CONTRACTOR REPORT

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Molten Salt Solar Receiver Subsystem Research Experiment Phase 1—Final Report Volume III—Appendices

Foster Wheeler Solar Development Corporation
Livingston, New Jersey

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PHASE 1--FINAL REPORT

MOLTEN SALT SOLAR RECEIVER SUBSYSTEM RESEARCH EXPERIMENT

VOLUME 3

APPENDICES

Prepared for

Sandia National Laboratories
Livermore, California

By

G. Carli
Project Manager

November 1982

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*Published in three separate volumes.

Appendix A

RECOMMENDED CHANGES TO RECEIVER SUBSYSTEM SPECIFICATION*

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1. Delete Section 1.2.1 Collector Subsystem,. in its entirety. The Collector Subsystem is not part of the Receiver Subsystem (RS).

2. Delete the heading "1.2.2 Receiver Subsystem."

3. In the fifth line from page bottom, delete the words "typical" and "may".

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4. In Item 8, change "trace heaters" to "sheathing".

5. To Item 9, add "and drain system" after the word "tanks".

6. Add to components list:

   "10. Aperture door and door-actuating mechanism.
   11. Service crane and/or service elevator.
   12. Trace heaters."

7. In second paragraph of Section 2, change "request for quotation" to "contract award".

8. To Section 2.1, add:

   "c. Legislation
   - National Environmental Policy Act (NEPA)
   - National Energy Conservation Policy Act of 1978
   - Power Plant and Industrial Fuel Use Act
   - Public Utilities Regulatory Policy Act of 1978".

9. To Section 2.2, Item a, Specifications, add:

   "- RS Configuration, Size, and Performance Specifications
   - RS Fabrication, Operation, and Maintenance Specifications
   - RS Interface Specifications with Collector, Energy Storage, Master Control, and Plant Services Subsystems".

*Copy attached (Pages A-5 through A-10)
†Page numbers refer to pages in the RFQ.

10. To Section 2.2, Item b, add:

"- ASME Boiler and Pressure Vessel Code
  Section II: Material Specifications
  Section V: Nondestructive Examination
  Section VIII-Div. 1: Pressure Vessels
  Section IX: Welding and Brazing Qualifications
- Nuclear Regulatory Commission Guides 1.60 and 1.61
- Institute of Electrical and Electronic Engineers (IEEE) Code"

To last line, add "Codes - 1975".

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11. In the second line from page top, change "AISC" to "ACI".

12. To Design, Construction and Fabrication Standards, add:

"Standards of AISC (American Institute of Steel Construction)".

13. In Section 3.1, change the word "System" to "Subsystem".

14. To Section 3.1, add the word "subsystem" before the word "must".

15. Delete Section 3.1.1, Collector Subsystem, in its entirety.

16. Before Section 3.1.2, add:

"3.1.1 Receiver Subsystem Terminal Points. (TBD)"

17. In Section 3.1.2, delete the word "tower" before the word "structure".

18. To Section 3.1.2.1 Modes of Operation - Normal, add "Number of occurrences: (TBD)" to each entry.

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19. To Section 3.1.2.2 Modes of Operation - Emergency, add "Number of occurrences: (TBD)" to each entry.

20. Add the following to Section 3.1.2.2 Modes of Operation - Emergency:

"d. Failure of any pipe - Number of occurrences: (TBD)
e. Failure of panel tube - Number of occurrences: (TBD)
f. Loss of receiver, collector, or salt flow control: Number of occurrences (TBD)".

21. In Section 3.1.4, delete the word "documented" since statistical reliability data for solar receivers on which to base any quantitative reliability and maintainability estimates are nonexistent.

22. In Section 3.1.4, change the word "inclusive" to "exclusive" after the word "assessment".

23. Before Section 3.2, add:

    "3.1.6 Drainability. The design shall provide for draining the RS by gravity. Dead spaces, crevices, or regions of fluid entrapment shall be avoided or held to an absolute minimum."

24. In Section 3.2, Item 2, change the word "Maximum" to "Design".

25. In Section 3.2, Item 3, change the minimum absorbed thermal power from "30" to "80".

26. In Section 3.2, add the receiver working fluid thermophysical properties.

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27. In Section 4.1, delete Items b, c, and d, since the Collector Subsystem is not a part of the Receiver Subsystem.

28. In Section 4.1, Item a, provide Barstow soil conditions.

29. In Section 4.1, Item e, change "30 feet" to "33 feet".

30. In Section 4.2, change "system" to "Receiver Subsystem" before the word "shall".

31. In Section 4.2, Item a, change "plant" to "Receiver Subsystem".

32. In Section 4.2, Item a, change "-20 to +120°F" to "(-22 to +122°F)."

33. In Section 4.2, Item a, delete "selected to be consistent with minimization of the overall cost of electricity production."

34. To Section 4.2, Item a, add "(TBD)" after the word "range".

35. In Section 4.2, Item b, change "(30 ft)" to "(33 ft)".

36. In Section 4.2, Item b, delete "for the most adverse combination of wind and temperature conditions selected to be consistent with minimizing the overall cost of thermal power."

37. To Section 4.2, Item b, add "for winds up to (TBD)." after the word "met".

38. To Section 4.2, add:

    "c. Insolation: The receiver shall be capable of accepting all reflected energy without heliostat defocus for insolation levels equal to or less than (TBD).

    d. Sun Angle: The receiver shall be capable of operating with all heliostat images for sun elevations greater than (TBD) above the horizon."

PAGE 12

39. In the first line, change "(30 ft)" to "(33 ft)".

40. In the third line from page top, change "evaluation" to "elevation".

41. To the sixth line from the page top, add "(3.5 m/s)" after the words "reference wind velocity".

42. In the fifth and sixth lines from page top, change the word "velocity" to "speed".

43. In Section 4.3, change the word "system" to "Receiver Subsystem" before the words "shall be".

44. In Section 4.3, add the words "(without damage)" before the word "appropriate".

45. In Section 4.3, Item a, change the word "plant" to "Receiver Subsystem" before the words "shall survive winds".

46. To Section 4.3, Item a, add the words "reference wind" before the word "speed".

47. In Section 4.3, Item d, change the word "plant" to "Receiver Subsystem" before the words "shall survive freezing rain".

48. In Section 4.3, Item e, add the word "response" before the word "spectrum".

49. In Section 4.3, Item e, change "Atomic Energy Commission" to "Nuclear Regulatory Commission (NRC)".

50. In Section 4.3, Item e, add the words "and the damping values given for the operating bases earthquake presented in NRC Guide 1.61" before the words "should be used as a guide".

51. In Section 4.3, Item f, change the word "plant" to "Receiver Subsystem" before the words "shall survive hail".

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MOLTEN SALT RECEIVER SUBSYSTEM SPECIFICATION

1. GENERAL

1.1 Scope. This specification defines the subsystem characteristics, design requirements, and environmental requirements for the second molten salt receiver subsystem phase I program. It will be revised and reissued, if required, so that all contractors will be working to the latest requirements.

1.2 Subsystem Characteristics

(1) 1.2.1 Collector Subsystem. The Collector Subsystem is composed of an array of heliostats and supporting power and control elements which interact with the master control. The heliostat array reflects solar radiation onto the receiver and provides auxiliary functions for other modes of operation and non-operational positionings. The Collector Subsystem components consist of:

a. Heliostats, including reflective surface, structural support, drive units, control sensors, pedestals, foundations, and cabling.

b. Controllers, including heliostat and field controllers, interface electronics, and power supplies.

c. Support equipment for alignment, washing, operations and maintenance.

(2) 1.2.2 Receiver Subsystem. The Receiver Subsystem provides a means of transferring the incident radiant flux energy from the Collector Subsystem into the molten salt working fluid. The Receiver Subsystem consists of an elevated receiver to intercept the radiant flux from the Collector Subsystem, the tower structure to support the receiver, and the riser from the ground to the receiver and downcomer from the receiver to the ground. The Receiver Subsystem also includes the pumps, valves, heat exchangers and control system necessary to regulate the fluid flow, temperature and pressure; and the required thermal control necessary for safe and efficient operation, startup, shutdown, and standby of the Receiver Subsystem.

(3) The typical components which may constitute the receiver subsystem are:

1. The tower and foundation.
2. The structural receiver supports.
3. Molten salt pump.
4. Riser and downcomer piping.

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5. Shop fabricated modular absorber panels.
6. Interconnecting piping.
7. Instrumentation and controls. 4
8. Thermal insulation and trace heaters.
9. Ancillary equipment (i.e. compressed air, inlet/outlet surge tanks). 5

6

2. APPLICABLE DOCUMENTS

The equipment, materials, design, and construction of the receiver subsystem shall comply with all Federal, state, local, and user standards, regulations, codes, laws, and ordinances currently applicable for the specific site and the user. These shall include, but not be limited to the government and nongovernment documents listed below. If there is an overlap in, or conflict between, the requirements of these documents and the applicable Federal, state, county, or municipal codes, laws, or ordinances, that applicable requirement which is the most stringent shall take precedence.

The following documents of the issue in effect on the date of request 7 for quotation form a part of this specification to the extent specified herein. In the event of conflict between the documents referred to herein and the contents of this specification, the contents of this specification shall be considered a superceding requirement.

2.1 Government Documents

a. Specifications
- Regulations of the Occupational Safety and Health Administration (OSHA)
- International System of Units, 2nd Revision, NASA SP-7012

b. Standards
- Applicable Human Engineering Design Criteria

8

2.2 Non-Government Documents

a. Specifications
9 (List of subsystem and interface specifications to be prepared by the contractor)

b. Standards and Codes
- Uniform Building Code, 1976 Edition by International Conference of Building Officials
- ASME Boiler and Pressure Vessel Code 10
- Institute of Electrical and Electronic Engineers (IEEE) Codes, as applicable.
- National Fire Protection Association (NFPA) National Fire

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Design, Construction and Fabrication Standards
(11) Standards of AISC (American Concrete Institute)
Standards of TEMA (Tubular Exchanger Manufacturer's Assoc.)
(12)

3. REQUIREMENTS

(13) 3.1 System Design. The molten salt receiver (14) must be designed to meet the design specifications of this section.

(15) 3.1.1 Collector Subsystem. The Collector Subsystem shall reflect solar radiation onto the Receiver Subsystem in a manner which satisfies receiver incident heat flux requirements. In addition, the Collector Subsystem shall execute alternative drive modes in response to commands from the Master Control Subsystem for emergency defocusing of the reflected energy or to protect the heliostat array against environmental extremes. The heliostat shall be properly positioned for repair or maintenance in response to either master control or local commands. Heliostat design shall provide for stored or safe position for use at night, during periodic maintenance and during adverse weather conditions.

(16) 3.1.2 Receiver Subsystem. The receiver and tower shall be designed to provide access for maintenance and inspection of tower structure, (17) receiver, working fluid, instruments and controls, power conversion equipment that may be located on the tower, utilities, etc. Consideration shall be given to ease of maintenance. Adequate provisions shall be made to ensure crew safety at all times for required operations, inspection, maintenance and repair. The receiver design shall be consistent with the intent of appropriate ASME codes.

3.1.2.1 Modes of Operation - Normal. The molten salt receiver subsystem shall be capable of functioning in the following modes:

1. Cold startup.
2. Diurnal startup. (18)
3. Sustained operation at the minimum to maximum rates specified.
4. Transient operation during intermittent cloud passage.
5. Hot standby during prolonged cloud passage.
6. Hot startup following cloud passage.
7. Diurnal shutdown and overnight hold.
8. Prolonged shutdown.

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3.1.2.2 Modes of Operation - Emergency. In addition, the receiver subsystem shall be capable of safe controlled shutdown resulting from upset and emergency conditions resulting from:

a. Molten salt pump trip (19)
b. Heliostat field scram
(20) c. Loss of power to the heliostat field

3.1.3 Lifetime. The receiver subsystem shall be designed for a 30-year operating life.

3.1.4 Receiver Subsystem Availability and Reliability. The subsystem shall be designed for 95% availability, based on documented (21) reliability and maintainability assessments, inclusive of (22) insolation conditions. Consideration shall be given in the design to achieving high reliability by providing design and operating margins and utilizing sound engineering design practices.

3.1.5 Maintainability.

a. The Receiver Subsystem shall be designed so that potential maintenance locations can be easily reached and components such as electronic units, motors, drives, etc., readily replaced.

b. Elements subject to wear and damage, such as supporting wheels, gears, etc., should be easily serviced or replaced.

c. The subsystem should be capable of being serviced by personnel of skills typical of those utilities currently employ for maintenance, and should require a minimum of specialized equipment or tools.

(23)

3.2 Nominal Interface Conditions and Receiver Size.

1. Receiver working fluid	Molten nitrate salt 60% $NaNO_3$/40% KNO_3 mixture by weight[3]
(24) 2. Maximum absorbed thermal power	320 MW_{th}
3. Minimum absorbed thermal power	(25) 30 MW_{th}
4. Nominal receiver outlet temperature	565°C
5. Nominal receiver inlet temperature	290°C

(26)

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4. ENVIRONMENTAL CONDITIONS

27 4.1 Baseline Design Point

a. Reference Site: Barstow, California 28
b. Insolation: Direct normal at 950 watts/m^2
c. Dynamic Performance: The maximum rate of change of incident flux shall be assumed as that which would result from the passage of an opaque cloud across an otherwise clear sky where the sharp leading or trailing edges of the shadow move across the collector field at a velocity of 20 metres per second.
d. Sun Angle: The sun azimuth and elevation angles for a given field layout at the time of the day and year for which the solar power to the receiver is at a maximum, assuming the direct normal insolation specified above (i.e. the best sun angle).
e. Wind Speed: 3.5m/sec (8 MPH) at a reference height of 10m (30 29 feet).
f. Temperature: Wet Bulb - 23°C (74°F)
Dry Bulb - 28°C (82.6°F)

4.2 Operating. 30 The system shall be able to operate in and survive appropriate combinations of 31 the following environments:

a. Temperature: The plant shall be able to operate in the ambient air temperature range from -30 to +50°C (-20 to +120°F). 32 Performance requirements shall be met throughout an ambient air temperature range selected to be consistent with minimization of 33 34 the overall cost of electricity production.

b. Wind: The wind speed specifications at a reference height of 10m (30 ft) shall be:

35

Speed, m/s	Frequency, Percent
0 - 2	29
2 - 4	21
4 - 6	19
6 - 8	14
8 - 10	8
10 - 12	5
12 - 14	3
14 -	Less than 1

Performance requirements shall be met for the most adverse 36 37 combination of wind and temperature conditions selected to be consistent with minimizing the overall cost of thermal power. wind velocity profile shall be assumed to vary exponentially with height to the 0.15 power, where the reference height is

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taken as 10m (30 ft); i.e. the model shown below shall be used for calculation of wind speed as a function of receiver evaluation.

$$V_H = V_1 \left(\frac{H}{H_1} \right)^C$$

Where: V_H = mean wind velocity at height H
V_1 = reference wind velocity
H_1 = reference height (assume 10 metres)
C = 0.15

4.3 Survival. The system shall be capable of surviving appropriate combinations of the environments specified below:

a. Wind: The plant shall survive winds with a maximum speed, including gusts of 40 m/s (90 mph), without damage.
b. Snow: The receiver shall survive a static snow load of 240 Pa (5 lb/ft^2) and a snow deposition rate of 0.3m (1 ft) in 24 hours.
c. Rain: The receiver shall survive the following rainfall conditions:
   Average annual - 750mm (30 in)
   Maximum 24-hr rate - 75mm (3 in)
d. Ice: The plant shall survive freezing rain and ice deposits in a layer 50mm (2 in) thick.
e. Earthquake: The receiver and tower must withstand an earthquake that would produce an acceleration on the order of 0.2g to 0.25g horizontal and vertical ground accelerations and shaking intensity of VII to VIII on the Modified Mercalli Scale. the spectrum presented in U.S. Atomic Energy Commission Regulatory Guide 1.60 (Revision 1 dated December 1973) should be used as a guide. In addition, the plant must satisfy the requirements specified for seismic zone 3 in the Uniform Building Code.
f. Hail: The plant shall survive hail impact up to the following limits:

Diameter	25mm (1 in)
Specific Gravity	0.9
Terminal Velocity	23 m/s (75 fps)

APPENDIX B

REQUIREMENTS SPECIFICATION

Molten Salt Solar Receiver

Subsystem Research Experiment

Prepared for

Sandia National Laboratories
Thermal Subsystem Division
Livermore, California

November 1981
Rev. 2: November 1982

Sandia Contract 84-2292C
FWSDC No. 9-71-9203

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION
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Section 1

SCOPE

The requirements defined in this specification shall apply to the design, manufacture, construction, erection, installation, checkout, operation, control, and performance of the Receiver Subsystem (RS) and its components.

The RS defined in this specification will be designed to be site independent to the greatest extent possible. However, to quantify site-dependent design parameters, SNLL selected Barstow, California, as the site location.

The RS, shown schematically in Figure B.1, provides a means of transferring the incident radiant flux energy from the Collector Subsystem (CS) into the molten salt working fluid. The RS consists of an elevated receiver to intercept the radiant flux from the CS, the tower structure to support the receiver, the riser pipe from the ground to the receiver, and the downcomer pipe from the receiver to the ground. The RS also includes the pumps, valves, and control system necessary to regulate fluid flow, temperature, and pressure and the required thermal conditioning necessary for its safe and efficient operation, start-up, shutdown, and standby.

The terminal points defining components within the scope of the RS are at the boundary of the tower structure where the riser and downcomer meet the cold and hot salt lines from the Thermal Storage Subsystem (TSS). These terminal points were selected so that the RS design is not dependent upon the physical layout

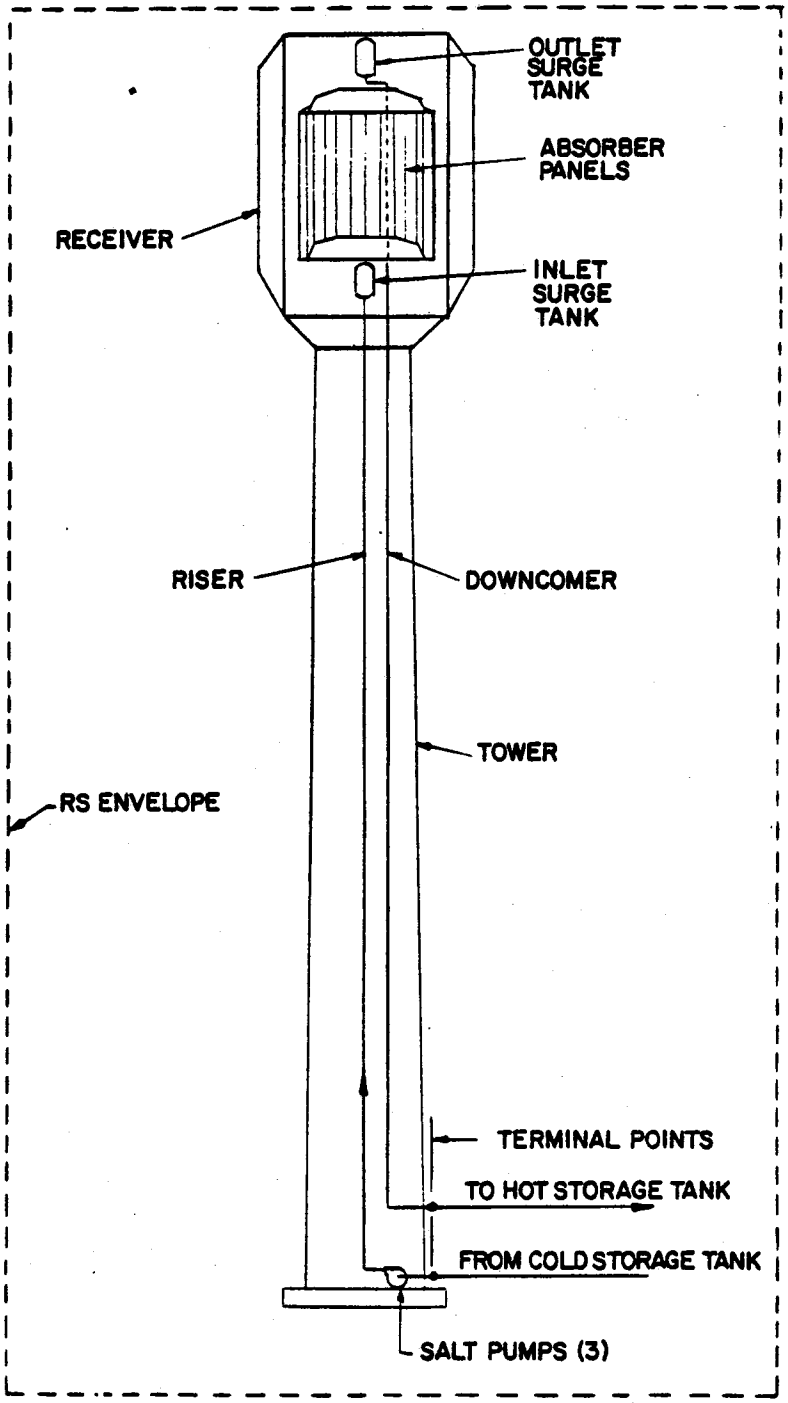

Figure B.1 Definition of RS

of a specific job-site. Consequently, interface piping between the RS and other plant components is not within the scope of the RS. The following items are included:

- Tower and its foundation
- Receiver structure
- Shop-fabricated modular absorber panels
- Aperture door and door-actuating mechanism
- Inlet Surge Tank (IST) and Outlet Surge Tank (OST) mounted with the receiver atop the tower
- Interconnecting piping and valves for panels and surge tanks
- Riser and downcomer piping
- Molten salt pumps
- Instrumentation and controls
- Thermal insulation and sheathing
- Drain system
- Trace and radiant heaters
- Ancillary equipment including:
  - Air compressors and dryers
  - Electrical power distribution (e.g., wiring, transformers, outlets)
  - Overhead crane
  - Service elevators.

Section 2

APPLICABLE CODES AND STANDARDS

The design, materials, equipment, and construction of the RS shall comply with all Federal, State, local, and user standards, regulations, codes, laws, and ordinances currently applicable for the specific site and the user. These shall include, but not be limited to, the government and nongovernment documents listed in Sections 2.1 and 2.2. If there is an overlap in or conflict between the requirements of these documents and the applicable Federal, State, county, or municipal codes, laws, or ordinances, that applicable requirement which is the most stringent shall take precedence.

The following documents of the issue in effect on the date of contract award form a part of this specification to the extent specified in the following sections. In the event of conflict between the documents referred to and the contents of this specification, the contents of this specification shall prevail.

2.1 GOVERNMENT DOCUMENTS

- Specifications:
  - Regulations of the Occupational Safety and Health Administration (OSHA)
  - International System of Units, 2nd Revision, NASA SP-7012
  - Rules and Regulations of the Department of Transportation
  - Regulations of the Federal Aviation Administration (FAA)
  - Regulations of the Civil Aeronautics Board (CAB)
  - State Codes and Regulations (for example State of California Administrative Codes and Regulations):
    - -- Manual - CAL/OSHA:
      Title 24 - Building Standards; Part 6 - Special Building Regulations; Section 30 - Asphalt Concrete Standard Specification,

State of California Department of Public Works, Division of Highways

Title 8 - Division of Industrial Safety; Chapter 4 - (Safety Orders) 1974

-- Water Release Regulations: State of California Water Quality Control Board; Lahontan Regional Water Quality Control Board

-- State of California: Standard Specification of the Department of Transportation

- Local Codes and Regulations (for example, San Bernardino County Uniform Building Code, California)

- Standards: Applicable Human Engineering Design Criteria

- Legislation:
  - National Environmental Policy Act (NEPA)
  - National Energy Conservation Policy Act of 1978
  - Power Plant and Industrial Fuel Use Act of 1978
  - Public Utilities Regulatory Policy Act of 1978
  - State legislation (for example, California Environmental Quality Act).

2.2 NONGOVERNMENT DOCUMENTS

- Specifications:
  - RS Configuration, Size, and Performance Specification
  - RS Operation Specification
  - RS Design Specification
  - RS Fabrication, Transportation, Erection, Installation, and Maintenance Specification
  - RS Interface Specifications With Collector, Energy Storage, Master Control, and Plant Services Subsystems

- Standards and Codes:
  - Uniform Building Code (1979 Edition), International Conference of Building Officials
  - Institute of Electrical and Electronic Engineers (IEEE) Codes, as applicable
  - National Fire Protection Association (NFPA) National Fire Codes (1975)

- ASME Boiler and Pressure Vessel Code
  - -- Section II — Materials Specification
  - -- Section V — Nondestructive Examination
  - -- Section VIII-Division 1 — Pressure Vessels
  - -- Section IX — Welding and Brazing Qualifications
- Nuclear Regulatory Guides 1.60 and 1.61
- American Concrete Institute (ACI)
  - -- ACI 318-77 — Building Code Requirements for Reinforced Concrete
  - -- ACI 315-74 — Detailing Reinforced Concrete Structures
  - -- ACI 305 — Recommended Practice for Hot Weather Concreting
  - -- ACI 306 — Recommended Practice for Cold Weather Concreting
  - -- ACI 347-68 — Recommended Practice for Concrete Formwork
  - -- ACI 614 — Recommended Practice for Selecting Proportions in Concrete
- American Insurance Association (AIA) (1967 and Errata Sheet) National Building Code
- American Institute of Steel Construction (AISC) (1969) with:
  - -- Supplement 1 (1970)
  - -- Supplement 2 (1971)
  - -- 7th Ed. (1974)--Manual of Steel Construction
- American Iron and Steel Institute (AISI); Specification for the Design of Cold-Formed Structural Members
- American National Standards Institute (ANSI)
  - -- A10.8-1969 — Safety Requirements for Scaffolding
  - -- A12.1-1973 — Safety Requirements for Floor and Wall Openings, Railings, and Toeboards
  - -- A14.1-1975 — Safety Code for Portable Wood Ladders
  - -- A14.2-1972 — Safety Code for Portable Metal Ladders
  - -- A14.3-1974 — Safety Code for Fixed Ladders
  - -- A17.1-1978 — Safety Code for Elevators
  - -- A58.1-1972 — Minimum Design Loads in Buildings and Other Structures
  - -- A64.1-1968 — Requirements for Fixed Industrial Stairs
  - -- A92.1-1971 — Standard for Manually Propelled Mobile Ladder Stands and Scaffolds
  - -- A92.2-1969 — Vehicle-Mounted Elevating and Rotating Work Platforms
  - -- A134.1 — Electric Fusion (Arc) Welded Steel Plate Pipe (16 in. and over)

--	B15.1-1972	Safety Code for Mechanical Power Transmission Apparatus
--	B16.5-1977	Steel Pipe Flanges and Flanged Fittings
--	B16.9	Factory-Made Wrought Steel Buttwelding Fitting
--	B16.34-1977	Steel Buttwelding End Valves
--	B19.1-1972	Safety Code for Compressed Air Machinery
--	B30.2-1967	Safety Code for Overhead and Gantry Cranes
--	B30.5-1968	Safety Code for Crawler and Truck Cranes
--	B31.1-1977	Power Piping
--	B56.1-1975	Safety Standard for Powered Industrial Trucks (Parts I and II)
--	B96.1	Specification for Welded Aluminum-Alloy Field-Erected Storage Tanks
--	C2-1977	National Electrical Safety Code
--	C37.03-C37.010	Alternating-Current High-Voltage Circuit Breakers (latest revisions)
--	C37.11-1972	Power Circuit Breaker Control
--	C37.12-1969	Guide Specifications for Alternating-Current Power Circuit Breakers
--	C37.20-1974	Switchgear Assemblies Including Metal-Enclosed Bus
--	C37.90a (IEEE 472)	Guide for Surge Withstand Capability Tests
--	C50.10	General Requirements for Synchronous Machines
--	S1.2	Method for Physical Measurement of Sound
--	S1.13	Methods for the Measurement of Sound Pressure Level
--	Z53.1-1971	Safety Color Code for Marking Physical Hazards

- American Standards Associates (ASA):

--	ASA A40.8 (1955)	National Plumbing Code
--	B31.1-1973	Code for Pressure Piping

- American Society for Testing and Materials (ASTM) Codes
- American Welding Society (AWS):

--	A5.1	Specifications for Mild Steel, Covered Arc-Welding Electrodes
--	AS.5	Specification for Low-Alloy Steel, Covered Arc-Welding Electrode
--	A3.0	Standard Qualification Procedures
--	D1.1	Structural Welding Code - Steel

- Concrete Reinforcing Steel Institute (CRSI) Manual: Manual of Standard Practice for Reinforced Concrete Construction
- Electronic Industries Association (EIA):
  - -- Recommended Standards, Specifications, and Engineering Publications (current issue)
  - -- EIA RS-310 Racks and Cabinets
- Illuminating Engineering Society (IES) Standards Lighting Handbook
- Instrument Society of America (ISA):
  - -- ISA - S5.1 Instrumentation Symbols and Identification
  - -- ISA - S5.2 Binary Logic Diagrams for Process Operations
  - -- ISA - S5.4 Instrument Loop Diagrams
  - -- ISA - S37.1 Electrical Transducer Nomenclature and Terminology
  - -- ISA - S50.1 Compatibility of Analog Signals for Electronic Industrial Process Instruments
  - -- ISA - S51.1 Process Instrumentation Terminology
- National Electric Manufacturers Association (NEMA):
  - -- ICS-1970 (Rev. '71, '72, and 73) Industrial Controls and Systems
  - -- II-1-1964 Electrical Indicating Instruments
  - -- KS1 Enclosed Switches
  - -- PB1 Panel Boards
  - -- SG3-1971 Low-Voltage Power Circuit Breakers
  - -- ST20-1972 Dry-Type Transformers for General Applications
  - -- VE1-1971 Cable Tray Systems
  - -- WD1-1974 General-Purpose Wiring Devices
  - -- WD5-1974 Wiring Devices, Specific Purposes
  - -- TR1-1974 Transformers, Regulators, and Reactors
- Steel Door Institute (SDI) Standards, 100
- Steel Structures Painting Council (SSPC) Manuals
- Tubular Exchanger Manufacturers' Association (TEMA) Standards
- Underwriters' Laboratories, Inc. (UL):
  - -- Manual (1974) w/supplements Building Materials Directory
  - -- List w/supplements Electrical Construction Materials
  - -- UL44, -- UL50, -- UL57, -- UL58 } Standards for Safety "Cabinets and Boxes."

Section 3

RS REQUIREMENTS

3.1 DESIGN

3.1.1 General

The center of the receiver aperture shall be located 216.0 ±1.0 m (708.7 ft ±3.3 ft) above grade at grade location (0, 0) (Figures B.2 and B.3). Tolerances at the center of the absorber aperture throughout the RS operating regime shall be as follows:

- In elevation: ±0.3 m (1 ft)
- In east-west direction: ±0.3 m (1 ft)
- In north-south direction: ±0.3 m (1 ft)

The absorber configuration shall conform to the geometry defined in Figure B.4.

The receiver shall be of the cavity type. The receiver heat-transfer fluid shall be molten nitrate salt (60-percent sodium nitrate and 40-percent potassium nitrate). The salt shall be maintained at a high purity level by means of a salt purification loop, which is not within the scope of the RS. Thermophysical properties of the salt shall be those stipulated by SNLL. The receiver design and operating parameters shall include the following:

- Design point absorbed power: 320 MW* (1092 x 10^6 Btu/h)
- Design point flux limit: 0.65 MW/m^2 (0.206 x 10^6 Btu/h•ft^2)

*Thermal unless otherwise specified.

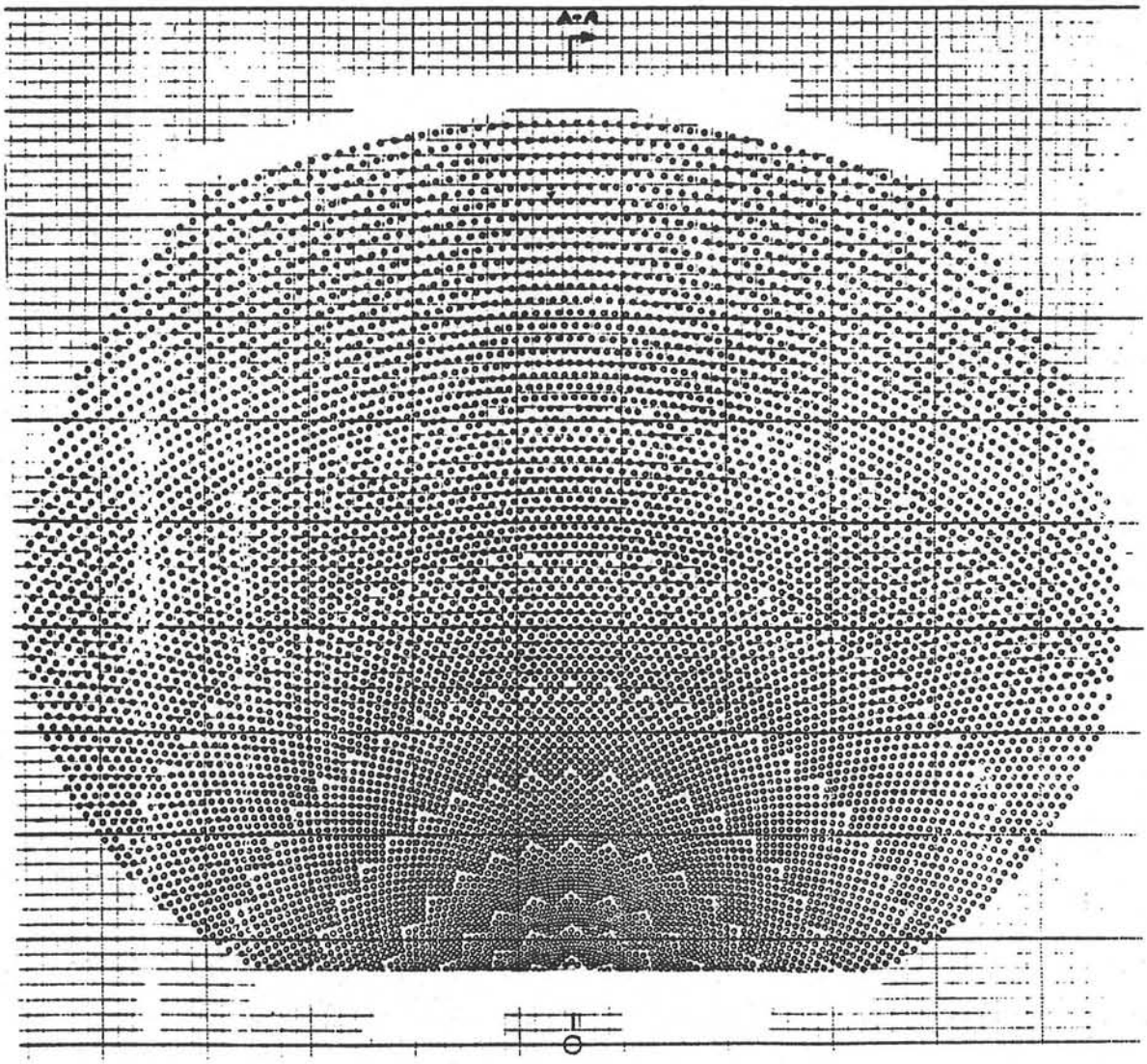

Figure B.2 Collector Field--DELSOL Derived (7907 heliostats)

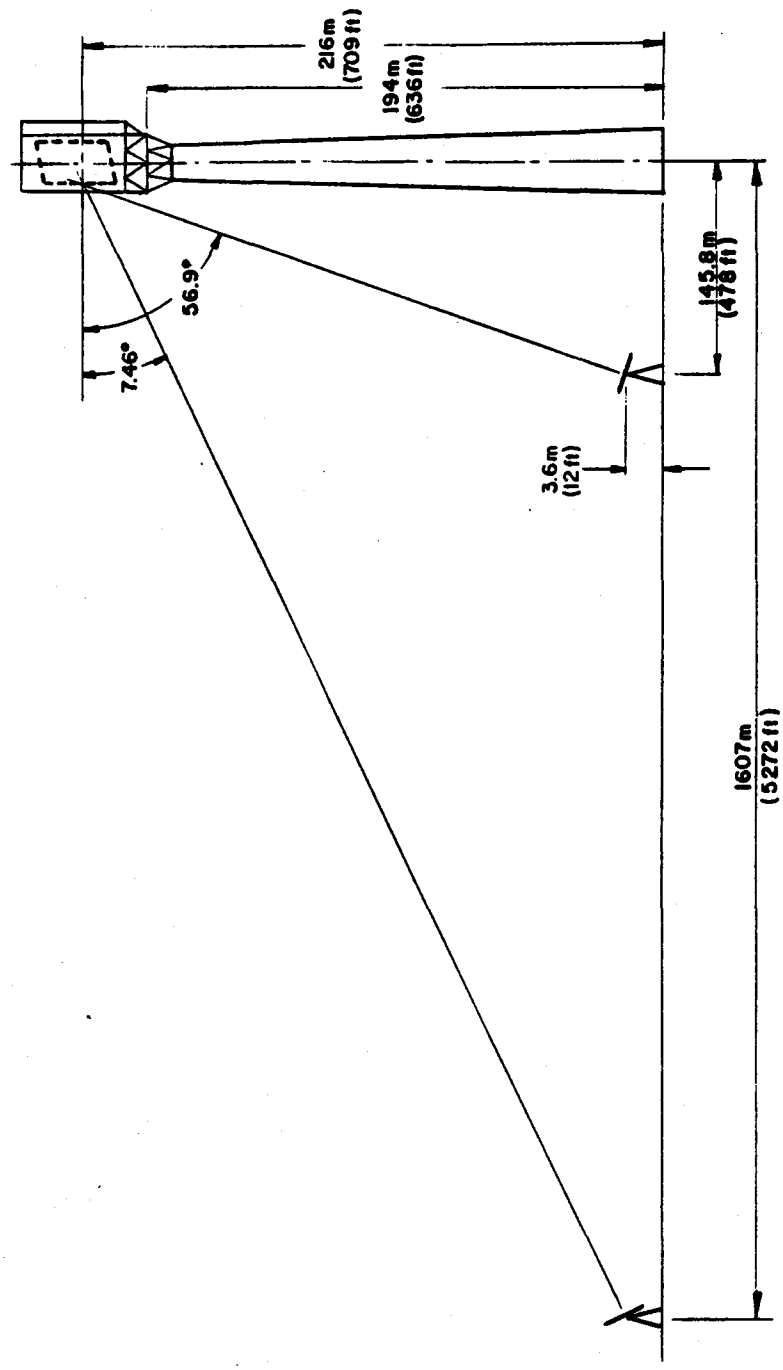

Figure B.3 RS/CS Interface Drawing

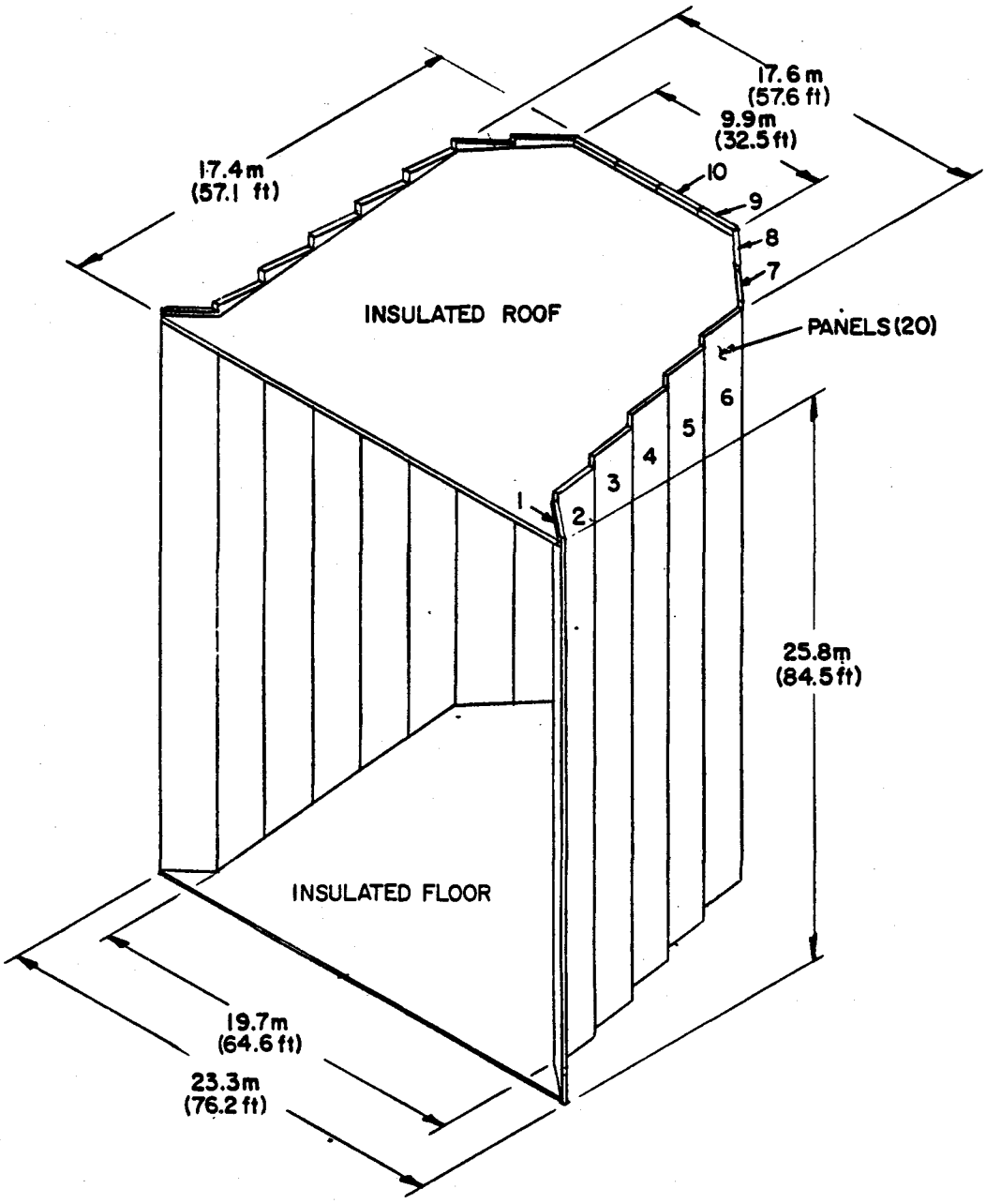

Figure B.4 Absorber Configuration

- Salt inlet temperature: 288°C (550°F)
- Salt outlet temperature: 566°C (1050°F)
- Minimum absorbed power at rated outlet conditions: 80 MW (273 x 10^6 Btu/h)

Other general design requirements shall include the following:

- Integrity. All RS salt components shall be designed to minimize potential leaks. Welded construction shall be used for all pressure boundaries.
- Safety and Control Instrumentation. All safety and control instrumentation shall be designed so that inspection, maintenance, repair, and replacement can be done during a normal shutdown interval.
- Connections, Accesses, and Appurtenances. Connections, accesses, and appurtenances shall meet the following requirements:
  - Access to the RS components shall be accomplished with minimum cutting of the pipes.
  - Supports shall be provided for the application of insulation and lagging required.
  - Identification plates and support brackets shall be furnished. The plates, mounted so that they are visible after installation of the thermal insulation, shall conform to the ASME Code.
  - Lifting lugs or other appropriate lifting devices shall be provided to permit safe handling during shipment, installation, operation, and maintenance for the life of the RS. Special equipment shall be supplied to permit lifting and handling of the RS components with standard construction equipment.
  - All piping connections shall be covered with suitable plugs to prevent water and other contaminants from leaking in during shipment, storage at the construction site, and erection.
  - The absorber panels shall be designed as an integral unit with tubes welded longitudinally to each other and each end of each tube welded to a header. Tubes are to be welded longitudinally to enhance heat transfer, promote panel structural integrity, and eliminate solar flux leaks.
  - Weld design of joints in the solar receiver panels shall not contain built-in crevices.
  - Supports shall be provided to the panel which will allow the receiver panel to move freely during thermal expansions.

- Threaded elements and bolts shall conform to the following:
  - -- Screw threads shall be in accordance with ANSI B1.1
  - -- Protectors and/or lubrication shall be applied to all threaded parts to prevent damage or degradation.

- Transportation. The RS components shall be designed and constructed so that they can be safely shipped by reasonable means to an inland site that has railroad and all-weather highway access.

- Preheat. The RS shall be designed to permit heat-up before salt fill from ambient temperature to 293°C (560°F) within 16 hours (two shifts).

- Draining. The design shall provide for complete draining of the RS by gravity in less than 60 minutes. Pockets, dead space, crevices, and other areas where salt or cleaning reagents might be trapped shall be avoided or kept to an absolute minimum. Salt-side vents shall be provided to remove trapped gas during salt fill.

- Availability and Reliability. The RS shall be designed for 95 percent availability, based on reliability and maintainability assessments, exclusive of insolation. Consideration shall be given in the design to achieving high reliability by providing design and operating margins and utilizing sound engineering design practices.

- Inspection. The RS design shall accommodate periodic in-service inspection, maintenance, and weld repair.

- Unit Cleanup. Provisions for cleaning excessively fouled heat-transfer surfaces resulting from contaminated salt shall be included in the design.

- Maintainability
  - The RS shall be designed so that maintenance locations can be easily reached and components such as electronic units, motors, and drives can be readily replaced.
  - Elements subject to wear and damage, such as supporting wheels and gears, shall be designed for easy service or replacement.
  - The RS shall be designed for servicing by personnel who are skilled to a level equal to personnel currently employed by utilities for maintenance. Such servicing shall require a minimum of specialized equipment or tools.

- Design Service Life. The RS components shall be designed and constructed for a total service life of 30 years.

- Environmental Conditions. See Section 5.

3.1.2 Thermal/Hydraulic

The RS design shall satisfy the following thermal/hydraulic performance requirements:

- Temperature, pressure, and flow requirements defined in Section 3.3
- Stable and predictable operation throughout the load range and the transients defined in Section 3.2
- Adequate flow distribution profile for all specified flow rates, pressures, and temperatures to prevent hot or cold spots, minimize thermal gradients, and avoid excessive thermal transient loadings
- Hydraulic characteristics consistent with the draining requirements discussed in Section 3.1.1
- Thermally stable behavior
- Internal recirculation of salt and reverse flow of salt will not occur under the specified service conditions
- Salt fouling resistance for the design analysis is TBD*
- Adequate response of the receiver to salt inlet flow and temperature transients
- At the maximum salt flow rate, maximum salt pressure drop between interface with the receiver feed pump outlet piping and OST salt cover gas at the midpoint of the hot salt surge tank not exceeding 5.5 MPa (800 lb/in^2)
- Orifices if required for flow distribution.

3.1.3 Structural

The receiver and tower shall be designed to provide access for maintenance and inspection of tower structure, receiver, riser and downcomer piping, instruments, and controls. Consideration shall be given to ease of maintenance.

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*High-temperature fouling data for molten salt is not presently available.

Adequate provisions shall be made to ensure crew safety at all times for required operations, inspection, maintenance, and repair. The structural design shall be in accordance with the applicable codes defined in Section 2. The RS shall be capable of withstanding the combined effects of seismic loads, dead loads, and thermally induced loads. Other structural requirements will include the following:

- Corrosion Allowance. 0.13 mm (0.005 in.)
- Structural Design Conditions. The receiver shall be designed for a creep-fatigue life of 30 years. The cumulative creep fatigue damage caused by start-up and shutdown cycles, cloud-cover cycles, and creep-rupture damage caused by steady-state operation shall be considered. Various passes of the receiver shall be designed to operate at the maximum metal temperatures and thermal gradients shown in Table B.1.
- Thermal Stresses. The RS shall accommodate differential expansion between individual tubes and between any connected parts of the RS without exceeding allowable ASME Code stresses.

Table B.1 Metal Temperatures and Thermal Gradients

Pass No.	Material	Maximum Metal Temperature °C (°F)	Maximum ΔT °C (°F)
1	304SS	470 (877)	150 (270)
2	304SS	520 (968)	155 (279)
3	316SS	570 (1058)	140 (252)
4	Incoloy 800	620 (1148)	120 (216)
5	Incoloy 800	635 (1175)	85 (153)

- Materials. All materials shall be identified and certified to the requirements of the applicable specification. Pressure boundary material shall meet the requirements of Section II of the ASME Code. The absorber panel tubes shall be seamless and shall be hydrotested and eddy-current tested at the mill. The hydrotesting fluid is subject to the purchaser's approval. Tubes shall be shipped packaged, clean, and dry. Preservatives which leave a film are not permitted.

The receiver and tower shall also be designed to withstand the environmental conditions and loads shown in Section 5.

3.1.4 Fabrication

- The RS components shall be constructed in accordance with the ASME Code, Section VIII-Division 1, and as specified in this document. ASME certification is to be provided for the absorber panels.

- All personnel used in manufacturing shall be qualified to the extent required by the ASME Code.

- A manufacturing and inspection plan shall be compiled giving the major manufacturing and inspection steps planned. It shall include the overall sequence for fabrication, cleaning, inspection, nondestructive examinations, welding, heat treating, assembly, testing, and handling. The procedures requiring approval and qualification shall be specified.

- Welding.
  - The absorber panels shall be of a welded construction except as approved by the customer. Welding procedures shall be qualified in accordance with Section IX of the ASME Code.
  - All absorber panel tube butt welds shall be visually inspected and dye-penetrant tested.
  - Weld repair must be in accordance with ASME Code requirements.

- Heat Treatment. All heat treatment during manufacturing shall be in accordance with the ASME Code. The heat-treating cycle shall be recorded.

- Fabrication Mockups. Mockups shall be used by the supplier to demonstrate difficult, new, and unusual procedures.

- Bending and Forming. Bending and forming operations shall be in accordance with the ASME Code. The wall thickness after forming shall meet the minimum design requirements.

- Plating and Coatings. Plating and coatings shall not be used on surfaces in contact with salt.

- Cleaning.
  - Interior surfaces of low-alloy steel pipe shall be cleaned, shot blasted, or pickled to remove mill scale, foreign matter, and debris. Stainless steel and alloys shall be cleaned to remove loose matter and debris.
  - Exterior surfaces of structural steel and supports shall be cleaned for painting. One coat of red oxide shop primer shall be applied. Stainless steel and alloy surfaces shall not be painted unless clearly specified.
  - The front surface of the absorber panels shall be thoroughly cleaned and coated with one coat of black, Pyromark high-temperature paint.

- Hydrotesting and Inerting.
  - Absorber panels shall be hydrotested using demineralized water with a chloride content that does not exceed 10 ppm.
  - After hydrotesting, the absorber panels shall be dried by the application of heat and/or vacuum internally. After drying is completed, the vacuum shall be relieved by filling the panels with dry nitrogen. The panels shall be sealed after a pressure of 69 kPa gage (10 lb/in^2g) nitrogen is applied. A pressure gage and refill valves shall be provided for recharging, if necessary.

- Preparation for Shipment.
  - Each absorber panel shall be assembled to a structural strongback, suitably braced and blocked to prevent shifting or damage in shipment.
  - Each absorber panel shall be suitably covered to prevent contamination by salt or chemical spray during transport.

- Unloading and Handling at Job-Site. The supplier shall compile a procedure to be submitted to the purchaser before shipment, giving a recommended method of unloading, handling, and storage at the job-site.
  - The supplier shall provide, if required, any special handling rig (exclusive of normal chains, slings, and tackle).
  - The procedure shall outline precautions and methods of unloading and handling for storage and installation.
  - A recommended program of preservation maintenance shall be outlined.

3.2 FUNCTIONAL

The RS shall efficiently convert reflected solar radiant energy into sensible thermal energy in the molten salt receiver fluid in an absorber mounted atop a tower located south of a collector field of sun-tracking heliostats. The molten salt shall enter the absorber at a nominal temperature of 288°C (550°F) and leave the absorber at a nominal temperature of 566°C (1050°F). The RS shall provide the necessary flow rates, flow control, and thermal conditioning for the following operations:

- Cold start-up including preheating of equipment and molten salt fill
- Hot standby
- Hot start-up after overnight or extended cloudy-period shutdowns or holds
- Outlet temperature control during normal clear-day operations whenever the sun angle is greater than 10 deg above the horizon
- Outlet temperature control or flow control during cloudy periods
- Hot (overnight) shutdown and conditioning
- Cold shutdown and drain
- Safe shutdown following emergency conditions resulting from any of the following:
  - Receiver salt pump trip or failure
  - Heliostat field scram
  - Loss of collector field control
  - Failure of salt piping, tanks, or absorber panel tubes
  - Failure or improper operation of isolation, relief, or control valves
  - Loss of salt flow control
  - Power failure
    - Whole plant
    - CS
    - RS

3.3 PERFORMANCE

3.3.1 Design Point Performance

At the design point with the incident flux delivered by the collector field as defined in Table B.2 (before losses caused by reflection, reradiation, and convection) and with each entry in the table multiplied by 0.923, the RS shall deliver 320 MW (1092 x 10^6 Btu/h) net thermal energy at an outlet salt temperature of 566°C (+3/-5°C) [1050°F (+5.4/-9°F)] under the following conditions:

- Salt supplied to the RS at 288°C (+10/-5°C) [550°F (+18/-9°F)]
- Environmental conditions as stated in Section 5.

3.3.2 Clear-Day Performance

The RS shall deliver hot salt at 566°C (+3/-5°C) [1050°F (+4.5/-9°F)] over the clear-day operating envelope whenever the following conditions are present:

- The warm salt supplied to the RS is at 288°C (+10/-5°C) [550°F (+18/-9°F)].
- The incident radiant power on the absorber panels (before heat losses caused by reflection, radiation, and convection) is less than or equal to 365 MW (12.45 x 10^6 Btu/h) and greater than or equal to 90 MW (307 x 10^6 Btu/h).
  - At maximum incident power, the incident flux profile shall conform to the values defined in Table B.2 (with each entry in the table multiplied by 0.972).
  - At minimum incident power, the incident flux profile shall conform to the following values (with the appropriate multiplication factors):

Date	Time	Flux Data	Multiplication Factors
21 Feb	Noon	Table B.2	0.242
21 Feb	10 a.m.	Table B.3	0.251
21 Feb	7:12 a.m.	Table B.4	0.843
21 June	5:42 a.m.	Table B.5	0.984

Table B.2 Design Point Incident Heat Flux Map--
Left or Right Side (Symmetrical), MW/m²

ROW NO	POS. CENT.M	AREA HT.M																										
1	23.00	.926	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	19.70	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	2	1	7	14	23	27	21	13	15	39
4	18.04	1.652	0	0	0	0	0	0	0	0	0	0	2	3	3	5	9	12	20	31	64	120	115	110	108	90	101	128
5	16.35	1.652	0	0	0	0	0	2	2	5	7	11	20	31	37	45	56	75	102	133	151	179	342	329	297	261	241	218
6	14.74	1.652	0	0	0	9	17	45	41	66	85	96	109	118	126	160	171	215	245	267	274	238	459	432	397	347	294	262
7	13.09	1.652	24	38	56	44	82	138	119	178	238	246	249	287	281	352	372	382	376	342	289	232	454	442	422	387	335	314
8	11.43	1.652	45	74	128	96	188	310	273	383	434	456	449	453	433	540	491	454	392	338	251	216	424	423	408	394	372	375
9	9.78	1.652	77	125	197	169	328	498	445	575	593	598	583	551	456	571	480	398	352	288	252	233	454	465	444	408	391	383
10	8.13	1.652	93	161	258	216	422	614	554	633	610	584	544	495	394	498	429	380	326	281	256	241	473	463	458	427	415	392
11	6.48	1.652	99	169	289	216	419	621	560	566	526	501	472	416	360	456	414	362	332	304	278	246	491	481	462	453	432	406
12	4.83	1.652	106	174	276	181	355	548	489	531	502	464	422	384	338	431	385	356	331	302	262	229	460	457	458	448	448	427
13	3.17	1.652	105	166	257	159	320	472	418	491	470	430	362	339	300	386	373	354	317	277	254	239	472	459	456	442	442	450
14	1.52	1.652	102	165	253	165	292	449	394	449	438	414	361	330	301	385	353	334	313	299	267	249	489	465	470	460	466	449
15	-.13	1.652	101	159	259	162	280	431	377	447	431	397	365	350	324	414	375	339	329	310	289	260	499	530	481	472	460	432
16	-1.78	1.652	102	169	264	157	270	405	353	417	425	408	379	370	342	435	392	355	328	305	268	238	460	446	439	414	409	383
17	-3.43	1.652	101	156	244	155	280	427	374	435	441	410	351	369	328	417	370	330	289	251	216	182	354	332	317	296	281	252
18	-5.09	1.652	90	136	219	150	272	408	359	424	433	413	358	326	266	339	289	237	201	158	129	99	197	186	172	152	136	122
19	-6.74	1.652	65	109	179	122	220	322	284	322	318	288	249	201	150	192	156	119	82	64	48	37	75	71	66	58	50	49
20	-8.35	1.652	48	72	121	61	108	161	141	161	156	142	108	67	51	67	50	35	31	22	19	16	32	30	28	26	23	21
21	-10.04	1.652	28	48	75	23	35	41	34	38	37	27	23	18	12	17	13	11	10	8	8	7	15	15	13	13	11	9
22	-11.70	1.652	14	22	36	6	8	10	8	8	6	5	4	4	3	4	4	4	3	3	3	2	3	3	2	2	2	1
23	-13.35	1.652	7	10	17	1	2	2	1	1	1	0	4	4	3	4	4	4	3	3	3	2	3	3	2	2	2	1
24	-15.00	1.652	7	10	17	1	2	2	1	1	1	0	4	4	3	4	4	4	3	3	3	2	3	3	2	2	2	1
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

Table B.3 Design Day Incident Heat Flux Map for 10 a.m.--
Left Side (Reversed for 2 p.m.), MW/m²

ROW NO	POS. CENT.M	AREA HT.M																										
1	23.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
2	21.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	12	14
3	19.70	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	6	14	16	28	34	48	64	107
4	18.04	1.652	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	6	13	30	63	122	143	168	169	214	256	235
5	16.39	1.652	0	0	0	0	0	2	2	9	15	11	14	23	29	35	48	59	78	119	133	163	318	362	373	360	405	381	350
6	14.74	1.652	0	0	0	0	23	63	57	75	86	93	97	107	117	149	165	201	240	253	236	217	425	415	413	414	396	355	295
7	13.09	1.652	35	48	71	61	102	160	140	168	204	223	233	235	235	295	321	357	348	320	254	213	414	397	389	375	344	329	317
8	11.43	1.652	56	83	124	122	214	312	277	345	386	377	398	373	342	429	447	426	343	306	251	207	396	389	371	371	363	345	335
9	9.78	1.652	82	128	194	189	396	535	484	527	549	538	533	462	399	501	448	408	344	298	252	216	414	434	394	376	363	354	341
10	8.13	1.652	95	153	251	240	456	647	589	683	668	632	550	436	374	473	413	364	330	283	243	230	451	437	429	390	375	356	366
11	6.48	1.652	97	163	253	199	435	625	564	682	674	595	497	389	331	420	377	345	322	288	249	225	444	442	426	411	393	356	371
12	4.83	1.652	100	157	249	172	366	531	474	610	631	547	449	363	314	402	378	366	324	280	250	224	443	436	433	425	431	422	405
13	3.17	1.652	97	155	239	159	312	467	411	547	592	515	430	353	309	397	377	348	307	271	239	225	442	449	449	441	436	425	411
14	1.52	1.652	104	161	246	172	318	454	400	526	543	444	379	304	294	377	363	332	305	277	264	247	481	479	455	449	437	435	414
15	-.13	1.652	99	159	255	180	287	439	385	475	478	424	389	359	335	428	390	350	320	295	275	255	494	489	485	462	446	415	408
16	-1.78	1.652	102	161	253	182	321	448	392	481	480	469	452	411	371	471	426	371	317	279	268	242	469	453	434	413	391	374	358
17	-3.43	1.652	103	161	248	201	342	490	434	490	510	490	470	402	337	426	363	302	257	223	194	172	332	332	308	301	268	258	229
18	-5.09	1.652	90	149	236	206	339	484	433	482	478	432	367	308	245	309	252	205	168	140	116	92	177	171	161	159	144	130	122
19	-6.74	1.652	65	115	191	171	270	389	350	372	336	284	242	191	132	167	131	105	84	64	49	38	73	71	68	68	62	61	56
20	-8.39	1.652	38	70	113	78	131	195	175	172	159	139	103	64	44	57	48	38	31	26	20	17	33	33	33	30	26	24	21
21	-10.04	1.652	19	34	60	30	42	46	39	42	43	27	18	14	13	17	15	12	10	9	8	8	15	15	14	12	12	10	10
22	-11.70	1.652	9	14	27	6	9	9	7	9	6	4	4	3	3	4	5	4	4	4	4	2	4	4	3	2	2	1	1
23	-13.35	1.652	3	8	14	1	1	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-15.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table B.3 (Cont) Design Day Incident Heat Flux Map for 10 a.m.--
Right Side (Reversed for 2 p.m.), MW/m^2

ROW NO	POS. CENT.M	AREA HT.M																											
1	23.00	.826	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	14	9	0	0	0	3	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	19.70	1.652	106	64	55	46	22	41	26	14	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	18.04	1.652	231	195	179	177	171	160	143	73	41	17	8	3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
5	16.39	1.652	347	340	324	324	315	320	324	166	150	103	73	61	52	39	32	19	16	12	8	6	1	1	0	0	0	0	0
6	14.74	1.652	295	291	305	337	347	363	365	189	223	227	204	183	177	162	131	105	87	76	69	60	43	47	22	0	0	0	0
7	13.09	1.652	318	319	325	353	372	374	375	194	235	283	306	344	363	344	275	242	218	197	181	154	113	127	83	34	43	28	13
8	11.43	1.652	338	362	371	389	401	399	402	209	238	266	318	410	488	486	387	373	367	372	323	265	216	244	158	87	98	61	40
9	9.78	1.652	342	369	392	416	434	431	438	226	245	280	313	389	466	532	422	446	454	494	465	418	348	390	257	131	158	101	59
10	8.13	1.652	366	383	403	420	421	428	418	213	243	271	299	347	386	447	354	409	481	530	548	511	453	531	351	170	212	146	80
11	6.48	1.652	367	383	403	413	429	426	420	214	243	266	289	318	348	374	292	347	416	498	522	497	440	492	340	169	252	158	94
12	4.83	1.652	402	413	416	425	440	431	408	206	227	255	282	318	337	363	283	303	366	428	457	449	403	453	290	139	253	160	103
13	3.17	1.652	408	422	439	446	452	438	410	209	223	236	267	300	332	359	280	295	355	370	408	439	373	421	255	128	259	167	107
14	1.52	1.652	412	433	439	446	451	447	440	225	235	243	275	311	328	352	274	303	323	368	398	409	327	372	247	133	256	167	104
15	-.13	1.652	406	426	445	450	456	451	441	224	252	274	284	311	341	378	297	327	353	381	398	388	320	365	240	140	241	157	97
16	-1.78	1.652	349	365	389	402	420	417	425	217	246	267	291	325	361	404	318	349	376	401	417	377	316	361	220	125	234	148	98
17	-3.43	1.652	229	245	280	299	305	313	305	153	179	209	258	290	328	375	295	347	377	403	412	385	303	344	236	139	229	145	93
18	-5.09	1.652	122	135	148	161	178	178	174	90	108	127	163	197	234	276	217	267	313	353	381	371	308	350	245	145	219	143	90
19	-6.74	1.652	55	61	63	67	70	72	75	38	47	60	72	90	110	148	117	150	192	224	270	276	234	285	202	127	188	120	76
20	-8.39	1.652	20	23	24	25	26	26	26	13	14	20	23	27	35	46	35	55	77	103	133	144	147	165	129	91	160	95	53
21	-10.04	1.652	9	10	10	10	11	11	12	6	7	8	10	11	13	15	11	12	17	27	31	36	51	58	59	34	105	66	36
22	-11.70	1.652	1	1	1	2	3	3	3	2	2	3	3	4	5	5	4	3	3	3	3	5	7	9	6	6	57	34	21
23	-13.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	23	19	11
24	-15.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table B.4 Design Day Incident Heat Flux Map for 10-Deg Sun Elevation (Sunrise)--
Left Side (Reversed for sunset), MW/m^2

ROW NO	POS. CENT.M	AREA HT.M																										
1	23.80	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3	19.78	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	4	6	11	12	18	26
4	18.84	1.652	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	4	7	11	21	23	31	39	45	53	62
5	16.39	1.652	0	0	0	0	0	0	0	1	3	3	4	8	8	10	18	21	26	32	34	32	62	67	73	82	89	89	88
6	14.74	1.652	0	0	0	0	7	22	19	25	38	33	36	48	40	51	57	62	59	59	51	46	91	92	102	109	111	103	101
7	13.89	1.652	11	16	24	21	35	56	48	59	78	77	81	84	89	113	112	104	94	82	68	63	123	118	126	131	131	130	120
8	11.43	1.652	18	28	44	37	67	97	84	110	138	148	138	133	123	155	142	121	101	94	85	73	144	143	142	146	141	137	125
9	9.78	1.652	25	42	64	48	98	135	118	149	178	174	177	148	130	165	139	123	110	104	88	75	158	154	151	153	147	141	135
10	8.13	1.652	34	53	81	58	99	153	132	182	211	197	168	140	117	151	137	126	112	100	87	77	152	157	159	156	151	143	132
11	6.48	1.652	36	60	92	59	96	164	142	186	201	182	154	133	114	147	135	118	105	95	86	78	155	159	159	157	151	146	136
12	4.83	1.652	48	65	95	62	95	134	114	151	170	163	143	125	106	137	126	113	99	91	86	79	155	159	159	154	148	144	137
13	3.17	1.652	38	61	93	61	90	124	104	142	167	155	137	125	106	136	124	107	97	93	87	83	161	158	154	150	144	138	137
14	1.52	1.652	35	55	89	60	92	126	106	144	166	149	130	115	99	128	118	108	100	94	91	86	168	165	161	157	159	158	155
15	-.13	1.652	32	51	86	54	93	134	114	141	148	146	128	111	98	126	119	114	107	100	93	87	170	176	179	176	170	164	153
16	-1.78	1.652	31	50	84	49	88	131	111	143	146	146	130	119	105	135	124	116	105	96	84	78	155	160	164	165	158	148	137
17	-3.43	1.652	28	47	79	47	83	132	114	143	147	146	129	114	98	125	114	102	88	78	69	61	120	118	118	115	110	102	94
18	-5.09	1.652	27	42	69	44	85	124	108	127	126	124	114	96	81	102	77	65	58	49	44	35	68	66	64	60	52	50	44
19	-6.74	1.652	20	33	55	34	59	85	74	89	90	84	74	58	41	52	40	35	29	25	19	15	28	29	28	26	23	20	18
20	-8.39	1.652	15	22	37	17	32	42	36	42	39	34	27	18	16	21	17	15	11	10	9	8	15	13	12	11	10	9	8
21	-10.84	1.652	8	13	21	7	8	11	9	10	8	7	6	5	4	5	5	4	4	4	4	3	6	5	5	5	4	4	3
22	-11.78	1.652	4	6	3	1	2	2	2	2	2	2	1	1	1	2	2	2	1	1	1	1	2	1	1	1	1	0	0
23	-13.35	1.652	1	2	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-15.80	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table B.4 (Cont) Design Day Incident Heat Flux Map for 10-Deg Sun Elevation (Sunrise)--
Right Side (Reversed for sunset), MW/m^2

ROW NO	POS. CENT.M	AREA HT.M																										
1	23.88	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	1	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	19.78	1.652	25	22	15	12	7	1	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	18.04	1.652	61	54	48	46	43	26	27	14	9	6	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5	16.39	1.652	87	85	83	84	80	76	62	32	34	29	26	22	14	7	6	4	3	2	2	1	0	0	0	0	0	0
6	14.74	1.652	100	95	91	93	101	94	84	43	53	60	61	61	58	53	42	35	30	23	19	14	9	18	4	0	0	0
7	13.09	1.652	119	117	114	108	107	101	96	48	57	73	86	86	98	97	78	74	67	61	52	43	32	37	25	15	19	13	8
8	11.43	1.652	122	125	122	120	113	110	106	52	60	71	91	99	110	122	97	107	109	100	91	78	61	70	50	31	36	25	16
9	9.78	1.652	132	132	132	130	127	118	117	57	61	70	88	98	118	128	102	120	127	124	109	98	80	93	71	45	59	40	25
10	8.13	1.652	128	130	129	132	128	120	115	55	60	66	82	92	102	126	99	117	122	119	106	105	91	106	84	57	79	53	33
11	6.48	1.652	133	130	131	131	128	122	118	57	62	66	75	91	103	114	88	102	105	105	97	98	92	107	82	61	92	61	39
12	4.83	1.652	132	135	132	133	130	125	119	57	62	67	74	87	102	110	86	99	100	93	87	87	79	93	75	53	95	63	41
13	3.17	1.652	134	137	140	137	135	129	117	57	62	68	77	89	103	115	90	98	103	93	83	77	83	98	78	52	94	64	42
14	1.52	1.652	151	151	151	139	137	129	124	61	65	72	81	95	109	121	95	107	110	106	95	86	85	100	83	52	90	60	38
15	-.13	1.652	149	150	147	141	132	129	123	60	64	74	87	101	116	132	105	117	119	116	104	99	88	104	81	47	88	58	36
16	-1.78	1.652	133	132	127	123	116	113	107	51	59	68	81	92	113	127	101	115	123	120	112	101	89	105	72	49	87	57	38
17	-3.43	1.652	91	94	91	85	84	83	77	36	42	51	64	79	97	112	89	105	116	119	114	108	90	105	80	53	86	55	35
18	-5.09	1.652	42	46	46	46	45	45	43	20	23	29	37	48	64	81	65	77	95	101	103	97	85	98	71	47	75	58	33
19	-6.74	1.652	17	18	18	19	19	19	17	8	9	10	15	20	29	41	32	45	58	65	69	65	58	67	51	34	59	37	22
20	-8.39	1.652	7	8	8	8	8	8	8	3	3	4	4	4	7	9	7	12	18	25	28	28	28	33	26	17	43	24	15
21	-10.04	1.652	3	3	3	3	3	2	3	1	1	1	1	1	1	2	1	1	1	3	4	5	6	8	5	5	24	16	10
22	-11.70	1.652	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	12	7	5
23	-13.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3	2
24	-15.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table B.5 Off-Design Point Flux Profile--Left Side
(Day 91, 5:42 a.m.), MW/m²

ROW NO	POS. CENT.M	AREA HT.M																									
1	23.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	19.70	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	7	9	11	11	13	14	20
4	18.04	1.652	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	5	10	14	25	47	44	42	41	44	46	51
5	16.39	1.652	0	0	0	0	0	0	0	0	3	5	8	7	10	12	13	19	30	40	47	46	89	87	78	74	69	69	78
6	14.74	1.652	0	0	0	0	10	18	16	23	26	31	34	38	41	51	60	68	77	72	59	50	98	96	90	96	87	84	84
7	13.09	1.652	10	16	22	24	38	59	52	63	71	76	92	100	95	117	117	112	101	78	58	44	88	99	106	107	105	104	95
8	11.43	1.652	21	33	47	52	94	133	119	145	146	156	162	159	142	175	145	127	96	73	58	52	103	109	109	112	113	112	101
9	9.78	1.652	29	45	68	77	143	193	174	196	204	202	195	168	145	180	142	110	91	71	59	53	107	109	108	109	108	108	104
10	8.13	1.652	30	51	80	85	156	217	195	203	201	196	183	151	123	154	129	101	83	68	61	53	108	139	113	114	112	113	109
11	5.48	1.652	30	48	77	68	130	206	185	182	159	162	148	124	104	131	113	91	76	69	59	54	110	112	114	123	123	117	112
12	4.83	1.652	30	46	76	62	120	183	164	170	160	140	127	115	98	123	110	92	80	69	63	59	118	121	120	122	120	115	111
13	3.17	1.652	30	48	72	58	107	159	142	159	149	138	126	118	107	134	115	100	83	68	64	60	121	121	119	122	123	122	115
14	1.52	1.652	30	46	69	50	103	132	115	133	138	137	131	124	107	134	112	97	83	72	66	62	124	126	128	131	130	129	125
15	-.13	1.652	28	45	72	53	100	138	121	137	144	150	144	137	118	147	119	107	92	82	74	66	131	130	130	141	138	134	123
16	-1.78	1.652	27	43	72	57	96	133	116	141	157	158	150	142	124	154	128	114	94	80	68	60	118	119	122	124	121	113	104
17	-3.43	1.652	24	39	65	53	89	138	122	153	159	160	151	137	115	142	117	96	77	64	52	45	87	83	85	82	80	72	69
18	-5.09	1.652	19	33	54	46	77	118	104	132	137	135	123	107	84	104	82	63	45	34	26	18	36	36	36	36	33	33	32
19	-6.74	1.652	12	21	40	29	54	81	72	85	87	80	70	55	40	50	34	22	13	11	8	7	13	12	12	11	11	11	10
20	-8.39	1.652	7	14	24	14	21	34	30	36	36	30	24	18	11	14	9	6	4	4	3	3	5	5	5	4	4	3	3
21	-10.04	1.652	4	5	9	3	4	8	7	6	4	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	0
22	-11.70	1.652	2	3	4	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	-13.35	1.652	2	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-15.80	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table B.5 (Cont) Off-Design Point Flux Profile--Right Side
(Day 91, 5:42 a.m.), MW/m^2

ROW NO	POS. CENT.M	AREA HT.M																										
1	23.88	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	19.78	1.652	20	13	14	12	12	8	4	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	18.04	1.652	52	50	47	48	38	33	25	13	8	5	2	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
5	16.39	1.652	71	83	81	75	67	61	49	26	25	20	14	11	9	6	5	6	6	6	4	2	0	0	0	0	0	0
6	14.74	1.652	83	85	88	81	74	70	68	36	41	35	33	28	27	26	21	23	21	19	16	11	7	7	4	0	0	0
7	13.09	1.652	94	91	94	89	82	78	76	39	46	51	50	49	53	58	47	48	46	39	32	23	18	21	14	8	6	4	3
8	11.43	1.652	100	99	99	95	91	90	87	43	48	56	58	62	75	79	62	69	72	68	56	48	38	43	31	18	20	12	7
9	9.78	1.652	104	105	102	98	97	97	92	45	49	52	60	68	80	92	71	82	91	89	87	75	64	72	49	28	41	23	13
10	8.13	1.652	108	106	103	101	99	103	98	47	49	54	55	61	70	90	69	84	89	106	102	94	84	95	66	34	56	37	22
11	6.48	1.652	112	112	111	103	105	103	99	48	51	54	57	58	62	72	55	71	89	97	103	98	83	95	70	37	71	43	25
12	4.83	1.652	111	111	115	114	111	110	107	51	53	56	59	61	60	66	50	59	78	81	88	88	73	85	68	39	74	45	27
13	3.17	1.652	115	116	117	119	111	106	103	50	53	55	56	59	60	60	45	55	73	84	80	79	64	76	57	37	73	45	27
14	1.52	1.652	126	122	124	118	115	114	110	53	55	57	59	61	62	65	48	54	64	75	73	74	54	76	49	29	68	43	28
15	-.13	1.652	123	122	127	126	126	118	117	57	60	63	64	66	67	71	53	57	61	67	69	66	64	76	49	29	72	45	29
16	-1.78	1.652	103	107	108	111	115	112	110	53	59	63	66	69	69	74	56	61	67	71	71	66	56	58	52	32	78	50	31
17	-3.43	1.652	68	71	78	83	85	84	83	39	44	49	53	58	60	64	48	57	64	69	75	68	63	72	53	33	80	52	33
18	-5.09	1.652	31	33	36	39	43	46	51	23	27	30	35	37	41	47	35	40	47	56	65	64	57	69	49	30	73	48	30
19	-6.74	1.652	9	11	12	14	15	16	16	7	9	12	15	16	18	23	17	22	27	37	46	51	47	55	42	25	58	39	23
20	-8.39	1.652	3	3	3	3	4	4	4	1	2	3	4	5	6	7	4	6	11	16	23	30	31	35	28	17	44	28	16
21	-10.04	1.652	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	1	1	3	6	10	13	15	12	8	30	20	12
22	-11.70	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	4	3	2	14	11	9
23	-13.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	4	3
24	-15.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

- At intermediate power, clear-day cloud reference flux profiles shall conform to the following values:

Date	Time	Flux Data	Multiplication Factor Range
21 Feb	Noon	Table B.2	0.242 - 0.972
21 Feb	10 a.m.	Table B.3	0.251 - 1.000
21 Feb	7:12 a.m.	Table B.4	0.843 - 1.000
21 June	5:42 a.m.	Table B.5	0.984 - 1.000

- The environmental conditions are within the operating limits, as defined in Section 5.2.

3.3.3 Cloudy-Period Performance

During partially cloudy periods, the RS shall deliver hot salt at 566°C (+3/-5°C) [1050°F (+5.4/-9°F)], provided that salt is supplied to the RS at 288°C (+10/-5°C) [550°F (+18/-9°F)] and the environmental conditions are within operating limits, as defined in Section 5.2, with the following exceptions:

- Total incident power is less than 90 MW (307 x 10^6 Btu/h).
- The rate of change of incident power is greater than 4 MW/s (13.65 x 10^6 Btu/h).
- The absorber incident flux peak-to-average value is greater than 2.5.
- The ratio of incident power between the left (east) and right (west) sides of the absorber is less than 0.600 and greater than 1.667.
- The incident power on the absorber panels downstream of the receiver control valves is less than 30 percent of the total incident power.
- The incident power on the absorber panels upstream of the control valves is less than 30 percent of the total incident power.

3.3.4 Hot and Overnight Shutdown

Over the environmental conditions defined for both operation and survival, the RS shall provide thermal conditioning to maintain all equipment in contact

with salt at not less than 288°C (550°F) with electrical power inputs and thermal power inputs (if applicable) not greater than 0.8 MW total (2.73 x 10^6 Btu/h) [where electrical and thermal inputs are added to define the total (i.e., MW_{total} = MWe + MWt)]. The annual power consumption for the RS during hot and overnight shutdown shall be less than 2500 MWhe/yr (8.530 x 10^9 Btu/yr.).

3.3.5 Auxiliary Requirements

- At the design point, defined in Section 3.3.1, the total RS electrical power requirement shall not be greater than 2.5 MWe (8.5 x 10^6 Btu/h). This value shall be designated as the design point RS auxiliary power requirement.
- At the minimum incident power clear-day operating point, defined in Section 3.3.2, the total RS electrical power requirements shall not be greater than 1.0 MWe (3.4 x 10^6 Btu/h).
- Over the clear-day operating range, including normal start-up and shutdown operations, the RS auxiliary power requirement shall not exceed 10 percent of the design point power requirement.
- At no time shall the total RS auxiliary power requirement exceed 120 percent of the design point RS auxiliary power requirement.
- The annual auxiliary power consumption for the RS including all operations shall be less than 11,500 MWhe/yr (39.24 x 10^9 Btu/yr).

3.4 OPERATION

The RS shall meet the following operating requirements:

- Minimum thermal load of 25 percent.
- Normal RS operating load range from 25 to 100 percent. Below 25 percent load, the RS will be at derated temperature operation or in a start-up or shutdown transition.

The load distribution for the RS over its 30-year (263,000-hour) design life will consist of 12.2 years (107,300 hours) at full or part load or derated temperature operation, with the remaining 17.8 years (155,700 hours)

in the shutdown or hot standby mode. The following operating modes and estimated times will be used in the design:

Operating Mode	Operating Time (h)	
Energy collection at rated temperature		
At <50% maximum power	17,300	
At >50% maximum power	75,000	
Total at rated temperature		92,300
Energy collection at derated temperature		15,000
Hot standby		151,000
Cold shutdown/standby		4,700
Total		263,000

3.4.1 Normal Operation

- Cold Start-Up. Over the operating range of environmental conditions, and with parasitic electric power requirements not greater than 750 kWe (2.56 x 10^6 Btu/h), the RS shall be capable of thermally conditioning all equipment for salt fill in no more than 16 hours. Equipment shall be defined as thermally conditioned for salt fill when all surfaces in contact with salt are at 288°C (550°F) or higher or at a temperature, verified experimentally, that will permit salt fill:
  - Without salt obstruction or freezing
  - Without rendering components (e.g., valves) inoperable for any period of time
  - Without damage to equipment (e.g., damage caused by thermal shock) or reduction in projected equipment lifetime.

  Once the RS is thermally conditioned, it shall be capable of salt fill within 60 minutes. The RS will be considered full when all operating lines and absorber tubing are filled with molten salt without residual pockets of gases and the IST and OST levels are at nominal operating or start-up conditions.

  Cold start-up will occur 60 times during the RS lifetime.

- Hot Standby. When the RS is thermally conditioned and is filled with salt, it shall be considered in a hot standby mode. During hot standby operation, there shall be no pumped salt circulation, the aperture door shall be closed, and the RS shall meet the performance requirements defined in Section 3.3.4. In addition, the thermal conditioning of the RS must be such that no component shall exceed its nominal maximum operating temperature.

  The RS will be in the hot standby mode for 151,000 hours during its 30-year design lifetime.

- Hot Start-Up. Hot start-up comprises the transition from hot standby to normal operation. It includes:
  - Initiation or ramping-up of salt circulation in the absorber before the aperture door is opened
  - Opening of the aperture door (time to open door not to exceed 2 minutes)
  - Focusing of heliostat images on the absorber (time to focus all heliostats shall be greater than 1 minute and less than 10 minutes) while a constant flow rate is maintained
  - Transition from flow control to temperature control of the absorber flow rate.

  Before attaining design temperature control, the RS shall divert the outlet salt from the receiver to the cold storage tank (CST). The hot start-up will be complete once design outlet temperature is attained, flow to the hot storage tank (HST) is established, and flow diversion to the CST is stopped.

  The RS shall complete hot start-up within 20 minutes. Hot start-up will occur 12,000 times during RS lifetime.

- Outlet Temperature Control. During outlet temperature control operations, the receiver flow rate shall be controlled to maintain the outlet temperature at 566°C (+3/-5°C) [1050°F (+5.4/-9°F)]. The RS shall meet the performance requirements for clear-day and partly cloudy period as defined in Sections 3.3.2 and 3.3.3.

  Outlet temperature control operation shall be terminated by either transition to alternative flow control operation during cloudy periods or hot shutdown operation.

- Transition From Outlet Temperature Control to Alternative Flow Control. The receiver control will change from outlet temperature control to alternative flow control whenever the outlet temperature cannot be maintained above 566°C (1050°F) with a receiver flow rate greater than or equal to 189 kg/s (1.5 x 10^6 lb/h). When the outlet temperature falls below 566°C (1050°F), the receiver flow rate shall be increased from the minimum value of 189 kg/s (1.5 x 10^6 lb/h) to 227 kg/s (1.8 x 10^6 lb/h) [±11 kg/s (0.09 x 10^6 lb/h)]. The ramp rate for this transition shall be 0.23 kg/s/s (6.6 x 10^6 lb/h/h) with "smooth" transitions on each end of the ramp.

- Alternative Flow Control. During alternative flow control operation, the receiver flow rate shall be controlled to a value of 227 kg/s (1.8 x 10^6 lb/h) [±11 kg/s (0.09 x 10^6 lb/h)], and the receiver outlet flow shall be diverted to either the HST or the CST. Alternative flow control operation shall be terminated by a transition to either outlet temperature control operation or hot standby.

- Transition From Alternative Flow Control to Outlet Temperature Control. During alternative flow control operation, if the outlet temperature exceeds 538°C (1000°F), the receiver flow control shall decrease the receiver flow rate with a ramp rate of 0.23 kg/s/s (6.6 x 10^6 lb/h/h) and transition to outlet temperature control operation.

- Hot Shutdown. Hot shutdown comprises the transition from outlet temperature or alternative flow control operations to hot standby operation. It may be initiated by the operator, by a timer, or by lower power condition identifying the end of normal clear-day operation.

  Hot shutdown shall consist of the following steps:

  - Remove all heliostat images from receiver aimpoints (time for and rate of removal not to exceed 3 minutes and 70/s respectively)
  - Close aperture door (time for closing not to exceed 1 minute)
  - Ramp receiver flow rate to zero in less than 3 minutes
  - Whenever receiver outlet temperature reaches 400°C (750°F), open diversion valve to divert outlet flow to the CST. Within 5 seconds after flow is established to the CST, close blocking valve to terminate flow to the HST. Electric heaters will be activated if component temperature drops below 293°C (560°F).

- Cold Shutdown. Cold shutdown includes the draining and purging, if required, of all molten salt lines; the shutdown of all electric heaters; and the cooling down of equipment. The draining of the RS system into the CST shall be accomplished in a period not to exceed 60 minutes. Once the system is drained, the thermal conditioning equipment shall be turned off in such a manner that it causes no undue thermal stress or reduction in equipment lifetime, and receiver and piping shall be filled with dry air. Cold shutdown will occur a maximum of 30 times during the receiver lifetime.

- Cold Standby. The RS shall be considered in cold-standby operation whenever all equipment is less than 20°C (68°F) above ambient temperature.

  During cold standby, the system may be vented and opened for repairs as necessary.

  The RS will be in cold shutdown/standby mode of operation for 4700 hours during the 30-year design lifetime.

3.4.2 Emergency Operation

- Emergency operation shall apply in the event of any one or more of the following conditions:
  - Receiver salt pump trip or failure (10 occurrences)
  - Heliostat field defocus (scram) (30 occurrences)
  - Loss of collector field control (30 occurrences)
  - Failure of salt piping, tanks, absorber panel tubes or headers (30 occurrences)
  - Loss of salt flow control (30 occurrences)
  - Power failures to one or more of the following (3 occurrences):
    - Whole plant
    - CS
    - RS
  - Detection of excessive temperature in molten salt, absorber panels, or related pipework

- Operation Following Salt Pump Trip or Failure. For a single pump failure, the spare pump will be started without discontinuing operations.

  For multiple pump failures:
  - The heliostats shall be defocussed in 1 minute or less
  - The IST salt inventory shall be expelled under pressure
  - If absorber back tubewall temperatures exceed 593°C (1100°F) or tube temperature rate of change exceeds 0.3°C/s (0.5°F/s) while salt is flowing, the aperture door shall be closed in 1 minute or less; otherwise, at the completion of salt flow from the IST, the door shall be closed in a normal manner
  - After the door is completely closed, damage shall be assessed and the receiver will either be drained or put into a hot standby condition with radiant cavity heaters thermostatically controlled

- Operation Following Heliostat Defocus (Scram). In the event of heliostat scram, the receiver shall shift to a hot standby condition in the following steps:
  - Within 2 minutes after all heliostat images are removed from the receiver, the aperture door shall be closed.
  - The receiver flow rate shall be ramped down at a rate of 3 kg/s/s (85×10^6 lb/h/h) with a smooth transition to a flow rate of 160 kg/s (1.27×10^6 lb/h).

- When the receiver outlet temperature reaches 400°C (752°F), the flow diversion valve to divert outlet flow to the CST shall be opened and, within 15 seconds after flow to the CST is established, the flow to the HST shall be terminated.
- If receiver start-up is not possible within 15 minutes, the flow will be ramped to zero.

- Operation Following Loss of Collector Field Control. In the event of loss of collector field control, the aperture door shall close in 1 minute or less, during which time all valves shall be positioned to allow the discharge of salt under pressure from the CSU.

- Operation Following Failure of Salt Piping, Tanks, or Absorber Panels. The initial indications of failure are either measured reductions in flow rate or excessive temperatures. If such a failure is detected, the following sequence shall occur:
  - The heliostats shall be defocussed from the receiver in 1 minute or less
  - The absorber temperatures shall be monitored. If back tubewall temperatures greater than 593°C (1100°F) or a change in tubewall temperature at a rate exceeding 0.3°C/s (0.5°F/s) are detected, the aperture door shall be closed in 1 minute or less
  - If excessive temperatures or changes in temperatures are not detected, the aperture door shall be closed at the completion of collector field defocus, and the receiver flow rate shall be reduced to zero
  - After assessment of damage, the receiver shall be drained or put into a hot standby mode

- Operation Following Loss of Salt Flow Control. Loss of salt flow control can result from problems with the IST level control valve, the receiver temperature control valves, or the OST level control valve.

  If the valve failure does not cause flow to be blocked excessively and panel temperatures or temperature ramp rates that are too high, the following sequence shall occur:

  - Heliostats shall be defocused from the receiver in 1 minute or less
  - The aperture door shall be closed in a normal fashion
  - The flow rate shall be reduced to zero
  - The damage shall be assessed and the system either drained or put into a hot standby condition

If the valve failure results in back tubewall temperatures above 593°C (1100°F) or temperature ramp rates greater than 0.3°C/s (0.5°F/s) before or during heliostat field defocus:

- The aperture door shall be closed in 1 minute or less
- The flow rate shall be ramped to zero
- After damage assessment, the system shall be drained or placed in a hot standby condition

- Operation Following Power Failures. When a power failure is detected, the aperture door shall close in 1 minute or less, during which all valves shall be positioned to allow the discharge of salt under pressure from the IST. Simultaneously, emergency power shall be provided to defocus the heliostats and then to provide adequate power to drain the system or to maintain it in a hot standby mode while damage is assessed.

- Operation Following Detection of Excessive Temperature in Molten Salt, Absorber Panels or Related Pipework. In the event of detection of molten salt bulk temperatures in excess of 570°C (1058°F) or temperature of absorber panel tubes or headers in excess of 650°C (1200°F), the RS shall command a heliostat defocus (scram) and increase receiver flow rate to the maximum with a ramp rate of 3 kg/s/s (85 x 10^6 lb/h/h).

  Following heliostat defocus within 60 seconds, the aperture door shall remain open until the temperature has fallen to its nominal design value, after which the door shall be closed within 6 minutes and the flow rate shall be decreased to zero. During these operations, when the outlet temperature falls to 538°C (1000°F), the diversion valve to the CST shall be opened and, within 60 seconds after flow is established to the CST, the flow to the HST shall be terminated.

3.5 SAFETY

The RS shall meet all ASME Code requirements relating to safety and shall be operated in a safe manner at all times.

3.5.1 Salt

All RS salt equipment shall be operated in a safe manner consistent with the following procedures and hazards:

- Normal Handling
  - Do not get in eyes or on skin or clothing
  - Do not take internally
  - Avoid breathing dust
  - Protect against physical damage
  - Store in a cool, dry place
  - Separate from combustibles, organic or other materials that are readily oxidized
  - Avoid storage on wood floors
  - Immediately remove and dispose of any spilled material.

Protective equipment:	Eye goggles, impervious gloves, coveralls, and impervious boots.
Ventilation requirements:	Local exhaust or general ventilation as dictated by airborne concentrations.

- Fire and Explosion

OSHA Classification:	Class 1 oxidizer.
Extinguishing Media:	Nitrate may fuse or melt in large fires and water may result in scattering of molten materials. Water should not be applied to molten salt baths.
Special Fire Hazard and Fire Fighting Procedures:	Use NIOSH/MSHA approved self-contained breathing apparatus where this material is involved in a fire.

- Health

Threshold Limit Value:	None established.
Symptoms of Overexposure:	Dizziness, abdominal cramps, vomiting, headache, mental impairment, cyanosis. May cause eye, skin, and mucous membrane irritation.

Emergency First-Air Procedures:

Skin:	Flush thoroughly with water.
Eyes:	Flush with water for 15 minutes, call a physician.
Ingestion:	Drink water, induce vomiting by sticking finger down throat, call a physician.
Inhalation:	Remove victim to fresh air, call a physician.

- Spill or Leak Control
  - Remove all sources of ignition
  - Wear NIOSH/MSHA approved dust respirator
  - Follow OSHA regulations for respirator use (See 29 CFR 1910.134)
  - Wear goggles, coveralls, impervious gloves and boots
  - Do not return material to original container
  - Place in a fresh container and isolate outside or in a well ventilated area
  - Do not seal the container
  - Flush any residual material with water
  - Wash all contaminated clothing before reuse.

- Waste Disposal
  - Dispose of contaminated product and materials used in cleaning up spills or leaks in a manner approved for this material
  - Consult appropriate Federal, State, and local regulatory agencies to ascertain proper disposal procedures.

3.5.2 High-Temperature Equipment

All RS equipment shall be insulated so that exterior surfaces accessible to maintenance or operating personnel shall be less than 60°C (140°F) throughout the operating range of environmental conditions.

Personnel shall not be allowed close to the absorber or uncooled receiver surfaces (e. g., doors) except when temperatures less than 60°C (140°F) are ensured. Appropriate locks and restraints, warning lights, and alarms shall be provided to keep personnel away from these areas and to warn them of unsafe conditions.

3.5.3 Heliostat Operations

All personnel shall be prohibited from areas subject to illumination by heliostat beams during heliostat operations. Appropriate locks and restraints, warning lights, and alarms shall be provided to keep personnel away from these areas and to warn them of unsafe conditions.

3.6 RS CONTROL REQUIREMENTS

The RS Control Subsystem shall provide the capability to operate the RS in accordance with the RS Functional (Section 3.2), Performance (Section 3.3), Operating (Section 3.4), and Safety (Section 3.5) Requirements. Instruments and controls shall be provided to monitor and ensure safe, stable operation of the RS. The following parameters shall be monitored and controlled:

- Salt inlet temperature
- Salt outlet temperature
- Total salt flow rate
- Bypass salt flow rate
- Heat tracing power
- Component minimum temperatures

Control valves will be either pneumatically or electrically actuated.

The RS Control Subsystem shall perform the sequencing and timing required for all receiver operations defined in Section 3.4.

The RS control system shall provide interlocks to protect all equipment from damage caused by improper sequencing or activation of equipment.

The RS Control Subsystem shall be capable of communicating with the central plant control system, which will be a distributed digital system.

3.6.1 RS Setpoints and Control Variables

The RS Control Subsystem shall maintain the defined setpoints and control variables in a manner consistent with the appropriate performance, operation, and safety requirements. These values are defined in Table B.6.

Table B.6 RS Control Variables and Setpoints

Control Variable	Nominal Setpoint	Setpoint Range
Outlet temperature, °C (°F)	565 (1050)	287 to 565 (500 to 1050)
IST		
Pressure, kPa gage (lb/in²g)	2410 (350)	Atmospheric to 2586 (375)
Level	Half full	1/4 to 3/4 full
OST		
Pressure, kPa gage (lb/in²g)	103 (15)	Atmospheric to 207 (30)
Level	Half full	1/4 to 3/4 full
Thermostatic controls for radiant, immersion, and trace heaters, °C (°F)	293 (560)	288 to 316 (550 to 600)
Salt flow rate, kg/s (10^6 lb/h)	---	0.0 to 836 (0.0 to 6.6)

The RS shall control the following variables to commanded setpoints:

- Pump sump tank level
- IST level
- OST level
- Receiver outlet temperature
- Pump sump tank pressure
- Pump recirculation flow rate (low flow only)
- IST pressure
- OST pressure
- Shop/instrument air tank pressure (high/low switch)
- High pressure dry air tank pressure (high/low switch)

3.6.2 Active Feedback Control of RS Equipment

The following equipment shall have active feedback control consistent with the requirements for performance, operation, setpoint control, and safety:

- The three main salt receiver feed pumps shall have active flow recirculation control for pump protection during low-flow operation.
- The IST shall have active pressure control.
- The absorber shall have four control valves with active position control to regulate panel flow rates and control receiver outlet temperature.
- The RS drag valve shall have active position control to control the level in the OST.
- The cavity radiant heaters and all trace heaters shall have active thermostatic control. These controls may be either proportional or on-off but must provide verification of proper operation to the control room.
- Pump sump level control valve.
- The pump sump tank shall have active pressure control.
- The OST shall have active pressure control.
- The IST shall have active salt level control.
- The shop/instrument air compressor shall have active outlet temperature/pressure control.

3.6.3 On-Off Control of RS Equipment

The following equipment shall have on-off or open-close control consistent with the requirements for performance, operation, setpoint control, active feedback control, and safety.

- Receiver feed pump motors (3)
- Aperture door activation system
- Flow diversion valve for diverting outlet flow to CST
- HST inlet blocking valve for diverting outlet flow from the HST
- Drag valve by-pass line blocking valve
- IST level control valve by-pass line blocking valve
- Pump outlet blocking valves (3)
- Riser drain line blocking valve
- Pump sump inlet blocking valve
- Pump recirculation line blocking valve
- Drain line to surge tank blocking valve
- Riser-downcomer drain/fill interconnect blocking valve
- Air cover gas blocking valve for IST
- Air cover gas blocking valve for OST
- Air cover gas blocking valve for pump sump tank
- Absorber salt drain valves (10)
- Absorber salt vent valves (13)
- High pressure air compressor motor shall have high/low pressure switch control
- Shop/instrument air compressor motor shall have high/low pressure switch control.

3.6.4 Remote Operation, Control Room Equipment, and Displays

The RS Control Subsystem shall be capable of remote operation from a central control room.

The RS shall be operable by either a single operator from a single control room CRT or by a master control system. Data available in the control room shall include but not be lmited to the following:

- Status of all on-off equipment
- All levels in all tanks
- Pressures in all tanks
- Temperatures in all salt tanks
- Flow rates as follows:
  - Pump sump tank inlet
  - Pump outlet for each pump
  - Riser
  - Main feeder for each half of the absorber
  - Each outlet absorber pass
  - OST inlet flow
- Outlet salt temperature from each outlet absorber pass
- Absorber inlet pressure
- Absorber outlet pressure
- Absorber back tubewall temperatures
- Receiver insulation temperatures at selected location
- Receiver flux measurements
- Pipework and valve temperatures
- Control valve positions

- Aperture door position
- Shop/instrument air tank pressure
- High pressure dry air tank pressure.

3.7 MISCELLANEOUS

3.7.1 Tower

The tower, which supports the receiver, piping, and other elements of the RS, shall be designed to meet the following requirements:

- Support the receiver and associated components.
- Provide access for maintenance and inspection of the receiver, instruments and controls, piping, and other equipment mounted on the tower.
- Provide aircraft warning lights and lightning protection as required by codes and standards listed in Section 2.
- Meet the environmental criteria discussed in Section 5.
- Limit allowable sway caused by wind during operation to 0.3 m (1 ft), measured at the receiver midpoint.
- Provide a foundation adequate for the soil conditions at the reference site.
- Meet the criteria given in the codes and standards discussed in Section 2.

3.7.2 Piping

Interconnecting piping within the RS terminal points shall be provided to transport molten salt. The applicable code requirements defined in Section 2 and corrosion allowance criteria for the selected materials and service application shall be used in determining wall thicknesses. The piping shall be arranged with adequate flexibility to permit thermal expansion and to minimize

loadings on receiver connections; the piping shall also drain completely. Welded connections shall be used.

3.7.3 Salt Pumps

Three 50-percent capacity heavy duty, high-temperature service salt pumps shall be provided to circulate salt through the RS. The pumps shall be of the vertical, centrifugal, wet-pit, closed-impeller type with design characteristics as follows:

Material	Type 316SS
Design flow, L/s (gal/min)	209 (3300)
Minimum flow, L/s (gal/min)	41.8 (660)
Turndown ratio	10:1
Operating pressure, MPa gage lb/in²g)	
Suction	0.35 (50)
Outlet	5.9 (850)
Operating temperature, °C (°F)	
Maximum	302 (575)
Minimum	260 (500)
Delivered head at design flow, m (ft)	305 (1000)

3.7.4 Insulation and Lagging

Insulation and lagging shall be provided for the receiver, interconnecting piping, valves, and all other RS components that are potentially a

significant heat-loss source to ambient temperature and that require personnel protection. The casing temperature shall not exceed 60°C (140°F).

3.7.5 Trace Heating

All RS components containing molten salt shall be equipped with electrical trace heaters. The trace heaters shall be designed to preheat each component from ambient temperature to 293°C (560°F) in 16 hours. The trace heaters shall also be able to maintain each component at 288°C (550°F) with -9°C (16°F) ambient temperature and 15.6 m/s (35 mph) wind velocity.

3.7.6 Fill and Drain

The RS shall contain the added piping and valves necessary to gravity drain all salt from the RS components to either of the storage tanks on a daily or occasional basis. Main flow piping shall be used where possible. Draining of the RS shall be completed within 120 minutes. Lines and components shall drain fully; trapped salt shall be avoided. The salt in the receiver, riser, and downcomer shall be gravity drained to the storage tanks to the extent possible. The residual salt in the riser, downcomer, and collector field piping to and from the storage tanks shall be drained to the auxiliary drain tank located near the base of the tower.

3.7.7 Support Structure, Foundations, and Dikes

A structure shall be provided for support and access to the receiver, interconnecting piping, and all other RS components requiring support to withstand the environmental criteria defined in Section 5. A foundation shall be provided for the support structure, pumps, and tanks that fall within the

scope of the RS. A soil-bearing load of 0.24 MPa (35 lb/in^2)* shall be used for foundation design. The foundation shall be designed with a dike to contain the salt in the RS in the event of a salt leak.

*Data for Barstow, California.

Section 4

RS INTERFACE REQUIREMENTS

The RS will have interfaces with the CS, TSS, and Master Control Subsystems. The requirements for the interfaces are defined below.

4.1 CS

The interface between the RS and the CS includes requirements for the physical arrangement, the incident flux profiles on the receiver, and the operations for focusing and defocusing the heliostats.

The geometry between RS and CS is defined in Section 3.1.1.

The collector field shall generate the incident flux profiles defined in Section 3.3.1.

Consistent with providing adequate power, power time gradients, and flux distributions, the collector field shall be required to focus on and off the receiver and the receiver shall be required to operate safely when heliostats are controlled as follows:

- Time to focus all heliostats on receiver aimpoints shall be greater than 1 minute with a linear build up.
- Time to remove all heliostats from receiver aimpoints shall be less than 2 minutes with a linear decrease.

4.2 TSS

The interface between the RS and the TSS includes requirements for the physical arrangement, process flow parameters at the physical interface, and transient flow conditions and operations.

The physical interface and pipework connections between the RS and the TSS shall be located at the base of the tower.

Molten salt shall be provided to the RS by the TSS at the conditions defined in Table B.7.

Molten salt provided by the RS to the TSS shall correspond to the conditions defined in Table B.7.

4.3 MASTER CONTROL SUBSYSTEM

The interface between the RS and the Master Control Subsystem includes the physical interfaces for control wiring and the data required for RS operation, control, and data acquisition.

The control and data transmission wiring interface between the RS and the Master Control Subsystem shall be at a central conveniently located set of J-boxes.

Data, data format, update rate, and data transmission lines used between RS and Master Control Subsystem shall be as specified by the Master Control Subsystem designer.

4.4 PLANT SUPPORT SERVICES SUBSYSTEM

The interface between the RS and the Plant Support Services Subsystem shall include the supply of electric power, instrument air, water, drainage, and wastewater disposal. Requirements for these support services are TBD.

Table B.7 Process Flow Interface Conditions

	Nominal	Minimum	Maximum	Maximum Rated Change
Inlet Temperature, °C (°F)	288 (550)	283 (541)	300 (572)	3/h (5.4/h)
Inlet Pressure, MPa gage (lb/in²g)	0.34 (50)	0.24 (35)	0.69 (100)	---
Outlet Temperature, °C (°F)	566 (1050)	283 (541)	568 (1055)	28/min (50/min)
Flow Rate kg/s (lb/h)	760 (6.018×10^6)	0.0 0.0	836 (6.62×10^6)	9.5/s (75×10^3/s)

Molten Salt Specification:

Component	Minimum (Wt%)	Maximum (Wt%)
$NaNO_3$	58	60
KNO_3	39	41
$NaNO_2$	---	1.0
NaLT	---	0.30
Na_2SO_4	---	0.30
CaO	---	0.03
MgO	---	0.03
SiO_2	---	0.02
Al_2O_3	---	0.025
Fe_2O_3	---	0.025
Insolubles	---	0.06
Na_2CO_3	---	0.15

Section 5

RS ENVIRONMENTAL CONDITIONS

5.1 BASELINE DESIGN POINT

- Reference Site. Barstow, California [As specified in "Pilot Plant Environmental Conditions - OPDD Appendix C," Aerospace Report No. ATR-78 (7695-05)-05, Revision 1, 15 August 1978].
- Insolation. Direct normal at 950 W/m² (300 Btu/h•ft²).
- Dynamic Performance. The maximum rate of change of incident flux shall be assumed as that which would result from the passage of an opaque cloud across an otherwise clear sky where the sharp leading or trailing edges of the shadow move across the collector field at a velocity of 13.4 m/s (30 mi/h).
- Sun Angle. The sun azimuth and elevation angles for a given field layout at the time of the day and year for which the solar power to the receiver is at a maximum, assuming the direct normal insolation specified (i.e., the best sun angle).
- Wind Speed. 3.6 m/s (8 mi/h) at a reference height of 10 m (33 ft).
- Temperature. Wet Bulb: 23°C (73.4°F)
  Dry Bulb: 28°C (82.4°F)
- Performance. Performance shall be evaluated on an annual basis using the 1976 year-long weather profile for Barstow ["Barstow Insolation and Meteorological Data Base," Aerospace Report No. ATR-78 (7695-05)-2, 13 March 1978].

5.2 OPERATIONAL LIMITS

The RS shall be able of operating and meeting performance requirements for appropriate combinations of the following environments:*

- Temperature. The RS shall be capable of meeting performance requirements over the ambient air temperature range from 0 to 50°C (32 to 122°F) and shall be capable of operating over the ambient air temperature range from -9 to +50°C (16 to 122°F).

*Providing that justification is given, alternative ranges may be chosen for RS operating limits on the basis of cost effectiveness.

- Wind. The wind speed specifications at a reference height of 10 m (32.8 ft) shall be:

Speed [m/s (mi/h)]	Frequency (%)
0-2 (0 -4.5)	29
2-4 (4.5 -8.9)	21
4-6 (8.9 -13.4)	19
6-8 (13.4-17.9)	14
8-10 (17.9-22.4)	8
10-12 (22.4-26.8)	5
12-14 (26.8-31.3)	3
14- (31.3)	Less than 1

The wind velocity profile shall be assumed to vary exponentially with height to the 0.15 power, where the reference height is taken as 10 m (32.8 ft). The equation shown below shall be used for calculation of wind speed as a function of receiver elevation:

$$V_h = V_{10}(h/h_{10})^C$$

where:

V_h = Mean wind speed at Height h

V_{10} = Wind speed at Reference Height h_{10}

h_{10} = Reference height 10 m (32.8 ft)

C = 0.15.

Performance requirements shall be met for wind speeds up to 12 m/s (26.8 mi/h) at the reference height, over the ambient air temperature range 0 to 50°C (32 to 122°F). The RS shall be capable of operating at wind speeds up to 16 m/s (35.8 mi/h) at the reference height.

Wind analysis shall satisfy the requirements of ANSI A58.1-1972.

- Insolation. The receiver shall be capable of accepting all reflected energy without heliostat defocus for insolation levels equal to or less than 1000 W/m² (317 Btu/h•ft²).

- Sun Angle. The receiver shall be capable of operating with all heliostat images for sun elevations greater than 10 deg above the horizon.

5.3 SURVIVAL

The RS shall be capable of surviving (without damage) appropriate combinations of the following specified environments:

- Temperature--over the ambient air temperature range -30 to +50°C (-22 to 122°F).

- Wind--winds with a maximum reference speed, including gusts, of 40 m/s (90 mi/h).

- Snow--a static snow load of 240 Pa (5 lb/ft²) and a snowfall of 0.3 m (1 ft) within 24 hours.

- Rain--the following rainfall:

  Average annual rate: 750 mm (29.5 in.)
  Maximum 24-hour rate: 75 mm (3 in.)

- Ice--freezing rain and ice deposits in a layer 50 mm (2 in.) thick.

- Hail--hail impact up to the following limits:

  Diameter: 25 mm (1 in.)
  Specific Gravity: 0.9
  Terminal Velocity: 23 m/s (75.5 ft/s)

- Earthquake--an earthquake that would produce on the order of 0.20 to 0.25 g horizontal and vertical ground accelerations and shaking intensity of VII and VIII on the Modified Mercalli Scale. The response spectrum presented in U.S. Nuclear Regulatory Commission (NRC) Guide 1.60 (Revision 1 dated December 1973) and the damping values given in NRC Guide 1.61 shall be used as a guide. In addition, the RS shall satisfy the requirements for Seismic Zone 3 in the Uniform Building Code.

Appendix C

ABSORBER SURFACE ARRANGEMENT

Four basic modifications to the absorber geometry were considered:

- Cooled vs. uncooled cavity floor and ceiling
- External absorber panels above and below the aperture
- Wing wall panel size and orientation
- Cavity size and shape.

Using DELSOL, collector field optimization analyses were performed for both tilted and vertical receiver configurations. The results of these analyses (summarized in Table C.1) showed little difference in cost or performance. Based on these results a single collector field layout (shown in Figure C.1) was developed for detailed flux mapping analyses.

Each of these configuration changes were modeled for a tilted configuration and selected changes were also modeled for vertical configurations. The modeled geometries were then input to the CONCEN computer code along with an aim strategy and flux data were generated. The incident flux data were first evaluated in terms of desirable characteristics (i.e., low peak fluxes, reasonable flux gradients across panels, and reasonable utilization of absorber surface area) and the more promising flux profiles were then modified to account for losses and used to determine panel tube temperatures. These latter data were finally used to modify the absorber configuration to improve its overall performance.

Table C.1 Comparison of Collector Fields--DELSOL II Results (MDC Second Generation Heliostats)

	TILTED APERTURE	VERTICAL APERTURE	
NO. H-STATS	8320	8349	(1)
	8302	8341	(2)
H_{TOWER}(m)	210	210	(1)
	212	212	(2)
ANNUAL ENERGY (GWt HR)	741	741	(1)
	741	741	(2)
CAPITAL COST* ($M)	93	93	(1)
	141	141	(2)
CAP COST ANN EN ($/KWth)	.126	.126	(1)
	.190	.190	(2)

*RECEIVER
TOWER
PUMPS
PIPING
COLL. FLD.

(1) H STATS $140/M^2$
(2) H STATS $240/M^2$

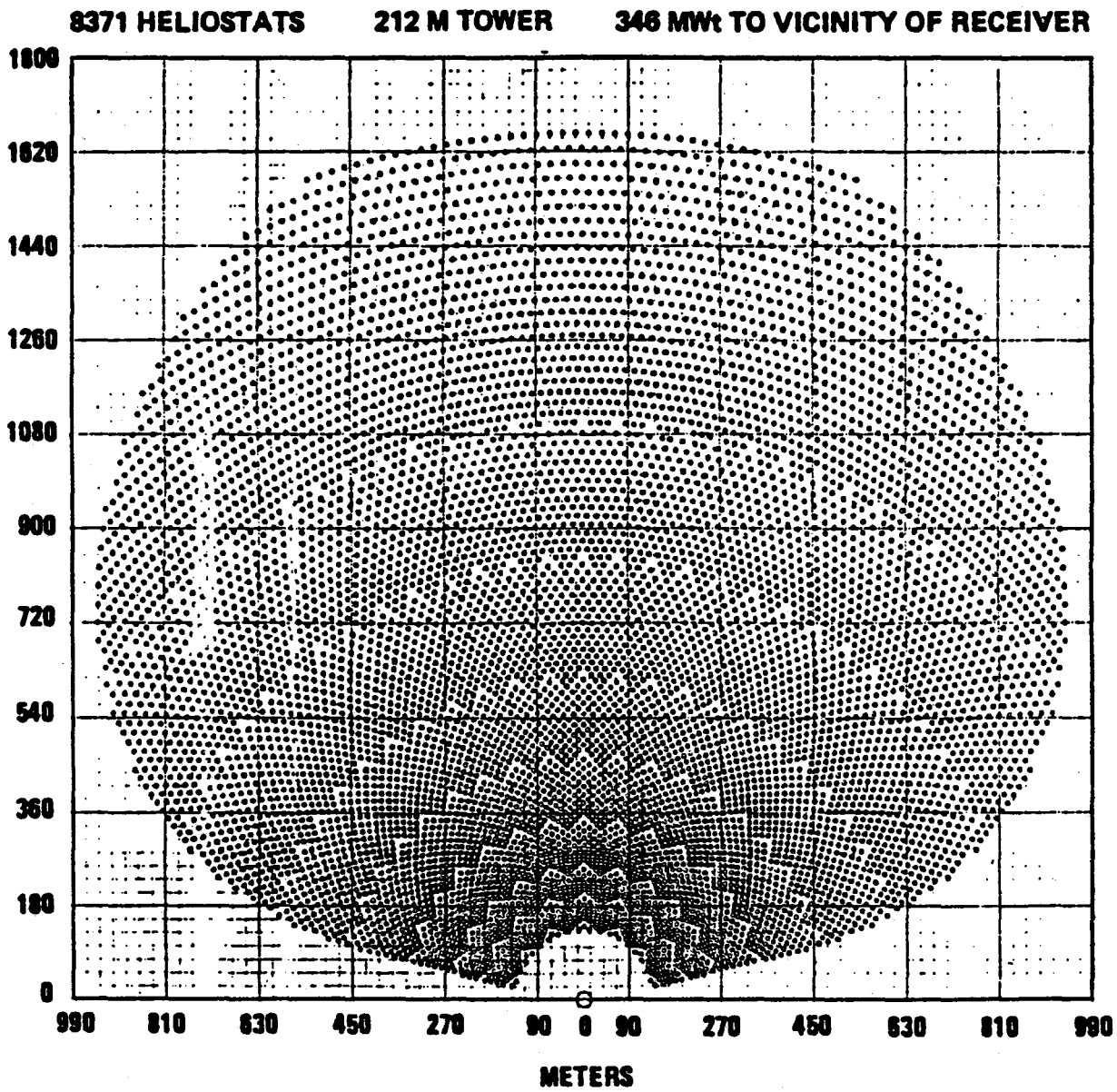


Figure C.1 DELSOL Collector Field (For tilted and vertical receivers)

The basic aim strategy which was developed during the Sierra Pacific Fort Churchill Repowering Program study is summarized in Figure C.2. The far out heliostats (Zone 1) with the largest images are aimed tangent to the top of the aperture so that they will miss the floor. The center of the beam for these heliostats projects somewhat below center on the rear central panels. Intermediate heliostats in Zones 2 and 3 are alternated high/low to spread out the flux profiles and Zone 1 heliostats are split-aimed so that they will hit the side panels and the wing panels rather than the ceiling. Figures C.3 and C.4 illustrate the projection of the receiver as seen from a heliostat at different locations in the field and the approximate size of the beam at the receiver for the different heliostats. During the evaluation of the selected configuration, slight modifications of the aim strategy were developed, primarily by biasing aim points away from edges.

During the initial evaluations, consideration was given to active cooling on the floor and ceiling. This approach was rejected for the following reasons:

- Because the current floor and ceiling have relatively poor visibility from much of the field, both substantial modifications of aim strategy and overall cavity geometry would be required. Figures C.5 and C.6 illustrate the low flux levels resulting for the baseline configuration and aim strategy.
- The complexity of building and supporting unevenly shaped coded panels, especially for SRE receiver sizes.
- Removal of panels.

A similar early evaluation was addressed to panels above and below the aperture. Figures C.7 and C.8 illustrate typical frontal plane flux maps for both a tilted and a vertical aperture plane. Noteworthy in these data is the

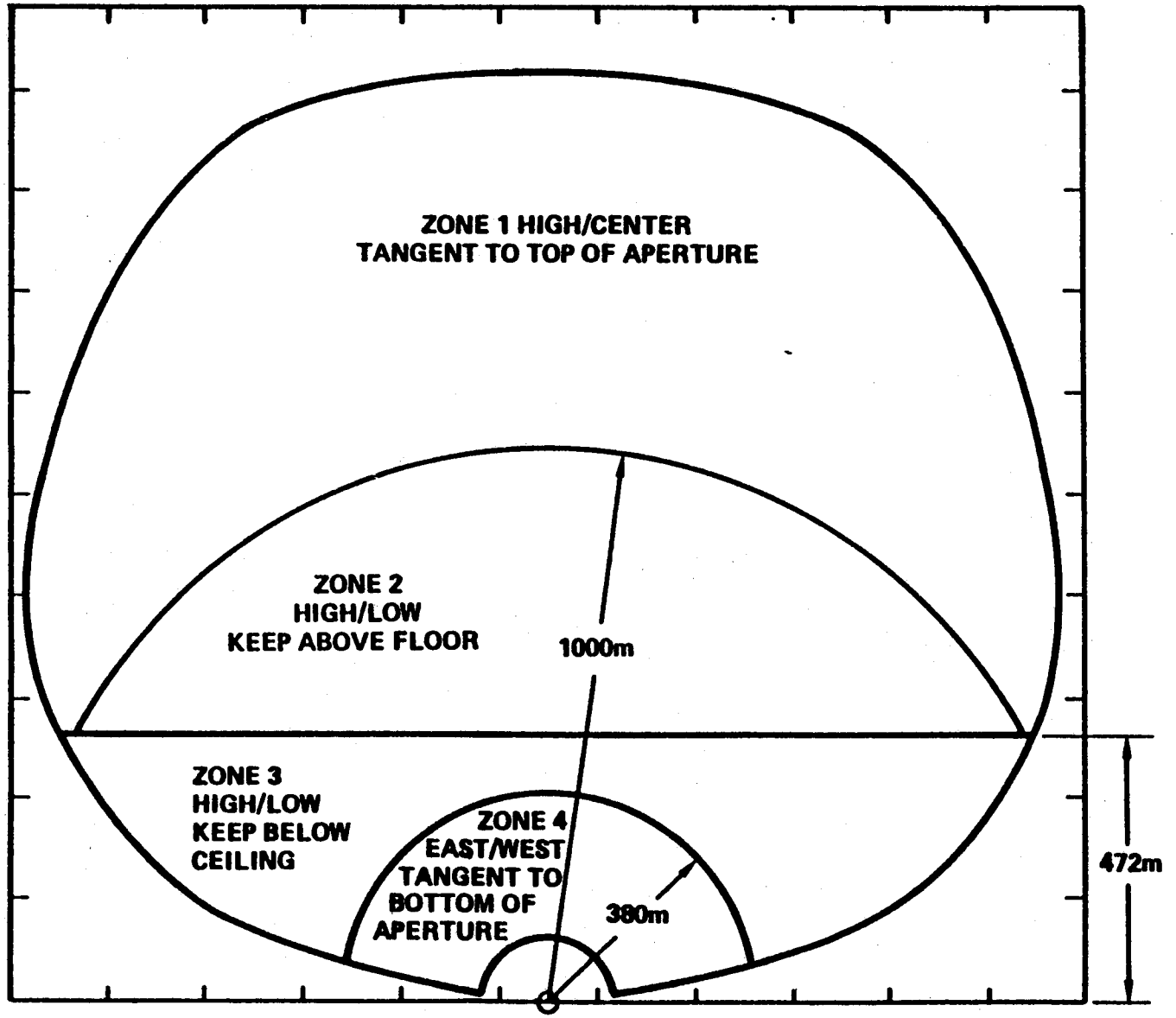


Figure C.2 Four-Zone Aim Strategy

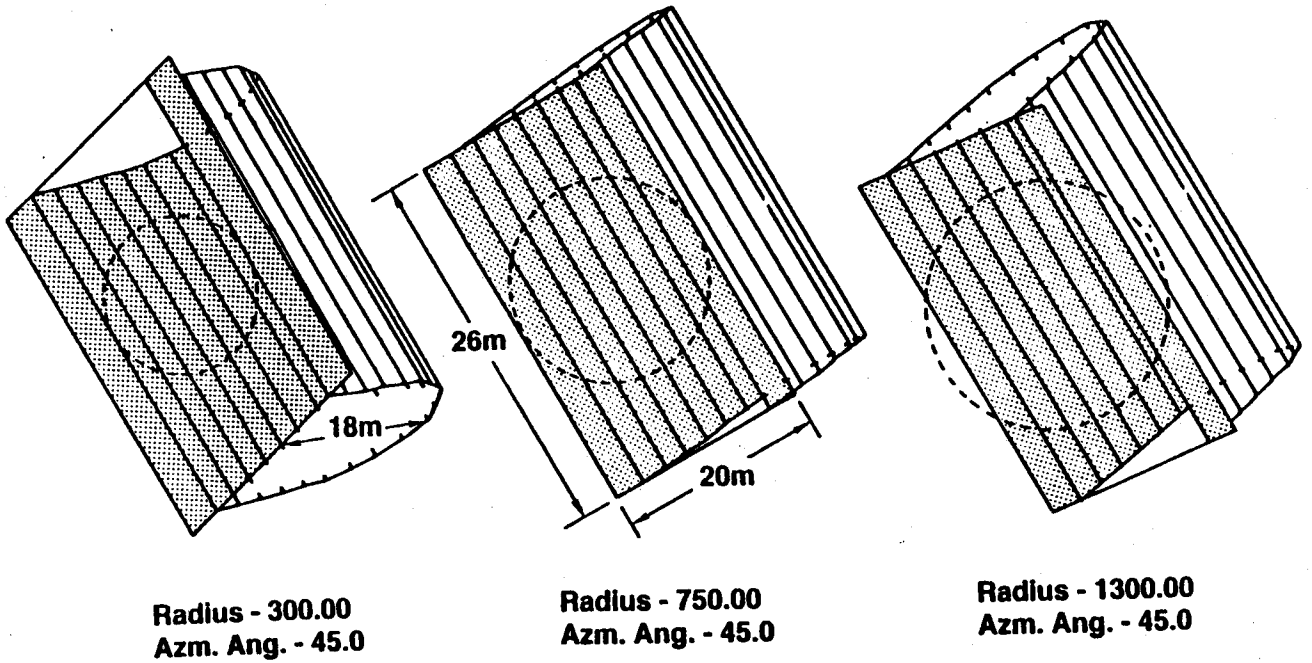
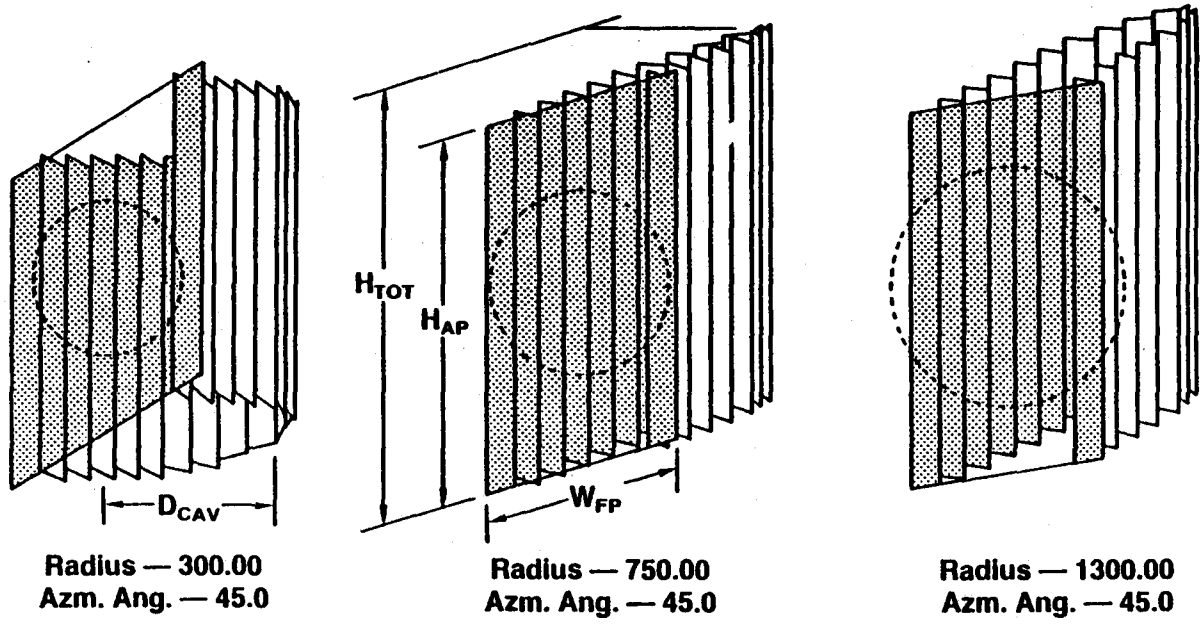


Figure C.3 Absorber Configurations (tilted 25 deg)



Configuration	H_{AP}	H_{TOT}	$WD2F_P$	D_{CAV}
V-11	26.0m	32.1m	20.0m	18.1m
V-11 Exp	27.3m	33.4m	20.0m	18.9m
V-12	26.0m	32.1m	20.0m	18.8m

Figure C.4 Absorber Configurations--Vertical (Constant panel widths)

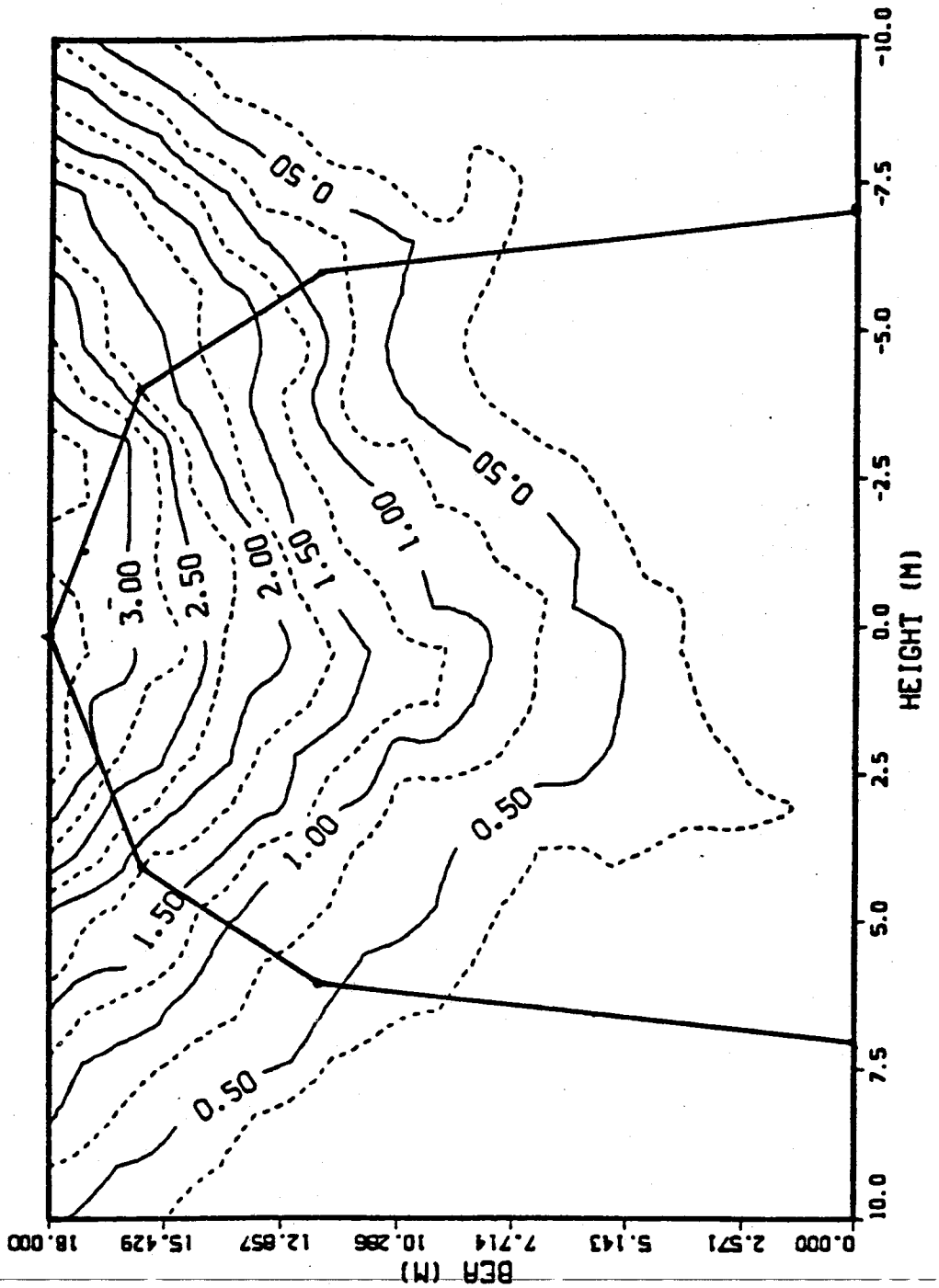


Figure C.5 Incident Heat Flux--Cavity Floor (kW/m^2)

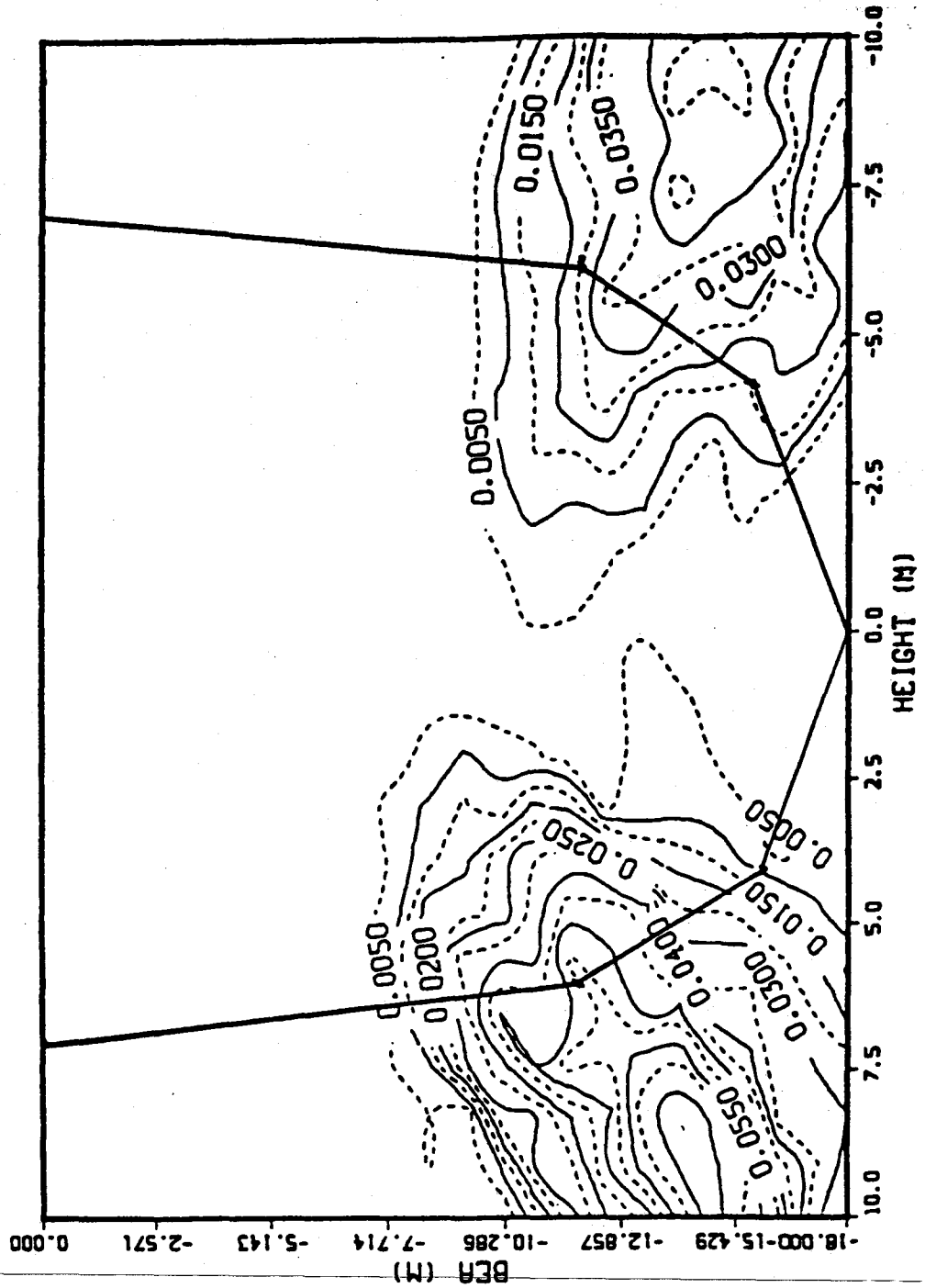


Figure C.6 Incident Heat Flux--Cavity Ceiling (MW/m^2)

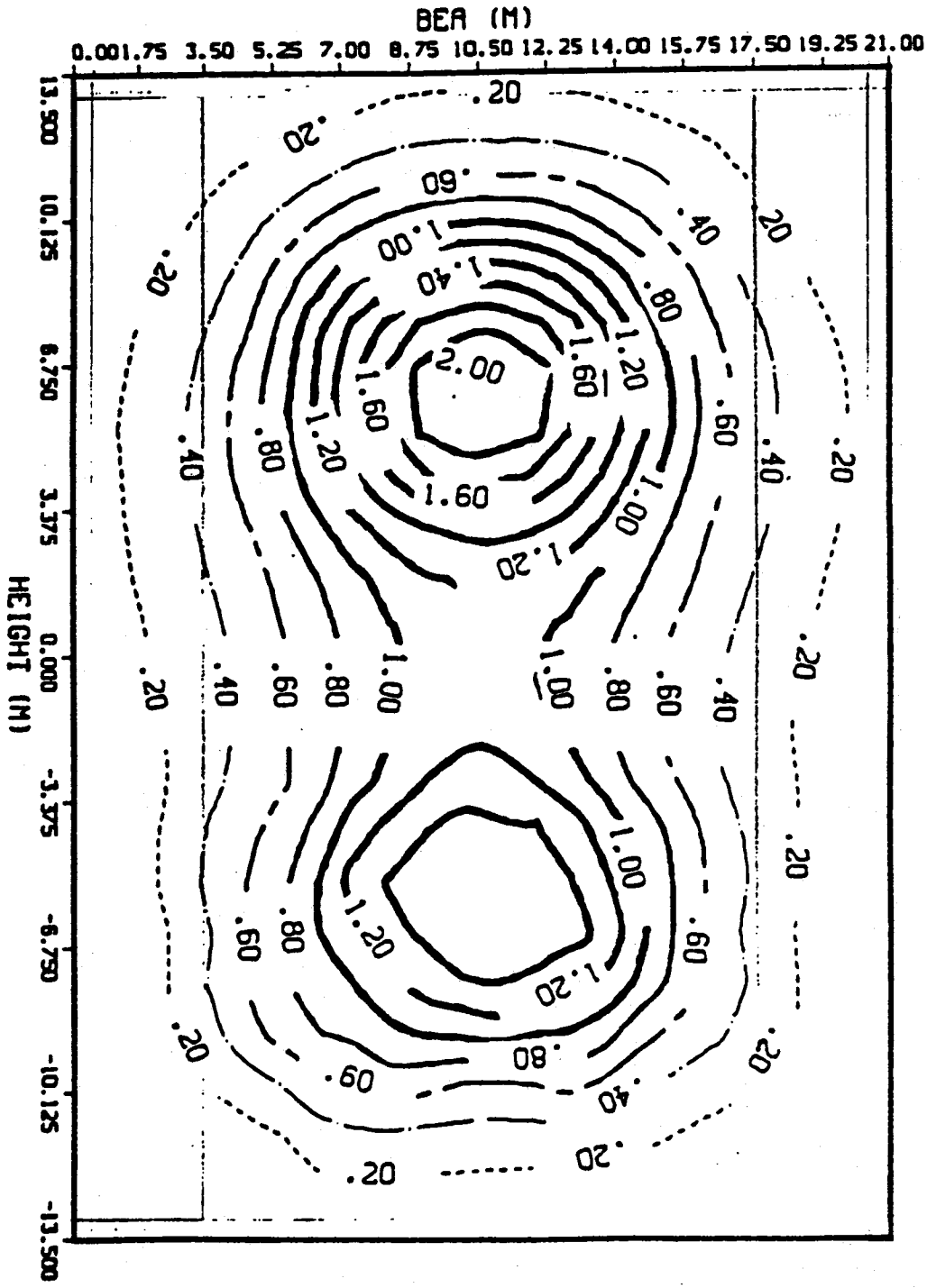


Figure C.7 Incident Heat Flux--Tilted Aperture Plane (MW/m^2)

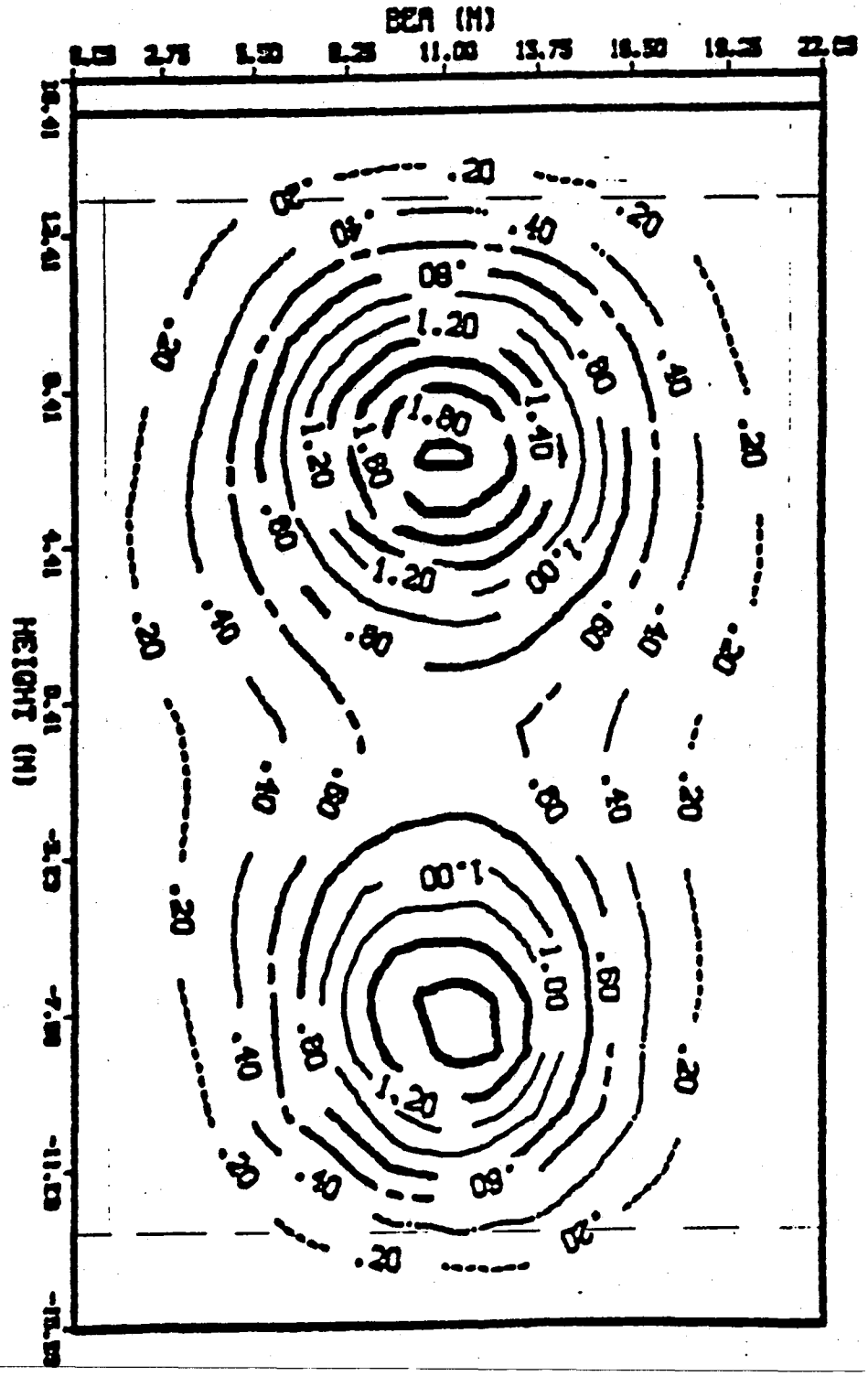


Figure C.8 Incident Heat Flux--Vertical Aperture Plane (MW/m^2)

short vertical dimension over which the flux rises to 0.6 MWt/m^2 (0.190 x 10^6 $Btu/h\text{-}ft^2$), approximately 2 to 2.5 m (6.6 to 8.2 ft), from the top and bottom edges. Because of these rapid rises, vertical panels would have short flow-path lengths, many tubes and most likely several passes. Conversely, horizontal arrangements, while avoiding the short path lengths and multiple passes, would have severe lateral gradients and present substantial complexities for header design and manifolding. Therefore it was decided to eliminate the addition of panels above and below the aperture from further consideration.

The last two absorber configuration issues, wing and wall panel size and orientation and cavity size and shape, were considered together. The initial approach was to develop sensitivity data to changes in absorber surface geometry for tilted configurations and check selected configurations for similar shaped vertical configurations. These sensitivities were similar and the final efforts centered on the vertical configurations (V-11 and V-12).

Figure C.9 presents a flux map for the initial baseline configuration T-1, with the cavity shape presented on the left-hand side of Figure C.10. This configuration was an approximation, using 4 plane surfaces, to the final Sierra Pacific Design.

The flux map of Figure C.9 shows the left-hand half of the receiver laid out flat, starting at the left side with the 3-m- (9.84 ft)-wide wing panel that is in the aperture plane. Next are 5 side panels, each 2.408-m (7.9 ft)-wide, that represent the long straight wall of Figure C.10. Finally, there are four

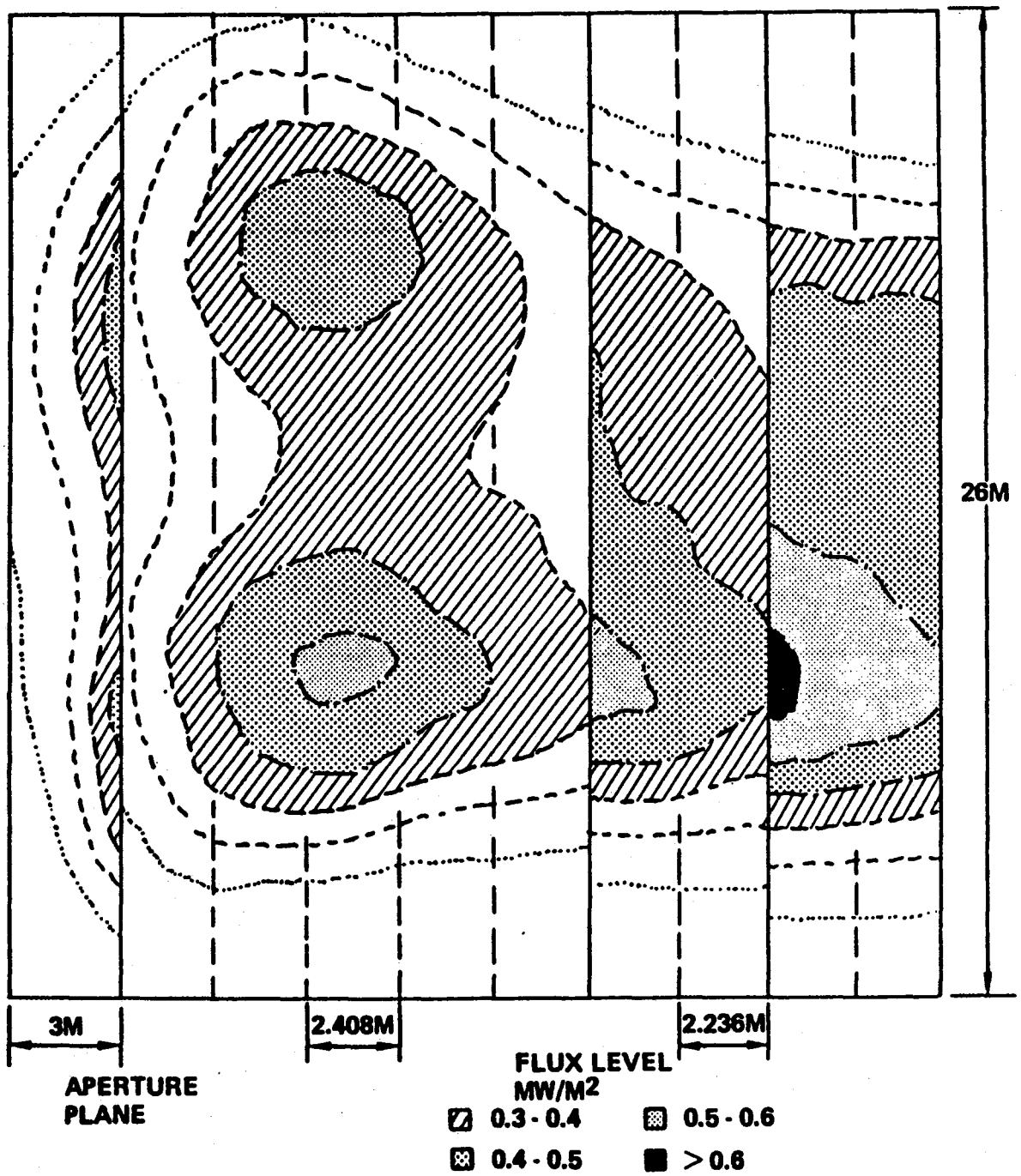


Figure C.9 Flux Profiles--Configuration T-1
(Variable panel widths, tilted 25 deg)

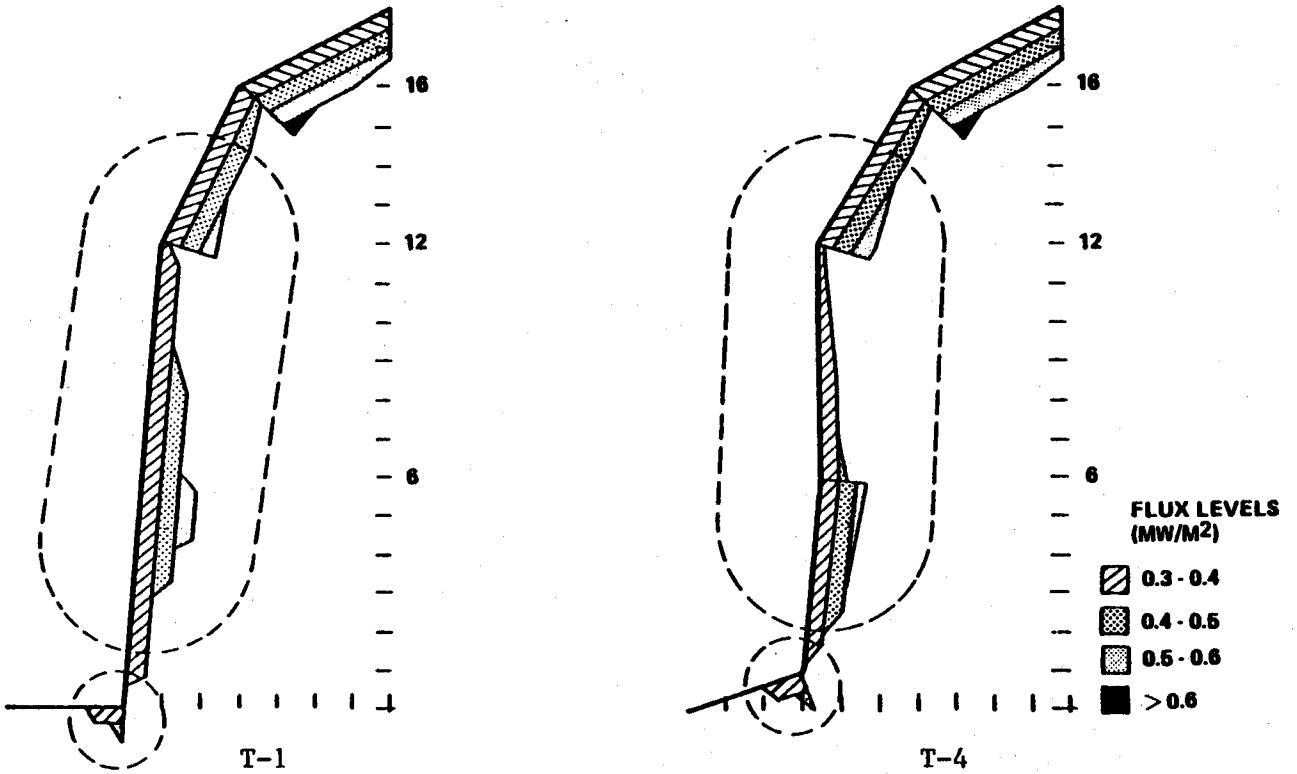


Figure C.10 Sensitivity of Flux Distribution to Wing and Sidewall Shape

panels at 2.236 m, two each for the two back sections of Figure C.10. The heated section of all 10 panels is 26 m (85.3 ft) as shown. All subsequent flux maps and cavity shapes follow the pattern just described, although the vertical aperture cases will show the panels staggered upward as you move from left to right. Also, many later configurations employ the same width [2.415 m (7.92 ft)] for all 10 panels. The cavity shapes (Figure C.10) are shaded to indicate flux levels and their extent across the panel width.

Noteworthy in the flux profile of Figure C.9 are the flux gradients across the wing panel, the relatively low flux (i.e., poor utilization) of the first sidewall panel, and the high fluxes in the back of the cavity.

From this starting point (T-1) a systematic variation of surface orientation was conducted. Figures C.10 through C.12 present the results of these variations for titled configurations. The configurations are identified below each sketch (e.g., T-1 and T-4 on Figure C.10). The regions of interest are enclosed in dotted lines on each figure. The tilting of the wing panel out of the aperture plane, configuration T-4, did little to reduce the magnitude of the wing panel flux level and lateral flux gradient. Configurations T-5 and T-6 show effects of various sidewall angles compared to T-1 (Figure C.11). The effect of rear sidewall angle can be seen in Figure C.12.

Figure C.13 presents a comparison of T-9 with a vertical configuration, V-9. Both configurations employ a standard 2.411-m- (7.92 ft)-wide panel whereas earlier configurations (e.g., T-1, Figure C.9) shows slightly higher flux on the wing panel and back panel, but better distribution just behind the aperture plane.

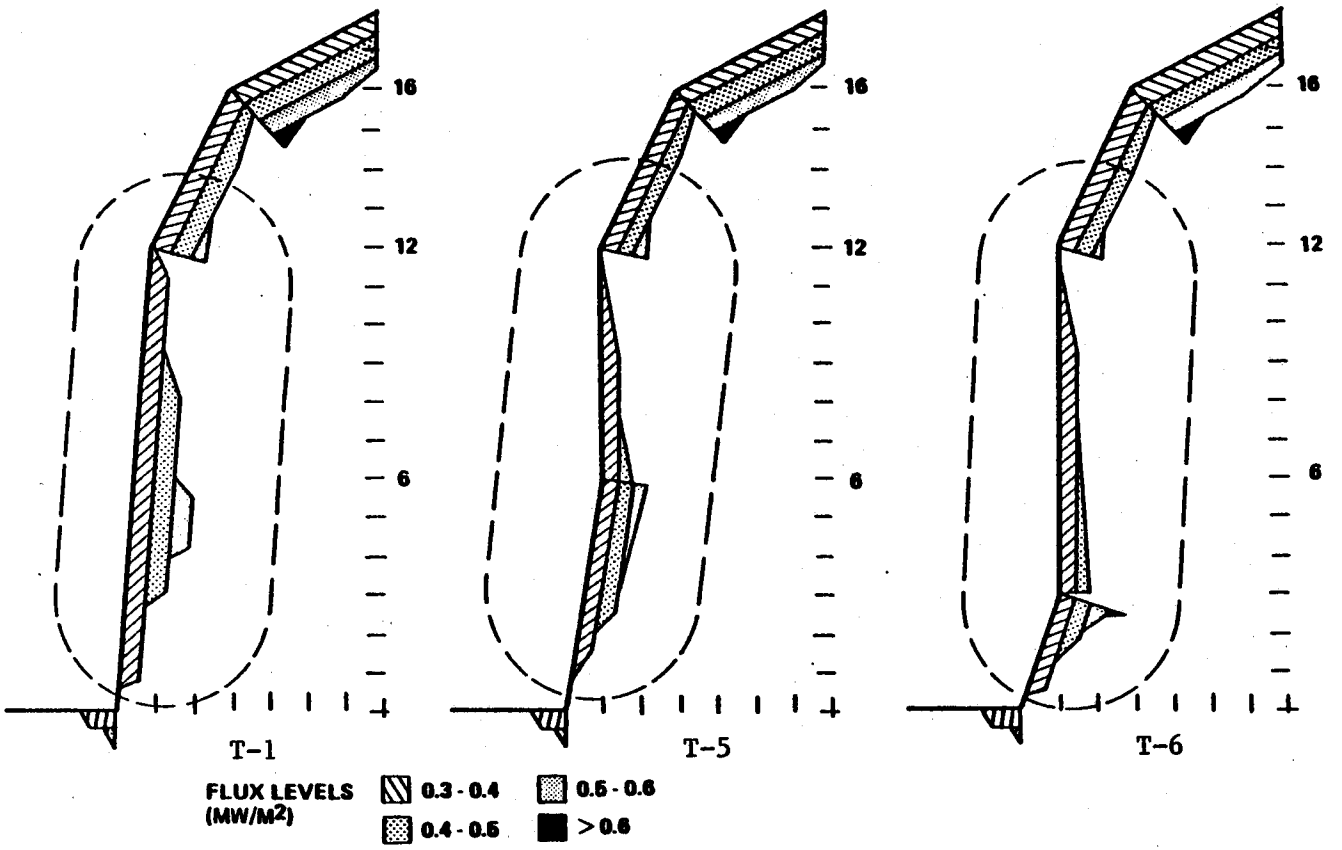


Figure C.11 Sensitivity of Flux Distribution to Initial Sidewall Angle

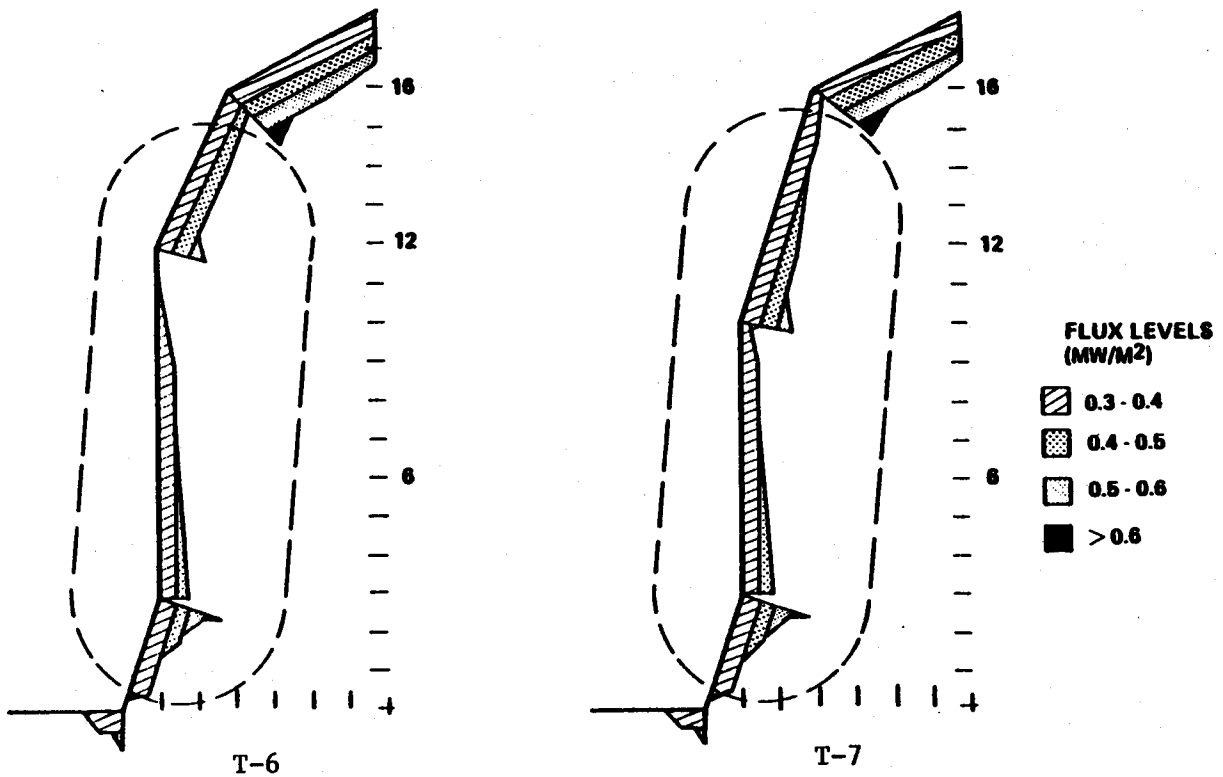


Figure C.12 Sensitivity of Flux Distribution to Rear Sidewall Angle

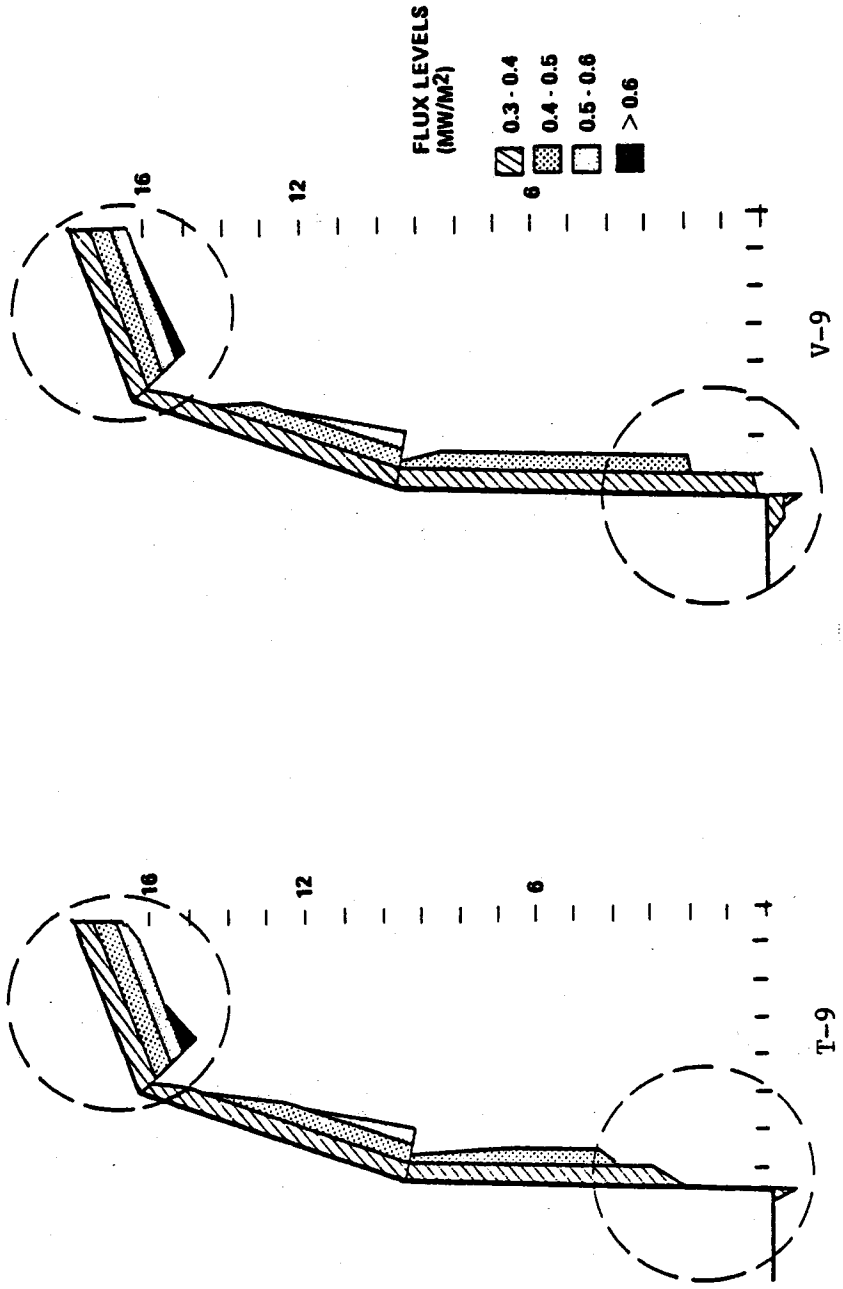


Figure C.13 Comparison of Flux Profiles (Tilted vs. vertical)

Figure C.14 presents a flux map for V-11 [expanded 5 percent in length from 26 m to 27.3 m (85.3 to 89.6 ft)]; this is one of the latest configurations, which was studied parametrically for a variety of sizes and for insolations 1100 W/m² (348.6 Btu/h-ft²) as well as the more typical 950 W/m² (301 Btu/h-ft²). The results of this parametric work are displayed in Figures C.15 and C.16.

The 2.415-m (7.923 ft.) panel of V-11 employs 87 tubes [2.54 cm (1.0-in.) OD with a 2.38 mm, (3/32 in.) weld space] as shown in the two left-hand sketches of Figure C.15. The right-hand sketch of the figure has 91 tubes; this large cavity showed a disadvantage in the back panel flux levels. The 27.3-m (89.6 ft) panel length version (5 percent expanded length) shows an advantage over the 26.0-m (85.3 ft) length in terms of flux level. The less expensive 26.0-m (85.3 ft) length is believed to be acceptable, however, and was chosen for the next configuration (V-12) which will be discussed subsequently.

The effect of 1100 W/m² (348.6 Btu/h-ft²) (specified in the RFP) is severe as seen in Figure C.16; however, a more realistic receiver design point is 1000 W/m² (317 Btu/h-ft²), based on an analysis of Barstow data relating to frequency of occurrence.

The thermal/hydraulic analysis, coupled with the tube stress analysis, indicated that the most severe problems occur on the last flow pass (Panels 7 and 8) as shown circled toward the back of the receiver in Figure C.17, configuration V-11. In addition, Panel 2 near the aperture is underutilized. Configuration V-12 of the figure further adjusts the receiver flux normal to the panel

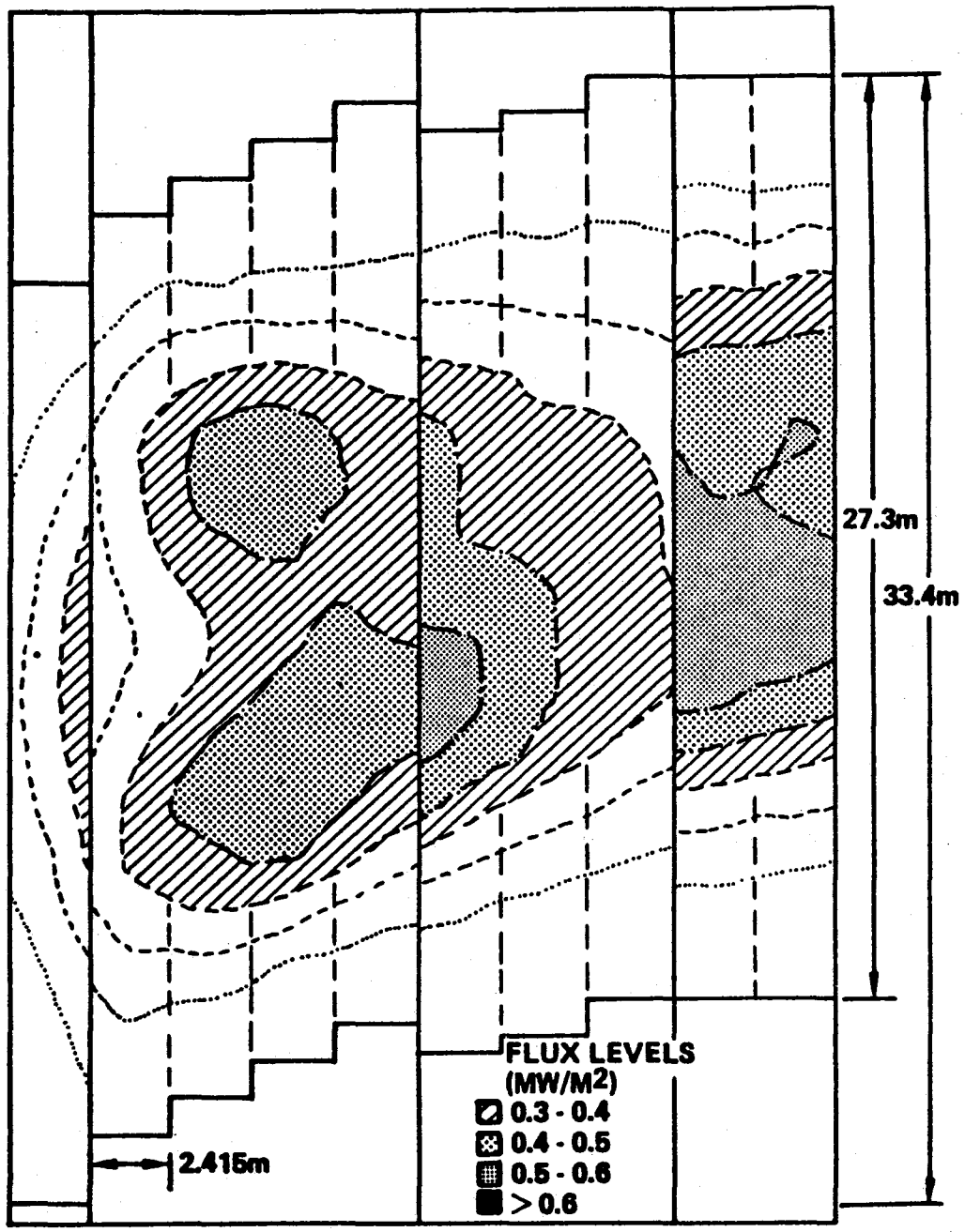


Figure C.14 Flux Profiles--Configuration V-11
(Constant panel widths, vertical)

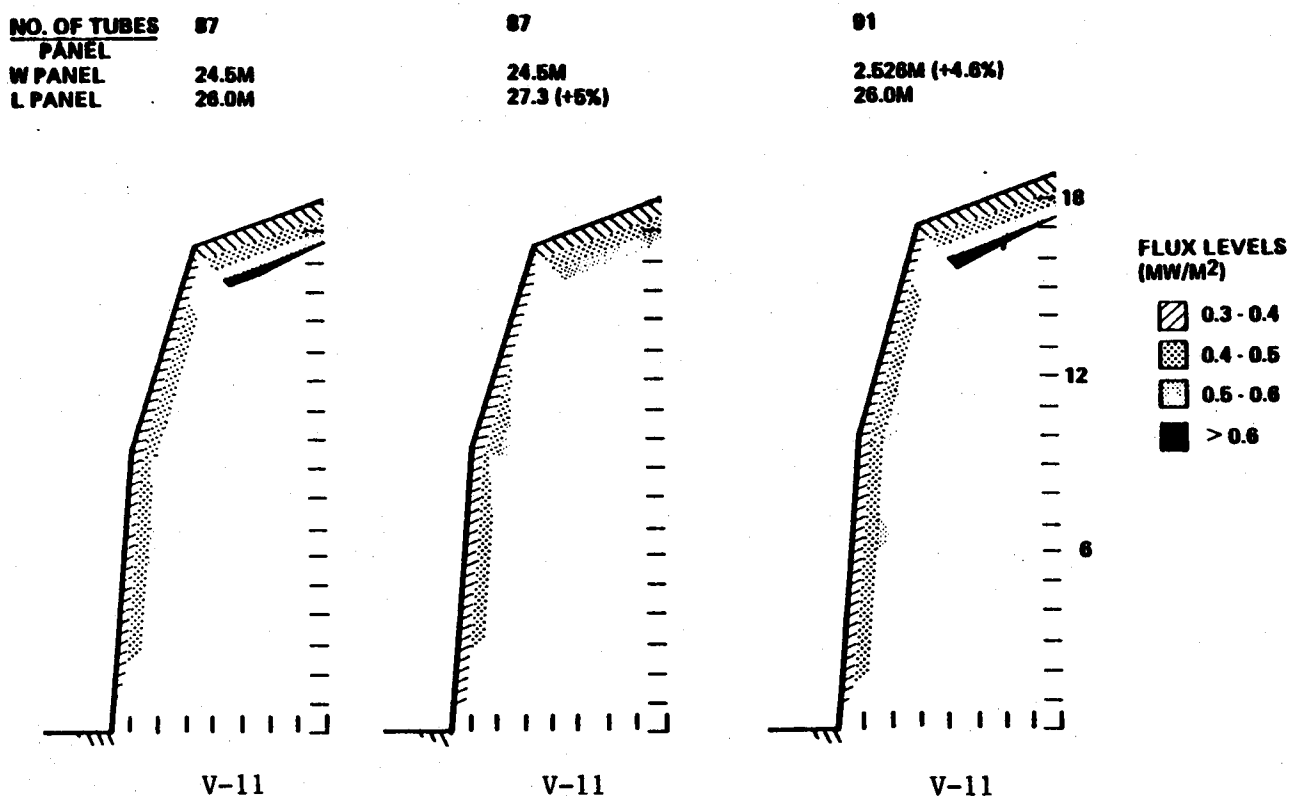


Figure C.15 Sensitivity of Flux Distribution to Configuration Size (950 W/m^2)

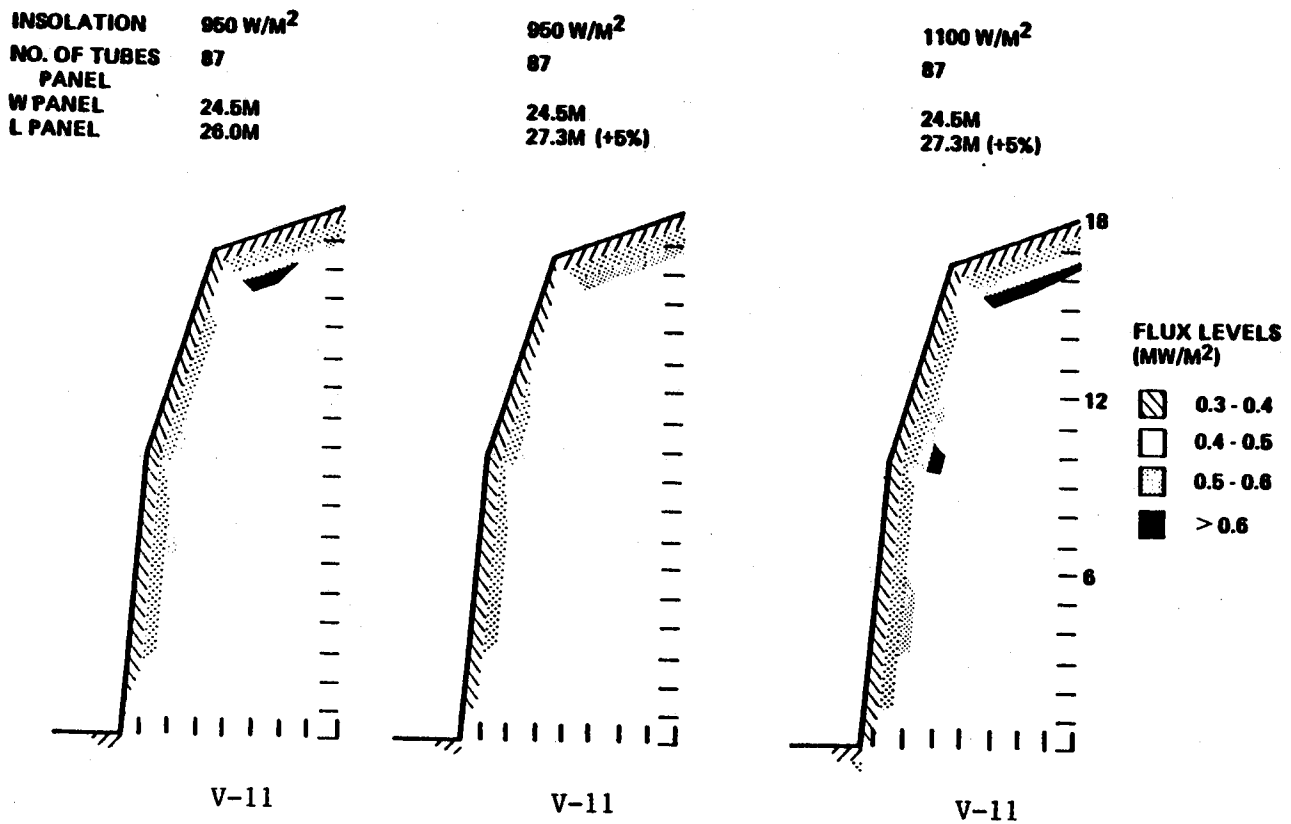


Figure C.16 Effect of 1100 W/m^2 Insolation on Flux Distribution

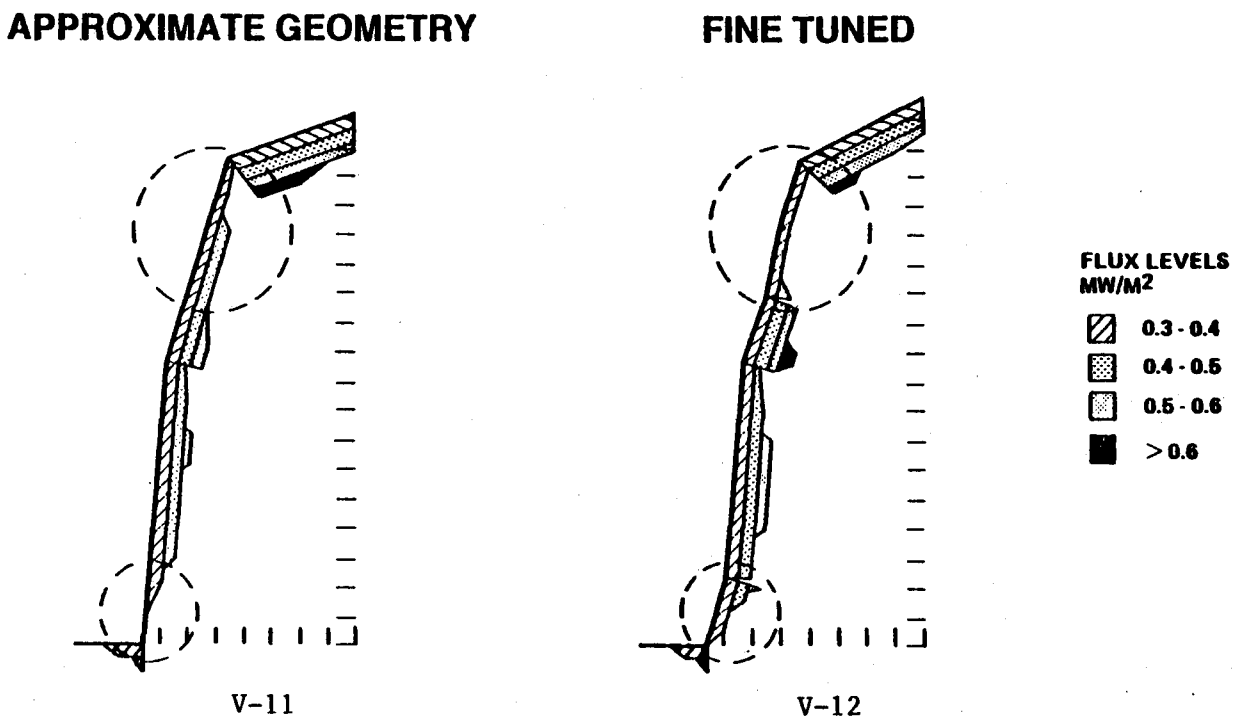


Figure C.17 Approach for Fine Tuning Final Absorber Geometry and Flux Distributions

surface by the cavity shape modifications shown. The resulting V-12 configuration is presented in Figure C.18 and the flux map (receiver left half rather than the right half shown in Figure C.18) is shown in Figure C.19.

Detailed analysis of the tube flux situation was performed. It was found the simplified analysis provided by CONCEN, wherein the flux is resolved into its component normal to the plane of the local receiver panel, can lead to significant errors on some critical panels. These critical panels tend to be toward the back of the cavity for configurations like V-11 and V-12, as noted in Figure C.20. A special CONCEN run was made for a typical tube in this location; the results are presented in Figures C.21 and C.22.

Figure C.22 presents a contour map of the tube. The abscissa represents the tube length, and the ordinate (BEA) represents the tube O.D. projected down on the plane of the dia [(25.4 mm (1 in.)]. Figure C.21 shows the flux density as a function of location on the tube O.D. as defined by the angle ϕ. This curve is at the location along the tube that has the highest flux values. The peak flux value is approximately 0.63 MW/m^2 (0.215×10^6 Btu/ft^2) at an angle of 45°. This compares with a value of approximately 0.38 MW/m^2 (0.130×10^6 Btu/ft^2) for a flat plate in the plane of the panel. This leads to an enhancement factor of about 1.65, which causes excessive tube O.D. and salt film temperatures as discussed next.

We did a detailed thermal/hydraulic/stress analysis evaluation of the vertical configuration (V12). Three main criteria were used in the evaluation:

- Maximum metal temperatures should not exceed 649°C (1200°F).

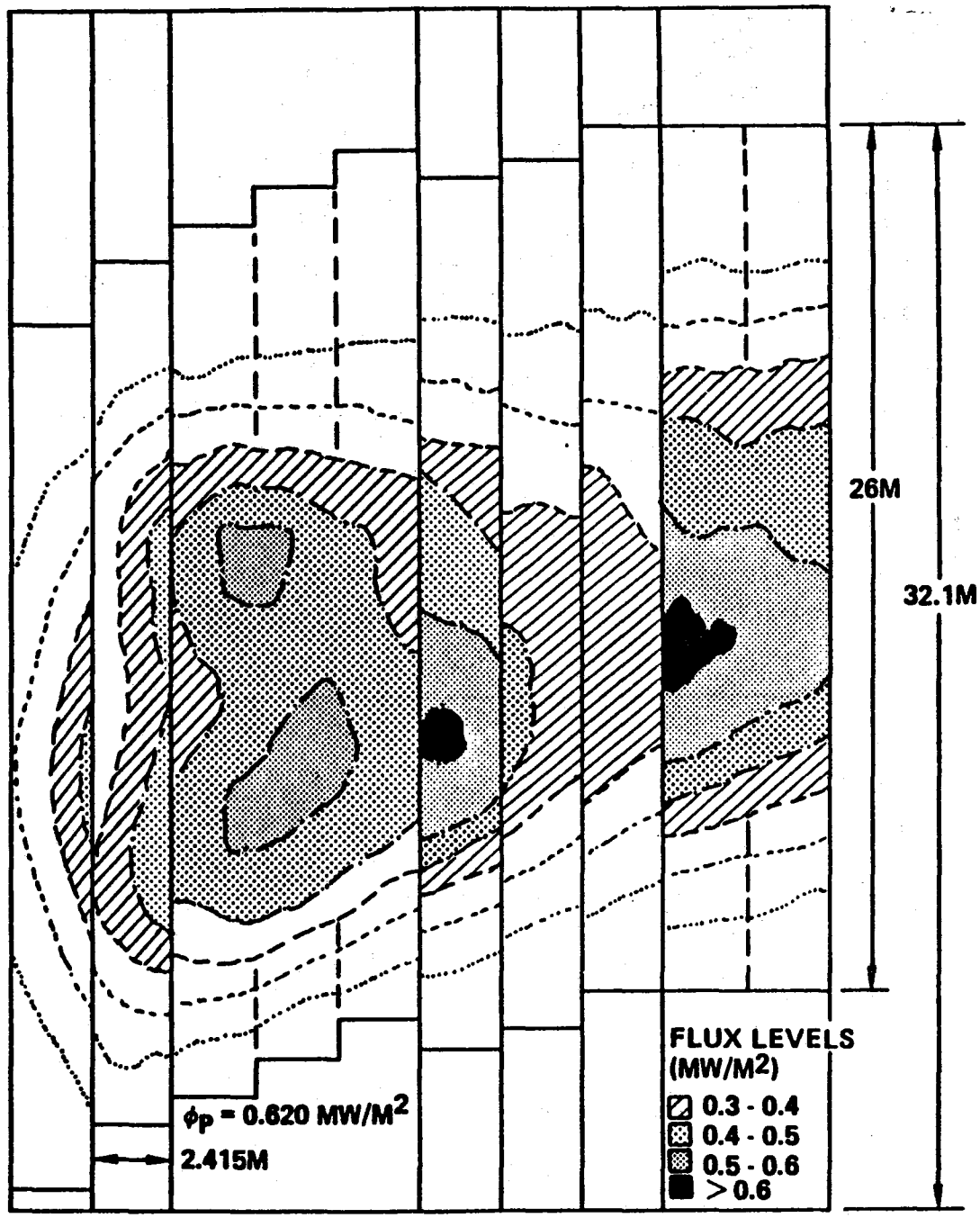


Figure C.18 Flux Profiles--Configuration V-12
(Constant panel widths, vertical)

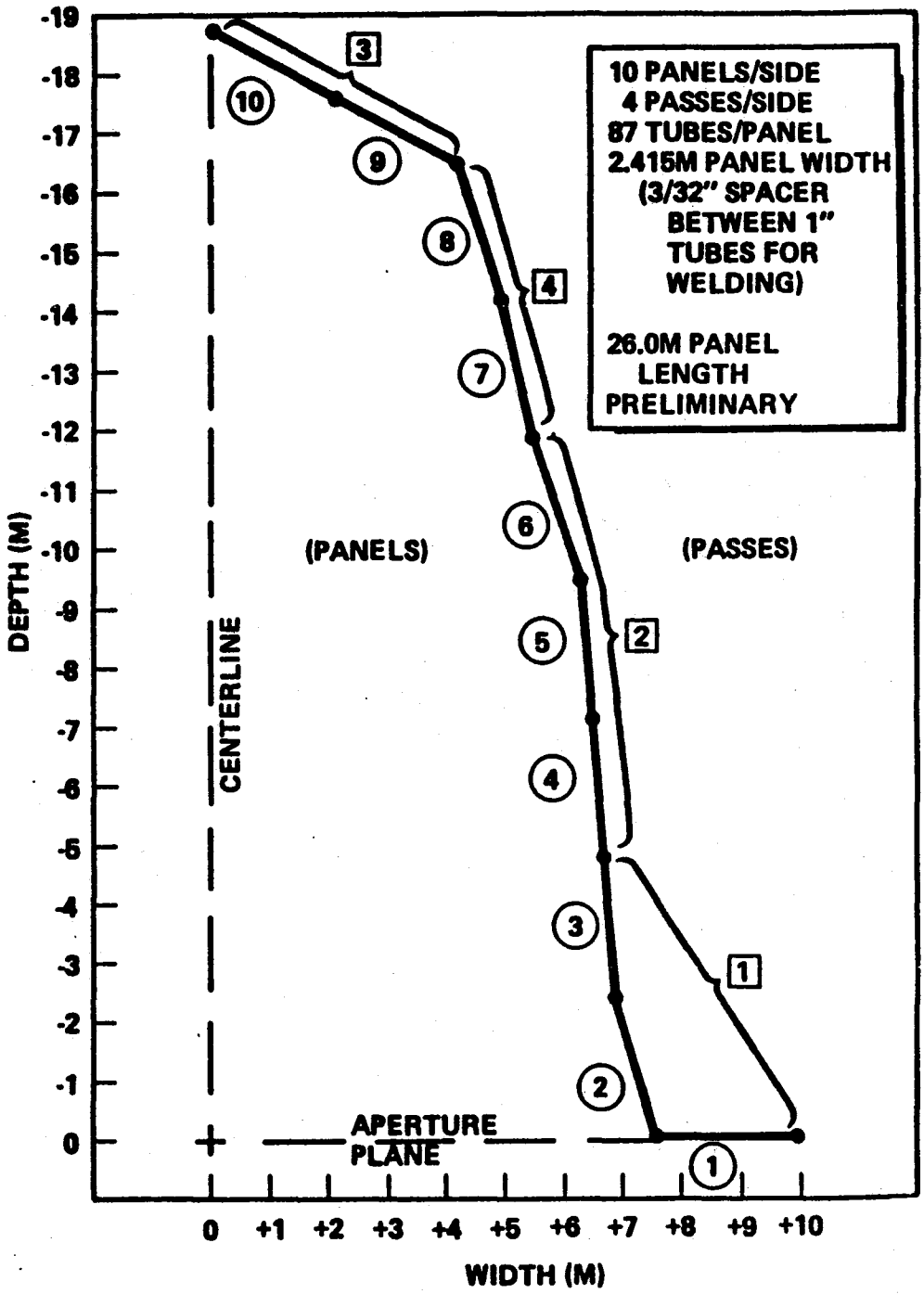


Figure C.19 Cross Section of Configuration V-12

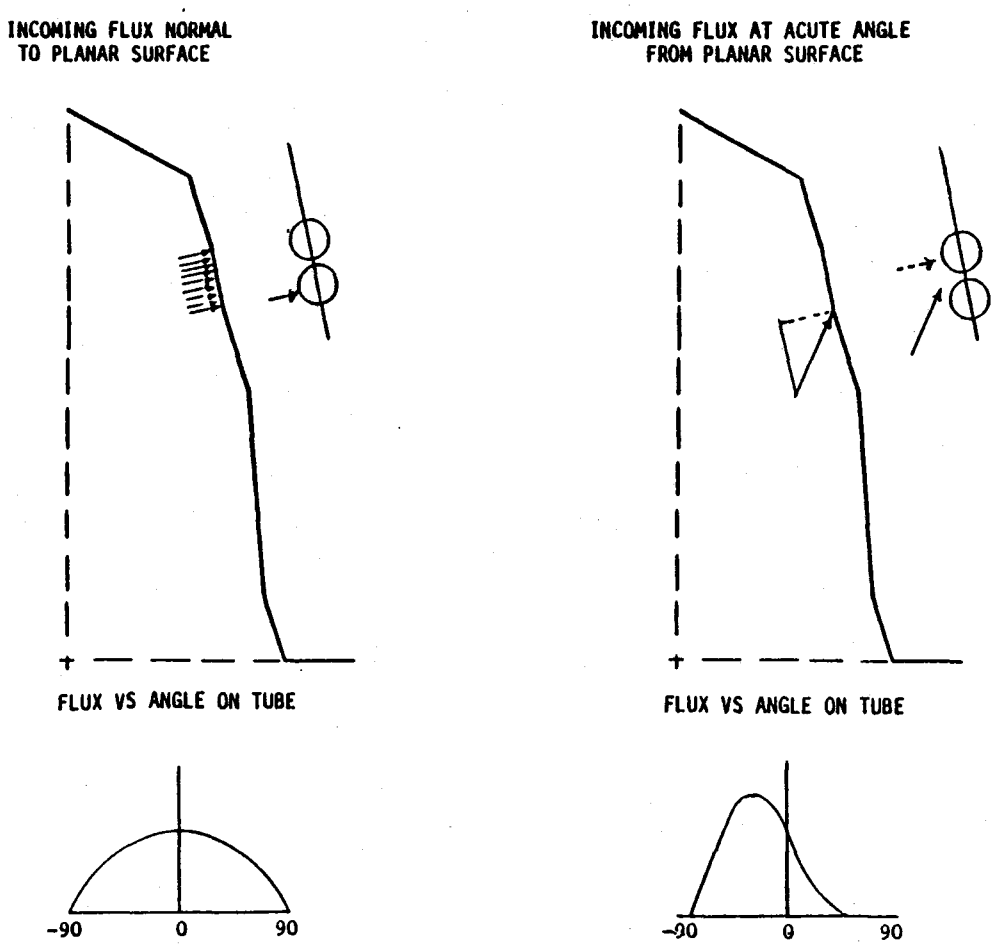


Figure C.20 Local Heat Flux Analysis

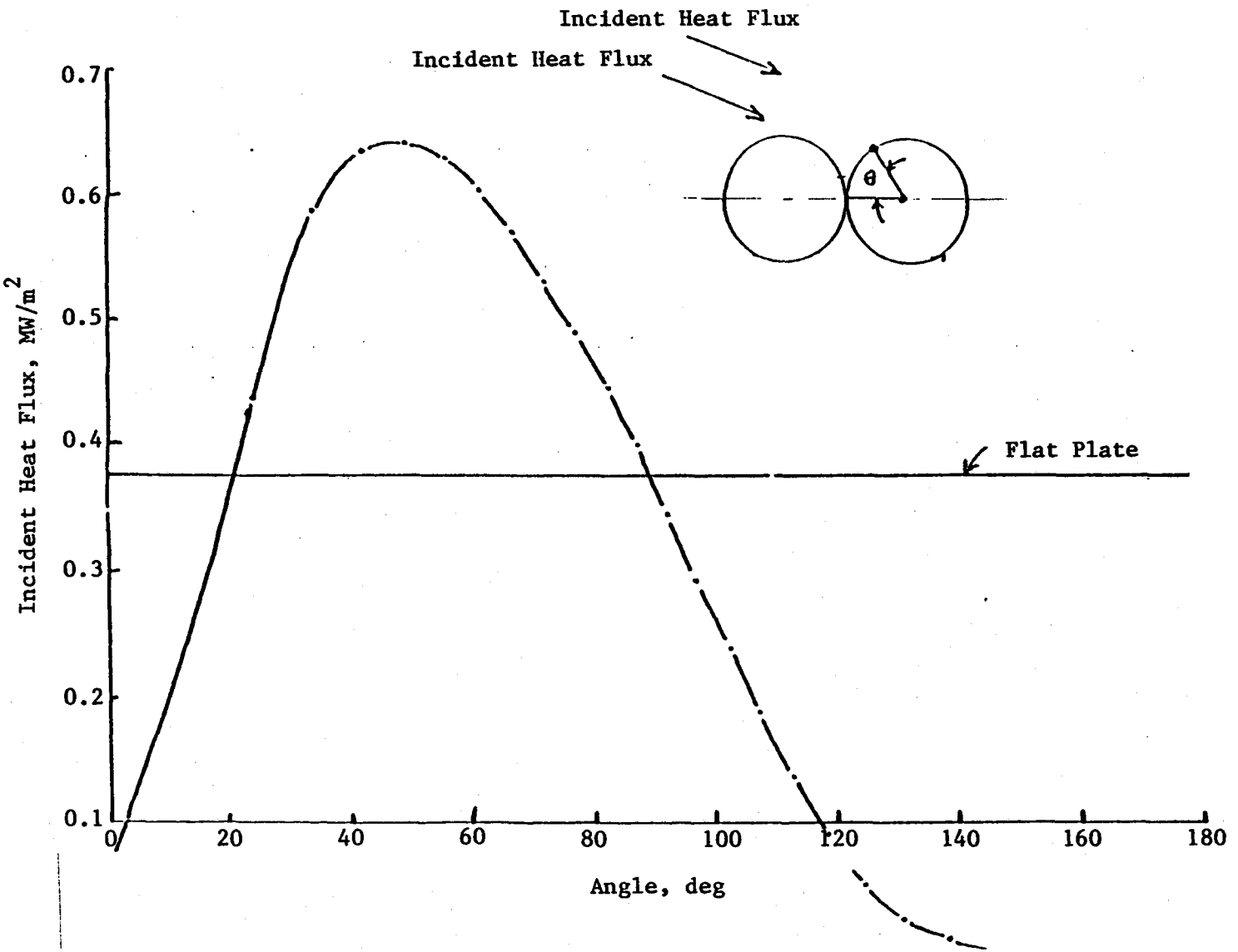


Figure C.21 Tube Flux Enhancement

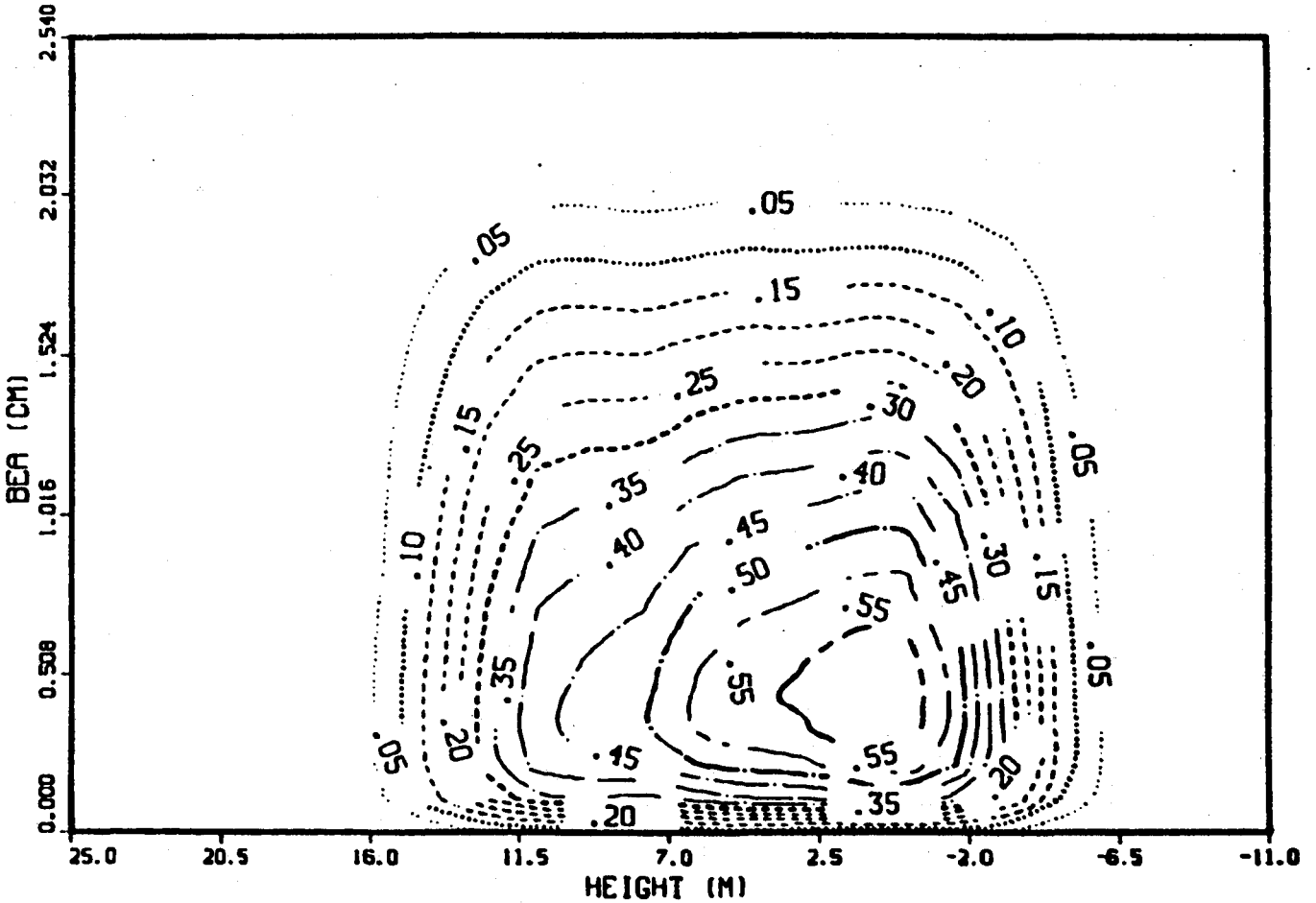


Figure C.22 Incident Heat Flux Distribution on Absorber Panel Tube

- Maximum salt film temperature should not exceed 593°C (1100°F). By definition, the salt film temperature is equal to the temperature of the inside surface of the tube.
- Allowable front-to-back temperature gradient should not exceed the values given by stress analysis. Its value is a function of the metal temperature and heat fluxes.

Using the fluxes provided by MDC, we calculated film and metal temperatures. We found that the front-to-back temperature gradient was excessive at some locations in Panels 1 through 6 and that the film temperature design limit was exceeded in Panels 7 and 8.

Using the enhancement factors discussed before, we recalculated metal and film temperatures for configuration V12. As a result of the higher flux values, all three design limits were exceeded. Figure C.23 shows the panel areas where the design limits were exceeded.

- The front-to-back temperature gradient increased in one particular location to 237.9°C (460.2°F), exceeding allowable values in Panels 2 through 6.
- The maximum film temperature increased from 606.7 to 638.7°C (1124 to 1181.7°F).
- The maximum metal temperature increased from 642.5 to 695.7°C (1188.5 to 1284.2°F).
- Film and metal temperature design limits were exceeded in Panels 7 and 8.

We then modifed the flow path so that Panels 7 and 8 became Pass 3 and Panels 9 and 10 became Pass 4. Passes 1 and 2 were unchanged. By rearranging the flow path, the maximum metal and film temperatures were reduced by about 25 and 17°C (45 and 30°F) to 670.7 and 621.8°C (1239.2 and 1151.2°F) respectively. These temperatures are still excessive.

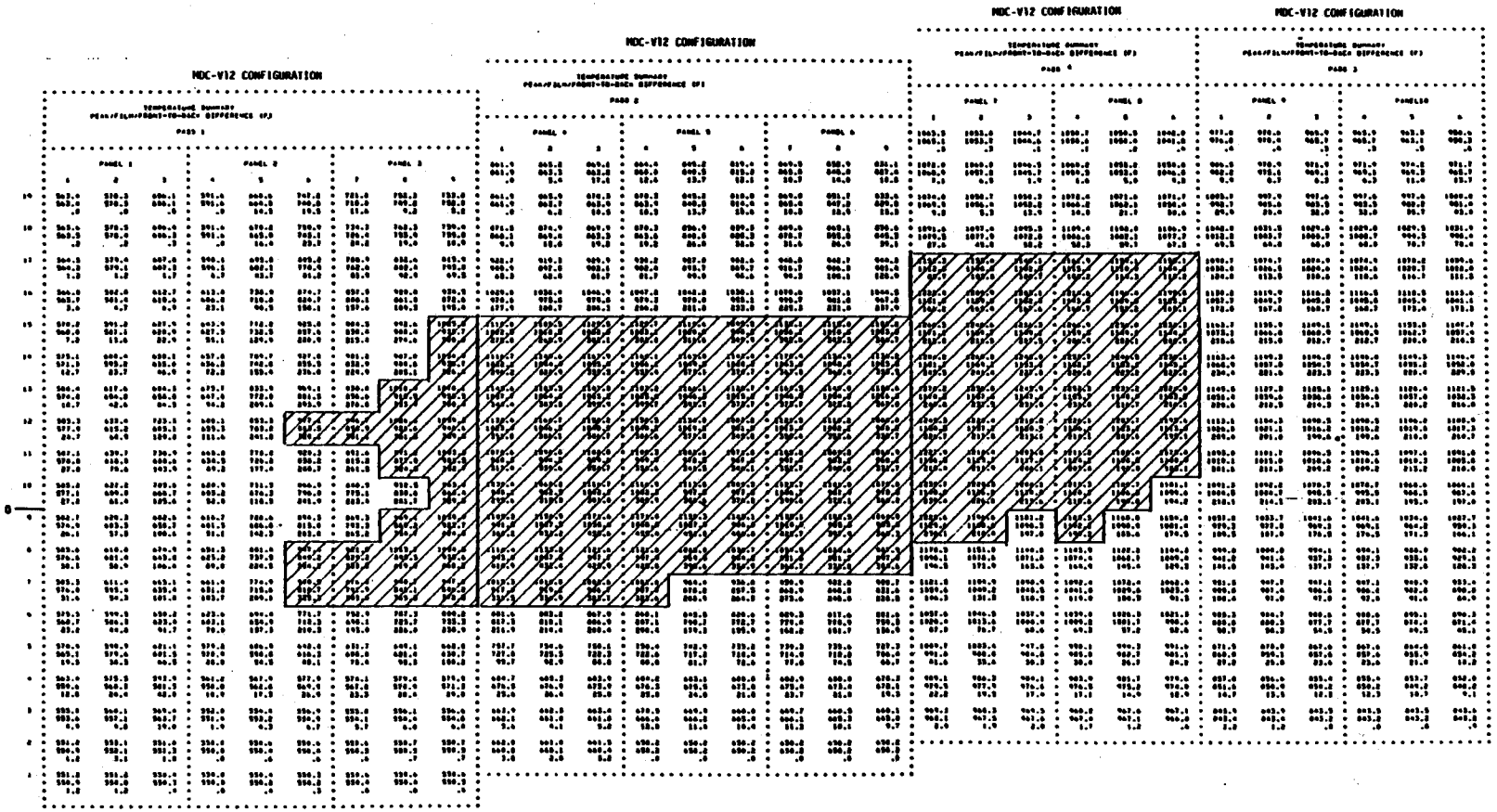


Figure C.23 Configuration V-12 (Crosshatching indicates panel area where design limits were exceeded)

The solution to the above problem basically requires the reduction of peak flux levels by spreading the flux more uniformly via collector field aimpoint strategies and/or increasing receiver surface area, which also permits reduction of peak fluxes. Section 4.3.11 describes an approach taken to alleviate the problem at the expense of receiver size and pressure drop.

Appendix D

ALLOWABLE FLUX LEVELS

To determine the maximum allowable flux levels, we did parametric thermal stress analyses. In these analyses, we used an in-house computer program, NONAX. This program is capable of temperature distribution analyses as well as elastic and inelastic thermal stress analyses. A single-tube model, used in this analysis, is shown in Figure D.1. This model was not exactly representative of the panel; it was, however, adequate to compare different tube sizes and materials. More accurate models, subsequently developed during Task 5, are described in Section 5. Generalized plane-strain conditions were assumed in this analysis.

Based on the thermal stress analysis, allowable flux levels were developed. These are shown as a function of the bulk temperature in Figure D.2. The criteria used in developing these curves is given by:

$(P + Q)_R \leq S_{yc} + S_{yh}$ (for temperatures below creep range)

$(P + Q)_R \leq S_{yc} + S_{rh}$ (for elevated temperatures)

where

$(P + Q)_R$ = Range of primary plus secondary stress

S_{yc} = Yield stress at the overnight shutdown temperature

S_{yh} = Yield stress at the operating temperature

S_{rh} = Creep rupture strength at the operating temperature.

The first criterion is equivalent to the $3S_m$ limit provided in Section VIII-Division 2. The rationale behind the second criterion is illustrated in

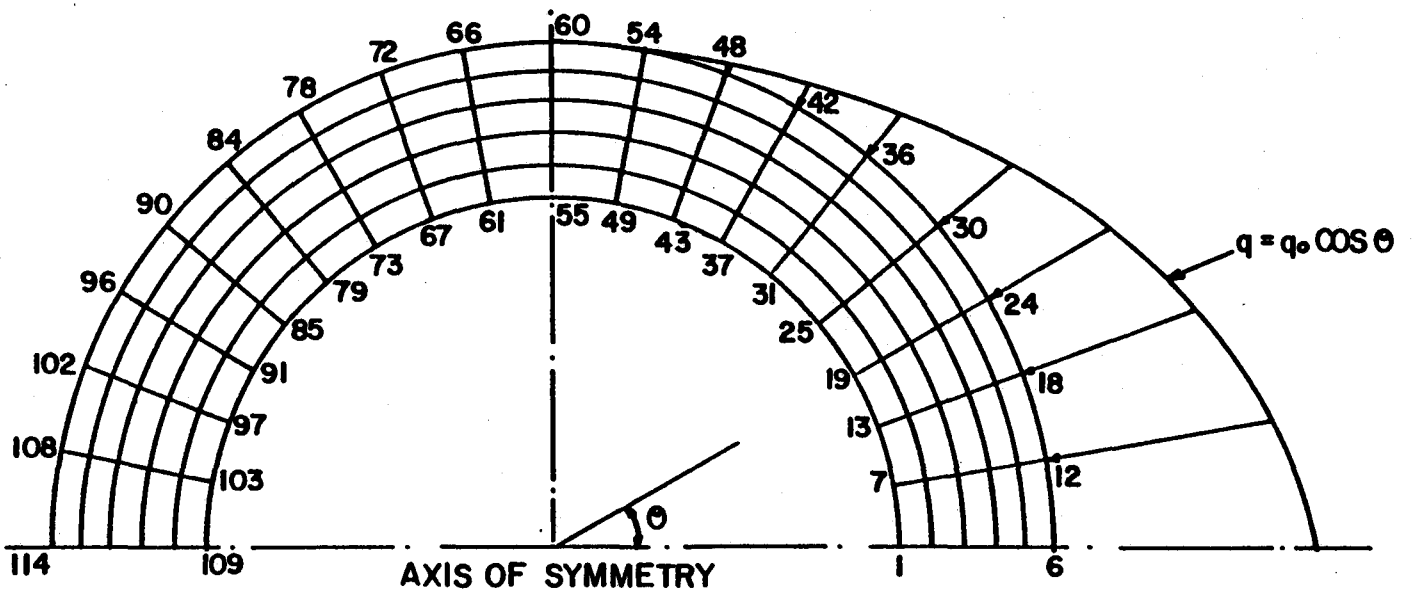


Figure D.1 Preliminary Tube Model

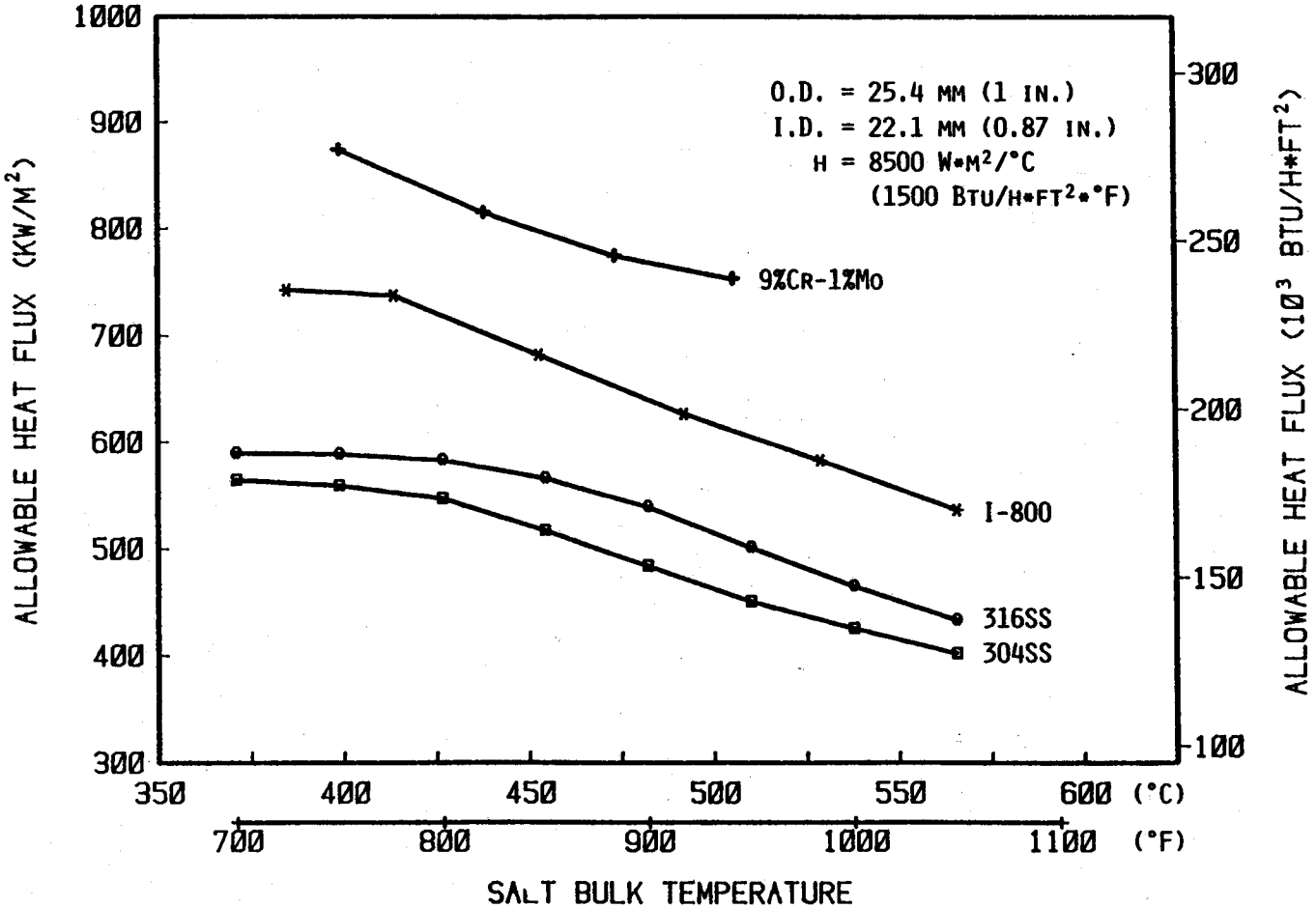


Figure D.2 Allowable Flux on Absorber Panels

Figure D.3. For Case (b) shown in the figure, where $(P + Q)_R > S_{yc} + S_{rh}$, stress reversal occurs during unloading and plastic yielding takes place. When the panel is reloaded, the operating stresses exceed S_{rh}. This cycling will be repeated. When $(P + Q)_R \leq S_{yc} + S_{rh}$, upon reloading after overnight shutdown, the panel stresses do not exceed S_{rh}. We assumed that, when this criterion is applied, the fatigue damage is not excessive. Thus this criterion was adequate as a simple, first-cut approximation to limit the flux levels during the concept selection stage. A more thorough creep-fatigue evaluation is part of Task 4.

The method used in applying these criteria to arrive at the curves shown in Figure D.2 are shown in Tables D.1 through D.4. For a given maximum metal temperature, $(S_{yc} + S_{rh})$ and $(S_{yc} + S_{yh})$ are calculated. The allowable flux level is then determined from parametric computer runs, so that the maximum equivalent stress does not exceed the lower of the two allowables. The temperature differential $(\Delta T = \Delta T_{metal} + \Delta T_{film})$ corresponding to the allowable flux value is then determined. The bulk temperature is obtained by subtracting ΔT from T_{max}.

From Figure D.2, the allowable flux levels for Incoloy 800 are higher than those for Types 304SS and 316SS because of the higher creep rupture strength of Incoloy 800. The allowable flux levels for 9%Cr-1%Mo, despite inferior creep-rupture properties, are even higher because of higher thermal conductivity, lower coefficient of thermal expansion, and consequently, lower thermal stresses.

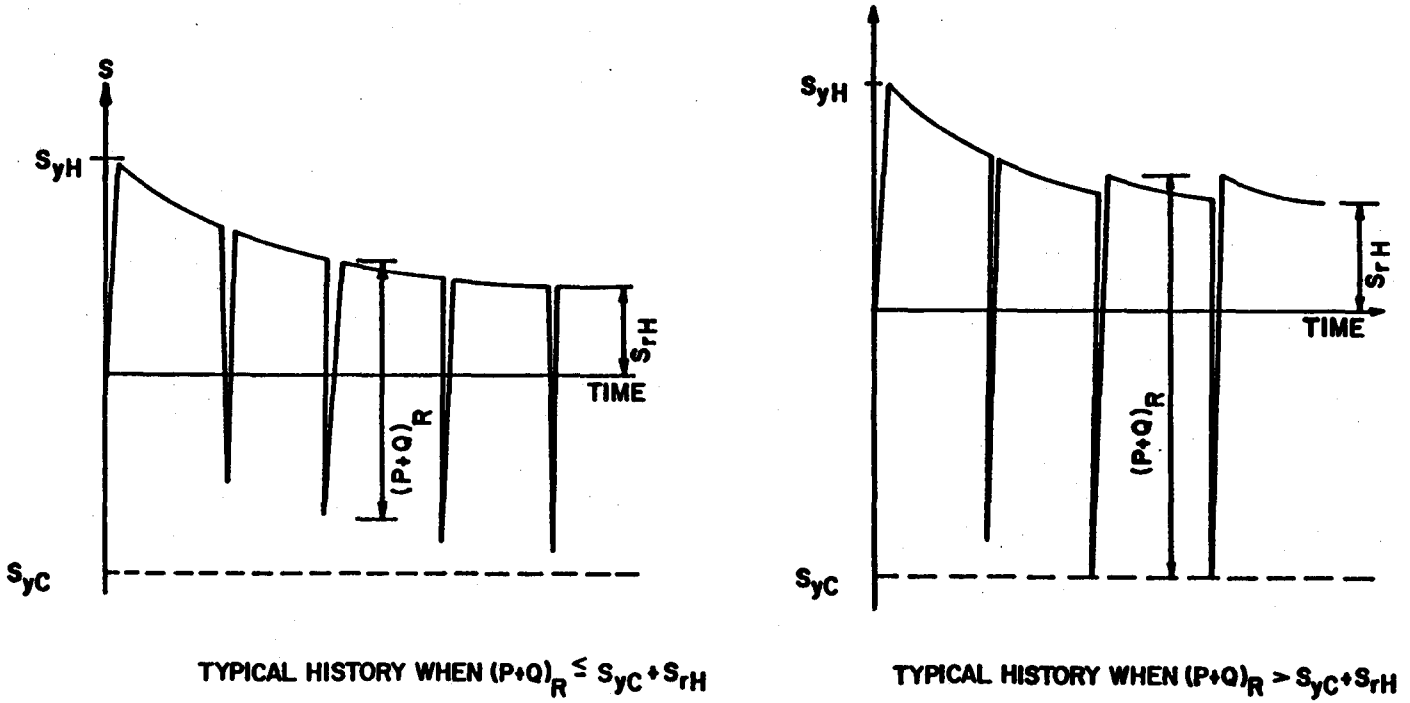


Figure D.3 Stress History

Table D.1 Parametric Analysis (Type 304SS)

T_{max} °C (°F)	S_{rh} MPa (kip/in²)	$S_{yc} + S_{rh}$ MPa (kip/in²)	$S_{yc} + S_{yh}$ MPa (kip/in²)	$q_{allowable}$ MW/m² (Btu/h·ft²)	ΔT °C (°F)	T_{bulk} °C (°F)
482	187.5	317.2	241.3	0.565	99.2	365.2
(900)	(27.2)	(46.0)	(35.0)	(179,119)	(210.6)	(689.4)
510	146.2	275.8	239.2	0.560	98.2	394.0
(950)	(21.2)	(40.0)	(34.7)	(177,584)	(208.8)	(741.2)
538	114.5	244.1	237.2	0.555	97.2	422.8
(1000)	(16.6)	(35.4)	(34.4)	(176,049)	(207.0)	(793.0)
566	89.6	219.3	234.4	0.513	88.5	459.3
(1050)	(13.0)	(31.8)	(34.0)	(162,740)	(191.3)	(858.7)
593	70.3	199.9	231.0	0.468	79.1	496.4
(1100)	(10.2)	(29.0)	(33.5)	(148,413)	(174.47)	(925.5)
621	55.2	184.8	228.9	0.433	71.8	531.6
(1150)	(8.0)	(26.8)	(33.2)	(137,154)	(161.2)	(988.8)
649	42.7	172.4	226.8	0.404	65.8	565.3
(1200)	(6.2)	(25.0)	(32.9)	(127,942)	(150.4)	(1049.6)

Table D.2 Parametric Analysis (Type 316SS)

T_{max} °C (°F)	S_{rh} MPa (kip/in²)	$S_{yc} + S_{rh}$ MPa (kip/in²)	$S_{yc} + S_{yh}$ MPa (kip/in²)	$q_{allowable}$ MW/m² (Btu/h·ft²)	ΔT °C (°F)	T_{bulk} °C (°F)
482	293.7	427.1	252.7	0.592	104.7	359.7
(900)	(42.6)	(61.95)	(36.65)	(187,563)	(220.5)	(679.5)
510	223.4	356.8	251.3	0.588	104.1	388.2
(950)	(32.4)	(51.75)	(36.45)	(186,540)	(219.3)	(730.7)
538	169.6	303.0	250.6	0.587	103.7	416.3
(1000)	(24.6)	(43.95)	(36.35)	(186,028)	(218.7)	(781.3)
566	129.6	263.0	248.6	0.582	102.7	445.1
(1050)	(18.8)	(38.15)	(36.05)	(184,493)	(216.9)	(833.1)
593	98.6	232.0	247.17	0.543	94.7	480.8
(1100)	(14.3)	(33.65)	(35.85)	(172,210)	(202.5)	(897.5)
621	75.2	208.6	246.5	0.488	83.3	520.0
(1150)	(10.9)	(30.25)	(35.75)	(154,810)	(182.0)	(968.0)
649	57.2	190.6	245.1	0.446	74.6	556.4
(1200)	(8.3)	(27.65)	(35.55)	(141,504)	(166.4)	(1033.6)

Table D.3 Parametric Analysis (9%Cr-1%Mo)

T_{max} °C (°F)	S_{rh} MPa (kip/in²)	$S_{yc} + S_{rh}$ MPa (kip/in²)	$S_{yc} + S'_{yh}$ MPa (kip/in²)	$q_{allowable}$ MW/m² (Btu/h·ft²)	ΔT °C (°F)	T_{bulk} °C (°F)
482	148.4	307.0	296.5	1.187	208.5	255.9
(900)	(21.53)	(44.53)	(43.0)	(376,200)	(407.3)	(492.7)
510	113.0	271.6	289.6	1.087	189.5	302.7
(950)	(16.39)	(39.39)	(42.0)	(344,600)	(373.1)	(576.9)
538	84.5	243.0	282.7	0.973	167.7	352.3
(1000)	(12.25)	(35.25)	(41.0)	(308,400)	(333.9)	(666.1)
566	61.9	220.5	275.8	0.883	150.6	397.2
(1050)	(8.98)	(31.98)	(40.0)	(279,800)	(303.0)	(747.0)
593	44.6	203.2	267.5	0.813	137.3	438.3
(1100)	(6.47)	(29.47)	(38.8)	(257,800)	(279.1)	(820.9)
621	31.5	190.1	256.5	0.761	127.3	476.0
(1150)	(4.57)	(27.57)	(37.2)	(241,200)	(261.2)	(888.8)
649	21.9	180.4	247.5	0.722	120.0	511.1
(1200)	(3.17)	(26.17)	(35.9)	(229,000)	(248.0)	(952.0)

Table D.4 Parametric Analysis (Incoloy 800)

T_{max} °C (°F)	S_{rh} MPa (kip/in²)	$S_{yc} + S_{rh}$ MPa (kip/in²)	$S_{yc} + S_{yh}$ MPa (kip/in²)	$q_{allowable}$ MW/m² (Btu/h·ft²)	ΔT °C (°F)	T_{bulk} °C (°F)
482	277.9	438.5	308.2	0.750	137.0	327.4
(900)	(40.3)	(63.6)	(44.7)	(237,892)	(278.62)	(621.38)
510	224.8	385.4	306.1	0.745	136.0	356.3
(950)	(32.6)	(55.9)	(44.4)	(236,296)	(276.75)	(673.25)
538	182.0	342.7	304.7	0.742	135.3	384.7
(1000)	(26.4)	(49.7)	(44.2)	(235,232)	(275.5)	(724.5)
566	147.5	308.2	302.7	0.737	134.2	413.6
(1050)	(21.4)	(44.7)	(43.9)	(233,635)	(273.6)	(776.4)
593	119.3	279.9	299.9	0.682	122.8	452.7
(1100)	(17.3)	(40.6)	(43.5)	(216,072)	(253.06)	(846.94)
621	96.5	257.2	297.9	0.626	111.4	491.9
(1150)	(14.0)	(37.3)	(43.2)	(198,510)	(232.5)	(917.5)
649	78.6	239.2	294.4	0.583	102.4	528.7
(1200)	(11.4)	(34.7)	(42.7)	(184,672)	(216.29)	(983.71)

Appendix E

PANEL STATIC STABILITY ASSESSMENT

INTRODUCTION

The molten salt solar receiver panels were analyzed to determine their static stability characteristics. The general procedure followed for analysis (details of which are included in "Calculation Procedures") was to compute and plot the static pressure difference between panel inlet and outlet headers as a function of mass flow rate. These curves were analyzed to note whether negative sloping regions exist indicating static Ledinegg instability.

A flow is subjected to a static instability when the flow conditions, changed by a small perturbation, will not return to the original steady-state conditions. Stability is exemplified by a continuous positive upward slope in the pressure-drop vs. flow-rate curve. A negative slope will indicate that the circuit being examined is statically unstable when operating in a matrix of manifolded circuits. More than one flow rate could exist in a different tube in the circuit for a given pressure drop, and the panel has potential for a flow-excursion or "flow-reversal" type of instability. In an unstable circuit of this type, the tubes could have as many as three different flows and the flows could fluctuate. Since a small flow disturbance in the system could lead to a spontaneous shift in mass flow rate or "flow reversal," design metal temperatures and thermal stresses could be exceeded and tube failure could result.

CALCULATION PROCEDURE

A single-tube model was developed based on panel arrangement information taken from the baseline configuration. For the purpose of calculating pressure drop, the model was divided into an unheated inlet section, a vertical heated section, and an unheated outlet section. Heat fluxes and operating conditions were taken from the Sierra Pacific Power Company Repowering Study.

Static pressure difference was computed between inlet and outlet headers for positive flow (upflow in upflow panels and downflow in downflow panels) and between outlet header and inlet header for negative flow (recirculated downflow in upflow panels and recirculated upflow in downflow panels). The average fluid conditions in the outlet header were used for the negative flow inlet conditions. Total pressure difference between headers was plotted as a function of the relative mass flow rate, which is the ratio of flow rate under perturbation to that of a normal operating condition of the specified load. The pressure-drop curves were then analyzed to note the following:

- Negatively sloping regions indicating static Ledinegg flow instability
- Possibility of reverse flow for the operating pressure drop between headers.

CALCULATION RESULTS

Upflow Panels

In the upflow direction, the frictional pressure drop and gravity head both work toward increasing the pressure drop with increasing flow. Figure 1 shows the components of pressure drop for a typical upflow panel (acceleration

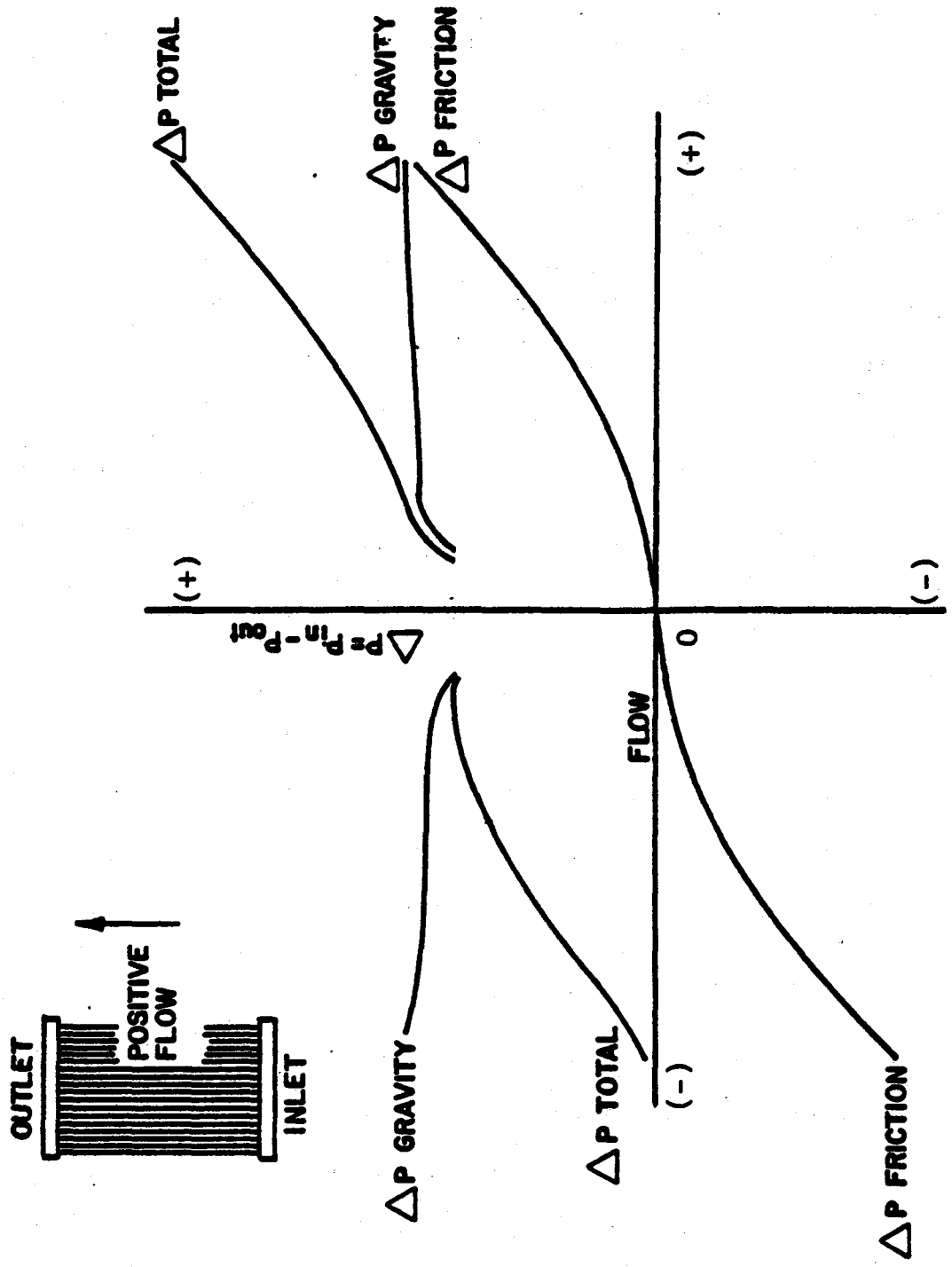


Figure 1 Pressure-Drop Components--Upflow Panel

component is not shown because acceleration is negligible). At the design condition (Figure 2), the frictional losses begin to dominate above 15 percent of the average flow and the flow is stable. At the design absorption rate, only one flow can exist, and only in the upflow direction, at the operating pressure drop. The same holds true for the maximum operating conditions. At the design and maximum conditions, the upflow panel is stable.

At the minimum operating conditions (25 percent load), the lower flow dictates lower frictional losses and gravity head dominates the pressure drop, decreasing the margin between positive and hypothetical reverse flow. At the minimum operating conditions, the panel is stable although the margin is reduced.

Downflow Panels

All heated downflow sections pass through a potentially unstable condition at low flows. Any time the frictional pressure drop is less than the gravity head (such as low flow), flow stagnation or reversal can occur. In the downflow panels, gravity head acts to decrease the pressure drop while frictional pressure drop increases it. The components of pressure drop for a typical downflow panel are shown in Figure 3 (acceleration component negligible).

At the design operating conditions (Figure 4), gravity head dominates the total pressure drop resulting in a net negative pressure drop. As flow decreases a negative sloping region of the curve exists indicating that the circuit is unstable and could go to reverse flow.

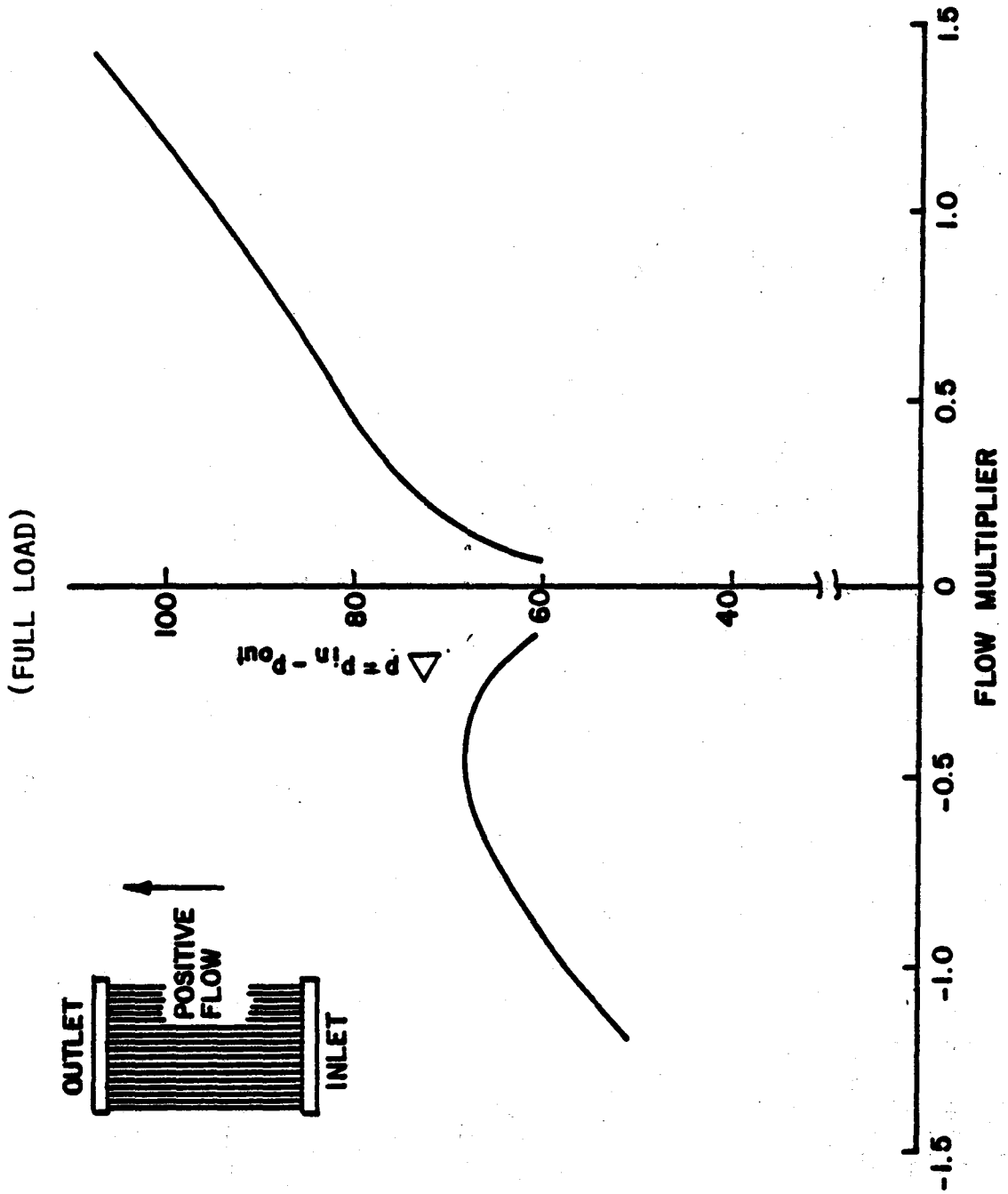


Figure 2 Upflow Panel

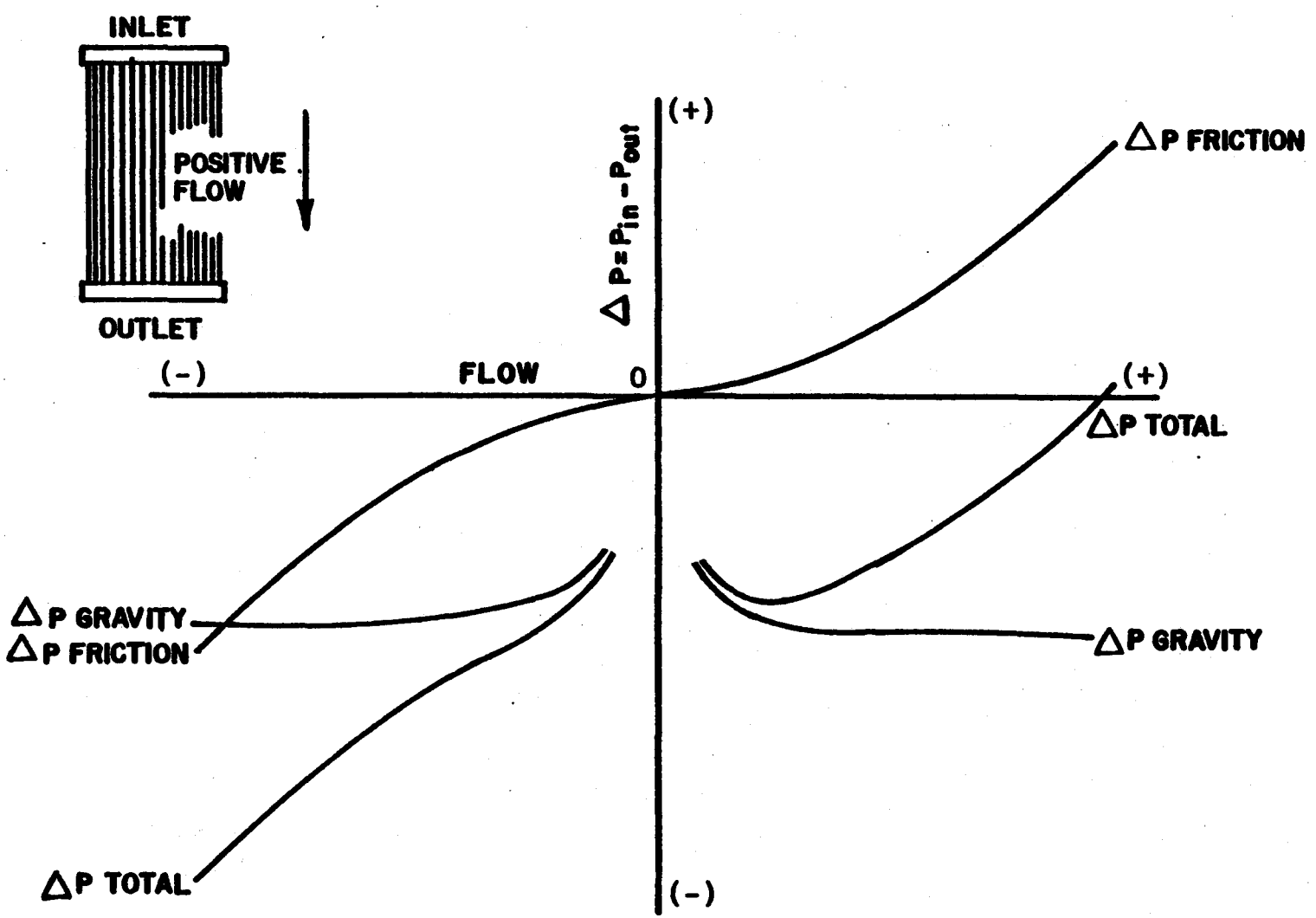


Figure 3 Pressure-Drop Components--Downflow Panel

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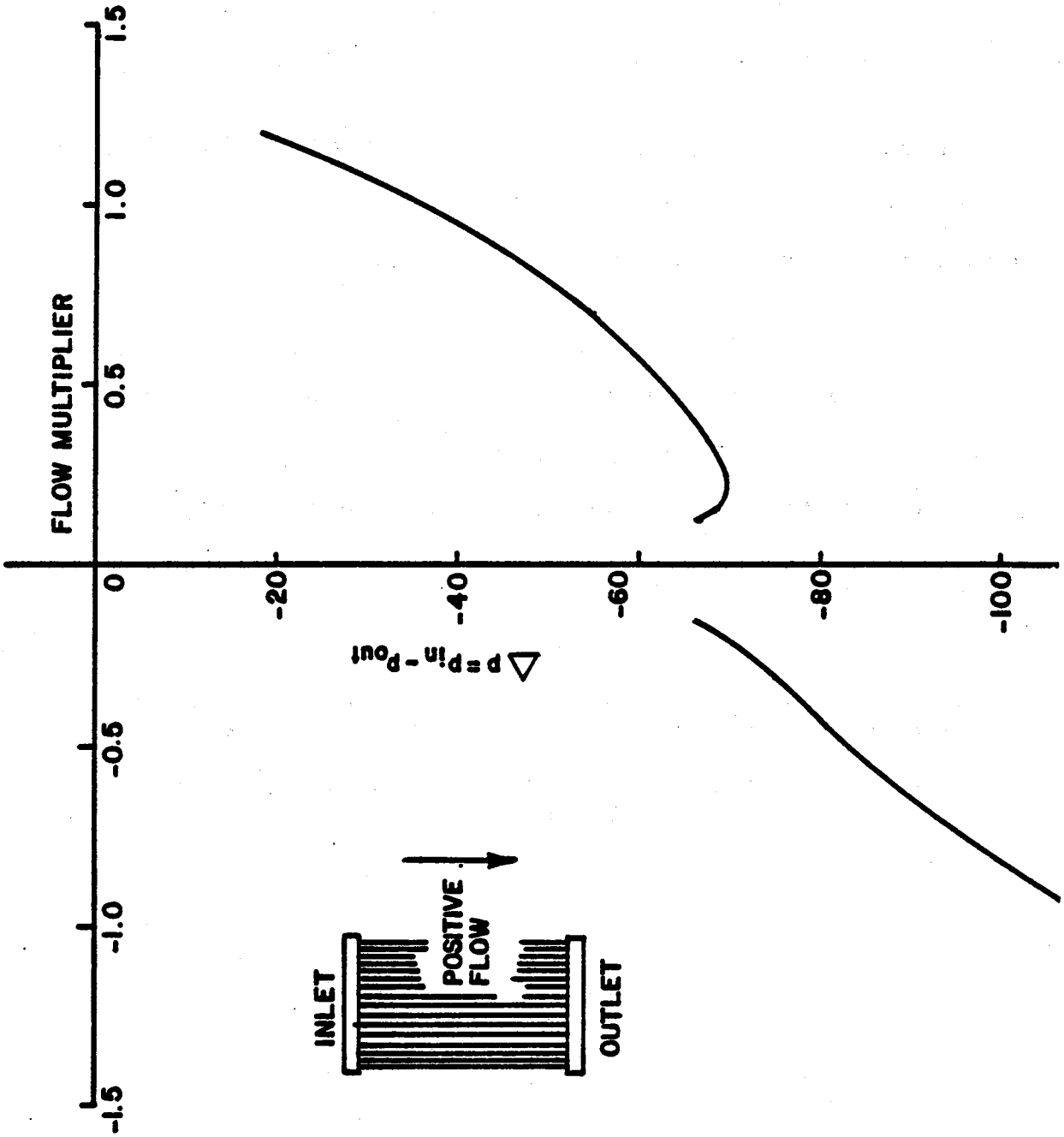

Figure 4 Downflow Panel (Full Load)

As the mass flow is increased, the frictional pressure drop increases sufficiently to yield a postive ΔP. This occurs at 40 percent above the normal operating flow (Figure 4). Operating with sufficient mass flow to ensure a positive ΔP will stabilize the panel.

At the minimum design conditions (25-percent flow), gravity head dominates the total pressure drop, and more than one flow rate may be in equilibrium at the operating pressure drop (Figure 5).

The use of a throttle valve upstream of each downflow pass or inlet flow restrictions (orificing) could change the flow characteristics of the downflow panels, thus making them stable. However, either of these changes adds complexity to the control system and increases pumping power requirements.

CONCLUSIONS

- Upflow panels are stable at the design, maximum and minimum load conditions; and no instability is expected as a result of heat-flux variations.
- Downflow panels are unstable and could be subject to flow stagnation or reversal at the design and minimum load conditions.

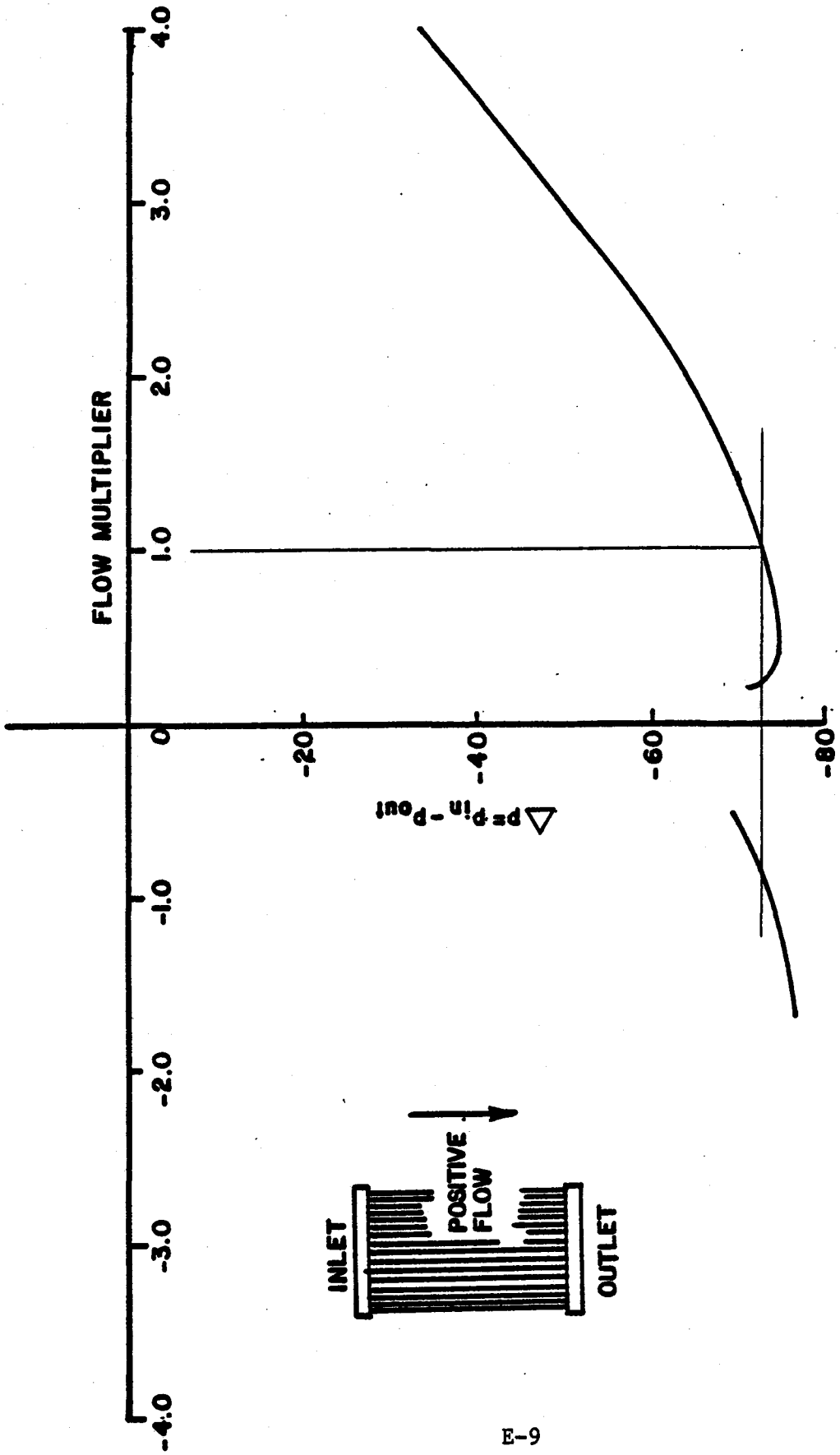

Figure 5 Downflow Panel (Minimum Load)

Appendix F

PANEL CONFIGURATION AND FLOW ROUTES

This section discusses the thermal and hydraulic aspects of the SRE receivers studied. The product of this effort is receiver frictional pressure drop and tubewall and fluid (film and bulk) temperatures throughout the receiver. This permits the identification of critical areas of the design and points the way for design improvements.

The thermal and hydraulic analysis was accomplished by a computer program OMEGA, which is summarized in Figure F.1. The length of each panel is broken into n elements or nodes (typically 17-20). Incident flux is available from CONCEN calculations and is assumed to act normal to the plane of the panel; the heat flux values fall along each edge of a panel and down the center. Hence, each of the ten panels is broken into three regions (strips). The salt properties are based on the RFQ requirements and are variable with temperature for each node. The key temperatures are defined in the sketch in the lower right-hand corner of Figure F.1. Salt film temperature, which should be limited to 593.3°C (1100°F), is the tube ID temperature (T_{ID}) at the point of highest flux.

The thermal performance for the T-1 configuration is presented in Figure F.2 for the left half of the receiver. Fluid flow, 1.232 x 10^6 kg/h (2.717 x 10^6 lb/h), follows the Sierra Pacific scheme. The cold salt, 288°C (550°F), flows through Panels L1, L2, and L3 (near the aperture) in parallel; the average exit temperature is 363°C (685°F). The panel outputs are combined and brought

- STEADY STATE
- n – NODES (17-20 TYPICAL)
- VARIABLE SALT PROPERTIES PER RFP (ρ, μ & k)
- VARIABLE k FOR TUBE
- THREE HEAT FLUX VALVES PER PANEL (EACH NODE) (EDGE – CENTER – EDGE)

- 10 PANELS, 30 STRIPS
- DITTUS – BOELTER HEAT TRANSFER COEFF
- INPUT – HEAT FLUXES, IN/OUT RECEIVER TEMPS AND TUBE/PANEL CHARACTERISTICS
- OUTPUT – T_{OD}, T_{ID}, T_{MEAN}, T_{BULK} AND $\Delta\rho$ BY PANEL, STRIP AND NODE

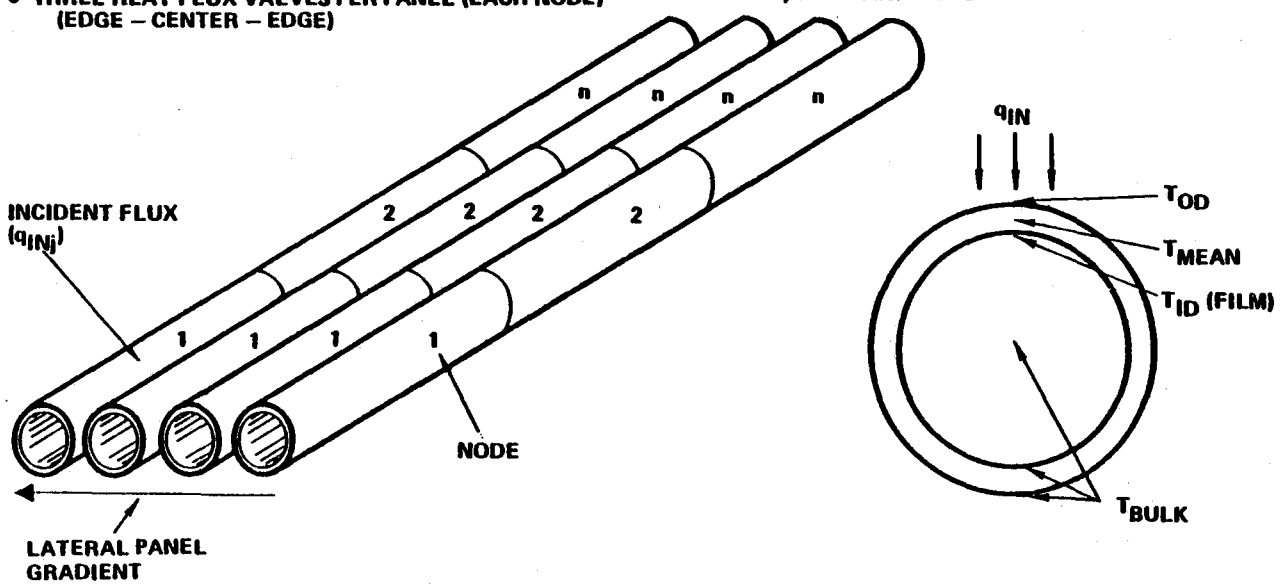

Figure F.1 Absorber Panel Thermal/Hydraulic Modeling (OMEGA)

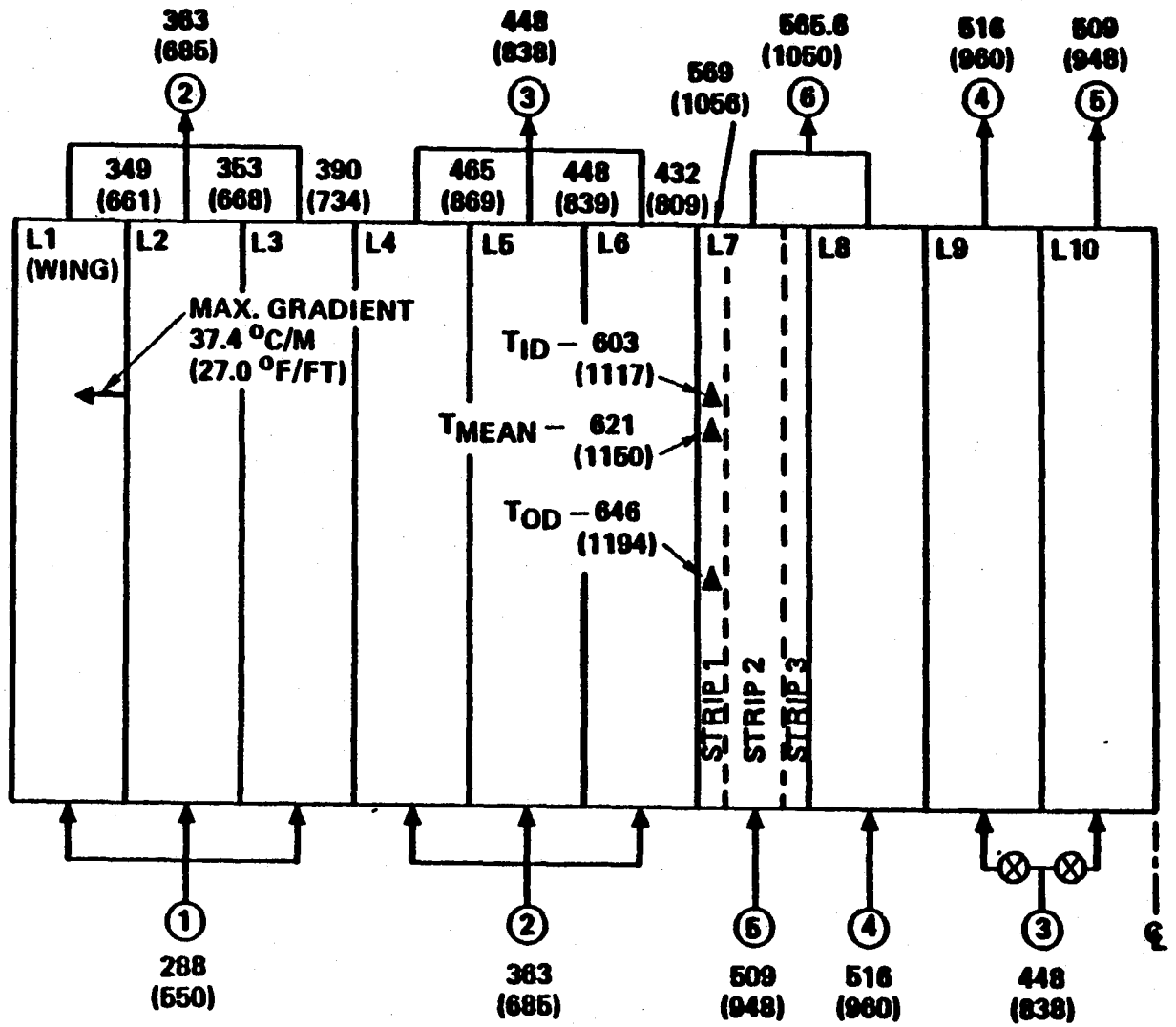

Figure F.2 Thermal Performance--Configuration T1, °C (°F)

to the bottom of Panels L4, L5 and L6 (Point 2) which are again in parallel. The average output at Point 3 is 448°C (838°F), which is the inlet condition for Pass 3 at Point 3. The Pass 3 flow is split between Panels L9 and L10, which are in series with Panels L8 and L7, respectively. Two panels in parallel rather than 3 provide higher velocity and better heat transfer coefficients in the critical hot end of the receiver, which is located at the back of the cavity to minimize radiation and convection losses. The flow split between Panels 9 and 10 depends on the Panel 9/8 heat input compared to the Panel 10/7 input; 0.6082 x 10^6 kg/h (1.341 x 10^6 lb/h) flows through Panels 9/8 and 0.6245 x 10^6 kg/h (1.377 x 10^6 lb/h) through Panels 10/7. The two valves control the total flow to maintain the bulk, mixed outlet temperature of 565.6°C (1050°F) at Point 6. The pressure drop through Panels 9/8 is 15.6 KPa (2.26 lb/in^2) less than the drop through Panels 10/7, because of the lower flow; this impalance is made up by a difference in Δp between the two valves. The cumulative frictional pressure drop through the panels, excluding manifold losses, is 696 KPa (101 lb/in^2).

The most critical temperatures for configuration T-1 are found in Strip 1 of Panel L7 as noted on Figure F.2; the bulk temperature out of this particular strip is 569°C (1056°F), somewhat higher than the mixed average outlet of 565.6°C (1050°F) at Point 6. The resulting 603°C (1117°F) film temperature is a little high and the T_{OD} value of 646°C (1194°F) is high, but perhaps acceptable, pending detail tube stress analysis.

The absorbed power for this case was 150.2 MW based on CONCEN incident flux, adjustmented (downward by a factor) of 0.98 for reflectivity, a 9.3 MW convection loss and a 5.9 MW radiation loss.

Figures F.3 and F.4 show tube OD and tube ID temperature contours, respectively, for the entire left half of the T-1 receiver. The panel numbers are marked at the top of the figure. More detailed contours for Panels 7 and 8 (Pass 4) are presented in Figures F.5 and F.6. The critical areas are seen to be in Panel 7 as noted earlier.

Mean metal temperature contours are presented in Figure F.7 for Wing Panel L1 for the T-1 receiver. The steepest lateral temperature gradients occur in this panel. The temperature profiles from panel inlet to outlet (Node 1 to Node 20) are shown in Figure F.8 for the section of the receiver with the highest tube and film temperatures (Panel 7, Strip 1). The peak OD temperature occurs in Node 8 and the peak film (ID) temperature in Node 15.

Thermal performance, similar to that presented above for T-1, is presented for the V-11 expanded configuration [27.3-m- (89.6-ft)-long panels] in Figures F.9 and F.10. As seen in Figure F.11, the expanded vertical configuration exhibits tubewall temperatures comparable to T-1 and superior tube stress performance. Figure F.11 shows the allowable flux as a function of salt bulk temperature for several candidate tube materials. The dotted and dashed lines show receiver fluxes in the critical regions. For example, the curve labeled T-1, P9S1 represents Strip 1 of Panel 9 for configuration T-1. The actual flux is higher for T-1 than for the comparable critical region of V-11 expanded, P9S2 [V-11, 27.3-m (89.6 ft) tubes, Panel 9, Strip 2)]. Hence, V-11 expanded has a larger margin of safety than T-1 with respect to the allowable. The curve also indicates the need to use Incoloy 800.

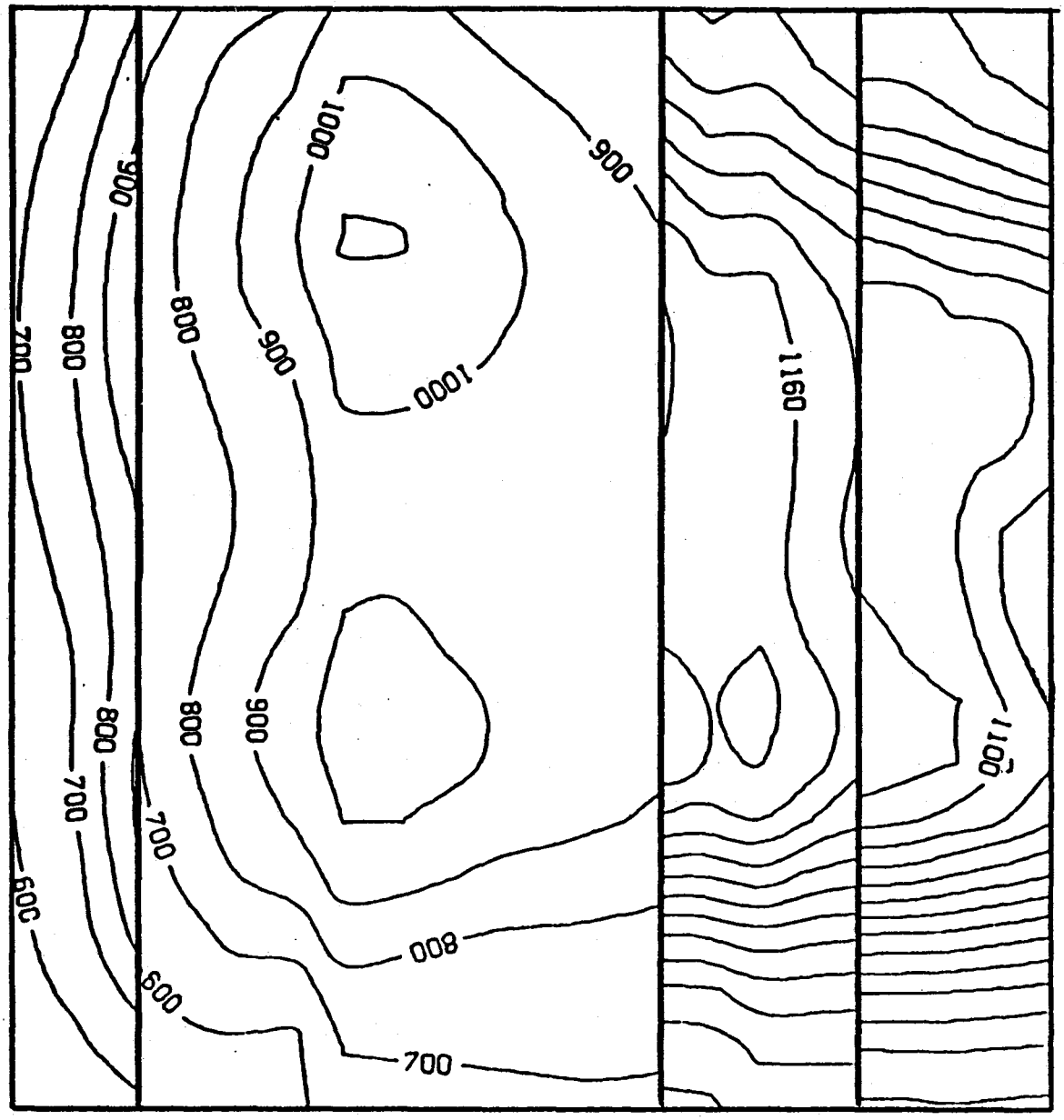

Figure F.3 Tubewall O.D. Temperature--Configuration T1 (°F)

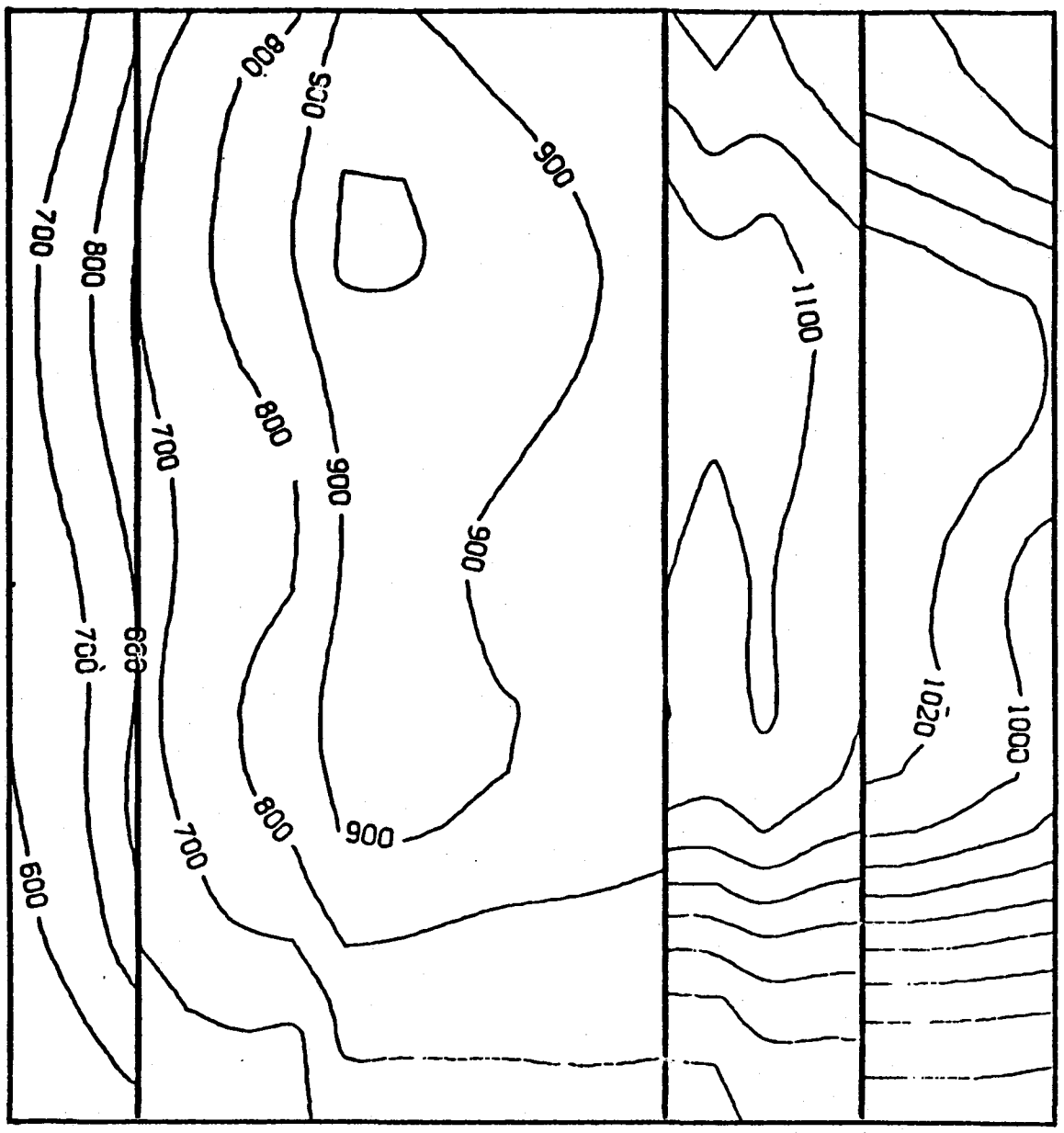

Figure F.4 Tubewall I.D. Temperature--Configuration T1 (°F)

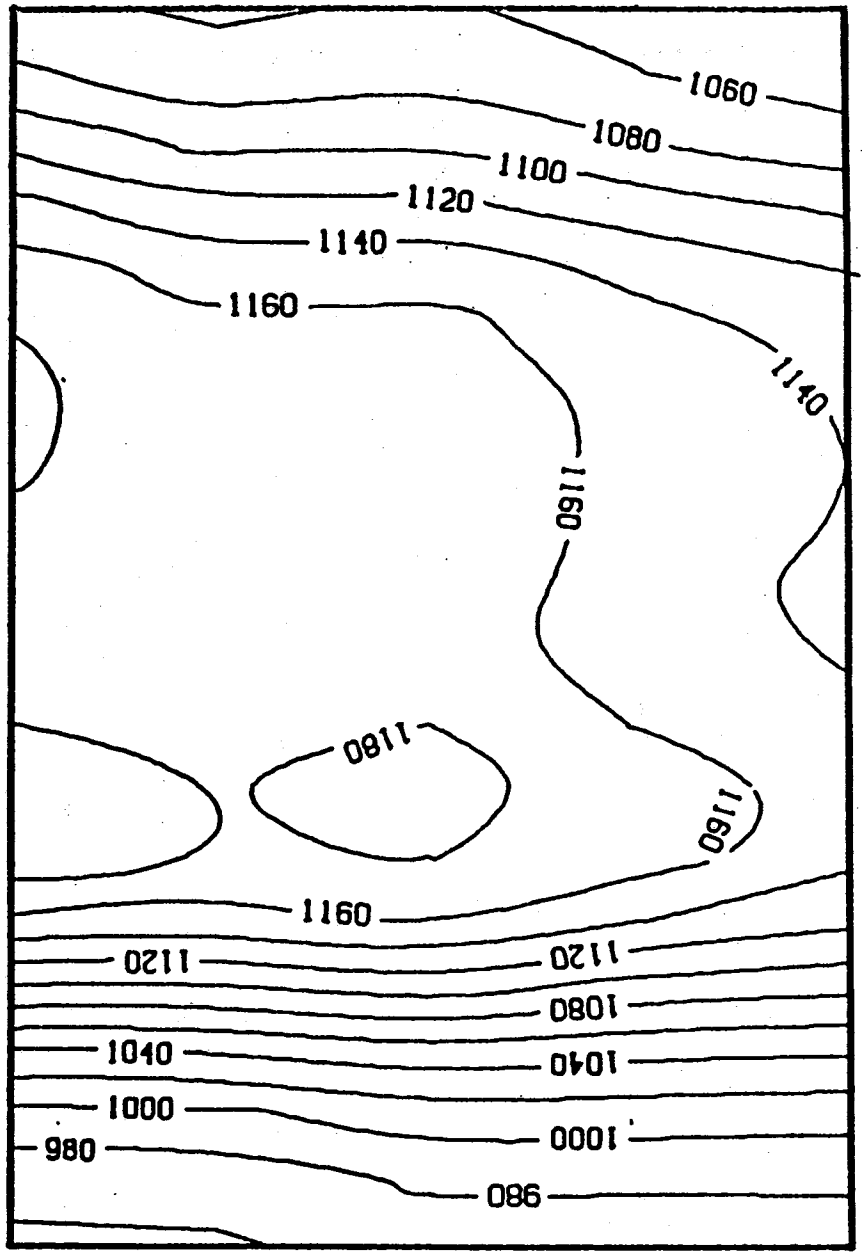

Figure F.5 Tubewall O.D. Temperature--Pass 4, Configuration T1 (°F)

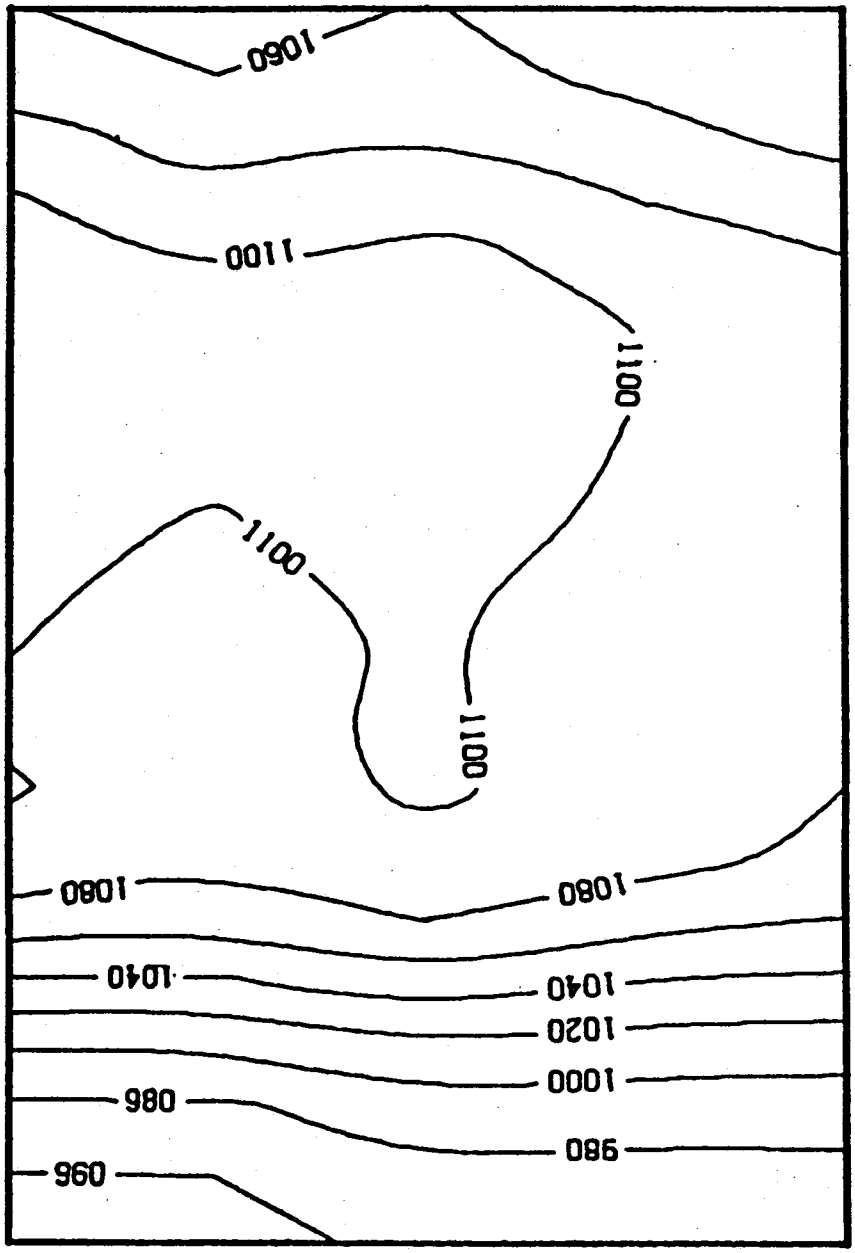

Figure F.6 Tubewall I.D. Temperature--Pass 4, Configuration T1 (°F)

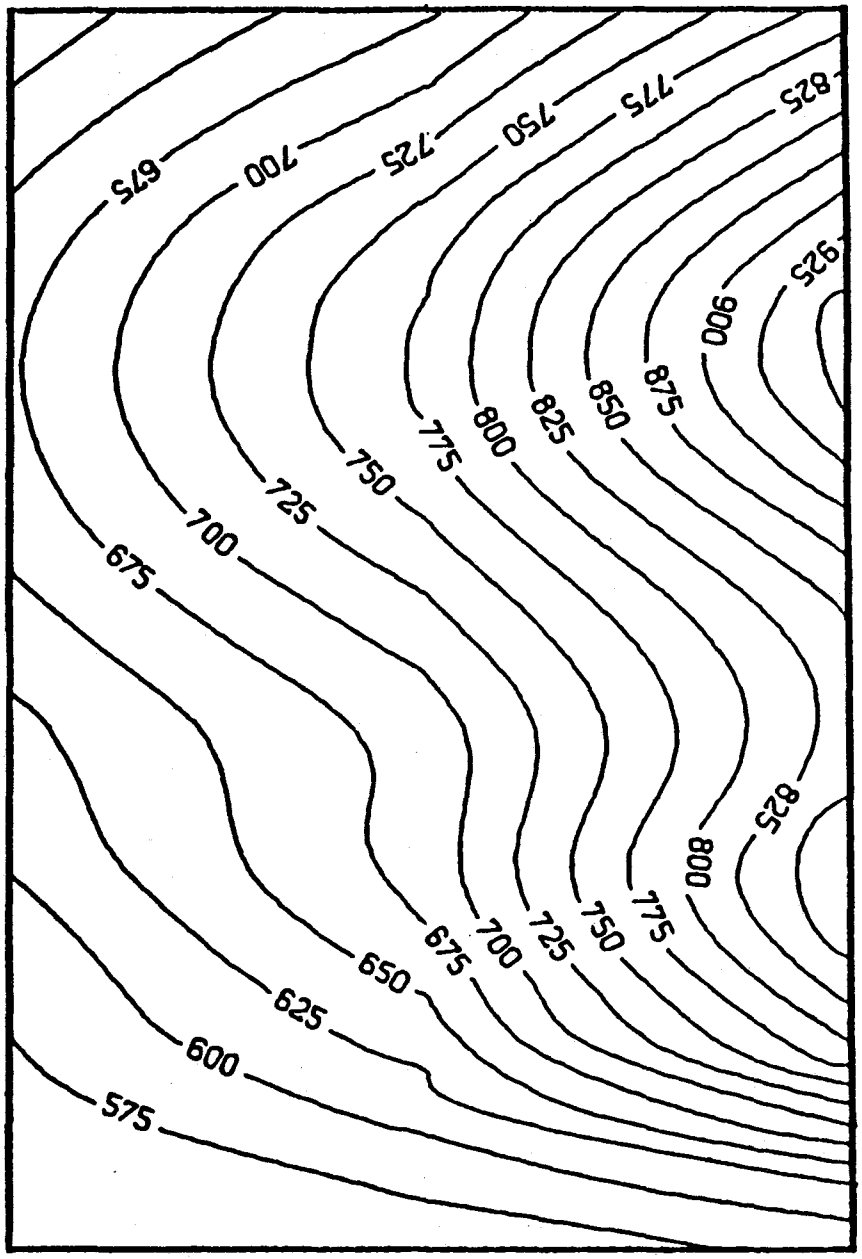

Figure F.7 Mean Tubewall Temperature--Wing Panel, Configuration T1 (°F)

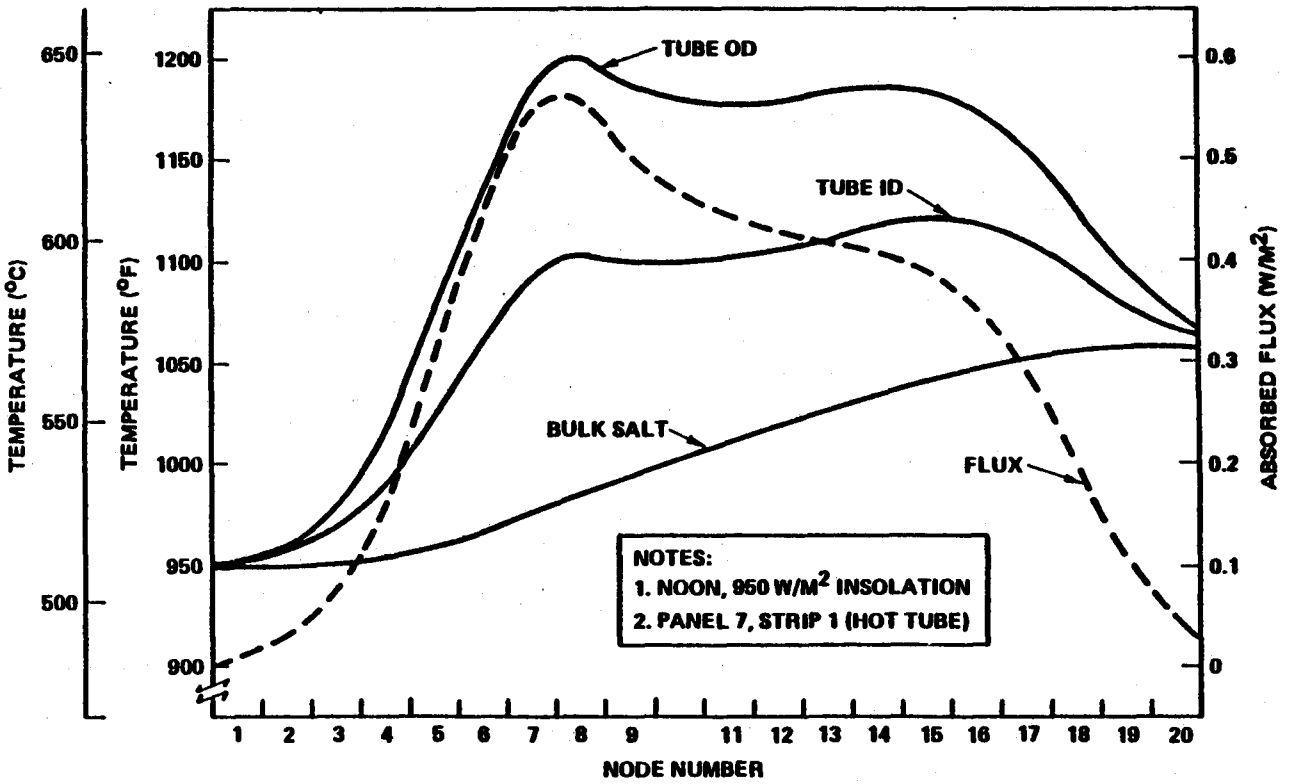

Figure F.8 Temperature Profile of Hottest Tube--Configuration T1 (°F)

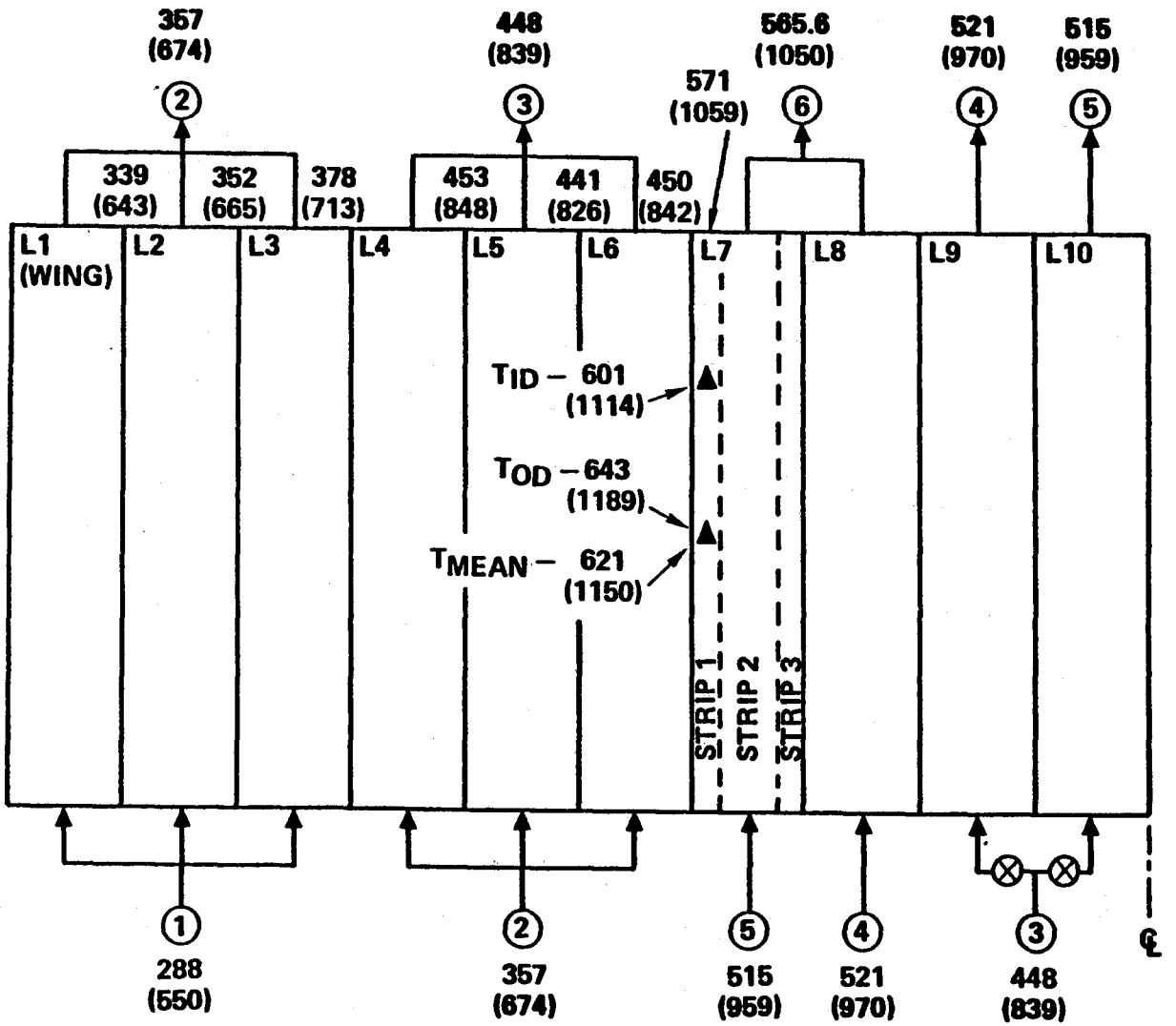

Figure F.9 Thermal Performance--Configuration V11 Expanded, °C (°F)

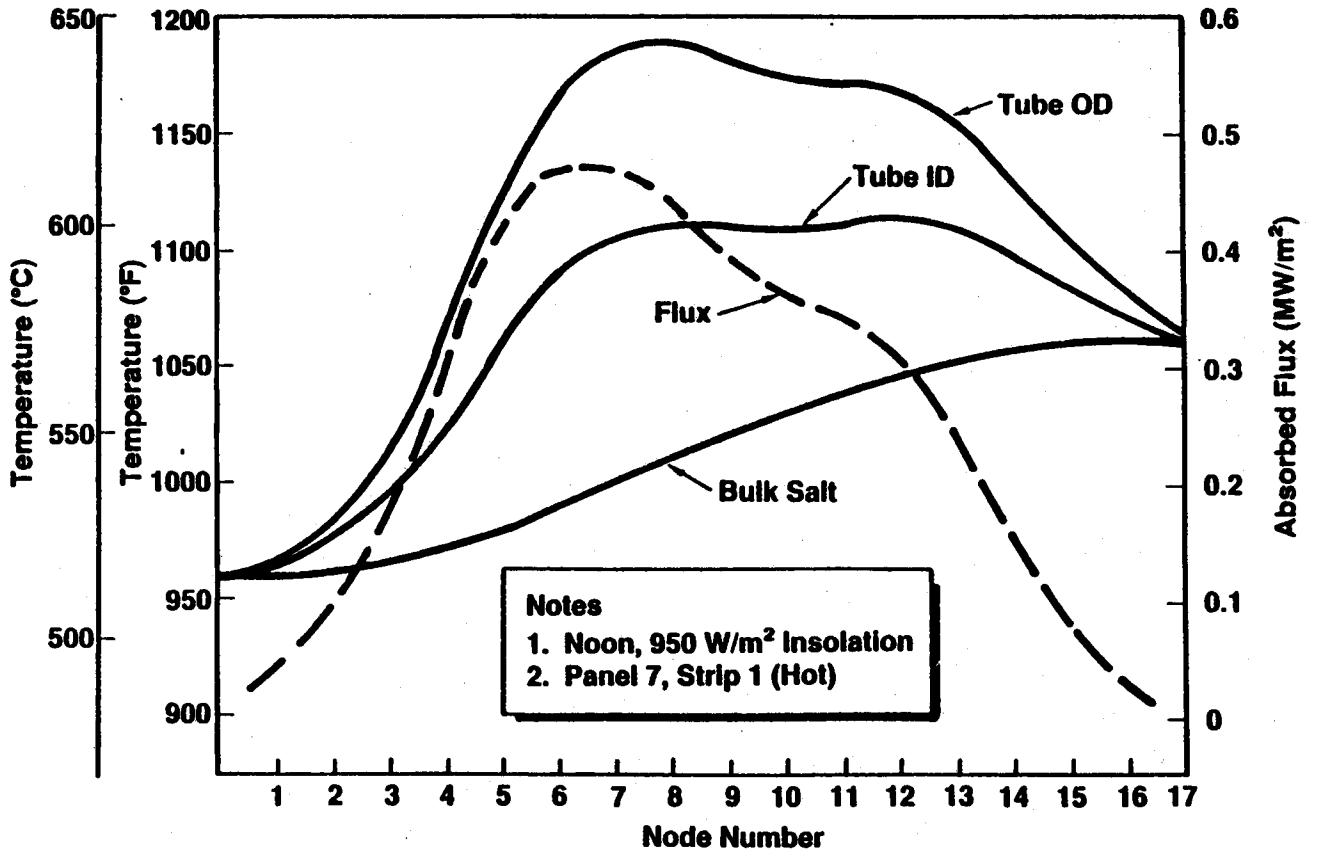

Figure F.10 Temperature Profile of Hottest Tube--Configuration V11 Expanded

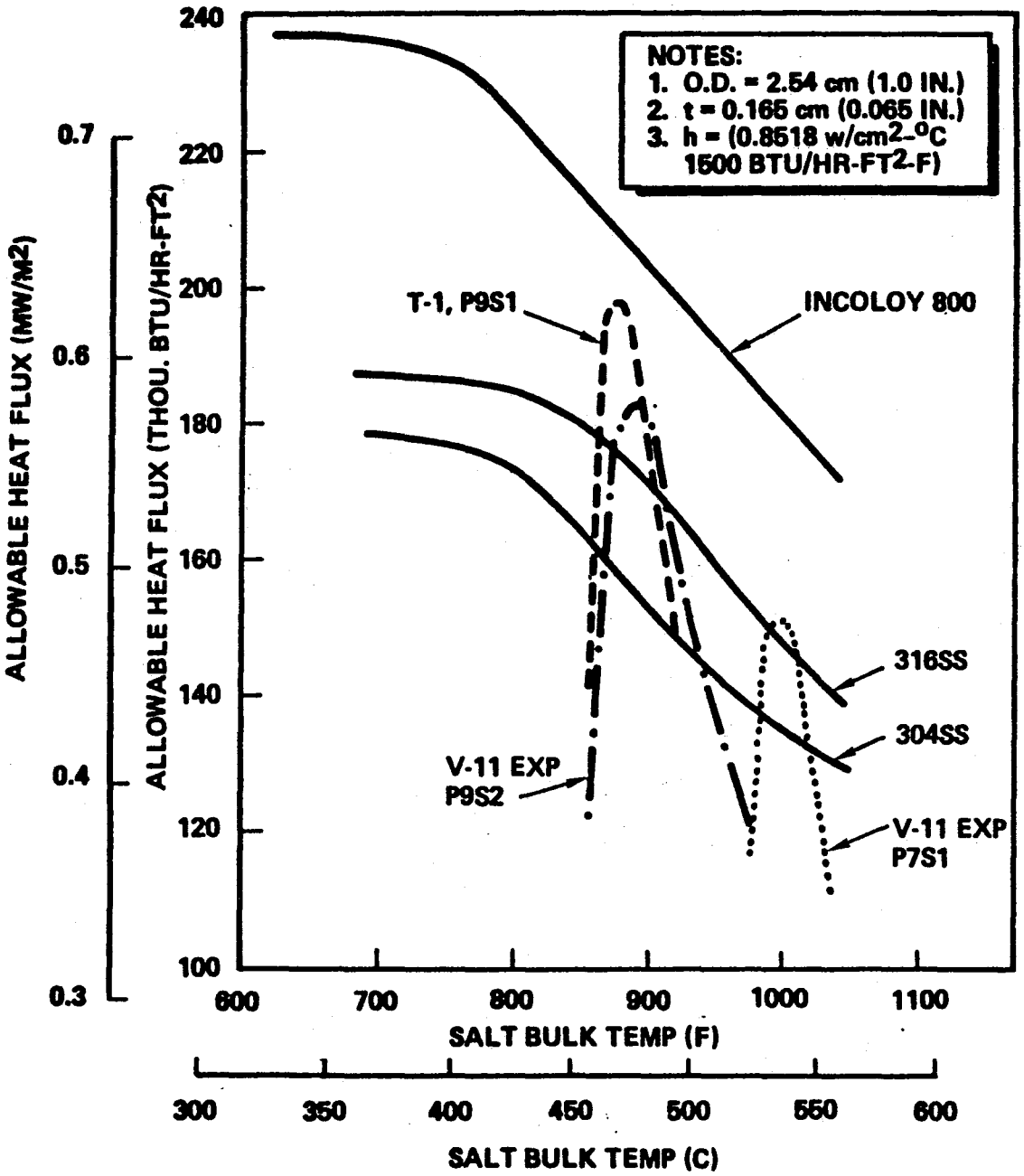

Figure F.11 Tube Performance

Appendix G

PRELIMINARY APERTURE DOOR CONFIGURATION

The receiver aperture door serves two major purposes. The primary purpose is to minimize heat losses from the panels at night or during other non-operating periods. Molten salt can be retained in the panels in a normal shutdown so that its heat capacity can be utilized and startup is simplified.

Secondly, the door is required to prevent catastrophic loss of the receiver if salt flow is interrupted with full flux on the panels and heliostat defocus capability is lost. Since the cost and risk of a door can only be justified with high operational reliability, this becomes the major design factor. The configuration presented here is not meant to be a final design but rather a preliminary solution to major problem areas.*

The basic design and operating requirements are as follows:

- The door shall cover the receiver aperture and wing panels [approximately 21 m (69 ft) wide x 28 m (92 ft)] high].
- It shall withstand an instantaneous temperature gradient of 550°C (288°F) (inside to outside surface) when closed.
- It shall be capable of closing without electrical power in less than one minute (nominally 30 seconds).
- Following an emergency closure, the door must survive full collector field flux and the subsequent decay as the solar image moves across the receiver for 9 minutes.
- The door must withstand 40.2 m/s (90 mi/h) winds and a peak ground acceleration of 0.26 g.

*For final aperture door design see Section 4.4, Volume 2.

- It will have a 30-year life.
- Convective losses through seals shall be limited to less than 150 kW with the cavity at 316°C (600°F).
- The temperature of the interior door structure shall not exceed 93.3°C (200°F).

The basic configuration shown in Figure G.1 consists of four sections which travel vertically along guide rails to a nested position when open. The total door load will be transmitted to the receiver structure through the roller track. Two cables and sheaves on each side of the sections provide support. Two 7.5 kW drive units are required to open the doors in 60 seconds. Emergency closure by gravity is accomplished by two 318-kg (700-lb) counterweights mounted on the two upper door sections. The door will accelerate for 16 seconds and decelerate for 4 seconds, requiring load brakes delivering an average braking power of 20 kW.

A typical door section shown in Figure G.2 consists of a steel I-beam structure with a 3.2-mm (1/8-in) steel diaphram attached to the cavity side. Tension rods are used for support as indicated. To limit thermal expansion and warping, ceramic fiber insulation blocks 0.15 mm (6 in.) are used with overlapping 0.4-mm (16-mil) stainless backing attached to the cavity facing side of the insulation. To help minimize unsymmetrical heating of the structure, 35 cutouts 0.3 m (12 in) O.D. are provided along each horizontal beam allowing increased convection.

On the exterior surface of door sections, replaceable ablative tiles are mounted. They consist of 50 percent dimethyl silicone, 47 percent phenolic microballons and 3 percent refrasil fibers contained in an aluminum honeycomb structure (Table G.1). A required thickness of 3.8 mm (1.5 in) was determined based on a

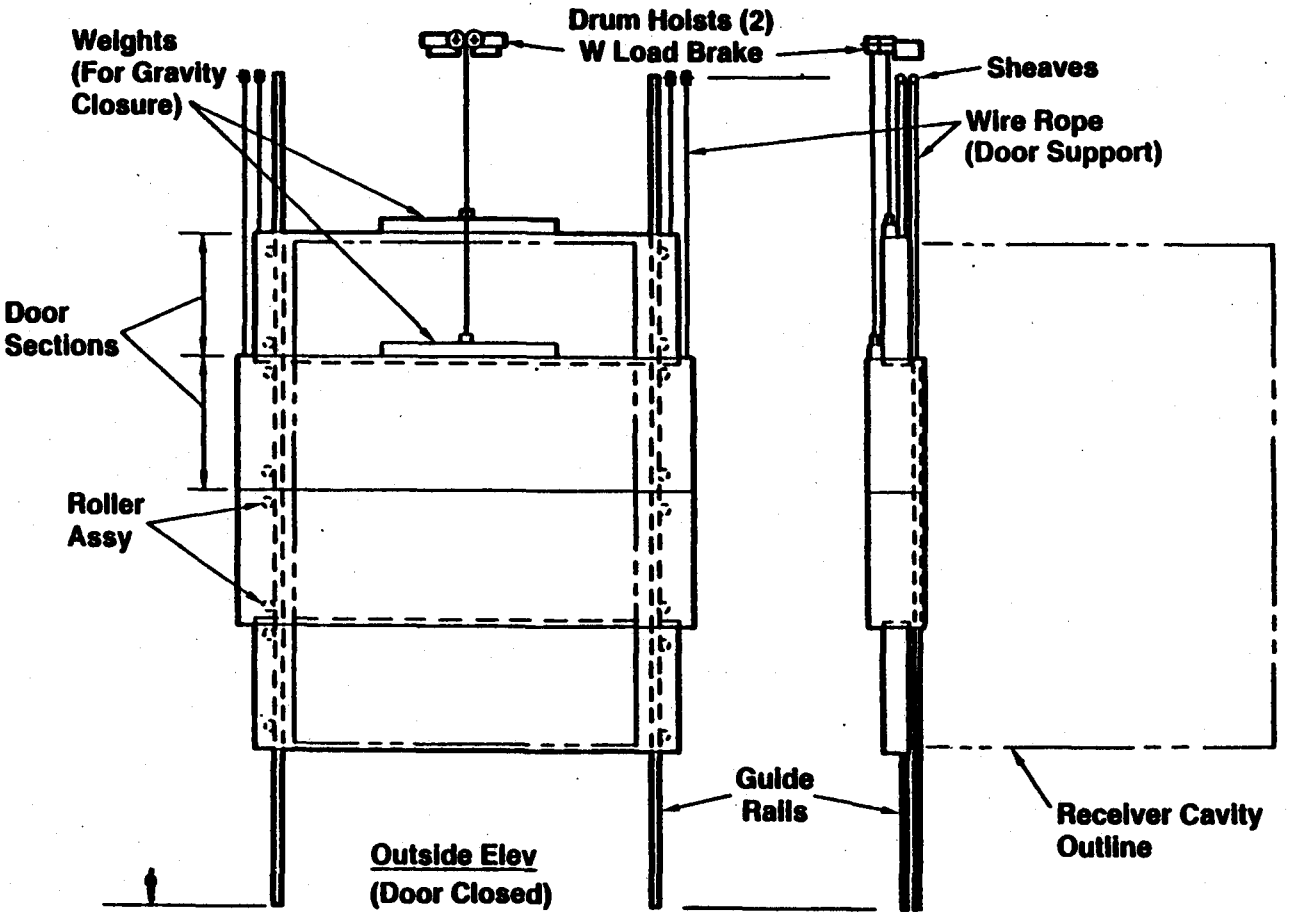

Figure G.1 Preliminary Aperture Door--Front and Side Views
(Used in trade-off analysis during Task 3)

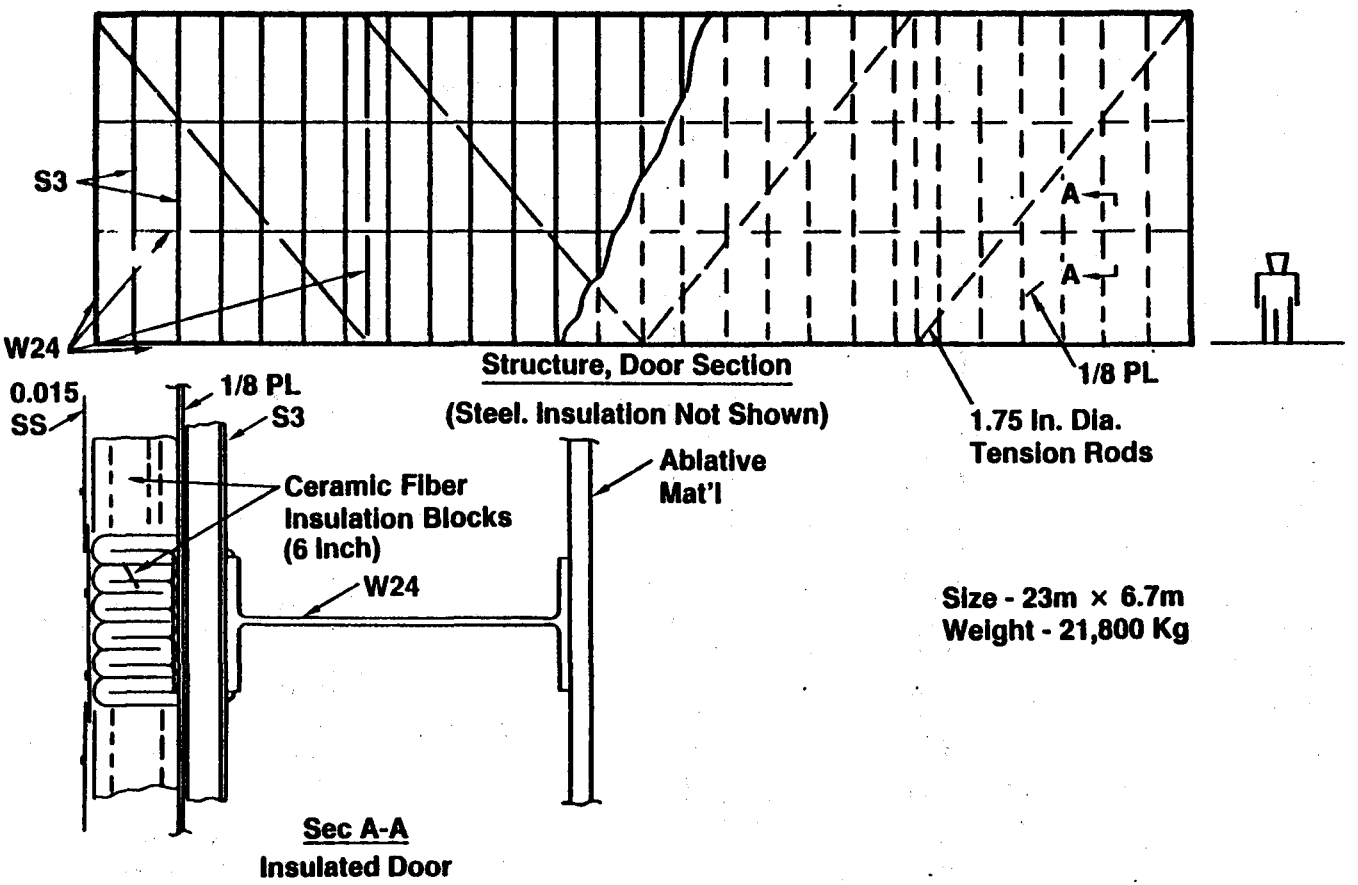

Figure G.2 Preliminary Aperture Door--Details

square wave flux simulation of 1.2 MW/m^2 for 7 minutes. This material exhibits good insulating characteristics in addition to high heats of ablation and low density.

Mechanical fastening techniques can be used with plugs to facilitate panel replacement. Based on the above design, each door panel will weigh 21,800 kg (48,000 lb).

A major design problem involves the seals to prevent convective losses. Door-to-door horizontal seals shown in Figure G.3 are a straight-forward design utilizing flexible stainless steel. The vertical door-to-receiver seals are more complex and may require active seals which swing into place after the doors have closed.

Table G.1 Ablative Protection

Composition:

50% Dimethyl Silicone
47% Phenolic Microbaloons
3% Refrasil Fibers

Thicknness	3.8 cm (1.5 in.)
Density	3.20 kg^3 (20 lb/ft^3)
Thermal conductivity	0.0013 W/cm°C (0.073 Btu/h/ft°F)
Structure	Aluminum honeycomb

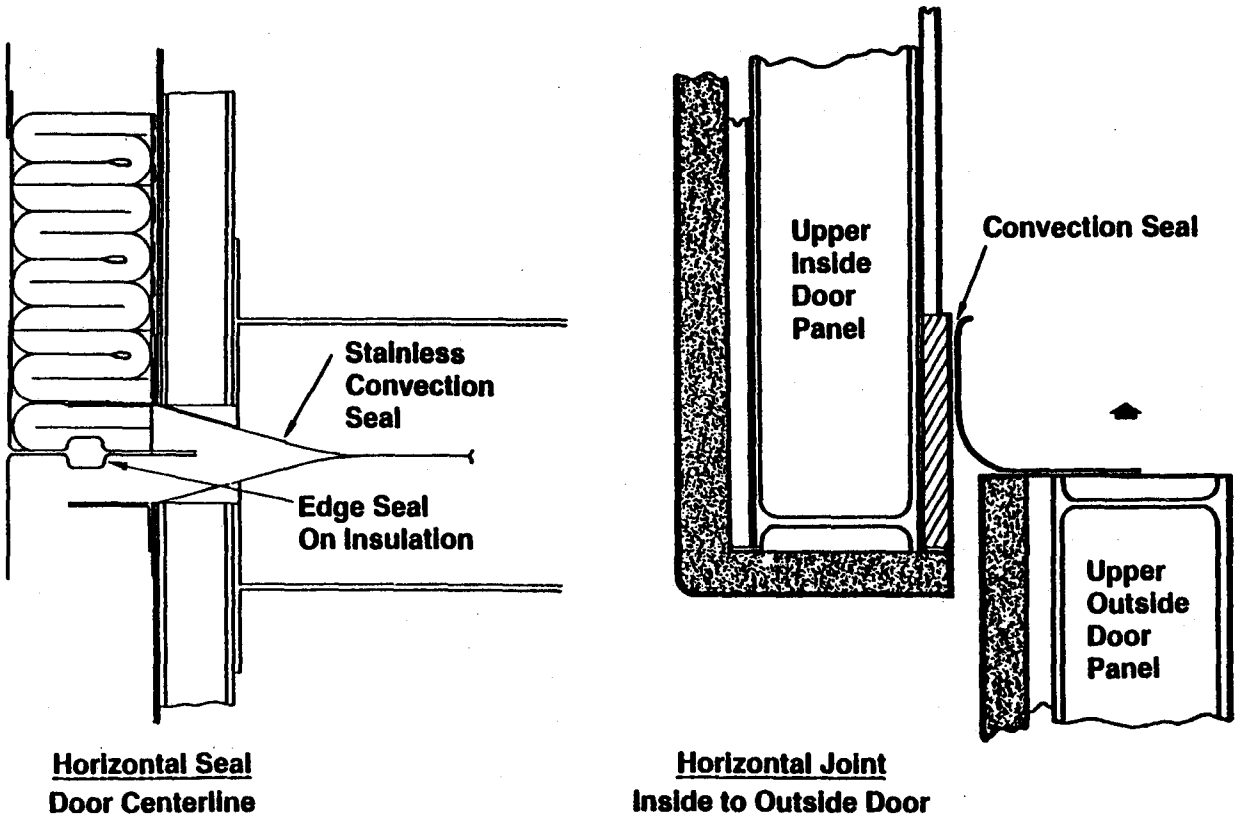

Figure G.3 Preliminary Aperture Door--Seals

Appendix H

APPROACH TO OVERNIGHT CONDITIONING

The following four cases were investigated with respect to overnight conditioning of the receiver.

CASE A--RECEIVER FILLED OVERNIGHT

After a normal shutdown, the aperture doors will be closed with the receiver tubes full of salt. The panels will lose heat by:

- Conduction through the outside insulation (19%)
- Radiation to the cold door (26%)
- Convection through the seals on the doors (39%)
- Conduction through the panel attachment structure (16%).

With the door closed, the interior cavity will reach equilibrium [440°C (824°F)] in approximately 20 minutes (Figure H.1). The wing panels do not view the interior, however, and will cool from 307 to 288°C (585 to 550°F) in 1.5 hours. These panels will require separately controlled trace heaters.

The cavity panels will continue to cool from heat losses mentioned above. The predicted temperature decay of the panels is shown in Figure H.2. The analysis assumed 0.25 mm (10 in) of insulation on the receiver. In 4.5 hours, the cavity temperature will decrease to 321°C (610°F) as shown in the figures. The greatest uncertainty involves the convective loss through the door seals. An average value of 230 kW was used in this analysis. This corresponds to a 6 mm (1/4 in.) gap.

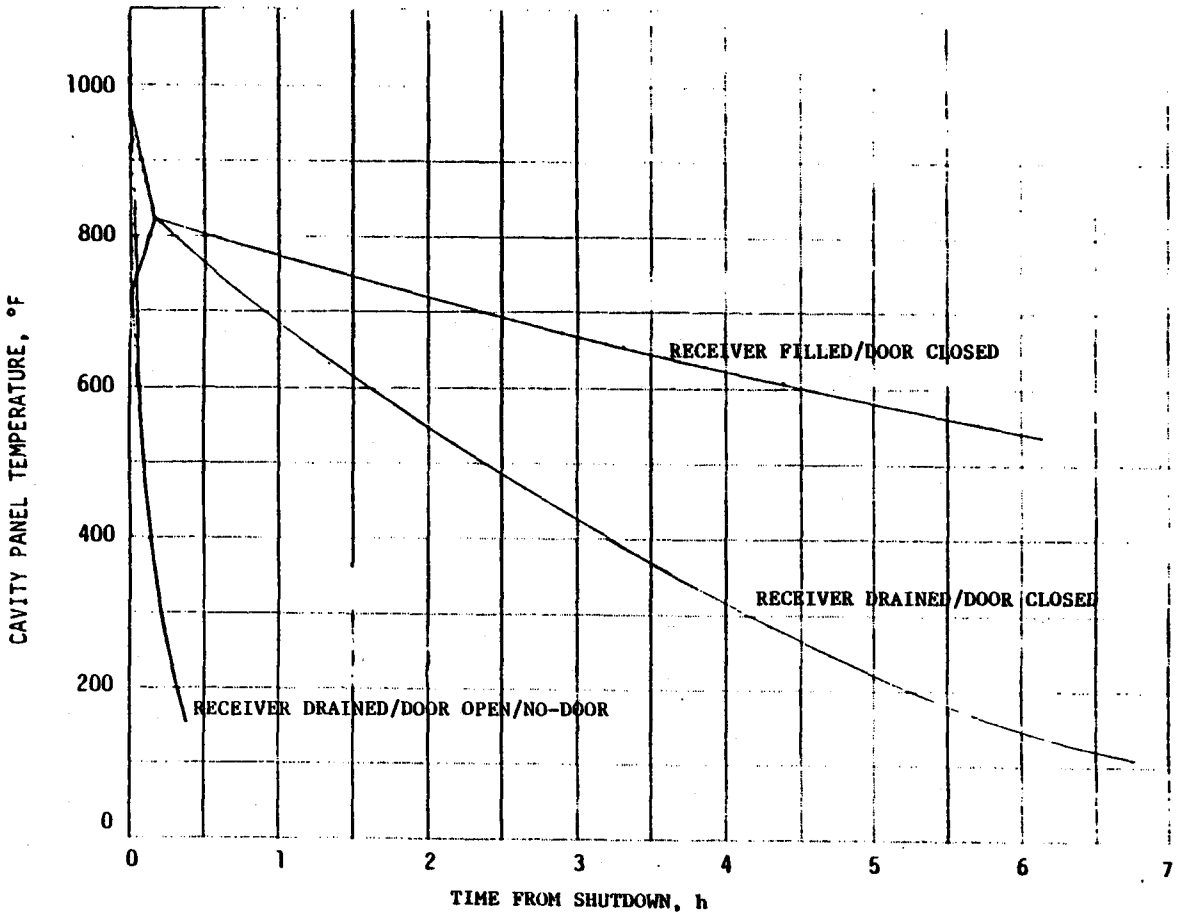

Figure H.1 Absorber Cooldown Transients

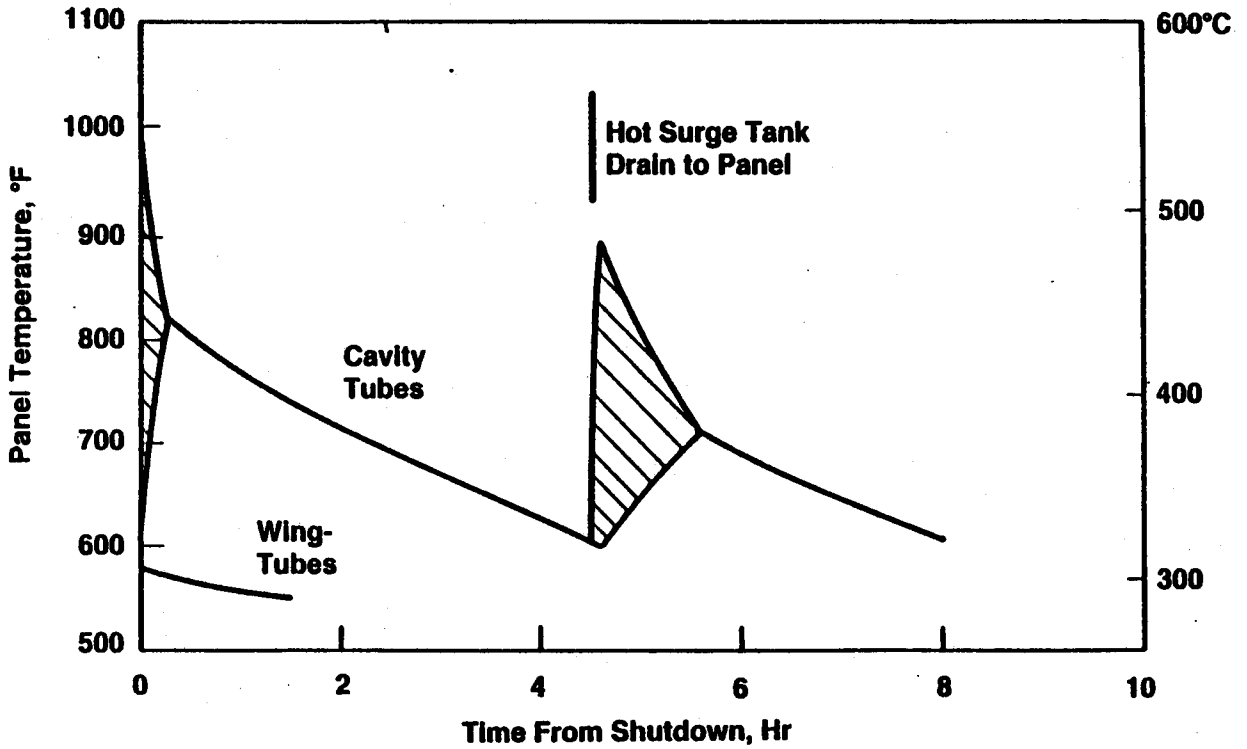

Figure H.2 Absorber Cooldown Transient With OST Drain to Panels

Panel Thermal Conditioning

Several methods of heating the cavity to maintain the temperature above 288°C (550°F) are possible. However, at shutdown the OST will be half full of salt at approximately 565°C (1050°F). By venting the IST and closing the control valves to panels L10 and R10, the hot salt will gravity-drain into the receiver panels. The cool salt in the panels will be displaced into the IST. If 36,300 kg (80,000 lb) of salt are drained, 10 panels and 4 downcomers will be filled, resulting in a tube/salt temperature of approximately 482°C (900°F) as shown in Figure H.2. Following radiation and conduction interchange between hot and cool panels and normal heat losses, the cavity temperature will reach 380°C (716°F). From this point, the cavity will cool to 321°C (610°F) in 3.5 hours. The same process can be repeated such that no auxiliary heating will be required for 11.7 hours following shutdown. This procedure will require the addition of an OST bypass line and two isolation valves in addition to an IST isolation valve. Also, an additional 24,500 kg (54,000 lb) of salt must be retained in the OST above the nominal half-full level at shutdown. Once the cavity temperature approaches 316°C (600°F) following the two drains, the heat loss rate will be approximately 570 kW.

Auxiliary Heating Options

During short operating days and nonoperating periods, an additional means of heating the panels must be provided. The daily requirements are shown in Table H.1, assuming two 36,300 kg (80,000 lb) fills/night from the OST.

Table H.1 Auxiliary Heating Requirements

Month	Cavity Heating Period (h/day)	Wing Heating Period (h/day)
June	0	10.1
May, July	0	10.3
April, August	0.9	11.1
March, September	2.0	12.2
February, October	3.1	13.3
January, November	4.2	14.4
December	4.6	14.8

For the purpose of estimating parasitic requirements, 60 nonoperating days were assumed per year. The following methods of providing supplementary heat to the receiver cavity were evaluated:

- Trace heaters attached to the absorber tubes
- Radiant panels located in the receiver floor
- Immersion heaters in the surge tanks
- Fired heaters in the surge tanks
- Circulating salt through a tower-mounted fired heater.

Because of the heat transfer area required, the length of a fired immersion heater [6 m (20 ft)] made this concept impractical and it was not considered further.

Electrical immersion heaters were sized to increase the temperature of 72,600 kg (160,000 lb) of salt in the OST from 316 to 454°C (600 to 850°F) in 3.5 hours. The inventory would be cycled between the surge tanks requiring heaters in both

vessels. This concept has several disadvantages. The heaters must be oversized to provide thermal conditioning capability for short or nonoperating days. Inefficient operation would result if early morning shutdown occurs. Salt will have been heated to 454°C (850°F) in the IST and be ready to fill the receiver following the use of 566°C (1050°F) salt from the OST. In the event that afternoon sun becomes available, the energy would be wasted. For these reasons in addition to high cost, this concept was also rejected.

The remaining concepts were examined in detail and compared.

- Electric Trace Heaters. This is the most thermal-efficient concept with trace heaters attached to the absorber tubes. The heaters were sized to provide approximately 300 kW to the cavity panels. The heaters would be factory installed; however, the major disadvantage of this concept is the inaccessibility of the heater elements after the receiver is installed.

- Floor-Mounted Radiant Heaters. Initially, reflecting heaters were rejected because of polishing requirements, as were fragile quartz lamps. Flat resistance heaters with woven refractory cloth (black ceramic coating) were examined. Chromalox heaters with an emitted temperature of 871°C (1600°F) provide 25 W/in². This corresponds to a peak emission wave length of 2.5 μm. (The reflectivity of the receiver coating does not vary significantly from the effective solar wave length up to this value.). The heaters were sized to provide 500 kW and were configured as shown in Figure H.3. A thyristor power controller was chosen over magnetic step controllers because of the low reliability associated with mechanical contactors. Obviously, high temperature wiring with ceramic insulation will be required.

  The major advantage of this concept over trace heating is that maintenance should be relatively simple because of the accessible location in the receiver floor.

- Salt Circulation Through Fired Heater. The final concept evaluated involves installing a tower-mounted gas-fired heater in parallel with the receiver inlet line (Figure H.4). One of the pumps in the drain sump would be upgraded to provide the required flow and a return line installed to the sump. Following the two-batch drains from the OST, salt would be continuously pumped through the heater and delivered to the receiver at 318°C (605°F) until start-up. A 440-kW salt heater is required along with a vertical pump.

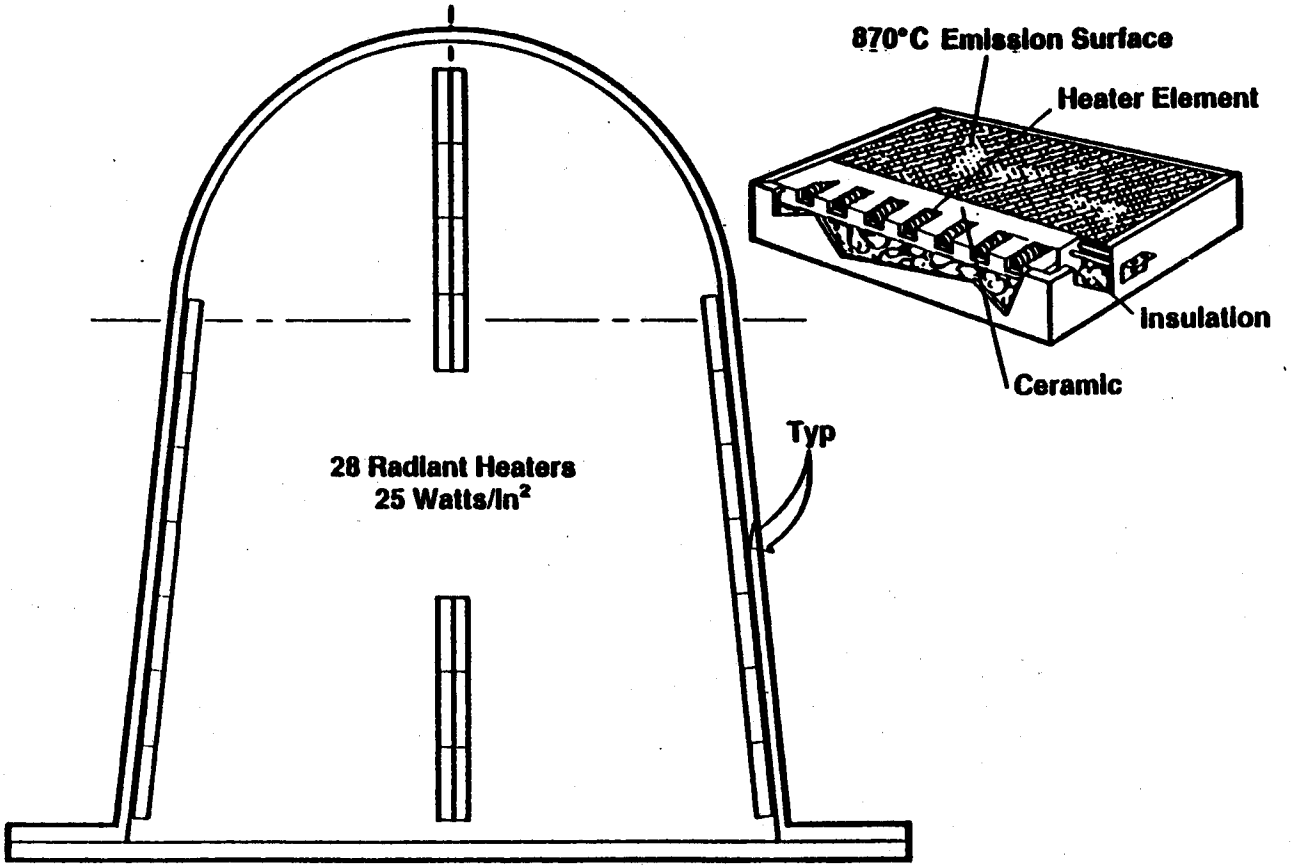

Figure H.3 Radiant Heater Concept

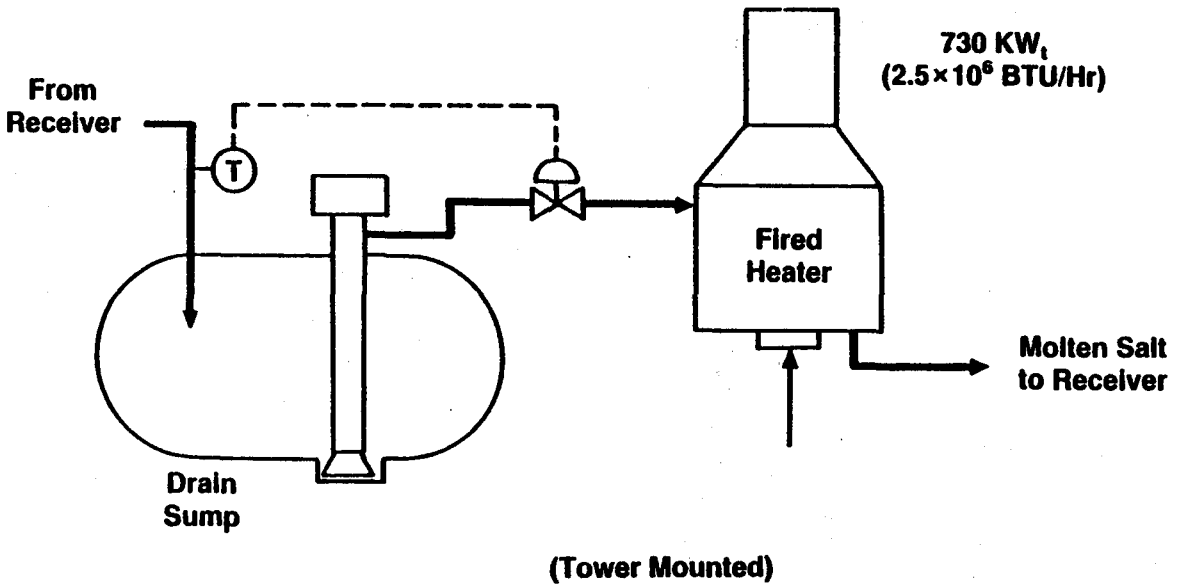

Figure H.4 Fired Heater Concept

Concept Comparisons and Selection

The concepts are compared in Table H.2 according to capital cost, weight, operating cost, maintainability, and disadvantages. The initial costs include material and installation estimates. Operating costs assume electricity at $0.07/kWh, gas at $3.7/1000 ft^3 and maintenance at 2 percent of capital. The annual operating costs for either heating concept is based on the operating periods given in Table H.1.

Of the three final concepts evaluated, the radiant heaters have the lowest initial cost, weight, and maintenance. However, the low operating cost of the fired heater allows a rapid recovery of the high capital cost. Due to the conservative nature of the analysis, it is felt that the operating periods will not be as severe as estimated. In other words, the receiver may not cool down as fast, especially if attention is paid to efficient seal designs. Also, there is some complexity associated with the operation of a fossil heater, pump, and valves that is not present with the radiant heaters.

Separately installed trace heaters on the wings will be activated at 288°C (550°F). Design specifications are for 37.5 kW on each wing. They will be oversized and operated at a lower voltage to increase reliability.*

*Final receiver configuration does not require trace heaters in the wing panels (Section 4.3).

Table H.2 Comparison of Overnight Conditioning Concepts

	Cost ($1000)	Weight (Lb)	Operating Cost ($1000/yr)	Maintain-ability	Disadvantages
1. Panel Tracing					
Heaters	28				1. Attachment Difficult
Control	4				2. Reliability
Misc	3	2000	64	Difficult	3. Inaccessible
Installation	10				
	45				
2. Radiant Heaters [Selected Concept]					
Heaters	18				1. Exposed During Normal Operation
Control	8				
Misc	4	1000	77	Easy	2. Highest Operating Cost
Installation	2				
	32				
3. Fired Heater					
Heater	60				1. Highest Initial Cost
Pump	10				2. Impact On Tower
Piping, Valves	28	4000	21	Moderate	3. Not usable For Cold Start
Control	(Inc.)				
Installation	20				
	118				

CASE B--RECEIVER WITH DOOR, DRAINED AT NIGHT USING HELIOSTATS FOR START-UP

The primary purpose of the door, in this concept, is to protect the receiver in emergency conditions since the receiver will be drained. The capital and operating cost of heaters from Case A would be eliminated and savings would be realized with less stringent design requirements on the door. If the door is closed with the receiver drained, the cavity will cool to 35°C (95°F) in approximately 7 hours (Figure H.1) so that morning warmup will occur from an ambient condition. Using approximately one-eighth of the heliostat field and an additional 100 heliostats focused on the wings, the receiver panels will heat up at different rates. Figure H.5 shows that by the time the coolest panel reaches 288°C (550°F), the hottest panel temperature will be 485°C (905°F). This occurs 14 minutes after the start of preheat. Utilization of more heliostats leads to an overly rapid heatup of the hottest panels with serious possibility of panel temperature in excess of 538°C (1000°F) prior to salt fill being achieved. Based on a 14-minute warmup, 5-minute fill, and 5 minutes before all heliostats are on the filled receiver, a start-up delay of 19 minutes will result in the loss of 1.3 percent of the annual collected energy (Figure H.6). This penalty will offset any savings realized from eliminating heaters and softening door requirements.

CASE C--RECEIVER WITH DOOR, DRAINED AT NIGHT USING HEATERS FOR STARTUP

As in Case B, the door is primarily a protective device. Again the receiver will be drained at night but heaters will be used to condition the panels before they are filled prior to start-up. Assuming the baseline heaters, the cavity will heat up from ambient to 288°C (550°F) in 9 hours (Figure H.7).

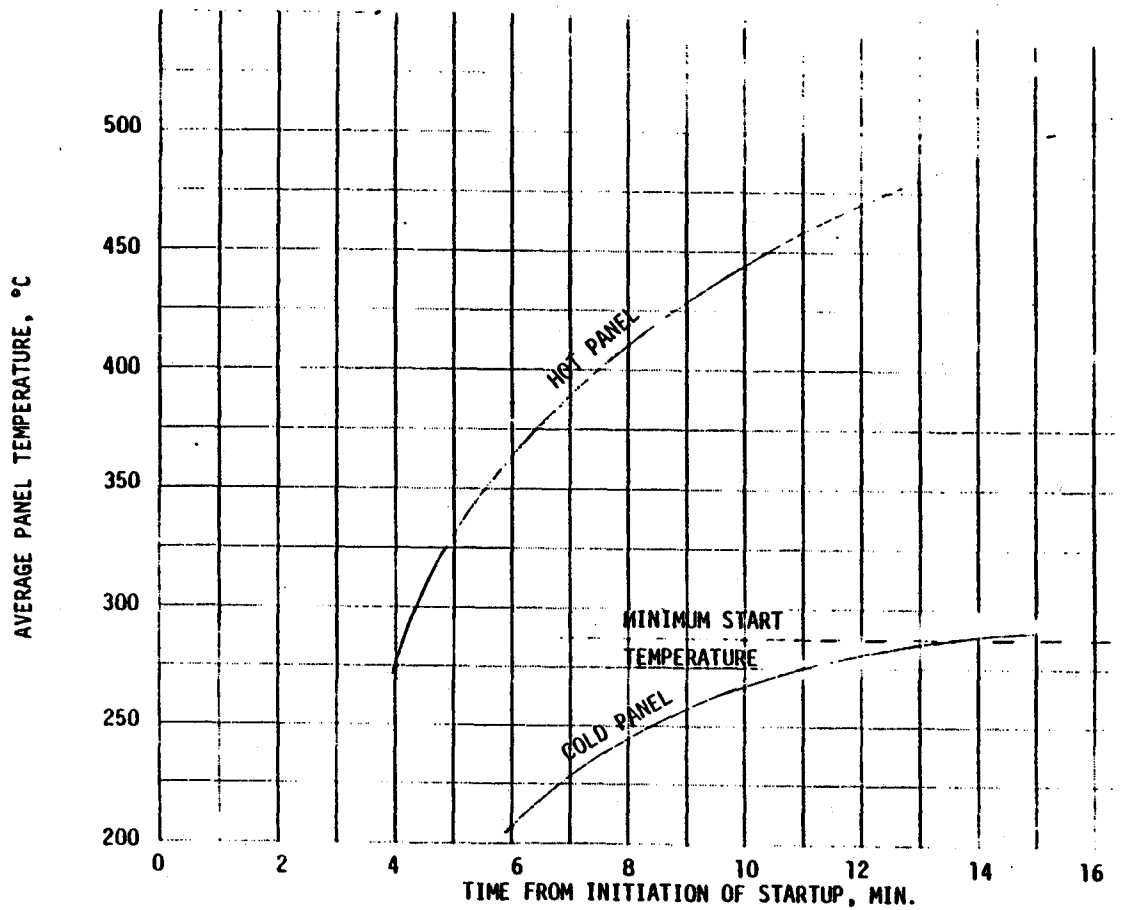

Figure H.5 Absorber Preheat Using Heliostats

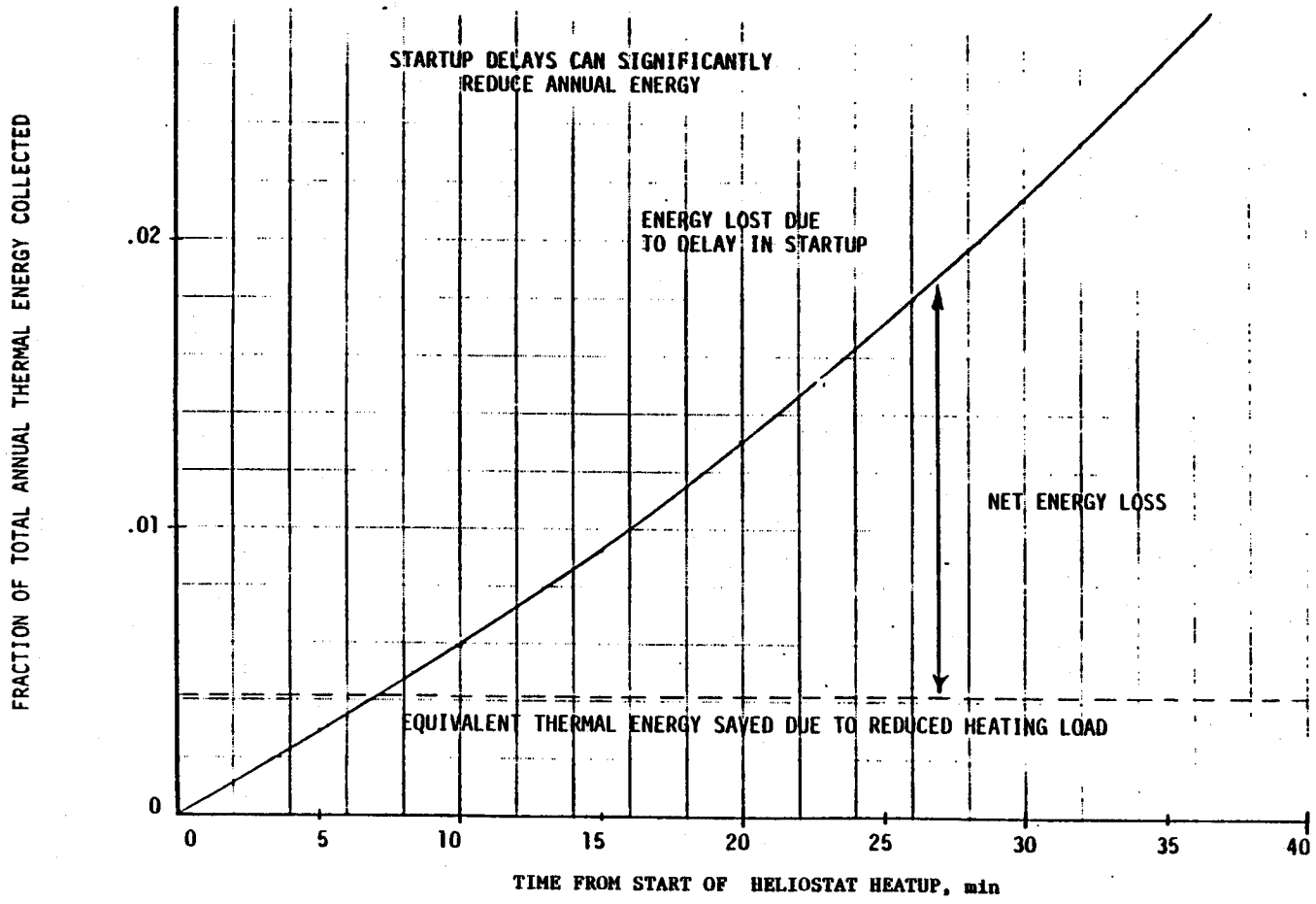

Figure H.6 Startup Time Delay--Heliostat Preheat

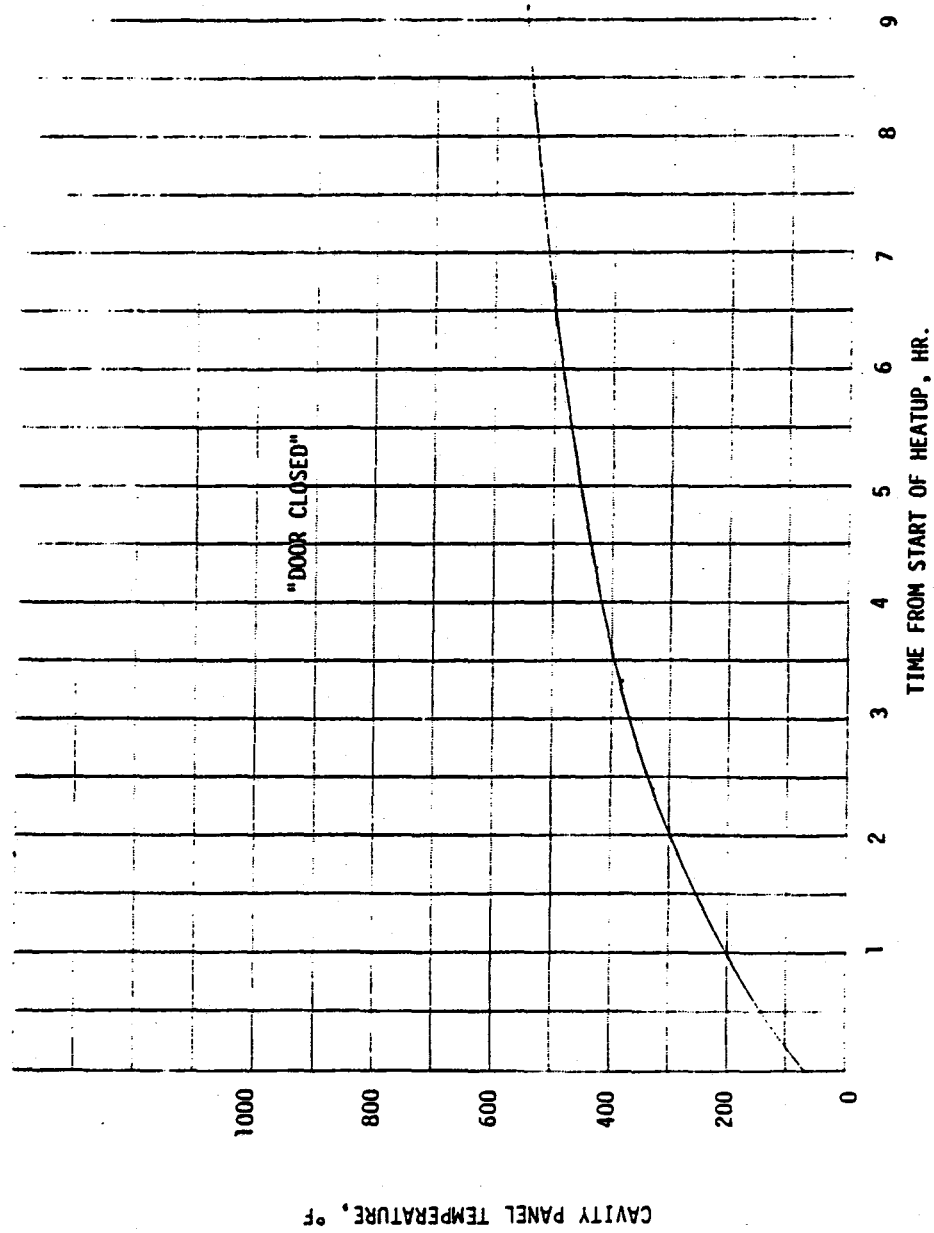

Figure H.7 Absorber Preheat Using Radiant Heaters

CASE D--RECEIVER WITHOUT DOOR

If a door is not used, there is no alternative but to drain at night and use the heliostats to preheat the receiver before fill each morning. Although the electricity saved by eliminating heaters amounts to 0.4 percent of the annual collected energy, the energy lost by postponing start-up by 19 minutes is 1.3 percent. The capital cost of the door would be nearly offset by the requirement to provide a larger surge tank or uninterruptible power supply for emergency power loss.

SELECTED APPROACH

The baseline concept (Case A) was selected which utilized both a door and heaters. Annual energy differences are not large, provided that the system availability penalties are equivalent. Specifically, it is felt that the major impact on annual energy will be due to time lost due either to door problems in the heated case and fill problems in the unheated case. While door availability has not been assessed, the panel preheat analysis has shown that substantial differences in panel temperatures are likely for a partial cavity configuration and that a slow and careful heatup will be required to preheat the panels in a safe manner. Further, it is realistic to expect some fraction of operating time beyond initial morning hours will be lost due to inability to fill. Final resolution of this trade study appears ultimately to depend on the door availability estimates.

APPENDIX I

DESIGN ANALYSIS PLAN

MOLTEN SALT RECEIVER SUBSYSTEM RESEARCH EXPERIMENT

Prepared for
Sandia National Laboratories
Solar Components Division
Livermore, California

December 1981

Revised: January 1982

Sandia Contract: 84-2292C
FWSDC No.: 9-71-9203

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION
12 Peach Tree Hill Road, Livingston, New Jersey 07039

TPS 81-S13

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Section 1. INTRODUCTION

This document constitutes the subsystem and component Design Analysis Plan (DAP) for the Molten Salt Receiver Subsystem (RS). The DAP will be reviewed and approved by Sandia National Laboratories, Livermore (SNLL) before the detailed analysis of the subsystem and components is begun. The objective of the plan is to define the required thermal/hydraulic and structural analyses and to show the sequence in which they will be performed and their interrelationships. Governing design criteria will be identified, along with computer codes and correlations to be used.

The RS configuration as described in Foster Wheeler Solar Development Corporation's (FWSDC's) Molten Salt RS proposal[1*] forms the baseline for this DAP. The analysis will show that the RS satisfies the RS Requirements Specification.[2]

Guidelines and procedures in the DAP will be used to demonstrate compliance with the requirements of the RS. Methods of analysis are given and types of documentation required are described.

The RS design will not be optimized. The selected design characteristics defined in Task 3 will be retained unless the selected design is proved to be inadequate or marginal, or unless changes will reduce cost or improve schedule.

Primarily, the DAP is limited to the RS major components and constitutes the minimum effort required to demonstrate by analysis that the selected design complies with the design requirements.

Design criteria generally acceptable to the A/E industry will be used for hardware selection to avoid detailed analyses for components, lines, and structural members whenever service requirements for the RS are similar to normal A/E requirements.

*Numbers designate references at the end of this DAP.

Section 2. DEFINITION OF RS

The RS provides a means of transferring the incident radiant flux energy from the Collector Subsystem (CS) into the molten salt working fluid. The RS consists of an elevated receiver to intercept the radiant flux from the CS, the tower structure to support the receiver, the riser pipe from the ground to the receiver, and the downcomer pipe from the receiver to the ground. The RS also includes the pumps, valves, and control system necessary to regulate fluid flow, temperature, and pressure and the required thermal control necessary for its safe and efficient operation, start-up, shutdown, and standby.

The RS defined in this Plan includes the following:

- The tower and its foundation
- The structural receiver supports
- The molten salt pumps
- Riser and downcomer piping
- Shop-fabricated modular absorber panels
- Inlet and outlet surge tanks mounted with the receiver atop the tower
- Interconnecting piping and valves for panels, surge tanks, and other salt equipment mounted above the top of the tower and connected with the riser outlet and downcomer inlet
- Instrumentation and controls
- Thermal insulation and sheathing
- Drain system
- Trace heaters
- Aperture door and door-actuating mechanism
- Service crane

- Service elevator
- Ancillary equipment including:
  - Compressed air
  - Electrical power distribution (e.g., wiring, transformers, outlets)
  - Other as required.

Section 3. ANALYSES

The DAP consists of five major subtasks:

- Operation Analysis
- Thermal/Hydraulic Analysis
- Structural Analysis
- Mechanical Design
- Control Analysis.

The subtasks are discussed in detail in the following sections. The flowchart shown in Figure 1 gives an overview of the design analysis process. The program schedule is shown in bar-chart form in Figure 2. The Plan is limited to items listed in Section 2.

The analytical techniques and results of the design analyses as described in this Plan will be summarized in a final report of the analyses, which will be submitted for SNLL's review and approval. The outline for the final report will consist of all the elements listed as major topics in the DAP Contents.

Informal interim reports will be submitted as necessary to inform SNLL of significant analytical results or problems. The status of all existing receiver analyses will be specifically reviewed during the planned RS Midterm Design Review Meeting.

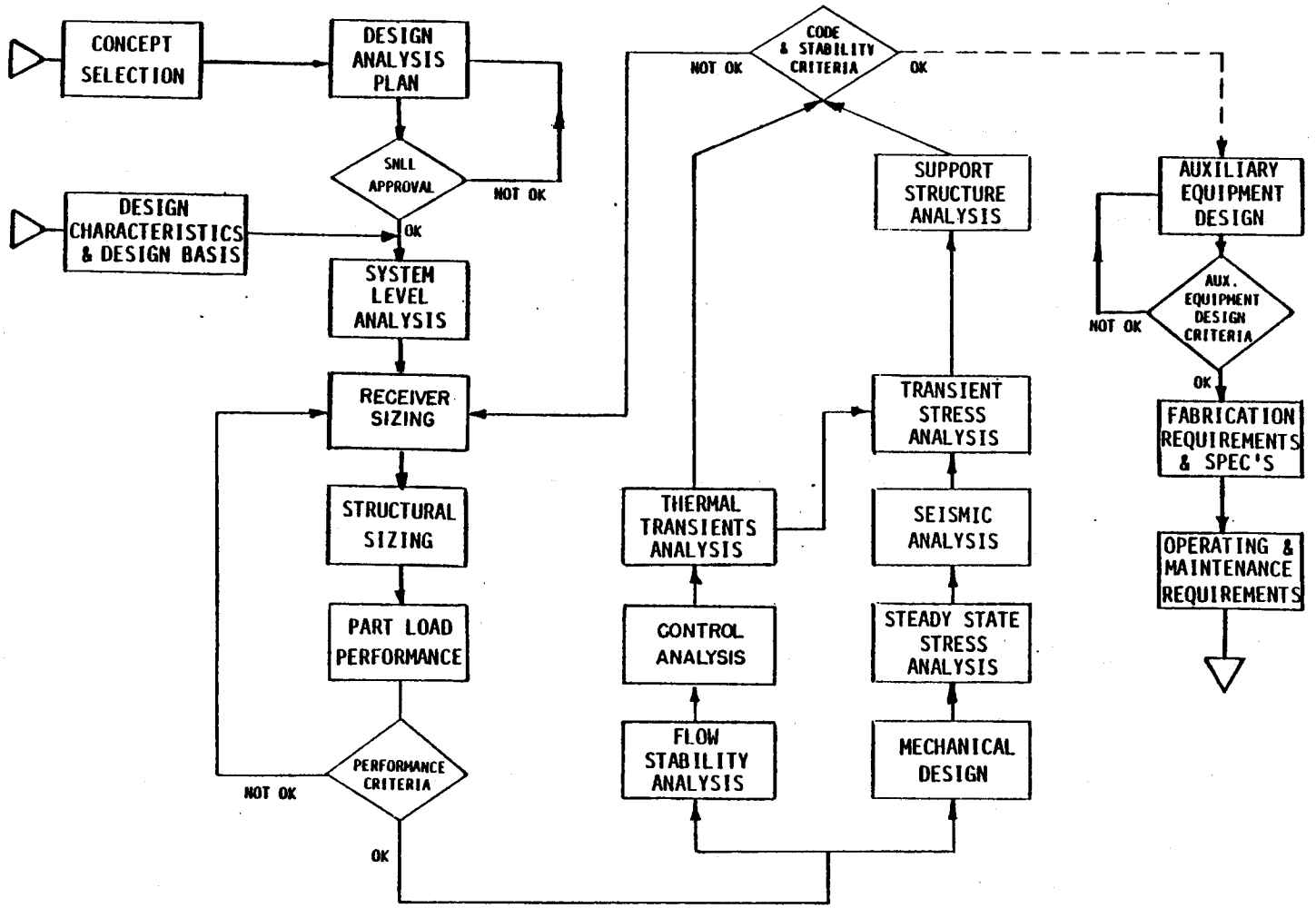

Figure 1 Flowchart--Design Analysis Process

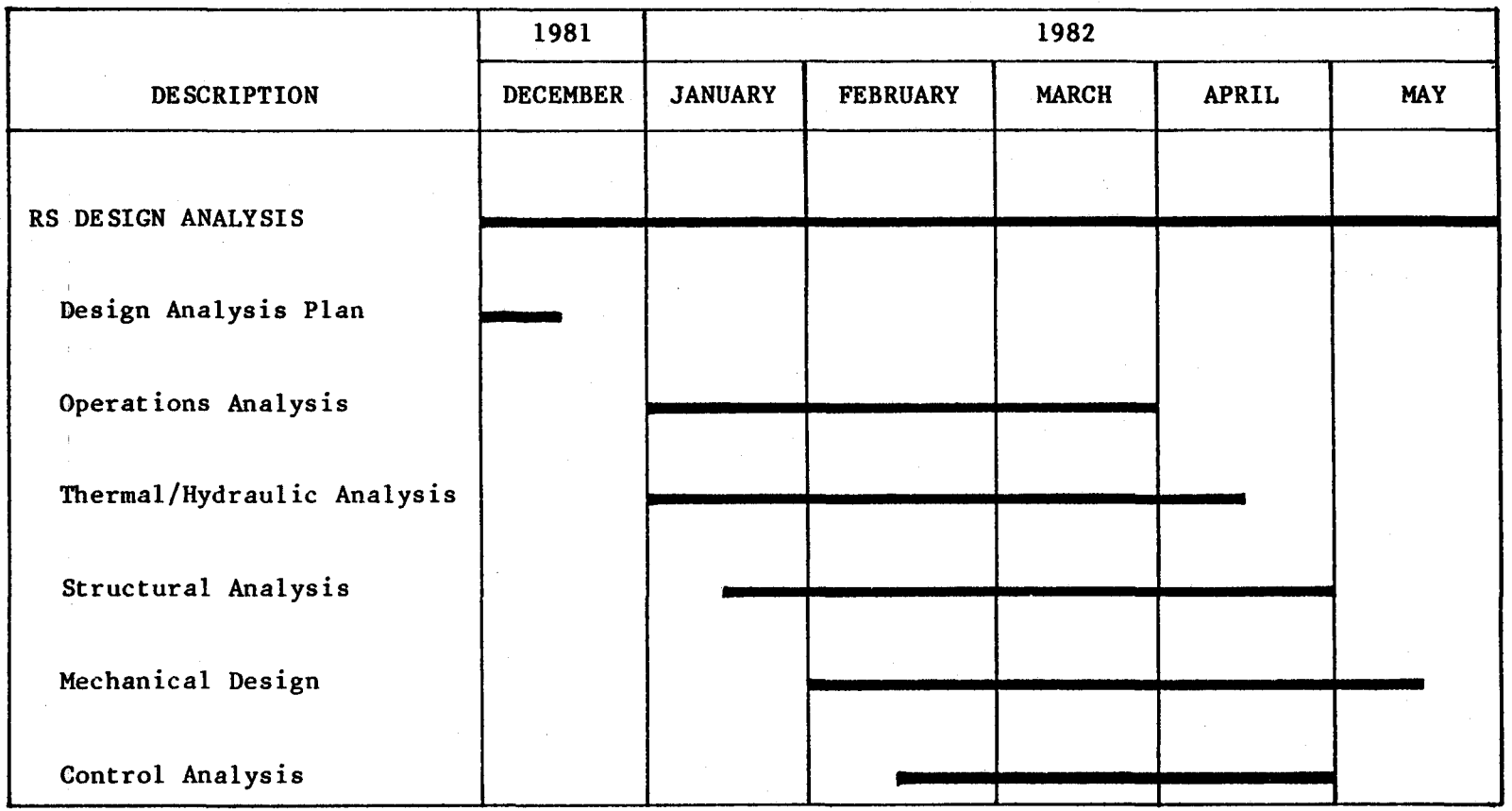

Figure 2 Program Schedule

Operations Analysis

The operations analysis will define the basic operation of the RS. Our approach to this analysis consists of sequencing the activities within the RS that will be required to control and operate the receiver throughout its operating range. Starting with the RS Piping and Instrumentation Diagram (P&ID), we will trace the progress of flows and flow control as the RS moves through cold start-ups and shutdowns, normal daily and overnight operation, and emergency operation. For overnight and warm standby operation, we will size and define thermal conditioning equipment. Finally, using the results defined above, we will investigate the implications of component failures to define requirements for interlocks, alarms, and the data to be supplied to the operator.

Sizing and Definition of Auxiliary Equipment for Overnight Conditioning

These analyses include the following:

- Estimation of losses from the receiver:
  - Convection losses from exterior surfaces using the Achenbach correlation
  - Heat losses caused by flows through gaps in the door
  - Conduction loss estimates based on simplified one-dimensional heat conduction to exterior surfaces that are cooled convectively
  - Internal heat transfer from the panel surfaces to the doors, both transient and quasi-steady-state values
- Estimation of usable thermal energy in hot salt surge tank to maintain receiver temperature
- Receiver temperature
- Sizing and definition of auxiliary equipment
  - Insulation
  - Trace heaters
  - Recirculating pumps, if required
  - Other equipment, if required.

Definition of Control Variables and Control Parameters

This analysis will identify the sensors and signals to be used to control the receiver when the receiver doors are closed and during start-up and shut-down transients before active control associated with normal solar operation (including cloud effects). Receiver control during these operations will be addressed in Task 4.6.

The primary effort will be aimed at identifying sensor locations that will be most effective in ensuring freeze protection. Analyses of heat transfer from trace heaters to the salt tube front wall and from salt flows will be used to check temperature distributions and sensor requirements.

Definition of Sequence of Events and Preliminary Time Lines

These analyses will be based on P&IDs and will identify valve, pump, door, and heliostat sequences associated with receiver operations. Also identified will be control ramps and handovers (e.g., switch from constant receiver flow control to receiver outlet temperature control).

Definition of Interlocks, Alarms, and Operator Data Requirement

Using the sequence and time-line data, the implications of out-of-sequence activities and failures will be used to identify requirements for interlocks, alarms, and operator data (particularly the need for trouble-shooting information).

Thermal/Hydraulic Design Analysis

This subtask consists of performing steady-state and transient thermal/hydraulic designs and analyses of the RS, sizing the RS components and evaluating their performance characteristics, and calculating the receiver efficiency. Part-load performance will be predicted for differing load conditions. Proper flow distributions will be calculated, particularly those affected by flux gradients on the absorber surface. Their effects on flow stability, tubewall temperature, and variations in tube-outlet temperature will be estimated. The analyses will define the requirements for thermal protection.

The major thermal/hydraulic analysis tasks to be performed are:

- Full load
- Stability
- Transient
- Performance.

Full Load

Thermal/hydraulic design and analysis will include establishment of appropriate design bases, preliminary sizing and design, performance predictions, and the necessary analyses to substantiate the selected design.

The design bases include thermal/hydraulic design conditions, thermophysical properties, and heat-transfer and pressure-drop correlations. Based on the requirements and specifications developed in Task 2, full-load design conditions will be defined for sizing the RS components.

The receiver will be sized using an in-house computer program (SOLAR) that requires the following inputs:

- Solar heat-flux maps at the receiver walls
- Inlet temperatures, pressures, and flow rates

- Physical properties of tube material and working fluid
- Tube diameter, thickness, and spacing
- Circuit arrangement and flow orientation.

The program performs a one-dimensional thermal analysis of a single tube within a receiver panel. The tube is divided into nodes along its length. The panel inlet conditions and the absorbed heat flux at the first node are used to calculate the temperature of the salt leaving the node. The tube-to-salt heat-transfer coefficient is calculated based on the average salt temperature using the Dittus-Boelter correlation. Once the heat-transfer coefficient has been calculated, the inside tubewall temperature is found using the Fourier heat-transfer equation for radial heat flow. Using the conductivity and wall thickness of the tube and the Fourier conduction heat-transfer equation, the outside tubewall temperature is calculated based on the inside tubewall temperature. The outlet salt temperature calculated for Node 1 is used as the inlet salt condition for Node 2 and the calculations are repeated as above. The calculation continues through all nodes, finally giving the outlet salt temperature.

The pressure drop of the salt through a tube will be calculated from a modified Bernoulli equation in one dimension using friction factors obtained from the Moody Diagram. The pressure drop through each node is calculated based on local salt conditions. The sum of the individual pressure drops gives the total tube pressure drop.

Salt properties will be calculated from equations obtained from Sandia Laboratories.

Full-load performance will be evaluated. The maximum nominal salt and tubewall temperature profiles along the tube length will be calculated, considering the effects of flow distribution, heat-flux variation, and tubewall thickness tolerance and the uncertainties in thermal/hydraulic design parameters such as heat-transfer coefficients, fouling factors, salt properties,

and tubewall thickness. The pressure drops through all components will be calculated, and the drops across the RS as a whole will be summarized.

Flow distribution through the tubes in a panel is determined by an iterative technique. The tubes that experience the highest, average, and lowest heat flux within a panel are used for the analysis. The flow in each tube is adjusted until the calculated pressure drops through the tubes are equal to each other, with the total flow kept constant. The pressure drop calculations are the same as those used in SOLAR.

A similar technique is used to obtain the flow distribution among separate panels connected to a common header. In this case, representative tubes from each panel are used for the flow distribution iteration.

Working fluid circuits will be arranged and apportioned for optimum thermal/hydraulic performance with due consideration for part-load operation. We will establish maximum allowable transient heating and cooling rates and will define the minimum operating flow rates.

Computed spillover losses from the receiver/collector and conduction losses from the receiver panels will be used to determine the heating effects on components installed within the tower and on structural parts of the tower. Analyses will be performed to determine the necessity for thermal insulation and protection of components and structures. The effects of thermal expansion of critical component supports and tower structural members will be considered for input to the stress analysis.

Stability

The possibility of static instability under operating conditions will be analyzed. The "Ledinegg"-type static instability analysis will be performed using a computer code that calculates tubeside pressure drops at various loads.

Static instability is an amplification of steady-state disturbances that encompass tube-circuit configurations, heating imbalances, and flow-rate perturbations. The static instability of primary importance is the Ledinegg excursive instability. A flow is subject to a static instability when the flow, changed by a small perturbation, will not return to original steady-state conditions. Using results from the SOLAR program, we will plot the pressure-drop vs. flow characteristics of the tubes within a panel that experience the highest and lowest heat flux to find out whether there will be any static instability. The operating point is stable if the derivative of the pressure-drop flow-rate curve is positive. It can be expressed as follows:

$$\delta\Delta P/\delta W > 0$$

where

W = Flow rate

ΔP = Pressure drop

If static instability occurs, the receiver design will have to be reevaluated, Inlet orifices may be required or the design may have to be changed to create the salt flow conditions needed to eliminate the unstable flow.

Transient

Transient responses to the various operating modes and upset and emergency conditions will be assessed. A detailed transient analysis, which requires extensive effort in computer modeling, is beyond the scope of this study. In connection with the control analysis, we will perform a simplified simulation of panel transients. The assessment of transient responses will be based primarily on the receiver heat capacities and the experience gained from previous receiver designs.

The thermal transient analysis will provide the fluid temperatures, pressures, and heat-transfer coefficients required for the transient stress analyses of the critical receiver components identified in Section 2. Receiver inlet and outlet salt temperature and pressure changes as a function of time will be identified. Based on these values, we will determine heat-transfer coefficients as a function of time. The computed inlet and outlet time-dependent parameters will be applied to the critical component for the transient stress analysis.

Analyses will be performed to determine limiting transient rates on critical components between the minimum and maximum defined operating power levels. The allowable heat-up and cool-down rates for critical components during limited operation will be defined.

Performance

We will analyze the receiver losses from conduction, convection, reflection, and reradiation and, using the results of these analyses, will calculate the receiver efficiency for both the design point and the annual average performance (i.e., net thermal energy delivered to thermal storage).

Receiver reflection and reradiation losses will be based on a TRASYS radiation analysis using temperature profiles on the panels estimated with a simplified flow-flux temperature analysis. Losses from natural convection will be determined using flat-plate natural convection correlations for external panels and the Abrams simplified model for cavity losses. To determine forced convection, we will use the Achenbach correlation for the external panels and for the cavity, with a weighting factor on effective cavity area. The combination of forced- and natural-convection heat-transfer coefficients will be based on a root sum square formula with an average wind velocity. Receiver conduction losses will be estimated with simplified one-dimensional heat conduction to exterior surfaces that are cooled convectively.

The annual receiver performance will be estimated using the McDonnell Douglas Corporation code CONCEN, with average monthly/daily insolation from

the Aerospace 1976 Barstow Model. In this analysis, receiver absorptivity will be treated as a constant; similarly, the radiation, convection, and conduction losses will be held constant over the plant operating time. Spillover losses will be calculated using CONCEN, which develops detailed flux profiles at the receiver by combining the images from individual heliostats. Because CONCEN will utilize the selected aim strategy, realistic spillover estimates will be obtained.

The thermal/hydraulic performance of the receiver will be computed for 25-, 50-, and 75-percent load, where load is defined as the fraction of the RS design load (320 MWt).

A complete energy and mass balance analysis will be performed for the RS. When performing the analysis, we will consider the limiting environmental conditions and operating modes defined in the RS Requirements Specification. The receiver performance analysis will be coordinated with performance predictions of interfacing subsystems to ensure that the receiver power output satisfies the performance specified in the RS Requirements Specification.

Analyses will be performed to determine heat losses so that proper thermal protection is provided on an overall subsystem basis. For these analyses, we will consider losses from, as well as losses to, components and structures so that subsystem performance and protection requirements are met.

Structural Design Analysis

In this subtask we will perform a stress analysis, including an elevated-temperature creep and fatigue evaluation. We will determine the stresses and strains developed in the receiver and support structure under normal and abnormal operating conditions and will ensure the structural integrity of the receiver by limiting those stresses and strains to the allowable values in Section VIII of the ASME Boiler and Pressure Vessel Code and other applicable design standards and criteria specified in Task 2.

During the life of the plant, the receiver and support structure will be subjected to various thermal and mechanical loads. The thermal loads consist of steady-state thermal gradients and start-up and shutdown transients. The mechanical loads include self-weight, pressure, external reaction, seismic, and wind loads. Thermal loads are cyclic in nature because of diurnal start-up, shutdown, and operating transients. The failure modes created as a result of these loads may include ductile rupture, creep rupture, fatigue failure, thermal ratcheting, buckling, and vibration.

The objective of the stress analysis is to ensure the structural integrity of the receiver within the requirements of the Design Specification, the ASME Boiler and Pressure Vessel Code, the Uniform Building Code (UBC), and other applicable codes and standards. There are no well-accepted criteria for creep-fatigue evaluation of solar components except those set forth in the ASME Code, (Section III and Code Case N-47). Because Section III and Code Case N-47 were written for nuclear components, their use in solar component design could lead to excessively conservative designs in some areas, and the receiver could suffer significant cost penalties. A Solar Energy Standards Committee appointed by the ASME is presently working on a Solar Code. Foster Wheeler team personnel are active on this committee. Foster Wheeler has also developed an "Interim Structural Design Standard for Solar Energy Applications,"[3] under contract from Sandia. Thus structural evaluation of the receiver in the high-temperature

regime will be guided by the rules of Code Case N-47, the consensus being generated by the Solar Energy Standards Committee, and the conclusions from the Interim Structural Design Standard. The structural analysis effort will consist of the stress analysis, evaluation, documentation, and reporting of key components of the molten salt RS. The major structural analyses tasks to be performed are:

- Structural sizing
- Steady-state stress
- Transient stress
- Seismic loads.

Structural Sizing

Preliminary components sizing calculations will be performed to establish the mechanical requirements for thermal/hydraulic performance. Using the requirements of the ASME Code, we will establish preliminary values for the following parameters:

- Tubewall thickness
- Header size
- Number of attachment lugs
- Interconnecting pipe size.

Final values for these parameters will be determined during the Mechanical Design subtask, defined in Section 5.

Steady-State Stress

Temperature distribution and thermal and pressure stress distributions in all critical elements of the receiver will be determined at steady-state operating conditions. The stresses will be calculated using simplified methods given in design handbooks and finite element programs ANSYS[4] and NONAX.[5,6]

ANSYS is a multipurpose finite-element program widely used in the nuclear power industry. It is capable of transient and steady-state heat-transfer analyses as well as static and dynamic stress analyses. Elastic, elastic-plastic,

and creep analyses can be done using this program. ANSYS contains many element types, such as beam, plane stress, axisymmetric solid, axisymmetric shell, general shell, and three-dimensional solid.

NONAX is a special-purpose program developed by Foster Wheeler Development Corporation to perform thermal and stress analyses on thick-walled cylinders made of homogeneous and isotropic materials. The loading may be axisymmetric or nonaxisymmetric. It may consist of an arbitrary combination of internal and external tractions, axial load, axial bending, and an arbitrary temperature distribution. Elastic, elastic-plastic, and creep analyses under varying load cycles and hold times can be done using this program. NONAX is considerably less expensive to run than a multipurpose finite-element program.

Transient Stress

Transient analysis of the receiver panels will determine the metal temperatures and stresses caused by start-up, shutdown, and cloud over. The finite-element program ANSYS will be used in this analysis. The results of the thermal/hydraulic transient analysis (i.e., the fluid temperatures, heat-transfer coefficients, and pressures as functions of time) will be the input in the transient stress analyses. The stresses will be evaluated using the fatigue curves of the ASME Code, Section VIII-Division 2 (for subcreep temperatures) and Code Case N-47 (for elevated temperatures).

Seismic

The receiver and support structure will be designed to withstand seismic loads corresponding to Zone 3 of the UBC. Simplified calculations will be used to determine the first and second mode frequencies. These will be combined with the response spectra given in NRC Regulatory Guide 1.60 and the damping factors given in NRC Regulatory Guide 1.61 to determine the seismic loads. These loads will be compared with the loads determined according to the UBC. The more conservative value will be used in the design. In the support structure, the stresses caused by earthquakes will be limited to the yield strength of the material. For the pressure boundary, the criteria of the ASME Code, Section VIII-Division 2, will be used.

Subsystem Mechanical Design Analysis

In this subtask we will prepare a preliminary design of the receiver, riser/downcomer piping, structural supports, surge and drain tanks, tower, and tower foundations and will select circulating pumps, valves, and controls. We will prepare subsystem and component-level design requirements and specifications and layout drawings for the RS in sufficient detail to allow preparation of a fabrication plan and estimation of the RS fabrication, shipping, construction, operating, and maintenance costs.

Engineering Drawings

In parallel with our activities in Subtasks 4.3 and 4.4, we will develop engineering drawings. Detailed plan, elevation, and cross-section engineering drawings of the receiver will be prepared. These drawings will cover pressure parts, insulation, casing, cavity doors and their supports, and supporting structure. All construction materials will be specified, together with the rationale for their selection. Weights and sizes of major receiver components will be tabulated. A piping and instrumentation drawing of the RS will be prepared, showing circuits, controls, and instrumentation. We will design the RS to drain completely.

Support Structure

The support structure will be designed to withstand all dead and live loads and loads caused by earthquakes, wind, and snow. Seismic stresses will be determined by an equivalent static-g analysis. The support structure design will satisfy the requirements of the UBC and the AISC Manual for the design of steel structures.

Tower

Engineering tradeoff studies and analyses will be conducted to select a preferred tower design. Consideration will be given to:

- Cost
- Height
- Accessibility
- Safety
- Materials
- Load capacity
- Deflection
- Accommodation of riser/downcomer piping
- Resistance to seismic loads.

A tower arrangement drawing will be prepared and design details of the tower foundations will be developed.

The tower assembly and all attached associated components will be designed to withstand the forces and loads induced by the operation of all attached RS equipment; by environmental conditions such as seismic loads, wind loads, rain; and by transportation described in RS Requirements Specification. The assembly will be designed so that these forces and loads do not induce conditions that exceed the structural capability of the assembly hardware.

The design parameters will include, but not be limited to, the following:

- Dead loads
- Live loads (including crane and elevator loads)
- Loads from attached piping and equipment
- Wind loads (steady-state and gusts)
- Seismic loads - static (equivalent lateral force) and dynamic (ground-response criteria)
- Stiffness requirements

- Absorber thermal restraint loads
- Insolation spillover impingement
- Handling/hoisting loads
- Stiffness requirements backup structures.

Miscellaneous

Riser and Downcomer Piping -- In the design of the riser and downncomer piping, we will consider:

- Salt pressure, temperature, and flow rate
- Line size vs. pressure drop
- Heat losses
- Materials
- Ease of installation, maintenance and support
- Thermal expansion
- Access to receiver
- Reliability
- Life
- Cost.

The piping will be analyzed for dead weight, pressure, wind, seismic, and hanger loads.

Salt Pumps and Valves -- Salt pumps, valves, and other equipment will be selected and specified after consultation with vendors. Type, number, cost, and power requirements of the pumps will be considered. Parasitic pumping power, heat loss, and cost will be estimated for the fluid transport system.

Insulation and Heat Tracing -- Insulation and heat-tracing requirements for the entire RS will be determined and specified, consistent with the receiver conduction loss computed in Subtask 4.3. Reflecting Martin Marietta Corporation experience at CRTFF, we will provide weatherproofing of exposed insulation and select trace heaters that eliminate problems of quality control and overheating of heater junctions.

Control Analysis

This subtask addresses the analysis and design of control loop configuration, receiver protection, and interlock logic functions. In addition, the hardware implementation methods and corresponding software implications will be developed.

The major portion of the task will be devoted to development of control loop configuration for receiver coolant temperature control. Using baseline process definition, computer models of the process will be developed. These models will include simulations for absorber panels, interconnecting piping, surge tanks, riser, downcomer, pumps, control valves, controllers, and sensors. Control configurations will be postulated and nominally tested through process simulation to develop a baseline control system. This baseline simulated system will then be tested over the range of insolation, flow, and other operating conditions expected and will be iterated as required to develop an updated baseline.

Development of logic requirements for a stand-alone protection function as well as for its implementation will be pursued along with the necessary interlock logic function.

The instruments and controllers necessary to meet the control and logic requirements will be defined, as will the related software implications.

Control Loop Design and Analysis

The following will be accomplished:

Requirements -- A set of basic receiver control requirements will be developed in conjunction with activities in Tasks 3.1 and 3.3.

- Steady state and transient coolant temperature
- Steady-state and transient (cloud) effects) panel flux levels
- Turndown ratios
- Fluid path logic during long-duration low-flux conditions.

Process Definition -- The process will be quantitatively defined by developing the appropriate mathematical equations. Assumptions and simplifications will be listed.

We will build a computer simulation of the process based on the math models developed. (The simulation will be constructed in such a way that run data for a variety of external and internal conditions can be easily obtained.)

Control Design -- Existing data available from salt receiver tests at CRTF, Solar I design data and methodology, and other in-house receiver analysis and control activity will be reviewed for background and possible use.

We will postulate a coolant temperature-control configuration using the baseline receiver flow path configuration and test against the process simulation--first, with no flux determination feed-forward and second, with flux determination feed-forward--and we will iterate this process until nominal performance is adequate.

A baseline simulation configuration of control algorithms and instrumentation functions will be defined.

Performance Analysis -- We will operate the baseline simulation configuration of process and control over the required range of panel fluxes and flow levels, steady state and transient, and iterate the design as necessary to develop a final baseline.

Protection and Interlock Logic

Protection Logic -- We will develop the conceptual requirements for a stand-alone receiver protective function, including such parameters as coolant temperature, cessation of coolant flow, door position, and panel temperatures, and will develop representative logic diagrams, implementing the protective function requirements.

Interlock Logic -- The conceptual requirements for the interlock logic system, including such parameters as door position, heliostat commands, and pump signals, will be developed.

Hardware Selection

Instruments -- As a result of the analyses conducted during "Control Loop Design and Analysis" and "Protection and Interlock Logic," we will define any special requirements for instruments such as fast response, unusual accuracy, and difficult operating environment.

Controllers -- Using the baseline configuration developed during "Control Loop Design and Analysis," representative controllers to develop cost data for mechanized control will be defined.

Plant Logic -- Using the representative logic diagrams developed in "Protection and Interlock Logic" for receiver protection and interlock logic, we will define implementation sufficiently to develop cost data for mechanized logic.

Software Approach

Based on the hardware selection, a software approach will be developed that includes a programmable device configuration generation, sufficient for cost estimation.

Section 4. REFERENCES

1. Foster Wheeler Solar Development Corporation, "Molten Salt Solar Receiver Subsystem Research Experiment," Vol. 1 - Technical Proposal, prepared for Sandia Laboratories, RFQ 84-2292, FWSDC No. 9-91-9509, May 15, 1981.

2. Foster Wheeler Solar Development Corporation, "Subsystem Requirements Specification: Molten Salt Steam Generator Subsystem Research Experiment," prepared for Sandia National Laboratories, Sandia Contract No. 20-9909B, FWSDC No. 9-71-9202, September 1981.

3. I. Berman, et al., "An Interim Structural Design Standard for Solar Energy Applications--Phase 1 Report," Foster Wheeler Development Corporation, prepared for Sandia Laboratories, Contract No. 87-9151, FWDC No. 9-41-441110, July 1978.

4. ANSYS Engineering Analysis System User's Manual, Swanson Analysis Systems, Inc., 1974.

5. M. S. M. Rao, T. V. Narayanan, and G. D. Gupta, "Inelastic Analysis of Non-axisymmetrically Heated Thick Cylindrical Shells," Transactions of the ASME, Journal of Pressure Vessel Technology, Vol. 101, 1979, pp. 235-241.

6. M. S. M. Rao, "NONAX - A Computer Program for Thermoelastic-Plastic-Creep Analysis of Thick-Walled Cylinders Under General Nonaxisymmetric Loading," Foster Wheeler Development Corporation, Report No. EST-78-5, 1979.

Appendix J

DESCRIPTION OF SOLAR COMPUTER PROGRAM

The thermal/hydraulic analysis of the receiver was made using an in-house computer program (SOLAR), that requires the following inputs:

- Heat-flux maps at the receiver walls
- Inlet temperatures, pressures, and flow rates
- Physical properties of tube material and working fluid
- Tube diameter, thickness, and spacing
- Circuit arrangement and flow orientation.

For the purpose of analysis each panel is divided into three regions (strips) with 17 nodal points (16 nodal elements) each along its length (51 nodes/panel, 1020 nodal points for the whole absorber surface). Incident heat flux values were specified for each nodal point in three columns per panel. The center column applies to the center half of the panel width; the left and right columns apply to the left and right quarters of the panel.

Normal incident heat flux values, multiplied by an absorptivity factor to account for reflection, reradiation, and convection losses are used by SOLAR to determine the nodal element absorbed power and salt bulk temperature change within the element. Absorbed power in each element is determined from the product of the average normal absorbed heat flux and the flat projected element area. Peak heat flux values are obtained by increasing the normal heat flux values by an enhancement factor that accounts for nonuniform heat flux distribution around the tube

(Section 4.3.11). The peak incident heat flux values are used by SOLAR to calculate tubewall and salt film (I.D.) temperatures.

SOLAR performs a one-dimensional thermal analysis of a single tube within each panel strip.* Using the normal and peak absorbed heat flux values, inlet salt bulk temperatures and flow rates, salt and tube material properties, and panel geometry, the program evaluates the left, center, and right tubes in each panel. Tubewall and salt temperatures are calculated at each nodal point; absorbed power, salt bulk temperature change, and frictional and gravitational pressure drops are calculated for each nodal element. The panel inlet salt conditions and the absorbed heat flux at the first nodal element are used to calculate the temperature of the salt leaving the element. The outlet salt conditions from the first element are used as the inlet salt conditions for the next element, and the calculation is repeated. The calculation continues upward through all element, finally giving the outlet salt temperature of the panel.

SOLAR can perform T/H analysis for all five passes continuously, one after the other, using the outlet conditions of the previous pass as inlet conditions for the next pass.

Depending upon the flow regime (laminar, transitional, or turbulent), one of three equations is used to estimate the molten salt heat-transfer coefficient, h.

*Tubewall temperatures calculated by SOLAR were less than 5°C (9°F) higher for the symmetric and unsymmetric heat flux cases than the temperatures calculated using the two-dimensional model described in Section 5.3.3.

In the laminar flow region (Reynolds Numbers less than 2100), the Sieder-Tate equation[1] is used.*

$$h = 1.86k(RePrD_i/L)^{1/3}(\mu/\mu_\omega)^{0.14}/D_i \tag{1}$$

The maximum value of h allowed in this flow region is calculated by:

$$h_{max} = (2wC_p)/(\pi D_i L) \tag{2}$$

If the value of h calculated by Eq. (1) exceeded this value, h is set equal to h_{max}.

In the transition flow region (Reynolds Numbers between 2100 and 10,000), the Hauzen equation[2] is used:

$$h = 0.116k(Re^{2/3} - 125)(Pr)^{1/3}(\mu/\mu_\omega)^{0.14}\,[1 + (D_i/L)^{2/3}]/D_i \tag{3}$$

In the fully turbulent flow region (Reynolds Numbers above 10,000), the Dittus-Boelter equation[3] is used:

$$h = 0.023k(Re)^{0.8}(Pr)^{0.4}/D_i \tag{4}$$

The inside tubewall temperature (or film temperature) is determined from the following equation:

$$T_i = T_b + q/h \tag{5}$$

Nomenclature is given on Page J-5; references on Page J-6

The temperature drop through the wall is determined by:

$$\Delta T = T_o - T_i = qD_o [\log (D_r)]/2k_m \quad (6)$$

The tubewall thermal conductivity data for Types 304SS, 316SS and Incoloy 800 is related to temperature by an equation of the form:

$$k_m = a + bT_m + cT^2m \quad (7)$$

Using Eqs. (5), (6), and (7), an iteration procedure was used to calculate the true values of T_o, T_i and T_m.

Panel pressure drop between headers (including tube entrance and exit losses and the unheated inlet and outlet jumper tubes used to connect the panel tubes with the headers) is computed by SOLAR using maximum tubewall thicknesses and the Darcy-Weisbach formula with friction factors from the Colebrook equation.* SOLAR computes the pressure drop through each nodal element based on local salt conditions. The sum of the individual pressure drops gives the total tube pressure drop.

By an iteration procedure, SOLAR calculates the flow distribution from variations in heat absorption. The program adjusts the flow in each tube (left, center, and right) until the calculated total pressure drops (frictional and gravity head) through the tubes are "equal" [within 6.9 Pa(0.1 lb/in^2)]. A similar technique is used to obtain the flow distribution between two separate panels connected to a common header (as in Passes 1 through 3). The SOLAR computer printout for the design point condition is attached to this Appendix.

The SOLAR computer printouts for the 320 MW Molten Salt Receiver at the design point condition (noon, February 19) are shown in the following pages:

- Pass 1 (Panels 1 and 2)--pages J-8 through J-18
- Pass 2 (Panels 3 and 4)--pages J-19 through J-29
- Pass 3 (Panels 5 and 6)--pages J-30 through J-40
- Pass 4 (Panels 7 and 8)--pages J-41 through J-51
- Pass 5 (Panels 9 and 10)--pages J-52 through J-62

Table J-1 gives the node element lengths used by the program. Each element length is 1.716 m (5.63 ft) except for the top and bottom elements, which were adjusted to match the top and bottom ends of each panel.

Table J-1 Node Element Lengths, m

Node	Panel Number									
	1	2	3	4	5	6	7	8	9	10
16	.229	.683	1.216	1.716	.568	1.103	1.542	1.716	.343	.343
15	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
14	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
13	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
12	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
11	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
10	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
9	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
8	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
7	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
6	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
5	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
4	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
3	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
2	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716	1.716
1	1.497	1.043	.510	.010	1.158	.623	.184	.010	1.383	1.383

NOMENCLATURE*

a, b, c = Constants
C_p = Molten salt specific heat
D_i = Tube I.D.
D_o = Tube O.D.
D_r = Diameter ratio = D_o/D_i
h = Convective heat-transfer coefficient
k = Molten salt thermal conductivity
k_m = Mean value of tubewall thermal conductivity
L = Tube length
Pr = Prandtl Number = $C_p\mu/k$
q = Heat flux to panel
Re = Reynolds Number = D_iV/μ
T_b = Molten salt bulk temperature
T_i = Tubewall I.D. temperature
T_m = Tubewall mean temperature = $(T_o + T_i)/2$
T_o = Tubewall O.D.temperature
V = Molten salt flow velocity
w = Molten salt mass flow rate

ΔT = Temperature drop through the tubewall
μ = Molten salt viscosity at T_b
μ_ω = Molten salt viscosity at T_i
ρ = Molten salt density

*Molten salt properties are evaluated at bulk temperature, unless otherwise specified.

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320 MW MOLTEN SALT RECEIVER

ABSORBED NORMAL HEAT FLUX (MW/M2)

PASS 1

	PANEL 1			PANEL 2		
17	.0057	.0103	.0582	.0583	.0684	.0964
16	.0065	.0119	.0637	.0785	.0911	.1344
15	.0226	.0423	.1245	.1533	.1889	.2622
14	.0546	.1019	.1807	.2226	.2709	.3651
13	.0659	.1355	.2212	.2724	.3221	.3866
12	.0760	.1853	.3060	.3768	.4325	.4754
11	.0813	.2276	.3660	.4507	.4928	.5094
10	.0665	.2016	.3000	.3694	.3551	.4364
9	.0570	.1452	.2235	.2752	.2333	.3684
0 LEVEL						
8	.0552	.1365	.2302	.2835	.2788	.4273
7	.0659	.1875	.3195	.3934	.4393	.5269
6	.0736	.2048	.2947	.3629	.4029	.4721
5	.0695	.1441	.2062	.2540	.2595	.2962
4	.0321	.0834	.1065	.1311	.1013	.1211
3	.0160	.0466	.0562	.0693	.0319	.0365
2	.0053	.0173	.0240	.0296	.0080	.0091
1	.0017	.0069	.0050	.0133	.0038	.0041

320 MW MOLTEN SALT RECEIVER

ABSORBED PEAK HEAT FLUX (MW/M2)

PASS 1

	PANEL 1			PANEL 2		
17	.0081	.0137	.0720	.0585	.0699	.1014
16	.0094	.0158	.0788	.0788	.0931	.1413
15	.0325	.0560	.1539	.1539	.1931	.2757
14	.0786	.1350	.2234	.2234	.2769	.3839
13	.0949	.1795	.2735	.2735	.3293	.4065
12	.1094	.2455	.3782	.3782	.4421	.4999
11	.1171	.3015	.4524	.4524	.5038	.5357
10	.0957	.2671	.3708	.3708	.3630	.4589
9	.0821	.1924	.2762	.2762	.2385	.3873
0 LEVEL						
8	.0795	.1809	.2846	.2846	.2851	.4493
7	.0949	.2484	.3949	.3949	.4491	.5540
6	.1060	.2714	.3643	.3643	.4119	.4964
5	.1000	.1910	.2549	.2549	.2653	.3114
4	.0462	.1106	.1316	.1316	.1036	.1274
3	.0231	.0617	.0695	.0695	.0326	.0384
2	.0077	.0230	.0297	.0297	.0081	.0096
1	.0025	.0092	.0062	.0133	.0039	.0043

320 MW MOLTEN SALT RECEIVER

ABSORBED POWER (MW)

PASS 1

	PANEL 1			PANEL 2			
16	.0009	.0031	.0085	.0285	.0666	.0481	
15	.0152	.0568	.0985	.1213	.2936	.2076	
14	.0404	.1512	.1598	.1967	.4822	.3283	
13	.0631	.2489	.2104	.2591	.6219	.3934	
12	.0743	.3364	.2759	.3398	.7914	.4512	
11	.0823	.4330	.3517	.4331	.9704	.5155	
10	.0774	.4501	.3486	.4292	.8893	.4950	
9	.0646	.3637	.2740	.3374	.6171	.4212	
0 LEVEL							
8	.0587	.2955	.2375	.2924	.5371	.4164	
7	.0634	.3398	.2877	.3543	.7532	.4994	
6	.0730	.4115	.3215	.3958	.8833	.5228	
5	.0749	.3660	.2622	.3229	.6947	.4021	
4	.0531	.2387	.1637	.2015	.3784	.2184	
3	.0252	.1364	.0852	.1049	.1397	.0825	
2	.0112	.0671	.0420	.0517	.0418	.0239	
1	.0032	.0222	.0133	.0136	.0075	.0042	
TOTALS	.781	3.920	3.140	3.882	8.168	5.030	24.92

320 MW MOLTEN SALT RECEIVER

VARIATION IN SALT TEMPERATURE ALONG PANEL (F)

PASS 1

	PANEL 1			PANEL 2		
17	569.8	599.7	629.6	648.4	653.3	677.4
16	569.8	599.6	629.4	647.7	652.4	676.1
15	569.4	598.9	626.9	644.6	648.7	670.9
14	568.4	597.0	622.9	639.6	642.7	662.6
13	566.8	593.8	617.6	633.1	634.8	652.7
12	564.9	589.6	610.6	624.5	624.8	641.3
11	562.8	584.1	601.7	613.5	612.6	628.3
10	560.9	578.4	592.8	602.6	601.3	615.7
9	559.2	573.8	585.9	594.1	593.5	605.1
0 LEVEL	*	*	*	*	*	*
8	557.7	570.1	579.9	586.7	586.7	594.5
7	556.1	565.7	572.6	577.7	577.2	581.8
6	554.3	560.5	564.4	567.6	566.0	568.6
5	552.4	555.9	557.7	559.4	557.2	558.4
4	551.0	552.9	553.6	554.3	552.4	552.8
3	550.4	551.1	551.4	551.7	550.6	550.7
2	550.1	550.3	550.3	550.3	550.1	550.1
1	550.0	550.0	550.0	550.0	550.0	550.0

320 MW MOLTEN SALT RECEIVER

TEMPERATURE SUMMARY
FILM (I.D.) TEMPERATURE (C)
PEAK (O.D.) TEMPERATURE (C)
FRONT-TC-BACK TEMPERATURE DIFFERENCE (C)

PASS 1

	PANEL 1			PANEL 2		
17	300.4	317.8	344.4	352.2	356.8	374.8
	301.1	319.1	350.9	337.5	363.0	383.7
	2.3	3.7	18.9	15.0	17.8	25.2
16	300.6	318.2	345.5	355.2	360.2	380.6
	301.5	319.7	352.6	342.3	368.4	392.9
	2.7	4.3	20.7	20.2	23.7	35.1
15	304.8	325.1	357.1	366.2	374.9	399.6
	307.8	330.2	370.8	379.8	391.8	423.2
	9.2	15.3	40.3	39.5	49.2	68.3
14	313.1	338.4	367.2	375.5	386.0	413.2
	320.3	350.6	386.8	395.0	409.9	445.7
	22.3	36.7	58.5	57.4	70.7	95.4
13	315.4	345.0	373.3	380.8	391.2	412.4
	324.1	361.0	397.2	404.5	419.5	446.8
	27.0	48.9	71.9	70.6	84.6	102.0
12	317.2	355.0	388.6	394.8	406.1	423.0
	327.2	376.8	421.2	427.3	443.6	464.9
	31.2	67.0	99.8	98.1	114.3	126.4
11	317.6	362.9	398.1	403.1	411.8	423.7
	328.3	389.4	436.7	441.5	454.3	468.5
	33.4	82.7	120.2	118.4	131.7	137.2
10	312.4	353.8	379.5	383.8	381.8	405.1
	321.3	377.5	411.7	415.9	413.3	444.1
	27.4	74.0	100.1	98.8	97.0	119.8
9	308.9	337.5	359.0	362.8	355.6	387.9
	316.5	354.8	383.4	387.1	376.8	421.2
	23.6	53.8	75.7	74.8	64.8	102.8
0 LEVEL	*	*	*	*	*	*
8	307.6	333.5	357.8	360.9	361.0	394.6
	315.0	349.9	382.9	386.0	386.1	433.0
	22.9	50.9	78.6	77.8	78.0	120.5
7	309.8	344.4	375.5	377.6	387.6	409.1
	318.6	366.6	409.8	411.8	426.2	455.8
	27.4	70.1	109.5	108.7	123.3	150.3
6	311.0	346.5	366.2	367.6	376.0	393.3
	320.8	370.7	398.1	399.4	411.8	435.7
	30.7	77.1	102.3	101.8	115.1	137.6
5	308.9	328.6	342.0	342.8	343.8	353.3
	318.1	345.9	364.8	365.6	367.5	380.9
	29.0	54.8	72.7	72.6	75.7	88.5
4	297.5	311.2	315.8	316.1	309.6	314.5
	301.8	321.4	327.8	328.2	319.2	326.2
	13.5	32.1	38.1	38.0	30.1	36.9
3	292.6	300.7	302.3	302.5	294.6	295.8
	294.7	306.4	308.8	308.9	297.6	299.4
	6.8	18.0	20.2	20.2	9.5	11.2
2	289.4	292.5	293.9	293.9	289.4	289.7
	290.1	294.7	296.6	296.6	290.2	290.6
	2.3	6.7	8.7	8.7	2.4	2.8
1	288.3	289.6	289.0	290.4	288.6	288.6
	288.5	290.5	289.6	291.7	288.9	289.0
	.7	2.7	1.8	3.9	1.1	1.3

320 MW MOLTEN SALT RECEIVER

TEMPERATURE SUMMARY
FILM (I.D.) TEMPERATURE (F)
PEAK (O.D.) TEMPERATURE (F)
FRONT-TO-BACK TEMPERATURE DIFFERENCE (F)

PASS 1

	PANEL 1			PANEL 2		
17	572.6	604.1	651.9	666.0	674.2	706.7
	574.0	606.4	663.6	675.4	685.4	722.7
	4.2	6.7	34.0	27.0	32.1	45.3
16	573.1	604.8	653.9	671.4	680.3	717.1
	574.6	607.4	666.6	684.1	695.2	739.3
	4.8	7.8	37.2	36.4	42.7	63.1
15	580.6	617.2	674.8	691.2	706.9	751.3
	586.1	626.4	699.4	715.6	737.3	793.8
	16.6	27.5	72.5	71.0	88.6	122.9
14	595.6	641.2	692.9	707.8	726.8	775.8
	608.6	663.1	728.2	742.9	769.9	834.3
	40.2	66.1	105.4	103.3	127.2	171.6
13	599.7	653.0	704.0	717.4	736.1	774.3
	615.4	681.9	747.0	760.1	787.1	836.2
	48.6	88.0	129.5	127.1	152.3	183.5
12	602.9	671.1	731.6	742.7	763.0	793.5
	621.0	710.2	790.2	801.1	830.5	868.8
	56.1	120.7	179.6	176.6	205.7	227.5
11	603.7	685.2	748.6	757.5	773.2	794.7
	623.0	732.9	818.1	826.7	849.7	875.2
	60.2	148.8	216.4	213.2	237.1	247.0
10	594.4	668.9	715.2	722.9	719.3	761.3
	610.3	711.5	773.0	780.6	775.9	831.3
	49.4	133.1	180.2	177.9	174.6	215.6
9	588.1	639.5	678.2	685.0	672.1	730.1
	601.7	670.7	722.1	728.8	710.2	790.2
	42.5	96.9	136.2	134.7	116.6	185.1
0 LEVEL						
8	585.7	632.3	676.0	681.6	681.8	742.3
	599.0	661.7	721.3	726.8	727.1	811.5
	41.3	91.7	141.4	140.1	140.3	217.0
7	589.7	651.9	707.8	711.7	729.7	768.3
	605.4	691.9	769.6	773.3	799.2	852.4
	49.3	126.2	197.0	195.6	222.0	270.6
6	591.9	655.7	691.1	693.6	708.9	739.9
	609.5	699.2	748.6	751.0	773.2	816.3
	55.2	138.7	184.2	183.3	207.2	247.7
5	588.0	623.5	647.6	649.0	650.8	668.0
	604.6	654.6	688.7	690.1	693.5	717.7
	52.3	98.7	130.9	130.6	136.3	159.3
4	567.5	592.2	600.4	601.0	589.3	598.1
	575.3	610.6	622.1	622.8	606.5	619.2
	24.2	57.7	68.5	68.4	54.1	66.4
3	558.6	573.2	576.2	576.5	562.3	564.4
	562.5	583.5	587.9	588.1	567.8	570.9
	12.2	32.4	36.4	36.4	17.1	20.2
2	552.8	558.5	560.9	561.0	553.0	553.5
	554.1	562.4	566.0	566.0	554.4	555.2
	4.1	12.1	15.6	15.6	4.3	5.1
1	550.9	553.3	552.2	554.[illegible]	551.4	551.5
	551.3	554.8	553.3	557.0	552.1	552.3
	1.3	4.8	3.3	7.0	2.1	2.3

SYMBOL	DEFINITION	UNITS
PN	PASS NUMBER	
SN	STRIP NUMBER	
NN	NODE NUMBER	
FLUX	ABSORBED PEAK FLUX	(BTU/H-FT2)
RE	REYNOLDS NUMBER	
H	HEAT TRANSFER COEFFICIENT	(BTU/H-FT2-F)
VEL	SALT VELOCITY	(FT/S)
SBT	SALT BULK TEMPERATURE	(F)
PST	PEAK SALT TEMPERATURE=ID TEMPERATURE	(F)
MWT	MEAN TUBEWALL METAL TEMPERATURE=(SFT+PMT)/2	(F)
PMT	PEAK METAL TEMPERATURE=OD TEMPERATURE	(F)
SDT	SALT TEMPERATURE DIFFERENCE=(SFT-SBT)	(F)
MDT	METAL TEMPERATURE DIFFERENCE=(PMT-SFT)	(F)
FBDT	FRONT-TO-BACK TEMPERATURE DIFFERENCE=(PMT-SBT)	(F)
AMT	AVERAGE METAL TEMPERATURE	(F)
OHC	OVERALL HEAT TRANSFER COEFFICIENT	(BTU/H-FT2-F)
FPD	FRICTIONAL PRESSURE LOSS	(LB/IN2)
GPD	GRAVITATIONAL PRESSURE LOSS	(LB/IN2)
TPD	TOTAL PRESSURE LOSS	(LB/IN2)

PASS NO. 1/ 5

PN	SN	NN	FLUX	RE	H	VEL	SBT	FST	MWT	PMT	SDT	MDT	FBDT	AMT	OHC	FPD	GPD	TPD
1	1	17	2582.	38149.	1058.	9.7	569.8	572.6	573.3	574.0	2.8	1.4	4.2	571.0	619.	1.99	1.85	3.85
1	1	16	2980.	38145.	1058.	9.7	569.8	573.1	573.8	574.6	3.2	1.6	4.8	571.1	619.	2.09	4.63	6.72
1	1	15	10295.	38078.	1057.	9.7	569.4	580.6	583.3	586.1	11.2	5.4	16.6	573.9	619.	2.09	4.64	6.72
1	1	14	24924.	37901.	1055.	9.7	568.4	595.6	602.1	608.6	27.1	13.0	40.2	579.2	620.	2.09	4.64	6.73
1	1	13	30071.	37624.	1052.	9.7	566.8	599.7	607.5	615.4	32.9	15.7	48.6	579.9	619.	2.09	4.64	6.73
1	1	12	34677.	37299.	1048.	9.7	564.9	602.9	612.0	621.0	38.0	18.1	56.1	580.0	618.	2.10	4.64	6.74
1	1	11	37115.	36939.	1044.	9.7	562.8	603.7	613.4	623.0	40.9	19.3	60.2	579.1	617.	2.10	4.64	6.74
1	1	10	30342.	36603.	1040.	9.7	560.9	594.4	602.3	610.3	33.5	15.9	49.4	574.2	614.	2.10	4.64	6.75
1	1	9	26008.	36323.	1037.	9.7	559.2	588.1	594.9	601.7	28.8	13.7	42.5	570.7	612.	2.11	4.64	6.75
1	1	8	25195.	36069.	1034.	9.7	557.7	585.7	592.4	599.0	28.0	13.2	41.3	568.8	611.	2.11	4.65	6.76
1	1	7	30071.	35795.	1030.	9.7	556.1	589.7	597.5	605.4	33.5	15.8	49.3	569.4	610.	2.11	4.65	6.76
1	1	6	33593.	35481.	1026.	9.7	554.3	591.9	600.7	609.5	37.6	17.6	55.2	569.2	609.	2.12	4.65	6.76
1	1	5	31697.	35161.	1023.	9.7	552.4	588.0	596.3	604.6	35.6	16.6	52.3	566.5	607.	2.12	4.65	6.77
1	1	4	14629.	34934.	1020.	9.7	551.0	567.5	571.4	575.3	16.5	7.8	24.2	557.5	603.	2.12	4.65	6.77
1	1	3	7315.	34826.	1019.	9.7	550.4	558.6	560.6	562.5	8.3	3.9	12.2	553.6	602.	2.12	4.65	6.78
1	1	2	2438.	34779.	1018.	9.7	550.1	552.8	553.5	554.1	2.8	1.3	4.1	551.2	601.	1.85	4.06	5.91
1	1	1	784.	34765.	1018.	9.7	550.0	550.9	551.1	551.3	.9	.4	1.3	550.4	601.	2.33	1.24	3.57
1	2	17	4338.	43422.	1118.	9.8	599.7	604.1	605.3	606.4	4.5	2.3	6.7	601.5	645.	1.96	1.84	3.81
1	2	16	5006.	43415.	1118.	9.8	599.6	604.8	606.1	607.4	5.1	2.6	7.8	601.7	645.	2.04	4.61	6.65
1	2	15	17750.	43286.	1116.	9.8	598.9	617.2	621.8	626.4	18.3	9.2	27.5	606.3	646.	2.04	4.61	6.65
1	2	14	42783.	42943.	1112.	9.8	597.0	641.2	652.1	663.1	44.2	21.9	66.1	614.7	647.	2.04	4.61	6.65
1	2	13	56892.	42379.	1106.	9.7	593.8	653.0	667.4	681.9	59.1	28.9	88.0	617.5	646.	2.05	4.61	6.66
1	2	12	77828.	41620.	1098.	9.7	589.6	671.1	690.7	710.2	81.5	39.2	120.7	622.0	645.	2.06	4.62	6.67
1	2	11	95578.	40648.	1087.	9.7	584.1	685.2	709.1	732.9	101.1	47.8	148.8	624.2	642.	2.06	4.62	6.69
1	2	10	84655.	39644.	1075.	9.7	578.4	668.9	690.2	711.5	90.5	42.6	133.1	614.3	636.	2.07	4.63	6.70
1	2	9	60988.	38837.	1066.	9.7	573.8	639.5	655.1	670.7	65.8	31.2	96.9	599.9	629.	2.08	4.63	6.71
1	2	8	57347.	38166.	1059.	9.7	570.1	632.3	647.0	661.7	62.3	29.4	91.7	594.8	626.	2.09	4.63	6.72
1	2	7	78738.	37441.	1050.	9.7	565.7	651.9	671.9	691.9	86.2	39.9	126.2	599.8	624.	2.10	4.64	6.73
1	2	6	86020.	36546.	1039.	9.7	560.5	655.7	677.4	699.2	95.1	43.6	138.7	598.1	620.	2.10	4.64	6.75

1	2	5	60533.	35757.	1030.	9.7	555.9	623.5	639.0	654.6	67.6	31.2	98.7	582.6	613.	2.11	4.65	6.76
1	2	4	35045.	35246.	1024.	9.7	552.9	592.2	601.4	610.6	39.4	18.3	57.7	568.4	607.	2.12	4.65	6.77
1	2	3	19571.	34955.	1020.	9.7	551.1	573.2	578.4	583.5	22.1	10.3	32.4	559.9	604.	2.12	4.65	6.77
1	2	2	7282.	34812.	1018.	9.7	550.3	558.5	560.4	562.4	8.2	3.9	12.1	553.5	602.	1.85	4.06	5.91
1	2	1	2915.	34765.	1018.	9.7	550.0	553.3	554.1	554.8	3.3	1.6	4.8	551.3	601.	2.33	1.24	3.57
1	3	17	22818.	48847.	1175.	9.8	629.6	651.9	657.8	663.6	22.3	11.7	34.0	638.7	672.	1.94	1.83	3.77
1	3	16	24975.	48608.	1175.	9.8	629.4	653.9	660.2	666.6	24.4	12.7	37.2	639.3	672.	2.00	4.58	6.58
1	3	15	48774.	48355.	1170.	9.8	626.9	674.8	687.1	699.4	47.9	24.6	72.5	646.3	673.	2.00	4.59	6.59
1	3	14	70811.	47621.	1162.	9.8	622.9	692.9	710.6	728.2	70.0	35.3	105.4	651.1	672.	2.01	4.59	6.59
1	3	13	86677.	46654.	1152.	9.8	617.6	704.0	725.5	747.0	86.5	43.0	129.5	652.2	669.	2.01	4.59	6.61
1	3	12	119879.	45389.	1139.	9.8	610.6	731.6	760.9	790.2	121.0	58.6	179.6	658.8	667.	2.02	4.60	6.62
1	3	11	143394.	43782.	1122.	9.8	601.7	748.6	783.3	818.1	147.0	69.5	216.4	660.0	663.	2.04	4.61	6.64
1	3	10	117528.	42199.	1104.	9.7	592.8	715.2	744.1	773.0	122.3	57.9	180.2	641.4	652.	2.05	4.61	6.66
1	3	9	87558.	40963.	1090.	9.7	585.9	678.2	700.1	722.1	92.3	43.9	136.2	622.6	643.	2.06	4.62	6.68
1	3	8	90203.	39699.	1078.	9.7	579.9	676.0	698.6	721.3	96.1	45.3	141.4	618.0	638.	2.07	4.63	6.70
1	3	7	125168.	38621.	1064.	9.7	572.6	707.8	738.7	769.6	135.3	61.8	197.0	625.9	635.	2.08	4.63	6.72
1	3	6	115471.	37208.	1047.	9.7	564.4	691.1	719.9	748.6	126.8	57.4	184.2	614.3	627.	2.10	4.64	6.74
1	3	5	80801.	36069.	1034.	9.7	557.7	647.6	668.1	688.7	89.9	41.1	130.9	593.2	617.	2.11	4.65	6.76
1	3	4	41722.	35365.	1025.	9.7	553.6	600.4	611.2	622.1	46.8	21.7	68.5	572.1	609.	2.12	4.65	6.77
1	3	3	22036.	35000.	1021.	9.7	551.4	576.2	582.0	587.9	24.8	11.6	36.4	561.2	605.	2.12	4.65	6.77
1	3	2	9402.	34821.	1018.	9.7	550.3	560.9	563.5	566.0	10.6	5.0	15.6	554.5	602.	1.85	4.06	5.91
1	3	1	1969.	34765.	1018.	9.7	550.0	552.2	552.8	553.3	2.2	1.1	3.3	550.9	601.	2.33	1.24	3.57
2	4	17	18543.	52252.	1210.	9.8	648.4	666.0	670.7	675.4	17.6	9.4	27.0	655.6	686.	2.45	3.03	5.48
2	4	16	24975.	52122.	1208.	9.8	647.7	671.4	677.7	684.1	23.8	12.6	36.4	657.3	686.	1.98	4.57	6.54
2	4	15	48774.	51566.	1203.	9.8	644.6	691.2	703.4	715.6	46.6	24.4	71.0	663.5	687.	1.98	4.57	6.55
2	4	14	70811.	50664.	1194.	9.8	639.6	707.8	725.4	742.9	68.2	35.1	103.3	667.2	685.	1.98	4.57	6.56
2	4	13	86677.	49474.	1182.	9.8	633.1	717.4	738.8	760.1	84.3	42.8	127.1	667.0	682.	1.99	4.58	6.57
2	4	12	119878.	47911.	1165.	9.8	624.5	742.7	771.9	801.1	118.2	58.3	176.6	671.8	679.	2.00	4.59	6.59
2	4	11	143384.	45923.	1145.	9.8	613.5	757.5	792.1	826.7	144.0	69.2	213.2	670.9	673.	2.02	4.60	6.61
2	4	10	117528.	43960.	1123.	9.8	602.6	722.9	751.7	780.6	120.2	57.7	177.9	650.5	661.	2.04	4.61	6.64
2	4	9	87558.	42426.	1107.	9.7	594.1	685.0	706.9	728.8	90.9	43.8	134.7	630.3	650.	2.05	4.61	6.66
2	4	8	90203.	41106.	1092.	9.7	586.7	681.6	704.2	726.8	94.9	45.2	140.1	624.4	644.	2.06	4.62	6.68
2	4	7	125167.	39520.	1074.	9.7	577.7	711.7	742.5	773.3	134.0	61.7	195.6	630.6	640.	2.07	4.63	6.70
2	4	6	115471.	37770.	1054.	9.7	567.6	693.6	722.3	751.0	126.0	57.4	183.3	617.3	630.	2.09	4.64	6.73
2	4	5	80800.	36362.	1037.	9.7	559.4	649.0	669.5	690.1	89.6	41.1	130.6	594.8	619.	2.11	4.64	6.75
2	4	4	41722.	35493.	1027.	9.7	554.3	601.0	611.9	622.8	46.7	21.7	68.4	572.8	610.	2.12	4.65	6.76
2	4	3	22036.	35044.	1021.	9.7	551.7	576.5	582.3	588.1	24.8	11.6	36.4	561.5	605.	2.12	4.65	6.77
2	4	2	9402.	34823.	1018.	9.7	550.3	561.0	563.5	566.0	10.6	5.0	15.6	554.6	602.	1.29	2.83	4.12
2	4	1	4223.	34765.	1018.	9.7	550.0	554.8	555.9	557.0	4.8	2.3	7.0	551.9	601.	2.33	1.24	3.57
2	5	17	22164.	53140.	1219.	9.9	653.3	674.2	679.8	685.4	20.9	11.2	32.1	661.8	690.	2.45	3.03	5.48
2	5	16	29504.	52988.	1217.	9.9	652.4	680.3	687.7	695.2	27.9	14.9	42.7	663.8	690.	1.97	4.56	6.53
2	5	15	61220.	52318.	1210.	9.8	648.7	706.9	722.1	737.3	58.1	30.4	88.6	672.3	691.	1.97	4.57	6.54
2	5	14	87773.	51215.	1199.	9.8	642.7	726.8	748.3	769.9	84.1	43.1	127.2	676.6	690.	1.98	4.57	6.55
2	5	13	104369.	49790.	1185.	9.8	634.8	736.1	761.6	787.1	101.3	51.0	152.3	675.5	685.	1.99	4.58	6.57
2	5	12	140143.	47975.	1166.	9.8	624.8	763.0	796.7	830.5	138.1	67.5	205.7	680.0	681.	2.00	4.59	6.59
2	5	11	159689.	45751.	1143.	9.8	612.6	773.2	811.4	849.7	160.6	76.5	237.1	676.4	673.	2.02	4.60	6.62
2	5	10	115064.	43722.	1121.	9.8	601.3	719.3	747.6	775.9	118.0	56.6	174.6	648.3	659.	2.04	4.61	6.64
2	5	9	75603.	42324.	1106.	9.7	593.5	672.1	691.2	710.2	78.6	38.0	116.6	624.9	648.	2.05	4.61	6.66
2	5	8	90355.	41114.	1092.	9.7	586.7	681.8	704.4	727.1	95.1	45.2	140.3	624.5	644.	2.06	4.62	6.68
2	5	7	142355.	39432.	1073.	9.7	577.2	729.7	764.4	799.2	152.5	69.5	222.0	637.3	641.	2.08	4.63	6.70
2	5	6	130554.	37486.	1050.	9.7	566.0	708.9	741.0	773.2	142.9	64.4	207.2	622.2	630.	2.09	4.64	6.73
2	5	5	84085.	35978.	1032.	9.7	557.2	650.8	672.1	693.5	93.6	42.7	136.3	594.1	617.	2.11	4.65	6.76
2	5	4	32823.	35167.	1023.	9.7	552.4	589.3	597.9	606.5	36.9	17.2	54.1	567.0	607.	2.12	4.65	6.77
2	5	3	10326.	34870.	1019.	9.7	550.6	562.3	565.0	567.8	11.6	5.5	17.1	555.2	602.	2.12	4.65	6.77

2	5	2	2582.	34781.	1018.	9.7	550.1	553.0	553.7	554.4	2.9	1.4	4.3	551.3	601.	1.29	2.83	4.12
2	5	1	1237.	34765.	1018.	9.7	550.0	551.4	551.7	552.1	1.4	.7	2.1	550.6	601.	2.33	1.24	3.57
2	6	17	32139.	57453.	1261.	9.9	677.4	706.7	714.7	722.7	29.3	16.0	45.3	689.4	709.	2.43	3.02	5.44
2	6	16	44795.	57238.	1259.	9.9	676.1	717.1	728.2	739.3	40.9	22.2	63.1	692.9	710.	1.95	4.54	6.49
2	6	15	87376.	56306.	1250.	9.9	670.9	751.3	772.5	793.8	80.4	42.5	122.9	703.6	711.	1.95	4.55	6.50
2	6	14	121666.	54823.	1235.	9.9	662.6	775.8	805.1	834.3	113.2	58.4	171.6	708.4	709.	1.96	4.55	6.51
2	6	13	128856.	53032.	1217.	9.9	652.7	774.3	805.3	836.2	121.7	61.9	183.5	701.7	702.	1.97	4.56	6.53
2	6	12	158443.	50966.	1197.	9.8	641.3	793.5	831.1	868.8	152.2	75.3	227.5	702.3	697.	1.98	4.57	6.56
2	6	11	169780.	48598.	1173.	9.8	628.3	794.7	835.0	875.2	166.4	80.5	247.0	694.6	687.	2.00	4.58	6.58
2	6	10	145446.	46323.	1149.	9.8	615.7	761.3	796.3	831.3	145.5	70.1	215.6	673.7	675.	2.01	4.59	6.61
2	6	9	122772.	44395.	1128.	9.8	605.1	730.1	760.2	790.2	125.1	60.0	185.1	654.9	663.	2.03	4.60	6.64
2	6	8	142405.	42500.	1107.	9.7	594.5	742.3	776.9	811.5	147.8	69.2	217.0	653.1	656.	2.05	4.61	6.66
2	6	7	175586.	40250.	1082.	9.7	581.8	768.3	810.4	852.4	186.5	84.1	270.6	655.2	649.	2.07	4.62	6.69
2	6	6	157336.	37930.	1056.	9.7	568.6	739.9	778.1	816.3	171.3	76.4	247.7	635.8	635.	2.09	4.64	6.73
2	6	5	98715.	36177.	1035.	9.7	558.4	668.0	692.8	717.7	109.6	49.7	159.3	601.5	620.	2.11	4.64	6.75
2	6	4	40371.	35237.	1024.	9.7	552.8	598.1	608.7	619.2	45.3	21.1	66.4	570.7	608.	2.12	4.65	6.77
2	6	3	12167.	34885.	1019.	9.7	550.7	564.4	567.7	570.9	13.7	6.5	20.2	556.2	603.	2.12	4.65	6.77
2	6	2	3042.	34783.	1018.	9.7	550.1	553.5	554.4	555.2	3.4	1.6	5.1	551.5	601.	1.29	2.83	4.12
2	6	1	1361.	34765.	1018.	9.7	550.0	551.5	551.9	552.3	1.5	.7	2.3	550.6	601.	2.33	1.24	3.57

TIN = 550.000 TOUT = 628.887

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PASS NUMBER/NUMBER OF PASSES =    1/ 5
MASS FLOW, PANEL A           =189.6  KG/S (  1.504 MLB/H)
MASS FLOW, PANEL B           =189.6  KG/S (  1.504 MLB/H)
PASS MASS FLOW               =379.1  KG/S (  3.009 MLB/H)
PASS INLET  TEMPERATURE      =    287.8 C (  550.0 F)
INLET TEMPERATURE,PANEL A    =    287.8 C (  550.0 F)
INLET TEMPERATURE,PANEL B    =    287.8 C (  550.0 F)
OUTLET TEMPERATURE, PANEL A  =    315.4 C (  599.7 F)
OUTLET TEMPERATURE, PANEL B  =    347.8 C (  658.1 F)
PASS OUTLET TEMPERATURE      =    331.6 C (  628.9 F)
PASS PEAK METAL TEMPERATURE  =    468.5 C (  875.2 F)
PASS PEAK SALT  TEMPERATURE  =    423.7 C (  794.7 F)
PASS PEAK FRONT-TO-BACK DT   =    150.3 C (  270.6 F)
PASS FRICTIONAL PRESS DROP   = 245.82 KPA (  35.66 LB/IN2)
CUMULATIVE FRICT. PRESS DROP = 245.82 KPA (  35.66 LB/IN2)
PASS PEAK ABSORBED HEAT FLUX = .554 MW/M2 (   .176 MBTU/H-FT2)
ABSORBED POWER, PANEL A      =    7.84 MW (  26.76 MBTU/H)
ABSORBED POWER, PANEL B      =   17.08 MW (  58.28 MBTU/H)
PASS ABSORBED POWER          =   24.92 MW ( 85.038 MBTU/H)
CUMULATIVE ABSORBED POWER    =   24.92 MW ( 85.038 MBTU/H)
CUMULATIVE INCIDENT POWER    =   26.88 MW ( 91.733 MBTU/H)
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SOLAR RECEIVER PASS 1 SUMMARY DATA

STRIP		1	2	3	4	5	6
MASS FLOW (KG/S)	=	2.118	2.139	2.155	2.167	2.168	2.179
FLOW VARIATION (PERCENT FROM AVERAGE	=	-1.69	-.91	.04	.74	.75	1.45
MASS VELOCITY (KG/M2-S)	=	5522.	5576.	5620.	5651.	5652.	5682.
MAXIMUM VELOCITY (M/S)	=	2.9	3.0	3.0	3.0	3.0	3.1
AVERAGE REYNOLDS NUMBER	=	35820.	38803.	41451.	43221.	43322.	45442.
FRICTIONAL PRESSURE LOSS (KPA)	=	238.49	239.83	240.93	241.78	241.82	242.69
GRAVITATIONAL PRESSURE LOSS (KPA)	=	497.46	496.02	494.80	493.84	493.80	492.79
TOTAL PRESSURE LOSS (KPA)	=	735.95	735.85	735.73	735.62	735.62	735.49
AVERAGE HEAT TRANSFER COEFFICIENT (W/M2-C)	=	5812.1	6029.2	6211.7	6331.5	6336.6	6473.3
SALT INLET TEMPERATURE (C)	=	287.8	287.8	287.8	287.8	287.8	287.8
SALT OUTLET TEMPERATURE (C)	=	299.0	315.6	332.0	342.1	344.8	357.7
SALT TEMPERATURE RISE (C)	=	11.2	27.8	44.2	54.3	57.0	69.9
PEAK SALT TEMPERATURE (C)	=	318.0	363.3	398.1	402.5	411.2	422.5
PEAK AVERAGE METAL TEMPERATURE (C)	=	304.7	329.2	348.9	355.1	359.7	374.9
PEAK METAL TEMPERATURE (C)	=	328.8	389.8	436.7	441.0	453.7	467.3
AVERAGE METAL TEMPERATURE (C)	=	298.9	314.4	327.5	332.9	334.3	345.0
AVERAGE SURFACE TEMPERATURE (C)	=	314.1	348.2	377.0	381.9	386.6	410.2
MAXIMUM WALL TEMPERATURE DIFFERENCE (C)	=	10.7	26.5	38.6	38.5	42.5	46.8
MAXIMUM FRONT TO BACK TEMPERATURE DIFFERENCE (C)	=	33.7	83.0	120.2	118.1	131.4	149.5
TUBE THERMAL EXPANSION (MM)	=	.0	.0	.0	.0	.0	.0
PEAK ABSORBED HEAT FLUX (MW/M2)	=	.117	.302	.452	.452	.504	.554
AVERAGE ABSORBED HEAT FLUX (MW/M2)	=	.050	.125	.202	.249	.262	.324
ABSORBED POWER (MW)	=	.781	3.920	3.140	3.882	8.168	5.030

SOLAR RECEIVER PASS 1 SUMMARY DATA

STRIP		1	2	3	4	5	6
MASS FLOW (LB/H)	=	16809.	16973.	17106.	17201.	17203.	17295.
FLOW VARIATION (PERCENT FROM AVERAGE	=	-1.69	-.91	.04	.74	.75	1.45
MASS VELOCITY (LB/FT2-S)	=	1131.	1142.	1151.	1157.	1158.	1164.
MAXIMUM VELOCITY (FT/S)	=	9.5	9.7	9.8	9.9	9.9	10.0
AVERAGE REYNOLDS NUMBER	=	35820.	38803.	41451.	43221.	43322.	45442.
FRICTIONAL PRESSURE LOSS (LB/IN2)	=	34.59	34.78	34.94	35.07	35.07	35.20
GRAVITATIONAL PRESSURE LOSS (LB/IN2)	=	72.15	71.94	71.76	71.63	71.62	71.47
TOTAL PRESSURE LOSS (LB/IN2)	=	106.74	106.73	106.71	106.69	106.69	106.67
AVERAGE HEAT TRANSFER COEFFICIENT (BTU/H-FT2-F)	=	1023.8	1062.0	1094.2	1115.3	1116.2	1140.3
SALT INLET TEMPERATURE (F)	=	550.0	550.0	550.0	550.0	550.0	550.0
SALT OUTLET TEMPERATURE (F)	=	570.2	600.0	629.6	647.8	652.6	675.9
SALT TEMPERATURE RISE (F)	=	20.2	50.0	79.6	97.8	102.6	125.9
PEAK SALT TEMPERATURE (F)	=	604.5	686.0	748.5	756.5	772.1	792.5
PEAK AVERAGE METAL TEMPERATURE (F)	=	580.4	624.6	660.0	671.2	679.4	706.8
PEAK METAL TEMPERATURE (F)	=	623.8	733.7	818.0	825.8	848.6	873.1
AVERAGE METAL TEMPERATURE (F)	=	570.1	597.9	621.4	631.2	633.8	653.1
AVERAGE SURFACE TEMPERATURE (F)	=	597.4	658.7	710.7	719.4	727.9	770.3
MAXIMUM WALL TEMPERATURE DIFFERENCE (F)	=	19.3	47.7	69.5	69.2	76.5	84.2
MAXIMUM FRONT TO BACK TEMPERATURE DIFFERENCE (F)	=	60.7	149.4	216.4	212.6	236.5	269.1
TUBE THERMAL EXPANSION (IN)	=	.0	.0	.0	.0	.0	.0
PEAK ABSORBED HEAT FLUX (MBTU/H-FT2)	=	.037	.096	.144	.144	.160	.176
AVERAGE ABSORBED HEAT FLUX (MBTU/H-FT2)	=	.016	.040	.064	.079	.083	.103
ABSORBED POWER (MBTU/H)	=	2.665	13.379	10.716	13.248	27.874	17.165

320 MW MOLTEN SALT RECEIVER

ABSORBED NORMAL HEAT FLUX (MW/M2)

PASS 2

	PANEL 3			PANEL 4		
17	.0668	.0569	.0353	.0137	.0197	.0213
16	.1344	.1299	.0880	.0880	.0780	.0915
15	.2622	.2659	.2495	.2495	.2383	.2333
14	.3651	.3846	.3829	.3829	.3395	.3421
13	.3866	.3936	.4110	.4110	.4126	.4019
12	.4754	.4556	.4731	.4731	.4765	.4398
11	.5094	.4847	.4752	.4752	.4709	.4219
10	.4364	.4250	.4197	.4197	.4048	.3792
9	.3684	.3607	.3836	.3836	.3725	.4019
0 LEVEL						
8	.4273	.4496	.4896	.4896	.5032	.4618
7	.5269	.5228	.5199	.5199	.4927	.4343
6	.4721	.4429	.4074	.4074	.3725	.3207
5	.2962	.2651	.2531	.2531	.2305	.1934
4	.1211	.1090	.1118	.1118	.0977	.0840
3	.0365	.0321	.0296	.0296	.0274	.0234
2	.0091	.0067	.0065	.0065	.0042	.0048
1	.0067	.0049	.0048	.0065	.0042	.0048

320 MW MOLTEN SALT RECEIVER

ABSORBED PEAK HEAT FLUX (MW/M2)

PASS 2

	PANEL 3			PANEL 4		
17	.0702	.0628	.0408	.0158	.0240	.0279
16	.1413	.1434	.1016	.1016	.0952	.1195
15	.2757	.2934	.2881	.2881	.2909	.3046
14	.3839	.4244	.4422	.4422	.4144	.4465
13	.4065	.4343	.4746	.4746	.5036	.5247
12	.4999	.5027	.5462	.5462	.5817	.5741
11	.5357	.5348	.5487	.5487	.5749	.5507
10	.4589	.4689	.4846	.4846	.4942	.4950
9	.3873	.3980	.4430	.4430	.4547	.5247
0 LEVEL	*	*	*	*	*	*
8	.4493	.4961	.5654	.5654	.6143	.6029
7	.5540	.5768	.6004	.6004	.6015	.5669
6	.4964	.4887	.4705	.4705	.4547	.4187
5	.3114	.2925	.2923	.2923	.2814	.2525
4	.1274	.1203	.1291	.1291	.1193	.1096
3	.0384	.0354	.0341	.0341	.0335	.0305
2	.0096	.0074	.0075	.0075	.0051	.0063
1	.0070	.0055	.0055	.0075	.0051	.0063

320 MW MOLTEN SALT RECEIVER

ABSORBED POWER (MW)

PASS 2

	PANEL 3			PANEL 4			
16	.0746	.1389	.0457	.0532	.1025	.0591	
15	.2076	.4151	.1766	.1766	.3317	.1700	
14	.3283	.6822	.3310	.3310	.6059	.3011	
13	.3934	.8162	.4155	.4155	.7887	.3894	
12	.4512	.8906	.4627	.4627	.9325	.4405	
11	.5155	.9862	.4963	.4963	.9937	.4510	
10	.4950	.9540	.4684	.4684	.9185	.4193	
9	.4212	.8240	.4204	.4204	.8153	.4088	
0 LEVEL	*	*	*	*	*	*	
8	.4164	.8499	.4571	.4571	.9185	.4521	
7	.4994	1.0198	.5284	.5284	1.0445	.4690	
6	.5228	1.0128	.4854	.4854	.9074	.3952	
5	.4021	.7426	.3457	.3457	.6325	.2691	
4	.2184	.3924	.1910	.1910	.3442	.1452	
3	.0825	.1480	.0740	.0740	.1312	.0562	
2	.0239	.0407	.0189	.0189	.0332	.0148	
1	.0025	.0036	.0018	.0000	.0001	.0000	
TOTALS	5.055	9.917	4.919	4.925	9.500	4.441	38.756

320 MW MOLTEN SALT RECEIVER

VARIATION IN SALT TEMPERATURE ALONG PANEL (F)

PASS 2

	PANEL 3			PANEL 4		
17	756.2	753.6	752.8	753.0	748.4	740.8
16	754.4	751.8	751.7	751.6	747.1	739.3
15	749.2	746.6	747.2	747.2	742.9	735.1
14	740.9	738.1	738.9	738.9	735.3	727.5
13	731.0	727.8	728.5	728.4	725.4	717.7
12	719.7	716.7	716.8	716.8	713.7	706.6
11	706.7	704.3	704.4	704.3	701.2	695.3
10	694.2	692.3	692.6	692.5	689.7	684.7
9	683.6	681.9	682.0	681.9	679.4	674.4
0 LEVEL	*	*	*	*	*	*
8	673.1	671.2	670.4	670.4	667.9	663.0
7	660.5	658.4	657.1	657.1	654.7	651.1
6	647.3	645.6	644.8	644.8	643.3	641.2
5	637.2	636.3	636.1	636.1	635.3	634.4
4	631.6	631.3	631.3	631.2	631.0	630.7
3	629.6	629.4	629.4	629.4	629.3	629.3
2	628.9	628.9	628.9	628.9	628.9	628.9
1	628.9	628.9	628.9	628.9	628.9	628.9

320 MW MOLTEN SALT RECEIVER

TEMPERATURE SUMMARY
FILM (I.D.) TEMPERATURE (C)
PEAK (O.D.) TEMPERATURE (C)
FRONT-TO-BACK TEMPERATURE DIFFERENCE (C)

PASS 2

	PANEL 3			PANEL 4		
17	412.6	410.1	406.4	402.9	401.5	397.9
	418.9	415.7	410.1	404.3	403.7	400.5
	16.6	14.9	9.7	3.8	5.7	6.7
16	422.0	421.0	414.8	414.7	411.3	410.8
	434.6	433.7	423.8	423.8	419.9	421.5
	33.3	33.8	24.0	24.0	22.6	28.5
15	439.1	440.4	439.9	439.9	438.1	436.2
	463.2	466.0	465.1	465.1	463.6	462.8
	64.8	69.0	67.7	67.7	68.6	72.2
14	450.9	455.6	458.6	458.6	452.7	453.8
	484.1	492.1	496.6	496.6	488.5	492.3
	90.3	99.9	103.9	103.9	97.8	105.9
13	449.4	452.1	458.5	458.5	461.4	461.0
	484.6	489.6	499.2	499.2	504.6	506.0
	96.3	103.0	112.3	112.3	119.3	125.0
12	458.2	457.2	463.9	463.9	467.9	463.6
	501.1	500.4	510.6	510.6	517.4	512.6
	119.0	120.0	130.1	130.1	138.7	137.8
11	457.7	456.4	458.6	458.6	461.3	454.8
	503.6	502.4	505.7	505.6	510.4	502.2
	128.8	128.9	132.1	132.1	138.6	133.7
10	440.0	440.6	443.2	443.2	443.4	441.3
	479.9	481.4	485.3	485.3	486.3	484.3
	112.0	114.6	118.3	118.3	120.9	121.7
9	423.7	424.6	431.8	431.8	432.5	441.5
	457.8	459.6	470.5	470.5	472.3	487.0
	95.8	98.5	109.4	109.4	112.6	130.1
0 LEVEL						
8	428.7	435.4	446.3	446.3	453.2	449.3
	468.1	478.7	495.2	495.1	505.9	501.2
	111.9	123.6	140.5	140.5	152.7	150.7
7	440.2	443.1	446.4	446.4	445.6	438.4
	488.3	493.0	498.2	498.2	497.6	487.6
	139.1	145.0	151.0	151.0	151.6	143.7
6	425.0	423.0	419.6	419.6	416.3	409.2
	468.6	466.0	461.1	461.1	456.5	446.5
	126.8	125.1	120.6	120.6	116.9	108.0
5	389.2	385.6	385.4	385.4	383.2	377.8
	417.4	412.1	412.0	411.9	408.8	400.8
	81.2	76.4	76.3	76.3	73.6	66.2
4	355.0	353.6	355.1	355.1	353.3	351.4
	366.9	364.8	367.1	367.1	364.4	361.7
	33.7	31.9	34.2	34.2	31.6	29.1
3	338.6	338.0	337.8	337.8	337.6	337.1
	342.2	341.4	341.0	341.0	340.8	340.0
	10.2	9.5	9.1	9.1	8.9	8.2
2	333.3	332.9	332.9	332.9	332.5	332.7
	334.2	333.6	333.6	333.6	333.0	333.3
	2.6	2.0	2.0	2.0	1.4	1.7
1	332.8	332.5	332.6	332.9	332.5	332.7
	333.5	333.1	333.1	333.6	333.0	333.3
	1.9	1.5	1.5	2.0	1.4	1.7

320 MW MOLTEN SALT RECEIVER

TEMPERATURE SUMMARY
FILM (I.D.) TEMPERATURE (F)
PEAK (O.D.) TEMPERATURE (F)
FRONT-TO-BACK TEMPERATURE DIFFERENCE (F)

PASS 2

	PANEL 3			PANEL 4		
17	774.7	770.2	763.6	757.1	754.7	748.3
	786.1	780.3	770.2	759.7	758.6	752.8
	29.8	26.7	17.4	6.8	10.3	12.0
16	791.7	789.8	778.6	778.5	772.4	771.4
	814.3	812.7	794.9	794.9	787.8	790.6
	59.9	60.9	43.2	43.2	40.7	51.3
15	822.3	824.7	823.8	823.8	820.6	817.1
	865.7	870.8	869.2	869.1	866.4	865.1
	116.6	124.2	121.9	121.9	123.5	130.0
14	843.6	852.0	857.5	857.5	846.9	848.8
	903.4	917.9	925.9	925.9	911.3	918.1
	162.5	179.8	187.0	187.0	176.0	190.6
13	841.0	845.8	857.3	857.2	862.5	861.8
	904.4	913.3	930.6	930.6	940.2	942.7
	173.3	185.4	202.2	202.2	214.8	225.0
12	856.7	854.9	867.0	867.0	874.3	866.4
	933.9	932.6	951.0	951.0	963.4	954.7
	214.3	216.0	234.2	234.2	249.7	248.0
11	855.8	853.6	857.5	857.5	862.3	850.7
	938.5	936.2	942.2	942.2	950.8	935.9
	231.8	232.0	237.8	237.8	249.6	240.7
10	824.0	825.2	829.8	829.8	830.2	826.4
	895.8	898.5	905.5	905.5	907.3	903.7
	201.6	206.2	212.9	212.9	217.6	219.0
9	794.6	796.3	809.2	809.2	810.5	826.6
	856.1	859.3	879.0	878.9	882.1	908.6
	172.4	177.4	197.0	197.0	202.6	234.2
0 LEVEL						
8	803.7	815.8	835.6	835.6	847.7	840.7
	874.6	893.6	923.3	923.3	942.7	934.2
	201.5	222.4	252.8	252.9	274.8	271.2
7	824.4	829.6	835.6	835.6	834.2	821.2
	910.9	919.4	928.8	928.8	927.6	909.8
	250.4	261.0	271.7	271.7	272.9	258.6
6	797.1	793.4	787.3	787.3	781.3	768.6
	875.5	870.7	861.9	861.9	853.6	835.6
	228.2	225.1	217.1	217.1	210.4	194.5
5	732.6	726.0	725.8	725.8	721.8	712.0
	783.3	773.8	773.5	773.5	767.8	753.5
	146.1	137.5	137.4	137.4	132.5	119.2
4	671.0	668.5	671.2	671.1	667.9	664.6
	692.6	688.7	692.8	692.8	687.9	683.0
	60.7	57.4	61.5	61.5	56.9	52.4
3	641.5	640.4	640.0	640.0	639.7	638.7
	648.0	646.5	645.8	645.8	645.4	643.9
	18.4	17.0	16.4	16.4	16.1	14.7
2	631.9	631.2	631.3	631.2	630.5	630.8
	633.6	632.5	632.5	632.5	631.4	631.9
	4.6	3.6	3.6	3.6	2.5	3.0
1	631.1	630.6	630.6	631.2	630.5	630.8
	632.3	631.5	631.5	632.5	631.4	631.9
	3.4	2.6	2.7	3.6	2.5	3.0

SYMBOL	DEFINITION	UNITS
PN	PASS NUMBER	
SN	STRIP NUMBER	
NN	NODE NUMBER	
FLUX	ABSORBED PEAK FLUX	(BTU/H-FT2)
RE	REYNOLDS NUMBER	
H	HEAT TRANSFER COEFFICIENT	(BTU/H-FT2-F)
VEL	SALT VELOCITY	(FT/S)
SBT	SALT BULK TEMPERATURE	(F)
PST	PEAK SALT TEMPERATURE=ID TEMPERATURE	(F)
MWT	MEAN TUBEWALL METAL TEMPERATURE=(SFT+PMT)/2	(F)
PMT	PEAK METAL TEMPERATURE=OD TEMPERATURE	(F)
SDT	SALT TEMPERATURE DIFFERENCE=(SFT-SBT)	(F)
MDT	METAL TEMPERATURE DIFFERENCE=(PMT-SFT)	(F)
FBDT	FRONT-TO-BACK TEMPERATURE DIFFERENCE=(PMT-SBT)	(F)
AMT	AVERAGE METAL TEMPERATURE	(F)
OHC	OVERALL HEAT TRANSFER COEFFICIENT	(BTU/H-FT2-F)
FPD	FRICTIONAL PRESSURE LOSS	(LB/IN2)
GPD	GRAVITATIONAL PRESSURE LOSS	(LB/IN2)
TPD	TOTAL PRESSURE LOSS	(LB/IN2)

PASS NO. 2/ 5

PN	SN	NN	FLUX	RE	H	VEL	SBT	PST	MWT	PMT	SDT	MDT	FBDT	AMT	OHC	FPD	GPD	TPD
3	1	17	22262.	70627.	1383.	10.1	756.2	774.7	780.4	786.1	18.5	11.3	29.8	764.0	746.	2.97	4.36	7.33
3	1	16	44795.	70337.	1381.	10.1	754.4	791.7	803.0	814.3	37.3	22.6	59.9	770.0	748.	1.89	4.47	6.37
3	1	15	87378.	69523.	1373.	10.0	749.2	822.3	844.0	865.7	73.1	43.4	116.6	779.7	750.	1.90	4.48	6.38
3	1	14	121666.	68217.	1361.	10.0	740.9	843.6	873.5	903.4	102.7	59.8	162.5	783.6	749.	1.90	4.49	6.39
3	1	13	128856.	66620.	1347.	10.0	731.0	841.0	872.7	904.4	110.0	63.4	173.3	776.6	743.	1.91	4.49	6.40
3	1	12	158443.	64749.	1329.	10.0	719.7	856.7	895.3	933.9	137.0	77.3	214.3	776.2	740.	1.91	4.50	6.42
3	1	11	169780.	62563.	1309.	10.0	706.7	855.8	897.2	938.5	149.1	82.7	231.8	767.9	732.	1.92	4.52	6.44
3	1	10	145446.	60418.	1289.	9.9	694.2	824.0	859.9	895.8	129.7	71.9	201.6	747.5	722.	1.93	4.53	6.46
3	1	9	122772.	58562.	1271.	9.9	683.6	794.6	825.4	856.1	111.0	61.4	172.4	729.2	712.	1.94	4.54	6.48
3	1	8	142405.	56702.	1253.	9.9	673.1	803.7	839.2	874.6	130.6	70.9	201.5	726.5	707.	1.95	4.54	6.50
3	1	7	175586.	54446.	1231.	9.9	660.5	824.4	867.7	910.9	163.9	86.5	250.4	727.1	701.	1.96	4.56	6.52
3	1	6	157336.	52061.	1208.	9.8	647.3	797.1	836.3	875.5	149.7	78.4	228.2	708.0	690.	1.98	4.57	6.54
3	1	5	98715.	50216.	1189.	9.8	637.2	732.6	757.9	783.3	95.4	50.7	146.1	676.0	676.	1.99	4.58	6.56
3	1	4	40371.	49212.	1179.	9.8	631.6	671.0	681.7	692.4	39.4	21.4	60.7	647.7	665.	1.99	4.58	6.58
3	1	3	12167.	48833.	1175.	9.8	629.6	641.5	644.7	648.0	11.9	6.5	18.4	634.4	660.	2.00	4.58	6.55
3	1	2	3042.	48723.	1174.	9.8	628.9	631.9	632.7	633.6	3.0	1.6	4.6	630.2	659.	.59	1.36	1.96
3	1	1	2220.	48712.	1174.	9.8	628.9	631.1	631.7	632.3	2.2	1.2	3.4	629.8	658.	2.28	1.22	3.50
3	2	17	19905.	70215.	1379.	10.1	753.6	770.2	775.2	780.3	16.6	10.2	26.7	760.5	744.	2.97	4.36	7.34
3	2	16	45446.	69944.	1377.	10.0	751.8	789.8	801.2	812.7	37.9	22.9	60.9	767.7	746.	1.89	4.48	6.37
3	2	15	92983.	69127.	1370.	10.0	746.6	824.7	847.7	870.8	78.0	46.1	124.2	779.2	749.	1.90	4.48	6.38
3	2	14	134511.	67764.	1357.	10.0	738.1	852.0	884.9	917.9	113.9	65.8	179.8	785.3	748.	1.90	4.49	6.39
3	2	13	137645.	66101.	1342.	10.0	727.[illegible]	845.8	879.5	913.3	117.9	67.5	185.4	776.6	742.	1.91	4.50	6.41
3	2	12	159324.	64247.	1325.	10.0	716.7	854.9	893.8	932.6	138.2	77.7	216.0	773.6	738.	1.91	4.51	6.42
3	2	11	169510.	62150.	1305.	10.0	704.3	853.6	894.9	936.2	149.3	82.7	232.0	765.6	731.	1.93	4.52	6.44
3	2	10	148615.	60080.	1286.	9.9	692.3	825.2	861.8	898.5	132.9	73.4	206.2	746.8	721.	1.93	4.53	6.46
3	2	9	126153.	58263.	1268.	9.9	681.9	796.3	827.8	859.3	114.3	63.1	177.4	728.8	711.	1.94	4.54	6.48
3	2	8	157235.	56366.	1250.	9.9	671.2	815.8	854.7	893.6	144.6	77.8	222.4	730.2	707.	1.95	4.55	6.50
3	2	7	182831.	54062.	1228.	9.9	658.4	829.6	874.5	919.4	171.2	89.8	261.0	727.8	700.	1.96	4.56	6.52
3	2	6	154884.	51754.	1205.	9.8	645.6	793.4	832.1	870.7	147.8	77.3	225.1	705.5	688.	1.98	4.57	6.55

3	2	5	92721.	50053.	1187.	9.8	636.3	726.0	749.9	773.8	89.7	47.8	137.5	672.8	674.	1.99	4.58	6.57
3	2	4	38133.	49153.	1178.	9.8	631.3	668.5	678.6	688.7	37.2	20.2	57.4	646.5	664.	1.99	4.58	6.58
3	2	3	11231.	48814.	1175.	9.8	629.4	640.4	643.5	646.5	11.0	6.0	17.0	633.9	660.	2.00	4.58	6.58
3	2	2	2351.	48720.	1174.	9.8	628.9	631.2	631.9	632.5	2.3	1.3	3.6	629.9	658.	.59	1.36	1.96
3	2	1	1730.	48712.	1174.	9.8	628.9	630.6	631.0	631.5	1.7	.9	2.6	629.6	658.	2.28	1.22	3.50
3	3	17	12935.	70097.	1378.	10.0	752.8	763.6	766.9	770.2	10.8	6.6	17.4	757.4	743.	2.98	4.36	7.34
3	3	16	32199.	69918.	1377.	10.0	751.7	778.6	786.7	794.9	26.9	16.3	43.2	763.0	745.	1.89	4.48	6.37
3	3	15	91317.	69222.	1370.	10.0	747.2	823.8	846.5	869.2	76.6	45.3	121.9	779.2	749.	1.90	4.48	6.38
3	3	14	140143.	67899.	1358.	10.0	738.9	857.5	891.7	925.9	118.6	68.4	187.0	788.1	749.	1.90	4.49	6.39
3	3	13	150436.	66205.	1343.	10.0	728.5	857.3	894.0	930.6	128.8	73.6	202.2	781.7	744.	1.91	4.50	6.40
3	3	12	173133.	64276.	1325.	10.0	716.8	867.0	909.0	951.0	150.2	84.0	234.2	778.6	739.	1.91	4.51	6.42
3	3	11	173925.	62161.	1305.	10.0	704.4	857.5	899.8	942.2	153.2	84.7	237.8	767.2	731.	1.92	4.52	6.44
3	3	10	153603.	60126.	1286.	9.9	692.6	829.8	867.7	905.5	137.3	75.7	212.9	748.9	721.	1.93	4.53	6.46
3	3	9	140407.	58269.	1268.	9.9	682.0	809.2	844.1	879.0	127.2	69.8	197.0	734.1	713.	1.94	4.54	6.48
3	3	8	179204.	56223.	1249.	9.9	670.4	835.4	879.3	923.3	164.9	87.9	252.8	737.6	709.	1.95	4.55	6.50
3	3	7	190288.	53829.	1225.	9.9	657.1	835.6	882.2	928.8	178.5	93.2	271.7	729.5	700.	1.97	4.56	6.52
3	3	6	149116.	51611.	1203.	9.8	644.8	787.3	824.6	861.9	142.4	74.6	217.1	702.6	687.	1.98	4.57	6.55
3	3	5	92637.	50025.	1187.	9.8	636.1	725.8	749.7	773.5	89.7	47.7	137.4	672.6	674.	1.99	4.58	6.57
3	3	4	40908.	49147.	1178.	9.8	631.3	671.2	682.0	692.8	39.9	21.6	61.5	647.6	665.	1.99	4.58	6.58
3	3	3	10821.	48807.	1175.	9.8	629.4	640.0	642.9	645.8	10.6	5.8	16.4	633.7	660.	2.00	4.58	6.58
3	3	2	2375.	48720.	1174.	9.8	628.9	631.3	631.9	632.5	2.3	1.3	3.6	629.9	658.	.59	1.36	1.96
3	3	1	1748.	48712.	1174.	9.8	628.9	630.6	631.1	631.5	1.7	.9	2.7	629.6	658.	2.28	1.22	3.50
4	4	17	5015.	70120.	1379.	10.0	753.0	757.1	758.4	759.7	4.2	2.6	6.8	754.7	742.	3.53	5.67	9.20
4	4	16	32199.	69911.	1377.	10.0	751.6	778.5	786.7	794.9	26.9	16.3	43.2	762.9	745.	1.89	4.48	6.37
4	4	15	91317.	69215.	1370.	10.0	747.2	823.8	846.5	869.1	76.6	45.3	121.9	779.1	749.	1.90	4.48	6.38
4	4	14	140143.	67892.	1358.	10.0	738.9	857.5	891.7	925.9	118.6	68.4	187.0	788.0	749.	1.90	4.49	6.39
4	4	13	150436.	66198.	1343.	10.0	728.4	857.2	893.9	930.6	128.8	73.4	202.2	781.7	744.	1.91	4.50	6.40
4	4	12	173133.	64269.	1325.	10.0	716.8	867.0	909.0	951.0	150.2	84.0	234.2	778.6	739.	1.91	4.51	6.42
4	4	11	173925.	62154.	1305.	10.0	704.3	857.5	899.8	942.2	153.2	84.7	237.8	767.2	731.	1.93	4.52	6.44
4	4	10	153603.	60118.	1286.	9.9	692.5	829.8	867.6	905.5	137.3	75.7	212.9	748.8	721.	1.93	4.53	6.46
4	4	9	140407.	58261.	1268.	9.9	681.9	809.2	844.0	878.9	127.2	69.8	197.0	734.0	713.	1.94	4.54	6.48
4	4	8	179204.	56215.	1249.	9.9	670.4	835.4	879.3	923.3	165.0	87.9	252.9	737.5	709.	1.95	4.55	6.50
4	4	7	190288.	53822.	1225.	9.9	657.1	835.6	882.2	928.8	178.5	93.2	271.7	729.4	700.	1.97	4.56	6.52
4	4	6	149116.	51604.	1203.	9.8	644.8	787.3	824.6	861.9	142.5	74.6	217.1	702.6	687.	1.98	4.57	6.55
4	4	5	92637.	50017.	1187.	9.8	636.1	725.8	749.6	773.5	89.7	47.7	137.4	672.6	674.	1.99	4.58	6.57
4	4	4	40908.	49139.	1178.	9.8	631.2	671.1	682.0	692.8	39.9	21.6	61.5	647.5	665.	1.99	4.58	6.58
4	4	3	10821.	48799.	1175.	9.8	629.4	640.0	642.9	645.8	10.6	5.8	16.4	633.7	660.	2.00	4.58	6.58
4	4	2	2375.	48712.	1174.	9.8	628.9	631.2	631.9	632.5	2.3	1.3	3.6	629.8	658.	.01	.03	.04
4	4	1	2363.	48712.	1174.	9.8	628.9	631.2	631.8	632.5	2.3	1.3	3.6	629.8	658.	2.28	1.22	3.50
4	5	17	7615.	69397.	1372.	10.0	748.4	754.7	756.7	758.6	6.4	3.9	10.3	751.0	740.	3.53	5.67	9.20
4	5	16	30186.	69195.	1370.	10.0	747.1	772.4	780.1	787.8	25.3	15.4	40.7	757.7	742.	1.90	4.48	6.38
4	5	15	92191.	68536.	1364.	10.0	742.9	820.6	843.5	866.4	77.7	45.8	123.5	775.3	747.	1.90	4.48	6.38
4	5	14	131351.	67317.	1353.	10.0	735.3	846.9	879.1	911.3	111.6	64.4	176.0	781.6	746.	1.90	4.49	6.39
4	5	13	159634.	65702.	1338.	10.0	725.4	862.5	901.4	940.2	137.1	77.7	214.8	782.0	743.	1.91	4.50	6.41
4	5	12	184382.	63751.	1320.	10.0	713.7	874.3	918.8	963.4	160.5	89.1	249.7	779.7	738.	1.92	4.51	6.43
4	5	11	182206.	61627.	1300.	9.9	701.2	862.3	906.5	950.8	161.1	88.5	249.6	767.2	730.	1.93	4.52	6.45
4	5	10	156643.	59625.	1281.	9.9	689.7	830.2	868.8	907.3	140.5	77.1	217.6	747.3	720.	1.94	4.53	6.47
4	5	9	144133.	57822.	1264.	9.9	679.4	810.5	846.3	882.1	131.0	71.6	202.6	733.1	711.	1.94	4.54	6.48
4	5	8	194716.	55765.	1244.	9.9	667.9	847.7	895.2	942.7	179.9	95.0	274.8	740.9	709.	1.96	4.55	6.50
4	5	7	190637.	53399.	1221.	9.9	654.7	834.2	880.9	927.6	179.4	93.5	272.9	727.4	699.	1.97	4.56	6.53
4	5	6	144133.	51328.	1200.	9.8	643.3	781.3	817.5	853.6	138.0	72.3	210.4	699.3	685.	1.98	4.57	6.55
4	5	5	89199.	49879.	1186.	9.8	635.3	721.8	744.8	767.8	86.5	46.0	132.5	670.5	673.	1.99	4.58	6.57
4	5	4	37801.	49089.	1178.	9.9	631.0	667.9	677.9	687.9	36.9	20.0	56.9	646.0	664.	2.00	4.58	6.58
4	5	3	10606.	48788.	1175.	9.8	629.3	639.7	642.5	645.4	10.4	5.7	16.1	633.6	660.	2.00	4.58	4.58

4	5	2	1632.	48712.	1174.	9.8	628.9	630.5	630.9	631.4	1.6	.9	2.5	629.5	658.	.01	.03	.04
4	5	1	1624.	48712.	1174.	9.8	628.9	630.5	630.9	631.4	1.6	.9	2.5	629.5	658.	2.28	1.22	3.50
4	6	17	8828.	68202.	1361.	10.0	740.8	748.3	750.5	752.8	7.5	4.5	12.0	743.9	736.	3.54	5.68	9.22
4	6	16	37874.	67964.	1359.	10.0	739.3	771.4	781.0	790.6	32.0	19.3	51.3	752.7	738.	1.90	4.49	6.39
4	6	15	96536.	67276.	1353.	10.0	735.1	817.1	841.1	865.1	82.0	48.0	130.0	769.2	742.	1.90	4.49	6.40
4	6	14	141529.	66042.	1341.	10.0	727.5	848.8	883.4	918.1	121.3	69.3	190.6	777.6	743.	1.91	4.50	6.41
4	6	13	166303.	64419.	1326.	10.0	717.7	861.8	902.3	942.7	144.1	80.9	225.0	777.0	739.	1.91	4.51	6.42
4	6	12	181965.	62547.	1309.	10.0	706.6	866.4	910.5	954.7	159.8	88.2	248.0	772.2	734.	1.92	4.52	6.44
4	6	11	174561.	60594.	1291.	9.9	695.3	850.7	893.3	935.9	155.5	85.2	240.7	758.9	725.	1.93	4.53	6.46
4	6	10	156906.	58749.	1273.	9.9	684.7	826.4	865.0	903.7	141.7	77.4	219.0	742.7	716.	1.94	4.53	6.47
4	6	9	166303.	56926.	1256.	9.9	674.4	826.6	867.6	908.6	152.2	81.9	234.2	736.5	710.	1.95	4.54	6.49
4	6	8	191078.	54887.	1236.	9.9	663.0	840.7	887.4	934.2	177.7	93.4	271.2	735.1	705.	1.96	4.55	6.51
4	6	7	179687.	52752.	1215.	9.9	651.1	821.2	865.5	909.8	170.0	88.6	258.6	720.0	695.	1.97	4.56	6.54
4	6	6	132701.	50942.	1197.	9.8	641.2	768.6	802.1	835.6	127.5	67.0	194.5	692.9	682.	1.98	4.57	6.56
4	6	5	80019.	49706.	1184.	9.8	634.4	712.0	732.8	753.5	77.7	41.5	119.2	666.0	672.	1.99	4.58	6.57
4	6	4	34741.	49038.	1177.	9.8	630.7	664.6	673.8	683.0	33.9	18.4	52.4	644.5	664.	2.00	4.58	6.58
4	6	3	9682.	48780.	1174.	9.8	629.3	638.7	641.3	643.9	9.5	5.2	14.7	633.1	660.	2.00	4.58	6.58
4	6	2	1993.	48712.	1174.	9.8	628.9	630.8	631.4	631.9	2.0	1.1	3.0	629.7	658.	.01	.03	.04
4	6	1	1982.	48712.	1174.	9.8	628.9	630.8	631.4	631.9	1.9	1.1	3.0	629.7	658.	2.28	1.22	3.50

TIN = 628.887 TOUT = 750.836

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PASS NUMBER/NUMBER OF PASSES =    2/ 5
MASS FLOW, PANEL A           =189.6  KG/S (  1.504 MLB/H)
MASS FLOW, PANEL B           =189.6  KG/S (  1.504 MLB/H)
PASS MASS FLOW               =379.1  KG/S (  3.009 MLB/H)
PASS INLET  TEMPERATURE      =    331.6 C (  628.9 F)
INLET TEMPERATURE,PANEL A    =    331.6 C (  628.9 F)
INLET TEMPERATURE,PANEL B    =    331.6 C (  628.9 F)
OUTLET TEMPERATURE, PANEL A  =    401.1 C (  754.1 F)
OUTLET TEMPERATURE, PANEL B  =    397.6 C (  747.6 F)
PASS OUTLET TEMPERATURE      =    399.4 C (  750.8 F)
PASS PEAK METAL TEMPERATURE  =    517.4 C (  963.4 F)
PASS PEAK SALT  TEMPERATURE  =    467.9 C (  874.3 F)
PASS PEAK FRONT-TO-BACK DT   =    152.7 C (  274.8 F)
PASS FRICTIONAL PRESS DROP   = 228.20 KPA (  33.10 LB/IN2)
CUMULATIVE FRICT. PRESS DROP = 474.02 KPA (  68.76 LB/IN2)
PASS PEAK ABSORBED HEAT FLUX = .614 MW/M2 (   .195 MBTU/H-FT2)
ABSORBED POWER, PANEL A      =   19.89 MW (  67.87 MBTU/H)
ABSORBED POWER, PANEL B      =   18.87 MW (  64.37 MBTU/H)
PASS ABSORBED POWER          =   38.76 MW (132.241 MBTU/H)
CUMULATIVE ABSORBED POWER    =   63.68 MW (217.279 MBTU/H)
CUMULATIVE INCIDENT POWER    =   68.69 MW (234.385 MBTU/H)
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SOLAR RECEIVER PASS 2 SUMMARY DATA

STRIP		1	2	3	4	5	6
MASS FLOW (KG/S)	=	2.156	2.154	2.154	2.157	2.154	2.149
FLOW VARIATION (PERCENT FROM AVERAGE	=	.10	.00	.00	.00	.00	.00
MASS VELOCITY (KG/M2-S)	=	5622.	5617.	5617.	5624.	5617.	5604.
MAXIMUM VELOCITY (M/S)	=	3.1	3.1	3.1	3.1	3.1	3.0
AVERAGE REYNOLDS NUMBER	=	58905.	58567.	58547.	58600.	58156.	57311.
FRICTIONAL PRESSURE LOSS (KPA)	=	228.11	227.88	227.87	228.15	227.84	227.25
GRAVITATIONAL PRESSURE LOSS (KPA)	=	485.19	485.36	485.37	485.16	485.40	485.84
TOTAL PRESSURE LOSS (KPA)	=	713.30	713.24	713.24	713.31	713.23	713.09
AVERAGE HEAT TRANSFER COEFFICIENT (W/M2-C)	=	7227.4	7207.0	7205.7	7211.6	7184.6	7133.4
SALT INLET TEMPERATURE (C)	=	331.6	331.6	331.6	331.6	331.6	331.6
SALT OUTLET TEMPERATURE (C)	=	402.3	400.9	400.5	400.5	398.0	393.9
SALT TEMPERATURE RISE (C)	=	70.7	69.3	68.8	68.8	66.4	62.3
PEAK SALT TEMPERATURE (C)	=	458.1	457.2	463.9	463.8	467.9	463.8
PEAK AVERAGE METAL TEMPERATURE (C)	=	417.5	418.5	420.0	419.9	416.7	414.4
PEAK METAL TEMPERATURE (C)	=	503.5	502.3	510.6	510.4	517.5	512.8
AVERAGE METAL TEMPERATURE (C)	=	388.7	388.2	389.0	390.2	389.3	386.8
AVERAGE SURFACE TEMPERATURE (C)	=	450.2	451.5	454.6	455.6	456.0	453.9
MAXIMUM WALL TEMPERATURE DIFFERENCE (C)	=	48.1	49.9	51.8	51.8	52.8	51.9
MAXIMUM FRONT TO BACK TEMPERATURE DIFFERENCE (C)	=	139.0	145.0	151.0	150.9	152.7	150.8
TUBE THERMAL EXPANSION (MM)	=	.0	.0	.0	.0	.0	.0
PEAK ABSORBED HEAT FLUX (MW/M2)	=	.554	.577	.600	.600	.614	.603
AVERAGE ABSORBED HEAT FLUX (MW/M2)	=	.324	.317	.315	.314	.302	.283
ABSORBED POWER (MW)	=	5.055	9.917	4.919	4.925	9.500	4.441

SOLAR RECEIVER PASS 2 SUMMARY DATA

STRIP		1	2	3	4	5	6
MASS FLOW (LB/H)	=	17114.	17098.	17097.	17117.	17096.	17056.
FLOW VARIATION (PERCENT FROM AVERAGE	=	.10	.00	.00	.00	.00	.00
MASS VELOCITY (LB/FT2-S)	=	1152.	1151.	1150.	1152.	1150.	1148.
MAXIMUM VELOCITY (FT/S)	=	10.1	10.1	10.0	10.1	10.0	10.0
AVERAGE REYNOLDS NUMBER	=	58905.	58567.	58547.	58600.	58156.	57311.
FRICTIONAL PRESSURE LOSS (LB/IN2)	=	33.08	33.05	33.05	33.09	33.04	32.96
GRAVITATIONAL PRESSURE LOSS (LB/IN2)	=	70.37	70.40	70.40	70.37	70.40	70.46
TOTAL PRESSURE LOSS (LB/IN2)	=	103.45	103.45	103.45	103.46	103.45	103.42
AVERAGE HEAT TRANSFER COEFFICIENT (BTU/H-FT2-F)	=	1273.1	1269.5	1269.3	1270.3	1265.6	1256.5
SALT INLET TEMPERATURE (F)	=	628.9	628.9	628.9	628.9	628.9	628.9
SALT OUTLET TEMPERATURE (F)	=	756.1	753.6	752.8	752.8	748.4	741.1
SALT TEMPERATURE RISE (F)	=	127.2	124.7	123.9	123.9	119.5	112.2
PEAK SALT TEMPERATURE (F)	=	856.5	854.9	867.0	866.8	874.3	866.9
PEAK AVERAGE METAL TEMPERATURE (F)	=	783.4	785.3	788.1	787.9	782.0	777.9
PEAK METAL TEMPERATURE (F)	=	938.3	936.2	951.0	950.8	963.4	955.1
AVERAGE METAL TEMPERATURE (F)	=	731.6	730.8	732.3	734.4	732.8	728.3
AVERAGE SURFACE TEMPERATURE (F)	=	842.4	844.7	850.2	852.0	852.8	849.0
MAXIMUM WALL TEMPERATURE DIFFERENCE (F)	=	86.5	89.8	93.2	93.2	95.0	93.4
MAXIMUM FRONT TO BACK TEMPERATURE DIFFERENCE (F)	=	250.3	261.0	271.7	271.6	274.8	271.5
TUBE THERMAL EXPANSION (IN)	=	.0	.0	.0	.0	.0	.0
PEAK ABSORBED HEAT FLUX (MBTU/H-FT2)	=	.176	.183	.191	.191	.195	.192
AVERAGE ABSORBED HEAT FLUX (MBTU/H-FT2)	=	.103	.101	.100	.100	.096	.090
ABSORBED POWER (MBTU/H)	=	17.250	33.842	16.785	16.805	32.419	15.154

320 MW MOLTEN SALT RECEIVER

ABSORBED NORMAL HEAT FLUX (MW/M2)

PASS 3

	PANEL 5			PANEL 6		
17	.0211	.0231	.0261	.0190	.0185	.0218
16	.0213	.0274	.0336	.0336	.0279	.0378
15	.0915	.1054	.1008	.1008	.1127	.1257
14	.2333	.2383	.2431	.2431	.2431	.2334
13	.3421	.3350	.3259	.3259	.3178	.3001
12	.4019	.3985	.3919	.3919	.3748	.3226
11	.4398	.4058	.3925	.3925	.3824	.3277
10	.4219	.3906	.3607	.3607	.3545	.3194
9	.3792	.3473	.3571	.3571	.3451	.3072
8	.4019	.3913	.3901	.3901	.3691	.3354
0 LEVEL						
7	.4618	.4361	.4153	.4153	.3824	.3303
6	.4343	.3848	.3511	.3511	.3121	.2687
5	.3207	.2736	.2551	.2551	.2273	.1975
4	.1934	.1661	.1476	.1476	.1361	.1161
3	.0840	.0744	.0696	.0696	.0658	.0558
2	.0234	.0217	.0210	.0210	.0184	.0160
1	.0109	.0100	.0097	.0149	.0131	.0116

320 MW MOLTEN SALT RECEIVER

ABSORBED PEAK HEAT FLUX (MW/M2)

PASS 3

	PANEL 5			PANEL 6		
17	.0276	.0322	.0382	.0278	.0288	.0362
16	.0279	.0381	.0493	.0493	.0433	.0629
15	.1195	.1465	.1478	.1478	.1753	.2089
14	.3046	.3312	.3564	.3564	.3782	.3879
13	.4465	.4657	.4779	.4779	.4945	.4987
12	.5247	.5540	.5747	.5747	.5831	.5360
11	.5741	.5641	.5755	.5755	.5949	.5445
10	.5507	.5430	.5289	.5289	.5516	.5307
9	.4950	.4828	.5236	.5236	.5368	.5104
8	.5247	.5440	.5720	.5720	.5742	.5573
0 LEVEL	*	*	*	*	*	*
7	.6029	.6062	.6090	.6090	.5949	.5488
6	.5669	.5350	.5148	.5148	.4856	.4465
5	.4187	.3804	.3740	.3740	.3536	.3282
4	.2525	.2308	.2165	.2165	.2118	.1929
3	.1096	.1034	.1021	.1021	.1024	.0927
2	.0305	.0301	.0308	.0308	.0286	.0266
1	.0142	.0139	.0142	.0219	.0203	.0193

320 MW MOLTEN SALT RECEIVER

ABSORBED POWER (MW)

PASS 3

	PANEL 5			PANEL 6			
16	.0074	.0176	.0103	.0177	.0312	.0201	
15	.0591	.1393	.0704	.0704	.1474	.0856	
14	.1700	.3604	.1800	.1800	.3732	.1880	
13	.3011	.6012	.2978	.2978	.5883	.2793	
12	.3894	.7693	.3757	.3757	.7264	.3259	
11	.4405	.8436	.4106	.4106	.7942	.3404	
10	.4510	.8352	.3942	.3942	.7729	.3387	
9	.4193	.7739	.3757	.3757	.7337	.3279	
8	.4088	.7746	.3911	.3911	.7490	.3363	
0 LEVEL							
7	.4521	.8678	.4216	.4216	.7882	.3484	
6	.4690	.8610	.4011	.4011	.7284	.3135	
5	.3952	.6906	.3173	.3173	.5657	.2440	
4	.2691	.4612	.2108	.2108	.3811	.1641	
3	.1452	.2522	.1137	.1137	.2118	.0900	
2	.0562	.1007	.0474	.0474	.0883	.0376	
1	.0121	.0224	.0108	.0068	.0120	.0053	
TOTALS	4.445	8.371	4.028	4.032	7.692	3.445	32.013

320 MW MOLTEN SALT RECEIVER

VARIATION IN SALT TEMPERATURE ALONG PANEL (F)

PASS 3

	PANEL 5			PANEL 6		
17	862.0	855.3	851.6	851.7	846.9	837.1
16	861.8	855.1	851.4	851.3	846.5	836.6
15	860.4	853.4	849.6	849.5	844.7	834.4
14	856.1	848.9	845.1	845.0	840.0	829.7
13	848.6	841.4	837.7	837.6	832.7	822.8
12	838.9	831.8	828.3	828.2	823.6	814.6
11	827.9	821.3	818.1	818.0	813.7	806.1
10	816.6	810.9	808.2	808.1	804.1	797.6
9	806.2	801.2	798.8	798.7	794.9	789.4
8	795.9	791.6	789.0	788.9	785.6	781.0
0 LEVEL	*	*	*	*	*	*
7	784.6	780.7	778.5	778.4	775.7	772.3
6	772.9	770.0	768.4	768.3	766.6	764.4
5	762.9	761.3	760.4	760.3	759.5	758.3
4	756.2	755.5	755.2	755.1	754.7	754.2
3	752.6	752.4	752.3	752.2	752.1	751.9
2	751.1	751.1	751.1	751.0	751.0	751.0
1	750.8	750.8	750.8	750.8	750.8	750.8

320 MW MOLTEN SALT RECEIVER

TEMPERATURE SUMMARY
FILM (I.D.) TEMPERATURE (C)
PEAK (O.D.) TEMPERATURE (C)
FRONT-TO-BACK TEMPERATURE DIFFERENCE (C)

PASS 3

	PANEL 5			PANEL 6		
17	464.8	461.7	460.5	459.1	456.6	452.2
	467.2	464.5	463.8	461.6	459.1	455.3
	6.1	7.1	8.5	6.2	6.4	8.1
16	464.7	462.6	461.8	461.8	458.4	455.5
	467.2	465.7	466.1	466.1	462.1	461.0
	6.1	8.4	10.9	10.9	9.6	14.0
15	476.2	476.0	474.2	474.1	475.2	474.3
	486.4	488.6	486.8	486.8	490.2	492.2
	26.2	32.3	32.6	32.6	38.7	46.4
14	498.7	498.5	500.0	499.9	500.3	496.3
	524.3	526.3	529.9	529.8	532.0	528.9
	66.5	72.5	78.1	78.1	83.1	85.7
13	513.9	512.9	512.6	512.6	512.4	508.0
	551.0	551.5	552.3	552.2	553.4	549.5
	97.3	101.8	104.7	104.7	108.6	110.2
12	519.6	520.1	521.2	521.1	520.0	509.1
	562.9	565.8	568.5	568.4	568.1	553.6
	114.6	121.4	126.1	126.1	128.3	118.8
11	520.9	516.3	516.3	516.2	516.8	506.1
	568.2	562.9	563.8	563.8	565.9	551.4
	126.0	124.4	127.1	127.1	131.6	121.3
10	512.1	508.2	505.0	504.9	506.1	500.0
	557.8	553.4	549.0	548.9	552.0	544.3
	121.9	120.6	117.8	117.8	123.0	119.0
9	499.2	495.1	499.6	499.5	499.6	493.1
	540.6	535.6	543.4	543.3	544.4	536.0
	110.5	108.2	117.4	117.4	120.6	115.2
8	498.3	498.9	501.7	501.6	500.3	495.7
	542.2	544.4	549.3	549.3	548.2	542.4
	117.8	122.4	128.8	128.8	129.6	126.3
0 LEVEL						
7	503.9	502.6	501.9	501.8	498.6	490.3
	554.1	553.0	552.6	552.5	548.2	536.4
	136.0	137.1	137.9	137.9	135.1	125.1
6	493.2	487.2	483.5	483.5	478.4	471.7
	540.7	532.2	527.0	527.0	519.6	509.8
	129.1	122.3	117.9	117.9	111.5	102.9
5	466.9	460.5	459.2	459.1	455.7	451.4
	502.8	493.3	491.4	491.3	486.3	479.9
	96.7	88.1	86.7	86.7	82.1	76.4
4	439.3	435.8	433.5	433.4	432.6	429.5
	461.4	456.0	452.5	452.5	451.2	446.5
	59.0	54.1	50.8	50.8	49.7	45.3
3	416.4	415.4	415.2	415.1	415.1	413.8
	426.2	424.6	424.3	424.2	424.3	421.9
	25.9	24.4	24.1	24.1	24.2	21.9
2	404.0	403.9	404.0	404.0	403.6	403.3
	406.8	406.7	406.8	406.8	406.2	405.8
	7.3	7.1	7.3	7.3	6.8	6.3
1	401.4	401.4	401.4	402.6	402.3	402.2
	402.7	402.6	402.7	404.5	404.2	403.9
	3.4	3.3	3.4	5.2	4.8	4.6

320 MW MOLTEN SALT RECEIVER

TEMPERATURE SUMMARY
FILM (I.D.) TEMPERATURE (F)
PEAK (O.D.) TEMPERATURE (F)
FRONT-TC-BACK TEMPERATURE DIFFERENCE (F)

PASS 3

	PANEL 5			PANEL 6		
17	868.7	863.1	860.9	858.4	853.9	845.9
	872.9	868.1	866.9	862.8	858.4	851.6
	10.9	12.8	15.2	11.1	11.5	14.5
16	868.5	864.3	863.3	863.2	857.0	852.0
	872.9	870.3	871.0	870.9	863.8	861.8
	11.0	15.2	19.6	19.6	17.3	25.3
15	889.1	888.8	885.5	885.6	887.4	885.7
	907.6	911.5	908.3	908.2	914.4	917.9
	47.2	58.1	58.7	58.7	69.7	83.5
14	929.7	929.3	931.9	931.8	932.5	925.3
	975.8	979.4	985.7	985.7	989.6	984.0
	119.6	130.5	140.6	140.6	149.6	154.3
13	957.1	955.1	954.7	954.6	954.3	946.4
	1023.7	1024.7	1026.1	1026.0	1028.1	1021.1
	175.1	183.3	188.4	188.4	195.4	198.3
12	967.3	968.2	970.1	970.0	968.1	948.6
	1045.2	1050.4	1055.3	1055.2	1054.5	1028.5
	206.3	218.5	227.0	227.0	230.9	213.9
11	969.6	961.3	961.3	961.2	962.3	943.0
	1054.7	1045.2	1046.8	1046.8	1050.7	1024.5
	226.8	223.9	228.8	228.8	236.9	218.4
10	953.9	946.8	940.9	940.8	943.0	932.0
	1036.0	1028.0	1020.2	1020.1	1025.6	1011.8
	219.3	217.1	212.0	212.0	221.5	214.2
9	930.6	923.1	931.3	931.2	931.2	919.7
	1005.1	996.0	1010.0	1009.9	1011.9	996.8
	199.0	194.8	211.2	211.2	217.0	207.3
8	929.0	930.1	935.0	934.9	932.6	924.3
	1008.0	1011.9	1020.8	1020.7	1018.8	1008.3
	212.1	220.3	231.8	231.8	233.2	227.3
0 LEVEL 7	939.1	936.6	935.4	935.3	929.4	914.5
	1029.3	1027.4	1026.7	1026.6	1018.8	997.5
	244.7	246.7	248.2	248.2	243.1	225.3
6	919.7	908.9	902.4	902.3	893.2	881.1
	1005.3	990.0	980.6	980.5	967.3	949.6
	232.4	220.1	212.2	212.2	200.7	185.2
5	872.5	861.0	858.5	858.4	852.3	844.6
	937.0	919.9	916.5	916.4	907.3	895.8
	174.0	158.6	156.1	156.1	147.8	137.5
4	822.7	816.4	812.2	812.1	810.6	805.1
	862.5	852.9	846.5	846.4	844.2	835.7
	106.3	97.3	91.4	91.4	89.4	81.6
3	781.5	779.7	779.3	779.2	779.2	776.4
	799.1	796.3	795.7	795.6	795.7	791.4
	46.6	44.0	43.4	43.4	43.6	39.5
2	759.2	759.1	759.3	759.2	758.5	758.0
	764.2	764.0	764.3	764.2	763.2	762.4
	13.1	12.9	13.2	13.2	12.2	11.4
1	754.6	754.5	754.6	756.6	756.2	755.9
	756.9	756.8	756.9	760.2	759.5	759.1
	6.1	5.9	6.1	9.3	8.7	8.2

SYMBOL	DEFINITION	UNITS
PN	PASS NUMBER	
SN	STRIP NUMBER	
NN	NODE NUMBER	
FLUX	ABSORBED PEAK FLUX	(BTU/H-FT2)
RE	REYNOLDS NUMBER	
H	HEAT TRANSFER COEFFICIENT	(BTU/H-FT2-F)
VEL	SALT VELOCITY	(FT/S)
SBT	SALT BULK TEMPERATURE	(F)
PST	PEAK SALT TEMPERATURE=ID TEMPERATURE	(F)
MWT	MEAN TUBEWALL METAL TEMPERATURE=(SFT+PMT)/2	(F)
PMT	PEAK METAL TEMPERATURE=OD TEMPERATURE	(F)
SDT	SALT TEMPERATURE DIFFERENCE=(SFT-SBT)	(F)
MDT	METAL TEMPERATURE DIFFERENCE=(PMT-SFT)	(F)
FBDT	FRONT-TO-BACK TEMPERATURE DIFFERENCE=(PMT-SBT)	(F)
AMT	AVERAGE METAL TEMPERATURE	(F)
OHC	OVERALL HEAT TRANSFER COEFFICIENT	(BTU/H-FT2-F)
FPD	FRICTIONAL PRESSURE LOSS	(LB/IN2)
GPD	GRAVITATIONAL PRESSURE LOSS	(LB/IN2)
TPD	TOTAL PRESSURE LOSS	(LB/IN2)

PASS NO. 3/ 5

PN	SN	NN	FLUX	RE	H	VEL	SBT	PST	MWT	PMT	SDT	MDT	FBDT	AMT	OHC	FPD	GPD	TPD
5	1	17	8733.	85202.	1516.	10.3	862.0	868.7	870.8	872.9	6.6	4.3	10.9	864.9	800.	2.24	2.62	4.86
5	1	16	8828.	85180.	1515.	10.3	861.8	868.5	870.7	872.9	6.7	4.3	11.0	864.7	800.	1.86	4.38	6.24
5	1	15	37874.	84997.	1514.	10.3	860.4	889.1	898.4	907.6	28.8	18.4	47.2	872.6	802.	1.86	4.38	6.24
5	1	14	96536.	84470.	1509.	10.3	856.1	929.7	952.7	975.8	73.5	46.1	119.6	887.2	807.	1.86	4.39	6.25
5	1	13	141529.	83526.	1500.	10.2	848.6	957.1	990.4	1023.7	108.4	66.7	175.1	894.2	808.	1.86	4.39	6.25
5	1	12	166303.	82266.	1489.	10.2	838.9	967.3	1006.3	1045.2	128.4	77.9	206.3	892.7	806.	1.86	4.40	6.27
5	1	11	181965.	80854.	1476.	10.2	827.9	969.6	1012.2	1054.7	141.7	85.1	226.8	887.2	802.	1.87	4.41	6.28
5	1	10	174561.	79354.	1462.	10.2	816.6	953.9	994.9	1036.0	137.2	82.1	219.3	874.0	796.	1.87	4.42	6.29
5	1	9	156906.	77924.	1449.	10.2	806.2	930.6	967.9	1005.1	124.4	74.5	199.0	858.2	789.	1.87	4.43	6.30
5	1	8	166303.	76497.	1436.	10.1	795.9	929.0	968.5	1008.0	133.1	79.0	212.1	851.4	784.	1.88	4.44	6.31
5	1	7	191078.	74877.	1422.	10.1	784.6	939.1	984.2	1029.3	154.5	90.2	244.7	848.8	781.	1.88	4.45	6.33
5	1	6	179687.	73150.	1406.	10.1	772.9	919.7	962.5	1005.3	146.9	85.5	232.4	833.8	773.	1.89	4.46	6.34
5	1	5	132701.	71657.	1393.	10.1	762.9	872.5	904.7	937.0	109.5	64.5	174.0	808.5	763.	1.89	4.47	6.36
5	1	4	80019.	70621.	1383.	10.1	756.2	822.7	842.6	862.5	66.5	39.8	106.3	784.0	753.	1.89	4.47	6.37
5	1	3	34741.	70055.	1378.	10.0	752.6	781.5	790.3	799.1	29.0	17.6	46.6	764.7	746.	1.89	4.48	6.37
5	1	2	9682.	69835.	1376.	10.0	751.1	759.2	761.7	764.2	8.1	5.0	13.1	754.5	742.	1.28	3.02	4.30
5	1	1	4494.	69788.	1376.	10.0	750.8	754.6	755.7	756.9	3.8	2.3	6.1	752.4	741.	2.26	1.19	3.45
5	2	17	10193.	84371.	1508.	10.3	855.3	863.1	865.6	868.1	7.8	5.0	12.8	858.7	797.	2.24	2.62	4.86
5	2	16	12089.	84344.	1508.	10.3	855.1	864.3	867.3	870.3	9.2	6.0	15.2	859.1	797.	1.86	4.39	6.25
5	2	15	46447.	84127.	1506.	10.2	853.4	888.8	900.2	911.5	35.5	22.6	58.1	868.4	800.	1.86	4.39	6.25
5	2	14	104982.	83562.	1501.	10.2	848.9	929.3	954.4	979.4	80.4	50.1	130.5	882.8	804.	1.86	4.39	6.25
5	2	13	147611.	82609.	1492.	10.2	841.4	955.1	989.9	1024.7	113.7	69.6	183.3	889.2	805.	1.86	4.40	6.26
5	2	12	175606.	81369.	1481.	10.2	831.8	968.2	1009.3	1050.4	136.3	82.2	218.5	888.9	804.	1.87	4.41	6.27
5	2	11	178787.	79982.	1468.	10.2	821.3	961.3	1003.2	1045.2	140.0	83.9	223.9	879.8	799.	1.87	4.42	6.28
5	2	10	172107.	78576.	1455.	10.2	810.9	946.8	987.4	1028.0	135.9	81.2	217.1	867.7	793.	1.87	4.43	6.30
5	2	9	153019.	77243.	1443.	10.1	801.2	923.1	959.6	996.0	121.9	72.9	194.8	852.2	786.	1.87	4.43	6.31
5	2	8	172425.	75898.	1431.	10.1	791.6	930.1	971.0	1011.9	138.5	81.8	220.3	849.3	783.	1.88	4.44	6.32
5	2	7	192149.	74312.	1417.	10.1	780.7	936.6	982.0	1027.4	155.9	90.8	246.7	845.5	779.	1.88	4.45	6.33
5	2	6	169562.	72717.	1402.	10.1	770.0	908.9	949.5	990.0	139.0	81.1	220.1	827.7	770.	1.89	4.46	6.35

5	2	5	120570.	71408.	1390.	10.1	761.3	861.0	890.4	919.9	99.7	58.9	158.6	802.8	760.	1.89	4.47	6.36
5	2	4	73169.	70519.	1382.	10.1	755.5	816.4	834.6	852.9	60.8	36.5	97.3	781.0	752.	1.89	4.47	6.37
5	2	3	32767.	70028.	1378.	10.0	752.4	779.7	788.0	796.3	27.3	16.6	44.0	763.8	745.	1.89	4.48	6.37
5	2	2	9544.	69831.	1376.	10.0	751.1	759.1	761.5	764.0	8.0	4.9	12.9	754.5	742.	1.28	3.02	4.30
5	2	1	4391.	69788.	1376.	10.0	750.8	754.5	755.6	756.8	3.7	2.3	5.9	752.4	741.	2.26	1.19	3.45
5	3	17	12112.	83905.	1504.	10.2	851.6	860.9	863.9	866.9	9.3	6.0	15.2	855.6	795.	2.24	2.62	4.87
5	3	16	15620.	83873.	1503.	10.2	851.4	863.3	867.2	871.0	11.9	7.7	19.6	856.5	795.	1.86	4.39	6.25
5	3	15	46861.	83652.	1501.	10.2	849.6	885.5	896.9	908.3	35.9	22.8	58.7	864.8	798.	1.86	4.39	6.25
5	3	14	112968.	83082.	1496.	10.2	845.1	931.9	958.8	985.7	86.8	53.8	140.6	881.7	803.	1.86	4.40	6.26
5	3	13	151461.	82130.	1488.	10.2	837.7	954.7	990.4	1026.1	117.0	71.4	188.4	886.8	804.	1.86	4.40	6.27
5	3	12	182143.	80908.	1476.	10.2	828.3	970.1	1012.7	1055.3	141.8	85.2	227.0	887.6	802.	1.87	4.41	6.28
5	3	11	182422.	79545.	1464.	10.2	818.1	961.3	1004.1	1046.8	143.2	85.6	228.8	877.9	797.	1.87	4.42	6.29
5	3	10	167639.	78206.	1452.	10.2	808.2	940.9	980.6	1020.2	132.7	79.3	212.0	863.6	791.	1.87	4.43	6.30
5	3	9	165965.	76902.	1440.	10.1	798.8	931.3	970.7	1010.0	132.5	78.8	211.2	854.1	786.	1.88	4.44	6.31
5	3	8	181306.	75513.	1427.	10.1	789.0	935.0	977.9	1020.8	146.0	85.8	231.8	849.8	782.	1.88	4.44	6.32
5	3	7	193022.	73979.	1414.	10.1	778.5	935.4	981.0	1026.7	157.0	91.3	248.2	843.6	778.	1.88	4.45	6.34
5	3	6	163176.	72483.	1400.	10.1	768.4	902.4	941.5	980.6	134.0	78.2	212.2	824.1	769.	1.89	4.46	6.35
5	3	5	118546.	71275.	1389.	10.1	760.4	858.5	887.5	916.5	98.1	58.0	156.1	801.3	760.	1.89	4.47	6.36
5	3	4	68617.	70460.	1382.	10.1	755.2	812.2	829.4	846.5	57.1	34.3	91.4	779.0	751.	1.89	4.47	6.37
5	3	3	32356.	70016.	1378.	10.0	752.3	779.3	787.5	795.7	27.0	16.4	43.4	763.6	745.	1.89	4.48	6.37
5	3	2	9763.	49830.	1376.	10.0	751.1	759.3	761.8	764.3	8.2	5.0	13.2	754.5	742.	1.28	3.02	4.30
5	3	1	4492.	69788.	1376.	10.0	750.8	754.6	755.7	756.9	3.8	2.3	6.1	752.4	741.	2.26	1.19	3.45
6	4	17	8807.	83916.	1504.	10.2	851.7	858.4	860.6	862.8	6.7	4.3	11.1	854.6	795.	2.82	3.99	6.82
6	4	16	15620.	83860.	1503.	10.2	851.3	863.2	867.1	870.9	11.9	7.7	19.6	856.4	795.	1.86	4.39	6.25
6	4	15	46861.	83639.	1501.	10.2	849.5	885.4	896.8	908.2	35.9	22.8	58.7	864.7	798.	1.86	4.39	6.25
6	4	14	112968.	83070.	1496.	10.2	845.0	931.8	958.7	985.7	86.8	53.8	140.6	881.6	803.	1.86	4.40	6.26
6	4	13	151461.	82117.	1487.	10.2	837.6	954.6	990.3	1026.0	117.0	71.4	188.4	886.7	804.	1.86	4.40	6.27
6	4	12	182143.	80895.	1476.	10.2	828.2	970.0	1012.6	1055.2	141.8	85.2	227.0	887.5	802.	1.87	4.41	6.28
6	4	11	182422.	79532.	1464.	10.2	818.0	961.2	1004.0	1046.8	143.2	85.6	228.8	877.8	797.	1.87	4.42	6.29
6	4	10	167639.	78193.	1452.	10.2	808.1	940.8	980.5	1020.1	132.7	79.3	212.0	863.6	791.	1.87	4.43	6.30
6	4	9	165965.	76888.	1440.	10.1	798.7	931.2	970.6	1009.9	132.5	78.8	211.2	854.0	786.	1.88	4.44	6.31
6	4	8	181306.	75498.	1427.	10.1	788.9	934.9	977.8	1020.7	146.0	85.8	231.8	849.7	782.	1.88	4.44	6.32
6	4	7	193022.	73964.	1413.	10.1	778.4	935.3	981.0	1026.6	157.0	91.3	248.2	843.5	778.	1.88	4.45	6.34
6	4	6	163176.	72468.	1400.	10.1	768.3	902.3	941.4	980.5	134.0	78.3	212.2	824.0	769.	1.89	4.46	6.35
6	4	5	118546.	71260.	1389.	10.1	760.3	858.4	887.4	916.4	98.1	58.0	156.1	801.2	760.	1.89	4.47	6.36
6	4	4	68617.	70444.	1382.	10.1	755.1	812.1	829.3	846.4	57.1	34.3	91.4	778.9	751.	1.89	4.47	6.37
6	4	3	32356.	70000.	1378.	10.0	752.2	779.2	787.4	795.6	27.0	16.4	43.4	763.5	745.	1.89	4.48	6.37
6	4	2	9763.	69814.	1376.	10.0	751.0	759.2	761.7	764.2	8.2	5.0	13.2	754.4	742.	.69	1.63	2.31
6	4	1	6927.	69788.	1376.	10.0	750.8	756.6	758.4	760.2	5.8	3.6	9.3	753.3	741.	2.26	1.19	3.45
6	5	17	9121.	83307.	1498.	10.2	846.9	853.9	856.1	858.4	7.0	4.5	11.5	849.9	792.	2.82	4.00	6.82
6	5	16	13736.	83257.	1498.	10.2	846.5	857.0	860.4	863.8	10.5	6.8	17.3	851.0	793.	1.86	4.39	6.26
6	5	15	55570.	83024.	1496.	10.2	844.7	887.4	900.9	914.4	42.7	27.0	69.7	862.8	797.	1.86	4.40	6.26
6	5	14	119882.	82430.	1490.	10.2	840.0	932.5	961.0	989.6	92.5	57.1	149.6	879.0	802.	1.86	4.40	6.26
6	5	13	156720.	81482.	1482.	10.2	832.7	954.3	991.2	1028.1	121.6	73.8	195.4	883.7	802.	1.87	4.41	6.27
6	5	12	184817.	80290.	1471.	10.2	823.6	968.1	1011.3	1054.5	144.4	86.5	230.9	884.0	800.	1.87	4.41	6.28
6	5	11	188564.	78961.	1459.	10.2	813.7	962.3	1006.5	1050.7	148.6	88.4	236.9	875.7	796.	1.87	4.42	6.29
6	5	10	174827.	77639.	1447.	10.1	804.1	943.0	984.3	1025.6	138.9	82.6	221.5	862.1	789.	1.87	4.43	6.30
6	5	9	170144.	76356.	1435.	10.1	794.9	931.2	971.6	1011.9	136.3	80.7	217.0	851.7	784.	1.88	4.44	6.32
6	5	8	182008.	75017.	1423.	10.1	785.6	932.6	975.7	1018.8	147.0	86.2	233.2	846.7	780.	1.88	4.45	6.33
6	5	7	188564.	73575.	1410.	10.1	775.7	929.4	974.1	1018.8	153.7	89.4	243.1	839.5	776.	1.88	4.46	6.34
6	5	6	153910.	72212.	1398.	10.1	766.6	893.2	930.2	967.3	126.6	74.1	200.7	819.2	767.	1.89	4.46	6.35
6	5	5	112077.	71133.	1388.	10.1	759.5	852.3	879.8	907.3	92.8	55.0	147.8	798.2	758.	1.89	4.47	6.36
6	5	4	67121.	70396.	1381.	10.1	754.7	810.6	827.4	844.2	55.9	33.6	89.4	778.1	751.	1.89	4.47	6.37
6	5	3	32468.	69983.	1377.	10.0	752.1	779.2	787.4	795.7	27.1	16.5	43.6	763.5	745.	1.89	4.48	6.37

6	5	2	9054.	69811.	1376.	10.0	751.0	758.5	760.9	763.2	7.6	4.6	12.2	754.2	742.	.69	1.63	2.31
6	5	1	6447.	69788.	1376.	10.0	750.8	756.2	757.9	759.5	5.4	3.3	8.7	753.1	741.	2.26	1.19	3.45
6	6	17	11461.	82050.	1487.	10.2	837.1	845.9	848.8	851.6	8.9	5.7	14.5	840.8	788.	2.83	4.00	6.83
6	6	16	19928.	81985.	1486.	10.2	836.6	852.0	856.9	861.8	15.4	9.9	25.3	843.1	789.	1.86	4.40	6.27
6	6	15	66202.	81708.	1484.	10.2	834.4	885.7	901.8	917.9	51.3	32.2	83.5	856.1	793.	1.87	4.40	6.27
6	6	14	122947.	81095.	1478.	10.2	829.7	925.3	954.7	984.0	95.6	58.7	154.3	869.9	797.	1.87	4.41	6.28
6	6	13	158075.	80174.	1470.	10.2	822.8	946.4	983.7	1021.1	123.6	74.7	198.3	874.5	797.	1.87	4.42	6.28
6	6	12	169896.	79081.	1460.	10.2	814.6	948.4	988.5	1028.5	133.8	80.1	213.9	870.5	794.	1.87	4.42	6.29
6	6	11	172599.	77918.	1449.	10.2	806.1	943.0	983.8	1024.5	136.9	81.5	218.4	863.3	790.	1.87	4.43	6.30
6	6	10	168208.	76738.	1439.	10.1	797.6	932.0	971.9	1011.8	134.4	79.8	214.2	853.7	785.	1.88	4.44	6.31
6	6	9	161790.	75572.	1428.	10.1	789.4	919.7	958.2	996.8	130.2	77.1	207.3	843.7	780.	1.88	4.44	6.32
6	6	8	176652.	74353.	1417.	10.1	781.0	924.3	966.3	1008.3	143.3	84.0	227.3	840.6	777.	1.88	4.45	6.33
6	6	7	173950.	73063.	1405.	10.1	772.3	914.5	956.0	997.5	142.3	83.0	225.3	831.4	772.	1.89	4.46	6.34
6	6	6	141524.	71880.	1395.	10.1	764.4	881.1	915.3	949.6	116.6	68.5	185.2	812.9	764.	1.89	4.47	6.35
6	6	5	104032.	70944.	1386.	10.1	758.3	844.6	870.2	895.8	86.3	51.2	137.5	794.3	757.	1.89	4.47	6.36
6	6	4	61136.	70307.	1380.	10.1	754.2	805.1	820.4	835.7	50.9	30.6	81.6	775.5	750.	1.89	4.47	6.37
6	6	3	29386.	69956.	1377.	10.0	751.9	776.4	783.9	791.4	24.5	14.9	39.5	762.2	745.	1.89	4.48	6.37
6	6	2	8444.	69808.	1376.	10.0	751.0	758.0	760.2	762.4	7.1	4.3	11.4	753.9	742.	.69	1.63	2.31
6	6	1	6114.	69788.	1376.	10.0	750.8	755.9	757.5	759.1	5.1	3.1	8.2	753.0	741.	2.26	1.19	3.45

TIN = 750.836 TOUT = 850.866

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PASS NUMBER/NUMBER OF PASSES =     3/ 5
MASS FLOW, PANEL A           =189.6  KG/S (  1.504 MLB/H)
MASS FLOW, PANEL B           =189.6  KG/S (  1.504 MLB/H)
PASS MASS FLOW               =379.1  KG/S (  3.009 MLB/H)
PASS INLET  TEMPERATURE      =     399.4 C (  750.8 F)
INLET TEMPERATURE,PANEL A    =     399.4 C (  750.8 F)
INLET TEMPERATURE,PANEL B    =     399.4 C (  750.8 F)
OUTLET TEMPERATURE, PANEL A  =     457.8 C (  856.1 F)
OUTLET TEMPERATURE, PANEL B  =     452.0 C (  845.6 F)
PASS OUTLET TEMPERATURE      =     454.9 C (  850.9 F)
PASS PEAK METAL TEMPERATURE  =     568.5 C ( 1055.3 F)
PASS PEAK SALT  TEMPERATURE  =     521.2 C (  970.1 F)
PASS PEAK FRONT-TO-BACK DT   =     137.9 C (  248.2 F)
PASS FRICTIONAL PRESS DROP   = 221.08 KPA (  32.07 LB/IN2)
CUMULATIVE FRICT. PRESS DROP = 695.09 KPA ( 100.83 LB/IN2)
PASS PEAK ABSORBED HEAT FLUX = .609 MW/M2 (    .193 MBTU/H-FT2)
ABSORBED POWER, PANEL A      =   16.84 MW (  57.48 MBTU/H)
ABSORBED POWER, PANEL B      =   15.17 MW (  51.76 MBTU/H)
PASS ABSORBED POWER          =   32.01 MW (109.234 MBTU/H)
CUMULATIVE ABSORBED POWER    =   95.69 MW (326.514 MBTU/H)
CUMULATIVE INCIDENT POWER    =  103.23 MW (352.220 MBTU/H)
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SOLAR RECEIVER PASS 3 SUMMARY DATA

STRIP		1	2	3	4	5	6
MASS FLOW (KG/S)	=	2.159	2.156	2.154	2.155	2.153	2.149
FLOW VARIATION (PERCENT FROM AVERAGE	=	.22	.00	.00	.00	.00	.00
MASS VELOCITY (KG/M2-S)	=	5629.	5620.	5616.	5620.	5613.	5602.
MAXIMUM VELOCITY (M/S)	=	3.1	3.1	3.1	3.1	3.1	3.1
AVERAGE REYNOLDS NUMBER	=	77819.	77143.	76784.	76823.	76351.	75488.
FRICTIONAL PRESSURE LOSS (KPA)	=	221.60	221.10	220.84	221.05	220.70	220.05
GRAVITATIONAL PRESSURE LOSS (KPA)	=	474.34	474.75	474.97	474.79	475.09	475.62
TOTAL PRESSURE LOSS (KPA)	=	695.95	695.85	695.81	695.85	695.78	695.67
AVERAGE HEAT TRANSFER COEFFICIENT (W/M2-C)	=	8228.6	8189.7	8169.0	8172.8	8145.6	8095.7
SALT INLET TEMPERATURE (C)	=	399.4	399.4	399.4	399.4	399.4	399.4
SALT OUTLET TEMPERATURE (C)	=	461.0	457.4	455.4	455.4	452.8	447.4
SALT TEMPERATURE RISE (C)	=	61.6	58.0	56.0	56.0	53.4	48.0
PEAK SALT TEMPERATURE (C)	=	520.7	520.0	521.2	521.1	520.1	509.3
PEAK AVERAGE METAL TEMPERATURE (C)	=	478.9	476.2	475.4	475.3	473.4	468.2
PEAK METAL TEMPERATURE (C)	=	568.0	565.7	568.5	568.4	568.1	553.9
AVERAGE METAL TEMPERATURE (C)	=	453.0	450.6	449.7	450.8	449.3	445.3
AVERAGE SURFACE TEMPERATURE (C)	=	514.0	511.9	512.1	513.1	512.4	506.2
MAXIMUM WALL TEMPERATURE DIFFERENCE (C)	=	50.1	50.5	50.7	50.7	49.7	46.6
MAXIMUM FRONT TO BACK TEMPERATURE DIFFERENCE (C)	=	135.8	137.0	137.9	137.9	135.1	126.4
TUBE THERMAL EXPANSION (MM)	=	.0	.0	.0	.0	.0	.0
PEAK ABSORBED HEAT FLUX (MW/M2)	=	.603	.606	.609	.609	.595	.557
AVERAGE ABSORBED HEAT FLUX (MW/M2)	=	.283	.266	.257	.257	.245	.220
ABSORBED POWER (MW)	=	4.445	8.371	4.028	4.032	7.692	3.445

SOLAR RECEIVER PASS 3 SUMMARY DATA

STRIP		1	2	3	4	5	6
MASS FLOW (LB/H)	=	17134.	17108.	17093.	17106.	17087.	17052.
FLOW VARIATION (PERCENT FROM AVERAGE	=	.22	.00	.00	.00	.00	.00
MASS VELOCITY (LB/FT2-S)	=	1153.	1151.	1150.	1151.	1150.	1147.
MAXIMUM VELOCITY (FT/S)	=	10.3	10.3	10.2	10.3	10.2	10.2
AVERAGE REYNOLDS NUMBER	=	77819.	77143.	76784.	76823.	76351.	75488.
FRICTIONAL PRESSURE LOSS (LB/IN2)	=	32.14	32.07	32.03	32.06	32.01	31.92
GRAVITATIONAL PRESSURE LOSS (LB/IN2)	=	68.80	68.86	68.89	68.86	68.91	68.98
TOTAL PRESSURE LOSS (LB/IN2)	=	100.94	100.93	100.92	100.92	100.92	100.90
AVERAGE HEAT TRANSFER COEFFICIENT (BTU/H-FT2-F)	=	1449.5	1442.6	1439.0	1439.6	1434.8	1426.1
SALT INLET TEMPERATURE (F)	=	750.8	750.8	750.8	750.8	750.8	750.8
SALT OUTLET TEMPERATURE (F)	=	861.8	855.3	851.7	851.7	847.0	837.3
SALT TEMPERATURE RISE (F)	=	110.9	104.4	100.8	100.8	96.1	86.5
PEAK SALT TEMPERATURE (F)	=	969.2	968.1	970.2	969.9	968.2	948.8
PEAK AVERAGE METAL TEMPERATURE (F)	=	894.0	889.1	887.7	887.5	884.1	874.8
PEAK METAL TEMPERATURE (F)	=	1054.3	1050.3	1055.3	1055.1	1054.6	1028.9
AVERAGE METAL TEMPERATURE (F)	=	847.3	843.1	841.5	843.4	840.7	833.6
AVERAGE SURFACE TEMPERATURE (F)	=	957.1	953.3	953.9	955.6	954.3	943.2
MAXIMUM WALL TEMPERATURE DIFFERENCE (F)	=	90.3	90.8	91.3	91.3	89.4	84.0
MAXIMUM FRONT TO BACK TEMPERATURE DIFFERENCE (F)	=	244.5	246.7	248.2	248.2	243.2	227.5
TUBE THERMAL EXPANSION (IN)	=	.0	.0	.0	.0	.0	.0
PEAK ABSORBED HEAT FLUX (MBTU/H-FT2)	=	.192	.193	.193	.193	.189	.177
AVERAGE ABSORBED HEAT FLUX (MBTU/H-FT2)	=	.090	.085	.082	.082	.078	.070
ABSORBED POWER (MBTU/H)	=	15.170	28.566	13.747	13.758	26.249	11.756

320 MW MOLTEN SALT RECEIVER

ABSORBED NORMAL HEAT FLUX (MW/M2)

PASS 4

	PANEL 7			PANEL 8		
17	.0253	.0190	.0340	.0265	.0390	.0472
16	.0623	.0920	.1000	.1000	.1081	.1099
15	.2068	.2138	.2082	.2082	.2081	.1975
14	.3841	.3428	.3225	.3225	.2871	.2586
13	.4939	.4395	.4011	.4011	.3702	.3484
12	.5308	.4897	.4389	.4389	.4082	.3712
11	.5392	.4909	.4450	.4450	.3942	.3584
10	.5255	.4467	.4093	.4093	.3642	.3246
9	.5055	.4323	.3950	.3950	.3412	.3096
8	.5519	.4598	.4083	.4083	.3562	.3235
0 LEVEL						
7	.5435	.4252	.3746	.3746	.3302	.2857
6	.4422	.3440	.3072	.3072	.2561	.2108
5	.3250	.2604	.2195	.2195	.1751	.1476
4	.1910	.1505	.1266	.1266	.0990	.0854
3	.0918	.0693	.0551	.0551	.0460	.0394
2	.0264	.0215	.0184	.0184	.0150	.0117
1	.0242	.0196	.0167	.0183	.0149	.0116

320 MW MOLTEN SALT RECEIVER

ABSORBED PEAK HEAT FLUX (MW/M2)

PASS 4

	PANEL 7			PANEL 8		
17	.0255	.0194	.0355	.0278	.0415	.0516
16	.0629	.0940	.1046	.1046	.1150	.1203
15	.2089	.2186	.2177	.2177	.2215	.2162
14	.3879	.3504	.3373	.3373	.3056	.2830
13	.4987	.4493	.4195	.4195	.3939	.3814
12	.5360	.5006	.4590	.4590	.4344	.4063
11	.5445	.5018	.4654	.4654	.4195	.3923
10	.5307	.4567	.4280	.4280	.3875	.3553
9	.5104	.4420	.4131	.4131	.3631	.3389
8	.5573	.4701	.4269	.4269	.3790	.3541
0 LEVEL	*	*	*	*	*	*
7	.5488	.4347	.3917	.3917	.3513	.3128
6	.4465	.3517	.3213	.3213	.2726	.2308
5	.3282	.2662	.2295	.2295	.1863	.1616
4	.1929	.1538	.1324	.1324	.1054	.0935
3	.0927	.0708	.0576	.0576	.0490	.0431
2	.0266	.0220	.0192	.0192	.0160	.0128
1	.0245	.0200	.0175	.0191	.0159	.0127

320 MW MOLTEN SALT RECEIVER

ABSORBED POWER (MW)

PASS 4

	PANEL 7			PANEL 8			
16	.0412	.1046	.0630	.0662	.1542	.0822	
15	.1408	.3207	.1613	.1613	.3316	.1609	
14	.3093	.5837	.2778	.2778	.5194	.2387	
13	.4595	.8205	.3788	.3788	.6894	.3177	
12	.5363	.9745	.4397	.4397	.8164	.3766	
11	.5600	1.0284	.4626	.4626	.8415	.3819	
10	.5573	.9833	.4471	.4471	.7954	.3575	
9	.5396	.9219	.4210	.4210	.7398	.3319	
8	.5534	.9357	.4204	.4204	.7314	.3313	
0 LEVEL							
7	.5733	.9282	.4097	.4097	.7198	.3188	
6	.5159	.8067	.3569	.3569	.6149	.2599	
5	.4015	.6338	.2757	.2757	.4522	.1876	
4	.2701	.4309	.1811	.1811	.2875	.1220	
3	.1480	.2305	.0951	.0951	.1521	.0653	
2	.0619	.0952	.0385	.0385	.0640	.0267	
1	.0028	.0046	.0020	.0001	.0002	.0001	
TOTALS	5.671	9.803	4.431	4.432	7.910	3.559	35.806

320 MW MOLTEN SALT RECEIVER

VARIATION IN SALT TEMPERATURE ALONG PANEL (F)

PASS 4

	PANEL 7			PANEL 8		
17	985.5	967.1	956.2	966.3	953.7	943.7
16	984.6	965.9	954.7	964.6	951.7	941.5
15	981.2	962.1	950.9	960.4	947.4	937.3
14	973.9	955.2	944.3	953.2	940.7	931.1
13	963.0	945.5	935.3	943.4	931.8	922.9
12	950.3	933.9	924.9	931.9	921.2	913.1
11	937.0	921.8	913.9	919.9	910.2	903.1
10	923.8	910.1	903.2	908.2	899.9	893.8
9	911.0	899.2	893.2	897.3	890.2	885.1
8	897.9	888.1	883.2	886.3	880.7	876.5
0 LEVEL	*	*	*	*	*	*
7	884.2	877.0	873.5	875.6	871.3	868.2
6	871.9	867.5	865.0	866.3	863.3	861.4
5	862.4	859.9	858.4	859.1	857.4	856.5
4	855.9	854.8	854.1	854.4	853.7	853.3
3	852.4	852.1	851.8	851.9	851.7	851.6
2	850.9	850.9	850.9	850.9	850.9	850.9
1	850.9	850.9	850.9	850.9	850.9	850.9

32C MW MOLTEN SALT RECEIVER

TEMPERATURE SUMMARY
FILM (I.D.) TEMPERATURE (C)
PEAK (O.D.) TEMPERATURE (C)
FRONT-TO-BACK TEMPERATURE DIFFERENCE (C)

PASS 4

	PANEL 7			PANEL 8		
17	532.8	521.8	517.7	522.6	517.5	513.2
	535.0	523.6	520.9	525.1	521.2	517.9
	5.3	4.1	7.5	6.0	9.1	11.4
16	536.6	530.1	525.2	531.6	525.9	521.0
	542.2	538.4	534.5	540.8	536.1	531.7
	13.0	19.6	21.9	22.7	25.1	26.5
15	552.1	542.9	536.8	543.9	537.5	531.4
	570.1	562.0	555.9	562.9	556.8	550.4
	42.8	45.3	45.4	47.1	48.3	47.4
14	569.4	555.1	547.8	555.6	544.9	536.9
	602.3	585.2	576.9	584.6	571.4	561.6
	79.0	72.3	70.1	72.8	66.6	62.1
13	577.0	562.0	553.1	561.2	551.8	545.5
	618.9	600.3	589.1	597.0	585.7	578.5
	101.7	92.8	87.3	90.7	85.8	83.6
12	575.0	562.3	552.5	560.5	551.7	543.8
	620.1	604.9	591.9	599.6	589.0	578.9
	109.9	103.8	95.9	99.6	95.0	89.4
11	569.3	556.2	547.7	555.2	544.1	536.7
	615.2	599.1	587.7	595.0	580.3	570.9
	112.4	104.8	97.8	101.7	92.4	86.9
10	560.8	544.6	537.5	544.2	534.4	526.9
	606.0	584.1	574.7	581.2	568.2	558.1
	110.5	96.2	90.7	94.4	86.1	79.3
9	551.8	537.2	530.5	536.5	526.1	520.2
	595.5	575.6	566.6	572.5	558.0	550.1
	107.2	93.8	88.1	91.8	81.2	76.1
8	551.0	535.0	527.1	532.8	523.4	517.7
	598.7	575.9	564.5	570.0	556.7	549.1
	117.6	100.3	91.5	95.4	85.2	79.9
0 LEVEL						
7	543.0	524.8	517.5	522.4	514.7	507.7
	590.3	563.0	552.1	556.9	545.8	535.6
	116.8	93.5	84.6	88.3	79.5	71.1
6	523.7	509.3	504.1	507.9	499.6	492.8
	562.9	540.6	532.8	536.6	524.1	513.7
	96.3	76.4	70.1	73.1	62.3	52.9
5	503.6	494.3	488.8	491.6	484.5	480.5
	533.0	518.4	509.6	512.2	501.5	495.4
	71.7	58.4	50.5	52.7	43.0	37.3
4	482.7	477.0	473.9	475.3	471.2	469.3
	500.4	491.2	486.1	487.5	481.0	478.0
	42.6	34.1	29.4	30.7	24.5	21.7
3	467.8	464.8	462.9	463.5	462.2	461.3
	476.4	471.4	468.3	468.9	466.8	465.4
	20.7	15.8	12.9	13.4	11.4	10.1
2	458.4	457.8	457.4	457.6	457.2	456.7
	460.9	459.9	459.3	459.4	458.7	457.9
	6.0	4.9	4.3	4.5	3.7	3.0
1	458.1	457.5	457.2	457.6	457.1	456.7
	460.4	459.4	458.8	459.4	458.6	457.9
	5.5	4.5	3.9	4.5	3.7	3.0

320 MW MOLTEN SALT RECEIVER

TEMPERATURE SUMMARY
FILM (I.D.) TEMPERATURE (F)
PEAK (O.D.) TEMPERATURE (F)
FRONT-TC-BACK TEMPERATURE DIFFERENCE (F)

PASS 4

	PANEL 7			PANEL 8		
17	991.0	971.3	963.9	972.8	963.4	955.8
	995.0	974.4	969.6	977.2	970.1	964.1
	9.5	7.3	13.4	10.9	16.4	20.5
16	997.9	986.1	977.4	988.9	978.7	969.9
	1007.9	1001.1	994.1	1003.5	997.0	989.1
	23.3	35.2	39.4	40.9	45.3	47.6
15	1025.7	1009.3	998.2	1011.1	999.4	988.5
	1058.2	1043.5	1032.6	1045.2	1034.3	1022.7
	77.0	81.5	81.7	84.8	86.9	85.3
14	1057.0	1031.2	1018.0	1032.1	1012.8	998.3
	1116.2	1085.4	1070.5	1084.2	1060.5	1042.8
	142.3	130.2	126.2	131.0	119.8	111.7
13	1070.6	1043.6	1027.6	1042.1	1025.3	1014.0
	1146.1	1112.5	1092.4	1106.5	1086.3	1073.3
	183.0	167.0	157.1	163.2	154.5	150.5
12	1067.0	1044.2	1026.6	1040.9	1025.0	1010.8
	1148.1	1120.8	1097.4	1111.3	1092.2	1074.1
	197.8	186.8	172.6	179.4	171.1	161.0
11	1056.7	1033.2	1017.8	1031.3	1011.3	998.1
	1139.4	1110.3	1089.9	1103.0	1076.6	1059.6
	202.4	188.6	176.0	183.1	166.4	156.5
10	1041.5	1012.4	999.6	1011.5	994.0	980.4
	1122.7	1083.3	1066.5	1078.1	1054.8	1036.6
	198.9	173.2	163.2	169.9	154.9	142.8
9	1025.2	998.9	986.9	997.8	979.0	968.3
	1103.9	1068.0	1051.8	1062.4	1036.4	1022.2
	192.9	168.8	158.6	165.2	146.2	137.1
8	1023.8	995.0	980.7	991.0	974.0	963.9
	1109.6	1068.5	1048.0	1058.0	1034.1	1020.3
	211.7	180.5	164.8	171.7	153.3	143.8
0 LEVEL						
7	1009.4	976.7	963.5	972.4	958.4	945.9
	1094.5	1045.4	1025.9	1034.5	1014.5	996.2
	210.3	168.3	152.4	158.9	143.2	128.0
6	974.7	948.7	939.3	946.2	931.3	919.0
	1045.3	1005.1	991.1	997.9	975.4	956.6
	173.3	137.6	126.1	131.6	112.1	95.3
5	938.5	921.7	911.8	916.5	904.1	897.0
	991.4	965.1	949.3	954.0	934.8	923.6
	129.0	105.1	90.9	94.9	77.3	67.2
4	900.9	890.7	885.0	887.6	880.2	876.8
	932.6	916.2	907.0	909.6	897.7	892.4
	76.7	61.4	52.9	55.2	44.1	39.1
3	874.1	868.6	865.3	866.4	864.0	862.4
	889.6	880.5	875.0	876.1	872.3	869.7
	37.2	28.4	23.2	24.2	20.6	18.1
2	857.2	856.1	855.4	855.7	854.9	854.1
	861.7	859.8	858.7	859.0	857.6	856.2
	10.7	8.9	7.7	8.1	6.7	5.4
1	856.6	855.5	855.0	855.7	854.9	854.1
	860.7	858.9	857.9	858.9	857.6	856.2
	9.9	8.1	7.1	8.0	6.7	5.3

SYMBOL	DEFINITION	UNITS
PN	PASS NUMBER	
SN	STRIP NUMBER	
NN	NODE NUMBER	
FLUX	ABSORBED PEAK FLUX	(BTU/H-FT2)
RE	REYNOLDS NUMBER	
H	HEAT TRANSFER COEFFICIENT	(BTU/H-FT2-F)
VEL	SALT VELOCITY	(FT/S)
SBT	SALT BULK TEMPERATURE	(F)
PST	PEAK SALT TEMPERATURE=ID TEMPERATURE	(F)
MWT	MEAN TUBEWALL METAL TEMPERATURE=(SFT+PMT)/2	(F)
PMT	PEAK METAL TEMPERATURE=OD TEMPERATURE	(F)
SDT	SALT TEMPERATURE DIFFERENCE=(SFT-SBT)	(F)
MDT	METAL TEMPERATURE DIFFERENCE=(PMT-SFT)	(F)
FBDT	FRONT-TO-BACK TEMPERATURE DIFFERENCE=(PMT-SBT)	(F)
AMT	AVERAGE METAL TEMPERATURE	(F)
OHC	OVERALL HEAT TRANSFER COEFFICIENT	(BTU/H-FT2-F)
FPD	FRICTIONAL PRESSURE LOSS	(LB/IN2)
GPD	GRAVITATIONAL PRESSURE LOSS	(LB/IN2)
TPD	TOTAL PRESSURE LOSS	(LB/IN2)

PASS NO. 4/ 5

PN	SN	NN	FLUX	RE	H	VEL	SBT	PST	MWT	PMT	SDT	MDT	FBDT	AMT	OHC	FPD	GPD	TPD
7	1	17	8091.	104751.	1716.	11.0	985.5	991.0	993.0	995.0	5.4	4.1	9.5	987.9	853.	3.57	4.98	8.55
7	1	16	19928.	104621.	1715.	11.0	984.6	997.9	1002.9	1007.9	13.4	10.0	23.3	990.5	854.	2.00	4.27	6.27
7	1	15	66202.	104178.	1711.	11.0	981.2	1025.7	1042.0	1058.2	44.5	32.5	77.0	1000.8	860.	2.00	4.28	6.28
7	1	14	122947.	103216.	1702.	11.0	973.9	1057.0	1086.6	1116.2	83.0	59.2	142.3	1010.2	864.	2.00	4.28	6.28
7	1	13	158074.	101808.	1689.	11.0	963.0	1070.6	1108.3	1146.1	107.6	75.4	183.0	1009.8	864.	2.00	4.29	6.29
7	1	12	169896.	100193.	1674.	10.9	950.3	1067.0	1107.6	1148.1	116.7	81.1	197.8	1001.0	859.	2.00	4.30	6.31
7	1	11	172598.	98529.	1658.	10.9	937.0	1056.7	1098.1	1139.4	119.7	82.7	202.4	988.9	853.	2.00	4.32	6.32
7	1	10	168207.	96884.	1643.	10.9	923.8	1041.5	1082.1	1122.7	117.7	81.2	198.9	974.8	846.	2.00	4.33	6.33
7	1	9	161790.	95295.	1628.	10.8	911.0	1025.2	1064.6	1103.9	114.2	78.7	192.9	960.5	839.	2.01	4.34	6.34
7	1	8	176652.	93661.	1613.	10.8	897.9	1023.8	1066.7	1109.6	125.9	85.9	211.7	952.2	834.	2.01	4.35	6.36
7	1	7	173949.	91953.	1597.	10.8	884.2	1009.4	1052.0	1094.5	125.2	85.1	210.3	938.2	827.	2.01	4.36	6.37
7	1	6	141524.	90396.	1583.	10.8	871.9	974.7	1010.0	1045.3	102.8	70.5	173.3	916.4	817.	2.01	4.37	6.39
7	1	5	104032.	89167.	1572.	10.7	862.4	938.5	964.9	991.4	76.1	52.9	129.0	895.4	806.	2.02	4.38	6.40
7	1	4	61136.	88330.	1564.	10.7	855.9	900.9	916.8	932.6	44.9	31.8	76.7	875.5	797.	2.02	4.39	6.40
7	1	3	29386.	87867.	1560.	10.7	852.4	874.1	881.8	889.6	21.7	15.5	37.2	861.9	790.	2.02	4.39	6.41
7	1	2	8444.	87673.	1558.	10.7	850.9	857.2	859.4	861.7	6.2	4.5	10.7	853.7	787.	.22	.47	.69
7	1	1	7756.	87664.	1558.	10.7	850.9	856.6	858.7	860.7	5.7	4.1	9.9	853.4	786.	2.47	1.17	3.64
7	2	17	6152.	102332.	1693.	11.0	967.1	971.3	972.8	974.4	4.2	3.1	7.3	968.9	843.	3.57	5.00	8.57
7	2	16	29800.	102172.	1692.	11.0	965.9	986.1	993.6	1001.1	20.2	15.0	35.2	974.8	846.	2.00	4.29	6.29
7	2	15	69274.	101686.	1687.	11.0	962.1	1009.3	1026.4	1043.5	47.2	34.3	81.5	982.8	850.	2.00	4.29	6.29
7	2	14	111071.	100806.	1679.	10.9	955.2	1031.2	1058.3	1085.4	76.0	54.2	130.2	988.4	853.	2.00	4.30	6.30
7	2	13	142419.	99582.	1668.	10.9	945.5	1043.6	1078.1	1112.5	98.2	68.9	167.0	988.2	853.	2.00	4.31	[illegible]
7	2	12	158673.	98141.	1654.	10.9	933.9	1044.2	1082.5	1120.8	110.2	76.6	186.8	981.8	849.	2.00	4.32	6.32
7	2	11	159060.	96628.	1640.	10.9	921.8	1033.2	1071.8	1110.3	111.5	77.1	188.6	970.1	843.	2.01	4.33	6.33
7	2	10	144741.	95184.	1627.	10.8	910.1	1012.4	1047.8	1083.3	102.3	70.9	173.2	954.5	836.	2.01	4.34	6.35
7	2	9	140097.	93825.	1614.	10.8	899.2	998.9	1033.5	1068.0	99.7	69.1	168.8	942.4	830.	2.01	4.35	6.36
7	2	8	148998.	92436.	1602.	10.8	888.1	995.0	1031.8	1068.5	106.9	73.5	180.5	934.4	826.	2.01	4.36	6.37
7	2	7	137775.	91046.	1589.	10.8	877.0	976.7	1011.0	1045.4	99.7	68.6	168.3	920.2	819.	2.01	4.37	6.38
7	2	6	111458.	89822.	1578.	10.8	867.5	948.7	976.9	1005.1	81.2	56.4	137.6	902.7	810.	2.02	4.38	6.39

7	2	5	84368.	88849.	1569.	10.7	859.9	921.7	943.4	965.1	61.8	43.3	105.1	886.8	803.	2.02	4.39	6.40
7	2	4	48763.	88181.	1563.	10.7	854.8	850.7	903.4	916.2	35.9	25.5	61.4	870.5	795.	2.02	4.39	6.40
7	2	3	22446.	87820.	1559.	10.7	852.1	848.6	874.5	880.5	16.5	11.9	28.4	859.3	789.	2.02	4.39	6.41
7	2	2	6966.	87672.	1558.	10.7	850.9	856.1	857.9	859.8	5.1	3.7	8.9	853.2	786.	.22	.47	.69
7	2	1	6344.	87664.	1558.	10.7	850.9	855.5	857.2	858.9	4.7	3.4	8.1	852.9	786.	2.47	1.17	3.64
7	3	17	11266.	100934.	1680.	10.9	956.2	963.9	966.7	969.6	7.7	5.7	13.4	959.6	839.	3.57	5.01	8.58
7	3	16	33154.	100744.	1679.	10.9	954.7	977.4	985.7	994.1	22.7	16.7	39.4	964.7	841.	2.00	4.30	6.30
7	3	15	69015.	100261.	1674.	10.9	950.9	998.2	1015.4	1032.6	47.4	34.3	81.7	971.7	845.	2.00	4.30	6.31
7	3	14	106906.	99431.	1666.	10.9	944.3	1018.0	1044.3	1070.5	73.7	52.5	126.2	976.5	847.	2.00	4.31	6.31
7	3	13	132955.	98309.	1656.	10.9	935.3	1027.6	1060.0	1092.4	92.3	64.8	157.1	975.5	846.	2.00	4.32	6.32
7	3	12	145473.	97012.	1644.	10.9	924.9	1026.6	1062.0	1097.4	101.7	70.8	172.6	969.0	843.	2.00	4.33	6.33
7	3	11	147503.	95650.	1631.	10.9	913.9	1017.8	1053.9	1089.9	103.9	72.1	176.0	959.0	838.	2.01	4.34	6.34
7	3	10	135662.	94332.	1619.	10.8	903.2	959.6	1033.0	1066.5	96.3	66.9	163.2	945.1	831.	2.01	4.35	6.35
7	3	9	130925.	93084.	1608.	10.8	893.2	986.9	1019.3	1051.8	93.6	65.0	158.6	933.9	826.	2.01	4.35	6.36
7	3	8	135323.	91829.	1596.	10.8	883.2	980.7	1014.4	1048.0	97.5	67.3	164.8	925.5	821.	2.01	4.36	6.38
7	3	7	124159.	90592.	1585.	10.8	873.5	963.5	994.7	1025.9	90.1	62.3	152.4	912.5	815.	2.01	4.37	6.39
7	3	6	101831.	89503.	1575.	10.7	865.0	939.3	965.2	991.1	74.3	51.8	126.1	897.3	807.	2.02	4.38	6.39
7	3	5	72736.	88653.	1567.	10.7	858.4	911.8	930.6	949.3	53.4	37.6	90.9	881.7	800.	2.02	4.38	6.40
7	3	4	41950.	88089.	1562.	10.7	854.1	885.0	896.0	907.0	30.9	22.0	52.9	867.6	793.	2.02	4.39	6.41
7	3	3	18269.	87791.	1559.	10.7	851.8	865.3	870.1	875.0	13.5	9.7	23.2	857.7	788.	2.02	4.39	6.41
7	3	2	6090.	87670.	1558.	10.7	850.9	855.4	857.0	858.7	4.5	3.3	7.7	852.9	786.	.22	.47	.69
7	3	1	5545.	87664.	1558.	10.7	850.9	855.0	856.4	857.9	4.1	3.0	7.1	852.7	786.	2.47	1.17	3.64
8	4	17	8796.	93241.	1572.	10.0	966.3	972.8	975.0	977.2	6.4	4.5	10.9	969.1	808.	3.19	5.43	8.62
8	4	16	33154.	93039.	1570.	10.0	964.6	988.9	997.2	1005.5	24.3	16.6	40.9	975.1	811.	1.70	4.29	5.99
8	4	15	69015.	92549.	1566.	10.0	960.4	1011.1	1028.1	1045.2	50.7	34.1	84.8	982.2	814.	1.70	4.30	5.99
8	4	14	106906.	91713.	1558.	10.0	953.2	1032.1	1058.2	1084.2	78.9	52.2	131.0	987.0	816.	1.70	4.30	6.00
8	4	13	132955.	90582.	1547.	10.0	943.4	1042.1	1074.3	1106.5	98.8	64.4	163.2	985.5	815.	1.70	4.31	6.01
8	4	12	145473.	89280.	1535.	9.9	931.9	1040.9	1076.1	1111.3	108.9	70.4	179.4	978.3	811.	1.70	4.32	6.02
8	4	11	147503.	87918.	1522.	9.9	919.9	1031.3	1067.1	1103.0	111.4	71.7	183.1	967.3	806.	1.70	4.33	6.03
8	4	10	135662.	86601.	1509.	9.9	908.2	1011.5	1044.8	1078.1	103.3	66.6	169.9	952.2	799.	1.70	4.34	6.04
8	4	9	130925.	85356.	1498.	9.9	897.3	957.8	1030.1	1062.4	100.5	64.7	165.2	940.0	793.	1.70	4.35	6.05
8	4	8	135323.	84105.	1486.	9.8	886.3	991.0	1024.5	1058.0	104.7	67.0	171.7	930.8	788.	1.71	4.36	6.06
8	4	7	124159.	82872.	1474.	9.8	875.6	972.4	1003.4	1034.5	96.8	62.1	158.9	916.8	782.	1.71	4.37	6.08
8	4	6	101831.	81785.	1464.	9.8	866.3	946.2	972.0	997.9	79.9	51.6	131.6	900.3	774.	1.71	4.38	6.09
8	4	5	72736.	80936.	1456.	9.8	859.1	916.5	935.2	954.0	57.4	37.5	94.9	883.6	767.	1.71	4.38	6.09
8	4	4	41950.	80373.	1451.	9.8	854.4	887.6	898.6	909.6	33.2	22.0	55.2	868.6	760.	1.71	4.39	6.10
8	4	3	18269.	80075.	1448.	9.8	851.9	866.4	871.2	876.1	14.5	9.7	24.2	858.1	755.	1.71	4.39	6.10
8	4	2	6090.	79954.	1447.	9.8	850.9	855.7	857.3	859.0	4.8	3.3	8.1	852.9	753.	.01	.03	.04
8	4	1	6060.	79954.	1447.	9.8	850.9	855.7	857.3	858.9	4.8	3.2	8.0	852.9	753.	2.07	1.17	3.24
8	5	17	13161.	91774.	1558.	10.0	953.7	963.4	966.8	970.1	9.7	6.7	16.4	957.9	803.	3.19	5.45	8.64
8	5	16	36446.	91543.	1556.	10.0	951.7	978.7	987.8	997.0	26.9	18.3	45.3	963.4	805.	1.70	4.30	6.00
8	5	15	70191.	91049.	1552.	10.0	947.4	959.4	1016.9	1034.3	52.0	34.9	86.9	969.8	808.	1.70	4.31	6.01
8	5	14	96851.	90278.	1544.	9.9	940.7	1012.8	1036.6	1060.5	72.1	47.7	119.8	971.6	808.	1.70	4.31	6.01
8	5	13	124860.	89261.	1535.	9.9	931.8	1025.3	1055.8	1086.3	93.5	61.0	154.5	971.7	808.	1.70	4.32	6.02
8	5	12	137683.	88060.	1523.	9.9	921.2	1025.0	1058.6	1092.2	103.9	67.2	171.1	965.4	805.	1.70	4.33	6.03
8	5	11	132959.	86824.	1512.	9.9	910.2	1011.3	1044.0	1076.6	101.1	65.3	166.4	953.3	799.	1.70	4.34	6.04
8	5	10	122835.	85652.	1501.	9.9	899.9	994.0	1024.4	1054.8	94.1	60.8	154.9	940.0	793.	1.70	4.35	6.05
8	5	9	115074.	84555.	1490.	9.8	890.2	979.0	1007.7	1036.4	88.8	57.4	146.2	928.1	787.	1.70	4.36	6.06
8	5	8	120135.	83463.	1480.	9.8	880.7	974.0	1004.1	1034.1	93.3	60.0	153.3	920.4	783.	1.71	4.36	6.07
8	5	7	111361.	82376.	1470.	9.8	871.3	958.4	986.5	1014.5	87.1	56.1	143.2	908.4	778.	1.71	4.37	6.08
8	5	6	86390.	81437.	1461.	9.8	863.3	931.3	953.4	975.4	68.0	44.1	112.1	892.3	771.	1.71	4.38	6.09
8	5	5	59055.	80739.	1455.	9.8	857.4	904.1	919.4	934.8	46.7	30.7	77.3	877.4	764.	1.71	4.38	6.09
8	5	4	33408.	80292.	1450.	9.8	853.7	880.2	889.0	897.7	26.5	17.6	44.1	865.0	758.	1.71	4.39	6.10
8	5	3	15523.	80054.	1448.	9.8	851.7	864.0	868.1	872.3	12.3	8.3	20.6	857.0	755.	1.71	4.39	6.10

8	5	2	5062.	79954.	1447.	9.8	850.9	854.9	856.2	857.6	4.0	2.7	6.7	852.6	753.	.01	.03	.04
8	5	1	5036.	79954.	1447.	9.8	850.9	854.9	856.2	857.6	4.0	2.7	6.7	852.6	753.	2.07	1.17	3.24
8	6	17	16363.	90615.	1547.	10.0	943.7	955.8	960.0	964.1	12.2	8.3	20.5	948.9	798.	3.19	5.46	8.65
8	6	16	38115.	90371.	1545.	10.0	941.5	969.9	979.5	989.1	28.4	19.3	47.6	953.7	801.	1.70	4.31	6.01
8	6	15	68531.	89895.	1541.	9.9	937.3	988.5	1005.6	1022.7	51.1	34.2	85.3	959.3	803.	1.70	4.32	6.02
8	6	14	89706.	89189.	1534.	9.9	931.1	998.3	1020.6	1042.8	67.2	44.5	111.7	959.9	803.	1.70	4.32	6.02
8	6	13	120892.	88253.	1525.	9.9	922.9	1014.0	1043.7	1073.3	91.1	59.4	150.5	961.7	803.	1.70	4.33	6.03
8	6	12	128784.	87145.	1515.	9.9	913.1	1010.8	1042.4	1074.1	97.7	63.3	161.0	954.7	800.	1.70	4.34	6.04
8	6	11	124357.	86018.	1504.	9.9	903.1	998.1	1028.9	1059.6	95.0	61.5	156.5	943.6	795.	1.70	4.35	6.05
8	6	10	112614.	84959.	1494.	9.9	893.8	980.4	1008.5	1036.6	86.6	56.2	142.8	930.7	789.	1.70	4.35	6.06
8	6	9	107416.	83969.	1485.	9.8	885.1	968.3	995.2	1022.2	83.2	53.9	137.1	920.6	784.	1.71	4.36	6.07
8	6	8	112229.	82972.	1475.	9.8	876.5	963.9	992.1	1020.3	87.4	56.4	143.8	913.7	780.	1.71	4.37	6.07
8	6	7	99139.	82003.	1466.	9.8	868.2	945.9	971.0	996.2	77.7	50.3	128.0	901.3	775.	1.71	4.38	6.08
8	6	6	73151.	81205.	1459.	9.8	861.4	919.0	937.8	956.6	57.6	37.7	95.3	886.0	768.	1.71	4.38	6.09
8	6	5	51206.	80623.	1454.	9.8	856.5	897.0	910.3	923.6	40.5	26.7	67.2	873.8	762.	1.71	4.39	6.10
8	6	4	29645.	80242.	1450.	9.8	853.3	876.8	884.6	892.4	23.5	15.6	39.1	863.4	757.	1.71	4.39	6.10
8	6	3	13668.	80038.	1448.	9.8	851.6	862.4	866.1	869.7	10.8	7.3	18.1	856.2	754.	1.71	4.39	6.10
8	6	2	4043.	79954.	1447.	9.8	850.9	854.1	855.2	856.2	3.2	2.2	5.4	852.2	753.	.01	.03	.04
8	6	1	4022.	79954.	1447.	9.8	850.9	854.1	855.1	856.2	3.2	2.2	5.3	852.2	753.	2.07	1.17	3.24

TIN = 850.866 TCUT = 962.007

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PASS NUMBER/NUMBER OF PASSES =     4/ 5
MASS FLOW, PANEL A           =198.3  KG/S (  1.574 MLB/H)
MASS FLOW, PANEL B           =180.8  KG/S (  1.435 MLB/H)
PASS MASS FLOW               =379.1  KG/S (  3.009 MLB/H)
PASS INLET  TEMPERATURE      =    454.9 C (  850.9 F)
INLET TEMPERATURE,PANEL A    =    454.9 C (  850.9 F)
INLET TEMPERATURE,PANEL B    =    454.9 C (  850.9 F)
OUTLET TEMPERATURE, PANEL A  =    520.5 C (  969.0 F)
OUTLET TEMPERATURE, PANEL B  =    512.4 C (  954.4 F)
PASS OUTLET TEMPERATURE      =    516.7 C (  962.0 F)
PASS PEAK METAL TEMPERATURE  =    620.1 C ( 1148.1 F)
PASS PEAK SALT  TEMPERATURE  =    577.0 C ( 1070.6 F)
PASS PEAK FRONT-TO-BACK DT   =    117.6 C (  211.7 F)
PASS FRICTIONAL PRESS DROP   = 237.08 KPA (  34.39 LB/IN2)
CUMULATIVE FRICT. PRESS DROP = 932.18 KPA ( 135.22 LB/IN2)
PASS PEAK ABSORBED HEAT FLUX = .557 MW/M2 (    .177 MBTU/H-FT2)
ABSORBED POWER, PANEL A      =   19.90 MW (  67.92 MBTU/H)
ABSORBED POWER, PANEL B      =   15.90 MW (  54.26 MBTU/H)
PASS ABSORBED POWER          =   35.81 MW (122.174 MBTU/H)
CUMULATIVE ABSORBED POWER    =  131.50 MW (448.687 MBTU/H)
CUMULATIVE INCIDENT POWER    =  141.85 MW (484.012 MBTU/H)
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SOLAR RECEIVER PASS 4 SUMMARY DATA

STRIP		1	2	3	4	5	6
MASS FLOW (KG/S)	=	2.260	2.252	2.248	2.060	2.055	2.051
FLOW VARIATION (PERCENT FROM AVERAGE	=	.29	.00	.00	.00	.00	.00
MASS VELOCITY (KG/M2-S)	=	5892.	5872.	5861.	5370.	5357.	5348.
MAXIMUM VELOCITY (M/S)	=	3.4	3.3	3.3	3.1	3.0	3.0
AVERAGE REYNOLDS NUMBER	=	95913.	94301.	93408.	86080.	85115.	84393.
FRICTIONAL PRESSURE LOSS (KPA)	=	238.15	236.81	236.07	201.54	200.77	200.18
GRAVITATIONAL PRESSURE LOSS (KPA)	=	463.86	464.91	465.49	464.98	465.67	466.19
TOTAL PRESSURE LOSS (KPA)	=	702.01	701.72	701.56	666.52	666.43	666.37
AVERAGE HEAT TRANSFER COEFFICIENT (W/M2-C)	=	9283.1	9190.2	9138.5	8547.6	8490.4	8447.7
SALT INLET TEMPERATURE (C)	=	454.9	454.9	454.9	454.9	454.9	454.9
SALT OUTLET TEMPERATURE (C)	=	529.5	519.5	513.6	518.9	512.1	506.6
SALT TEMPERATURE RISE (C)	=	74.6	64.6	58.6	64.0	57.2	51.7
PEAK SALT TEMPERATURE (C)	=	576.7	562.4	553.3	561.0	551.8	545.7
PEAK AVERAGE METAL TEMPERATURE (C)	=	543.2	531.4	524.9	530.4	522.1	516.6
PEAK METAL TEMPERATURE (C)	=	619.8	604.9	592.1	599.4	589.0	579.1
AVERAGE METAL TEMPERATURE (C)	=	513.6	505.0	500.3	504.2	498.6	494.4
AVERAGE SURFACE TEMPERATURE (C)	=	570.4	555.1	547.1	552.5	542.8	535.8
MAXIMUM WALL TEMPERATURE DIFFERENCE (C)	=	47.7	42.8	40.0	39.8	37.3	35.1
MAXIMUM FRONT TO BACK TEMPERATURE DIFFERENCE (C)	=	117.5	104.8	97.9	101.6	95.0	89.5
TUBE THERMAL EXPANSION (MM)	=	.0	.0	.0	.0	.0	.0
PEAK ABSORBED HEAT FLUX (MW/M2)	=	.557	.502	.465	.465	.434	.406
AVERAGE ABSORBED HEAT FLUX (MW/M2)	=	.361	.312	.283	.282	.252	.228
ABSORBED POWER (MW)	=	5.671	9.803	4.431	4.432	7.910	3.559

SOLAR RECEIVER PASS 4 SUMMARY DATA

STRIP		1	2	3	4	5	6
MASS FLOW (LB/H)	=	17935.	17874.	17840.	16347.	16306.	16277.
FLOW VARIATION (PERCENT FROM AVERAGE	=	.29	.00	.00	.00	.00	.00
MASS VELOCITY (LB/FT2-S)	=	1207.	1203.	1200.	1100.	1097.	1095.
MAXIMUM VELOCITY (FT/S)	=	11.0	11.0	10.9	10.0	10.0	9.9
AVERAGE REYNOLDS NUMBER	=	95913.	94301.	93408.	86080.	85115.	84393.
FRICTIONAL PRESSURE LOSS (LB/IN2)	=	34.54	34.35	34.24	29.23	29.12	29.03
GRAVITATIONAL PRESSURE LOSS (LB/IN2)	=	67.28	67.43	67.51	67.44	67.54	67.62
TOTAL PRESSURE LOSS (LB/IN2)	=	101.82	101.78	101.75	96.67	96.66	96.65
AVERAGE HEAT TRANSFER COEFFICIENT (BTU/H-FT2-F)	=	1635.2	1618.8	1609.7	1505.7	1495.6	1488.1
SALT INLET TEMPERATURE (F)	=	850.9	850.9	850.9	850.9	850.9	850.9
SALT OUTLET TEMPERATURE (F)	=	985.1	967.2	956.4	966.1	953.8	943.8
SALT TEMPERATURE RISE (F)	=	134.3	116.3	105.6	115.2	102.9	93.0
PEAK SALT TEMPERATURE (F)	=	1070.1	1044.3	1028.0	1041.8	1025.3	1014.3
PEAK AVERAGE METAL TEMPERATURE (F)	=	1009.8	988.5	976.8	986.7	971.7	961.9
PEAK METAL TEMPERATURE (F)	=	1147.6	1120.8	1097.8	1110.9	1092.2	1074.3
AVERAGE METAL TEMPERATURE (F)	=	956.4	940.9	932.6	939.5	929.4	921.9
AVERAGE SURFACE TEMPERATURE (F)	=	1058.7	1031.2	1016.8	1026.6	1009.1	996.4
MAXIMUM WALL TEMPERATURE DIFFERENCE (F)	=	85.9	77.1	72.1	71.7	67.2	63.3
MAXIMUM FRONT TO BACK TEMPERATURE DIFFERENCE (F)	=	211.5	188.6	176.2	182.9	171.1	161.1
TUBE THERMAL EXPANSION (IN)	=	.0	.0	.0	.0	.0	.0
PEAK ABSORBED HEAT FLUX (MBTU/H-FT2)	=	.177	.159	.148	.148	.138	.129
AVERAGE ABSORBED HEAT FLUX (MBTU/H-FT2)	=	.115	.099	.090	.090	.080	.072
ABSORBED POWER (MBTU/H)	=	19.352	33.453	15.120	15.124	26.992	12.145

320 MW MOLTEN SALT RECEIVER

ABSORBED NORMAL HEAT FLUX (MW/M2)

PASS 5

	PANEL 9			PANEL 10		
17	.0430	.0413	.0446	.0446	.0476	.0575
16	.0496	.0479	.0532	.0532	.0551	.0666
15	.1156	.1098	.1105	.1105	.1096	.1216
14	.2078	.1929	.1936	.1936	.1817	.1731
13	.2721	.2851	.2761	.2761	.2708	.2705
12	.3666	.3664	.3478	.3478	.3435	.3407
11	.3906	.3749	.3627	.3627	.3541	.3558
10	.3771	.3561	.3448	.3448	.3382	.3328
9	.3415	.3348	.3179	.3179	.3195	.3207
8	.3258	.3482	.3310	.3310	.3218	.3171
7	.3404	.3500	.3185	.3185	.2919	.2947
0 LEVEL	*	*	*	*	*	*
6	.3007	.3021	.2737	.2737	.2532	.2457
5	.2219	.2287	.2109	.2109	.1940	.1876
4	.1553	.1529	.1470	.1470	.1325	.1228
3	.0899	.0910	.0819	.0819	.0709	.0647
2	.0415	.0400	.0353	.0353	.0299	.0260
1	.0179	.0166	.0145	.0145	.0119	.0099

320 MW MOLTEN SALT RECEIVER

ABSORBED PEAK HEAT FLUX (MW/M2)

PASS 5

	PANEL 9			PANEL 10		
17	.0447	.0422	.0450	.0450	.0477	.0575
16	.0516	.0490	.0537	.0537	.0552	.0666
15	.1203	.1122	.1116	.1116	.1099	.1216
14	.2162	.1972	.1955	.1955	.1822	.1731
13	.2830	.2915	.2788	.2788	.2715	.2705
12	.3814	.3746	.3512	.3512	.3443	.3407
11	.4063	.3832	.3663	.3663	.3549	.3558
10	.3923	.3640	.3482	.3482	.3390	.3328
9	.3553	.3423	.3210	.3210	.3202	.3207
8	.3389	.3560	.3343	.3343	.3226	.3171
7	.3541	.3578	.3216	.3216	.2926	.2947
0 LEVEL	*	*	*	*	*	*
6	.3128	.3088	.2764	.2764	.2538	.2457
5	.2308	.2338	.2130	.2130	.1945	.1876
4	.1616	.1563	.1484	.1484	.1328	.1228
3	.0935	.0930	.0827	.0827	.0711	.0647
2	.0431	.0409	.0356	.0356	.0300	.0260
1	.0186	.0169	.0147	.0147	.0120	.0099

320 MW MOLTEN SALT RECEIVER

ABSORBED POWER (MW)

PASS 5

	PANEL 9			PANEL 10			
16	.0097	.0187	.0102	.0102	.0215	.0130	
15	.0865	.1654	.0857	.0857	.1728	.0985	
14	.1693	.3175	.1592	.1592	.3055	.1542	
13	.2512	.5013	.2458	.2458	.4746	.2321	
12	.3343	.6833	.3265	.3265	.6443	.3199	
11	.3963	.7774	.3718	.3718	.7316	.3645	
10	.4018	.7666	.3703	.3703	.7261	.3604	
9	.3761	.7246	.3468	.3468	.6898	.3420	
8	.3493	.7163	.3396	.3396	.6726	.3338	
7	.3486	.7322	.3399	.3399	.6437	.3202	
0 LEVEL							
6	.3355	.6839	.3099	.3099	.5717	.2828	
5	.2735	.5567	.2536	.2536	.4691	.2268	
4	.1974	.4002	.1873	.1873	.3424	.1625	
3	.1283	.2557	.1198	.1198	.2133	.0982	
2	.0688	.1374	.0613	.0613	.1057	.0475	
1	.0250	.0478	.0210	.0210	.0354	.0152	
TOTALS	3.752	7.485	3.549	3.549	6.820	3.371	28.520

320 MW MOLTEN SALT RECEIVER

VARIATION IN SALT TEMPERATURE ALONG PANEL (F)

PASS 5

	PANEL 9			PANEL 10		
17	1051.5	1051.1	1046.3	1052.8	1049.3	1048.6
16	1051.3	1050.9	1046.0	1052.5	1049.1	1048.3
15	1049.0	1048.7	1043.8	1050.5	1047.1	1046.0
14	1044.7	1044.6	1039.7	1046.8	1043.5	1042.3
13	1038.2	1038.2	1033.4	1041.0	1037.9	1036.9
12	1029.5	1029.4	1024.9	1033.3	1030.3	1029.3
11	1019.3	1019.3	1015.3	1024.5	1021.7	1020.7
10	1008.9	1009.4	1005.7	1015.8	1013.1	1012.2
9	999.1	1000.1	996.7	1007.6	1005.0	1004.1
8	990.1	990.8	987.9	999.6	997.1	996.2
7	981.1	981.3	979.1	991.5	989.5	988.7
0 LEVEL						
6	972.4	972.5	971.1	984.2	982.7	982.0
5	965.3	965.3	964.5	978.2	977.2	976.6
4	960.1	960.1	959.6	973.8	973.2	972.8
3	956.8	956.8	956.5	970.9	970.6	970.5
2	955.0	955.0	954.9	969.5	969.4	969.3
1	954.4	954.4	954.4	969.0	969.0	969.0

320 MW MOLTEN SALT RECEIVER

TEMPERATURE SUMMARY
FILM (I.D.) TEMPERATURE (C)
PEAK (O.D.) TEMPERATURE (C)
FRONT-TC-BACK TEMPERATURE DIFFERENCE (C)

PASS 5

	PANEL 9			PANEL 10		
17	571.8	571.3	569.0	572.1	570.6	571.2
	575.6	574.9	572.8	576.0	574.6	576.2
	9.2	8.7	9.3	8.9	9.5	11.4
16	572.5	572.0	569.9	573.0	571.3	572.1
	576.9	576.2	574.5	577.6	576.0	577.8
	10.7	10.1	11.1	10.6	10.9	13.2
15	579.6	578.4	575.7	578.4	576.3	577.0
	589.8	588.0	585.2	587.9	585.7	587.4
	24.8	23.1	23.1	22.0	21.7	24.1
14	588.9	586.5	583.7	585.8	582.5	580.9
	607.0	603.1	600.2	602.3	597.9	595.5
	44.4	40.6	40.3	38.5	36.0	34.2
13	593.5	594.6	590.5	592.1	589.6	589.0
	617.2	618.9	613.8	615.4	612.4	611.6
	58.2	59.9	57.5	54.9	53.5	53.4
12	601.1	600.1	594.9	596.2	593.9	593.0
	632.6	631.2	624.2	625.4	622.6	621.4
	78.4	77.1	72.5	69.2	68.0	67.3
11	598.8	596.0	591.8	593.4	590.6	590.2
	632.5	627.8	622.3	623.9	620.2	619.9
	84.0	79.3	76.1	72.5	70.4	70.4
10	591.7	588.4	584.5	586.7	584.3	583.1
	624.4	618.9	613.7	615.9	612.7	611.0
	81.7	75.9	72.8	69.3	67.7	66.5
9	582.0	580.8	576.4	579.2	577.8	577.4
	611.9	609.6	603.5	606.3	604.9	604.5
	74.5	71.8	67.6	64.3	64.3	64.4
8	575.2	577.7	573.4	576.6	573.9	572.8
	603.8	607.7	601.8	604.8	601.2	599.7
	71.6	75.1	70.7	67.3	65.1	64.0
7	572.4	573.0	567.2	570.8	566.4	566.2
	602.4	603.3	594.6	598.2	591.3	591.3
	75.1	75.9	68.4	65.1	59.4	59.8
0 LEVEL						
6	562.5	562.1	557.2	561.6	558.2	556.8
	589.3	588.5	580.9	585.3	580.0	578.0
	66.8	66.0	59.2	56.3	51.8	50.2
5	548.2	548.6	545.5	550.9	548.2	547.1
	568.2	568.9	564.0	569.4	565.1	563.4
	49.7	50.4	46.0	43.7	40.0	38.6
4	536.5	535.8	534.5	540.9	538.7	537.3
	550.7	549.5	547.6	553.8	550.3	548.1
	35.1	33.9	32.2	30.6	27.4	25.4
3	525.9	525.8	524.3	531.5	529.9	529.1
	534.2	534.1	531.7	538.8	536.2	534.8
	20.4	20.3	18.1	17.2	14.8	13.5
2	518.4	518.1	517.3	525.1	524.4	523.8
	522.2	521.7	520.5	528.2	527.0	526.2
	9.5	9.0	7.8	7.4	6.2	5.4
1	514.8	514.6	514.3	522.3	522.0	521.7
	516.5	516.1	515.7	523.6	523.0	522.6
	4.1	3.7	3.2	3.1	2.5	2.1

320 MW MOLTEN SALT RECEIVER

TEMPERATURE SUMMARY
FILM (I.D.) TEMPERATURE (F)
PEAK (O.D.) TEMPERATURE (F)
FRONT-TC-BACK TEMPERATURE DIFFERENCE (F)

PASS 5

	PANEL 9			PANEL 10		
17	1061.2	1060.3	1056.1	1061.9	1059.0	1060.2
	1068.1	1066.8	1063.1	1068.8	1066.4	1069.1
	16.6	15.7	16.8	16.0	17.0	20.5
16	1062.5	1061.5	1057.8	1063.4	1060.3	1061.8
	1070.5	1069.1	1066.0	1071.6	1068.8	1072.0
	19.2	18.2	20.0	19.1	19.7	23.7
15	1075.2	1073.2	1068.2	1073.1	1069.3	1070.6
	1093.6	1090.4	1085.4	1090.2	1086.2	1089.3
	44.6	41.6	41.5	39.6	39.1	43.3
14	1091.9	1087.8	1082.6	1086.4	1080.5	1077.5
	1124.6	1117.6	1112.3	1116.1	1108.2	1103.9
	80.0	73.0	72.6	69.3	64.7	61.6
13	1100.4	1102.2	1094.8	1097.8	1093.3	1092.1
	1142.9	1146.0	1136.8	1139.7	1134.3	1132.9
	104.7	107.8	103.5	98.7	96.4	96.1
12	1113.9	1112.2	1102.9	1105.2	1101.0	1099.3
	1170.7	1168.1	1155.5	1157.8	1152.7	1150.5
	141.2	138.7	130.6	124.5	122.4	121.2
11	1109.9	1104.8	1097.2	1100.1	1095.1	1094.3
	1170.5	1162.1	1152.2	1155.0	1148.4	1147.8
	151.2	142.8	136.9	130.5	126.7	127.1
10	1097.0	1091.2	1084.1	1088.1	1083.7	1081.5
	1155.9	1146.0	1136.7	1140.6	1134.9	1131.9
	147.0	136.6	131.0	124.8	121.8	119.7
9	1079.6	1077.5	1069.5	1074.7	1072.1	1071.3
	1133.3	1129.4	1118.4	1123.4	1120.7	1120.1
	134.2	129.3	121.6	115.8	115.7	116.0
8	1067.3	1071.8	1064.2	1069.8	1065.0	1063.1
	1118.9	1125.9	1115.2	1120.7	1114.2	1111.5
	128.8	135.1	127.2	121.1	117.1	115.2
7	1062.2	1063.4	1053.0	1059.5	1051.4	1051.1
	1116.3	1117.9	1102.3	1108.7	1096.4	1096.3
	135.2	136.6	123.2	117.2	106.9	107.7
0 LEVEL						
6	1044.5	1043.7	1034.9	1042.9	1036.8	1034.3
	1092.7	1091.3	1077.6	1085.5	1076.0	1072.3
	120.3	118.8	106.6	101.3	93.3	90.4
5	1018.8	1019.5	1013.9	1023.7	1018.8	1016.7
	1054.8	1055.9	1047.2	1056.9	1049.1	1046.1
	89.5	90.7	82.8	78.7	71.9	69.4
4	997.7	996.6	994.2	1005.5	1001.6	999.1
	1023.2	1021.1	1017.7	1028.9	1022.6	1018.5
	63.1	61.1	58.0	55.2	49.4	45.7
3	978.6	978.5	975.8	988.7	985.9	984.4
	993.6	993.3	989.0	1001.8	997.2	994.7
	36.8	36.6	32.5	30.9	26.6	24.2
2	965.1	964.5	963.2	977.1	975.8	974.9
	972.0	971.1	969.0	982.8	980.6	979.1
	17.0	16.1	14.1	13.3	11.2	9.8
1	958.7	958.3	957.8	972.1	971.5	971.1
	961.7	961.1	960.2	974.5	973.5	972.7
	7.6	6.7	5.8	5.5	4.5	3.7

SYMBOL	DEFINITION	UNITS
PN	PASS NUMBER	
SN	STRIP NUMBER	
NN	NODE NUMBER	
FLUX	ABSORBED PEAK FLUX	(BTU/H-FT2)
RE	REYNOLDS NUMBER	
H	HEAT TRANSFER COEFFICIENT	(BTU/H-FT2-F)
VEL	SALT VELOCITY	(FT/S)
SBT	SALT BULK TEMPERATURE	(F)
PST	PEAK SALT TEMPERATURE=ID TEMPERATURE	(F)
MWT	MEAN TUBEWALL METAL TEMPERATURE=(SFT+PMT)/2	(F)
PMT	PEAK METAL TEMPERATURE=OD TEMPERATURE	(F)
SDT	SALT TEMPERATURE DIFFERENCE=(SFT-SBT)	(F)
MDT	METAL TEMPERATURE DIFFERENCE=(PMT-SFT)	(F)
FBDT	FRONT-TO-BACK TEMPERATURE DIFFERENCE=(PMT-SBT)	(F)
AMT	AVERAGE METAL TEMPERATURE	(F)
OHC	OVERALL HEAT TRANSFER COEFFICIENT	(BTU/H-FT2-F)
FPD	FRICTIONAL PRESSURE LOSS	(LB/IN2)
GPD	GRAVITATIONAL PRESSURE LOSS	(LB/IN2)
TPD	TOTAL PRESSURE LOSS	(LB/IN2)

PASS NO. 5/ 5

PN	SN	NN	FLUX	RE	H	VEL	SBT	PST	MWT	PMT	SDT	MDT	FBDT	AMT	OHC	FPD	GPD	TPD
9	1	17	14169.	104395.	1676.	10.2	1051.5	1061.2	1064.7	1068.1	9.7	6.9	16.6	1055.8	853.	1.84	1.97	3.80
9	1	16	16363.	104358.	1675.	10.2	1051.3	1062.5	1066.5	1070.5	11.2	8.0	19.2	1056.2	853.	1.69	4.22	5.90
9	1	15	38115.	104025.	1672.	10.2	1049.0	1075.2	1084.4	1093.6	26.2	18.4	44.6	1060.4	855.	1.69	4.22	5.91
9	1	14	68531.	103380.	1666.	10.2	1044.7	1091.9	1108.3	1124.6	47.3	32.7	80.0	1065.2	857.	1.69	4.22	5.91
9	1	13	89706.	102443.	1658.	10.1	1038.2	1100.4	1121.6	1142.9	62.2	42.5	104.7	1065.1	857.	1.69	4.23	5.92
9	1	12	120891.	101229.	1647.	10.1	1029.5	1113.9	1142.3	1170.7	84.4	56.8	141.2	1065.9	856.	1.69	4.24	5.92
9	1	11	128784.	99837.	1634.	10.1	1019.3	1109.9	1140.2	1170.5	90.6	60.6	151.2	1058.2	852.	1.69	4.24	5.93
9	1	10	124356.	98468.	1621.	10.1	1008.9	1097.0	1126.5	1155.9	88.2	58.9	147.0	1046.8	846.	1.69	4.25	5.94
9	1	9	112614.	97224.	1610.	10.1	999.1	1079.6	1106.4	1133.3	80.4	53.8	134.2	1033.7	839.	1.69	4.26	5.95
9	1	8	107416.	96098.	1599.	10.0	990.1	1067.3	1093.1	1118.9	77.2	51.6	128.8	1023.3	834.	1.69	4.27	5.96
9	1	7	112229.	94995.	1589.	10.0	981.1	1062.2	1089.3	1116.3	81.2	54.0	135.2	1015.9	830.	1.69	4.28	5.97
9	1	6	99139.	93953.	1579.	10.0	972.4	1044.5	1068.6	1092.7	72.2	48.1	120.3	1003.3	824.	1.69	4.29	5.98
9	1	5	73151.	93115.	1571.	10.0	965.3	1018.8	1036.8	1054.8	53.5	36.0	89.5	988.3	817.	1.70	4.29	5.99
9	1	4	51206.	92516.	1565.	10.0	960.1	997.7	1010.5	1023.2	37.6	25.5	63.1	976.3	811.	1.70	4.30	5.99
9	1	3	29645.	92128.	1562.	10.0	956.8	978.6	986.1	993.6	21.8	14.9	36.8	966.2	807.	1.70	4.30	6.00
9	1	2	13668.	91921.	1560.	10.0	955.0	965.1	968.6	972.0	10.1	6.9	17.0	959.4	803.	1.37	3.47	4.83
9	1	1	5910.	91847.	1559.	10.0	954.4	958.7	960.2	961.7	4.4	3.0	7.4	956.3	802.	2.09	1.15	3.23
9	2	17	13367.	104332.	1675.	10.2	1051.1	1060.3	1063.5	1066.8	9.2	6.5	15.7	1055.1	853.	1.84	1.97	3.80
9	2	16	15528.	104296.	1675.	10.2	1050.9	1061.5	1065.3	1069.1	10.7	7.6	18.2	1055.5	853.	1.69	4.22	5.90
9	2	15	35576.	103978.	1672.	10.2	1048.7	1073.2	1081.8	1090.4	24.5	17.2	41.6	1059.4	855.	1.69	4.22	5.91
9	2	14	62504.	103376.	1666.	10.2	1044.6	1087.8	1102.7	1117.6	43.1	29.9	73.0	1063.3	856.	1.69	4.22	5.91
9	2	13	92380.	102442.	1658.	10.1	1038.2	1102.2	1124.1	1146.0	64.0	43.8	107.8	1065.9	857.	1.69	4.23	5.92
9	2	12	118718.	101205.	1647.	10.1	1029.4	1112.2	1140.2	1168.1	82.9	55.9	138.7	1065.0	856.	1.69	4.24	5.92
9	2	11	121470.	99842.	1634.	10.1	1019.3	1104.8	1133.4	1162.1	85.4	57.3	142.8	1056.1	851.	1.69	4.24	5.93
9	2	10	115377.	98539.	1622.	10.1	1009.4	1091.2	1118.6	1146.0	81.8	54.8	136.6	1044.6	845.	1.69	4.25	5.94
9	2	9	108497.	97340.	1611.	10.1	1000.1	1077.5	1103.4	1129.4	77.4	51.9	129.3	1033.3	839.	1.69	4.26	5.95
9	2	8	112822.	96184.	1600.	10.1	990.8	1071.8	1098.9	1125.9	81.0	54.1	135.1	1025.6	835.	1.69	4.27	5.96
9	2	7	113411.	95027.	1589.	10.0	981.3	1063.4	1090.6	1117.9	82.0	54.5	136.6	1016.5	830.	1.69	4.28	5.97
9	2	6	97884.	93967.	1579.	10.0	972.5	1043.7	1067.5	1091.3	71.2	47.6	118.8	1003.1	824.	1.69	4.29	5.98

9	2	5	74101.	93116.	1571.	10.0	965.3	1019.5	1037.7	1055.9	54.2	36.5	90.7	938.6	817.	1.70	4.29	5.99
9	2	4	49531.	92510.	1565.	10.0	960.1	996.4	1008.8	1021.1	36.4	24.7	61.1	975.8	811.	1.70	4.30	5.99
9	2	3	29483.	92125.	1562.	10.0	956.8	978.5	985.9	993.3	21.7	14.9	36.6	966.1	807.	1.70	4.30	6.00
9	2	2	12973.	91918.	1560.	10.0	955.0	964.5	967.8	971.1	9.6	6.6	16.1	959.1	803.	1.37	3.47	4.83
9	2	1	5369.	91847.	1559.	10.0	954.4	958.3	959.7	961.1	4.0	2.7	6.7	956.1	802.	2.09	1.15	3.23
9	3	17	14269.	103618.	1669.	10.2	1046.3	1056.1	1059.6	1063.1	9.8	7.0	16.8	1050.6	850.	1.84	1.97	3.81
9	3	16	17022.	103579.	1668.	10.2	1046.0	1057.8	1061.9	1066.0	11.7	8.3	20.0	1051.1	850.	1.69	4.22	5.91
9	3	15	35382.	103255.	1665.	10.2	1043.8	1068.2	1076.8	1085.4	24.4	17.1	41.5	1054.4	852.	1.69	4.22	5.91
9	3	14	61967.	102660.	1660.	10.2	1039.7	1082.6	1097.5	1112.3	42.9	29.7	72.6	1058.3	853.	1.69	4.23	5.91
9	3	13	88360.	101760.	1652.	10.1	1033.4	1094.8	1115.8	1136.8	61.5	42.0	103.5	1059.9	854.	1.69	4.23	5.92
9	3	12	111311.	100594.	1641.	10.1	1024.9	1102.9	1129.2	1155.5	78.0	52.6	130.6	1058.5	852.	1.69	4.24	5.93
9	3	11	116092.	99305.	1629.	10.1	1015.3	1097.2	1124.7	1152.2	81.9	55.0	136.9	1050.5	848.	1.69	4.25	5.94
9	3	10	110355.	98058.	1618.	10.1	1005.7	1084.1	1110.4	1136.7	78.4	52.6	131.0	1039.4	842.	1.69	4.26	5.95
9	3	9	101748.	96920.	1607.	10.1	996.7	1069.5	1093.9	1118.4	72.8	48.9	121.6	1028.0	836.	1.69	4.26	5.96
9	3	8	105956.	95829.	1597.	10.0	987.9	1064.2	1089.7	1115.2	76.3	51.0	127.2	1020.7	833.	1.69	4.27	5.96
9	3	7	101939.	94758.	1587.	10.0	979.1	1053.0	1077.6	1102.3	73.8	49.3	123.2	1010.8	828.	1.69	4.28	5.97
9	3	6	87595.	93799.	1578.	10.0	971.1	1034.9	1056.3	1077.6	63.8	42.8	106.6	998.5	822.	1.69	4.29	5.98
9	3	5	67513.	93023.	1570.	10.0	964.5	1013.9	1030.6	1047.2	49.4	33.3	82.8	985.8	816.	1.70	4.29	5.99
9	3	4	47049.	92455.	1565.	10.0	959.6	994.2	1005.9	1017.7	34.6	23.5	58.0	974.5	811.	1.70	4.30	5.99
9	3	3	26202.	92094.	1561.	10.0	956.5	975.8	982.4	989.0	19.3	13.2	32.5	964.8	806.	1.70	4.30	6.00
9	3	2	11284.	91910.	1560.	10.0	954.9	963.2	966.1	969.0	8.3	5.7	14.1	958.5	803.	1.37	3.47	4.83
9	3	1	4656.	91847.	1559.	10.0	954.4	957.8	959.0	960.2	3.4	2.4	5.8	955.9	802.	2.09	1.15	3.23
10	4	17	14269.	114667.	1805.	11.2	1052.8	1061.9	1065.3	1068.8	9.1	6.9	16.0	1056.8	891.	2.18	1.97	4.15
10	4	16	17022.	114628.	1805.	11.2	1052.5	1063.4	1067.5	1071.6	10.8	8.3	19.1	1057.4	891.	1.99	4.22	6.21
10	4	15	35382.	114296.	1802.	11.2	1050.5	1073.1	1081.6	1090.2	22.6	17.1	39.6	1060.5	892.	1.99	4.22	6.21
10	4	14	61967.	113685.	1797.	11.1	1046.8	1086.4	1101.2	1116.1	39.6	29.7	69.3	1064.3	894.	1.99	4.22	6.21
10	4	13	88360.	112760.	1789.	11.1	1041.0	1097.8	1118.7	1139.7	56.8	42.0	98.7	1066.0	895.	1.99	4.23	6.22
10	4	12	111311.	111560.	1778.	11.1	1033.3	1105.2	131.5	1157.8	72.0	52.6	124.5	1064.9	894.	1.99	4.23	6.23
10	4	11	116092.	110234.	1766.	11.1	1024.5	1100.1	1127.5	1155.0	75.6	54.9	130.5	1057.7	890.	1.99	4.24	6.23
10	4	10	110355.	108950.	1754.	11.1	1015.8	1088.1	1114.3	1140.6	72.3	52.5	124.8	1047.5	884.	2.00	4.25	6.24
10	4	9	101748.	107778.	1744.	11.1	1007.6	1074.7	1099.0	1123.4	67.1	48.7	115.8	1037.0	878.	2.00	4.25	6.25
10	4	8	105956.	106657.	1733.	11.0	999.6	1069.8	1095.2	1120.7	70.3	50.8	121.1	1030.4	875.	2.00	4.26	6.26
10	4	7	101939.	105557.	1723.	11.0	991.5	1059.5	1084.1	1108.7	68.0	49.2	117.2	1021.3	870.	2.00	4.27	6.27
10	4	6	87595.	104572.	1714.	11.0	984.2	1042.9	1064.2	1085.5	58.7	42.6	101.3	1010.0	864.	2.00	4.27	6.27
10	4	5	67513.	103777.	1707.	11.0	978.2	1023.7	1040.3	1056.9	45.5	33.2	78.7	998.2	858.	2.00	4.28	6.28
10	4	4	47049.	103196.	1701.	11.0	973.8	1005.5	1017.2	1028.9	31.8	23.4	55.2	987.8	853.	2.00	4.28	6.28
10	4	3	26202.	102827.	1698.	11.0	970.9	988.7	995.2	1001.8	17.7	13.1	30.9	978.8	848.	2.00	4.29	6.29
10	4	2	11284.	102639.	1696.	11.0	969.5	977.1	980.0	982.8	7.6	5.7	13.3	972.9	845.	1.61	3.46	5.07
10	4	1	4656.	102575.	1696.	11.0	969.0	972.1	973.3	974.5	3.2	2.4	5.5	970.4	844.	2.49	1.14	3.63
10	5	17	15125.	114105.	1801.	11.2	1049.3	1059.0	1062.7	1066.4	9.7	7.4	17.0	1053.6	889.	2.18	1.97	4.15
10	5	16	17507.	114063.	1800.	11.2	1049.1	1060.3	1064.5	1068.8	11.2	8.5	19.7	1054.1	889.	1.99	4.22	6.21
10	5	15	34828.	113733.	1797.	11.1	1047.1	1069.3	1077.8	1086.2	22.3	16.8	39.1	1057.0	890.	1.99	4.22	6.21
10	5	14	57736.	113156.	1792.	11.1	1043.5	1080.5	1094.4	1108.2	37.0	27.7	64.7	1059.9	892.	1.99	4.22	6.21
10	5	13	86046.	112275.	1784.	11.1	1037.9	1093.3	1113.8	1134.3	55.4	40.9	96.4	1062.3	893.	1.99	4.23	6.22
10	5	12	109140.	111107.	1774.	11.1	1030.3	1101.0	1126.9	1152.7	70.7	51.6	122.4	1061.4	892.	1.99	4.23	6.23
10	5	11	112493.	109817.	1762.	11.1	1021.7	1095.1	1121.7	1148.4	73.4	53.4	126.7	1053.9	888.	1.99	4.24	6.24
10	5	10	107464.	108571.	1751.	11.1	1013.1	1083.7	1109.3	1134.9	70.5	51.3	121.8	1044.1	882.	2.00	4.25	6.25
10	5	9	101504.	107418.	1740.	11.1	1005.0	1072.1	1096.4	1120.7	67.0	48.7	115.7	1034.5	877.	2.00	4.26	6.25
10	5	8	102249.	106316.	1730.	11.0	997.1	1065.0	1089.6	1114.2	67.9	49.2	117.1	1026.9	873.	2.00	4.26	6.26
10	5	7	92751.	105283.	1721.	11.0	989.5	1051.4	1073.9	1096.4	62.0	44.9	106.9	1016.7	868.	2.00	4.27	6.27
10	5	6	80458.	104379.	1712.	11.0	982.7	1036.8	1056.4	1076.0	54.0	39.3	93.3	1006.5	863.	2.00	4.28	6.27
10	5	5	61648.	103647.	1706.	11.0	977.2	1018.8	1033.9	1049.1	41.5	30.4	71.9	995.5	857.	2.00	4.28	6.28
10	5	4	42092.	103118.	1701.	11.0	973.2	1001.6	1012.1	1022.6	28.4	21.0	49.4	985.7	852.	2.00	4.28	6.28
10	5	3	22536.	102791.	1698.	11.0	970.6	985.9	991.6	997.2	15.3	11.3	26.6	977.4	848.	2.00	4.29	6.29

10	5	2	9499.	102628.	1696.	11.0	969.4	975.8	978.2	980.6	6.4	4.8	11.2	972.2	845.	1.61	3.46	5.07
10	5	1	3795.	102575.	1696.	11.0	969.0	971.5	972.5	973.5	2.6	1.9	4.5	970.1	844.	2.49	1.14	3.63
10	6	17	18222.	113982.	1799.	11.2	1048.6	1060.2	1064.7	1069.1	11.6	8.9	20.5	1053.8	889.	2.18	1.97	4.15
10	6	16	21097.	113932.	1799.	11.2	1048.3	1061.8	1066.9	1072.0	13.5	10.3	23.7	1054.3	889.	1.99	4.22	6.21
10	6	15	33550.	113556.	1796.	11.1	1046.0	1070.6	1080.0	1089.3	24.7	18.6	43.3	1056.9	890.	1.99	4.22	6.21
10	6	14	54852.	112975.	1790.	11.1	1042.3	1077.5	1090.7	1103.9	35.2	26.4	61.6	1057.9	891.	1.99	4.22	6.22
10	6	13	85730.	112115.	1783.	11.1	1036.9	1092.1	1112.5	1132.9	55.3	40.8	96.1	1061.2	892.	1.99	4.23	6.22
10	6	12	107978.	110957.	1772.	11.1	1029.3	1099.3	1124.9	1150.5	70.0	51.1	121.2	1060.1	891.	1.99	4.24	6.23
10	6	11	112772.	109674.	1761.	11.1	1020.7	1094.3	1121.1	1147.8	73.6	53.5	127.1	1053.1	887.	1.99	4.24	6.24
10	6	10	105434.	108439.	1750.	11.1	1012.2	1081.5	1106.7	1131.9	69.3	50.4	119.7	1042.7	882.	2.00	4.25	6.25
10	6	9	101649.	107294.	1739.	11.0	1004.1	1071.3	1095.7	1120.1	67.2	48.8	116.0	1033.6	877.	2.00	4.26	6.25
10	6	8	100498.	106201.	1729.	11.0	996.2	1063.1	1087.3	1111.5	66.8	48.4	115.2	1025.6	872.	2.00	4.26	6.26
10	6	7	93402.	105173.	1720.	11.0	988.7	1051.1	1073.7	1096.3	62.4	45.2	107.7	1016.1	868.	2.00	4.27	6.27
10	6	6	77867.	104280.	1711.	11.0	982.0	1034.3	1053.3	1072.3	52.3	38.1	90.4	1005.0	862.	2.00	4.28	6.28
10	6	5	59455.	103572.	1705.	11.0	976.6	1016.7	1031.4	1046.1	40.1	29.3	69.4	994.3	856.	2.00	4.28	6.28
10	6	4	38933.	103069.	1700.	11.0	972.8	999.1	1008.8	1018.5	26.3	19.4	45.7	984.4	851.	2.00	4.28	6.28
10	6	3	20521.	102767.	1697.	11.0	970.5	984.4	989.5	994.7	13.9	10.3	24.2	976.6	847.	2.00	4.29	6.29
10	6	2	8247.	102621.	1696.	11.0	969.3	974.9	977.0	979.1	5.6	4.2	9.8	971.8	845.	1.61	3.46	5.07
10	6	1	3146.	102575.	1696.	11.0	969.0	971.1	971.9	972.7	2.1	1.6	3.7	969.9	844.	2.49	1.14	3.63

TIN = 962.007 TOUT = 1050.008

```
PASS NUMBER/NUMBER OF PASSES =     5/ 5
MASS FLOW, PANEL A           =180.8  KG/S (  1.435 MLB/H)
MASS FLOW, PANEL B           =198.3  KG/S (  1.574 MLB/H)
PASS MASS FLOW               =379.1  KG/S (  3.009 MLB/H)
PASS INLET  TEMPERATURE      =     516.7 C (  962.0 F)
INLET TEMPERATURE,PANEL A    =     512.4 C (  954.4 F)
INLET TEMPERATURE,PANEL B    =     520.5 C (  969.0 F)
OUTLET TEMPERATURE, PANEL A  =     565.6 C ( 1050.0 F)
OUTLET TEMPERATURE, PANEL B  =     565.6 C ( 1050.0 F)
PASS OUTLET TEMPERATURE      =     565.6 C ( 1050.0 F)
PASS PEAK METAL TEMPERATURE  =     632.6 C ( 1170.7 F)
PASS PEAK SALT  TEMPERATURE  =     601.1 C ( 1113.9 F)
PASS PEAK FRONT-TO-BACK DT   =      84.0 C (  151.2 F)
PASS FRICTIONAL PRESS DROP   = 199.76 KPA (  28.98 LB/IN2)
CUMULATIVE FRICT. PRESS DROP =1131.94 KPA ( 164.19 LB/IN2)
PASS PEAK ABSORBED HEAT FLUX = .406 MW/M2 (    .129 MBTU/H-FT2)
ABSORBED POWER, PANEL A      =   14.79 MW (  50.45 MBTU/H)
ABSORBED POWER, PANEL B      =   13.74 MW (  46.88 MBTU/H)
PASS ABSORBED POWER          =   28.53 MW ( 97.334 MBTU/H)
CUMULATIVE ABSORBED POWER    =  160.02 MW (546.021 MBTU/H)
CUMULATIVE INCIDENT POWER    =  172.62 MW (589.009 MBTU/H)
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SOLAR RECEIVER PASS 5 SUMMARY DATA

STRIP		1	2	3	4	5	6
MASS FLOW (KG/S)	=	2.056	2.056	2.054	2.254	2.253	2.252
FLOW VARIATION (PERCENT FROM AVERAGE	=	.03	.00	.00	.00	.00	.00
MASS VELOCITY (KG/M2-S)	=	5360.	5360.	5355.	5878.	5874.	5873.
MAXIMUM VELOCITY (M/S)	=	3.1	3.1	3.1	3.4	3.4	3.4
AVERAGE REYNOLDS NUMBER	=	97788.	97797.	97325.	108311.	107928.	107798.
FRICTIONAL PRESSURE LOSS (KPA)	=	199.86	199.87	199.56	236.14	235.89	235.80
GRAVITATIONAL PRESSURE LOSS (KPA)	=	456.27	456.26	456.53	455.55	455.75	455.82
TOTAL PRESSURE LOSS (KPA)	=	656.13	656.13	656.10	691.70	691.64	691.62
AVERAGE HEAT TRANSFER COEFFICIENT (W/M2-C)	=	9166.8	9167.3	9140.7	9925.0	9903.9	9896.6
SALT INLET TEMPERATURE (C)	=	512.4	512.4	512.4	520.6	520.6	520.6
SALT OUTLET TEMPERATURE (C)	=	566.4	566.2	563.5	567.1	565.2	564.8
SALT TEMPERATURE RISE (C)	=	54.0	53.7	51.1	46.5	44.7	44.2
PEAK SALT TEMPERATURE (C)	=	601.0	600.1	595.0	596.2	593.9	593.0
PEAK AVERAGE METAL TEMPERATURE (C)	=	574.4	574.3	571.1	574.4	572.4	571.8
PEAK METAL TEMPERATURE (C)	=	632.6	631.1	624.2	625.4	622.6	621.4
AVERAGE METAL TEMPERATURE (C)	=	552.7	552.5	550.1	555.2	553.5	553.0
AVERAGE SURFACE TEMPERATURE (C)	=	591.5	590.5	585.9	589.5	586.2	585.4
MAXIMUM WALL TEMPERATURE DIFFERENCE (C)	=	33.7	31.8	30.6	30.5	29.6	29.7
MAXIMUM FRONT TO BACK TEMPERATURE DIFFERENCE (C)	=	84.0	79.3	76.1	72.5	70.4	70.6
TUBE THERMAL EXPANSION (MM)	=	.0	.0	.0	.0	.0	.0
PEAK ABSORBED HEAT FLUX (MW/M2)	=	.406	.383	.366	.366	.355	.356
AVERAGE ABSORBED HEAT FLUX (MW/M2)	=	.240	.239	.227	.227	.218	.216
ABSORBED POWER (MW)	=	3.752	7.485	3.549	3.549	6.820	3.371

SOLAR RECEIVER PASS 5 SUMMARY DATA

STRIP		1	2	3	4	5	6
MASS FLOW (LB/H)	=	16315.	16315.	16300.	17892.	17880.	17876.
FLOW VARIATION (PERCENT FROM AVERAGE	=	.03	.00	.00	.00	.00	.00
MASS VELOCITY (LB/FT2-S)	=	1098.	1098.	1097.	1204.	1203.	1203.
MAXIMUM VELOCITY (FT/S)	=	10.2	10.2	10.2	11.2	11.2	11.1
AVERAGE REYNOLDS NUMBER	=	97788.	97797.	97325.	108311.	107928.	107798.
FRICTIONAL PRESSURE LOSS (LB/IN2)	=	28.99	28.99	28.94	34.25	34.21	34.20
GRAVITATIONAL PRESSURE LOSS (LB/IN2)	=	66.18	66.18	66.21	66.07	66.10	66.11
TOTAL PRESSURE LOSS (LB/IN2)	=	95.16	95.16	95.16	100.32	100.31	100.31
AVERAGE HEAT TRANSFER COEFFICIENT (BTU/H-FT2-F)	=	1614.7	1614.8	1610.1	1748.3	1744.6	1743.3
SALT INLET TEMPERATURE (F)	=	954.4	954.4	954.4	969.0	969.0	969.0
SALT OUTLET TEMPERATURE (F)	=	1051.5	1051.1	1046.4	1052.7	1049.4	1048.6
SALT TEMPERATURE RISE (F)	=	97.1	96.7	92.0	83.7	80.4	79.6
PEAK SALT TEMPERATURE (F)	=	1113.9	1112.2	1103.0	1105.2	1101.1	1099.4
PEAK AVERAGE METAL TEMPERATURE (F)	=	1065.8	1065.8	1060.0	1066.0	1062.4	1061.3
PEAK METAL TEMPERATURE (F)	=	1170.7	1168.1	1155.6	1157.8	1152.7	1150.5
AVERAGE METAL TEMPERATURE (F)	=	1026.9	1026.4	1022.2	1031.4	1028.3	1027.3
AVERAGE SURFACE TEMPERATURE (F)	=	1096.8	1094.9	1086.7	1093.1	1087.2	1085.7
MAXIMUM WALL TEMPERATURE DIFFERENCE (F)	=	60.6	57.3	55.0	54.9	53.4	53.5
MAXIMUM FRONT TO BACK TEMPERATURE DIFFERENCE (F)	=	151.2	142.7	136.9	130.5	126.7	127.1
TUBE THERMAL EXPANSION (IN)	=	.0	.0	.0	.0	.0	.0
PEAK ABSORBED HEAT FLUX (MBTU/H-FT2)	=	.129	.122	.116	.116	.113	.113
AVERAGE ABSORBED HEAT FLUX (MBTU/H-FT2)	=	.076	.076	.072	.072	.069	.069
ABSORBED POWER (MBTU/H)	=	12.802	25.542	12.111	12.111	23.274	11.505

Appendix K

INCIDENT HEAT FLUX MAPS

Table K.1 Design Day Incident Heat Flux Map for 10-Deg Sun Elevation (Sunrise)--
Left Side (Reversed for sunset), MW/m^2

ROW NO	POS. CENT.M	AREA HT.M																									
1	23.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3	19.70	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	4	6	11	12	18	26
4	18.04	1.652	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	4	7	11	21	23	31	39	45	53	62
5	16.39	1.652	0	0	0	0	0	0	0	1	3	3	4	8	8	10	18	21	26	32	34	32	62	67	73	82	89	89	85
6	14.74	1.652	0	0	0	0	7	22	19	25	30	33	36	40	40	51	57	62	59	59	51	46	91	92	102	109	111	103	101
7	13.09	1.652	11	16	24	21	35	56	48	59	70	77	81	84	89	113	112	104	94	82	68	63	123	118	126	131	131	130	120
8	11.43	1.652	18	28	44	37	67	97	84	110	130	140	138	133	123	155	142	121	101	94	85	75	144	143	142	146	141	137	125
9	9.78	1.652	25	42	64	48	90	135	118	149	178	174	177	148	130	165	139	123	110	104	88	75	150	154	151	153	147	141	135
10	8.13	1.652	34	53	81	58	99	153	132	182	211	197	168	140	117	151	137	126	112	100	87	77	152	157	159	156	151	143	132
11	6.48	1.652	36	60	92	59	96	164	142	186	201	182	154	133	114	147	135	118	105	95	86	78	155	159	159	157	151	146	136
12	4.83	1.652	40	65	95	62	95	134	114	151	170	163	143	125	106	137	126	113	99	91	86	79	155	159	159	154	148	144	137
13	3.17	1.652	38	61	93	61	90	124	104	142	167	155	137	125	106	136	124	107	97	93	87	83	161	158	154	150	144	138	137
14	1.52	1.652	35	55	89	60	92	126	106	144	166	149	130	115	99	128	118	108	100	94	91	86	168	165	161	157	159	158	155
15	-.13	1.652	32	51	86	54	93	134	114	141	140	146	128	111	98	126	119	114	107	100	93	87	170	176	179	176	170	164	153
16	-1.78	1.652	31	50	84	49	88	131	111	143	146	146	130	119	105	135	124	116	105	96	84	78	155	160	164	165	158	148	137
17	-3.43	1.652	28	47	79	47	83	132	114	143	147	146	129	114	98	125	114	102	88	78	69	61	120	118	118	115	110	102	94
18	-5.09	1.652	27	42	69	44	85	124	108	127	126	124	114	96	81	102	77	65	58	49	44	35	68	66	64	60	52	50	44
19	-6.74	1.652	20	33	55	34	59	85	74	89	98	84	74	58	41	52	40	35	29	25	19	15	28	29	28	26	23	20	18
20	-8.39	1.652	15	22	37	17	32	42	36	42	39	34	27	18	16	21	17	15	11	10	9	8	15	13	12	11	10	9	8
21	-10.04	1.652	8	13	21	7	8	11	9	10	8	7	6	5	4	5	5	4	4	4	4	3	6	5	5	5	4	4	3
22	-11.70	1.652	4	6	3	1	2	2	2	2	2	2	1	1	1	2	2	2	1	1	1	1	2	1	1	1	1	0	0
23	-13.35	1.652	1	2	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-15.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table K.2 Design Day Incident Heat Flux Map for 10-Deg Sun Elevation (Sunrise)--
Right Side (Reversed for sunset), MW/m^2

ROW NO	POS. CENT.M	AREA HT.M																										
1	23.88	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	1	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	19.78	1.652	25	22	15	12	7	1	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	18.04	1.652	61	54	48	46	43	26	27	14	9	6	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5	16.39	1.652	87	85	83	84	80	76	62	32	34	29	26	22	14	7	6	4	3	2	2	1	0	0	0	0	0	0
6	14.74	1.652	100	95	91	93	101	94	84	43	53	60	61	61	58	53	42	35	30	23	19	14	9	18	4	0	0	0
7	13.09	1.652	119	117	114	108	107	101	96	48	57	73	86	86	98	97	78	74	67	61	52	43	32	37	25	15	19	13	8
8	11.43	1.652	122	125	122	120	113	110	106	52	60	71	91	99	110	122	97	107	109	100	91	78	61	70	50	31	36	25	16
9	9.78	1.652	132	132	132	130	127	118	117	57	61	78	88	98	118	128	102	120	127	124	109	98	80	93	71	45	59	40	25
10	8.13	1.652	128	130	129	132	128	120	115	55	60	66	82	92	102	126	99	117	122	119	106	105	91	106	84	57	79	53	33
11	6.48	1.652	133	130	131	131	128	122	118	57	62	66	75	91	103	114	88	102	105	105	97	98	92	107	82	61	92	61	39
12	4.83	1.652	132	135	132	133	130	125	119	57	62	67	74	87	102	110	86	99	100	93	87	87	79	93	75	53	95	63	41
13	3.17	1.652	134	137	140	137	135	129	117	57	62	68	77	89	103	115	90	98	103	93	83	77	83	98	78	52	94	64	42
14	1.52	1.652	151	151	151	139	137	129	124	61	65	72	81	95	109	121	95	107	110	106	95	86	89	100	83	52	90	60	38
15	-.13	1.652	149	150	147	141	132	129	123	60	64	74	87	101	116	132	105	117	119	116	104	99	88	104	81	47	88	58	36
16	-1.78	1.652	133	132	127	123	116	113	107	51	59	68	81	92	113	127	101	115	123	120	112	101	89	105	72	49	87	57	38
17	-3.43	1.652	91	94	91	85	84	83	77	36	42	51	64	79	97	112	89	105	116	119	114	108	98	103	80	53	86	55	35
18	-5.09	1.652	42	46	46	46	45	45	43	20	23	29	37	48	64	81	65	77	95	101	103	97	85	98	71	47	75	50	33
19	-6.74	1.652	17	18	18	19	19	19	17	8	9	10	15	20	29	41	32	45	58	65	69	65	58	67	51	34	59	37	22
20	-8.39	1.652	7	8	8	8	8	8	8	3	3	4	4	4	7	9	7	12	18	25	28	28	28	33	26	17	43	24	15
21	-10.04	1.652	3	3	3	3	3	2	3	1	1	1	1	1	1	2	1	1	1	3	4	5	6	8	5	5	24	16	10
22	-11.70	1.652	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	12	7	5
23	-13.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3	2
24	-15.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table K.3 Design Day Incident Heat Flux Map for 10 a.m.--
Left Side (Reversed for 2 p.m.), MW/m^2

ROW NO	POS. CENT.M	AREA HT.M																										
1	23.08	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
2	21.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	12	14	
3	19.78	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	6	14	16	28	34	48	84	107
4	18.04	1.652	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	6	13	30	63	122	145	168	168	214	256	235
5	16.39	1.652	0	0	0	0	0	2	2	9	15	11	14	23	29	35	48	59	78	119	133	163	318	362	373	360	405	381	350
6	14.74	1.652	0	0	0	0	23	63	57	75	86	93	97	107	117	149	165	201	240	253	236	217	425	415	413	414	396	355	295
7	13.09	1.652	36	48	71	61	102	160	140	168	204	223	233	235	235	295	321	357	348	328	254	213	414	397	389	375	344	329	317
8	11.43	1.652	56	83	124	122	214	312	277	345	386	377	398	373	342	429	447	426	343	306	251	207	396	389	371	371	363	345	335
9	9.78	1.652	82	128	194	189	396	535	484	527	549	538	533	462	399	501	448	408	344	298	252	216	414	404	394	376	363	354	341
10	8.13	1.652	95	153	251	240	456	647	589	683	668	632	550	436	374	473	413	364	330	283	243	230	451	437	429	390	375	356	366
11	6.48	1.652	97	163	253	199	435	625	564	682	674	595	497	389	331	420	377	345	322	288	249	225	444	442	426	411	390	366	371
12	4.83	1.652	108	157	249	172	366	531	474	610	631	547	449	363	314	402	378	366	324	280	250	224	443	436	433	425	431	422	405
13	3.17	1.652	97	155	239	159	312	467	411	547	592	515	430	353	309	397	377	348	307	271	239	225	442	443	449	441	436	425	411
14	1.52	1.652	184	161	246	172	318	454	408	526	543	444	379	304	294	377	363	332	305	277	264	247	481	479	455	449	437	435	414
15	-.13	1.652	99	159	255	188	287	439	385	475	478	424	389	359	335	428	390	350	320	295	275	255	494	489	485	462	446	415	408
16	-1.78	1.652	102	161	253	182	321	448	392	481	480	469	452	411	371	471	426	371	317	279	260	242	469	453	434	413	391	374	358
17	-3.43	1.652	183	161	248	201	342	490	434	490	516	498	470	402	337	426	363	302	257	223	194	172	332	332	308	301	268	258	229
18	-5.09	1.652	90	149	236	206	339	484	433	482	478	432	367	308	245	309	252	205	168	140	116	92	177	171	161	159	144	130	122
19	-6.74	1.652	65	115	191	171	270	389	350	372	336	284	242	191	132	167	131	105	84	64	49	38	73	71	68	68	62	61	56
20	-8.39	1.652	38	70	113	78	131	195	175	172	159	139	103	64	44	57	48	38	31	26	20	17	33	33	33	30	26	24	21
21	-10.04	1.652	19	34	60	30	42	46	39	42	43	27	18	14	13	17	15	12	10	9	8	8	15	15	14	12	12	10	10
22	-11.70	1.652	9	14	27	6	9	9	7	9	6	4	4	3	3	4	5	4	4	4	4	2	4	4	3	2	2	1	1
23	-13.35	1.652	3	8	14	1	1	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-15.08	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table K.4 Design Day Incident Heat Flux Map for 10 a.m.--
Right Side (Reversed for 2 p.m.), MW/m^2

ROW NO	POS. CENT.M	AREA HT.M																											
1	23.00	.826	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0
2	21.35	1.652	14	9	0	0	0	3	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
3	19.70	1.652	106	64	55	46	22	41	26	14	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	9	0
4	18.04	1.652	231	195	179	177	171	160	143	73	41	17	8	3	1	1	1	0	0	0	0	0	0	0	0	0	0	9	6	0
5	16.39	1.652	347	340	324	324	315	320	324	166	150	103	73	61	52	39	32	19	16	12	8	6	1	1	0	0	0	0	0	0
6	14.74	1.652	295	291	305	337	347	363	365	189	223	227	204	183	177	162	131	105	87	76	69	60	43	47	22	0	0	0	0
7	13.09	1.652	318	319	326	353	372	374	375	194	235	283	306	344	363	344	275	242	218	197	181	154	113	127	83	34	43	28	19
8	11.43	1.652	338	362	371	389	401	399	402	209	238	266	318	410	488	486	387	373	367	372	323	265	216	244	158	87	98	61	40
9	9.78	1.652	342	369	392	416	434	431	438	226	245	280	313	389	466	532	422	446	454	494	465	418	348	390	257	131	158	101	59
10	8.13	1.652	366	383	403	420	421	428	418	213	243	271	299	347	386	447	354	409	481	530	548	511	453	531	351	170	212	140	80
11	6.48	1.652	367	383	403	413	429	426	420	214	243	266	289	318	348	374	292	347	416	498	522	497	448	492	340	189	252	158	94
12	4.83	1.652	402	413	416	425	440	431	408	206	227	255	282	318	337	363	283	303	366	428	457	449	403	453	290	139	253	160	103
13	3.17	1.652	408	422	439	446	452	438	410	209	223	236	267	300	332	359	280	295	355	370	408	439	373	421	255	128	259	167	107
14	1.52	1.652	412	433	439	446	451	447	440	225	235	243	275	311	328	352	274	303	323	368	398	409	327	372	247	133	256	167	104
15	-.13	1.652	406	426	445	450	456	451	441	224	252	274	284	311	341	378	297	327	353	381	398	388	320	365	248	140	241	157	97
16	-1.78	1.652	349	365	389	402	420	417	425	217	246	267	291	325	361	404	318	349	376	401	417	377	316	361	220	125	234	148	98
17	-3.43	1.652	229	245	280	299	305	313	305	153	179	209	258	290	328	375	295	347	377	403	412	385	300	344	236	139	229	145	93
18	-5.89	1.652	122	135	148	161	178	178	174	90	108	127	163	197	234	276	217	267	313	353	381	371	308	350	245	145	219	143	90
19	-6.74	1.652	55	61	63	67	70	72	75	38	47	60	72	90	110	148	117	150	192	224	270	276	254	285	202	127	188	120	76
20	-8.39	1.652	20	23	24	25	26	26	26	13	14	20	23	27	35	46	35	55	77	103	133	144	147	165	129	91	160	95	53
21	-10.04	1.652	9	10	10	10	11	11	12	6	7	8	10	11	13	15	11	12	17	27	31	36	50	58	59	34	105	66	36
22	-11.70	1.652	1	1	1	2	3	3	3	2	2	3	3	4	5	5	4	3	3	3	3	5	7	9	6	6	67	34	21
23	-13.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	23	19	11
24	-15.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table K.5 Design Point Incident Heat Flux Map--
Left or Right Side (Symmetrical), MW/m^2

ROW NO	POS. CENT,M	AREA HT,M																											
1	23.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	19.70	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	2	1	7	14	23	27	21	13	15	39
4	18.04	1.652	0	0	0	0	0	0	0	0	0	0	2	3	3	5	9	12	20	31	64	120	115	110	108	90	101	128	
5	16.35	1.652	0	0	0	0	0	2	2	5	7	11	20	31	37	45	56	75	102	133	151	179	342	329	297	261	241	218	218
6	14.74	1.652	0	0	0	0	17	45	41	66	85	96	109	118	126	160	171	215	245	267	274	238	459	432	397	347	294	262	253
7	13.09	1.652	24	38	56	44	82	138	119	178	238	246	249	287	281	352	372	382	376	342	289	232	454	442	422	387	335	314	311
8	11.43	1.652	45	74	120	96	188	310	273	383	434	456	449	453	433	540	491	454	392	338	251	216	424	423	408	394	372	375	367
9	9.78	1.652	77	125	197	169	328	498	445	575	593	598	583	551	456	571	480	398	352	280	252	233	454	465	444	408	391	383	385
10	8.13	1.652	93	161	258	216	422	614	554	633	610	584	544	495	394	498	429	380	326	281	256	241	473	463	458	427	415	392	381
11	6.48	1.652	99	169	289	216	419	621	560	566	526	501	472	416	360	456	414	362	332	304	278	246	491	481	462	453	432	406	399
12	4.83	1.652	106	174	276	181	355	548	489	531	502	464	422	384	338	431	385	356	331	302	262	229	460	457	458	448	448	427	411
13	3.17	1.652	105	166	257	159	320	472	418	491	470	430	362	339	300	386	373	354	317	277	254	239	472	459	456	442	442	450	421
14	1.52	1.652	102	165	253	165	292	449	394	449	430	414	361	330	301	305	353	334	313	299	267	249	489	465	470	468	466	449	435
15	-.13	1.652	101	159	259	162	280	431	377	447	431	397	365	358	324	414	375	339	329	310	289	260	499	530	481	472	460	432	415
16	-1.78	1.652	102	169	264	157	270	405	353	417	425	408	379	370	342	435	392	355	328	305	268	238	460	446	439	414	409	383	369
17	-3.43	1.652	101	156	244	155	280	427	374	435	441	410	351	369	320	417	370	330	289	251	216	182	354	332	317	296	281	252	240
18	-5.09	1.652	90	136	219	150	272	408	359	424	433	413	358	326	266	339	289	237	201	158	129	99	197	186	172	152	136	122	109
19	-6.74	1.652	65	109	179	122	220	322	284	322	318	288	249	201	150	192	156	119	82	64	48	37	75	71	66	58	50	49	44
20	-8.35	1.652	48	72	121	61	108	161	141	161	156	142	108	67	51	67	50	35	31	22	19	16	32	30	28	26	23	21	19
21	-10.04	1.652	28	48	75	23	35	41	34	38	37	27	23	18	12	17	13	11	10	8	8	7	15	15	13	13	11	9	8
22	-11.70	1.652	14	22	36	6	8	10	8	8	6	5	4	4	3	4	4	4	3	3	3	2	3	3	2	2	2	1	1
23	-13.35	1.652	7	10	17	1	2	2	1	1	1	0	4	4	3	4	4	4	3	3	3	2	3	3	2	2	2	1	1
24	-15.00	1.652	7	10	17	1	2	2	1	1	1	0	4	4	3	4	4	4	3	3	3	2	3	3	2	2	2	1	1
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table K.6 Design Point Incident Heat Flux Map with East Half of Field Covered by Clouds--Left Side, kW/m^2

ROW NO	POS. CENT.,M	AREA HT.,M																										
1	23.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	19.70	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	1	6	13	23	26	18	9	10	17
4	18.04	1.652	0	0	0	0	0	0	0	0	0	0	2	4	5	6	8	10	19	33	59	111	122	103	104	77	71	68
5	16.39	1.652	0	0	0	0	0	2	2	4	8	11	20	31	40	48	54	76	102	127	146	175	323	320	268	225	191	146	112
6	14.74	1.652	0	0	0	0	15	45	41	68	85	98	109	120	131	164	175	214	246	264	266	233	438	396	359	288	230	162	139
7	13.09	1.652	15	24	35	44	78	139	122	175	234	248	261	289	281	349	371	372	366	341	280	224	424	407	372	317	252	206	166
8	11.43	1.652	29	47	70	92	180	306	272	378	436	462	452	454	444	550	501	453	390	332	247	209	391	373	344	317	279	239	198
9	9.78	1.652	49	77	115	165	308	485	436	572	592	607	575	552	455	566	474	394	349	285	246	227	423	412	387	334	283	242	201
10	8.13	1.652	50	89	141	205	416	606	551	641	611	587	549	490	401	503	439	375	322	270	245	231	433	413	393	347	304	247	152
11	6.48	1.652	50	85	150	205	414	615	559	582	521	490	467	416	363	458	417	360	332	256	261	234	442	424	390	359	308	252	207
12	4.83	1.652	48	82	138	170	337	537	484	525	505	468	431	384	331	419	376	351	327	295	254	218	414	413	384	357	318	280	224
13	3.17	1.652	48	77	129	154	312	468	419	468	471	430	365	327	301	383	363	350	310	270	248	230	429	407	380	346	317	287	235
14	1.52	1.652	46	81	127	156	284	433	385	448	428	415	363	321	300	379	343	326	303	289	261	241	445	410	389	368	337	289	242
15	-.13	1.652	48	75	126	150	270	431	383	441	431	399	369	349	322	407	367	335	326	305	281	254	456	452	404	375	337	278	228
16	-1.78	1.652	51	75	126	155	267	402	355	411	418	408	366	365	332	420	391	353	329	301	267	235	434	399	373	329	297	244	193
17	-3.43	1.652	51	76	119	150	275	414	367	429	437	414	393	369	324	409	363	327	282	247	214	180	334	309	267	241	206	161	119
18	-5.05	1.652	44	68	106	144	269	400	356	417	430	406	359	327	269	338	288	236	196	154	125	97	181	167	145	125	102	79	57
19	-6.74	1.652	28	48	83	115	205	311	276	322	309	288	253	234	150	190	154	119	85	62	46	34	64	60	54	45	38	32	27
20	-8.39	1.652	14	21	46	64	105	150	133	156	148	139	105	65	51	65	50	36	29	20	19	16	29	26	24	20	16	14	11
21	-10.04	1.652	6	11	19	21	31	38	32	34	36	27	23	19	13	17	13	10	9	8	7	7	13	13	11	10	9	7	5
22	-11.70	1.652	1	3	6	5	6	8	7	7	5	4	4	4	3	4	4	4	3	3	3	2	3	3	3	2	1	0	0
23	-13.35	1.652	1	1	1	1	1	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-15.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table K.7 Design Point Incident Heat Flux Map with East Half of Field Covered by Clouds--Right Side, kW/m^2

ROW NO	POS. CENT.M	AREA HT.M																										
1	23.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	19.70	1.652	17	12	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
4	18.04	1.652	63	42	21	11	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	16.39	1.652	102	72	47	24	18	13	8	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	14.74	1.652	123	90	60	45	33	25	18	4	3	3	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0
7	13.09	1.652	146	114	85	66	49	37	24	6	5	4	4	3	2	2	0	0	0	0	0	0	0	2	2	1	24	14	9
8	11.43	1.652	173	143	104	80	65	45	32	8	7	6	4	3	3	3	0	0	0	0	0	0	0	3	3	2	47	27	15
9	9.78	1.652	176	145	124	95	70	50	33	8	7	6	5	5	4	3	0	0	0	0	0	0	0	4	3	3	78	44	25
10	8.13	1.652	168	147	121	97	76	53	36	9	8	7	6	4	4	3	1	1	1	0	0	0	0	4	4	3	111	70	36
11	6.48	1.652	180	152	117	89	70	50	38	9	8	7	6	5	4	3	1	1	1	1	1	0	0	5	4	3	133	87	52
12	4.83	1.652	196	154	115	87	65	51	38	9	8	8	7	6	5	4	1	1	1	1	1	0	0	5	4	4	144	95	56
13	3.17	1.652	207	165	127	97	66	49	39	9	8	8	7	6	5	4	1	1	1	1	1	1	1	5	4	4	138	91	55
14	1.52	1.652	213	178	138	92	66	48	36	8	7	7	6	6	5	5	1	1	1	1	1	1	1	6	6	5	130	81	46
15	-.13	1.652	200	163	125	97	70	53	35	8	8	7	6	5	5	4	1	1	1	1	1	0	0	6	5	5	125	77	45
16	-1.78	1.652	169	139	114	83	59	46	30	7	7	6	6	5	5	4	1	1	1	1	1	1	1	5	5	5	118	73	45
17	-3.43	1.652	105	90	72	55	43	30	23	5	5	5	5	4	4	4	1	1	1	1	1	1	1	5	5	4	115	73	43
18	-5.09	1.652	49	44	36	30	25	19	13	3	3	3	3	3	2	2	0	0	0	0	0	0	0	4	4	4	105	65	43
19	-6.74	1.652	23	21	18	15	14	10	7	2	2	2	2	2	2	2	0	0	0	0	0	0	0	3	3	3	94	57	32
20	-8.39	1.652	9	9	8	8	6	4	4	1	1	1	1	1	1	1	0	0	0	0	0	0	0	2	2	2	80	50	30
21	-10.04	1.652	4	4	3	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	56	37	25
22	-11.70	1.652	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	21	14
23	-13.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	13	10
24	-15.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table K.8 Design Point Incident Heat Flux Map with North Half of Field Covered by Clouds--Left or Right Side, kW/m^2

ROW NO	POS. CENT.M	AREA HT.M																										
1	23.35	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	19.70	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	1	6	13	23	26	18	11	15	38
4	18.04	1.652	0	0	0	0	0	0	0	0	0	0	2	4	5	6	6	6	13	27	54	103	115	57	59	73	87	111
5	16.39	1.652	0	0	0	0	0	2	2	3	4	4	9	11	11	14	18	34	56	88	110	138	262	258	212	180	156	138	131
6	14.74	1.652	0	0	0	0	8	17	16	27	32	33	39	45	56	69	80	123	162	184	154	163	312	281	258	205	165	116	122
7	13.09	1.652	3	3	5	12	28	61	57	86	128	125	138	160	159	196	223	230	235	220	172	126	244	238	221	186	146	123	112
8	11.43	1.652	7	13	19	33	63	167	155	238	276	287	282	286	264	247	307	270	219	181	110	86	165	167	160	156	147	137	134
9	9.78	1.652	20	28	39	76	178	307	288	359	400	401	378	360	271	331	251	186	156	115	95	50	172	181	177	148	129	130	134
10	8.13	1.652	19	34	58	136	271	417	395	457	411	381	346	296	219	268	214	162	125	95	50	53	181	180	180	162	154	139	129
11	6.48	1.652	18	29	63	132	272	432	408	408	325	255	275	231	186	228	192	149	137	119	105	98	196	195	182	180	169	146	151
12	4.83	1.652	21	34	53	73	203	360	341	362	328	282	244	201	157	192	156	145	132	118	96	84	170	176	177	176	172	172	164
13	3.17	1.652	20	31	48	67	192	312	294	342	306	255	187	160	121	162	147	142	116	57	51	65	172	171	168	161	168	191	180
14	1.52	1.652	20	31	46	71	169	282	265	306	270	244	190	158	134	164	141	131	122	120	112	106	201	188	190	200	209	202	201
15	-.13	1.652	17	25	47	62	156	280	262	258	274	232	157	161	165	202	175	159	159	154	147	133	245	250	235	230	231	216	220
16	-1.78	1.652	18	31	53	70	151	256	235	277	270	250	225	211	192	237	226	201	185	172	154	135	252	235	235	221	222	218	208
17	-3.43	1.652	20	34	56	74	170	285	264	315	315	285	263	245	212	263	232	206	171	146	125	103	193	163	161	158	151	133	122
18	-5.09	1.652	24	5	61	84	188	301	278	321	328	310	266	239	150	235	155	150	115	88	68	49	92	85	71	61	57	47	42
19	-6.74	1.652	20	34	63	71	145	246	226	265	250	225	157	153	106	121	59	72	44	26	14	6	11	10	10	7	8	7	5
20	-8.39	1.652	20	29	57	41	76	116	107	128	119	111	77	40	29	35	23	13	8	2	2	2	4	3	1	1	0	0	6
21	-10.04	1.652	14	24	37	9	16	20	18	21	22	16	11	6	3	4	0	3	8	0	0	0	0	0	0	0	0	0	0
22	-11.70	1.652	9	14	22	1	1	3	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	-13.35	1.652	4	8	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-15.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table K.9 Design Point Incident Heat Flux Map with South Half of Field Covered by Clouds--Left or Right Side, kW/m^2

ROW NO	POS. CENT.M	AREA HT.M																										
1	23.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	21.35	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	19.70	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	18.04	1.652	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	6	7	6	9	9	10	11	12	12	17
5	16.39	1.652	0	0	0	0	0	0	0	1	5	7	12	23	28	34	36	42	44	40	38	40	77	78	78	79	85	87	85
6	14.74	1.652	0	0	0	0	7	28	25	41	53	66	70	74	76	96	96	93	86	84	76	75	146	143	142	137	138	139	141
7	13.09	1.652	19	32	49	33	51	79	65	88	106	119	123	128	122	155	150	145	135	126	113	104	204	209	206	203	195	195	194
8	11.43	1.652	36	57	93	61	99	142	117	141	160	176	170	158	160	205	198	186	176	157	144	131	257	254	250	242	234	234	230
9	9.78	1.652	51	93	150	92	133	181	148	173	193	206	197	193	184	238	226	212	198	175	159	145	283	280	277	269	261	256	247
10	8.13	1.652	66	115	188	101	148	193	156	184	201	207	203	194	183	238	229	217	203	182	163	147	291	285	282	275	266	258	247
11	6.48	1.652	76	128	214	106	146	188	151	174	192	196	193	185	178	233	229	216	201	184	165	147	291	287	286	279	268	259	243
12	4.83	1.652	73	131	220	101	138	181	143	163	177	187	188	183	175	231	225	213	203	187	169	147	293	286	284	280	274	262	248
13	3.17	1.652	76	128	215	91	124	161	125	147	166	175	178	178	171	225	221	215	200	182	168	153	304	298	289	279	272	259	243
14	1.52	1.652	77	129	199	89	120	156	121	143	159	172	174	173	167	220	208	201	190	178	159	146	291	283	276	271	260	248	238
15	-.13	1.652	77	127	204	92	125	157	121	144	158	166	172	169	158	209	198	186	174	159	142	131	259	257	247	241	228	219	204
16	-1.78	1.652	76	128	206	90	121	152	117	134	148	159	162	155	141	187	170	158	146	135	120	108	215	213	207	199	186	172	162
17	-3.43	1.652	73	115	182	80	109	134	103	114	123	130	130	124	113	150	135	125	115	107	95	83	164	161	151	143	136	126	117
18	-5.09	1.652	59	96	149	54	85	103	79	87	92	96	94	89	79	106	96	89	81	71	62	53	107	104	100	95	85	80	71
19	-6.74	1.652	41	68	108	46	59	69	52	58	59	59	56	51	44	60	57	48	43	38	34	30	62	61	57	52	46	43	39
20	-8.39	1.652	24	40	65	25	31	36	26	26	29	28	28	24	22	30	28	24	21	19	17	14	29	29	28	25	23	21	19
21	-10.04	1.652	12	21	33	13	16	19	14	14	14	12	12	11	10	14	13	11	9	9	8	7	14	15	13	13	11	9	7
22	-11.70	1.652	4	8	13	4	5	5	4	4	4	4	4	4	3	4	4	4	3	3	3	2	3	3	3	2	2	1	0
23	-13.35	1.652	2	3	4	1	1	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-15.00	.826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Table K.10 Design Point Incident Heat Flux Map for Cavity Test at CRTF Left Side, kW/m^2

ROW NO	POS. CENT.M	AREA HT.M																								
1	3.15	.113	-3	-3	-3	7	7	-4	-14	-13	-11	-10	-8	-2	4	6	2	1	10	9	8	9	7	4	4	4
2	2.92	.226	-3	-3	-3	7	7	-4	-14	-13	-11	-10	-7	2	8	18	23	34	33	35	45	49	42	39	33	33
3	2.70	.226	-3	-3	-3	7	7	-4	-14	-13	-8	1	15	26	48	58	92	96	98	99	96	101	91	78	76	74
4	2.47	.226	-3	-3	-3	7	7	-4	-13	6	24	45	62	83	103	112	182	185	174	169	159	167	156	139	128	132
5	2.25	.226	-3	-3	-3	7	8	8	25	50	79	103	132	157	177	185	302	298	281	262	246	257	237	227	205	206
6	2.02	.226	-3	-3	-2	8	33	45	64	103	142	183	213	240	257	264	431	412	396	362	326	338	320	311	289	281
7	1.79	.226	0	6	23	28	54	79	118	169	217	260	292	320	333	325	527	510	479	439	386	397	389	371	349	346
8	1.57	.226	0	11	38	38	78	116	167	227	289	336	363	387	386	367	597	583	550	495	437	449	426	402	385	382
9	1.34	.226	2	21	57	53	97	145	201	268	330	380	402	413	409	383	624	621	585	536	476	486	463	433	414	411
10	1.12	.226	8	28	71	62	111	156	217	294	353	394	419	429	420	397	652	636	600	548	481	489	484	456	438	435
11	.89	.226	13	38	90	74	118	169	232	301	360	398	419	424	417	396	656	637	605	557	500	511	502	480	456	448
12	.66	.226	18	50	104	81	127	176	229	293	344	381	402	406	406	380	635	637	605	539	491	506	502	482	464	465
13	.44	.226	25	62	119	88	132	174	217	274	324	358	372	380	380	356	601	555	545	520	474	492	494	473	461	464
14	.21	.226	30	69	135	96	136	170	202	253	293	316	339	347	342	281	487	498	498	445	406	425	433	431	429	431
15	-.02	.226	32	70	138	95	127	150	179	219	249	271	286	291	246	230	397	392	383	365	326	342	356	366	371	377
16	-.24	.226	27	63	124	85	110	127	147	175	196	212	189	191	182	165	286	286	277	260	232	244	259	267	276	283
17	-.47	.226	19	45	93	64	82	94	106	124	133	127	127	123	118	102	172	174	170	157	141	149	154	165	168	175
18	-.69	.226	10	25	57	42	54	56	59	70	68	68	66	65	63	53	84	83	77	72	59	62	71	75	77	73
19	-.92	.226	3	12	27	24	30	25	21	24	28	27	25	26	27	18	25	25	18	19	10	12	13	16	17	18
20	-1.15	.226	0	2	8	13	14	6	-3	-1	1	1	-1	1	4	4	0	-1	0	2	2	2	2	2	3	3
21	-1.37	.226	-2	-2	0	8	8	-2	-13	-11	-10	-10	-8	-2	4	4	-1	-1	0	2	2	2	2	2	3	3
22	-1.60	.226	-3	-3	-3	7	7	-4	-14	-13	-11	-10	-8	-2	4	4	-1	-1	0	2	2	2	2	2	3	3
23	-1.82	.226	-3	-3	-3	7	7	-4	-14	-13	-11	-10	-8	-2	4	4	-1	-1	0	2	2	2	2	2	3	3
24	-2.05	.113	-3	-3	-3	7	7	-4	-14	-13	-11	-10	-8	-2	4	4	-1	-1	0	2	2	2	2	2	3	3
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Table K.11 Design Point ncident Heat Flux Map for Cavity Test at CRTF--
Right Side, kW/m^2

ROW NO	POS. CENT.M	AREA HT.M	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	3.15	.113	-4	-4	-4	6	6	-5	-15	-13	-12	-9	-7	-5	-3	-1	-4	-5	4	3	2	13	11	7	5	5
2	2.92	.226	-4	-4	-4	6	6	-5	-15	-13	-12	-9	-6	-1	1	11	17	28	27	29	39	53	46	41	35	35
3	2.70	.226	-4	-4	-4	6	6	-5	-15	-13	-9	1	16	23	41	51	86	90	92	93	90	105	96	80	77	75
4	2.47	.226	-4	-4	-4	6	6	-5	-14	6	23	46	64	81	96	105	176	179	168	163	153	172	160	142	130	133
5	2.25	.226	-4	-4	-4	6	7	7	24	49	78	104	133	154	170	178	296	292	275	256	240	261	241	229	207	208
6	2.02	.226	-4	-4	-3	7	32	44	64	102	141	184	214	237	251	257	425	406	390	356	320	343	325	314	290	283
7	1.79	.226	-1	6	23	27	53	78	117	168	216	260	294	317	327	318	521	504	473	433	380	401	393	374	350	347
8	1.57	.226	0	10	37	37	77	115	166	227	288	336	364	384	379	[illegible]	591	577	543	489	431	453	430	405	386	383
9	1.34	.226	2	21	57	52	96	145	201	268	329	380	403	410	403	[illegible]	618	615	579	530	470	490	467	436	416	413
10	1.12	.226	8	28	70	61	110	155	217	293	352	394	420	427	413	390	646	629	594	542	475	494	488	458	439	436
11	.89	.226	12	37	89	73	117	168	231	300	359	398	420	421	410	389	[illegible]	631	599	551	494	515	506	483	457	450
12	.66	.226	17	49	104	80	126	175	228	292	343	381	403	403	399	373	[illegible]	630	599	532	485	510	506	485	465	466
13	.44	.226	25	62	119	88	131	173	217	273	323	358	373	377	373	349	595	549	539	513	468	496	498	475	462	465
14	.21	.226	29	68	135	95	135	169	202	253	292	317	340	344	335	274	481	[illegible]	492	439	399	429	438	434	431	433
15	-.02	.226	31	69	138	94	126	149	179	218	248	271	287	288	239	223	391	386	377	359	320	346	361	369	373	379
16	-.24	.226	27	63	123	84	109	127	146	175	195	212	190	188	176	159	280	280	271	254	226	249	263	269	278	284
17	-.47	.226	18	45	92	63	81	93	106	123	132	127	128	121	111	95	166	168	163	151	135	154	158	168	170	176
18	-.69	.226	9	25	57	41	53	55	58	69	68	69	67	63	56	46	78	77	71	66	53	66	76	77	78	75
19	-.92	.226	3	11	27	23	29	24	20	24	27	28	27	23	20	11	19	19	12	13	4	16	18	19	18	19
20	-1.15	.226	-1	2	8	12	13	5	-4	-1	0	1	0	-2	-3	-3	-6	-7	-6	-4	-4	6	6	5	4	4
21	-1.37	.226	-3	-3	-1	7	7	-3	-13	-12	-11	-9	-7	-5	-3	-3	-7	-7	-6	-4	-4	6	6	5	4	4
22	-1.60	.226	-4	-4	-4	6	6	-5	-15	-13	-12	-9	-7	-5	-3	-3	-7	-7	-6	-4	-4	6	6	5	4	4
23	-1.82	.226	-4	-4	-4	6	6	-5	-15	-13	-12	-9	-7	-5	-3	-3	-7	-7	-6	-4	-4	6	6	5	4	4
24	-2.05	.113	-4	-4	-4	6	6	-5	-15	-13	-12	-9	-7	-5	-3	-3	-7	-7	-6	-4	-4	6	6	5	4	4
COL.NO.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Table K.12 Design Point Incident Heat Flux Map for Flat Panel Test at CRTF, kW/m^2

ROW NO.	POS. CENT.M	AREA HT.M							
1	7.63	.332	0	0	0	0	0	0	0
2	6.96	.663	0	0	0	0	0	0	0
3	6.30	.663	0	0	0	0	0	0	0
4	5.64	.663	0	1	1	2	2	3	3
5	4.97	.663	5	7	9	13	16	18	19
6	4.31	.663	18	26	37	50	63	72	75
7	3.65	.663	43	69	107	150	186	209	220
8	2.98	.663	70	126	191	261	317	354	363
9	2.32	.663	77	134	212	300	384	448	467
10	1.66	.663	64	120	203	300	387	444	462
11	.99	.663	54	106	193	295	404	489	521
12	.33	.663	51	96	182	289	421	519	552
13	-.33	.663	43	88	158	270	434	554	604
14	-.99	.663	40	83	157	272	422	561	608
15	-1.66	.663	41	78	145	260	415	569	620
16	-2.32	.663	29	67	127	216	359	510	589
17	-2.98	.663	32	55	114	205	318	451	508
18	-3.65	.663	34	71	117	174	238	293	326
19	-4.31	.663	24	37	59	100	149	175	194
20	-4.97	.663	15	29	45	71	86	87	92
21	-5.64	.663	2	5	14	26	39	39	36
22	-6.30	.663	1	2	6	12	16	9	4
23	-6.96	.663	0	0	0	2	1	0	0
24	-7.63	.332	0	0	0	0	0	0	0
COL.NO.			1	2	3	4	5	6	7

Appendix L

RECEIVER THERMAL LOSSES

RADIATION AND REFLECTION LOSS ANALYSES

REFLECTION LOSSES - CONFIGURATION V-12 26.0m Panels

WING PANELS

$$L_{WING\ REFL} = \underbrace{A_{WING} \quad \phi_{INC}} \times .05$$

$$= 2 \times 6.31\ MW \times .05 = .631\ MW$$

CAVITY

$$L_{CAVITY\ REFL} = \qquad = 4.74\ MW\ *$$

$$L_{TOTAL\ REFL} = 5.37\ MW$$

RADIATION

WING PANELS

$$L_{RAD\ WING} = A_{WING} \times \varepsilon\, \sigma\, (T_w^4 - T_{SPACE}^4)$$

$$= 2 \times 62.79 \times .9 \times .1713 \times 10^8\ [(634°E+460)^4 - (-50-1960)^4] \times (3.281\ ft/m)^2/(3.412\ Btu/hr/w)$$

$$= 2 \times 62.79 \times 6.830\ kw/m^2 = .858\ MW$$

CAVITY

$$L_{RAD\ CAV} = \Sigma\, A_n \times BB_n{}^{**} \times \varepsilon \times \sigma \times (T_{wn}^4 - T_s^4)$$

$$= 6.56\ MW_t$$

$$L_{TOTAL\ RAD} = 7.42\ MW$$

$A_n = 225.3\ ft^2 = 20.93\ m^2$

* TRASYS output TRASYS nodes are shown in attached figures.

** BB_n is the net flux factor for interchange between an individual node and the aperture. It is calculated by TRASYS and includes internal cavity radiative interchange. Values for individual nodes are shown on the attached table.

FOR NEW BASELINE CONFIGURATION

REFLECTION LOSSES

$$L_{REFL\ NBC} = L_{REFL\ V-12} \times \frac{\left(\frac{A_{APER}}{A_{PANEL}}\right)_{NBC}}{\left(\frac{A_{APER}}{A_{PANEL}}\right)_{V-12}}$$

$$L_{REFL\ V-12} = 4.74\ MW_t$$

$$\left(\frac{A_{APER}}{A_{PANEL}}\right)_{NBC} = \frac{598.9}{1275.5} = 0.4695$$

$$\left(\frac{A_{APER}}{A_{PANEL}}\right)_{V-12} = \frac{394.4}{1130.2} = 0.3490$$

$$L_{REFL\ NBC} = 6.38\ MW_t$$

RADIATION LOSSES

$$L_{CAV\ RAD\ NBC} = L_{CAV\ RAD\ V-12} \times \frac{\left(\frac{A_{APER}}{A_{PANEL}}\right)_{NBC}}{\left(\frac{A_{APER}}{A_{PANEL}}\right)_{V-12}} \times \frac{A_{APER\ NBC}}{A_{APER\ V-12}}$$

$$L_{CAV\ RAD\ V-12} = 6.56\ MW_t$$

$$\frac{A_{APER\ NBC}}{A_{APER\ V-12}} = \frac{598.9}{394.4} = 1.519$$

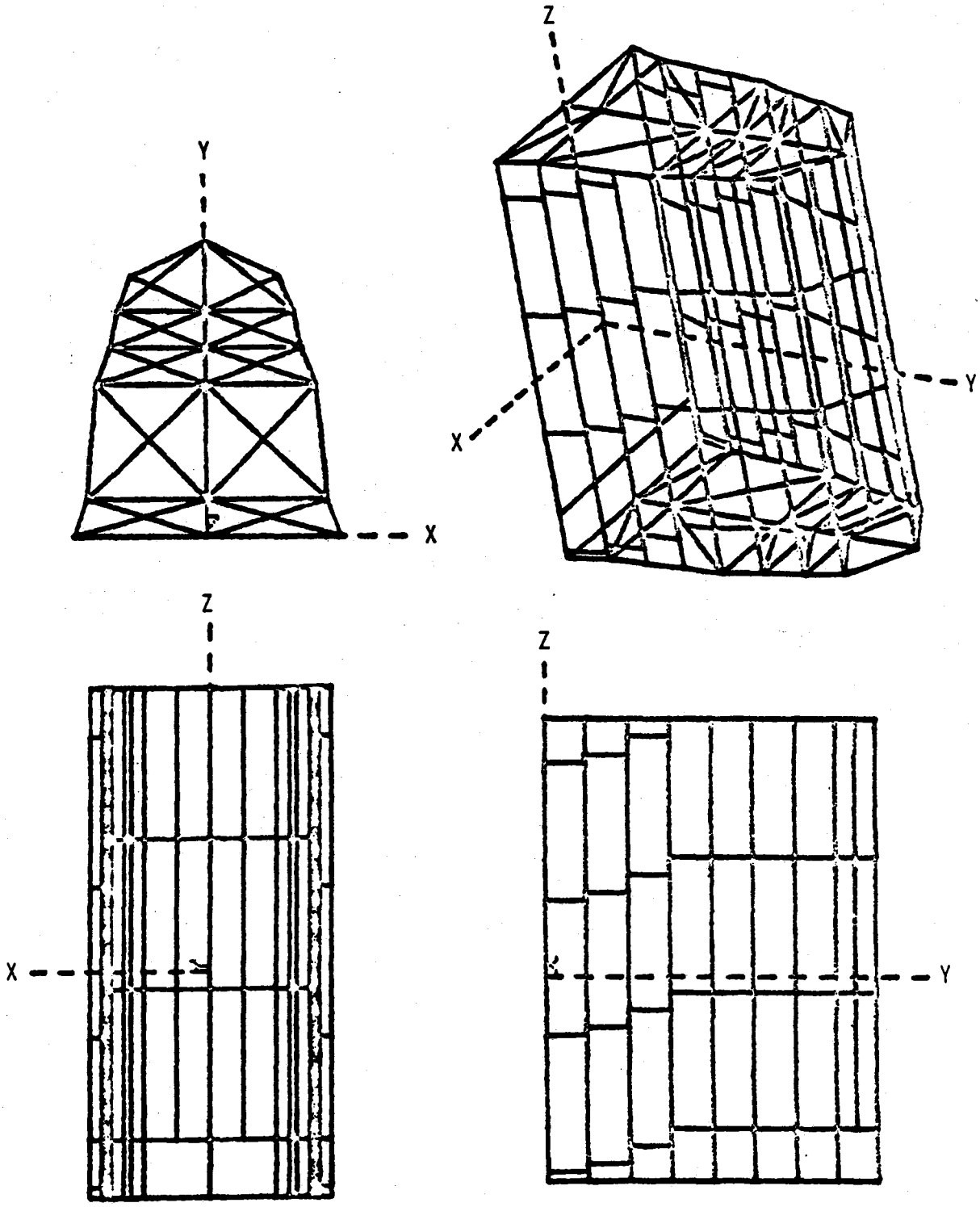
$$L_{CAV\ RAD\ NBC} = 13.41$$

FLUX AND WALL TEMPERATURE DATA FOR REFLECTION AND RADIATION LOSS ANALYSIS
PANEL -- CAVITY CONFIGURATION V-12

TOP	2	3	4	5	6	7	8	9	10	
AVERAGE WALL TEMPERATURE	419.6	511.5	531.6	502.7	491.3	588.5	590.8	566.3	562.6	°C
	787.4	952.9	989.1	937.1	916.5	1091.5	1095.6	1051.5	1044.8	°F
FLUX FACTOR	.58395	.413082	.293892	.204402	.226499	.151207	.141044	.225741	.204892	
	429.9	536.1	597.8	569.1	583.6	627.2	622.7	617.9	610.5	
	806.0	997.1	1108.3	1056.5	1082.6	1161.2	1153.0	1144.5	1131.1	
	.588401	.437163	.340415	.255670	.284853	.189308	.175360	.279313	.252113	
	324.8	343.7	455.2	447.1	477.8	569.7	564.9	521.8	514.0	
	616.9	650.9	851.5	837.0	892.3	1057.6	1049.0	971.5	957.4	
	.559378	.407787	.306663	.235591	.260065	.172392	.160331	.254853	.230795	

BOTTOM

A_{NODE} = 225.3 ft^2 = 20.93 m^2



V12 CONFIGURATION

TRASYS II

Function

1. Provides internode radiation interchange data.
2. Provides incident and absorbed heat rate data from environmental radiant sources.

Assumptions

a. All surfaces are considered to be semi-gray (accounts for absorptions and reflection, but no emission in the ultra-violet portion of the spectrum; accounts for absorption and reflection as well as emission in the infrared portion of the spectrum).

b. Equations are developed for use in analyzing radiation enclosures consisting of diffuse, specular, and/or diffuse-plus-specular surfaces using an imaging technique.

c. All surfaces are considered to emit diffusely and to reflect with diffuse and specular components such that the relationship

$$\varepsilon_i + \rho_i d + \rho_i s + \tau_i = 1.$$

is satisfied.

d. All surfaces with specular components of reflectance are restricted to planar surfaces to simplify imaging.

e. Only first-order images are considered (that is, no images of images or images in images are generated).

Input

1. Surface number
2. Surface type (ex, rectangle, cylinder, sphere, etc.)
3. Surface geometry data (ex, coordinate pts)
4. Surface emissivity and absorptivity
5. Specify active side of surface, (the side that is radiating)

TRASYS II (continued)

OUTPUT (for radiation interchange from surface i to surface j)

Radiation interchange factor (Fij), where Fij is defined to be ε_i x Bij

Bij is the fraction of the energy leaving surface i that is finally absorbed by surface j equals the sum of

a. the energy that goes directly from surface i to surface j and is absorbed,
b. the energy that goes from surface i to surface j by all possible first-order specular reflections and is absorbed,
c. that fraction of the energy that goes directly from surface i to each of the surfaces in the enclosure, finally arrives at surface j by all possible paths due to diffuse reflections, and is absorbed.
d. that fraction of the energy that goes from surface i to each of the surfaces in the enclosure by all possible first-order specular reflections, thence to surface j by all possible paths due to diffuse reflections, and is absorbed.

ε is the emissivity of surface i

The net heat interchange for N surfaces can then be calculated using the equation.

$$q_i = \sigma \sum_{j=1}^{N} F_{ij} \left(T_i^4 - T_j^4 \right)$$

CONVECTIVE LOSS CALCULATIONS - V-12

L PANEL = 26.0 m

1. Natural Convection from Cavity - Unpublished data correlation from John Kraabel, Sandia Livermore. Properties are evaluated at ambient temperature.

$Q = N_u\ k\ A\ \Delta T$

$N_u = .058\ Gr^{.355}$

$Gr = g\beta\ (T_{W_{avg}} - T_{amb})\ b^3/\nu^2$

$g = 9.8$ m/sec

$\beta = 3.67 \times 10^3/^oK$ = Coefficient of vol. expansion

$T_{amb} = 70^oF$

$T_{W_{avg}} = 980^oF$ = Avg. cavity wall temp.

$b = 26$ m = Aperture height

$\nu = 1.44 \times 10^{-5}\ m^2/sec$ = Kinematic viscosity

$k = .025\ w/m^oC$ = Thermal conductivity

$A = .560\ m^2$ = Cavity internal area including floor and ceiling

$Q = 10.85$ MW

2. Natural Convection from Wings (<u>Heat Transmission</u>, McAdams p. 172)

$Q = N_u\ k\ A\ \Delta T/b$

$N_u = 0.13\ (Gr\ Pr)^{1/3}$

$Gr = \dfrac{g\beta\ \Delta T\ b^3}{\nu^2}$ at $T_f = \dfrac{634^oF + 70^oF}{2} = 352^oF$

$g = 9.8$ m/sec

$\beta = 3.67 \times 10^{-3}/^{o}C$

$\Delta T = 564^{o}F$

$\nu = 3.18 \times 10^{-5}$ m^2/sec

$b = 26.0$

$k = 0.0372$ W/$m^{o}C$

$A = 125.58$ m^2

$Pr = 0.68$

$Q = 0.373$ MW

3. Forced Convection from Cavity - Wind blowing normal to aperture plane (private communication from John Kraabel) properties evaluated at film temperature.

$$Q = \frac{N_u \, k \, A \, \Delta T}{b}$$

$N_u = \sqrt{Re}$

$Re = VD\rho/\mu$

$v = 5.69$ m/sec

$D = 20$ m = Receiver width

$\rho = 0.65$ kgm/m^3 = Density

$\mu = 2.86 \times 10^{-5}$ kgm/sec m = Viscosity

$k = .04$ watts/$m^{o}C$ = Thermal conductivity

$A = 1560$ m^2

$\Delta T = 910^{o}F$

$Q = 2.758$ MW

4. Forced Convection from Wings - Wind blowing normal to aperture plane ($\theta = 90^o$). (Heat Transfer, Jakob, p. 562).

$$Q = \frac{N_u \, k \, A \, \Delta T}{b}$$

$$N_u = .092 \, Re^{.675} = 4.167 \times 10^3$$

$$Re = VD/\nu = 7.903 \times 10^6 \quad \text{At atm conditions}$$

$$V = 5.69 \text{ m/sec}$$

$$D = 20 \text{ m}$$

$$\nu = 1.44 \times 10^{-5} \text{ m}^2/\text{sec}$$

$$k = .0215 \text{ Btu/m ft } ^oF = .0372 \text{ W/m}^oC \quad @ \; T_f = \frac{T_W + T_o}{2}$$

$$\Delta T = 563^oF = 312^oC = T_W - T_o$$

$$b = 20 \text{ m}$$

$$A = 2 \times 2.415 \times 26.0 \text{ m} = 125.58 \text{ m}^2$$

$$Q = 304.4 \text{ KW}$$

5. Forced Convection from Cavity Plus Wings - Wind blowing parallel, or at angles less than 90° to aperture plane. (Heat Transfer, Jakob, p. 473)

$$Q = .664 \, k \left(\frac{V_o L}{\nu}\right)^{1/2} \left(\frac{\nu}{\alpha}\right)^{1/3} W \, (T_W - T_{amb})$$

$$k = .04 \text{ W/m}^oC$$

$$V_o = 5.69 \text{ m/sec}$$

$$\nu = 1.44 \times 10^{-5} \text{ m}^2/\text{sec}$$

$$L = 20 \text{ m}$$

$$Re = \frac{V_o L}{\nu} = 7.903 \times 10^6$$

$$\alpha = k/\rho c_p$$

$$\frac{\nu}{\alpha} = \frac{\mu}{\rho} / k/\rho c_p = \frac{\mu\, c_p}{k} = \frac{1}{Pr}$$

$$Q = .664\ k \left(\frac{V_o L}{\nu}\right)^{1/2} Pr^{1/3}\ W\ (T_W - T_{amb})$$

$Pr = 0.71$

$W = 26.0$ m

$T_W = 895^oF$ = Approximation for cavity and wing panel frontal plane.

$T_{amb} = 70^oF$

$Q = 0.794$ MW

CONVECTIVE LOSS CALCULATION

NEW BASELINE CONFIGURATION (NBC)

1. Natural Convection

$$Q_{loss_{NBC}} = Q_{loss_{V-12}} \times \frac{A_{c_{av_{nc}}}}{A_{c_{av_{V-12}}}} -$$

$$= 10.85 \times \frac{1902}{1560} = 13.22 \text{ MW}$$

2. Forced Convection - $\theta = 90^{o}$ - Flow normal to cavity

$$Q_{loss_{NBC}} = Q_{loss_{V12}} \times \frac{A_{c_{av_{NBC}}}}{A_{c_{av_{V-12}}}}$$

$$= 2.758 \times \frac{1902}{1560} = 3.363$$

3. Forced Convection - $\theta = 0^{o}$-60° - Flow at angle to aperture plane.

$$Q_{loss_{NBC}} = Q_{loss_{V12}} \times \frac{A_{aper_{NBC}}}{A_{aber_{V-12}}}$$

$$= 0.794 \times \frac{598.9}{526} = 0.904$$

Convection Loss Estimates Summary

V-12 20 panels 2.4 5m wide x 26.0m long
aperture 15.17m x 26.0m Wing Panels 2 @ 2.415m x 26.0m

Natural Convection		Forced Convection		Combined (RSS)	
		θ = 90°	θ = 0° - 60°	θ = 48°	θ = 0° - 60°
Kraabel		Jacob			
Cavity	10.85 MW	2.76 MW	0.79 MW	11.20 MW	11.24 MW
Wings	0.37 MW	0.30 MW		0.48 MW	
Total[1]	11.22 MW	3.76 MWt	0.79 MW	11.68 MW	11.24 MW

Modification for New Baseline Configuration
20 panels 2.476m wide x 25.754m long
aperture 23.256m x 25.754m No Wing Panels

Natural Convection	Forced Convection		Combined (RSS)	
	θ = 0°	θ = 60°	θ = 0°	θ = 60°
13.22 MW	3.363 MW	0.904 MW	13.64 MW	13.25 MW
Values For Performance	Design Point			13.6 MW
	. Annual Average			13.4 MW

VISCOUS DISSIPATION

Viscous dissipation is the mechanism for conversion of molten salt potential energy and kinetic energy into thermal energy as the salt flows from the receiver outlet at the top of the tower to the storage tank. The additional thermal energy in the salt in the tanks is given by

$$P_{VD} = \dot{\omega} \left(g\,\Delta h + \frac{V_{EXIT}^2}{2}\right)$$

where

$\Delta h = h_{REC\ OUTLET} - h_{AVG\ TANK\ LEVEL}$

$h_{REC\ OUTLET} = 767.8$ ft.

$h_{AVG\ TANK\ LEVEL} = 20$ ft.

$V_{EXIT} = \dot{\omega}/A_{DOWNCOMER}\,\rho$

$A_{DOWNCOMER} = 108.4\ in^2 = 07528\ ft^2$

P_{REC} (MWe)	V (ft/sec)	P_{VD} (MWt)
80	5.1525	0.423
160	10.305	0.847
240	15.4575	1.274
320	20.61	1.705

Appendix M

COMPARISON OF ELASTIC AND INELASTIC STRAIN RANGE FOR SOLAR RECEIVER TUBES

To compare the elastic and inelastic strain ranges in a solar receiver tube, we did elastic, elastic-plastic and elastic-plastic-creep analysis on a tube heated by solar flux from one side.

We used our inhouse computer NONAX in this analysis. NONAX is a special-purpose program developed by Foster Wheeler Development Corporation to perform thermal and stress analyses on thick-walled cylinders made of homogeneous and isotropic materials.[1,2]* The loading may be axisymmetric or nonaxisymmetric. It may consist of an arbitrary combination of internal and external tractions, axial load, axial bending, and an arbitrary temperature distribution. Elastic, elastic-plastic, and creep analyses under varying load cycles and hold times can be done using this program. NONAX is considerably less expensive to run than a multipurpose finite-element program.

Analytical Model: The receiver tube is assumed to be a long, thick, cylindrical shell. The ends of the tube are welded to headers which are supported in such a way that axial expansion of the tube is allowed. Hence in the thermal stress analysis, a generalized plane strain model is assumed. The heat flux is assumed to have a cosine distribution (i.e., $q = q_o \cos \theta$) on the "sun" side of

*Numbers refer to the references listed at the end.

the tube and the rear side is assumed to be insulated. Because of symmetry only half a tube is considered. This half is divided in 114 nodes as shown in Figure M.1. The boundary conditions used for thermal and stress analyses are shown in Table M.1. Since the molten salt pressure is low, the pressure stresses are also low compared to thermal stresses. Hence we have considered only the thermal stresses in this comparison.

The geometry of the tube, material properties and other input conditions used in this analysis are described below:

Inner radius of the tube r_i = 11.0 mm (0.435 in.)
Outer radius of the tube r_o = 12.7 mm (0.5 in.)
Young's modulus E = 157,872 MPa (22.9 x 10^6 lb/in^2)
Poisson's ratio ν = 0.30
Plastic modulus H = 1792.4 MPa (0.26 x 10^6 lb/in^2)
Coefficient of thermal expansion α = 1.71 x 10^{-5}/°C (0.95 x 10^{-5}/°F)

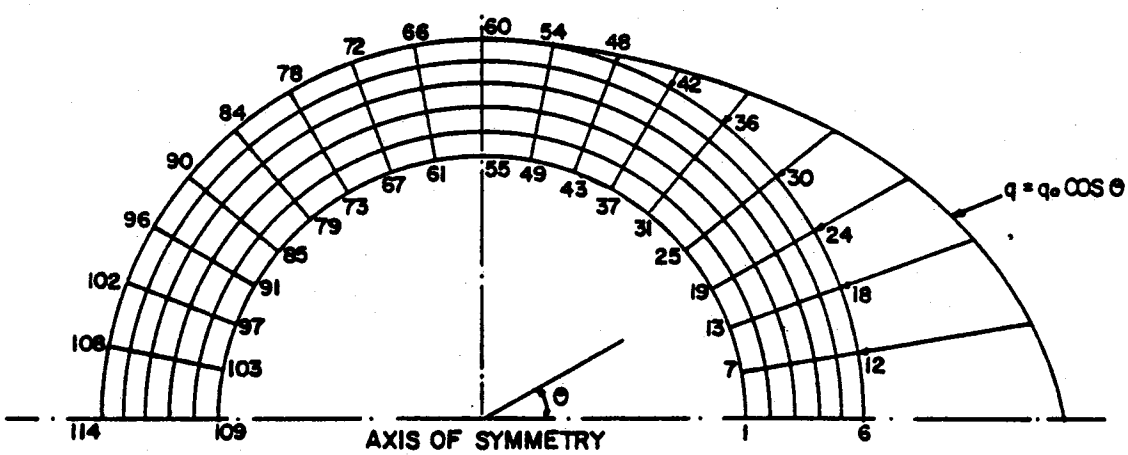


Figure M.1 Tube Model

Table M.1 Boundary Conditions for Tube Analysis

Boundary	Thermal	Stress
$r = r_o$, $0 < \theta < \pi/2$	$K\,\partial T/\partial r = -q_o \cos\theta$	$\sigma_{rr} = 0$, $\tau_{r\theta} = 0$
$r = r_o$, $\pi/2 < \theta < \pi$	$\partial T/\partial r = 0$	
$r = r_i$, $0 < \theta < \pi$	$K\,\partial T/\partial r = h_i\,(T - T_f)$	$\sigma_{rr} = 0$, $\tau_{r\theta} = 0$
$r_i \leq r \leq r_o$, $\theta = 0$	$\partial T/\partial \theta = 0$	$v = 0$, $\tau_{r\theta} = 0$
$r_i \leq r \leq r_o$, $\theta = \pi$		
$z = 0$	$\partial T/\partial z = 0$	w = constant, $\int_A \sigma_{zz}\, dA = 0$
$z = 1$		

where

r, o, z = Polar coordinates
T = Metal temperature
T_f = Fluid temperature
u, v, w = Displacements in r, o, z directions respectively
K = Thermal conductivity
σ_{rr}, σ_{zz} = Normal stresses
τ_{ro} = Shear stress
h_i = inside salt film coefficient

The plastic modulus H is defined as the effective stress divided by the effective plastic strain. Temperature dependent yield stress as shown in Table M.2 was used in this analysis.

The properties E, ν, χ and yield stress were obtained from Code Case N-47[3] and the value of H was obtained from Reference 4. The creep information for

Table M.2 Temperature Dependent Yield Stresses

Temperature °C (°F)	Yield Stress MPa (kip/in²)
315.5 (600)	126.2 (18.3)
371.1 (700)	120.7 (17.5)
426.7 (800)	115.8 (16.8)
482.2 (900)	112.4 (16.3)
537.8 (1000)	108.9 (15.8)
593.3 (1100)	105.5 (15.3)
648.9 (1200)	102.0 (14.8)
704.4 (1300)	98.6 (14.3)

Incoloy 800 was developed by W. Jones[5] based on the information in Reference 6.

The creep equation used is of the form

$$\varepsilon_c = A\sigma^n t^m$$

where

ε_c = Creep strain, percent
σ = Stress kip/in² (1 kip/in² = 6.895 MPa)
t = Time, h
A,n,m = Functions of T
T = Absolute temperature, °R

For the base case, the values used were

$$A = 10^{-n(3.50 - 0.001307)}$$
$$n = 18{,}400/10{,}630 - 4.46T)$$
$$m = 3 \times 10^{-5}nT$$

The flux and salt film coefficient values used are:

Flux q_{max} = 0.782 MW/m² (248,000 Btu/h•ft²)

Film Coefficient h = 8.52 MW/m² (1500 Btu/h•ft•°F)

The maximum metal temperature was 649°C (1200°F).

The flux histogram used in the analysis is shown in Figure M.2. The flux is increased from 0 to 0.782 MW/m^2 in small steps. The flux is then kept constant for 8 hours to simulate the steady-state operation. The flux is then reduced to zero and the next day the same cycle is continued. The elastic-plastic and elastic-plastic-creep analyses were carried up to 10 cycles. The strain ranges at the end of each cycle are plotted in Figure M.3. The elastic strain ranges are obviously constant. The elastic-plastic and elastic-plastic-creep strain ranges decrease considerably up to the second cycle and do not change considerably thereafter. The elastic-plastic-creep strain range is 9.09 percent higher than the elastic strain range at the end of 10 cycles. Thus it appears reasonable to do an elastic analysis and obtain the inelastic strain ranges by increasing the elastic strain range by 10 percent.

Since completing the above study, we have done considerably more work in this area in connection with the Preliminary Design for Solar Repowering at Pioneer Mill Company. We have done nine different inelastic analyses for different tube materials (Incoloy 800 and Type 316SS), different flux conditions, and metal temperatures. The effect of pressure stresses are also included in this study. These data have been curve fitted so that once the elastic strain range is known, the inelastic strain ranges can be obtained easily. These analyses also have shown that the inelastic strain ranges are about 10 percent higher than the elastic strain ranges.

The above conclusions are significant because now we can determine the inelastic strains without going through the agony of inelastic analysis and

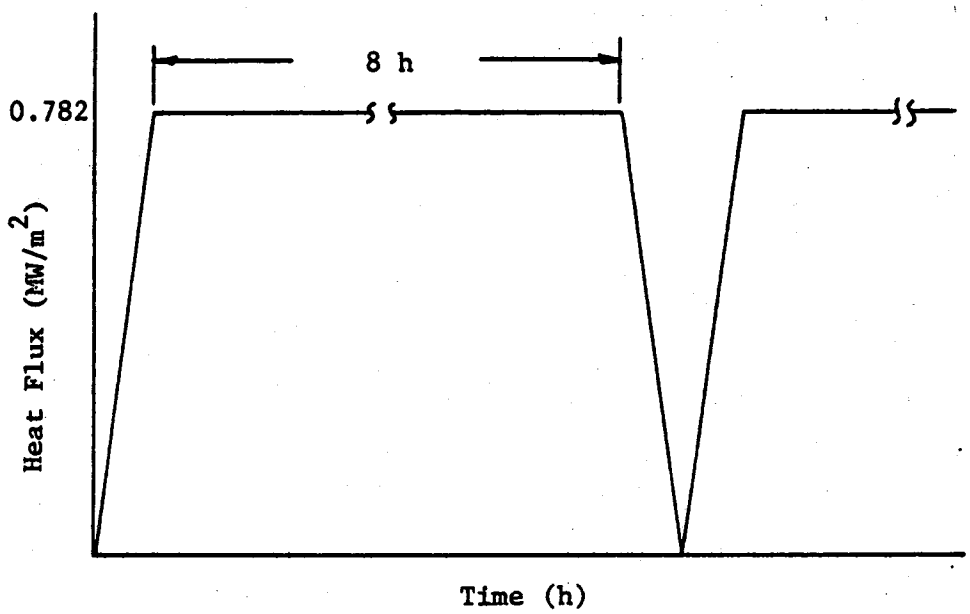


Figure M.2 Heat Flux Histogram

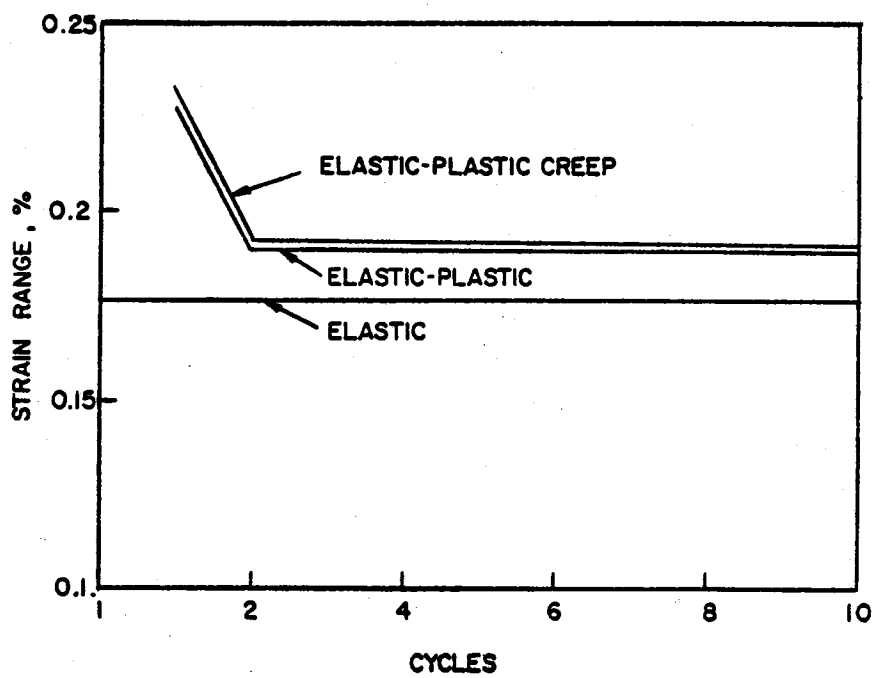


Figure M.3 Comparison of Elastic and Inelastic Analysis

without incurring the expenses that go with it. The inelastic strains thus determined may be used in conjunction with Figure T-1420 of Code Case N-47 (rather than Figure T-1430, which is much more conservative) to determine the fatigue damage.

REFERENCES

1. G. D. Gupta, et al., "Thermoelastic Analysis of Nonaxisymmetrically Heated Thick Cylindrical Shells," Journal of Pressure Vessel Technology, Transactions of the ASME, Vol. 100, No. 1, February 1978, pp. 107-111.

2. M. S. M. Rao, T. V. Narayanan, and G. D. Gupta, "Inelastic Analysis of Nonaxisymmetrically Heated Thick Cylindrical Shells," submitted for publication in the Journal of Pressure Vessel Technology, Transactions of the ASME.

3. ASME Boiler and Pressure Vessel Code, Code Case N-47, 1980.

4. Nuclear Systems Materials Handbook, Hanford Engineering Development Laboratory, TID 26666, February 1975.

5. G. E. Sessions and P. J. McGehar, "ASME BPVC Recommendations of Design Stresses for Use of Annealed Alloy 800 in Elevated Temperature Nuclear Vessels, ORNL/Sub-4308, December 1978.

Appendix N

TRANSIENT ANALYSIS RESULTS

This appendix contains the complete results of the transient analyses:

- Morning Hot Startup - Passes 2 and 4
- Noon Hot Startup NS17 - Passes 2 and 4
- Noon Hot Startup NS12 - Passes 2 and 4
- Emergency Shutdown - Passes 2 and 4
- Cloud Cover - Passes 2 and 4.

The assumptions made in these analyses and other details are given in Section 5.2.2 and 5.3.6. For each transient, the following results are graphically shown in the figures that follow.

- Maximum metal temperatures
- Minimum metal temperatures
- Average metal temperatures
- DT Maximum - Maximum minus average metal temperature
- DT Minimum - Minimum minus average metal temperatures.

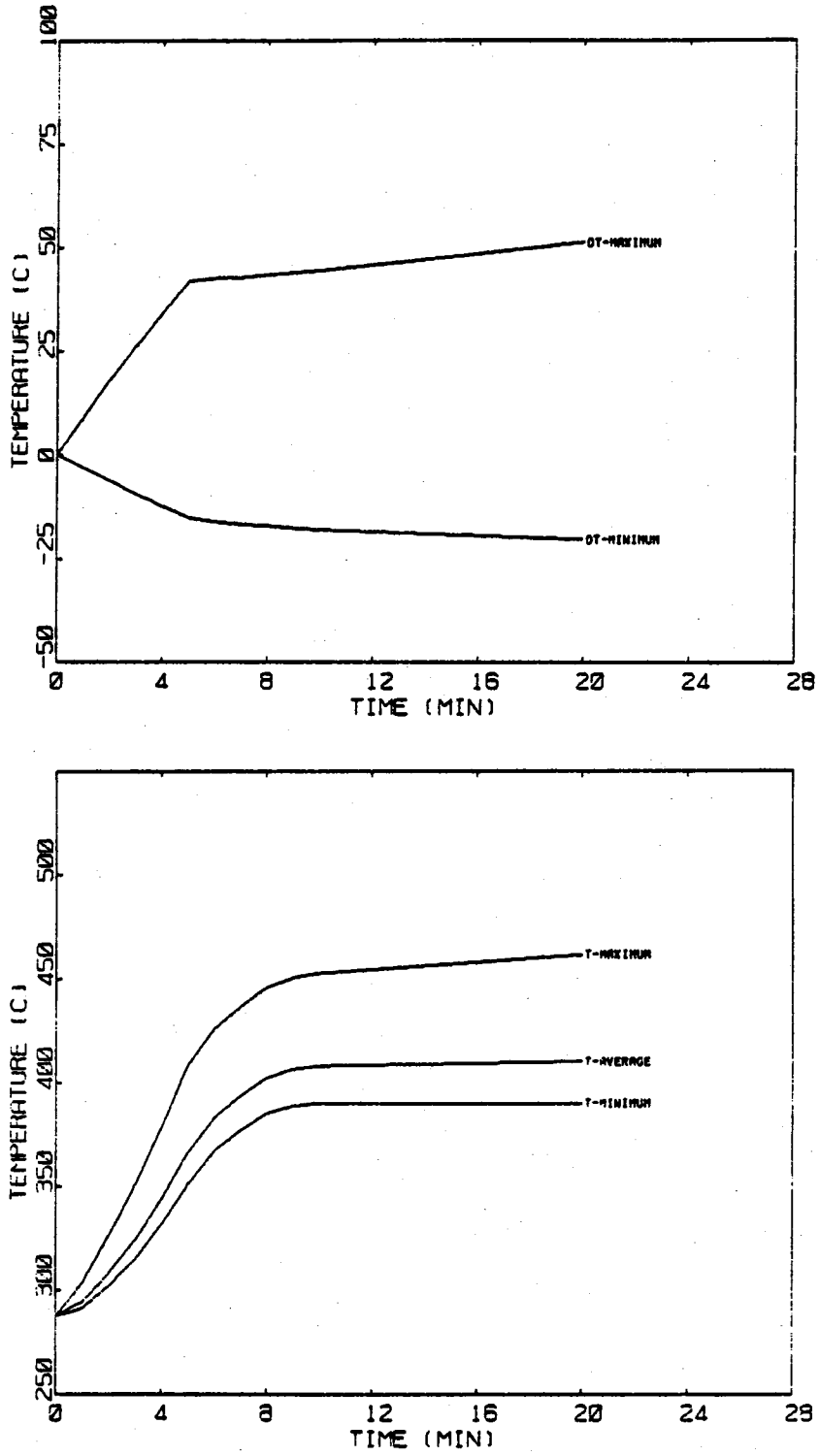
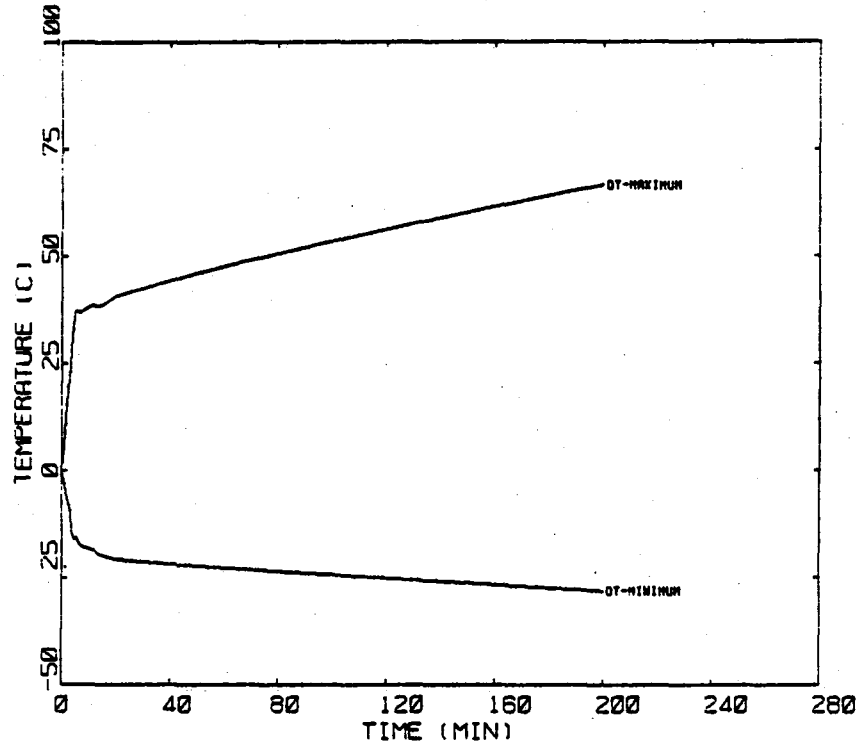


Figure N.1 Morning Hot Startup--Pass 2



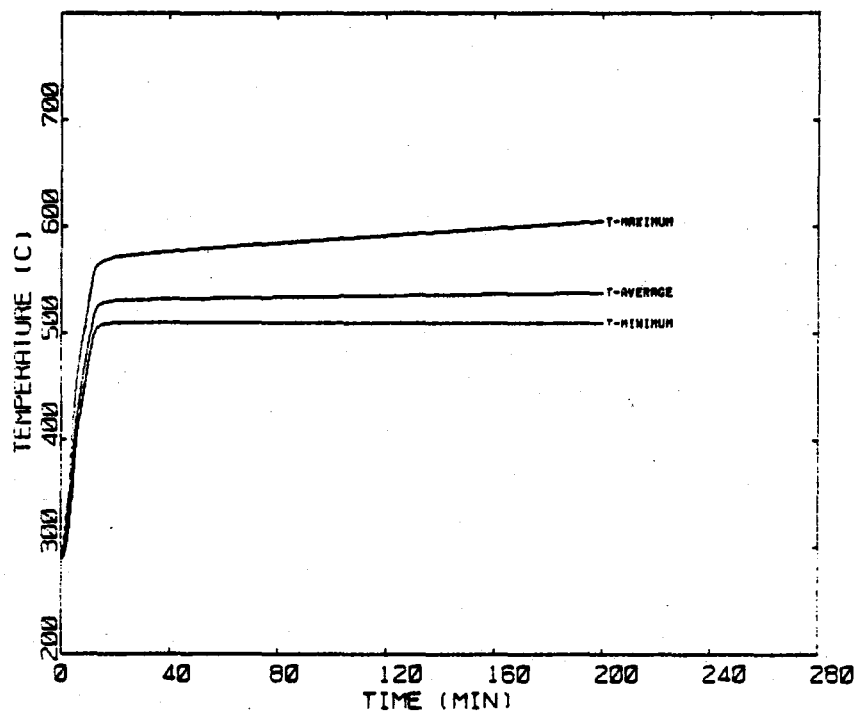


Figure N.2 Morning Hot Startup--Pass 4

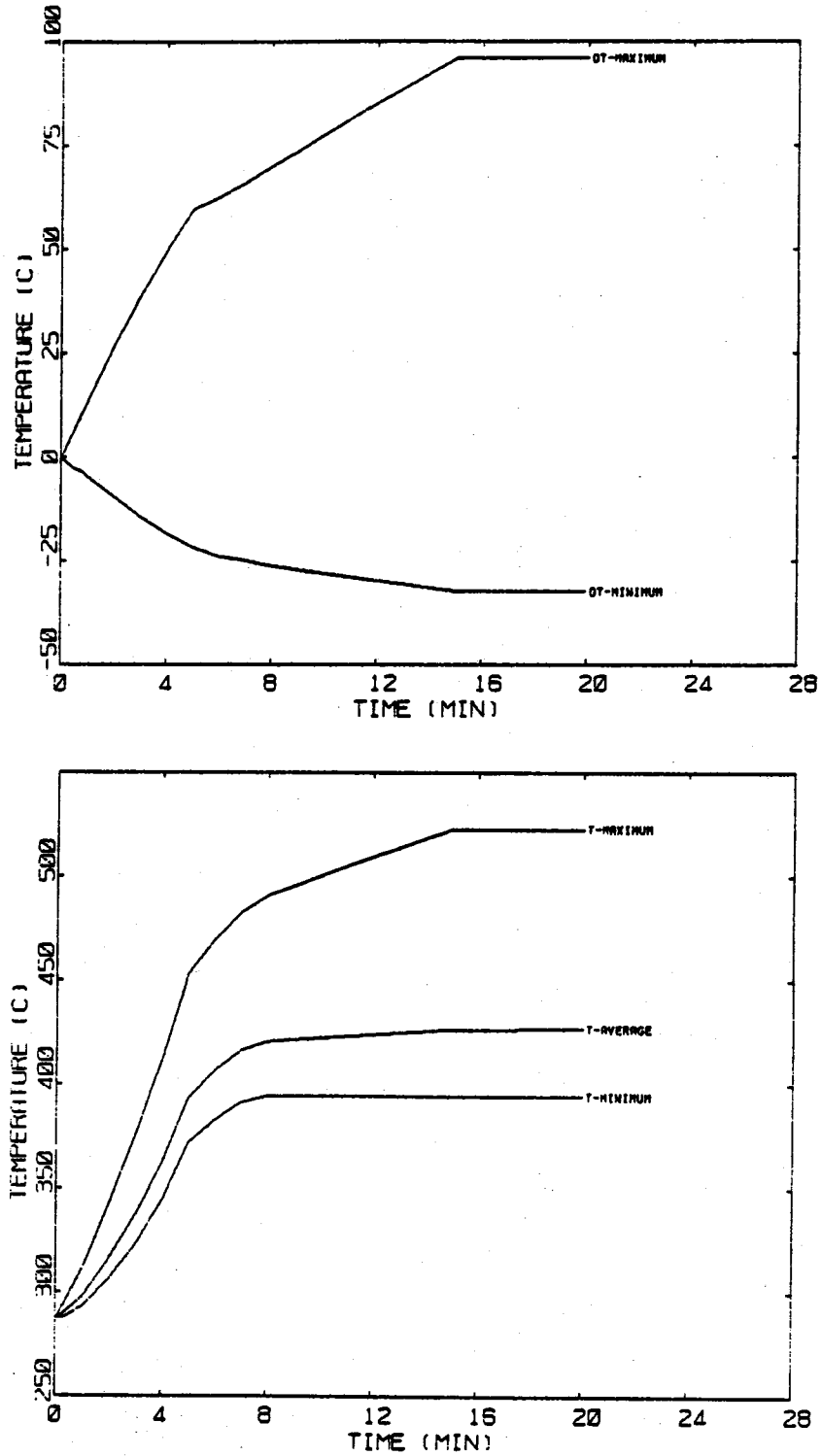
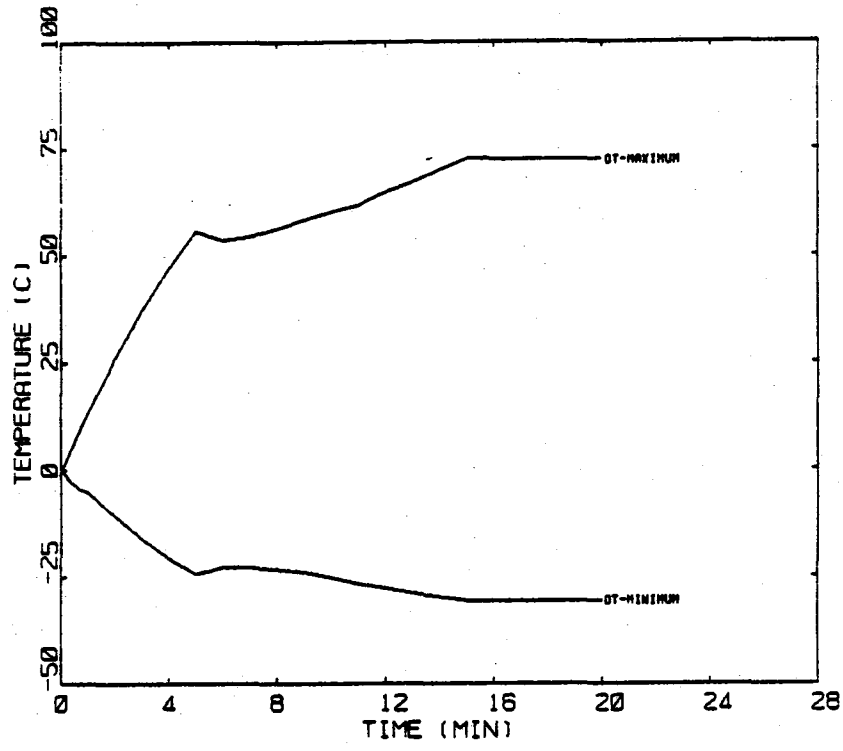


Figure N.3 Noon Hot Startup (NS17)--Pass 2



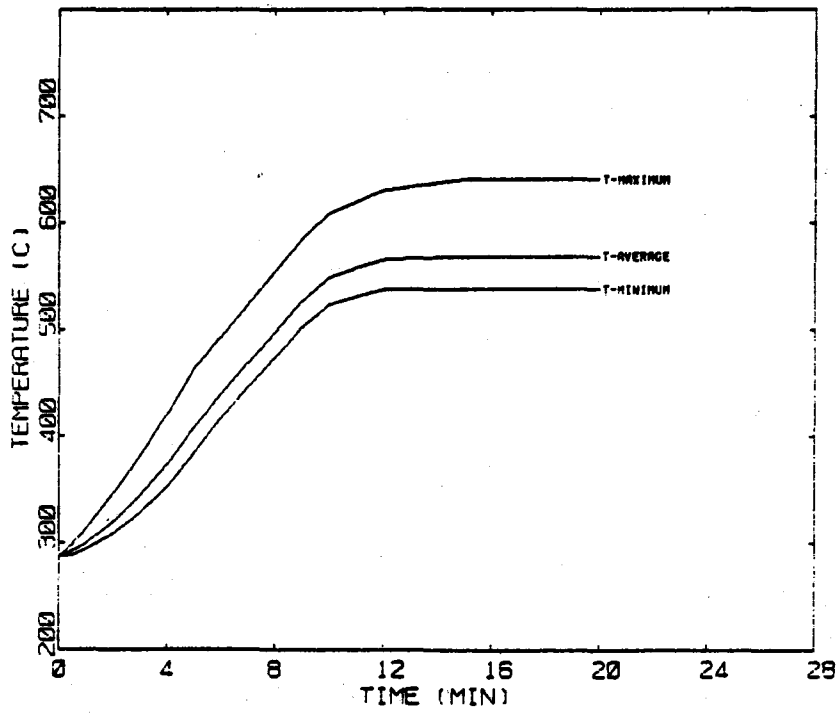
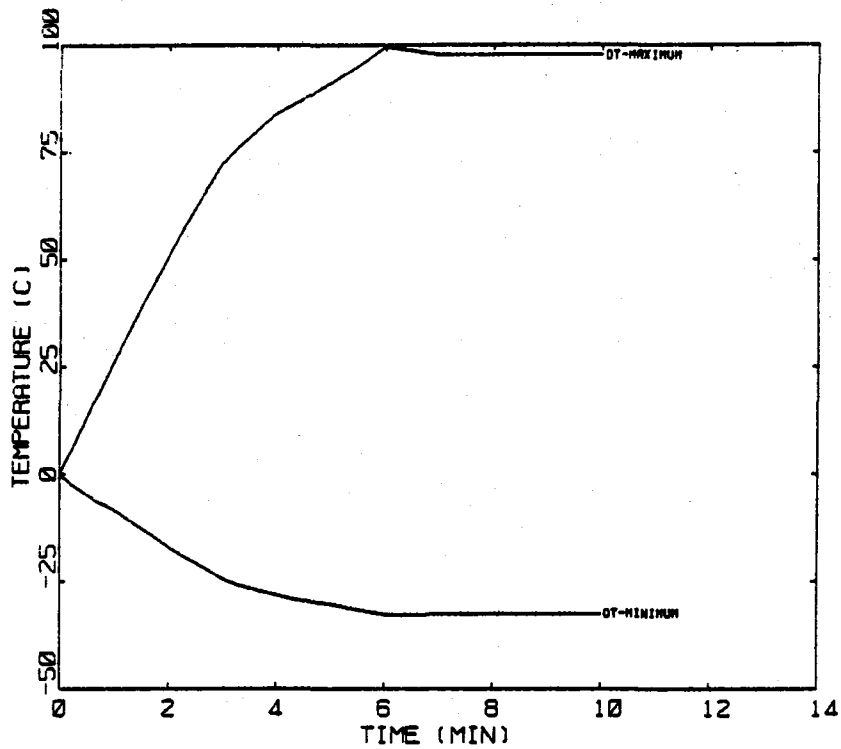


Figure N.4 Noon Hot Starup (NS12)--Pass 4



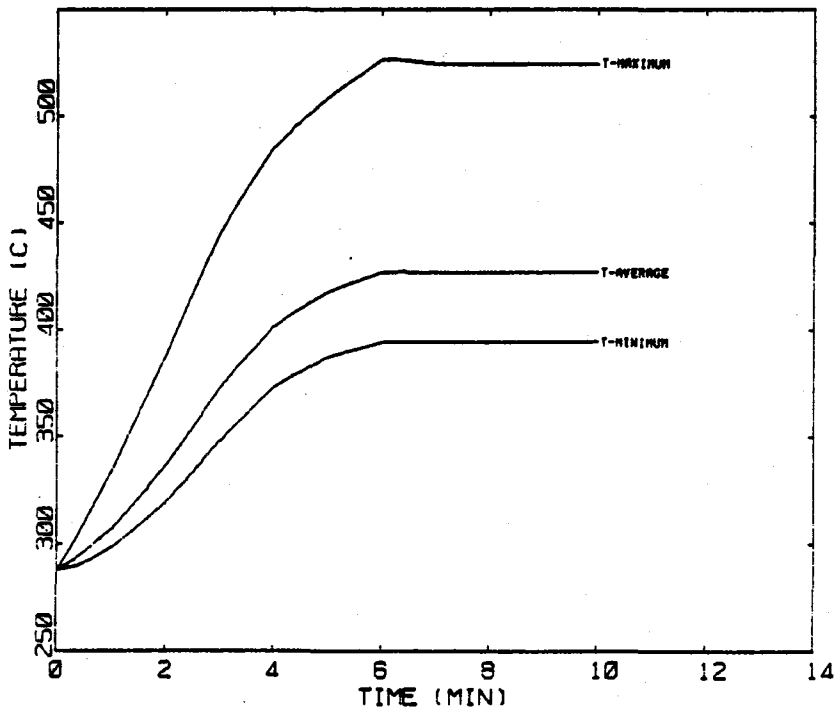
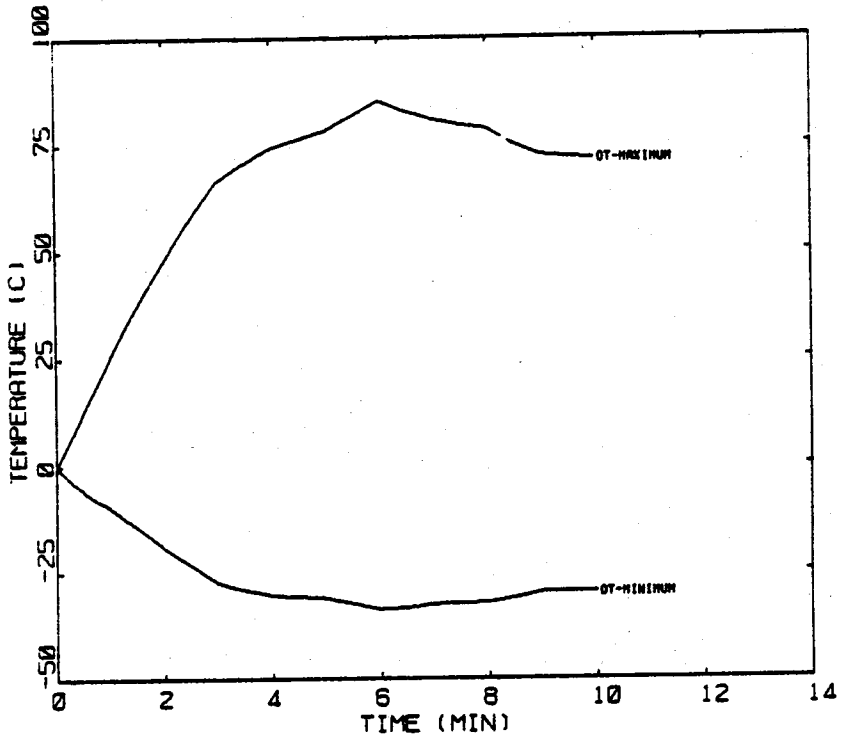


Figure N.5 Noon Hot Starup (NS12)--Pass 2



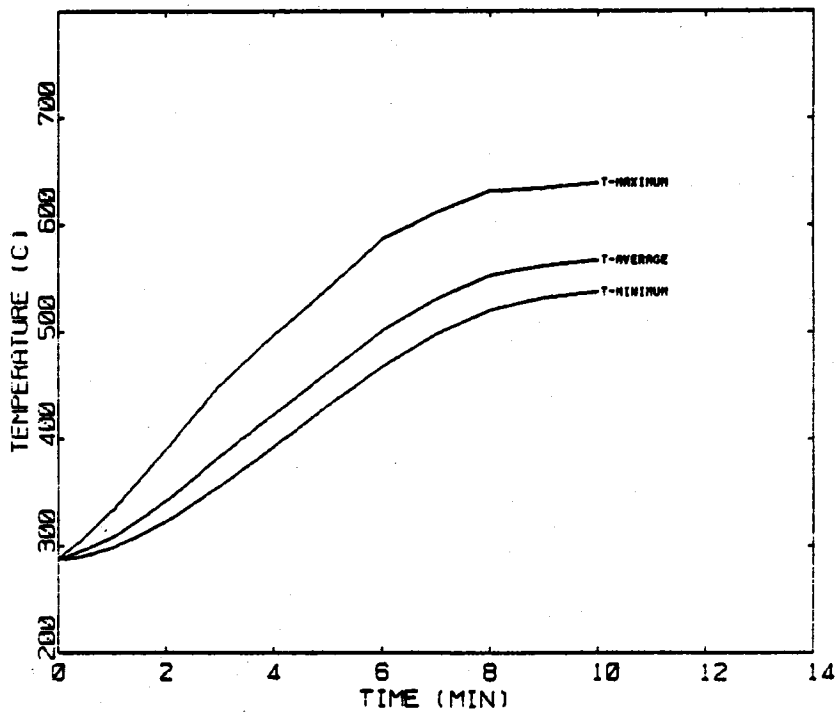
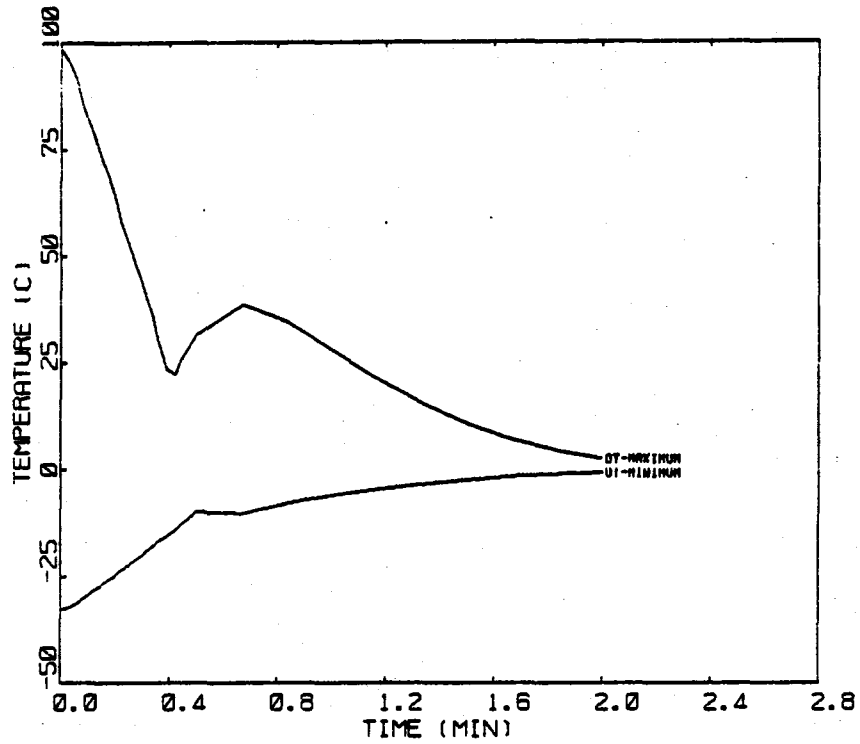


Figure N.6 Noon Hot Startup (NS12)--Pass 4



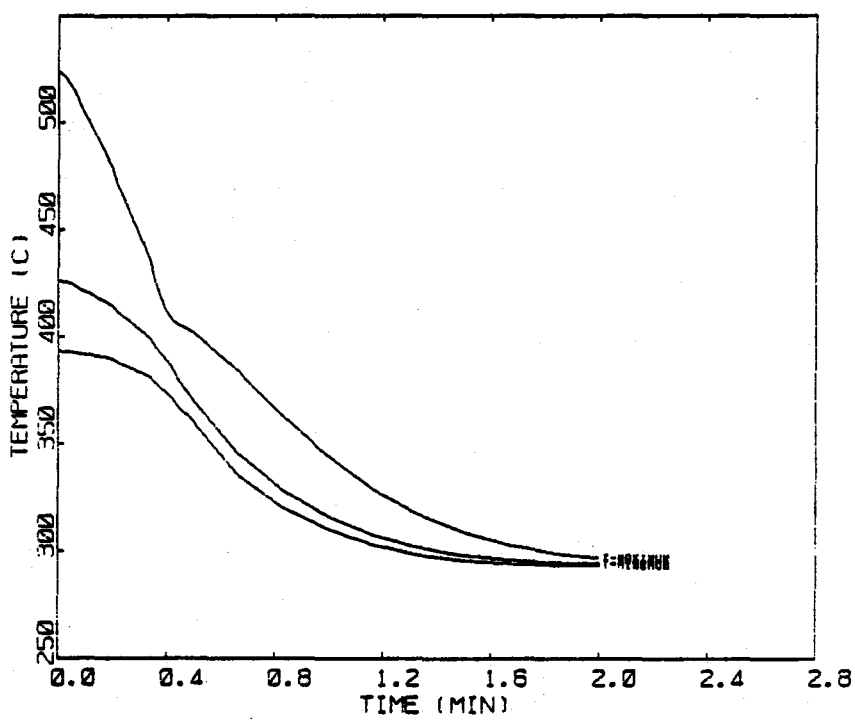
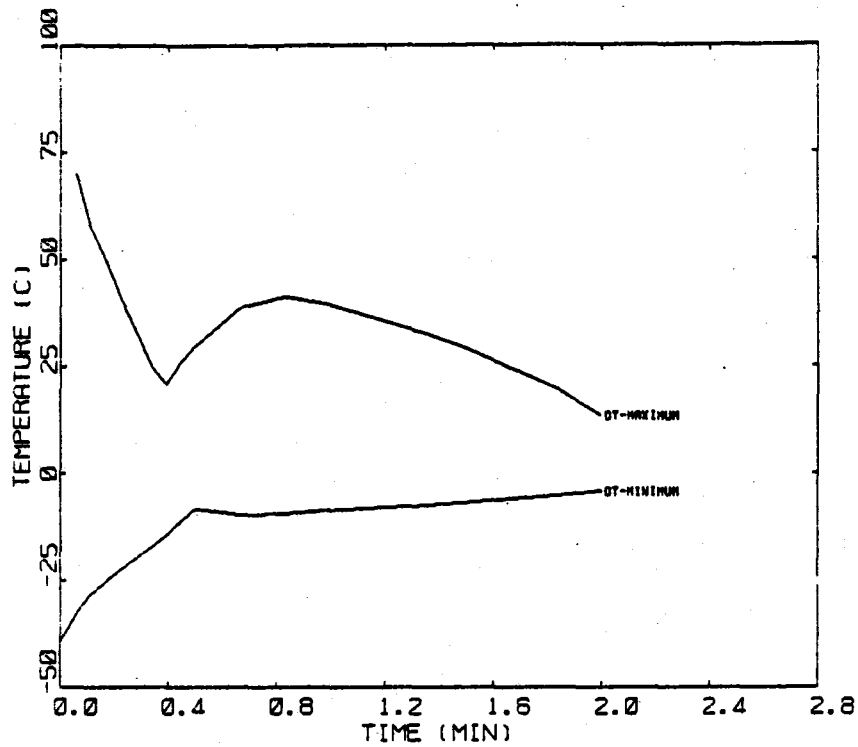


Figure N.7 Emergency Shutdown--Pass 2



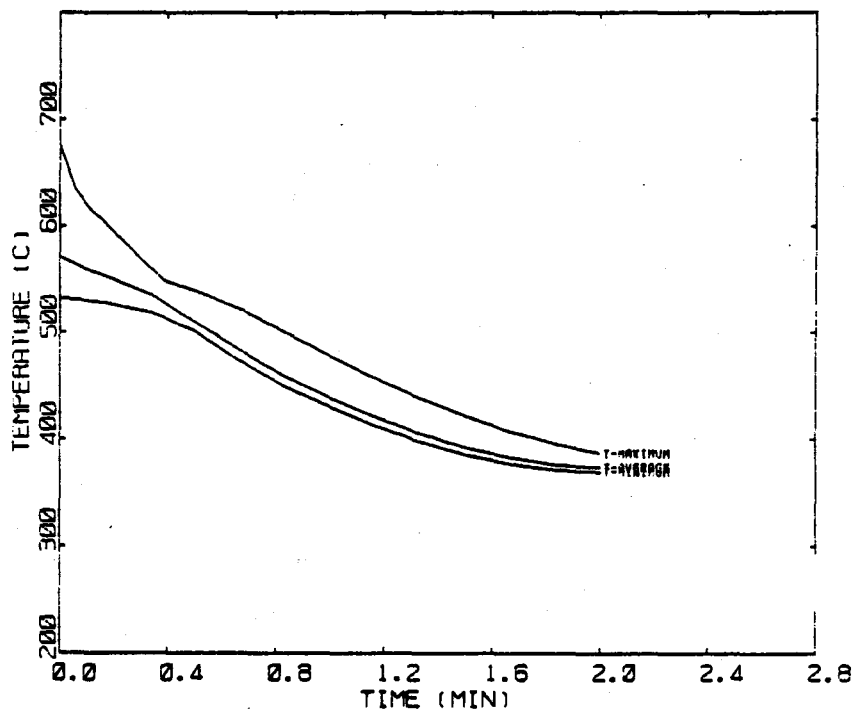


Figure N.8 Emergency Shutdown--Pass 4

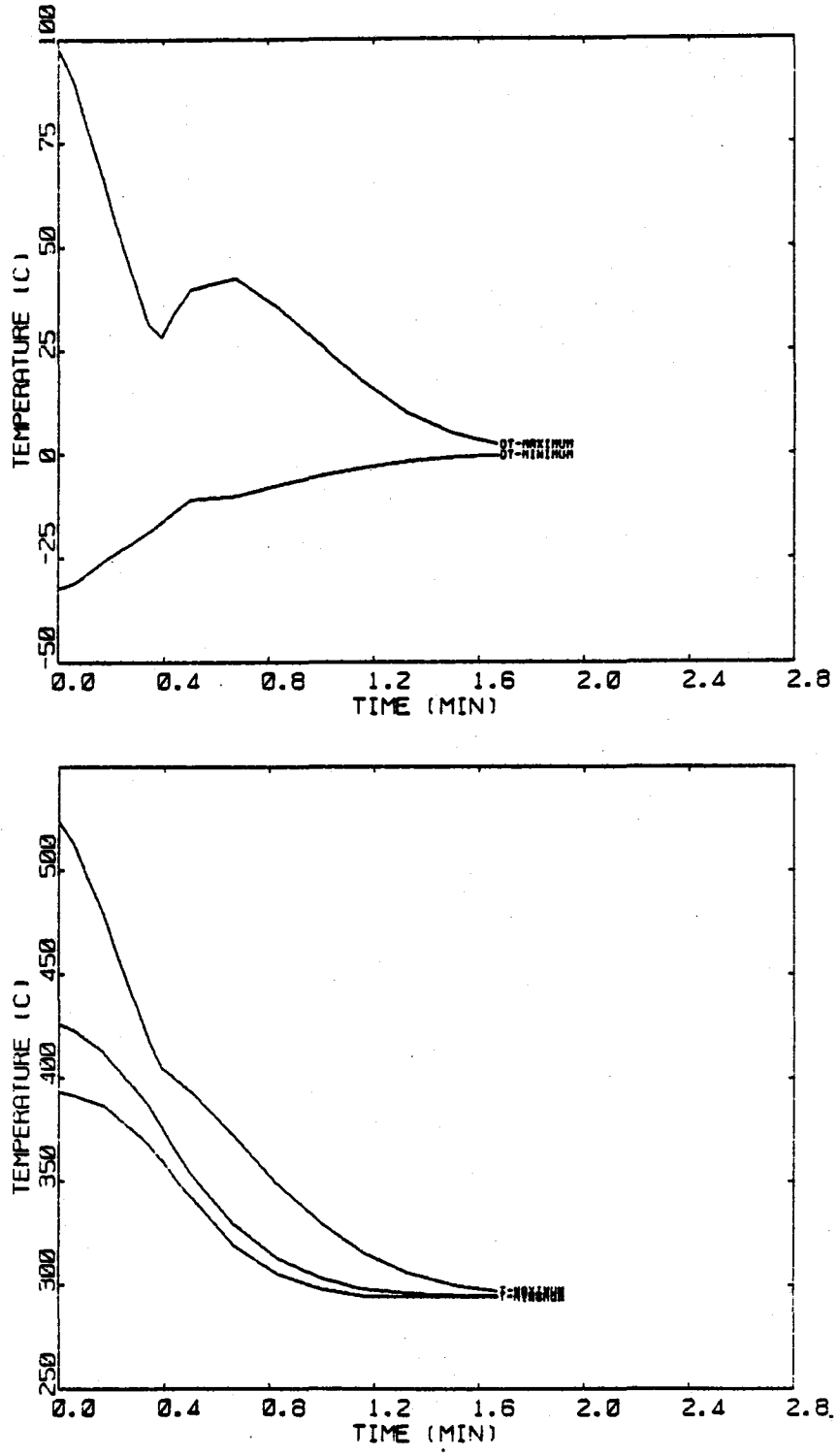
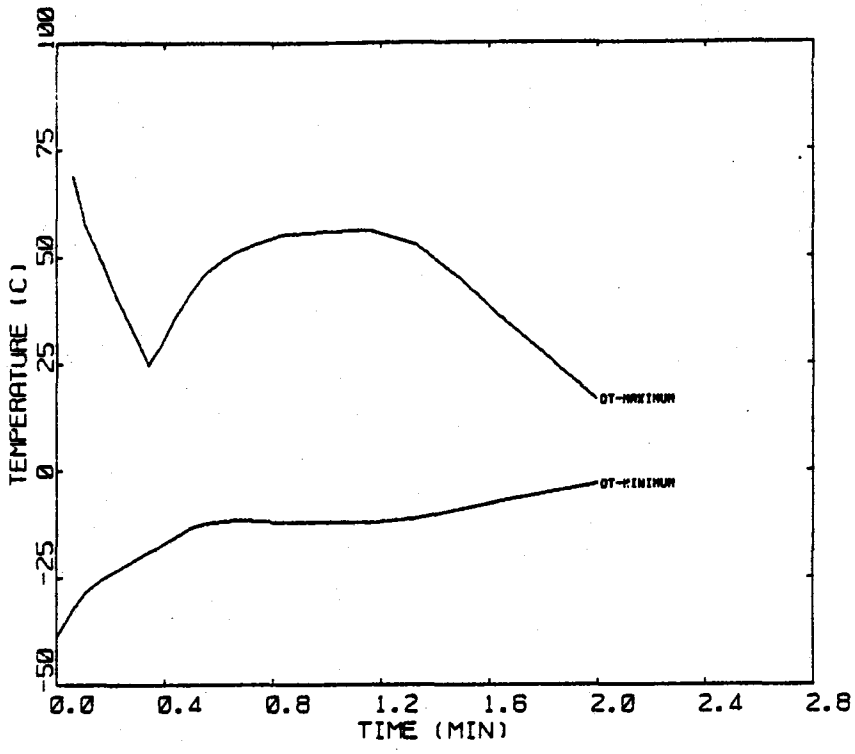


Figure N.9 Cloud Cover--Pass 2



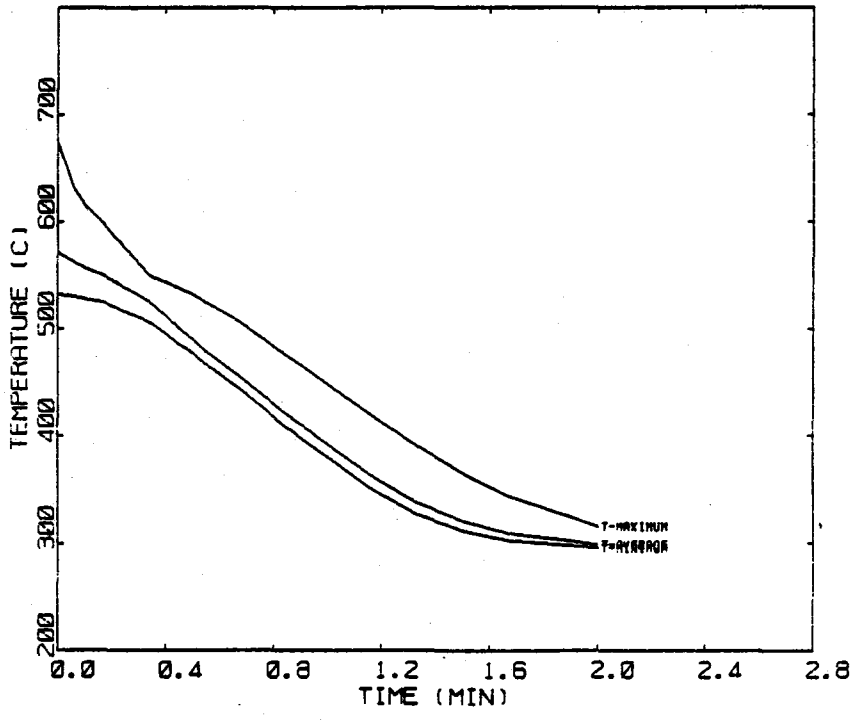


Figure N.10 Cloud Cover--Pass 4

Appendix O

ORTHOTROPIC PROPERTIES

AVERAGE TUBEWALL TEMPERATURE

The orthotropic properties were determined by performing microanalyses of the tube-spacer-weld combination using the finite-element program ANSYS. One of the inputs to the program is the nodal temperature. The nodal temperature is assumed to be the average tubewall temperature, which is obtained by integrating the tubewall temperatures over the tube cross-sectional area and then dividing by the cross-sectional area. Assuming a cosine distribution of the flux around the tube and expanding the temperatures in series:

$$T\ (r,\ \theta) = \sum_{n=o}^{\infty} T_n(r) \cdot \mathrm{Cos}\ (n\theta)$$

The average tubewall temperature is given by:

$$\bar{T} = (1/A) \int_{o}^{2\pi} \int_{r_i}^{r_o} \sum_{n=o}^{\infty} T_n(r) \cdot \mathrm{Cos}\ (n\theta) \cdot r dr d\theta$$

Since

$$\int_{o}^{2\pi} \mathrm{Cos}\ (n\theta) \cdot d\theta = 0$$

$$\bar{T} = \int T(r) r dr / \int r dr$$

and

$$T(r) = T_b - [\ln\ (r_i) - k/hr_i]Q/\pi + \ln\ (r) \cdot Q/\pi$$

the following can be shown:

$$\overline{T} = T_b + (Qr_o/\pi k)\,[k/hr_i - 0.5 + r_o^2/(r_o^2 - r_i^2) \cdot \ln(r_o/r_i)]$$

where

r_i, r_o = Inner and outer radii of the tube respectively
Q = Peak absorbed heat flux
h = Salt film conductance
T_b = Salt bulk temperature
k = Tubewall thermal conductivity.

ORTHOTROPIC PLATE PROPERTIES

We modeled the panel as an orthotropic plate (Figure 0.1). The orthotropic elastic properties of the equivalent plate were determined by microanalyses using ANSYS and the finite-element model shown in Figure 0.2. Note that the coordinate system shown in Figure 0.2 is the local coordinate system rather than the global coordinate system shown in Figure 0.1. As shown in Figure 0.1, the plate model is divided into 376 elements (432 nodes). The following notations are used in the analyses:

N_y, N_z, N_{yz} = Forces/unit length of effective panel
t_e = Effective thickness = A/(a)
A = Cross-sectional area of tube-spacer combination
(a) = Center-to-center tube spacing
$\overline{E}_y$, $\overline{E}_z$, $\overline{G}_{yz}$, $\overline{\nu}_{yz}$ = Effective elastic constants

- Effective Modulus $\overline{E}_y$: To determine $\overline{E}_y$, a force (N_y) is applied in the y direction and the displacement Δy is determined by finite element analysis.

$$\overline{E}y = N_y/\Delta_y \cdot a/D \cdot D/t_e$$

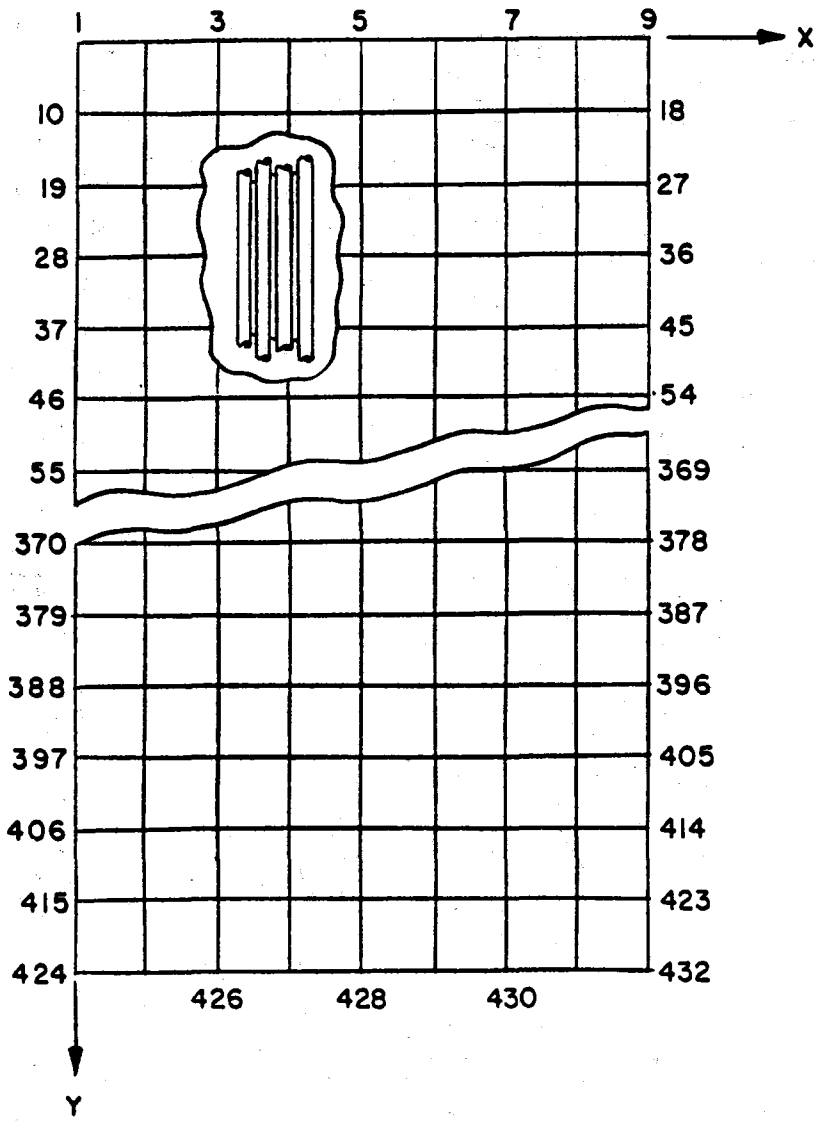


Figure 0.1 Finite Element Model of the Panel

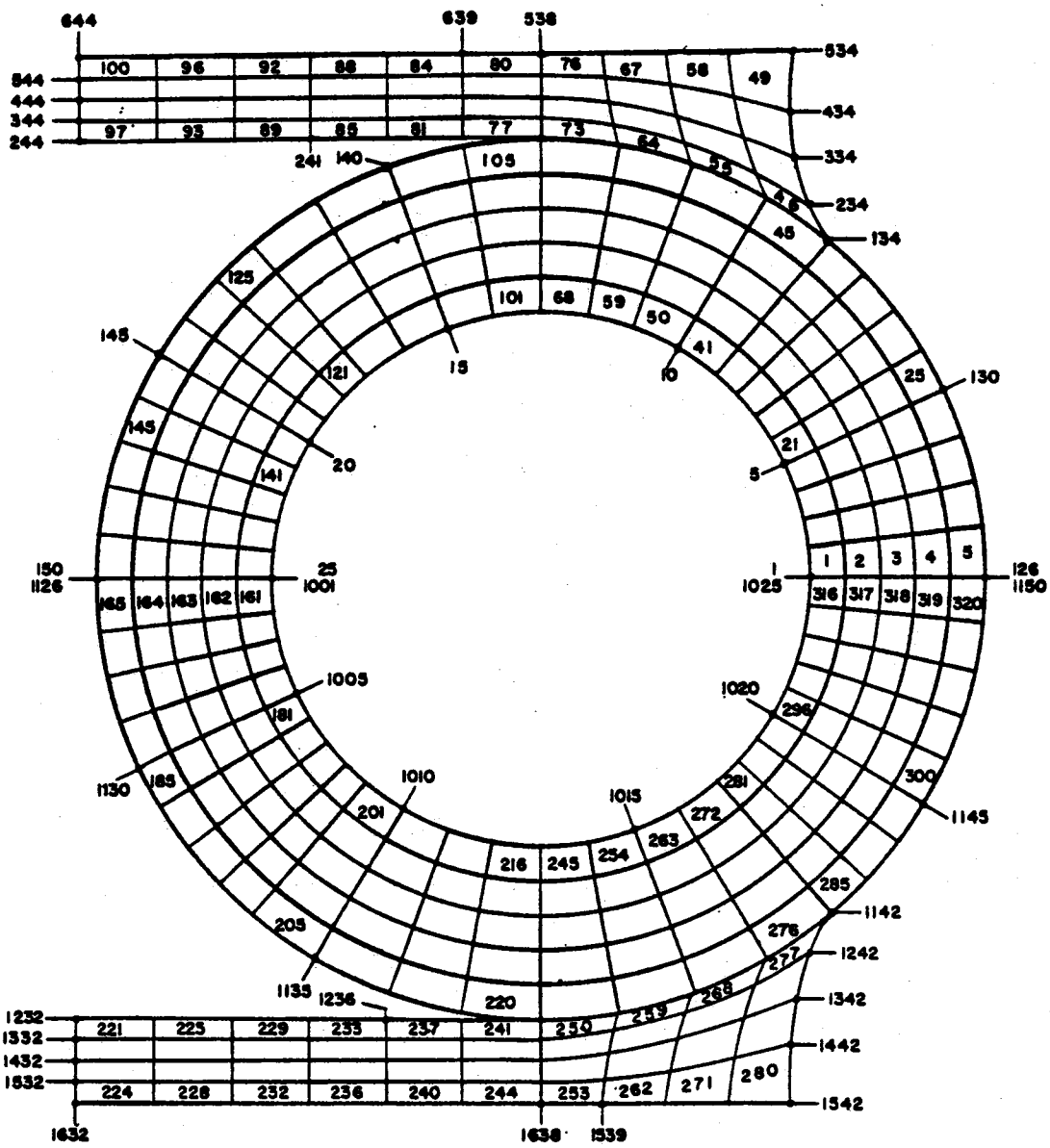


Figure 0.2 Finite Element Model of Tube With Spacer Strips

- Effective Modulus E_z: The strain ϵ_z is the same for real and effective plates; hence no microanalysis is needed to determine the effective modulus.

$$\overline{E}_z = A/aD \cdot E \cdot D/t_e$$

- Shear Modulus $\overline{G}_{yz}$: The shear modulus is $\overline{G}_{yz}$ determined by using a thermal analogy. The governing differential equation for a two-dimensional shear problem is:

$$\partial^2 w/\partial x^2 + \partial^2 w/\partial y^2 = 0$$

which is analogous to the two-dimensional heat conduction equation:

$$\partial^2 T/\partial x^2 + \partial^2 T/\partial y^2 = 0$$

Hence by solving the thermal problem shown in Figure 0.3, the equivalent shear modulus can be determined:

$$w \propto T$$

$$\tau \propto q$$

The equivalent shear modulus is given by:

$$\overline{G}_{yz} = Q/T_{max} \cdot a/D \cdot G \cdot D/t_e$$

- Microstresses: The microstresses (i.e., the stresses caused by the loading) in the three cases mentioned are as follows:

$$\sigma_x, \sigma_y, \sigma_z, \tau_{xy} = \sigma_i \quad \text{in-plane stress}$$

$$(\sigma_i) = N_y/D \cdot (\sigma_i)_{N_y/D = 1} + N_z/D \cdot (\sigma_i)_{N_z/D = 1}$$

$$(\sigma_i)_{N_z/D = 1} = \begin{Bmatrix} o \\ o \\ aD/A \\ o \end{Bmatrix}$$

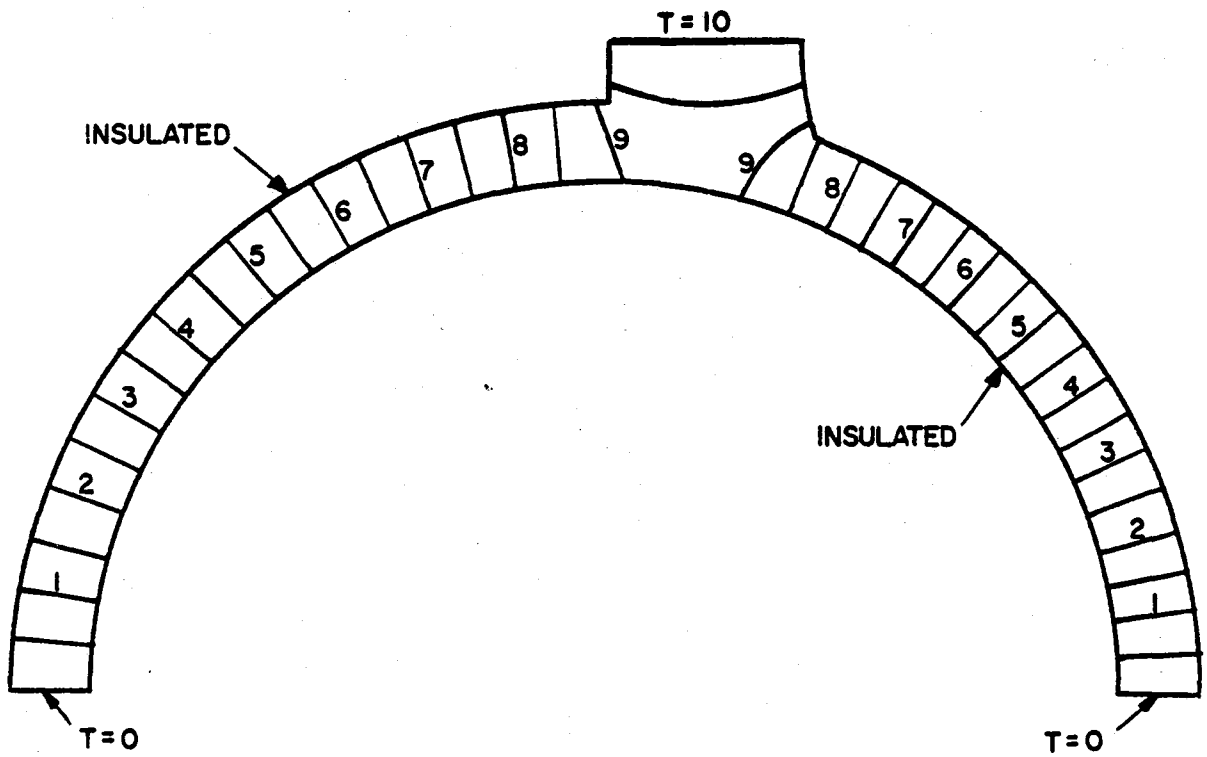


Figure 0.3 Micromodel for $\bar{G}_{yz}$

The out-of-plane shear stress is given by:

$$\tau_z = T'D/Q$$

where

T' = Temperature gradient
Q = Total heat flux on heated surface

RESULTS

Since the wing panels (L1, R1) have the highest ΔT, we chose them for analysis. The equivalent properties for a wing panel, referring to the global coordinate system in Figure 0.1 are:

$$\bar{E}_x = 248.58 \text{ MPa } (36{,}053 \text{ lb/in}^2)$$
$$\bar{E}_y = 160{,}648 \text{ MPa } (23.3 \times 10^6 \text{ lb/in}^2)$$
$$\nu_{xy} = 0.31$$
$$G_{xy} = 30{,}120 \text{ MPa } (4.37 \times 10^6 \text{ lb/in}^2)$$

Using these properties and the finite-element model shown in Figure 0.1, the stresses in the equivalent plate were obtained. The boundary conditions are free-free on all four sides. They are the stresses in the equivalent panel. The actual stresses in the real panel can be obtained by multiplying them by appropriate concentration factors developed by microstress analysis. These factors are as follows:

- If we apply a unit stress $\bar{\sigma}_x = 1$ (global coordinates), the maximum micro-stresses are:

$$\sigma_x = 19.2$$
$$\sigma_y = 22.0$$
$$\sigma_z = 11.04$$
$$\tau_{xy} = 9.52$$

- If we apply a unit stress of $\bar{\sigma}_y = 1$, the microstresses are:

$$\sigma_y = 1$$
$$\sigma_x = 0$$
$$\sigma_z = 0$$
$$\tau_{xy} = 0$$

- For a unit stress of $\bar{\tau}_{xy} = 1$, the microstresses are:

$$\sigma_x = \sigma_y = \sigma_z = 0$$
$$\tau_{xy} = 1.715$$

If these concentration factors are applied and all stresses are added, the maximum stresses anywhere in the plate for the free-free boundary conditions are:

$$\sigma_x = 1082 \text{ kPa } (157 \text{ lb/in}^2)$$
$$\sigma_y = 5212 \text{ kPa } (756 \text{ lb/in}^2)$$
$$\sigma_z = 621 \text{ kPa } (90 \text{ lb/in}^2)$$
$$\tau_{xy} = 793 \text{ kPa } (115 \text{ lb/in}^2)$$

Appendix P

OPERATING MODES AND TIMELINES

Table P.1 System Mode Condition

Component	Mode					
	Cold Drained	Hot Drained	Hot Standby	Derated Operation	Rated Operation	Overnight Standby
Block Valves						
Sump	Closed	Closed	Open	Open	Open	Open
Riser (1)	Open	Open	Open	Open	Open	Closed
Riser (2)	Open	Open	Closed	Closed	Open	Closed
Riser (3)	Open	Open	Closed	Closed	Closed	Closed
Cold Salt Tank (1)	Open	Open	Open	Open	Open	Open
Cold Salt Tank (2)	Open	Open	Closed	Open	Open	Closed
Drain Line	Open	Open	Closed	Closed	Closed	Closed
Vent Line	Open	Open	Closed	Closed	Closed	Closed
Receiver Drain	Open	Open	Closed	Closed	Closed	Closed
Receiver Vent	Open	Open	Closed	Closed	Closed	Closed
Bypass	Open	Open	Closed	Open	Closed	Closed
Hot Storage	Open	Open	Closed	Closed	Open	Closed
Cold Storage	Open	Open	Open	Open	Open	Open
Main Drain	Open	Open	Closed	Closed	Closed	Closed
Control Valves*						
Sump Level	D/Open	D/Open	A/Level	A/Level	A/Level	A/Level
Recirculation (1)	D/Open	D/Open	"Closed"	A/Flow	A/Flow	"Closed"
Recirculation (2)	D/Open	D/Open	"Closed"	Closed	A/Flow	"Closed"
Recirculation (3)	D/Open	D/Open	"Closed"	Closed	Closed	"Closed"
Cold-Salt Tank Level	D/Open	D/Open	D/Open	A/Level	A/Level	D/Open
Cold-Salt Tank Pressure	D/Closed	D/Closed	A/Press	A/Press	A/Press	A/Press
Receiver Temperature (1)	D/Open	D/Open	D/Open	A/Temp	A/Temp	D/Open
Receiver Temperature (2)	D/Open	D/Open	D/Open	A/Temp	A/Temp	D/Open
Receiver Temperature (3)	D/Open	D/Open	D/Open	A/Temp	A/Temp	D/Open
Receiver Temperature (4)	D/Open	D/Open	D/Open	A/Temp	A/Temp	D/Open
Hot-Salt Tank Pressure	D/Closed	D/Closed	A/Press	A/Press	A/Press	A/Press
Hot-Salt Tank Level	D/Open	D/Open	D/Open	A/Level	A/Level	D/Open
Pumps (1)	Off	Off	Off	On	On	Off
Pumps (2)	Off	Off	Off	Off	On	Off
Pumps (3)	Off	Off	Off	Off	Off	Off
Sump Heater	Off	On	On	On	On	On
Receiver Heaters	Off	On	On	Off	Off	On
Trace Heaters						
Sump	Off	On	On	On	On	On
Piping	Off	On	On	On	On	On
Vent/Drain	Off	On	Off	Off	Off	Off
Door	Closed	Closed	Closed	Open	Open	Closed
Heliostats						
Warmup	Stow	Stow	Stdby/Track	Rec/Track	Rec/Track	Stow
Field	Stow	Stow	Stdby/Track	Rec/Track	Rec/Track	Stow

*D = Deactivated; A = Activated

Table P.2 Sequence of Transition Events

Event	Status	Contingent Event/Comment
Cold Drained to Hot Drained		
Trace heaters (all)	On	Temperature control
Receiver heaters	On	Temperature control
Sump level control valve	Activate	Minimum sump temperature = 288°C (550°F)
Sump block valve	Open	
Sump immersion heater	On	Sump level set point = half
Sump block valve	Close	
Sump level control valve	Deactivate	
Hot Drained to Hot Standby		
Sump level control valve	Activate	Level control
Sump block valve	Open	
Riser block valves	Close	
Bypass block valve	Close	
Pump 1	On	Minimum sump salt temperature = 288°C (550°F)
		Minimum loop temperature = 288°C (550°F)
		Sump level set point = high
		Pump cooling system operational
Warmup heliostats	Standby	
Door	Open	
Warmup heliostats	Track	
Hot storage block valve	Close	
Pumps 2 and 3	On	Pump 1 operating
		Minimum receiver tube temperature = 204°C (400°F)

Table P.2 Sequence of Transition Events (Cont)

Event	Status	Contingent Event/Comment
Bypass block valve	Open	Minimum receiver tube temperature = 288°C (550°F)
Riser block valves	Open	
Main drain valve	Close	
Cold storage block valve	Close	
Riser block valves 2 and 3	Close	
Pumps 2 and 3	Off	
Recirculation valves 2 and 3	Close command	Prevent backflow through pumps
Cold surge tank block valve 1	Close	Cold surge tank level set point = half
Recirculation valve 1	Close command	Hot surge tank level set point = minimum
Pump 1	Off	Hot surge tank level set point = half
Receiver vent valves	Close	Gang operated
Receiver drain valves	Close	Gang operated
Cold surge tank block valve 2	Close	
Cold surge tank pressurizing	Activate	Set point = 34.5 kPa (5 lb/in^{2}g)
Hot surge tank pressurizing	Activate	Set point = 69 kPa (10 lb/in^{2}g)
Cold surge tank block valve 1	Open	
Drain block valve	Close	Vent and drain lines empty
Vent block valve	Close	
Cold surge tank pressurizing set point	Increase	To set point = 69 kPa (10 lb/in^{2}g)
Vent and drainline trace heaters	Off	
Warmup heliostats	Standby	

Table P.2 Sequence of Transition Events (Cont)

Event	Status	Contingent Event/Comment
Door	Close	
Bypass block valve	Close	
Cold tank block valve	Open	
Hot Standby to Derated Operation		
Recirculation valve 1	Activate	Valve will open
Pump 1	On	Minimum sump salt temperature = 288°C (550°F)
		Minimum loop temperature = 288°C (550°F)
		Sump level set point - high
		Pump cooling system operational
		Minimum receiver temperature = 288°C (550°F)
Hot-salt surge tank level control valve	Activate	Level control
Bypass block valve	Open	Loop flow established
Hot-salt surge tank pressurization set point	Increase	To set point - 103.4 kPa gage (15 lb/in²g)
Cold surge tank pressurization set point	Increase	To set point - 2410 kPa gage (350 lb/in²g)
Cold-salt surge tank level control valve	Activate	
Cold-salt surge tank block valve 2	Open	
Door	Open	Heliostats at standby verification
Heliostats	Track	
Receiver heaters	Off	
Receiver temperature control valves	Activate	Receiver outlet temperature = 427°C (800°F)

Table P.2 Sequence of Transition Events (Cont)

Event	Status	Contingent Event/Comment
Receiver temperature control valves	Activate	Receiver outlet temperature = 427°C (800°F) (Valves will close to minimum open position)
Derated to Rated Operation		
Hot storage block valve	Open	Receiver outlet temperature ≥552°C (≥1025°F)
Bypass block valve	Close	
Pump 2	On	Receiver flow = 40% maximum Receiver outlet temperature ≥566°C (≥1050°F)
Recirculation valve 2	Activate	
Riser block valve 2	Open	Receiver flow = 45% maximum
Hot Standby to Overnight Standby		
Heliostats	Stow	
Riser block valve 1	Close	
Cold-salt surge tank pressurizing set point	Decrease	To set point = 34.5 kPa (5 lb/in²g)
Receiver temperature control valves 2 and 4	Close command	Minimum receiver temperature = 316°C (600°F)
Cold-salt surge tank block valve 2	Open	
Cold-salt surge tank block valve 2	Close	Cold-salt surge tank level set point = maximum
Cold-salt surge tank pressurization set point	Increase	To set point = 69 kPa (10 lb/in²g)

Table P.2 Sequence of Transition Events (Cont)

Event	Status	Contingent Event/Comment
Receiver temperature control valves 2 and 4	Deactivate	Valves will open
Receiver heaters	On	Minimum receiver temperature = 288°C (550°F)
Overnight Standby to Hot Drained		
Vent/drain trace heaters	On	
Sump block valve	Close	
Sump level control valve	Deactivate	Valve will open
Vent block valve	Open	Vent/drain line temperature = 288°C (550°F)
Receiver vent valves	Open	
Receiver drain valves	Open	
Cold surge tank block valve 1	Closed	
Drain block valve	Open	
Cold surge tank block valve 2	Open	
Main drain block valve	Open	
Hot tank block valve 1	Open	
Cold surge tank block valve 1	Open	Receiver drained indication
Recirculation control valve 1	Deactivate	Valve will open
Bypass block valve	Open	Riser drained indication
Riser block valves	Open	
Surge tank pressurization	Deactivate	

Table P.2 Sequence of Transition Events (Cont)

Event	Status	Contingent Event/Comment
Hot Drained to Cold Drained		
Receiver heaters	Off	Riser/downcomer drained
Vent and drain trace heaters	Off	
Riser block valves 1 and 3	Close	
Bypass block valve	Close	
Pump 1	On	
Sump immersion heater	Off	
Pump 1	Off	Minimum pumping level reached
Riser block valves 1 and 3	Open	
Bypass block valve	Open	
Recirculation valves 2 and 3	Deactivate	
Sump bottom drain	Open	
Piping trace heaters	Off	
Sump trace heaters	Off	
Overnight Standby to Hot Standby		
Heliostats	Standby/ trace	Favorable weather forecast Time of day = sunrise
Riser block valve 1	Open	
Rated Operation to Derated Operation*		
Bypass block valve	Open	Receiver outlet temperature $\leq$552°C ($\leq$1025°F)
Hot tank block valve	Close	

Table P.2 Sequence of Transition Events (Cont)

Event	Status	Contingent Event/Comment
Derated Operation to Hot Standby		
Heliostats	Standby/ track	Receiver outlet temperature <427°C (<800°F) for 10 min
Door	Close	Heliostats at standby
Receiver temperature control valves	Deactivate	Valves open
Cold surge tank pressurization set point	Decrease	To set point = 69 kPa (10 lb/in²g)
Hot surge tank pressurization	Decrease	To set point = 69 kPa (10 lb/in²g)
Recirculation valve 1	Deactivate	Valve will go full open
Riser block valve	Close	Cold surge tank pressure = 69 kPa (10 lb/in²g)
Bypass block valve	Close	
Cold surge tank block valve 2	Close	
Pump 1	Off	
Cold surge tank level control valve	Deactivate	
Hot surge tank level control valve	Deactivate	
Recirculation valve 1	Closed	
Riser block valve 1	Open	

*As total flow to the receiver falls below the capacity of one pump, pump 2 will automatically cut off, riser block valve 2 will close, and recirculation control valve will be commanded closed.

Table P.3 Emergency Sequence

Equipment	Event	Comment
Block of Inlet Flow		
Heliostats	Defocus	
Door	Emergency Close	Quick (gravity) close command
Receiver Temperature Control Valves	Deactivate	Valves go full open
Cold-Salt Surge Tank Pressurization	Emergency Vent	At cold-salt surge tank level = minimum
Hot-Salt Tank Block Valve	Close	Hot-salt surge tank level control valve position = closed
Cold-Salt Surge Tank Block Valve (2)	Close	Minimum level reestablished
Surge Tank Pressurizing Set Points	Decrease	To set point = 69 kPa gage (10 lb/in²g)
Pumps	Off	
Recirculation Valves	Closed Command	
Failure Assessment		
Block of Outlet Flow		
Heliostats	Defocus	
Door	Emergency Close	Quick (gravity) close command
Receiver Temperature Control Valves	Deactivate	Valves go full open
Cold-Salt Surge Tank Pressurization	Emergency Vent	Door position = close
Recirculation Valves	Deactivate	Valves go full open
Pumps	Off	
Cold-Salt Surge Tank Block Valve (2)	Close	At cold surge tank level = maximum
Hot-Salt Tank Block Valve	Close	
Surge Tank Pressurizing Set Points	Decrease	To set point = 69 kPa gage (10 lb/in²g)
Recirculation Valves	Closed Command	
Failure Assessment		

Table P.3 Emergency Sequence (Cont)

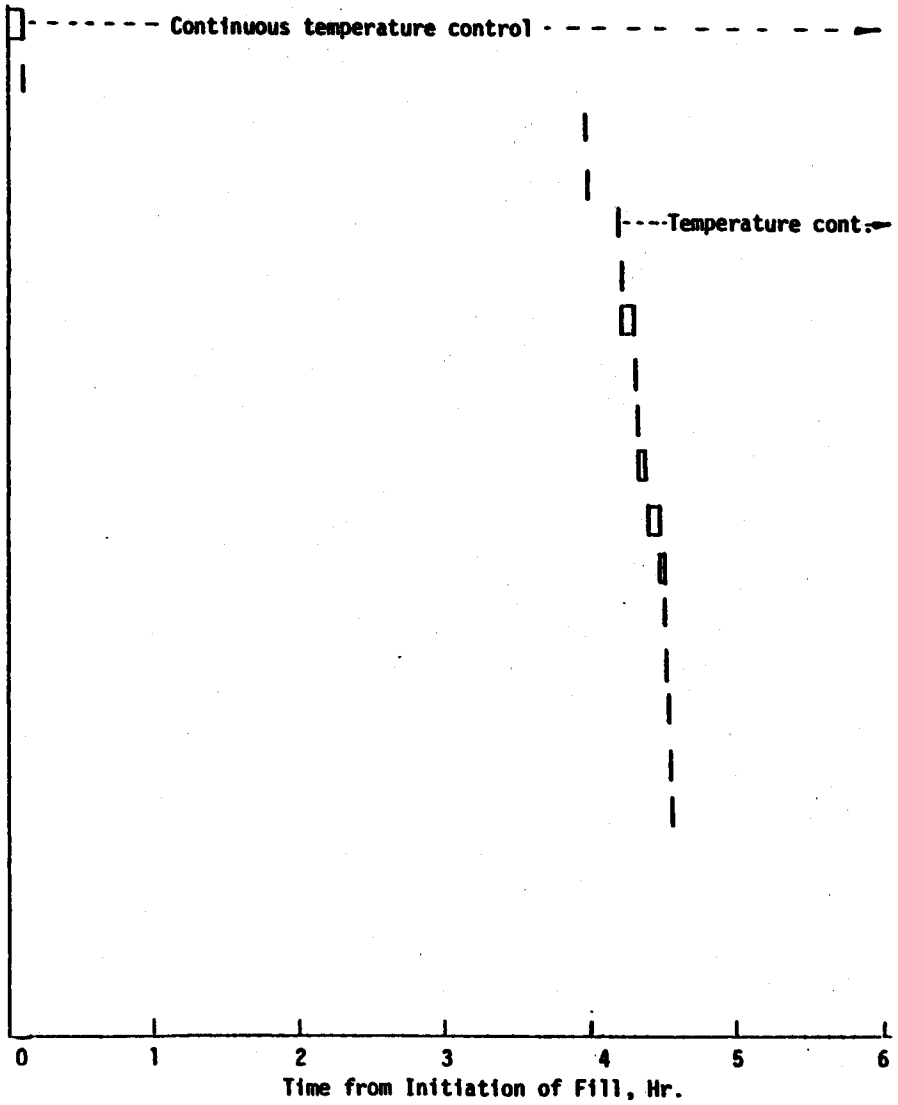
Equipment	Event	Comment
Block of Cold-Salt Tank Pressurization		
Heliostats	Defocus	
Door	Emergency Close	Quick (gravity) close command.
Receiver Temperature Control Valves	Deactivate	Valves go full open.
Cold-Salt Surge Tank Block Valve (2)	Close	
Cold-Salt Surge Tank Level Control Valve	Deactivate	Valve goes full open.
Bypass Block Valve	Open	
Hot-Salt Tank Block Valve	Close	
Recirculation Valves	Deactivate	
Riser Block Valves	Close	
Bypass Block Valve	Close	
Pumps	Off	
Hot-Salt Surge Tank Level Control Valve	Deactivate	
Recirculation Valves	Closed Command	
Riser Block Valve (1)	Open	
Failure Assessment		
Block of Power Failure		
Door	Emergency Close	Quick (gravity) close.
Diesel Generator	On	
Heliostats	Defocus	(Power from diesel generator).
Hot-Salt Tank Block Valve	Close	Hot-salt surge tank level control valve closed indication.
Cold-Salt Surge Tank Block Valve (2)	Close	

Table P.3 Emergency Sequence (Cont)

Equipment	Event	Comment
Recirculation Valves	Closed Command	
Surge Tank Level Control Valves	Deactivate	
Receiver Temperature Control Valves	Deactivate	
Night Standby to Hot Drained Transition	Initiate	Drain lines heated to 260°C (500°F) by emergency power.
Hot Drained to Cold Drained Transition	Initiate	Pump to drain sump operated by emergency power.
Failure Assessment		
Block of Piping/Tube Failure		
Heliostats	Defocus	
Door	Emergency Close	Quick (gravity) close.
Drain Line Heaters On		
Receiver Temperature Control Valves	Deactivate	Valves go full open.
Recirculation Valves	Deactivate	Valves go full open.
Pumps	Off	
Cold-Salt Surge Tank Block Valve (2)	Close	
Bypass Drain Valve (1)	Open	
Hot-Salt Tank Block Valve	Close	At hot surge tank level = minimum.
Hot-Salt Surge Tank Pressure Setting	Increase	To set point = (TBD).
Main Drain Block Valve	Open	
Bypass Drain Valve (2)	Open	
Night Standby to Hot Drained Transition	Initiate	Drain line temperature = 288°C (550°F).
Failure Assessment		

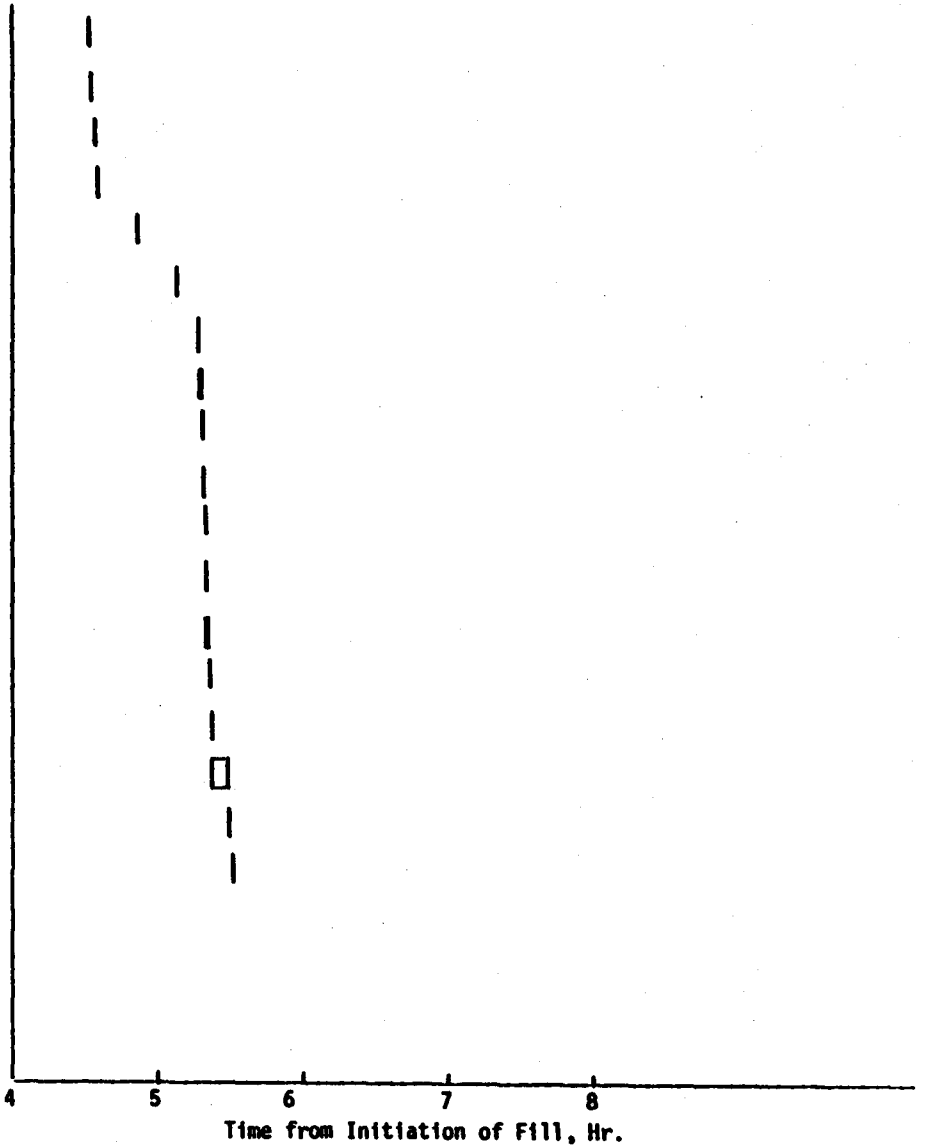
Fill

1.	Trace heaters	- on
2.	Receiver heaters	- on
3.	Sump LCV	- activate
4.	Sump BV	- open
5.	Sump immersion heater	- on
6.	Riser BV (all)	- close
7.	System temp. verification	
8.	Bypass BV	- close
9.	Pump (1)	- on
10.	Warmup heliostats to standby	
11.	Door	- open
12.	Warmup heliostats	- track
13.	Hot tank BV	- close
14.	Pumps 2 & 3	- on
15.	Bypass BV	- open
16.	Riser BV (all)	- open
17.	Main drain valve	- close



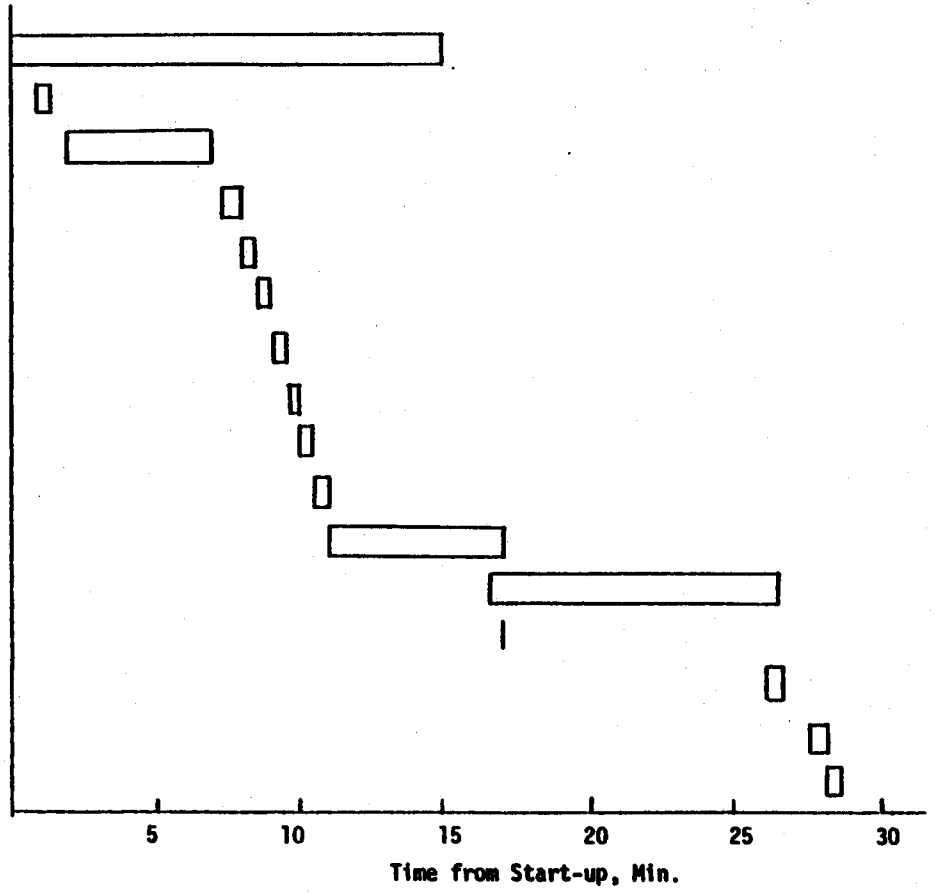
Fill (con't)

18. Cold tank BV - open
19. Riser BV 2 & 3 - close
20. Pumps 2 & 3 - off
21. Recirc. valves 2 & 3 - close
22. CST BV (1) - close
23. Recirc. valve 1 - close
24. Pump (1) - off
25. Rec. vent & drain valves - close
26. CST BV (2) - close
27. HST - pressurize
28. CST BV (1) - open
29. Vent & drain BV - close
30. CST - pressurize
31. Vent & drain trace heaters - off
32. Warmup heliostats to standby
33. Door - close
34. Bypass BV - close
35. Cold tank BV - open



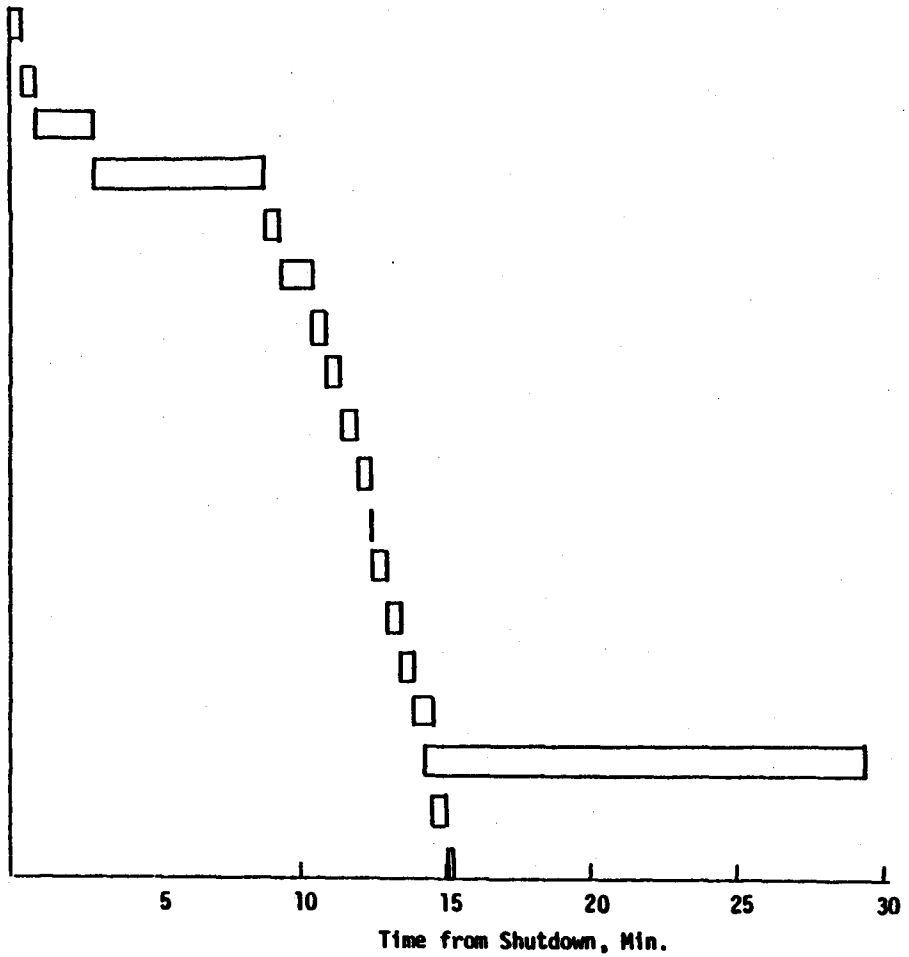
Startup

1. Heliostats to standby/track
2. Riser block valve - open
3. Verify sump, loop, rec. temps.
4. Recirc valve - activate
5. Pump (1) - on
6. HST LCV - activate
7. Bypass BV - open
8. Surge tanks pressurized (verification)
9. CST LCV - activate
10. CST BV (2) - open
11. Door - open
12. Heliostats - track
13. Receiver heaters - off
14. Receiver TCV (1-4) - activate
15. Hot storage BV - open
16. Bypass BV - close



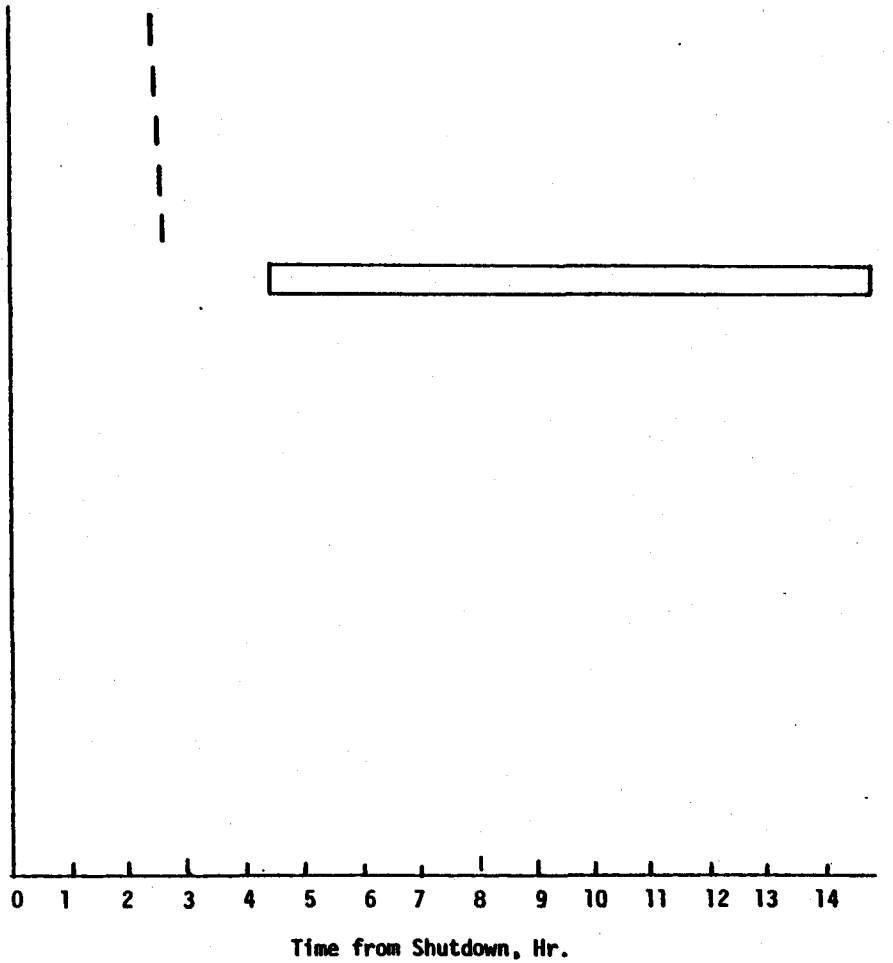
Shutdown

1. Bypass BV - open
2. Hot storage BV - close
3. Heliostats to standby track
4. Door - close
5. Receiver TCV (1-4) - deactivate
6. Surge tanks depressurize
7. Recirculation valve - open
8. Riser BV - close
9. Bypass BV - close
10. CST BV (2) - close
11. Pump - off
12. CST LCV - deactivate
13. HST LCV - deactivate
14. Recirculation valve - close
15. Riser block valve - open
16. Heliostats to stow
17. Riser BV - close
18. CST depressurize to min. setting



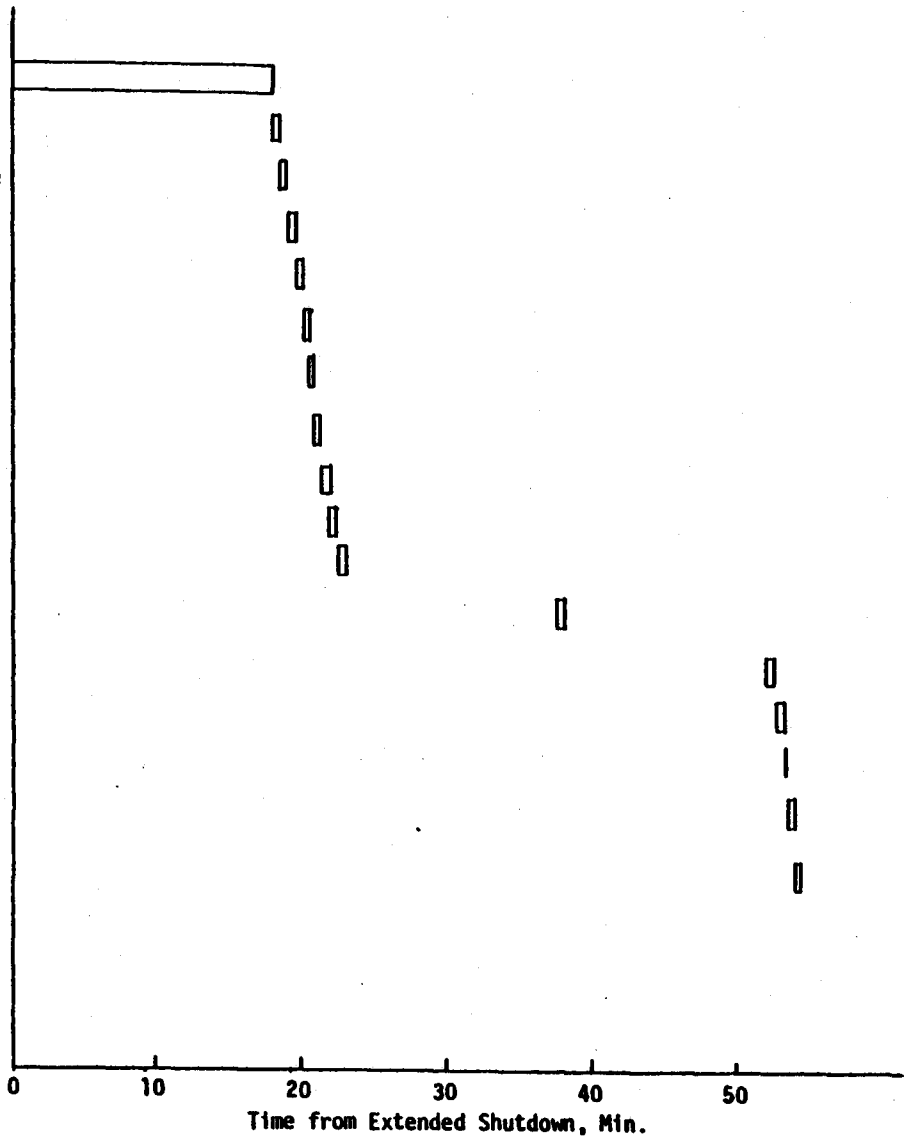
Shutdown (Con't)

19. Receiver TCV (2 & 4) - close
20. CST BV (2) - open
21. CST BV (2) - close
22. CST - repressurize
23. Receiver TCV (2 & 4) - deactivate
24. Receiver heaters - on



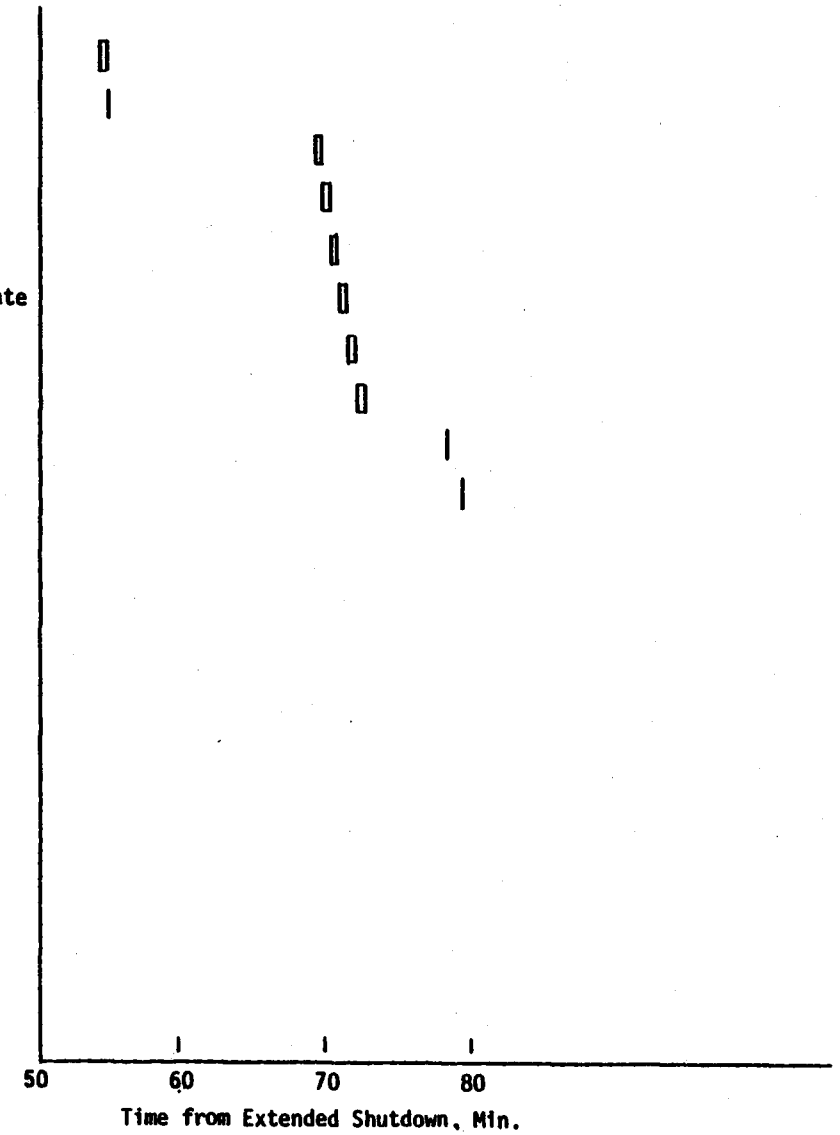
Extended Shutdown

1. Vent/drain trace heaters - on
2. Sump BV - close
3. Sump LCV - deactivate
4. Vent line BV - open
5. Receiver vent valves - open
6. Receiver drain valves - open
7. CST BV (1) - close
8. Drain line BV - open
9. CST BV (2) - open
10. Main drain BV - open
11. Hot tank BV - open
12. CST BV (1) - open
13. Bypass BV - open
14. Surge tanks - depressurize
15. Receiver heaters - off
16. Bypass BV - close
17. Recirculation valve (1) - deactivate



Extended Shutdown (con't)

18.	Pump (1)	- on
19.	Sump immersion heater	- off
20.	Pump (1)	- off
21.	Riser BV (all)	- open
22.	Bypass BV	- open
23.	Recirc. valves (2 & 3)	- deactivate
24.	Sump bottom drain	- open
25.	Check valve drain	- open
26.	Piping trace heaters	- off
27.	Sump trace heaters	- off



Appendix Q

CONTROL SYSTEM RESPONSE

PANEL TUBE MODELING EQUATIONS

Each panel tube in the model is subdivided into eight equal-length segments (nodes). The standard heat-transfer equations for each panel tube node are given in Figure Q.1. The salt convective coefficient is calculated by using the Dittus-Boelter equation for fluids heating in smooth tubes with fully developed turbulent flow.

The general form for the back-tube mass heat balance equation is:

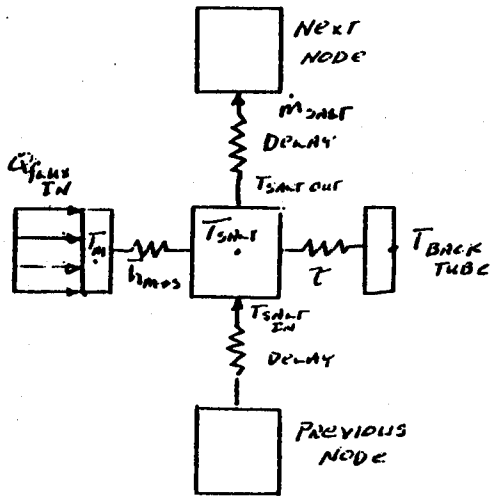
$$Q = \dot{W}\,[(T_b\,C_p)_{out} - (T_b\,C_p)_{in}] + \sum_{i=1}^{N} M\,C_p\,(T_i - T_i')/\Delta t$$

where:

- Q = Incident energy
- $\dot{W}$ = Salt mass flow rate
- T_b = Salt bulk temperature
- C_p = Specific heat
- N = Number of panel tube nodes
- M = Mass of the panel tube node
- T_i = Back tubewall temperature
- T_i' = Back tubewall temperature at the last sample time
- Δt = Sample time

SURGE TANK/ACCUMULATORS MODELING EQUATIONS

Each surge tank/accumulator consists of a tank with air vent and supply valves. Approximately 50 percent of the tank is filled with molten salt; the rest is compressed air. The surge tank model illustrated in Figure Q.2 accommodate the



MODEL NODE

Tube Wall:

$$M_{ass_{Tube}}\, C_{metal} \frac{dT_m}{dt} = q_{flux}\, f_{Rad}\, A_{Rad_{Tube\ OD}} - \bar{h}_{m\to s}\, A_{Lin_{Tube\ ID}} (T_m - T_s)$$

$$\frac{dT_m}{dt} = \frac{q_f\, f_R\, A_{OD} - \bar{h}_{m\to s}\, A_{ID}\, (T_m - T_s)}{M_m\, C_m}$$

$$T_m = T_{m_{I.C.}} + \int_0^t \frac{dT_m}{dt}\, dt$$

SALT:

$$M_{ass_{SALT}}\, C_{p_{SALT}} \frac{dT_s}{dt} = \bar{h}_{m\to s}\, A_{ID}\, (T_m - T_s) + \dot{m}_{SALT}\, C_{p_s} (T_{IN} - T_{OUT})$$

$$\frac{dT_s}{dt} = \frac{\bar{h}_{m\to s}\, A_{ID}\, (T_m - T_s) + \dot{m}_s\, C_{p_s}\, (T_{IN} - T_{OUT})}{M_s\, C_{p_s}}$$

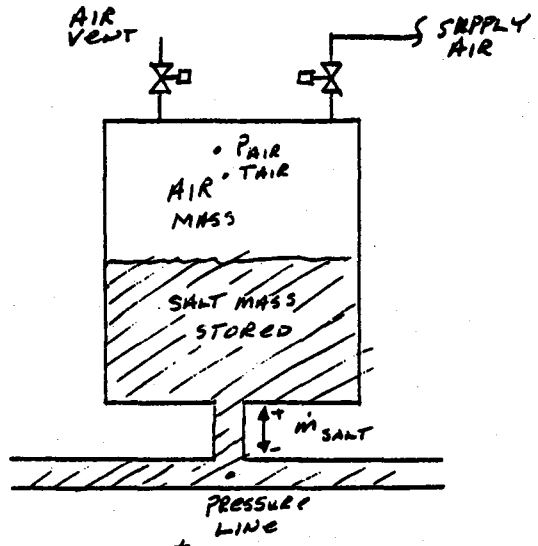
$$T_s = T_{s_{I.C.}} + \int_0^t \frac{dT_s}{dt}\, dt$$

Back Tube Temperature Sensors:

$$T_{BACK\ TUBE} = T_s \left(\frac{1}{s+\tau} \right)$$

where τ = DELAY BETWEEN SALT & BACK OF TUBE PLUS THE THERMOCOUPLE DELAY

Figure Q.1 Panel Tube Modeling Equations



$$M_{AIR_2} = M_{AIR_1} + \int_0^t \frac{\dot{m}_{AIR\,in}}{dt}\,dt - \int_0^t \frac{\dot{m}_{AIR\,out}}{dt}\,dt$$

$$M_{SALT_2} = M_{SALT_1} + \int_0^t \frac{\dot{m}_{SALT}}{dt}\,dt$$

$$V_{SALT_2} = M_{SALT_2} / \rho_{SALT}$$

$$V_{AIR_2} = V_{TANK} - V_{SALT_2}$$

$$P_{AIR_2} = P_{AIR_1} \left(\frac{V_{AIR_1}}{V_{AIR_2}}\right)^{k_{AIR}}$$

$$T_{AIR_2} = T_{AIR_1} \left(\frac{P_{AIR_2}}{P_{AIR_1}}\right)^{\left(\frac{k_{AIR}-1}{k_{AIR}}\right)}$$

$$\dot{m}_{SALT} = C_{V_{LINE}} \sqrt{(P_{AIR_2} - P_{LINE})\,\rho_{SALT}}$$

Figure Q.2 Surge Tank/Accumulator Modeling Equations

compression of the air and the mass momentum of the salt. The standard pressure, temperature, and mass equations are also shown in Figure Q.3.

SYSTEM RESPONSE WITH SIMULATED ANALOG CONTROLLER

Insolation and flux levels were set at the design point. The total model was allowed to come within ±0.14°C (±0.25°F) of the 566°C (1050°F) set point. At 5 seconds, the model was subjected to a cloud that reduced the insolation by 10 percent. The time history of the salt outlet temperature of Pass 5 of the receiver is shown in Figure Q.3.

The temperatures in the figure are the outlet temperatures for the two parallel panels in the final pass. For this analysis the feed-forward information about flux reduction was derived from back tubewall temperature data. Although these results offered some encouragement, we decided to upgrade the controller model before further tuning of the controller gains.

PRELIMINARY SYSTEM RESPONSE WITH BECKMAN CONTROLLER

After the controller was upgraded, runs were made with the new controller model and back tubewall temperature feed-forward information. Preliminary results from these runs are shown in Figures Q.4 and Q.5 for 10- and 50-percent clouds. These figures show a -2/+1°C (-4/+2°F) outlet temperature variation for the 10-percent cloud and a -14/+8°C (-25/+15°F) outlet temperature variation for a 50-percent cloud.

Next, the back tube, mass heat-balance equations used to estimate the amount of flux reaching the receiver were replaced with flux meters to determine the

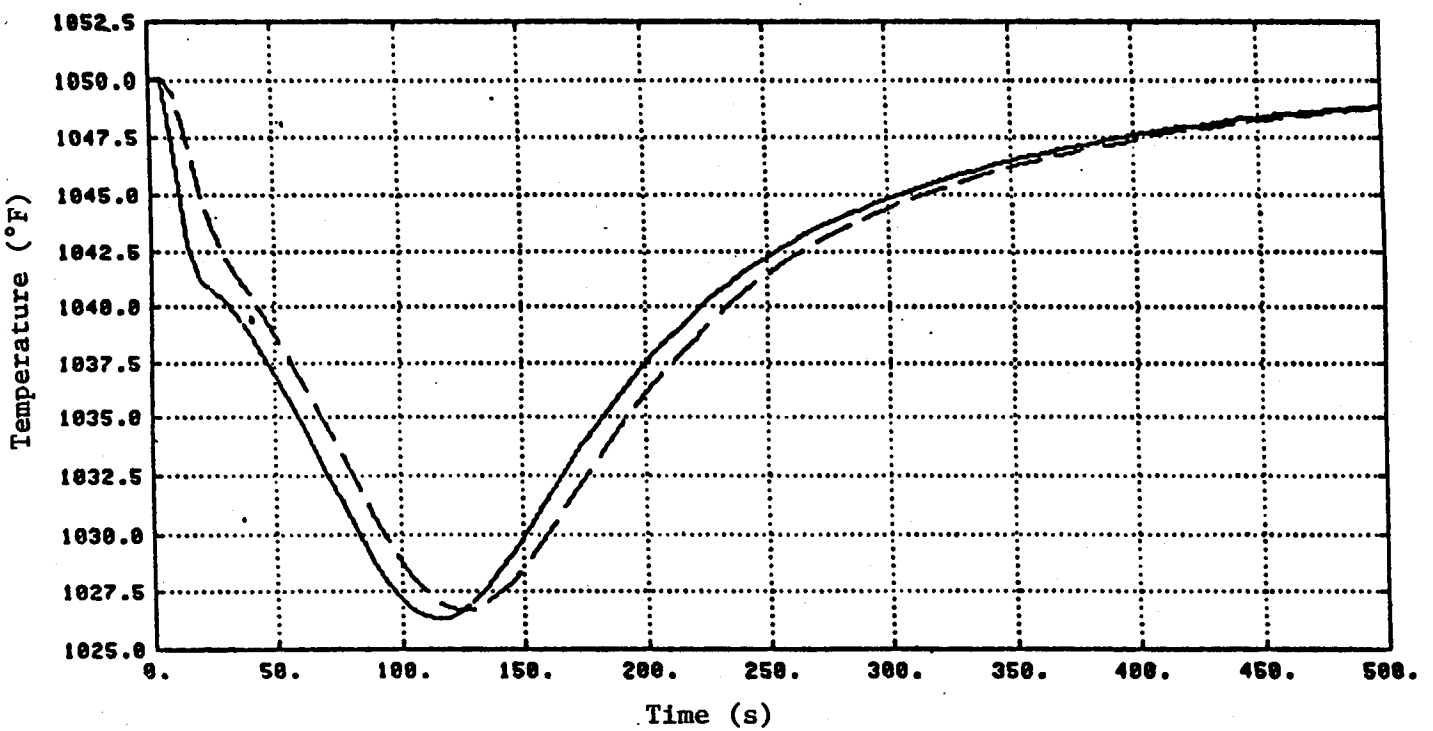


Figure Q.3 Salt Outlet Temperature in Panels 9 and 10 for 10-Percent Cloud Cover--Back Tubewall Temperature Control

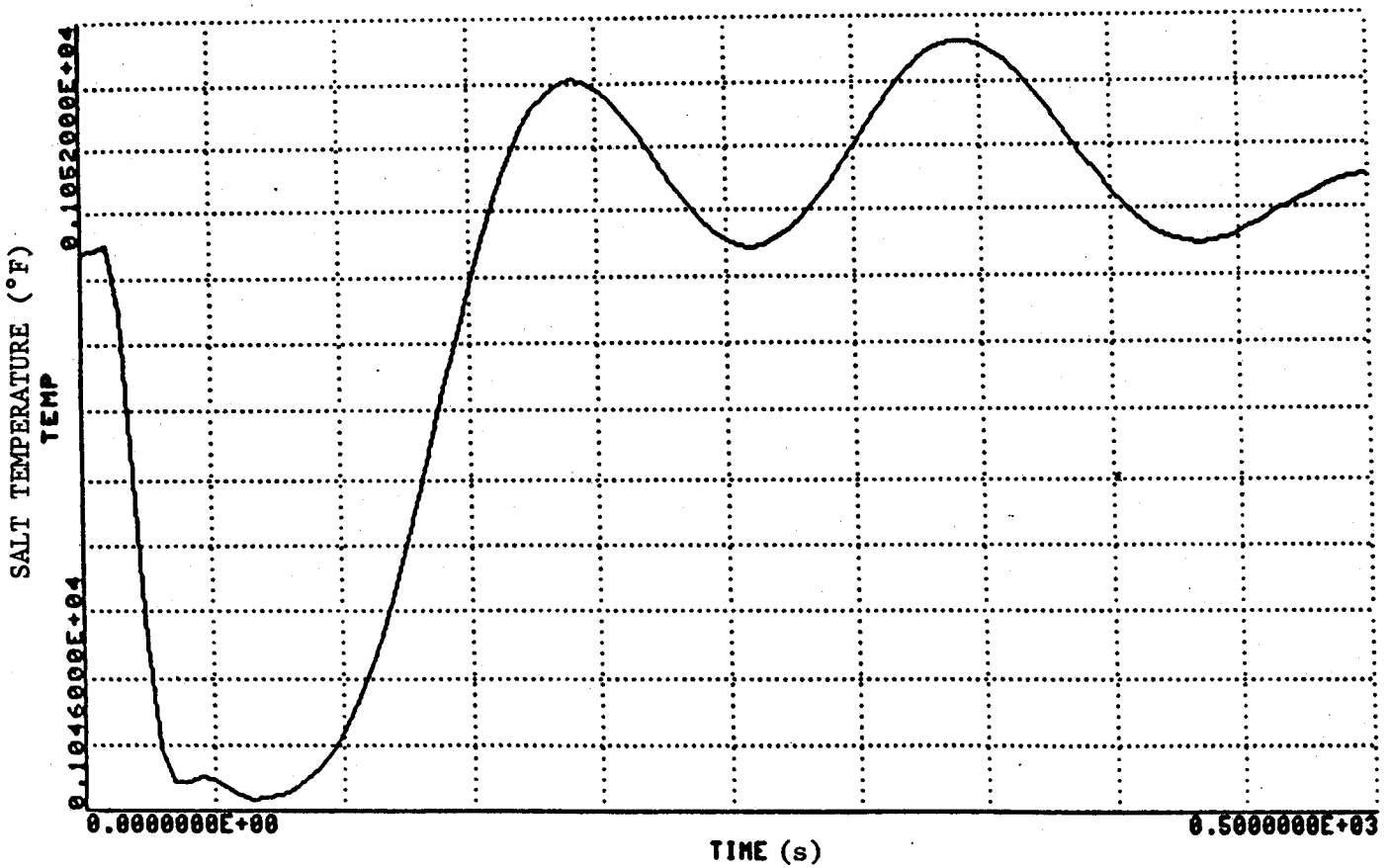


Figure Q.4 Receiver Outlet Temperature for 10-Percent Cloud Cover--
Back Tubewall Temperature Control

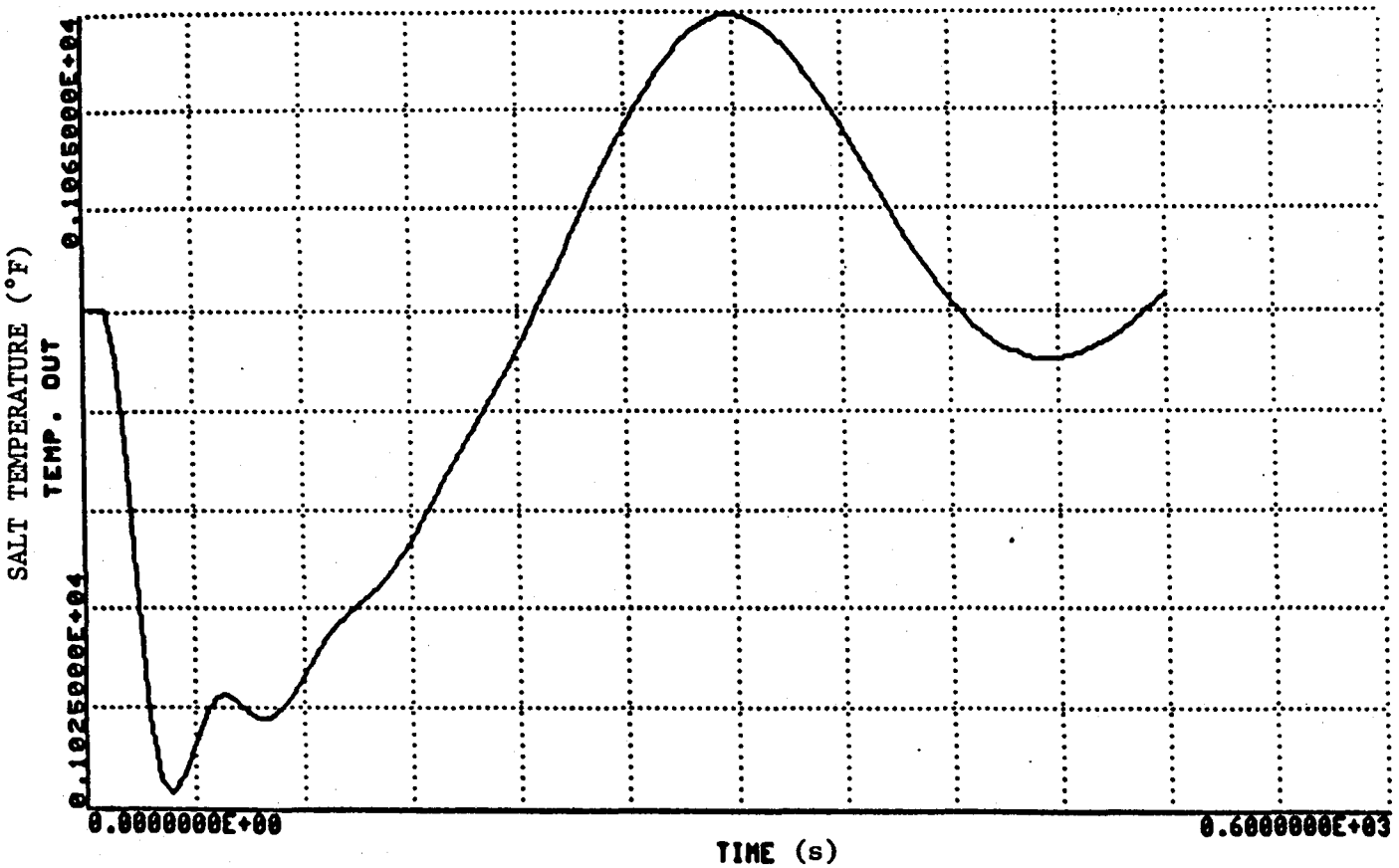


Figure Q.5 Receiver Outlet Temperature for 50-Percent Cloud Cover--
Back Tubewall Temperature Control

effect they would have on system response. The flux meters were modeled as perfect, instantaneous measures of flux, and four of them were placed along the length of each panel. Based on the results of this analysis, discussed later, far fewer than 80 flux meters can be used without significantly affecting performance.

Figures Q.6 and Q.7 present preliminary control response for a 10- and 50-percent cloud. From a comparison of these data with the data in Figures Q.4 and Q.5, it is apparent that flux meters slightly improve system response.

REVISED SYSTEM RESPONSE WITH BECKMAN CONTROLLER

The final control system analyses were performed with a Beckman controller model and a 50-percent flux reduction cloud sequentially shading the field at a rate of 13.4 m/s (30 mi/h). Figures Q.8 through Q.11 present data for control system operation with back tubewall temperatures. Similar data are presented for the same cloud with flux gage feed-forward information in Figures Q.12 through Q.15.

Figures Q.8 and Q.12 present calculated or measured flux, salt flow and outlet temperature for Outlet Panel 9, and total receiver outlet temperature. Figures Q.9 and Q.13 showing IST and OST level variations, illustrate the fluctuations in flow to and from the surge tanks during rapid transients. These fluctuations are caused by the high-frequency response characteristics of the receiver temperature control valves contrasted with the lower frequency response of the level control valves. Figures Q.10 and Q.14 show the flow rate differences between the riser and downcomer during this transient. Finally, Figures Q.11 and Q.15 show the salt flow rates for each of the four outlet panels.

The different starting points for Panels 10 and 19 and Panels 9 and 20 reflect the variation in flow rate because of the slight variation in incoming energy between the two sets of outlet panel passes.

The results indicate that 50-percent step changes in power level will produce transient temperature variations, of approximately +10/-15°C (+18/-27°F) damping down to ±3°C (±5.4°F) in approximately 150 seconds. The flux gage data showed a slight advantage [≈3°C (≈5.4°F) less undershoot in temperature]. Both systems appear promising based on the simulation results. Actual test data will be essential to validate the simulation models for the key physical processes and the simulation results.

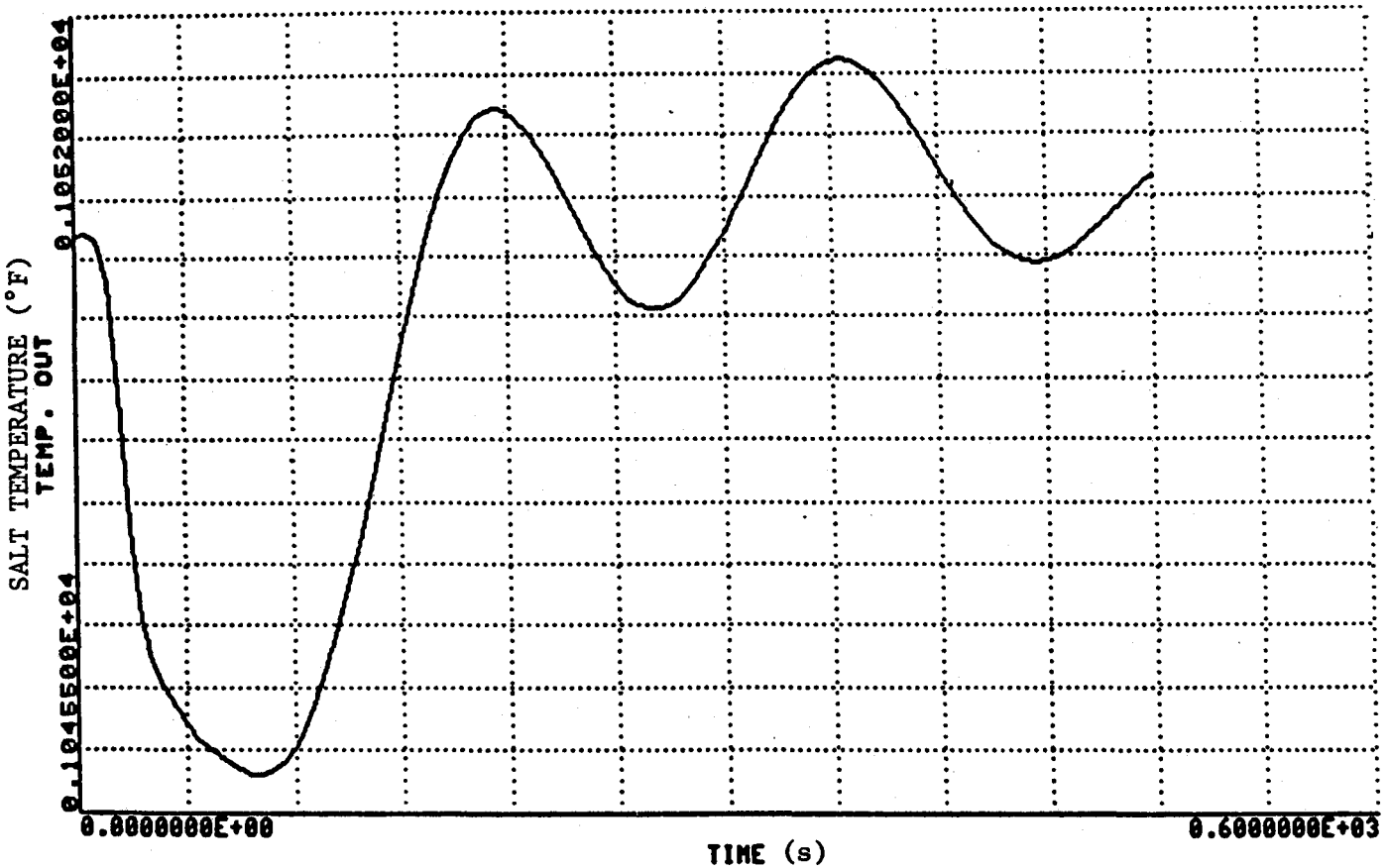


Figure Q.6 Receiver Outlet Temperature for 10-Percent Cloud Cover--
Flux Meters Control

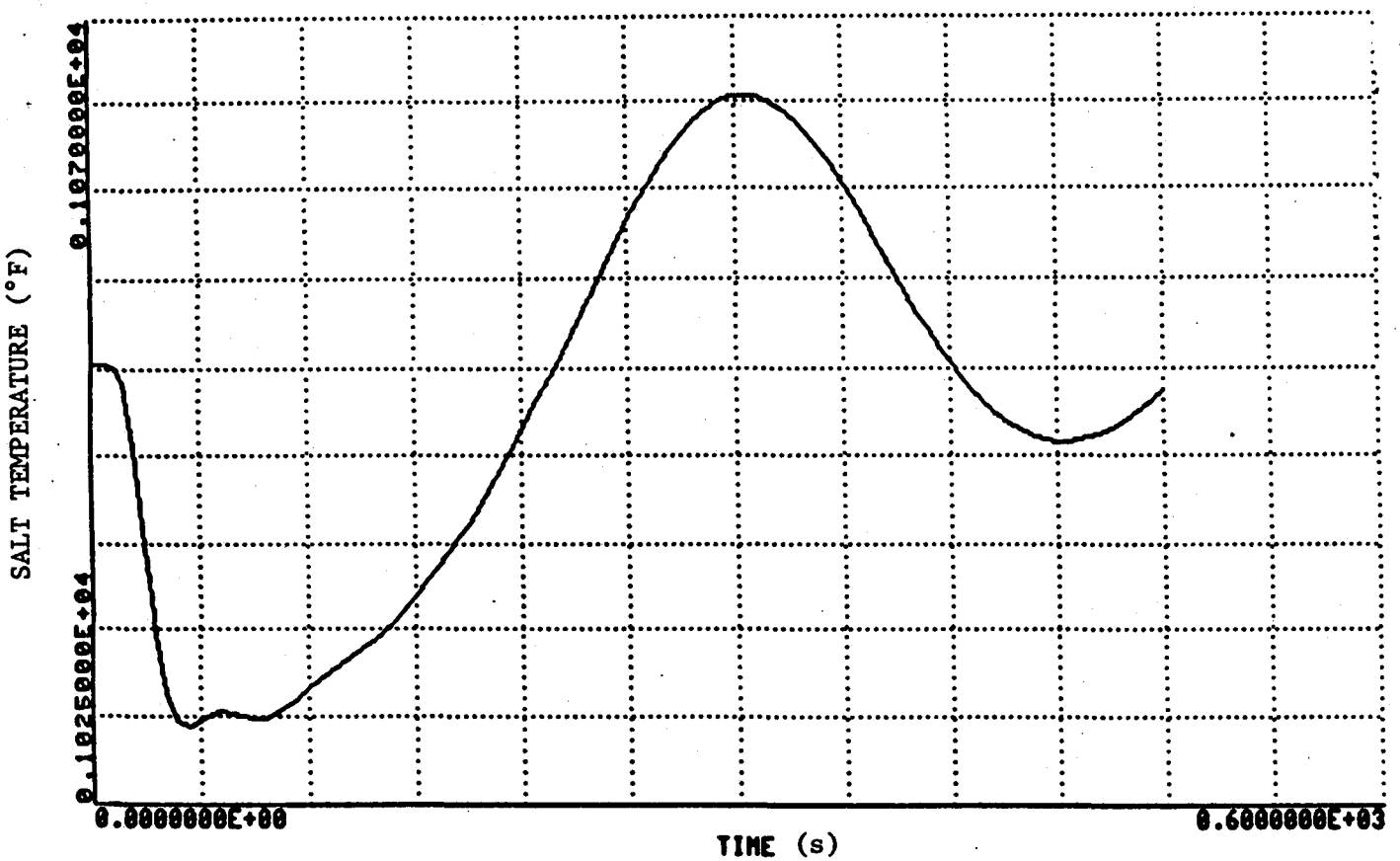


Figure Q.7 Receiver Outlet Temperature for 50-Percent Cloud Cover--
Flux Meters Control

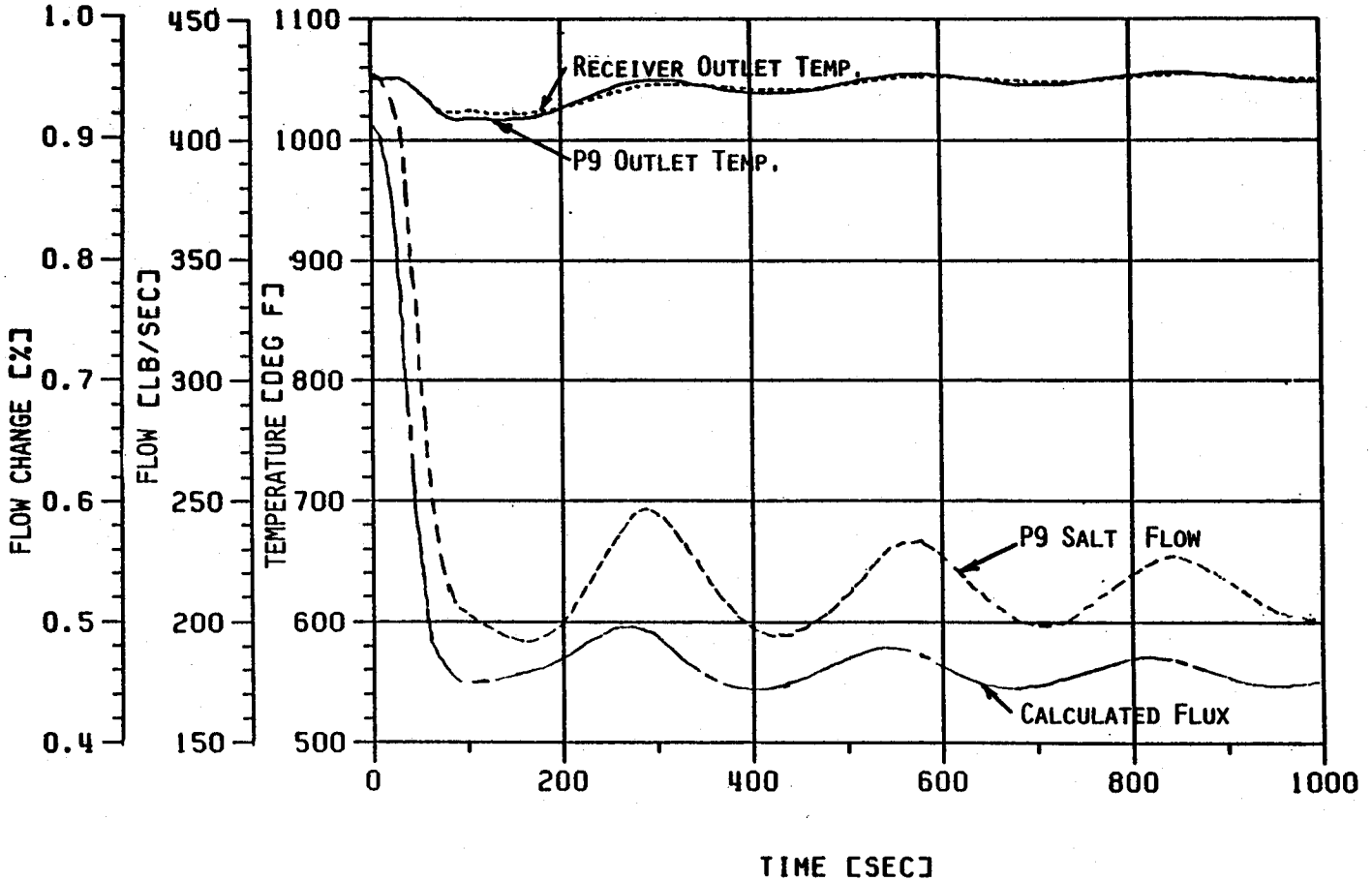


Figure Q.8 Control Response for 50-Percent Cloud Cover at 5 Seconds--
Back Tubewall Temperature Control

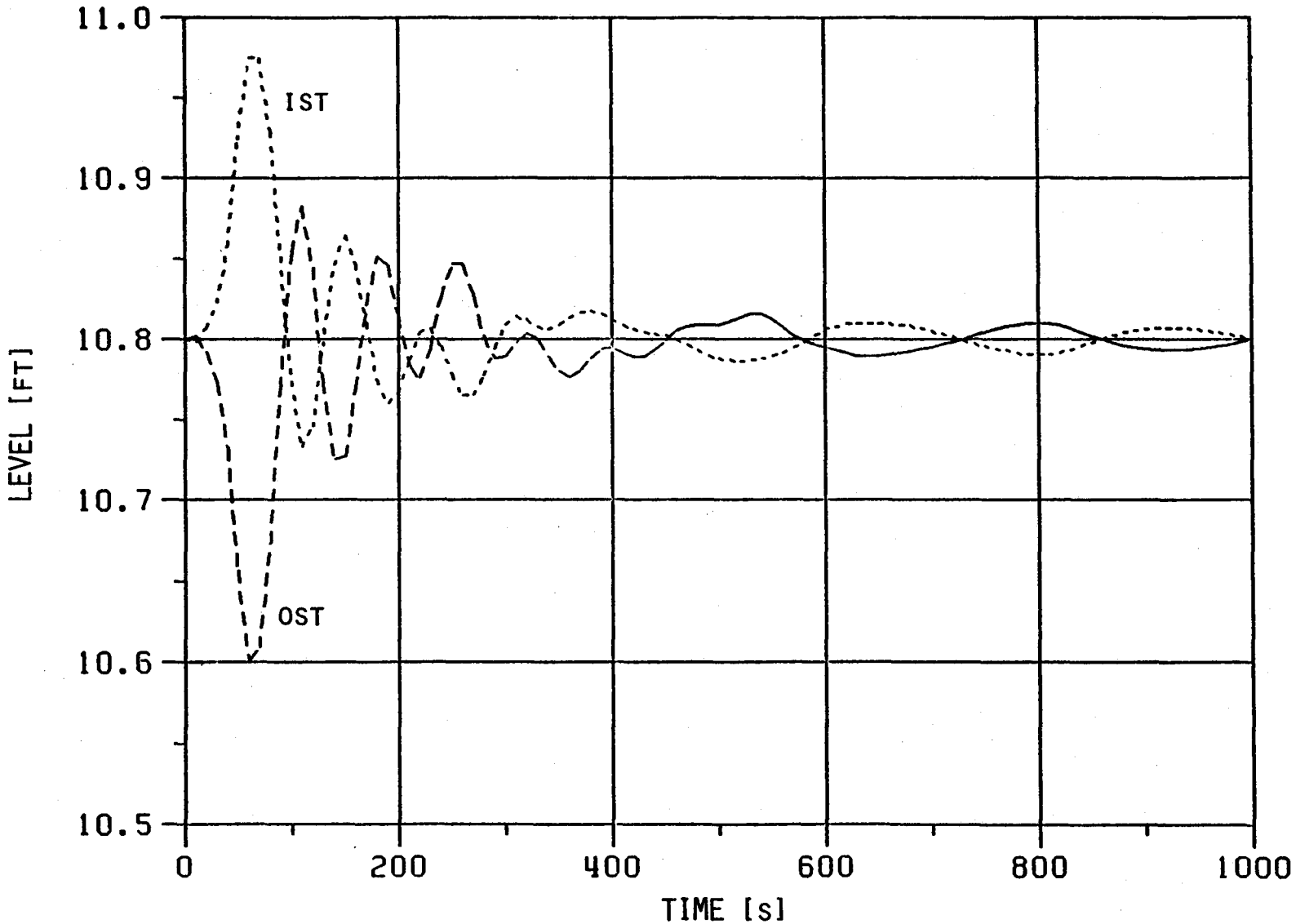


Figure Q.9 Surge Tank Level for 50-Percent Cloud Cover at 5 Seconds--
Back Tubewall Temperature Control

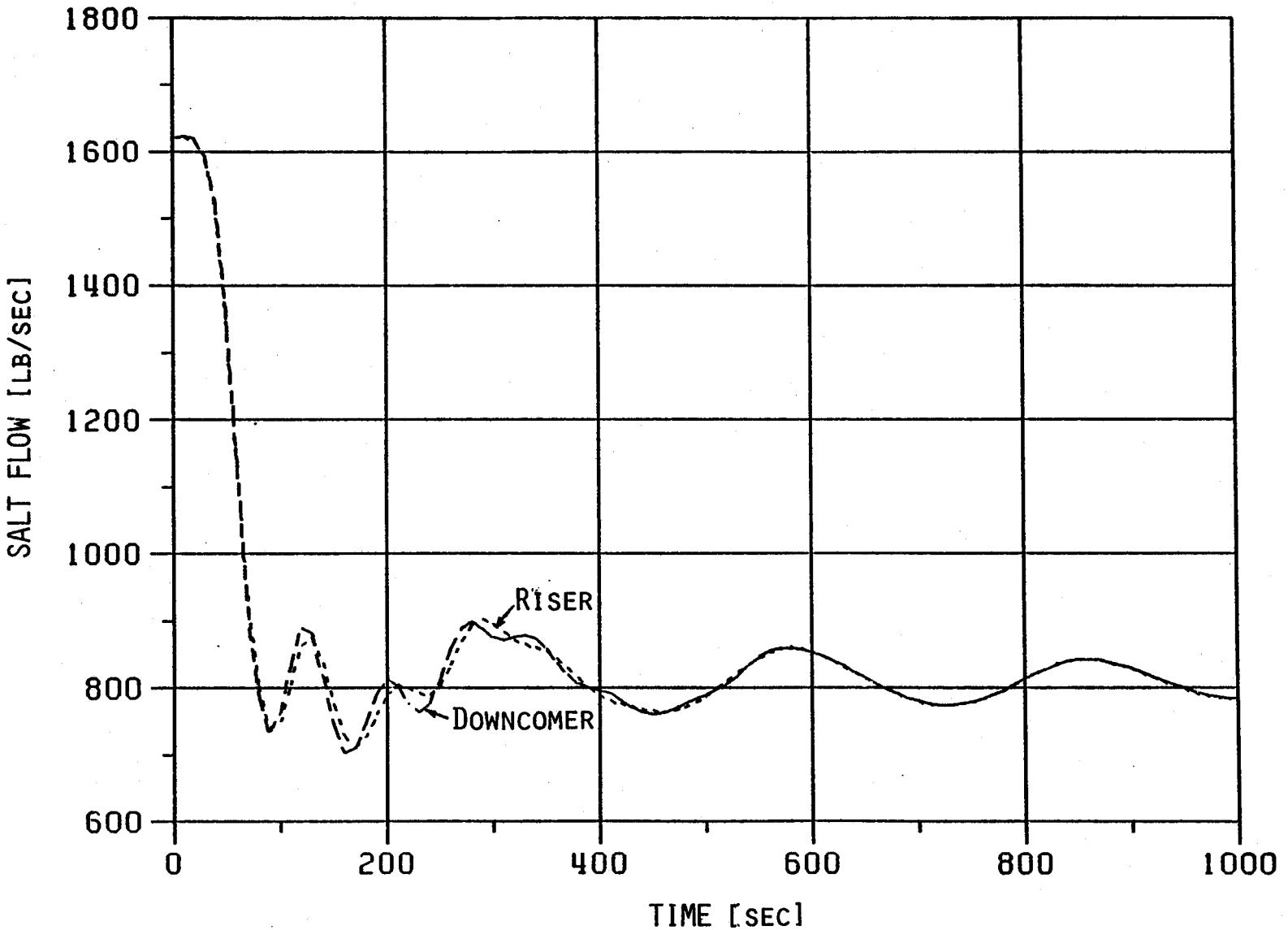


Figure Q.10 Riser/Downcomer Salt Flow Rate for 50-Percent Cloud Cover at 5 Seconds--Back Tubewall Temperature Control

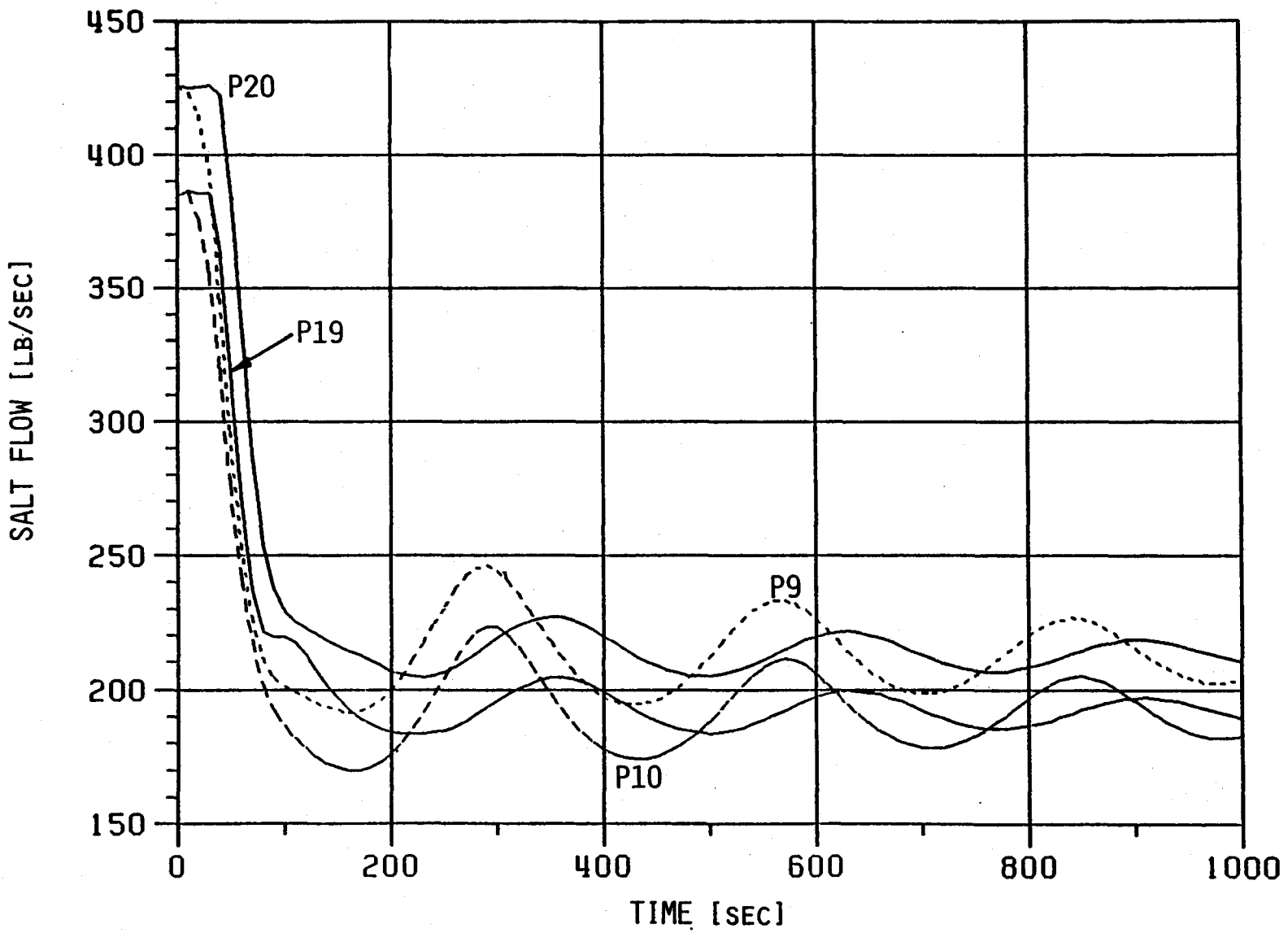


Figure Q.11 Salt Flow Rate in Pass 5 Panels for 50-Percent Cloud Cover at 5 Seconds--Back Tubewall Temperature Control

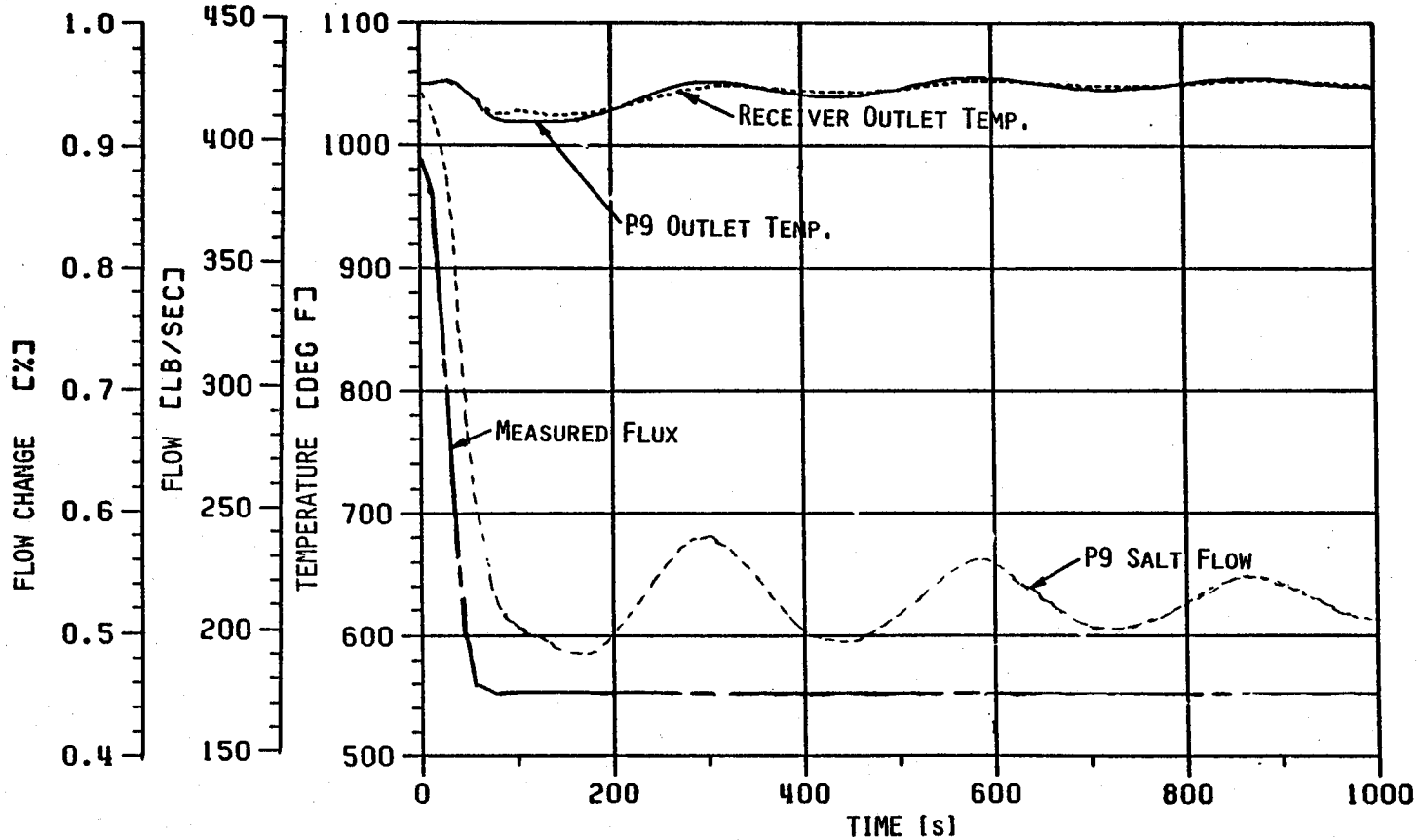


Figure Q.12 Control Response for 50-Percent Cloud Cover at 5 Seconds--
Flux Meters Control

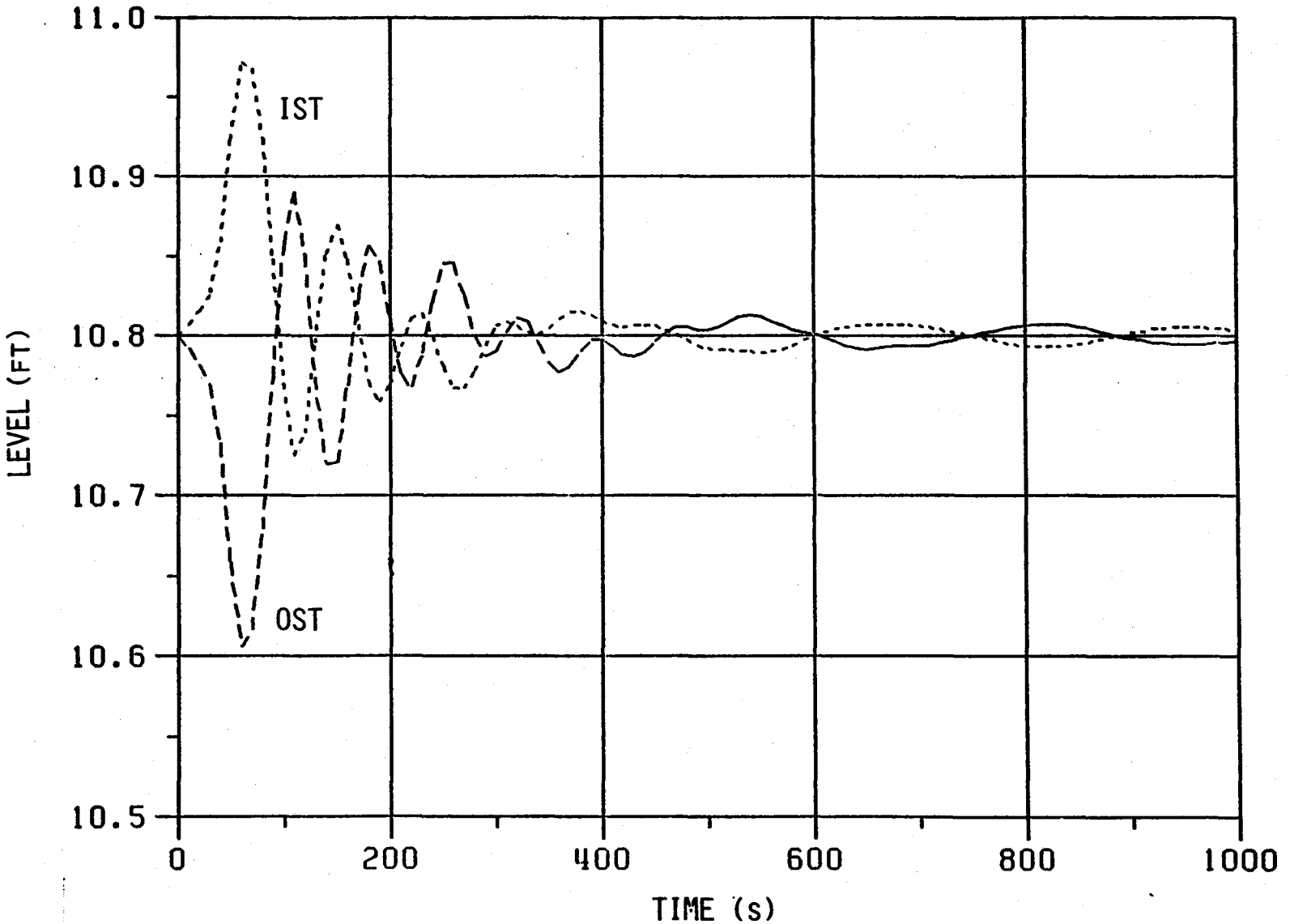


Figure Q.13 Surge Tank Level for 50-Percent Cloud Cover at 5 Seconds--
Flux Meters Control

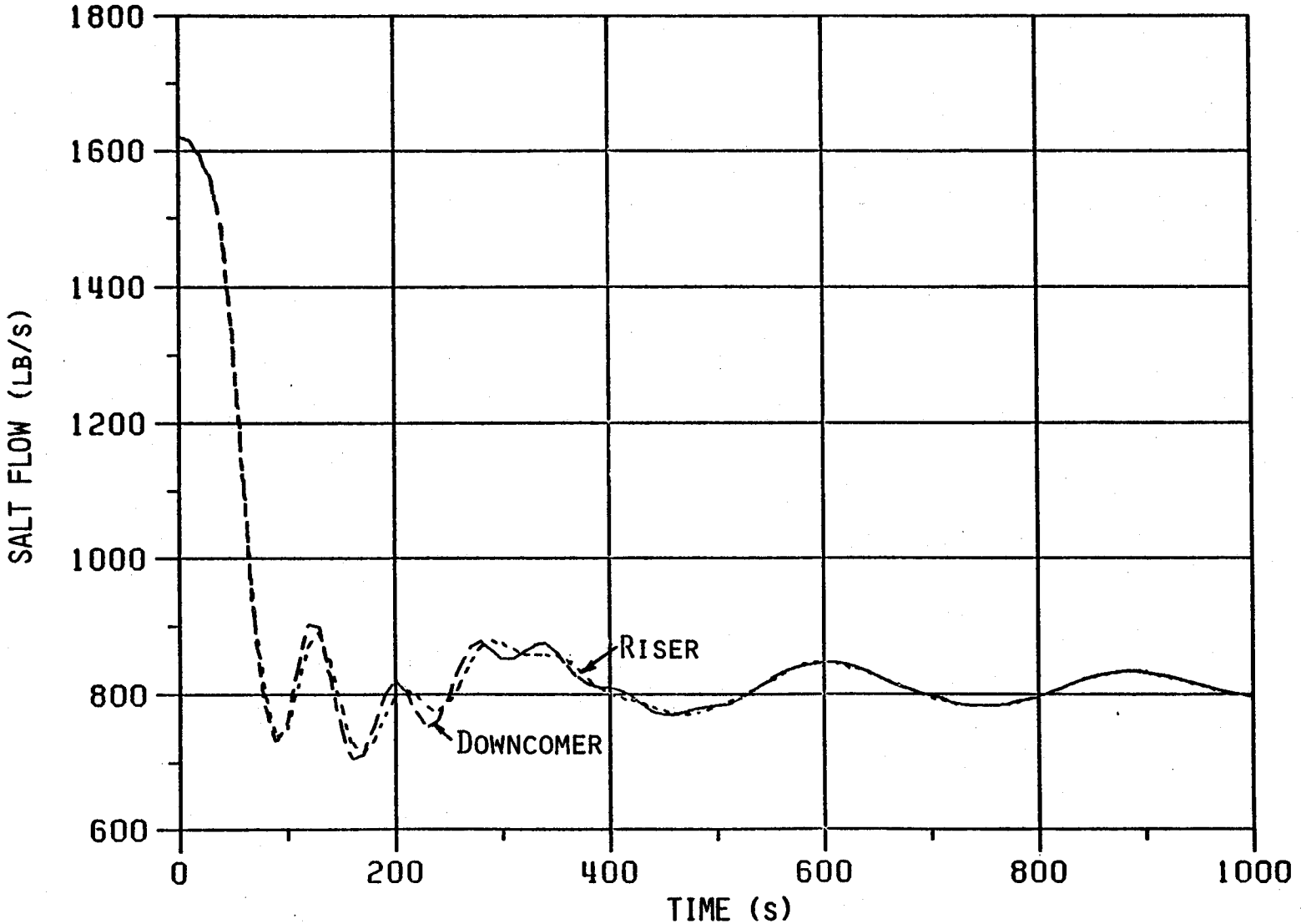


Figure Q.14 Riser/Downcomer Salt Flow Rate for 50-Percent Cloud Cover at 5 Seconds--Flux Meters Control

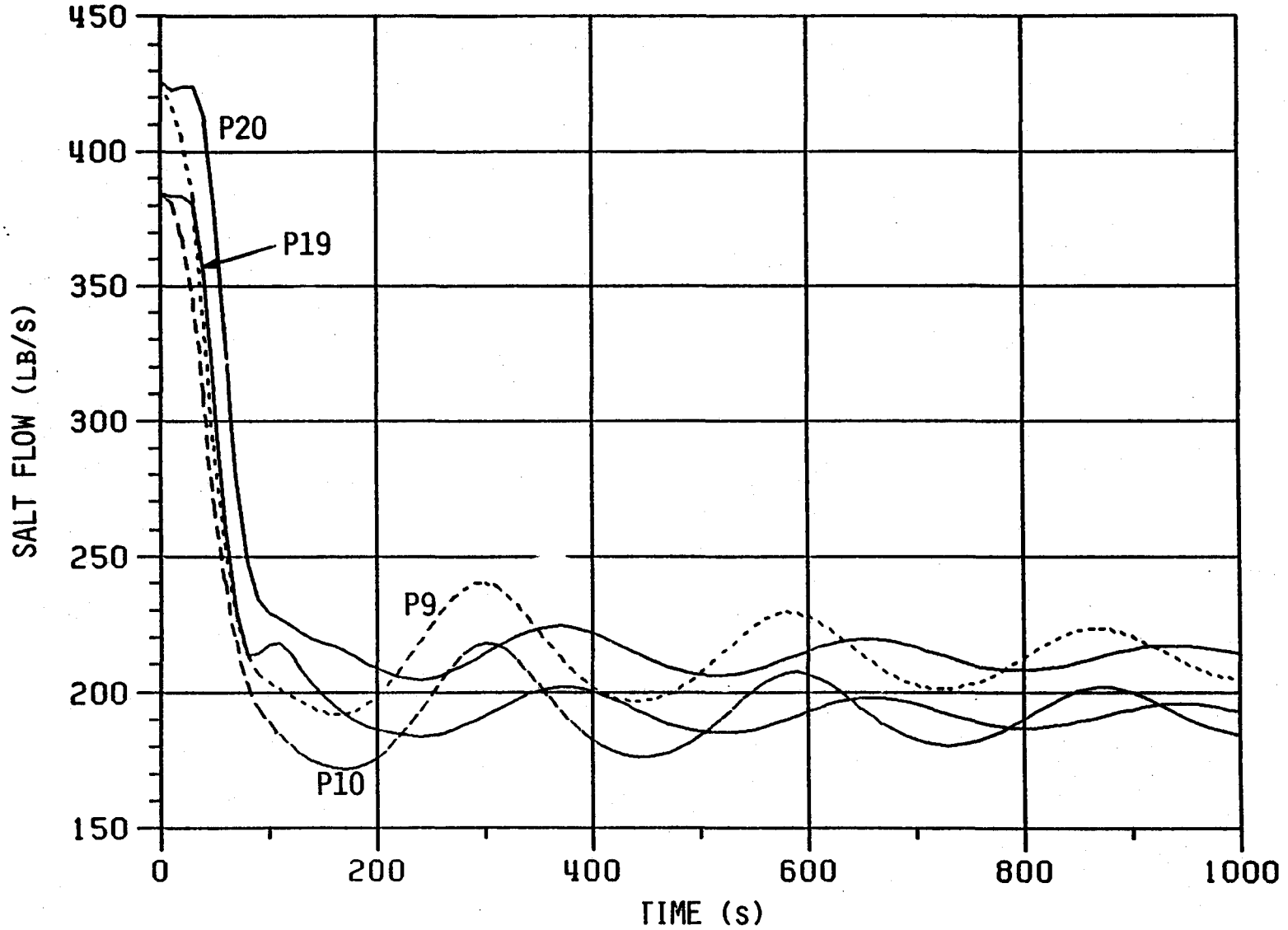


Figure Q.15 Salt Flow Rate in Pass 5 Panels for 50-Percent Cloud Cover at 5 Seconds--Flux Meters Control

APPENDIX R

FABRICATION PROCESS DEVELOPMENT PLAN

MOLTEN SALT SOLAR RECEIVER

SUBSYSTEM RESEARCH EXPERIMENT

Prepared for

Sandia National Laboratories
Thermal Subsystem Division
Livermore, California

October 1981

Sandia Contract 84-2292C
FWSDC No. 9-71-9203

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION
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TPS 81-S9

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1. INTRODUCTION

This Fabrication Process Development Plan (FPDP) is the basic guideline for the development work that will establish the optimum methods for joining tubes to tubes and attaching support lugs to tube panels. In addition, as a part of this effort FWSDC will select the best method of welding tubes to headers and will design the weld joint. This FPDP will be followed as closely as possible, but if a different, improved approach to a particular task becomes obvious, FWSDC's program manager will advise Sandia and will have this FPDP amended.

Foster Wheeler has extensive experience in the fabrication of tube panels and the operations that are involved in their construction. The basis for the development techniques for fabrication of the solar panels will be this experience; thus many of the problems which arise during such a program can hopefully be avoided.

2. MATERIALS

The materials to be included in the development program have been identified as follows:

- Panel Tubes: 1-in.-O.D. x 0.065-in. wall seamless, cold drawn, and mill-annealed Incoloy 800.
- Panel Support Lugs: Incoloy 800 strip. The size and number of the lugs will be determined by analysis.
- Weld Filler Wire: Inconel 82 filler wire. The optimum wire diameter will be determined during the program.

3. JOINING PROCESSES

The following processes will be investigated for performing the respective welds.

- Tube-to-Tube Panel Welding: The metal inert gas (MIG) method will be used with 0.015- to 0.030-in.-dia filler wire in the short-arc transfer mode.
- Support Lug Attachment: Either MIG or tungsten inert gas (TIG) methods will be utilized, depending upon the lug design and loading requirements.
- Tube-to-Header Welding: Commercially available welding equipment that utilizes the TIG process will be used.

4. WORK PLAN

4.1 Tube-to-Tube Panel Welding Development

While awaiting delivery of the Incoloy tubing from the vendor, existing Foster Wheeler welding procedures pertinent to this process will be reviewed. All welding equipment required for the development program will be modified and assembled during this time and checked out to verify proper operation.

Basic Welding Parameters

Short lengths of tubing, up to 30-in., will be joined using the MIG short-arc process. The following optimum welding parameters will be determined:

- Welding voltage
- Wire feed rates and resultant amperage
- Weld travel speed
- Weld start and stop event sequence timing
- Argon gas shielding
- Torch guide requirements
- Defective weld repair procedures.

A minimum of 10 test welds will be required.

Weldment Physical and Metallurgical Examinations

Selected weldments achieved during the tests will be sectioned and examined as they are made. Physical measurements will be made to determine the following:

- Weld-induced tube-to-tube transverse shrinkage
- Weld-induced axial tube distortion
- Weld-induced transverse panel distortion.

The tube-to-tube welds will be sectioned and examined micro- and macroscopically for the following:

- Weld penetration
- Any weld-induced discontinuities
- Microhardness and microstructural characteristics of the tube, weld, and heat-affected zone.

The welding parameters will be modified as required to optimize the joining conditions. The resultant weld will be selected based on the stress analysis that will be conducted. This analysis will determine the amount of weld metal required for joint strength, the effect of spacers between the tubes, and whether one-sided or two-sided panel welds are required. This information, in conjunction with the weld-induced panel distortion, weld penetration depth, and weld bead configuration will be the basis for selecting the optimum weld. The observed axial and transverse distortion will provide the basis for design of the panel hold-down fixtures.

4.2 Custom Welding Torch

Using the welding parameters that were determined during the development program, a custom welding torch will be designed and fabricated. This torch will incorporate the required features determined during the previous tests and will have

the necessary tracking capability to ensure proper arc position during the weld cycle.

The custom welding torch will have the features shown in Figure 1 and described below:

- Basic Welding Head: The basic welding head will consist of a velocity-governed wire feed mechanism which will supply filler wire to the welding tip at the required rate for start-up, constant welding, and stopping. The welding tip will have a gas cup to introduce the gas shielding mixture to the weld site. Welding gap and tracking will be maintained by follower rolls attached to the welding head. The rolls will contact the panel tube immediately ahead of the welding tip.

- Floating Cross Feed: The floating cross feed will allow the welding tip to follow the exact path prescribed by the follower rolls and will also allow several tubes to be welded without repositioning the panel assembly.

- Vertical Slide: The vertical slide will position the welding head vertically. This slide will be designed to allow part of the weight of the welding head and cross slide assembly to be borne by the follower rolls.

- Side-Beam Carriage: The motor-driven side-beam carriage will support the welding equipment and provide constant axial motion to the welding tip at a preset velocity.

4.3 Panel Clamping Fixtures

The panel clamping fixtures will be designed to hold the panel securely during welding so that alignment is maintained and weld-induced axial and transverse distortions are kept to a minimum. The clamps will be pneumatically actuated and programmed to release and reactuate as the welding head passes each clamp. The number and size of these clamps will be determined during the early welding parameters development phase.

4.4 Test Panel Fabrication and Testing

After completion and check-out of the custom welding equipment, two 36-in. wide x 96-in. long test panels will be fabricated using the joining procedures

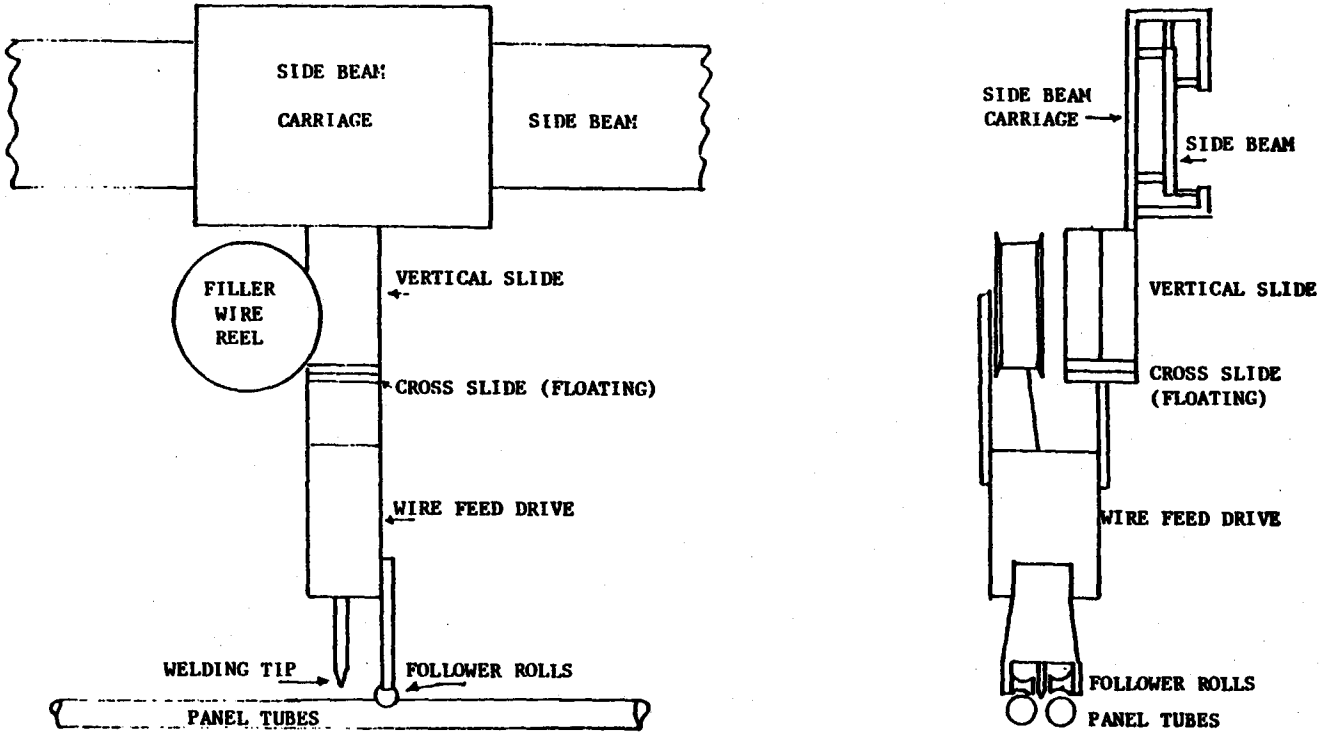


Figure 1 Panel Welding Equipment

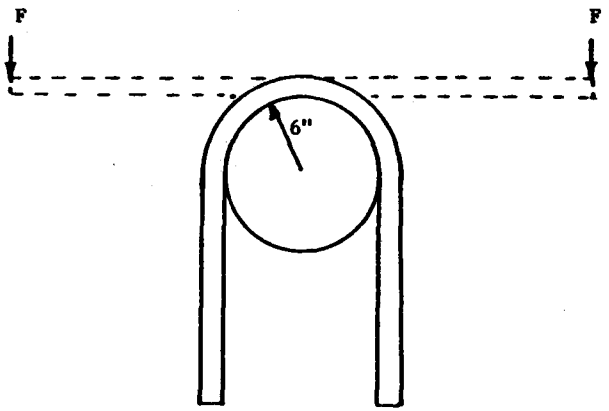
previously developed. The tests described below are not meant to yield quantitative results, but are being conducted to provide a basis for qualifying the panel joining methods. The tests are designed to subject the panel sections to loading and bending conditions which far exceed those anticipated during normal operation. Failures during these tests will not necessarily mean that the panel is defective, but will identify the areas that may be prone to failures. If failures do occur, they will be metallurgically examined to determine where and why the crack was formed and the significance of the the failure on the production panels.

- Longitudinal Bends: Sections three tubes wide and 48 in. long will be bent 180 deg longitudinally, with the weld face at the outer radius, at a radius of approximately 6 in., as shown in Figure 2a. Two tests will be performed at ambient temperature. The bent, welded zones will be examined macroscopically for evidence of failure within the weld metal and weld-to-tube interface.

- Transverse Bend Tests: Sections of test panels 20 tubes wide and 6 in. long will be bent 90 deg in the transverse direction, with the weld face at the outer radius, at a 6 in. radius, as shown in Figure 2b. Two sections will be tested at ambient temperature. The bent sections will be examined macroscopically for evidence of weld failure.

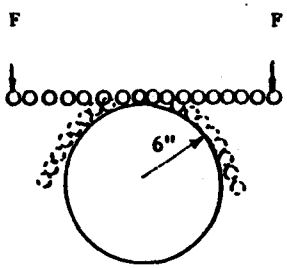
- Transverse Panel Tensile Test: A transverse tensile test will be conducted at ambient temperature on a 6-in.-long x 6-tube-wide panel section. The loading will be perpendicular to the direction of the welds, as shown in Figure 2c. The loading will continue until a tensile failure occurs in the panel. Photographs will be taken at numerous hold points to record the visual behavior of the panel at these predetermined loading conditions.

- Thermal Cyclic Test: A 24-in.-long x 10-tube-wide panel section will be thermally cycled 1000 times from 550 to 1150°F using quartz lamps as a heating medium. The section will be heated from the front face only, and the temperature will be held for approximmately 30 min to introduce a creep-relaxation state to the panel. Manifolds attached to both ends of the section will permit gas flow through the panel for cooling and will also provide approximately 60 lb/in^2g pressure to check for gross tubewall failure. The panel welds will be dye-penetrant tested before and after cyclic testing to monitor the possible formation of thermal fatigue cracks. If dye-penetrant indications are found, these areas will be examined metallographically to determine the nature of the material degradation.



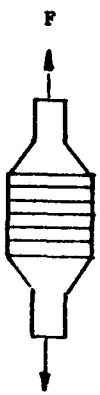
2a

LONGITUDINAL-BEND TEST



2b

TRANSVERSE-BEND TEST



2c

TENSILE TEST

Figure 2 Tube Panel Testing

4.5 Support Lug Attachment and Testing

When the design requirements of the panel support lugs are known, a lug attachment method will be developed. The current plan is to perform the lug and the longitudinal tube-to-tube welds simultaneously. The feasibility of this attachment method will be determined finally when the welding parameters and characteristics are known.

After the support lug design and attachment methods are chosen, the lugs will be attached to the test panel and mechanically loaded to verify that they do not jeopardize the tube integrity. The magnitude and direction of loading will be determined later when these forces are known.

4.6 Tube-to-Header Joint Design

The tube-to-header joint design will utilize internal bore welding or other suitable state-of-the-art welding techniques. The ideal joint configuration will be designed based upon the final tube panel header design and the welding method chosen.

The design will be based primarily upon welding torch accessibility, header wall thickness, tube diameter and wall thickness, and joint strength requirements.

Depending upon header design, a commercially available welding torch will be introduced through the header end or through strategically placed access holes that can be plugged.

5. DATA COLLECTION AND REPORTING

The following data will be recorded, retained, and included in the final test report:

- As-received tubing physical dimensions
- All welding parameters as follows:
  - Weld head travel speed
  - Weld filler metal deposit speed
  - Welding voltage
  - Welding arc length.
- Tube panel weld transverse weld shrinkage
- Tube panel axial and transverse distortion
- Bend test results
- Tensile test results
- Metallurgical observations
- Thermal-cycle test temperatures and cycle rates
- Dye penetrant test observations.

All measurement tolerances will meet standard shop practice.

A final test report will be prepared, outlining the welding tests performed and describing the resultant welds. The criteria used to qualify the final weld configuration will be discussed. The report will include all data recorded during the testing and will discuss the observed test results and the impact these results may have on the production panel performance. All jigs and fixtures designed for panel fabrication will be shown in detail. This report will also be the basis for the final procedure for fabricating the production tube panel, lug supports, and tube-to-header attachments.

6. PROJECT SCHEDULE

The schedule for the work described in the FPDP is 9 months from the date of contract award. The detailed task schedule breakdown is presented in Figure 3.

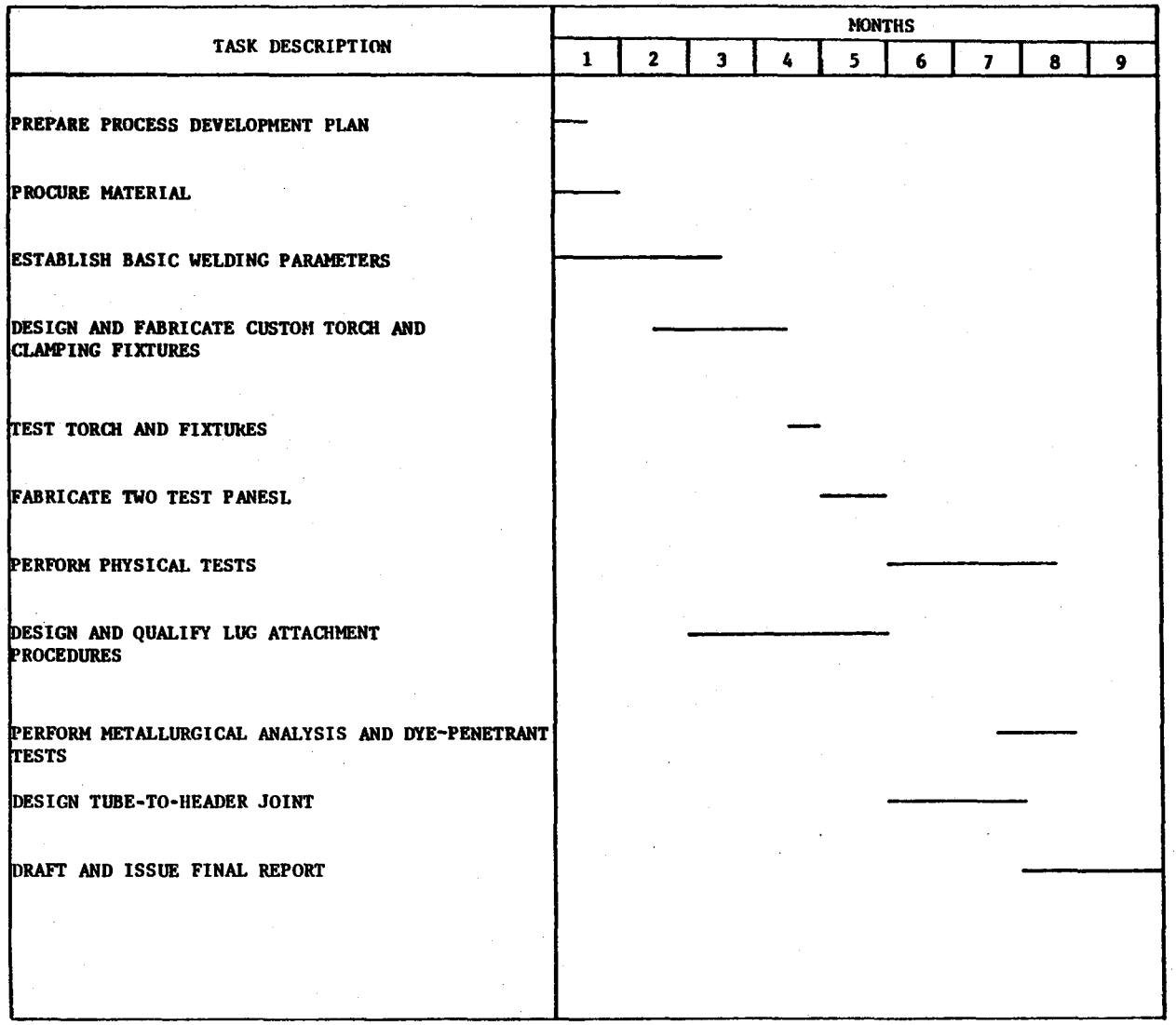


Figure 3 Fabrication Process Development Schedule

Appendix S

LIST OF AUXILIARY EQUIPMENT

Vertical Molten Salt Drain Pumps (Lawrence Pump and Engine Company)

Model Number	2 x 3 HBD-M
Capacity, gal/min	50
Total Head, ft	150
Pumping Temperature, °F	900
Rev/min	1750
Efficiency, %	20
Brake Horsepower, Op. C-Maximum	17 and 25
Driver Horsepower	25
Motor Enclosure	TEFC
Impeller Diameter, in.	11.75
Material of Construction	304SS

Valve List . All salt valves are self-draining, globe-type with internal bellows seals and are capable of both manual and pneumatic actuation.

Quantity	Function	Temperature (°F)	Pressure (lb/in²g)	Nominal Pipe Dia (in.)	Material	Comments
4	Main Control	1050	300	10	316SS	Includes Air Operator
10	Salt Vent/ Drain	1050	300	4	316SS	Includes Air Operator
4	Salt Vent/ Drain	900	300	4	1-1/4%Cr-1%Mo	Includes Air Operator
9	Salt Vent/ Drain	800	300	4	CS	Includes Air Operator
1	Air Vent	600	300	3	CS	Includes Air Operator
1	Pressure Relief	600	1100	4	CS	Set Pressure 1100 lb/in²g
2	Salt Riser	500	300	12	CS	Includes Air Operator

Cavity Radiant Heaters (Chromalox Corporation).

Model Number	CPH-6043T
Size, in.	60 long x 12 wide
Power, kW	18.0
Voltage, V	480 (3 phase)
Weight, lb	30 (each)
Number	50

- Emission Surface--Woven refractory cloth with black ceramic coating for high radiant-energy transfer.
- Heater Element--Precision iron-base resistance wire, designed to give extended life and uniform emission over entire radiating surface.
- Heater Element Support--Fibrous ceramic material, specially developed for high insulation qualities and durability; shock resistant and asbestos free.
- Insulation--Fiberglass insulation to minimize heat loss from the back of the heater.
- Frame--Heavy gauge, heat-resistant, aluminized steel.
- Terminals--Stainless steel terminals in a standard 4 in. x 4 in. junction box.
- Thermowell--Quality tubular-quartz thermowell, with strain relief, to accept a thermocouple.

Instrument Air Compressors (Ingersoll-Rand). Package includes automatic dual control, inlet filter-silencer, aftercooler, and air receiver-separator.

Compressor Model Number	ESV-IPNL 8 x 7
Type	30 nonlubricated
Bore x Stroke, in.	8 x 7
Compressor Speed, rev/min	514
Discharge Pressure, lb/in^2g	135 maximum
Piston Displacement, ft^3/min	206
Actual Air Delivery, aft^3/min	148 at 100 lb/in^2g
Compressor Brake Horsepower	33.9
Motor Horsepower	40

High-Pressure Air Compressors (Ingersoll-Rand). Package includes automatic stop and start and low-oil-level switch.

Model Number	15T2 X
Discharge Pressure, lb/in^2g	1000
Piston Displacement, ft^3/min	41.2
Actual Delivery, ft^3/min	30.8
Compressor Speed, rev/min	750
Motor, hp	15
Power Required, V	460 (60 cycles/3 phase)

Instrument Air Dryers (Deltech). Package includes automatic drain trap.

Model Number	D-14
Inlet Air Pressure, lb/in^2g	100
Inlet Air Temperature, °F	100
Ambient Air Temperature, °F	100
Power Required, V	230 (60 cycle/1 phase)
Air Capacity, sft^3/min	140
Dewpoint, °F	35

High-Pressure Air Dryers (Pall Company).

Model Number	6MD46056
Type	Semiautomatic, dual tower, high pressure, electrically heated, desiccant air dryer. Off-line tower regenerates automatically after switch-over
Inlet Flow Rate, sft^3/min	31
Inlet Pressure, lb/in^2g	1000
Inlet Temperature, °F	100-120
Outlet Moisture Content	<0°F dewpoint at 1000 lb/in^2g
Adsorbent Type	Activated alumina
Power Required, V	115 (60 cycle/1 phase)
Heater Size, kW	0.5
Average Power Consumption, kWh/24h	9

Shop Air Storage Tank and Interconnect Piping. One 3-ft-dia x 9-ft-long tank is required; designed for 125 lb/in²g with a material thickness of 5/16 in. The tank is constructed of carbon steel and weighs 1250 lb. It has three, 1-in.-dia nozzles, one each for fill, drain, and outlet. The interconnect, 1-in. Schedule 40 carbon steel piping from the compressor and dryer, is approximately 35 ft long and contains three hand-controlled shut-off valves. The outlet piping is 1 in. Schedule 40 carbon steel.

Instrument Air Storage Tank and Interconnect Piping. One 3-in.-dia x 9-in. long tank is required; designed for 125 lb/in²g with a nominal material thickness of 5/16 in. The tank is constructed of carbon steel and weighs 1250 lb. It has two 1-in.- and 1/2-in.-dia nozzles--one each for fill, drain, and outlet. The interconnect, 1 in. Schedule 40 carbon steel piping for the compressor and dryer, is approximately 25 ft long and contains three hand controlled shut-off valves. The outlet piping is 1/2-in. stainless tubing.

Receiver Personnel/Equipment Elevator

Number Required	1
Capacity, lb	2000
Size, ft	6 x 8 x 8 high

Equipment Hoist

Number Required	1
Capacity, lb	2000
Lift, ft	175

Overhead Crane (Lively Company)

Capacity	15 ton
Span	Approximately 62 ft - 0 in.
Hoisting Speed	40 FPM
Trolley Speed	73 FPM
Bridge Speed	72 FPM
Trolley Weight	17,500 lb
Bridge Weight	35,000 lb
Wheel Load	31,000 lb
Hoist Motor	50 HP at 1200 RPM
Trolley Motor	3 HP at 1200 RPM
Bridge Motors	2 x 2 HP at 1200 RPM
Reeving	4 part single (5/8 in. dia Monitor AA-IWRC)
Hoist Drum	60 in. dia, approximately 14 ft - 0 in. long
Bridge Wheels	15 in. dia
Trolley Wheels	10 in. dia
Bridge Drive Type	(C.M.A.A.) Type A4

Hoisting Machinery for Aperture Doors (Lively Company)

Closing Speed	Approximately 35 and 13 FPM
Motor	20 HP at 1200/450 (W.R.)
Brakes	1 disc and 1 shoe type
Drum	30 in. dia, approximately 8 ft - 0 in. long
Wire Rope	1-1/8 in. dia

- Each door will be lifted by 4 parts of cables so each door will have one wire sheave attached to each end.
- Approximate opening and closing time: 1.5 min.
- The electrical controls will include a battery charger and battery for emergency operation. The closing speed of the door will thus be controlled by the motor. The limit switches mounted on the door tracks will slow down and stop the doors as under the normal condition operation. The closing time will be 45 seconds or less.

Lightning Rods--20 required

Lightning Rod Grounding Cable--1030 ft required

Aircraft Warning Lights--25 required

Transformers--1 required

Size: 22 kVa at P.F. = 1
Voltage: 110 V

Instrumentation. Table S.1 lists instrumentation; Table S.2, controllers; and Table S.3, indicators.

Emergency Power

- Exide Battery Power Pack: lead acid, 60 cell, 125 V, 400 ampere-hours
- Battery Charger (Converter): 110 Vac, 125Vdc, 50 amperes
- Uninterruptible Power System: 3 kVA, 110 Vac, 125 Vdc, consisting of inverter and control logic for solid-state switching of emergency power.

Table S.1 Instrument List

Instrument	Location	Number	Monitoring Function
Thermocouples	Panel rear wall	400	Panels for local high salt temperatures
	Panel headers	80	Salt temperature entering and leaving each panel
	Inlet surge tank	3	Inlet surge tank salt temperature
	Outlet surge tank	3	Outlet surge tank salt temperature
	Drain tank	3	Drain tank salt temperature
	Salt piping	196	Salt temperature for preheat and freeze-protection control
	Structure, door, casing	50	Nonpressure-part temperature for excessive rates of spilling
	Between panels	115	Panels for local high metal temperatures
Thermowells	Pass 5 outlet pipes	4	Outlet salt temperature for flow control
Flux Sensors	Between panels	115	Local incident heat flux levels
Flow Meters	Receiver inlet	1	Salt flow entering receiver
	Pass 4 inlet	4	Salt flow rate through respective flow circuits
	Pass 1 inlet	2	Salt flow rate through each half of the receiver
	Receiver outlet	1	Salt flow leaving receiver
Level Indicator	Inlet surge tank	1	Salt level to control flow into receiver
	Outlet surge tank	1	Salt level to control flow leaving receiver
	Drain tank	1	Overflow salt level to activate salt pump
Pressure Sensor	Inlet surge tank	1	Tank pressure for constant pressure control
	Primary riser	1	Receiver total pressure loss
	Primary downcomer	1	Receiver total pressure loss
Position Indicator	Receiver door valves	1	Door position for safety interlock system
	Valve	30	Valve position

Table S.2 Controller List

Instrument	Location	Number	Manufacturer/ Model Number
Pressure Indicator Controller	Inlet Surge Tank	1	Fischer & Porter/ Spec. 51PE with chemical seals
Level Indicator Controller	Inlet Surge Tank	1	Fischer & Porter/ 1451W
Level Indicator Controller	Outlet Surge Tank	1	Fischer & Porter/ 1451W
Level Indicator Controller	Drain Tank	1	Fischer & Porter/ 1451W
Temperature Controller	Heat tracing	32	Omega/4001KF
Pneumatic Converter		40	Fischer & Porter/ 50ES

Table S.3 Indicator List

Indicator	Location	Number	Manufacturer/ Model Number
Electrical Power	Drain tank pump	1	Fischer & Porter/ 51PG
Flow	Receiver inlet and outlet, Pass 1 right and left inlets, Pass 4 right and left inlets	8	Fischer & Porter/ 51PG
Pressure	Receiver inlet and outlet	2	Fischer & Porter/ 51PGW
Position	Door	2	Fischer & Porter/ 51PG
Position	Salt line drain valve	30	Fischer & Porter/ On-off switch with light on when valve is partially/fully open
Microswitch	On redline unit	26	Fischer & Porter/ Process Relay Type 55PA
Annunciator	On redline unit	15	Ronan
Microswitch	On receiver unit	10	Fischer & Porter/ Process Relay Type 55PA

Appendix T

FABRICATION AND CONSTRUCTION PLANS

RECEIVER FABRICATION

Receiver shop fabrication will take 28 months as shown in Figure T.1.

Tube Fabrication

- Receive and inspect
  - Check dimensions and finish. Purchase clean and with one end square.
  - Check for shipping damage.
  - Check mill certifications.
  - Store in a protected area. Keep clean.
- Long panel tubes
  - Cut tube to length and deburr.
  - Bend both ends.
  - Check against template.
  - Clean and hold for assembly.
- Jumper Tubes
  - Cut tubes to length with excess at both ends.
  - Bend jumper tubes. Check against template.
  - Clean and hold in protected storage.

Header Fabrication

- Receive and inspect header pipes.
  - Check dimensions and finish.
  - Check mill certifications.
- Cut to length with excess at each end.
- Lay out and cut holes for branch connections.
- Inspect.

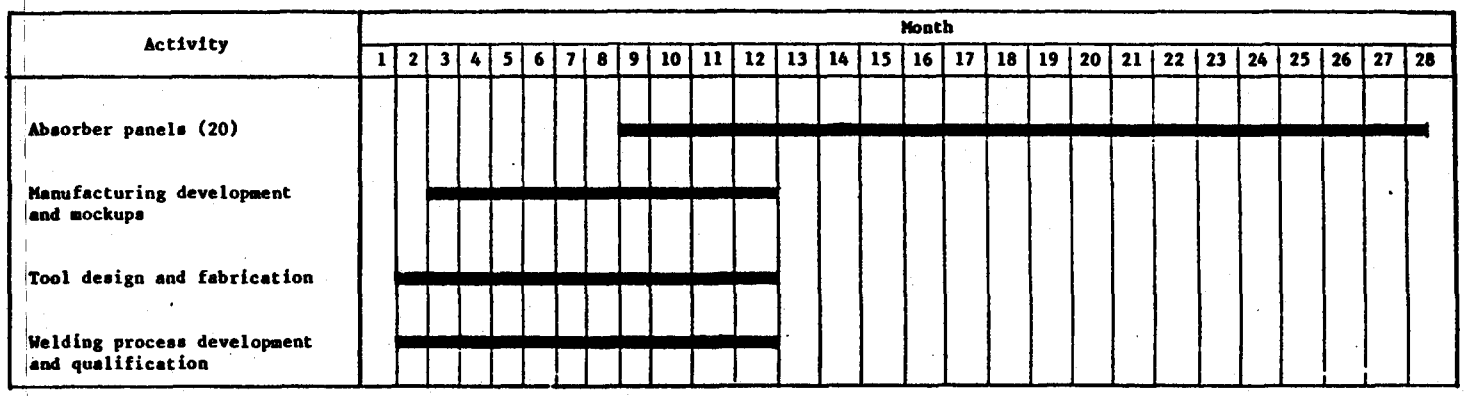


Figure T.1 Fabrication Schedule of Receiver

- Set up and weld branch connections and bimetallic end.
  - Full-penetration nozzle weld.
  - Butt-weld safe end--bimetallic weld.
- Penetration test weld.
- Visually inspect.
- Straighten header.
- Lay out and drill holes for stubs.
- Inspect.
- Set up and weld stub ferrules.
- Penetration test final weld.
- Visually inspect.
- Set up and weld attachments.
- Penetration test attachment welds.
- Straighten as required.
- Machine header length and prep edges.
- Machine stub length and drill through.
- Inspect.
- Clean and hold for further assembly.

Structural Support Clips

- Receive and inspect.
  - Check dimensions and cleanliness.
  - Check material certifications.
- Hold for assembly to receiver panels.

Panel Fabrication (20 required--material as specified)

- Fabricate eight-tube subassemblies, welding tubes longitudinally.
  - Weld two tubes tangent to tangent--automatic weld on fixtures provided.
  - Weld two 2-tube assemblies longitudinally to make a 4-tube assembly.
    - -- Straighten using fixtures as required.
    - -- Inspect.
- Fabricate two 28-tube sections and one 32-tube section for each panel.
  - Weld four sections together and weld eight 4-tube sections together to obtain the two 28-tube and one 32-tube sections required for each panel.
- Pass a steel ball [0.8 mm (1/32 in.) clearance] through each tube to ensure no longitudinal obstructions.
- Pneumatically test each tube [69 kPa gage (10 lb/in^2g)] and check for leaks as a result of longitudinal welding, using soap and water or submersion in water. Clean to remove testing medium.
- Set up and machine and deburr tube ends--both ends to ensure proper fit to header at one end and to jumper tubes at the other end. Maintain cleanliness.
- Pass a felt pellet through each tube using air pressure and ensure that it exits clean.
- Close and protect open tube ends with plastic caps to maintain cleanliness.
- Use handling fixture for moving panels.
- Hold in protected storage for further assembly.

Panel Assembly and Test

- Set up panel and headers in fixture.
  - Ensure proper header spacing and orientation.
  - Match tubes to header stubs at one end.
- Automatically orbital weld the tube ends to the header.
- Inspect nondestructive examination tube welds.
  - Visually inspect O.D.
  - Visually inspect I.D. using fibrescope.

- Penetration test O.D. of each weld.
- Sample radiographic test welds using ytterbium.

- Progressively set up and weld jumper tubes to the panel and header stubs--second end.
  - Set up, align, and weld inner row of tubes before welding outer row of tubes.
  - Trim and cut jumper tubes to fit as required to maintain fit-up tube-welding tolerances.
  - Weld jumpers to panel tubes and to header stub two welds. Automatic orbital weld.

- Inspect nondestructive tube welds.
  - Visually inspect at O.D.
  - Visually inspect at I.D. using fibrescope.
  - Penetration test O.D. of each weld.
  - Sample radiographic test welds using ytterbium.

- Preliminary pneumatic test, applying 69 kPa gage (10 lb/in^{2}g) to each tube and checking at butt welds using soap and water.

- Repair weld as required and repeat nondestructive examination/inspection cycle.

- Set up and weld heads to header ends using single-sided TIG/manual weld.

- Nondestructive examination weld
  - Penetration test root pass and final weld.
  - Spot radiographic test.

- Inspect.

- Set up and weld attachments to panel according to drawing.

- Penetration test attachment welds.

- Inspect.

- Weld hydroclosures to openings.

- Hydrotest panel.
  - Fill with demineralized water and test at approximately 5.17 MPa gage (750 lb/in^{2}g)

- Certify test according to ASME Code Section VIII.
- Drain unit completely.

- Dry internally by heating until dry and draw vacuum internally.
- Purge and pressurize internally to 69 kPa gage (10 lb/in²g) using nitrogen.
  - Seal and apply pressure gage and refill valves.
- Clean and protect panel by covering with poly film.
- Hold for final assembly.

Structural Back-Up Steel Assembly for Each Receiver Panel

- Make linkages and hangers, T-bars and strongbacks, and shipping braces.
- Paint carbon steel with one coat of red oxide primer.
- Inspect.
- Hold for further assembly to panel.

Final Panel Assembly

- Obtain structural back-up steel assembly for each receiver panel (20 required), and set up horizontally.
- Assemble completed panel--one to each back-up assembly.
- Paint panels with black Pyromet heat-resistant paint.
- Inspect.
- Obtain Quality Control release.
- Block, cover, and protect for shipment.
- Ship 20 panel assemblies to field.

Structural Support Steel

- Fabricate according to approved Foster Wheeler drawings and AISC Code.

- Shop-inspect structural support modules at vendor.
  - Inspect dimensions and workmanship.
  - Inspect finish--one coat of red oxide primer.
- Ship to field in modules according to approved drawings and shipping plan.

Risers, Downcomers, Transfer Piping, Tanks and Seals

- Receive and inspect materials and certifications.
- Fabricate according to approved Foster Wheeler drawings.
- Stamp and certify pressure parts per ASME Pressure Vessel Code, Section VIII-Division 1.
- Shop inspect.
- Ship knocked down to field.

Floor and Roof Structure and Doors

- Fabricate according to approved Foster Wheeler drawings.
- Inspect at vendor's shop.
  - Check dimensions and workmanship.
  - Check finish and painting as required.
- Ship to field in subassemblies as specified on approved drawings and according to shipping plan.

Procedures

The following fabrication procedures will be submitted for approval or information:

- All pressure-part welding procedures.
- Penetrant-testing procedures.
- Receiver panel hydrotesting procedures.
- Drying and inerting procedure.
- Field handling, storage, and preservation procedure.

FIELD FABRICATION AND ERECTION PLAN

All of the work assignments in the field will be totally subcontracted, with management of such subcontracted work by Foster Wheeler. Foster Wheeler will prepare all of the documentation required for subcontracting construction work, solicit bids, and prepare bid evaluations for placement of subcontracted work orders. Foster Wheeler will manage all subcontracted work and will control all aspects of the work such as cost control and schedules. The construction superintendent will be responsible for subcontracts, working with the procurement coordinator on inquiries and selection of subcontractors and continuing through all phases of the work to completion.

A master construction project schedule will be prepared. This schedule will indicate delivery of vessels, heat-transfer equipment, piping, instrumentation, electrical equipment. In conjunction with the master construction schedule, a detailed construction subcontracting schedule will be prepared. The construction subcontracting schedule will consist of four phases:

Phase 1 Establishing Subcontract Package

Phase 2 Preparing Requisition

Phase 3 Awarding Subcontracts

Phase 4 Construction

The schedule for field construction and erection of the molten salt receiver is shown in Figure T.2 and is approximately 4 months.

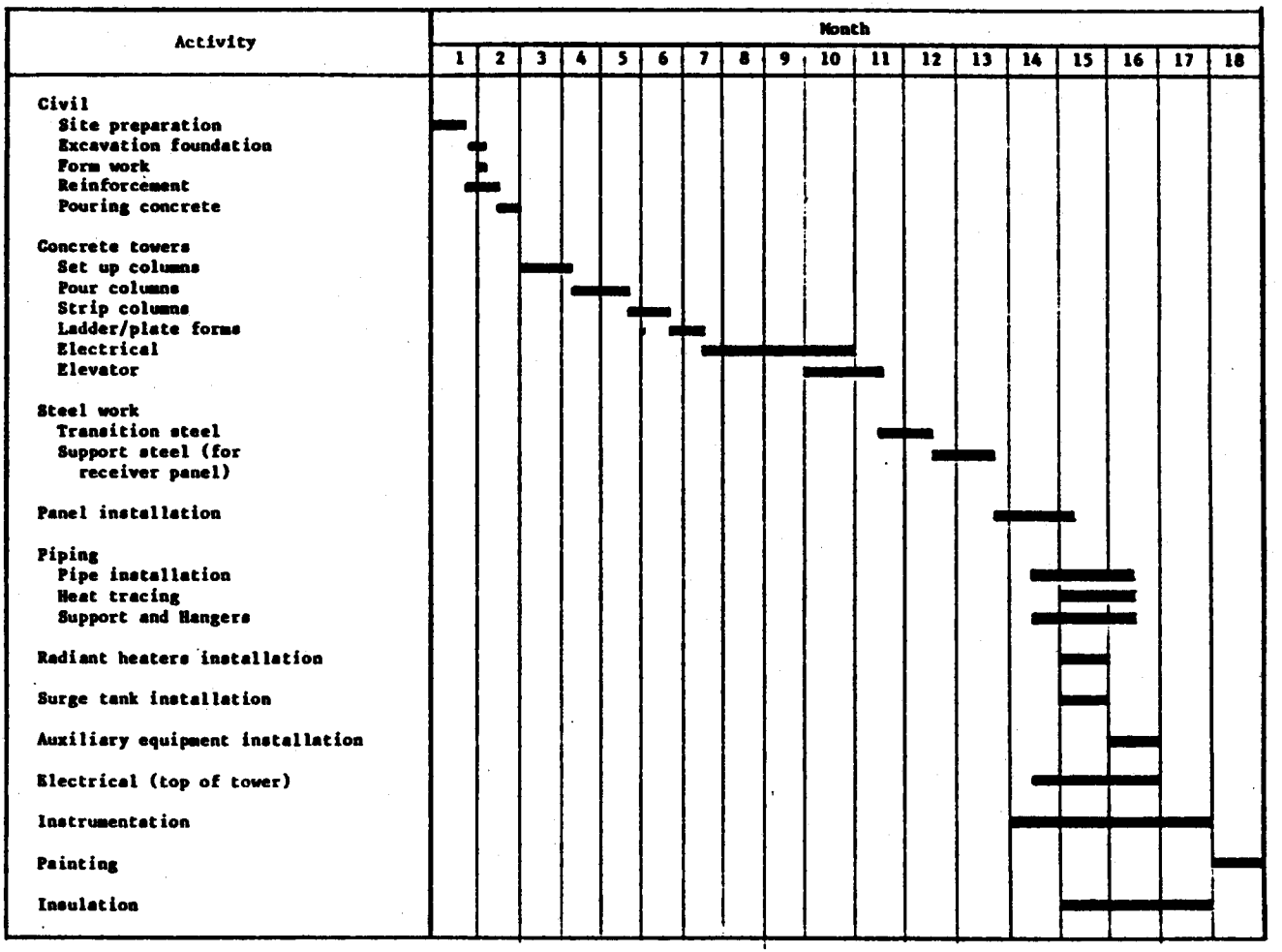


Figure T.2 Master Project Construction Schedule

The time period from the start of field activities to completion is estimated to be 18 months. An additional 2 weeks is allowed for hydrostatic test before checkout and start-up. The period identified begins with the start of construction of the concrete tower and foundation.

Essentially, the construction schedule is divided into the following main areas:

- Site Preparation and Foundations
  - The assignment involves clearing and grubbing the job-site to an existing grade.
  - This work may mean the removal of grass and shrubs and other obstructions and top soil stripping, stock piling, replacing, filling, and compacting.
  - Once site grading is completed and centerlines and boundaries are established, excavation for foundations can begin.
  - Before the receiver arrives, all footings and concrete work will be installed.
- Erection of Concrete Tower and Tower Auxiliaries
  - Sufficient level space will be allowed during site grading for subcontractor to store materials and equipment.
  - Site clearance requirements are indicated on Figure T.3.
  - Slipform systems especially designed for construction of the conical concrete tower will be utilized by the subcontractor.
  - The concrete tower will be designed to meet requirements of the specifications for the design and construction of reinforced concrete chimneys (ACI 307-79) and the building code requirements for reinforced concrete (ACI 318-77).
  - Ready-mix concrete used in construction of this tower will conform to the requirements of the Standard Specification for ready mixed concrete, ASTM C94-74a.
  - Cement used in mixing concrete will be delivered by truck and meet the requirements of ASTM C150-77. The same brand and type of cement will be used throughout the construction.
  - Aggregate will meet requirements of ASTM C33-77.
  - Reinforcing will meet requirements of ASTM A615-76a.

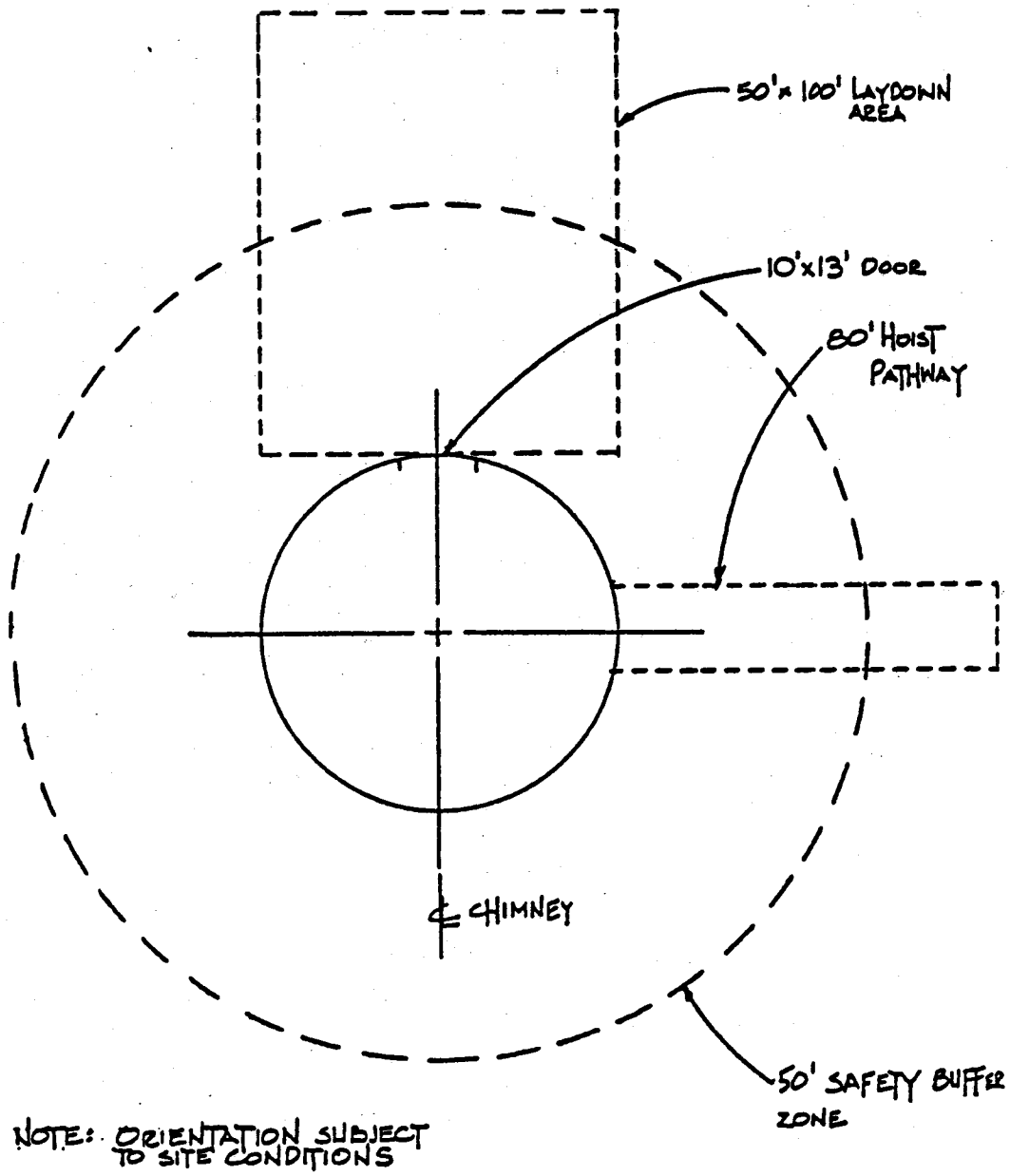


Figure T.3 Site Clearance Requirements

- Since the slipforming techniques will utilize derrick-type equipment, these same derricks will be used for the installation of the structural steel transition piece or the top of the concrete tower. The overall height of the tower including transition piece is 194 m (635 ft).

  Once the concrete slipforming is completed, the personnel/service elevator will be installed within the tower. The elevator will then be used to lift some construction material to the 184 m (605 ft level).

- Internal platforms, ladder, and interior lighting will follow elevator installation.

- Installation of the Molten Salt Receiver

  - The shop fabricated receiver will be shipped to the job-site as individual components and erected in a field-fabricated support structure.
  - Since the concrete tower subcontractor is accustomed to making heavy lifts to great heights and to using hoisting equipment, he is qualified to install steel structures and will include the absorber panels in his work.
  - The panel structural steel members will tie into the 9.1-m (30-ft) high steel section of the concrete tower.
  - After the installation of the support structural steel and checkout, the elevator from level 194 to 219 m (635 to 719 ft) can be installed.
  - Installation of the overhead crane and equipment hoist will follow. Once the overhead crane is installed, the derrick will be disassembled and lowered to the ground.
  - The individual panel components will be hoisted with the overhead crane to the top of the tower through the inner open area. The panel installation will start from the center and proceed left and right simultaneously. Once the panels are installed, the piping, elecric heat tracing, and installation of radiant heaters will take place. The OST and IST will be installed during the support steel erection phase.

- Installation of Riser and Downcomer Piping. Embedments to support the piping will have been installed during the concrete tower erection phase. A system of anchors, guides, and spring hangers will support the riser and downcomer piping. Conventional expansion loops will be utilized. Shop-fabrication pipe will be shipped to the job-site in convenient lengths for field installation. Piping will be installed from top to bottom.

- Instrumentation and Electrical

  - A power riser will be installed and supported from the internal platforming of the tower.
  - Electric tracing and panel heaters at receivers will be installed when receiver panels are in place.

- Other Supporting Systems and Insulation

  - Instrument air and emergency air systems and drain tanks will be installed in the final phase of construction. These items are installed in the final phase to permit sufficient construction work area at the bottom of the tower.
  - Insulation will be one of the final work assignments.

The molten salt RS is one of the many subsystems that comprise the overall 100-MWe solar power station. Construction and erection of the RS will coincide with construction of other subsystems, and this construction and erection plan may be modified as required by the overall system construction schedule.

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