454.3	457.6	454.2	445.2	431.4	412.9	391.5
331.1	343.9	355.1	363.4	368.9	370.8	369.0	363.7	355.4	344.3	331.3
281.2	287.6	293.2	297.4	300.1	301.2	300.2	297.7	293.8	288.3	281.8
245.7	247.8	249.6	251.1	252.0	252.3	252.1	251.3	250.0	248.2	246.1

CONVECTION LOSS(W)

251.6	261.7	270.1	276.2	280.0	281.4	280.0	276.1	270.0	261.5	251.5
248.2	258.0	266.1	272.1	275.8	277.2	275.7	272.0	266.0	257.7	247.9
240.8	249.9	257.5	263.0	266.5	267.8	266.4	262.9	257.3	249.6	240.5
230.9	239.1	246.0	251.0	254.1	255.3	254.1	250.9	245.9	239.0	230.8
220.1	227.3	233.3	237.7	240.5	241.5	240.4	237.6	233.2	227.2	220.0
208.8	214.9	220.0	223.8	226.2	227.0	226.1	223.7	220.0	214.9	208.8
197.2	202.2	206.3	209.4	211.4	212.1	211.3	209.4	206.4	202.2	197.2
185.4	189.2	192.4	194.8	196.3	196.8	196.2	194.8	192.4	189.2	185.4
173.7	176.3	178.5	180.1	181.2	181.5	181.2	180.2	178.6	176.4	173.7
162.7	164.2	165.5	166.4	167.0	167.3	167.1	166.5	165.6	164.4	162.9
154.0	154.6	155.1	155.4	155.6	155.7	155.7	155.5	155.1	154.7	154.1

NODE SODIUM TEMPERATURES(DEG. F)

1020.9	1062.5	1097.2	1122.4	1138.0	1144.0	1137.8	1122.1	1096.7	1061.7	1020.2
1000.1	1039.9	1073.0	1097.2	1112.2	1117.9	1111.9	1096.7	1072.3	1038.8	999.1
965.3	1001.8	1032.2	1054.5	1068.4	1073.6	1068.1	1054.1	1031.6	1000.8	964.4
922.8	955.3	982.4	1002.3	1014.8	1019.4	1014.5	1002.0	982.0	954.6	922.1
877.0	905.2	928.7	946.0	956.9	960.9	956.6	945.8	928.5	904.8	876.6
829.6	853.1	872.9	887.4	896.6	899.9	896.4	887.3	872.9	853.0	829.3
781.0	799.7	815.5	827.2	834.6	837.2	834.4	827.1	815.6	799.7	780.8
731.8	745.7	757.5	766.1	771.6	773.6	771.6	766.2	757.6	745.9	731.8
684.0	693.0	700.7	706.4	710.1	711.4	710.1	706.6	701.1	693.5	684.3
641.8	646.4	650.3	653.3	655.2	655.9	655.3	653.6	650.8	646.9	642.3
611.4	612.7	613.8	614.7	615.2	615.3	615.2	614.8	614.0	612.9	611.7

PAUSE

LINE CALLING-ROUTINE

1120 ATPFW

SODIUM HEAT TRANSFER COEFFICIENTS(BTU/HR*F*FT**2)

1693.5	1679.6	1668.2	1660.2	1655.3	1653.4	1655.3	1660.3	1668.4	1679.8	1693.8
1700.7	1687.1	1676.1	1668.2	1663.4	1661.6	1663.5	1668.4	1676.3	1687.5	1701.1
1713.0	1700.1	1689.7	1682.2	1677.6	1675.9	1677.7	1682.3	1689.9	1700.5	1713.4
1728.6	1716.7	1706.9	1700.0	1695.6	1694.1	1695.7	1700.1	1707.1	1716.9	1728.9
1746.1	1735.3	1726.4	1720.0	1716.1	1714.6	1716.2	1720.1	1726.5	1735.4	1746.3
1765.1	1755.6	1747.7	1742.1	1738.5	1737.3	1738.6	1742.1	1747.7	1755.6	1765.2
1785.5	1777.5	1770.9	1766.1	1763.0	1762.0	1763.1	1766.1	1770.9	1777.5	1785.6
1807.4	1801.1	1795.8	1792.0	1789.6	1788.7	1789.6	1792.0	1795.8	1801.0	1807.4
1829.9	1825.6	1821.9	1819.2	1817.5	1816.9	1817.4	1819.1	1821.7	1825.3	1829.8
1851.0	1848.6	1846.6	1845.1	1844.2	1843.8	1844.1	1845.0	1846.4	1848.4	1850.7
1866.9	1866.2	1865.6	1865.2	1864.9	1864.8	1864.9	1865.1	1865.5	1866.1	1866.8

TUBE CONDUCTANCE(BTU/HR*F*FT**2)

934.8	935.6	936.1	936.5	936.7	936.7	936.7	936.5	936.1	935.6	934.8
934.9	935.7	936.3	936.7	936.9	937.0	936.9	936.7	936.3	935.7	934.9
934.5	935.3	935.9	936.4	936.6	936.7	936.6	936.4	935.9	935.3	934.5
933.7	934.5	935.2	935.6	935.9	936.0	935.9	935.6	935.2	934.5	933.7
932.6	933.4	934.1	934.6	934.8	934.9	934.8	934.6	934.1	933.4	932.6
931.3	932.1	932.8	933.2	933.5	933.6	933.5	933.2	932.8	932.1	931.3
929.8	930.6	931.2	931.6	931.9	932.0	931.9	931.6	931.2	930.6	929.8
928.2	928.8	929.4	929.7	930.0	930.1	930.0	929.7	929.4	928.8	928.2
926.3	926.8	927.3	927.6	927.8	927.8	927.8	927.6	927.3	926.8	926.3
924.3	924.7	925.0	925.2	925.3	925.4	925.3	925.2	925.0	924.7	924.4
922.5	922.7	922.8	922.9	922.9	923.0	923.0	922.9	922.8	922.7	922.5

TUBE WALL CONDUCTIVITY(BTU/HR*F*FT)

11.5	11.7	11.9	12.0	12.1	12.1	12.1	12.0	11.9	11.7	11.5
11.4	11.6	11.8	11.9	12.0	12.0	12.0	11.9	11.8	11.6	11.4
11.3	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.6	11.4	11.3
11.1	11.2	11.4	11.5	11.5	11.5	11.5	11.5	11.4	11.2	11.1
10.9	11.0	11.1	11.2	11.3	11.3	11.3	11.2	11.1	11.0	10.9
10.6	10.8	10.9	10.9	11.0	11.0	11.0	10.9	10.9	10.8	10.6
10.4	10.5	10.6	10.6	10.7	10.7	10.7	10.6	10.6	10.5	10.4
10.2	10.3	10.3	10.4	10.4	10.4	10.4	10.4	10.3	10.3	10.2
10.0	10.0	10.0	10.1	10.1	10.1	10.1	10.1	10.0	10.0	10.0
9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6

PEAK TUBE TEMPERATURE (DEG. F)

1028.1	1070.2	1105.4	1130.9	1146.7	1152.8	1146.7	1130.8	1105.1	1069.8	1027.7
1017.6	1058.9	1093.4	1118.5	1134.1	1140.1	1133.8	1118.1	1092.8	1058.0	1016.7
989.3	1028.0	1060.2	1083.8	1098.5	1103.9	1098.2	1083.3	1059.5	1026.8	988.1
949.4	984.4	1013.6	1035.0	1048.3	1053.3	1048.0	1034.6	1013.1	983.6	948.6
904.9	935.7	961.3	980.3	992.2	996.4	991.8	980.0	961.1	935.1	904.3
858.3	884.6	906.6	922.8	933.1	936.8	932.8	922.7	906.6	884.3	857.9
810.4	831.9	850.1	863.5	872.0	875.0	871.9	863.5	850.2	831.9	810.1
761.3	778.0	792.2	802.6	809.3	811.7	809.1	802.6	792.3	778.1	761.1
711.9	723.8	733.9	741.2	746.0	747.7	746.0	741.4	734.0	724.0	711.9
664.5	671.6	677.6	682.1	685.0	686.1	685.1	682.4	678.2	672.3	665.1
625.2	628.0	630.4	632.3	633.4	633.8	633.6	632.5	630.9	628.5	625.7

CONTINUE ITERATION?(YES=1 NO=0)?0

F UNIFORM FLUX, 20 GPM FLOW, 120°F AMBIENT

ATPFW 13:49EDT 09/05/79

AIR TEMP.,CONV. COEFF.,CI?120.,2.0,.6366

FLUX PLOT FILENAME?FLUXTF

FULL PRINT(YES=1,NO=0)?1

RECEIVER SUMMARY

FLOW	=	8398.LB/HR
INCIDENT	=	496896.W
RAD. LOSS	=	76468.W
CONV. LOSS	=	22156.W
REFL. LOSS	=	24845.W
EFFICIENCY	=	0.7515

TUBE GROUP	FLOW LB/HR	INCIDENT W	RADIATION W	CONVECTION W	EFFICIENCY
1	763.	38877.	5977.	1904.	0.7473
2	763.	42468.	6510.	1967.	0.7504
3	763.	45500.	6985.	2020.	0.7521
4	763.	47727.	7351.	2059.	0.7529
5	763.	49116.	7587.	2083.	0.7531
6	763.	49650.	7676.	2092.	0.7533
7	763.	49108.	7583.	2083.	0.7532
8	763.	47711.	7347.	2058.	0.7529
9	763.	45476.	6981.	2020.	0.7521
10	763.	42427.	6502.	1967.	0.7504
11	763.	38836.	5969.	1904.	0.7473

F
2 of 5

OUTSIDE TUBE TEMPERATURES(DEG. F)

1026.4	1067.8	1102.3	1127.5	1143.0	1149.0	1142.9	1127.2	1102.0	1067.2	1025.9
1011.8	1052.0	1085.6	1110.1	1125.2	1131.0	1124.9	1109.6	1084.9	1051.0	1010.9
980.9	1018.4	1049.5	1072.3	1086.6	1091.8	1086.2	1071.9	1048.8	1017.3	979.9
940.1	973.7	1001.8	1022.3	1035.2	1040.0	1034.9	1022.0	1001.3	972.9	939.4
895.2	924.6	949.1	967.2	978.6	982.7	978.3	967.0	948.9	924.1	894.6
848.3	873.2	894.2	909.5	919.3	922.8	919.1	909.4	894.1	873.0	848.0
800.2	820.4	837.5	850.1	858.1	860.9	858.0	850.1	837.6	820.4	800.0
751.1	766.6	779.8	789.4	795.5	797.8	795.4	789.4	779.9	766.7	751.0
702.4	713.1	722.2	728.8	733.2	734.7	733.2	729.1	722.4	713.4	702.5
656.9	662.9	668.2	672.0	674.5	675.5	674.6	672.4	668.7	663.6	657.4
620.6	622.8	624.7	626.2	627.1	627.4	627.2	626.4	625.1	623.2	621.0

NODE EFFICIENCIES(P.U.)

0.415	0.409	0.403	0.399	0.395	0.394	0.398	0.402	0.409	0.417	0.424
0.621	0.619	0.617	0.614	0.612	0.612	0.612	0.614	0.617	0.620	0.623
0.698	0.698	0.696	0.695	0.693	0.693	0.694	0.695	0.696	0.697	0.697
0.735	0.735	0.735	0.735	0.734	0.734	0.734	0.734	0.735	0.735	0.734
0.760	0.763	0.763	0.764	0.764	0.763	0.763	0.763	0.763	0.762	0.760
0.782	0.786	0.788	0.789	0.789	0.790	0.789	0.789	0.788	0.785	0.782
0.803	0.807	0.810	0.812	0.813	0.813	0.813	0.812	0.810	0.807	0.803
0.820	0.825	0.829	0.831	0.832	0.833	0.832	0.831	0.828	0.824	0.819
0.830	0.836	0.841	0.844	0.845	0.846	0.845	0.843	0.840	0.835	0.829
0.823	0.832	0.838	0.842	0.845	0.846	0.845	0.842	0.838	0.832	0.823
0.776	0.789	0.799	0.806	0.809	0.811	0.810	0.807	0.801	0.791	0.779

PAUSE

LINE CALLING-ROUTINE

980 ATPFW

INCIDENT FLUX(W/SQ.CM)

5.4	5.9	6.3	6.7	6.8	6.9	6.9	6.7	6.4	6.0	5.5
8.5	9.3	10.0	10.5	10.8	10.9	10.8	10.5	10.0	9.3	8.5
10.3	11.2	12.0	12.6	13.0	13.1	13.0	12.6	12.0	11.2	10.2
10.8	11.8	12.7	13.3	13.7	13.8	13.7	13.3	12.6	11.8	10.8
10.9	12.0	12.8	13.4	13.8	13.9	13.8	13.4	12.7	11.9	10.9
10.9	11.9	12.8	13.4	13.8	13.9	13.7	13.4	12.8	11.9	10.9
10.9	11.9	12.7	13.3	13.7	13.8	13.7	13.3	12.7	11.8	10.9
10.7	11.6	12.5	13.1	13.4	13.6	13.4	13.0	12.4	11.6	10.6
10.0	10.9	11.7	12.2	12.6	12.7	12.6	12.2	11.6	10.8	9.9
8.2	9.0	9.6	10.1	10.4	10.6	10.4	10.1	9.7	9.0	8.2
5.3	5.8	6.2	6.5	6.7	6.8	6.7	6.6	6.3	5.9	5.4

1244

ABSORBED FLUX(W/SQ.CM)

2.2	2.4	2.6	2.7	2.7	2.7	2.7	2.7	2.6	2.5	2.3
5.3	5.7	6.2	6.4	6.6	6.7	6.6	6.4	6.2	5.8	5.3
7.2	7.8	8.4	8.8	9.0	9.1	9.0	8.8	8.3	7.8	7.1
8.0	8.7	9.3	9.8	10.0	10.1	10.0	9.7	9.3	8.7	7.9
8.3	9.1	9.7	10.2	10.5	10.6	10.5	10.2	9.7	9.1	8.3
8.5	9.4	10.1	10.6	10.9	11.0	10.8	10.5	10.0	9.3	8.5
8.7	9.6	10.3	10.8	11.1	11.2	11.1	10.8	10.3	9.6	8.7
8.7	9.6	10.3	10.8	11.2	11.3	11.1	10.8	10.3	9.6	8.7
8.3	9.1	9.8	10.3	10.7	10.7	10.6	10.3	9.8	9.1	8.2
6.8	7.5	8.1	8.5	8.8	8.9	8.8	8.5	8.1	7.5	6.8
4.1	4.6	5.0	5.3	5.4	5.5	5.5	5.3	5.0	4.7	4.2

RADIATION LOSS(W)

885.0	990.1	1084.8	1157.7	1204.5	1223.0	1204.2	1157.0	1083.8	988.7	883.8
849.9	949.0	1038.1	1106.8	1151.1	1168.3	1150.2	1105.5	1036.3	946.6	847.7
779.1	865.5	942.6	1002.2	1040.8	1055.3	1039.9	1001.0	940.9	862.9	776.8
692.2	763.2	826.4	875.1	906.7	918.6	905.9	874.3	825.4	761.5	690.7
605.0	661.1	710.7	749.0	773.9	783.0	773.2	748.5	710.2	660.1	604.0
522.7	565.4	603.1	631.9	650.7	657.6	650.3	631.7	603.0	565.0	522.2
447.1	477.9	505.0	525.7	539.2	544.0	539.0	525.7	505.1	477.9	446.7
378.4	399.2	417.5	431.2	440.2	443.5	440.0	431.3	417.6	399.3	378.2
317.8	330.4	341.5	349.7	355.2	357.0	355.2	350.0	341.8	330.9	318.0
267.8	274.1	279.6	283.8	286.5	287.5	286.6	284.1	280.2	274.8	268.4
232.1	234.1	235.9	237.4	238.2	238.5	238.3	237.6	236.3	234.5	232.4

CONVECTION LOSS(W)

218.1	228.1	236.4	242.4	246.2	247.6	246.1	242.4	236.3	227.9	218.0
214.6	224.3	232.3	238.2	241.9	243.3	241.8	238.1	232.2	224.0	214.4
207.2	216.2	223.7	229.2	232.6	233.8	232.5	229.0	223.5	215.9	206.9
197.3	205.4	212.2	217.1	220.2	221.4	220.1	217.0	212.1	205.2	197.2
186.5	193.6	199.5	203.9	206.6	207.6	206.5	203.8	199.4	193.5	186.4
175.2	181.2	186.3	190.0	192.3	193.2	192.3	190.0	186.3	181.2	175.2
163.7	168.5	172.6	175.7	177.6	178.3	177.6	175.7	172.7	168.5	163.6
151.9	155.6	158.8	161.1	162.6	163.1	162.5	161.1	158.8	155.6	151.8
140.1	142.7	144.9	146.5	147.5	147.9	147.5	146.6	145.0	142.8	140.2
129.2	130.6	131.9	132.8	133.4	133.7	133.5	132.9	132.0	130.8	129.3
120.5	121.0	121.5	121.8	122.0	122.1	122.1	121.9	121.5	121.1	120.6

NODE SODIUM TEMPERATURES(DEG. F)

1021.6	1062.6	1096.9	1121.8	1137.2	1143.2	1137.0	1121.5	1096.4	1061.9	1020.9
1000.5	1039.7	1072.4	1096.2	1111.1	1116.7	1110.8	1095.8	1071.7	1038.6	999.5
965.5	1001.5	1031.5	1053.5	1067.2	1072.3	1066.9	1053.1	1030.9	1000.5	964.6
923.0	955.0	981.7	1001.4	1013.7	1018.2	1013.4	1001.1	981.4	954.3	922.3
877.2	905.0	928.1	945.2	956.0	959.8	955.7	945.0	928.0	904.5	876.8
829.8	853.0	872.5	886.8	895.9	899.1	895.7	886.7	872.5	852.9	829.5
781.3	799.7	815.3	826.8	834.1	836.7	833.9	826.8	815.4	799.8	781.1
732.2	745.9	757.4	765.9	771.4	773.3	771.3	766.0	757.6	746.1	732.2
684.4	693.3	700.9	706.5	710.1	711.4	710.1	706.7	701.3	693.8	684.7
642.2	646.7	650.6	653.5	655.4	656.0	655.5	653.8	651.1	647.3	642.7
611.6	612.8	613.9	614.8	615.3	615.5	615.3	614.9	614.2	613.1	611.8

PAUSE

LINE CALLING-ROUTINE

1120 ATPFW

SODIUM HEAT TRANSFER COEFFICIENTS(BTU/HR*F*FT**2)

1704.0	1690.1	1678.8	1670.8	1666.0	1664.1	1666.0	1670.9	1679.0	1690.3	1704.2
1711.3	1697.8	1686.8	1679.0	1674.2	1672.5	1674.3	1679.2	1687.1	1698.1	1711.7
1723.8	1710.9	1700.6	1693.1	1688.6	1686.9	1688.7	1693.3	1700.8	1711.3	1724.1
1739.4	1727.6	1717.9	1711.0	1706.7	1705.1	1706.8	1711.1	1718.1	1727.8	1739.7
1757.0	1746.3	1737.5	1731.2	1727.2	1725.8	1727.3	1731.2	1737.6	1746.4	1757.2
1776.1	1766.7	1758.9	1753.3	1749.8	1748.5	1749.8	1753.3	1758.9	1766.7	1776.2
1796.6	1788.7	1782.1	1777.4	1774.4	1773.3	1774.4	1777.4	1782.1	1788.7	1796.7
1818.6	1812.4	1807.1	1803.4	1801.0	1800.1	1801.0	1803.3	1807.1	1812.3	1818.6
1841.2	1836.9	1833.3	1830.6	1828.9	1828.3	1828.9	1830.5	1833.1	1836.7	1841.1
1862.4	1860.1	1858.1	1856.6	1855.7	1855.3	1855.6	1856.5	1857.9	1859.8	1862.2
1878.6	1877.9	1877.3	1876.8	1876.6	1876.5	1876.5	1876.8	1877.2	1877.8	1878.4

TUBE CONDUCTANCE(BTU/HR*F*FT**2)

938.6	939.4	939.9	940.3	940.5	940.6	940.5	940.3	939.9	939.4	938.6
938.6	939.5	940.1	940.5	940.7	940.8	940.7	940.5	940.1	939.5	938.6
938.2	939.1	939.7	940.1	940.4	940.5	940.4	940.1	939.7	939.0	938.2
937.3	938.2	938.9	939.3	939.6	939.7	939.6	939.3	938.9	938.2	937.3
936.2	937.1	937.8	938.2	938.5	938.6	938.5	938.2	937.8	937.1	936.2
934.9	935.7	936.4	936.8	937.1	937.2	937.1	936.8	936.4	935.7	934.9
933.4	934.1	934.7	935.2	935.5	935.6	935.5	935.2	934.8	934.1	933.4
931.7	932.3	932.9	933.2	933.5	933.6	933.5	933.2	932.9	932.3	931.7
929.8	930.3	930.7	931.0	931.2	931.3	931.2	931.0	930.7	930.3	929.8
927.7	928.1	928.3	928.6	928.7	928.7	928.7	928.6	928.4	928.1	927.7
925.8	926.0	926.1	926.2	926.3	926.3	926.3	926.2	926.1	926.0	925.9

TUBE WALL CONDUCTIVITY(BTU/HR*F*FT)

11.5	11.7	11.9	12.0	12.1	12.1	12.1	12.0	11.9	11.7	11.5
11.4	11.6	11.8	11.9	12.0	12.0	12.0	11.9	11.8	11.6	11.4
11.3	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.6	11.4	11.3
11.1	11.2	11.4	11.5	11.5	11.5	11.5	11.5	11.4	11.2	11.1
10.9	11.0	11.1	11.2	11.3	11.3	11.2	11.2	11.1	11.0	10.9
10.6	10.8	10.9	10.9	11.0	11.0	11.0	10.9	10.9	10.8	10.6
10.4	10.5	10.6	10.6	10.7	10.7	10.7	10.6	10.6	10.5	10.4
10.2	10.3	10.3	10.4	10.4	10.4	10.4	10.4	10.3	10.3	10.2
10.0	10.0	10.0	10.1	10.1	10.1	10.1	10.1	10.0	10.0	10.0
9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6

PEAK TUBE TEMPERATURE (DEG. F)

1029.2	1070.7	1105.5	1130.7	1146.3	1152.4	1146.3	1130.5	1105.2	1070.3	1028.8
1018.3	1059.1	1093.2	1117.9	1133.3	1139.2	1133.0	1117.5	1092.5	1058.1	1017.4
989.8	1028.0	1059.8	1083.1	1097.6	1103.0	1097.3	1082.6	1059.1	1026.8	988.6
949.9	984.4	1013.2	1034.3	1047.5	1052.4	1047.2	1033.9	1012.7	983.6	949.1
905.4	935.8	961.1	979.8	991.5	995.7	991.2	979.5	960.8	935.2	904.8
858.8	884.8	906.5	922.5	932.6	936.3	932.4	922.4	906.5	884.5	858.5
811.0	832.3	850.2	863.4	871.8	874.8	871.7	863.4	850.2	832.2	810.7
762.0	778.5	792.5	802.8	809.3	811.7	809.2	802.7	792.6	778.6	761.8
712.6	724.4	734.3	741.6	746.4	748.0	746.3	741.8	734.5	724.6	712.7
665.3	672.2	678.2	682.6	685.5	686.6	685.6	683.0	678.8	672.9	665.8
625.7	628.5	630.9	632.8	633.9	634.3	634.0	633.0	631.4	629.0	626.3

CONTINUE ITERATION?(YES=1,NO=0)?0

9 PEAK FLUX, 70°F AMBIENT

ATPFW 16:48EST 11/28/79

AIR TEMP.,CONV. COEFF.,C?70.,2.0,.6366

FLUX PLOT FILENAME?FLUXXX

FULL PRINT(YES=1,NO=0)?1

RECEIVER SUMMARY

FLOW = 50992.LB/HR
INCIDENT = 2499415.W
RAD. LOSS = 83421.W
CONV. LOSS = 23559.W
REFL. LOSS = 124971.W
EFFICIENCY = 0.9072

TUBE GROUP	FLOW LB/HR	INCIDENT W	RADIATION W	CONVECTION W	EFFICIENCY
1	4636.	202164.	6695.	2061.	0.9067
2	4636.	212825.	7051.	2095.	0.9070
3	4636.	227435.	7574.	2142.	0.9073
4	4636.	236122.	7895.	2170.	0.9074
5	4636.	245598.	8259.	2201.	0.9074
6	4636.	251126.	8472.	2219.	0.9074
7	4636.	245598.	8259.	2201.	0.9074
8	4636.	236122.	7895.	2170.	0.9074
9	4636.	227435.	7574.	2142.	0.9073
10	4636.	212825.	7051.	2095.	0.9070
11	4636.	202164.	6695.	2061.	0.9067

OUTSIDE TUBE TEMPERATURES(DEG. F)

1046.4	1069.9	1101.9	1120.9	1142.5	1154.6	1142.5	1120.9	1101.9	1069.9	1046.4
1055.3	1079.8	1112.9	1133.0	1152.9	1166.0	1152.9	1133.0	1112.9	1079.8	1055.3
1081.8	1107.3	1139.5	1159.6	1180.5	1193.6	1180.5	1159.6	1139.5	1107.3	1081.8
1092.5	1118.9	1159.4	1180.4	1204.9	1218.0	1204.9	1180.4	1159.4	1118.9	1092.5
994.9	1013.6	1044.9	1062.6	1084.0	1090.0	1084.0	1062.6	1044.9	1013.6	994.9
888.6	905.0	926.9	938.7	951.4	961.3	951.4	938.7	926.9	905.0	888.6
725.6	732.3	735.0	739.7	742.5	747.2	742.5	739.7	735.0	732.3	725.6
635.1	637.0	639.0	640.9	641.8	643.8	641.8	640.9	639.0	637.0	635.1
609.9	609.9	609.9	609.9	611.9	611.9	611.9	609.9	609.9	609.9	609.9
604.1	604.1	604.1	604.1	604.1	604.1	604.1	604.1	604.1	604.1	604.1
600.1	600.1	600.1	600.1	600.1	600.1	600.1	600.1	600.1	600.1	600.1

NODE EFFICIENCIES(P.U.)

0.354	0.321	0.272	0.242	0.331	0.314	0.331	0.242	0.272	0.321	0.354
0.760	0.761	0.757	0.759	0.750	0.754	0.750	0.759	0.757	0.761	0.760
0.892	0.892	0.888	0.888	0.886	0.886	0.886	0.888	0.888	0.892	0.892
0.922	0.922	0.921	0.921	0.921	0.921	0.921	0.921	0.921	0.922	0.922
0.928	0.928	0.928	0.928	0.928	0.928	0.928	0.928	0.928	0.928	0.928
0.933	0.933	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.933	0.933
0.927	0.928	0.928	0.928	0.928	0.929	0.928	0.928	0.928	0.928	0.927
0.889	0.892	0.895	0.897	0.897	0.899	0.897	0.897	0.895	0.892	0.889
0.768	0.768	0.768	0.768	0.798	0.798	0.798	0.768	0.768	0.768	0.768
0.653	0.653	0.653	0.653	0.653	0.653	0.653	0.653	0.653	0.653	0.653
0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070

PAUSE

LINE CALLING-ROUTINE

980 ATPFW

INCIDENT FLUX(W/SQ.CM)

5.2	5.2	5.2	5.2	6.2	6.2	6.2	5.2	5.2	5.2	5.2
16.6	17.6	18.6	19.7	19.7	20.7	19.7	19.7	18.6	17.6	16.6
58.0	61.1	62.1	64.2	65.2	67.3	65.2	64.2	62.1	61.1	58.0
121.1	128.3	139.7	144.9	151.1	155.2	151.1	144.9	139.7	128.3	121.1
124.2	129.4	140.8	147.0	155.2	155.2	155.2	147.0	140.8	129.4	124.2
121.1	128.3	139.7	144.9	151.1	155.2	151.1	144.9	139.7	128.3	121.1
58.0	61.1	62.1	64.2	65.2	67.3	65.2	64.2	62.1	61.1	58.0
16.6	17.6	18.6	19.7	19.7	20.7	19.7	19.7	18.6	17.6	16.6
5.2	5.2	5.2	5.2	6.2	6.2	6.2	5.2	5.2	5.2	5.2
3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

ABSORBED FLUX(W/SQ.CM)

1.8	1.7	1.4	1.3	2.1	1.9	2.1	1.3	1.4	1.7	1.8
12.6	13.4	14.1	14.9	14.7	15.6	14.7	14.9	14.1	13.4	12.6
51.7	54.5	55.2	57.0	57.8	59.6	57.8	57.0	55.2	54.5	51.7
111.6	118.3	128.7	133.5	139.1	142.9	139.1	133.5	128.7	118.3	111.6
115.3	120.1	130.7	136.4	144.1	144.1	144.1	136.4	130.7	120.1	115.3
113.0	119.7	130.4	135.3	141.1	145.0	141.1	135.3	130.4	119.7	113.0
53.7	56.6	57.6	59.6	60.5	62.5	60.5	59.6	57.6	56.6	53.7
14.7	15.7	16.7	17.6	17.6	18.6	17.6	17.6	16.7	15.7	14.7
4.0	4.0	4.0	4.0	5.0	5.0	5.0	4.0	4.0	4.0	4.0
2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

RADIATION LOSS(W)

941.1	1002.0	1089.9	1144.6	1209.4	1246.8	1209.4	1144.6	1089.9	1002.0	941.1
963.8	1028.6	1121.3	1180.4	1241.3	1282.5	1241.3	1180.4	1121.3	1028.6	963.8
1034.1	1105.2	1200.2	1262.4	1329.5	1373.1	1329.5	1262.4	1200.2	1105.2	1034.1
1063.4	1138.8	1261.8	1329.3	1411.3	1456.7	1411.3	1329.3	1261.8	1138.8	1063.4
817.0	860.5	937.2	983.0	1040.1	1056.7	1040.1	983.0	937.2	860.5	817.0
599.2	629.6	672.1	695.7	721.9	742.8	721.9	695.7	672.1	629.6	599.2
352.1	360.4	363.9	369.9	373.5	379.5	373.5	369.9	363.9	360.4	352.1
252.3	254.2	256.1	258.0	258.9	260.8	258.9	258.0	256.1	254.2	252.3
228.6	228.6	228.6	228.6	230.4	230.4	230.4	228.6	228.6	228.6	228.6
223.4	223.4	223.4	223.4	223.4	223.4	223.4	223.4	223.4	223.4	223.4
219.8	219.8	219.8	219.8	219.8	219.8	219.8	219.8	219.8	219.8	219.8

CONVECTION LOSS(W)

235.0	240.6	248.3	252.9	258.1	261.0	258.1	252.9	248.3	240.6	235.0
237.1	243.0	251.0	255.8	260.6	263.7	260.6	255.8	251.0	243.0	237.1
243.5	249.6	257.4	262.2	267.2	270.4	267.2	262.2	257.4	249.6	243.5
246.0	252.4	262.1	267.2	273.1	276.2	273.1	267.2	262.1	252.4	246.0
222.6	227.1	234.6	238.9	244.0	245.4	244.0	238.9	234.6	227.1	222.6
197.0	200.9	206.2	209.0	212.1	214.5	212.1	209.0	206.2	200.9	197.0
157.8	159.4	160.0	161.2	161.8	163.0	161.8	161.2	160.0	159.4	157.8
136.0	136.4	136.9	137.4	137.6	138.1	137.6	137.4	136.9	136.4	136.0
129.9	129.9	129.9	129.9	130.4	130.4	130.4	129.9	129.9	129.9	129.9
128.5	128.5	128.5	128.5	128.5	128.5	128.5	128.5	128.5	128.5	128.5
127.6	127.6	127.6	127.6	127.6	127.6	127.6	127.6	127.6	127.6	127.6

NODE SODIUM TEMPERATURES(DEG. F)

1043.8	1067.5	1099.9	1119.1	1139.6	1151.8	1139.6	1119.1	1099.9	1067.5	1043.8
1037.1	1060.5	1092.7	1111.6	1131.8	1143.7	1131.8	1111.6	1092.7	1060.5	1037.1
1007.3	1029.1	1060.6	1078.4	1098.3	1108.9	1098.3	1078.4	1060.6	1029.1	1007.3
931.8	949.2	975.5	990.3	1007.2	1015.2	1007.2	990.3	975.5	949.2	931.8
826.8	838.9	855.5	865.4	876.1	882.4	876.1	865.4	855.5	838.9	826.8
721.2	728.0	734.7	739.7	744.2	748.7	744.2	739.7	734.7	728.0	721.2
644.1	646.4	647.7	649.5	650.9	652.7	650.9	649.5	647.7	646.4	644.1
612.4	612.9	613.3	613.8	614.7	615.1	614.7	613.8	613.3	612.9	612.4
603.8	603.8	603.8	603.8	604.2	604.2	604.2	603.8	603.8	603.8	603.8
601.0	601.0	601.0	601.0	601.0	601.0	601.0	601.0	601.0	601.0	601.0
600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0

PA JSE

LINE CALLING-ROUTINE

1120 AIPEW

SODIUM HEAT TRANSFER COEFFICIENTS(BTU/HR*F*FT**2)

3490.3	3474.0	3452.2	3439.5	3426.1	3418.3	3426.1	3439.5	3452.2	3474.0	3490.3
3495.0	3478.7	3456.9	3444.4	3431.2	3423.5	3431.2	3444.4	3456.9	3478.7	3495.0
3516.0	3500.6	3478.6	3466.6	3453.2	3446.2	3453.2	3466.6	3478.6	3500.6	3516.0
3572.1	3558.8	3539.2	3528.4	3516.1	3510.4	3516.1	3528.4	3539.2	3558.8	3572.1
3656.8	3646.6	3632.8	3624.7	3615.9	3610.8	3615.9	3624.7	3632.8	3646.6	3656.8
3752.2	3745.7	3739.3	3734.7	3730.5	3726.3	3730.5	3734.7	3739.3	3745.7	3752.2
3829.9	3827.5	3826.1	3824.2	3822.7	3820.8	3822.7	3824.2	3826.1	3827.5	3829.9
3864.2	3863.7	3863.2	3862.7	3861.7	3861.2	3861.7	3862.7	3863.2	3863.7	3864.2
3873.8	3873.8	3873.8	3873.8	3873.3	3873.3	3873.3	3873.8	3873.8	3873.8	3873.8
3876.9	3876.9	3876.9	3876.9	3876.9	3876.9	3876.9	3876.9	3876.9	3876.9	3876.9
3878.0	3878.0	3878.0	3878.0	3878.0	3878.0	3878.0	3878.0	3878.0	3878.0	3878.0

TUBE CONDUCTANCE(BTU/HR*F*FT**2)

1397.6	1401.7	1407.1	1410.3	1413.8	1415.7	1413.8	1410.3	1407.1	1401.7	1397.6
1398.8	1403.0	1408.6	1411.9	1415.2	1417.2	1415.2	1411.9	1408.6	1403.0	1398.8
1402.2	1406.5	1411.9	1415.2	1418.6	1420.7	1418.6	1415.2	1411.9	1406.5	1402.2
1402.2	1406.7	1413.4	1416.9	1420.8	1422.9	1420.8	1416.9	1413.4	1406.7	1402.2
1383.9	1387.3	1392.9	1396.0	1399.7	1400.8	1399.7	1396.0	1392.9	1387.3	1383.9
1362.5	1365.6	1369.7	1371.9	1374.2	1376.1	1374.2	1371.9	1369.7	1365.6	1362.5
1329.8	1331.2	1331.8	1332.7	1333.3	1334.3	1333.3	1332.7	1331.8	1331.2	1329.8
1311.1	1311.5	1311.9	1312.3	1312.5	1312.9	1312.5	1312.3	1311.9	1311.5	1311.1
1305.7	1305.7	1305.7	1305.7	1306.1	1306.1	1306.1	1305.7	1305.7	1305.7	1305.7
1304.4	1304.4	1304.4	1304.4	1304.4	1304.4	1304.4	1304.4	1304.4	1304.4	1304.4
1303.6	1303.6	1303.6	1303.6	1303.6	1303.6	1303.6	1303.6	1303.6	1303.6	1303.6

TUBE WALL CONDUCTIVITY(BTU/HR*F*FT)

11.6	11.7	11.9	12.0	12.1	12.1	12.1	12.0	11.9	11.7	11.6
11.6	11.7	11.9	12.0	12.1	12.1	12.1	12.0	11.9	11.7	11.6
11.6	11.7	11.9	12.0	12.1	12.1	12.1	12.0	11.9	11.7	11.6
11.5	11.6	11.7	11.8	11.9	12.0	11.9	11.8	11.7	11.6	11.5
11.0	11.1	11.2	11.2	11.3	11.3	11.3	11.2	11.2	11.1	11.0
10.5	10.5	10.6	10.6	10.7	10.7	10.7	10.6	10.6	10.5	10.5
9.9	9.9	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.9	9.9
9.6	9.6	9.6	9.7	9.7	9.7	9.7	9.7	9.6	9.6	9.6
9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6
9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5

PEAK TUBE TEMPERATURE (DEG. F)

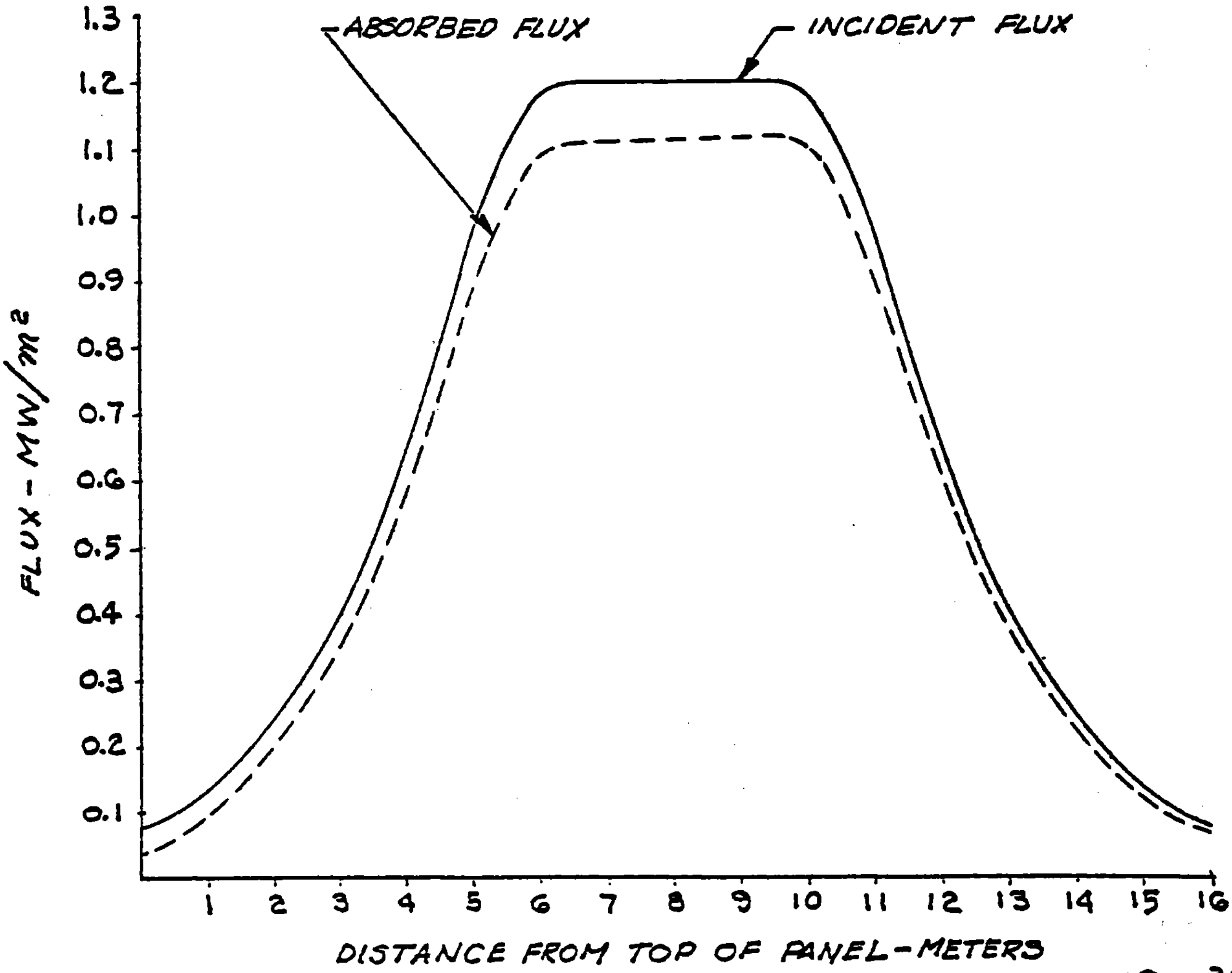
1047.9	1071.2	1103.0	1121.9	1144.2	1156.2	1144.2	1121.9	1103.0	1071.2	1047.9
1065.6	1090.8	1124.4	1145.1	1164.9	1178.7	1164.9	1145.1	1124.4	1090.8	1065.6
1124.3	1151.9	1184.5	1206.0	1227.4	1242.0	1227.4	1206.0	1184.5	1151.9	1124.3
1184.2	1215.8	1264.4	1289.0	1317.7	1333.8	1317.7	1289.0	1264.4	1215.8	1184.2
1090.9	1113.3	1153.0	1175.2	1202.6	1208.5	1202.6	1175.2	1153.0	1113.3	1090.9
984.1	1006.0	1036.7	1052.3	1069.7	1082.7	1069.7	1052.3	1036.7	1006.0	984.1
772.2	781.3	784.9	791.2	794.8	801.2	794.8	791.2	784.9	781.3	772.2
648.0	650.8	653.6	656.4	657.3	660.1	657.3	656.4	653.6	650.8	648.0
613.4	613.4	613.4	613.4	616.3	616.3	616.3	613.4	613.4	613.4	613.4
605.9	605.9	605.9	605.9	605.9	605.9	605.9	605.9	605.9	605.9	605.9
600.2	600.2	600.2	600.2	600.2	600.2	600.2	600.2	600.2	600.2	600.2

CONTINUE ITERATION?(YES=1,NO=0)?0

AUG 8, 1979

FIGURE 3-5, FLUX DISTRIBUTION FOR CYCLIC LIFE

INCIDENT FLUX(MW/SQ.M)	NODE EFFICIENCIES(P.U.)	ABSORBED FLUX(MW/SQ.M)
~~0.100~~ TOP	~~0.5973~~	~~0.060~~
0.180	0.7530	0.136
0.330	0.8417	0.278
~~0.510~~	~~0.8802~~	~~0.449~~
0.800	0.9058	0.725
1.100	0.9189	1.011
~~1.200~~	~~0.9242~~	~~1.109~~
1.200	0.9273	1.113
1.200	0.9302	1.116
~~1.200~~	~~0.9327~~	~~1.119~~
1.100	0.9340	1.027
0.800	0.9320	0.746
~~0.510~~	~~0.9263~~	~~0.472~~
0.330	0.9173	0.303
0.180	0.8950	0.161
~~0.100~~ BOTTOM	~~0.8555~~	~~0.086~~



3.1.2.3 Instrumentation Interface

- All measuring instrumentation shall be attached and routed by others.

3.1.2.4 Solar Interface

Absorber panel testing will require the following mutually independent incident solar beam characteristics:

- A flux distribution which is nearly uniform with an intensity of 0.5 MW/M^2 over the active panel heat exchanger area.
- A flux distribution which provides a peak intensity of 1.55 MW/M^2 near the center of the panel.

3.1.2.5 Containment Interface

- The absorber solar panel shall be isolated from the primary circulating equipment by a fire resistant and leak resisting barrier provided by others.

3.1.3 MAJOR COMPONENT LIST

The absorber panel can be organized into the following subassembly and parts breakdown.

3.1.3.1 Panel Assembly

Consists of tubes, tube spacers, header assembly, inlet pipe, outlet pipe, strain sensors (provided by others) tube thermocouple assembly (provided by others), attachment brackets, header and pipe heater elements, assembly hardware, absorptive coating, header thermocouple assembly (provided by others).

3.1.3.2 Support Structure

Consists of panel support structure, attachment points to fluid circulating equipment support structure, thermal insulation attachment hardware, attachment hardware panel to structure, header/pipe guides/supports as required.

3.1.3.3 Thermal Insulation Assemblies

Consists of absorber panel back side rigid insulation, insulation support structure, panel heaters, heater attachment hardware, inlet/output header insulation, inlet/outlet piping insulation.

3.1.4 GOVERNMENT FURNISHED EQUIPMENT

None

3.2 CHARACTERISTICS

3.2.1 PERFORMANCE CHARACTERISTICS

The abosrber panel shall be designed to provide the following performance:

3.2.1.1 Incident Solar Beam Acceptance

The absorber panel shall accept a maximum steady state incident solar power of 2.5 MW on the absorber panel active heat exchanger surface. The active region of the panel shall be able to accept this power level in any distribution which is symmetric about the vertical centerline of the panel, between the extremes of uniform flux and single point aiming flux of para. 3.1.2.4. Flux and thermodynamic data for the uniform intensity and maximum single point aiming strategy are shown in Table 3-4.

3.2.1.2 Absorber Panel Inlet Sodium Temperature (For information only, not a requirement)

The absorber panel inlet temperature (measured at the inlet pipe on the panel inlet header) shall be maintained at a set point between 500°F and 700°F under all incident solar power levels between 0.25 MW and 2.5 MW including transient as well as steady state condition. This specification shall be met under all operating environmental conditions listed in 3.2.5.1.

3.2.1.3 Absorber Panel Outlet Sodium Temperature

The absorber panel outlet temperature (measured at the outlet pipe on the panel outlet header) shall be maintained at 1100°F ± 5°F under all steady state and transient insolation conditions from 0.25 MW to 2.5 incident power under all operating environments as defined in 3.2.5.1.

3.2.1.4 Design Life Requirements

The absorber panel shall be designed to provide 30 year life with respect to corrosion and thermal cycling damage of the metallic parts. For corrosion, 30 year life shall be defined as 131,000 hours of exposure to full load operating temperatures and environments. For thermal cycling damage, 30 year life shall be as defined in Figure 3-2 with the flux distribution shown in Figure 3-5. In addition the panel shall survive a limited number of cycles corresponding to the single point aiming strategy defined in 3.2.1.1.

3.2.1.5 Design Operating Modes (for information only, not a requirement)

The absorber panel shall be capable of performing in the following modes:

- Operating - In this mode the sodium pump and the heat dump are under an automatic control which responds to variations in the solar heat input to maintain the absorber panel inlet/outlet Na temperatures at approximately 600°F/1100°F respectively.
- Hot Hold - This is a hot shutdown condition in which the panel moveable insulation is closed and the trace heaters function under automatic control to maintain the loop Na temperature at approximately 600°F.
- Preheat - This is the transition from a cold ambient temperature condition to hot hold.
- Startup - This is the transition from hot hold to operation.
- Shutdown - This is the transition from operation to hot hold.
- Emergency Dump - In this mode all of the sodium is drained rapidly out of the panel into the dump tank and the panel is filled with inert gas.
- Calibration Maneuvers - Calibration modes shall be provided as required for instance the sodium flowmeter calibration using the surge tank level gages. T/C calibration may be run over a range of isothermal temperatures from 600°F to 1100°F.

3.2.1.6 Pressure Drop-Flow

Pump flow as measured at pump outlet is variable from 20 to 250 GPM. The fluid pressure drop measured from the weld prep face of the inlet nozzle to the weld prep face of the outlet nozzle at the outlet operating temperature of 3.2.1.3 and incident flux of 3.2.1.1 and a fluid flow of 144 gallons per minute shall not exceed 5 psi due to friction and momentum losses (excluding gravity head). The pressure at the face of the inlet nozzle at this condition is 45 psig.

3.2.2 PHYSICAL CHARACTERISTICS

3.2.2.1 Dimensional Limits

The absorber panel assembly shall not exceed the dimensional limits of Figure 3-3.

3.2.2.2 Weight Limit

The absorber panel assembly shall not exceed 16000 pounds, with an operating sodium content. The vendor shall determine and provide the total dry weight and wet weight of the absorber panel assembly.

3.2.2.3 Surface Obstruction

No structural feature of the test assembly will obstruct the optical path between the active panel region and heliostats in the field, see Ref. 2.3.

3.2.3 RELIABILITY - NA

3.2.4 MAINTAINABILITY

The absorber panel assembly shall be designed and constructed to provide access for maintenance operations. The design should minimize the necessity to cut the sodium loop or move large components, requiring a crane, in order to calibrate, repair or replace instrumentation and trace heaters.

3.2.5 ENVIRONMENTAL CHARACTERISTICS

3.2.5.1 Operating Requirements

The absorber panel assembly shall be designed to operate under the following environmental conditions:

Temperature (Dry Bulb):	-20 to 120°F
Wind Speed:	0 to 14 M/S (30 mph)

3.2.5.2 Survival Requirements

The absorber panel assembly shall be capable of surviving without damage combinations of the environments specified below:

Wind Speed:	45 M/S gusts from any direction (100 mph)
Snow:	5 lb/ft^2 snow deposition
Lightning:	Direct hit
Rain:	3 inches in 24 hours
Ice:	2 inch thick deposit
Earthquake:	0.5 g constant lateral acceleration at top of tower
Hail:	1 inch diameter 0.9 specific gravity 75 fps

Realignment prior to returning to operation after surviving these conditions is allowable.

3.2.6 TRANSPORTABILITY

The Absorber Panel Assembly shall be constructed in modular form, and all of the modules shall be of a size which may be shipped by truck. Shipment assembled as one unit is acceptable.

3.2.7 INSTALLATION

The absorber panel assembly and attachment to the supporting structure shall be designed and constructed to minimize field installation labor with particular emphasis on minimizing field welding.

3.2.8 CLEANLINESS

Fabrication, assembly and shop testing operations shall be conducted to facilitate cleaning, inspection for cleanliness and to minimize contamination during these operations. The equipment as delivered shall be suitable for installation without additional cleaning. Cleaning and cleanliness control shall be implemented according to vendor procedures approved by the contractor.

3.3 DESIGN AND CONSTRUCTION

As a minimum the components in contact with sodium shall be designed and manufactured to meet the requirements of ASME Section VIII Division I and appropriate mandatory appendices with the exception that code stamping and marking is not required. Alternate rules for design for buckling and creep-fatigue failure may be developed and used as approved by the contractor. For design purposes the maximum absorber panel internal pressure shall be 125 psig. The structure elements of the test assembly shall comply with accepted design standards (Ref. 2.2) and for elevated temeprature service shall be designed to the allowable stress values of ASME Section VIII. All electrical power distribution equipment and electrical components shall be designed to the National Electric Code (Ref. 2.5) and National Electrical Manufacturers Association Standards (2.6). All critical non-pressure system structural welds, those critical to function or safety, shall be identified and shall have the root and final weld pass inspected by magnetic particle or liquid penetrant methods. All non critical, non-pressure system structural welds may be to Ref. 2.2 requirements. All lifting attachments to be used for assembly or handling shall be designed for 5 g in all directions. Loads encountered during shipping shall be provided for in the item design or with suitable shipping only structure.

3.3.1 MATERIALS, PROCESSES AND PARTS

3.3.1.1 Sodium Loop Materials

All material in contact with sodium shall be Incoloy 800 in accordance with contractor supplied specifications or in accordance with the ASME Section II product forms listed below.

Tubing SB-407
Pipe SB-407
Plate SB-409
Weld Rod SFA 5.14 Type ERNiCr-3

3.3.1.2 Braze Material - (to be determined)

3.3.1.3 Structural Material

All structural material shall meet the requirements of ASME Section II part A Ferrous Materials or equivalent commercial designations. Equivalency shall be approved by the contractor.

3.3.1.4 Absorber Panel Tube Material

The Incoloy 800 tube material shall be procured by the vendor to specifications supplied by the contractor and concurred to by the seller. Receiving inspection in accordance with the tubing specification shall be performed by the vendor.

3.3.1.5 Insulating Material

All insulation shall be compatible with materials in close proximity and shall be water resistant or protected from moisture contamination.

3.3.1.6 Brazing Process

The vendor shall provide a detail brazing procedure based on a general procedure supplied by the contractor and concurred with by a brazing supplier to be identified by the contractor. The vendor shall provide the necessary fixtures required for brazing tubes together and other attachments as required.

3.3.1.7 Corrosion Protection

All non corrosion resistant structural components shall be painted with a suitable rust preventative to protect it from the environment.

3.3.2 ELECTROMAGNETIC RADIATION - NA

3.3.3 IDENTIFICATION AND MARKING

The panel assembly shall bear a name plate with the following minimum information:

Manufacturer

Serial Number (Part Number)

Material of Construction

Design Temperature

Design Pressure

Weight, Dry, Wet

The support structure assembly and back side rigid insulation assembly shall each bear a name plate or be marked with the following minimum information:

Manufacturer

Serial Number (Part Number)

Weight

3.3.4 WORKMANSHIP

Unless otherwise specified workmanship shall be that commensurate with normal commercial practice. Nuclear service, codes, and practices are not required.

3.3.5 INTERCHANGEABILITY - NA

3.3.6 SAFETY - NA

3.3.7 HUMAN ENGINEERING - NA

3.3.8 DOCUMENTATION

3.3.8.1 Design Documentation

Documents required with the delivery of vendor supplied and manufactured components shall include pertinent design analysis to show code and specification adherence, performance characteristics, manufacturing quality results, pressure and leak test results, as-built drawings and information required for safe handling, packaging and unpacking. The following items shall be supplied. Other items may be added as appropriate:

1) Quality Records
   - Material Certification and Properties
   - Leak Test and Pressure Test Results
   - Dimensional Inspection Results
   - Welding Records

2) As Built Interface Dimensions and Drawings

3) Design Analysis

4) Component Operating Characteristics

5) Packing, Packaging and Unpacking Instructions

6) Special Handling/Shipping Requirements

3.4 MAJOR COMPONENT CHARACTERISTICS

3.4.1 PANEL ASSEMBLY

The absorber panel consists of a single row of 51 Incoloy 800 seamless tubes welded to an inlet header at one end and an outlet header at the other end. The tubes will be 3/4" OD 0.050" wall with an effective heat transfer length of 15 ft. and a panel width of ∿ 3.28 ft. The tubes will be metallurgically bonded together by brazing and will be coated on the side exposed to the solar radiation with a high absorptivity coating. The tube-header and header joints shall be formed by welding and be capable of radiographic inspection. The panel configuration shall be as shown in Figure 3.2. The inlet and outlet headers may be located in the plane of the tube bundle or behind it (alternate configuration). The headers and tube header joints shall be shielded from direct solar insolation. Inlet and outlet pipes are attached by welding to the inlet and outlet headers respectively. The panel tubes, headers and inlet/outlet piping shall be self draining in the operating configuration. The inlet/outlet pipes shall be prepared by the panel manufacturer with weld preparation for welding to 3 inch diameter, shcedule 40 type 304 stainless steel pipe.

3.4.1.1 Trace Heating

The headers shall be supplied with trace heaters to maintain a hot hold temperature of 600°F ± 50°F with moveable and fixed insulation in place. Heater design to be supplied by the vendor shall be 480 volts 60 cps alternating current.

3.4.1.2 Instrumentation (Surface Temperature & Strain Measurement

The tube bundle shall be instrumented (provided by others) at approximately seventy seven locations on the active heat exchange surface as shown in Figure 3-3. This instrumentation shall include thirty front surface temperature sensors, seventy seven back surface temperature sensors and fifteen strain gages mounted on the back surface. Special features (to be determined) for access for thermocouples to the front side of the panel shall be supplied by the vendor.

3.4.1.3 Instrumentation (Sodium Temperature)

The header insulation shall be removeable to provide access to surface mounted thermocouples, supplied and installed by others, at three locations on the inlet header and three locations on the outlet header, to measure sodium temperature at the inlet/outlet and the extreme ends of each header.

3.4.1.4 Absorptive Coating

The front surface of the tube bundle shall be coated with a material which has the following properties at 600-1200°F

Solar absorptivity: 0.95 (minimum)
Infrared emissivity: 0.90 (maximum)
Life: 5000 hours (minimum)

In addition the thermal conductivity and thickness of the coating shall be such that the temperature rise across the coating layer is less than 50°F at an absorbed flux of 1.2 MW/M^2.

3.4.1.5 Examination and Test

The panel assembly shall be hydrostatically or pneumatically pressure tested in accordance with ASME Boiler and Pressure Vessel Specifications Section VIII, paragraph UG-99 or UG-100.

The complete panel assembly shall be inspected for leak tightness by subjecting it to a helium leak test using the hood method per ASME Section V by approved procedures. The total allowable integrated leak rate shall not exceed 1 x 10^{-8} std cc/sec of helium.

3.4.2 SUPPORT STRUCTURE

As shown in Figure 3-3, the receiver tube and header assembly shall be mounted on a panel support structure in a manner which will accommodate both axial and lateral thermal expansion and contraction during temperature changes between ambient and maximum operating temperatures support the weight and maintain flatness of the tube bundle. Vertical expansion shall be downward from the outlet end.

3.4.2.1 Flatness

The panel support structure shall maintain flatness of the tube bundle to within ± 1 inch while allowing movement for thermal expansion, under all the operating conditions defined in paragraph 3.2.1.5.

3.4.2.2 Assembly

The panel support structure shall mate with and be easily fastened to the fluid circulation equipment support structure.

3.4.3 THERMAL INSULATION ASSEMBLIES

3.4.3.1 Tube Insulation

The back side of the tube bundle shall be insulated. The insulation design shall be based on a maximum cold side surface temperature of 150°F.

3.4.3.2 Trace Heating

The panel tube bundle shall have trace heaters on the back side to assure a hot hold temperature of 600°F ± 50°F and provide the following:

- Heater electrical power, supplied by others, shall be 480 volts, 60 cps, 3 phase, alternating current.
- The heaters shall be 0.50 "dia and rated at 125 watts/ft. minimum. Heater sheath shall be suitable for operation to 1250°F.
- Total heating capacity shall be 10 kw. The heaters shall be

electrically connected in five horizontal banks of approximately equal output. Each bank shall be wired to provide independent control.

- Heater control will be on-off type. Switch gear will be provided by others.

3.4.3.3 Assembly

The back side insulation and trace heaters shall be capable of ready removal and installation to provide access for instrumentation installation.

3.4.3.4 Header and Header Pipe Insulation

Insulation on inlet and outlet headers with inlet and outlet pipe extensions shall be designed to provide a nominal cold side surface temperature of not more than 150°F. Insulation shall be provided on the panel front surface from the header to the active solar region.

3.5 PRECEDENCE

In the event of conflict between this document and the reference documents, the contents of this specification shall be the superseding requirement.

4.0 QUALITY ASSURANCE PROVISIONS

This section specifies the methods for verification of the design, construction and performance requirements specified in Section 3.0 of this document.

4.1 GENERAL

The primary method of assuring compliance of the absorber panel assembly with the requirements of this specification will be through inspection of drawings, hardware and the design documentation specified in paragraph 3.3.8.1, item 3.

A limited number of demonstrations (~ 3) and tests (~ 1) will be performed to verify compliance with performance requirements.

4.1.1 RESPONSIBILITIES

All testing and demonstrations will be performed by the vendor according to approved procedures. The results of each test as well as any corrective action or retest required shall be documented.

Tests and demonstrations performed at the vendors (or their subcontractor) facilities will be done according to procedures developed by the vendor and approved by the contractor.

Witnessing of Foster Wheeler tests and demonstrations by GE will be determined on a case by case basis.

4.1.2 SPECIAL TESTS AND EXAMINATIONS

4.1.2.1 Absorber Panel

The panel tubes shall be welded to the jumper tubes in a manner that allows for radiographic inspection of each weld. This data will be available for inspection by the contractor as part of the welding records identified in 3.3.8.1, item 1.

4.1.3 DATA REQUIREMENT

4.1.3.1 Test Procedures

Test procedures will be written by the vendor to verify the performance of those characteristics requiring verification by test. As a minimum the test procedure shall include:

- Equipment/Software Requirements
- Test Equipment
- Test Prerequisites
- Test Restrictions
- Safety Considerations
- Test Procedure
- Test Set Up and Instrumentation Block Diagrams
- Data Sheets
- Data Reduction and Analysis
- Pass/Fail Criteria

4.1.3.2 TEST REPORTS

Reports shall be provided for each test. These reports will consist of data acquired during the performance of testing, test configuration, environmental condition and data analysis (as required) to assess performance of the equipment under test.

4.2 VERIFICATION DEFINITIONS

Each performance requirement in Section 3 of this specification shall be verified using the following evaluation methods.

4.2.1 INSPECTION (I)

Verification by determination of physical characteristics.

4.2.2 SIMILARITY (S)

Similarity is a procedure used to show that an article is comparable with, or identical in design and manufacturing processes to, another ariticle previously qualified to equivalent or more stringent critiera.

4.2.3 ANALYSIS (A)

Verification by examination of technical data, mathematical derivations, or analytical combination of measured data and/or other technical data of component units.

4.2.4 DEMONSTRATION (D)

Verification by operation of any item or by performance of any function without a requirement for analysis of quantitative data that might result from instrumentation of recorded observations during the verification.

4.2.5 TEST (T)

Verification by operating of any device or performance of any function that requires analysis of quantitative data that results from required instrumentation or from recorded observations during the verification.

4.3 VERIFICATION MATRIX

The verification matrix shows the classification and methods of evaluation for all Section 3 requirements. Verification of performance and design requirements shall be based on evaluation by inspection, similarity, analysis, demonstration, and/or test. Inspection shall be used to check adequacy of design documentation and applicable specifications and conformance of hardware to design documentation and applicable standards. Similarity shall be used in verifying the performance of a component that has been proven in another application.

Analysis shall be used in lieu of, or to supplement, test data. Demonstration is used when quantitative measurements are not required for verification. Tests shall be conducted when an acceptable level of confidence cannot be established by other methods or when testing can be shown to be most cost-effective method.

The Section 3 paragraphs for which verification is not applicable are indicated in the table as N/A, or the basis of the following criteria:

a. The paragraph contains the title only.

b. The paragraph is descriptive and no requirement is stated.

c. The paragraph is introductory and the requirements are stated in subsequent subparagraphs.

4.4 VERIFICATION METHODS

This section establishes the test verification methods and concepts that shall be used to verify the requirements of section 3.0. The verification matrix (Ref. 4.3) includes a cross reference to the appropriate section 3.0 Requirement paragraph and verification method.

Tests may be combined or rearranged in order to accommodate a more cost effective program or to maintain the program schedule.

In the following paragraphs the number in the parenthesis refers to the appropriate section 3.0 paragraph.

4.4.1 ITEM DEFINITION (3.1)

An inspection of the drawings and hardware of the absorber panel shall be done to assure compliance with this requirement.

4.4.2 INTERFACE DEFINITION (3.1.2)

Same as paragraph 4.4.1.

4.4.3 STRUCTURAL INTERFACE (3.1.2.1)

An inspection of the drawings and mounting structures will assure the physical compatibility of the interface.

An analysis will be performed to verify the ability of the structure to support the absorber panel over the full range of its operating environment and modes.

GENERAL ELECTRIC
ENERGY SYSTEMS PROGRAMS DEPARTMENT

ENGINEERING SPECIFICATION

SPECIFICATION NUMBER 29SA4724
ORIGINAL ISSUE DATE AUG 8, 1979

VERIFICATION MATRIX SECTION 3.0

REQUIREMENT REFERENCE	N/A	I	S	A	D	T		COMMENTS
3.0 REQUIREMENTS	X							
3.1 ITEM DEFINITION		X						
3.1.1 ITEM DIAGRAMS	X							
3.1.2 INTERFACE DEFINITION		X						
3.1.2.1 STRUCTURAL INTERFACE		X		X				
3.1.2.2 FLUID INTERFACE		X						
3.1.2.3 INSTRUMENTATION INTERFACE								TBA
3.1.2.4 SOLAR INTERFACE				X				
3.1.2.5 CONTAINMENT INTERFACE		X						
3.1.3 MAJOR COMPONENT LIST	X							
3.1.3.1 PANEL ASSEMBLY		X						
3.1.3.2 SUPPORT STRUCTURE		X						
3.1.3.3 THERMAL INSULATION ASSEMBLIES		X						
3.1.4 GOVERNMENT FURNISHED EQUIPMENT	X							

REVISION NUMBER
REVISION DATE
SUPERSEDES
CLASSIFICATION

ESJ 605.5 78.

VERIFICATION MATRIX
SECTION 3.0

REQUIREMENT REFERENCE	N/A	I	S	A	D	T		COMMENTS
3.2 CHARACTERISTICS	X							
3.2.1 PERFORMANCE CHARACTERISTICS	X							
3.2.1.1 INCIDENT SOLAR BEAM ACCEPTANCE				X				
3.2.1.2 ABSORBER PANEL INLET TEMP.	X							
3.2.1.3 ABSORBER PANEL OUTLET TEMP				X				
3.2.1.4 DESIGN LIFE				X				
3.2.1.5 DESIGN OPERATING MODES	X							Not a requirement
3.2.1.6 PRESSURE DROP-FLOW				X				
3.2.2 PHYSICAL CHARACTERISTICS	X							
3.2.2.1 DIMENSIONAL LIMITS		X						
3.2.2.2 WEIGHT LIMIT				X	X			
3.2.3 RELIABILITY	X							
3.2.4 MAINTAINABILITY		X	X					

VERIFICATION MATRIX SECTION 3.0 REQUIREMENT REFERENCE	N/A	VERIFICATION METHOD I	S	A	D	T		COMMENTS
3.2.5 ENVIRONMENTAL CHARACTERISTICS	X							
3.2.5.1 OPERATING REQUIREMENTS				X				
3.2.5.2 SURVIVAL REQUIREMENTS				X				
3.2.6 TRANSPORTABILITY		X			X			
3.2.7 INSTALLATION		X						
3.2.8 CLEANLINESS		X			X			
3.3 DESIGN AND CONSTRUCTION		X		X				
3.3.1 MATERIALS, PROCESSES AND PARTS	X							
3.3.1.1 SODIUM LOOP MATERIALS		X						
3.3.1.2 BRAZE MATERIAL								TBD
3.3.1.3 STRUCTURAL MATERIAL		X						
3.3.1.4 ABSORBER PANEL TUBE MATERIAL		X				X		Venfor Responsibility
3.3.1.5 INSULATING MATERIAL		X	X	X				
3.3.1.6 BRAZING PROCESS		X			X			Vendor Responsibility
3.3.1.7 CORROSION PROTECTION		X						

VERIFICATION MATRIX SECTION 3.0 REQUIREMENT REFERENCE	N/A	VERIFICATION METHOD I	S	A	D	T		COMMENTS.
3.3.2 ELECTROMAGNETIC RADIATION	X							
3.3.3 IDENTIFICATION AND MARKING		X						
3.3.4 WORKMANSHIP		X						
3.3.5 INTERCHANGEABILITY	X							
3.3.6 SAFETY	X							
3.3.7 HUMAN ENGINEERING	X							
3.3.8 DOCUMENTATION	X							
3.3.8.1 DESIGN DOCUMENTATION		X						

VERIFICATION MATRIX
SECTION 3.0

REQUIREMENT REFERENCE	N/A	I	S	A	D	T		COMMENTS
3.4 MAJOR COMPONENT CHARACTERISTICS	X							
3.4.1 PANEL ASSEMBLY		X						
3.4.1.1 TRACE HEATING		X		X				
3.4.1.2 INSTRUMENTATION (TEMP & STRAIN)		X	X					
3.4.1.3 INSTRUMENTATION (NO TEMP)		X	X					
3.4.1.4 ABSORPTIVE COATING		X	X					
3.4.1.5 EXAMINATION AND TEST						X		At Vendor Facility
3.4.2 SUPPORT STRUCTURE		X						
3.4.2.1 FLATNESS		X		X				
3.4.2.2 ASSEMBLY		X						
3.4.3 THERMAL INSULATION ASSY	X							
3.4.3.1 TUBE INSULATION		X		X				
3.4.3.2 TRACE HEATING		X		X				
3.4.3.3 ASSEMBLY		X						
3.4.3.4 HEADER & HEADER PIPE INSULATION		X		X				
3.5 PRECEDENCE	X							

4.4.4 FLUID INTERFACE (3.1.2.2)

Same as paragraph 4.4.1.

4.4.5 INSTRUMENTATION INTERFACE (3.1.2.3)

T.B.D.

4.4.6 SOLAR INTERFACE (3.1.2.4)

See paragraph 4.4.11.

4.4.7 CONTAINMENT INTERFACE (3.1.2.5)

Same as paragraph 4.4.1.

4.4.8 PANEL ASSEMBLY (3.1.3.1)

Same as paragraph 4.4.1.

4.4.9 SUPPORT STRUCTURE (3.1.3.2)

Same as paragraph 4.4.1.

4.4.10 THERMAL INSULATION ASSEMBLIES (3.1.3.3)

Same as paragraph 4.4.1.

4.4.11 INCIDENT SOLAR BEAM ACCEPTANCE (3.2.1.1)

An analysis of the absorber panel design over its range of operating modes and environmental conditions will verify the ability of the panel to satisfy this requirement.

4.4.12 ABSORBER PANEL INLET TEMPERATURE (3.2.1.2)

For information only.

4.4.13 ABSORBER PANEL OUTLET TEMPERATURE (3.2.1.3)

Same as paragraph 4.4.11.

4.4.14 DESIGN LIFE REQUIREMENTS (3.2.1.4)

An analysis will be performed using commercial panel characteristics provided to verify life requirements.

4.4.15 PRESSURE DROP-FLOW (3.2.1.6)

An analysis will be performed at operating conditions provided to verify conforance to requirement.

4.4.16 DIMENSIONAL LIMITS (3.2.2.1)

Same as paragraph 4.4.1.

4.4.17 WEIGHT LIMIT (3.2.2.2)

An analysis will be performed to determine the weight of the panel assembly under operating conditions.

A demonstration of the panel assembly dry weight will verify it does not exceed the requirements of this paragraph.

4.4.18 MAINTAINABILITY (3.2.4)

An inspection of the drawings and equipment will substantiate the ease of maintenance requirement. The ability of the equipment to support the operational requirement will be verified by data from use in similary applications.

4.4.19 OPERATING REQUIREMENTS (3.2.5.1)

Same as paragraph 4.4.11.

4.4.20 SURVIVAL REQUIREMENTS (3.2.5.2)

Same as paragraph 4.4.11.

4.4.21 TRANSPORTABILITY (3.2.6)

An inspection of drawings and hardware shall substantiate the ability of the equipment to meet these requirements. Actual compliance will be demonstrated by shipping the equipment via truck.

4.4.22 INSTALLATION (3.2.7)

Same as paragraph 4.4.1.

4.4.23 CLEANLINESS (3.2.8)

An inspection of the facilities and procedures used for the fabrication and assembly of the equipment will substantiate compliance with requirement. The ability to integrate the panel assembly into the sodium receiver test assembly without additional cleaning will demonstate compliance with this requirement.

4.4.24 DESIGN AND CONSTRUCTION (3.3)

Paragraph 3.3 has essentially four specific verification requirements:

Code compliance - Inspection of the documentation required in paragraph 3.3.8.1 will verify compliance with the codes and standards requirements.

4.4.25 SODIUM LOOP MATERIALS (3.3.1.1)

Same as paragraph 4.4.1.

4.4.26 BRAZE MATERIAL (3.3.1.2)

TBD.

4.4.27 STRUCTURAL MATERIAL (3.3.1.3)

Same as paragraph 4.4.1.

4.4.28 ABSORBER PANEL TUBE MATERIAL (3.3.1.4)

Receiving inspection of this material will be the responsibility of Foster-Wheeler. Receipt inspection records shall be included in data package.

4.4.29 INSULATING MATERIAL (3.3.1.5)

The ability of the insulating material to satisfy this requirement can be verified by data from use in similar applications or when this is not available by analysis of the materials. An inspection of the drawing and hardware will verify that the insulation is protected from moisture contamination.

4.4.30 BRAZING PROCESS (3.3.1.6)

An inspection of the procedure will verify that it complies with the GE requirements. Compliance with the brazing fixturing and attachments requirements will be demonstrated during the actual brazing of the panel.

4.4.31 CORROSION PROTECTION

Same as paragraph 4.4.1

4.4.32 IDENTIFICATION AND MARKING (3.3.3)

Same as paragraph 4.4.1.

4.4.33 WORKMANSHIP (3.3.4)

Inspection of the documentation required in 3.3.8.1 will verify compliance with this requirement.

4.4.34 DESIGN DOCUMENTATION (3.3.8.1)

An inspection of the documentation shall verify compliance.

4.4.35 PANEL ASSEMBLY (3.4.1)

Same as paragraph 4.4.1.

4.4.36 TRACE HEATING (3.4.1.1)

Inpsection of the drawing and equipment shall verify the presence of the trace heating units. An analysis of the design will substantiate its ability to maintain the required temperature under the specified conditions.

4.4.37 INSTRUMENTATION (TEMPERATURE AND STRAIN GAUGES) (3.4.1.2)

An inspection of drawing and equipment will verify the quantity and location of the access required.

4.4.38 INSTRUMENTATION (SODIUM TEMPERATURE) (3.4.1.3)

An inspection of the drawings and equipment will verify the ability to remove insulation for instrumentation access.

4.4.39 ABSORPTIVE COATING (3.4.1.4)

An inspection of the drawings and equipment will verify the presence and quality of an absorptive coating. The ability of the coating to comply with the requirements will be verified by data from use in similar applications.

4.4.40 EXAMINATION & TEST (3.4.1.5)

The panel assembly shall be hydrostatically or pneumatically pressure tested in accordance with ASME Boiler and Pressure Vessel Specifications Section VIII, paragraph UG-99 or UG-100.

The completed panel assembly shall be inspected for leak tightness by subjecting it to a helium leak test using the hood method per ASME Section V by approved procedures. The total allowable integrated leak rate shall be as specified.

4.4.41 SUPPORT STRUCTURE (3.4.2)

Same as paragraph 4.4.1.

4.4.42 FLATNESS (3.4.2.1)

An inspection of the drawings and equipment will identify the method of allowing movement for thermal expansion. An analysis of the design will substantiate the ability of the equipment to maintain the flatness tolerance.

4.4.43 ASSEMBLY (3.4.2.2)

Same as paragraph 4.4.1.

4.4.44 TUBE INSULATION (3.4.3.1)

An inspection of the drawings and hardware will verify the presence of the required equipment.

An analysis of the design will verify compliance with the state requirements.

4.4.45 TRACE HEATING (3.4.3.2)

Same as paragraph 4.4.44.

4.4.46 ASSEMBLY (3.4.3.3)

Same as paragraph 4.4.1.

4.4.47 HEADER AND HEADER PIPE INSULATION (3.4.3.4)

Same as paragraph 4.4.44.

5.0 PREPARATION FOR DELIVERY

5.1 GENERAL

All packaging, protective covers, attachments, holddown devices, skids, and other equipment required for shipment of the absorber panel shall be designed and furnished by the vendor. The arrangement of the equipment, and plan and procedures for preparation, marking and shipment shall be submitted to the contractor for review and comment prior to shipping equipment fabrication.

5.2 PREPARATION FOR SHIPMENT

5.2.1 CLOSURES

All nozzles and openings shall be sealed and covered, plugged or capped so as not to damage the weld preps or flange faces.

5.2.2 PURGING

The sodium containing unit shall be purged with dry nitrogen until the gas within the assembly has attained a dew point of -25°F or lower. The assembly shall be fitted with a suitable nitrogen pressure system to maintain a positive pressure inside.

5.2.3 PROTECTION

The assembly shall be protected during shipment from moisture, dirt, dust, or any other contaminants.

5.2.4 HANDLING

Non standard lifting devices, if required, shall be provided to permit safe handling during shipment, installation, and removal of the assembly. Standard lifting devices, such as eyebolts shall be defined by the vendor.

5.3 INSTRUCTIONS

The vendor shall supply packing, unpacking and handling and rigging instructions.

6.0 NOTES

6.1 VENDOR SUBMITTALS

6.1.1 FOR APPROVAL

The following shall be supplied to the contractor for approval:

- Layout and assembly drawings from which are made detailed manufacturing part drawings. As a minimum to consist of major component assemblies of para. 3.1.3.

- The purchase order requirements for the absorber panel tube material of paragraph 3.3.1.4.

- The detail braze procedure as required by paragraph 3.3.1.6.

- The design and characteristics of the trace heater systems of paragraph 3.4.1.1 and 3.4.3.2.

- The cleaning procedures and cleanliness control specified in paragraph 3.2.8.

- The arrangement of and implementation and instructions for preparation for delivery as specified in Section 5.0.

6.1.2 FOR INFORMATION

All other verification requirements of Section 4.0 Quality Assurance Provisions shall be supplied to the contractor for information purposes.

☆U.S. GOVERNMENT PRINTING OFFICE: 1980-740-145/919