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FORT HOOD SOLAR TOTAL ENERGY PROJECT
VOLUME II: PRELIMINARY DESIGN

Part 1: System Criteria and Design Description, Final Report

January 1979

Work Performed Under Contract No. EM-78-C-04-4231

American Technological University
Killeen, Texas

MASTER

U.S. Department of Energy

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Solar Energy

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VOLUME II: PRELIMINARY DESIGN

PART 1

SYSTEM CRITERIA AND DESIGN DESCRIPTION

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FINAL REPORT
JANUARY 1979

Prepared for

U.S. DEPARTMENT OF ENERGY
DIVISION OF CENTRAL SOLAR TECHNOLOGY
Under Contract No. EM-78-C-04-4321

By

AMERICAN TECHNOLOGICAL UNIVERSITY
Killeen, Texas 76541

With Subcontracting Support From

WESTINGHOUSE ELECTRIC CORPORATION
GEORGIA INSTITUTE OF TECHNOLOGY
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FOREWORD

The Fort Hood Solar Total Energy Project is a large-scale experiment which is part of the Department of Energy's Solar Total Energy Program. The project is a military residential application of solar total energy, and is to be installed at Fort Hood's 87000 Troop Housing Complex where it will provide a substantial portion of the electricity, space heating, cooling, and domestic water heating for approximately 700 people.

The preliminary design for the Fort Hood Solar Total Energy System has been completed and is the principal subject of this four-volume report:

Volume I. Executive Summary
Volume II. Preliminary Design
Volume III. Engineering Drawings
Volume IV. Management Plan

The preliminary design is a mature design as a result of several prior iterations in design criteria and design approach. Hence, it provides a sound point of departure for the subsequent definitive design and construction phases, leading to operational testing early in 1981.

The many persons who have contributed to the project are too numerous to acknowledge individually, but it is appropriate to list several U.S. Army/Corps of Engineers organizations whose cooperation and assistance have made it possible for the Department of Energy and the project team to bring the project to its present state of development:

Office, Chief of Engineers
Headquarters, U.S. Army Forces Command
Headquarters, III Corps and Fort Hood
Headquarters, Training and Doctrine Command Combined Army Test Activity
Fort Worth District, Corps of Engineers
Fort Hood Directorate of Facilities Engineering
Headquarters, 6th Cavalry Brigade (Air Combat)
Headquarters, Atmospheric Sciences Laboratory
Corps of Engineers Central Texas Area Office
U.S. Army Communications Command
Detachment 14, 5th Weather Squadron
Fort Hood Medical Department Activity
Fort Hood ASL Meteorological Team

The cooperation and assistance of the Texas Power and Light Company and Lone Star Gas Company are also gratefully acknowledged.

ABSTRACT

The preliminary design of the Solar Total Energy System recommended for installation at Fort Hood, Texas, is presented in this volume. Part 1 gives the design criteria and describes the system. Part 2 gives the system performance and documents the major supporting studies. The Fort Hood System will be the first solar total energy Large Scale Experiment under the Solar Total Energy Program (STEP)—a separate activity of the National Solar Electric Applications Program supported by the United States Department of Energy. A Solar Total Energy System (STES) maximizes the overall use of collected solar energy by providing both high-grade electrical generation and low-grade heating, cooling, and hot water energy needs for specific site applications. A Large Scale Experiment (LSE) provides program experience in cost-effective design, component fabrication, construction, control, and operation of large-scale STE systems which are essential for the future development of larger full-scale demonstration and commercial STE installations with strong participation by private industry. To achieve simultaneous technological advances, an LSE also must provide for the testing and evaluation of design features and of alternate operational modes.

As a military residential application, the recommended Fort Hood STES design will provide, by solar-derived energy, approximately 57% of the space heating and cooling and domestic hot water requirements of a five-building barracks complex, while also providing up to 250 kw gross electrical output. An oil-thermal storage system supports 24-hour operation in periods of normal insolation. During periods of sustained poor insolation or of maintenance, an auxiliary heater, included in the STES design, can provide all thermal loads. System testing in late 1980 and initial operation in January, 1981 will provide the opportunity for detailed evaluation of the unique control scheme, overall system operation, and individual component performance. Continued operation will provide improved knowledge of operation and maintenance requirements as well as long-term trends in system performance significant to future larger installations.

CONTENTS

PART 1

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

GLOSSARY

TERMS

Auxiliary Oil-Fired Heater - A standby heater fueled by #2 fuel oil which will supply thermal energy during periods of insufficient insolation or major maintenance.

Average Load Day - Total yearly heating (or cooling) load divided by the number of heating (or cooling) days per year.

Chilled Water - Water cooled to 42°F for use in space cooling.

Collector Field - The entire array of 2072 collector modules. These are grouped into the 3 subfields A1 (1008 modules), A2 (728 modules), and A3 (336 modules).

Collector Group - A group of 12 or 13 individual collector modules which are mechanically and hydraulically connected axially in series and rotated by a single drive system.

Collector Module - An individual parabolic collector approximtely 10 ft. in length with a 6 ft. aperture. Included in this is the reflector, receiver, support structure and associated hardware.

Collector Row (String) - A series of collector groups which are hydraulically coupled (axially) in series.

Cooling Season - That period of the year during which the absorption chiller is being used to produce chilled water for space cooling.

Desteer - Rotating the collectors out of focus to temporarily reduce fluid heating for system protection.

87000 (Troop Housing) Complex - Group of buildings on the Fort Hoot Reservation from which 5 were chosen for the STE-LSE program. The specific buildings are: 87012, 87013, 87014, 87015, and 87016.

Electrical Generation Mode - Operation of the system at reduced condenser pressure in order to increase low pressure turbine output. Chilled water may be produced simultaneously, but hot water generated in this mode.

Full Load Day - The daily load used to determine the system design capacity. The actual daily load will be equal to or less than this amount 99% of the time.

Heating Season - That period of the year during which hot water is being used for space heating.

High Grade Energy - Energy supplied in the form of steam, electricity, or mechanical work, or thermal energy stored in oil at a nominal temperature of 225°C (438°F) or above.

High Temperature Operating Mode - Operation of the system when oil is being supplied to the steam generator at nominal 288°C (550°F). In this mode the high pressure turbine is always utilized, while the low pressure turbine and absorption chiller may be used depending on the thermal load (heating or cooling).

High Temperature Storage - Oil stored at a nominal temperature of 288°C (550°F).

Hot Water - 60°C (140°F) water used for space heating or heating domestic water.

Intermediate Temperature Mode - Operation when oil is supplied to the Power Conversion Subsystem at a nominal temperature of 225°C (438°F). In this mode, the high pressure turbine is not used while either or both the low pressure turbine and absorption chiller are used.

Intermediate Temperature Storage - Oil stored at a nominal temperature of 225°C (438°F).

Low Grade Energy - Thermal energy stored in water at a temperature of 65°C (150°F) or less.

Low Temperature Storage - Oil stored at a nominal temperature of 158°C (316°F).

Part-Power Operation - Operation of the system when the total output of electricity, hot and/or chilled water is below the rated capacity.

Peaking Operation - Operation of the system when the steam generator output is at rated capacity.

Solar Total Energy System - An energy system designed to maximize the overall use of collected solar energy by meeting both low grade and high grade energy needs for selected applications.

Thermal Load - The combined energy requirements for winter space heating, production of chilled water used for summer space cooling, and year round domestic hot water.

ABBREVIATIONS

AR	Army Regulation
ATU	American Technological University
CHR/CHS	Chilled Water - Return/Supply
CPU	Central Process Unit
CW	Cold Water (Domestic)
CWS	Chilled Water Cooling Subsystem
DHS	Domestic Hot Water Subsystem
DOD	Department of Defense
DOE	Department of Energy
DPU	Distributive Process Unit
EES-GIT	Engineering Experiment Station - Georgia Institute of Technology
ERDA	Energy Research and Development Administration
EPA	Environmental Protection Agency
FMEA	Failure Mode and Effects (Criticality) Analysis
FTA	Fault Tree Analysis
G	Gas
H&H	Heery & Heery, Inc.
HT	Heat Transfer (Oil)
HWR/HWS	Hot Water - Return/Supply
HWS	Hot Water Heating Subsystem
I&CS	Instrumentation and Control Subsystem
LSE	Large Scale Experiment
MTBF	Mean Time Between Failure
MTTR	Mean Time to Repair
MWS	Makeup Water Subsystem
NIS	Nitrogen Inerting System
PC	Pumped Condensate
PCS	Power Conversion Subsystem
QA	Quality Assurance
SCS	Solar Collector Subsystem

GLOSSARY (Continued)

SS	Sanitary Sewer
STE	Solar Total Energy
STEP	Solar Total Energy Program
STES	Solar Total Energy System
STM	Steam
SUPR	Solar Utilization Program
TSS	Thermal Storage Subsystem
UPS	Uninterruptible Power Supply
W	City Water Supply
W-AESD	Westinghouse Electric Corporation - Advanced Energy Systems Division
WBS	Work Breakdown Structure

1.0 INTRODUCTION

This volume documents the preliminary design developed for the Solar Total Energy System to be installed at Fort Hood, Texas. Current system, subsystem, and component designs are described and additional studies which support selection among significant design alternatives are presented. Because of its size, the volume is bound in two parts. Sections 1, 2 and 3 comprise Part 1 while Sections 4, 5 and 6 comprise Part 2.

Overall system requirements which form the system design basis are presented in Section 2. These include program objectives; performance and output load requirements; industrial, statutory, and regulatory standards; and site interface requirements. Material in this section will continue to be issued separately in the Systems Requirements Document and maintained current through revision throughout future phases of the project.

Overall system design and detailed subsystem design descriptions are provided in Section 3. Consideration of operation and maintenance is reflected in discussion of each subsystem design as well as in an integrated overall discussion. Included are the solar collector subsystem; the thermal storage subsystem, the power conversion subsystem (including electrical generation and distribution); the heating/cooling and domestic hot water subsystems; overall instrumentation and control; and the STES building and physical plant.

The design of several subsystems has progressed beyond the preliminary stage; descriptions for such subsystems are therefore provided in more detail than others to provide complete documentation of the work performed. In some cases, preliminary design parameters require specific verification in the definitive design phase and are identified in the text. Subsystem descriptions will continue to be issued and revised separately to maintain accuracy during future phases of the project.

System performance analysis and evaluation are described in Section 4. Feedback of completed performance analyses on current system design and operating philosophy is discussed. The basic computer simulation techniques and assumptions are described and the resulting energy displacement analysis is presented.

Supporting technical studies are presented in Section 5. These include health and safety and reliability assessments; solar collector component evaluation; weather analysis; and a review of selected trade studies which address significant design alternatives.

Additional supporting studies which are generally specific to the installation site are reported in Section 6. These include solar availability analysis; energy load measurements; environmental impact assessment; life cycle cost and economic analysis; heat transfer fluid testing, meteorological/solar station planning; and information dissemination.

In this volume, reference is frequently made to engineering drawings other than those included as figures. These drawings, are presented separately in Volume III.

Detailed plans for the definitive design are presented in Volume IV where task descriptions, schedule, and management and procurement plans are provided. An overview of the entire Fort Hood Solar Total Energy Project, including a brief description of the system design, is given in Volume I, Executive Summary.

2.0 SYSTEM DESIGN CRITERIA

As a large scale experiment of the United States Department of Energy Solar Total Energy Program, the Fort Hood Solar Total Energy System design is predicated on fulfillment of program objectives. Those program objectives are discussed first, followed by consequential system performance and other design criteria which form the basis for this specific design application.

2.1 PROGRAM OBJECTIVES

Three "top-level" design criteria have been taken from Solar Total Energy Program documents to establish the rationale for more detailed "low-level" requirements.

1) Provide a Solar Total Energy System (STES) design, producing both electrical and thermal energy outputs, tailored to the specific Fort Hood site requirements.

2) Develop the technology base and system engineering experience needed for subsequent design of larger commercial-scale solar total energy systems.

3) Obtain, through STE-LSE operations,sufficient data to evaluate the feasibility and cost effectiveness of STES in the 2MW range for eventual commercial applications.

Nine specific program objectives apply directly to the Fort Hood Project:

4) Five buildings of the 87000 Troop Housing Complex have been selected for this application. At least 50% of the annual thermal energy requirements (space heating, air conditioning and domestic hot water) of those buildings shall be provided by solar energy.

5) Sufficient thermal storage capacity shall be provided to satisfy thermal loads during 24 hour operation.

6) A standby fossil fired energy source shall satisfy 100% of the peak thermal loads when solar energy is unavailable or insufficient.

7) To simulate larger scale turbine generators with inter-stage steam extraction, a multi-stage turbine generator with capacity between 200 - 500 KW electric shall be used.

8) Electrical power generation should be synchronized for possible parallel operation with existing power sources.

9) Although secondary to satisfaction of thermal load requirements, the system should provide positive net generation of electricity with peak shaving capability.

10) Once started up, the STES shall be capable of operation independent from existing energy sources.

11) The ability to return buildings to the existing energy sources with a minimum disruption shall be provided to minimize impact of the experiment on operation of the 87000 building complex.

12) To maximize the use of collected solar energy with minimum operator input, a computer control system shall identify and establish (subject to operator override) the most advantageous operating configurations depending on all relevent energy availability and demand parameters.

2.2 SYSTEM PERFORMANCE REQUIREMENTS

Specific, quantitative requirements result from the program objectives as follows:

1) The system shall be designed to satisfy a peak heating load of 66.4 x 10^6 Btu/day per the hourly load profile of Figure 2.2-1.

2) The system shall be designed to satisfy a peak cooling load of 49.5 x 10^6 Btu/day per the hourly load profile of Figure 2.2-2.

3) The domestic hot water system shall be designed to produce 32,000 gallons/day of 140^{o}F water. Domestic hot water demand shall be as shown on Figure 2.2-3.

4) The electrical system shall be sized to produce at least 200 KW gross of electricity during periods of peak electrical demand.

5) To assure proper consideration of electrical generation, a target of 1600 KW/hour gross electric generation per day on an average annual basis is established.

6) To reflect the use of commercial application quality equipment, a plant availability of 85% shall be used in performance evaluations.

2.3 ENVIRONMENTAL CONDITIONS

The STES shall be designed to survive the following environmental conditions:

• Temperature - System to be operable with ambient temperatures: - Min.	$-12^{o}C$ ($10^{o}F$)
- Max.	$50^{o}C$ ($122^{o}F$)
• Snow and Ice - per ANSI A58.1-1972 - on the ground:	238 Pa (5 lb/ft^2)
• Earthquake - per ANSI A58.1-1972:	Zone 1
• Rain and Humidity	
Average Annual Rainfall	825 mm (32.5 in)
Maximum Rainfall in 24 Hours	180 mm (7 in)
Relative Humidity - Normal Range	53 - 88%
• Lightning	
Peak discharge current	100,000 amps
Rise Time	1 Ms
• Hail - Diameter:	13 mm (0.5 in)
Terminal Velocity:	15.5 m/s (51 Fps)
• Wind (Maximum)	
Operating	16 m/s (35 mph)
Survival - collectors unstowed	22 m/s (35 mph)
collectors stowed	34 m/s (75 mph)

2.4 SITE INTERFACE REQUIREMENTS

1) The STE Facility shall be located adjacent to the 87000 Troop Housing Complex at Fort Hood, on a site bounded by Battalion Avenue, Martin Drive, 15th Street and Central Avenue (Future) as shown in Drawing 1-1 in Volume III. Displaced parking and recreation facilities shall be relocated.

2) All interfaces shall be compatible with existing Fort Hood systems (energy, power, plumbing, drainage, alarm, etc.) and the presence, operation, or non-operation of the STES shall not impair existing services.

3) All oil storage units shall utilize dikes, catchment areas and relief vessels to contain leaks and prevent the contamination of the environment.

4) All waste discharges shall be monitored for the presence of oil and toxic or hazardous substances.

5) The fossil fueled boiler shall be equipped with air pollution abatement equipment or will use the type of fuel necessary to meet requirements for air pollution abatement.

6) The STE facility shall be aesthetically compatible with the local environs, and shall meet necessary environmental requirements including applicable Federal, State and local pollution control standards and criteria.

2.5 OPERATION AND MAINTENANCE REQUIREMENTS

1) To assure the large scale experiment is conducted with commercial application quality equipment, the STES shall be designed with the goal of achieving a system operating life of 20 years with normal maintenance.

2) A reliable power supply shall be provided to critical system controls to allow continual operation through momentary power transients and safe shutdown upon loss of all power.

3) To maximize the availability of the STES, no scheduled maintenance shutdowns will occur during the operating day. Normal maintenance will be accomplished during the evening for the solar collectors and during the early morning hours for the remainder of the power plant.

4) Controls and indicators shall be mounted and located for personnel access.

5) All equipment shall be designed to be maintained using standard tools. When special tools or fixtures are required, they shall be furnished by the equipment supplier.

6) All parts or equipment which may require servicing, repair or replacement during the lifetime of the equipment shall be accessible without minimum interruption of adjacent mounted equipment and with a logical removal path defined and documented.

2.6 HEALTH AND SAFETY REQUIREMENTS

1) The STES shall be designed to prevent injury to personnel and potential damage to structures resulting from exposure to concentrated solar beams.

2) The STES shall be designed to prevent the exposure of personnel to high temperatures by providing sufficient insulation around all high temperature components.

3) The STES shall be designed to minimize the potential fire hazards and burn hazards which could result from leaks of heated hydrocarbon oils.

4) Adequate precautions shall be incorporated into the design of the STES to reduce the hazards of exposure to high voltage, superheated steam and equipment-generated high noise levels. Fencing shall be used to enclose installations and separate areas within installations which require maximum security and/or protection of life.

2.7 APPLICABLE CODES, REGULATIONS AND STANDARDS

The following standards, regulations, manuals, and codes shall be used as design guidelines:

- American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code:
    - Section I, Power Boilers
    - Section II, Material Specifications
    - Section V, Nondestructive Examination
    - Section VIII, Pressure Vessels
    - Section IX, Welding and Brazing Qualifications
- American Petroleum Institute (API)
    - API Standard 650: Welded Steel Tanks for Oil Storage
    - API Standard 610: Centrifugal Pumps for General Refinery Services
- National Fire Protection Association (NFPA):
    - Fire Protection Handbook
    - National Fire Codes:

        Standard No. 15: Water Spray Fixed Systems
        Standard No. 30: Flammable and Combustible Liquids Code
        Standard No. 68: Explosion Prevention Systems
        Standard No. 70: National Electrical Code
- American National Standards Institute (ANSI):
    - ANSI A13.1, Scheme for the Identification of Piping Systems
    - ANSI A58.1, Building Code Requirements for Minimum Design Loads in Buildings and other Structures
    - ANSI B31.1, Power Piping Code
    - ANSI B31.3, Petroleum Refining Piping
    - ANSI Z53.1, Safety Color Code for Marking Physical Hazards and Identification of Equipment

- Occupational Safety and Health Administration (OSHA):
  - OSHA 2206 (29 CFR 1910) General Industry Safety and Health Standards
  - 39-FR-125 Standards
- Army Regulations (AR) and Memorandum:
  - AR-385-10, Army Safety Program
  - AR 385-16, Safety System
  - AR 385-30, Safety Color Code Markings and Signs
  - AR 420-49, Heating, Energy Selection and Fuel Storage, Distribution, and Dispensing Facilities.
  - AR 420-28, Spill Prevention Control and Countermeasure Plan
  - C2, AR 200-1, Chapter 6, Hazardous and Toxic Materials Management
  - C2, AR 200-1, Chapter 9, Oil and Hazardous Substances Spill Control and Contingency Plan
  - Army Memorandum, Campaign HEAL
- Energy Research and Development Administration (ERDA)
  - 77-47/5, Environmental Factors, Solar Total Energy Systems
- Environmental Protection Agency (EPA):
  - EPA-600/7-77-016
- Department of Defense (DOD)
  - DOD 4270.1M, Construction Criteria Manual
- American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE):
  - ASHRAE Standards of Design of HVAC Equipment
  - ASHRAE Standard 90-75, Energy Conservation in New Building Design
  - ASHRAE Standard 93, Solar Collectors
  - ASHRAE Standard 94, Thermal Storage Devices
- Air Conditioning and Refrigeration Institute (ARI):
  - Standards for Cooling Towers and Condensers

- Hl-Code for Hydraulic Pumps
- American Insurance Association
  - National Building Code
- National Electric Manufacturers Association (NEMA):
  - Standards for Electrical Equipment and Controls
- Safety Rules for the Installation and Maintenance of Electric Supply and Communication Lines
- Steel Boiler Institute (SBI):
  - Codes for Boilers
- Tubular Exchanger Manufacturers Association (TEMA):
  - Standards for Heat Exchangers
- Underwriters' Laboratory (UL) Standards
- Uniform Building Code
- Standards of American Institute of Steel Construction and American Concrete Institute
- Interstate Commerce Commission (ICC) Shipping Standards and Regulations
- National Safety Council
  - Accident Prevention Manual for Industrial Operations
- Quality Assurance
  - TME 2908, "Quality Assurance Program Plan, Fort Hood STE-LSE", (W) AESD, June, 1978.
- Factory Material Handbook of Industrial Loss Prevention
- "Texas Air Control Board, General Rules," Texas Air Control Board, Austin, Texas, April 25, 1977.
- "Texas Air Control Board, Regulation I, Control of Air Pollution from Visible Emmissions and Particulate Matter," Texas Air Control Board, Austin, Texas.
- "Texas Air Control Board, Regulation II, Control of Air Pollution from Sulfur compounds," Texas Air Control Board, Austin, Texas.

- "Texas Air Control Board, Regulation IV, Control of Air Pollution from Motor Vehicles," Texas Air Control Board, Austin, Texas.
- "Texas Air Control Board, Regulation V, Control of Air Pollution from Volatile Carbon Compounds," Texas Air Control Board, Austin, Texas.
- "Texas Air Control Board, Regulation VI, Control of Air Pollution by Permits for New Construction or Modification," Texas Air Control Board, Austin, Texas.
- "Regulation VII, Control of Air Possution from Nitrogen Compounds," Texas Air Control Board, Austin, Texas.
- "Regulation VIII, Control of Air Pollution Episodes," Texas Air Control Board, Austin, Texas.

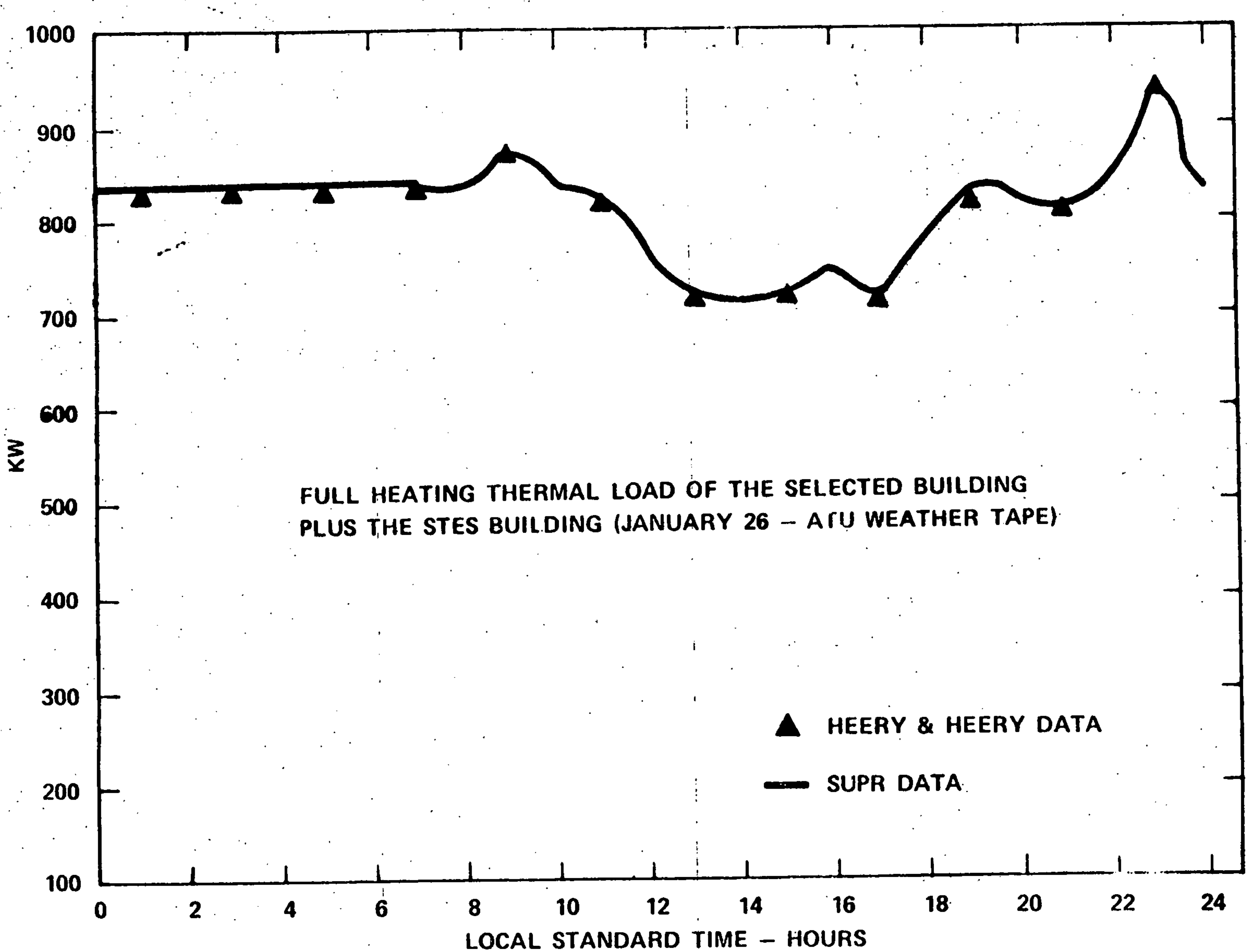


Figure 2.2-1. Peak Heating Thermal Load

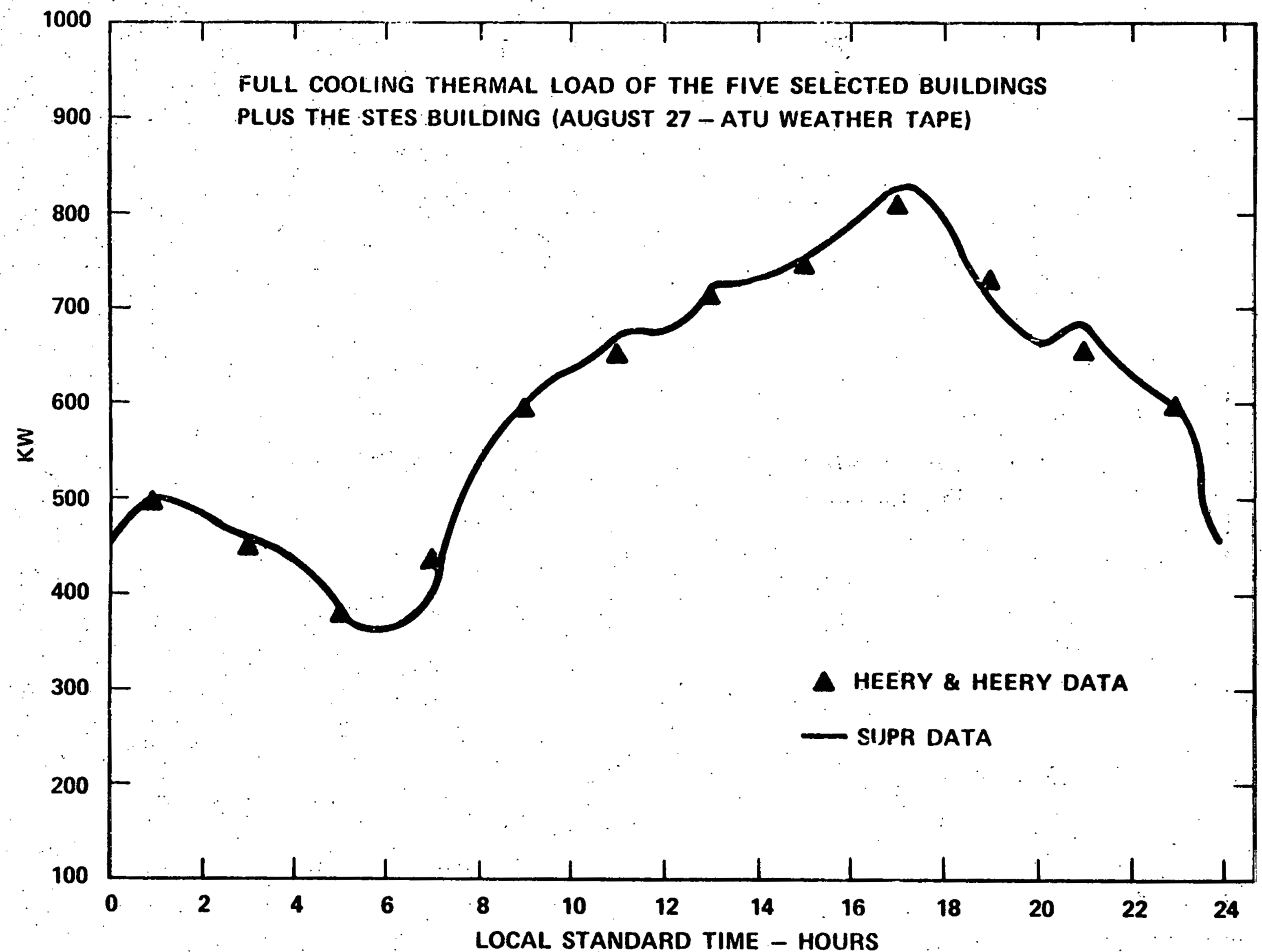


Figure 2.2-2. Peak Cooling Thermal Load

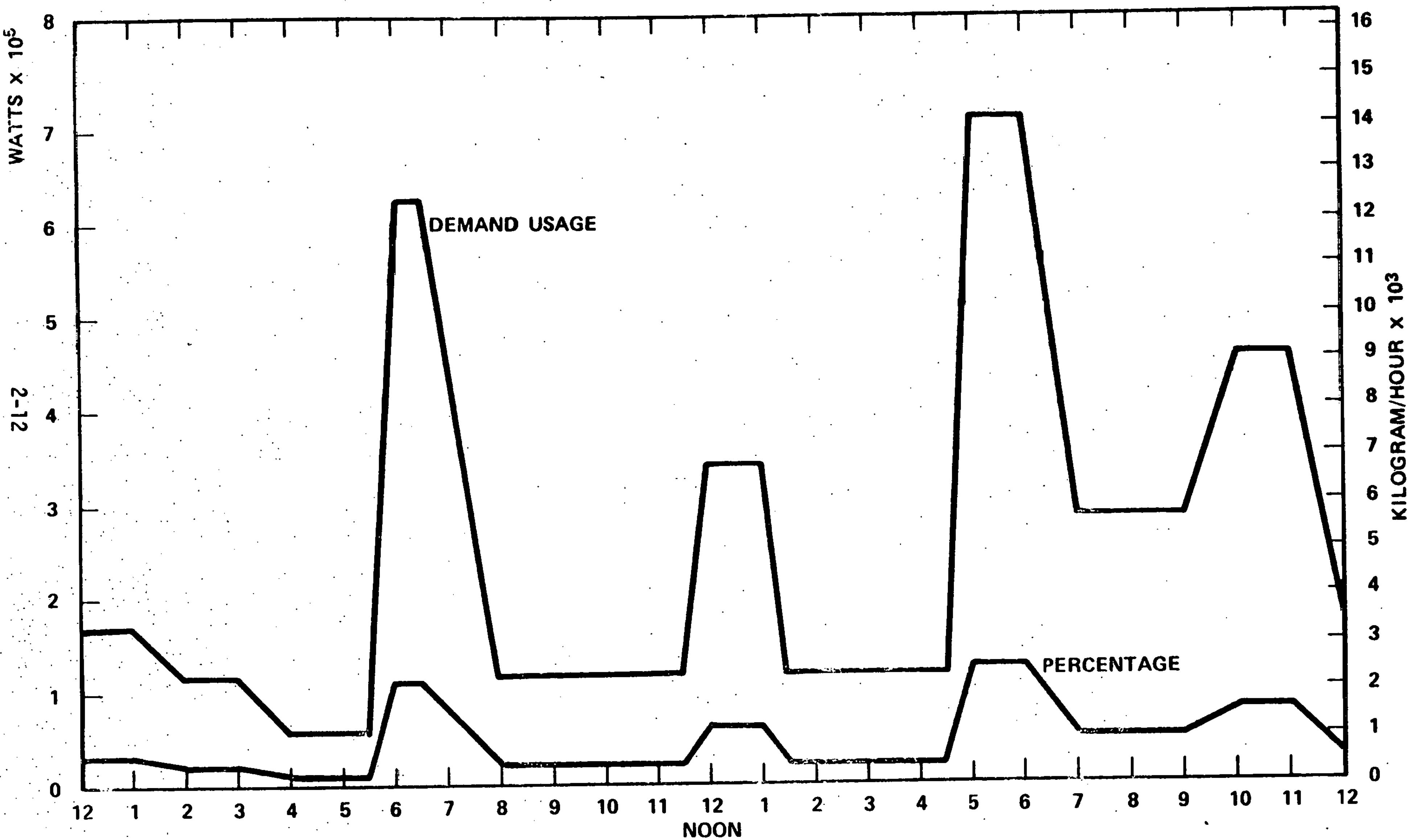


Figure 2.2-3. Domestic Hot Water Demand

3.0 SYSTEM DESCRIPTION

3.1 OVERALL SYSTEM

The Solar Total Energy - Large Scale Experiment (STE-LSE) at Fort Hood is comprised of the following major mechanical subsystems: solar collector, thermal storage; power conversion; hot water heating; chilled water cooling; and domestic hot water. Associated with each of these subsystems for the STE-LSE are various control and instrumentation components, the STES building, and specific modifications to and interfaces with the Fort Hood facilities.

This section briefly describes the overall system and the major subsystems in the STE-LSE that generate electrical power and provide the thermal power for the space heating, cooling, and domestic hot water requirements for the barracks and administration building complex. A brief summary of the STES operating and control philosophy is given along with a summary description of the site at Fort Hood.

3.1.1 STES SUMMARY DESCRIPTION

Figure 3.1-1 presents an overall schematic of the system, along with components and piping associated with each subsystem. Flow paths and the direction of flow are indicated by the solid arrows on the figure for the high temperature mode heating season in which electrical power, hot water heating, and domestic hot water are provided. The alternate chilled water cooling flow paths and direction of flow for air conditioning purposes during the high temperature mode cooling season are denoted by the open arrows. The overall system characteristics are given in Table 3.1-1.

3.1.1.1 SOLAR COLLECTOR SUBSYSTEM

As shown in Figure 3.1-1, the solar collector is comprised primarily of a series-parallel arrangement of solar parabolic trough collectors placed in a collector field with associated piping and control, isolation and drain valves.

TABLE 3.1-1

OVERALL SYSTEM CHARACTERISTICS

CHARACTERISTICS:

• Application	Commercial/Residential
• Energy Utilization	Electric Domestic Hot Water Air Conditioning Heating
• Plant Operation	24 hours/day
• Estimated Annual Energy Consumption:	
- Cooling	624 GJ (5.8 x 10^9 Btu)
- Heating	452 GJ (4.2 x 10^9 Btu)
- Domestic Hot Water	785 GJ (7.3 x 10^9 Btu)
• Electric Utility Interface	Parallel Synchronous or Independent Operation
• Annual Average Direct Insolation	597 GJ/m^2 (515.7 MBtu/sq-ft)*
• Annual Energy Displacement	
- Electrical	58%
- Thermal	57%
• Site Size	6.1 Hectares (15.1 Acres)
• Normal Collector Aperture Area	11,612 m^2 (125,000 sq-ft)
• Solar Heat Transfer Fluid (oil)	SUN 21
- Maximum Bulk Oil Temperature	288°C (550°F)
- Maximum Flow Rate	21 ℓ/sec (330 GPM)
• Thermal Electric Working Fluid	Steam
- Normal Operating Steam Temperature	260°C (500°F)
- Normal Operating Steam Throttle Pressure	2164 kPa (300 psig)
- Maximum Flow Rate at 260°C (500°F)	45.3 kg/sec (6000 lb/hr)
• Domestic Hot Water:	
- Temperature	60°C (140°F)
- Daily Consumption	121 x 10^3 ℓ (32,000 gal)
• Cooling	604 kW (172 tons)
• Peak Daily Heating	7.14 GJ (66.4 MBtu)
• System Mechanical Availability, Estimated	85%
• Overall System Thermal Efficiency	71%

*Killeen, Texas Data

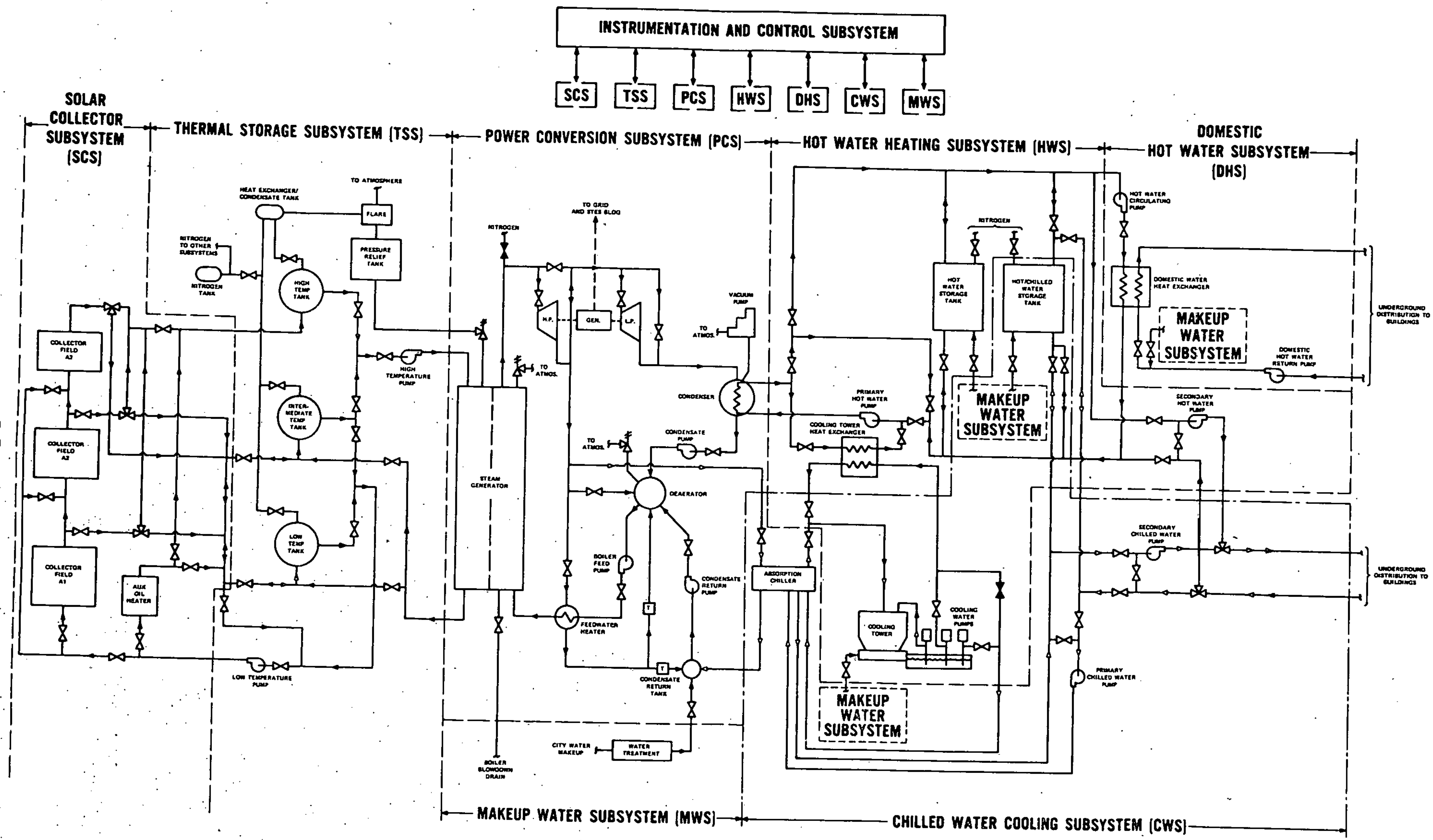


Figure 3.1-1. System Schematic for STE-LSE at Fort Hood

The solar collectors collect and convert solar flux to increase the enthalpy of the heat transfer fluid. The solar collector subsystem receives the heat transfer fluid from the thermal storage system. Thermal energy is transferred to the heat transfer fluid, increasing the fluid's temperature, before returning the oil back to the thermal storage subsystem. During periods of good insolation, the thermal energy is provided by parabolic line focusing through type collectors. An auxiliary oil-fired heater provides the thermal energy during extended periods of poor insolation or during major maintenance of the collector field. The oil-fired heater may also be utilized to augment the collector field in parallel arrangement. The oil-fired heater is also considered part of the solar collector system. The solar collector subsystem mechanically and hydraulically interfaces with the thermal storage subsystem and electrically interfaces with the control system.

Groups of 12 to 13 collector modules are mechanically coupled so that a single drive system rotates the group of modules. The drive system receives a position demand from the control system based on computed sun position and positions the collector group to the demanded position. External signals can be input to the drive system to command operation in the different modes (normal tracking, desteer and stow). Normal tracking occurs when the sun is out and the wind is acceptably low. Desteer is used to direct the collector off-focus to temporarily reduce fluid heating for system protection and to avoid fluid over-temperature damage. In the stow mode, the collectors are rotated to a near-inverted position to avoid damage and to simplify cleaning procedures. The groups are hydraulically coupled in series to produce a row or string.

The collector field is divided into three subfields. The row axis orientation is 17° east of north with a spacing of 4.0m between rows. The collector field has 84 rows (28 in each subfield) with a total of 2072 modules of a representative size.

The flow rate into each subfield is controlled by flow control valves. Flow is directed into the largest subfield. Depending on temperature, the heated oil from this subfield is either mixed with flow from the pump and directed into the intermediate-sized subfield, or the flow is split between the inlet to the intermediate-sized field and recirculated to the pump. In turn, the heated oil from the intermediate-sized field is mixed with oil from the pump and directed to the smallest subfield. From the smallest subfield, the heated oil is returned to the oil storage tanks. The solar collector subsystem characteristics are given in Table 3.1-2.

The solar collector subsystem is described in detail in Section 3.2.

3.1.1.2 THERMAL STORAGE SUBSYSTEM

The thermal storage subsystem provides two basic functions. First, this subsystem transfers the thermal energy collected in the solar collector subsystem to the power conversion subsystem. Secondly, the storage subsystem provides a three temperature level heat transfer fluid storage capability. This capability allows several different modes of 24-hour operation of the STE-LSE for varying requirements and seasons.

The thermal storage subsystem contains the following components: three (high, intermediate and low temperature) storage tanks, pressure relief tank, liquid nitrogen storage tank and subsystem, various control, isolation and drain valves, high temperature circulating pumps, low temperature circulating pumps, and all of the associated piping.

During heat storage operation, also called charging, oil is withdrawn from the low temperature tank, pumped through the solar collector subsystem, heated, and returned to the high (or sometimes intermediate) temperature storage tank. During discharging operation, when heat is extracted from storage for steam generation, oil is withdrawn from the high or intermediate temperature tank, pumped through to power conversion subsystem steam generator, cooled, and returned to the low temperature tank.

The storage tanks for oil are blanketed with nitrogen in the tank ullage to prevent fluid oxidation. The nitrogen is supplied to the system from a centrally located liquid nitrogen storage system. The nitrogen inerting blanket is maintained automatically through pressure regulation and bleed-off. The storage tanks containing the oil are interconnected such that when one tank is emptying and another tank is filling, the nitrogen flows from the tank

TABLE 3.1-2

SOLAR COLLECTOR SUBSYSTEM CHARACTERISTICS

CHARACTERISTIC:	
• Solar Collectors	
- Type	Parabolic Trough
- Size	1.83 x 3.05 m (6 x 10 ft)*
- Total Area	11,550 m^2 (124,320 sq-ft)*
- Number of Modules	2072*
- Tracking	Single Axis
- Tracking Accuracy:	
- Open-Loop Computer Designated	$\pm$4m radian ($\pm 0.25^{\circ}$)
- Slew Rate in 22.4 m/s (50 mph) wind	4m radian/sec (15°/min) minimum
- Concentration Ratio	37*
- Reflective Surface	Coilzak Lighting* Sheet Reflector
- Reflectivity	0.75 to 0.80
• Collector Field:	
- Number of Collector Strings	87 (3 Subfields of 28)*
- Spacing	4m (13.2 ft)*
- Orientation (degrees east of north)	17
- Loop Losses and Thermal Capacity:	
- Loop Losses (10^3 Btu/hr)	95 kW (325 x 10^3 Btu/hr)
- Thermal Capacity, Receivers only at 260^{o}C (500^{o}F)	1.45 MJ/^{o}C (7486 Btu/^{o}F)
- Fluid Capacity (Receivers Only)	3255 ℓ (860 gal)
- Inlet/Outlet Temperature	158/288^{o}C (316/550^{o}F)
- Heat Transfer Fluid Flow Rate:	
- Volumetric	10.6 ℓ/s (168 gpm)
- Mass	483 kg/s (64,000 lb/hr)
• Oil Fired Heater	
- Inlet/Outlet Temperature (Normal)	158/226^{o}C (316/438^{o}F)
- Fuel	No. 2 Oil
- Heat Capacity	1.5 MW (5 x 10^6 Btu/hr)

*Reference Collector Value (Acurex 3001 chosen as a representative design).

being filled back to the tank being emptied without introducing pressure differences which affect system operation.

The thermal storage subsystem is described in detail in Section 3.3. Characteristics of the thermal storage subsystem are given in Table 3.1-3.

TABLE 3.1-3

THERMAL STORAGE SUBSYSTEM CHARACTERISTICS

CHARACTERISTICS:	
• Maximum Thermal Capacity	11.8 GJ (110 x 10^6 Btu)
• Storage Medium	SUN 21
• Number of Tanks	3
• Tank Capacity (Total/Active):	
- High Temperature	197/127 m^3 (50,680/33,570 gal)
- Intermediate Temperature	529/442 m^3 (140,100/116,450 gal)
- Low Temperature	498/413 m^3 (132,170/108,690 gal)
• Oil Storage Temperature:	
- High Temperature	288°C (550°F)
- Intermediate Temperature	226°C (438°F)
- Low Temperature	158°C (316°F)
• Maximum Charging Rate	766 kg/s (101,500 lb/hr)
• Maximum Discharging Rate	565 kg/s (74,850 lb/hr)
• Oil Inventory	406 Mg (894,400 lb)

3.1.1.3 POWER CONVERSION SUBSYSTEM

A power conversion subsystem converts the thermal energy collected and/or stored in the collector and thermal storage subsystems into useful electrical energy and into steam or hot water that can be utilized for space heating and cooling, and domestic hot water for the Fort Hood complex. The power conversion subsystem is composed of the following components: steam generator, preheater, boiler, and superheater, high pressure turbine, low pressure turbine, gear reducer, electrical generator, condenser, condensate pump, deaerator, boiler feed pump, feedwater heater, all of the associated piping, and control and isolation valves. Water quality in the boiler is controlled by treatment of the makeup water that is added continuously while particulates are removed by continuous blowdown.

This power conversion subsystem generates electrical power for the STES and the Fort Hood grid, fulfills the space heating and domestic hot water requirements at the condenser interface, and provides energy to the absorption chiller for chilled water (air conditioning) purposes. Two single-stage turbines are used in the subsystem; these turbines are representative of larger extraction turbine technology.

The power conversion subsystem provides the means of meeting the load requirements for the overall system as described in Section 2. The electric generation part of the power conversion subsystem is provided by a turbine generator single-skid mounted package containing two turbines; a synchronous generator, a gear reducer, clutches mounted between each turbine and the gear reducer, and the associated controls. Most of the components and piping associated with the power conversion subsystem are contained within the STES building. The power conversion subsystem is described in detail in Section 3.4. Characteristics of the power conversion subsystem are given in Table 3.1-4 for several operating conditions.

3.1.1.4 HEATING, COOLING AND DOMESTIC HOT WATER SUBSYSTEMS

Circulating water subsystems provide the heating, cooling and domestic hot water requirements of the Fort Hood STE-LSE. Heat is extracted from the steam cycle at the condenser during the heating season and is delivered to the selected buildings by the circulating hot water heating system. The same system is used to heat the domestic hot water. An absorption chiller driven by steam provides the chilled water for cooling in the cooling subsystem. These subsystems are described below. Table 3.1-5 gives the characteristics of the hot water heating, chilled water cooling, and domestic hot water subsystems.

TABLE 3.1-4

POWER CONVERSION SUBSYSTEM CHARACTERISTICS

STEAM GENERATOR (Peak Cooling Mode):

	High Temperature	Intermediate Temperature
SUN 21 Flow Rate	440 kg/s (58,318 lb/hr)	353 kg/s (46,743 lb/hr)
Inlet Temperature	288°C (550°F)	226°C (438°F)
Discharge Temperature	226°C (438°F)	158°C (316°F)
Steam Flow Rate	35.3 kg/s (4675 lb/hr)	30.3 kg/s (4011 lb/hr)
Pressure	2164 kPa (300 psig)	445 kPa (50 psig)
Steam Temperature	260°C (500°F)	148°C (298°F)
Feed Water Temperature	144°C (291°F)	144°C (291°F)
Blowdown Flow Rate	0.45 kg/s (60 lb/hr)	0.45 kg/s (60 lb/hr)
Configuration:		
- Preheater	Yes	Yes
- Boiler	Yes	Yes
- Superheater	Yes	No

STEAM GENERATOR (Peak Heating Mode):

SUN 21 Flow Rate	565 kg/s (74,850 lb/hr)	353 kg/s (46,743 lb/hr)
Inlet Temperature	288°C (550°F)	226°C (438°F)
Discharge Temperature	226°C (438°F)	158°C (316°F)
Steam Flow Rate	45.3 kg/s (6000 lb/hr)	30.3 kg/s (4011 lb/hr)
Pressure	2164 kPa (300 psig)	445 kPa (50 psig)
Steam Temperature	260°C (500°F)	148°C (298°F)
Feed Water Temperature	144°C (291°F)	144°C (291°F)
Blowdown Flow Rate	0.45 kg/s (60 lb/hr)	0.45 kg/s (60 lb/hr)
Configuration:		
- Preheater	Yes	Yes
- Boiler	Yes	Yes
- Superheater	Yes	No

TABLE 3.1-4 (Continued)

	High Temperature	Intermediate Temperature
TURBINE/GENERATOR (Peak Cooling Mode):		
Throttle Temperature	260°C (500°F)	148°C (298°F)
Throttle Pressure	2164 kPa (300 psig)	445 kPa (50 psig)
Throttle Flow HP/LP	35/16.2 kg/s (4675/2143 lb/hr)	0/11.7 kg/s (0/1546 lb/hr)
Extraction Temperature	153°C (307°F)	148°C (298°F)
Extraction Pressure	445 kPa (50 psig)	445 kPa (50 psig)
Extraction Flow	19.1 kg/s (2532 lb/hr)	18.6 kg/s (2465 lb/hr)
- Process Steam (Absorption Chiller)	15 kg/s (1986 lb/hr)	15.1 kg/s (1996 lb/hr)
- Deaerator	1.8 kg/s (239 lb/hr)	1.5 kg/s (198 lb/hr)
L.P. Turbine Discharge Temperature	72°C (161°F)	72°C (161°F)
L.P. Turbine Discharge Pressure	33.7 Pa (4.9 psia)	33.7 Pa (4.9 psia)
L.P. Turbine Discharge Flow	16.2 kg/s (2143 lb/hr)	11.7 kg/s (1546 lb/hr)
Electrical Output (Gross/Net)	135/48 kW	27/-51 kW
TURBINE/GENERATOR (Peak Heating Mode):		
Throttle Temperature	260°C (500°F)	148°C (298°F)
Throttle Pressure	2164 kPa (300 psig)	445 kPa (50 psig)
Throttle Flow HP/LP	44.9/39.2 kg/s (6000/5234 lb/hr)	0/26.1 kg/s (0/3487 lb hr)
Extraction Temperature	148°C (298°F)	148°C (298°F)
Extraction Pressure	445 kPa (50 psig)	445 kPa (50 psig)
Extraction Flow	5.8 kg/s (765 lb/hr)	3.9 kg/s (513 lb/hr)
- Process Steam (Absorption Chiller)	0	0
- Deaerator	2.8 kg/s (370 lb/hr)	1.9 kg/s (246 lb/hr)
L.P. Turbine Discharge Temperature	72°C (161°F)	72°C (161°F)
L.P. Turbine Discharge Pressure	33.7 Pa (4.9 psia)	33.7 Pa (4.9 psia)
L.P. Turbine Discharge Flow	39.5 kg/s (5234 lb/hr)	26.3 kg/s (3487 lb/hr)
Electrical Output (Gross/Net)	247/178 kW	76/20 kW

TABLE 3.1-5

HEATING, COOLING AND DOMESTIC HOT WATER SUBSYSTEM CHARACTERISTICS

CHARACTERISTIC:	
• Chilled Water Absorption Air Conditioner:	
- Capacity (at 50 psig inlet steam)	611 kW (174 tons)
- Design Load	604 kW (172 tons)
- Operating Fluid	Steam/Li Br Solution
- Temperature	153°C (307°F)
• Cooling Tower	2.14 MW (7.3 MBtu/hr)
• Domestic Hot Water Heat Exchanger	0.59 MW (2 MBtu/hr)
• Hot Water Storage:	
- Capacity	882 MJ (8.2 MBtu)
- Volume (Total/Active)	132.5/94.6 m^3 (35,000/25,000 gal)
• Domestic Hot Water:	
- Maximum Flow Rate	3.85 ℓ/s (61 gpm)
- Temperature	57.2°C (135°F)
• Chilled Water Storage:	
- Capacity	591 MJ (5.5 MBtu)
- Volume	197/155 m^3 (52,000/41,000 gal)
• Chilled Water Supply (Peak):	
- Flow Rate	20.5 ℓ/s (325 gpm)
- Plant Inlet Temperature	5.5°C (42°F)
- Plant Discharge Temperature	14.4°C (58°F)
• Hot Water Heating (Peak):	
- Flow Rate	20.5 ℓ/s (325 gpm)
- Plant Inlet Temperature	60°C (140°F)
- Plant Discharge Temperature	37.8°C (100°F)

HOT WATER HEATING SUBSYSTEM

The hot water heating subsystem contains the following components: hot water storage tank, hot water pump, hot water/condenser pump, condenser/cooling tower heat exchanger, condenser cooling water pump, associated piping connecting these components, and appropriate control, isolation, purge and drain valves. The condenser from the power conversion subsystem and the cooling tower and hot/chilled water storage tank from the chilled water cooling subsystems are used in the operation of the hot water heating subsystem. The existing Fort Hood system, with 12 psi steam, has not been utilized so that more efficient power conversion can be attained; however, the existing system remains in place as a backup for space heating and domestic water heating.

Hot water space heating is provided to the Fort Hood complex by utilizing the thermal energy that is transferred from the power conversion subsystem through the condenser. Energy in excess of the immediate demand is stored in the hot water storage tanks. The hot water storage tank is filled first. Then the storage tank of the chilled water cooling system (referred to as the hot/chilled water storage tank) is used for additional hot water storage capacity during the heating season. (Note: During the cooling season, only the hot water storage tank is used for hot water storage for use with the domestic hot water system. In the cooling season, only the hot/chilled water storage tank is used for chilled water storage.) When these tanks are thermally charged, excess heat is rejected to the cooling tower by a plate-type heat exchanger in a separate loop. Periods of operation for the STE-LSE when excess energy is available occur particularly during the spring and fall. During operation in the cooling season, only domestic hot water is provided to the selected buildings; the space heating system is not used and is isolated by control valves from the domestic hot water storage piping. Makeup water to the hot water heating closed loop is supplied as required from base domestic supply. Also, nitrogen over-pressure is maintained in the storage tanks and acts as a buffer for surge control.

The thermal distribution loop for the selected buildings is shown in Figure 3.1.2. The hot water heating subsystem is described in detail in Section 3.5.

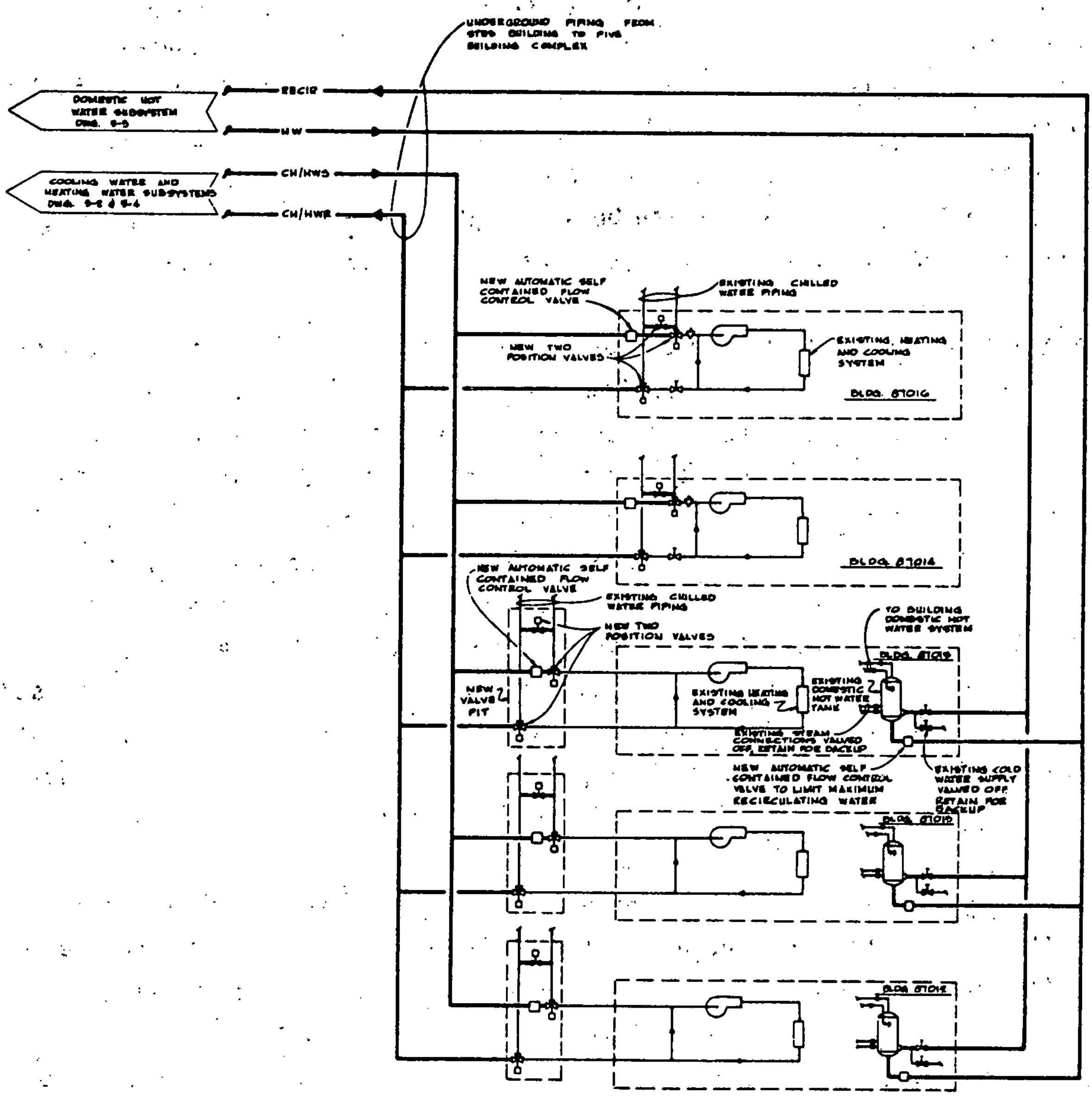


Figure 3.1-2. Primary/Secondary Thermal Distribution

CHILLED WATER COOLING SUBSYSTEM

The chilled water cooling subsystem provides cooling (air conditioning) to the selected buildings. This subsystem is comprised of the following components: two-stage absorption chiller, chilled water/hot water storage tank, chilled water pump, chilled water booster pump, cooling tower, chiller condenser pump, all of the associated piping, and control, isolation and drain valves. Chilled water is produced by an absorption chiller that is driven by low-pressure steam from the power conversion subsystem. The cooling tower and chiller condenser pump are used with the chilled water cooling subsystem to provide for waste heat rejection from the absorption chiller.

The chilled water storage tank supplies chilled water when the cooling demand is greater than chiller output and collects chilled water when the demand is less than chiller output. As with the hot water heating subsystem, makeup water is supplied to this closed loop as required from the base domestic supply. Also, nitrogen overpressure is maintained in the storage tank.

The thermal distribution water loop is shown schematically in Figure 3.1-2 and the chilled water subsystem is described in detail in Section 3.5.

DOMESTIC HOT WATER SUBSYSTEM

The domestic hot water subsystem is comprised of the hot water heat exchanger a hot water circulating pump, a pump for circulation of the domestic hot water, associated piping, and control and isolation valves. As shown in Figure 3.1-2 STES domestic hot water is supplied to just three of the five selected buildings - those with residential equipment. The other two buildings are administrative with low requirements which do not justify connection to the STES. The subsystem is connected to a city water makeup line that provides a supply of water to fulfill the domestic hot water requirements. Heating of the water is provided by the plate heat exchanger that extracts heat from the hot water heating subsystem through the condenser and hot water and hot/chilled water storage tanks.

The hot water storage tank is used to provide the needed domestic hot water during the summer months when the hot/chilled water tank is being used to store chilled water.

3.1.2 OPERATION AND CONTROL PHILOSOPHY

The basic philosophy of the operation of the STES is to absorb as much solar energy as is available and convert it to either process thermal energy or electrical energy. The domestic hot water and space heating (or cooling) loads are satisfied first and then, when possible, electrical power generation is supplied for load peak shaving. However, when the collection of solar energy is inadequate (due to poor solar insolation weather conditions) to satisfy daily thermal requirements, the oil-fired heater will be used. If solar insolation exceeds the thermal load, the excess energy is used to generate electricity.

In the operation of the STES, the following different operating categories can be defined:

- Normal operation
- Start-up and shutdown
- Abnormal operation

For normal operation, there are days when space heating is required, days when cooling is required and periods when electrical power is generated at reduced condenser pressure. During both heating and cooling seasons, modes of operation utilizing oil flow from the high temperature and the intermediate temperature storage tanks are needed for peaking operation of the power conversion subsystem (design flow, temperature and pressure) and for part power (less than design rated conditions) operation of the power conversion subsystem.

Electrical power is generated with modes that use oil flow from the high temperature storage tanks for peaking conditions and part power conditions. Part power electric generation also is accomplished in a mode that uses oil flow from the intermediate storage tank. In total, during normal operation, ten different operating modes have been defined and are tabulated in Table 3.1-6. The normal operating mode sequences of the STES are described in Section 3.7 with the corresponding state points of performance for the defined operating modes detailed in Section 4.2.

TABLE 3.1-6

FORT HOOD STES NORMAL OPERATING MODES

Mode	Oil Flow to PCS*	Type**
Full Load Heating Season	From High Temperature Storage Tank	Peaking Condition
Full Load Heating Season	From High Temperature Storage Tank	Part Power Condition
Full Load Heating Season	From Intermediate Temperature Storage Tank	Peaking Condition
Full Load Heating Season	From Intermediate Temperature Storage Tank	Part Power Condition
Full Load Cooling Season	From High Temperature Storage Tank	Peaking Condition
Full Load Cooling Season	From High Temperature Storage Tank	Part Power Condition
Full Load Cooling Season	From Intermediate Temperature Storage Tank	Part Power Condition
Electric Generation Only	From High Temperature Storage Tank	Peaking Condition
Electric Generation Only	From High Temperature Storage Tank	Part Power Condition
Electric Generation Only	From Intermediate Temperature Storage Tank	Part Power Condition

*PCS = Power Conversion Subsystem
**Peaking Condition is design flow, temperature and pressure conditions of the PCS; Part Power Condition is Less than design rated conditions of the PCS.

Operating conditions other than the normal operating modes described above include startup, shutdown and abnormal conditions. The latter are considered in detail relative to the overall STES in Sections 3.7.4 and 3.7.5 and further described relative to the individual subsystems in Sections 3.2, 3.3, 3.4 and 3.5.

3.1.3 SITE DESCRIPTION

The Fort Hood STE-LSE is located in the east-central part of Texas, in the western half of Bell County. The geology of the area generally consists of a limestone plain known as the Grand Prairie. This formation consists of shallow-to-deep soils overlying limestone of varying hardness, often in striated bands.

The site is located near the city of Killeen, Texas, within the confines of the Fort Hood military reservation. The 87000 Troop housing complex, which lies west of Fifteenth Street, becomes the western boundary of the STE-LSE site. The site is further bounded by Battalion Avenue on the south, Martin Drive on the east, and the future extension of Central Avenue on the north. The site so described consists of approximately 15 acres.

The climate of the site is that of east-central Texas, being generally that of the southwestern prairie. The site is located close to the line of equal evapotranspiration/rainfall and enjoys some 32.5 inches of average rainfall, a mean annual maximum temperature of 76°F, and a mean annual minimum temperature of 57°F.

The site as it exists today is mown lawn, consisting of a variety of grass species. The western side of the site contains two large parking lots with spaces for some 270 cars. Also located on the site is Yellow Ribbon Park consisting of several medium-sized trees and some playground equipment.

The overall plan calls for the parking areas to be relocated to the south of Battalion Avenue in two lots. These lots will be related to existing circulation pattern of the 87000 complex.

The area adjacent to these parking areas will be developed into a recreation area to replace the facilities presently on the site.

The general topography of the site is a plateau at the headwaters of South Fork of Nolan Creek, which flows into the Leon Creek near the center of the county. The site gently slopes to the southeast between two and eight percent. Drainage for the STES will follow the existing pattern.

The overall site plan shown on Heery & Heery Drawing 1-1 has four major elements:

- Solar Collector Field
- Heated Oil Storage Tanks
- Visitor Parking and Access
- STES building which houses energy conversion equipment, computer control room, training and visitors' facilities with display areas

The solar field consumes by far the largest part of the acreage. The collectors are arranged in rows, the center-to-center distance being determined by site economics, row-to-row shading, and the space necessary to negotiate service vehicles for washing of mirrors and inspection. The general arrangement of the collectors is parallel to Martin Drive with access roads at each end and at the approximate center of the rows. Connecting piping transfers the heating oil from the collector field to the oil s rage tanks, which comprise the second major element on the site.

The cluster of oil storage tanks is encircled by a retaining berm to contain the volume of oil should the improbable occur and a tank burst. The circular berm is interconnected to a lower level retention area away from the tanks themselves. The entire collector field and tank farm are to be surrounded by a security fence and partially surrounded by low berms for oil spill containment which also soften the visual impact.

The building itself serves as the entry point for the public and employees, as a barrier to separate public and non-public functions, and as an interface between solar energy collection and energy consumption. In conjunction with its associated visitor parking, it serves to provide a point of visual relationship between the 87000 complex and the solar collector field.

3.2 SOLAR COLLECTOR SUBSYSTEM

3.2.1 SUMMARY DESCRIPTION

The solar collector subsystem (SCS) is comprised primarily of a series-parallel arrangement of solar parabolic trough collectors placed in a collector field (Figure 3.2-1), and the associated piping and control, isolation and drain valves. The auxiliary oil-fired heater is also part of the solar collector system. The SCS mechanically and hydraulically interfaces with the thermal storage subsystem and electrically interfaces with the control system.

3.2.2 SOLAR COLLECTOR SUBSYSTEM FUNCTION

The primary function of the solar collector subsystem is to collect and convert solar flux to increase the enthalpy of the heat transfer fluid. The solar collector subsystem receives the heat transfer fluid (Sun 21 oil) from the thermal storage subsystem. Thermal energy is transferred to the heat transfer fluid, increasing the fluid's temperature to a nominal value of 288°C (550°F) before returning the oil back to the thermal storage subsystem. During period of good insolation the thermal energy is provided by parabolic line focusing trough type collectors. An auxiliary oil-fired heater provides the thermal energy during extended periods of poor insolation or during major maintenance of the collector field. The auxiliary oil heater may also be utilized to augment the collector field in parallel arrangement.

3.2.3 DESIGN REQUIREMENTS

It is important to note as a prefacing remark to this section on requirements that the specific solar collector for this plant has not yet been selected. The collector modules will be procured under competitive bidding against an equipment specification ("Equipment Specification for Parabolic Trough Solar Collectors," E-677542 [Draft], September 29, 1978). For purposes of system design and performance analysis, a collector with the published characteristics of the Acurex 3001 collector was used as representative of better quality parabolic trough solar collectors. The information in this requirements sections primarily reflects the provisions of the subsystem description document and the equipment specification, and does not necessarily correspond to the representative collector which is used in the system model. In other words, it is not implied

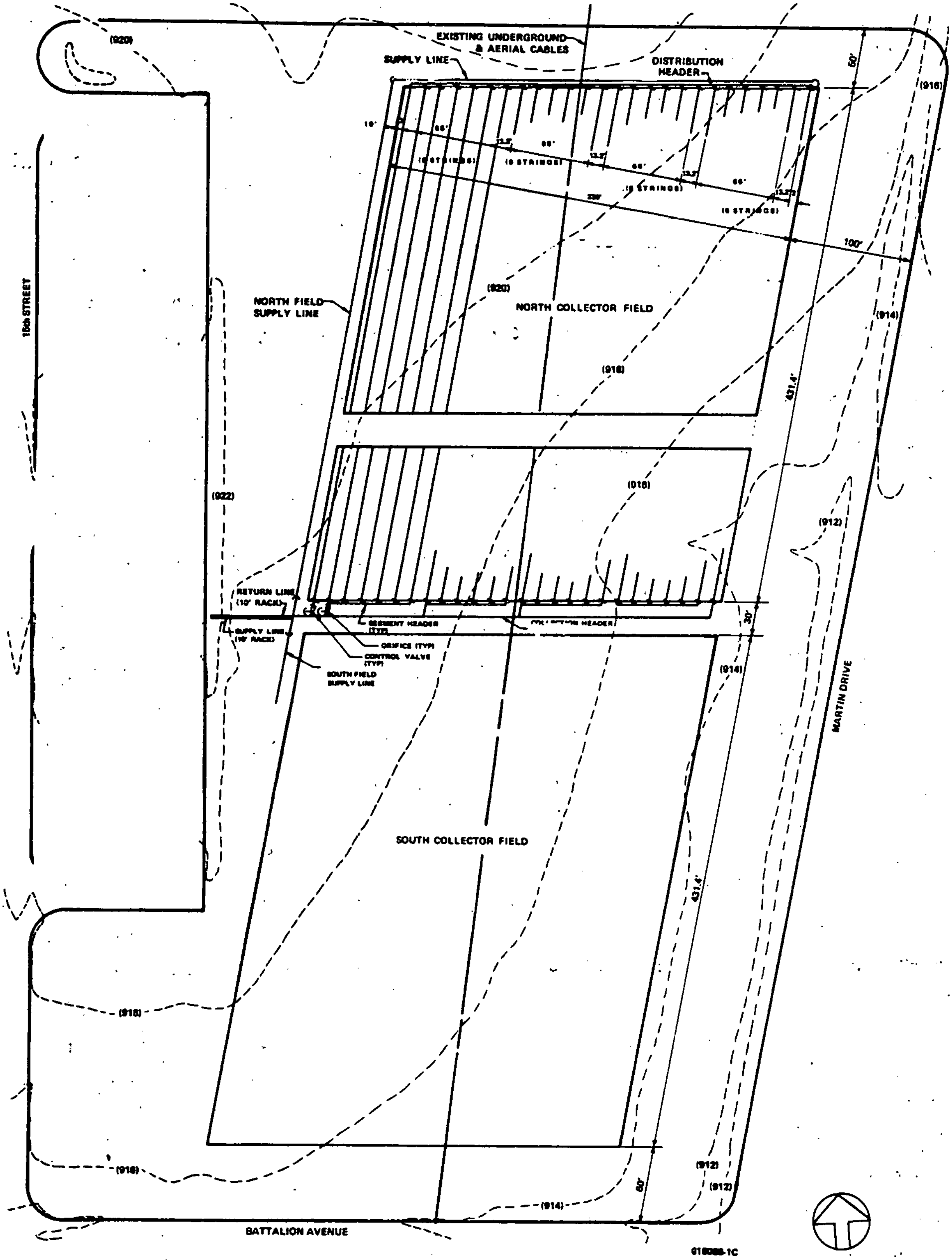


Figure 3.2-1. Solar Collector Field Configuration

that the representative collector as utilized in the system analysis meets all the design requirements listed in this section.

The overall subsystem requirement is to serve as the energy source for the remainder of the STE-LSE. The sizing of the collector field and the oil fired heater are such as to meet the load requirements described in Section 2. The plant service life is 20 years, with some parts replacement acceptable as defined for individual components. The range of normal operating conditions for the SCS can be seen in Table 3.2-3, presented as a partial description of the interface with the thermal storage subsystem.

3.2.3.1 SOLAR COLLECTOR PERFORMANCE REQUIREMENTS

Considering current solar collector state of the art, it was not judged appropriate to set collector performance (energy collection efficiency) requirements per se. However, performance objectives were established based on the following:

- An "optimum" parabolic trough collector design, utilizing best currently available and reasonably well-proven components. This design is described in Section 5.3.2.3.
- Meteorological conditions as represented in the Fort Hood model year (Section 5.4) for January 3, March 23, June 28, and September 21; four bright days in the vicinity of the solstices and equinoxes.
- Plant nominal thermal/hydraulic conditions as specified in Section 3.1.1 of Equipment Specification E-677542.

The performance objective consistent with the above for the nominal SCS aperture area of 11,600 in^2 (125,000 ft^2) integrated over the four days is 7.6×10^{11} J (7.2×10^8 Btu) for solar collector calculations performed in the customary manner (Section 3.1 of E-677542).

3.2.3.2 SOLAR COLLECTOR OPERATIONAL REQUIREMENTS

The following design requirements apply to the solar collector modules and to assemblies of such modules in groups (associated with a single drive system) and in strings (series assemblies connected to field manifold piping at each end):

- The solar collector modules shall be high temperature, horizontal, single axis-tracking, parabolic-trough-concentrating, liquid types designed for high efficiency operation.

- Several solar collector modules shall be connectable in series hydraulically and mechanically into a linear solar collector group which is provided with a single drive mechanism.

- Several solar collector groups shall be connectable in series hydraulically to form a linear solar collector string. Each collector string shall be isolable by manually operated valves.

- The solar collector groups shall be provided with supports and drive mechanisms, including motors, if required, capable of moving collector groups at a rate which will enable the controller to keep the image of the sun focused on the receiver and which will enable the controller to stow the collector modules in a face-down position. Overall pointing accuracy of the collector assembly including the accuracy of the position indicator and the characteristics of the drive system will be within ±4 milliradians (±0.25°) of the demanded position.

- The reflector structure shall be of metallic construction with identified measures against corrosion.

- The reflector and all other components of the solar collector module shall be capable of withstanding 34 m/s (75 mph) winds in the stowed position without permanent damage.

- The reflector structure will have sufficient torsional rigidity to prevent twisting and pointing errors beyond the specified pointing accuracy in winds up to 16 m/s (35 mph).

- The specular surface and fasteners shall be such as to allow simple replacement of the reflective surface.

- Maximum permissible degradation of the installed reflective surface shall be no more than two percent per year.

- The receiver will be compatible with Sun 21 oil, whose temperature may be between -23°C (10°F) and 371°C (700°F), and whose pressure may be as high as 690 kPa (100 psia).

- The pressure drop through a 128 m (420 ft) collector string shall be less than 140 kPa (20 psi) for a flow rate of Sun 21 of 0.149 kg/s·m of aperture width (260-lb/h·ft of aperture width) at a temperature of 233°C (432°F).

- The support structure shall allow stowage of the solar modules in a face-down position.

- The drive mechanisms and motors shall provide a slew rate of no less than 15 degrees of reflector/receiver rotation per minute in a wind up to 22 m/s (50 mph) for emergency stowing.

- Each electric drive for a solar collector group will include an electric motor with overtemperature protection devices, speed reducer and end-position limit switches to prevent damage resulting from overdriving, and disconnect switch, all housed in a rain-tight NEMA 3R enclosure. For hydraulic drive systems, movement limiting devices will be provided, similarly protected against environmental disabling.

- Working parts shall be shielded from environemtnal effects that could impede smooth operation, cause premature wearout or require cleaning and lubrication more frequently than monthly.

3.2.3.3 AUXILIARY OIL HEATER

The heater shall meet the following design requirements:

- Rating at 1172 to 1465 kW (4 to 5 million Btu/hr) when raising the heat transfer fluid temperature from 158°C (316°F) to 226°C (438°F)

- Capability of delivering 316°C (600°F) fluid for inlet fluid temperatures of 149°C to 288°C (300 to 500°F) (heater design conditions, not necessarily intended operating conditions)

- Maximum film temperature: 343°C (650°F) (Heater design conditions, not necessarily intended operating condition)

- Turn-down ratio of at least 5:1

- The heater shall be of forced draft design

- The local control panel shall be weatherproof

3.2.3.4 PIPING AND VALVES

The piping and valve general provisions are:

- Accommodation of a 316°C (600°F) maximum bulk temperature and wide variations between ambient and the maximum level.

- Conformance to ANSI Standard B31.3. (Chemical Plant and Refining Piping)

- Provisions for thermal expansions of the segments to prevent undue loading of the fixed points.

- Welded construction except where flanges are absolutely necessary. Flanges will be 300#, raised face, using spiral wound gaskets.

- Valving limited to gate, globe, angle and check swing types. Sizes 1/2 through 2", forged steel (ASTM A-105) with 600# rating at 850°F; above 2", cast steel bodies (ASTM A216 Grade WEB) or forged steel (ASTM A-105) with 300# rating at 850°F.

A summary of the design requirements for piping, valves, and fittings is presented in tabular form in Table 3.2-1. Functional requirements of the valves are best understood from operational descriptions as provided in Section 3.2.4.1 and 3.2.5.

3.2.4 SOLAR COLLECTOR SUBSYSTEM DESCRIPTION

3.2.4.1 OVERALL SYSTEM

The total system is described next, with the necessary introduction to the general modes of operation essential to understanding the hardware description.

FLOW DIAGRAM

The SCS flow diagram is shown in Figure 3.2-2. It will be noted that the field is divided into three subjields, each a different size, as part of a unique scheme for safe and efficient control of working fluid field outlet temperature. This operating scheme, referred to as the "feed-forward control method," is detailed in the discussion which follows and in Section 3.6, "Overall Instrumentation and Control." Sun 21 oil is supplied from the thermal storage subsystem at 158°C (316°F). Normally most of the flow is directed to the largest field (A1). The flow exiting subfield A1 is either mixed with flow from the pump and directed into the intermediate sized field (A2), or the flow from A1 is split between field A2 and the pump for recirculation. The flow exiting the intermediate sized field (A2) is directed to the smallest field (A3). The remaining flow from field A2 is directed to either high temperature storage or recirculated. The flow from field A3 is normally directed to high temperature storage, except on startup and shutdown when the flow is directed to either the low temperature or intermediate temperature storage tanks.

The inlet fluid temperature for each field increases from field A1 and A3 and therefore the desired fluid temperature rise in each field decreases from field A1 to A3. With this control method, the fluid temperature entering the smallest field (A3) is sufficiently high so that, even if only a fraction of the temperature rise desired is obtained, the fluid temperature exiting the field (A3) is acceptable for directing into high temperature storage. The flow into each subfield is based on the inlet fluid temperature, the demanded exit temperature and an assumption of maximum solar insolation. This feed-forward control method inherently prevents any collector string from overtemperaturing.

The auxiliary oil heater is used independently or in parallel with the field. During the independent operation mode, the heater is operated when the collectors are not collecting solar energy. During this operating mode Sun 21 oil is pumped from the Thermal Storage Subsystem to the auxiliary oil heater where it is heated and returned to the Thermal Storage Subsystem. Normally the heat transfer fluid is pumped by the Collector Feed Pump (Low Temperature Pump) from Cold Temperature Storage at 158°C (316°F), heated and returned to Intermediate Temperature Storage at 226°C (438°F). However, fluid can be received from the Intermediate Storage Tank and delivered to High Temperature Storage at 288°C (550°F).

The exit temperature of the fluid is controlled by flow control valves and the heater firing rate. Flow to and from the heater is supplied by the Thermal Storage Subsystem pump, while recirculation is supplied by a pump associated with the heater.

The heater may be used to augment the solar collector heat output and to adjust the temperature of the stored fluid. These functions can be accomplished by the independent mode outlined above or by operating the heater in parallel with the collectors. In the parallel operating mode, the heater outlet temperature

TABLE 3.2-1

PIPE, VALVES AND FITTINGS DESIGN REQUIREMENTS SUMMARY

ITEM	SIZE RANGE	DESCRIPTION	SPECIFICATION
	Thru 1½"	Seamless Carbon Steel Tube Drawn to Schedule 40 Nominal Pipe Size	ASTM A 106 Grade B
PIPE	2" thru 8"	Schedule 40 Seamless Carbon Steel	ASTM A 53 Type S Grade B Material
	½" thru 2"	3000 lb socket-welding, forged steel	ANSI B16.11
	½" thru 2"	2000 lb screwed, forged steel, back-welded with no exposed thread.	ANSI B16.11
FITTINGS	2" thru 8"	Standard Weight, Carbon Steel Buttwelding	ASTM A 234 Grade WPA or WPB Material USAS B16.9 Dimensions
	Thru 8" (Branch)	Standard Weight Forged Carbon Steel Welding Outlet, Buttweld Connection	ASTM A 105 Material
WELDING ELECTRODES	ALL	Coated Electrodes	ASTM A 233 E60 Series
		Bare Electrodes for GMAW Process	ASTM A 559 Class E60S-2
JOINTS	½" thru 2"	Piping runs: 3000 lb socket-welding couplings or buttweld	ANSI B16.11
	3" thru 8"	Piping runs: buttweld	
FLANGES	½" thru 8"	Maintenance, blanking, and fit up to flanged valves and equipment: USAS 300 lb Forged Steel Welding Neck, 1/16" Raised Face, Schedule 40 Bore, 125 AA finish or smoother.	ASTM A 181 Material USAS B16.5 Dimensions
GASKETS	Thru 8"	.175" Thick 300 lb Type 304 Stainless Steel and Asbestos Spiral Wound	API STD 601
BOLTING	ALL	Alloy Steel Continuous Threaded Studs	ASTM A 193 Grade B7
		Heavy Hex Nuts	ASTM A 194 Grade 2H
		Washers: Bellville spring type	

Cold bending of pipe through 6" shall be used where space permits and if economical bending facilities are available. Otherwise, long-radius elbows shall be used except where specified differently.

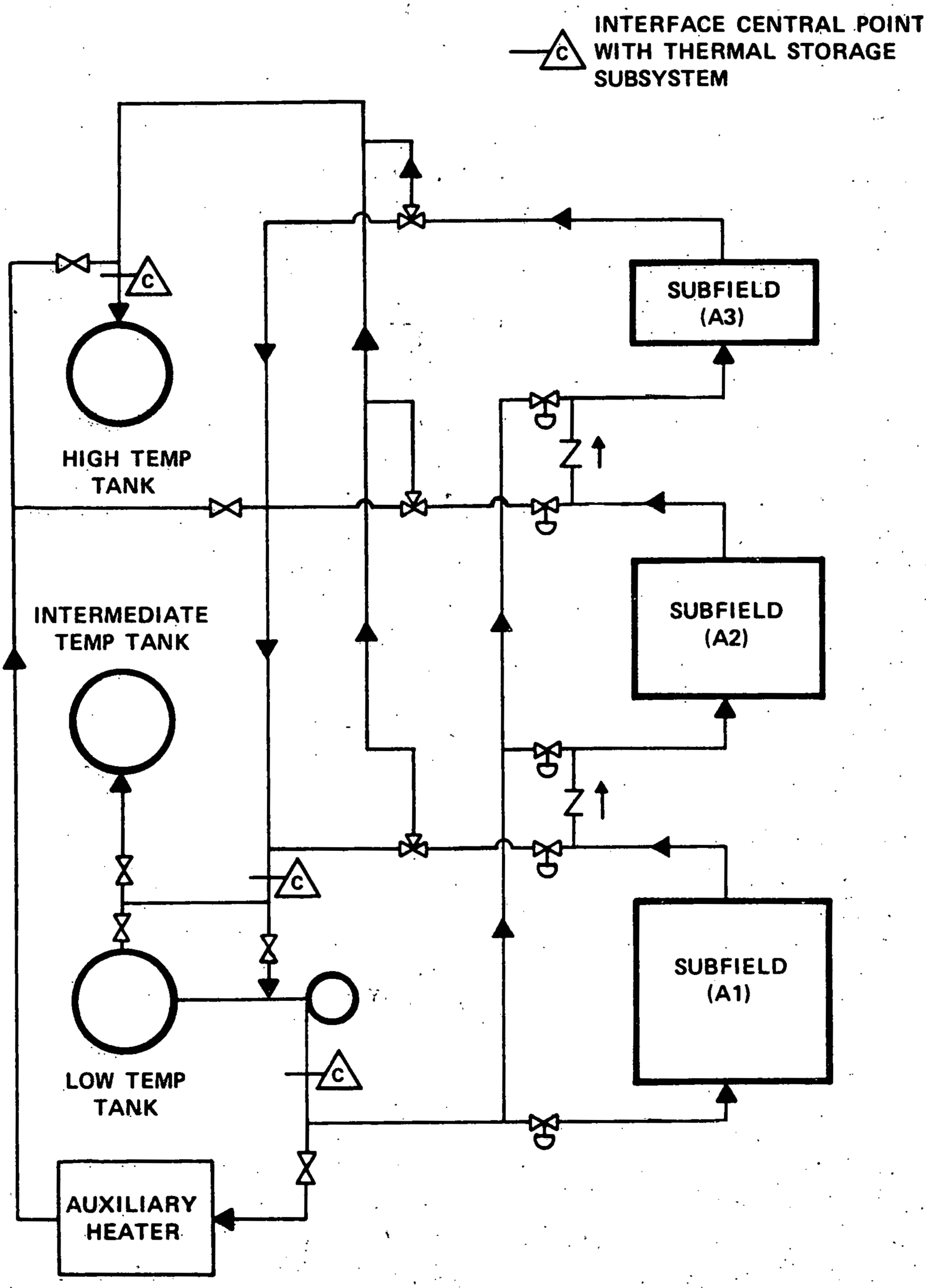


Figure 3.2-2. Solar Collector Subsystem Flow Schematic

will be regulated so that the combined flow is controlled at the desired temperature.

PERFORMANCE

The field layout involving the three subfields and the feed-forward control method has been evaluated on a static basis only in this section. Defining a subfield solar factor as:

$$F(i) = \frac{\eta_i q_i}{q_{max}}$$

so that the power transferred to the fluid in each subfield is:

$$Q(i) = A(i)\ q_{max}\ F(i)$$

where:

η_i = collector efficiency

q_i = direct component of solar flux

q_{max} = maximum q

A_i = subfield aperture area

The demand flow rate (ω_i) into each subfield is based on the measured subfield inlet temperature (TI_i), maximum solar flux, and the full operating demand exit temperature (TO).

$$\omega_i = \frac{A_i\ q_{max}}{C_p\ (TO - TI_i)}$$

If the fluid temperature rise in the subfield A1 is low, most of this fluid is then directed into subfield A2 without mixing any flow from the pump. However, above a certain fluid temperature rise in subfield A1 (depends on the ratio of subfields A1 and A2 aperture areas), flow from the pump is mixed with flow from subfield A1 for introduction into subfield A2. This same procedure is used for subfield A3 dependent on the temperature exiting subfield A2. The desired fluid inlet temperatures for subfields A2 and A3 as a function of fluid exit temperatures for subfields A1 and A2 are shown in Figure 3.2-3.

The static performance (field exit temperature into thermal storage) for a range of solar factors for each subfield is shown in Figure 3.2-4. The results shown on this figure are pessimistic because q_{max} can be adjusted to take into account atmospheric conditions (visibility, humidity, etc.) so as to keep the solar factors higher.

PROCESS AND INSTRUMENTATION DIAGRAM

Drawing 102E118 (Volume III) diagrams the solar collector subsystem instrumentation and controls as required to:

- Monitor the oil flow rate and temperature, and control the flow rate and flow path through the subsystem
- Monitor the oil temperature in each subfield
- Monitor each collector group's position
- Control each collector group's position
- Monitor the oil flow through each string
- Monitor and control the auxiliary heater

The instrumentation and control system also includes informational data collection and malfunction monitoring.

3.2.4.2 DESCRIPTION OF COMPONENTS

SOLAR COLLECTOR

The solar collector module consists of a reflecting surface that reflects incident rays from the sun onto a linear receiver. The reflector is a trough with a parabolic cross section. The linear receiver is located along the focal line of the reflecting surface. Suitable structures maintain the parabolic cross section of the reflecting surface and maintain the linear receiver at the focal line. Means are also provided for supporting the reflector so that the linear receiver is horizontal and so that the reflector/receiver structure can be rotated to keep the image of the sun always on the receiver. The driven

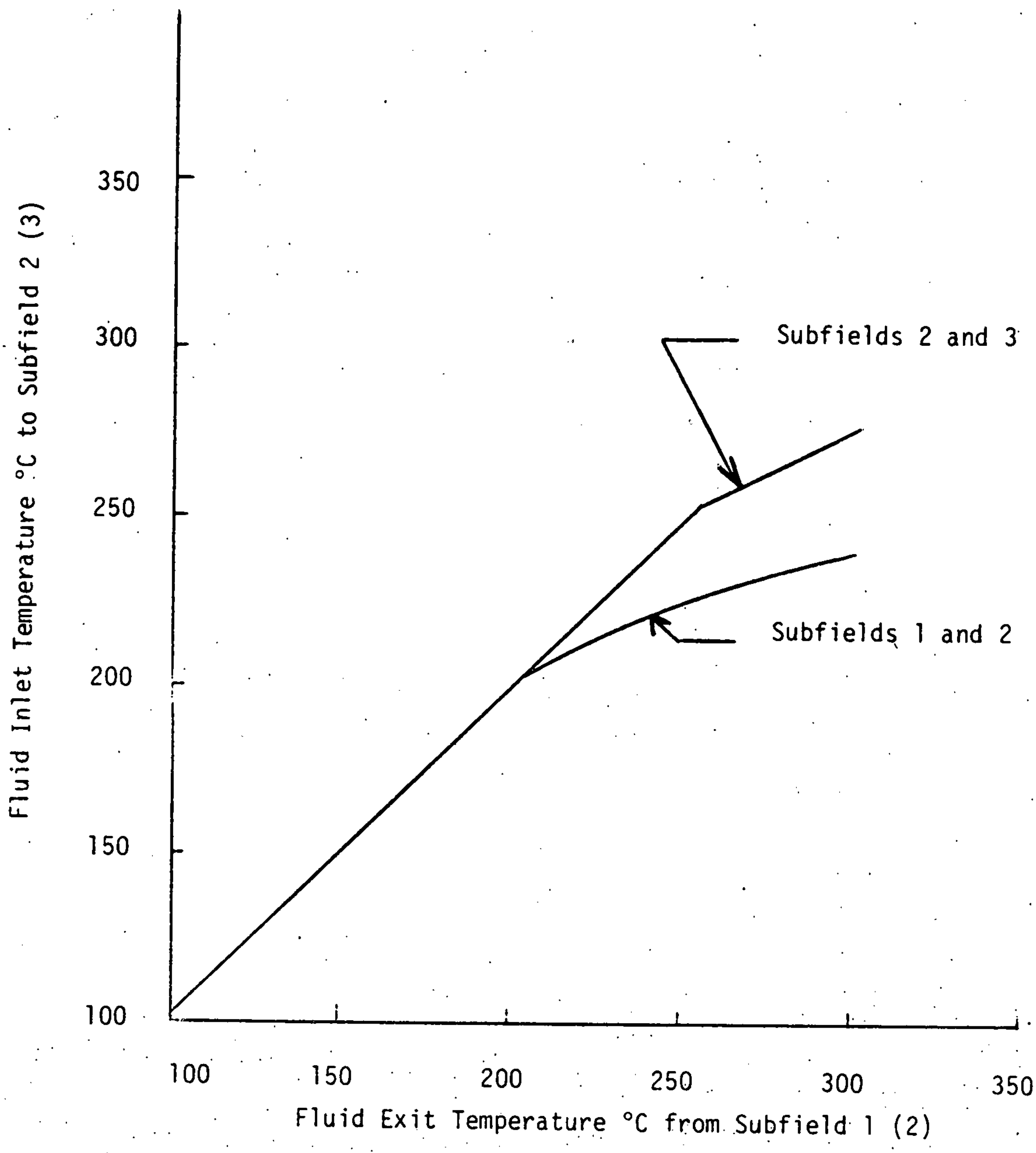


Figure 3.2-3: Fluid Inlet Temperatures for Following Subfield versus Subfield Exit Temperature

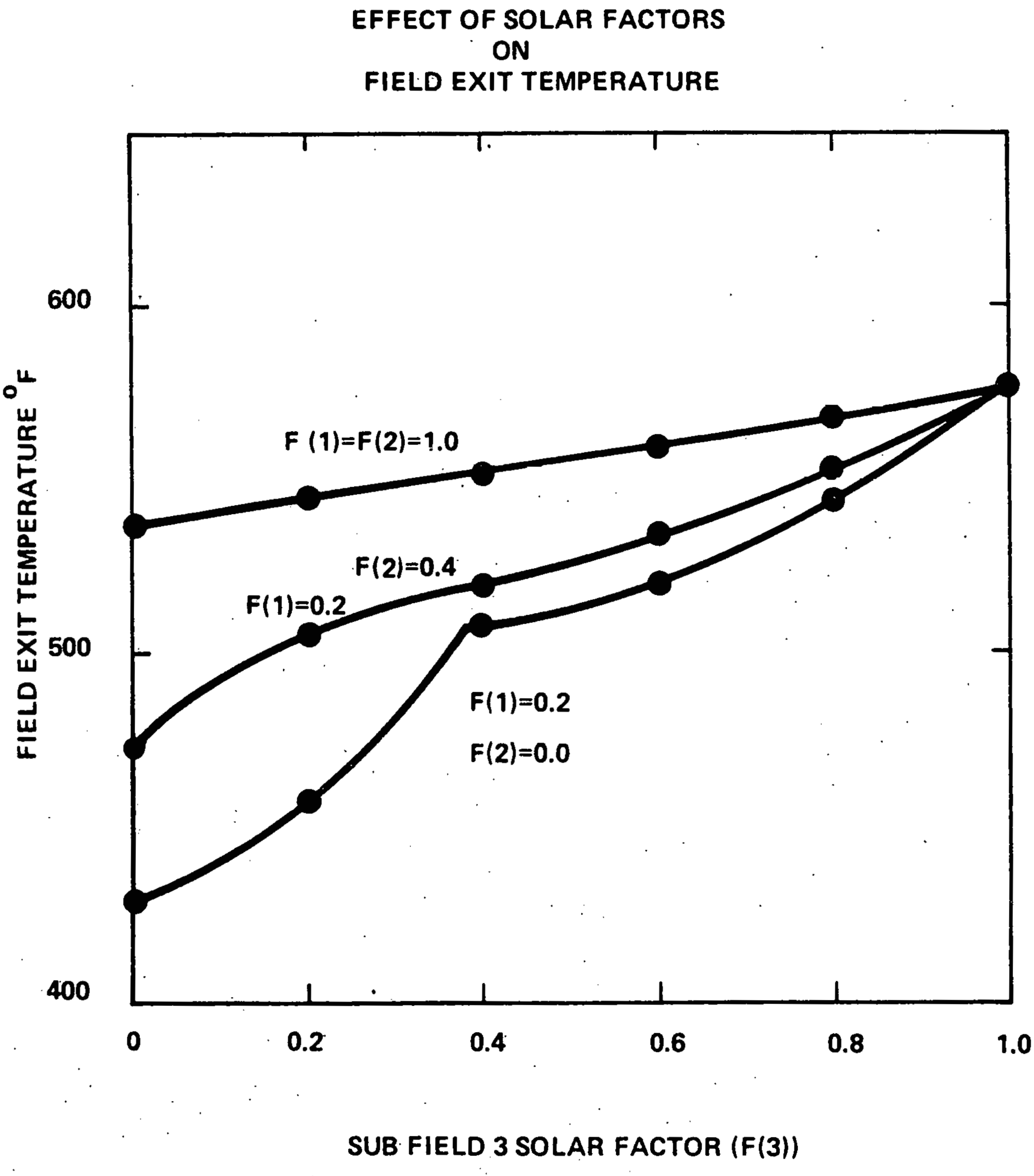


Figure 3.2-4. Effect of Solar Factors on Field Exit Temperature

mechanisms provide for rotation of the reflector/receiver at rates consistent with tracking the sun. Special provisions include rapid or nominal rotation to the stowed (face down) condition and automatic defocusing for conditions which threaten receiver tube overheating.

AUXILIARY OIL HEATER

The oil heater consists of a forced draft burner, fluid heating oil, fluid circulating pump, motor control center, combustion chamber, heat transfer surfaces, flue gas stack, valving, instrumentation, controls and a local control panel. The control system provides for an automatic startup with proper sequencing and safeguards. Several design configurations exist, but most incorporate radiant and convective heat transfer while some use only convective transfer. Use of a circulating pump provides better control of film temperatures. Forced draft combustion is safer, thermally more efficient, and easier to control over a wide turndown range. In the size range required, a skid mounted package is available.

The instrument and control list is given in Section 3.6 (Table 3.6-5).

The fuel oil supply system consists of a fuel oil buried storage tank, oil circulating pump and motor control system. The fuel oil system is actuated by an external signal (manual or automatic) to the motor control system. The fuel oil pump circulates No. 2 fuel oil through a piping loop where the auxiliary oil heater burner may draw fuel for firing the heater.

PIPING AND VALVES

Piping conveys the heat transfer fluid from and to appropriate locations in the circuit. This piping must provide leak-proof paths and be capable of handling wide variations in fluid temperatures through a daily operating cycle as well as providing for the initial startup temperature and associated transients. The design must accommodate the 316°C (600°F) maximum bulk temperature as well as the daily temperature variations. The purpose of the valves is to perform various duties of control, draining, venting, safety and isolation within the associated loops in the system.

SOLAR COLLECTOR SUBSYSTEM INSTRUMENTATION AND CONTROL COMPONENT DESCRIPTION

The placement and function of the instrumentation and control components are presented in Section 3.2.4.1 and 3.6. The characteristics of individual I&C elements are provided below:

- Flow Element Transmitter - These are in-line flange-mounted instruments with an output of 4 to 20 MA. Types will be specified in Phase IV.
- Thermocouples - Thermocouples are grounded junction metal sheathed, and ceramic insulated. The type will be specified in Phase IV. Installation will be into a welded in-place thermowell, or direct insertion using either a compression fitting or gland.
- Reference Junction - A Reference Junction will be provided at the I/O for all thermocouple inputs.
- Control Valves
  - Three-way divertor valves, air-operated, using a solenoid pilot valve
  - Pneumatic control valves with I/P valve positioner and pilot valve
  - Pneumatically activated isolation valve with solenoid pilot valve
- Flow Switch - Paddle-type with adjustable linkage and microswitch
- Collector Position Sensors - An absolute position optical encoder providing a 12-bit parallel digital output

HEAT TRANSFER FLUID

Sun 21 heat transfer oil will be used in the solar collector subsystem. Sun 21 is specifically designed for use in closed circulating systems with operating conditions up to 316°C (600°F). The evaluation of this oil is presented in Section 5.5.4, "Oil Stability/Handling/Temperature Evaluation."

Standardized properties for use in project analyses are provided in graphical form in Figures 3.2-5 and 3.2-6; and in approximate functional form on Table 3.2-2.

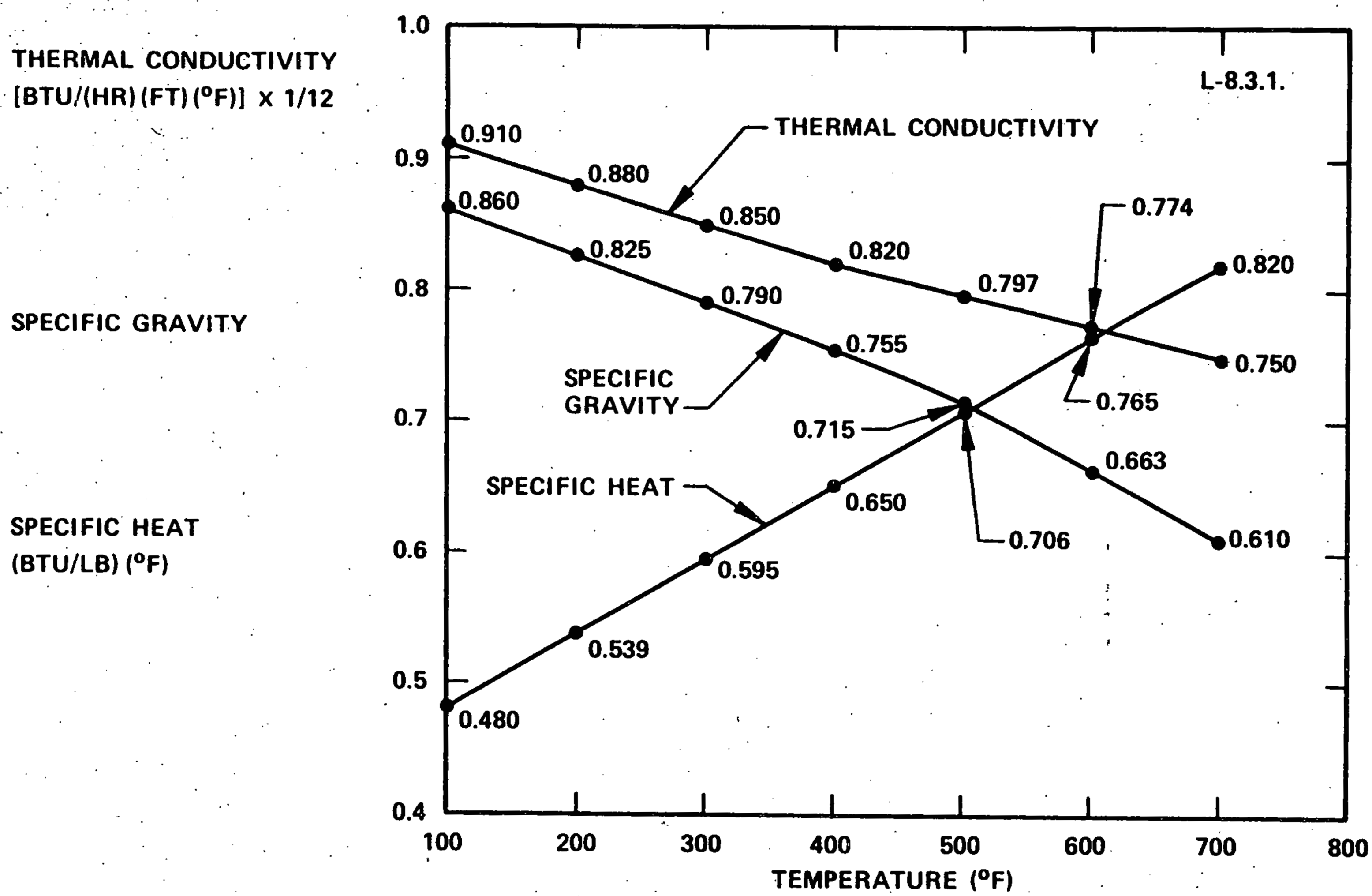


Figure 3.2-5. Thermal Properties of Sun 21/25 Heat Transfer Oil

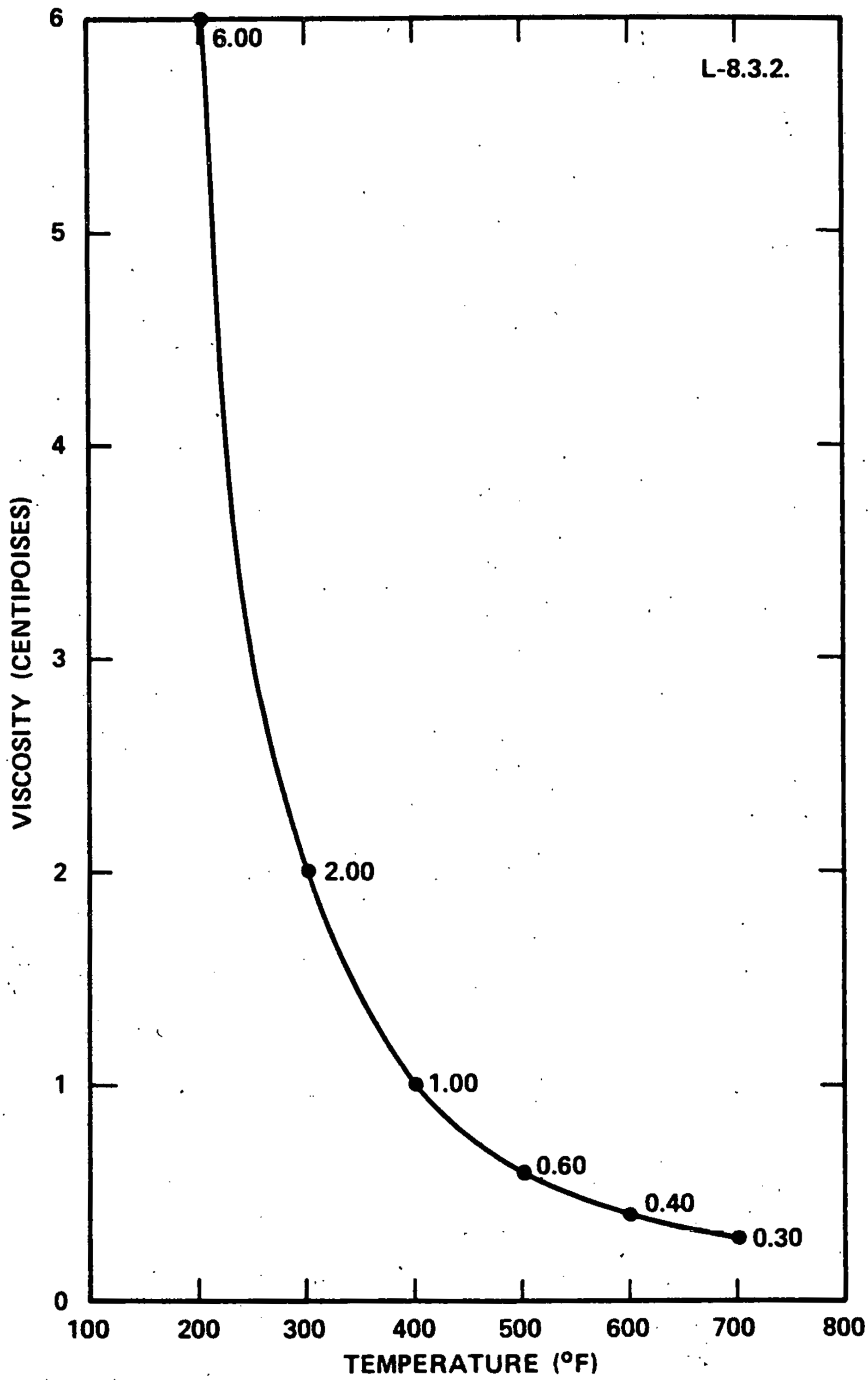


Figure 3.2-6. Viscosity of Sun 21 Versus Temperature

TABLE 3.2-2

PROPERTIES OF SUN 21 OIL

- Specific Heat: $C_p = 0.4322 + 0.00056667T \left(\frac{Btu}{lb\text{-}°F}\right)$
- Enthalpy: $H = 0.4322T = 0.00028333T^2 \left(\frac{Btu}{lb}\right)$
- Thermal Conductivity: $k = 0.07810 - 0.2266 \cdot 10^{-4}T \left(\frac{Btu}{hr\text{-}ft\text{-}°F}\right)$
- Density: $\rho = 53.66 - 0.0149T - 0.1386 \cdot 10^{-4}T^2 \left(\frac{lb}{ft^3}\right)$
- Viscosity: $\mu = 1154T^{-2.396} \left(\frac{lb}{ft\text{-}sec}\right)$

Notes: 1. Temperature, T, in °F
2. Viscosity relationship valid from 200° to 700°F, others valid from 100° to 700°F.

Tests are underway at Sandia Laboratory to confirm the behavior of this heat transfer oil. Preliminary results on temperature stability are available and are reported elsewhere.

3.2.5 SOLAR COLLECTOR SUBSYSTEM OPERATION

3.2.5.1 NORMAL OPERATION

SOLAR COLLECTORS

A feed-forward mode of controlling the field mixed mean fluid exit temperature is used. The flow rate into each subfield is controlled by flow control valves (FCV) based upon measured inlet temperature and assuming maximum solar insolation. Flow from the pump is directed into the largest subfield (A1), part of the heated oil from subfield A1 is mixed with flow from the pump and directed into the intermediate sized subfield A2, in turn part of the heated oil from subfield A2 is mixed with oil from the pump and directed into subfield A3. The portions of the oil remaining from subfield A1 and A2 are directed into the high temperature oil storage if the oil temperature is greater than 275°C (525°F). (This and other conditions discussed in this section on operations are subject to validation in the final system design process.) Otherwise it is returned to the suction side of the pump and recirculated. All of the oil flow rate from subfield A3 is either piped to the high temperature oil storage or recirculated, based on its temperature. Two-speed pumps (covering the total field flow rate range) are used to reduce pumping power. During periods of field flow rates of less than 5 kg/s (40,000 lb/hr) the pump will be running at its low speed setting. If the insolation changes, the FCVs will change positions and adjust the flow rate through the field. If the average FCV position becomes greater than 70%, the control will increase the pump speed to its high setting thereby forcing the FCV positions into the normal operating range.

During normal operation, the conditions in the collector field are as follows:

- Collectors are tracking the sun so as to keep the line image of the sun focused on the receivers.
- Oil at 158°C (316°F) is pumped from the cold tank to the collector field.
- Oil at 288°C (550°F) is discharged from the collector field.
- The normal operating pressure for the oil in the collectors will be less than 690 kPa (100 psia).

AUXILIARY OIL HEATER

The heater has been located in the oil system rather than in the steam system to provide a better "thermal" location, for experimental flexibility. It is recognized that oil degradation and thermal losses may be incurred in this location, but it is felt that in an experimental facility, the operational benefits obtained outweigh these penalties. In a strictly commercial application, a boiler might be located in the water/steam loop. The following are several of the possible operating modes of the auxiliary oil heater:

- Normal Operation

  The auxiliary oil heater will be used to supplement the solar collector field to satisfy the thermal loads. In this mode the heat transfer oil is supplied from the low temperature 158°C (316°F) oil storage tank, is heated in the auxiliary oil heater to 226°C (438°F) and piped to the intermediate oil temperature storage tank. After the test operational phase, this mode of operation of the auxiliary oil heater is expected to be the only operational mode.

- High Temperature Operation

  Oil is supplied from the intermediate oil temperature 226°C (438°F) storage tank and is heated in the auxiliary heater to 288°C (550°F) and directed to the high temperature oil storage tank.

- Thermal Conditioning Operation

  The auxiliary oil heater may also be utilized for thermal conditioning to maintain the temperature of the oil above a minimum temperature level during major maintenance of both the solar collector and power conversion subsystem.

In the above operating modes, operation is continuous and automatic. Operating conditions (outlet temperature and mode of operation) will be chosen by the operator in the main control room, all secondary conditions (flow, firing rate, combustion air, etc.) will be automatically controlled. Temperature is controlled by automatic adjustment of fluid flow and firing rates. Primary operating parameters will be constantly available to the operator via display devices (to be chosen). Secondary operating parameters will be transmitted and stored by the computer. Unless abnormal conditions or upsets occur, the operator will not be required to closely monitor the heater operation.

3.2.5.2 STARTUP AND SHUTDOWN

For the SCS to operate properly the following conditions must be satisfied:

- Direct component of normal insolation must be at least 158 W/m^2 (50 $Btu/hr \cdot ft^2$).
- At least 57 m^3 (2000 ft^3) of oil must be available in the thermal storage subsystem for transfer to the SCS.
- The wind speed must be less than 15 m/s (35 mph) for solar collector operation.
- The instrumentation and control system must be available
- Electrical power must be available for the low temperature oil pumps and the drive (tracker) system.
- There must be at least 68 m^3 (2400 ft^3) thermal storage available for 288°C (550°F) oil.
- For auxiliary heater operation there must be at least 0.3 m^3 (10 ft^3) of fossil fuel available.

SOLAR COLLECTORS

- Startup

Start pump (initiates oil circulation) and bring to low flow setting. Oil will flow from the low temperature oil storage tank, through the collector field and back to the low temperature tank.

Deploy collector groups to sun-tracking position.

When the collector field outlet temperature reaches 226°C (438°F), switch output of the field to the intermediate temperature oil tank.

When the collector field outlet temperature reaches 274°C (525°F) switch output of the field to the high temperature oil storage tank and open valve so that recirculation flow may be utilized.

When any of the subfield FCVs open beyond 70%, bring flow to high flow setting.

- Shutdown

When the solar insolation drops to a level where the FCVs average position is less than 30% (low-speed flow setting), close valve so that recirculation flow is not possible and divert the collector field flow to the intermediate oil storage tank.

When the solar insolation drops to a level where the field exit temperature is less than 226°C (438°F), divert the collector field flow to the low temperature oil storage tank.

When the field outlet temperature drops below 158°C (316°F), stow the field collectors and shut the pump down.

AUXILIARY OIL HEATER

The heater is likely to be operated over a wide variety of inlet temperatures. The necessary conditions for operation include sufficient fuel and correctly functioning electrical, mechanical and control interfaces. The heater will generally be started from a "cold" condition. By current plans, subject to confirmation, it will not be kept in a "warm" standby condition.

- **Startup**

  Startup is a mixture of manual and automatic events:

  - Select outlet temperatures by adjusting temperature controller setpoint
  - Select operating mode by placing selector mode in desired position
  - Start No. 2 fuel oil circulating pump by placing control switch in automatic position and pushing start button
  - If in independent mode, start collector feed pump (if in parallel modes this pump is already running)
  - Start heater circulating pump
  - Line up thermal storage system valves for desired flow and establish flows
  - Start the heater by pressing "startup" button. This will begin an automatic, sequenced start-up culminating in the desired operating rate.

- **Shutdown**

  Line up the thermal storage subsystem valves for the desired flow. Push the heater "shutdown" button This will automatically remove the heater from the oil flow circuit and shut down the heater in the proper sequence with proper time intervals. All heater equipment, including the circulating pump, will be shut down.

3.2.5.3 ABNORMAL OPERATION

SOLAR COLLECTOR

- **Stow Mode**

  The collector will be stowed in an inverted position. Stowage will take place automatically under the following conditions:

  - Solar insolation insufficient to keep the outlet temperature of the collector field at or above 158°C (316°F)
  - Wind speed greater than 18 m/s (40 mph)

  Stowage will likewise take place for other conditions judged by operating personnel to represent a threat of significant damage to the collectors.

- <u>Loss of Flow</u>

  In the case of loss of heat transfer fluid flow through the receivers, the solar collectors will automatically de-steer so as to remove the image of the sun from the receivers in a time period less than one minute.

- <u>Loss of Power</u>

  In the case of loss of primary plant power, the collector group will de-steer automatically so as to remove the image of the sun from the receivers in a time period of less than one minute.

AUXILIARY OIL HEATER

Shutdown of any rotating equipment (fuel oil pump, circulating pump, TSS pump, or forced draft fan) will shut down the heater. While the heater can sustain such shutdown, it is relatively hard on the combustion area to do so. In most cases, the circulating pump will continue operating to minimize these problems.

A number of safety interlocks (e.g., flame safeguard) will also cause the heater to shut down.

3.2.6 SOLAR COLLECTOR SUBSYSTEM INTERFACES

3.2.6.1 SUBSYSTEM INTERFACES

The SCS interfaces mechanically and hydraulically with the thermal storage subsystem (TSS) and electrically interfaces with the control subsystem. The SCS I&C interfaces with other subsystems only through the computer.

THERMAL STORAGE SUBSYSTEM

The points of interface with the thermal storage subsystem are:

- Oil line at the collector field inlet header
- Oil line at the collector field outlet header
- Oil recirculation line at collector recirculation header
- Oil line inlet to auxiliary oil heater at first connection to heater
- Oil line return from auxiliary oil heater at first connection to heater

Table 3.2-3 lists the range of normal SCS operation; these conditions define the expected ranges of thermohydraulic parameters at the interface with the thermal storage subsystem.

TABLE 3.2-3

INTERFACE CONDITIONS BETWEEN SOLAR COLLECTOR SUBSYSTEM AND THERMAL STORAGE SUBSYSTEM

	Pump Flow Rate (lb/hr)	Temp. (°F)	Field ΔP (psia)	Recirculation Flow Rate (lb/hr)	Temp. (°F)	Into Storage (lb/hr)	Temp. (°F)
Peak Insolation	101,520	316	36	0		101,520	575
Peak Flow	113,160	380	47	38,030	508	76,460	510
Nominal	67,620	317	28	460	472	67,160	551
Minimum	64,690	332	26	9,980	430	55,610	532

INSTRUMENTATION AND CONTROL SYSTEM

The SCS will provide to the control system:

- Angular position of each collector group (168 groups)
- Temperature signals from 107 sensors
- Signals from 78 flow switches
- Flow measurements signals from 12 sensors and the position of each FCV (13)

The control system will provide to SCS:

- Demand drive positions
- Demand drive positions to any (or all) number of groups for the de-steer and stow operation
- A position demand for each FCV
- A position demand for each isolation valve affecting mode of operation
- Set point and high and low limits, where necessary, for measurement instruments

Additional information regarding the interface with I&C is provided in:

- The Process and Instrumentation Diagram (Figure 3.2-5)
- The Block Diagram (Figure 3.2-8)
- The Measurement Requirements List (tabulated in Section 3.6)
- Section 3.2.7, SCS Instrumentation and Control Description

AUXILIARY SYSTEMS

Electrical power is required for SCS operation and the power requirements are defined in Section 3.2.6.3.

Special treated water will be required for periodic washing of the collectors, as described in Section 3.2.8.1. Major quantities of mild water and probably deionized water will be needed. The source of this water is not yet defined and may be provided from an on-site or off-site supply system.

3.2.6.2 MECHANICAL/HYDRAULIC INTERFACES

The piping and connections between the SCS and the Thermal Storage Subsystem as well as among components within the SCS have been described in Sections 3.2.6.1. and 3.2.4.2.

3.2.6.3 ELECTRICAL POWER INTERFACES

SOLAR COLLECTORS

Electrical power is required to aim, stow and (depending on the selected collector design) defocus the collectors. The total power required to operate the drive motors associated with the solar collectors is estimated to be 15.6 kW at 480 volts ac. This represents a peak requirement (all groups stowing); the average requirement will be about 10 percent of the peak value.

AUXILIARY OIL HEATER

The total electric power required to operate the oil-fired heater and fuel supply blower, pump motors, control and heaters is estimated to be 11.4 kW at 220/440 volts ac. The heater will provide to the control subsystem the angular position of each FCV (2), the open/closed position of each isolation valve, and a temperature signal from five sensors. The control subsystem will provide on/off signals to the motor control centers for the pump and blower drive motors. Each FCV and each isolation valve will require a position from the control subsystem.

3.2.7 INSTRUMENTATION AND CONTROL

There are two basic control functions associated with the solar collector field:

- Position the collectors to follow the sun (also de-steer or stow under appropriate conditions)
- Control the flow rates, flow paths and subfield inlet and outlet temperatures

Instrumentation in the field is provided to support these control functions, to detect possible over-temperature conditions, to allow operation monitoring and to collect experimental data. In most cases, the installed instrumentation fulfills several of these purposes.

3.2.7.1 DESCRIPTION AND CONTROL ALGORITHMS

COLLECTOR POSITIONING

Control of collector positioning is directed by a microcomputer located in the collector field. The required functions of this controller are as follows:

- <u>Required Functions</u>
  - Position the collectors to follow the sun
  - Provide a de-steering function to prevent overheating
  - Provide automatic stowing (at night, in periods of extended low insolation and for adverse weather conditions)
  - Provide information to the operator to monitor operation
  - Provide information for data collection

The collector positioning controller operates as follows: First, a desired position is determined. This is developed in the microcomputer either by computing a pointing angle from time and date information provided by the central computer, or by receiving commands to stow, de-steer or point in another externally specified direction. Subsequently, the current position of a collector group is determined by decoding the output of a position encoder mounted on the collector group. The encoder will provide a grey code signal of approximately 12 digital bits to represent the collector position. The number of bits is dependent upon the point accuracy required by the selected solar collector. Finally, based upon the difference between the desired and measured positions, signals are sent to the collector group drive motor to either go forward or reverse or stop.

Ordinarily, no data are sent to the central computer for operational purposes. Periodic data reports are transmitted for data logging. Malfunctions detected by the positioning controller are communicated to the central controller.

FLOW AND TEMPERATURE CONTROLLER

The objective of the flow and temperature controller is to produce a field exit temperature in the desired range from the collector field while ensuring that the fluid temperature in the collector does not become excessive.

The controller conditions the subfield flow and inlet temperature to satisfy two objectives: First, based upon the existing inlet temperature, a flow rate is established that would result in acceptable subfield outlet temperatures if the insolation were at the maximum attainable. Second, the subfield inlet temperature is raised to the maximum value for which the first objective is not violated (with too high an inlet temperature, the demanded flow may be greater than the available flow). In addition, the controller determines the disposition of subfield outlet flow that is removed from the main flow path. This flow can be routed to the high temperature storage tank or recirculated, depending upon its temperature.

The flow and temperature controller is contained in a microcomputer in the field. The controller senses field flow rates, temperatures and control valve positions. Based upon this information, adjustments are made to valve positions in order to satisfy the above criteria.

SUPERVISORY SAFETY SYSTEM

An auxiliary function associated with the collector field is a supervisory safety system. This system observes the outlet temperature of each collector string. If excessive temperatures are sensed, a signal is sent to the position controller to adjust the position of the collector groups in that string to a de-steer position where the heat input to the collector is reduced, allowing the temperature to drop to acceptable levels. Loss of flow to a collector string is detected by a low flow switch that also initiates a de-steer command for the affected string.

MEASUREMENTS

Most of the measurements that are made in the collector field were discussed as part of the discussion of the controls. Several other measurements, such as subfield outlet temperatures and total field outlet temperatures, are made for information and evaluation of system operation. A few measurements, such as temperatures along a few strings and extra flowmeters, are made to assist in engineering evaluation. The Measurements Requirements List (MRL) (Section 3.6.6.1) outlines these extra measurements.

3.2.7.2 BLOCK DIAGRAM

The block diagram of the solar collector field controls is shown in Drawing No. 102E118 (Volume III). This shows the flow of measurements and commands between the collector field and the controllers.

3.2.8 MAINTENANCE

Maintenance considerations for the solar collector subsystem include as a minimum, the following items:

- Maintenance schedule
- Estimated repairs
- Personnel requirements
- Parts inventory

- Materials
- Special maintenance equipment and facilities

Maintenance efforts for the solar collector subsystem are performed mainly during the overnight shutdown of the collectors in order to minimize interference with the solar collection. Accordingly, maintenance manpower is heaviest during the overnight period.

3.2.8.1 SOLAR COLLECTOR

The field maintenance of the solar collector subsystem includes periodic calibration and lubrication of the drive assemblies and the washing of the mirrors. When the collectors are non-operable, the units will be stowed in a down position to lessen the material degradation of the assemblies. It is estimated that the collector mirrors will require cleaning using a mild water/detergent mix and rinsing with demineralized water. The source of the water for cleaning and rinsing operations is not yet defined. Cleaning of the mirrors and receivers is planned for three-week intervals. Routine visual inspection of the subsystem is conducted daily. Calibration and lubrication of drive components are conducted every month. The maintenance estimates are given in Table 3.2-4.

3.2.8.2 AUXILIARY OIL HEATER

The following preventative maintenance activity is expected to occur on a periodic basis:

- Lubrication of moving parts
- Checking of operating fidelity and accuracy of readings of safety controls and temperature limit controls. Adjusting as necessary
- Inspection of heater tubes, burner, refractory linings
- Periodic inspection of heater surfaces
- Inspection of water cooling at the circulating pump

TABLE 3.2-4

MAINTENANCE ESTIMATES - SOLAR COLLECTORS

Estimates for Annual Maintenance Labor Per Group
(720-ft^2 - 12 Modules)

Task	Time	Number Per Year	Annual Maintenance Labor
Collector Surface Washing	60 min.	17	17 hours
Monthly Inspection, Lube & Adjust Drive	10 min.	12	2 hours
Daily Visual Inspection	0.6 min.	365	3.5 hours
Unscheduled Mechanical or Electrical	2 hours	1	2 hours
- Repair/Touchup Paint	1.5 hours	0.5	0.8 hours
Major Overhaul of:	24 hours	0.1 (once every 10 years)	2.4 hours
- Reflector			
- Receiver			
- Motor			
- Bearings			
- Chain and Sprockets			
- Insulation			
TOTAL FOR EACH GROUP			27.7 hours
TOTAL FOR FIELD (168 GROUPS)			3225 hours

Estimated Replacement Parts Cost Per Group
(720-ft^2) Per 10-Year Period

Parts	Cost (Dollars)	$/Year
Receiver Tube Assembly	$ 75	$ 7.50
Motor	75	7.50
Bearings	25	2.50
Chain and Sprockets	30	3.00
Insulation	23	2.30
Miscellaneous (Nuts, Bolts, etc.)	10	1.00
Flex Hose, Fittings, etc.	100	10.00
TOTAL FOR EACH GROUP		$ 33.8
TOTAL FOR FIELD (168 GROUPS)		$ 5,678.00

- Repacking of stuffing boxes (according to manufacturers' specifications)

- Checking of forced draft fan drive belt tension

Curative maintenance will primarily concern moving parts replacement (especially the pump mechanical seal), attention to insulation, and elimination of leaks. If a malfunction occurs in the system, decoking the inside of tubes or soot blowing the outside may be required. However, these are unlikely. Overall maintenance of the heater is expected to require an average of one man-day per month.

3.2.8.3 PIPING, VALVES AND FITTINGS

A properly controlled construction process will lead to minimum maintenance requirements for these flow control and ducting components.

Maintenance practice will parallel that followed in the Thermal Storage Subsystem and described in Section 3.3.8.3. The unique piping component that may be present in the SCS is flexible hoses between the solar collector strings and the manifolding. If the collector procurement leads to the selection of a collector with a flexible connection requirement, collector supplier maintenance recommendations will be implemented. It can be expected that the flexible hose will require special attention during piping inspections and periodic replacement (approximately 10-year cycle estimated).

3.2.8.4 INSTRUMENTATION AND CONTROL

All instrumentation and control equipment, including cabling, connectors, capillary lines, etc., will be subject to a preventative maintenance program. The preventative maintenance program identifies schedules for performing visual inspections (typically every six months), and for performing routine maintenance (annually). The latter operation can be extensive and may be staggered over the course of the year. A manual(s) maintained at the facility will provide maintenance procedures and instructions for such operations as: equipment disassembly and component inspection; troubleshooting; repair; parts replacement schedules (e.g., "O" rings); calibration testing; and installation and check-out. Section 3.6.8 provides a more complete discussion of I&C maintenance projections.

3.2.9 SPECIAL FEATURES AND PRECAUTIONS

3.2.9.1 HEALTH AND SAFETY CONSIDERATIONS

SOLAR REFLECTANCE HAZARDS

Several different hazardous conditions could result from the effects of concentrated solar insolation or reflectance from the parabolic trough-type collector modules in the collector subsystem. A severe eye hazard exists for those personnel whose eyes are looking at, and happen to be located near, the focal point of a collector during periods of sunshine. In addition, a glare hazard may also exist when personnel are located in or near the collector field. A skin hazard (concentrated sunburn) is also a consideration for the design of an SCS.

Most of the above solar hazards are of concern primarily to the construction, testing, operating and maintenance personnel, and to the visitors, authorized or unauthorized, to the LSE facility. Techniques that will be used to eliminate, reduce the frequency of, or mitigate the severity of, some of these potential hazards include: the use of fencing to enclose the collector field; requiring eye protection, protective clothing and/or gloves when working near the collectors; proper instruction of LSE personnel on the methods to avoid these hazards; proper design of the insulation and supports at the end of the receiver tube; and the use of safety and warning devices and signs.

OIL HAZARDS (SUN 21)

A paraffinic oil, Sunoco heat transfer oil No. 21, is the heat collecting and transport fluid in the collector and thermal storage subsystems. Sun 21 has flash point and fire point temperatures of ~227°F (440°F) and 254°C (490°F), respectively, while its auto-ignition temperature is about 379°C (715°F). This material meets the definition of a Class III-B liquid when cold. However, since it is stored and handled above the flash point, relevant standards require treatment as a Class I liquid regarding electrical equipment design, and a Class II liquid for civil structure design purposes. The bulk of the heat transfer oil by far is in the Thermal Storage Subsystem. A detailed discussion of the health and safety implications of using the Sun 21 is presented for the TSS itself, and for the TSS portion of the site in Sections 3.3.9.1 and 3.8.4.2, respectively. Oil leakage into an absorptive and wicking insulation can lead to spontaneous combustion.

ELECTRICAL HAZARDS

Three general types of electrical hazards have been identified for consideration. First, an electrical shock or burn hazard may be possible in the SCS as by accidental contact with exposed wiring to electrically driven components and from the power distribution subsystem. The second type of hazard is an electrical fire hazard that could result in an ignition spark from the combustion of leaky oil or oil vapors. The third type of electrical hazard is a possible current surge to sensitive electronic or electrical equipment. Such current surges might result from lightning. In light of the extensive background and experience in the electrical power generation field, particularly by the Westinghouse team, the minimization or elimination of significant electrical hazards are expected to be competently accomplished.

MECHANICAL HAZARDS

During tracking operations, emergency defocus or normal stowing operations of the collectors for the solar collector subsystem, the parabolic trough and/or the receiver tube assemblies are set into motion, creating a potential mechanical hazard. Attendant with these tracking and stowing operations are limit switches to control the maximum rotary motion of the collectors and/or receiver tube assemblies. Due to the low speed of the drive system (15°/minute), no injury is anticipated to operating or maintenance personnel or visitors, authorized or unauthorized, to the STE facility.

Some components of the SCS can be damaged during severe wind, hail or storm conditions. Debris from this damage or destruction (for example, broken glass from the solar collectors) constitutes a health and safety consideration for personnel with access to the field.

A number of methods will be utilized to eliminate, mitigate the severity of, or reduce the frequency of, these potential hazardous conditions. These methods include: the implementation of cleanup procedures for debris subsequent to hail, wind or storm conditions; and arrangement of actual working areas to prevent access by the general public.

Mechanical hazards associated with the auxiliary heater include rotating equipment (fuel pump, circulating pump, and fan) and various control linkages, valves and dampers which may move and injure personnel, if proper maintenance procedures are not followed.

MALFUNCTION HAZARDS

Loss of flow in the collectors can cause overheating of the Sun 21 Oil in the subsystem and significant degradation in performance, offgassing, and charring of the oil may be possible. The auxiliary oil heater likewise carries some threat of overheating or oil leakage.

Several techniques will be used to eliminate or mitigate these malfunction hazards. These include the use of selected redundancy in the temperature and flow controllers to insure adequate flow to the collector field subsystem; the proper design of an emergency defocus subsystem to insure that the collectors are either slightly defocused or put into a stowed condition when overheating is detected; and the adequate use of existing standards for the design of the oil-fired heater.

3.2.9.2 ENVIRONMENTAL CONSIDERATIONS

AIR QUALITY EFFECTS

Fuel and stack characteristics are required to assess the potential impact of a new or modified facility on air quality. In this case, the auxiliary oil heater will use No. 2 residual oil and will be operational for only about 2200 hours during the year. Emissions from the heater fall far below the value set by the Environmental Protection Agency as a new pollution source.

LAND USE EFFECTS

Approximately seven acres of land will be required for the SCS. However, there is no land use conflict, since the land has no present important use. The entire area is owned by Fort Hood and no land purchase will be required.

3.3 THERMAL STORAGE SUBSYSTEM

3.3.1 SUMMARY DESCRIPTION

The Thermal Storage Subsystem (TSS), shown in Drawing A-2119-1001 (Volume III), is an all-liquid sensible heat storage system that incorporates three storage vessels: a high-temperature vessel that operates at a nominal 288°C (550°F) level, an intermediate temperature vessel that operates at a nominal 226°C (438°F) level, and a low temperature vessel that operates at a nominal 158°C (316°F) level.

The TSS incorporates two sets of redundant fluid pumps that provide the fluid transfer to other interfacing subsystems or components such as the Solar Collector Subsystem (including the Auxiliary Heater) and the Power Conversion Subsystem, and provide for internal (vessel-to-vessel) transfers.

A nitrogen supply system is incorporated into the TSS to provide an inert atmosphere within the vessel ullage spaces to prevent storage fluid oxidation and to eliminate any potential for ignition.

3.3.2 FUNCTION

The TSS provides the required "buffer" between the Solar Collector Subsystem and the Power Conversion Subsystem and incorporates components, fluid transport lines and control logic suitable for the accommodation of the widely varying solar collection characteristics anticipated for the Fort Hood, Texas site. The TSS provides for utilization of the Auxiliary Heater in periods of low solar insolation or in possible situations requiring that the heat transfer fluid (thermal storage fluid) be "conditioned" to provide acceptable temperature conditions for required operating temperature levels supplied to the Power Conversion Subsystem. There are also provisions incorporated into the TSS piping system such that the storage fluid can be pumped between storage vessels as required during start-up and normal operations.

During sunlight hours with normal operations the thermal storage fluid is pumped by centrifugal pumps either CP2460 or CP2461 from the nominally 158°C (316°F) low temperature storage vessel (T2399) through the solar collectors where it is heated to a nominal 288°C (550°F) and returned to high temperature storage vessel (T2199). The nominal 288°C (550°F) fluid is then pumped from T2199 by either CP2560 or CP2561 through the steam generator (Power Conversion Subsystem) to produce high pressure superheated steam and returned to the nominal 226°C (438°F) intermediate temperature vessel (T2299).

In the intermediate temperature operational mode the storage fluid is pumped from the intermediate temperature vessel (T2299) (using either CP2560 or CP2561) through the steam generator (Power Conversion Subsystem) to produce low-pressure saturated steam and then returned at a nominal 158°C (316°F) to the low temperature storage vessel (T2399). The cycle is then repeated on a daily basis whenever sufficient sunlight is available.

During periods of essentially zero solar insolation, or on days when the solar insolation is insufficient to meet operational requirements, and there is an experimental reason to do so, the nominally 158°C (316°F) fluid in the low temperature vessel (T2399) can be pumped, either totally or in parallel with the solar collectors, through the Auxiliary Heater where it will be heated to a nominal 288°C (550°F) so as to provide for normal daily operations.

Normally, however, when there is insufficient insolation, the fluid is pumped from the low temperature storage vessel through the Auxiliary Heater and heated to a nominal 226°C (438°F) and returned to the intermediate temperature vessel for subsequent use to generate low pressure steam.

During active operation, and during periods of non-operational shutdown, an inert nitrogen ullage is maintained in the storage vessels at a nominal overpressure of 4-inches of water column to prevent storage fluid oxidation or ignition.

3.3.3 DESIGN REQUIREMENTS

The design requirements for the Thermal Storage Subsystem are as follows:

- Provide for all-liquid sensible heat energy storage without capability for future retrofit with dual-media (i.e., oil plus rock)

- Accept heat transfer fluid at 316°C (600°F) maximum at a maximum rate of 51,360 kg/hr (113,160 lb/hr)

- Discharge heat transfer fluid at temperatures up to 316°C (600°F) at a maximum rate of 33,950 kg/hr (74,850 lb/hr)

- Discharge heat transfer fluid at temperatures up to 232°C (350°F) at a maximum rate of 51,500 kg/hr (113,500 lb/hr)

- Store a maximum of 84,300 kg (185,850 lb) of heat transfer fluid at a maximum temperature of 316°C (600°F)

- Store a maximum of 318,850 kg (694,200 lb) of heat transfer fluid at a maximum temperature of 260°C (500°F)

- Provide for oxidation protection of the heat transfer fluid

- Provide for heat transfer fluid maintenance and replenishment

- Provide for removal of "low boiling" oil cracking products containment for disposal or by environmentally acceptable "flaring"

- Provide for fluid discharge rates over a turndown range of three-to-one maximum

- Operate on demand continuously or for intermittent time periods

- Operate reliably for a 20-year service life

- Design in accordance with existing codes, standards and regulations

- Provide for energy containment in accordance with economic/operational criteria established during system design

- Provide valving and valve-logic such that automatic and safe shutdown will occur in the event of system failure (modes to be analyzed during detail design) or system power or pneumatic failure

- Provide piping and valving such that initial startup and daily operational startup can be accomplished without introducing undesirable fluid temperature levels into designated storage vessels

- Provide vessels for fluid storage at three nominal temperature levels of 288°C (550°F), 226°C (438°F) and 158°C (316°F)

- Utilize a commercially available petroleum oil (heat transfer fluid), SUNOCO 21 or 25, as the storage media

- Provide for independent storage fluid flow from the 288°C (550°F) vessel and from the 158°C (316°F) vessel with flow from the 226°C (438°F) vessel (using a common pumping system to the 288°C (550°F) vessel) occurring at times when flow from the 288°C (550°F) vessel is not required

- Provide suitable field devices such that the instantaneous status of the energy storage can be assessed and utilized in a control logic sequence

3.3.4 THERMAL STORAGE SUBSYSTEM DESCRIPTION

3.3.4.1 OVERALL SUBSYSTEM

The TSS at the Preliminary Design level is described by two essential drawings given in Volume III:

- Subsystem Flow Diagram, Dwg. No. A-2119-1002, sheets 1-3

- Subsystem Process and Instrumentation Diagram, Dwg. No. A-2119-1003, sheets 1-3

FLOW DIAGRAM

The Subsystem Flow Diagram presents the principal piping connections arrangement between major subsystem components (the storage vessels, fluid pumps, nitrogen system and condenser/flare) and the interfacing subsystems and components.

PERFORMANCE PARAMETERS

Drawing A-2119-1002 includes the basic subsystem diagram, and Drawing A-2119-1003 presents the fluid conditions existing at the principal subsystem locations during the defined Heating and Cooling Season operating conditions.

The calculations to determine the fluid conditions at the principal locations were made using preliminarily defined piping sizes and insulation thicknesses as described in Section 3.3.4: Description of Components.

PROCESS AND INSTRUMENTATION DIAGRAM

The TSS Process and Instrumentation Diagram is presented in Drawing A-2119-1003, Sheets 1, 2 and 3. The P&ID includes all components incorporated into the Thermal Storage Subsystem preliminary design. Sheets 1 and 2 include the total TSS P&ID diagram, and Sheet 3 provides the interpretation details for the P&ID.

3.3.4.2 DESCRIPTION OF COMPONENTS

STORAGE VESSELS

The requirements for the storage vessels for the TSS have been defined by an evolutionary process of overall STES requirements, economic considerations,* and explicit code design and construction coverage.

The results of the various considerations produced vessel requirements having minimum active volume requirements of:

Vessel	Active Volume
High Temperature	127.4 m^3 (4500 ft^3)
Intermediate Temperature	442.0 m^3 (15,610 ft^3)
Low Temperature	413.1 m^3 (14,590 ft^3)

Using the minimum active volumes and incorporating a one-foot deep volume increment for minimum vessel draw-down, one foot for clear ullage space, plus an "engineering reserve" volume of "one hour at maximum discharge rate" from the high temperature vessel, resulted in vessels having volumes of:

Vessel	Total Volume
High Temperature	196.5 m^3 (6940 ft^3)
Intermediate Temperature	528.7 m^3 (18,670 ft^3)
Low Temperature	498.4 m^3 (17,600 ft^3)

*See Section 5.5--Trade Studies

The storage vessels evolved in the Preliminary Design are shown in Figure 3.3-1 in profile, and the vessel specifications are presented in Table 3.3-1.

PUMPS

The fluid pumps that have been defined for the service requirements of the two principal fluid circuits within the STES (i.e., the Solar Collector Subsystem circuit and the Power Conversion Subsystem), are dual (redundant) installations of horizontal, center-line supported, heavy duty API 610 service, centrifugal pumps with two-speed drivers (Note: The determination of required speeds will be predicated on the minimization of parasitic power consumption.).

The fluid pumps are described in Table 3.3-2. The included initial specifications for developed head are based on standard commercial/marine piping sizes and are subject to decreases during the detailed design, phase IV, to reduce the parasitic pumping power on the system.

PIPING AND VALVES

The piping system for the TSS will be designed in compliance with the provisions of ANSI B31.3, Petroleum Refinery Piping, and will incorporate flexibility provisions to sustain the 20-year diurnal operational requirements.

Initial piping and valving sizes were established based on usual practice and after a preliminary analysis of parasitic pumping power requirements, were increased in size to reduce the pumping head required. The results of the preliminary design are presented in Table 3.3-3. Associated valving was incorporated into the TSS on the basis of sizes equal to line size up to 7.6 cm (3 inches) and one line size less in diameters over 7.6 cm (3 inches).

All valves are specified as 300# for the specific service conditions associated with the operation and for Sun 21 oil containment. All valves, except flow control valves, are specified to be gate valves (to assure tight shut-off) to minimize the pressure drop through the fluid circuits, and consequently, the parasitic pumping power requirements.

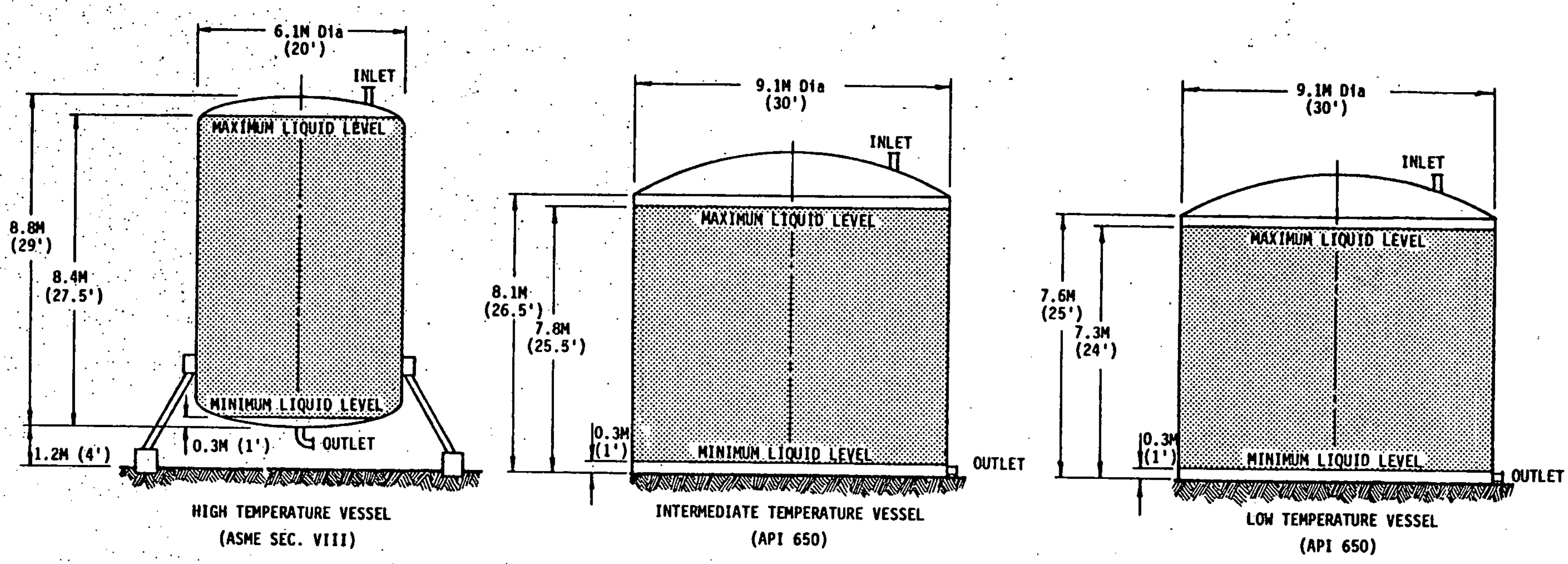


Figure 3.3-1. Thermal Storage Subsystem Vessel Elevation Profiles

TABLE 3.3-1

THERMAL STORAGE SUBSYSTEM STORAGE VESSEL SPECIFICATIONS

	High Temperature Vessel	Intermediate Temperature Vessel	Low Temperature Vessel
Vessel Type	Cylindrical Section, ASME Heads	Cylindrical Flat Bottom	Cylindrical Flat Bottom
Vessel Life	20 Years	20 Years	20 Years
Construction Details	ASME Section VIII	API 650	API 650
Shell Diameter	6.1 m (20 ft)	9.1 m (30 ft)	9.1 m (30 ft)
Shell Height	8.8 m (29 ft)	8.1 m (26.5 ft)	7.6 m (25 ft)
Vessel Volume	196.5 m^3 (6940 ft^3)	528.7 m^3 (18,670 ft^3)	498.4 m^3 (17,600 ft^3)
Vessel Material	Carbon Steel	Carbon Steel	Carbon Steel
Stored Material	Sun 21 Oil	Sun 21 Oil	Sun 21 Oil
Weight Stored Material	85,238 kg (187,915 lb)	374,810 kg (826,300 lb)	374,810 kg (826,300 lb)
Volume Stored Material	135.9 m^3 (4800 ft^3) at 288°C (550°F)	521.6 m^3 (18,420 ft^3) at 226°C (438°F)	491.6 m^3 (17,360 ft^3) at 158°C (316°F)
Operating Pressure	996 Pa (4" Water Gauge)	996 Pa (4" Water Gauge)	996 Pa (4" Water Gauge)
Maximum Pressure	1494 Pa (6" Water Gauge)	1494 Pa (6" Water Gauge)	1494 Pa (6" Water Gauge)
Operating Temperature	288°C (550°F)	226°C (438°F)	158°C (316°F)
Structural Design Temperature	316°C (600°F)	260°C (500°F)	260°C (500°F)
Temperature Variations	28°C (50°F), 7000 Cycles	11°C (20°F), 7000 Cycles	8°C (15°F), 7000 Cycles
	56°C (100°F), 100 Cycles	42°C (75°F), 100 Cycles	28°C (50°F), 100 Cycles
	278°C (500°F), 50 Cycles	208°C (375°F), 50 Cycles	139°C (250°F), 50 Cycles

TABLE 3.3-2

THERMAL STORAGE SUBSYSTEM FLUID PUMP CHARACTERISTICS

- Collector Field Pumps (Tandem redundant installation)
  - Deliver 18.7 ℓ/s (296 GPM) at 72.5 m (238 ft) Head at operating temperature of 260°C (500°F)
  - Pump Sun 21 oil at 260°C (500°F), 0.60 cp
  - Pump Sun 21 oil at -6°C (22°F), 667 cp and at intermediate temperatures
  - Duty: Daily startup from ambient temperature, continuous for 12 hours (7000 cycles)
  - Dual Speed: 3500 rpm maximum
  - Maximum NPSH Available = 25 feet
  - API Standard 610 Design
  - Over-temperature protection for pump and drive
  - High-pressure cut-out for motor
  - Driver 15 kW (20 hp) at 3500 rpm
- Steam Generator Pumps (Tandem redundant installation)
  - Deliver 14.3 ℓ/s (226 GPM) at 89.3 m (293 ft) Head at operating temperature of 316°C (600°F)
  - Pump Sun 21 oil at 316°C (600°F), 0.47 cp
  - Pump Sun 21 oil at -6°C (22°F), 667 cp and at intermediate temperatures
  - Duty: Continuous, periodic startup from ambient temperature with 7000 cycles; 316°C (600°F) to 204°C (400°F); 50 cycles, 316°C (600°F) to ambient
  - Dual Speed: 3500 rpm maximum
  - Maximum NPSH available = 20 feet
  - API Standard 610 Design
  - Over-temperature protection for pump and driver
  - High-temperature cut-out for motor
  - Driver 15 kW (20 hp) at 3500 rpm

TABLE 3.3-3

THERMAL STORAGE SUBSYSTEM PIPING LIST

Piping Section	Size	Material
Collector Field Discharge Header to (288°C/550°F) Storage Vessel Inlet (36-37)*	8.9 cm (3-1/2"), Sch 40	A-53, Gr. B
High Temperature Storage Vessel (288°C/550°F) to Steam Generator Pump Inlet (45-44)	12.7 cm (5"), Sch 40	A-53, Gr. B
Steam Generator Pump Discharge to Steam Generator (43-20)	7.6 cm (3"), Sch 40	A-53, Gr. B
Intermediate Temperature Storage Vessel (226°C/438°F) to Steam Generator Pump Inlet (46-44)	12.7 cm (5"), Sch 40	A-53, Gr. B
Low Temperature Storage Vessel (158°C/316°F) to Collector Field/ Auxiliary Heater Pump Inlet (39-41)	15.2 cm (6"), Sch 40	A-53, Gr. B
Intermediate Temperature Storage Vessel (226°C/438°F) to Collector Field/Auxiliary Heater Pump Inlet (46-41)	15.2 cm (6"), Sch 40	A-53, Gr. B
Collector Field/Auxiliary Heater Pump Discharge to Collector Field (38-55)	12.7 cm (5"), Sch 40	A-53, Gr. B
Collector Field/Auxiliary Heater Pump Discharge to Auxiliary Heater Inlet (38-48)	12.7 cm (5"), Sch 40	A-53, Gr. B
Steam Generator Discharge to Intermediate Temperature Vessel (226°C/438°F) Inlet (21-49)	7.6 cm (3"), Sch 40	A-53, Gr. B
Steam Generator Discharge to Low Temperature Vessel (158°C/316°F) Inlet (21-50)	7.6 cm (3"), Sch 40	A-53, Gr. B
Auxiliary Heater Discharge to High Temperature Vessel (288°C/ 550°F) Inlet (47-37)	8.9 cm (3-1/2"), Sch 40	A-53, Gr. B
Auxiliary Heater Discharge to Intermediate Temperature Vessel (226°C/438°F) Inlet (47-49)	10.2 cm (4"), Sch 40	A-53, Gr. B
Collector Field Discharge Header to Collector Field/Auxiliary Heater Pump Inlet (42-41)	7.6 cm (3"), Sch 40	A-53, Gr. B

*Numbers in parenthesis refer to subsystem locations shown in Dwg. A-2119-1002 (Volume III).

INSTRUMENTATION AND CONTROLS

Instrumentation has been incorporated into the Thermal Storage Subsystem such that the operational status of the system can be determined at any instant. Fluid level (static head) sensing and transmitting equipment and temperature sensing devices are utilized so as to provide for instantaneous determination of storage energy levels as well as fluid inventory.

The principal fluid loops are instrumented to sense and transmit fluid flow in order to assess the dynamic status of the system at any time. Fluid pressure sensing and transmitting equipment is provided to assess fluid capability of the system. A summary of the TSS instrumentation is presented in Table 3.3-4 with detail listings in Tables 3.3-5, 3.3-6 and 3.3-7.

Use of operational temperature sensors has been kept to a minimum; only instrumentation required for recognition of system status during initial and daily start-up is included. Over-temperature sensing devices protecting the fluid temperature entry into the storage system are not included in the Thermal Storage Subsystem. Except for the 60 thermocouples identified in Table 3.3-4 for diagnostic purposes, all instrumentation is typical of commercial STES applications.

AUXILIARY SYSTEMS

The TSS Auxiliary Systems include:

- The Nitrogen Inerting System (NIS)
- The Oil Management System (OMS)
- The Oil Vapor and Gas Management System (OVGMS)
- The Oil Preconditioning System (OPS)

NITROGEN INERTING SYSTEM

The NIS provides for the prevention of fire and oxidation degradation of the storage fluid by maintaining the storage vessel(s) ullage space at a low nitrogen pressure level (the order of inches of water) and will provide for the

TABLE 3.3-4

THERMAL STORAGE SUBSYSTEM INSTRUMENTATION CHARACTERISTICS

- Storage Vessel Level Sensors:
  - 3 dp cells w/output of 4 to 20 ma at 0 to 69 kPa (0 to 10 psi ΔP with 158°C (316°F), 226°C (438°F) and 288°C (550°F) fluid nominal operating temperatures and "cold" connections

- Flow Sensors:
  - 2 dp cells w/output 4 to 20 ma at 0 to 48 kPa (0 to 7 psi) ΔP
  - 2 Annubars at 0 to 48 kPa (0 to 7 psi) range
  - 316°C/260°C (600/500°F) operating temperatures using "cold" connections

- Pressure Sensors:
  - 6 Pressure sensor/transmitters 4 to 20 ma output at 0 to 690 kPa (0 to 100 psi) and -35 to 69 kPa (-5 to 10 psi)

- Temperature Sensors:
  - 25 Thermocouples - Type J with thermal-wells and operating capability to 316°C (600°F) for analysis of available energy content of storage vessels
  - 60 Thermocouples - Type J with direct spot-weld and capability to 316°C (600°F) for start-up and initial operation diagnostic purposes (field installed)

TABLE 3.3-5

THERMAL STORAGE SUBSYSTEM TEMPERATURE MEASUREMENTS LIST

Quantity	Component	Function
7	Thermocouple Type J Iron-Constantan	Measure temperature at various levels in high temperature storage vessel for purposes of available energy content analysis.
7	Thermocouple Type J Iron-Constantan	Measure temperature at various levels in intermediate temperature storage vessel for purposes of available energy content analysis
7	Thermocouple Type J Iron-Constantan	Measure temperature at various levels in low temperature storage vessel for purposes of available energy content analysis
4	Thermocouple Type J Iron-Constantan	Measure temperature of pumps to detect over-heating
60	Thermocouple Type J Iron-Constantan	To be used where required for start-up and diagnostic purposes

TABLE 3.3-6

THERMAL STORAGE SUBSYSTEM PRESSURE AND FLOW MEASUREMENTS LIST

Quantity	Component	Function
3	Differential Pressure Cell Transmitter	Measure height of oil in storage vessels and to be used for available energy calculations
2	Differential Pressure Cell Transmitter	Measure flow of oil to solar collectors and steam generator
4	Force-Balance Pressure Transmitter	Measure inlet and outlet pressures of collector field and steam generator pumps
1	Differential Pressure Cell Transmitter	Measure pressure of nitrogen blanket system
2	Pressure Switch	Indicate sufficient water pressure to seals of steam generator pumps
2	Flow Indications	Indicate proper flow of water to seals of steam generator pumps
3	High and Low Pressure Alarm	Protection of storage vessels from pressure variations
3	High Level Alarm	Protection of storage vessels from over filling
1	Flow Detector	Activate flare
3	Differential Pressure Cell Transmitter	Measure height of oil in storage vessels and to be used for available energy calculations
2	Differential Pressure Cell Transmitter	Measure flow of oil to solar collectors and steam generator
4	Force-Balance Pressure Transmitter	Measure inlet and outlet pressures of collector field and steam generator pumps
1	Differential Pressure Cell Transmitter	Measure pressure of nitrogen blanket system

TABLE 3.3-6 (Continued)

Quantity	Component	Function
2	Pressure Switch	Indicate sufficient water pressure to seals of steam generator pumps
2	Flow Indications	Indicate proper flow of water to seals of steam generator pump
3	High and Low Pressure Alarm	Protection of storage vessels from pressure variations
3	High Level Alarm	Protection of storage vessels from over-filling
1	Flow Detector	Activate flare

TABLE 3.3-7

THERMAL STORAGE SUBSYSTEM SYSTEM CONFIGURATION CONTROL AND INDICATION LIST

Quantity	Component	Function
2	Remotely actuated, Valve with open/closed position indication switches	Blowdown for Storage vessel protection
4	Remotely actuated, Valve with open/closed position indication switches	Control direction of flow from storage vessel outlets
5	Remotely actuated, Valve with open/closed position indication switches	Isolation and control direction of flow at storage vessel inlets
5	Remotely actuated, Valve with open/closed position indication switches	Isolation of storage vessels nitrogen blanket system
1	Remotely actuated, Valve with open/closed position indication switches	Low temperature pump recycle for protection from overheating
1	Remotely actuated, Valve with open/closed position indication switches	To allow oil to be recycled to collectors
1	Remotely actuated, Valve with open/closed position indication switches	To by-pass liquid seal in order to purge ullage space

accommodation of (1) normal operation temperature variations, and (2) short- and long-term shutdown situations.

The NIS provides nitrogen to the ullage system as required to maintain the ullage positive pressure and will provide for the relief of pressure build-up caused by temperature increases within the storage vessels during initial start-up and daily start-up. The NIS utilizes a cryogenic nitrogen supply system capable of replenishment from mobile transport units.

The Preliminary Design Nitrogen Inerting System requirements are presented in Table 3.3-8.

OIL MANAGEMENT SYSTEM

The oil management system is comprised of a defined program of fluid evaluation that is designed to reveal any degradation of the storage fluid in a timely manner so as to allow for appropriate development of countermeasures before the storage fluid degradation is critical. The management program combines initial reduction of vessel ullage oxygen content, and periodic measurement of acid number, flash point, viscosity and C_5/C_6 insolubles and periodic fluid vacuum degassing. To complete the program, SUNOCO SUNTECH personnel will be consulted periodically to take advantage of their experience and knowledge of SUN 21 oil.

As operational experience is obtained, the need for more extensive fluid maintenance will be evaluated. Such steps are not anticipated, but should include:

- Replacement of the storage fluid at extended intervals
- Dilution of the storage fluid with fresh fluid on a periodic schedule
- Installation of a vacuum distillation "side stream processor" at a future date if one is found to be necessary

The range of properties that establish the fluid operating conditions from "initial" to "critical" are presented in Table 3.3-9.

TABLE 3.3-8

THERMAL STORAGE SUBSYSTEM NITROGEN INERTING SYSTEM REQUIREMENTS

- Cryogenic Nitrogen Storage Vessel:
  - 5.7 m^3 (1500 gallon). Capacity with pressure sensor, vaporizer, relief valve, check valve and pressure regulation to deliver 4.7 ℓ/s (600 scfh) at 10.2 cm (4-in.) water gauge
- Feed Line:
  - 1.9 cm (0.75-in.) dia. Type 316 SS tubing to vessel header
- Liquid Seal Drum:
  - 0.76 m (2-1/2-ft) dia., 0.38 m^3 (100 gallon) with dual slotted orifices and 10.2 cm (4-in.) water gauge pressure drop maximum
- Flare:
  - Capable of burning 68 kg/hr (150 lb/hr) of hydrocarbon vapors, with flow actuated sequence-starting of auxiliary gas pilot, igniter, multiple jet burners, and a steam supply, if necessary, operating from the 448 kPa (65 psia) steam system
- Continuously monitor the vessel ullage spaces for oxygen to actuate an alarm if oxygen contents exceed one percent
- Comply with NPFPA:
  - #69-73, Explosion Prevention Systems, and other codes and standards as applicable

TABLE 3.3-9

STORAGE FLUID PROPERTIES RANGES POSSIBLE DURING FLUID OPERATING LIFE

Measurement	Initial Values	Warning Values	Critical Values
Acid Number, mg/gm	0 to 0.01	0.5	0.8
Flash Point, °C (°F), Cleveland Open Cup	218°C ± 3 (425°C ± 5)	213°C (415°F)	(TBD)*
Viscosity at 38°C (100°F) (SUS)	200 to 215	220 to 235	(TBD)*
C_5/C_6 Insolubles	0	0.1	(TBD)*

*To be determined in the detailed design phase

OIL VAPOR AND GAS MANAGEMENT SYSTEM

The OVGMS is comprised of an air-cooled condenser located in the vapor/gas transfer line between the high and intermediate temperature vessels, a condensed liquid receiver vessel, an oxygen detector and a hydrocarbon vapor detector. The OVGMS requirements are presented in Table 3.3-10.

The vapor condenser will normally operate with natural convection transfer from the air-side of the condenser but will provide for an estimated initial fluid heat-up vapor generation of approximately three percent (over 90 hours), based on Figure 3.3-2, for the solar Sun 21 data, with a temporary forced convection fan. This will provide valuable operational understanding as well as minimize the quantities of hydrocarbon vapors that must be burned to environmentally acceptable levels in the flare, thereby reducing the parasitic energy consumption by that auxiliary component in the TSS.

The oxygen detector will provide for detection of initial start-up oxygen content in the ullage space all will provide on a continuous basis the necessary safety monitoring of the ullage spaces to assure non-hazardous operation and storage fluid protection.

TABLE 3.3-10

THERMAL STORAGE SUBSYSTEM OIL VAPOR AND GAS MANAGEMENT REQUIREMENTS

- Precondition the oil before introduction into the system to remove dissolved gasses by vacuum degassing
- Provide an air-cooled condenser to remove the condensables from the ullage gas prior to flaring
- Provide a liquid seal upstream of the flare to insure system pressure maintenance and to prevent back-diffusion of oxygen (air) from the flare
- Provide a non-continuous, demand-type flare, with sensing gas/vapor flow downstream of the liquid seal to ignite the flare burners
- Periodically blow-down the ullage space to prevent continuous build-up of non-condensable low flash point vapors in the ullage, using a continuous hydrocarbon monitoring of the ullage spaces to determine when (TBD) percent hydrocarbons exist before initiating blow-down
- Air Condenser - Capable of condensing 34 kg/hr (75 lb/hr) of C_3/C_6 hydrocarbons normal operation, and 68 kg/hr (150 lb/hr) of C_3/C_6 hydrocarbons during start-up using forced air circulation

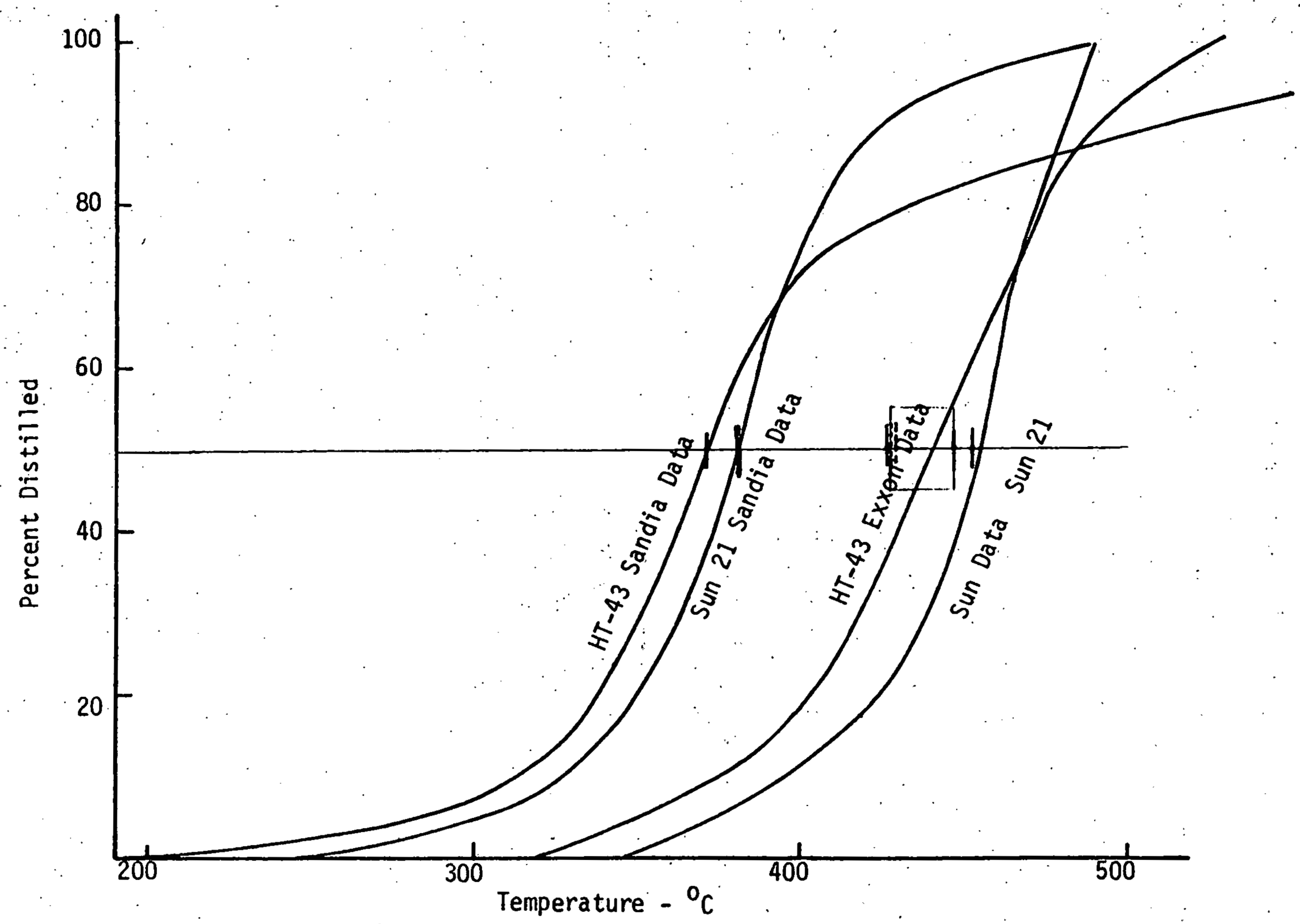


Figure 3.3-2. Distillation Curves for Sun 21 and Caloria HT-43

The hydrocarbon sensor provides for the detection of unacceptable and potentially unsafe levels of hydrocarbon vapors within the ullage spaces. The vapor pressure of Sun 21 at 288°C (550°F) is approximately 3448 Pa (0.5 psia), and at 226°C (438°F), approximately 345 Pa (0.05 psia). The degree to which the ullage space becomes saturated or displaces nitrogen with C_5/C_6 vapor from the storage fluid is dependent on a number of factors:

- Time of residence of the oil at the high temperature level
- Volume of the ullage space
- Area of the liquid interface
- Manner in which the oil is fed to the vessel
- Age of the oil in the system
- Mass transport to the low temperature vessel with condensation
- Rate of evolution and escape of vapor during operation

Hence, the actual quantity of these oil vapors in the gas space above the liquid can vary significantly. If an unacceptable condition develops, provisions have been made to allow the vessel ullage space to be "blown-down" through the vapor flare to bring the vapor content of the ullage space back to acceptable levels.

OIL PRECONDITIONING SYSTEM

The OPS is comprised of a vacuum vessel through which the storage fluid will be "sprayed" during initial filling of the system to remove oxygen and other dissolved gases from the "fresh" storage fluid. Exposure time to the vacuum will be a minimum of 10 seconds at 635 mm (25 inches) mercury. Such preconditioning is normal practice in the petrolem industry.

3.3.5 THERMAL STORAGE SUBSYSTEM OPERATION

3.3.5.1 NORMAL OPERATION

HIGH TEMPERATURE MODES

The Thermal Storage Subsystem operates in the high temperature mode whenever fluid is being heated to 288°C (550°F) by the Collector Subsystem and/or the

Auxiliary Heater and/or high-pressure superheated steam is being generated. The high temperature modes are identified as follows:

- High Temperature Peaking Mode Cooling Season - Full Load Day
- High Temperature Fast Power Mode Cooling Season - Full Load Day
- High Temperature Peaking Mode Heating Season - Full Load Day
- High Temperature Part Power Mode Heating Season - Full Load Day
- High Temperature Part Power Electrical Generation Mode
- High Temperature Peak Electrical Generation Mode

In all of these cases, the storage fluid flow paths are the same with the exception of the case where the Auxiliary Heater may be operated in parallel with the Collector Subsystem, or unless the Auxiliary Heater is used exclusively as the energy input source.

System operation and flow is as follows:

- Fluid is extracted from the low temperature vessel at a temperature of approximately 158°C (316°F) and pumped to the Collector Subsystem (or to the Auxiliary Heater, or to both the Collector Subsystem and the Auxiliary Heater) where it is heated to approximately 288°C (550°F) and discharged into the high temperature vessel.
- When sufficient fluid is contained in the high temperature vessel to assure continuous supply from the high temperature vessel to the Steam Generator (this depends on operational mode), the high temperature fluid is pumped to the Steam Generator where superheated steam (high pressure) is generated and the fluid is cooled to approximately 226°C (438°F) and returned to the intermediate temperature vessel. This continues as long as sufficient solar insolation is available or until all of the storage fluid is discharged from the low temperature vessel, through the Solar Collectors and/or the Auxiliary Heater and the Steam Generator, and into the intermediate temperature vessel.

INTERMEDIATE TEMPERATURE OPERATION

The intermediate temperature operating modes are identified as follows:

- Intermediate Temperature Part Power Mode Cooling System - Full Load Day

- Intermediate Temperature Peaking Mode Cooling Season - Full Load Day
- Intermediate Temperature Part Power Mode Heating Season - Full Load Day
- Intermediate Temperature Part Power Electrical Generation Mode

In the intermediate temperature mode of operation, system flow is as follows:

- Fluid at approximately 226°C (438°F) is extracted from the intermediate temperature vessel (rate depends on operating mode) and pumped through the Steam Generator to produce low pressure steam
- The fluid is returned from the Steam Generator to the low temperature vessel at approximately 158°C (316°F)

3.3.5.2 STARTUP AND SHUTDOWN

INITIAL SYSTEM HEAT-UP

Initial system heat-up occurs only once after construction or major maintenance shutdown. The appropriate procedures for initial system heat-up are best accomplished using the Auxiliary Heater rather than the Solar Collector Subsystem since the Auxiliary Heater can be modulated easily to a low output level that allows for careful and cautious initial system heating.

The general initial heating approach would follow a relatively slow schedule where not more than 28°C (50°F) temperature increments are imposed on the system for each "oil pass." This would be accomplished along the following procedural lines:

- Oil would be pumped from the low temperature vessel at a rate of 54,360 kg/hr (100,000 lb/hr) maximum through the Auxiliary Heater where it would be heated by 28°C (50°F), and would flow into the high temperature vessel. Even at the lowest historical ambient temperature, the oil will remain above its 0°F pour point and will be pumpable.
- Simultaneously, but at a lower rate, the oil would be pumped from the high temperature vessel through the steam generator (no steam generation but filled with water), and into the intermediate temperature vessel.
- When the high temperature vessel is filled to maximum level, the fluid discharge rate from this vessel would be increased to the inlet level.

- The balanced flow would continue until all of the fluid was extracted from the low temperature vessel, heated by 28°C (50°F), passed through the high temperature vessel and into the intermediate temperature vessel until all of the fluid is transferred to the intermediate temperature vessel.

- At this point, the temperatures of the high temperature and intermediate temperature vessels are approximately 28°C (50°F) above the low temperature vessel. The fluid is then pumped from the intermediate temperature vessel through the Collector Subsystem and into the low temperature vessel.

- The cycle is repeated (approximately six times) until all three vessels are approximately 158°C (316°F).

- At this point, the low temperature vessel is eliminated from further heating and the fluid is circulated in a similar manner through the high and intermediate temperature vessels until both vessels, the Solar Collector Subsystem and the Steam Generator, are at approximately 226°C (438°F).

- Next, the fluid is pumped at a rate of 40,000 kg/hr (88,000 lb/hr) from the intermediate temperature vessel and through the Auxiliary Heater, heated to approximately 260°C (500°F), and placed in the high temperature vessel until it is filled to maximum level.

- When the high temperature vessel is filled to maximum level, flow from the high temperature vessel is initiated through the Steam Generator where superheated steam is generated at a rate such that the returned fluid to the intermediate temperature vessel is approximately 226°C (438°F). This is continued until all of the fluid charge has passed through the Auxiliary Heater.

- Next, the fluid is heated to 288°C (550°F) using the Auxiliary Heater (226° to 288°C/438° to 550°F) and again, when the high temperature vessel is filled, superheated steam is generated and the fluid is returned to the intermediate temperature vessel at 226°C (438°F).

- When all of the fluid has been heated to 288°C (550°F) and has been used to generate superheated steam and returned to the intermediate temperature vessel, the fluid is then pumped from the intermediate temperature vessel through the Steam Generator where saturated steam is generated and the fluid is returned to the low temperature vessel at 158°C (316°F).

- At this point, the subsystem is completely preheated to normal operating conditions, the Collector Field has been heated initially to about 226°C (438°F) (approximately the "average" normal operating condition), the Auxiliary Heater performance has been verified, the Steam Generator has operated through two complete cycles (high and low pressure generation) and the Subsystem is ready to perform the normal operations.

SUBSYSTEM SHUTDOWN

The Thermal Storage Subsystem can be shutdown from normal or abnormal condition of dynamic operating status by shutting off the fluid pumps and the storage fluid flow over a time period of 15 seconds minimum, followed by appropriate valving configurations to avoid fluid circuit "lock-up." (Note: Even though a failure event might affect the ability of the valving to be properly actuated in such a short time interval, the "normal" valving positions will override and provide a safe ("soft") subsystem configuration.)

The major requirement for continued subsystem viability under both dynamic normal and abnormal operating conditions, and including shutdown, is the protection of the integrity of the nitrogen supply system and the proper functioning of the nitrogen supply to the vessel's ullage space and interconnecting piping.

3.3.5.3 ABNORMAL OPERATION AND NON-OPERATIONAL STANDBY

OFF-NOMINAL TEMPERATURES

There will undoubtedly be conditions of operation that will result in off-nominal subsystem operating temperatures. Such conditions, however, can be accommodated by the total system by small adjustments to operating points; i.e., the mass flows, pressures or temperatures of the adjacent fluids, which can safely be accommodated by the energy transfer equipment interfacing with the Thermal Storage Subsystem or the adjacent equipment, as the energy is "cascaded" down the system. In those cases where the temperatures that exist might be defined as "abnormal per se" and unusable, then the conditions can be accommodated by the use of blending or minor conditioning using the Auxiliary Heater.

FLOW REDUCTION OR BLOCKAGE

In the event that a flow blockage or reduction occurs, the observation instruments on adjacent subsystems would detect the off-nominal conditions and would alert the operations personnel to take corrective action or the safety diagnostic instrumentation would interject a safety override command which protects the sensitive components or areas.

NON-OPERATIONAL PERIODS

Non-operational periods, either of "short" or "long" term duration, are of no consequence to the subsystem so long as the integrity of the nitrogen blanket over the storage fluid is maintained. Temperature variations that develop with time can easily be accommodated by proper procedures of blending, mixing, or conditioning (using the auxiliary heater) and brought back into "normal" operating levels.

3.3.6 THERMAL STORAGE SUBSYSTEM INTERFACES

3.3.6.1 SUBSYSTEM INTERFACES

The subsystem interfaces with the TSS are defined as follows where the numbers refer to Drawing A-2119-1002 in Volume III and to Figure 3.3-3.

SOLAR COLLECTOR SUBSYSTEM INTERFACES

55. Oil line inlet to collector field at connection to collector inlet header at field

36. Oil line return from collector field at connection to collector outlet header at field

42. Oil recirculation line from collector field at connection to collector recirculation header at field

48. Oil line inlet to auxiliary oil heater at first connection to heater

47. Oil line return from auxiliary oil heater at first connection to heater

POWER CONVERSION INTERFACES

20. Oil line inlet to steam generator at first connection to packaged steam generator

21. Oil line return from steam generator at first connection to packaged steam generator

HOT WATER HEATING/CHILLED WATER COOLING SUBSYSTEM INTERFACES

56. Connection at (TBD) of hot water heating/chilled water cooling nitrogen line to nitrogen line at nitrogen supply

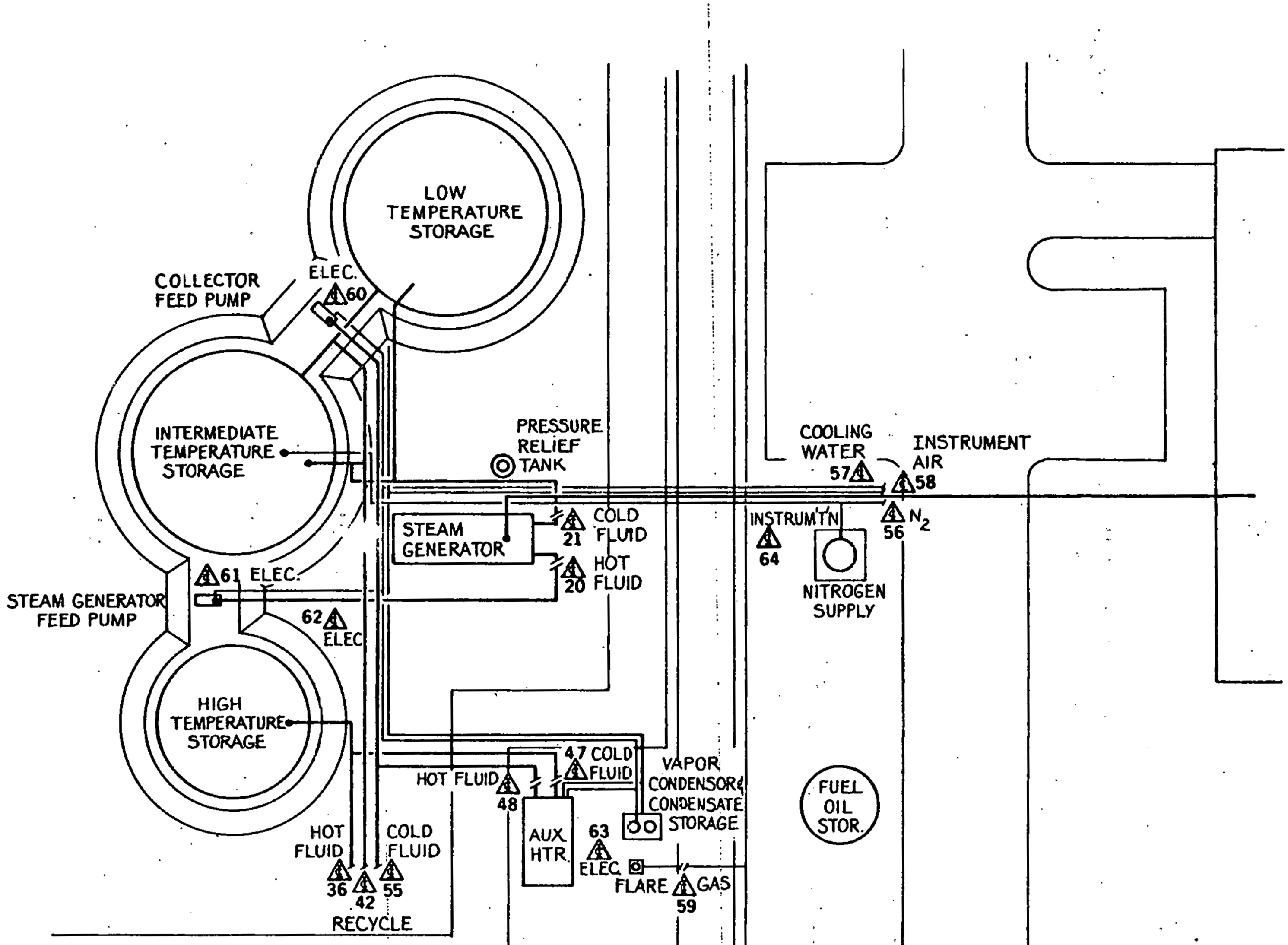


Figure 3.3-3. Thermal Storage Subsystem Site Interface Drawing

INSTRUMENTATION AND CONTROL INTERFACES

64. Connections at the I/O Board of instrumentation and control signal lines to lines to DPU

3.3.6.2 MECHANICAL INTERFACES

The Thermal Storage Subsystem mechanical interfaces includes those identified as subsystem interfaces under Figure 3.3-3 and the following site interfaces. The mechanical interfaces are summarized in Table 3.3-11.

SITE INTERFACES

57. Connection of site water line to thermal storage subsystem water line

58. Connection of site compressed air line to thermal storage subsystem compressed air line

59. Connection of site natural gas line to natural gas line to flare

3.3.6.3 ELECTRICAL POWER INTERFACES

Electrical interfaces consist of connections for electric power to thermal storage subsystem electric motors. Requirements for the electric power interfaces are given in Table 3.3-12. This table also lists instrumentation and control signal connections as an electrical interface.

ELECTRICAL INTERFACES

60. Connection of site electrical power line to collector field pump drive

61. Connection of site electrical power line to steam generator feedpump drive

62. Connection of site electrical power line to heat exchanger fan drive

63. Connection of site electrical power line to flare electrical input

TABLE 3.3-11

THERMAL STORAGE SUBSYSTEM MECHANICAL INTERFACES

Interface Identification	Pipe	Type Connection	Maximum Temperature K	Maximum Temperature (°F)	Fluid	Maximum Flow Rate kg/hr	Maximum Flow Rate (lb/hr)
20	7.6 cm (3") Sch 40, A-53, Gr. B	Weld	589	(600)	Oil	33,952	(74,850)
21	7.6 cm (3") Sch 40, A-53, Gr. B	Weld	505	(450)	Oil	33,952	(74,850)
36	8.9 cm (3-1/2") Sch 40, A-53, Gr. B	Weld	589	(600)	Oil	39,191	(86,400)
42	7.6 cm (3") Sch 40, A-53, Gr. B	Weld	561	(550)	Oil	20,866	(46,000)
55	12.7 cm (5") Sch 40, A-53, Gr. B	Weld	450	(350)	Oil	51,484	(113,500)
47	8.9 cm (3-1/2") Sch 40, A-53, Gr. B	Weld	589	(600)	Oil	13,154	(29,000)
48	12.7 cm (5") Sch 40, A-53, Gr. B	Weld	533	(500)	Oil	13,154	(29,000)
56	TBD	Screw	Ambient		Nitrogen	TBD	
57	TBD	Screw	Ambient		Water	TBD	
58	TBD	Screw	Ambient		Air	TBD	
59	TBD	Screw	Ambient		Natural Gas	TBD	

TABLE 3.3-12

THERMAL STORAGE SUBSYSTEM ELECTRICAL INTERFACES

Interface Identification	Type Connection	Voltage	Power Rating of Drive Motor (kW)	(hp)
60	TBD*	480 volts three phase	15	(20)
61	TBD	480 volts three phase	15	(20)
62	TBD	110 volts single phase	0.56	(3/4)
63	TBD	110 volts single phase	0.37	(1/2)
64	TBD	(TBD) MV to (TBD) MV 4-20 ma		

*To be defined during detailed design phase

3.3.7 INSTRUMENTATION AND CONTROL

3.3.7.1 CONTROL ALGORITHMS

COLLECTOR FIELD PUMPS

The collector field pumps will be powered by two speed motors. The motor speed will depend on the flow requirements of the collector field and/or auxiliary heater. In general, if the flow is less than 35 percent of the rated flow, the pumps would be at low speed. The high speed would be used when the flow is 35 percent or greater. For specific control logic for a two-speed pumping system, refer to Figure 3.3-4.

AUXILIARY OIL HEATER

The auxiliary heater will be designed to operate with the collector field pumps in the low speed configuration when the collector field is not operating. The control logic is reflected in Figure 3.3-4.

POWER CONVERSION SUBSYSTEM PUMPS

The speed of the steam generation pumps will depend only on the operational mode of the steam generator. For specific control logic refer to Figure 3.3-5.

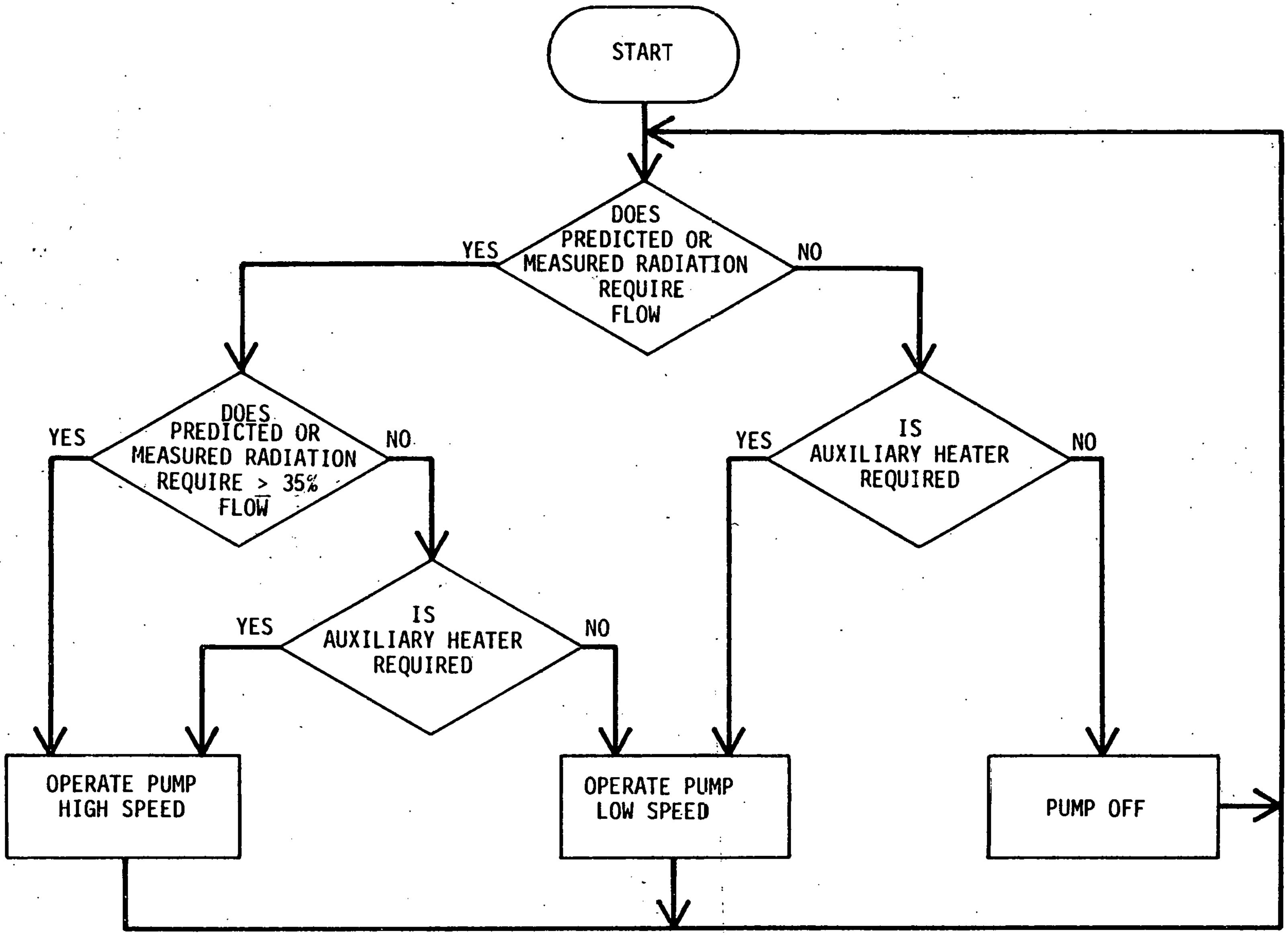


Figure 3.3-4. Collector Field Pump Control Flow Diagram

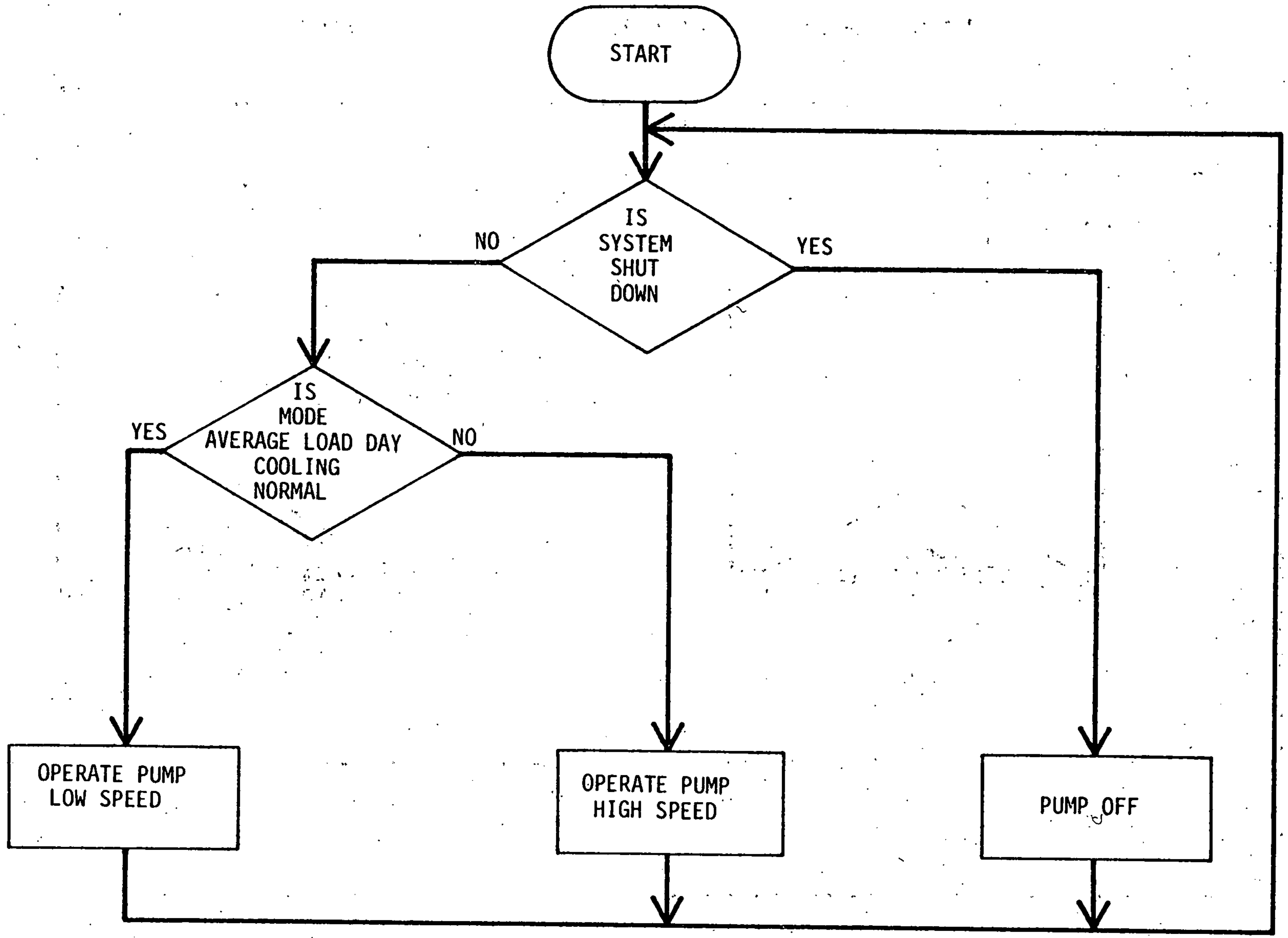


Figure 3.3-5. Steam Generator Pump Flow Diagram

AVAILABLE ENERGY CALCULATION

The purpose of this calculation is to estimate the thermal energy that is available from the Thermal Storage Subsystem at any time.

- Outputs:
  - Q1 = Usable heat contained in oil in the high temperature vessel that can be used in the high temperature operation mode.
  - Q2 = Usable heat presently contained in the intermediate temperature vessel.
  - Q3 = Usable heat that will be contained in the intermediate temperature vessel after all of the useable oil in the high temperature vessel has been used in the high temperature operation mode
- Definition of variables:
  - P = Pressure in lb/in^2
  - X_α = Approximate height of oil in feet
  - S_t = Actual height of oil in feet
  - L = Height of a specific vessel zone in feet
  - ℓ = Partial height of vessel zone L
  - n = Specific vessel zone
  - N = Number of complete vessel zones filled by the oil
  - T = Temperature in °F
  - ρ = Density in lb/ft^3
  - H = Enthalpy in Btu/lb
- Key Relationship:
  - $\rho = 53.66 - 0.0149T - 0.1386\,(10^{-4})\,T^2$ lb/ft^3
  - $H = 0.43222T + 0.0002833T^2$ Btu/lb
  - Reference temperature = 0°F
  - Dimensions are assumed at operating temperature

The Available Energy Calculation Flow Diagram is presented in Figure 3.3-6.

CONDENSER FAN

The temporary fan to the condenser will be operated during the initial heating of the storage oil. It is anticipated that this fan will not be required during normal operation.

FLARE FORCE DRAFT FAN

The fan on the flare will operate to provide a forced draft any time the flare is operated.

3.3.7.2 BLOCK DIAGRAM

The TSS Block Diagram is included in Drawing 102E145 (Volume III).

3.3.8 MAINTENANCE REQUIREMENTS

In general, maintenance requirements will be detected by instrumentation or inspection and if they are not critical will be scheduled for a period when that section (line, pump, valve) is not operating. This will reduce down time and facilitate scheduling the maintenance operations that lead to efficient and effective maintenance management. The entire system, except for the oil pumps, has industrially demonstrated long life expectancy and quick maintenance time features which allows for planned outages and overnight repair.

Estimates of maintenance man-hour requirements for the TSS after initial start-up/shake-down were made. They are:

Skill	Estimated Annual Man-Months
Electrician	1
Mechanic	4
Instrument Technician	3
Foreman	1
TOTAL	9

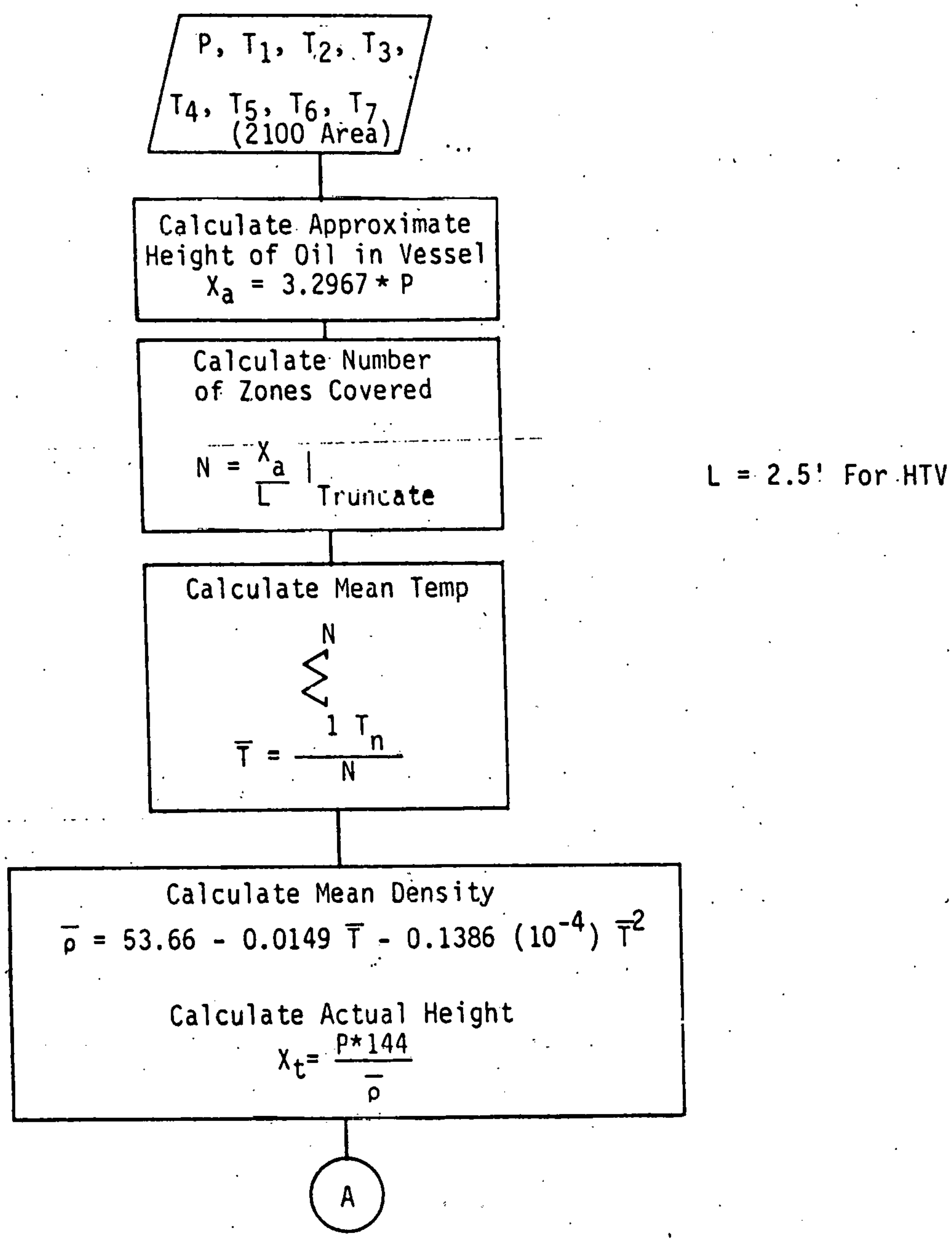
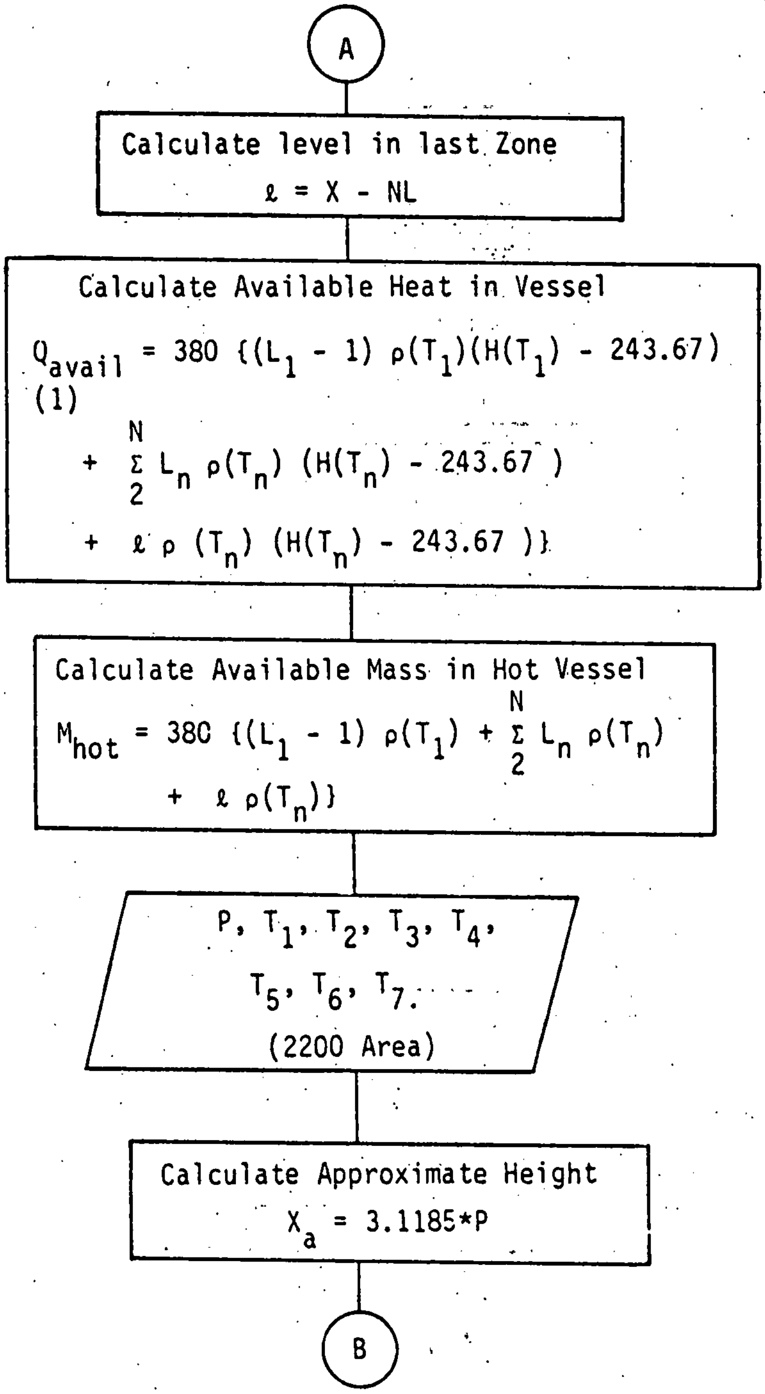


Figure 3.3-6. Available Energy Calculation Flow Diagram



$$380 = \frac{\pi D^2}{4}$$

$$D = 22'$$

$$243.67 = H(438^{o}F)$$

Figure 3.3-6. (Continued)

(B)

Calculate Number of Zones Covered by Oil

$$N = \frac{X_a}{L} \Big| \text{ Truncate}$$

L = 3,4' for ITV

Calculate Mean Temp

$$\bar{T} = \frac{\sum_{1}^{N} T_n}{N}$$

Calculate Mean Density

$$\bar{\rho} = 53.66 - 0.0149\,\bar{T} - 0.1386\,(10^{-4})\,\bar{T}^2$$

Calculate Height

$$X = \frac{P * 144}{\bar{\rho}}$$

Calculate level in last Zone

$$\ell = X - NL$$

Calculate Available Heat in Vessel

$$Q_{avail} = 706.9 \quad (L_1 - 1)\,\rho(T_1)\,(H(T_1) - 164.87$$

(2)

$$+ \sum_{2}^{N} L_n\,\rho(T_n)\,(H(T_n) - 164.87$$

$$+ \ell\,\rho(T_n)\,(H(T_n) - 164.87$$

$$706.9 = \frac{\pi \; D^2}{4}$$

D= 22'

164.87 = H(316°F)

(C)

Figure 3.3-6. (Continued)

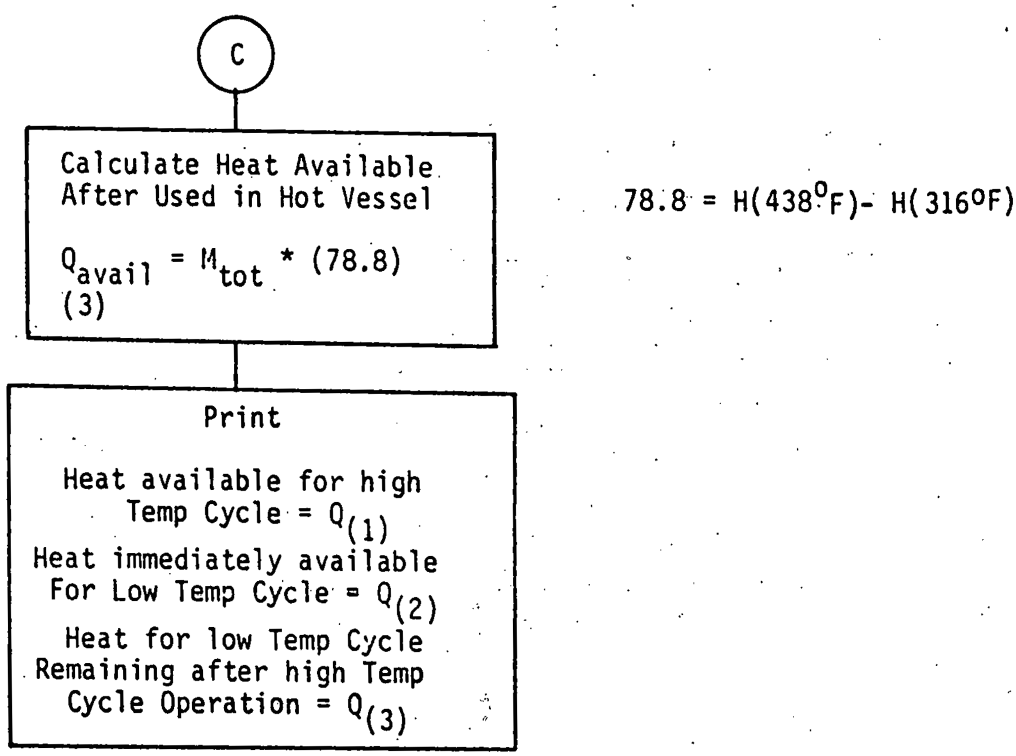


Figure 3.3-6. (Continued)

3.3.8.1 STORAGE VESSELS

There are no unusual maintenance requirements related to the storage vessels of the TSS. Insulation may require occasional repair due to physical abuse, and in general, maintenance will be associated with either insulation or close-proximity vessel associated valves.

Should a vessel seam rupture, repair would require drainage of the vessel (pumping to another vessel) followed by welding repair as required by applicable code requirements. Maintenance preparations may require entry into the vessel and steam cleaning of the oil side tank area prior to welding repair. Such failure is not anticipated because of adherance to proven design and fabrication standards.

3.3.8.2 PUMPS

The pumps used in the system will require weekly checking of the oil lubricator reservoir and occasional changing of the seal flush liquid filter. The high temperature pumps have water-cooled bearings and seals which require weekly checking for leaks and blockage in the water system.

Physical maintenance will be required to change the shaft seals on these pumps; however, the frequency is unpredictable. The redundant nature of each pumping system permits ample time for this operation since seal replacement or pump section replacement is expected to require only six to eight hours.

3.3.8.3 PIPING VALVES AND FITTINGS

The piping is not expected to require any significant maintenance. Occasional replacement of a section of insulation caused by physical abuse may be necessary.

Should a line crack occur, this would require isolation of the affected area, draining the oil from the pipe section, possible steam cleaning of the oil side, followed by welding repair of the affected area according to established codes. Such failure is not anticipated.

It will be necessary to periodically check all piping supports to detect any "binding points" and to assure that all spring hangers are operating within their established range.

Maintenance on the valves will require weekly examination of the valve seals to determine if (or when) they start leaking (externally) and determined whether the packing can be tightened to eliminate leaking or if the valve packing-set needs to be replaced.

Should the valve trim become worn or damaged and require service, depending on type of valve, the seating surface can either be resurfaced in situ or the entire valve trim replaced during non-use periods or, if necessary, the entire valve can be removed and replaced.

Mechanical joint fittings are limited to connections at the fluid pumps where expansion bellows will be utilized and to certain vessel vapor space nozzles or entry ways; all other connections within the TSS will be welded connections or will be threaded and seal-welded.

3.3.8.4 INSTRUMENTATION

Maintenance of the TSS instrumentation will consist primarily of replacing the sensors/transmitters in the event of failure (with the element serviced in an instrument shop, if economically feasible). The selection of the instrument type and quality will be such that little maintenance is expected to be required on the instrumentation.

Periodic calibration checks will be required on the transducers within the TSS I&C system.

3.3.8.5 AUXILIARY SYSTEMS

These systems include the nitrogen inerting system, the condenser and condensate system, the liquid seal and flare system, and the vacuum degassing system.

NITROGEN INERTING SYSTEM (NIS)

Maintenance of the NIS will consist of periodic filling of the cryogenic nitrogen storage tank, and weekly checking of any safety valves in the system. The oxygen sensor will probably have limited life in this system, and consequently will require replacement at infrequent intervals, a change-out requiring only a few minutes.

In the event a vacuum relief is actuated, an alarm will be actuated and will require immediate action to locate the cause and replace or re-set the unit to prevent oxygen contamination and large usage of nitrogen blanketing gas. It is estimated that this unit can be replaced in approximately one hour, limiting potential contamination and nitrogen usage.

CONDENSER AND CONDENSATE SYSTEM

Maintenance on the air vapor condenser will be minimal. The liquid condensate will require periodic removal for disposal in an environmentally acceptable manner. No maintenance problems are anticipated with the condensate storage tanks or valves.

LIQUID SEAL AND FLARE

Daily monitoring of the liquid level in the liquid seal supply system will be required, and periodic replacement if the seal liquid becomes contaminated such as to change its volumetric characteristics. Provision for periodic removal and replenishment will be made in the detailed piping design.

Flare maintenance primarily will entail periodic examination of the flame barrier to insure it is not accumulating a coating and thus decreasing its effectiveness. If replacement becomes necessary, this can be readily accomplished during periods when the flare is inactive. The burner and ignition systems are expected to be essentially maintenance free, except for occasional replacement of igniter rods, and flow sensor element.

VACUUM DEGASSING SYSTEM

This system is used only during the addition of fresh oil (at ambient temperature) to the storage subsystem. Consisting of a vacuum tank, a liquid separator and a vacuum pump, maintenance will only be required in preparation for use when there is addition of oil to the TSS. During use, the liquid separator will need occasional liquid draw-off. The vacuum pump may require addition of oil during any major storage media fill but the overall usage of the system is occasional and there may not be any major type maintenance required during the plant lifetime, provided that the units (primarily the vacuum pump) are protected from the environment during non-use periods following manufacturer recommendations.

3.3.9 SPECIAL FEATURES AND PRECAUTIONS

3.3.9.1 HEALTH AND SAFETY

Plant health and safety protection is achieved by conservative operation and compliance with applicable codes in the design and construction of the system. The TSS has potential safety hazards in the following areas:

- Oil leakage or spray and fire
- Oil vapor escape into the surrounding area
- Oil spray or flow causing personnel burns
- Oil contamination of foodstuffs that may be consumed on the premises

None of these areas is considered to be of high risk to safety and health. Oil leakage or spray does present the possibility of fire, however, the storage fluid has a very high flash point of 216°C (420°F) and any liquid or spray will cool very quickly when it escapes and is exposed to ambient conditions. Should a sudden and catastrophic rupture of a vessel or vessel connection occur, the fluid will be contained within the diked safety area and if ignited, will be maintained under control by the plant fire system which would quickly cool the escaped oil to below its flash point.

The principal concern for fire in such systems comes from entrapment of oil seepage or leakage in high-surface area insulating materials which, when suddenly exposed to air through rupture of the insulation lagging, may spontaneously ignite. To preclude this possibility, the system insulation has been prescribed to be a closed-cell foamed glass insulation that will not absorb any leaking fluid.

Personnel burns will be minimal (perhaps a hand or finger on a hot valve stem or body) by administrative controls and supervisory adherence to safe working practices when in the TSS area. It is doubtful that oil spray or flow will cause personnel burns, since the visual recognition of such fluid escape is easy and personnel will avoid contact with such situations.

Vapor escape into the surrounding area will not be sufficient to cause concern for STES or base personnel because of the very low vapor pressure of the cold fluid and the incorporation of sealed transport lines to the vapor flare which will oxidize the vapors to form carbon dioxide and water.

3.3.9.2 ENVIRONMENT

The TSS presents no significant concerns relative to the environment. Although the system represents new operational technology at the subsystem level, there are no new or technologically different features or components that differ from well developed design and operating knowledge. All elements of the design and operation, including the storage fluid, involves materials and processes that have demonstrated, and have environmentally acceptable and safe industrial applications histories.

Emissions or spills from the TSS are controlled by appropriate measures such as the vapor flare and the diked control area and any escape will be held to a very small amount which could result in the event of flare failure or valve, pump or piping leakage.

The TSS will continuously release heat to the surrounding area after it is started up, but this is only a very slow redistribution of the normal solar heat from the collector area that will be quickly assimilated into the surrounding air and terrain features with no significance towards the creation of a "thermal island" which could affect any viable ecology that resides in the local area by virtue of daytime temperature effects, or the slight effect through the nighttime of a diurnal cycle.

3.4 POWER CONVERSION SUBSYSTEM

3.4.1 SUMMARY DESCRIPTION

The Power Conversion Subsystem (PCS) receives thermal energy from the Thermal Storage Subsystem in the form of hot oil. It converts this energy into high 2164 kPa (300 psig) and/or low 445 kPa (50 psig) pressure steam and uses this steam to produce electricity via the turbine/generator and hot water via the condenser. It also supplies low pressure steam to the absorption chiller for the production of chilled water for cooling.

The PCS is composed of the following components: steam generator, turbine/generator, condenser, condensate pump(s), condensate return unit, deaerator, boiler feed pump(s), feedwater heater and the associated piping, valves and controls necessary for the subsystem operation.

3.4.2 FUNCTION

The functional requirements of the power conversion subsystem are as follows:

- Receive Sun 21 oil from the Thermal Storage Subsystem at flow rates, temperatures and pressures as defined in the state point performance, Section 4.1,
- Produce at least 200 kW of electricity as measured at the generator output terminals
- Heat 57,470 kg (126,700 lb) of water from 37.8°C (100°F) to 60°C (140°F) in one hour
- Supply steam to the absorption chiller at the flow rates, pressures and temperatures specified in the state point performance, Section 4.2.
- Receive startup, mode change, control setpoint and shutdown commands from the plant control system
- Transmit data on operating parameters (temperatures, pressures, valve position, turbine speed, etc.) to the plant control and to the data acquisition system

3.4.3 DESIGN REQUIREMENTS

3.4.3.1 FLUID/MECHANICAL SYSTEMS

- The Power Conversion Subsystem will operate in a stable fashion in all of the operating modes defined in Section 3.7.3
- The PCS will be capable of a smooth transition from any operating mode to any other operating mode
- The design life of the PCS will be 20 years
- The PCS will be designed for maximum efficiency in meeting thermal loads. Electrical generation mode performance will be of secondary importance
- Each major component will have its own control loop
- Each major component will be equipped with all necessary safety devices (pressure relief valves, rupture discs, overspeed trip, minimum flow bypass, etc.)
- In the event of a loss of signal from the plant control system, PCS will assume a safe shutdown configuration
- The PCS will contain sufficient local instrumentation for the proper operation of its components. Output signals to the plant control system and the Data Acquisition System will be as defined in the P&ID (Section 3.4.4.1).
- Water chemistry within the PCS will be maintained within the limits defined in Table 3.4-3

3.4.3.2 ELECTRICAL DISTRIBUTION SYSTEM

- Condition the 480 volt output of the STES turbine generator to 12,470 volts for connection to the Fort Hood system
- Provide 480 volt and 110 volt power to the STES from the 12,470 volt Fort Hood system when the STES turbine/generator is not operating
- Distribute power within the STES
- Automatically disconnect from the Fort Hood system if the utility grid fails
- Prevent reconnection of the STES to the Fort Hood system when no voltage is present on the Fort Hood system

- Provide synchronizing signals to the turbine/generator automatic synchronization equipment
- Conditionally provide the ability for continued operation of the STES in the event of a loss of utility grid power. STES startup without utility grid power will not be required

3.4.4 POWER CONVERSION SUBSYSTEM DESCRIPTION

3.4.4.1 OVERALL SUBSYSTEM

FLOW DIAGRAM

The flow diagram for the Power Conversion Subsystem is shown in Drawing 102E110 (Volume III). It consists of a conventional steam/condensate loop with components as defined in subsequent subsections. It has interface connections with the thermal storage subsystem at the steam generator, with the Hot Water Heating Subsystem at the condenser and, in addition, it supplies low pressure steam to the absorption chiller. Auxiliaries required by the PCS include makeup water, control air and nitrogen for inerting the system during shut down.

PERFORMANCE PARAMETERS

Performance parameters for the various PCS components in the high temperature and intermediate temperature peak heating modes are given in Table 3.4-1.

PROCESS AND INSTRUMENTATION DIAGRAM

The P&ID for the Power Conversion Subsystem is Drawing 102E127 (Volume III), which shows the relationship between the subsystem and the overall Instrumentation and Control System (Section 3.6). It also defines the local instrumentation available for monitoring component operation.

SINGLE-LINE DIAGRAM

The STES Electrical Single-Line Diagram shown in Drawing 5-2 (Volume III) describes the electrical relationship between the turbine/geneator, the balance of the STES and the site. Included is generator and grid protection logic and the automatic synchronizing equipment.

TABLE 3.4-1

POWER CONVERSION SUBSYSTEM PERFORMANCE PARAMETERS

Parameter	High Temperature	Intermediate Temperature
Steam Generator		
• Oil Inlet Temperature, °F	550	438
• Oil Outlet Temperature, °F	438	316
• Oil Flow, lb/hr	74,850	46,743
• Steam Pressure, psia	315	65
• Steam Flow, lb/hr	6,000	4,011
• Steam Temperature, °F	500	298
• Feedwater Temperature, °F	291	291
Turbine/Generator		
• H.P. Turbine Flow, lb/hr	6,000	0
• H.P. Turbine Output, kW	125	0
• L.P. Turbine Flow, lb/hr	5,234	3,487
• L.P. Turbine Output, kW	122	76
• Generator Output, kW	247	76
Condenser/Deaerator		
• Steam Flow, lb/hr	5,234	3,482
• Condenser Pressure, psia	4.9	4.9
• Deaerator Pressure, psia	22	22
• Cooling Water Flow, lb/hr	126,700	84,810
• Cooling Water Inlet Temperature, °F	100	100
• Cooling Water Outlet Temperature, °F	140	140
Feedwater Pumps and Heater		
• Pump Discharge Pressure, psia	355	83
• Feedwater Flow, lb/hr	6,000	4,000
• Pump Motor, hp	10	1
• Heater Inlet Temperature, °F	230	230
• Heater Outlet Temperature, °F	291	291

3.4.4.2 DESCRIPTION OF COMPONENTS

A tabulation of components is given in Table 3.4-2.

STEAM GENERATOR

The steam generator package consists of a preheater, a combination evaporator and superheater, piping, control valves, relief valves, instruments, supporting steel frame, insulation and accessories. It is sized to produce 6000 pounds per hour of 500°F superheated steam at 315 psia when supplied with 94,850 pounds per hour of Sun 21 oil at 550°F (high temperature mode). It is also sized to produce 4000 pounds per hour of saturated steam at 65 psia when supplied with 46,480 pounds per hour of Sun 21 oil at 438°F (intermediate temperature mode).

TURBINE/GENERATOR

The turbine/generator package consists of a single-stage high-pressure turbine and a single-stage low-pressure turbine connected to a generator through a dual input speed reducer. It also includes piping, valves, controls and instrumentation necessary for its operation. The high-pressure turbine is sized for a steam flow of 6000 pounds per hour at 315 psia and 500°F inlet conditions, exhausting to a 65 psia back pressure. Shaft horsepower at these conditions is approximately 165 hp, generating approximately 125 kW.

The low-pressure turbine is sized for a saturated steam flow rate of 5234 pound-per hour at an inlet pressure of 65 psia and an exhaust pressure of 4.9 psia. Shaft horsepower at these conditions is approximately 165 hp, generating approximately 125 kW.

The generator is sized to produce 250 kW of electricity at 0.8 power factor with both turbines operating at their design rating.

Turbine/generator controls include a backpressure controller and a speed controller, an automatic startup controller and an automatic synchronizing control system.

TABLE 3.4-2

POWER CONVERSION SUBSYSTEM COMPONENTS LIST

- Steam Generator Including:
  - Superheater
  - Boiler
  - Preheater
  - Superheater Temperature Control Valve
  - Steam Pressure Control Valve
  - Water Level Control System*
  - Preheater Temperature Control Valve
  - Blowdown Conductivity Control System
  - Steam Pressure Relief(s)
  - Oil System Rupture Disc
  - Oil Piping Interconnects Between Components
  - Steam Piping Interconnects Between Components
  - Thermal Insulation
- Turbine/Generator Including:
  - High Pressure Turbine
  - Low Pressure Turbine
  - Gear Reducer
  - Turbine Discount Coupling(s)
  - Generator (or Alternator)
  - Turbine Bypass Control System
  - Automatic Synchronization System
  - Turbine Protection System
  - Generator Protection System
  - Turbine Control System
  - Automatic Startup System
  - Thermal Insulation
- Condenser Including:
  - Pressure Relief Valve(s)
  - Condensate Level Control System

*All control systems include Controller, Sensor and Control Valve

TABLE 3.4-2 (continued)

- Condenser Including: (Continued)
  - Condensate Pump(s)
  - Air Removal Equipment
  - Thermal Insulation
- Deaerator Including:
  - Pressure Control System
  - Condensate Level Control System
  - Pressure Relief Valve(s)
  - Air Removal Equipment
  - Thermal Insulation
  - Boiler Feed Pumps
- Condensate Return Unit Including:
  - Condensate Return Tank
  - Condensate Return Pumps
  - Condensate Level Control System
- Feedwater Heater
- Feedwater Temperature Control System
- Steam Piping
- Steam Piping Insulation
- Feedwater Piping
- Feedwater Flowmeter
- Feedwater Piping Insulation
- Isolation Valves
- Local Instrumentation

CONDENSER AND CONDENSATE RETURN

The steam surface condenser is a package unit consisting of tubes, shell, frame, water boxes, hotwell, vacuum pump air ejector, dual condensate pumps, relief valves and the necessary valves and controls for proper operation. It is sized to condense and cool 5234 pounds per hour of steam with an enthalpy of 1092 Btu per pound to condensate at 156.4°F when supplied with approximately 250 gpm of 100°F cooling water. The condenser is designed so that the cooling water will leave the condenser at 140°F. The condenser also is capable of operating with 68°F cooling water to reduce the condenser pressure and increase the generator output during the electrical generation mode.

The condensate return unit is a collection tank into which all unpressurized condensate return lines are directed. Included are returns from the absorption chiller, various traps and seal leakages, and the makeup water. The unit is sized by the cooling season load when it must handle the absorption chiller condensate in addition to makeup and miscellaneous condensate returns.

DEAERATOR

The deaerator package consists of the deaerating tank, boiler feed pumps, spray nozzles, pressure reducing station and necessary instruments and control. It is sized to deliver 6000 pounds per hour of deaerated feedwater produced from 5234 pounds per hour of condensate from the condenser at 156°F and 395 pounds per hour of condensate from the feedwater at 290°F. To heat these condensate streams to the 22 psia saturation temperature of 230°F requires 370 pounds per hour of 65 psia saturated steam.

FEEDWATER HEATER

The feedwater heater is a shell and tube heat exchanger with feedwater in the tubes and low pressure steam on the shell side. It is sized to heat 6000 pounds per hour of 230°F feedwater to 290°F, approximately 130°F below saturation temperature at 315 psia.

PUMPS

Two different sizes of feedwater pumps have been selected because of the differing operating conditions between the high temperature and the intermediate temperature operating modes. The high pressure pump, used during high temperature operation, is a multi-stage (approximately 25 stages) diffuser type with a 10 hp motor. It is sized to deliver 6000 pounds per hour (12 gpm) at 355 psia (750 foot head).

The low pressure pump used during intermediate temperature operation, is also a multi-stage (approximately 17 stages) diffuser type with a 1 hp motor. It is sized to deliver 4000 pounds per hour (8 gpm) at 85 psia (150 foot head).

- Condensate Pumps: The condenser is equipped with two condensate pumps, each sized to deliver the total peaking condensate flow of 5234 lb/hr from the condenser hotwell to the deaerator.
- Condensate Return Pump: Two different sizes of condensate return pumps have been selected, one for the heating season and one for the cooling season. The cooling season pump is sized for approximately 2200 lb/hr to handle the absorption chiller condensate, makeup, and trapped condensate and seal leaking. The heating season pump, which does not have the absorption chiller condensate, is sized at approximately 200 lb/hr. This small pump is required to prevent the "slugging" of cold makeup water into the deaerator which would occur if the larger pump were used.

PIPING AND VALVES

Piping and valves in the Power Conversion Subsystem will conform to American National Standard Code for Pressure Piping. Oil piping will conform to Section 3, Chemical Plant and Refining Piping, ANSI B31.5. All other piping will conform to Section 1, Power Piping, ANSI B31.1.

Piping for 300 psig steam will be Schedule 40 with 300 pound class flanges. Piping for 50 psig steam will be Schedule 40 with 150 pound class flanges. Condensate and feedwater piping will be Schedule 80.

After installation, piping will be hydrostatically tested at 1-1/2 times operating pressure.

Pipe sizes range from 1-in. for condensate to 4-in. for steam.

INSTRUMENTATION AND CONTROLS

Flow Element Transmitter

In-line flange mounted instruments with an output of 4 to 20 mA type(s) will be specified in Phase IV.

Thermocouple

Thermocouples are grounded junction and metal sheathed with ceramic insulation. The type will be specified in Phase IV.

A welded in-place thermowell, or direct insertion using a compression fitting, will be used.

Thermometer

Mercury type with 9-inch scale.

Pressure Transmitter

Transmitters will produce an output of 4 to 20 mA. Tne type will be specified in Phase IV.

Installation will be into process lines with taps (welded or plug), and into components at flanged parts or plug taps.

Pressure Gage

Type to be specified in Phase IV.

Level Transmitters

Transmitter will produce an output of 4 to 20 mA. Type will be specified in Phase IV.

Installation will be to flanged parts.

Level Switch

Float-type with adjustable linkage and microswitch(es).

Installation will be to flanged parts.

Level Glass

Scale to be specified in Phase IV.

Conductivity Probe

Type to be specified in Phase IV.

Analog Controllers

Rack-mounted analog controllers receiving an analog 4 to 20 mA signal, and outputting a 4 to 20 mA control signal. Types will be specified in Phase IV.

Control Valves

- Three-way mixing type, air-operated by 3 to 15 psig air using an I/P valve positioner (4 to 20 mA input)
- Solenoid valves
- Pneumatic control valves with I/P valve positioners

AUXILIARY SYSTEMS

The Power Conversion Subsystem requires the following supporting systems:

- Nitrogen (inerting)
- Instrument air
- Cooling water
- AC power

BOILER FEEDWATER/CONDENSATE CHEMICAL TREATMENT

Water chemistry control within the PCS will follow routine industry practice for recirculating boilers using makeup and blowdown to keep chemical concentrations in the boiler within prescribed limits. Demineralized water will be used for makeup with hydrazine added for oxygen scavenging and morpholine added for pH control. This all volatiles treatment (AVT) will not contribute any solids to the boiler water. Specified rates of blowdown will ensure that impurities in the feedwater due to condenser in-leakage and corrosion products do not accumulate in the boiler. Makeup and boiler water chemistry specifications are given in Table 3.4-3. Maintenance of water chemistry within these specifications, and periodic boiler inspection and cleaning should result in trouble-free boiler operation over the design lifetime of the plant.

TABLE 3.4-3

WATER CHEMISTRY REQUIRED WITHIN THE POWER CONVERSION SUBSYSTEM

Makeup Water Specification:	
• Conductivity (cation)	1 μmho/cm at 25°C (max)
• Suspended Solids	0.1 ppm (max)
• Silica	0.2 ppm (max)
• Chlorides	0.1 ppm (max)
• Oxygen	0.1 ppm (max)
• Sodium	0.01 ppm (max)
Boiler Water Specification (Blowdown)	
• Conductivity (cation)	2 μmho/cm at 25°C (max)
• Suspended Solids	1 ppm (max)
• Silica	1 ppm (max)
• Chlorides	0.15 ppm (max)
• Sodium	0.1 ppm (max)
• Free hydroxide (as $CaCO_3$)	0.15 ppm (max)
• Morpholine	4 ppm (min)
• pH	9.0 to 9.6

3.4.5 POWER CONVERSION SUBSYSTEM OPERATION

3.4.5.1 NORMAL OPERATION

HIGH TEMPERATURE OPERATING MODE

High temperature operating mode is characterized by the PCS receiving high temperature (550°F) oil from the thermal storage subsystem and producing steam at 300 psig and 500°F (78° superheat). This steam is passed through the high pressure turbine, exhausting at 65 psia to the low pressure heater. A small percentage of this 65 psia steam is bled-off to the deaerator and the feed-water heater. The balance is fed to the low pressure turbine and, in season, the absorption chiller. The low pressure turbine exhausts to the condenser at 4.9 psia for hot water production. The absorption chiller discharges condensate to the condensate return unit at 180°F.

Steam Generator

- Preheater: Oil flow to the preheater is regulated to heat the boiler feedwater to within several degrees of the saturation temperature at 315 psia (421°F).
- Boiler: Oil flow to the boiler is regulated to boil enough water in the boiler section to maintain a pressure in the high pressure steam header of 315 psia. Boiler operations is load following since an increase in load (steam flow rate) causes a reduction header pressure that causes an increase in oil flow rate, which increases steam production.
- Superheater: Oil flow to the superheater is regulated to maintain a steam outlet temperature of 500°F.
- Feedwater Flow: Feedwater flow to the steam generator is regulated to maintain a constant water level in the boiler.

Turbine/Generator

- High-Pressure Turbine: The governor valve in back pressure control regulates steam flow through the turbine to maintain 65 psia in the low pressure steam header.
- Low Pressure Turbine: The governor valve in position control regulates steam flow through turbine to maintain approximately 5 psia in the condenser. Speed of both turbines is regulated by the 60 cycle grid frequency seen by the generator. If the generator is not synchronized to the grid, both turbines are operated in speed control.

If, during the cooling season, the hot water storage tank becomes filled, the low pressure turbine and condenser are secured and all of the high pressure turbine exhaust is directed to the absorption chiller, deaerator and feedwater heater. The low pressure turbine is uncoupled from the generator at this time.

Condenser and Condensate Return

Condenser pressure is controlled either by the governor valve of the low pressure turbine as described above or by the outlet cooling water temperature. In the event the turbine is not operational, a turbine bypass valve and pressure controller performs the same function. Heat removal from the condenser is controlled by the Hot Water Heating subsystem. Water level in the condenser hotwell is controlled by a level controller that operates a modulating valve downstream of the condensate pump. Non-condensable gases are removed by a vacuum pump operating intermittently.

Condensate from the various traps and drains and, in the cooling season from the absorption chiller, are collected in the condensate return tank. A level switch controls the condensate return pump that transfers the collected condensate back to the deaerator.

Deaerator

Deaerator pressure is maintained at 22 psia by steam supplied from the low pressure header through a pressure control valve. Non-condensable gasses, stripped from the feedwater in the deaerator, are vented to the atmosphere.

Water level in the deaerator hotwell is maintained by the makeup water subsystem. The deaerator hotwell serves as the main condensate storage volume for the loop.

Feedwater Pump and Heater

The high pressure boiler feed pump operates continuously to supply feedwater to the boiler.

The feedwater heater uses low pressure steam to heat the feedwater to 290°F prior to injection into the preheater. Steam flow is regulated by a throttle valve that is responsive to feedwater temperature leaving the heater.

INTERMEDIATE TEMPERATURE OPERATING MODE

Intermediate temperature operation is characterized by the PCS receiving intermediate temperature (438°F) oil from the thermal storage subsystem and producing dry, saturated steam at 65 psia. This steam bypasses the high pressure turbine and is fed directly to the 65 psia loads described in the high temperature operation section; i.e., deaerator, feedwater heater, low pressure turbine and/or the absorption chiller.

Steam Generator Operation

- Preheater: Oil flow to the preheater is regulated to heat the boiler feedwater to within several degrees of the saturation temperature at 65 psia (298°F)
- Boiler: Oil flow to the boiler is regulated to boil enough water in the boiler section to maintain a pressure in the high pressure steam header of 65 psia
- Superheater: The superheater is not used during intermediate temperature operation. Oil flow is shut off and the saturated steam from the boiler passes through the superheater section without heat addition
- Feedwater Flow: To the steam generator is regulated to maintain a constant water level in the boiler

Turbine/Generator Operation

- High Pressure Turbine: Not used during intermediate temperature operation. The high pressure turbine bypass is opened to pass the 65 psia steam directly to the low pressure steam header. The turbine output shaft is uncoupled from the gear reducer to prevent friction and windage losses.
- Low Pressure Turbine: Operation is the same as discussed under Section 3.4.5.1.

Condenser and Condensate Return

Operation is the same as discussed under Section 3.4.5.1.

Feedwater Pump and Heater

The low pressure boiler feed pump operates continuously to supply feedwater to the boiler. Note that this is a different pump from that used during high temperature operations (the reduced flow and head requirements results in a pump of approximately 1/10 the horsepower). Feedwater heater operation is the same as described in Section 3.4.5.1.

ELECTRICAL GENERATION MODE

Electrical generation modes occur at both high and intermediate temperature operations and are characterized by lower-than-normal condenser pressure. The reduced condenser pressure is achieved by lowering the condenser cooling water temperature in the Hot Water Heating Subsystem via cooling tower operation.

The reduced condenser pressure of this operating mode results in increased power from the low pressure turbine and increased electrical output from the generator.

Operation of components other than the condenser are the same as in high and intermediate temperature operations.

3.4.5.2 STARTUP AND SHUTDOWN

INITIAL CONDITIONS FOR STARTUP

- Power Conversion Subsystem cold and depressurized
- Thermal Storage Subsystem available in the intermediate temperature mode
- Condenser cooling water available
- Makeup water system available
- Utility power available
- Plant control system available

FILL AND VENT

- Close nitrogen overpressure control valve
- Using makeup water and condensate return unit, establish proper water level in deaerator
- Using low pressure boiler feed pump, establish proper water level in boiler
- Establish proper water chemistry in boiler by makeup and blowdown

STEAM GENERATOR STARTUP

- Start intermediate temperature oil flow to boiler; establish 25 psia steam pressure
- Vent non-condensable gases from all steam lines, steam generator, turbines, condenser and deaerator

CONDENSER AND DEAERATOR STARTUP

- Place turbine bypass in pressure control at 4.9 psia condenser pressure
- Start condenser cooling water flow to reduce condenser pressure to 4.9 psia
- Start condenser vacuum pump
- Start condensate pump to maintain condenser hotwell water level
- Increase steam pressure to 65 psia
- Make final check of boiler water chemistry; PCS is now at hot standby condition

INITIAL CONDITIONS FOR SHUTDOWN

- PCS is in hot standby condition

COOLDOWN

- Adjust system water chemistry for layup
- Secure oil flow to steam generator
- If rapid cooldown is desired, start condenser cooling water flow

- Secure blowdown
- When steam pressure reaches 25 psia, open turbine bypass valve
- Open nitrogen overpressure supply valve
- When steam pressure reaches 20 psia, secure condenser cooling water, condensate pump and boiler feed pump
- When system pressure reaches 17 psia, nitrogen system will maintain this pressure; PCS is now shut down

3.4.5.3 ABNORMAL OPERATION

MANUAL OPERATION

Sufficient local instrumentation and analog controllers will be provided to permit the manual operation of the PCS in the intermediate temperature mode. This feature will permit the thermal loads of the five buildings to be satisfied in the event the plant digital control system is inoperative. Operation of the turbine/generator during manual operation is at the discretion of the operator.

OPERATION WITHOUT TURBINE/GENERATOR

A turbine bypass line and control valve are provided to permit the operation of the condenser to satisfy thermal loads in the event the turbine/generator is inoperative. The bypass control valve is operated by a pressure controller to maintain the proper condenser pressure. Turbine bypassing is permitted only in the intermediate temperature operating mode.

3.4.5.4 HOT STAND-BY OPERATION

Hot stand-by operation maintains steam pressure at 65 psia and a minimum of steam flow to keep the lines hot and the deaerator pressurized at 22 psia. Water level is maintained in the boiler, the condenser hotwell and the deaerator while steam flow to absorption chiller and cooling water flow to the condenser are turned off.

3.4.6 POWER CONVERSION SUBSYSTEM INTERFACES

3.4.6.1 SUBSYSTEM INTERFACES

The interfaces of the PCS with adjacent subsystems are defined as follows with numbers referring to the state points shown on the Subsystem Flow Diagram. Fluid conditions at the interfaces are tabluated by state point number in Section 4.2.

THERMAL STORAGE SUBSYSTEM

20. Interface to the hot oil inlet line at the inlet to the superheating inlet check valve

21. Interface to the cold oil return line at the outlet of the oil flow control valve

HEATING, COOLING AND DOMESTIC HOT WATER SUBSYSTEMS

7. Interface to the steam inlet of the absorption chiller at the steam throttle valve inlet

8. Interface to the condensate return line at the condensate connection of the absorption chiller

18. Interface to the condenser cooling water supply line at the condenser nozzle

19. Interface to the condenser cooling water return line at the condenser nozzle

INSTRUMENTATION AND CONTROL SYSTEM

All electrical I&C channels interface with the local I/O and microprocessor. As described in Section 3.6.4.2, the I/O provides all signal conditioning functions. In addition, certain channels also interface with local analog controllers to provide control signals for certain valves.

AUXILIARY SYSTEMS

50. Makeup water connection at the condensate return tank

51. Blowdown connection at the boiler drain or blowdown nozzle

52. Oil pressure relief line at rupture disc flange

53. Nitrogen connection at the inlet to the nitrogen check valve

3.4.6.2 MECHANICAL INTERFACES

STEAM GENERATOR

Mechanical interfaces between the steam generator and its foundation, feedwater line, steam line, oil lines, blowdown line and relief valves will be defined on the steam generator vendor drawings to be supplied during the procurement phase.

TURBINE GENERATOR

Mechanical interfaces between the turbine generator and its foundation and steam nozzle definitions will be included on the turbine generator vendor drawings to be supplied during the procurement phase.

CONDENSER

Mechanical interfaces between the condenser and its foundation and the definition of steam, cooling water and condensate connections will be included on condenser vendor drawings to be supplied during the procurement phase.

3.4.6.3 ELECTRICAL POWER INTERFACES

The electrical power interfaces include:

- 12,470 volt, 3-phase, 4-wire tie into the existing Fort Hood base and a 12,470 volt, 3-phase to 480/277 volt, 3-phase, 4-wire transformation at the STES plant
- A system by which power from the STES generator, in excess of that required by the STES plant load, can be fed back into the Fort Hood base to reduce peak demand requirements and consumption on the base system
- A system to assure safety of personnel and protection of equipment in the event of a loss of base system, yet conditionally provides the ability for continued operation of the STES plant's loads.

SITE POWER DISTRIBUTION

The STES plant will be served electrically by connecting into the base 12,470 volt primary distribution system and by extending service to a new 300 kVA transformer (12,470V to 480/277 volt, 3-phase, 4-wire) for the STES building, as shown on Drawing 8-13 in Volume III.

A sensor and relay with an upper current limit to detect net reverse current flow back into TP&L and Fort Hood distribution system will be provided. The relay will be installed on the line side of the new transformer to detect net reverse current due to a failure of the Fort Hood base system rather than merely the fact that the STES plant generator output exceeds load requirements for the STES plant. If net reverse current is detected, ACB "A" will trip.

A zero sequence over-voltage relay will be connected through a Y-open delta connected potential transformer on the 12,470 volt system to trip 480 volt, ACB "A" upon phase to phase or phase to ground faults and to isolate fault from STES Systems. Total separate isolation of the STES Facility will be by means of a new 12KV oil circuit breaker placed ahead of the new transformer.

Service from the 300 KVA, 12,470 volt to 480/277 volt, 3-phase, 4-wire transformer will be underground to the STES switchboard.

STES PLANT POWER DISTRIBUTION SYSTEM

The STES Plant Power Distribution System and control sequences are illustrated on Drawings 8-14 and 8-15 (Volume III). The STES plant power distribution system consists of three parts:

- The feed into the main switchboard from the base service
- The feed into the main switchboard from the generator source
- Branch circuit distribution within the STES facility and at the solar collector field

THE 480 VOLT BASE SYSTEM SERVICE

The feeder from the 480 volt base service is connected to air circuit breaker ACB "A". The following metering will be provided on the line side of ACB "A" in the switchboard:

- Recording watt-hour meters to measure power <u>in</u> and power <u>out</u>
- A voltmeter to measure each of three phases
- An ammeter to measure each of three phases

The operation of ACB "A" will be as follows:

- Normally closed with base service energizing main bus in STES plant; ACB "A" will open upon:
  - Reverse power indication
  - Fault on base system
  - Abnormal over-voltage, under-voltage or frequency on the main bus in the STES plant

<u>Generator Source</u>

Service from the 480 volt, 3-phase generator will be fed through a 480 volt, 3-phase to 480 volt, 3-phase, 4-wire isolation transformer (used to provide short circuit protection and to reduce harmonics) to the main switchboard through ACB "B". The generator will feed the main bus as described in preceeding sections. Excess power generated (that which is in excess of the power required by the STES plant) will be fed into the Fort Hood Base System to assist in shaving peak demand on the system and reducing total consumption. Actual hours of operation of the generator will be determined as the STES design progresses. The generator package will include the following:

- A generator neutral grounding transformer with resistor used to provide ground fault protection for the generator and suppress unwanted resonances. Transformer and resistor rating to be as specified after selection of the generator and transformer.
- Ground fault relay that will shut generator down and open electrically operated power circuit breaker ACB "B".

- A time delay ground fault relay circuit that will trip ACB "B".
- A series of protective relays: phase over-voltage, phase imbalance, generator over-voltage, and reverse power which will trip ACB "B" and shut the generator down.

Metering on the generator side of ABC "B" will include the following:

- An ammeter for each of three phases
- A recording voltmeter for each of three phases
- A recording watt-hour meter to measure power <u>out</u>
- A recording wattmeter
- A recording VAR meter
- A recording frequency meter

Recording meters will be provided in the Central Control System.

<u>Synchronizer Switches and Breaker Operations</u>

A single set of synchronizer switches and indicator (included as a part of the generator) will be provided.

A synchronized condition across both secondary breakers (ACB "B" for the generator and ACB "A" for the base 480 volt source) and the main bus must be met before the STES facility main 480 volt bus can be connected to both sources.

If ACB "A" (480 volt base source breaker) is closed and STES main bus is energized from base source, ACB "B" (generator source breaker) cannot be closed unless generator output is synchronized with the base source. If base source is down and ACB "A" (base source breaker) is closed, then ACB "B" (generator source breaker) cannot be closed at all, i.e., ACB "B" (generator source breaker) can connect generator output to STES bus only if (a) in sync with the base source or (b) isolated from base source.

Likewise, if STES main bus is energized from generator only (through ACB "B"), ACB "A" (base source breaker) cannot be closed unless synchronized with generator source. In this case, generator must manually be brought into sync with base source and ACB "A" must be manually closed.

Under normal operating conditions, the synchronizing function is to be carried out automatically. This condition exists when the STES main bus is normally energized by the base system and when generator comes up as programmed. Once in sync with base source, the generator is <u>automatically</u> connected into the STES main bus and the base system by the closing of ACB "B". A shutdown of the generator, whether due to normal or abnormal circumstances, isolates the generator from main bus by tripping the generator source breaker ACB "B".

<u>Distribution Within the STES Facility and to the Collector Field</u>

Distribution within STES and to the collector field will comprise standard electrical power feeder breakers and control power connections. The systems fed can be broken down as follows:

- Motor control center which includes pump motor loads for the solar collector subsystem, thermal storage subsystem, power conversion subsystem, domestic hot water and make-up water subsystems
- Power panel for the solar collector field
- Building lighting panel and miscellaneous power panel
- Security lighting for the STES plant collector field and surrounding area
- An emergency panel battery powered to feed emergency lighting circuits.
- A static Uninterruptible Power Supply System to power the critical load of the ICS.

STES Building Power Plan (Drawing 8-16, Volume III) indicates equipment requiring power connections. Branch circuit distribution for this equipment and details of electrical control will be completed in Phase IV.

3.4.7 INSTRUMENTATION AND CONTROL

The Power Conversion Subsystem instrumentation consists of local indications, instrument signals that are processed by the local microcomputers (μC) and controls, some of which are local analog controls, and some of which are digital controls through the microcomputers. There are two microcomputers provided for the PCS. One is located near the steam generator, and the other is located in the STES building. Each μC communicates with the central minicomputer.

Each μC provides several functions. Measurements of important subsystem parameters are made by the μC and are periodically transmitted to the central computer. The parameters are compared against plant limits and, if a parameter is out of bounds, the central computer is notified and protective action is initiated. Control functions provided by the μC are generated by the μC using information about overall system status and desired operating modes provided by the central computer and the measurements made by the μC. Control outputs are transmitted by the μC to the plant.

3.4.7.1 SUBSYSTEM CONTROL ALGORITHMS

Power conversion subsystem operation modes are determined by the energy management program that operates in the control computer. This program determines an operating mode for the entire STES based upon energy inventory, anticipated energy supply and demand, and equipment operational status. The desired operating mode is transmitted to the PCS μC controllers that then align the PCS to the desired operating mode by starting up desired equipment and establishing operational setpoints.

3.4.7.2 SUBSYSTEM BLOCK DIAGRAM

The power conversion subsystem block diagram, sheet 2 of Drawing No. 102E145, Volume III, shows the instrument signals being measured by the microcomputer or being processed by analog controllers that are developed by the microcomputer or by the analog controllers.

3.4.7.3 INDIVIDUAL COMPONENT CONTROLS

STEAM GENERATOR CONTROLS

Preheater Outlet Temperature

The preheater outlet temperature is controlled by adjusting the flow of oil through the preheater tubes by adjusting the position of a 3-way modulating valve on a preheater bypass line. The modulating valve is controlled by the μC which measures preheater outlet temperature and compares this against a desired temperature that is generated in the central computer.

Steam Pressure

Steam pressure is controlled by adjusting the flow of oil through the boiler tubes. The oil flow rate is controlled by a modulating valve that controls the flow of oil to the steam generator. The modulating valve position is controlled by the μC based upon the measured steam pressure and a desired pressure generated in the central computer.

Superheater Outlet Temperature

Superheater outlet temperature is controlled by adjusting the flow of oil through the superheater tubes by adjusting the position of a 3-way modulating valve on the superheater bypass line. The modulating valve is controlled by the μC which measures superheater outlet temperature and compares this against a desired temperature that is generated in the central computer.

Boiler Water Level

Boiler water level is controlled by adjusting the feedwater flow regulating valve. The valve is controlled using a conventional analog controller that measures water level. Backup control is provided by local manual control of the feedwater flow regulating valve.

TURBINE/GENERATOR CONTROLS

- Back Pressure Control: Steam flow through the turbine is regulated by the governor valve to maintain a constant turbine exhaust pressure.

- Speed Control: Steam flow through the turbine is regulated by the governor valve to maintain a constant turbine speed.
- By-pass Control: A low pressure turbine by-pass valve is provided for use during plant startup and shutdown. It can also be used to satisfy thermal loads if the turbine/generator is inoperative.
- Automatic Startup: A control system that automatically starts the turbine/generator, including venting and draining, and brings it up to operating speed.
- Automatic Synchronization: A control system that adjusts turbine/generator speed to match generator output frequency and phase angle to that of the utility grid and then automatically connect the generator output to the grid.

CONDENSER CONTROLS

Condenser Hotwell Level Control

The condenser hotwell is drained by two condensate pumps operating in parallel. The first pump is turned on by the μC when the condenser begins operation. The second pump is started by a level switch if the condenser hotwell level is too high. The flow is controlled by a control valve at the common condensate pump discharge. The valve is controlled by an analog controller with a hotwell level feedback.

Condenser Vacuum Pump

The condenser vacuum pump will be operated intermittently as required to remove non-condensables from the condenser.

DEAERATOR CONTROLS

Deaerator Pressure Controller

The deaerator pressure is controlled by a modulating valve that controls the rate of steam flow to the deaerator from the low pressure steam header. This valve is regulated by an analog controller reacting to deaerator pressure.

Deaerator Level Control

Level control is provided for low level by drawing water from the makeup water subsystem to the condensate return unit that then sends the water to the deaerator. The flow of water from the makeup water subsystem is regulated by a control valve that is operated by an analog controller which responds to low deaerator level. No provision is made for automatically dealing with high water level because high water level is not expected to occur.

Condensate Return Unit

The water level in the condensate return unit (CRU) is controlled by an analog controller on a valve in the condensate return pump outlet. There are two pumps; the first is turned on by the μC when the unit is placed in operation. The second is placed in service by a local controller when the CRU water level exceeds a high level set point.

Feedwater Heater Temperature Control

Feedwater heater water outlet temperature is regulated by adjusting the flow rate of low pressure steam to the unit. The steam flow rate is controlled by a modulating valve that is regulated by an analog controller responding to outlet water temperature.

3.4.8 MAINTENANCE REQUIREMENTS

Maintenance requirements for the Power Conversion Subsystem include routine inspection and servicing of mechanical components as well as periodic performance testing of the major subsystem components. The designated performance tests and maintenance requirements are judged to be identical, or very similar to those required of conventional plants of the same capacity. It is anticipated that the complete subsystem performance tests will provide the information for appraising the performance of the major components so that separate testing of each component is not necessary. The plant process computer can be used to provide a printout of the performance data necessary to assess plant and component performance, so special performance test runs will not be required.

Most of the routine major maintenance operations can be scheduled for performance in the spring and/or fall when thermal loads on the system are light. This will reduce the impact of inspection and maintenance on overall system operation.

The maintenance requirements for the Power Conversion Subsystem are discussed in the ensuing paragraphs, and are summarized in Table 3.4-4, which also includes an estimate of the annual cost of replacement parts. These estimates show a known annual labor requirement of 527 man-hours and a parts/supplies cost estimate of $180.

3.4.8.1 COMPLETE SUBSYSTEM

PERFORMANCE TESTING (6-MONTH INTERVALS, SPRING AND FALL)

A) Start-up and operate over the load range with PCS connected to the utility grid. Verify proper mechanical operation of all components. Measure and record thermal inputs and outputs (flow rates, pressures and temperatures, and electrical output parameters) at selected load points. Estimated manpower requirement, excluding startup, four crew-hours.

B) Repeat A) with PCS not connected to the utility grid. Verify frequency control (speed control) accuracy. Estimated manpower requirement, same as A), above.

C) Simulate contingencies (TBD, such as loss of utility grid connection) and check-out emergency response operation. Manpower requirement, TBD.

ROUTINE INSPECTIONS

A) Periodically check and record pressure drop in interconnecting piping as a check against deposit formation or other blockage. Estimated manpower requirement, 1/2 manhour per check.

B) Periodically inspect piping connections for evidence of leaks, especially at gasketed joints. Insulation jackets (muffs) should be removed during a plant down-time to reduce personnel hazard. Estimated manpower requirement, 4 manhours per connection.

TABLE 3.4-4

MAINTENANCE ESTIMATES—POWER CONVERSION SUBSYSTEM

ESTIMATED ANNUAL MAINTENANCE LABOR

Task	Time (Hours)	No. Per Year	Annual Labor (Man-Hours)
1. System			
A. Performance Testing and Appraisal	48.0	2	96.0
B. Leakage Inspection	200.0	0.2*	40.0
C. Emergency Response	TBD	2	TBD
2. Steam Generator			
A. Thermal Efficiency	---------- Part of 1.A ----------		
B. Pressure Drop Tests	---------- Part of 1.A ----------		
C. Flow Control Valve Testing (3)**	1.0/valve	1	3.0
D. Safety Valve Inspection (1)	4.0	1	4.0
E. Water Level Control (1)	8.0	1	8.0
F. Valve & Instrument Packing Inspection (13)	0.25/item	12	39.0
G. Pressure Gauge Calibration (6)	1.5/gauge	1	9.0
H. Pressure Transducer Calibration (5)	1.0/transducer	1	5.0
I. Temperature Gauge (Thermometer) Calibration	None	None	None
J. Temperature Transducer Calibration (9)	1.0/transducer	1	9.0
K. Flow Control Valve Inspection (3)	1.0/valve	1	3.0
L. Air Filter Inspection & Cleaning/ Replacement (5)	0.5/valve	12	30.0
3. Turbine Generator			
A. Performance Testing	---------- Part of 1.A ----------		
B. Steam Inlet Strainer	2.0	1	2.0
C. Governor System (Mechanical) (2)	1.0	2	4.0
D. Governor System (Hydraulic) (2)	0.5	12	12.0

*Assumes 50 joints to inspect and 20 percent of plant inspected each year.
**Numbers in parentheses () indicate number of units in the plant.

TABLE 3.4-4 (Continued)

Task	Time (Hours)	No. Per Year	Annual Labor (Man-Hours)
3. Turbine Generator (Continued)			
E. Overspeed Trip Inspection/Cleaning (2)	0.25	2	1.0
F. Lube Oil Chemistry (3)	4	2	24.0
G. Lube Oil Level, Inspection/Replenishment, All	0.25	52	13.0
H. Clutch Inspection (2)	2.0	4	16.0
4. Condenser Condensate Return, Deaerator, Feedwater Heater			
A. Performance Testing	---------- Part of 1.A ----------		
B. Leak Tests (Condenser & Feedwater Heater)	8.0/each	2/each	32.0
C. Level Controls (Condenser & Condensate Return)	4.0/each	2/each	16.0
D. Deaerator Vent Inspection	0.5	2	1.0
5. Condensate & Boiler Feedwater Pumps			
A. Bearing Lubricant (4)			
1) Inspection (4)	0.125/each	4	2.0
2) Replenishment (4)	0.25/each	2	4.0
B. Seals (4)			
1) Inspection (4)	2.0	2	4.0
2) Replacement (4)	8.0	0.2*	6.4
6. Piping, Valves and Fittings			
A. Power Actuated Valves			
1) Response to Control Signal** (L12)	1.0/valve	2	24.0
2) Power Required (Air Actuated) (6)	---------- Part of 6.A.1 ----------		
3) Packing Inspection (12)	---------- Part of 6.A.1 ----------		
4) Packing Replacement	4.0/valves	0.2***	9.6

*Assumes Seal Life of 5 years
**May be Part of A.1
***Assumes 5-Year Packing Life

TABLE 3.3-4 (Continued)

Task	Time (Hours)	No. Per Year	Annual Labor (Man-Hours)
6. Piping, Valves and Fittings (Continued)			
B. Manual Valves (20)			
1) Packing Inspection	0.25/valve	2	10.0
2) Packing Replacement	2.0/valve	1*	4.0
7. Instruments and Controls	TBD	TBD	TBD
Unscheduled Maintenance & Contingencies	60	1	60
SUBTOTAL: ANNUAL MAINTENANCE			491
MAJOR OVERHAUL OF:			
Steam Generator (Cleaning, Plugging Leaks, 0.8)	160	0.1*	16
Turbines	100	0.1*	10
Electrical Generator	50	0.1	5
Motors, Pumps	10	0.1	1
Insulation (Thermal)	20	0.1	2
Feedwater Heater, Condenser, Deaerator	20	0.1	2
SUBTOTAL: MAJOR OVERHAUL (ANNUAL BASIS)			36
TOTAL ANNUAL MAINTENANCE			527

(Continued)

*Assumes 10-Year Life

TABLE 3.3-4 (Continued)

ESTIMATED ANNUAL REPLACEMENT PARTS COSTS

Part	Estimated Cost ($)	No. Per Year	Annual Cost ($)
Pump Motor	75	0.1	7.50
Bearings, Turbine (9)	25	0.1	10.00
Bearings, Generator (2)	25	0.1	5.00
Bearings, Pumps (4)	25	0.1	10.00
Seals, Turbine (4)	40	0.2	32.00
Seals, Pumps (4)	40	0.2	32.00
Packings, Valves			
- Power Actuated (12)	5	0.2	12.00
- Manually Actuated (20)	5	0.1	10.00
Insulation	25	0.1	2.50
Gaskets (5)	10	0.1	50.00
Miscellaneous (Nuts, Bolts, Tubing, etc.)	50	0.1	5.00
Lubricants	40	0.1	4.00
TOTAL			$180.00

3.4.8.2 STEAM GENERATOR

The steam generator is an unfired boiler that contains no moving parts. It consists of a preheater plus a combination evaporator and superheater, each of which is comprised of a U-tube heat exchanger containing hot oil on the primary side and water and/or steam on the secondary side. While the preheater will each have single-phase fluid on both the primary and secondary sides and is expected to exhibit no significant operational problems throughout the lifetime of the plant, periodic tests and inspections are indicated to confirm continuing efficient operation. The evaporator section of the steam generator will contain single-phase fluid (oil) on the primary side and two-phase fluid (water/steam) on the secondary side. Some problems associated with the boiling of water can be anticipated in the evaporator section even though the water chemistry will be closely controlled and water cleanliness will be maintained by periodic blowdown operations. Typical problems in the evaporator sections are sludge deposits and chemical hide-out. Sludge is formed when minute particles of dirt are "left behind" as water evaporates; these particles can build up on the evaporator tubes reducing heat transfer efficiency, or in flow channels increasing the flow pressure losses. Chemical hide-out can occur in regions poorly flushed by the water (such as in the crevices between tube bundle support plates and tubes); this leads to higher chemical levels in these regions, which can accelerate corrosive attack and, in turn lead to tube leakage. The periodic inspections are designed to detect these types of conditions. The superheater section will have single-phase fluid (oil) on the primary side and may have two-phase fluid (steam plus some carry-over water) on the secondary side. Superheater operation can cause "plate-out" of solids and chemicals on the superheater tubes. The plate-out can affect superheater efficiency. The periodic tests are designed to detect this condition.

PERFORMANCE TESTING (SEMI-ANNUAL)

<u>Thermal Efficiency</u>

Start-up and operate the steam generator at several load points. Measure and record primary fluid (oil) equilibrium inlet and outlet temperatures and flow rates in each section of the steam generator at each load point.

Simultaneously measure and record the secondary fluid (water/steam) inlet and outlet temperatures and flow rates in each section of the steam generator at each load point. Use the data obtained to monitor the heat transfer efficiency of the steam generator; the data may be obtained from the overall plant test list of Section 3.4.8.1. Estimated manpower requirement; one crew shift.

Pressure Drop Tests

These tests should be performed concurrently with the thermal efficiency test, above. At each load point, measure and record the inlet and outlet pressures of the primary and secondary fluids at each section of the steam generator. These data will reveal any flow blockages before they become critical to plant operation. Estimated manpower requirement; none, if performed as part of Thermal Efficiency, above.

Flow Control Valve Operation

The oil and water flow control valves will be operated remotely and observed locally for proper operation. Estimated manpower requirement; one manhour per valve.

ROUTINE INSPECTIONS

Steam Safety Valve (Annual)

The steam safety valve will be removed from the unit, cleaned if necessary, checked for lift-off (full flow) setting, and reset if necessary by an organization authorized to do so (ASME licensed shop). Estimated man-power requirement; four man-hours.

Boiler Water Level Control (Semi-Annual)

The boiler water level control will be calibrated over the flow range and reset if required. Estimated man-power requirement; eight man-hours.

Valve and Instrument Packings (Monthly)

All valves and instrument packings, primary and secondary, will be inspected for leakage and tightened as necessary. Estimated man-power requirement; one-fourth man-hour per item.

Pressure Gauges and Transducers

Pressure gauges will be calibrated annually; pressure transducers will be calibrated as indicated in Section 3.4.8.7, Instrumentation.

Temperature Gauges and Transducers

Temperature gauges (thermometers) used for local temperature indication will not normally require servicing or inspection other than possible cleaning to maintain legibility. This is considered incidental. Temperature transducers (thermocouples and/or resistance temperature detectors) will be inspected and maintained as indicated in Section 3.4.8.7, Instrumentation.

Oil Control Valves

Each oil flow control valve will be operated through its stroke. Proper response to the control signals will be verified.

Air Filters (Monthly)

Filters in the air supply for pneumatic valve actuators will be inspected and cleaned, or replaced as required.

3.4.8.3 TURBINE/GENERATOR

The turbine/generator has a high reliability and will not normally require, at intervals of less than 10 years, any major maintenance involving removal/replacement of rotor, buckets, diaphragms, bearings, seals, valve or governing mechanisms. Such major maintenance, if needed, should be performed under the supervision of the manufacturer's representative.

PERFORMANCE TESTING

The performance testing will be done as part of the complete system performance tests.

ROUTINE INSPECTIONS AND MAINTENANCE

- Inspect and clean, if necessary, the steam inlet strainer after the first day and first week of operation and annually thereafter
- Clean and lubricate external pivots of governor system; replenish lubricant in lever system bearings once per month
- Check oil level in hydraulic governor system once per month
- Check out over-speed trip on each turbine once per month; clean and lubricate, if required, outside moving parts of over-speed trip control
- Test oil neutralization number, flash point, viscosity, etc. (every six months)
- Maintain oil levels, as required, in turbine bearing reservoir, speed reducer gear box, generator bearing reservoir (if required)
- Inspect clutches semi-annually for wear effects
- Review data from Section 3.4.8.1.1 to detect wear/deposition effects

3.4.8.4 STEAM CONDENSER, CONDENSATE RETURN, DEAERATOR AND FEEDWATER HEATER

These units contain no moving parts, and are expected to require very little maintenance over the design life of the plant(except pumps associated with "packaged" units).

PERFORMANCE TESTING

The condensate return tank does not require performance testing. Thermal performance testing of the remaining units will be done as part of the system performance tests.

ROUTINE INSPECTION AND MAINTENANCE

- <u>Leak Tests</u>: The steam condenser and feedwater heater will be checked for leak-tightness at intervals of not less than six months; leaking tubes will be repaired as required. All units will be inspected for external leakage at intervals of not less than one year.
- Condensate return and condenser hotwell level controls will be inspected and calibrated at intervals of not less than six months.

- Deaerator vents will be inspected and cleaned as required at intervals of not less than 6 months.

- Deaerator relief valve will be inspected and calibrated at intervals of six months.

- Data from system performance tests (Section 3.4.8.1.1) will be evaluated to assess steam condenser and feedwater heater thermal performance.

3.4.8.5 CONDENSATE AND BOILER FEEDWATER PUMPS

These units are rotary pumps that are highly reliable and should require very little maintenance during the design life of the plant.

PERFORMANCE TESTING

Following initial plant checkout of flow/head/power characteristics, no performance testing is anticipated.

ROUTINE INSPECTION AND MAINTENANCE

- Bearings are either grease-packed or oil-lubricated and will be checked on a semi-annual basis. Annual lubricant replenishment is anticipated.

- Seals are designed for long life and should not require replacement at intervals of less than five years. Seals will be inspected for evidence of leakage semi-annually and replaced as necessary.

3.4.8.6 PIPING, VALVES AND FITTINGS

System and component piping and fittings are static elements that should not require any maintenance except at gasketed joints. Three categories of valves are present in the system:

- Manually operated isolation and shut-off valves

- Power actuated control valves

- Self-actuated relief valves

Relief valve maintenance has been discussed in conjunction with the equipment that they are designed to protect. Manually operated valves should require little more maintenance than the pipes and fittings; some attention must be given to the stem packings. The power-actuated control valves will require periodic maintenance as indicated.

PERFORMANCE TESTING

No specific performance testing is required for manual valves, pipes and pipe fittings. Testing of relief valves have been described. Performance testing of power actuated valves should include:

- Response of valve actuator to control signal (semi-annual)
- Measurement of power (air pressure) required for valve actuator (semi-annual)

ROUTINE INSPECTION AND MAINTENANCE

Pipes, fittings and manual valves will not require routine inspection or maintenance except for observation of gasketed joints (and packings, for valves) for leakage. Requirements for relief valves have been discussed. For power actuated valves, the following inspection and maintenance are indicated:

- Air filter inspection and replacement, if required, for pneumatically actuated valves
- Valve steam packings will be inspected and adjusted for leak-free operation on a semi-annual basis. Packing replacement is anticipated at not less than five-year intervals.

3.4.8.7 INSTRUMENTATION AND CONTROL

- Periodically inspect the general condition of all I&C equipment, including cabling and connectors. Unsatisfactory conditions would be subject to immediate maintenance.
- Periodically recalibrate each I&C equipment item or channel. This includes confirmation of setpoint accuracies, deadband, etc., for switching functions.
- Perform routine maintenance and/or repair/replacement as recommended by maintenance manual.

3.4.9 SPECIAL FEATURES AND PRECAUTIONS

3.4.9.1 HEALTH AND SAFETY

Steam Generator

The steam generator will be supplied and constructed in accordance with the Class R mechanical standards of the tubular Exchanger Manufacturer's Association and the ASME Code for unfired pressure vessels.

In addition, the packaged boiler will be provided with the following features:

- ASME Steam Safety Valve
- Valve vent and drain connections arranged to completely drain the boiler of all water
- Blow-off connection and tandem blow-off valves
- Each tube bundle head will have a 1-1/2 in. rupture disc set to relieve excess pressure
- Standard instrumentation and control indicators to give indications of possible hazardous generating conditions

Turbine/Generator

The turbine/generator will be provided as a packaged skid-mounted unit using standard single-stage turbine designs and a standard generator rated at approximately 350 kW. Design pressures and temperatures (315 psia, 500°F) are low in comparison to the conventional industrial TG systems, thus reducing the inherent hazards of industrial power plants. However, the designs of the turbine/generator will meet ASME, ANSI, NFPA, NEMA and OSHA requirements. In addition, procedures of safe operation will be incorporated into the design and into the actual operating sequences. Special features like Automatic Turbine Start (ATS) over-speed control, load control, speed control and automatic synchronization to the utility grid will be provided for the safe operation of the turbine/generator. Also, indications of generator output power, voltage and frequency will be displayed on a control panel and protection against over/under voltage, over/under frequency and reverse current will be incorporated into the generator protective system.

The skid-mounted design of the turbine/generator package will minimize the boundary available to local electrical shocks. Where necessary, barriers will be incorporated and interlocks used on electrical power and control panels. Signs identifying potential electrical shock hazards will be posted in areas where personnel access becomes necessary. These signs will warn of the specific hazard and request "authorized personnel (trained for maintenance or repair) only."

Condenser and Condensate Return System

The condenser will operate at approximately 5 psia and will be provided with an atmospheric relief valve to prevent excessive shell pressure in the event of primary instrumentation failure. A vacuum alarm will be provided to warn operators in time for corrective action such as shutdown of vacuum pump.

Piping and Insulation

Proper insulation will be used to prevent accidental burns due to local contact with hot water and/or steam lines.

Insulation will also give partial protection and in some instances reduce the hazard caused by rupture or leaks in piping, pumps or turbines. Piping runs will be made in accordance with the proper codes, including ASME, ANSI and OSHA requirements. Piping between equipment will be run to minimize personnel exposure to leakage of hot water or steam.

Pressure relief devices will be installed in the steam generator, condenser and associated piping to prevent possible leakage or rupture caused by oil, hot water or steam. In addition to operational instrumentation, which will give continuous and early indications of an off-design (i.e., high pressure, high temperature) condition, instrumentation will be designed to detect and mitigate effects of steam release from leakage or rupture of the various equipment.

3.4.9.2 ENVIRONMENT

The PCS has been designed to keep discharges to the environment to a minimum. The following are the discharge points of the subsystem and the environmental treatment of each:

- Oil drains on the steam generator - collected in an oil drain tank
- Oil rupture discs on steam generator - discharge is manifolded to a pressure relief tank
- Boiler blowdown - treatment as necessary to comply with EPA standards and discharge to drain
- Steam relief valves - vent to atmosphere
- Condensate relief valves - vent to drain
- Condenser vacuum pump - vent to atmosphere

3.5 HEATING/CHILLED AND DOMESTIC HOT WATER SUBSYSTEM

3.5.1 SUMMARY DESCRIPTION

The existing Fort Hood steam and chilled water system for the five selected buildings will be abandoned for a more efficient total energy heating/chilled and domestic hot water subsystem. The existing systems will remain in place and in operating condition to serve as a redundant backup for space cooling, heating and domestic hot water needs.

The five selected buildings will be served by a new two-pipe, change-over system; chilled water in the cooling season; hot water in the heating season. The two conditions cannot occur simultaneously as the same pair of pipes (supply and return) are used for both seasons.

The heating/chilled and domestic hot water subsystem interfaces mechanically, hydraulically or thermally with the Power Conversion Subsystem, Makeup Water Subsystem and existing cold water makeup system, Heating Water System and Chilled Water System.

3.5.2 FUNCTION

3.5.2.1 HEATING WATER

The function of the heating water system is to provide heating water to the existing Fort Hood five selected buildings and the STES building.

3.5.2.2 DOMESTIC HOT WATER

The function of the domestic hot water system is to provide recirculating potable hot water to Fort Hood for three of the buildings and for the STES building. Two buildings, 87014 and 87016, have small electric domestic water heaters which will remain.

3.5.2.3 CHILLED WATER

The function of the chilled water system is to provide chilled water to the existing Fort Hood five selected buildings and the STES building.

3.5.3 DESIGN REQUIREMENTS

3.5.3.1 HEATING WATER

The 66,000 gallon effective heating water storage capacity in two tanks is 25,000 gallons and 41,000 gallons (shared with the chilled water system). (From either cooling tower heat exchanger or heating system return.)

- Heating water entry to condenser at 100°F
- Heating water exit from condenser to be controlled at 140°F
- Heating water storage tank will be a thermocline type

3.5.3.2 DOMESTIC HOT WATER

- 40-gallon/day/person daily usage
- 3660-gallons/hour peak demand
- 20 x 10^6 Btu-hr/day energy requirements
- 2-4hour supply of domestic hot water
- 140°F temperature into storage
- 75°F makeup water temperature with seasonal variations
- 796 people

3.5.3.3 CHILLED WATER

- 41,000-gallons effective chilled water storage capacity
- Chilled water return to absorption chiller at 58°F
- Chilled water exit from absorption chiller at 42°F
- Chilled water storage tank will be a thermocline type
- Steam supply at 65 psia and 298°F
- Steam mass flow rate - 1992 lb/hr

3.5.4 SUBSYSTEM DESCRIPTION

3.5.4.1 OVERALL SUBSYSTEM

All of the major components of the subsystem do not operate simultaneously, therefore, the heating water, domestic hot water, chilled water and secondary thermal distribution components are described separately herein.

FLOW DIAGRAMS

Flow diagrams identify state points and schematically illustrate piping arrangements, points of interface, major system components and flow paths for particula systems. The following diagrams are given in Volume III:

- Drawing 5-2 - Heating Subsystem Flow Diagram
- Drawing 5-3 - Domestic Hot Water Subsystem Flow Diagram
- Drawing 5-4 - Cooling Subsystem Flow Diagram
- Drawing 5-6 - Thermal Distribution Flow Diagram
- Drawing 5-7 - Heating/Cooling and Domestic Hot Water Subsystem Mode Diagram

HEATING WATER COMPONENTS

The heating water piping is illustrated in Flow Diagram Drawing 5-2, and Process and Instrumentation Drawing 5-1 in Volume III. Heating water is pumped through a primary loop. In this path, heating water enters the surface condenser and absorbs thermal energy from the steam turbine discharge steam, with the heating water discharge temperature controlled at 140°F. The 140°F water will be available from the primary loop to the secondary heating water pump for supply through the new underground secondary thermal distribution piping, as described hereinafter, to the five selected buildings. During off-peak periods, the heating water storage tank and/or the heating/chilled water storage tank is charged with heating water. The piping and flow control arrangements at these tanks is such that during peak demand periods, flow is reversed through the tanks and stored heating water may be supplied to the primary loop.

During periods when all of the energy available in the surface condenser is not removed by the heating water primary loop, part of the flow from the surface condenser can be diverted through the condenser heat exchanger where excess energy is transferred to cooling tower water to be dissipated by the cooling tower.

DOMESTIC HOT WATER COMPONENTS

The domestic hot water piping is illustrated on Flow Diagram Drawing 5-3 and P&ID Drawing 5-1 given in Volume III. Heating water is pumped from the primary heating water loop through the domestic hot water heat exchanger by the domestic hot water pump. A thermal energy exchange takes place at this point, from the heating medium to the domestic hot water subsystem.

Domestic hot water is supplied to the existing barracks buildings through a new underground supply and recirculating system that connects to the existing cold water inlet at the existing hot water generator. This new underground piping will be installed in the same trench with the new secondary thermal distribution piping. A new domestic hot water recirculating pump will be installed in the new STES building to insure that a uniform water temperature is available to the three existing barracks buildings.

Makeup water will be supplied to the domestic hot water supply line in the new STES building.

In the event the new domestic hot water subsystem is out of service, the new automatic two-position steam valve will open allowing steam to enter the existing hot water generator. As steam enters the existing hot water generator, a new automatic valve in the STES hot water supply line closes and a new automatic valve in the existing cold water inlet opens.

The existing electric water heaters supplying buildings #87014 and #87016 are to remain in service.

CHILLED WATER COMPONENTS

The chilled water piping is illustrated in Flow Diagram Drawing 5-4, and Process & Instrumentation Drawing 5-1 given in Volume III. Steam is supplied to the absorption chiller from the Power Conversion Subsystem. Condensate from the absorption chiller is returned by gravity to the Power Conversion Subsystem. Chilled water is pumped through a primary loop. In this path chilled water returns to the absorption chiller at 58°F and rejects thermal energy to the refrigerant, allowing the chilled water leaving temperature to be controlled at 42°F. Thermal energy absorbed by the refrigerant is transferred to the condenser water.

At full load, the condenser water enters the absorption chiller at 85°F and exits at 90.5°F. The condenser water is conveyed to the cooling tower by a condenser water pump where thermal energy absorbed from the refrigerant is rejected to the atmosphere. The 42°F chilled water will be available from the primary loop to the secondary chilled water pump for supply through the new underground secondary thermal distribution piping to the five project buildings. During off-peak periods, the heating/chilled water storage tank is charged with chilled water. The piping and flow control arranagement at these tanks is such that during peak demand periods, flow is reversed through the tanks and stored chilled water may be supplied to the primary loop.

SECONDARY THERMAL DISTRIBUTION COMPONENTS

The new secondary heating water pump or chilled water pump takes water from the primary heating or chilled water loop and supplies water to the five buildings through new underground piping, referred to herein as heating/chilled water piping.

The heating/chilled water piping enters new valve pits to be constructed at each of the three existing barracks buildings and connects to the existing piping with new automatic three-way two-position isolation valves. A new bypass arrangement with new automatic two-way, two-position bypass valve connects the existing supply and return piping. When the heating/chilled water is being supplied to the mechanical room from the new heating/chilled water piping, the path of flow from the existing heating/chilled water is blocked by the new three-way valves. When water is supplied from the new STES facility, the flow path of water in the existing piping is through the new two-way by-pass valve, which causes no effect upon the flow characteristics of the existing chilled water pump and water supply to buildings being served by the existing system.

Existing three-way valves in the heating/chilled water piping will be fitted with automatic valve positioners where deemed possible, otherwise the existing valves will be replaced with new automatic valves. The function of these three-way valves is to facilitate changeover from the existing heating to the new heating/cooling water supply system.

Piping arrangements similar to those described above for the barracks buildings are required for buildings #87014 and #87016 (Administration and Supply), except connections to the existing piping will occur in the existing mechanical rooms. In addition, two new automatic three-way, two-position valves will be installed in the existing heating/chilled water piping to supply heating water only to new unit heaters in the storage areas of buildings #87014 and #87016 only. Existing air handling units will remain in service with the steam heating only coils serving as a backup to new heating/chilled water piping to existing water coils being served by the STES.

A new automatic two-way, two-position valve will be installed in the existing steam supply line and a check valve will be installed in the existing pumped condensate return line serving the five project buildings. The new steam valve will be sequenced to open to furnish steam to the existing building converters if heating water is not available from the solar total energy heating subsystem.

PERFORMANCE PARAMETERS

The Heating/Chilled and Domestic Hot Water Subsystem will be capable of the following:

- Heating water effective storage capacity of 66,000 gallons of water at 140°F, 90.05 x 10^6 Btu/day
- Chilled water effective storage capacity of 41,000 gallons of water at 42°F, 71.15 x 10^6 Btu/day
- Domestic hot water supply to the three existing buildings, 67 total gallons per minute at 135° with a recirculating rate of 6 gallons per minute
- Heating water supply to the existing five buildings, 325 gallons per minute at 140°F
- Chilled water supply to the existing five buildings, 325 gallons per minute at 42°F

PROCESS AND INSTRUMENTATION DIAGRAMS

Process and instrumentation diagrams schematically illustrate piping arrangements, major system components and flow paths. Signal transmitters, gauges, sensors, computer control interfaces and the action of valves and motors are indicated symbolically on drawings included in Volume III:

- Drawing 5-1 - Heating/Chilled and Domestic Hot Water P&ID
- Drawing 5-5 - Thermal Distribution P&ID

3.5.4.2 COMPONENTS

The major components of the heating/cooling and domestic hot water subsystems are the absorption chiller, the cooling tower, the heat exchangers (one for heating domestic hot water and one for heat rejected from the steam surface condenser), the outdoor tanks for heating and heating/chilled water storage and pumps to move water through the subsystem.

ABSORPTION CHILLER

The absorption chiller is a 385-ton two-stage unit of hermetic design, factory assembled and leak tested, to be operated at 175-tons capacity with 65 psia steam.

The chiller uses a double effect, two-stage concentrator. The heat of refrigeration generated in the first stage is used to generate additional refrigerant in the second-stage concentrator. The first-stage concentrator is ASME construction with stainless steel tubes; the second-stage concenerator uses copper tubes.

Steam is to be introduced into the first-stage concentrator to provide heat to boil out the refrigerant (which is water) from a dilute solution of distilled water and lithium bromide salt. This refrigerant vapor is used as 4 psig steam to heat the second-stage concentrator.

Dilute lithium bromide solution from the abosrber section of the machine is sent to the first-stage concentrator, where it is partially concentrated, and then to the second-stage concentrator, where the concentration process is completed.

Cooling water from the cooling tower flows through the tubes of the condenser to condense the refrigerant generated in the second-stage concentrator. This refrigerant is combined with the refrigerant that is condensed in the tubes of the second stage concentrator, and is passed through an orifice in the evaporator section.

The refrigerant effect is produced in the evaporator section, because the pressure in the evaporator is substantially lower than in the second-stage concentrator and condenser section of the machine. Refrigerant passing through an orifice from the high- to low-pressure side causes this refrigeration effect.

Returned water flows through the evaporator tubes and is chilled by refrigerant to approximately 40°F sprayed over the tube bundle. Transfer heat to the refrigerant causes the refrigerant to vaporize. The vapor is drawn into the absorber section where it is absorbed in the concentrated lithium bromide solution.

The absorption chiller is provided with a control panel with electric relays, gauges and indicating lights to indicate operating conditions.

THERMOCLINE TANKS

Chilled and heated water storage uses thermocline-type tanks. These tanks differ from normal storage in that when water of the desired temperature is removed, it is replaced by water from the system return. That is, water that has given up its thermal heat or become less chilled due to absorbing heat. Normal storage tanks would remove water and replace the water volume with a gas. For each normal supply tank, a second return storage tank is required to store the displaced water. Thermocline tanks eliminate the second tank by storing return water in the same tank. Since the supply water and return water are at different temperatures, a stratified thermal profile (thermocline) exists in the tank. Hot water is on top, cold on the bottom. Hot (or warm) water is removed or returned to the top while cold water flows to or from the bottom.

The required effective storage capacities are 41,000 gallons for the hot/chilled water storage tank and 25,000 gallons for the hot water storage. These values were obtained by calculating and profiling daily heating and cooling requirements shown in Section 4.1.1. The hot/chilled water tank size is based on the full-load cooling requirements. The hot water tank size is based on the domestic hot water requirements during the cooling season, as described in Section 4.1.1.

Effective storage is that amount of storage produced during charging mode (off-peak demand) that can be used in the system during the discharge mode when the load exceeds the capacity of the STES plant.

Because of thermal conductivity, unavoidable mixing and other non-ideal effects, the thermocline tank must be somewhat larger than the normal storage tank. Preliminary computer modeling indicates that, considering steady-state flows and no wall effects, the height of the non-usable section of water is 1.4-feet for the cold storage tank and 2.1-feet for the hot storage tank. For the purposes of design, these values are doubled. Sidewall effects could be substantially eliminated by the use of internal insulation, and internal manifolding could minimize flow disturbances.

Since the storage tank and distribution system fluid contents vary in temperature, the fluid volume varies. This requires expansion room in the system. The storage tanks have extra room to accommodate the expansion. The space above the liquid level is filled with nitrogen. The tank does not breathe nitrogen; it operates as a closed pressure vessel.

Tank design parameters are given in Table 3.5-1. Geometric parameters will be re-examined during the definitive design phase.

HEAT EXCHANGERS

Two heat exchangers are used in this subsystem. One is for the domestic hot water, which is heated by an exchange of heat with circulating heating water flowing from the steam surface condenser at 140°F, or from stored heating water. This raises the temperature of the incoming city water to 135°F for delivery to the three barrack buildings served. A hot water recirculating line returns from the buildings approximately 6 gallons per minute. The amount of water delivered to the buildings is the 6 gpm for recirculation plus the amount required to satisfy the demand by the showers and lavatories as the hot water is used.

The other is the condenser heater exchanger. This is used to reject energy from the surface condenser when the storage tanks are full. In the event the condenser heat exchanger is used to cool the circulating water discharged from the condenser from 140° to 100°F. Cooling water from the cooling tower passes through the exchanger and cools the warm water discharged from the condenser.

TABLE 3.5-1

THERMAL STORAGE TANK PARAMETERS

Cold Tank

- Hot Storage Temperature . . . . 58°F
- Cold Storage Temperature . . . . 42°F
- Effective Storage Volume Required . . . . 41,000 gallons
- Diameter 22-feet
- Height 19-feet
- Steel Tank . . . . Thickness 1/4-inch Plate
- Insulation . . . . 2-inch Fiberglass (external)
- Minimum Hot Side Temperature Acceptable . 54°F
- Maximum Cold Side Temperature Acceptable. 44°F
- Cycle (11-hour Charge) . . . . 42°F Fluid In

  . . . . 58°F Fluid Out

  Followed by 13-hour Discharge . . . . . . 42°F Fluid Out

  . . . . 58°F Fluid In

  Period 24-hours

Hot Tank

- Hot Storage Temperature . . . . 140°F
- Cold Storage Temperature . . . . 100°F
- Effective Storage Volume Required . . . . 25,000 gallons
- Diameter 18-feet
- Height 19-feet
- Insulation . . . . 2-inch Fiberglass (external)
- Minimum Hot Side Temperature Acceptable . 135°F
- Maximum Cold Side Temperature Acceptable. 105°F
- Cycle (11-hour Charge) . . . . 140°F Fluid In

  100°F Fluid Out

  Followed by 13-hour Discharge . . . . . . 100°F Fluid In

  . . . . 140°F Fluid Out

  Period 24-hours

COOLING TOWER

The cooling tower is used to reject heat from the absorption chiller. When the steam surface condenser cannot be used in providing domestic hot water or water for heating the five building complex, the cooling tower rejects the energy absorbed from the surface condenser into the atmosphere. The tower is an induced draft cross-flow type with a propeller fan at the top of the tower and water distribution basins on each side. Water flows over the honeycomb fill below the water distribution basins where it is cooled by evaporation in contact with the direct air. The cold water at 85°F or cooler is collected in a below-ground sump for recirculation to the condenser of the absorption chiller and/or to the condenser heat exchanger.

PUMPS

1. <u>Primary Heating Water Pump</u>: Electric motor driven, end suction, vertical split case frame mounted, flex coupled bronze impeller, stainless steel shaft.

   Electrical: 480 volts, 3-phase, 60 Hz, 5 hp motor

   Capacity: 253 GPM vs. 49.9-ft water column

2. <u>Domestic Hot Water Pump</u>: Electric motor driven, end suction, vertical split case frame mounted, flex coupled bronze impeller, stainless steel shaft.

   Electrical: 480 volts, 3-phase, 60 Hz, 3 hp motor

   Capacity: 253 GPM vs. 29-ft water column

3. <u>Primary Chilled Water Pump</u>: Electric motor driven, end suction, vertical split case frame mounted, flex coupled bronze impeller, stainless steel shaft.

   Electrical: 480 volts, 3-phase, 60 Hz, 5 hp motor

   Capacity: 371 GPM vs. 26.4-ft water column

4. Secondary Heating Water Pump:	Electric motor driven, end suction, vertical split case frame mounted, flex coupled bronze impeller, stainless steel shaft.
Electrical:	480 volts, 3-phase, 60 Hz, 15 hp motor
Capacity:	325 GPM vs. 112.4-ft water column
5. Secondary Chilled Water Pump:	Electric motor driven, end suction, vertical split case frame mounted, flex coupled bronze impeller, stainless steel shaft.
Electrical:	480 volts, 3-phase, 60 Hz, 15 hp motor
Capacity:	325 GPM vs. 112.4-ft water column
6. Domestic Hot Water Recirculating Pump:	Electric motor driven, end suction, vertical split case frame mounted, flex coupled bronze impeller, stainless steel shaft.
Electrical:	480 volt, 3-phase, 60 Hz, 2 hp motor
Capacity:	6 GPM vs. 112-ft water column
7. Condenser Water Pump to Absorption Chiller Unit:	Multistage vertical turbine, bronze impeller, cast iron discharge head, steel pipe column, stainless steel shaft.
Electrical:	480 volt, 3-phase, 60 Hz, 25 hp motor
Capacity:	1250 GPM vs. 50.5-ft water column
8. Condenser Water Pump to Condenser Heat Exchanger:	Multistage vertical turbine, bronze impeller, cast iron discharge head, steel pipe column, stainless steel shaft.
Electrical:	480 volt, 3-phase, 60 Hz, based on 530 gpm hp motor
Capacity	TBD

PIPING, VALVES AND FITTINGS

Underground Heating/Chilled Water Piping

Schedule 40 black steel pipe ASTM A-53, Grade B, factory encased in polyurethane foam insulation with a rigid PVC outer jacket. Gasketed joints will be used. The system will satisfy the dual temperature requirement for an operating range of 42° to 140°F and a working pressure rating of 150 psi.

Underground Domestic Hot Water and Hot Water Recirculating Piping

Type K, hard drawn copper pipe ASTM B-88, factory encased in 1/2-inch polyurethane foam insulation with a rigid PVC outer jacket. Joints in straight piping will be of the gasketed or O-ring type. The system will satisfy the requirements for a temperature rating of 140°F and a working pressure rating of 150 psi. Fittings will be wrought copper, silver soldered with field applied insulation and jacket.

Pipe Above Grade

Hot water, chilled water and condensing water piping; black carbon steel ASTM A53 Grade B Schedule 40, except water piping 8-in. and larger will be Schedule 30. Domestic hot water and recirculating hot water piping will be Type L hard-drawn, wrought copper fittings with silver soldered joints.

Above Grade Piping Joints and Fittings

Fittings in copper pipe will be wrought copper, silver soldered joints. Joints in piping 2-in. and smaller steel pipe will be screwed. Fittings will be 125-lb rated standard cast iron or 150 rated standard malleable iron. Joints in piping 2-1/2-in. and larger will be welded, except flanged or grooved end joints will be used at connections to equipment. Flanges will be forged steel raised face, welding neck, class 150 conforming to ANSI B16.5. Flange gaskets will be asbestos composition. Grooved end fittings will be malleable iron.

Fittings 2-1/2-in. and larger will be butt-type carbon steel conforming to ANSI B16.9 and ASTM A234 and the same schedule as the pipe. Factory made fittings will be used for reducers and elbows; miter will not be used for turns but machine-made bends may be used. Factory made tees will be used for branch connections, except that forged steel welding saddles may be used on 2-1/2-in. and larger mains where the branch is smaller than the main. Unions will be provided at connections to equipment. Pressure ratings of unions will equal or exceed the ratings specified for other fittings in the system. Unions 2-in. and smaller will be threaded end ground joint type; unions 2-1/2-in. and larger will be bolted flange-type with gaskets, or grooved end couplings may be used as unions.

Valves

Gate valves will be 150-lb union bonnet, bronze body, solid wedge, screwed end type for 2-in. piping and smaller. Valves 2-1/2-in. and larger will be flanged end, iron body, solid wedge, bronze fitted, non-rising stem, 125-lb class. Butterfly valves 2-1/2-in. and larger will be lug type, cast iron body, aluminum-bronze disc, stainless steel stem, flexible seat-liner, 150-lb water working pressure. Butterfly valves larger than 4-in. will have worm gear operation, 4-in. and smaller will have lever handle and all valves used for balancing will have memory stops. Check valves will be swing type, regrinding metal disc, same make and construction as gate valves. Check valves at pumps will be spring loaded non-slam type. Ball valves 2-in. and smaller will have threaded ends, bronze body, ball and stem, steel handle, teflon seats, packing and gasket.

Strainer

2-in. and smaller: Y pattern 250-lb cast iron or semi-steel screwed ends, screwed cover and stainless steel or monel screen, 1/32-in. openings. Strainers 2-1/2-in. and larger: Y pattern semi-steel or cast iron, 125-lb flanged ends, bolted cover, brass screen with 1/16-in. openings.

Pipe sizes vary from 2- to 10-inches.

INSTRUCTION AND CONTROL

1. <u>Temperature Indicators</u>: Bimetallic thermometers, mounted locally.

2. <u>Pressure Indicators</u>: Helix type Bourdon tube pressure gauge, mounted locally

3. <u>Temperature Transmitters</u>:

Primary Element:	Thermocouple housed in thermowell on process
Amplifier:	EMF/current converter and transmitter
Electrical:	110 volt a.c. power input
Signal:	5 to 20 milliamps output

4. <u>Pressure Transmitters</u>:

Primary Element:	Metallic bellows-type pressure sensor
Amplifier:	Current amplifier
Electrical:	110 volt a.c. power input
Signal:	5 to 20 milliamps output

5. <u>Flow Transmitter</u>:

Primary Element:	Orifice plate with high- and low-pressure taps
Amplifier:	Differential pressure transmitter with high- and low-pressure taps
Electrical:	110 volt a.c. power input
Signal:	5 to 20 milliamps output

6. <u>Level Transmitter</u>:

Primary Element:	Diaphragm with two pressure chambers and high- and low-pressure taps

6. Level Transmitter: (Continued)

Amplifier:	Differential pressure transmitter with high- and low-pressure taps
Electrical:	110 volt a.c. power input
Signal:	5 to 20 milliamps output

7. Transducer: Milliamp current signal to pneumatic air signal converter

Air Supply:	20 psi
Signal Input:	5 to 20 milliamps
Signal Output:	0 to 15 psi

8. Control Valve Positioner: Pneumatic operator with controller and supply air inlets. Mechanical stem link attachment for redundant feedback position control.

HEAT TRANSFER FLUID TREATMENT

The cooling water that is circulated from the steam surface condenser through the heat exchangers and the storage tanks will be treated to prevent corrosion and scale development. This water will be treated with corrosion inhibitors and pH adjustment chemicals. Cooling water that is circulated through the tower will be treated with biocides to kill slime and algae and with corrosion inhibitors and pH adjustment chemicals to prevent corrosion and scale.

Currently, the water treatment at the 87000 complex consists of the following:

- Chiller - Bromine Nitrite used in chilled water as corrosion inhibitor and pH control
- Cooling Tower Water - Hydro-Chem 1340 composed of Tri Sodium Phosphate, Acrylic Polymer, Organic Phosphate, Sodium Hydroxide and Sodium Lingnosulfanate is used at rate of 300 ppm
- Boilers - Sodium Hydroxide is used in the boiler for acid control; Cyclo Hexylamine is used as a corrosion inhibitor in the condensate

A water treatment will be used which is compatible with those above where the possibility of STES water mixing with existing Central Energy Facility exists.

3.5.5 SUBSYSTEM OPERATION

This subsystem operates to provide 24-hour supply of domestic hot water, heating water for building heating during the winter months, and chilled water for building cooling during the summer months. Heating water and chilled water are not supplied simultaneously, but are supplied seasonally. The supply and return piping to the five buildings is a two-pipe system and can handle only one-temperature water at a time. The domestic hot water is supplied 24-hours a day all year.

3.5.5.1 NORMAL OPERATION

Normal operation of the heating/cooling and domestic hot water subsystem is controlled from the microprocessor and the main computer. Each component in the system is started from the main computer control room and in normal operation, continues until manually stopped at the end of the winter or summer season. The domestic hot water system will operate throughout the year.

HEATING WATER SUBSYSTEM

In normal operation, the heating water subsystem will run continuously throughout the heating season and will operate so that heating water is generated at a constant temperature and a varying rate depending on the operational mode of the steam surface condenser. A constant rate of flow of heating water with varying temperature is supplied to the buildings 24-hours a day every day of the heating season. Return water from the buildings will be a constant 100°F. The varying supply temperature is accomplished by mixing the 140°F water from the condenser or from the storage tanks with 100°F return water. The supply water temperature is reduced as the outdoor temperature rises so that the return temperature can be held constant.

During the day, excess thermal energy rejected from the steam surface condenser and not required to heat the five buildings will be retained in the storage tanks. When the energy available from the surface condenser is not sufficient to meet the heating demand, the heating water will be supplied from the hot water storage tanks.

CHILLED WATER SUBSYSTEM

In normal operation, the chilled water subsystem will run continuously throughout the cooling season and will operate so that chilled water is generated at a constant rate and temperature 24-hours a day every day of the cooling season. A constant rate of flow of chilled water with varying temperature is supplied to the buildings 24-hours a day every day of the cooling season. Again the return temperature is held constant (at 58°F). The varying temperature is accomplished by mixing the 42°F water from the chiller or storage tank with 58°F return water. The supply water temperature is increased as the outdoor temperature decreases so that the return water temperature can be held constant.

During the night, excess chilled water produced but not required to cool the five buildings will be retained in the storage tank. During the day, when the peak cooling load occurs, this chilled water is used to supplement the absorption chiller output in meeting the load.

DOMESTIC HOT WATER SUBSYSTEM

The domestic hot water subsystem normally operates to provide domestic hot water to the three barracks buildings 24-hours a day all year. The temperature of incoming city water is increased in the heat exchanger, which uses hot water from the steam surface condenser or from storage as the energy source. The domestic hot water recirculating pump will run continuously to maintain a constant flow of return water from the building so that hot water is available when required without considerable delay. The amount of domestic hot water flowing through the heat exchanger is the combination of recirculating water and the makeup from city water due to the consumption of hot water at showers or lavatories. The output temperature of the domestic hot water heat exchanger will be controlled at 135°F by varying the flow rate on the heating water side of the heat exchanger.

START-UP AND SHUTDOWN

Initiation of start-up and shutdown will be accomplished for each part of the heating/cooling and domestic hot water subsystems from the main control computer transmitting control signals through the appropriate microprocessor.

HEATING WATER SUBSYSTEM

The heating water subsystem start-up will require that the valves allowing heating water to flow to the five buildings be positioned so chilled water flow is prechecked. These valves are positioned automatically from the STES control room. The primary and secondary heating water pumps will be started. When these pumps have been started, steam will be admitted to the condenser and hot water begins to flow either to the storage tanks or out to the buildings.

Shutdown is essentially the reverse of start-up. As soon as the steam stops being delivered to the condenser, the circulating pumps will be stopped, and the system will be out of service.

CHILLED WATER SUBSYSTEM

For start-up of the chilled water subsystem, the chiller will be brought into service as steam becomes available from the power conversion subsystem. The steam control valve will be energized and the primary chilled water pump will be brought into service. The condenser water pump and the cooling tower will now be started. The control valves will be positioned to permit the flow of chilled water to the storage tank. The system secondary chilled water pump will be started and chilled water will begin to flow to the buildings.

Shutdown of the chilled water system is essentially the reverse of start-up. The steam control valve is de-energized, and the chiller and appropriate pumps are turned off.

DOMESTIC HOT WATER SUBSYSTEM

The domestic hot water subsystem must operate all year 24-hours of every day. Accordingly, start-up will be infrequent and will only be required when the plant goes into service for the first time or has to be re-started because of a necessary shutdown. Start-up will take place after steam is available from the power conversion subsystem. The domestic hot water recirculating pump will be started, and the heating water pumps - if not already running - will be started.

Shutdown of the domestic water system is essentially the reverse of start-up and consists of stopping the two pumps associated with the domestic hot water system.

3.5.5.2 ABNORMAL OPERATION

In the event of loss of flow to the buildings in the case of the heating water or chilled water, an alarm signal will be transmitted to the control room to alert the facility operator. Corrective action will then be taken to deal with the situation.

In the event of a deviation from set output temperature of the heating water or chilled water being delivered to the building system, an alarm signal likewise will be transmitted to alert the operator. The operator may take corrective action to correct the condition. Other alarms will be transmitted to warn the operator of other abnormal conditions such as loss of control air pressure, pump motor contacts not closed, etc.

3.5.6 HEATING/CHILLED AND DOMESTIC HOT WATER SUBSYSTEM INTERFACES

3.5.6.1 SUBSYSTEM INTERFACES

POWER CONVERSION SUBSYSTEM

The Heating/Cooling and Domestic Hot Water Subsystem interfaces thermally, hydraulically and mechanically with the Power Conversion Subsystem at the inlet and outlet connections to the surface condenser and the steam supply and condensate return connections to the absorption chiller. Their interface points are identified on Flow Diagrams 5-2 and 5-4 (Volume III).

EXISTING SITE SYSTEMS

Heating Water

Interface with the existing heating water piping occurs in the form of fitting existing manual three-way heating/chilled water changeover valves in the three selected barracks buildings equipment rooms with new automatic actuators or replacing the existing three-way valves with new automatic three-way valves.

A new automatic two-way, two-position valve will be installed in the existing steam supply line and a new check valve will be installed in the existing pumped condensate return line serving the five selected buildings.

Chilled Water

Interface with the existing chilled water piping supplying the three selected barracks buildings occurs in new valve pits to be constructed adjacent to the three existing barracks buildings. (See Figure 3.8-4 for location of new valve pits.) In the new pits, new automatic three-way, two-position isolation valves will be installed in the existing chilled water supply and return lines. A new by-pass arrangement with a new automatic two-way, two-position by-pass valve connects the existing chilled water supply line to the existing chilled water return line. Interface occurs at the point of connection of the new valves and by-pass piping to the existing piping.

Interface with the existing chilled water piping supplying buildings #87014 and #87016 (Company and Administration Buildings) is of the same arrangement as described above for the three project barracks buildings, except that there are no new valve pits at these buildings and the interface occurs in the existing mechanical equipment rooms. Another point of interface occurs at the point where new automatic three-way, two-position control valves are to be installed in the existing chilled water piping to supply heating water only to new unit heaters.

Domestic Hot Water

Interface with the existing domestic hot water system occurs in the mechanical equipment rooms of the three project barracks buildings, with new domestic hot water supply and recirculating connections to the existing hot water generators and the addition of a new drain valve.

INSTRUMENTATION AND CONTROL

The Heating/Cooling and Domestic Hot Water Subsystem instrumentation interfaces with the ICS at the terminal board of the microprocessor cabinet. The absorption chiller steam control valve, which physically interfaces with the power conversion subsystem, is controlled from the absorption chiller control panel. Data collection for stored energy availability and load demand forecasts are obtained and transmitted to the energy management and control system through the microprocessor.

3.5.6.2 MECHANICAL INTERFACES

Site interface occurs along the route of the new secondary heating/chilled water underground distribution piping. This will involve replacement of paving and sidewalk material removed and reseeding areas where grass is removed and generally restoring the site to its original condition. Foundation interface occurs at the base of the new heating water storage tank and chilled/heating water storage tank. Both storage tanks rest on concrete foundations. Interface occurs from the cooling tower basin and supporting structure foundation. Interface also occurs between the overhead exterior piping and supporting structure foundation.

3.5.6.3 ELECTRIC POWER INTERFACE

Interface with the Electrical Distribution System occurs at the motor control center housing starters for the following equipment:

- Primary Heating Water Pump . . . . 480V, 3ϕ, 5 hp
- Domestic Hot Water Pump . . . . 480V, 3ϕ, 3 hp

- Primary Chilled Water Pump . . . . 480V, 3ϕ, 5 hp
- Secondary Heating Water Pump . . . . 480V, 3ϕ, 15 hp
- Secondary Chilled Water Pump . . . . 480V, 3ϕ, 15 hp
- Domestic Hot Water Recirculating Pump . . . . . . 480V, 3ϕ, 2 hp
- Condenser Water Pump to Absorption Chiller . . . . 480V, 3ϕ, 25 hp
- Condenser Water Pump to Condenser Heat Exchanger . 480V, 3ϕ, 7-1/2 hp
- Cooling Tower Fan (two-speed motor) . . . . 480V, 3ϕ, 20 hp

Interface will also occur at power connections to absorption chiller control cabinet.

3.5.7 INSTRUMENTATION AND CONTROL

3.5.7.1 OVERALL SUBSYSTEM CONTROLS

Instrumentation and control components for the heating/chilled and domestic hot water subsystem are illustrated in the Process and Instrumentation Drawing 5-1 in Volume III. The control requirements for the heating/cooling and domestic hot water subsystem includes not only providing the five selected buildings with more efficient automatic total energy system, but also data collection for stored energy availability and load demand forecasts.

The operator interface allows for operational flexibility along with set point and control parameter override. The controlling sequences for each system are discussed herein.

The subsystem changeover controls from heating to cooling cycles are handled through the microprocessor or manually from the control room. An exterior temperature sensor measures the prevailing weather conditions and relays them to the microprocessor. Once activated, the subsystem changeover controls divert the flow in the supply and return lines of the secondary thermal distribution component by reverse operations of the two modulating temperature control valves ahead of each subsystem's primary loop. Two additional valves located at the outlet and inlet lines of the heating water component and chilled water component interfaces to the hot/chilled water storage tank operate transversely to divert the flow of the tank. Another two-way valve isolates the domestic hot water component of the primary hot water loop during the cooling season.

HEATING WATER SUBSYSTEM CONTROLS

A control system associated with the surface condenser maintains a constant 140°F at the outlet of the condenser by varying the inlet temperature in a manner that is inversely proportional to the amount of energy being added in the condenser. The variation in inlet temperature is accomplished by mixing 140°F water from the condenser outlet with 100°F water being returned from the buildings or from the thermal storage tanks. In this manner, a constant 140°F supply temperature to thermal storage and a constant 100°F return temperature from thermal storage are accommodated while keeping the flow rate through the condenser high enough for good heat transfer.

In a similar manner, the temperature of water being supplied to the five selected buildings (and STES) is varied to maintain a constant 100°F return temperature at a constant circulation rate. The variation in supply temperature is achieved by blending 100°F return water with 140°F water from the condenser or thermal storage tanks.

During periods when the thermal storage tanks are fully charged and turbine operation is to continue (electrical generation mode) condenser cooling water is diverted to the condenser heat exchanger. In this operating mode, condenser outlet temperature is not controlled but permitted to fall, which reduces condenser pressure and increases turbine output power.

DOMESTIC HOT WATER SUBSYSTEM CONTROLS

The domestic hot water subsystem pumps 140°F heated water from the primary hot water loop through the domestic hot water heat exchanger by the continuously running domestic hot water pump. A modulating temperature control valve located between the domestic hot water pump and the domestic heat exchanger is controlled by a thermocouple at the domestic hot water outlet of the heat exchanger. As demand drops, the amount of flow through the temperature control valve also drops proportionately, thus maintaing the domestic hot water at a constant temperature. As demand surpasses heat available from the primary loop, two temperature diverting valves allow hot water to be taken from the charged chilled/heating water storage tank.

CHILLED WATER SUBSYSTEM CONTROLS

Control of the chilled water subsystem is similar to that of the heating water subsystem. Chilled water flow is maintained through the primary chilled water loop by the continuously operating primary chilled water pump. Constant flow rate is maintained through the absorption chiller by means of a by-pass loop with a modulating flow control valve. Chiller outlet temperature is held constant at 42°F by throttling the steam supply to the chiller. (For details of the chiller controls, see Section 3.5.7.3.)

The secondary chilled water loop, like the heating system, maintains a constant flow rate and constant return temperature (58°F) with variable supply temperature to the buildings, which are dependent upon the thermal load. Temperature variation is achieved by mixing 42°F water from the chiller or thermal storage tank with 58°F return water. Chilled water in excess of that which is needed to satisfy the thermal load is stored in the chilled water tank for use when the thermal load exceeds the capacity of the chiller.

3.5.7.2 SUBSYSTEM BLOCK DIAGRAM

The Heating/Cooling and Domestic Hot Water Block Diagram Drawing 5-9 in Volume III) schematically illustrates the interface between field and locally mounted instruments and control components with the STES control and energy management system. Types of instruments, method of control, number of components, and appropriate subsystems are shown.

3.5.7.3 INDIVIDUAL COMPONENT CONTROLS

ABSORPTION CHILLER CONTROLS

In addition to packaged controls, the chiller will be controlled in at least two modes of operation from the main computer. The first mode will be ON/OFF; when ON, the chiller will be operated at full load to make the most efficient use of available steam. The output temperature control will remain at a fixed set point (approximately 42°F), and the return water temperature will be held steady at the maximum chiller load value. The second mode of control is used to modulate the chiller load, based on a varying return water temperature. The second mode, modulating control, occurs when the outdoor chilled water tank is fully charged with chilled water and there is no other place to put chilled water other than through the buildings. This type of control is available, but will not be normally used.

In any event, the chilled water flow through the chiller will remain constant at approximately 370 gallons per minute. A modulating valve controlled by a flow controller, which will sense flow through the chiller, will regulate the amount of water in a "run-around" bypass, so that the bypass water and return water will add up to a constant flow of 370 gpm in either mode of operation.

COOLING TOWER

The cooling tower and associated condenser water lines incorporate four modes of operation or a combination thereof to maintain 85°F condenser water leaving the cooling tower.

A thermocouple located between the mixed condenser water junction and the modulating three-way temperature control bypass valve sets the mode of operation. Peak heat dissipation occurs with the two-speed cooling tower fan operating on high speed. A second speed can be used on other than full load day heat dissipation. If deemed desirable, the cooling tower fan can be totally stopped, relying upon gravity feed. Finally, any portion of the condenser water flow can be diverted for the least heat dissipation, or with any other mode, to maintain the maximum 85°F output condenser water set point.

3.5.8 MAINTENANCE

Installation and maintenance manuals will be obtained from the manufacturers of each piece of major equipment and will be provided to the STES operating personnel as part of a permanent library of necessary information. In addition, specifications for each piece of this equipment will be written to require each manufacturer to provide the services of technical personnel to instruct the designated station personnel in the operation and maintenance of equipment supplied by that manufacturer. To the greatest extent possible, station personnel will perform preventive maintenance on equipment to insure that equipment will operate properly and efficiently and will be out of service for the shortest length of time.

As a part of a preventive maintenance prgram, shift supervisors will be trained to make a brief inspection of equipment when they come on duty and to examine the log of the previous shift for any item that indicates a developing need for specific maintenance.

It is estimated that the average daily manpower required for maintenance of the heating/cooling and domestic hot water subsystem will be one-half man-hour. Annually, the manpower for the entire year, excluding daily requirements, will be 80 man-hours. The annual cost of maintenance supplies for this subsystem will vary depending on the hours of use of the system and will probably vary between $500 to $1000.

3.5.8.1 ABSORPTION CHILLER

The manufacturers' maintenance manual will be used as a text for teaching maintenance of the absorption chiller. In addition, once a month the machine will be checked for purge pump and motor pulley alignment, V belt checked for tension and adjusted, the purge pump oil changed, unit strainer cleaned, inspect the main control valve for binding and proper operation. Annually the purge pump motor would be lubricated, absorber additive added, control settings checked for adjustment, inspect absorber tubes and condenser tubes. Consideration would be given to contracting for annual service inspection and maintenance with the manufacturers' service department in order to keep the machine up to date and in good working order over many years.

3.5.8.2 THERMOCLINE TANKS

The two outdoor water storage tanks for heating water and chilled/heating water will be used as thermocline tanks with a blanket of nitrogen gas at the top of the water of each one. Normally these tanks require very little maintenance; however, they would be inspected externally at least once a month for any signs of deterioration of the insulation or breakdown in the insulating jacket.

3.5.8.3 HEAT EXCHANGER

The two heat exchangers would be inspected externally monthly to determine the condition of their insulation, supports and weatherproofing jacket. At that time, a review of the performance record of each unit would be made to determine if there has been any change in the thermal performance of each exchanger. A deterioration of performance indicates possible scaling of tubes, blocking or other trouble. The exchangers would be cleaned, descaled, if necessary, and any internal problems corrected.

3.5.8.4 COOLING TOWER

The cooling tower would be inspected once a week during any period in which it is operating. The motor and drive would be inspected to determine that it is in proper operating conditon; the upper basin inspected for algae formation; the lower basin inspected in the same manner for algae and scale; general condition observed throughout.

The motor and fan drive would be lubricated in accordance with the manufacturers' recommendations. The cooling tower sound would be observed - a sudden change in sound or unsual vibration indicates some other change that would be investigated. Annually the tower would be inspected internally for condition of fill, structure, tightness of bolts, condition of basins and general overall soundness.

3.5.8.5 PUMPS

Pumps and their motors would be "listened to" daily for any change in their usual sound which can indicate developing trouble. Annually, pump performance would be checked and if deterioration in performance is found, the pump would be disassembled and checked for internal conditions of wear, corrosion or other causes, and indicated repairs made.

3.5.8.6 PIPING, VALVES AND FITTINGS

Piping valves and fittings would be inspected visually daily for leaks. Once a month an inspection would be made noting the condition of supports, insulation, valve mechanism and packing, and general condition.

3.5.8.7 INSTRUMENTATION AND CONTROL

The manufacturers' maintenance information will be used to develop a maintenance program for the various instruments and controls in the heating/cooling and domestic hot water subsystems.

3.5.8.8 HEAT TRANSFER FLUID CHEMICAL TREATMENT

The chemical treatment equipment for the heating/cooling and domestic hot water subsystem consists of simple injection equipment for introducing inhibitors into the circulating water and cooling tower treatment. The injection equipment is to be kept clean when not in use. The cooling tower equipment will be inspected weekly for its condition with attention to any developing corrosion, calibration of sensing elements and tightness of piping and electrical wiring.

3.5.9 SPECIAL FEATURES AND PRECAUTIONS

3.5.9.1 HEALTH AND SAFETY

No health hazards will exist in the STES Facility.

Safety hazards are limited to burns personnel may receive from contact with steam or hot water piping or the leakage of steam or hot water therefrom. The possibility of injury is limited through the use of thermal insulation on hot pipe surfaces. As piping systems will be leak tested after installation and all leaks must be repaired and retested, no leaks in piping systems are expected to occur.

3.5.9.2 ENVIRONMENT

Thermal energy and a limited quantity of moisture are rejected to the atmosphere from the cooling tower. This results in a humid condition in the immediate area of the cooling tower, but is deemed to produce no adverse environmental effect.

3.6 OVERALL INSTRUMENTATION AND CONTROL

3.6.1 SUMMARY DESCRIPTION

The Instrumentation and Control Subsystem (ICS) is comprised of a central processing unit (CPU), real time operating software system, associated computer input/output (I/O) devices, an operator control console, and a control panel(s) located in the STES control room, and certain local control panel(s) such as on the oil fired heater and absorption chiller.

Distributed process units (DPU) are located in the major subsystems they monitor and control. The DPU (microprocessors) are linked to conventional instrumentation in the subsystems via signal conditioned I/O terminals and data lines. The DPU's are also linked to the CPU via independent data transmission lines, and therefore are located between subsystem instrumentation and control actuators, and the master computer (CPU).

The operator control console and panel, and the computer I/O terminals, provide I/O control and monitor capability to the STE-LSE operator.

3.6.2 DESIGN REQUIREMENTS

For the ICS to operate properly the following are required:

- The design will provide means of data acquisition of system measurements and performance evaluation
- The design will make use of conventional computer hardware and software
- The design will make use of standard conventional control devices
- The design will provide alarms for system malfunction
- The design will provide automatic protection for faulted or alarmed conditions
- The design will provide operator override of automatic control
- The design will provide local manual control
- Electrical power available and backup power for emergency conditions

- Instrumentation must have signal conditions
- Instrumentation should be calibrated
- Distributed Process Units located external to STES should be enclosed in cabinets for protection against environment.
- STES Control Room must have separate air conditioning

3.6.3 FUNCTIONS

The ICS system provides remote automatic and local manual control interface for all subsystems, plant system operational mode selection and energy management of the STE-LSE plant.

The ICS will provide for storage of data and instrumentation for measurement of system parameters and perform calculations for evaluation of plant performance and experimental data.

The ICS hardware and software will provide flexible plant operational modes to satisfy electrical and thermal load demands, and allow for experimental and prototypical control evaluation.

The ICS will provide interactive operator communication with the plant control system.

3.6.3.1 INSTRUMENTATION

The major components of the control system are the operator control console, the central processing unit, and the distributed processing units. The subsystem instrumentation consists of conventional analog and digital signals and signal conditioning circuitry. Typical sensing elements are position encoders; temperature, pressure and flow transducers; binary status switches; and voltage, power and frequency indicators. The command conditioned signals are conventional analog and digital signals of appropriate format and scale to drive the various current, pneumatic and hydraulic actuators.

3.6.3.2 CONTROL

The ICS is basically a computer based, software driven, control system with the capability to provide on/off control and setpoint commands to conventional hardware-orientated (analog) systems.

The ICS analog control subsystem consists of conventional control components where straightforward feedback control is applicable, and where fail-safing the system in case of computer failure or power failure is necessary.

The ICS digital control subsystem provides flexibility and versatility to the overall plant control by system configuration control. The ICS may be reconfigured by changing software or changing coefficients via operator I/O terminals (CRT) thereby eliminating calibration of analog modules at remote locations.

3.6.3.3 DATA ACQUISITION

The ICS generates a data base via measured data received via DPU and meteorological, energy and weather forecasting data via operator or existing system data storage devices. The data base is used for performance and experimental evaluation of the plant as well as for overall system control and energy management.

The measured data is received from the instrumentation transmitters at the I/O terminals of the DPU's and is further conditioned (i.e., reference junction for thermocouples) if necessary.

The input data is converted into digital format via multiplexed analog-to-digital convertors. The data is temporarily stored in the DPU and is averaged or linearlized over a given time period until CPU requests data input. The CPU operating system then performs the desired engineering scaling, statistical analysis and other engineering calculations prior to output or storage of the data.

The data output is stored automatically on disk and then transferred to magnetic tape on a daily operating basis. Hard copy or CRT display of key parameters is provided automatically or under operator control.

3.6.4 OVERALL INSTRUMENTATION AND CONTROL DESCRIPTION

The instrumentation and control subsystem is composed of computers and control equipment. With this equipment the control and operational programs are implemented.

The operator has ultimate control of the equipment. He has override power over most automatic functions and can assign modes of operation or system startup or shutdown, and is a backup in the event of failure of a lower level component. He communicates with the central computer via CRT terminals, the control panel and the various other readout devices. His commands are generated via the terminal keyboard and by controls on the control panel.

The second level of the control equipment is the central computer. The central computer receives orders from the operator and receives data from the distributive processing units. It processes the data, stores data, generates, displays, communicates with the operator and downloads information to the DPU's. The central computer is described more fully in Section 3.6.4.3.

The third level is the distributed processing units (DPU). The DPU's, along with their associated input/output devices, receive data from the plant equipment, send commands to the plant equipment, and communicate with the central computer. The DPU's are located in the field near the equipment that they control and are described in Section 3.6.4.3.

The lowest level in the control equipment are the instrument transducers that convert plant parameters to electrical signals that can be interpreted by the DPU I/O equipment and the control actuators that turn on or off motors, open or shut valves, etc. This level also includes analog controllers for some equipment.

The highest level of control or operational program is created in the operator by training. The operator makes decisions on overall operations using information that may not be available to the computer such as the appearance of a large storm cloud that could cause a loss of insolation, a report that a pump is making unusual noises, and the fact that a special test is being planned. The operator has the ability to select operating modes and to change control set-points.

The second level of operational program, the energy management program, is implemented in the central computer. This program selects a mode of operation for the plant based upon information on the inventory of energy in the storage tanks and the anticipated energy demand and solar availability that are derived from weather forecasts.

The next level is a supervisory program that is also located in the central computer. This program implements the mode of operation determined by the energy management program or by the operator and transmits instructions, revised setpoints, and rates of changes to the DPUs. The supervisory program monitors the overall system status, performs safety functions and communicates with the operator.

The fourth level of operational program is located in the distributed process units. These DPU's incorporate the control algorithms that control equipment operation and send out signals to operate the plant valves, motors, etc. The DPU programs also collect data for transmission for the supervisory program and perform limit checking for safety purposes.

3.6.4.1 PLANT SUBSYSTEM CONTROL CONCEPT SELECTION

The description of the ICS given herein gives an evaluation of alternate control designs that were considered and presents the selected control system configuration.

3.6.4.1.1 SELECTED CONTROL DESIGN

The instrumentation and control subsystem consists of analog and digital control elements combined and interfaced through the CPU to form the overall plant control system.

The choice of digital or analog control of a subsystem or a subsystem component is based on the following:

- Analog controllers are used when they are a convenient and conventional part of a vendor's hardware package, and do not require significant modification to provide interface to the overall control system. These analog elements are typically turned on/off and provided a set point via the central process unit (CPU).

- Digital control of components and subsystem is used where flexibility and versatility are required in the control loop. These are the components that are critical to configuring operational modes, energy management strategy and changes to control algorithms required for system stability.

The following is a list of major component controls.

Analog Control Elements

- Turbine - Generator
- Boiler Feedwater Valve
- Cooling Tower
- Absorption Chiller
- Auxiliary Heater
- Condensate Return Unit
- Condenser
- Deaerator
- All oil and water transport pumps
- Minimum configuration control valves

Digital Control

- Solar field collectors and associated flow valves
- Steam Generator
- Power conversion subsystem and flow control valves

- Domestic hot water subsystem flow control valves
- Hot/chilled water heating subsystem valves
- Thermal storage subsystem valves

3.6.4.1.2 BLOCK DIAGRAM OF SELECTED DESIGN

The I&C System Block Diagram (Drawing No. 102E145 in Volume III) is a schematic of the system hardware: Sheet 1 shows the control room equipment, "the uninterruptable power supply," and the parallel-series data bus communications link to the microprocessors at local stations in the field. Sheet 2 contains block diagrams for the solar collector and thermal storage subsystems, and Sheet 3 contains the power conversion and heating and cooling subsystems. Each subsystem diagram indicates the microprocessor, types and quantities of instruments, the signal level required to control each instrument, and the typical I/O signal conditioning devices required for each type of instrument.

For reasons of clarity, the block diagram does not show hard-wired redundant instruments and controllers that are required in the event of computer malfunction. The extent of this redundancy is described in the following sections.

3.6.4.1.3 DESIGN TRADE-OFFS

The block diagram represents the selec d design configuration. The following paragraphs explain the alternatives that were considered and the rationale for the selected design:

ANALOG VERSUS DIGITAL

The ICS represents the best combination of analog and digital control techniques. Several analog control circuits with digital set-point control have been built into the basic digital control system. At these points the additional interfaces required to use digital control were more complex and costly than the conventional analog controls supplied as a part of a vendor package. The digital system selected therefore allows more flexibility than an analog system to be programmed, and is easier to change by reprogramming.

The digital system also allows extensive automatic operational interlock sequencing to be built in and then easily modified as experience is gained with the system.

A total analog control system was estimated to cost 20 to 25 percent more than the selected design. This system included an automatic relay sequencer and a digital data acquisition system. Due to these cost considerations and the fact that it would require significantly more operator action including operator selection of system operating mode and set point adjustment to allow for operation under different plant operating conditions, a total analog control system was not selected.

CPU VS. DPU

The digital controls of the ICS are distributed in a star network to meet the STES efficiency needs. The CPU handles the centralized functions of operator interactive communication, central control display, data collection, and formating total system efficiency and protection, controls and interlocks. These functions require a higher level of computer intelligence with the ability to switch complex tasks effectively and efficiently, and to handle large quantities of data. The DPU's which are local to each subsystem allow an 80 to 90 percent cabling cost savings, since hard-wiring each instrument to the central control room is eliminated. The distributed intelligence of the parallel DPU's allows efficient initial process of data and fast real time control. The DPU's free the CPU to project supply and demand, and coordinate and select system-wide operation. The DPU capability to operate independently of the CPU, with direct operator input, provides a potential means of control redundancy.

LOCAL VS. REMOTE

The entire system is a combination of local DPU's at each subsystem and the remote CPU in the control room. All indications can be remotely displayed for the operator in the control room through the CPU via CRT's or the partially redundant, hard-wired control board. Some remote indications are duplicated by a local device at each sensing point. The DPU uses the measurements locally for control and sends them to the CPU for remote display and storage.

The DPU's local control is setup and adjusted by the CPU which has ultimate control through the operator's console. The operator may manually control the CPU's selection of the STES mode or even set individual valve and motor states, and control set points. Otherwise the program in the CPU will automatically tell the DPU's how to run the STES.

Without the CPU each DPU is in full control of its subsystem without automatic remote coordination. The system also provides an option of operating the local DPU's by means of a portable keyboard and CRT unit.

PARTIAL VS. FULL

Considerations of system redundancy ultimately reduce to those of cost performance and safety. Two failure modes requiring redundant equipment were investigated, loss of grid power without the STES turbine generator operating, and internal failure of computer components.

The loss of grid power can be momentary (less than a second) or for longer periods of time. Momentary interrupts causing loss of temporary core memory can be satisfied by a small motor generator set with an inertial fly wheel driven by grid power or an Uninterruptable Power Supply (UPS); continuous operation is thus maintained. If power is lost for longer periods of time, an Uninterruptable Power Supply (UPS) for the data acquisition system (not pump or valves) consisting of a battery inverter combination would permit following the system coastdown to assess a restart. A 10 kWhr system capability is estimated for one-half hour operation to provide this function. This option of one-half hour operation with loss of grid is approximately five times more costly than supplying power for momentary interrupts only. Due to cost considerations, it is recommended therefore that momentary loss of grid power be satisfied with an MG set or UPS and that loss of grid power for longer periods of time without the turbine generator operating will result in unassessed system shutdowns.

In the event that the control system has a component failure (failed board, shorted communications line, etc.), a "fail-safe" operating mode is defined to be operation of the steam generator at the low pressure (60 psia) mode with energy being supplied by the auxiliary heater (collection field is stowed). This is expected to meet typical minimum requirements of a prototypical LSE application. Three levels of backup analog redundancy were considered in order to determine this fail-safe operating mode; full redundancy for all modes of operation, partial redundancy with remote control at the control room, and partial redundancy with control at local control panels to minimize wiring costs. Full redundancy (not DAS) would increase the cost of the basic system by 60 to 70 percent. Partial remote redundancy has a relative increase of 20 to 30 percent, and the partial local redundancy amounts to a 5 to 10 percent increase in cost. This last option was selected due to cost consideration and it defines the operational capability of the plant when computer failure occurs. Under conditions of a failed CPU, the SCS is placed in a safe configuration and the auxiliary oil heater is operated. A backup operator is assigned to the thermal storage area to operate the Thermal Storage Subsystem as well as the auxiliary oil heater at the local control panel. Another operator is assigned to the Power Conversion Subsystem control panel. Various control signals an status conditions are hard-wired back to the control room for the control r m operator's use to insure safe plant operation as well as directing local con ro operations. These critical indications are provided to the control room since operating conditions of the other subsystems are not available local control panel operators. Communication links are provided from e h system to the central control room.

COLLECTOR FIELD CONTROL CONCEPT SELECTION

The distributive field configuration concept reference in Section 3.2.4.1 was selected on the basis that stable flow control and thermal conditioning are more easily achieved, and it also provides protection against over-temperature due to cloud cover changes.

The control concept is based on conditioning the subfield inlet temperature to achieve acceptable outlet temperatures via adjustment of field flow based on maximum solar insolation conditions.

Figure 3.2-2 shows the collector field layout and instrumentation, and as shown the total field scheme is separated into a series and parallel flow arrangement. First, a feed forward path is provided for thermal conditioning of each field inlet temperature. Second, a high temperature storage path is provided from each field for storage when each field yields the demanded field exit temperature conditions. Finally, a low or intermediate temperature or recirculation path is provided for conditions of low insolation, but containing enough energy for either storage or for conditioning field inlet temperature to maximize final field exit temperatures. Figure 3.6-1 shows the control function schematic.

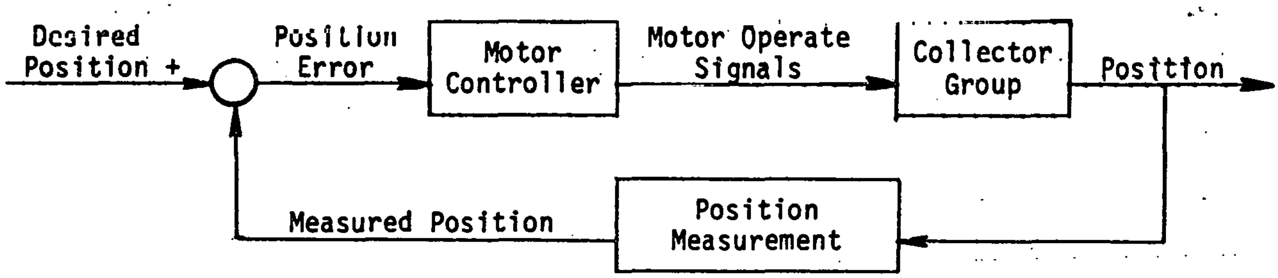


Figure 3.6-1. Collector Positioning Controller

Temperature control of the field segments (subfields 1, 2 and 3) consist of setting the field flow rates to correspond to maximum temperature differences (T_{max}) allowable under "perfect" insolation conditions. This prevents a sudden change in cloud cover to cause an over-temperature in any field string. The field inlet throttle valve is set to allow a flow split between fields 1, 2 and 3. Part of the flow goes to field one and the remaining flow difference is diverted to the feed forward path (FFP) which splits fields 2 and 3 depending upon inlet temperature and flow requirements needed, and the solar insolation conditions of each field. The feed forward flow mixes with an amount of the previous field exit flow to achieve the desired inlet temperature. Depending upon the amount of mix necessary to achieve this temperature, a portion of the previous exit field flow may be dumped to either the high temperature storage (HTS) path, the low-intermediate storage path, or the recirculation (LIR) path as conditions dictate. Therefore, field inlet and exit temperatures are controlled via only five flow control valves which feed forward, dump and/or mix flow for thermal conditioning. All components are controlled via DPU's located in the field, as shown in Section 3.2.4.1.

This concept was chosen over a two-parallel segment field with parallel flow modulation strings. Table 3.6-1 shows a comparison of performance features for the collector field configuration.

3.6.4.1.4 DESCRIPTION OF MAJOR CONTROL LOOPS

The major control loops in the plant are introduced in this section. The task inputs, and outputs for each loop are identified. Safety limits and protective actions are identified. A control block diagram is presented for these control loops. Development of specific control algorithms will be based on use of the system simulation programs described in Section 3.6.9. Detailed information on the physical implementations of the various control loops is presented as a part of the appropriate subsystem description.

COLLECTOR POSITIONING

Task: The task of the collector positioning control system is three-fold. First, the collector is directed to track the sun. Second, the collector is directed to a desteer position, and finally the collector is directed to stow. Each of these is accomplished in a similar manner by comparing a directed position against a measured position and then operating the motor drive system as required. Collector positioning is on a group basis where each group is controlled independently.

Inputs: The inputs to the collector positioning control system are a directed position and a measured position. The directed position is obtained from another control program. The measured position is derived from an absolute position encoder on each collector group.

Outputs: The output of the collector position controller is a motor operate signal that is Forward, Reverse or Off, with also possibly a Fast or Slow control, depending upon the design.

Control Function: The control function is to control the collector position by operating a drive motor in response to a desired position command. The block diagram is shown schematically in Figure 3.6-1.

TABLE 3.6-1

COMPARISON OF PERFORMANCE FEATURES FOR COLLECTOR FIELD

Performance Feature	Parallel Field Segments with Parallel Flow Modulation	Distributed Field Configuration (Selected Concept)
Over-temperature due to change in insolation	High Risk - dependent on field transport time	Low Risk - eliminated by design
Over-temperature due to loss of flow	Small Risk	Small Risk
Temperature control performance	Continuous modulation of 16 valves for exit temperature optimization creates tendency for control instability	Temperature control external to field. Also, number of control valves reduced to 5. Decreased sensitivity when a string is defocused.
	Maintain desired outlet temperature for all static operating conditions	Outlet temperature differs for some static operating conditions.
Flow control strategy	Highly dependent on temperature feedback from set thermocouple for optimum energy collection	Flow control is more adaptive via using field temperature difference as well as field exit temperature for obtaining optimum energy collection. Each field inlet temperature and flow can be independently regulated.
Pumping Power	Fixed by collector string length and connecting manifolds and piping	Relatively higher due to additional piping, manifolds, mixing tees and cascading pressure levels.
Instrument and Control Costs	The difference is relatively small to overall I&C cost; less than 5 percent.	

Limit Values: There are limits to the allowable travel at each that the collector must not exceed. This limit is determined by the position detector. In addition, if the collector is directed to move, but the position detector does not detect motion, the motor will be directed to stop to prevent any further physical damage or to avoid overheating the motor.

Protective Actions: The protective action is to stop the drive motor.

Control Algorithm: The anticipated control algorithm is to drive the motor for a calculated time based upon the position error if the position error is beyond a specified dead-band.

COLLECTOR FIELD FLOW AND TEMPERATURE CONTROL

Task: The controller for the field flow and temperature is a combined controller that simultaneously controls flows and diverting valves with the objective of delivering a specified outlet temperature to the storage tank.

Inputs: Temperatures are measured at the field inlet, at the inlet to each subfield, and at the field outlet. Flow is measured at each subfield inlet and at the total field inlet or outlet.

Outputs: The field outlet temperature is controlled by controlling subfield flows and by mixing subfield flows. The lowest level output is control valve positions.

Control Function: The collector field control function consists of a nest of control functions and plant responses.

The flow and temperature control algorithm for the collector field has not yet been completely formulated. However, several basic principles have been established. First, a temperature feed-forward control approach determines a set of flow demands. These demands are met by flow controllers around each of the control valves. A minimum flow to each subfield is determined to limit the outlet temperature of an acceptable value based on a maximum insolation that is determined based upon long-term weather conditions, time and date.

Flow from the feed-forward path is mixed with outlet flow from the previous subfield to condition the inlet temperature to that field. The maximum allowable subfield inlet temperature is limited by the obtainable flow through that subfield and the subfield inlet temperature should be as high as possible within that limit.

Excess flow leaving a subfield is sent to a bypass path. Depending upon its temperature, it is sent to either the cold bypass or the hot bypass path. This control function is shown schematically in Figure 3.6-2.

Limit Values: Over-temperature can occur if the flow is too low or the inlet temperature is too high. If low subfield flow or high string outlet temperature is measured, protective action is required. The maximum allowable outlet temperature will be determined in transmit response studies during definitive design.

Protective Action: The protective action for a string with high outlet temperature or a subfield with low flow is to desteer the string or subfield to limit the heat input. To do this, a signal is sent to the position controller.

Control Algorithm: The control algorithm will be developed based upon the basic control function described above and will be tested by simulation.

STEAM GENERATOR CONTROL

Task: The primary objective of the steam generator controls is to supply steam at a demanded flow rate at a desired pressure and temperature. There are several individual parameters to be controlled to accomplish this objective. These are boiler water level, boiler pressure, preheater temperature and superheater temperature. Each of these has its own controller but since they all interact, they will be considered together.

Inputs:

- For the water level control, the input is the observed water level

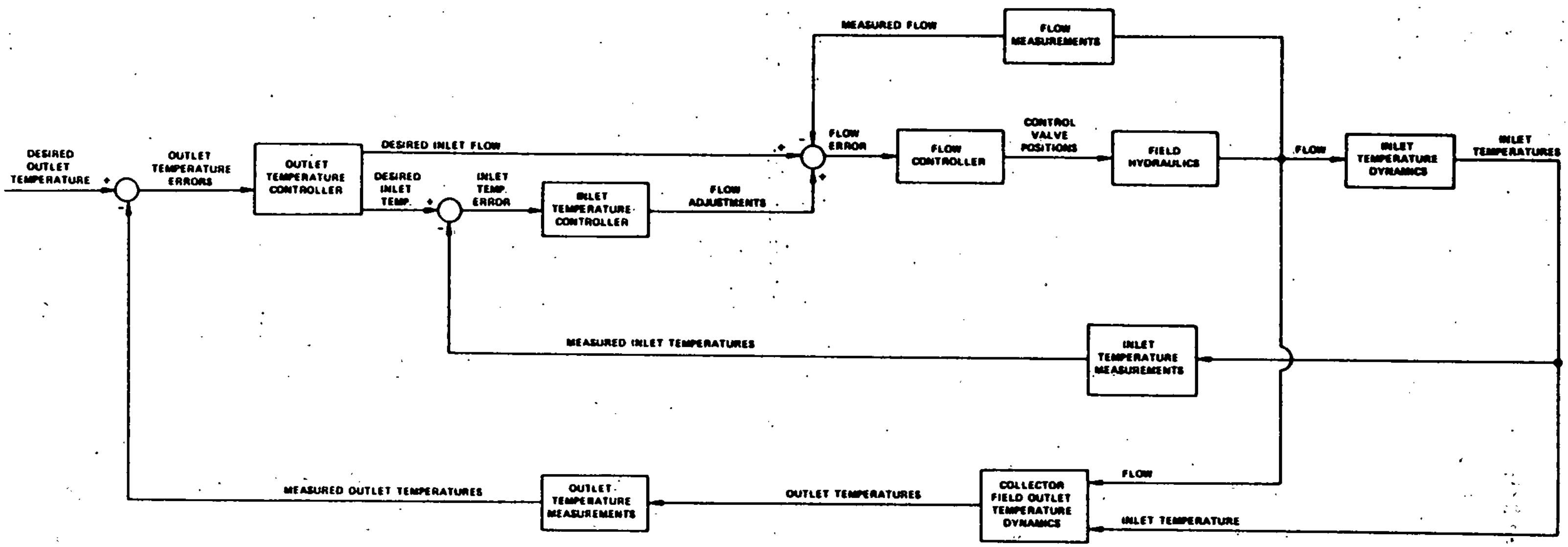


Figure 3.6-2. Collector Field Flow and Temperature Controller

- For the boiler pressure control, the inputs are observed pressure and demanded pressure
- For the preheater temperature control, the inputs are observed temperature and demanded temperature
- For the superheater temperature control, the inputs are superheater temperature and demanded temperature

Outputs:

- The output of the water level controller is the position of the feedwater flow valve
- The output of the boiler pressure controller is the position of the oil flow valve
- The output of the preheater temperature controller is the position of the preheater oil bypass control valve
- The output of the superheater temperature controller is the position of the superheater oil bypass control valve

Control Function: The control function for each of the controllers is similar, and is shown in Figure 3.6-3.

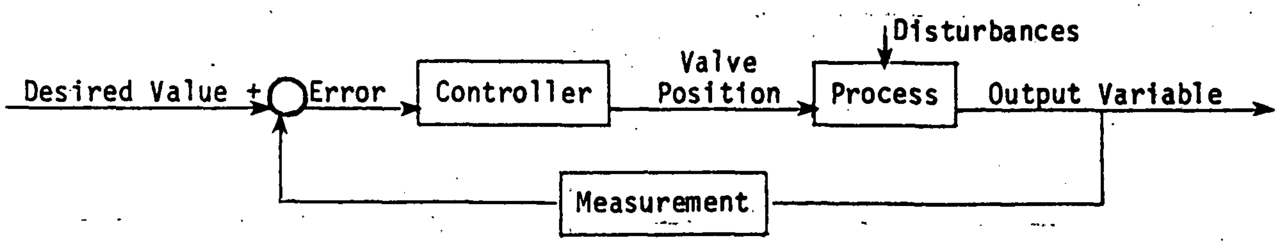


Figure 3.6-3. Steam Generator Controller

Limit Values: The primary variable that has safety significance is boiler outlet pressure which has a maximum allowable value. Low water level is undesirable since it can lead to deposition of scale on the tubes.

Protective Actions: The protective action for high boiler pressure is to stop oil flow. For low water level the protective action is to stop steam flow.

Control Algorithm : The water level will be controlled using a conventional analog controller. The other parameters will be controlled by algorithms in the control microcomputer.

DEAERATOR PRESSURE CONTROL

Task: The deaerator receives water from many sources at various temperatures. The water is heated with a steam flow that bypasses the turbine. Sufficient steam flow must be provided to heat the incoming fluid. The measure of the heating is the saturation pressure in the deaerator.

Inputs: The input to the pressure controller is the deaerator pressure.

Outputs: The output of the pressure controller is the valve position of the steam flow control valve.

Control Function: The block diagram is given in Figure 3.6-4.

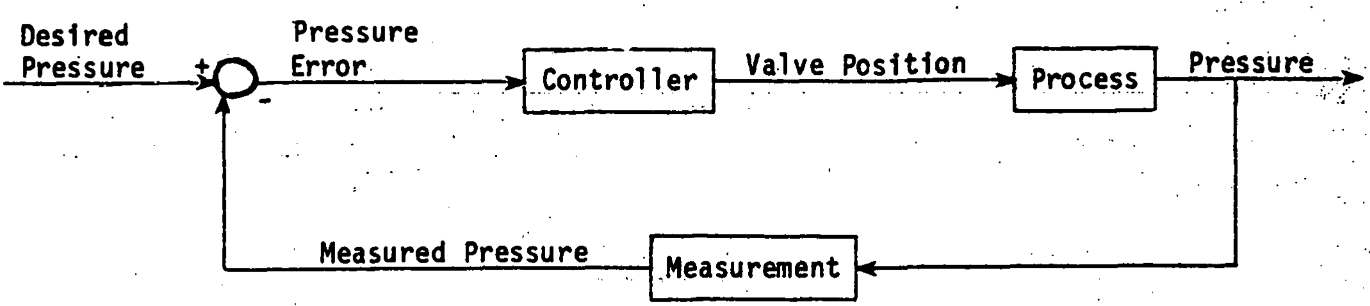


Figure 3.6-4. Deaerator Pressure Controller

Limit Values: The deaerator is protected against overpressure by relief valves. However, it is prudent to avoid the need for this overpressure protection. Therefore, the controller will alarm at a high pressure below the relief valve set point.

Protective Action : The protective action, aside from relief valves, is to stop steam flow into the deaerator. It will be desirable to shut off the feedwater pumps to prevent cavitation that could occur when the pressure decreases with the steam valve shut off.

CHILLER CONTROL

The chiller is supplied with its own control system. The only control necessary is a valve upstream of the chiller to supply steam slowly to the chiller to avoid overload on the remainder of the steam supply. Similar rate control will be used during shutdown.

Task: The chiller steam supply flow valve will control the rate of change of steam flow during startup and shutdown to avoid strong perturbations throughout the steam supply system.

Inputs: The control valve position will be based on steam flow measurement. Rate command may not be satisfactory because of the likely non-linear valve characteristic and the possibility of interaction with the chiller control valve. Since steam flow is measured for energy management, it will be used for control also.

Outputs: The output is chiller shutoff valve position.

Control Function: The chiller controller schematic is shown in Figure 3.6-5.

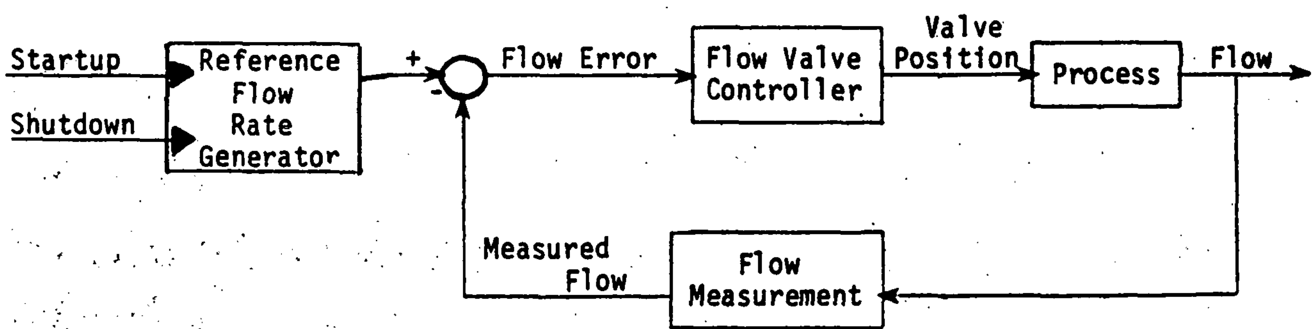


Figure 3.6-5. Chiller Controller

All scanning for limits will be performed in the prepackaging chiller unit. Only an alarm output will be provided.

Protective Action: The response to chiller alarm will be to shut the inlet control valve.

CONDENSER CONDENSATE LEVEL CONTROL

Task: The task of the condenser condensate level control is to control the water level in the condenser hot well. A secondary task is to limit the rate of change of condensate flow to the deaerator which could result in loss of adequate suction pressure to the feed pumps.

Input: The input to the level controller is condenser hot well level.

Output: The output of the level controller is a throttle valve position and a signal to operate the second pump if required.

Control Function: The block diagram of the control function is given in Figure 3.6-6.

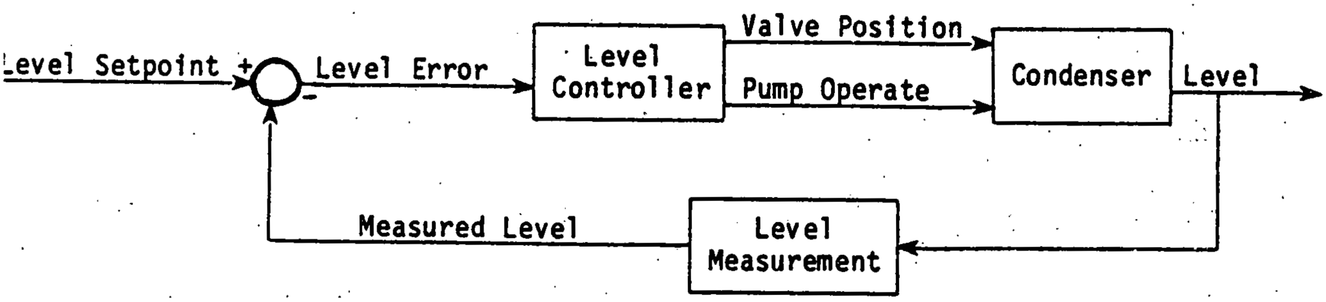


Figure 3.6-6. Condenser Condensate Controller

Limit Values: The hotwell level can go out of control high or low.

Protective Action: High water level is unacceptable because it will blanket the tubes and potentially lead to overpressurization of the condenser. The response to high level is to shut off steam flow to the condenser. Low level is acceptable to the condensate pump which are designed to work under cavitation conditions; however, an informational message will be sent to the operator.

HOT WATER HEATING SUBSYSTEM CONTROL

Task: The hot water heating subsystem encompasses the condenser cooling flow, the hot/chilled water storage tank and the connection to the heating system. The task of the controller to the hot water heating subsystem is to extract heat from the condenser at a desired temperature, deliver hot water to the heating system, store the excess heat or extract the needed heat from the hot/chilled water storage tank, and control the temperature of water returned from the heating system to the storage tank.

Inputs: There are a number of inputs to the controller for the hot water subsystem. These are for the condenser heat exchanger, inlet and outlet temperature and flow. For the hot water storage tank, a number of temperature sensors defines the energy storage. Flow and temperature sensors measure the flow and energy transfer into and out of the tank. Flow and temperature sensors measure the energy usage of the heating system. Additional measurements identify the flows and temperatures to the cooling tower and to the domestic hot water system.

Outputs: The output of the hot water system controller is a valve configuration which will give the appropriate energy transfer rates and return water temperatures.

Control Function: The HWS Controller is shown in Figure 3.6-7.

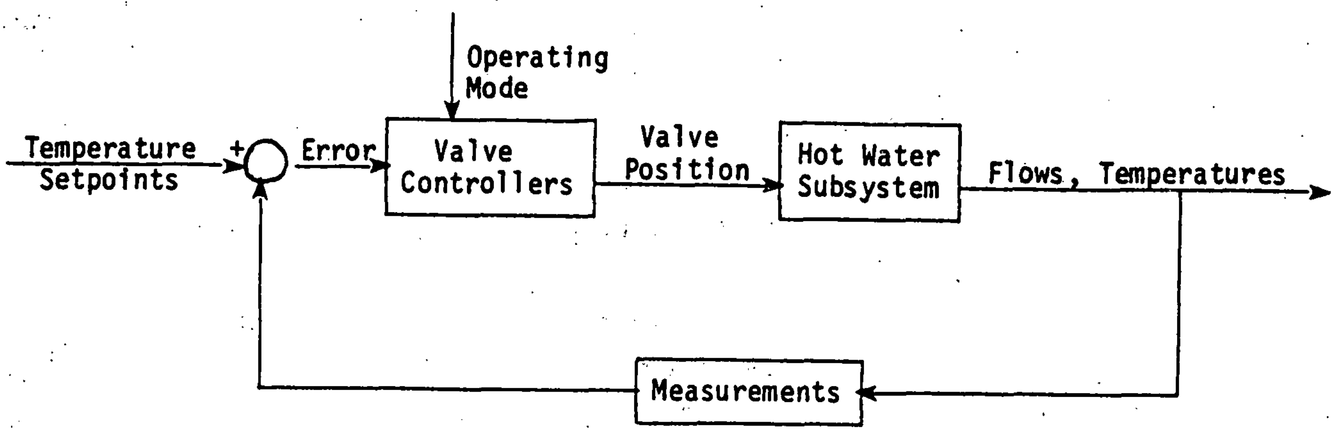


Figure 3.6-7. HWS Controller

Limit Values: Protective limits are loss of flow to condenser, to domestic hot water, or to the site heating system. A related system limit is condenser pressure. High or low temperature out of the condenser, the hot water system, or to the heating system are cause for informational alarm.

Protective Actions: The protection against high condenser outlet temperature or loss of condenser outlet temperature or loss of condenser flow is to stop steam flow to the condenser.

CHILLED WATER SUBSYSTEM CONTROL

Task: The chilled water subsystem collects chilled water from the chiller, delivers chilled water to the buildings, either stores or draws upon stored chilled water depending upon the demand, and returns water from the buildings to the chilled water storage tank at the desired temperature.

Inputs: Measurements are made of flow and temperature in various parts of the chilled water system.

Outputs: The outputs of the chilled water system controller are valve positions to control flow rates.

Control Function: The schematic of the CWS is given in Figure 3.6-8.

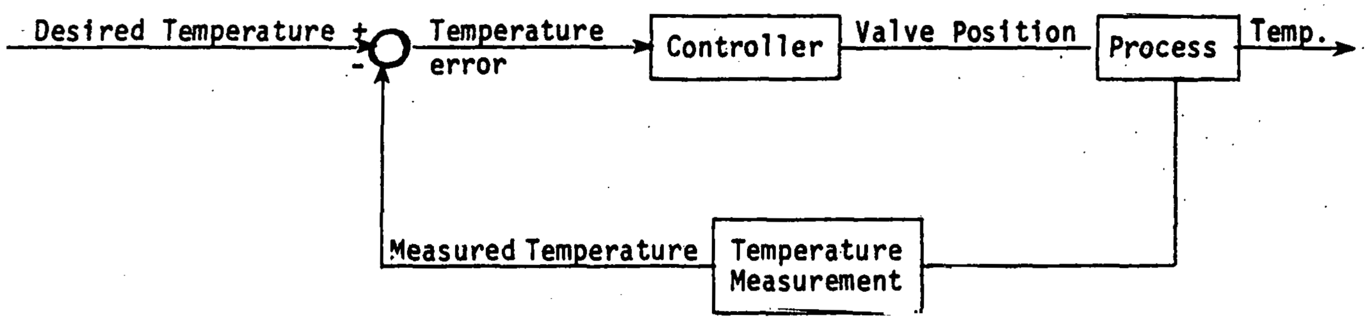


Figure 3.6-8. CWS Controller

Limit Values: There are no safety related limits associated with the chilled water system. Informational signals may be produced due to high or low temperature out of the chiller or delivered to the buildings. Also, low inventory of the stored water in the storage tank will be annunciated.

Protective Actions: No protective actions are required in the chilled water system.

FEEDWATER HEATER CONTROL

Task: The task of the feedwater heater is to heat the feedwater to a desired temperature for delivery to the preheater.

Inputs: The input to the feedwater heater controller is measured outlet temperature.

Output: The output of the feedwater heater controller is the low pressure steam supply control valve.

Control Function: The block diagram given in Figure 3.6-9 shows the control function.

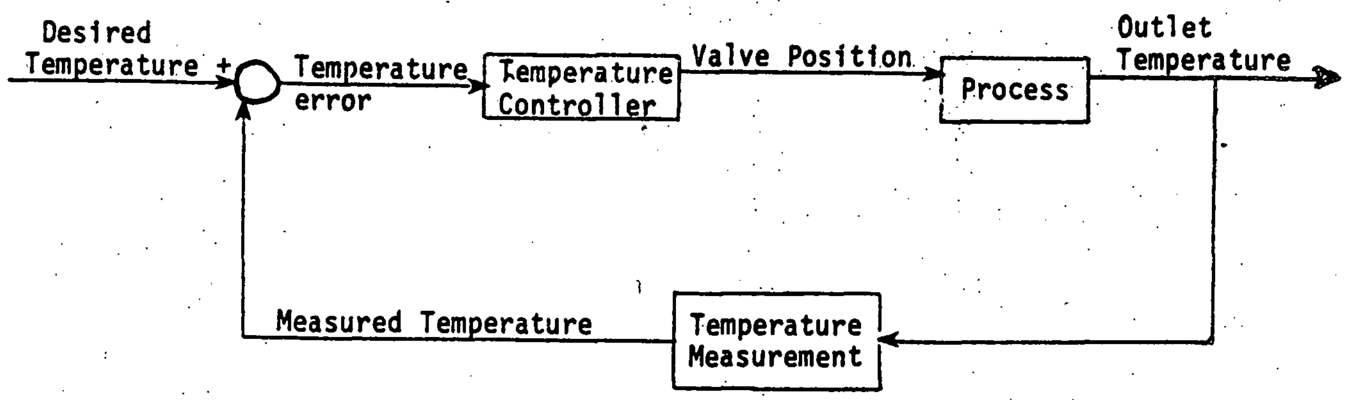


Figure 3.6-9. Feedwater Heater Controller

Limit Values: The feedwater outlet temperature cannot obtain dangerous levels; however, information alarms should be generated for high or low temperature.

Protective Action: None required.

3.6.4.2 CONTROLS ANALYSIS

The controls analysis is accomplished through a process of deriving logic diagrams, developing of transient simulation of the total plant, using this mathematical model to study various control strategies and response to perturbations, and lastly to impose on the model various system malfunctions to determine the controlled response.

Logic Diagrams

Operational Logic Diagrams are provided for the various subsystems that comprise the STES at Fort Hood. All operational decisions as well as selected control functions are incorporated into a software flowchart hierarchy. Flowcharting illustrates how each subsystem cycles through the startup/run/shutdown sequence.

It should be noted that as each subsystem cycles through the logic diagram, decisions are being made with consideration to overall plant operating conditions that are present at the time of decision. Depending on the decision, different logic paths will be followed. At the same time, data from all subsystems are being fed into the Overall Plant Control Logic. The Overall Plant Control Logic then can interrupt into the cycle of any subsystem to control path deviation so that operation response is in accordance with overall plant control and energy management. A flow schematic of overall plant operation is given in Figure 3.6-10 to illustrate how control information will be transferred between various I&C components. Subsystem logic diagrams are presented in Figures 3.6-11 through 3.6-19.

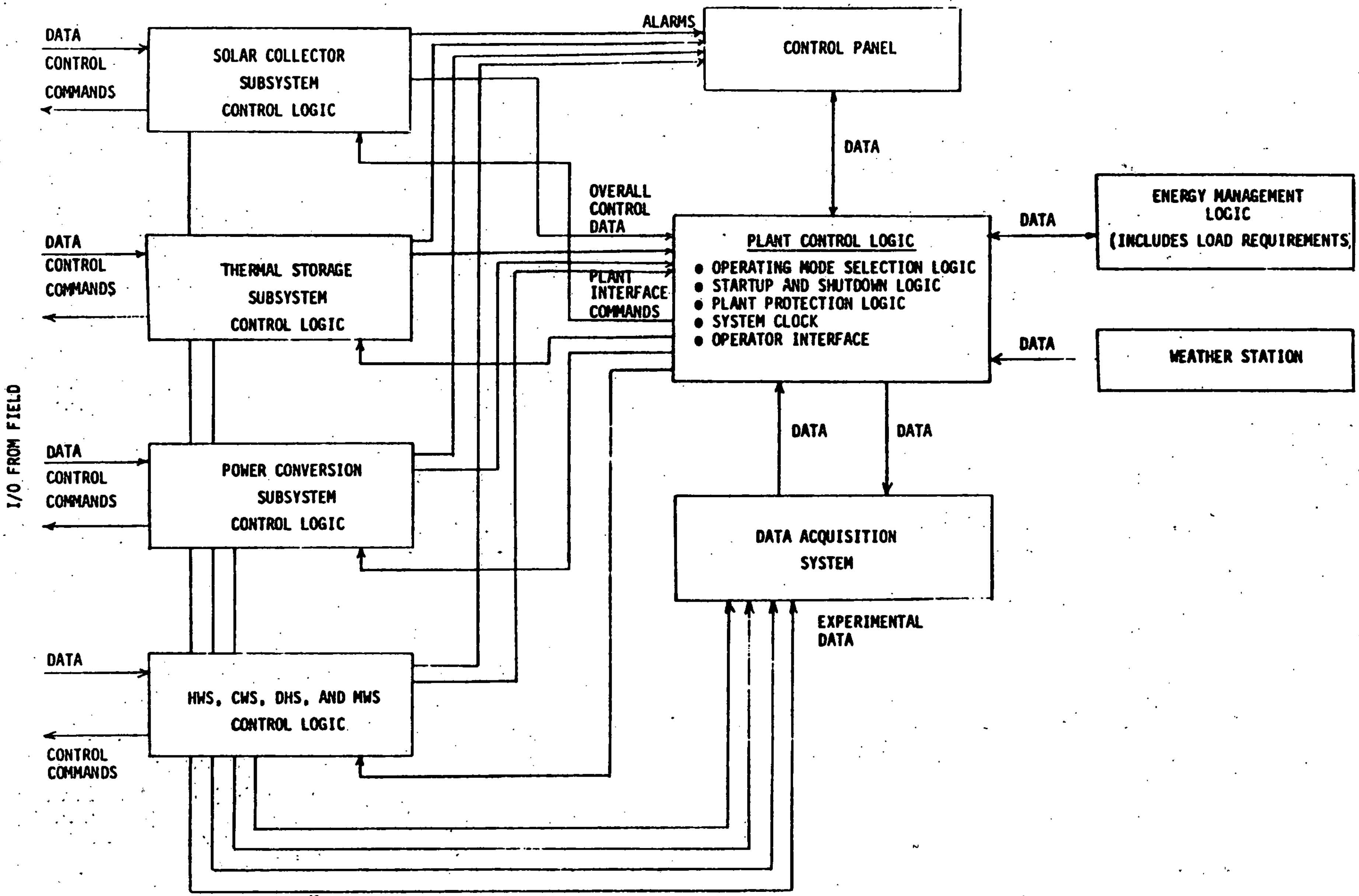


Figure 3.6-10. Overall Plant Operational Flow Schematic

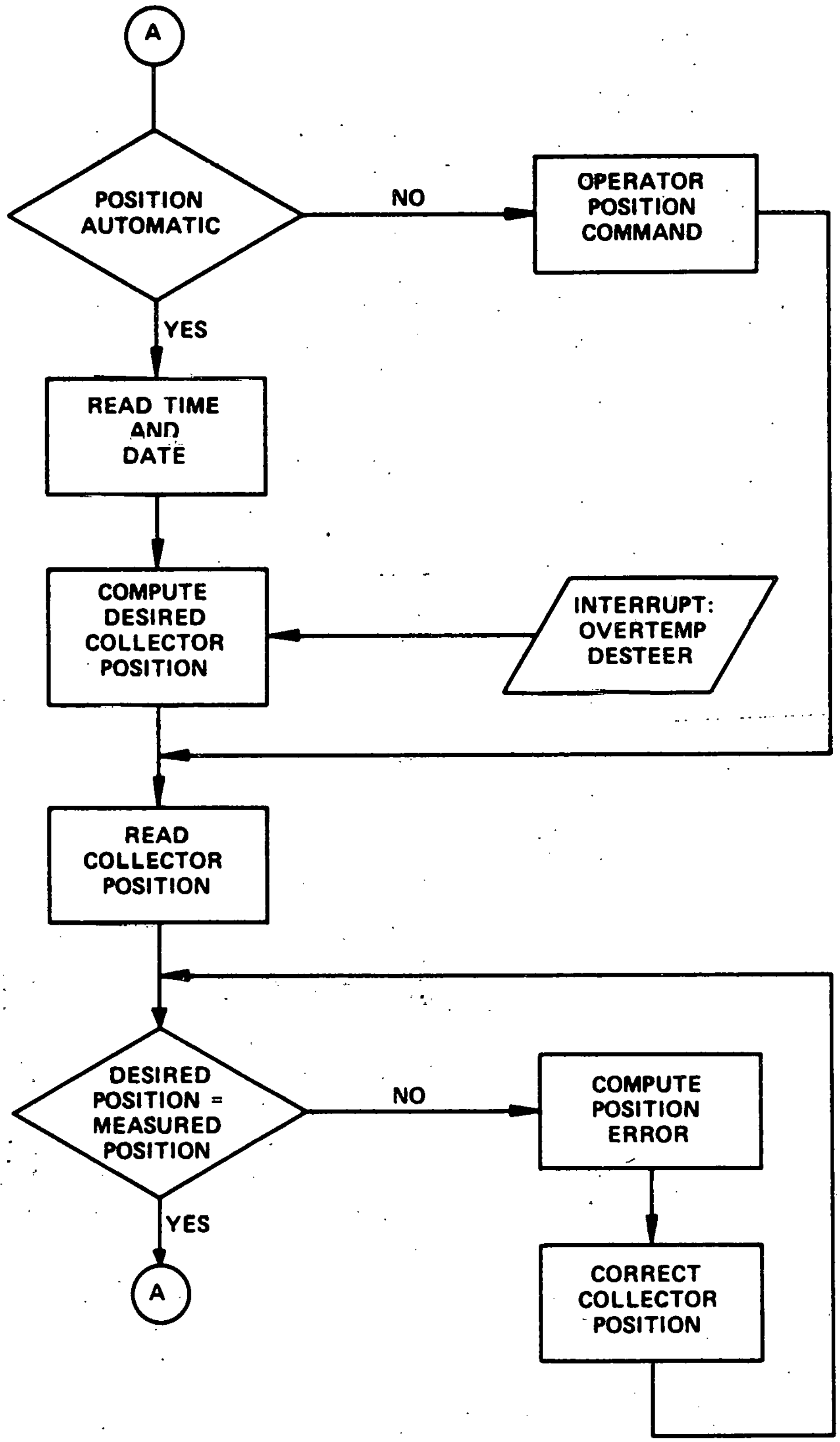


Figure 3.6-11. Collector Position Control Logic Diagram

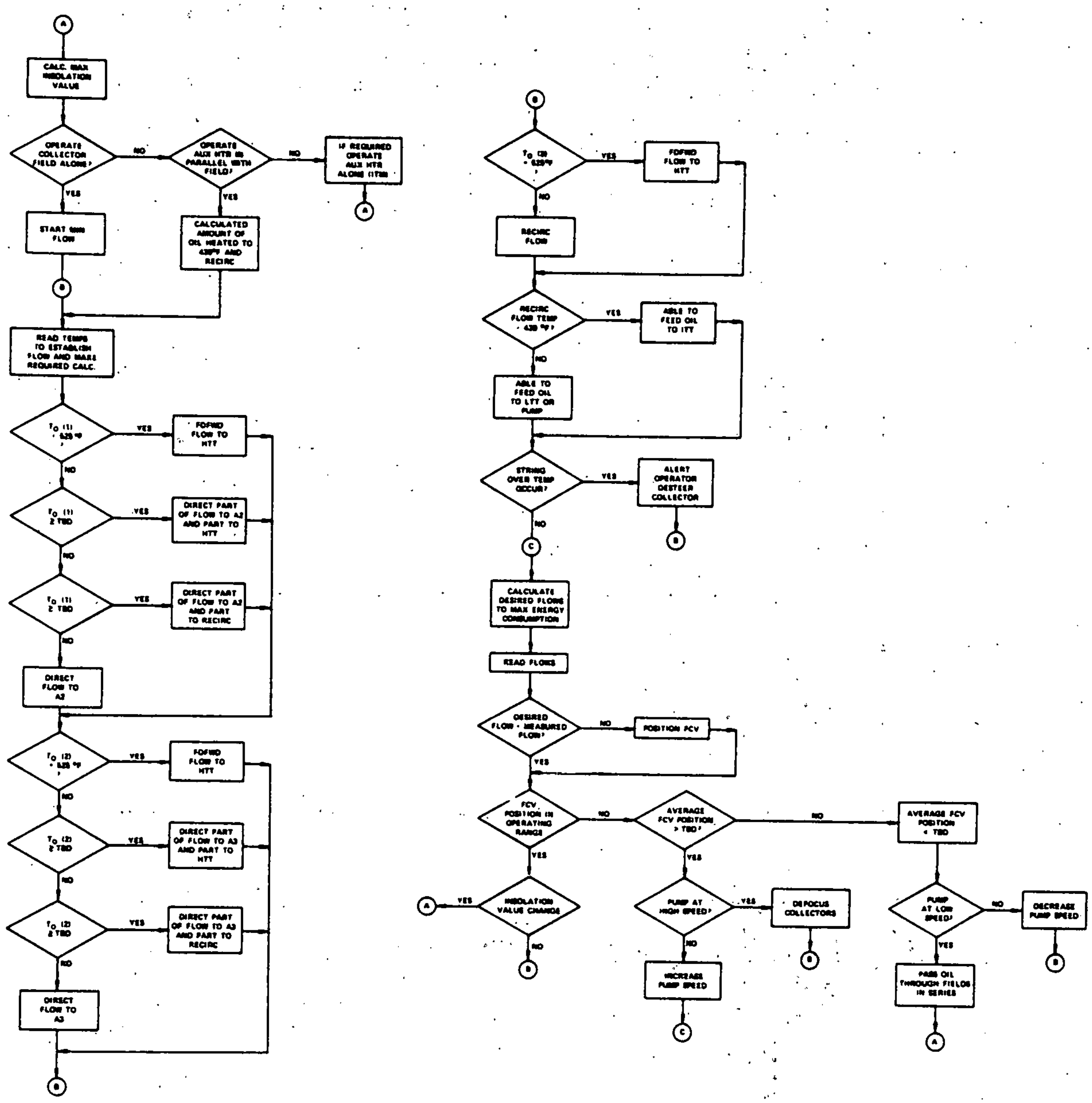


Figure 3.6-12. SCS Flow Control Logic

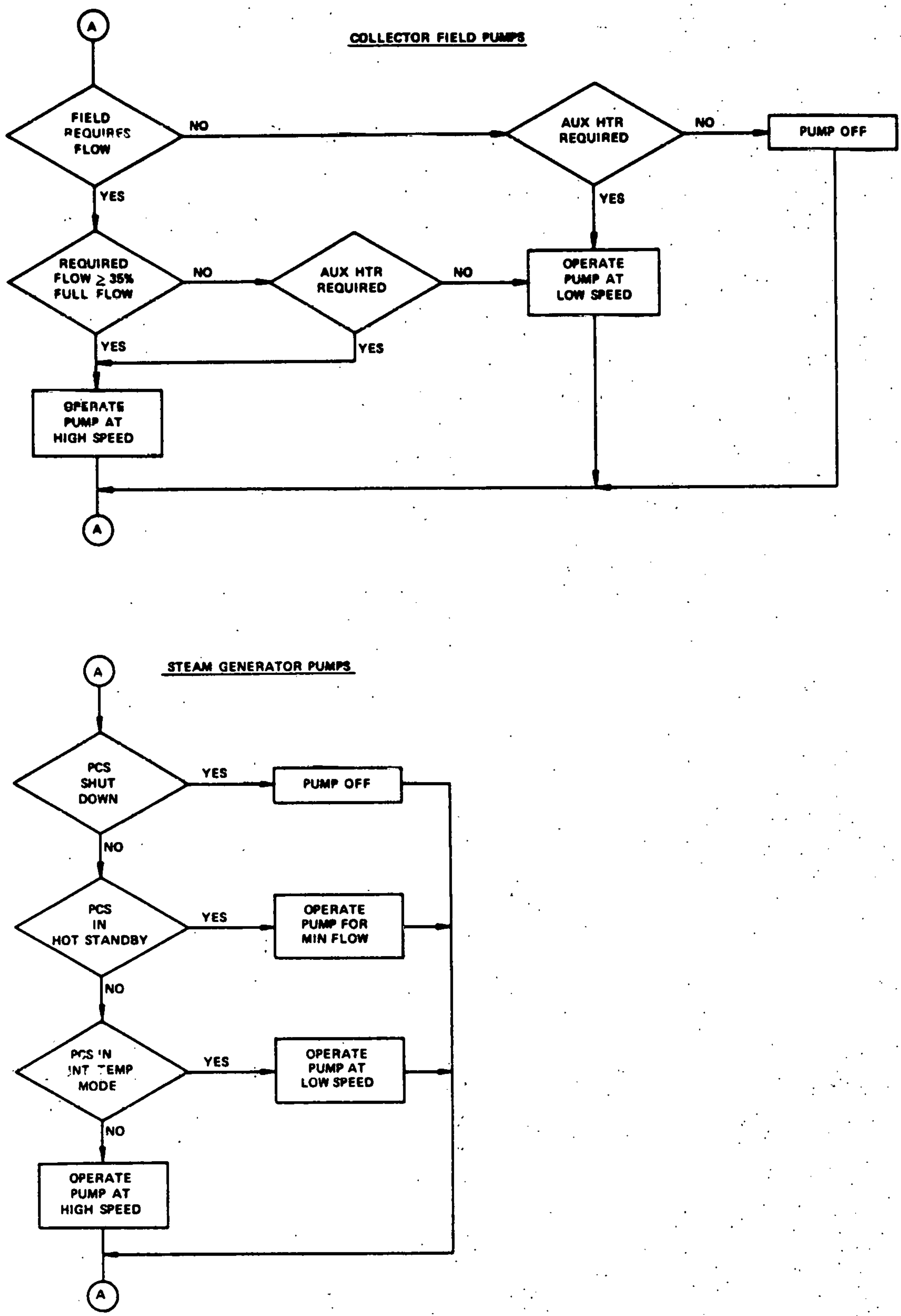


Figure 3.6-13. Pump Control Logic Diagram

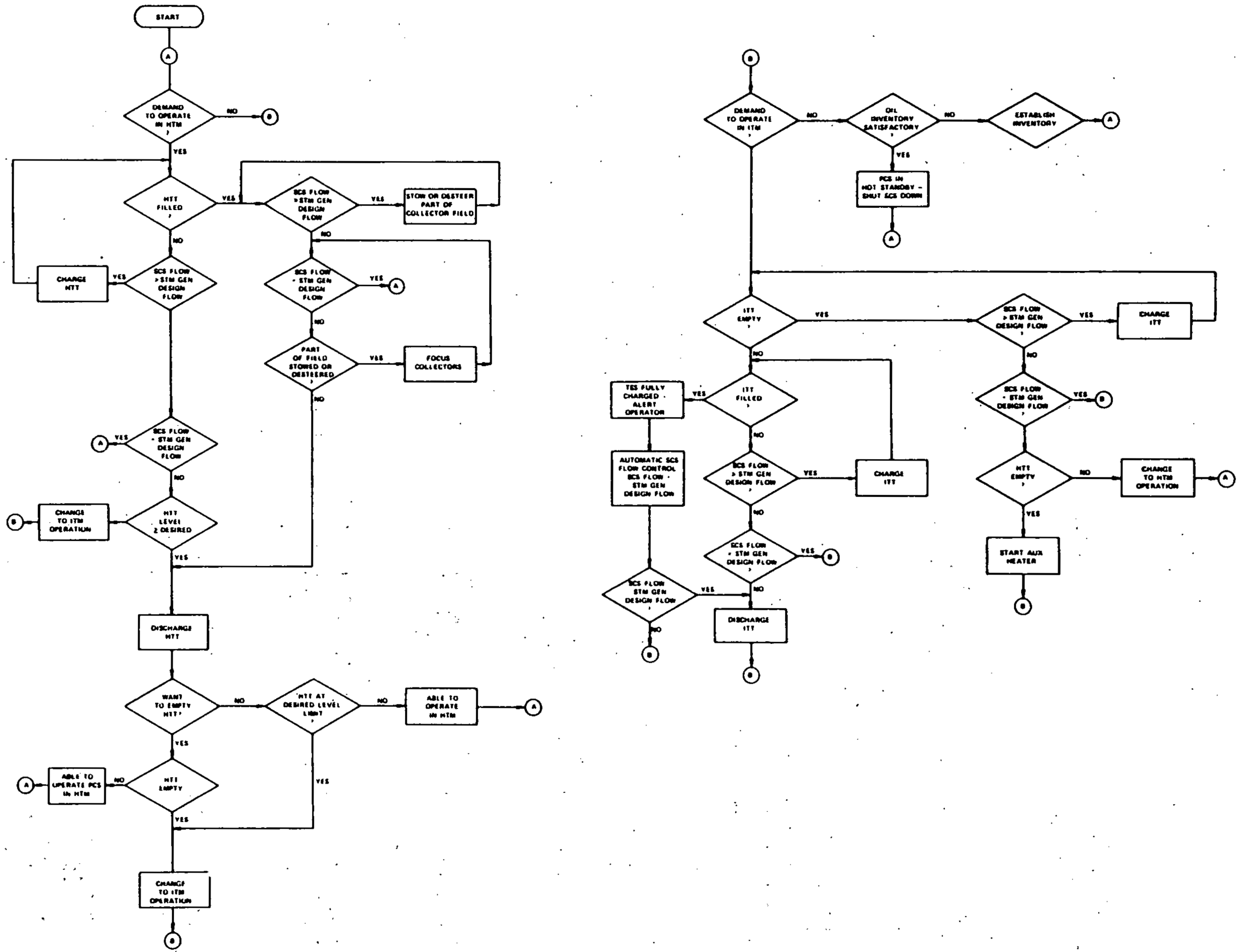


Figure 3.6-14. TSS Tank Storage Control Logic Diagram

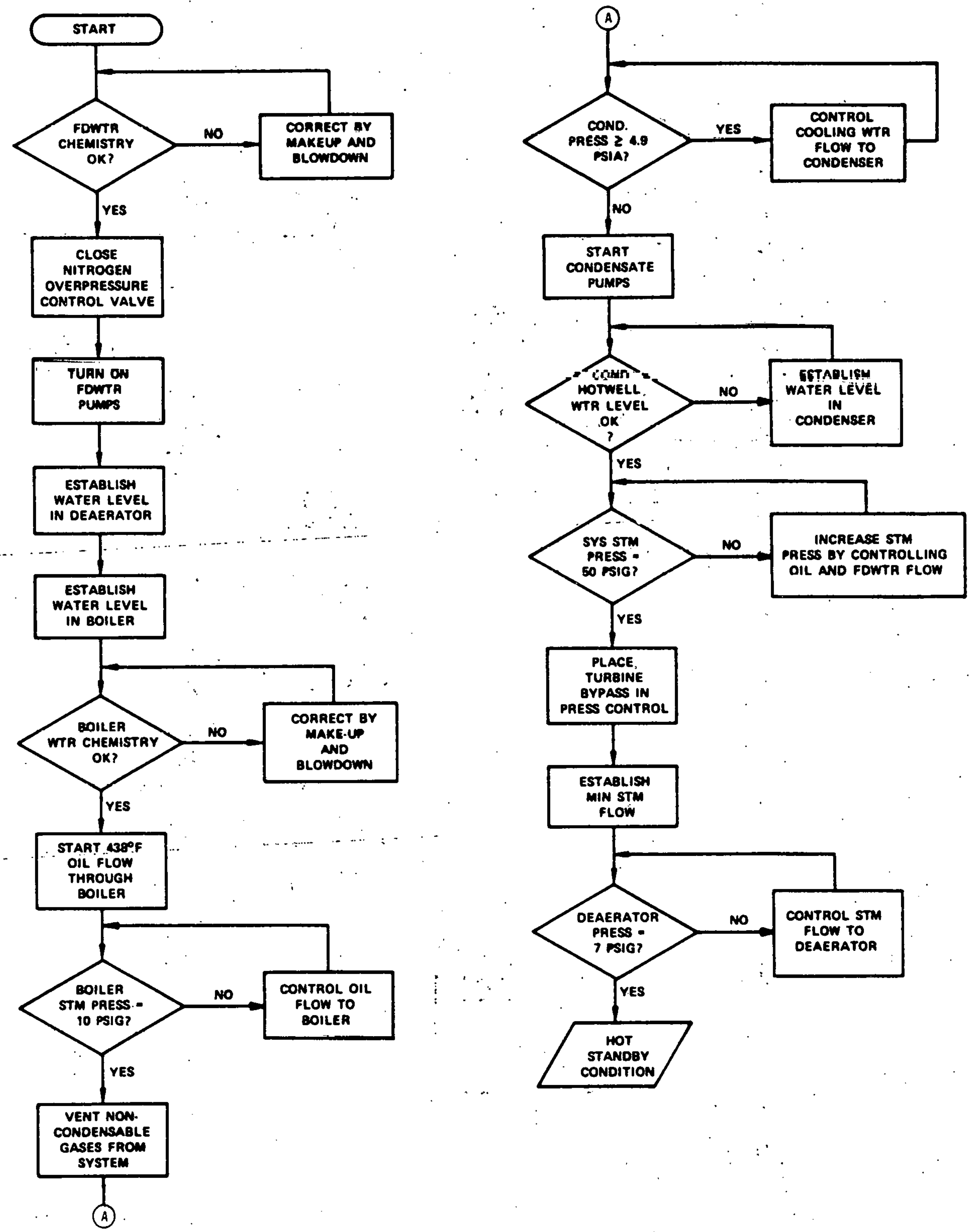


Figure 3.6-15. PCS Startup Control Logic Diagram

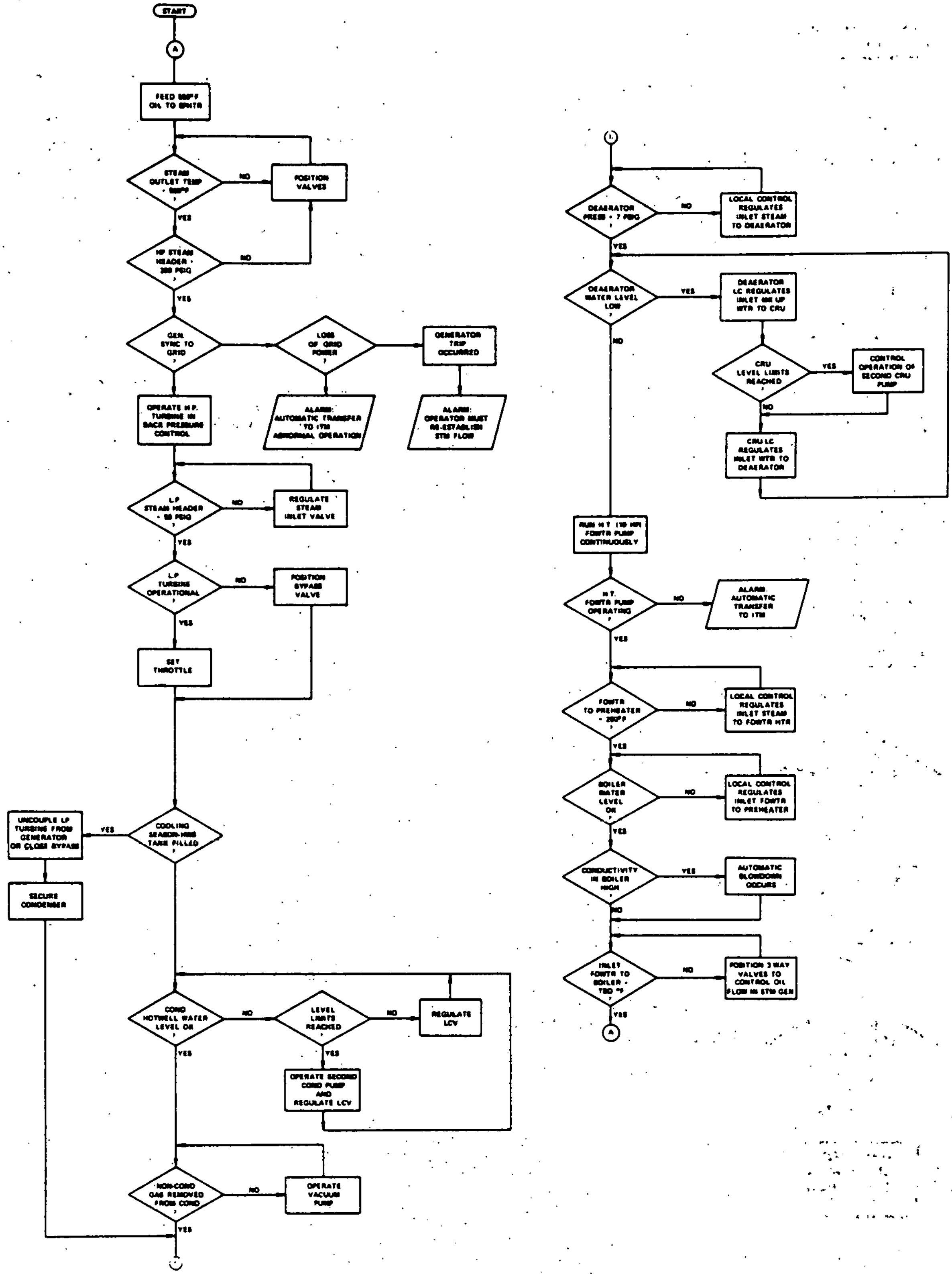


Figure 3.6-16. PCS Normal Operation

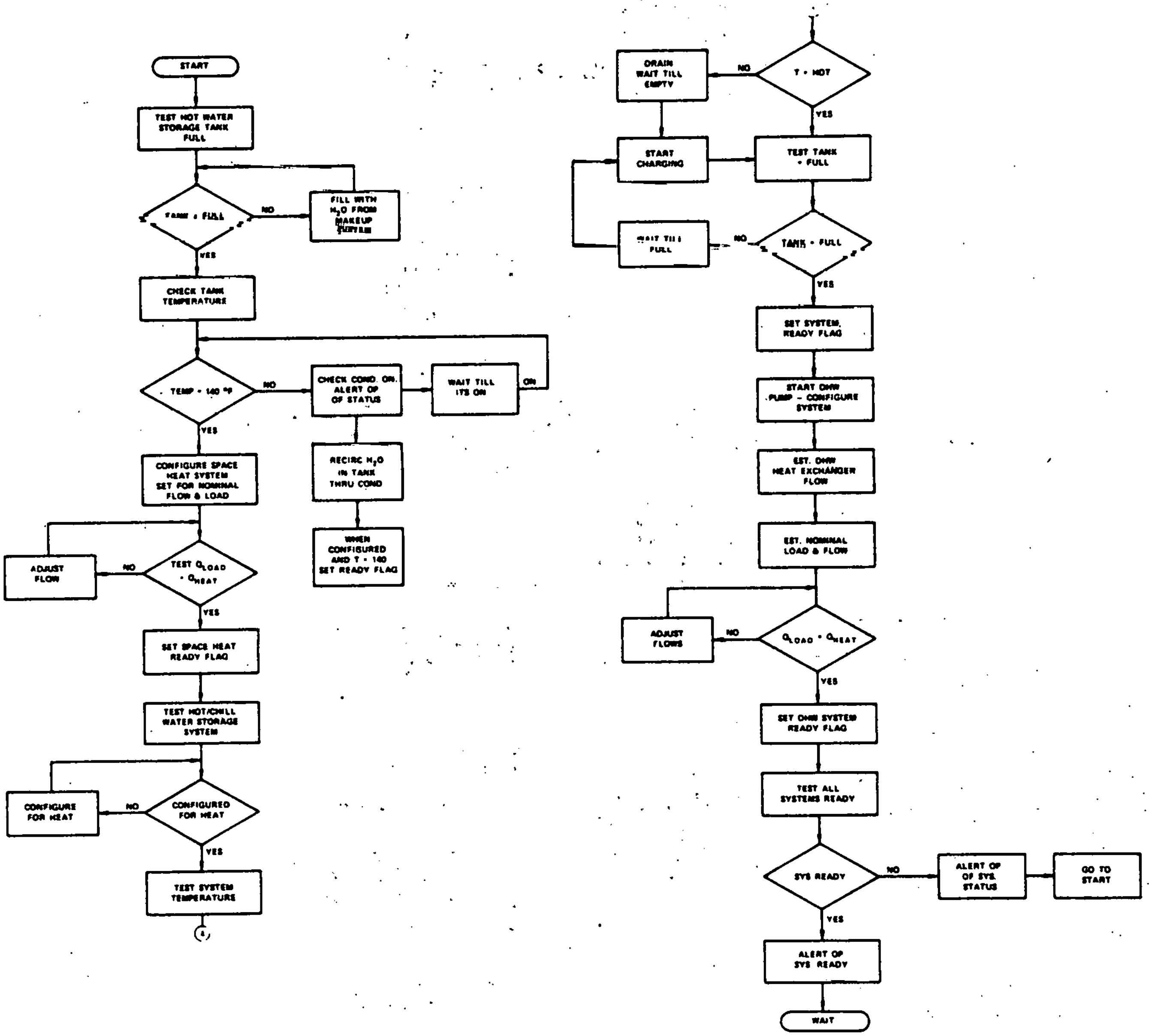


Figure 3.6-17. HWS, CW and DHS Startup Control Logic Diagram

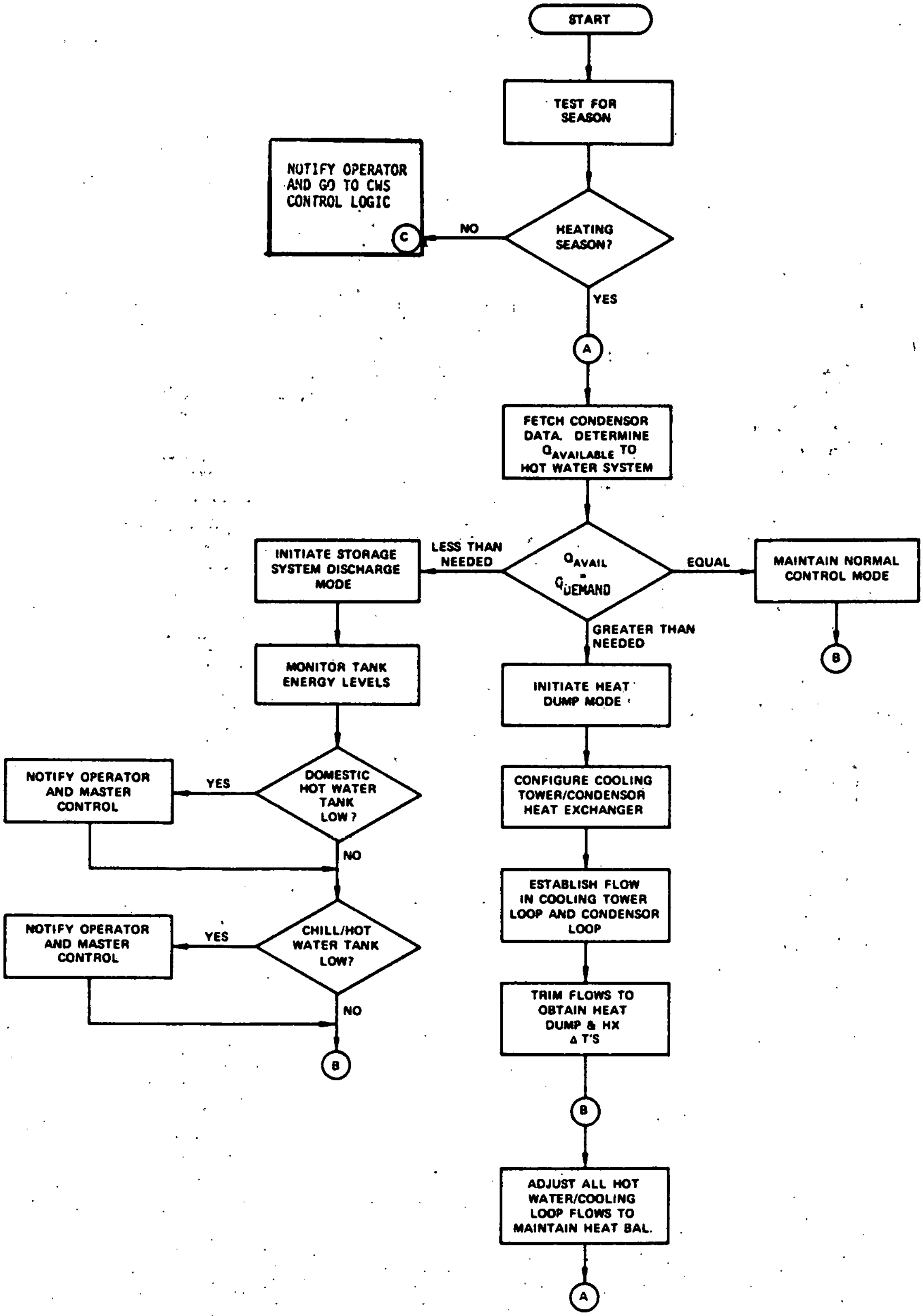


Figure 3.6-18. HWS Thermal Utilization Control Logic Diagram

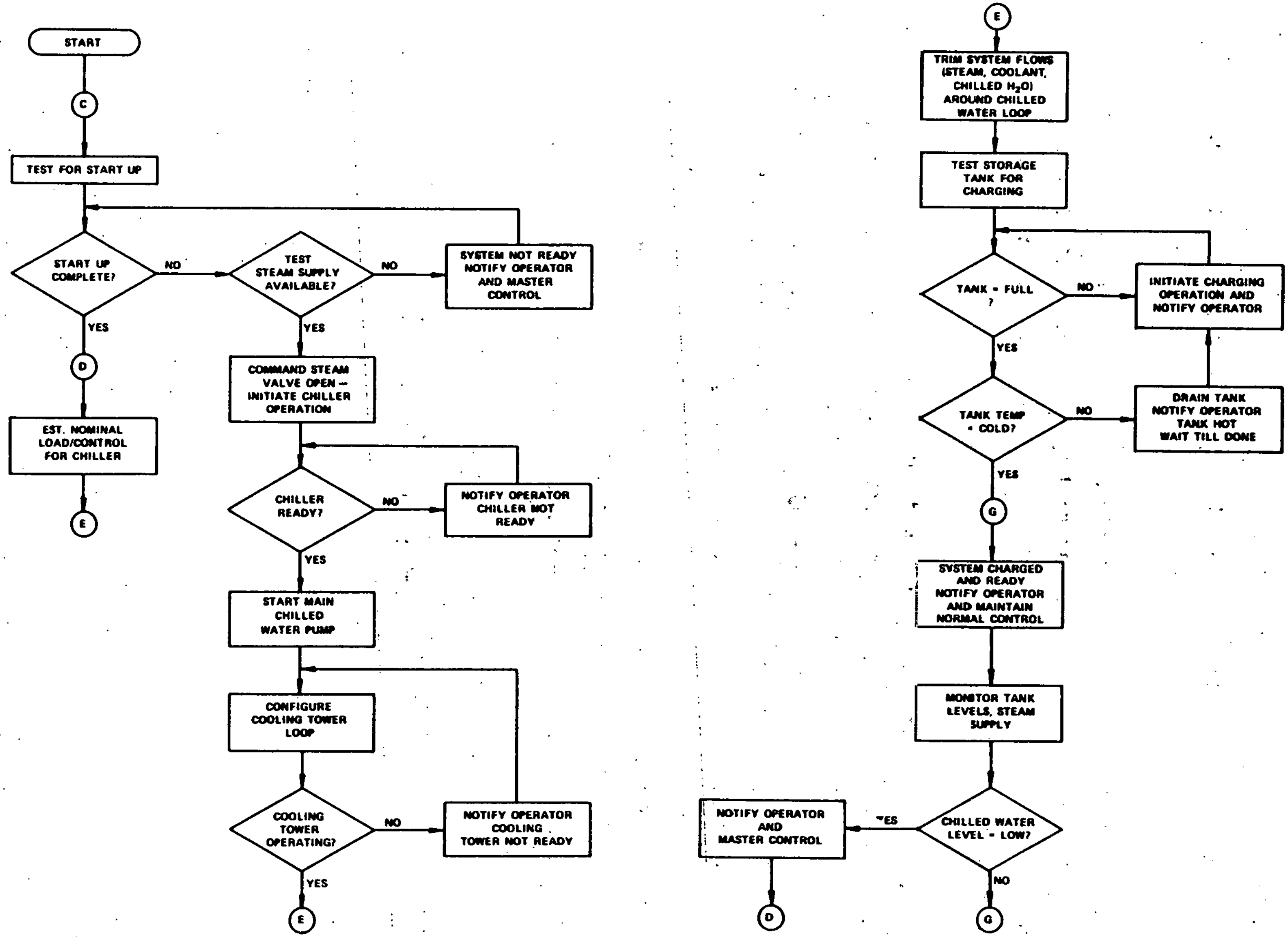


Figure 3.6-19. CWS Thermal Utilization Control Logic Diagram

Transient Model

An analytic model has been developed to provide time transient responses of the Fort Hood STES.

The tool can be used to obtain system frequency responses in evaluating alternate models as well as providing overall systems responses for the development of control system algorithms and strategies, and also to be used in developing energy management control schemes.

The energy equation and conservatism of mass and momentum have been used to generate differential equations that represent the thermal-hydraulic dynamics of the Fort Hood System. The system of equations has been divided into two discrete portions at the thermal storage subsystem interface for the purpose of transient response and malfunction analysis. The two sections can be connected as required for energy management analysis.

The system of equations in Section 3.6.9 have been incorporated into a general purpose simulation program which solves:

- Steady-state - by a matrix method using partial derivations and iterates to a solution
- Frequency responses - by using a matrix method
- Time transient responses - by using a variable time step with high order Runge-Kutta numerical integration

3.6.4.2.1. TRANSIENT RESPONSE OF THE POWER CONVERSION SUBSYSTEM

To demonstrate the dynamic capabilities and test preliminary control algorithms for the plant power conversion subsystem, (PCS), and the hot water heating subsystem, a mode transition transient was made using the transient model and associated controllers described in Section 3.6.9.

Figures 3.6-20 thru 3.6-26 show system temperatures, flows and pressures for the components in the PCS. The transient begins with initial conditions identical to the heating season high temperature peaking mode and changes under demand control to the heating season high temperature normal mode as given in (Tables 4.2-3 & 4.2-4). Basically this involves a change in a thermal load demand reduction and reduced electrical power generation. Load changes and power requirements do not require relatively fast changes to the power conversion subsystem. Therefore, control of mode changes were made on the basis that a smooth transition from one mode to another is most desirable.

The control and transient results used state point data from Table 4.2-3 of this report to calculate system heat transfer and pressure drop coefficients. The preliminary control system design gains and time constants are based on step response data contained in this section. Also Table 3.6-2 contains model assumptions used in the transient case presented.

The high and low pressure turbine flow rates are controlled via changes in hand valves or position valves to reflect changes in load demand. Condenser coolant flow rate is controlled to maintain condenser pressure, deaerator steam flow is controlled to maintain pressure and feedwater heater steam flow is controlled to maintain temperature. The control change of these variables reflects the thermal load and power generation demand changes.

As the flow rates decrease while following lower thermal load demand for the normal mode operation the oil throttle valve closes to maintain boiler pressure at 365 psia. The superheater and preheater oil flow valves open and close as required to maintain superheater exit steam temperature,

TABLE 3.6-2

MODEL ASSUMPTIONS FOR TRANSIENT

- All valve characteristics are linear (i.e. flow is proportional to valve position)
- Turbine and pump dynamics are neglected
- Thermal transport delays between components are neglected
- Instrumentation lags and delays are not considered in feedback control loops along with actuator dynamics and characteristics
- All controllers are either proportional - integral type or integral type elements
- Feedwater flow control is based on an assumed time lag between steam flow and feedwater flow.
- Actual control demand signals are precalculated and entered as set points rather than being calculated from actual load change
- Turbine flow control is via flow demand assumed for governor valve position control mode of turbine control system
- Turbine efficiency assumed constant
- Condenser pressure controlled via condenser coolant flow rate
- Oil flow dynamics neglected
- Consensate levels are constant (i.e. no pump operation simulated)

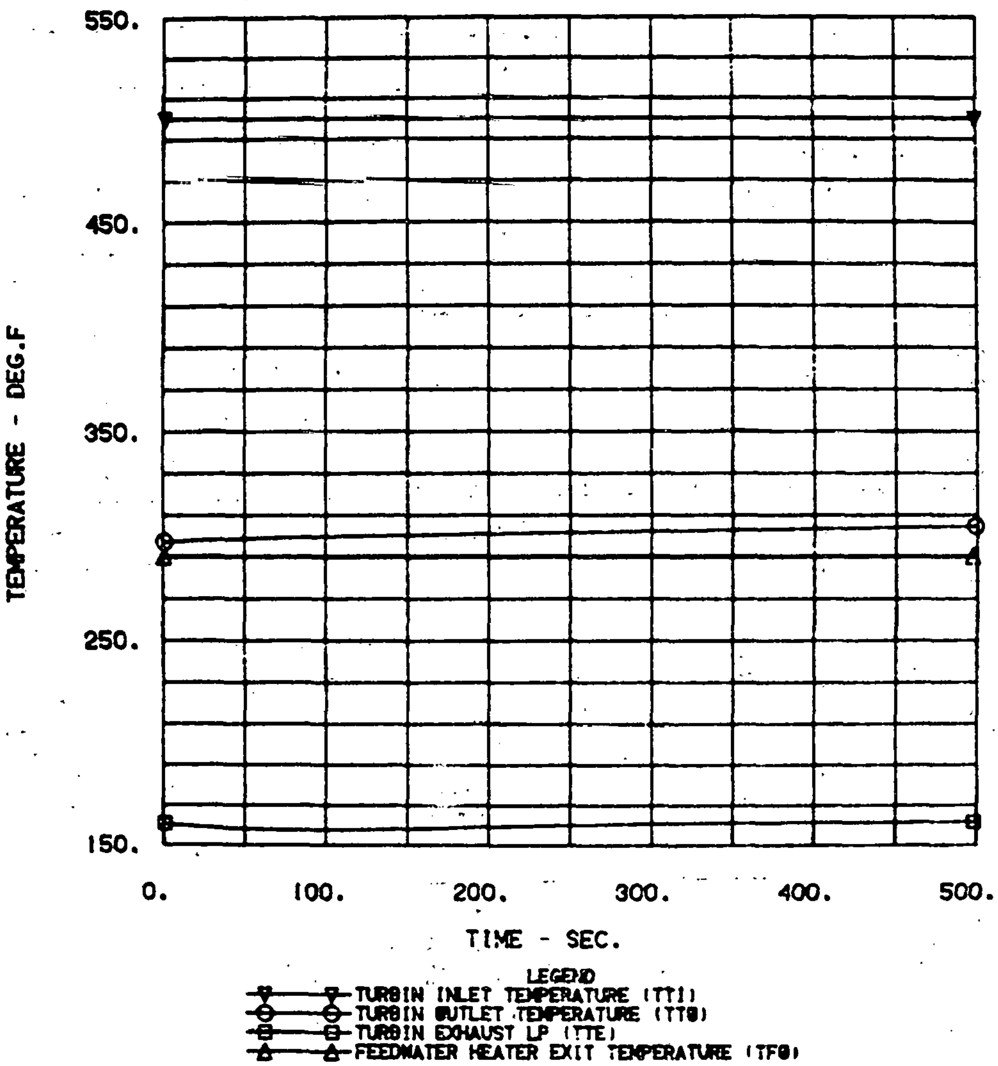


Figure 3.6-20. Turbine and Steam Temperatures During Plant Mode Change Transient - High Temperature Peaking Mode to High Temperature Normal Mode

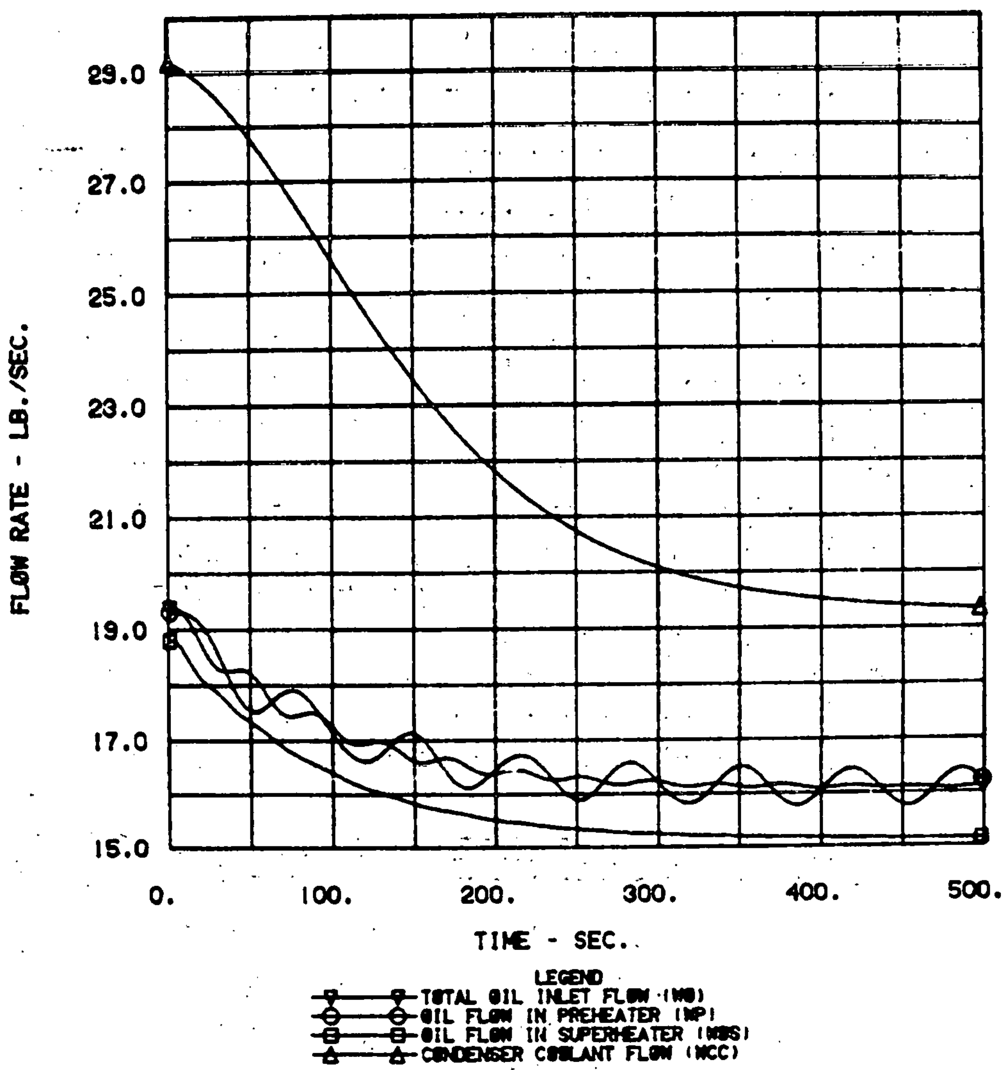


Figure 3.6-21. Oil Flowrates During Plant Mode Change Transient - High Temperature Peaking Mode to High Temperature Normal Mode

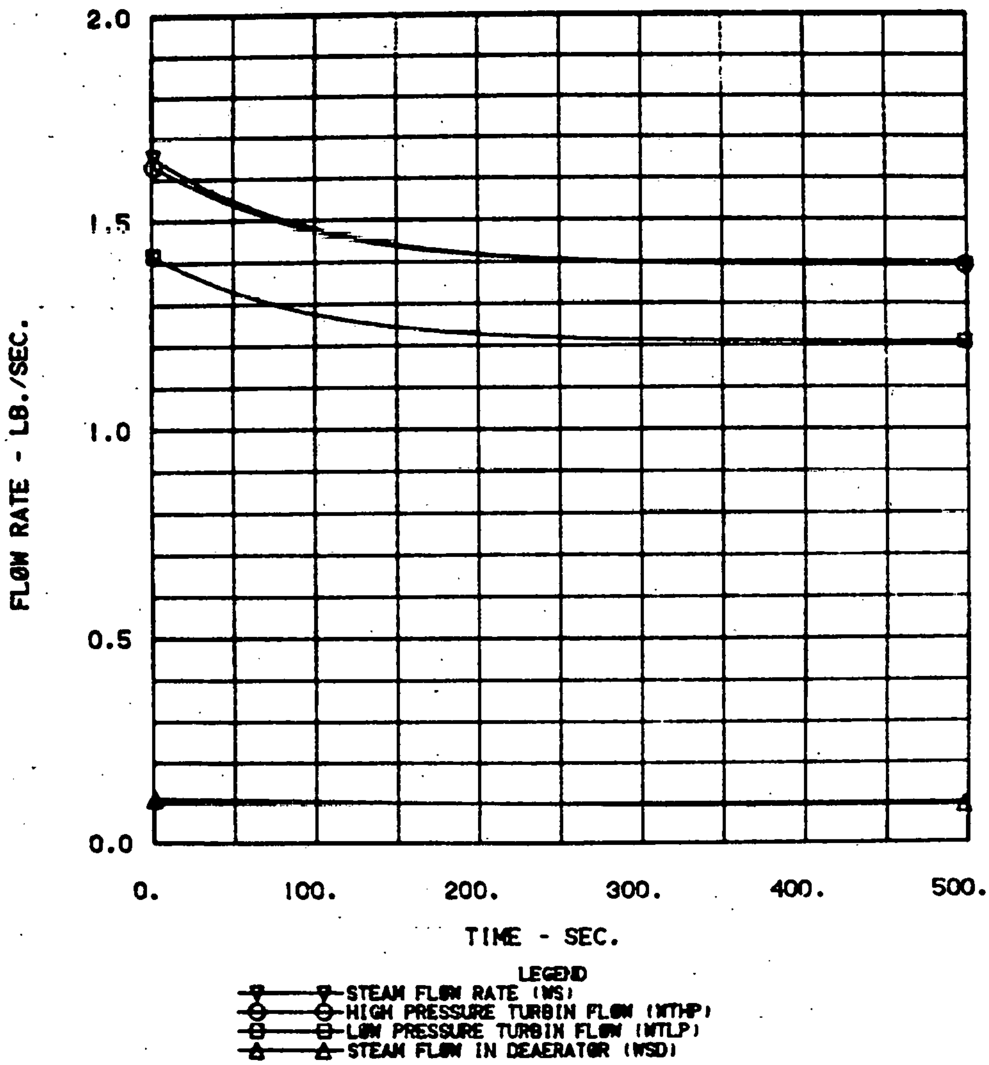


Figure 3.6-22. Steam Flowrates During Plant Mode Change Transient - High Temperature Peaking Mode to High Temperature Normal Mode

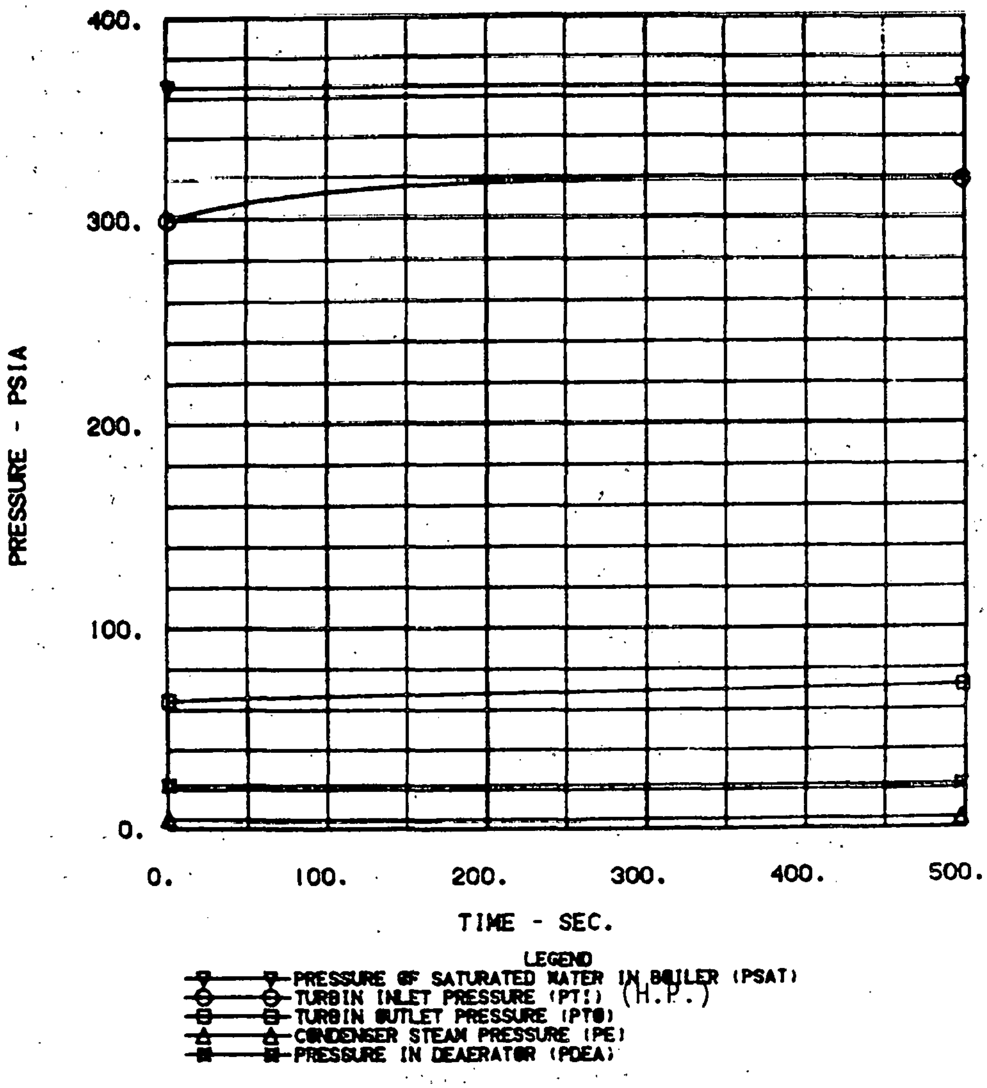


Figure 3.6-23. Steam Pressures During Plant Mode Change Transient - High Temperature Peaking Mode to High Temperature Normal Mode.

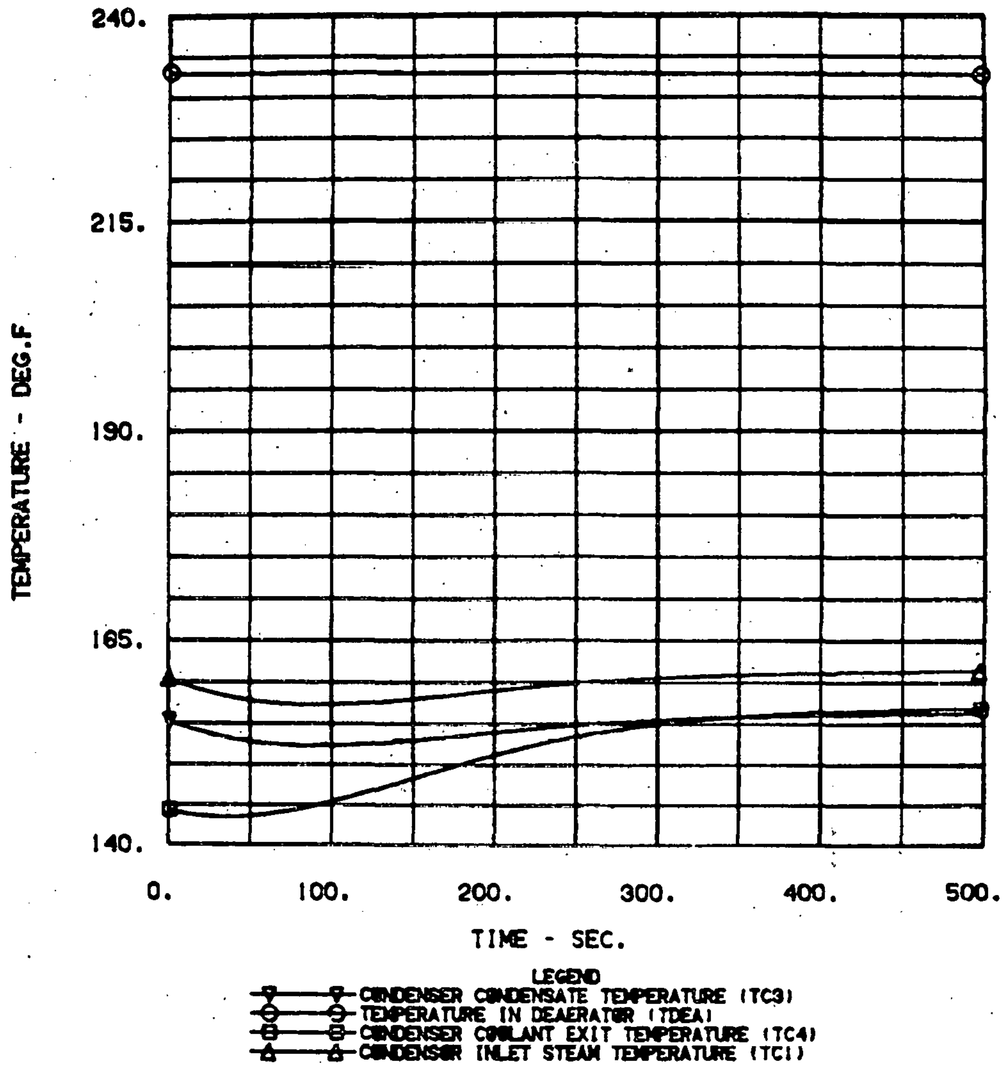


Figure 3.6-24. Condenser and Deaerator Temperatures During Plant Mode Change Transient - High Temperature Peaking Mode to High Temperature Normal Mode

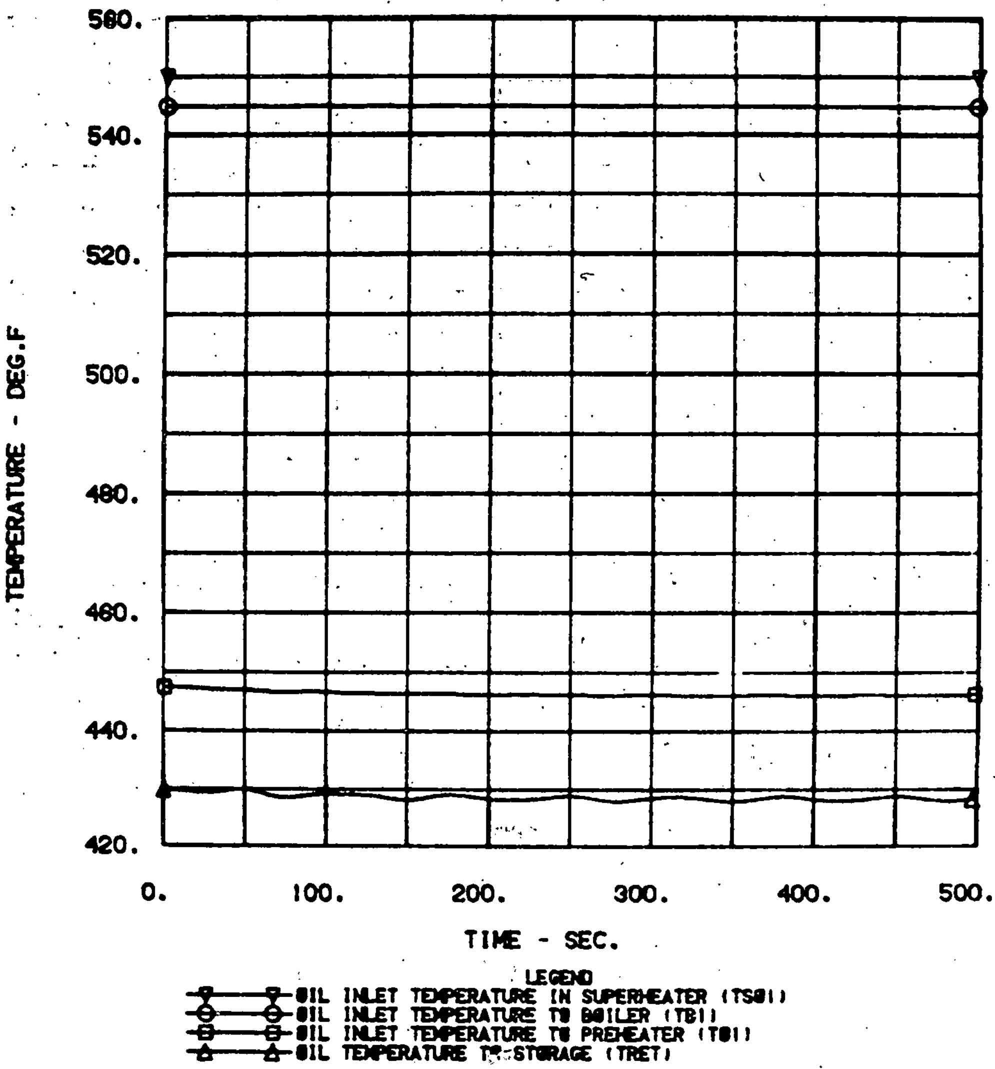


Figure 3.6-25. Steam Generator Oil Temperatures During Plant Mode Change Transient - High Temperature Peaking Mode to High Temperature Normal Mode

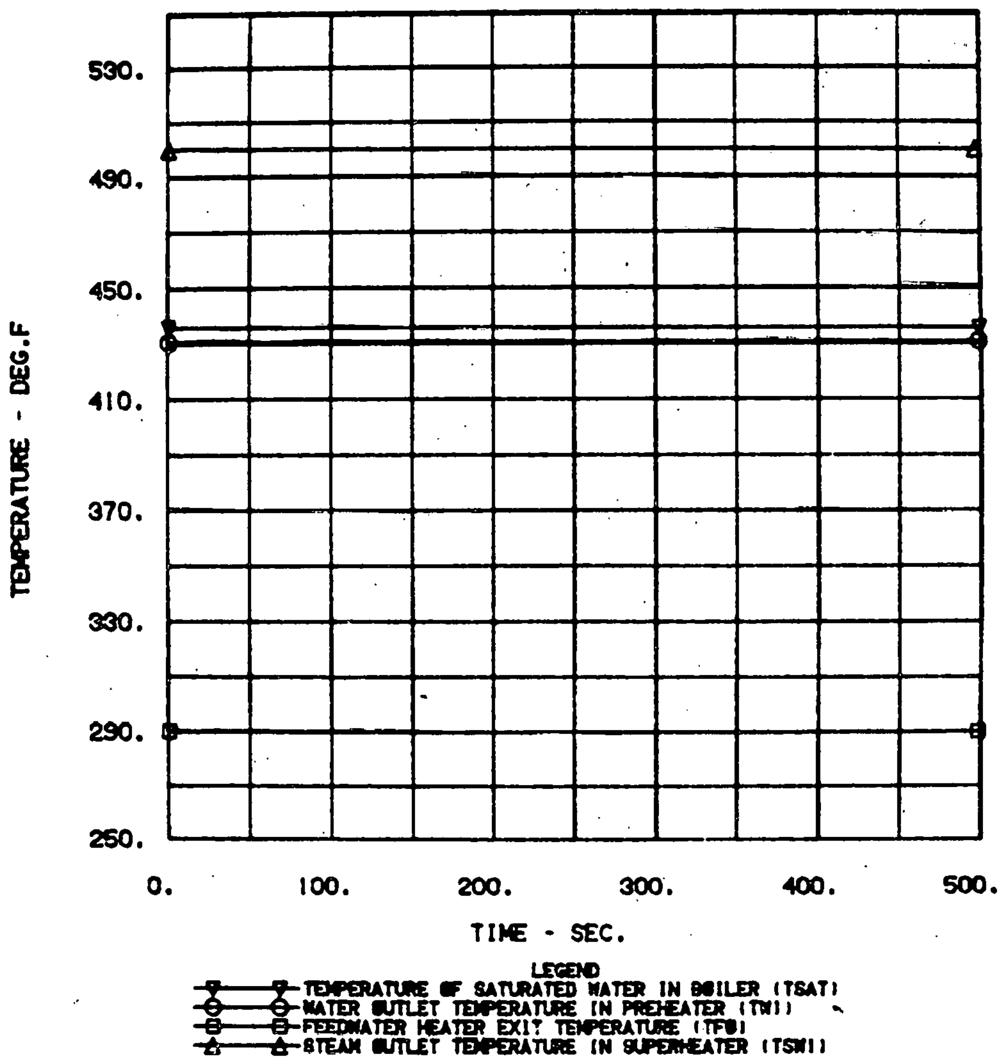


Figure 3.6-26. PCS Steam Temperatures During Plant Mode Change Transient - High Temperature Peaking Mode to High Temperature Normal Mode

and preheater exit water temperature at $5^{O}F$ subcooled (boiler saturated water temperature $-5^{O}F$).

Similarly, the deaerator and feedwater heater steam flow modulating valves close to maintain deaerator pressure and feedwater heater exit water temperature.

As shown in Figure 3.6-78 the high pressure turbine exhaust pressure (Low Pressure header) changes to compensate for turbine flow changes. However, the pressure changes are relatively small (<10%) and do not seem to cause adverse conditions. All other system parameters follow thermal load changes without adverse behavior. The overall net result is a stable transition from one operating mode to another.

Figures 3.6-27 thru 3.6-33 show a similar plant mode transition transient with condenser coolant temperature control added. The inlet coolant flow is mixed with storage or return fluid to obtain desired inlet temperature. This transient starts from time = 110 seconds and terminates at ∿275 seconds.

The major difference in the two mode transition cases is that the condenser exit coolant temperature is controlled to $145^{O}F$ by decreasing condenser inlet coolant temperature to $\sim 97^{O}F$ while coolant flow decreases to match load demand.

STEP RESPONSE

Figures 3.6-34 thru 3.6-49 show steam generator and turbine parameter responses to large step changes in oil inlet temperature and flow rate at the inlet to the steam generator. The plant operating mode conditions are for the heating season high temperature peaking mode. Step changes occur at time = 5 seconds.

The transient responses are the results of either stepping inlet oil temperature $-50^{O}F$, Figure 3.6-41, or oil flow rate -50%, Figure 3.6-34, while maintaining constant feed water temperature or drum water level

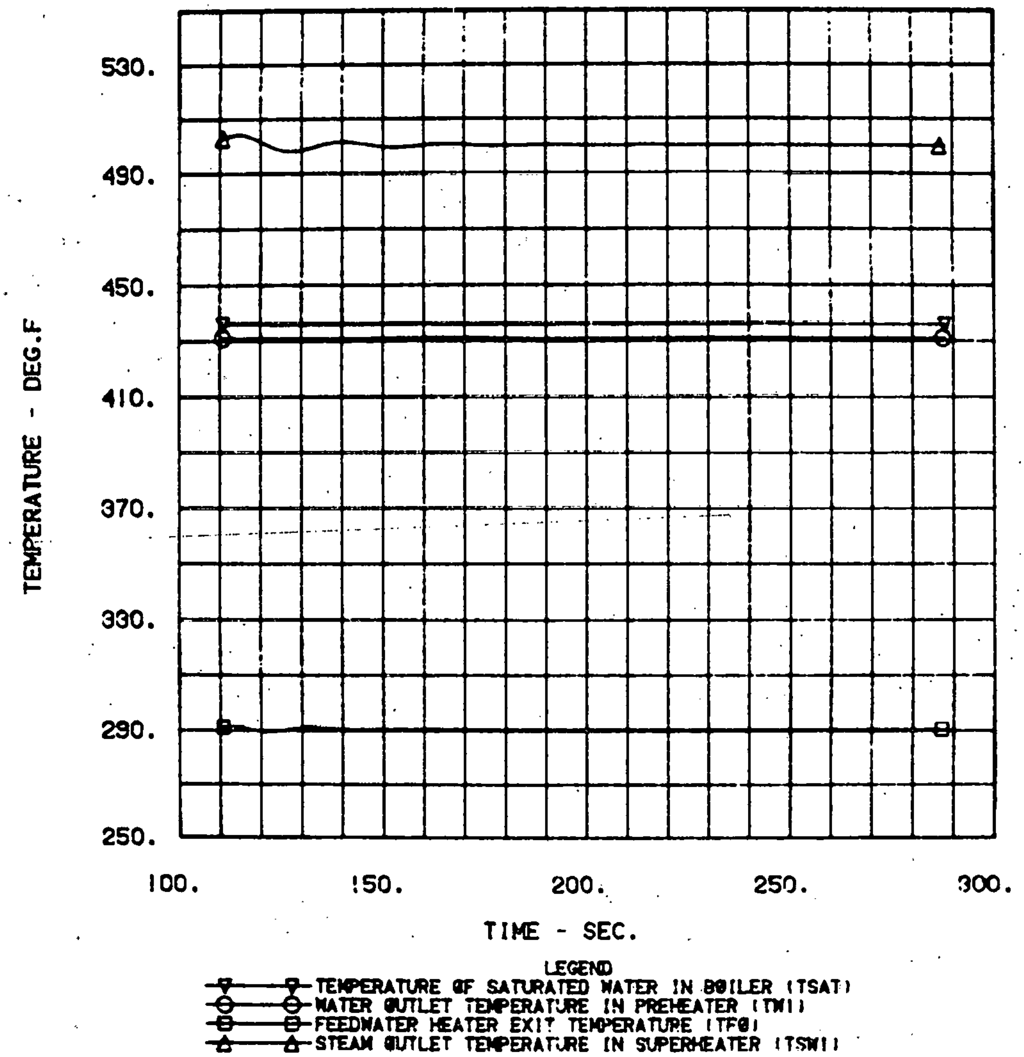


Figure 3.6-27. Steam/Water Temperatures During Mode Change Transient (With Condenser Coolant Temperature Control)

(ie. feed flow = steam flow) and without system controllers. (Open loop)

The relatively large values in step size were chosen to demonstrate that the system is reasonably linear and well behaved. Also, the results provide a dynamic check of the transient model as well as providing preliminary data for control system synthesis.

An interesting result of the step change in oil flow (Figures 3.6-34 thru 3.6-40) is noted by the increase of superheater exit temperature (Figure 3.6-35). This is due to an increase of heat flux caused by a decrease in steam inlet temperature, which yields a larger mean ΔT between the oil and steam in the superheater. The decrease in steam temperature is the result of the decrease in flux to the steam boiler which lowers saturation conditions in the boiler. The net effect of this causes steam flow to decrease 36% rather than an anticipated 50%.

Figures 3.6-41 thru 3.6-49 are system responses to a -50°F step change in inlet oil temperature.

The comparison of Figures 3.6-45 and 3.6-48 shows that the preheater water exit temperature (inlet to the boiler) remains at least 2°F below the steam saturation temperature of the boiler. This indicates an inherent design feature exists that gives a temperature margin in preheater water temperature without the aid of oil bypass flow control, which is a desired feature for transition to a fail safe configuration mode.

The superheater exit temperature has a 6°F overshoot due to the change in mean temperature difference in the superheater and the decay of stored energy in the boiler along with the sudden change in oil inlet temperature.

The remaining figures illustrate that the PCS is a reasonably well behaved system and that large pertubations do not cause adverse effects.

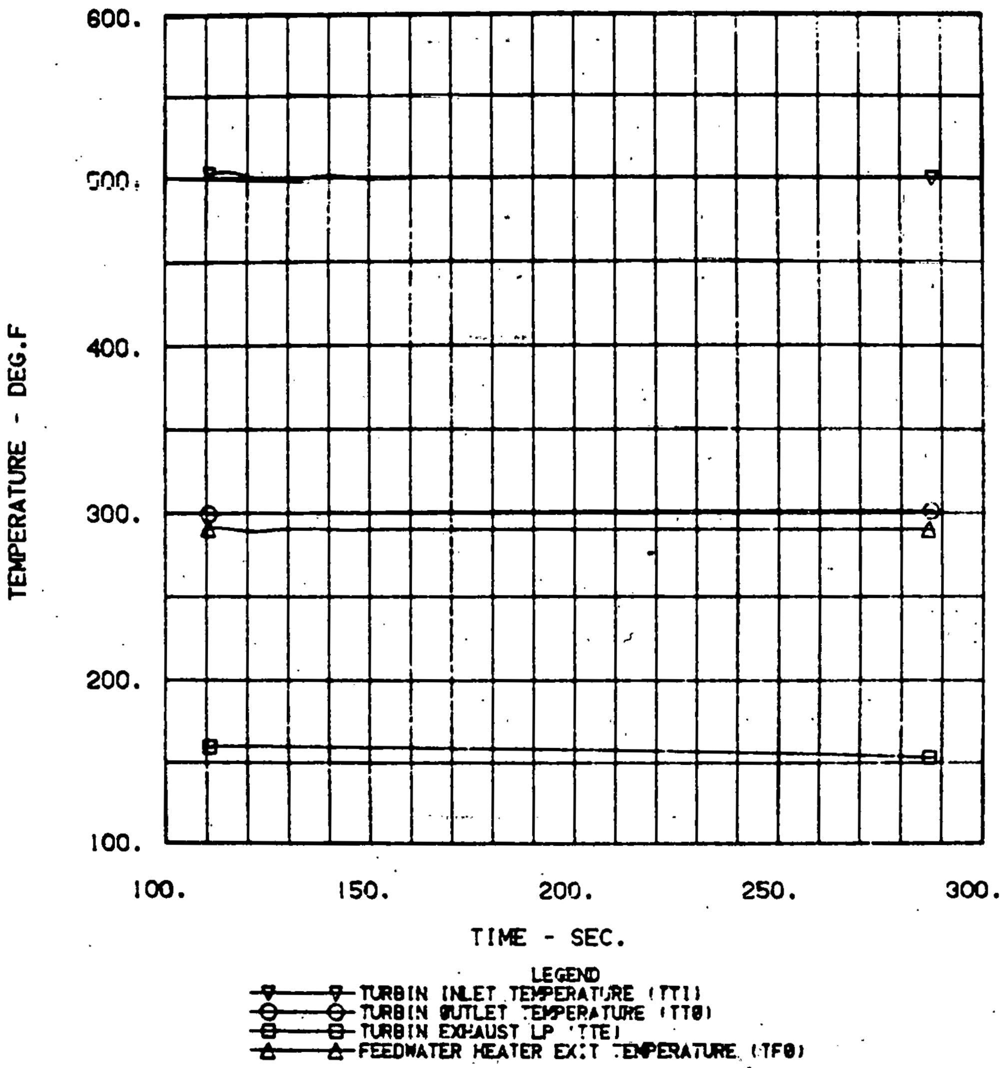


Figure 3.6-28. Turbine Temperatures During Mode Change Transient (With Condenser Coolant Temperature Control)

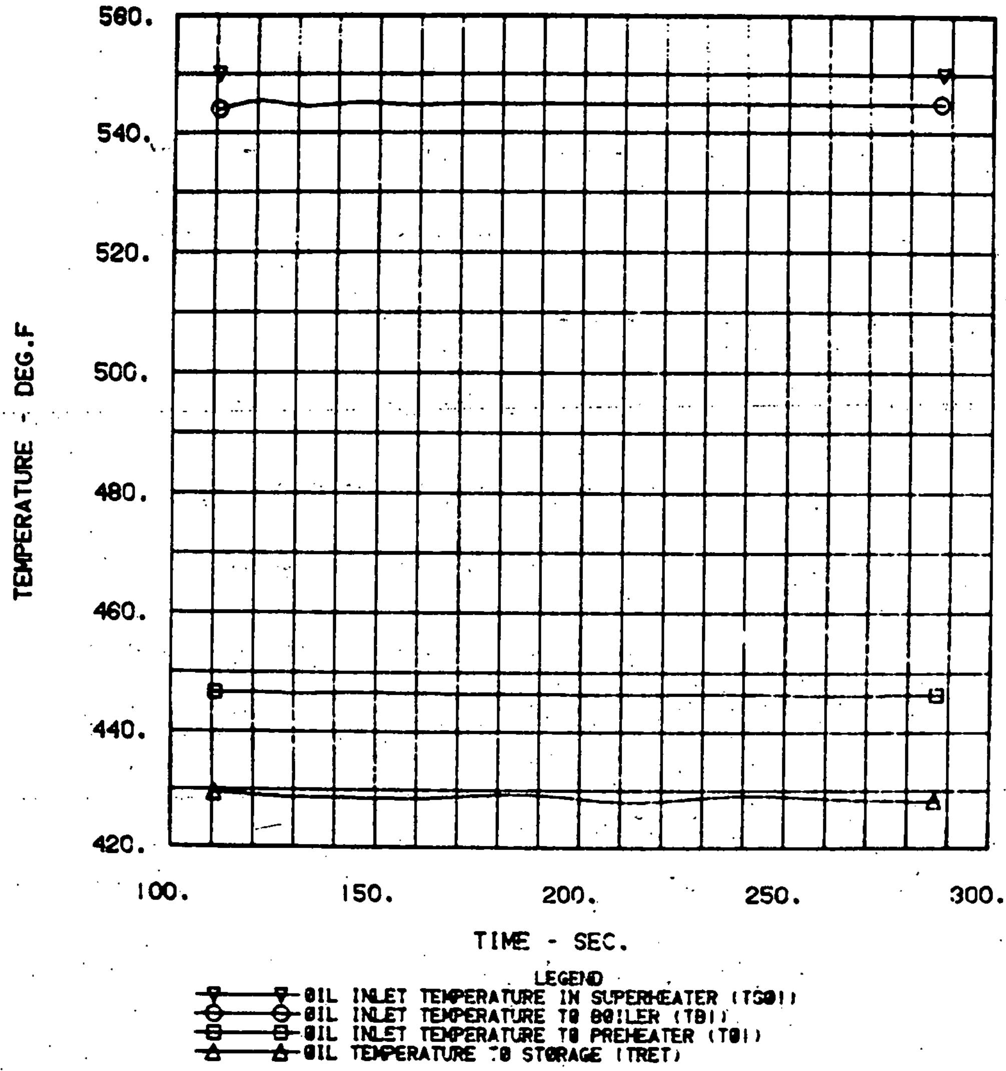


Figure 3.6-29. Steam Generator Oil Temperatures During Mode Change Transient (With Condenser Coolant Temperature Control)

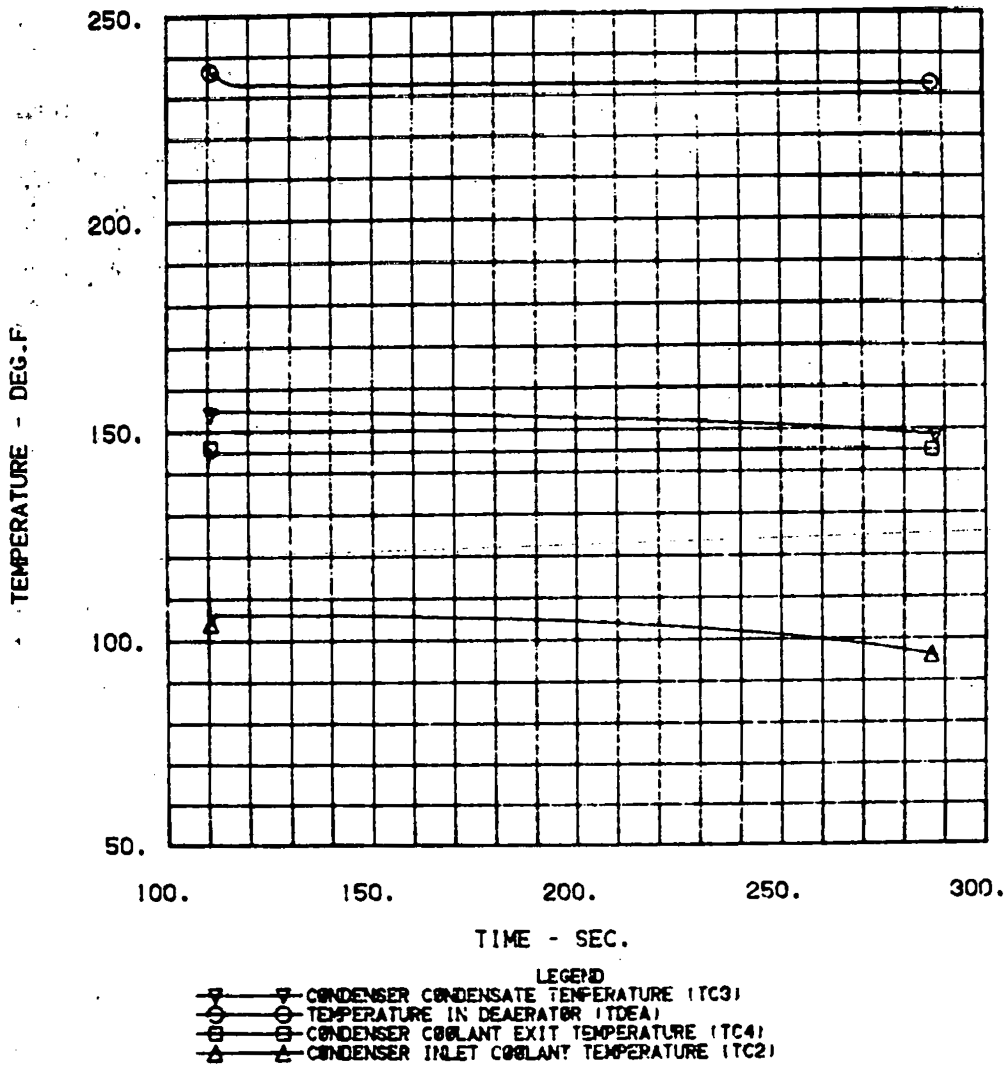


Figure 3.6-30. Condenser and Deaerator Temperatures During Mode Change Transient (With Condenser Coolant Temperature Control)

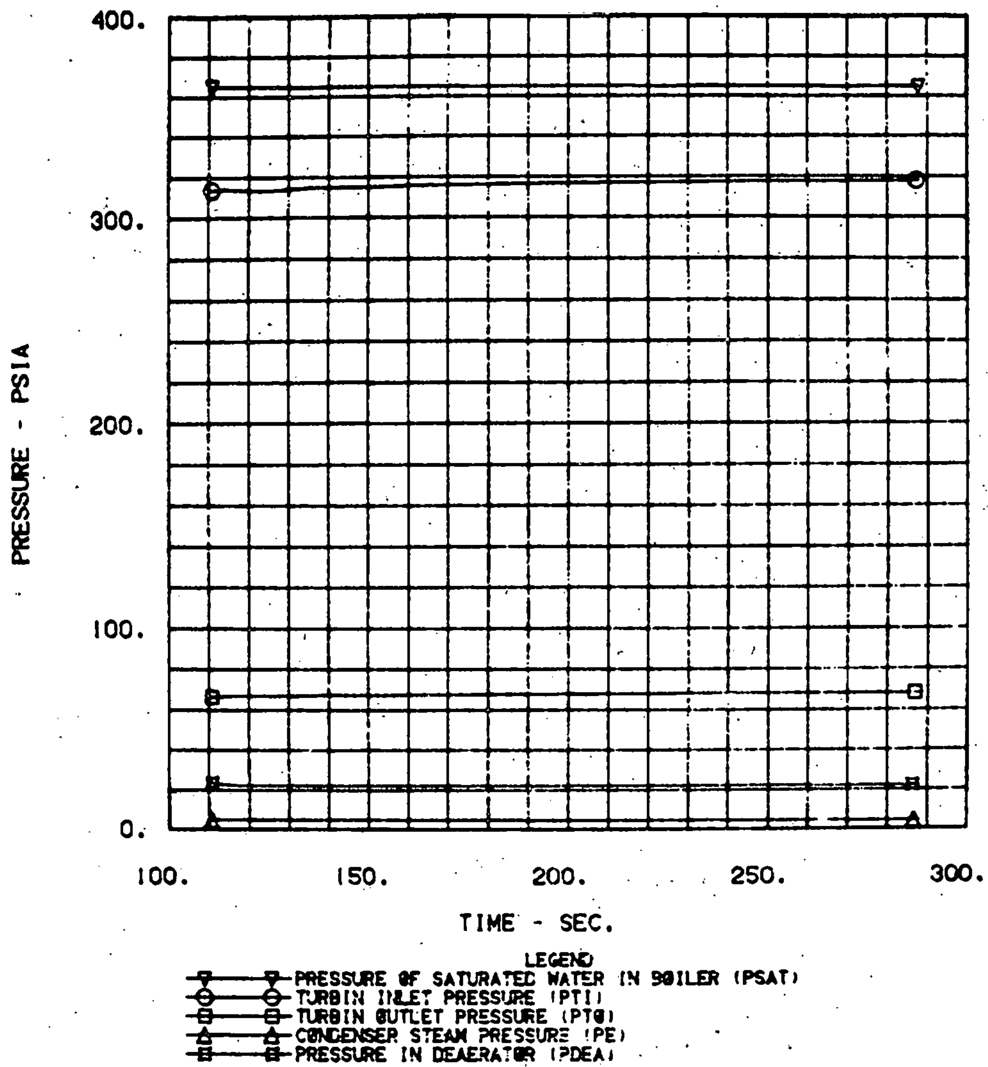


Figure 3.6-31. Steam Pressure During Mode Change Transient (With Condenser Coolant Temperature Control)

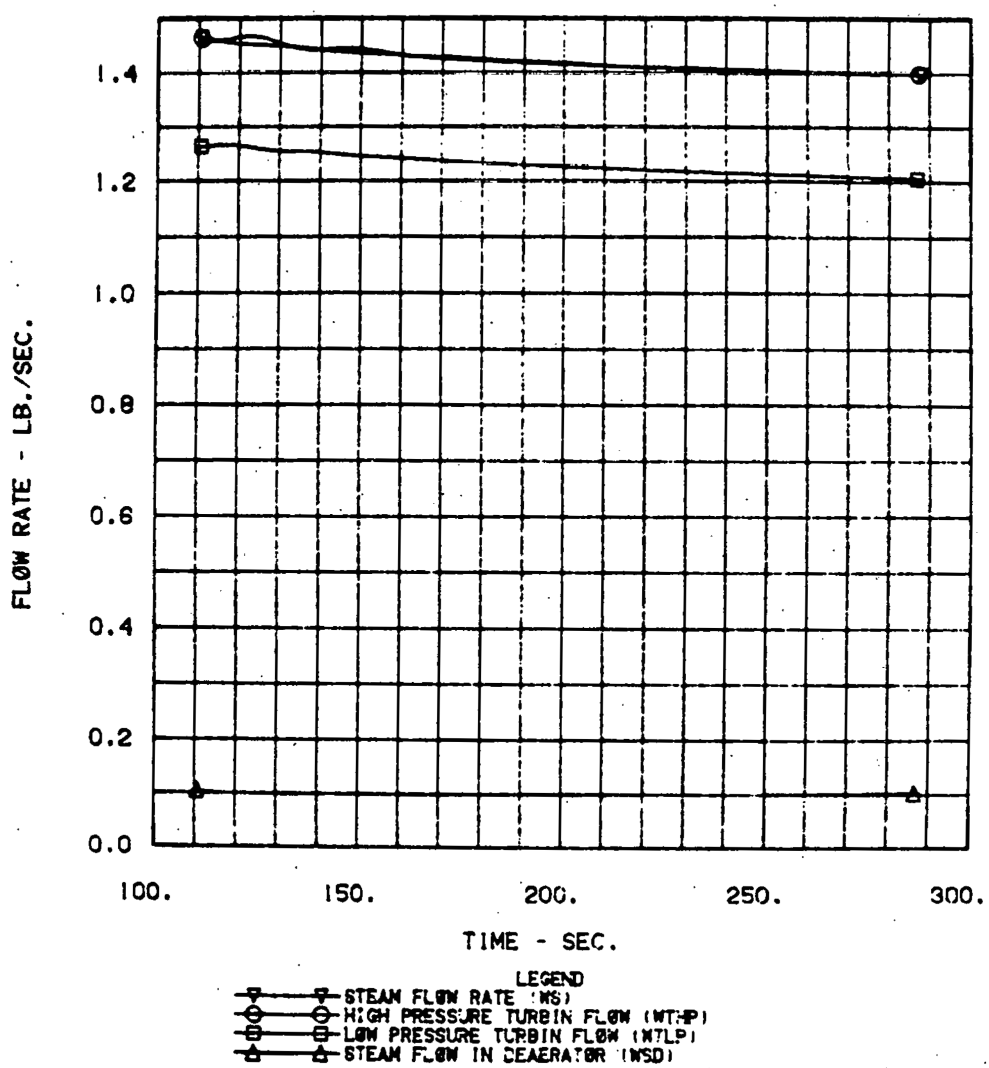


Figure 3.6-32. Steam Flowrates During Mode Change Transient (With Condenser Coolant Temperature Control)

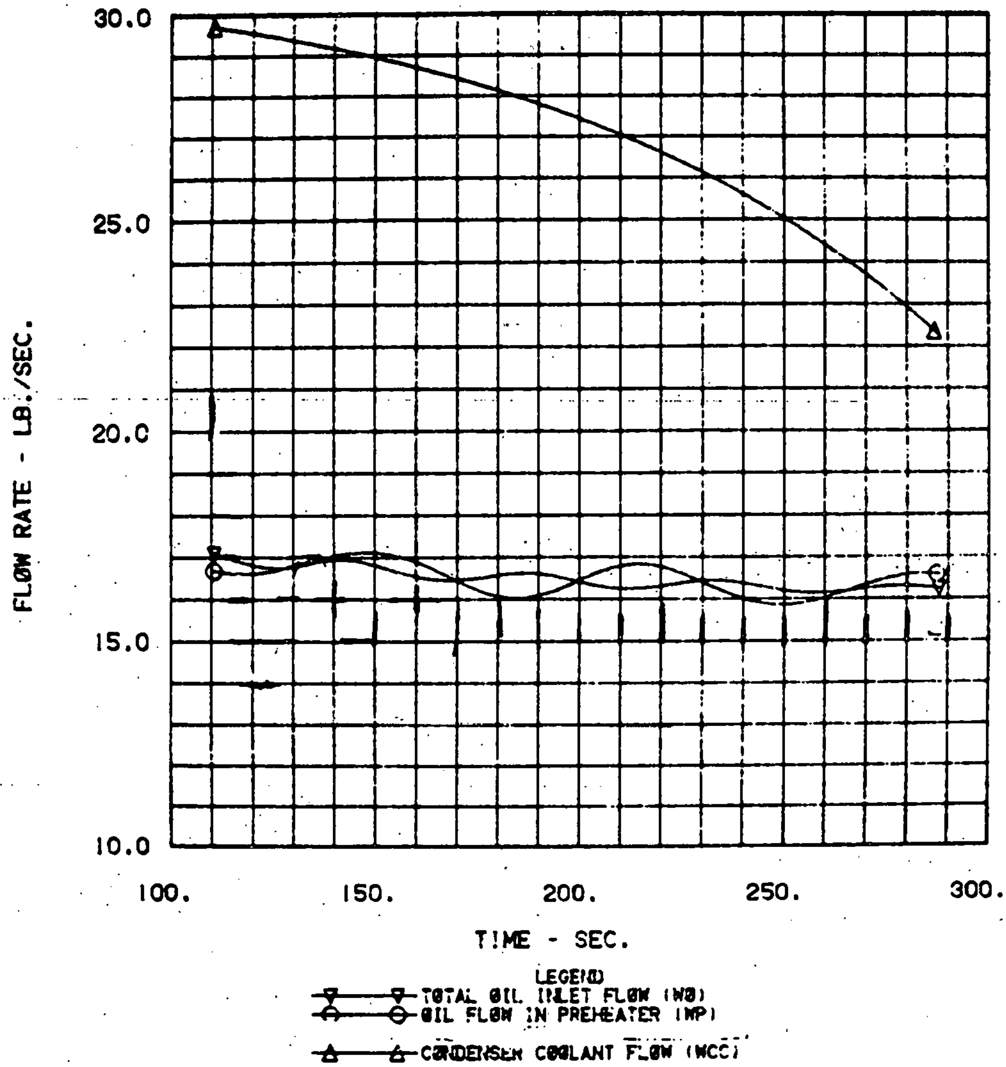
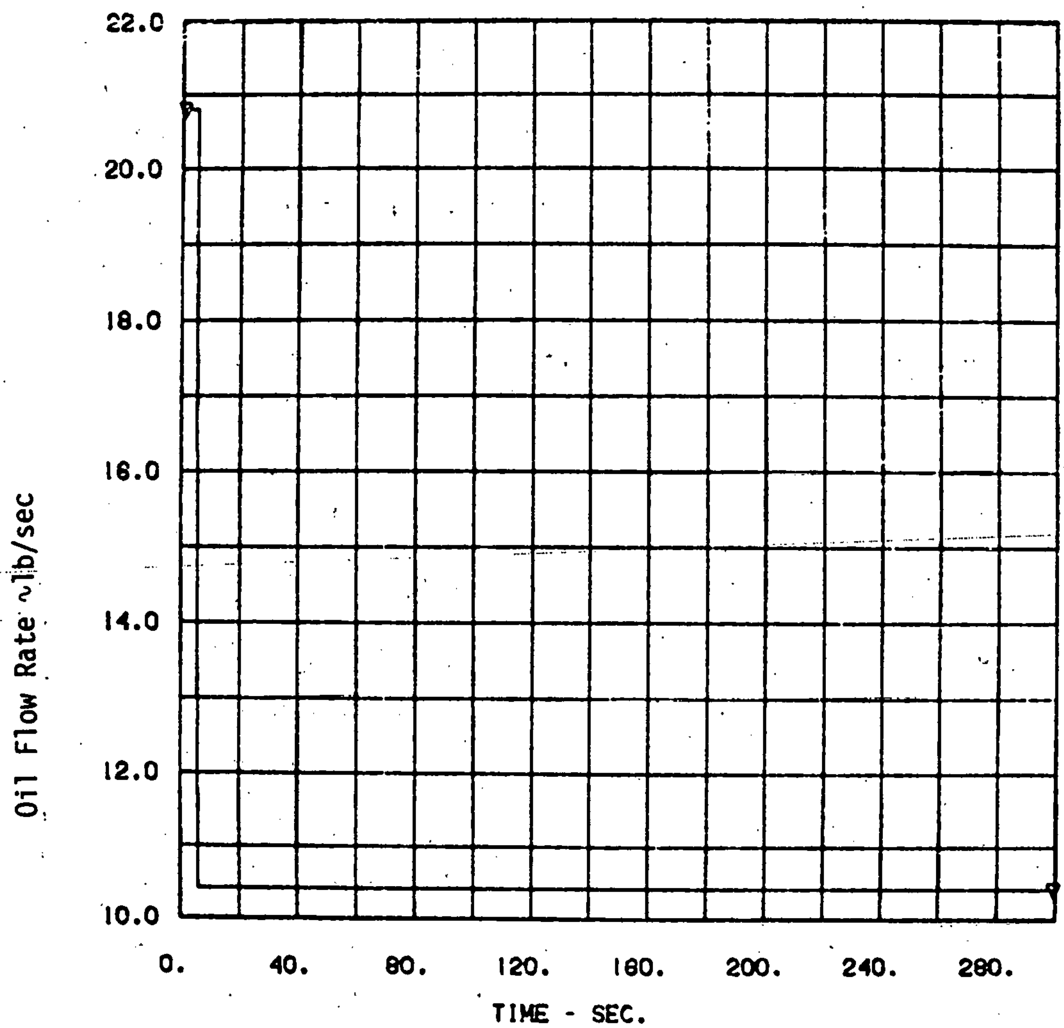


Figure 3.6-33. Steam Generator Oil Flowrates During Mode Change Transient (With Condenser Coolant Temperature Control)



Total Flow to Steam Generator

Figure 3.6-34 Step Input in Oil Flow to Steam Generator

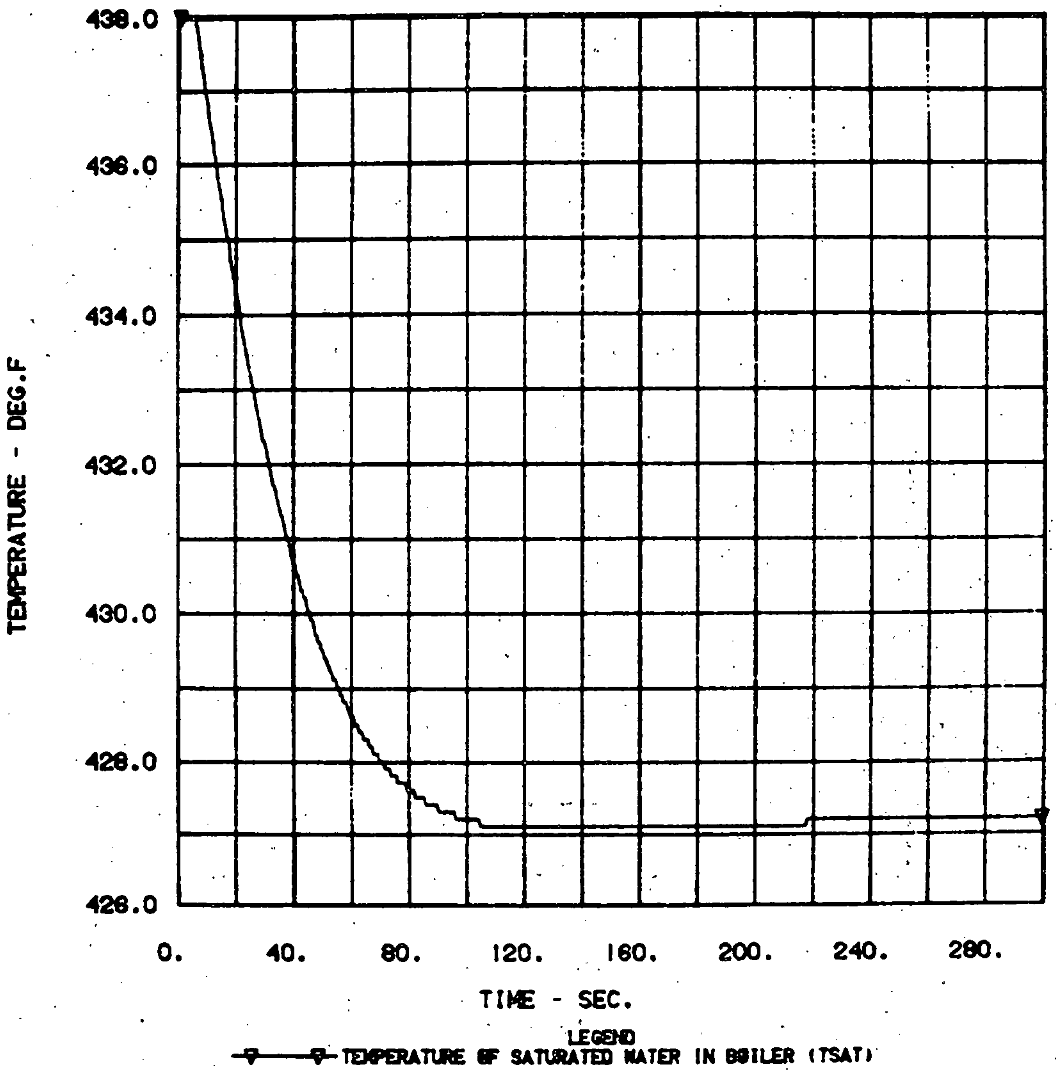


Figure 3.6-35. Boiler Saturation Temperature Response to Oil Flow Step of -50 Percent

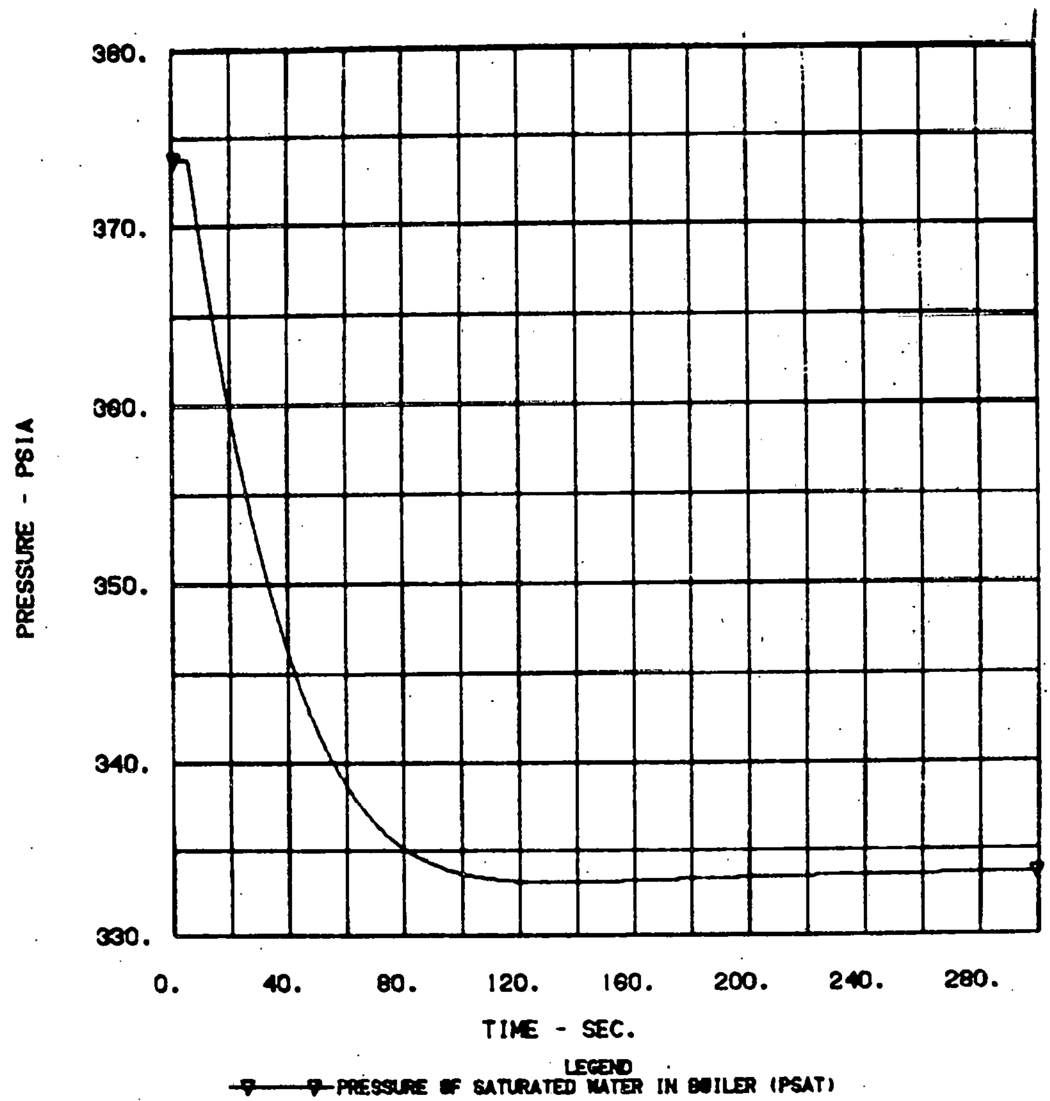


Figure 3.6-36. Boiler Steam Pressure Response to Oil Flow Step of -50 Percent

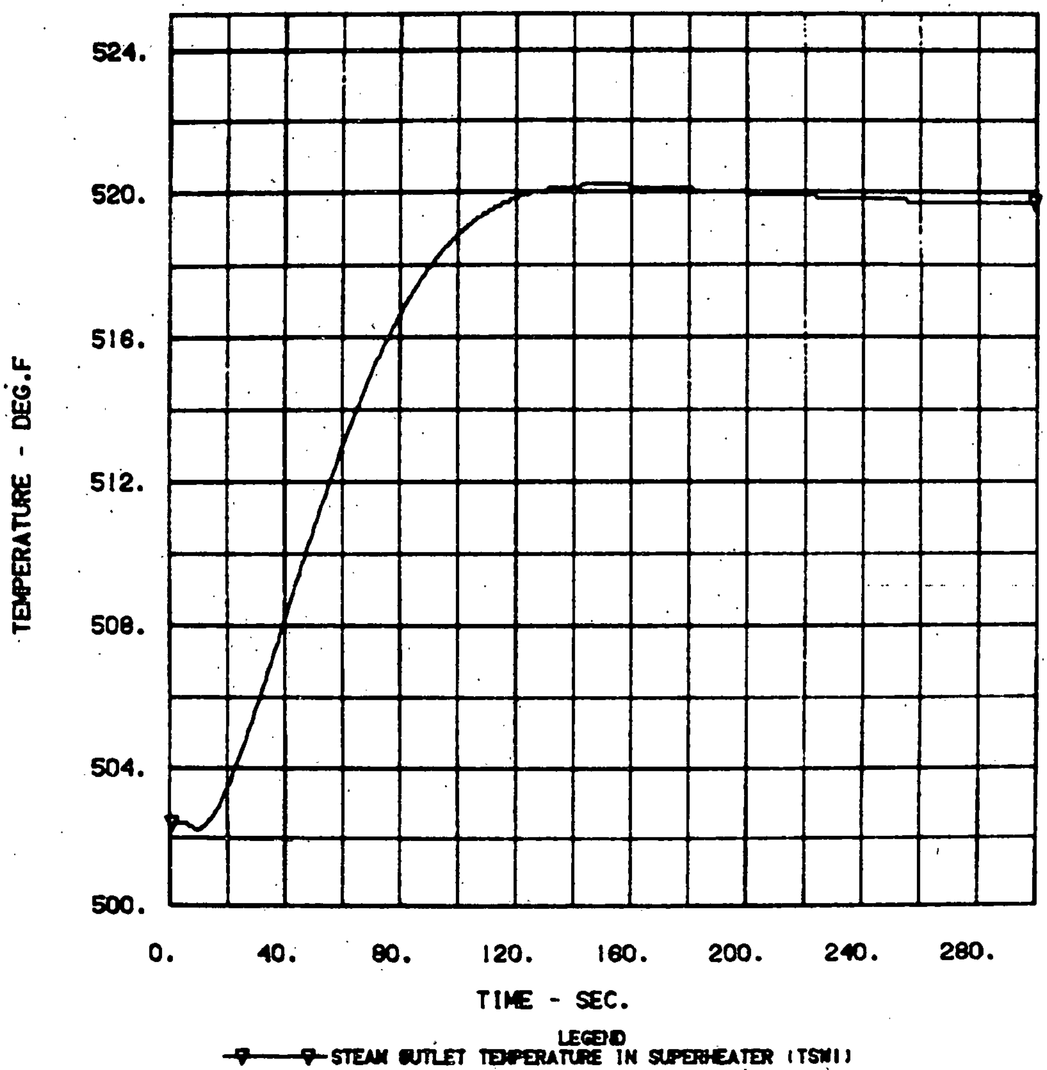


Figure 3.6-37. Superheater Exit Steam Temperature Response to Oil Flow Step of -50 Percent

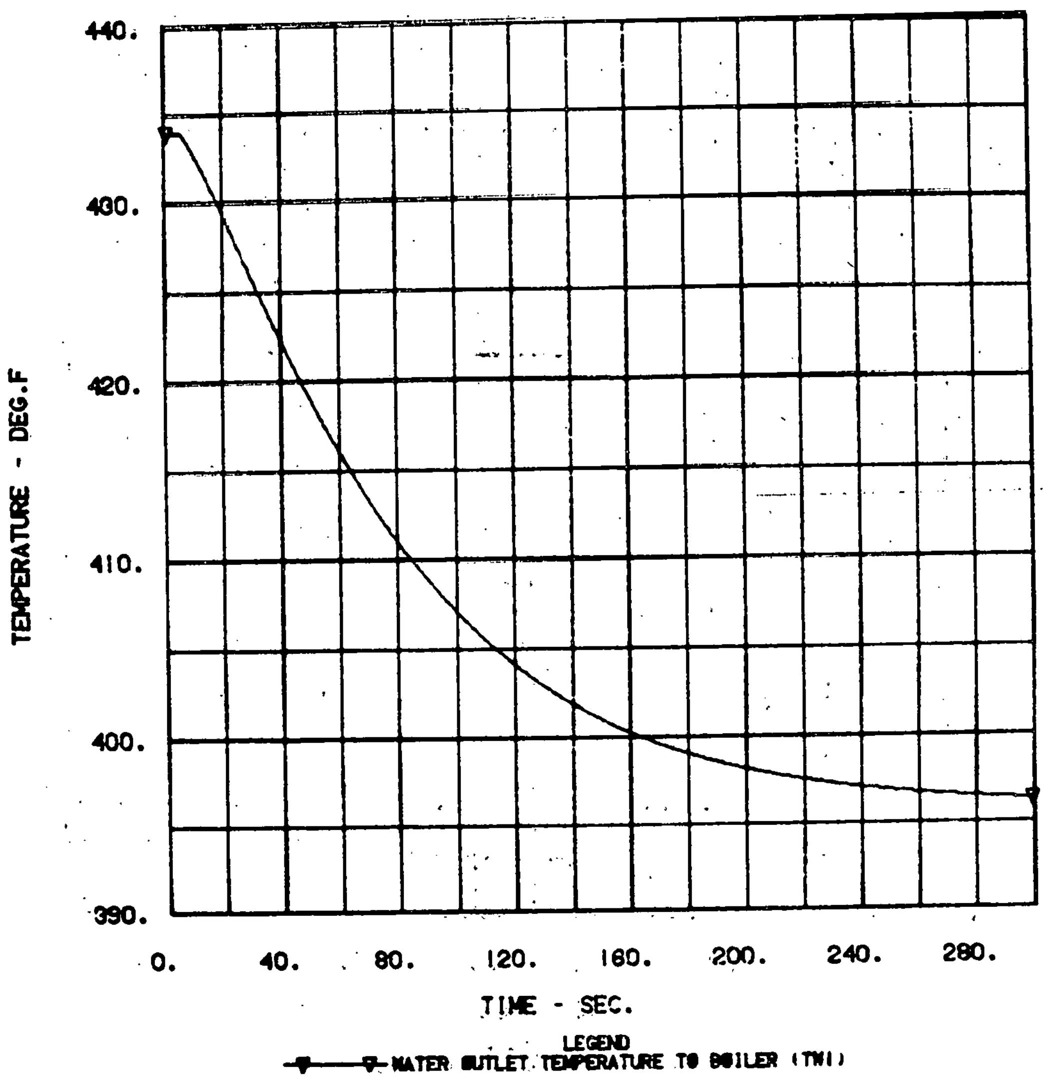


Figure 3.6-38. Preheater Exit Water Temperature Response to Oil Flow Step of -50 Percent

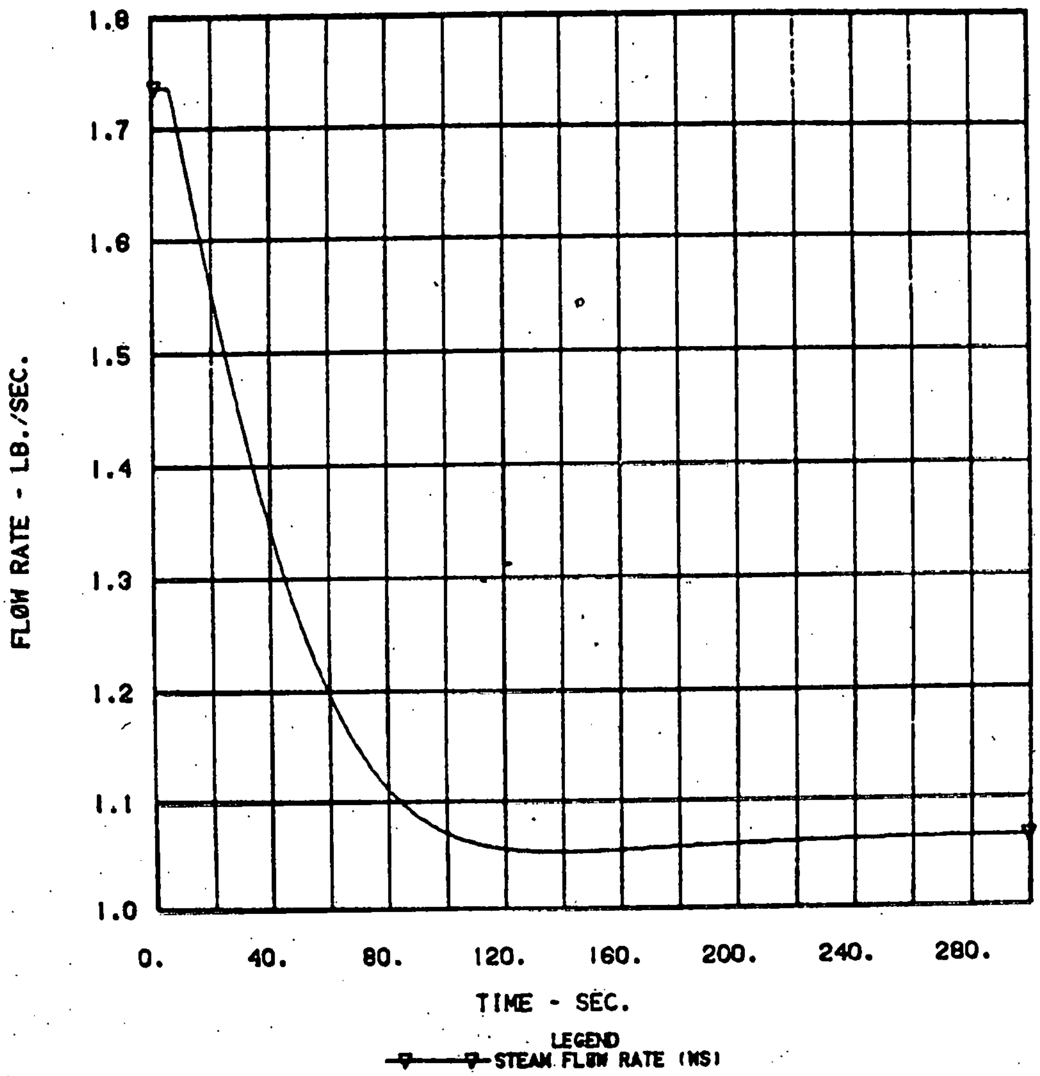


Figure 3.6-39. Response of Steam Flow to Oil Flow Step of -50 Percent

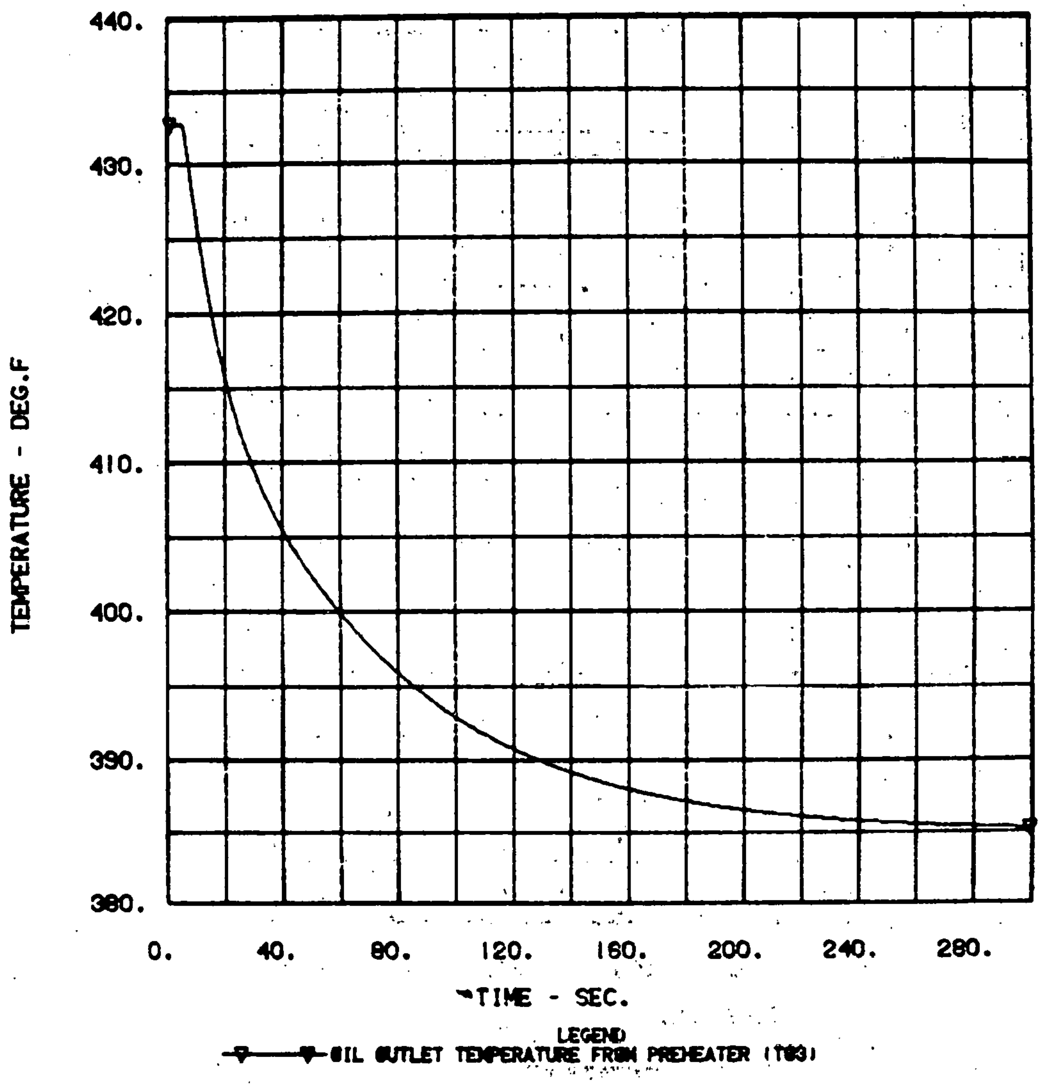


Figure 3.6-40. Preheater Exit Oil Temperature Response to Oil Flow Step of -50 Percent

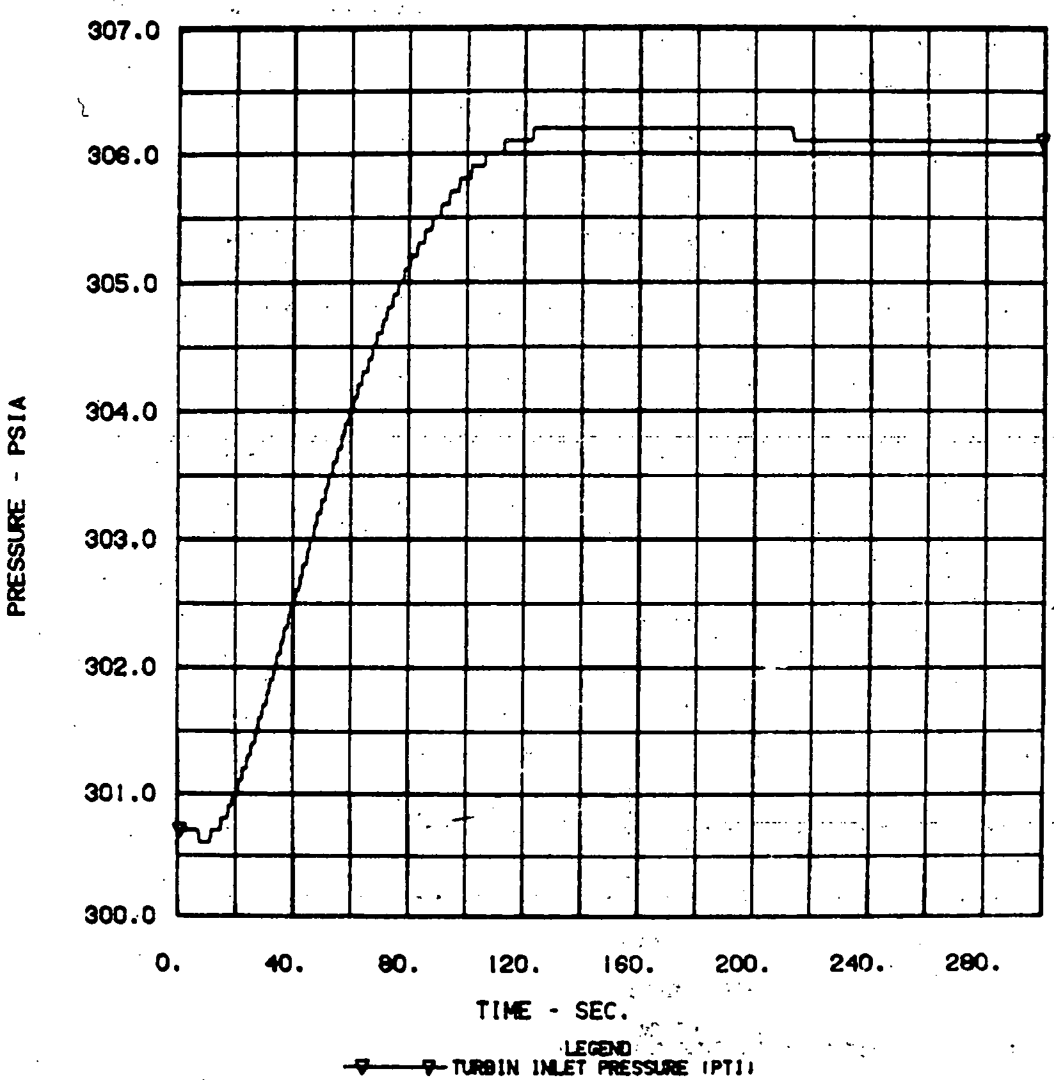


Figure 3.6-41. Turbine Inlet Pressure Response to Oil Flow Step of -50 Percent

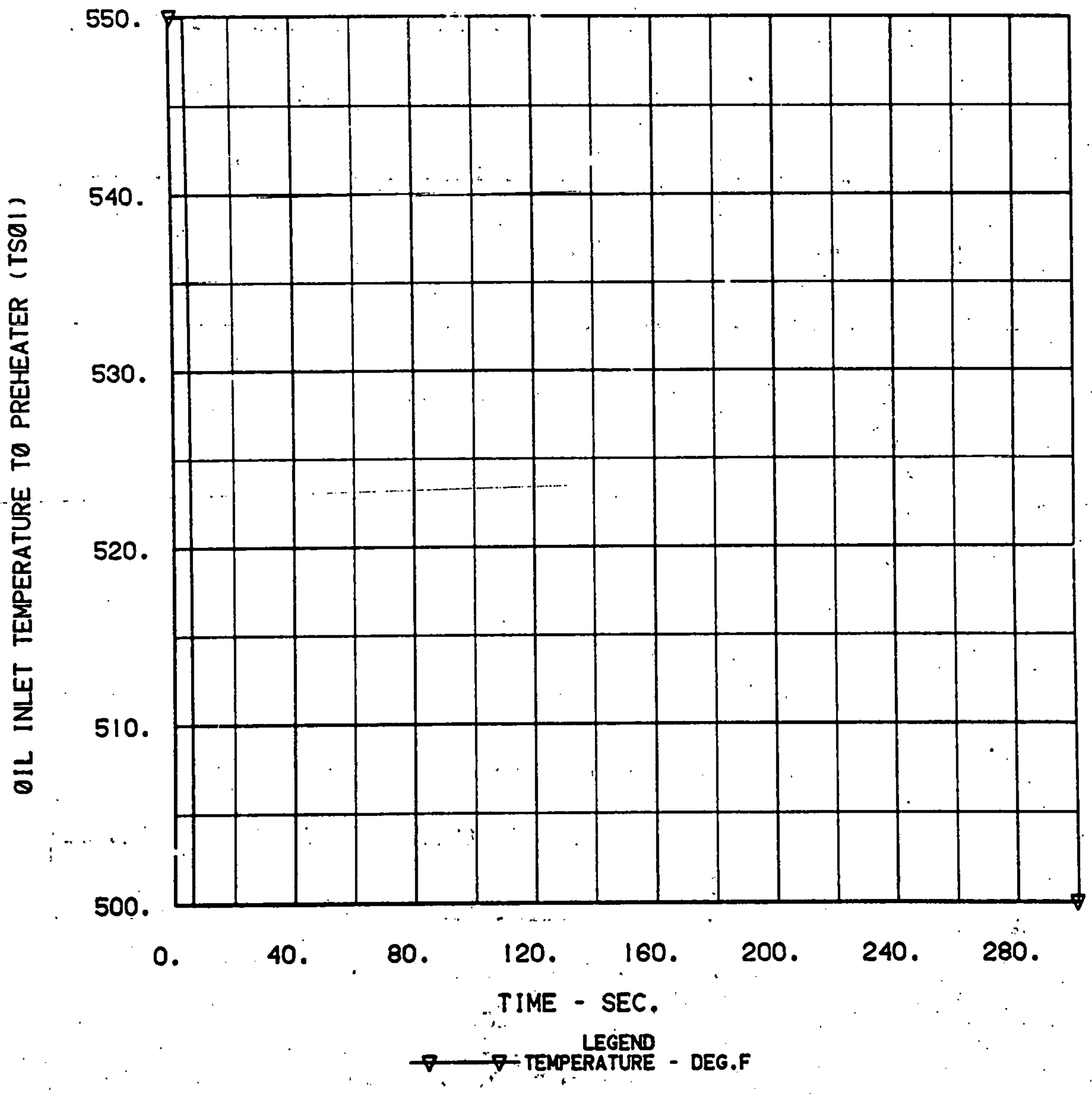


Figure 3.6-42. Oil Inlet Temperature Step -50 Degrees

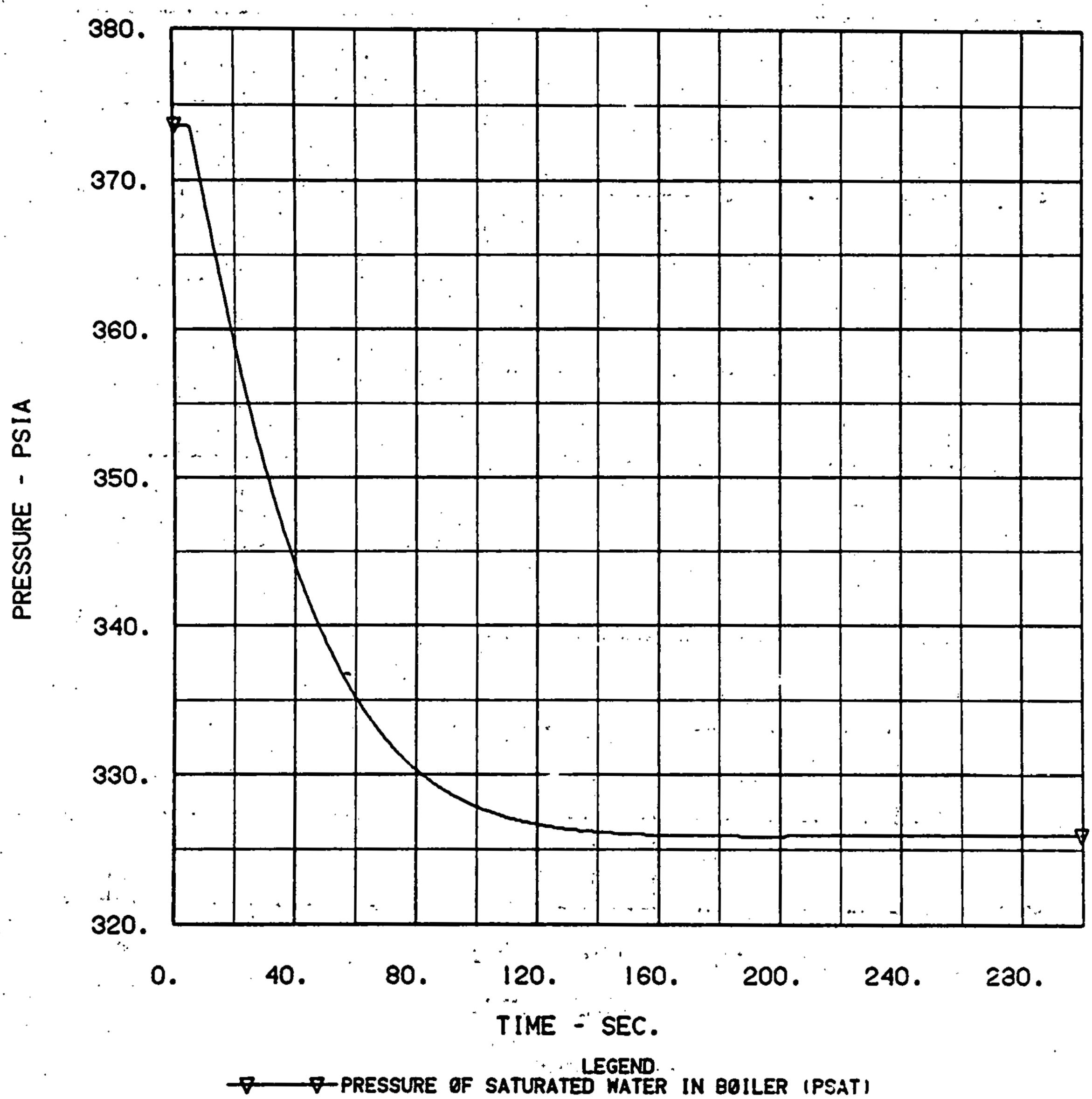


Figure 3.6-43. Boiler Steam Pressure Response to Oil Inlet Temperature Step of -50 Degrees

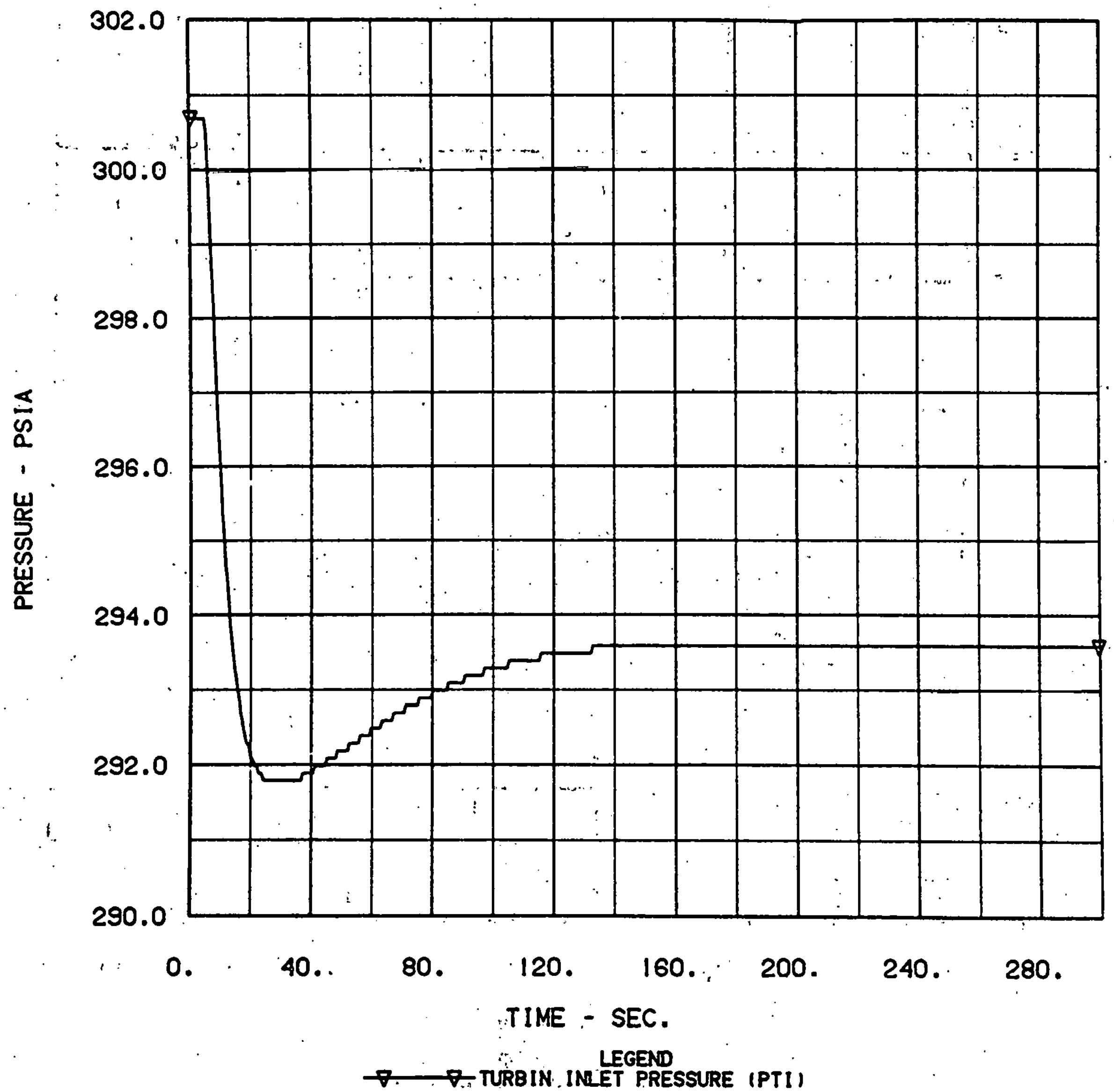


Figure 3.6-44. Turbine Inlet Pressure Response to Oil Inlet Temperature Step of -50 Degrees

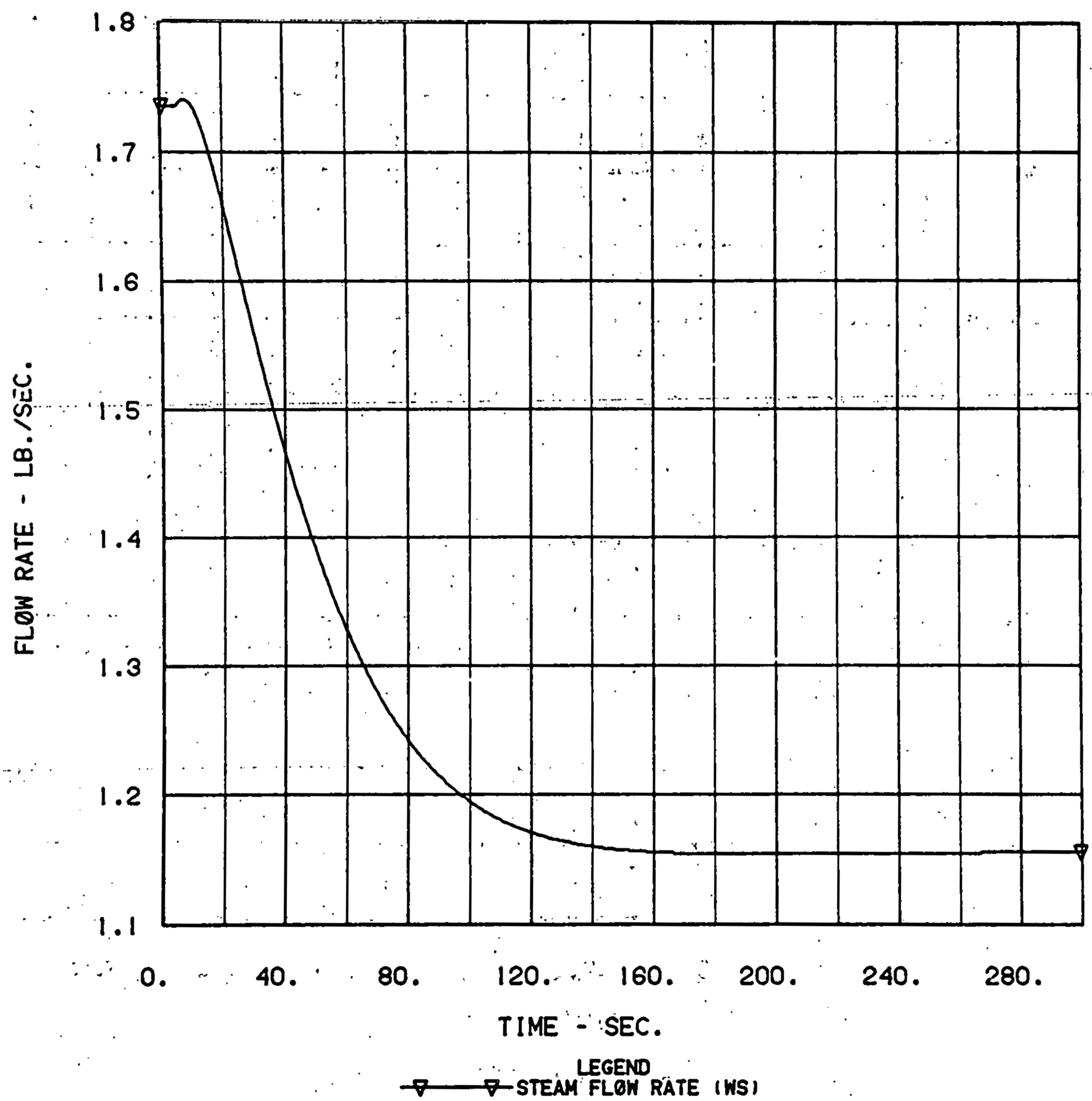


Figure 3.6-45. Steam Flow Rate Response to Oil Inlet Temperature Step of -50 Degrees

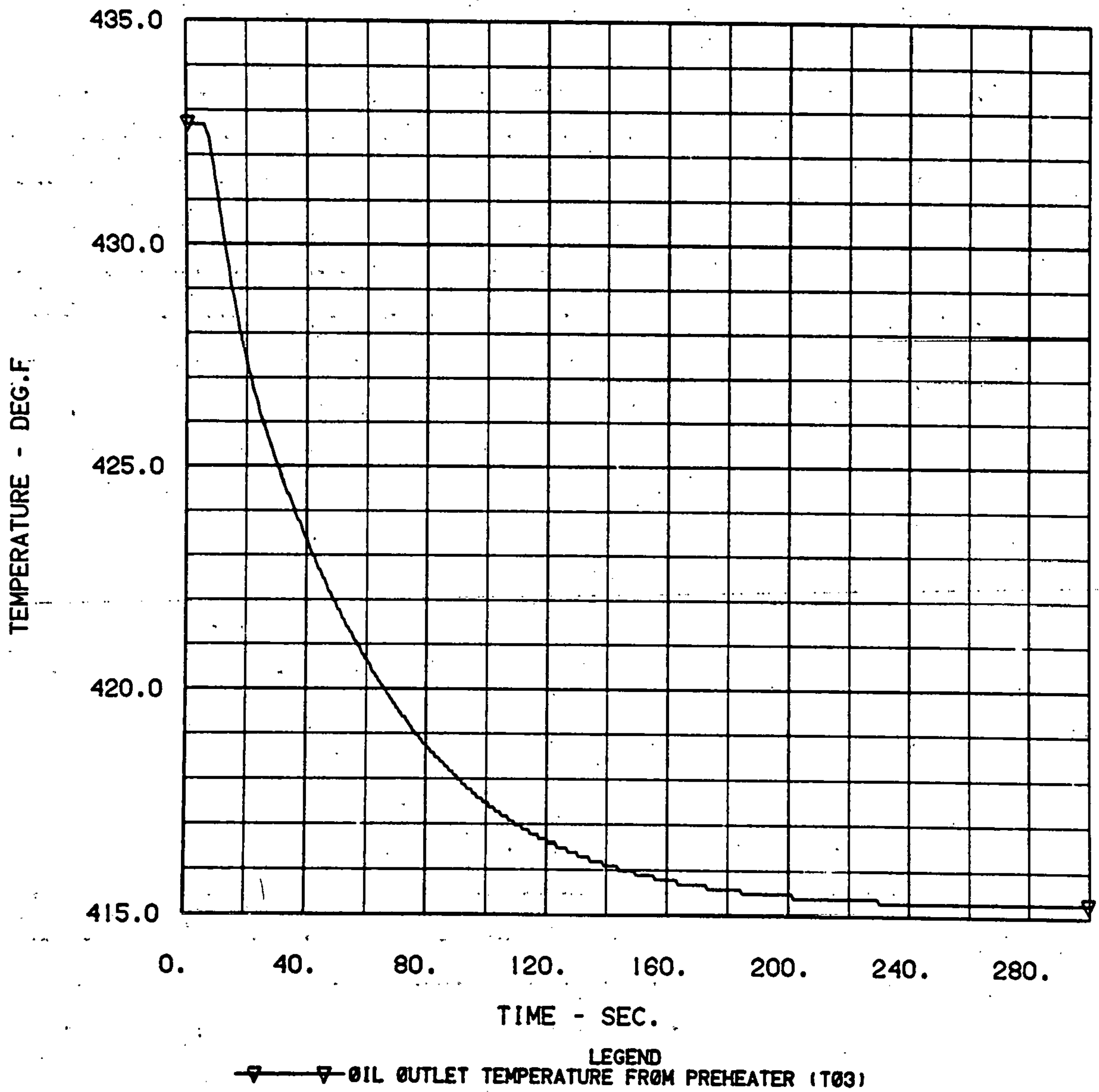


Figure 3.6-46. Preheater Exit Oil Temperature Response to Oil Inlet Temperature Step of -50 Degrees

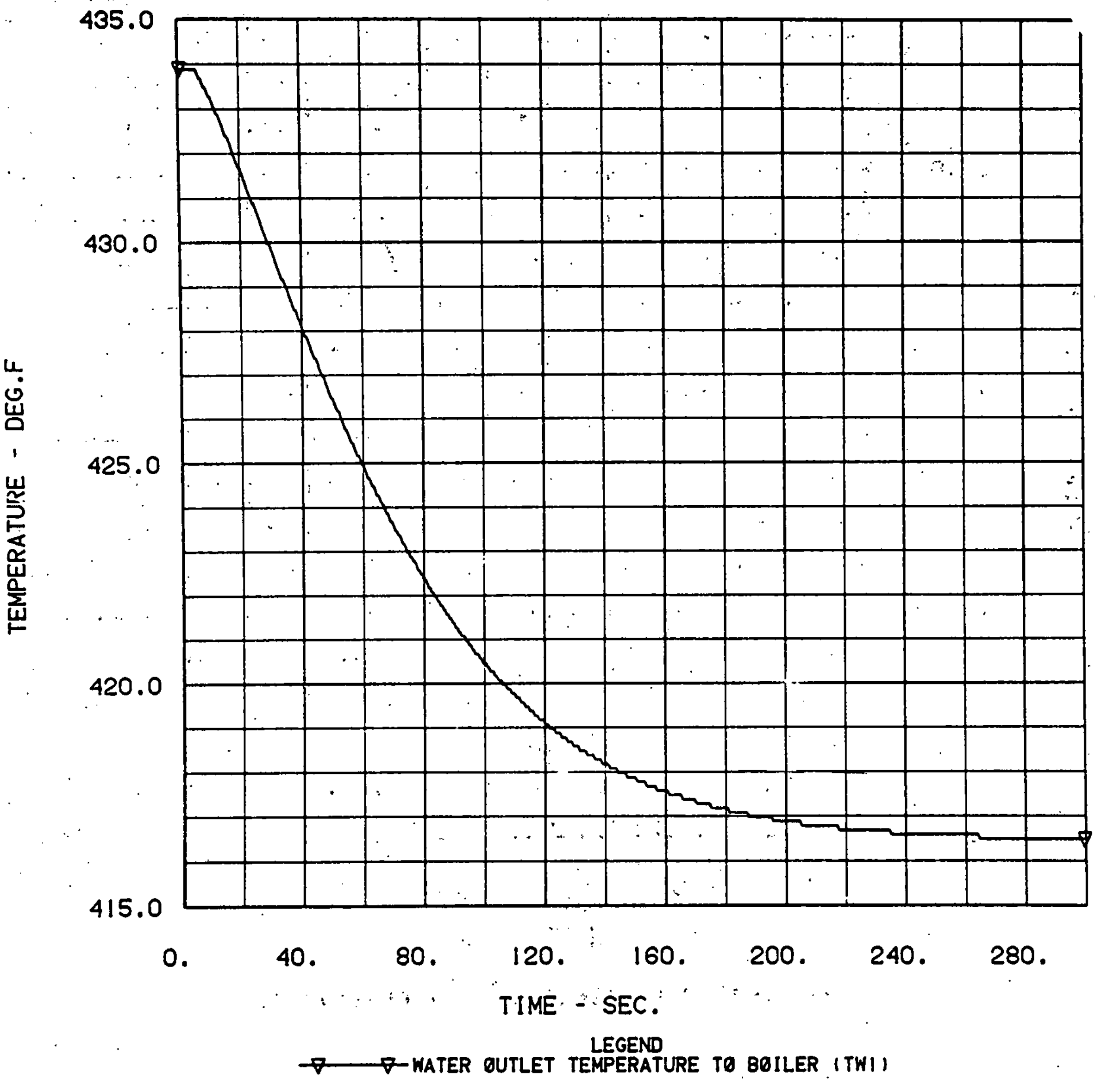


Figure 3.6-47. Preheater Exit Water Temperature Response to Oil Inlet Temperature Step of -50 Degrees

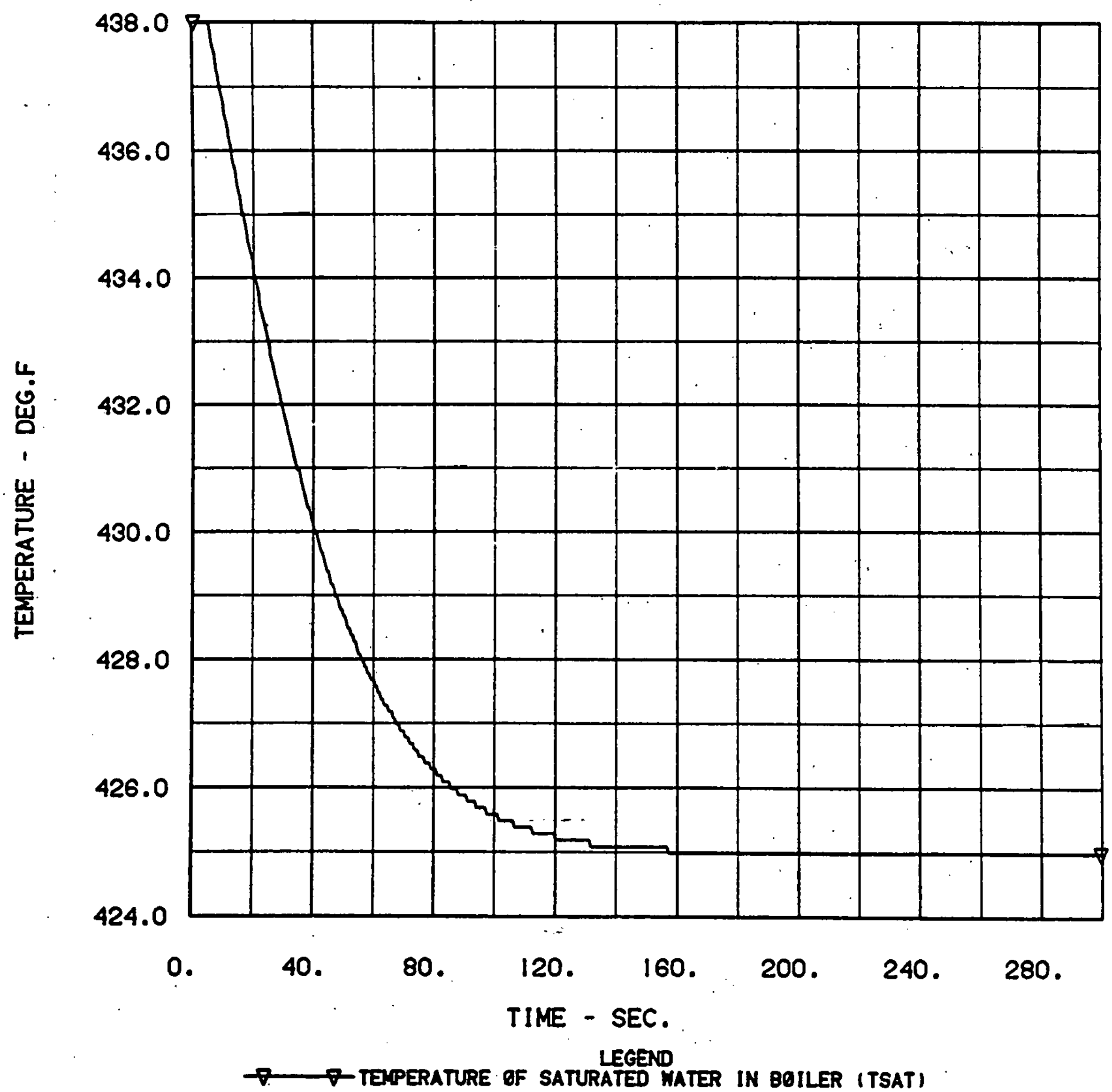


Figure 3.6-48. Boiler Steam Temperature Response to Oil Inlet Temperature Step of -50 Degrees

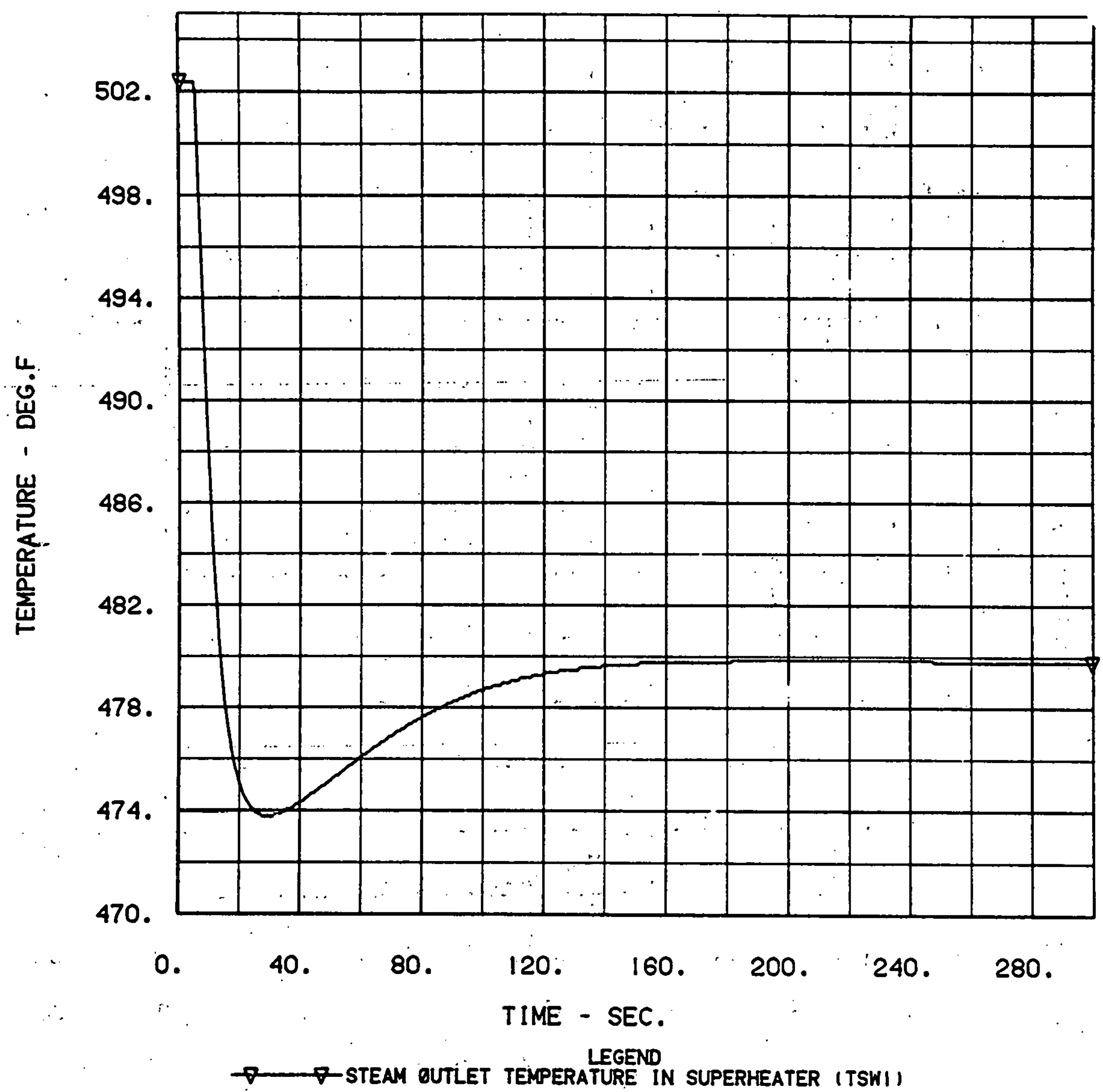


Figure 3.6-49. Superheater Exit Steam Temperature Response to Oil Inlet Temperature Step of -50 Degrees

OPEN LOOP FREQUENCY RESPONSE

Preliminary frequency response results were calculated for the power conversion subsystem to determine system dynamic characteristics and relative stability of the system with respect to control variables such as oil flow rate and temperature, and feedwater flow rate and temperature. No controllers were used for these responses so the results are open loop results. Bode plots of response of steam generator parameters to feedwater flow, oil flow and feedwater temperature are shown in Figures 3.6-50 thru 3.6-63. The steady state conditions are for the high temperature peak mode (heating season).

CLOSED LOOP FREQUENCY RESPONSE

Based on the open loop system frequency response data, proportional and integral control elements described in Section 3.6.9.6 were added to the system transient for model validation and for preliminary transient analysis.

Figures 3.6-64 thru 3.6-67 are Bode plots of closed loop frequency response of the power conversion subsystem. The initial conditions are identical to the high temperature peaking mode (heating season).

The results shown are responses of system pressures with respect to change in boiler pressure demand with all PCS control elements active.

As indicated proportional control action is needed to provide more phase margin in the pressure control elements. This will be incorporated as system hardware and design sizing is updated. As well as control design for other operation modes.

3.6.4.2.2 SOLAR COLLECTOR FIELD TRANSIENT ANALYSIS

Analysis of the solar collector field was conducted using the model of the field and the controller described in Section 3.6.9.1 of this report.

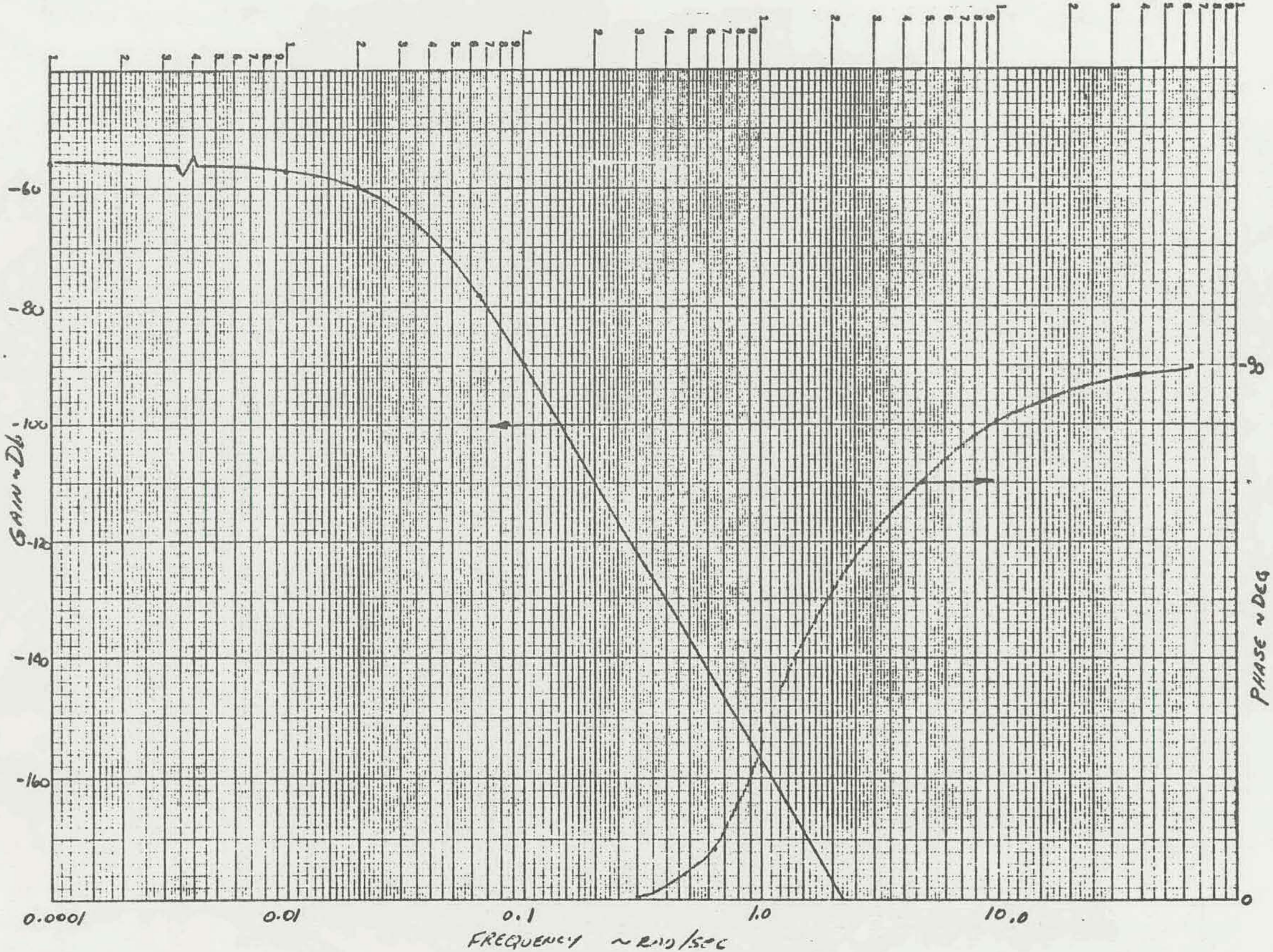


Figure 3.6-50 Open Loop Frequency Response of Superheater Exit Pressure to Feedwater Temperature

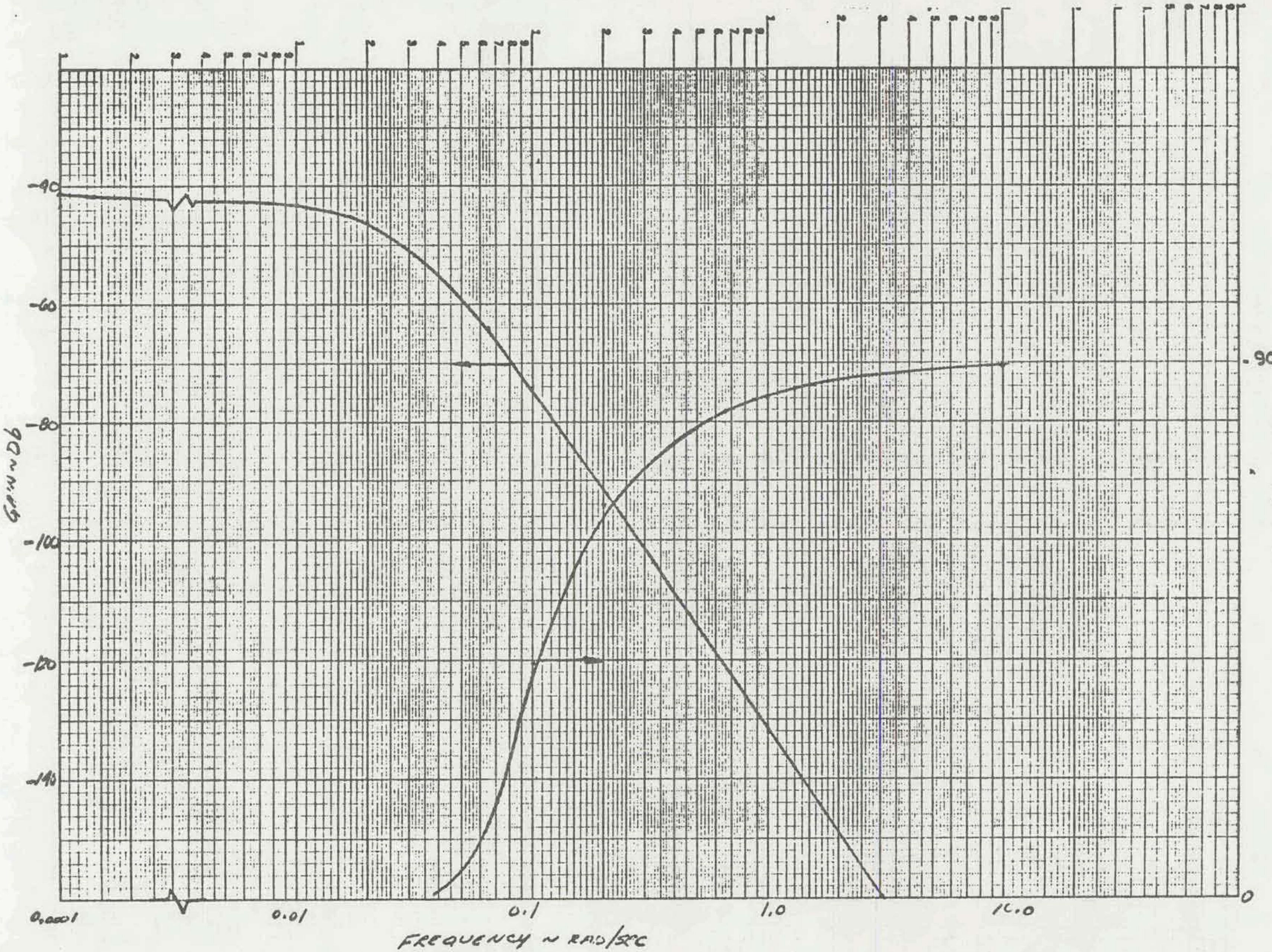


Figure 3.6-51 Open Loop Frequency Response of Boiler Steam Temperature to Feedwater Temperature

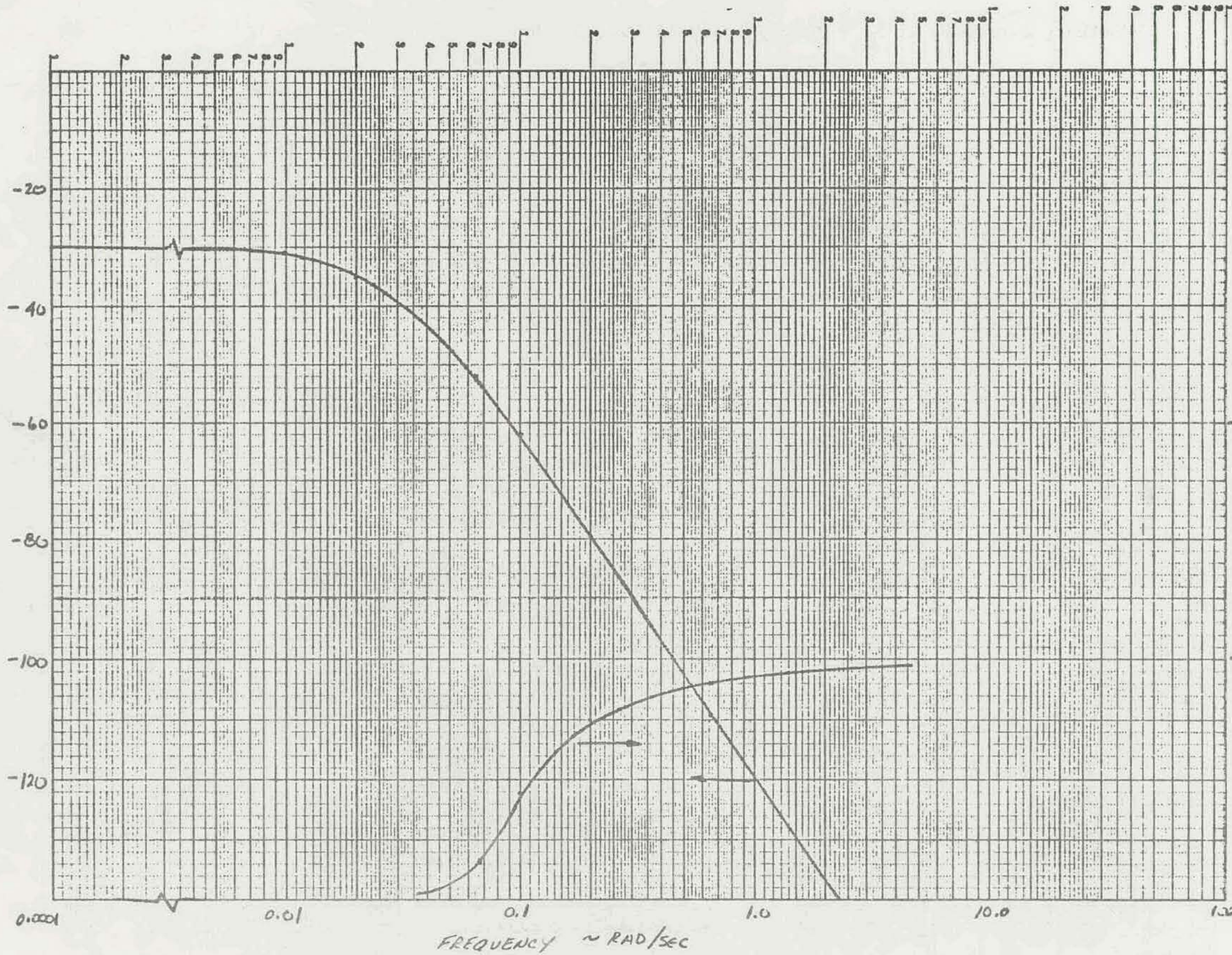


Figure 3.6-52 Open Loop Frequency Response of Boiler Pressure to Feedwater Temperature

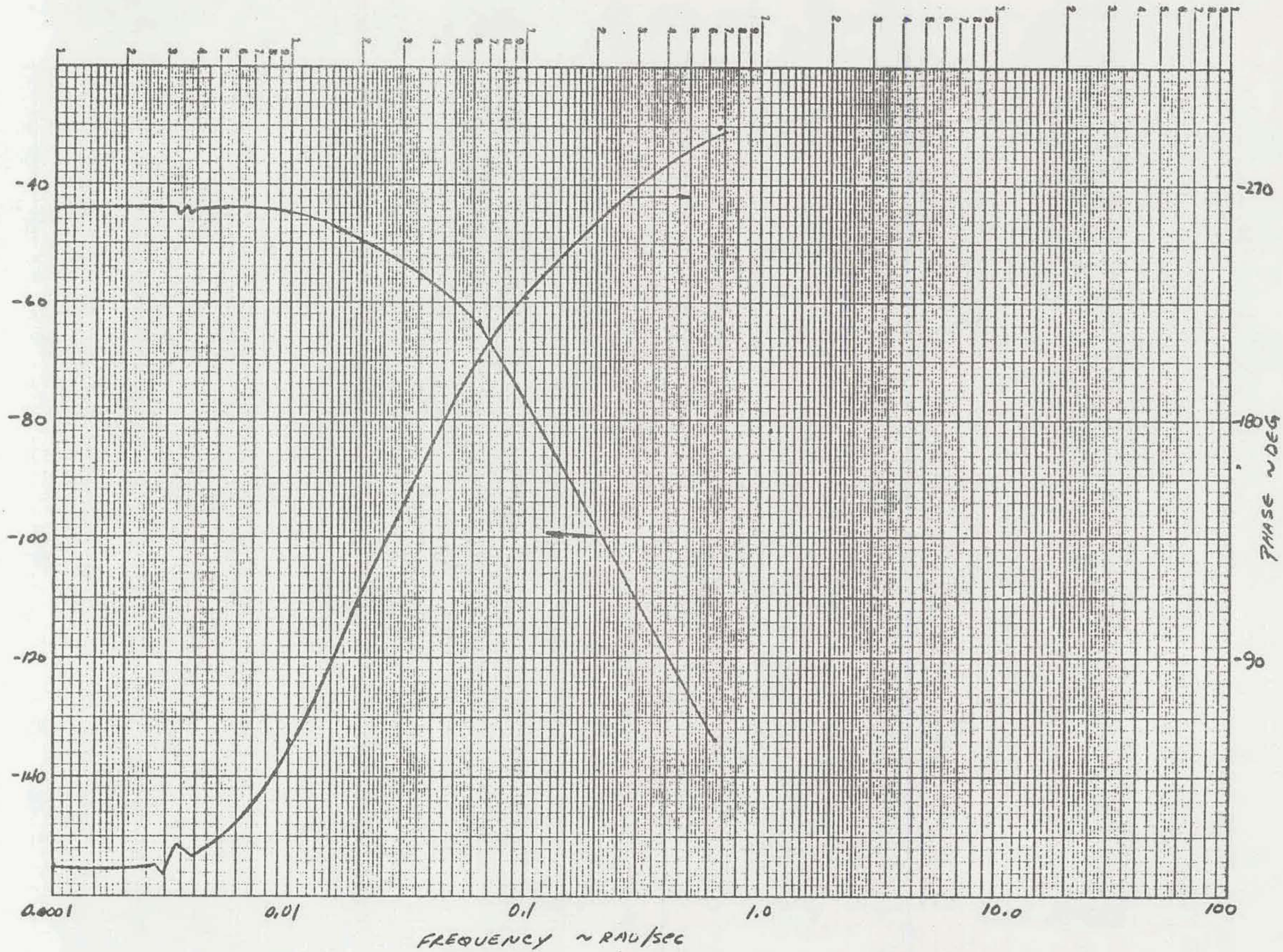


Figure 3.6-53 Open Loop Frequency Response of Superheater Exit Temperature to Feedwater Temperature

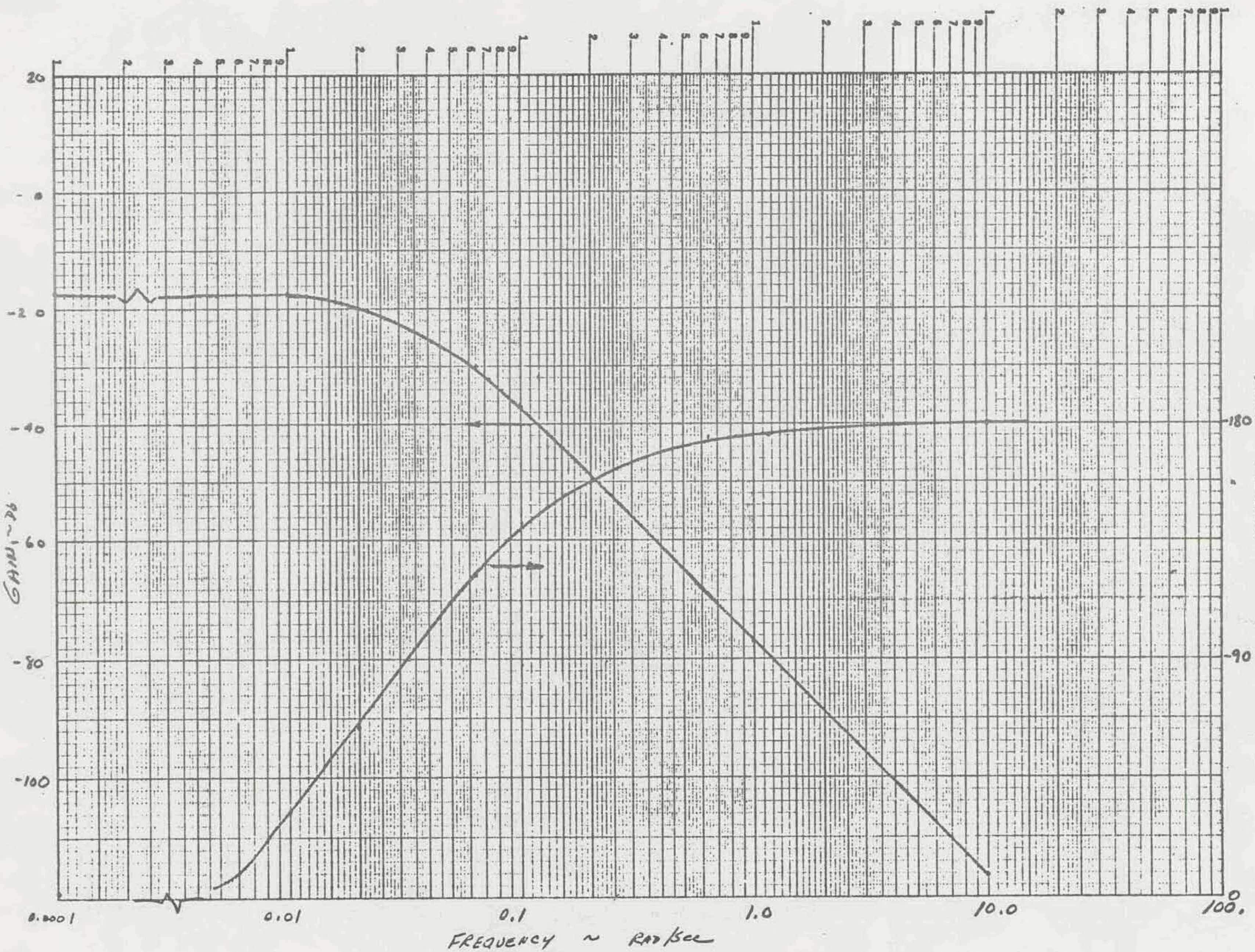


Figure 3.6-54 Open Loop Frequency Response of Preheater (Water) Exit Temperature to Feedwater Temperatur

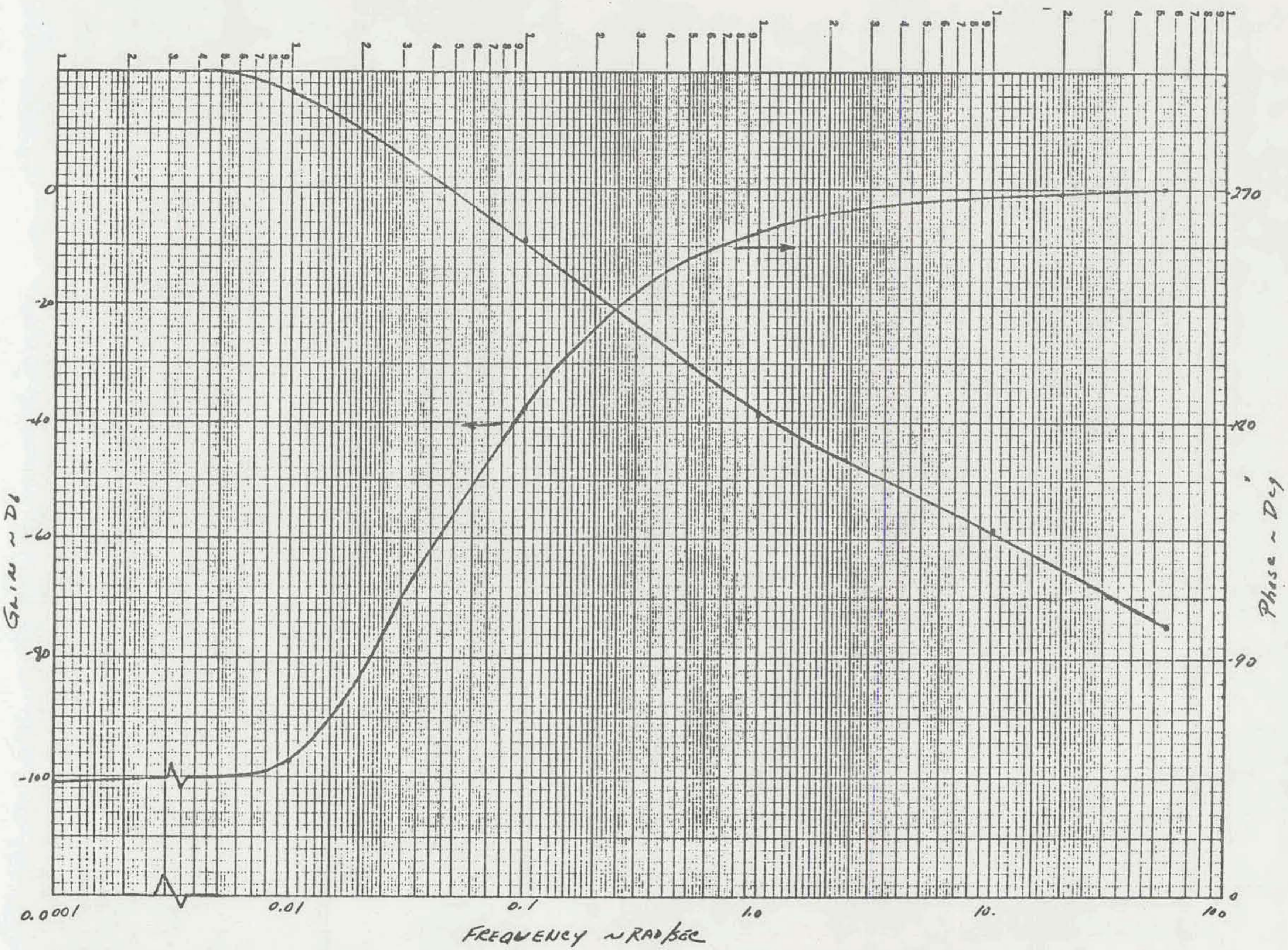


Figure 3.6-55 Open Loop Frequency Response of Boiler Pressure to Feedwater Flow

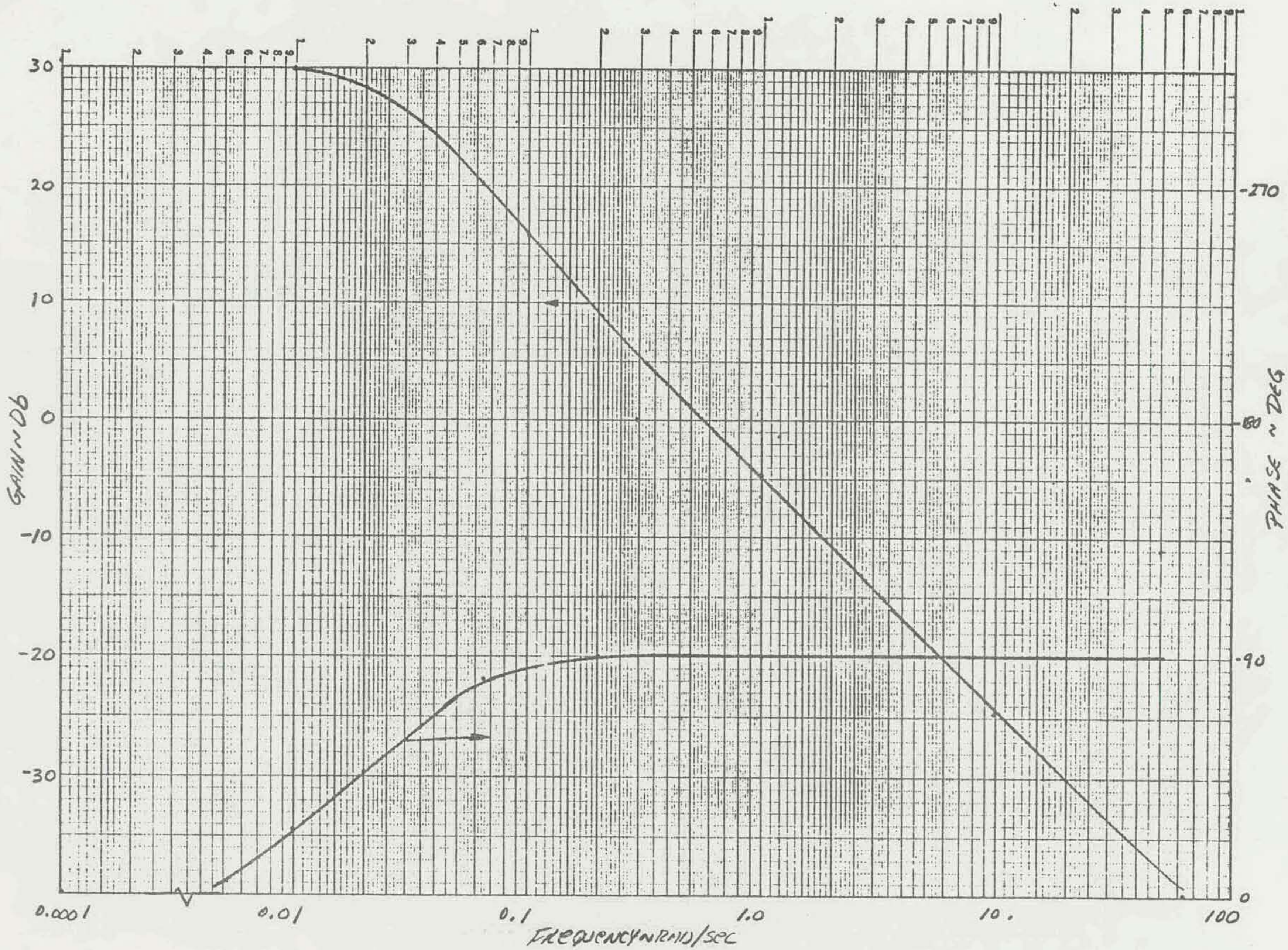


Figure 3.6-56 Open Loop Frequency Response of Preheater Exit Water Temperature to Feedwater Flow

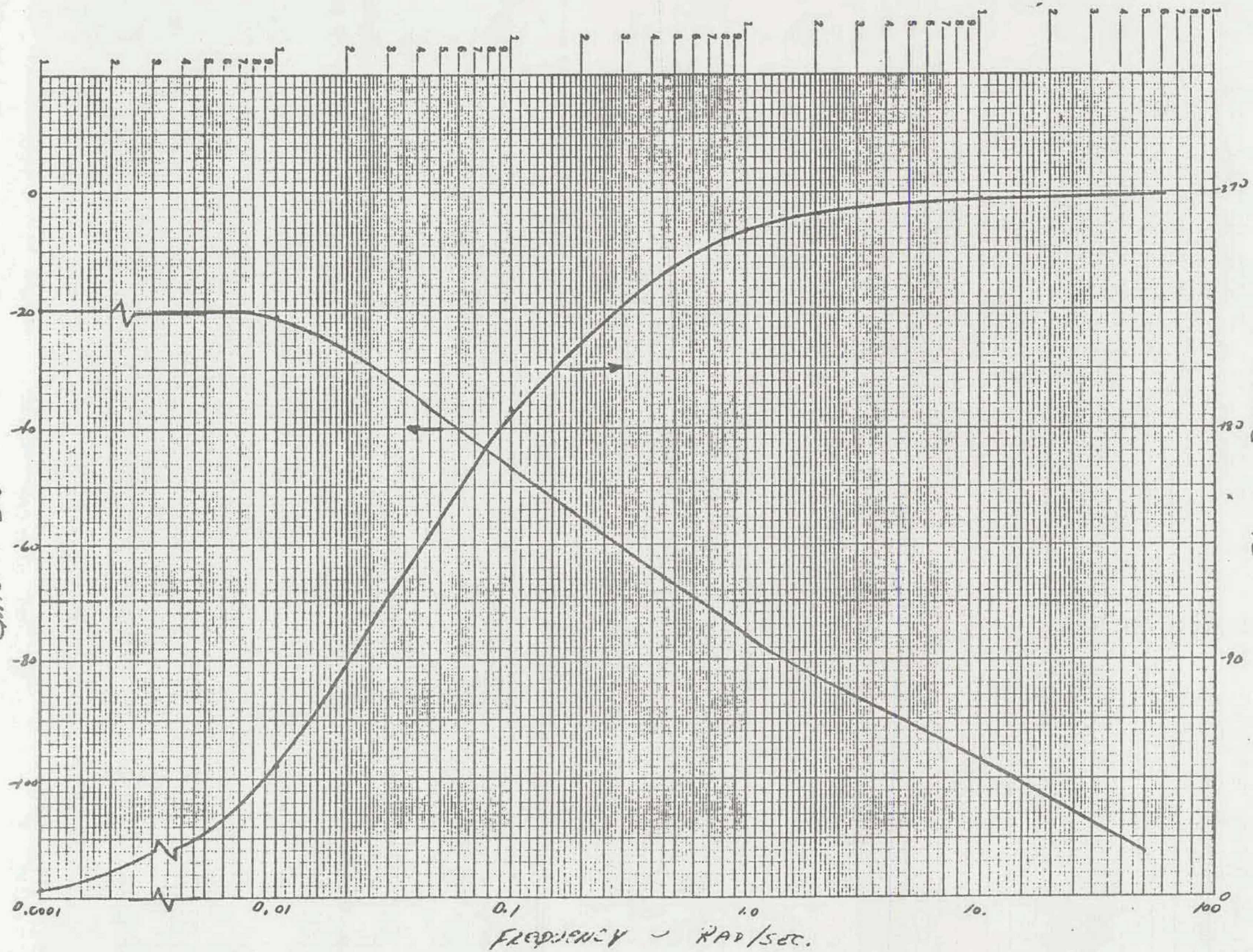


Figure 3.6-57 Open Loop Frequency Response of Boiler Steam Temperature to Feedwater Flow

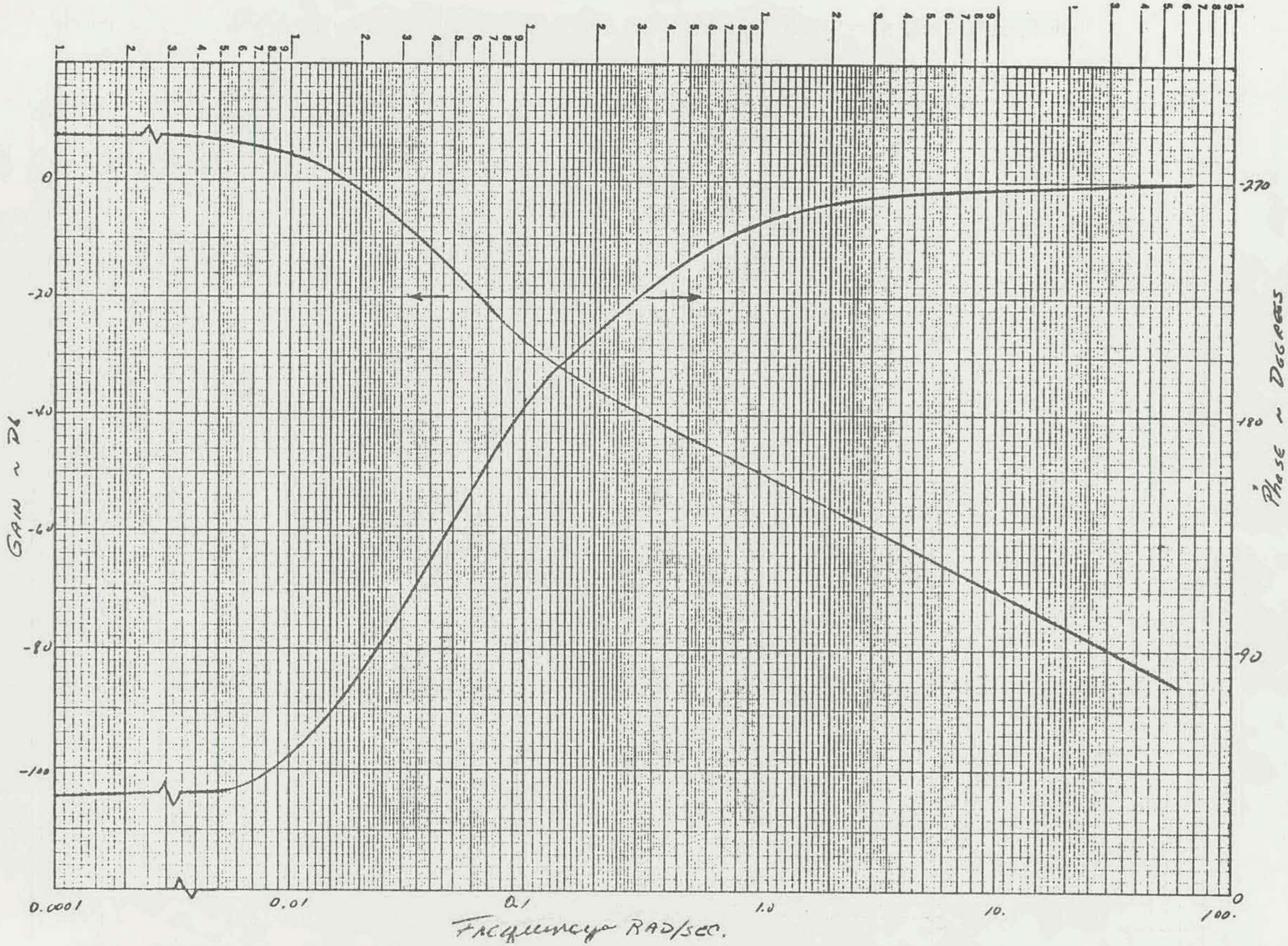


Figure 3.6-58 Open Loop Frequency Response of Steam Flow Rate to Feedwater Flow

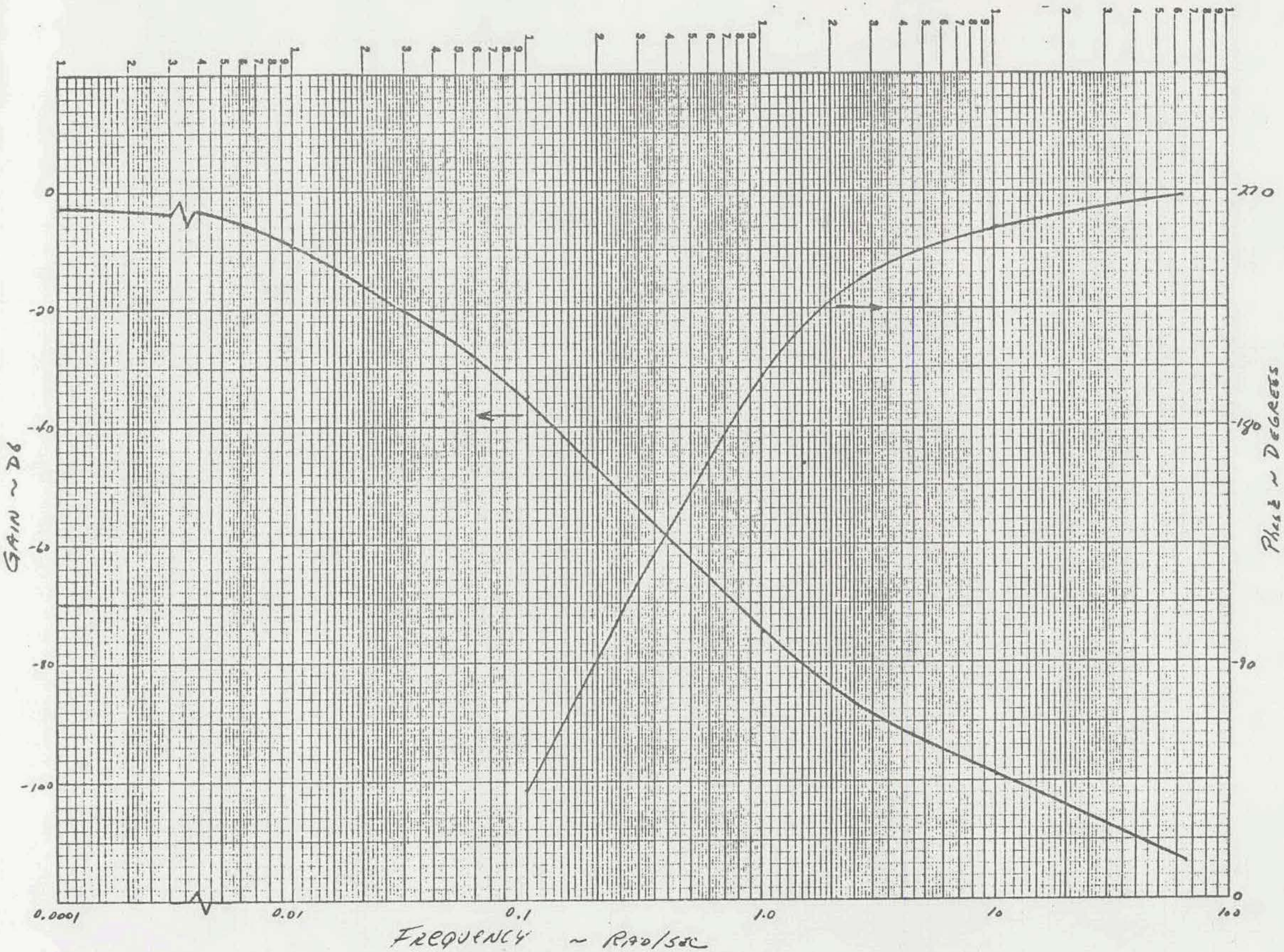


Figure 3.6-59 Open Loop Frequency Response of Superheater Exit Steam Pressure to Feedwater Flow

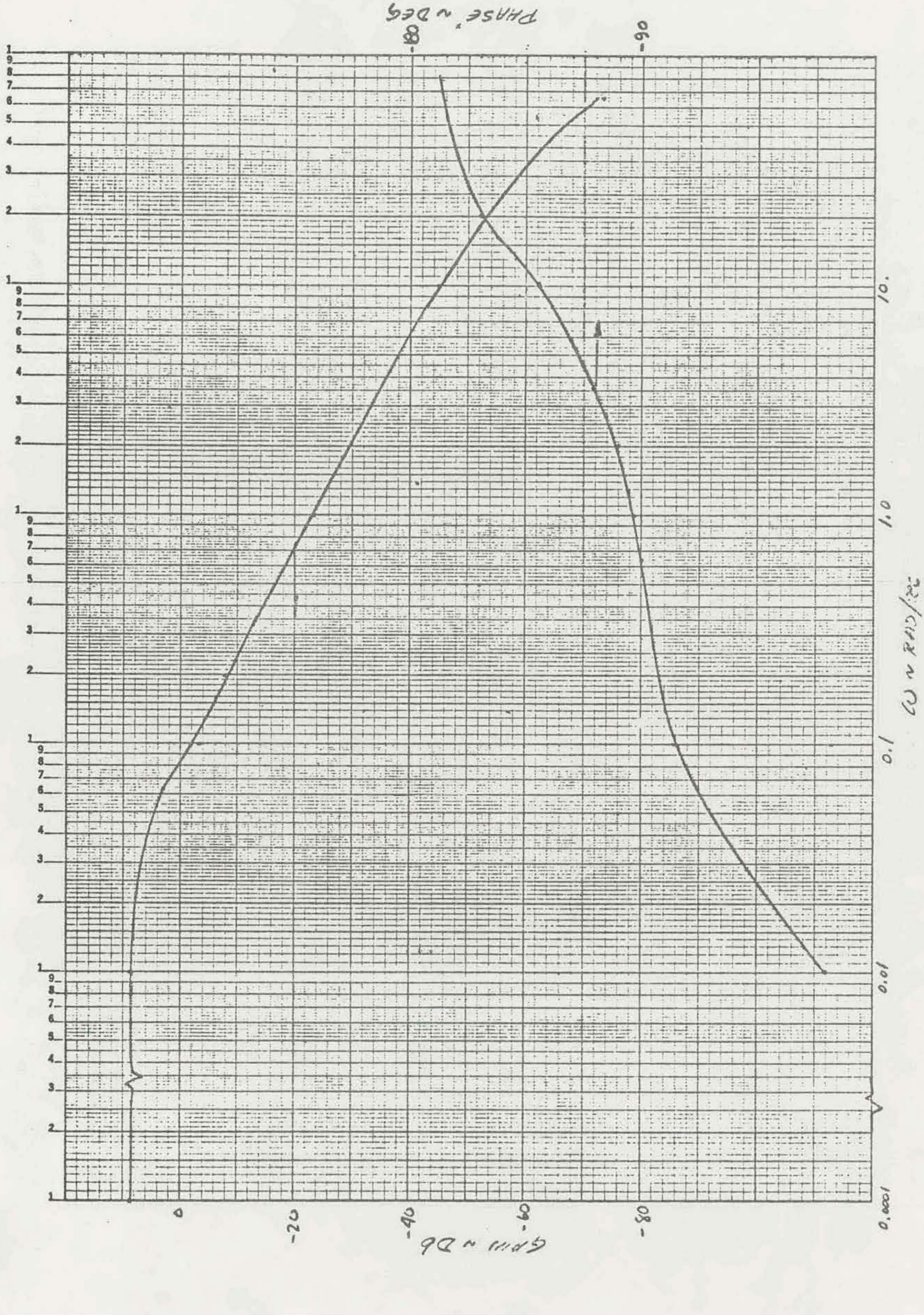


Figure 3.6-60 Open Loop Frequency Response of Boiler Pressure to Oil Flow Rate

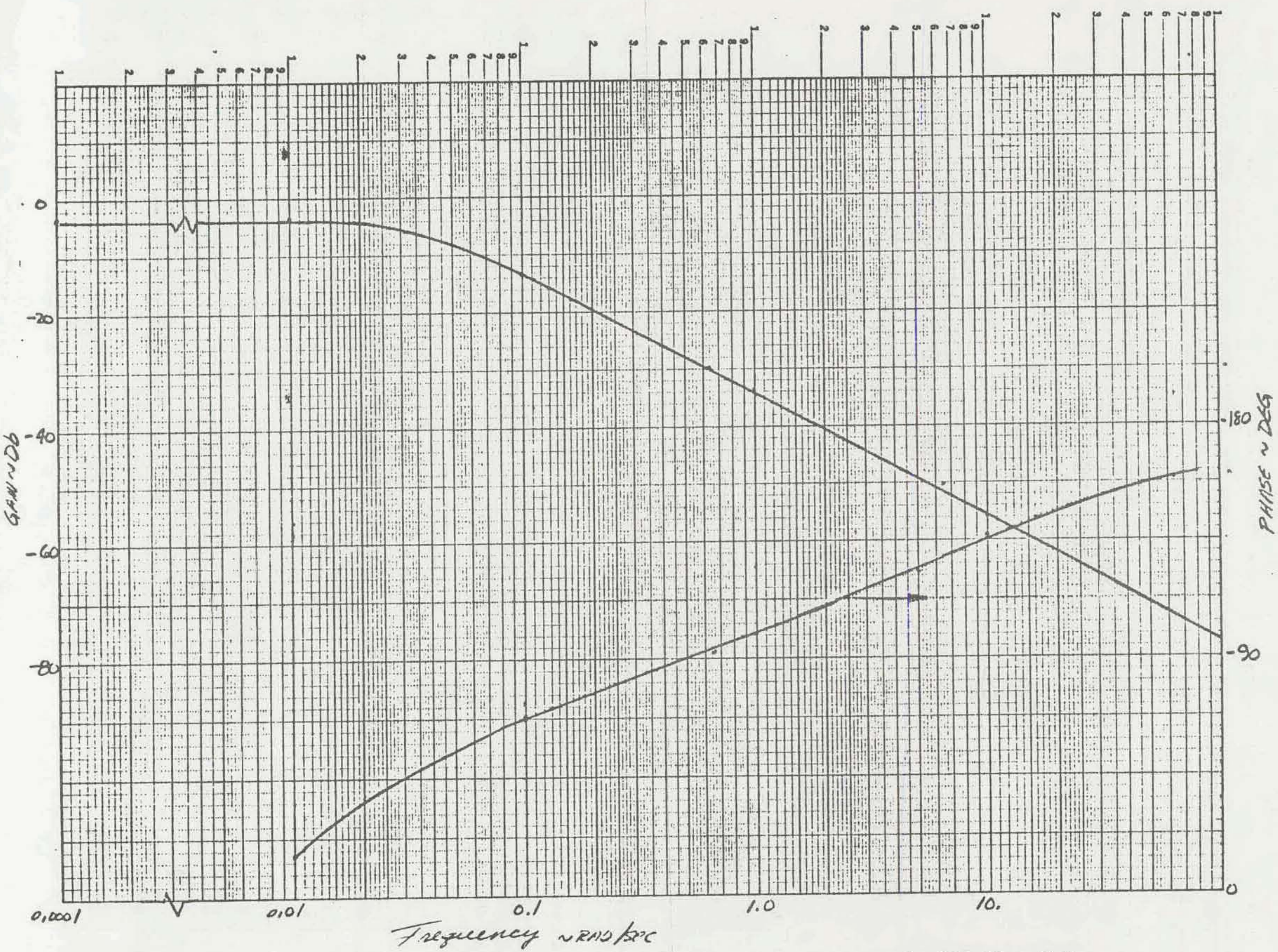


Figure 3.6-61 Open Loop Frequency Response of Boiler Steam Temperature to Oil Flow Rate

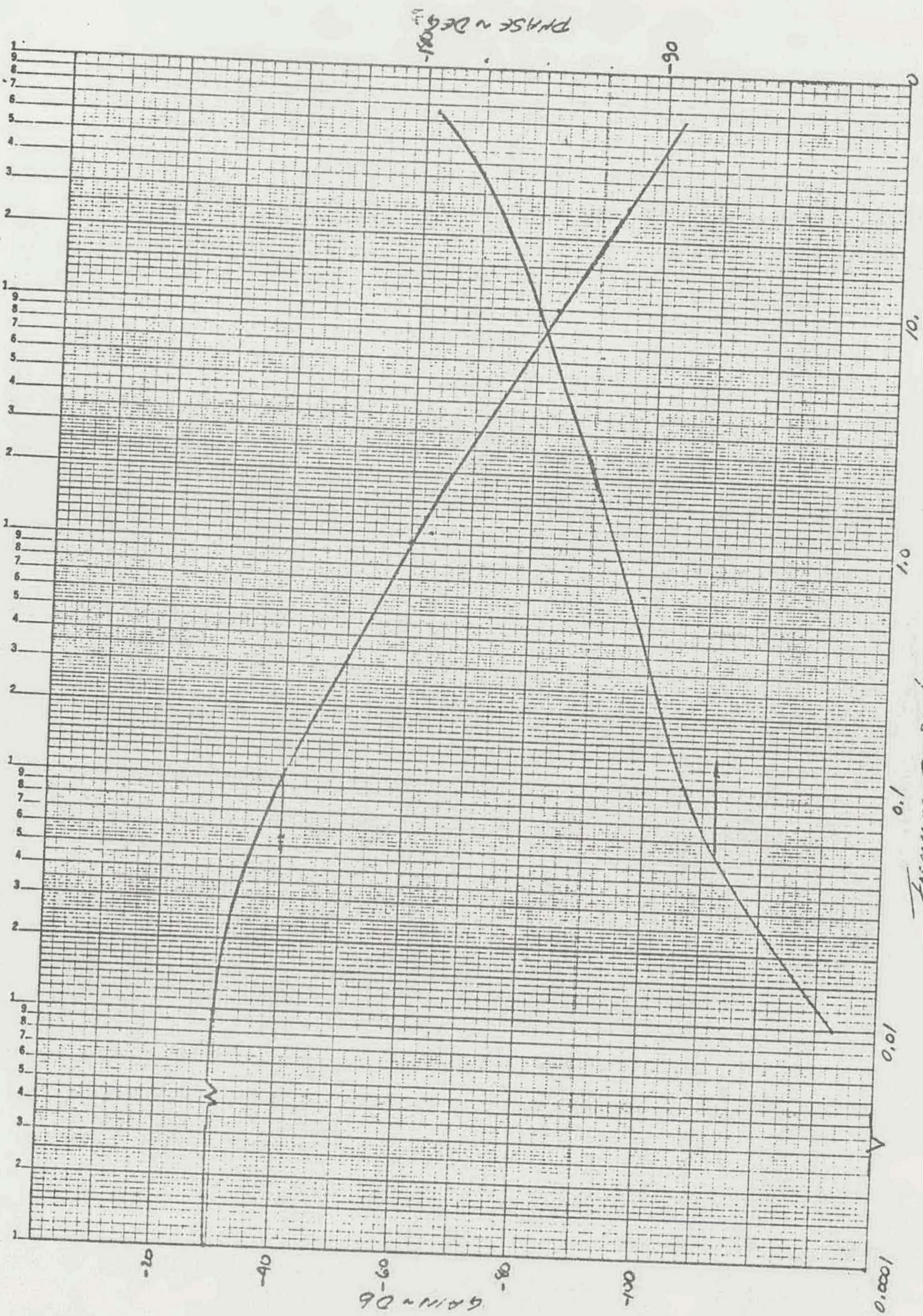


Figure 3.6-62 Open Loop Frequency Response of Steam Flow Rate to Oil Flow Rate

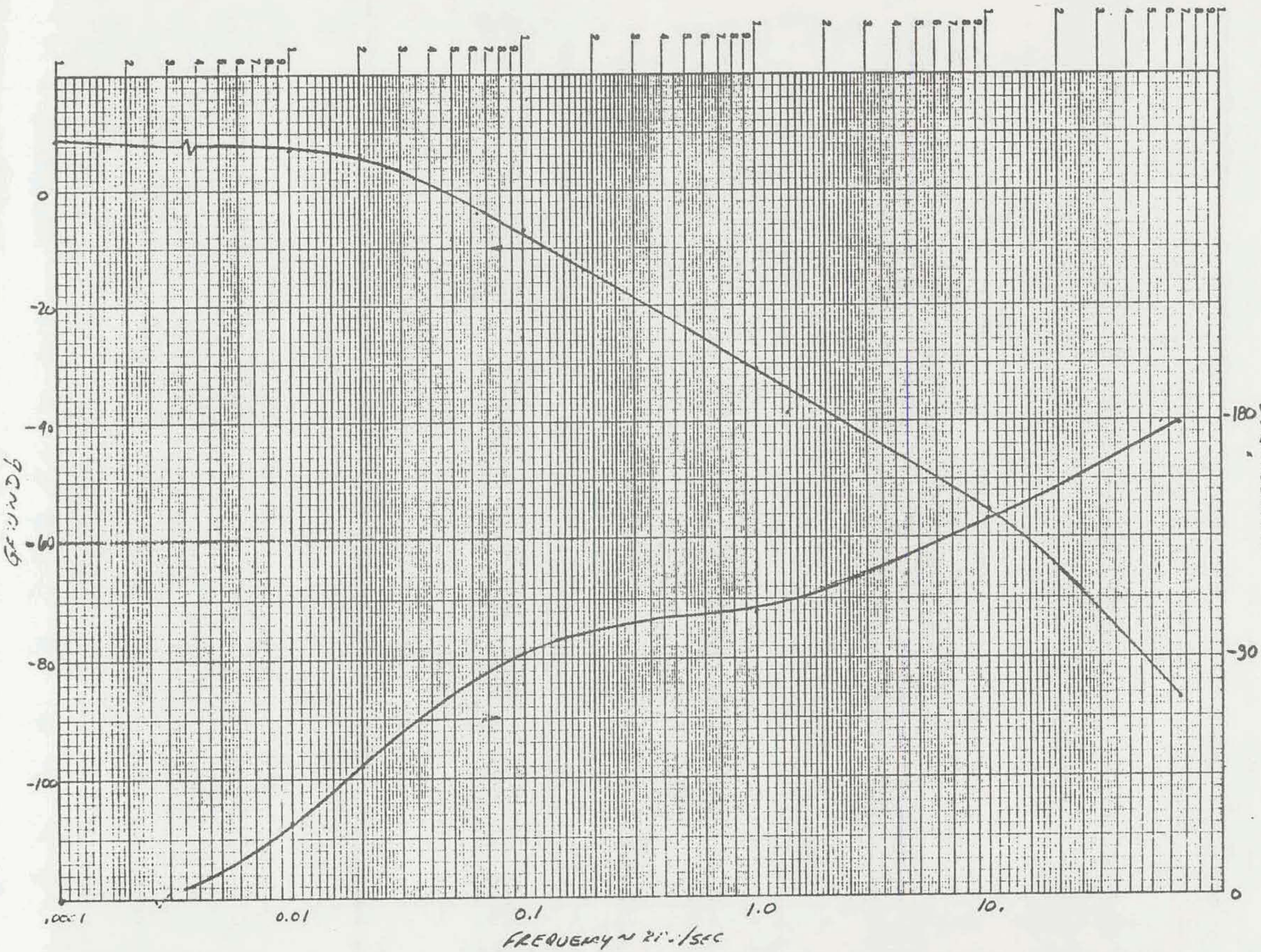


Figure 3.6-63 Open Loop Frequency Response of Preheater Exit Water Temperature to Oil Flow Rate

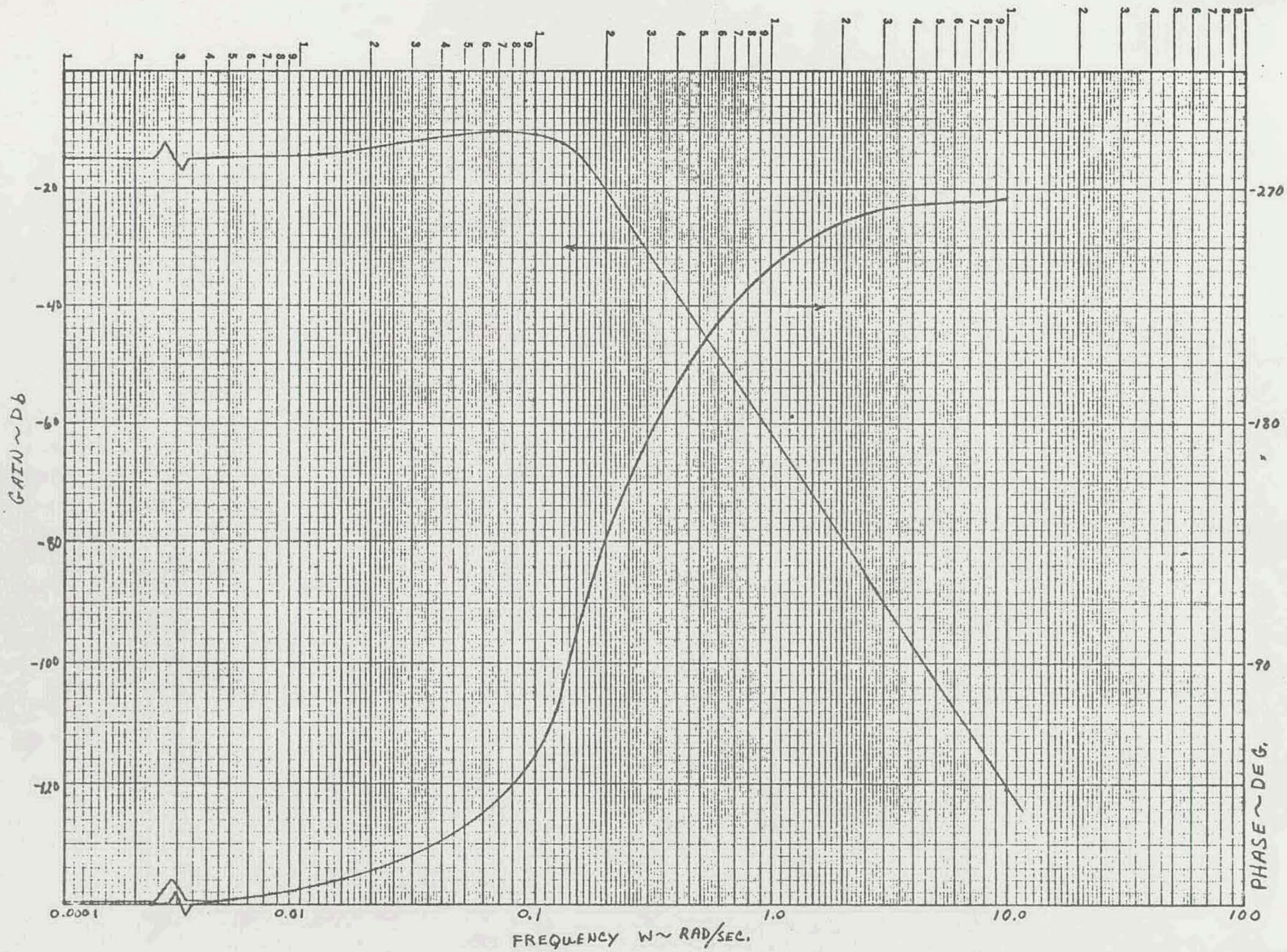


Figure 3.6-64 Closed Loop Frequency Response of Low Pressure Header Pressure to Boiler Pressure Demand

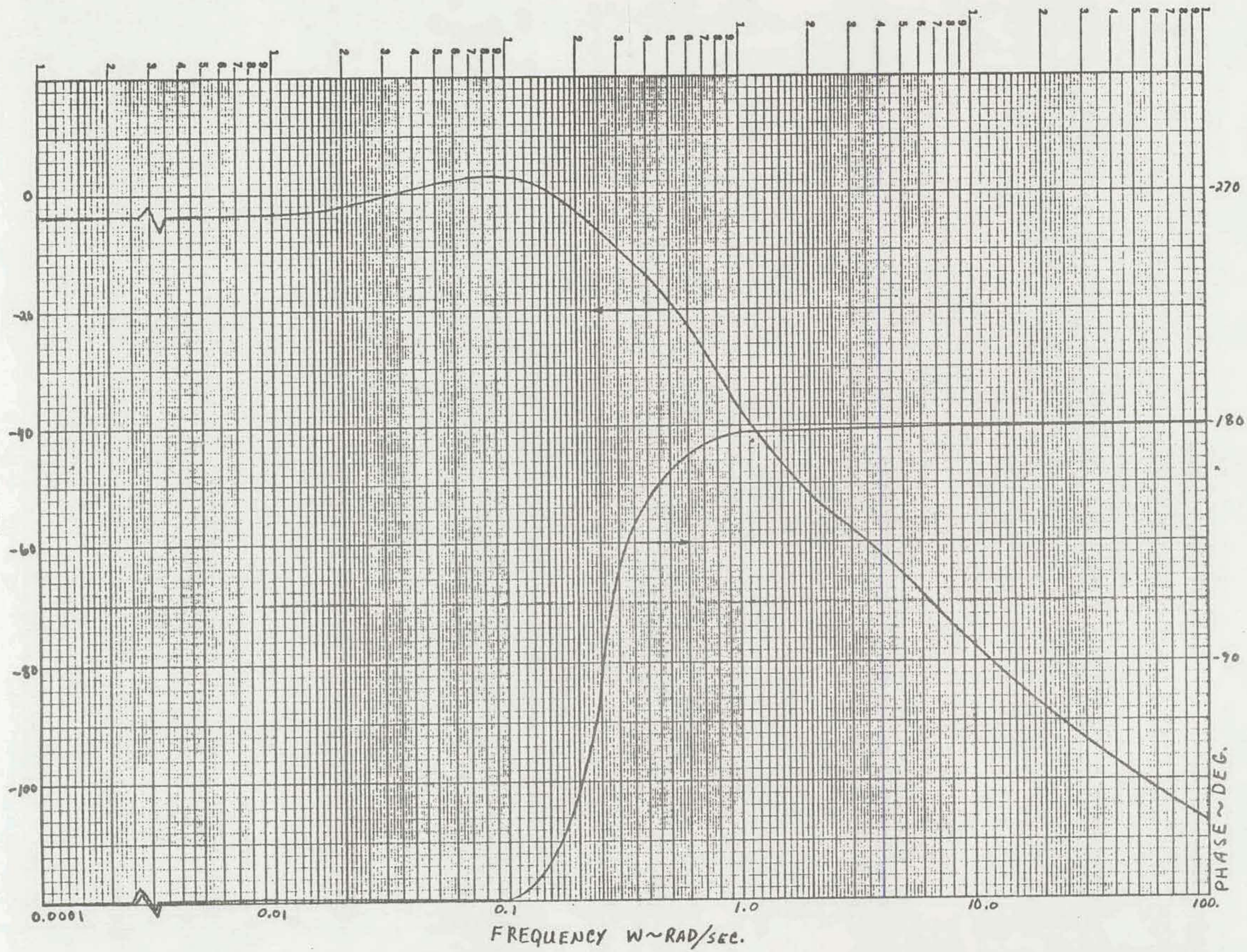


Figure 3.6-65 Closed Loop Response of High Pressure Turbine Inlet Pressure to Boiler Pressure Demand

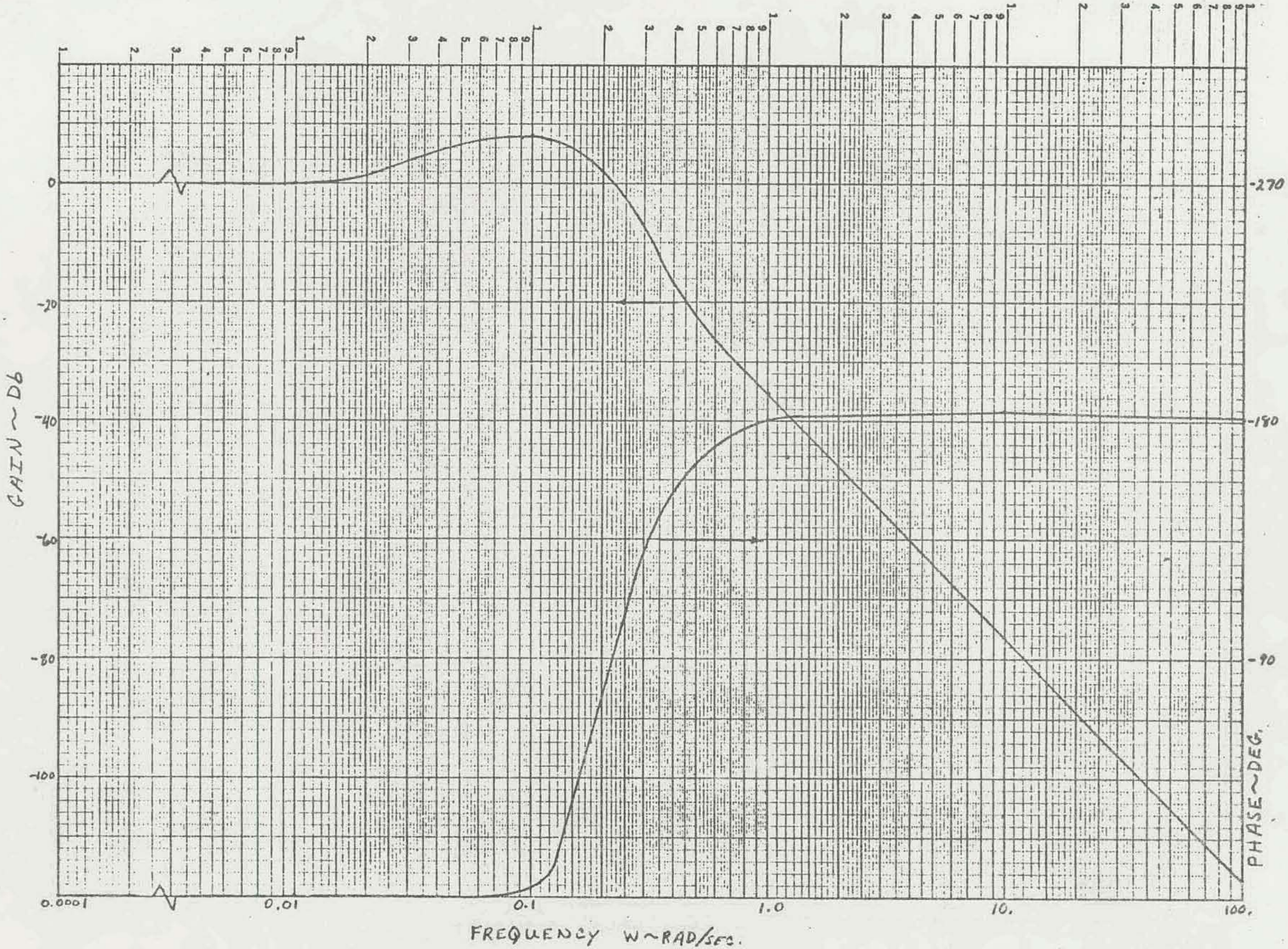


Figure 3.6-66 Closed Loop Frequency Response of Boiler Pressure to Boiler Pressure Demand

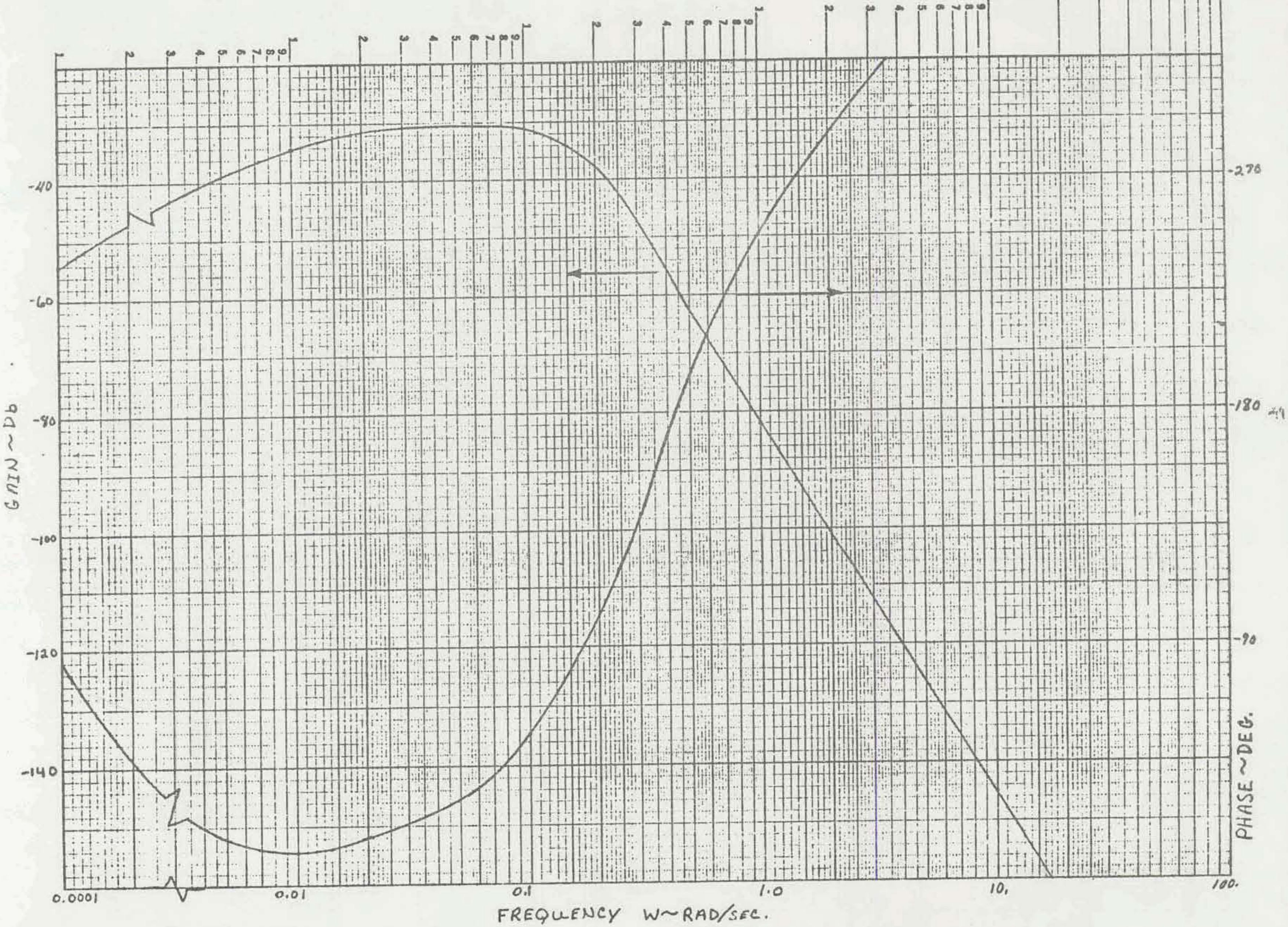


Figure 3.6-67 Closed Loop Frequency Response of Condenser Steam Pressure to Boiler Pressure Demand

The basic conclusion of this analysis is that the controller performs as well for transients as it does for steady state evaluations. Except for certain unusual situations there is no tendancy to overshoot the design temperature. There is no pronounced tendancy for the temperature to undershoot the temperature that would occur for an equivalent steady state condition. Some problems were observed with the controller, the analysis model and the system design, but they are all considered to be relatively minor and will be further addressed in future analysis. Previous analysis of response of a single collector subfield was reported in DRM: DA-0568 of September 11, 1978.

TRANSIENT EVALUATIONS

Insolation Reduced To Half-All Subfields

Several basic transients were run to characterize the response of the solar collector field with the controller. The first of these is shown in Figure 3.6-68. This transient was initiated from a steady state condition at maximum insolation. The insolation was reduced to half in all subfields at the start of transient. Field 1 outlet temperature dropped from the initial value of 305^{o}C to 229^{o}C after the field 1 basic response time of about 600 seconds. This condition was maintained until at about 1800 seconds recirculation caused the field 1 inlet temperature to begin to increase slowly. This temperature increase was matched by a corresponding small flow increase so there was no increase in field 1 outlet temperature.

The temperature that reaches the field 2 inlet mixing junction (at node 6) is the temperature that leaves field 1 but delayed by a large transport delay. At this time,the transport delay is modeled as a tank node at the outlet of field 1 in flow path 3, and as a tank node in flow path 4. This causes the temperature entering node 6 to be a slowly varying function rather than a more rapid change delayed in time as would be a better representation of transport delay. Future analysis will have a string of nodes to give a better representation of this time delay. Table 3.6-3 shows the magnitude of the transport times in the collector field, including the effect of the pipe heat capacity.

TABLE 3.6-3

SOLAR COLLECTOR SUBSYSTEM TRANSPORT TIMES

FIELD 1	378 sec. at 5.3 kg/sec.
FIELD 2	157 sec. at 9.2 kg/sec.
FIELD 3	67 sec. at 9.9 kg/sec.
PUMP TO FIELD 1	342 sec. at 10.9 kg/sec.
FIELD 1 TO FIELD 2	694 sec. at 5.3 kg/sec.
FIELD 2 TO FIELD 3	204 sec. at 9.2 kg/sec.

The inlet flow and temperature for field 2 are conditioned by the field controller. As the temperature of the fluid arriving from field 1 decreases, the controller acts to simultaneously reduce the flow into field 2 and to increase the inlet temperature to field 2 (above that which would occur with no controller) by decreasing the amount of cold fluid being added through path 12. Thus, the inlet temperature to field 2 does not fall as quickly as the temperature leaving field 1.

Due to the reduced insolation to field 2, the field 2 temperature rise drops from an initial value of 235°C inlet to 299°C outlet ($\Delta T = 64°C$) to 228°C to 259°C ($\Delta T = 31°C$) at 30 minutes into the transient. Thus, although the insolation was reduced by half and the effective heat collected was reduced by more than half, the temperature out of field 2 only dropped by 40°C.

The fluid that reaches the field 3 inlet junction is the temperature that leaves field 2 delayed by the transport delay. This fluid is conditioned by the controller by first reducing the amount of cold fluid that mixes with the field 2 outlet flow, and then, when this flow reaches zero, by reducing the flow entering field 3 by bypassing flow through path 13. These actions reduce the decrease in temperature leaving field 3. The initial temperature rise across field 3 was from 287°C at the inlet to 299°C ($\Delta T = 14°C$). At 30 minutes, the inlet temperature had dropped to 255°C and the outlet temperature was 269°C ($\Delta T = 14°C$). With no controller, the field outlet temperature with half insolation would be about 227°C so the controller reduced the size of the out temperature drop by about half. The performance of the controller would be improved at longer times as recirculation flow becomes effective at increasing the field outlet temperature.

Insolation Increased from 0.5 to 1.0 - All Fields

Figure 3.6-69 shows a continuation of this same transient with insolation reduced to half and then restored at 2350 seconds. The temperature and flows return to the design conditions with no significant overshoot which demonstrates that the controller is performing as desired.

Initial Condition: Maximum Insolation In All Fields,
Reduce Insolation by One Half

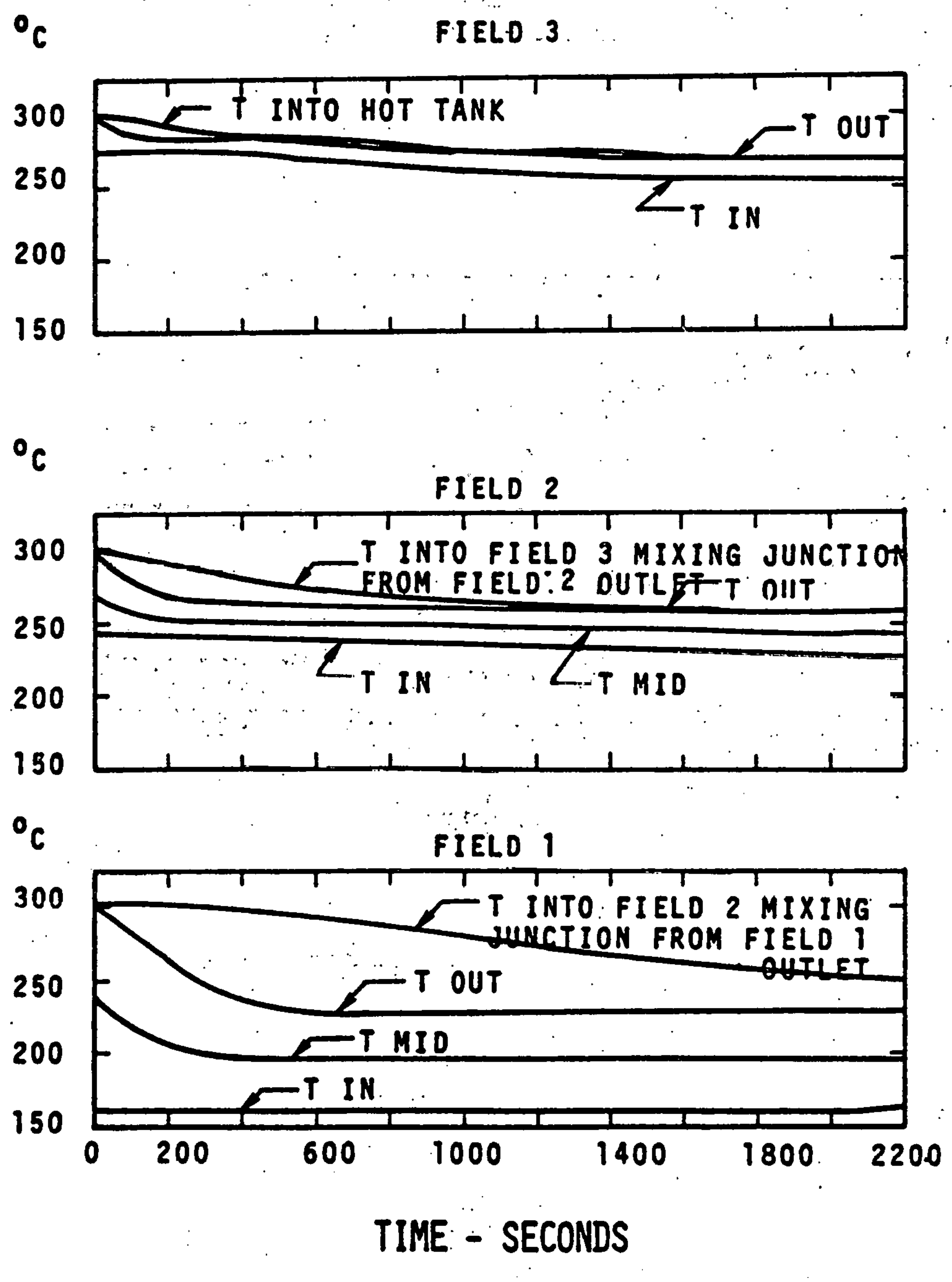


Figure 3.6-68.a. Temperature Response With Closed Loop Field Control

Initial Condition: Maximum Insolation In All Fields, Reduce Insolation By Half

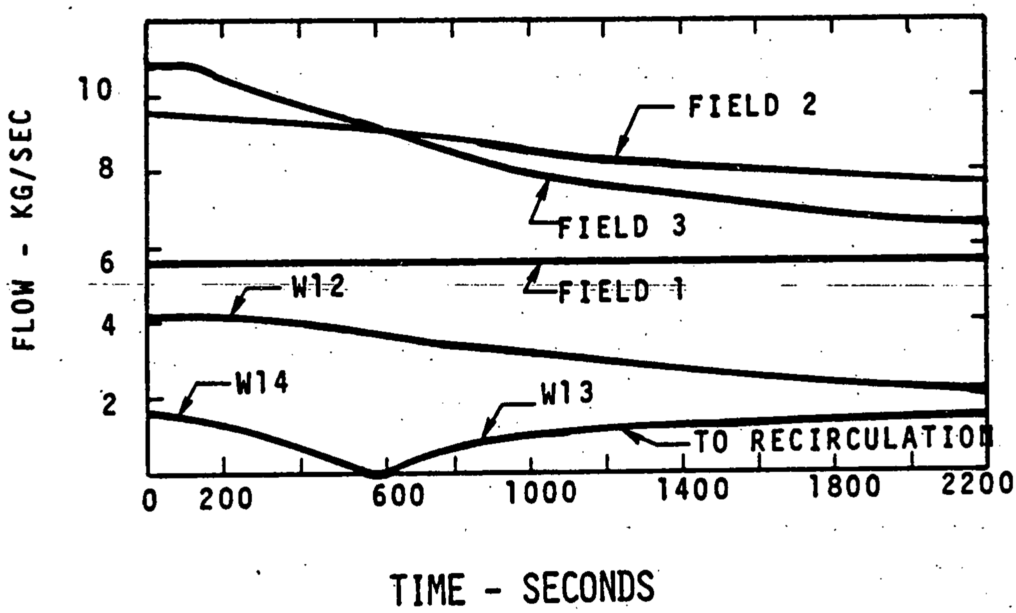


Figure 3.6-68.b. Flow Response With Closed Loop Field Control

Insolation increased from 0.5 Q max to 1.0 Q max at 2350 seconds

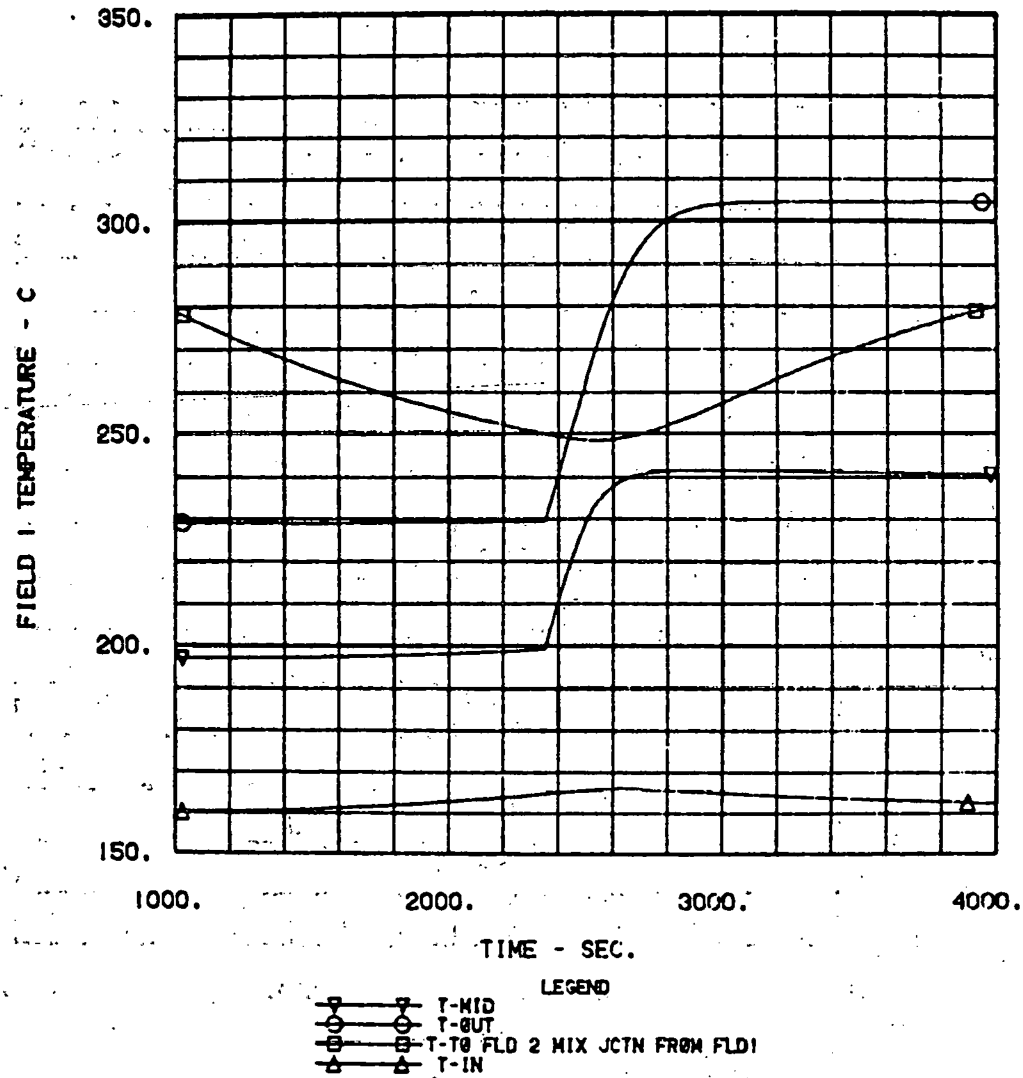


Figure 3.6-69.a. Field 1 Temperature

Insolation increased from 0.5 Q max to 1.0 Q max at 2350 seconds

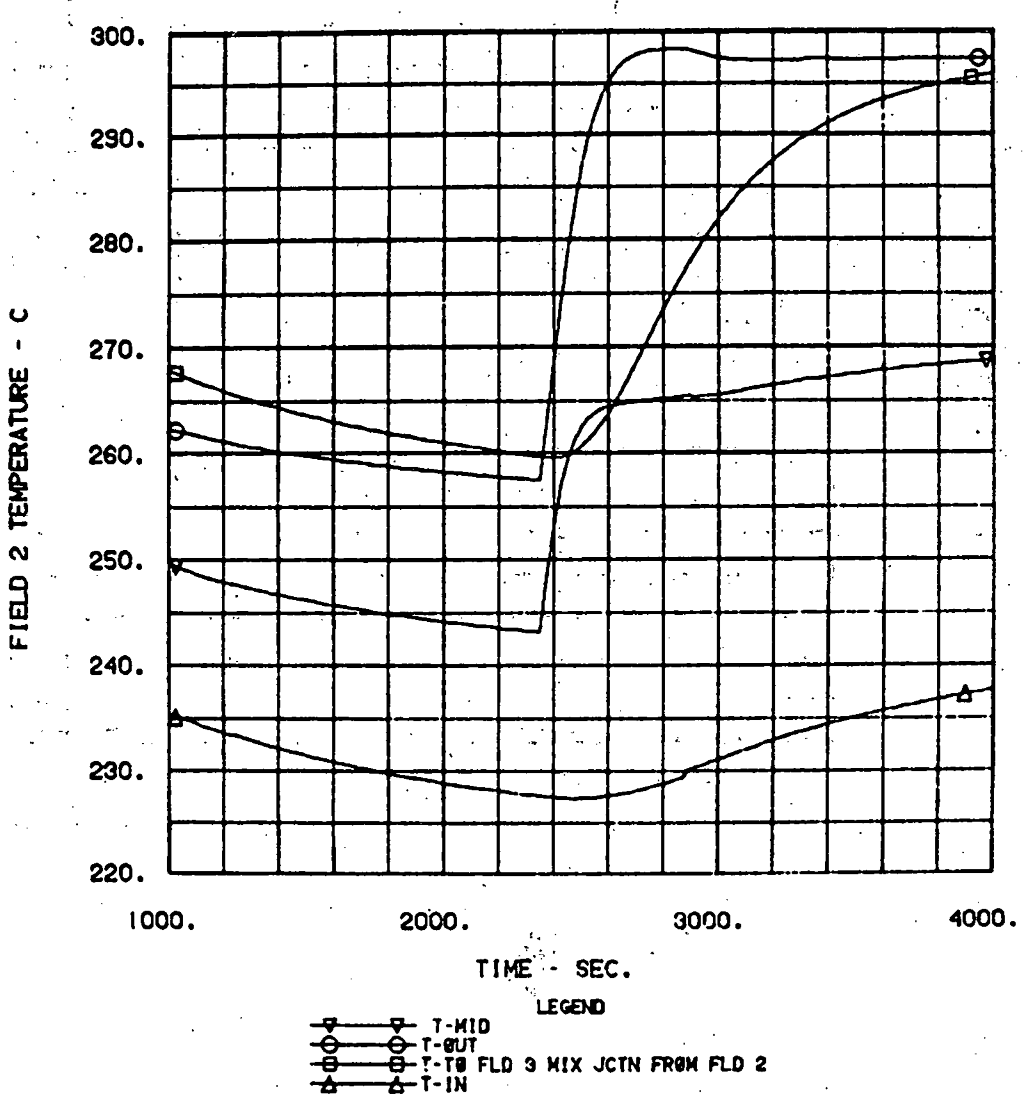


Figure 3.6-69.b. Field 2 Temperature

Insolation increaed from 0.5 Q max to 1.0 Q max at 2350 seconds

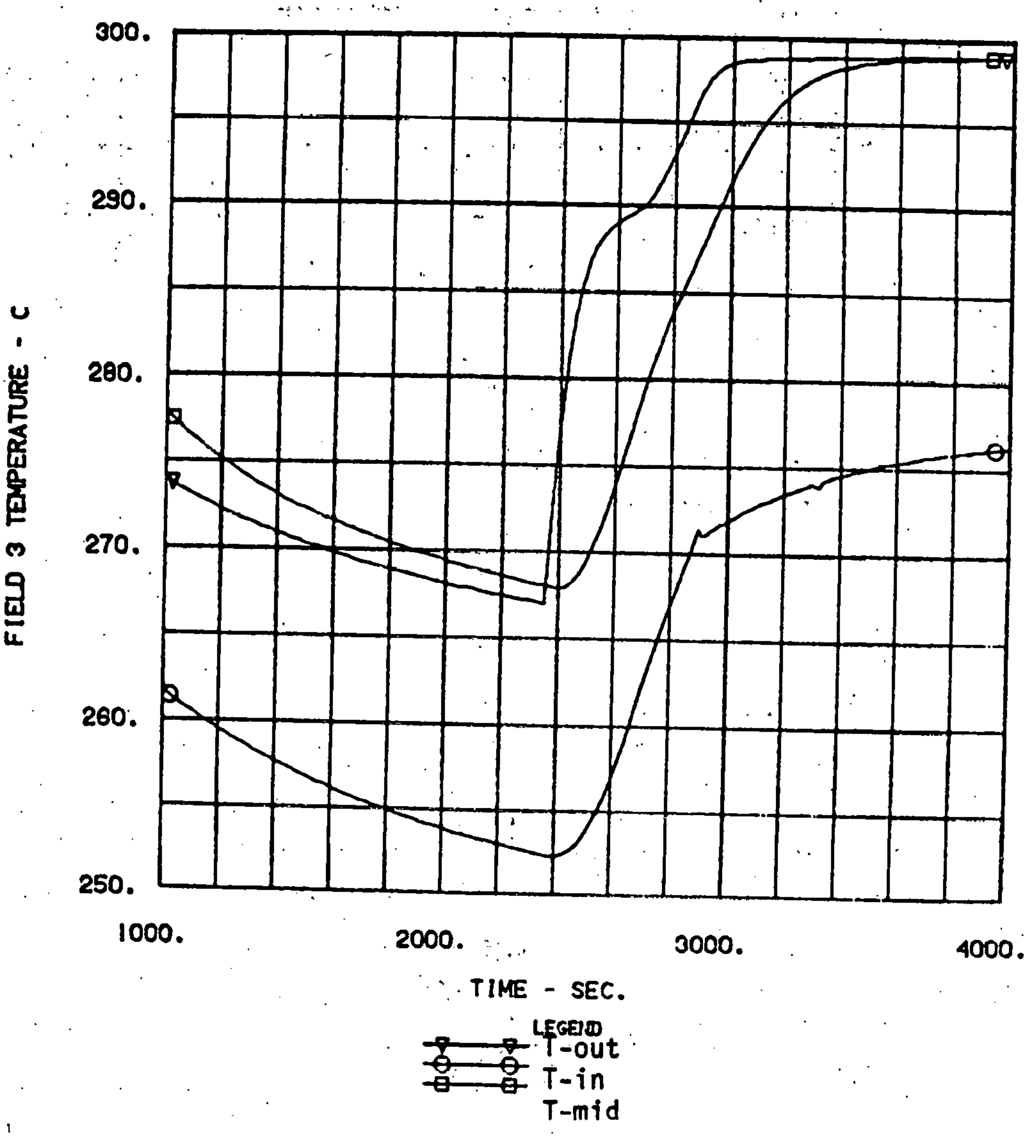


Figure 3.6-69.c. Field 3 Temperature

Insolation increased from 0.5 Q max to 1.0 Q max at 2350 seconds

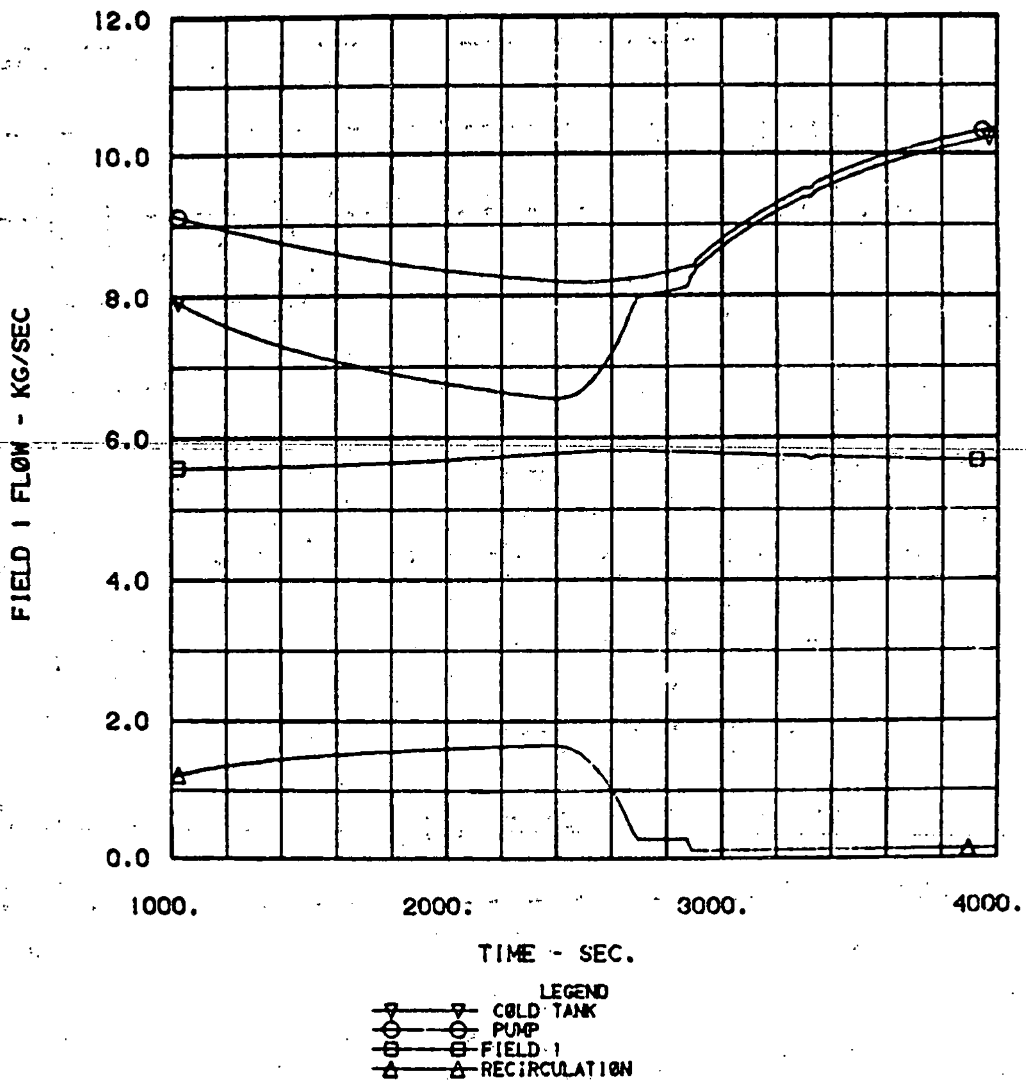


Figure 3.6-69.d. Field 1 Flow

Insolation increased by 0.5 Q max to 1.0 Q max at 2350 seconds

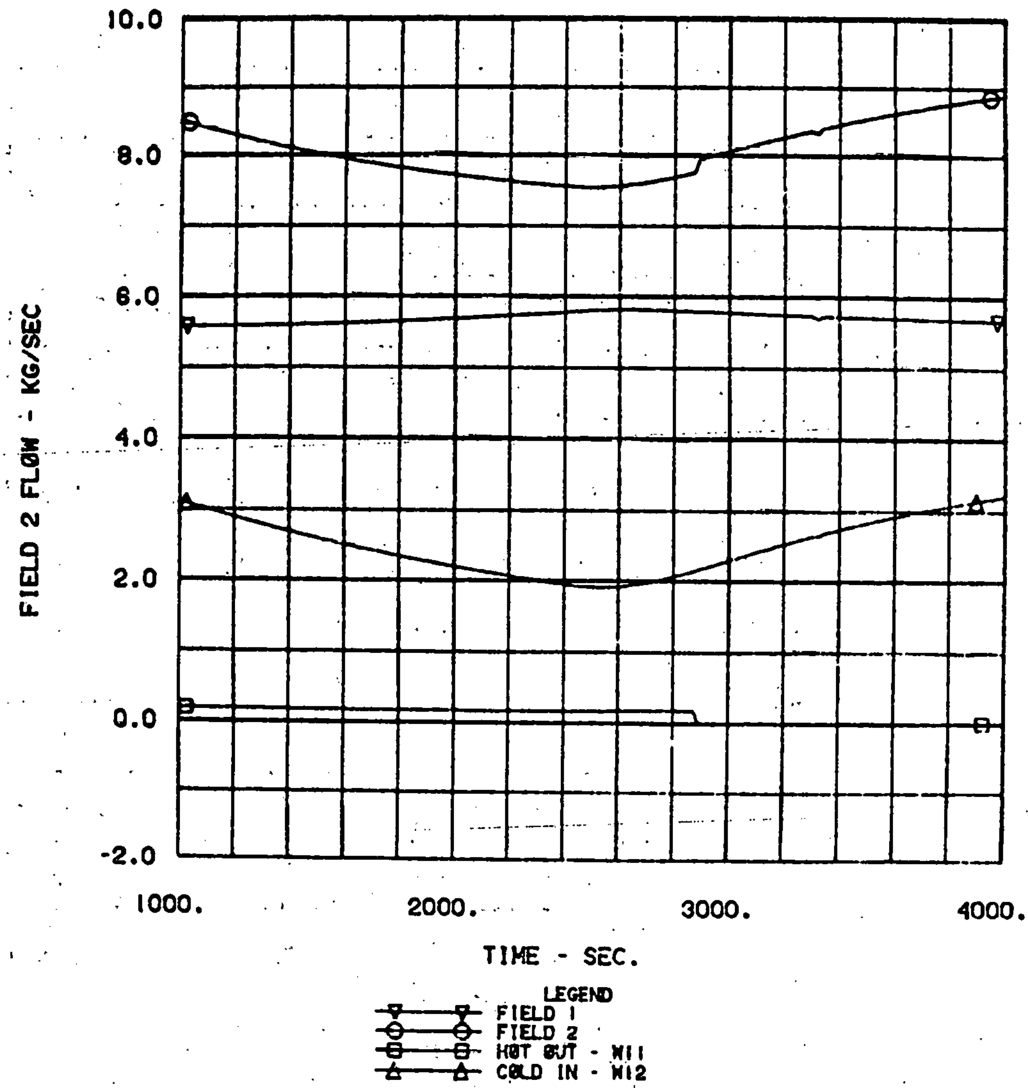


Figure 3.6-69.e. Field 2 Flow

Insolation increased from 0.5 Q max to 1.0 Q max at 2350 seconds

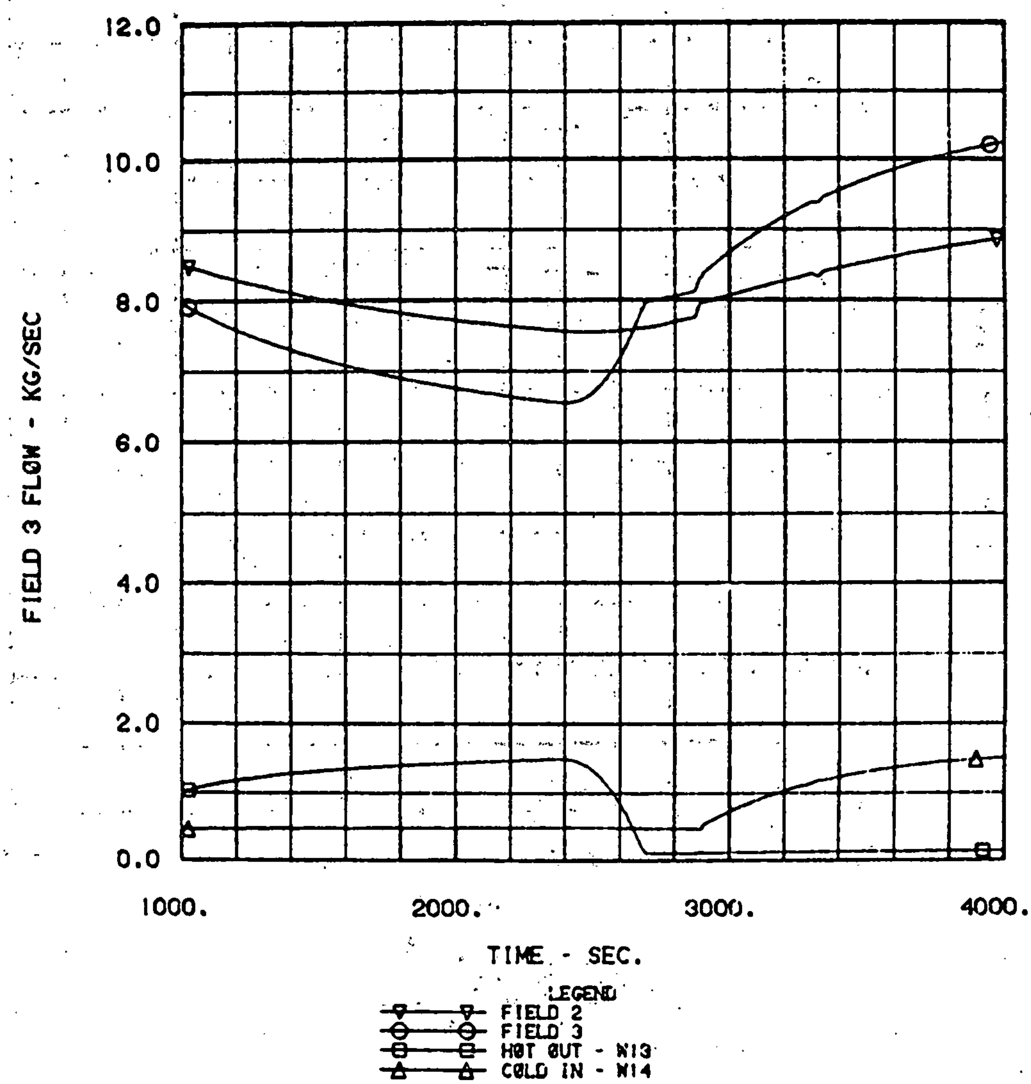


Figure 3.6-69.f. Field 3 Flow

Insolation increased by 0.5 Q max to 1.0 Q max at 2350 seconds

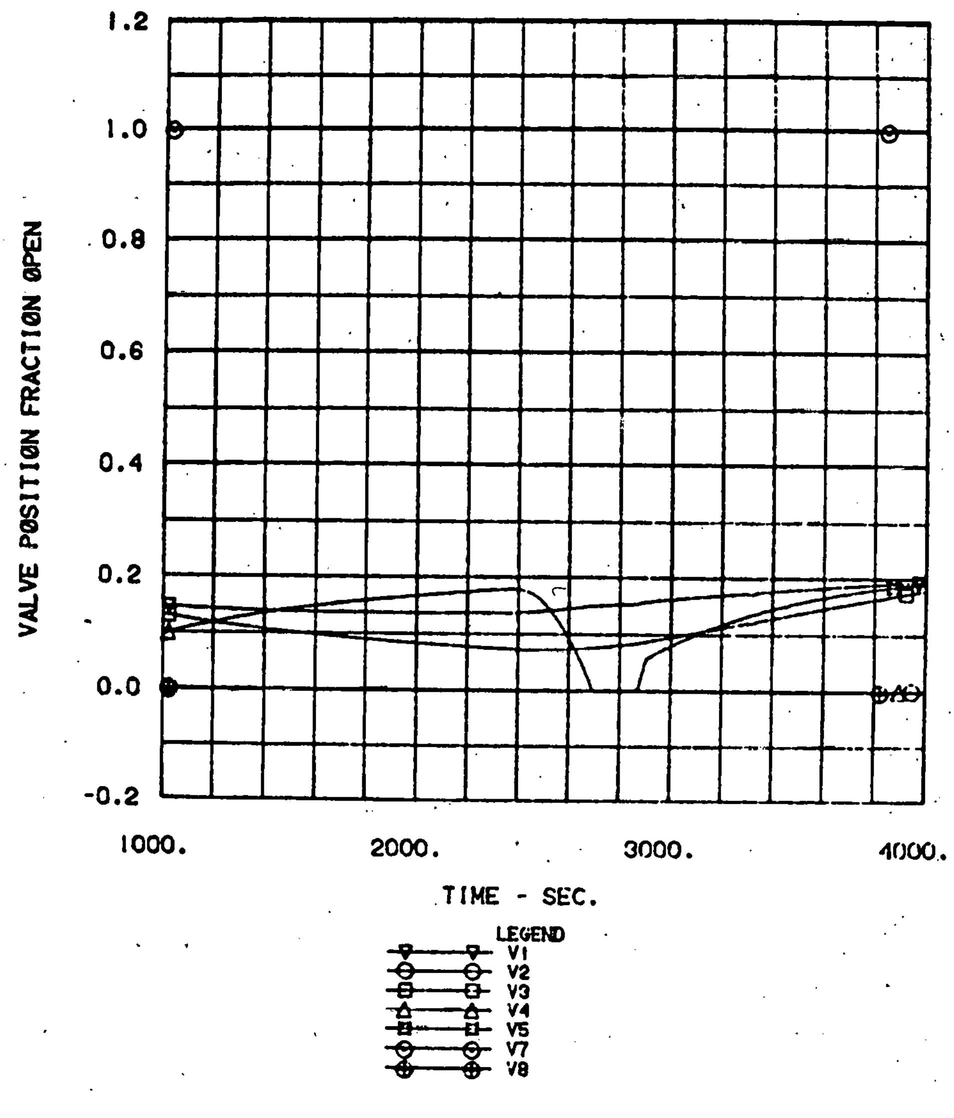


Figure 3.6-69.g. Valve Position

The strange behavior in field 3 outlet temperature at 2600 to 2800 seconds is caused by a fault in the computer program which allows a leakage of about 0.5 kg/second through path 14 with valve 5 closed. This causes the inlet temperature to field 3, and thus the outlet temperature, to be low by about 8^{o}C. This is corrected after 2900 seconds when valve 5 begins to control the flow in path 14.

Insolation Reduced to 0.0 in Field 1

A second transient shows better performance for the field. This transient, which is shown in Figure 3.6-70 was also initiated at steady state with maximum insolation over the entire field. At the start of the transient, the insolation to field 1 was reduced to zero while fields 2 and 3 are maintained at maximum insolation. Field 1 outlet temperature dropped to 142^{o}C at about 600 seconds. This is below the inlet temperature due to continuing heat losses.

The fluid reaching field 2 from field 1 slowly dropped in temperature to about 165^{o}C at 3600 seconds. Until about 1800 seconds, the flow controller was conditioning the flow to field 2 by reducing the amount of cold fluid added through path 12. When this flow reached zero, the valve in path 11 opened to further reduce the flow into field 2 to preserve the desired field temperature rise across field 2, if, as the case in this example, maximum insolation occurs at field 2. The desired result is obtained that field 2 outlet temperature remains at very nearly the design value throughout the transient.

Although the outlet temperature from field 2 is nearly constant, the flow through field 2 decreases. This causes the flow controller to act to reduce the inlet temperature and flow through field 3 so that its temperature is maintained at its desired value. Field 3 outlet temperature is nearly unaffected.

Initial Condition: Maximum Insolation All Fields, Then Field 1, Insolation to Zero, Continue Maximum Insolation to Other Fields

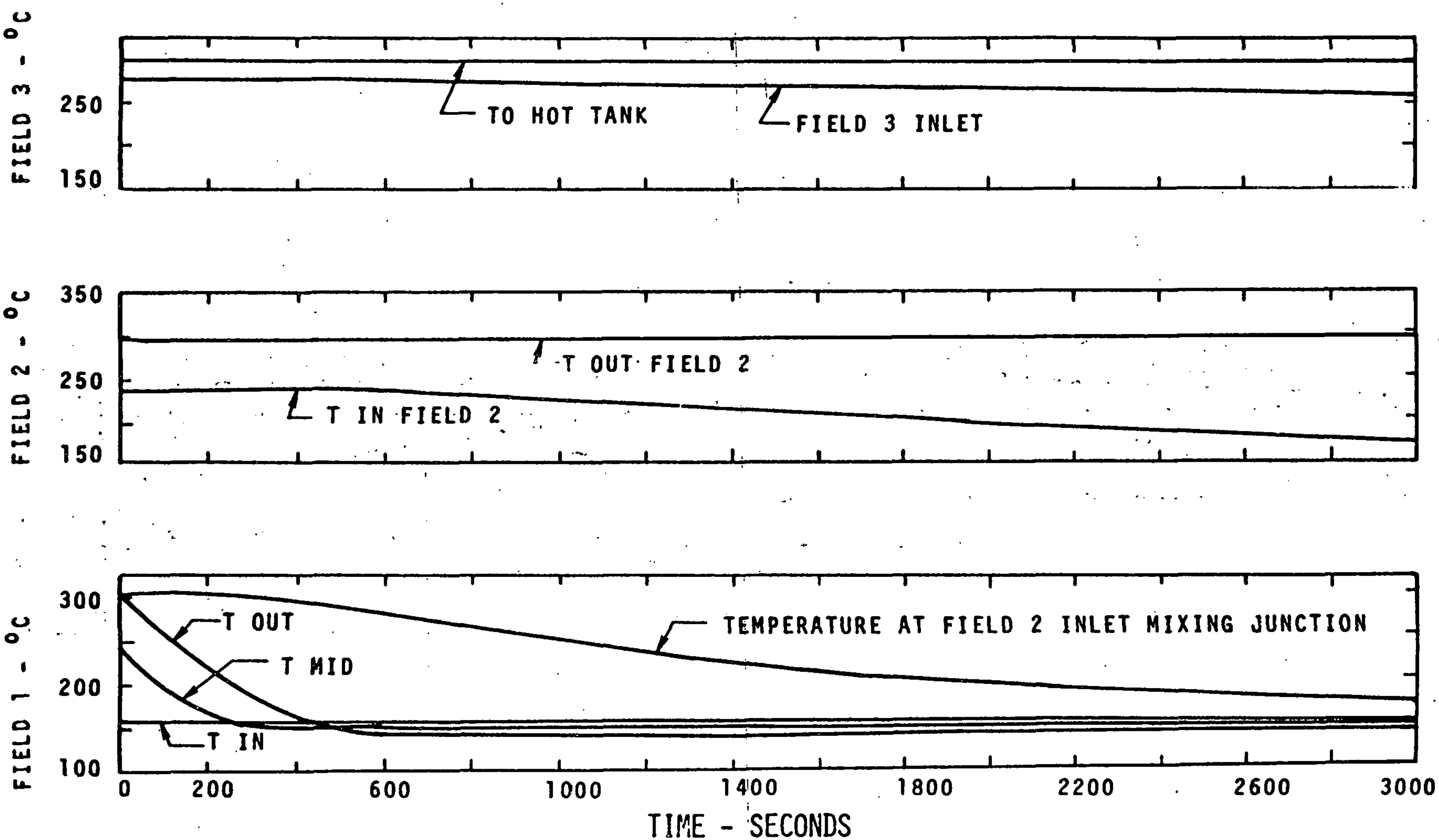


Figure 3.6-70.a. Temperature Response With Closed Loop Field Control

Initial Condition: Maximum Insolation All Fields, Then Field 1, Insolation To Zero, Continue Maximum Insolation to Other Fields

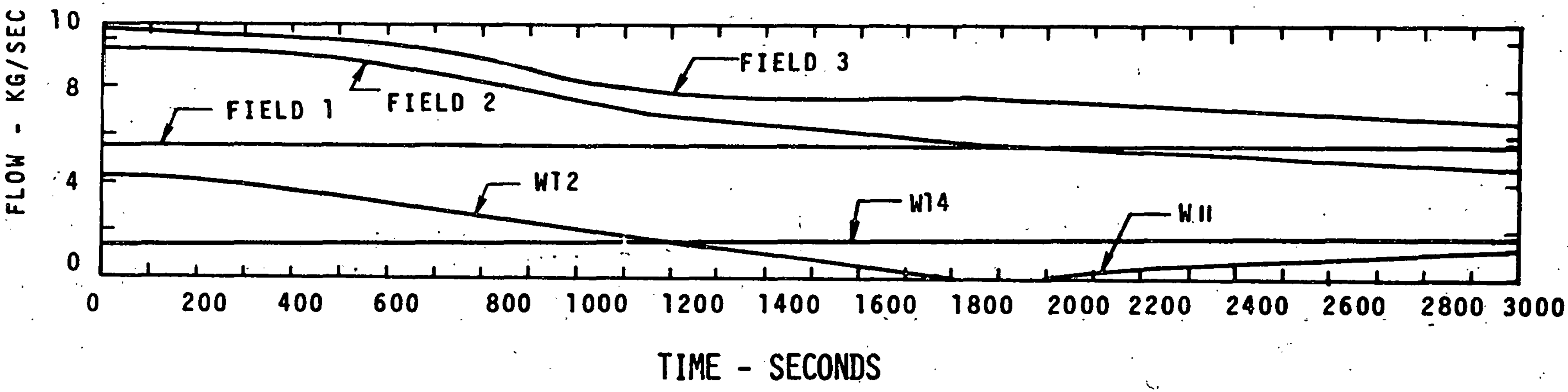


Figure 3.6-70.b. Flow Response With Closed Loop Field Control

Even though the field outlet temperature remains near 300°C, the amount of energy collected is reduced because the total field flow rate is reduced. This is shown by the reduction in flow through field 3.

Insolation Increased From 0.0 to 1.0 in Field 1

Figure 3.6-71 shows a continuation of the same transient as before with the insolation to field 1 reduced to zero. The insolation was restored at 1330 seconds. This transient shows that the temperatures were restored to their original values with no detectible overshoot. The transient also had little effect on field 2 or 3 outlet temperatures, although the inlet temperatures and flow were affected.

Startup Transient

One simple startup transient has been run Figure 3.6-72. This started with all temperatures in the field at the cold tank temperature of 160°C. Insolation was added at half the maximum value. The value of maximum insolation in the controller was the design maximum of 0.806 kW/M^2. Throughout the transient,which ran for slightly over an hour, all fluid was recirculated and none was delivered to the cold tank because the fluid temperature did not reach the 265°C setpoint at the outlet of the field which is required to direct flow to the hot tank, although the temperature was approaching this setpoint.

The field 1 outlet temperature increased to 230°C in about 600 seconds. Fluid was recirculated from the outlets of all three fields to the inlet of field 1 so the field 1 inlet temperature began to rise at about 300 seconds. Due to the rise in inlet temperature, the flow through field 1 was increased by the controller from an initial value of 5.6 kg/sec to nearly double this rate. This caused a reduction in the field 1 temperature rise which continued until the field 1 inlet flow control valve reached its full open position at 3200 sec.

INSOLATION IN FIELD 1 INCREASED FROM ZERO TO 1.0 Q_{max}, OTHER FIELDS REMAIN AT 1.0 Q_{max}

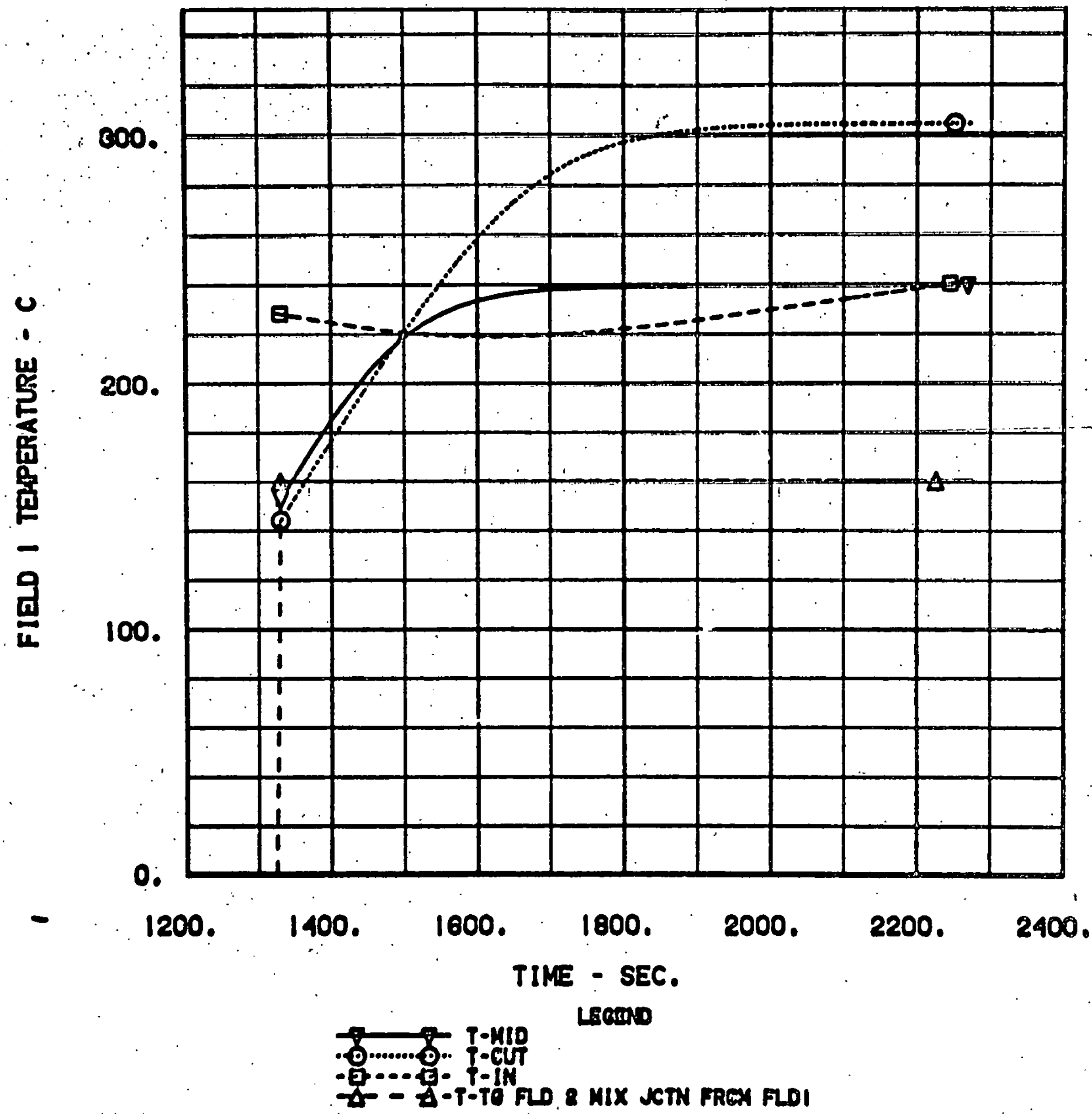


Figure 3.6-71.a. Field 1 Temperature

INSOLATION IN FIELD 1 INCREASED FROM ZERO TO 1.0 Q_{max}, OTHER FIELDS REMAIN AT 1.0 Q_{max}

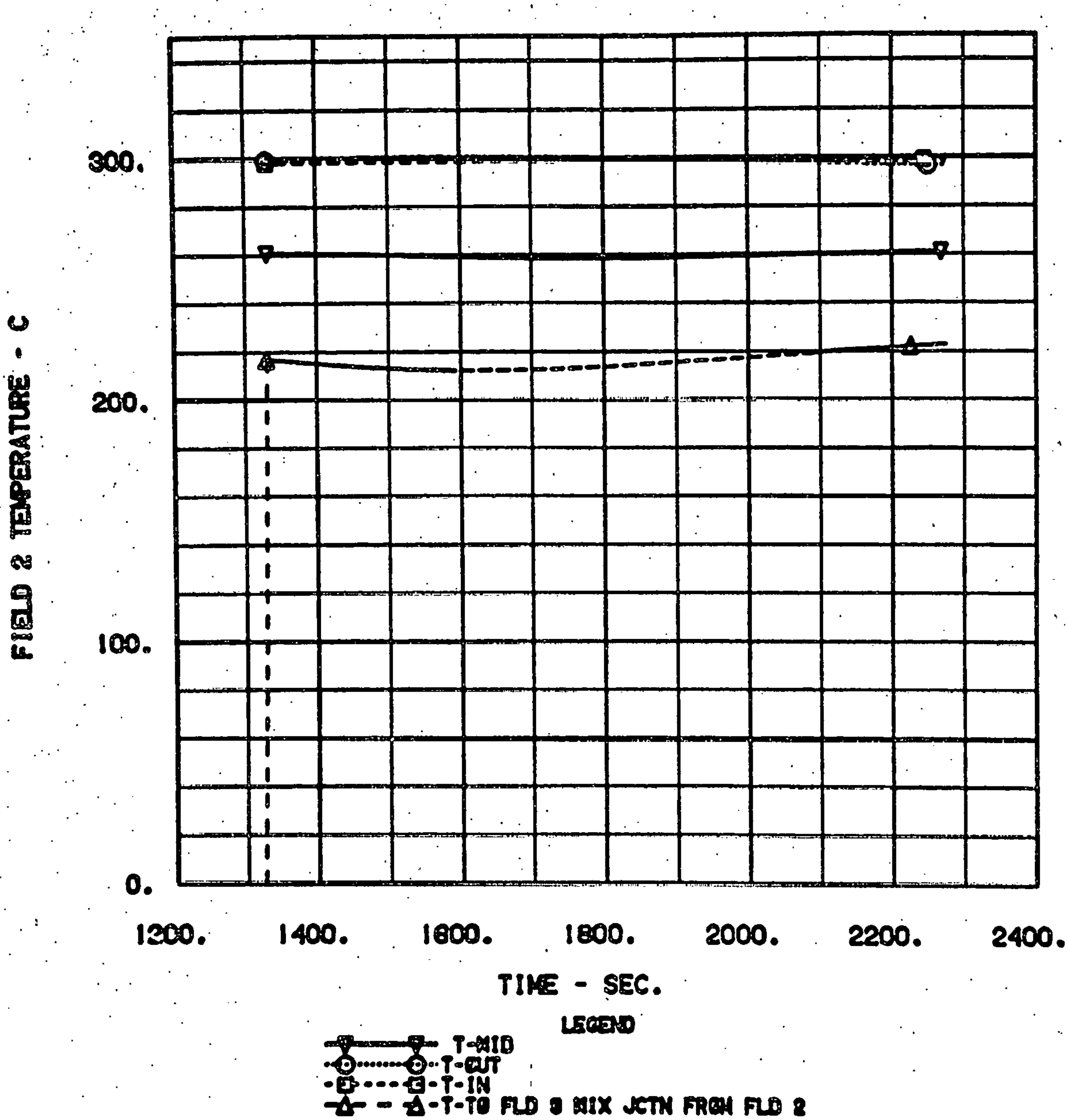


Figure 3.6-71.b. Field 2 Temperature

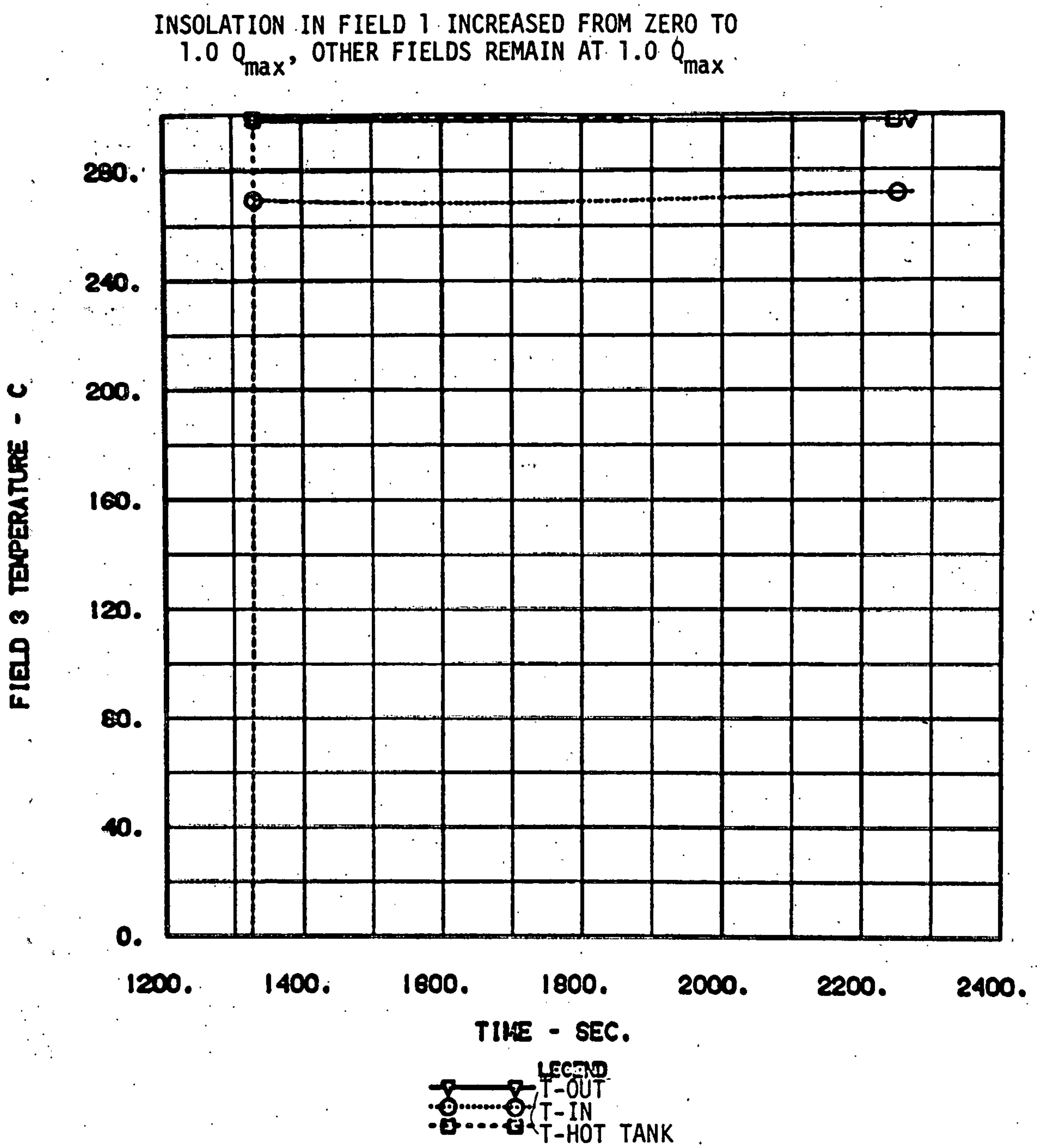


Figure 3.6-71.c. Field 3 Temperature

INSOLATION IN FIELD 1 INCREASED FROM ZERO TO 1.0 Q_{max}, OTHER FIELDS REMAIN AT 1.0 Q_{max}

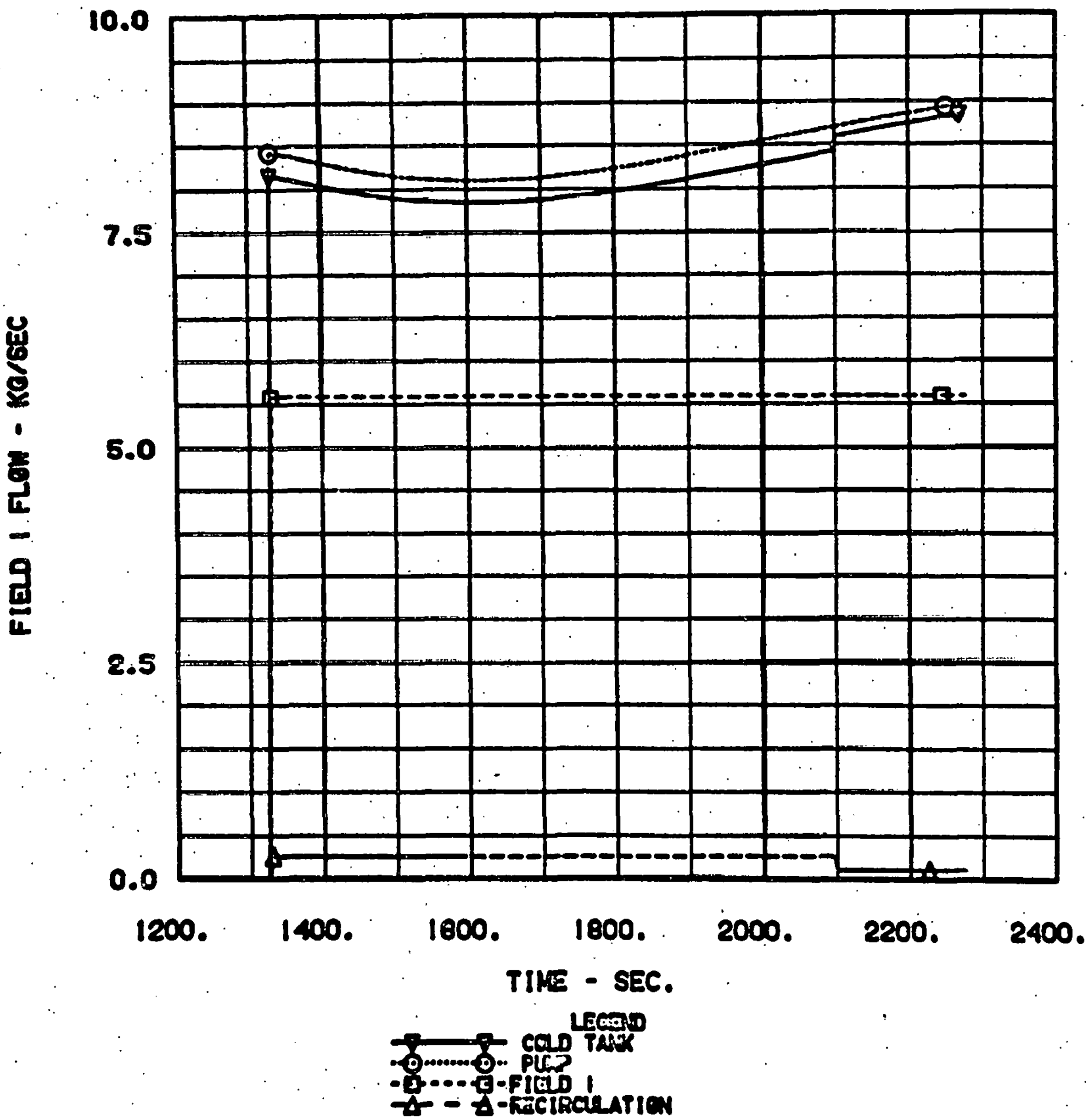


Figure 3.6-71.d. Field 1 Flow

INSOLATION IN FIELD 1 INCREASED FROM ZERO TO 1.0 Q_{max}, OTHER FIELDS REMAIN AT 1.0 Q_{max}

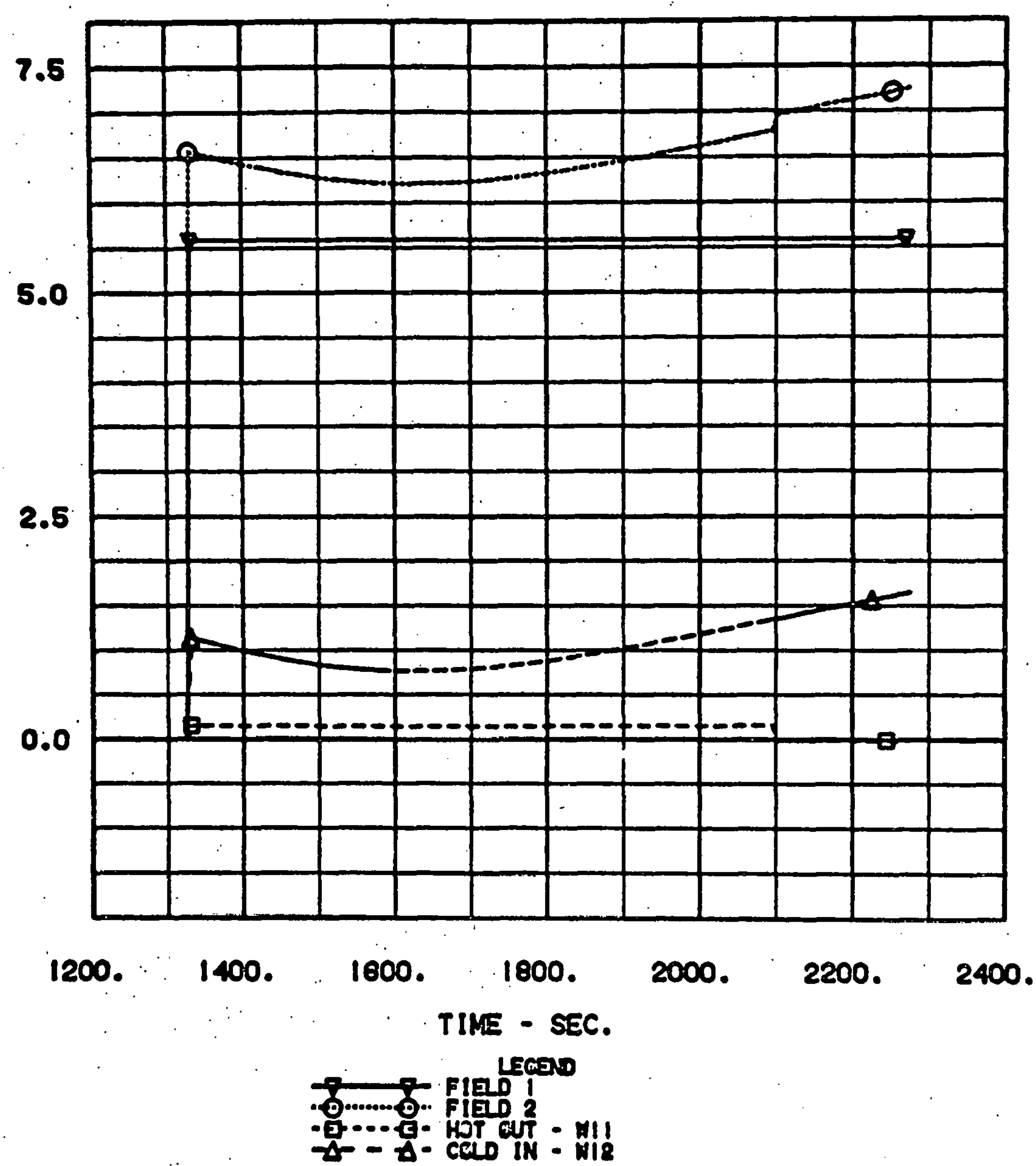


Figure 3.6-71.e. Field 2 Flow

INSOLATION IN FIELD 1 INCREASED FROM ZERO TO 1.0 Q_{max}, OTHER FIELDS REMAIN AT 1.0 Q_{max}

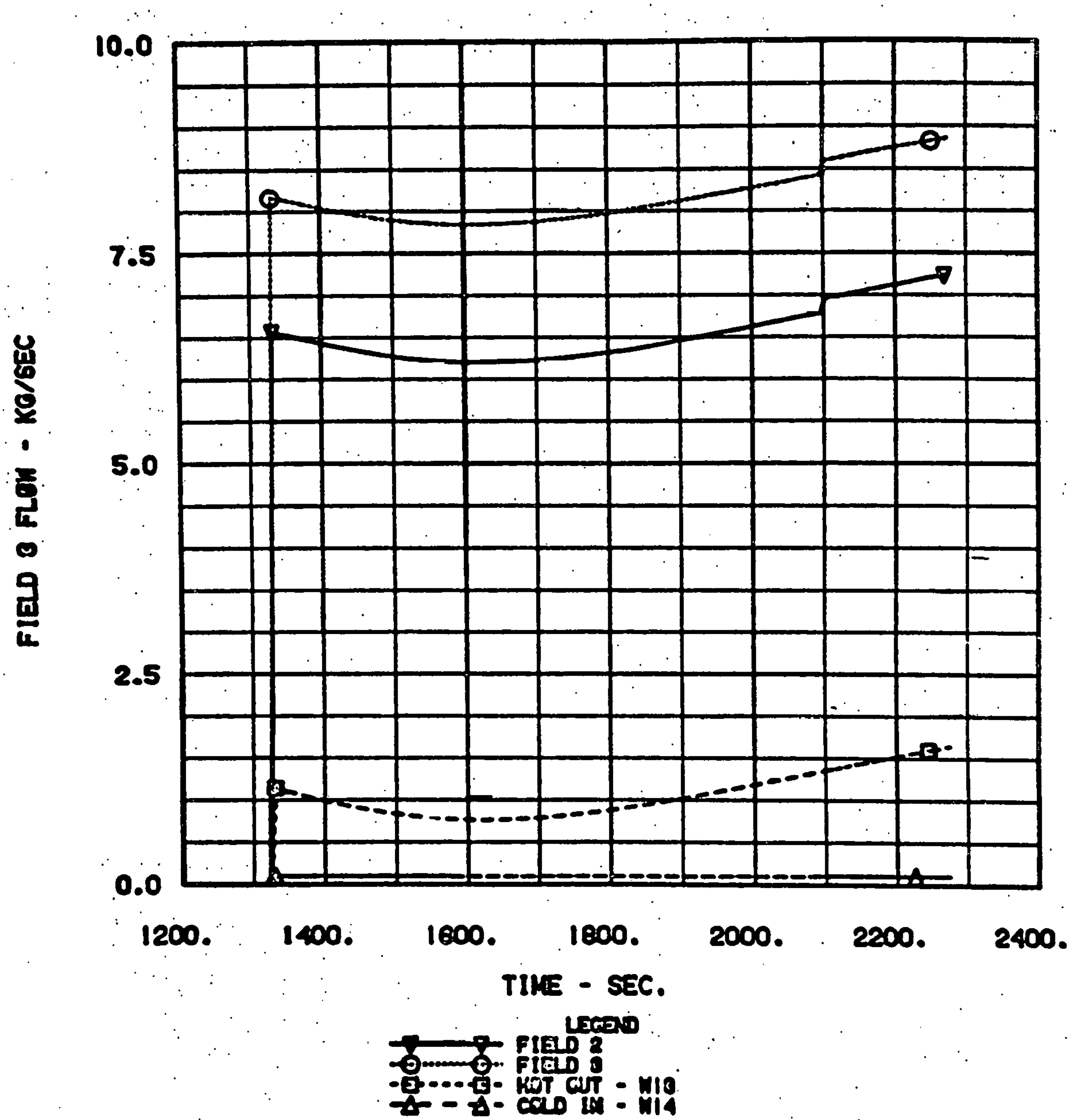


Figure 3.6-71.f. Field 3 Flow

Startup from 160°C

Insolation at 0.5 Q max, Controller used 1.0 Q max

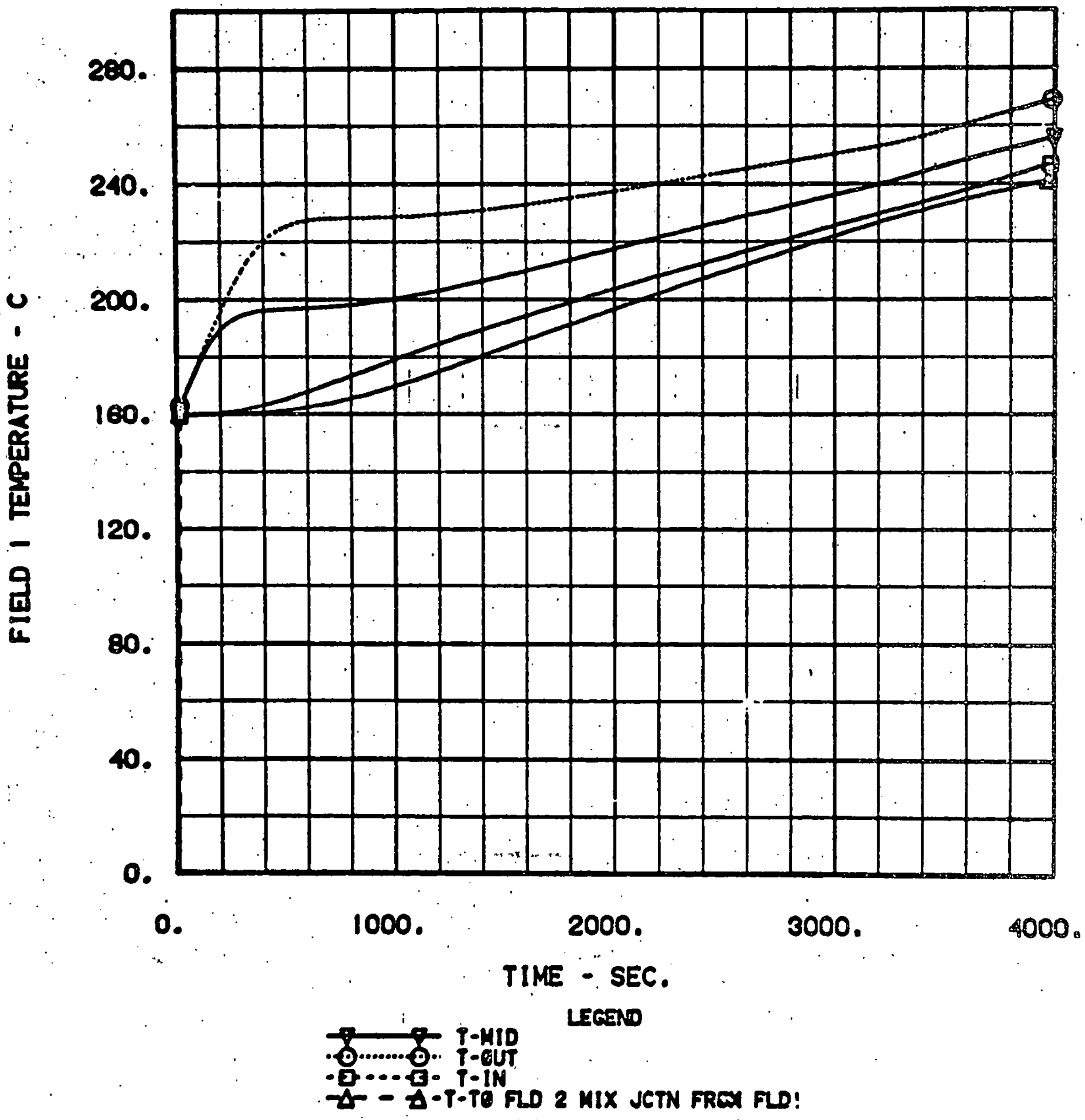


Figure 3.6-72.a. Field 1 Temperature

Startup from 160°C

Insolation at 0.5 Q max, Controller used 1.0 Q max

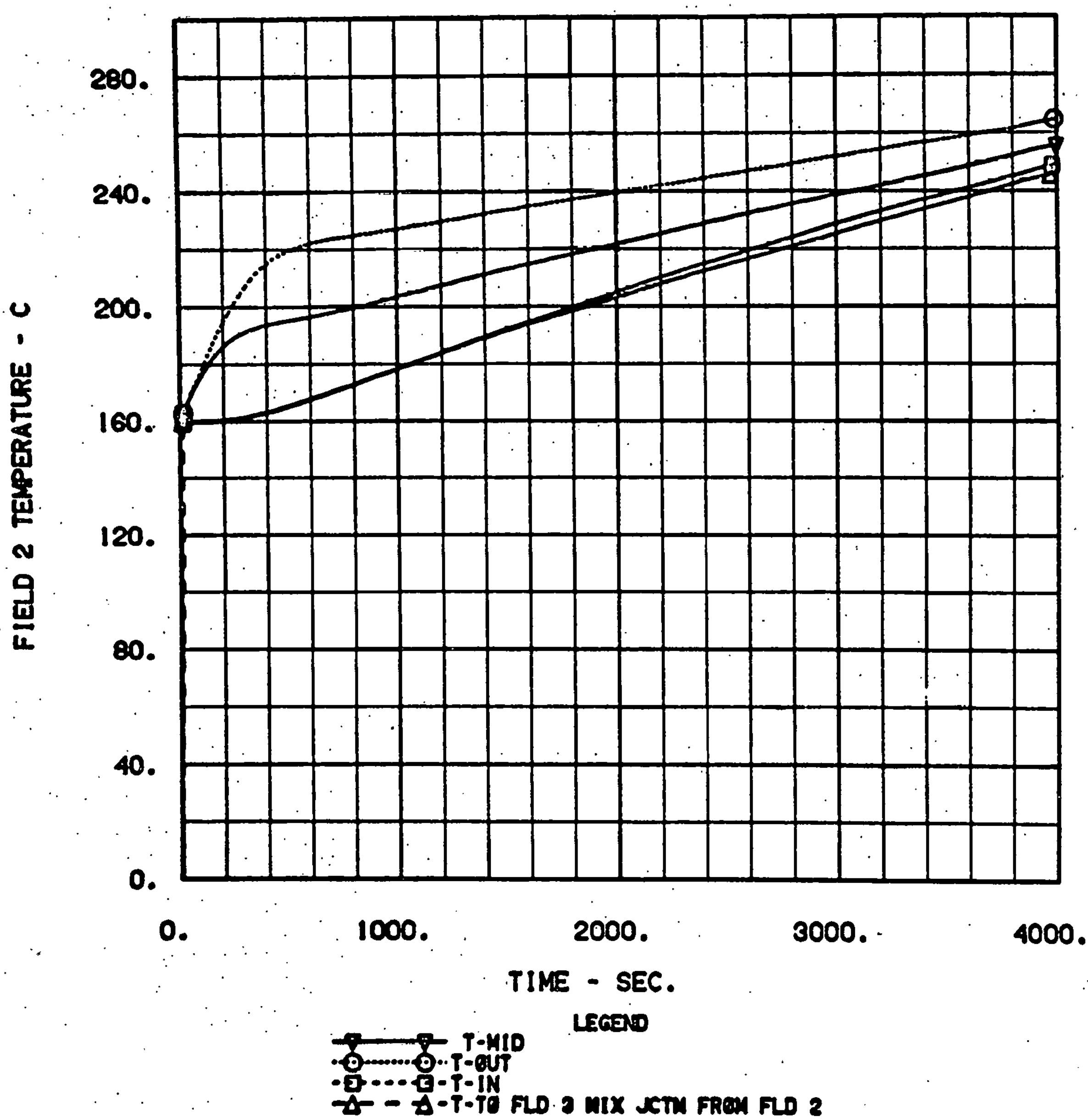


Figure 3.6-72.b. Field 2 Temperature

Startup from 160°C

Insolation at 0.5 Q max, Controller used 1.0 Q max

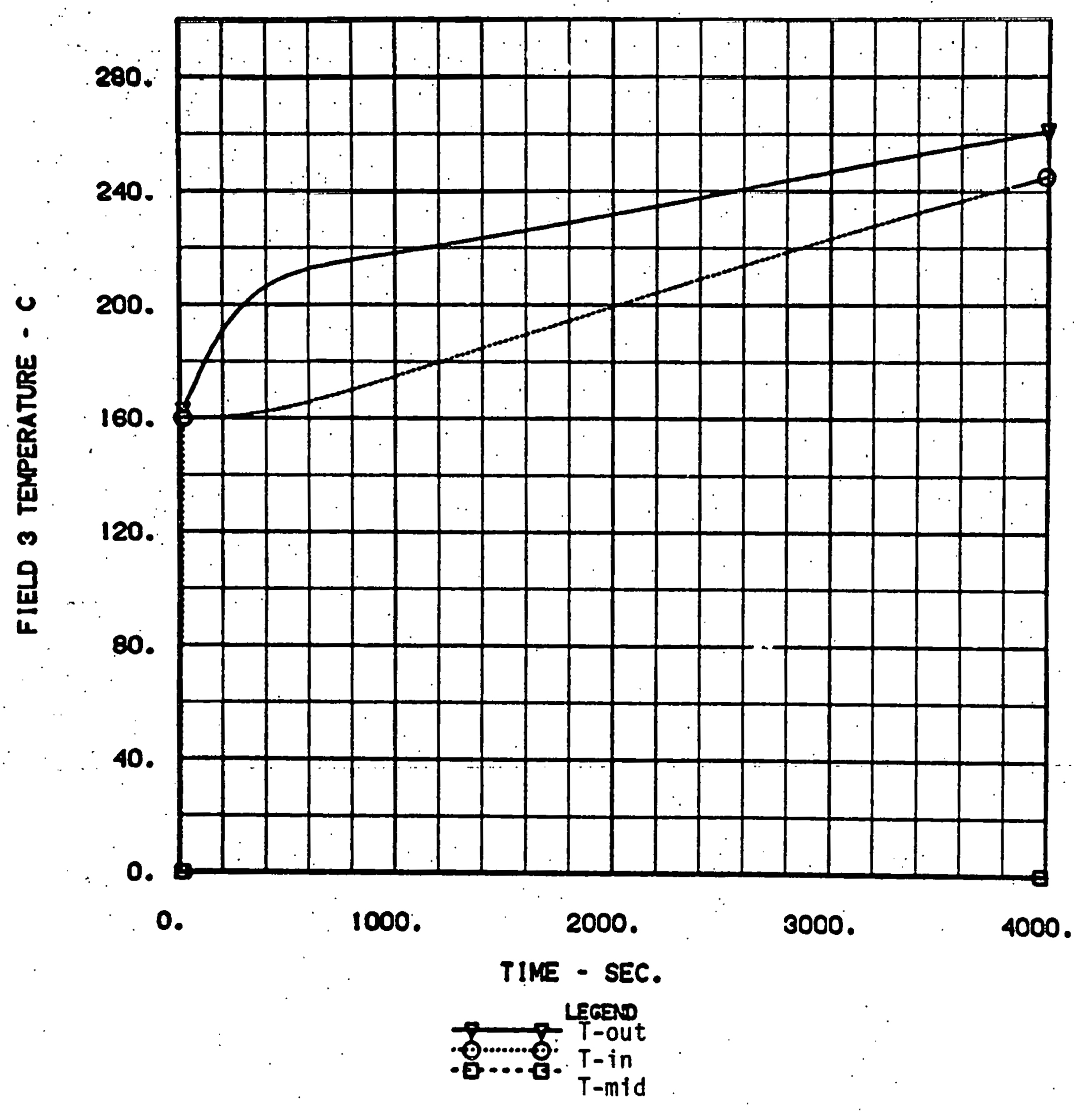


Figure 3.6-72.c. Field 3 Temperature

Startup from 160°C

Insolation at 0.5 Q max. Controller used 1,0 Q max

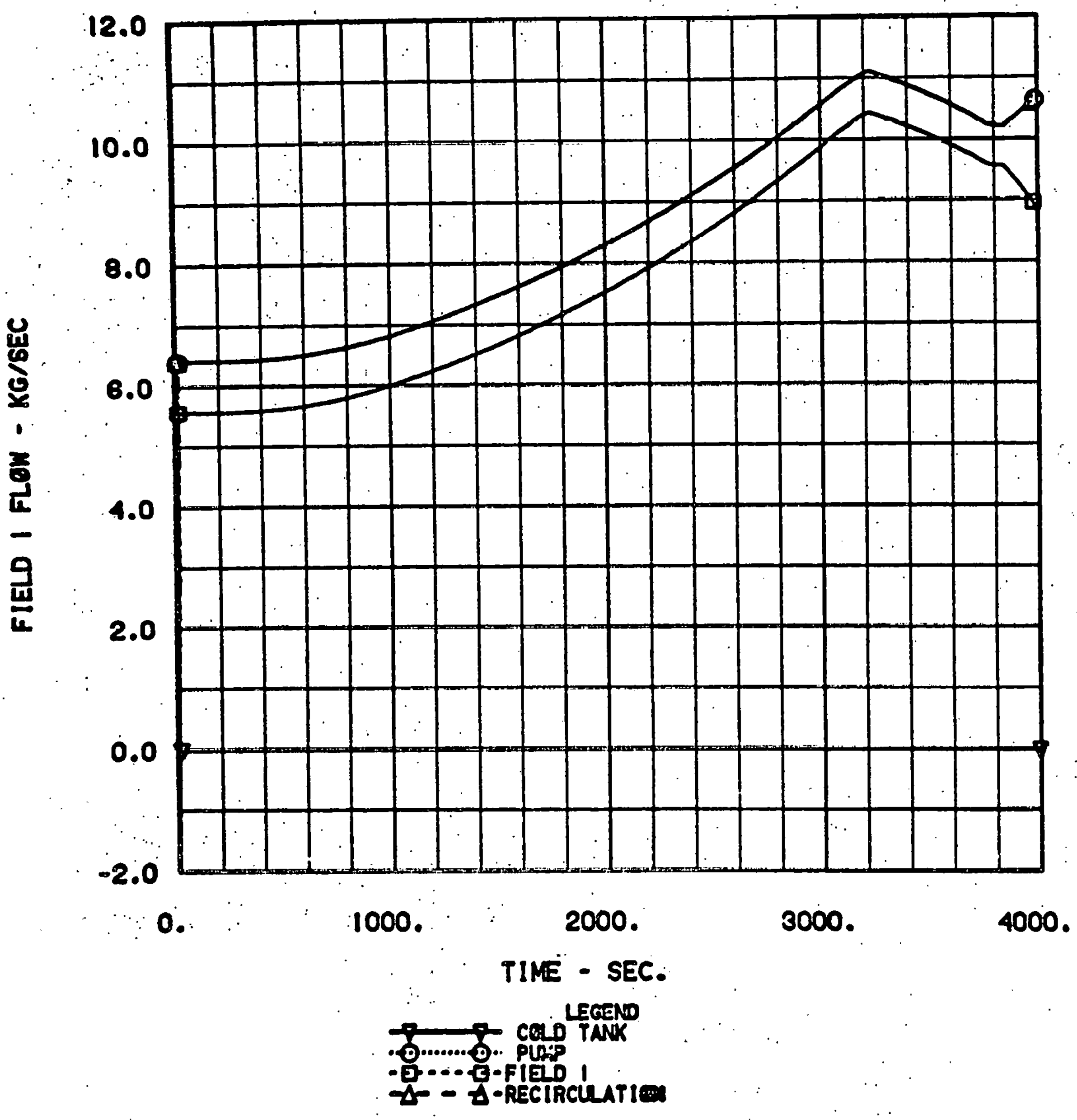


Figure 3.6-72.d. Field 1 Flow

Startup from 160°C

Insolation at 0.5 Q max, Controller used 1.0 Q max

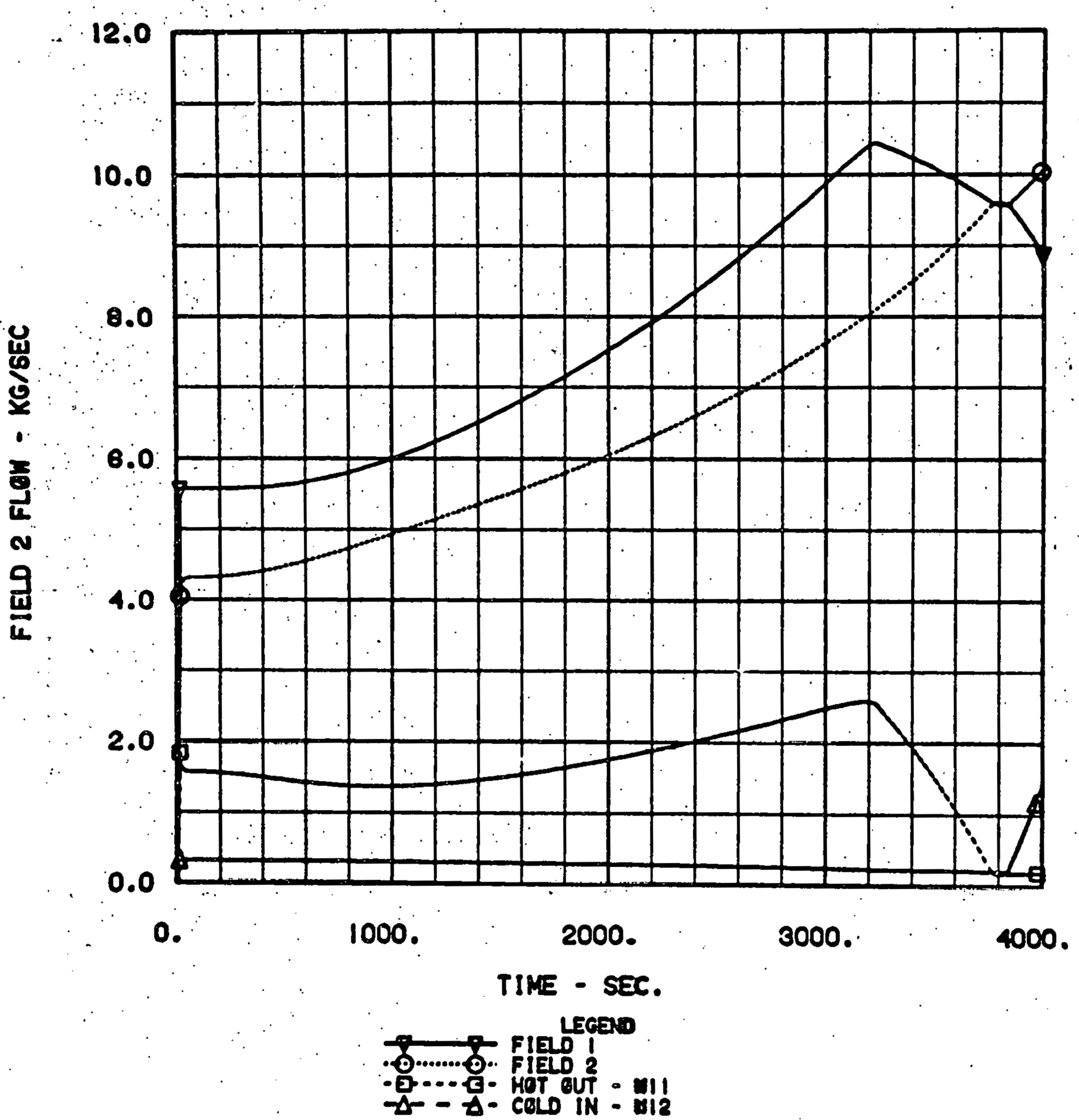


Figure 3.6-72.e. Field 2 Flow

Startup from 160°C

Insolation at 0.5 Q max, Controller used 1.0 Q max

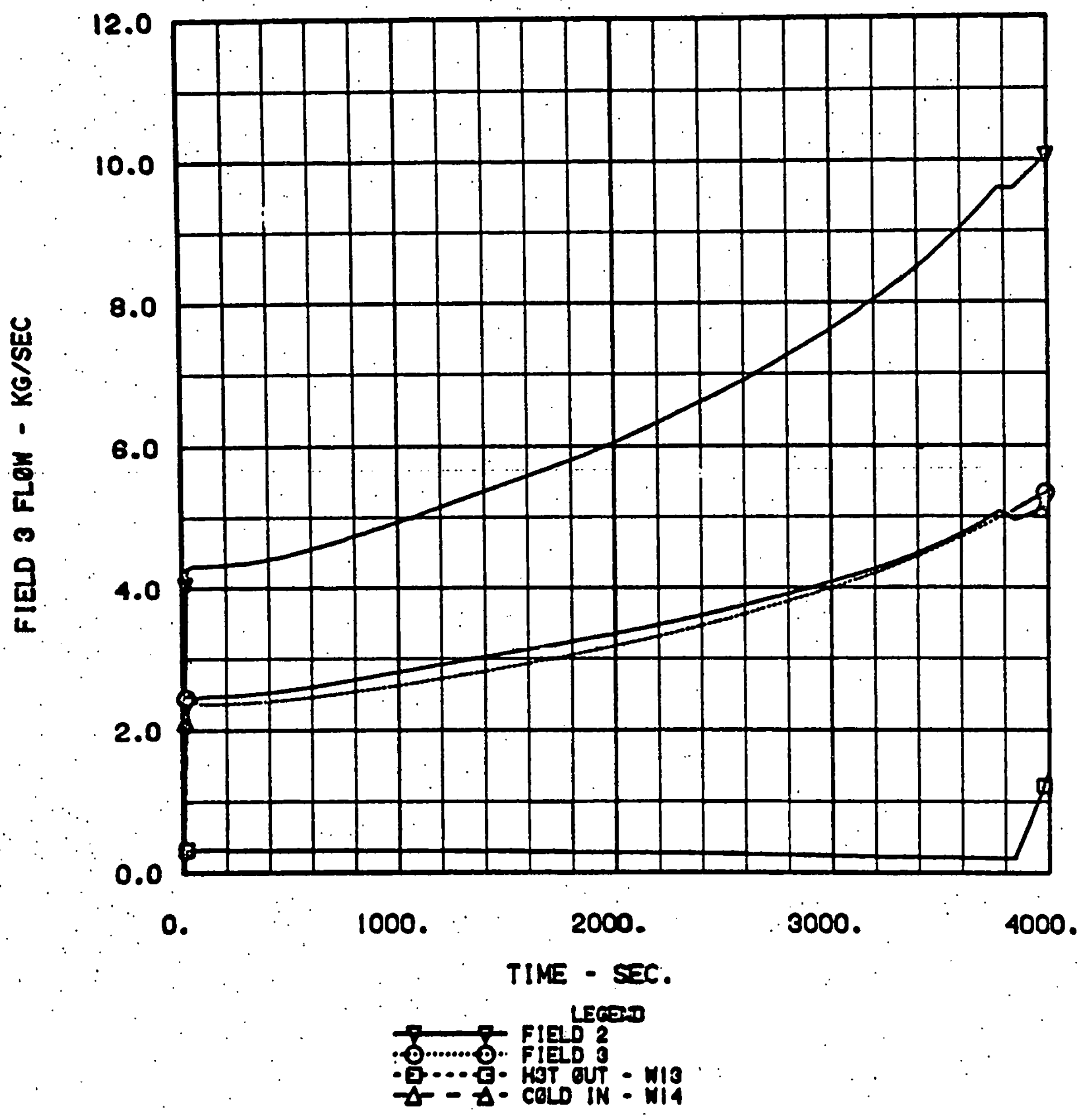


Figure 3.6-72.f. Field 3 Flow

Startup from 160°C

Insolation at 0.5 Q max, Controller used 1.0 Q max

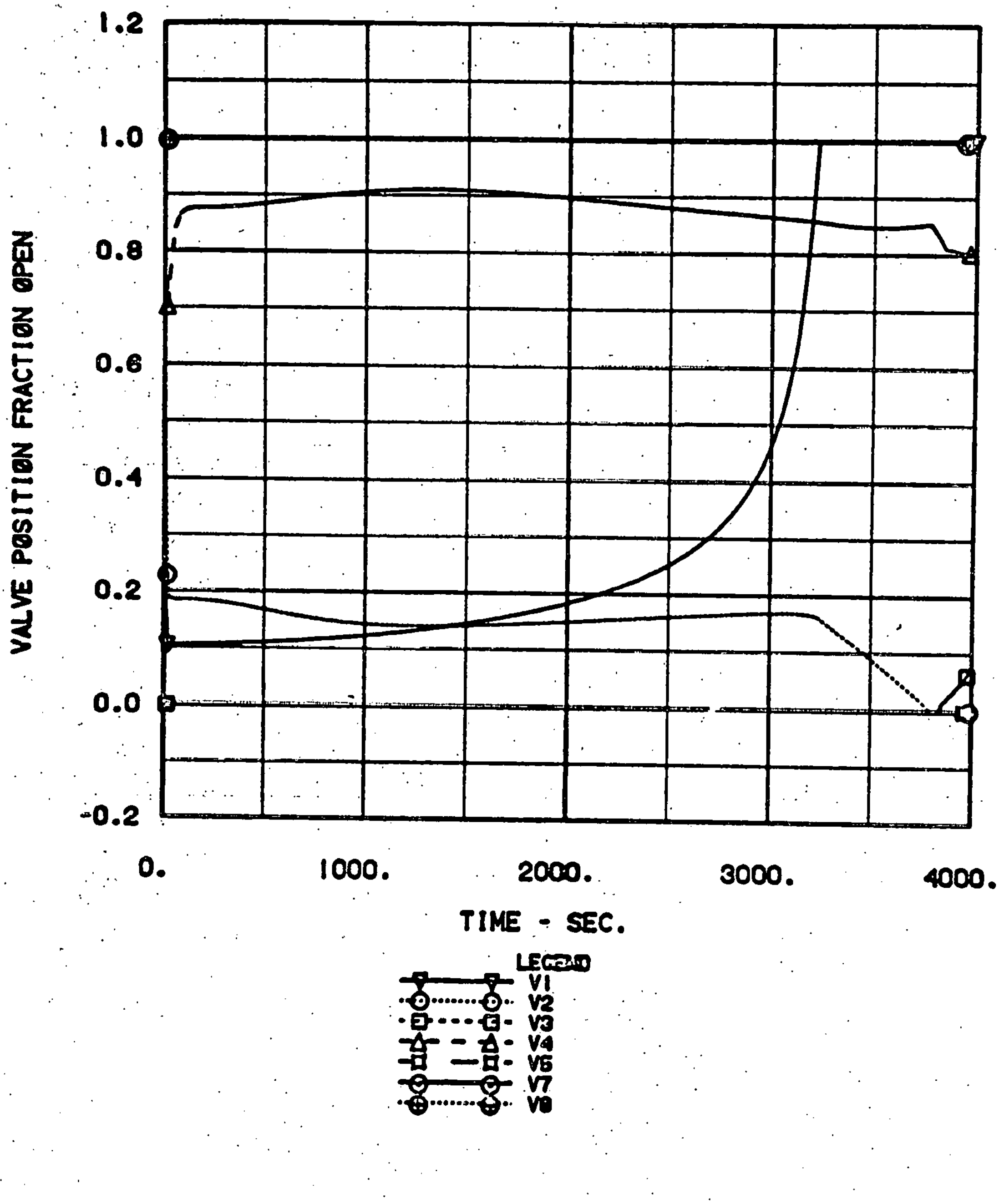


Figure 3.6-72.g. Valve Position

The inlet temperatures to field 2 and 3 also increased resulting in an increased flow and decreased temperature rise for these fields.

The response of the field and controller to this transient are not the most desirable. To start with, the controller was not set to charge fluid to the intermediate temperature tank during warm up. As a consequence of this, all of the fluid in the field is heated to around 250^{o}C which is undesirable because the field probably would not be able to compensate for an increase in insolation to the design maximum. Also, it is undesirable to store all of this fluid at such a high temperature in the piping. Changes to the controller that are suggested for startup are to direct outlet flow to either the cold or intermediate tank rather than to the pump inlet. Also, the field 1 inlet temperature should not be allowed to increase as high as in this case. Further, it is desirable to use a maximum insolation value closer to the attainable maximum, particularly in the morning when it is desirable to increase the temperature at the output as quickly as possible. These aspects will be considered further in the next phase of development.

Clouds

The previous analyses have been directed toward understanding the performance of the collector field and controller under certain simple and easily understood circumstances. The true test of the controller and field design is the response to clouds passing over the field. This is shown in Figure 3.6-73.

A cloud pattern was defined for this transient which consisted of a random series of clouds. The clouds were normally distributed with both the cloud and clear spaces having mean lengths of 500 meters with a standard deviation of 300 meters. The clouds drift across the field from south to north (the predominant wind direction at Ft. Hood) at 6 m/sec (about 15 mph). The mean cloud duration was 83 seconds. The clear portion had an insolation of 1.0 times the design value and the clouds had 0.2 times the design value of insolation. The average insolation was 0.6.

The primary result of this transient is that the field was well behaved. The outlet temperature varied from about 262 to 288°C with a rough average of about 277°C (530°F). These temperatures are reasonable for collection on this relatively heavily clouded day. There is no evidence of temperature overshoot or unstability in the controller. Figure 3.6-73.h shows the instantaneous energy delivery rate to the hot tank. This is the product of the hot tank flow with the total field temperature rise. This function tends to respond to a longer term average of several clouds. The value for steady state at maximum insolation is about 1500 kg - °C/sec so the collected energy during this transient is a little more than half of that value.

Future Analytical Considerations

The current studies have disclosed a number of areas for future development of the model, of the controller and of the field design. The most significant of these is that a strong effort should be made to reduce the intra-field piping volumes and thus reduce transport delays. This will strongly help startup transients and reduce the energy wasted during shutdown via losses to ambient. The second point is that valve V_2 is only open when the temperature of the fluid is below 200°C due to the design of the controller. Thus, there is no need to send fluid from this path to the hot tank so valve V_6 and path 19 can be eliminated. At this time it is not clear whether valve V_7 and path 16 are required because the temperature of fluid in this path is higher and the valve V_4 shutoff point is more variable. This will be studied further in future analysis.

The basic field controller appears to work quite well at this time. However, more attention is required to the programming of the on-off valves for startup and shutdowns. Also, a function should be added to temporarily maintain high flow after an inlet temperature decrease to prevent overshoot of temperature of "old" oil. The temperature at which the on-off valves change state should be based on a stronger foundation.

Cloud Field - Average Coverage 50 Percent

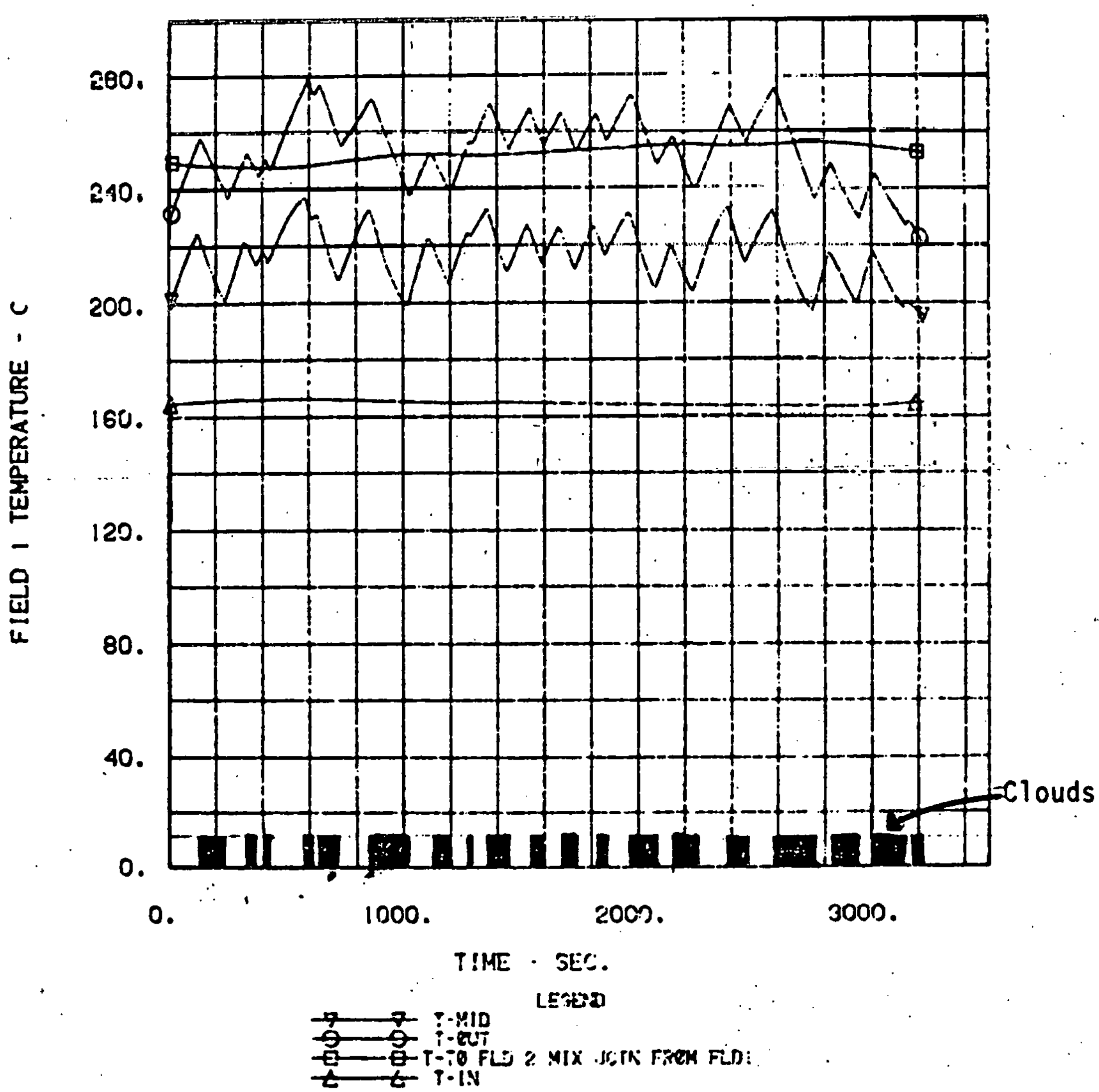


Figure 3.6-73.a. Field 1 Temperature

Cloud Field - Average Coverage 50 Percent

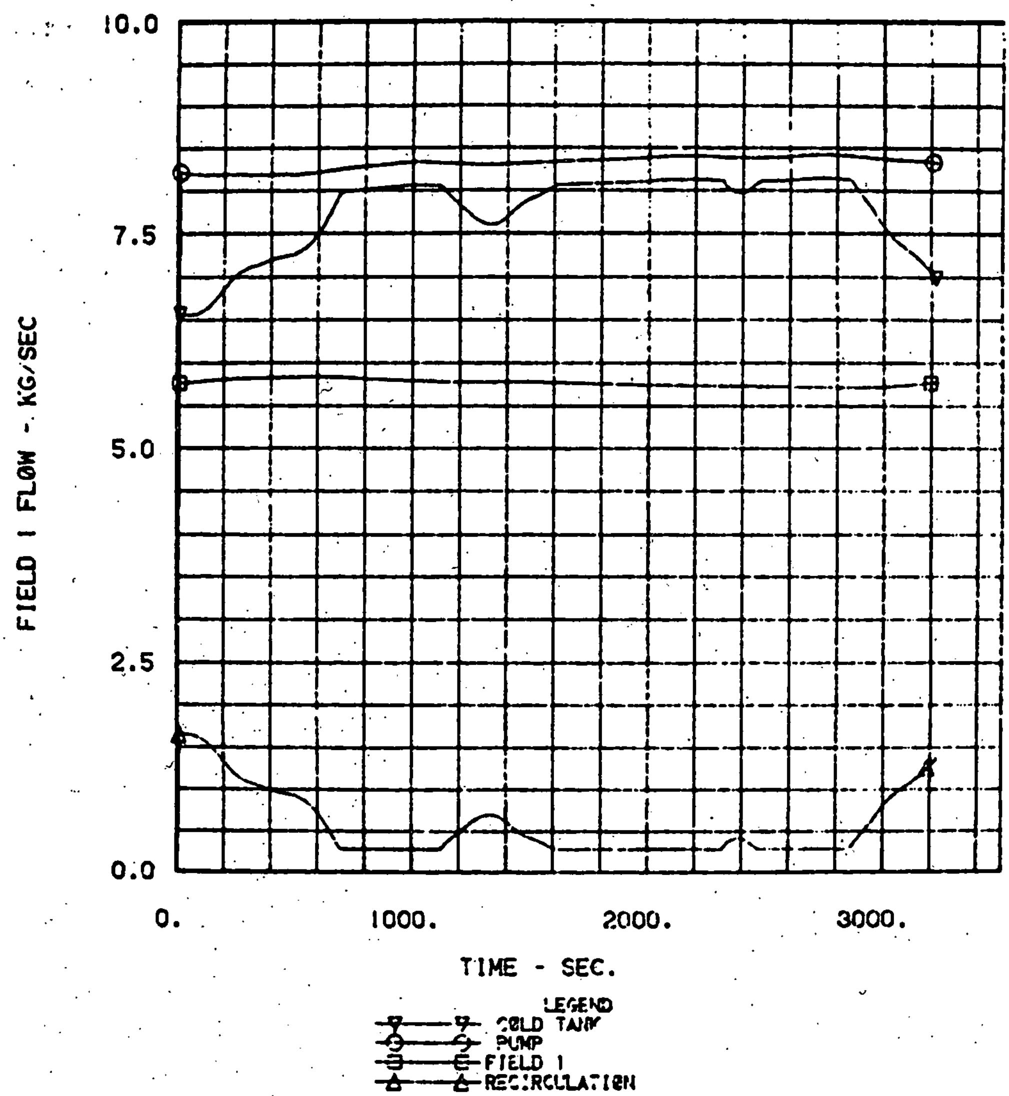


Figure 3.6-73.b. Field 1 Flow

Cloud Field - Average Coverage - 50 Percent

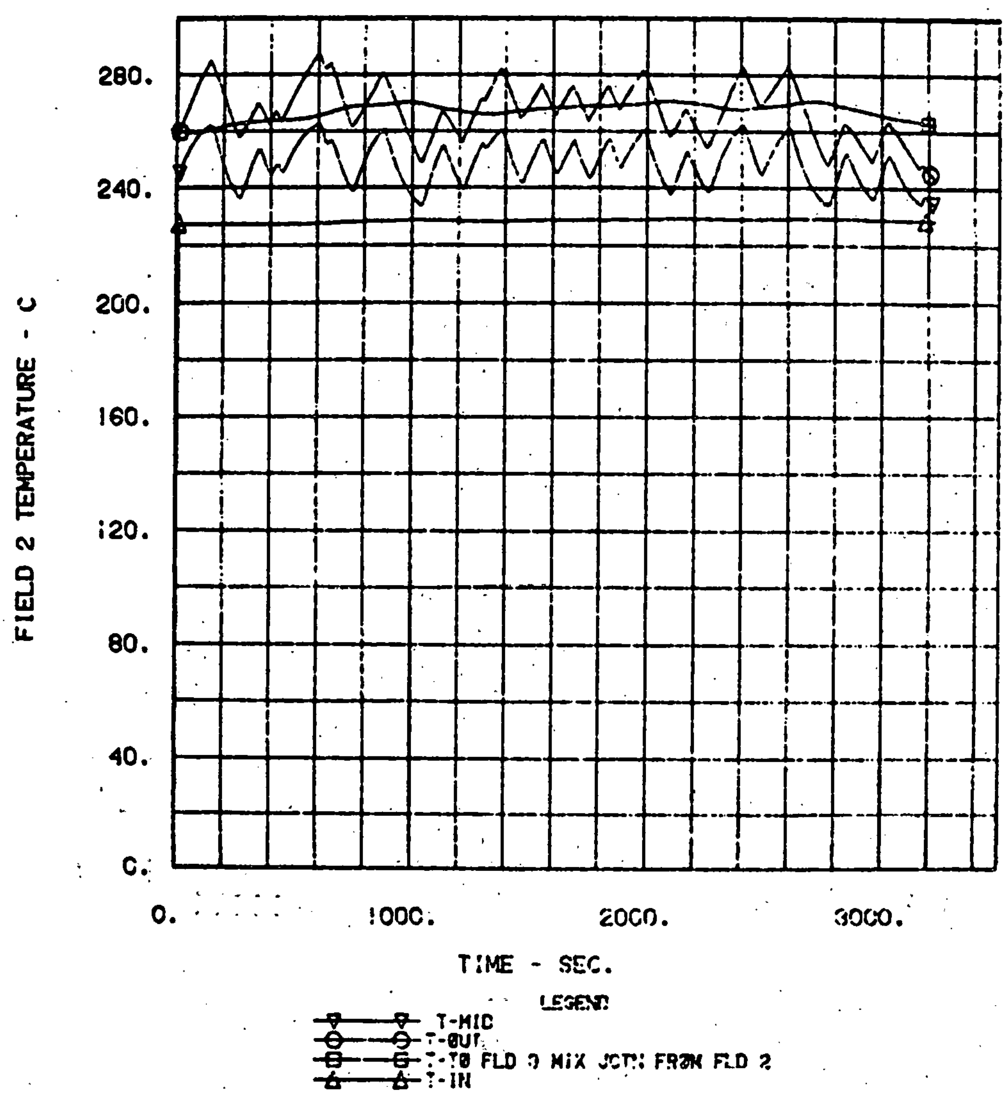


Figure 3.6-73.c. Field 2 Temperature

Cloud Field - Average Coverage 50 Percent

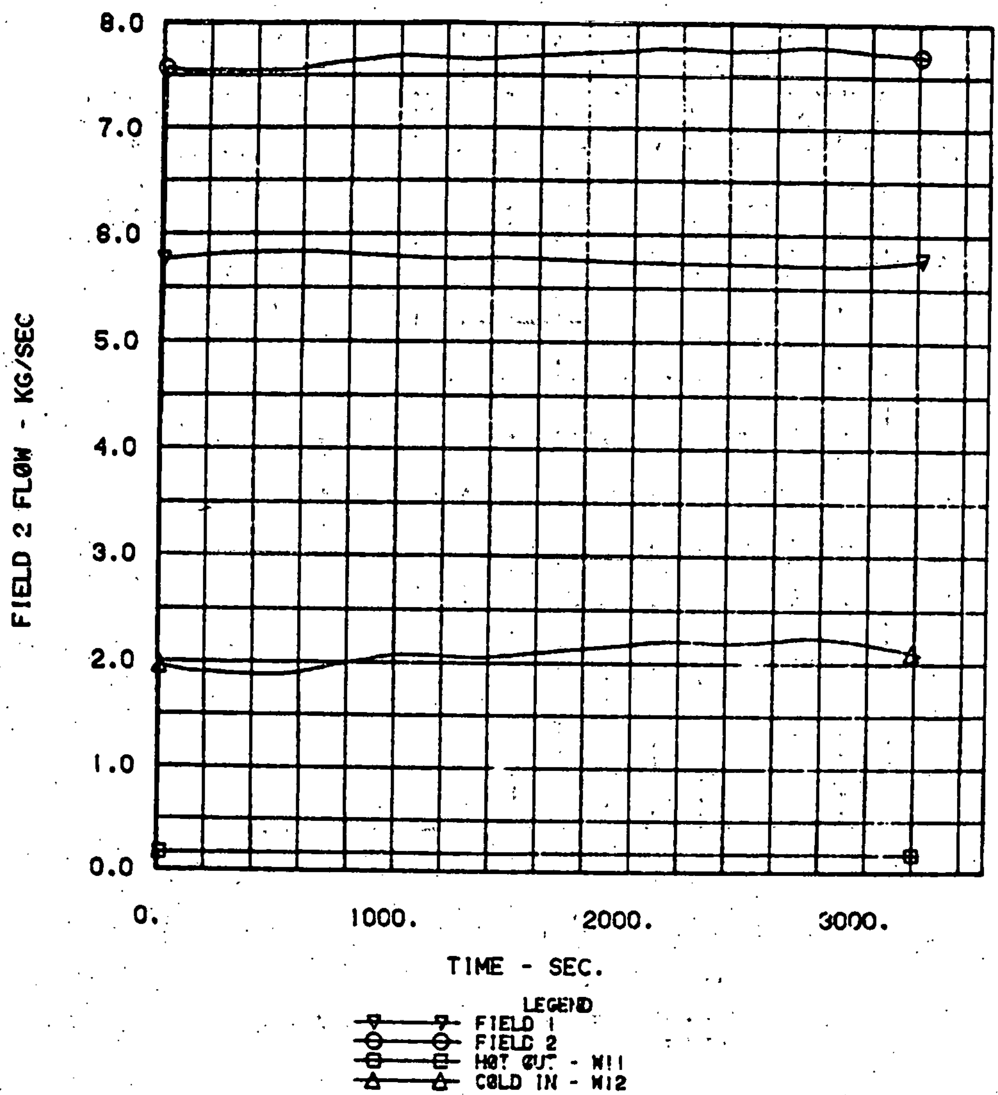


Figure 3.6-73.d. Field 2 Flow

Cloud Field - Average Coverage 50 Percent

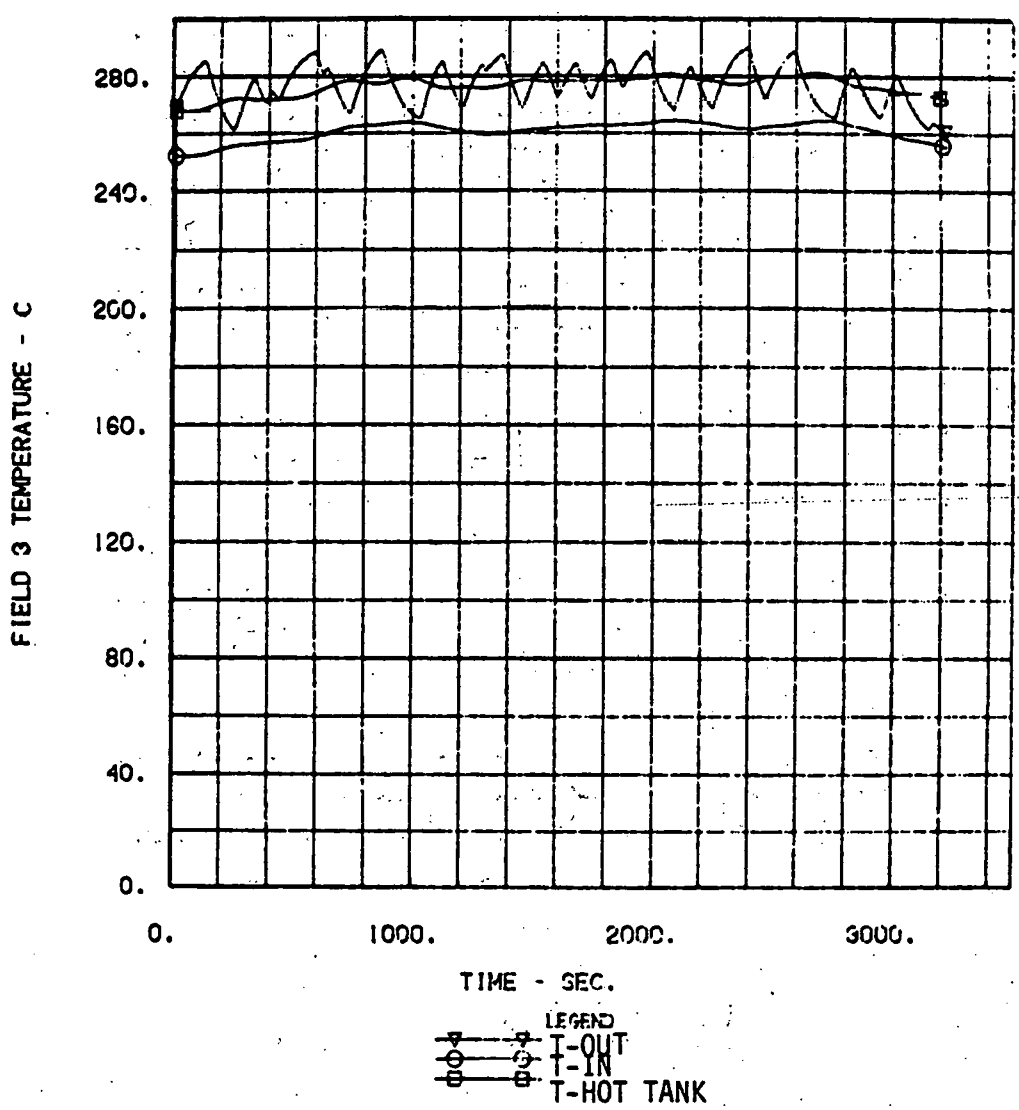


Figure 3.6-73.e. Field 3 Temperature

Cloud Field - Average Coverage 50 Percent

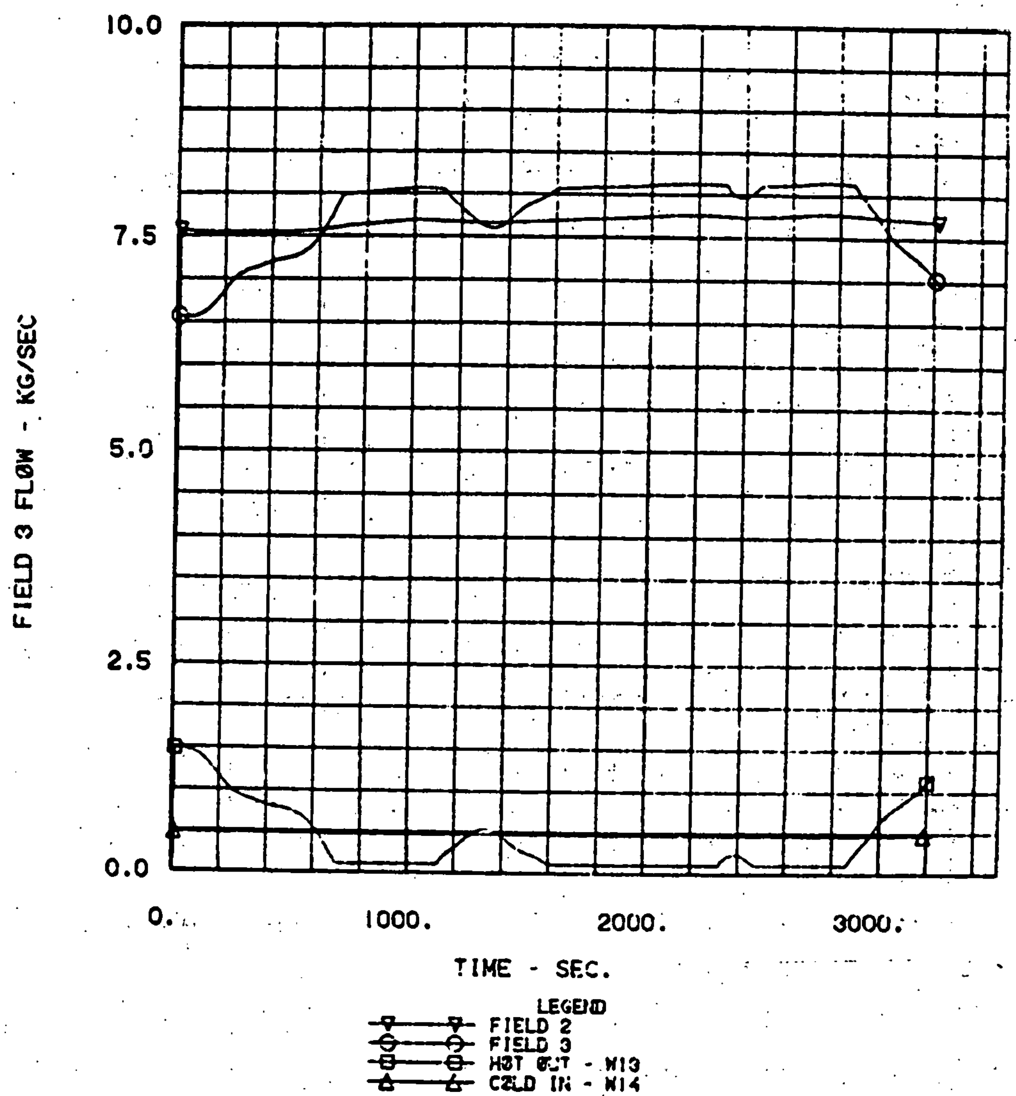


Figure 3.6-73.f. Field 3 Flow

Cloud Field - Average Coverage 50 Percent

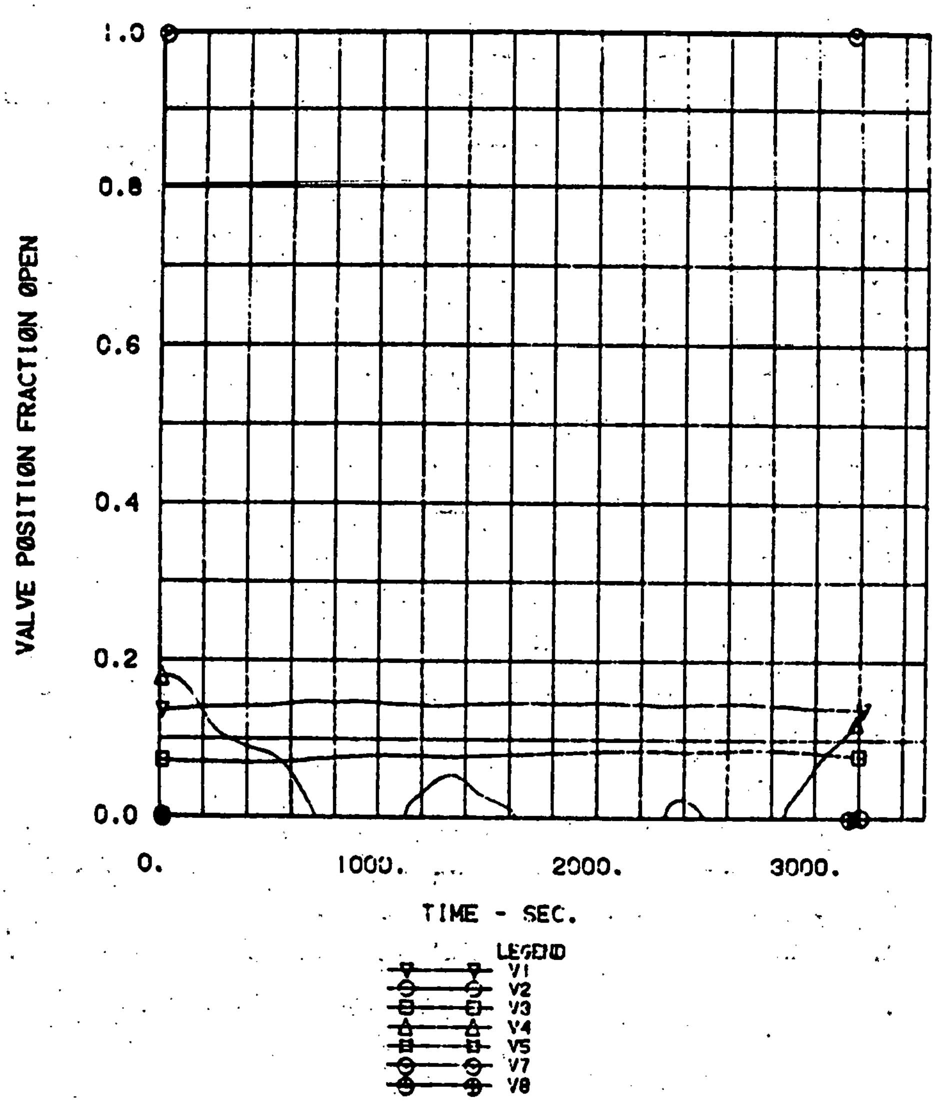


Figure 3.6-73.g. Valve Position

Cloud Field - Average Coverage 50 Percent

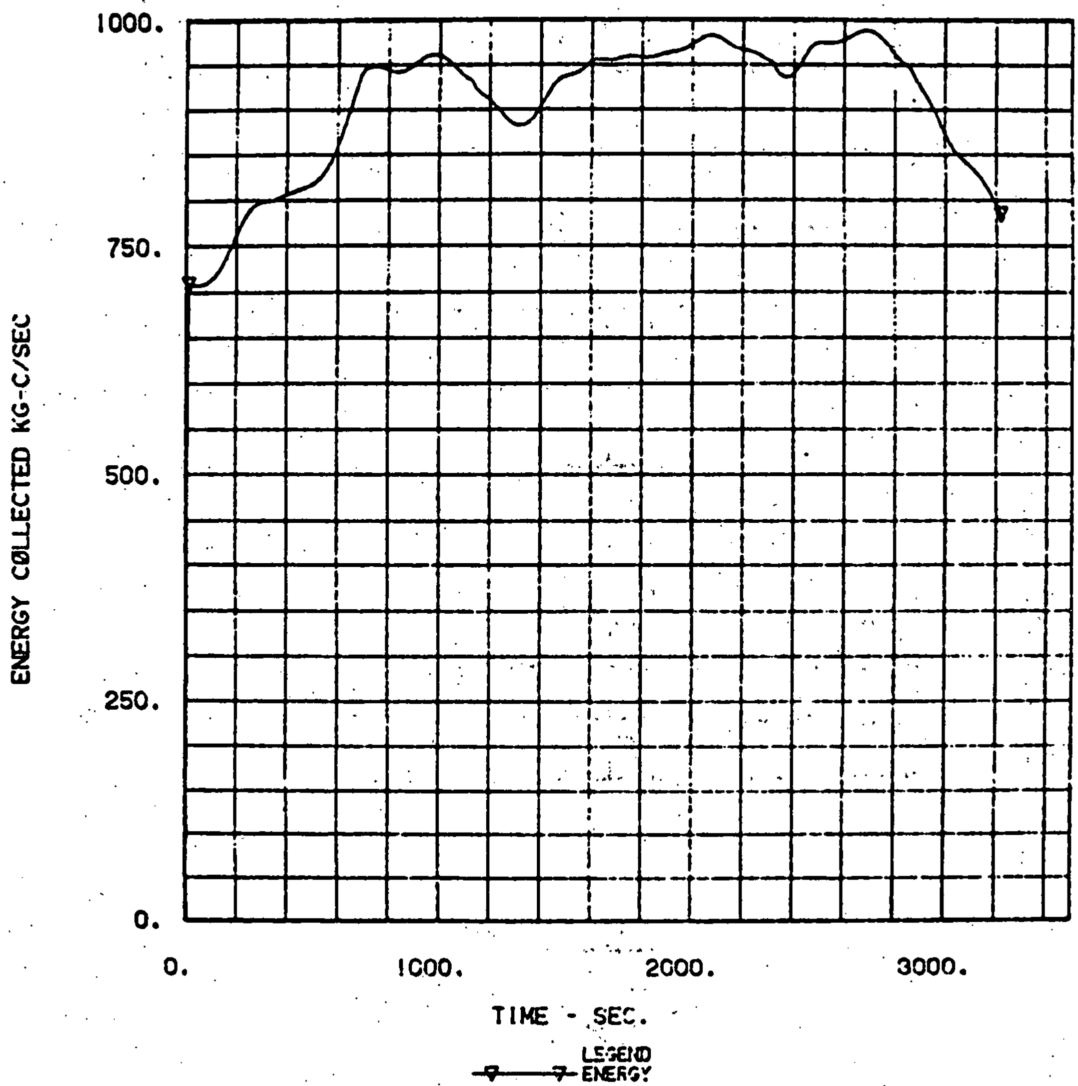


Figure 3.6-73.h. Energy Collected

Modeling of the intrafield transport delay should be improved by either including more mixing nodes or using other techniques in these paths. This also includes adding transport lag between the mixing junction at the inlet of the field and the actual field inlet.

Field hydraulics will be revised based on recent information which reduces the collector resistance by about one-fourth. More realistic valve loss factors will be incorporated. Some changes to the hydraulic network connections for the bypass paths will be considered.

The equations which predict the field temperature rise are a linear fit over a given range and have resulted in steady state outlet temperature differences of the subfields of about 5°C. A better fit will be generated for the future analysis.

A very simple controller has been implemented for the control valves which feedback on a desired flowrate. No account has been taken for any potential stability problems of these controllers. Particularly, momentum pressure changes have been neglected in the flow paths. This aspect will be evaluated in the next phase.

With these modeling and controller changes a fuller set of transients will be evaluated to better characterize field performance.

3.6.4.2.3 MALFUNCTION ANALYSIS

MALFUNCTION OF SOLAR COLLECTOR FIELD

Loss of Flow

The most severe malfunction that can occur in the solar collector field is a loss of flow (not including loss of coolant due to a pipe rupture which would be a casualty.) Figure 3.6-74 shows the response of the first subfield to a complete loss of flow with maximum insolation. The initial fluid outlet temperature was 300°C. With loss of flow the fluid temperature increased by 1°C in about 3.6 seconds. When the fluid temperature reached

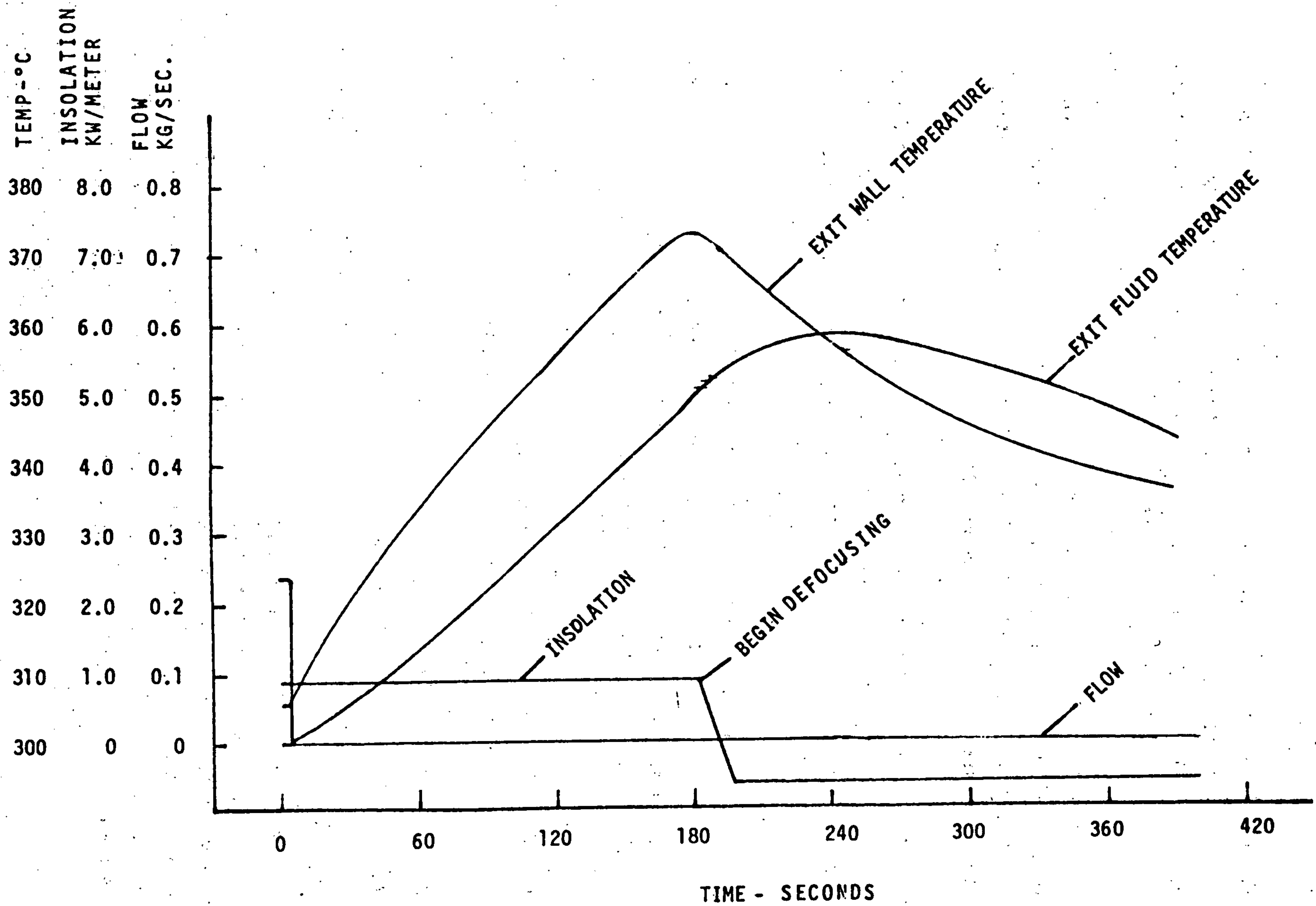


Figure 3.6-74 Malfunction: Loss of Flow in Field 1, Maximum Insolation

the trip point at the exit of the collector string at 180 seconds, the collector began to defocus. The trip point was arbitrarily established at 350 °C for this transient. The collector defocused in 10 seconds and the heat losses to ambient immediately began to cool the pipe wall. Since the pipe wall temperature was initially higher, the fluid temperature continued to increase reaching a peak of 358 °C about one minute after the collector was defocused. Much of the reason for the large difference between pipe and fluid temperatures is due to the flow decrease which lowered the heat transfer coefficient between the fluid and pipe. A minimum heat transfer coefficient of 10% of the normal coefficient is imposed in the program. The fluid temperature overshoot should be included in the consideration when establishing the overtemperature trip point.

EFFECTS OF CONTROLLER MALFUNCTION

Fields 2 and 3 cannot easily be subjected to a loss of flow unless the pump would fail. However, a failure of the field inlet temperature controller can cause lower flow and higher inlet temperature than desired.

The transient was initiated from an initial steady state condition at maximum insolation. The inlet temperature controller for field 2 failed and demanded higher inlet temperature to field 2. The result was that V_2 opened and V_3 shut (Figure 3.6-75.f.). The flow to field 2 (Figure 3.6-75.d.) decreas~~ed from 9.7 kg/sec to 1.4 kg/sec and the field inlet~~ temperature (Figure 3.6-75.a.) increased from 235 °C to 273 °C as a result of these valve actions. Since the insolation had not changed, the temperature of the fluid in field 2 increased from an initial outlet temperature of 297 °C to the field trip point of 310 °C in about 40 seconds. The insolation was decreased to five percent in field 2 in response to the trip signal by desteering the collectors in this field.

This case is interesting because a fault at the inlet to field 2 caused a temperature excursion in field 3. At the start of this run, field 3 was being supplied with almost all of its flow (Figure 3.6-75.e.) from the outlet of field 2, 9.5 kg/sec at 297 °C (Figure 3.6-75.b.), and only a small flow from the cold bypass line through valve 5, 0.7 kg/sec at 160 °C. The field 3 inlet flow was 10.2 kg/sec at 287 °C. When the field 2 flow decreased to 1.4 kg/sec, the field 3 inlet controller readjusted its valves and established a new condition of 3.2 kg/sec at a temperature of 218 ^{o}C which would have an acceptable temperature rise in steady state. However, the fluid in field 3 was at a temperature that required a high flow rate to avoid overtemperature. In this transient the outlet temperature rose from an initial 299 ^{o}C to a peak of 307 ^{o}C after 100 seconds then decreased to a value of 297 ^{o}C after 600 seconds.

It is judged that the magnitude of the peak overtemperature in this case was underpredicted. Field 3 is simulated by only 2 mixing modes. Therefore, part of the effect of reduced inlet temperature would reach the fluid exit earlier in the model than in the actual case. This is compensated by longer time at high temperature. This will be corrected for future evaluations.

POWER CONVERSION SUBSYSTEM MALFUNCTION

Malfunction Turbine Trip

While in the high temperature peaking mode (heating season) a high pressure turbine trip due to a system malfunction is simulated by stepping turbine flow to zero and allowing the bypass valve to open to control the low pressure header pressure. Ten seconds after the trip occurs the boiler pressure demand is ramped from 365 psia to 65 psia at 10 psia/sec. At the same time the oil flow is switched from the high temperature tank to the low temperature tank. The change in oil inlet temperature to the steam generator is simulated by ramping the temperature from 550 ^{o}F to 438 ^{o}F at 10 ^{o}F/sec.

One other condition is imposed on the system to maintain a reasonable amount of oil flow to the steam generator, and this is to set a 30 per cent minimum limit on the oil throttle valve in the steam generating system.

Figures 3.6-76 thru 3.6-81 show the transient results following the turbine trip (Trip Time = 3.0 seconds).

As shown, the system recovers from the initial effect of the high pressure turbine trip and begins transition to heating season intermediate normal mode of operation as defined in Table 4.2-5. First, the superheater bypass

Malfunction at Field 2 Inlet

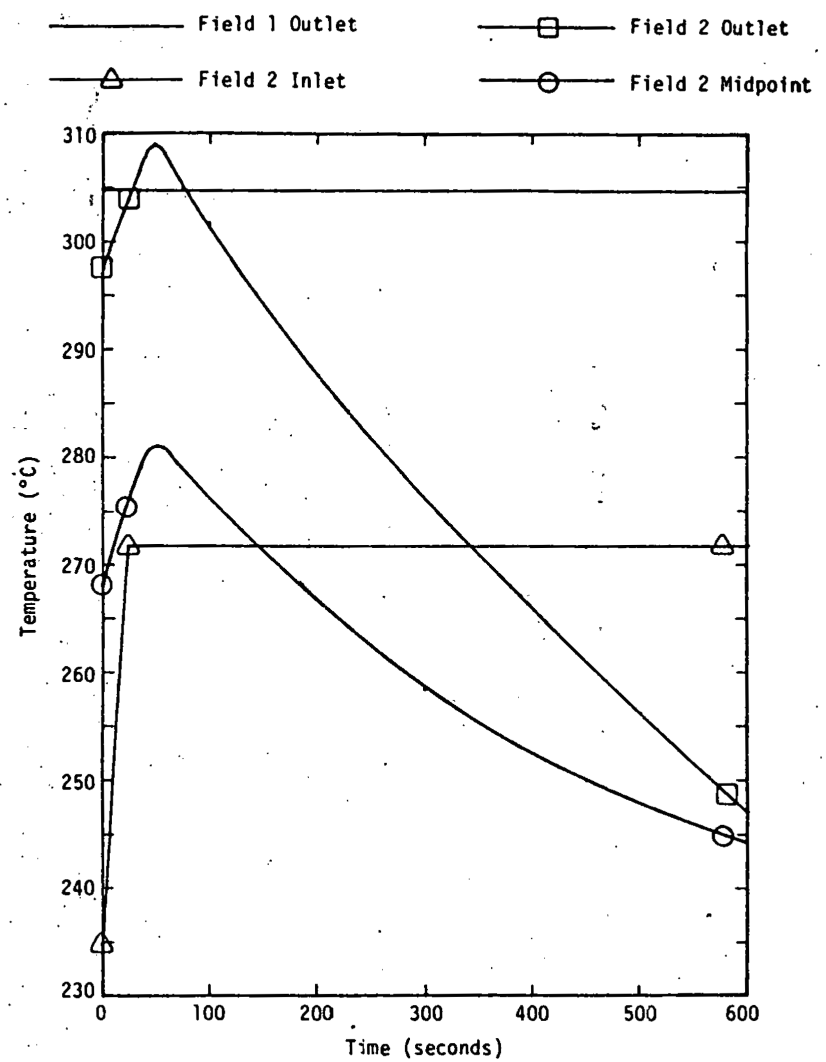


Figure 3.6-75.a. Field 2 Temperature

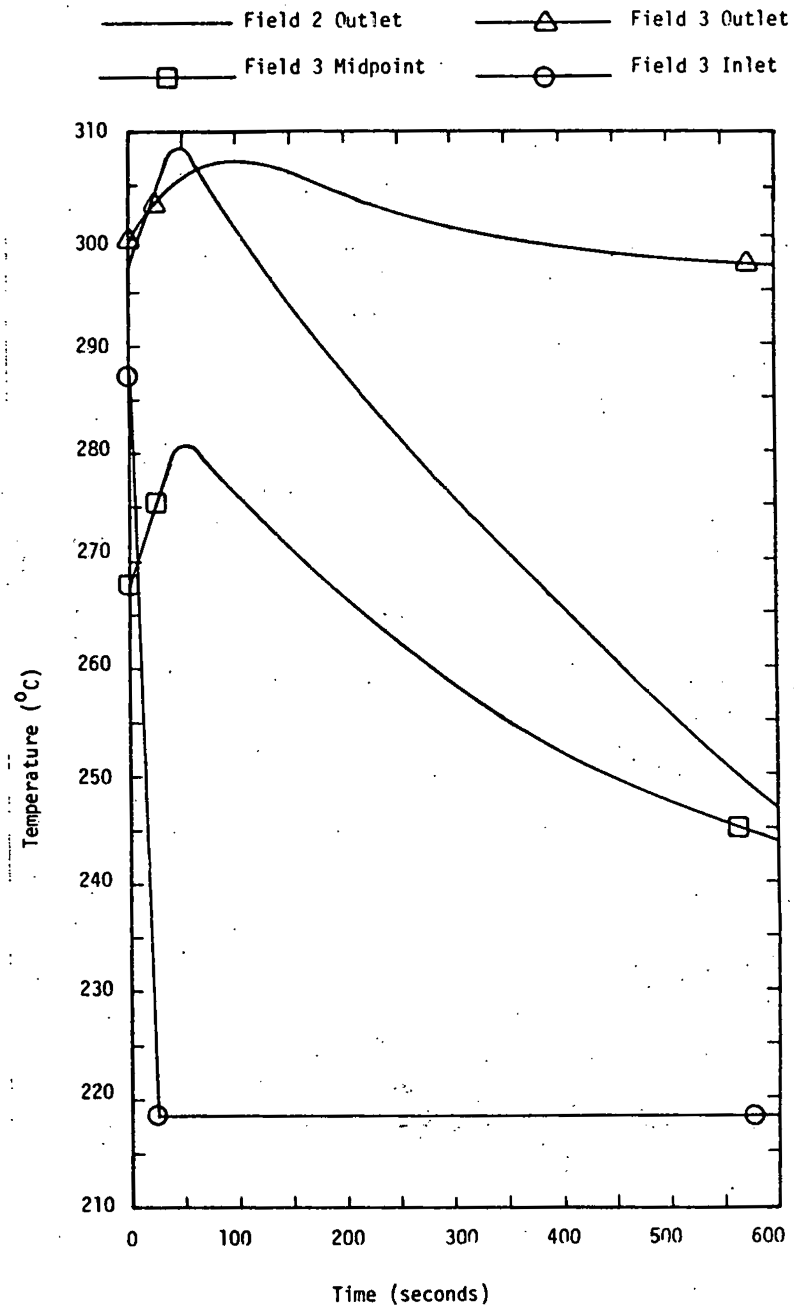


Figure 3.6-75.b. Field 3 Temperature

R-E-V-I-S-E-D

Malfunction at Field 2 Inlet

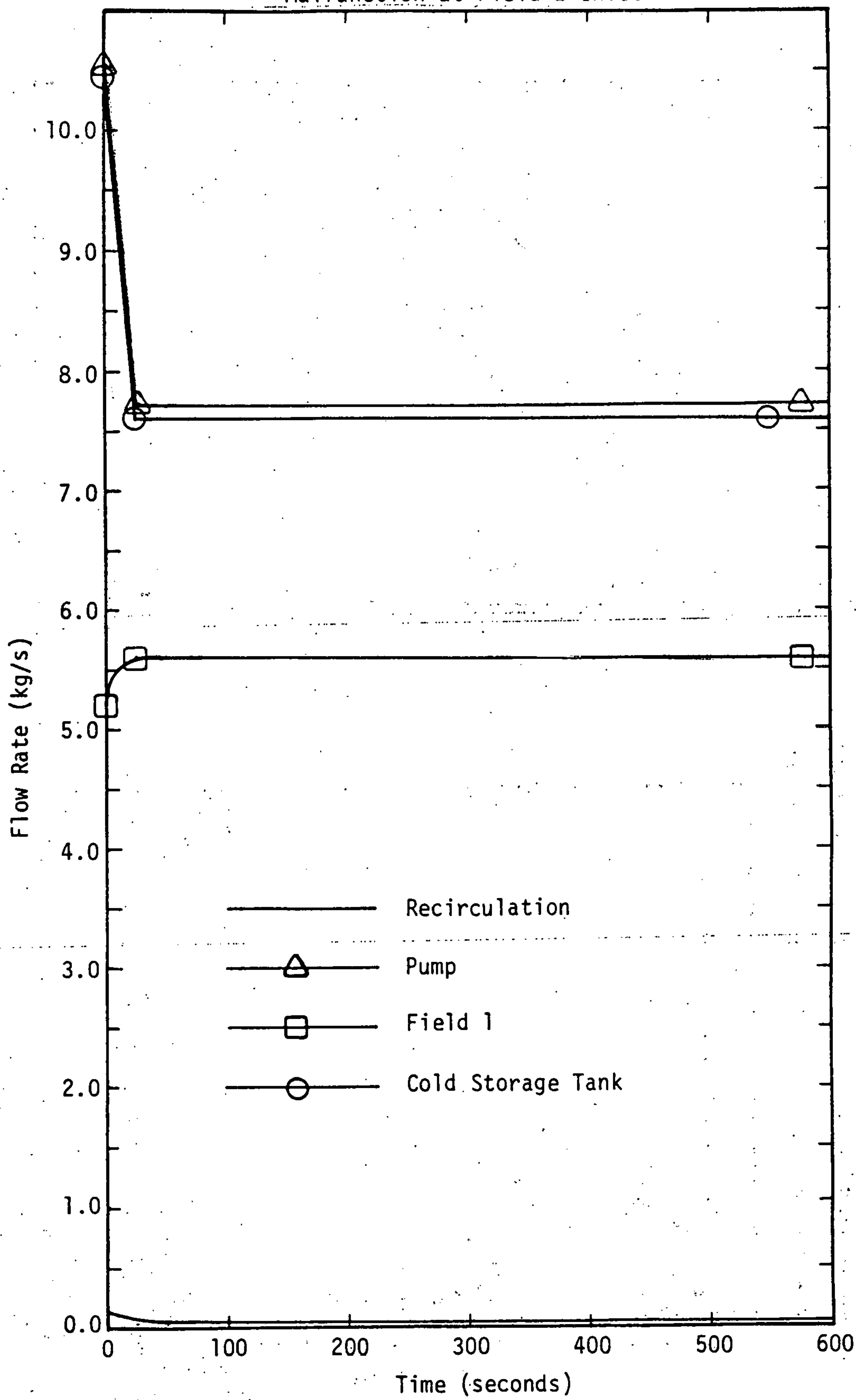


Figure 3.6-75.c. Field 1 Flow

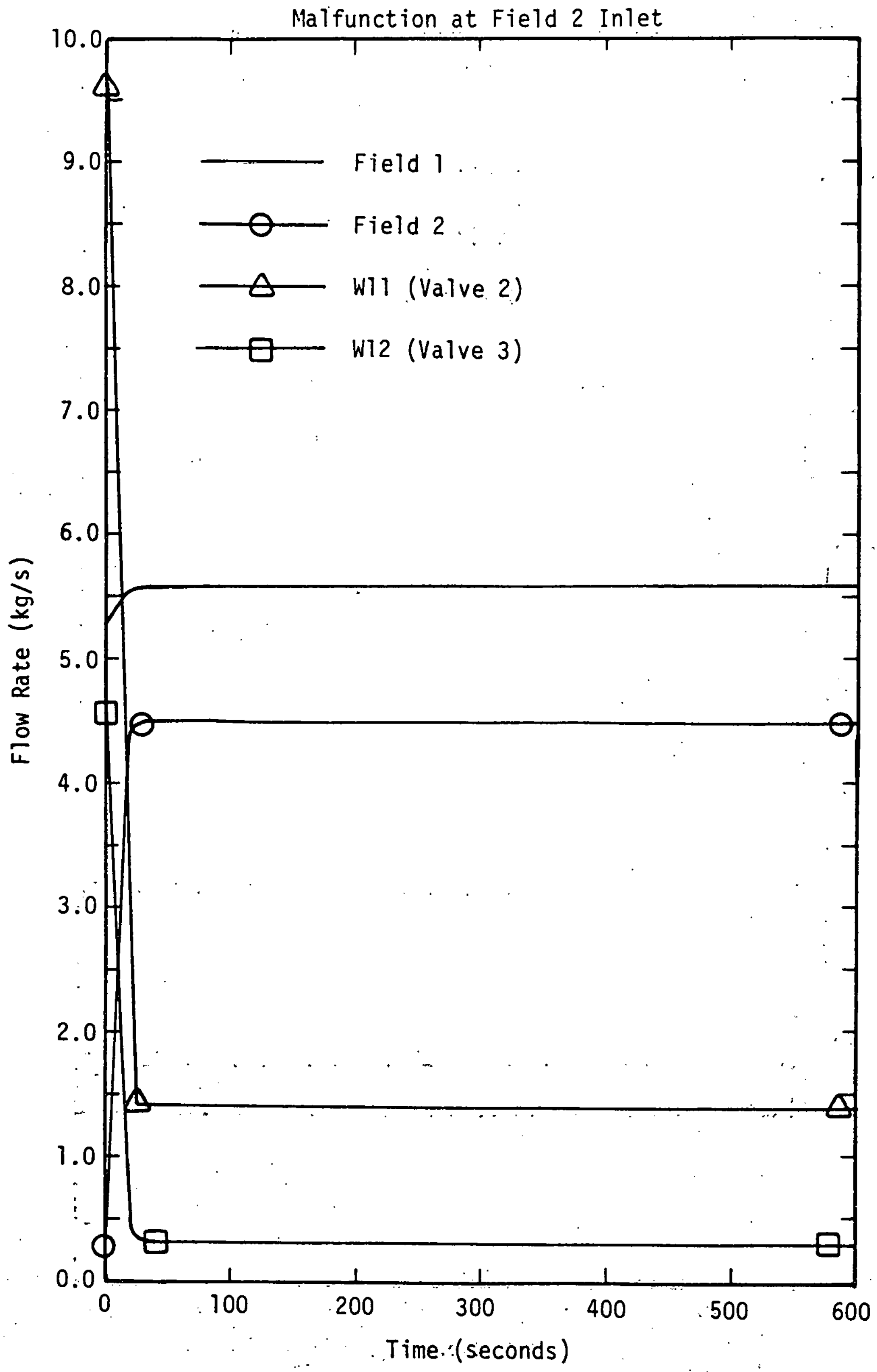


Figure 3.6-75.d. Field 2 Flow

R-E-V-I-S-E-D

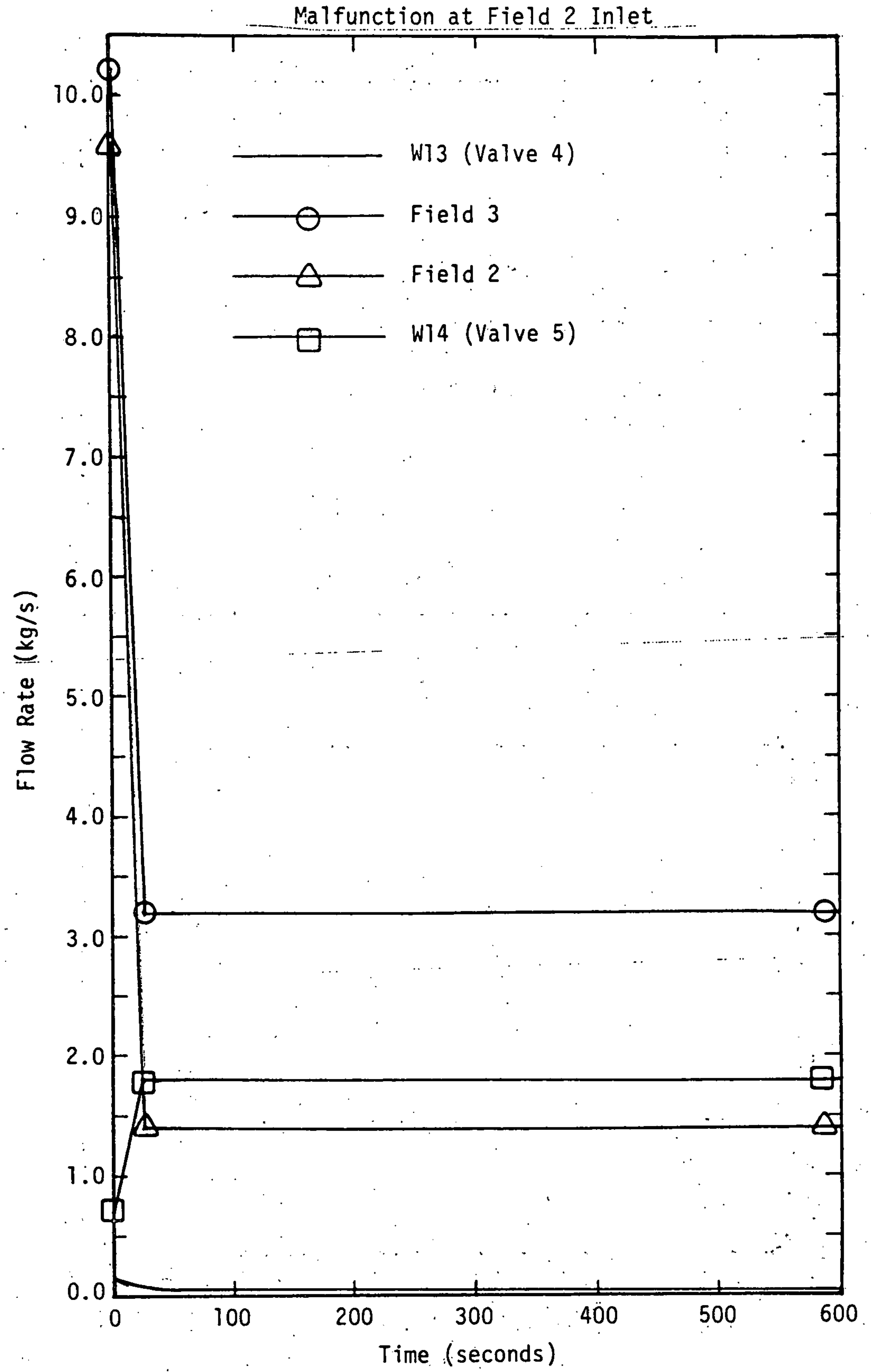


Figure 3.6-75.e. Field 3 Flow

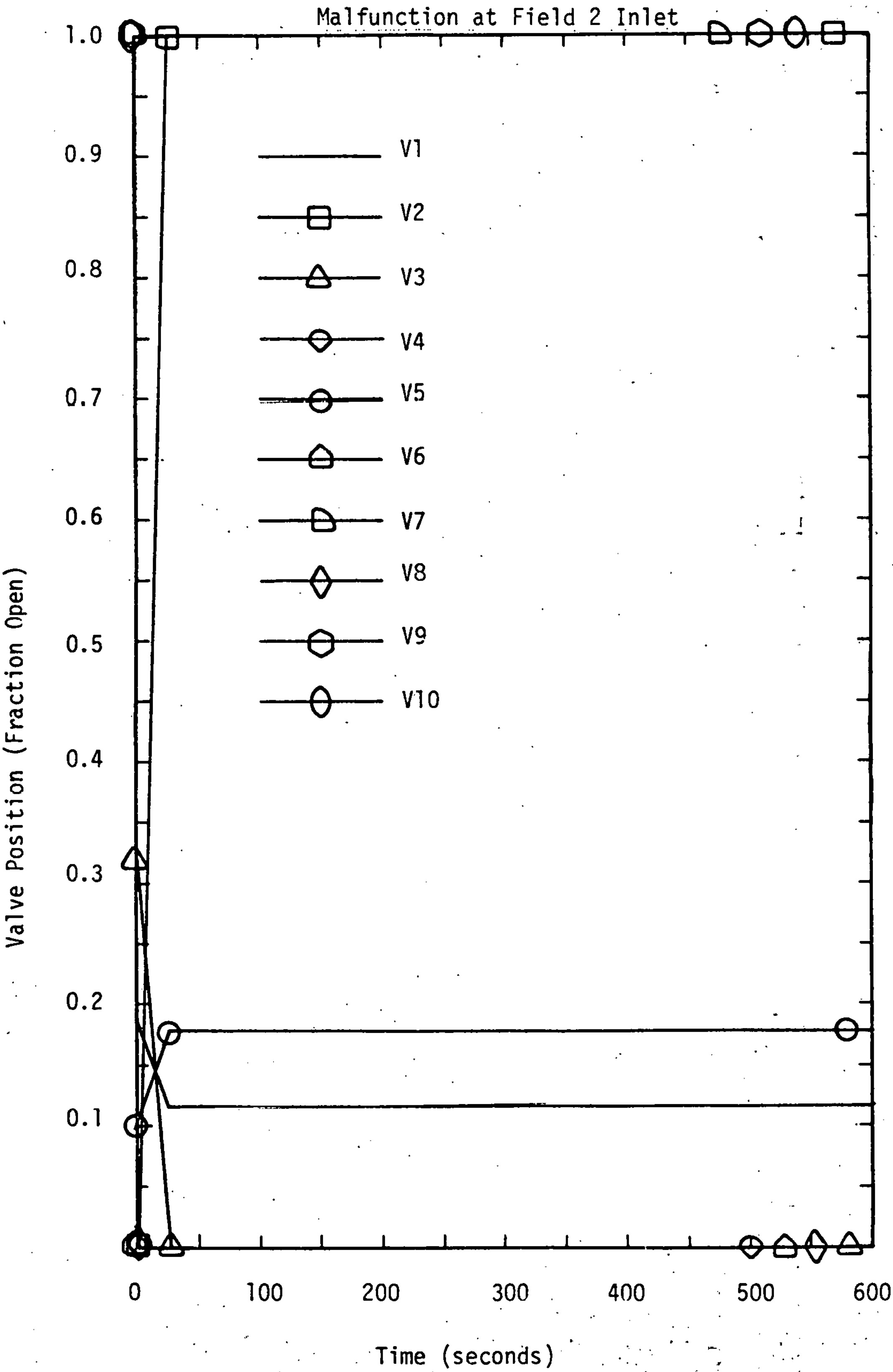


Figure 3.6-75.f. Valve Position

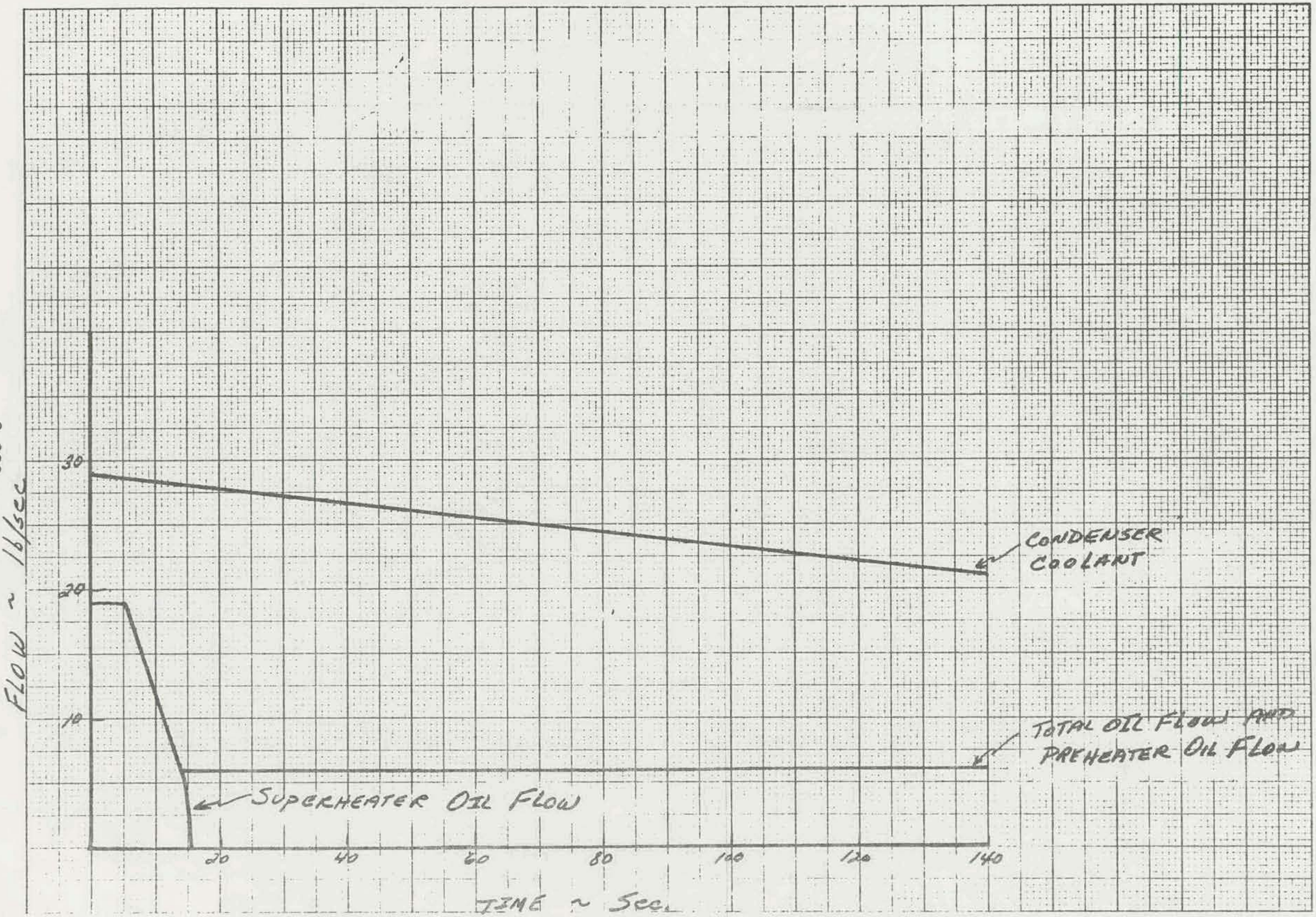


Figure 3.6-76. Oil Flow Rates in Steam Generator During Turbine Trip Malfunction

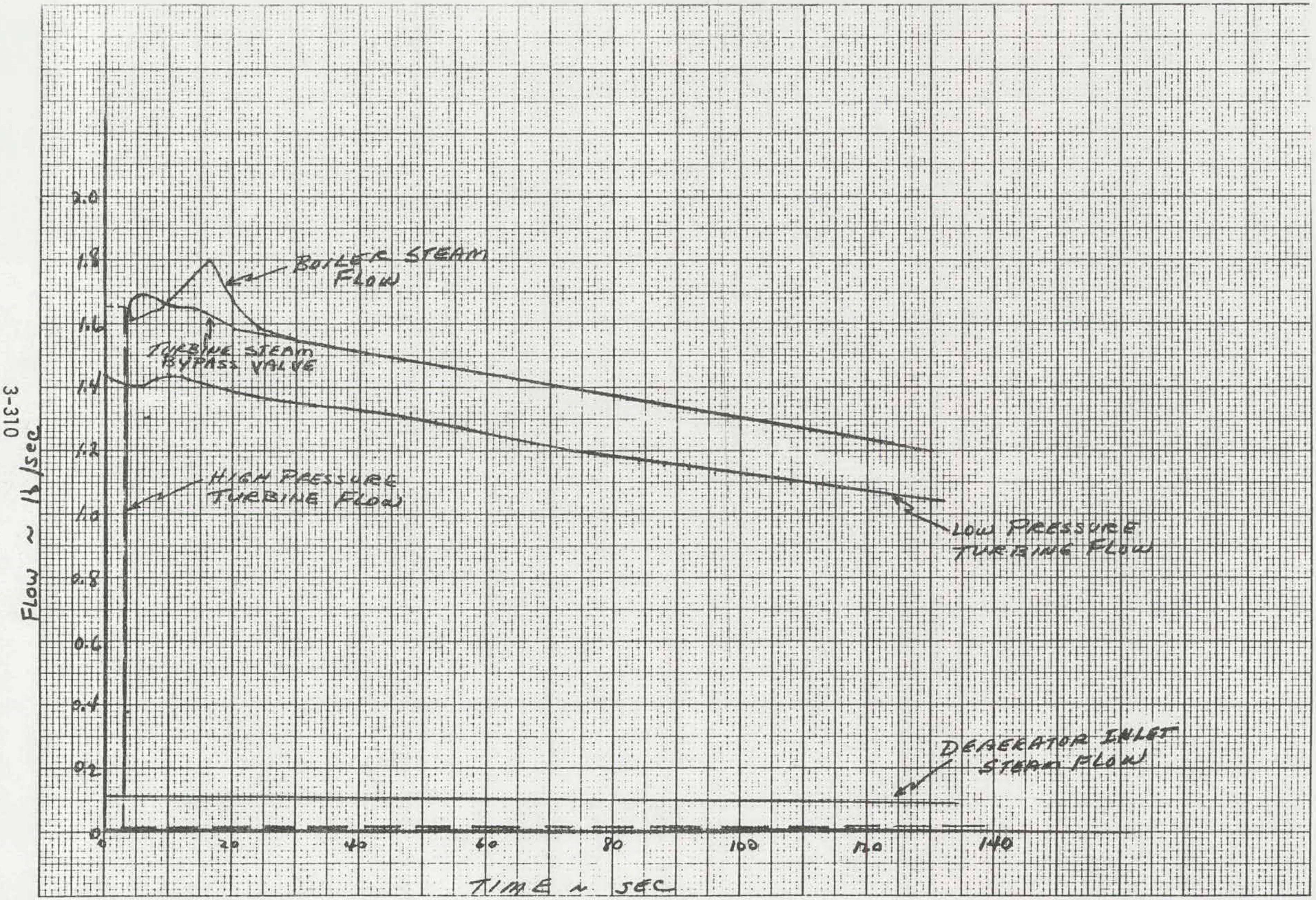


Figure 3.6-77. Steam Flow Rates During Turbine Trip Transient

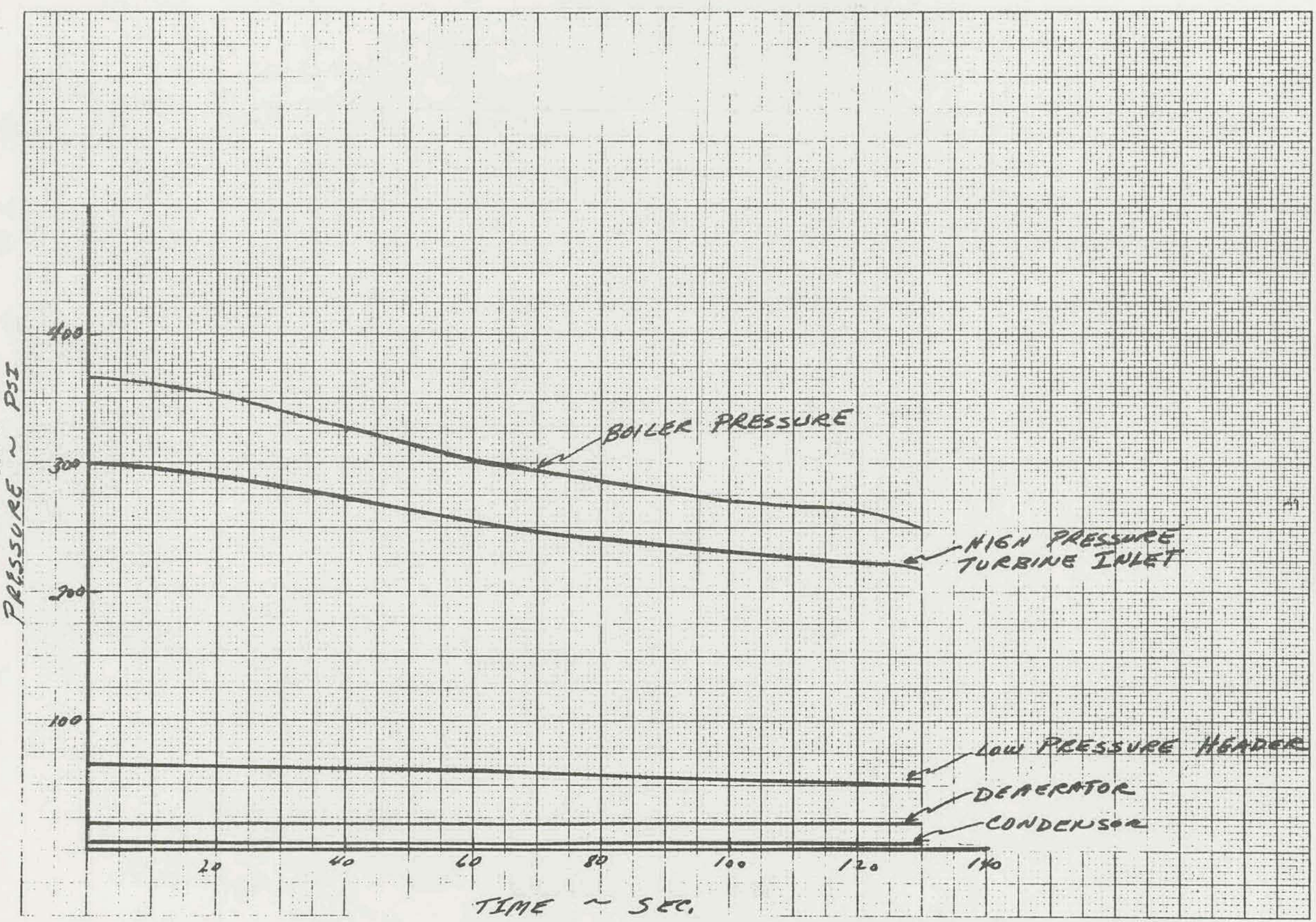


Figure 3.6-78. Steam Pressures During Turbine Trip Transient

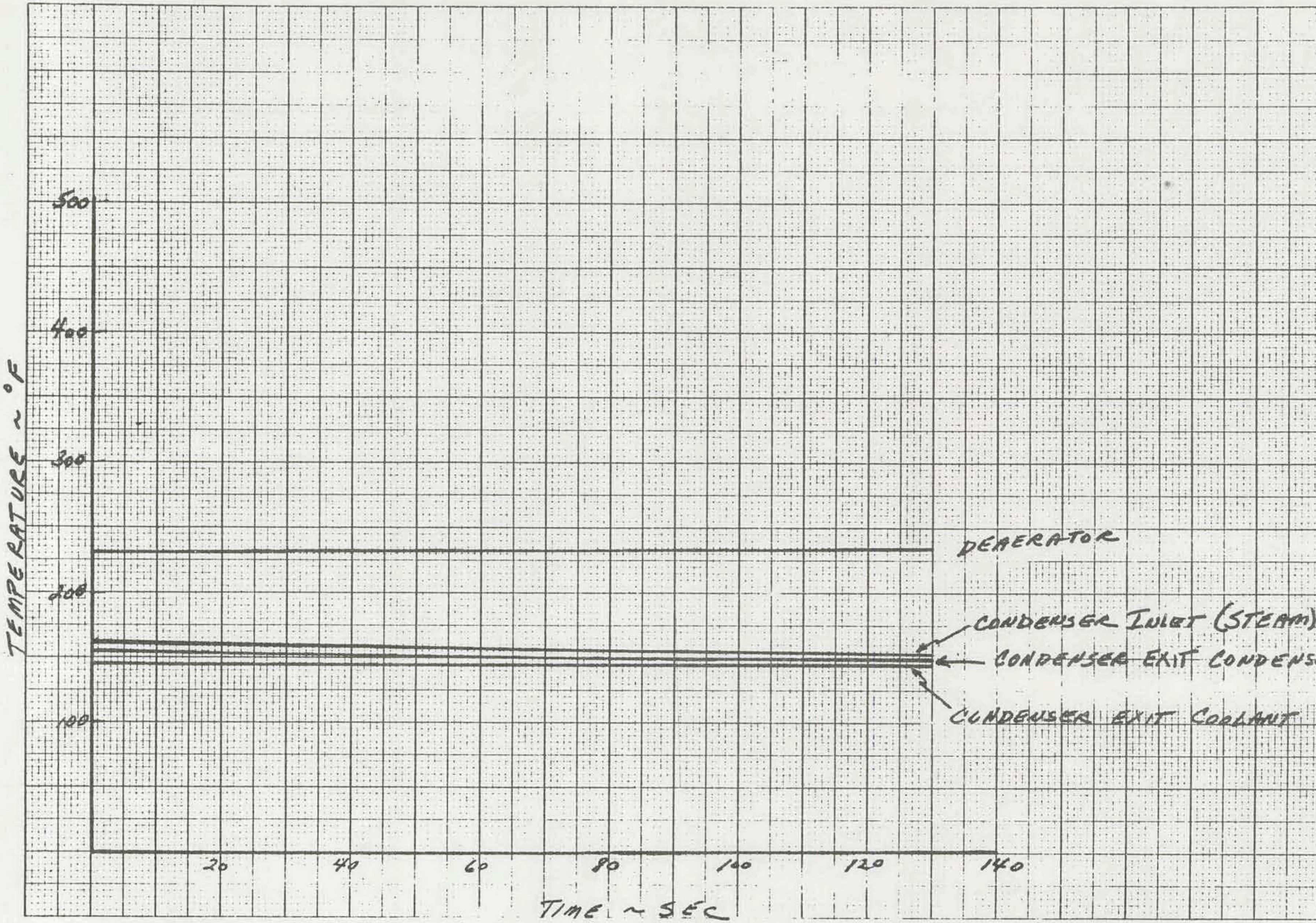


Figure 3.6-79.a. Steam Temperatures During Turbine Trip Transient

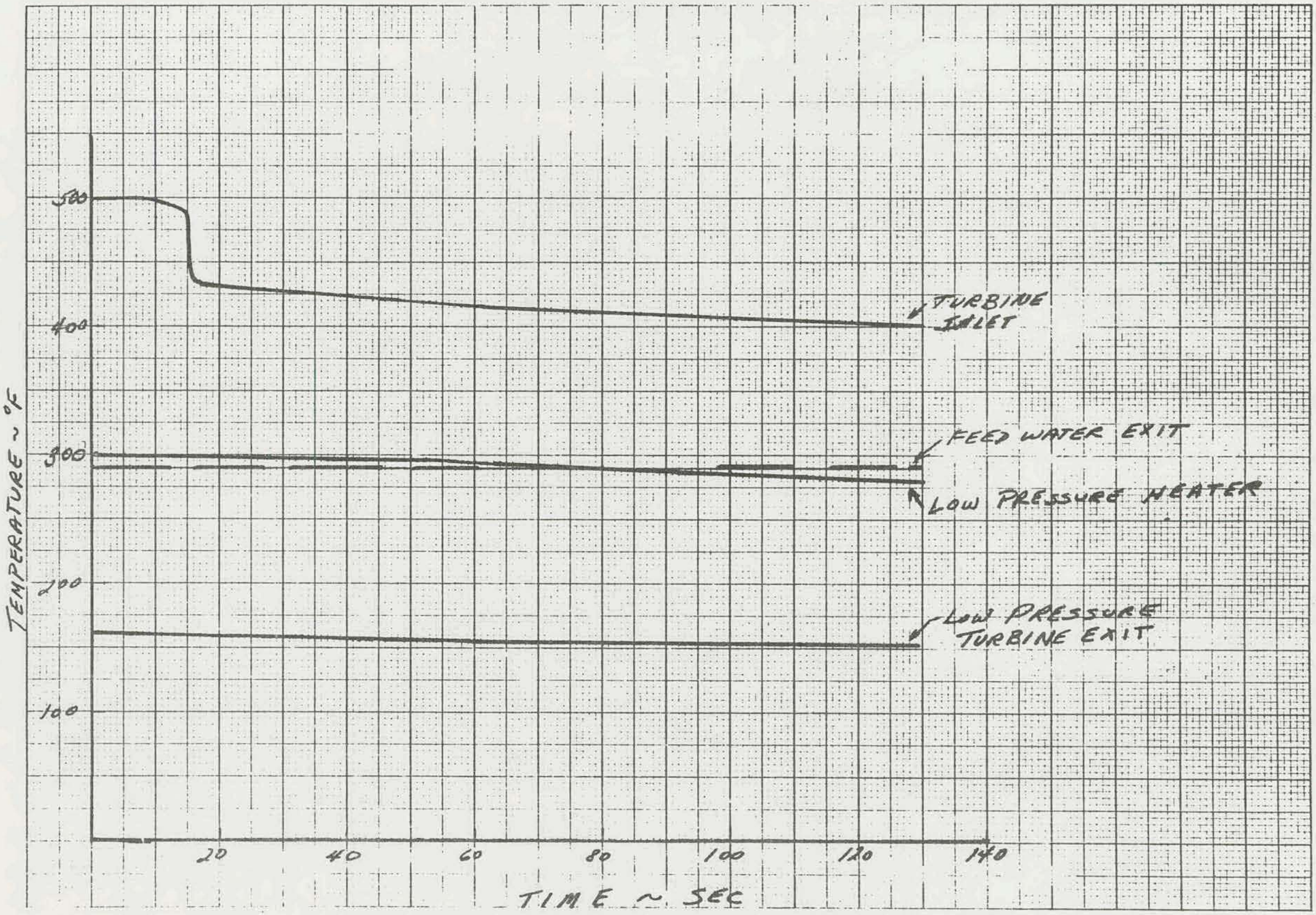


Figure 3.6-79.b. Steam Temperatures During Turbine Trip Transient

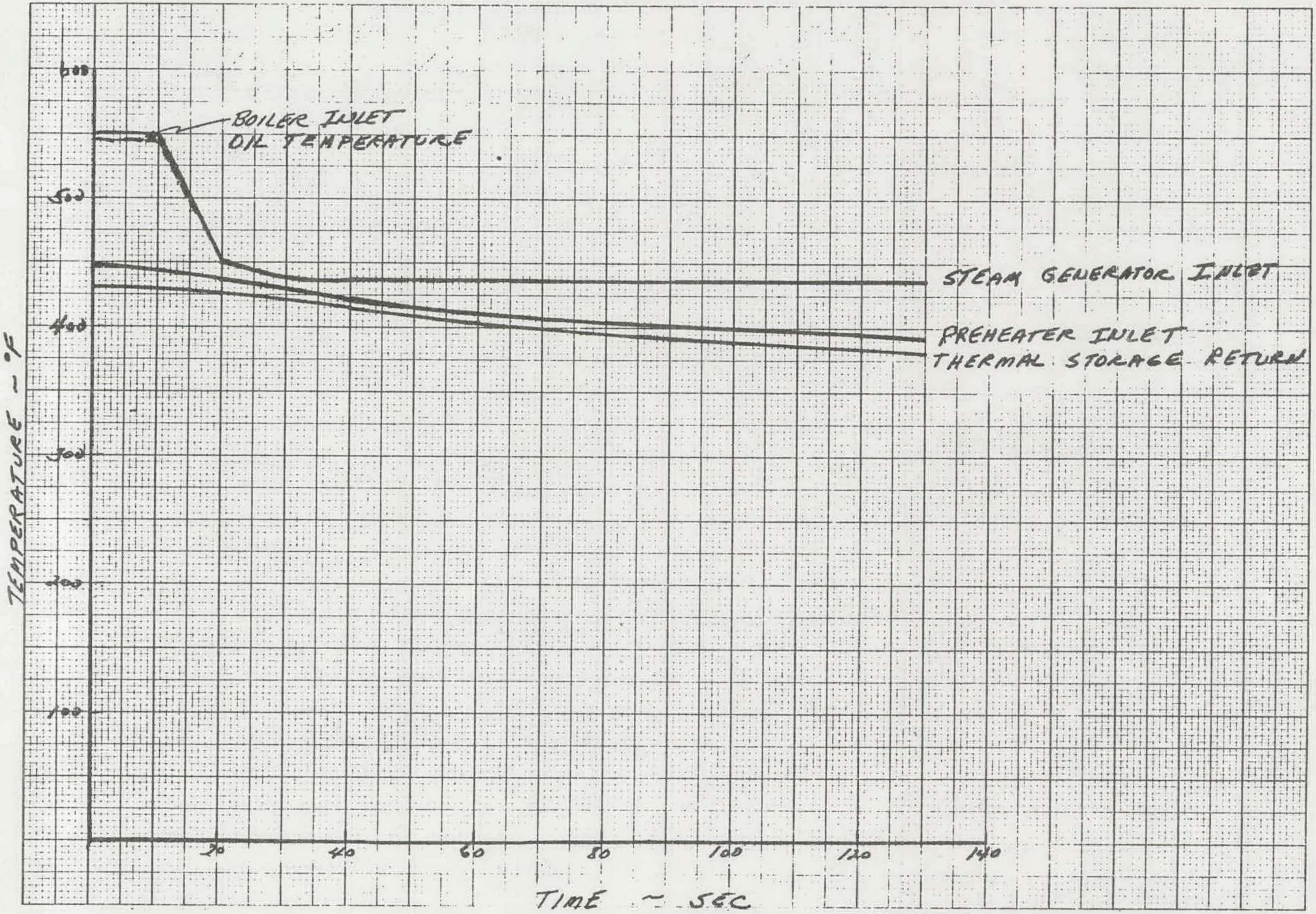


Figure 3.6-80. Steam Generator Oil Temperatures During Turbine Trip Transient

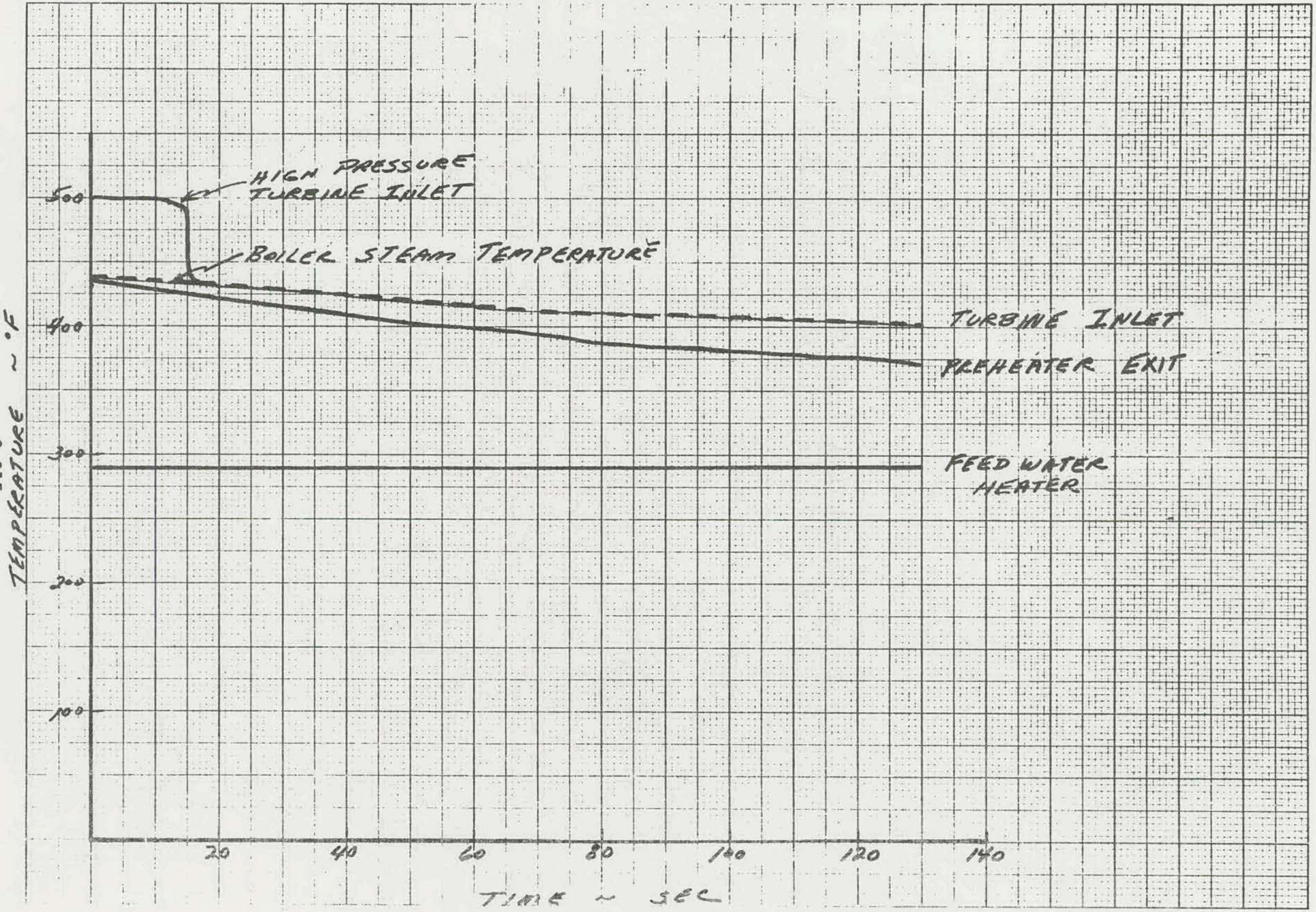


Figure 3.6-81. Steam/Water Temperatures During Turbine Trip

valve closes (t = 16 sec) removing the superheater from the system heat transfer and flow path. The system follows the steam pressure and flow demand for ~100 seconds. However, the demand for power generation which remained fixed at the high temperature peak mode set point, becomes larger than the energy available. This causes oil flow control valves to become saturated at full open positions, and the PCS system to become uncontrollable since the demand flow required for pressure and temperature control cannot be met. Therefore, the pressure and temperature in the low pressure header begin to collapse, as well as the terminal temperature difference in the feedwater heater which becomes dangerously small, and would probably cause tube burnout at the less than $2^{o}F$ difference.

The probable cure for the adverse result following the trip would be to change the power generation set point (ie. flow demand to low pressure turbine), and change the feedwater heater temperature demand to track low pressure header temperature conditions by some $5^{o}F$ difference. This would lower energy demands to turbine and feedwater heater. Also, more detailed analysis in the control system is needed to adjust for gain changes required to state point operating conditions.

Partial Loss of Steam Generator Oil Flow

The hypothetical partial loss of oil flow to the system steam generator caused by system control valve failures, flow blockage, or loss of pump flow set point or other events that lead to a 50% change in flow can be interrupted from the step response data in Figures 3.6-34 thru 3.6-41.

The step response data provides a further insight into the inherent system design safety. As shown in the figures a large step change in system flow does not cause unsafe or adverse operating conditions, but only an undesired system operating point. The important result is that the system responds and settle to a new operating point at a lower energy level. The only period of time where this may be a problem is when the hot/chilled water storage tank is depleted, and this loss of energy availability would thereby create a situation where the thermal load demand could not be met.

3.6.4.3 DESCRIPTION OF COMPONENTS

The components of ICS span from the control room to each subsystem's instrumentation. The central control is in the CPU that communicates with the operators control console and the DPU's. The DPU's monitor the instruments and control the subsystems under the guidance of the CPU, through the I/O channels and signal conditioners.

Central Processing Unit (CPU)

The description of the STES CPU includes the central minicomputer mainframe and the central computer peripherals as well. The mainframe is sized with 64K words of memory to allow efficient operation of a real-time multiprocessing, disc-based operating system executive. Efficient floating point capability allows data conversion and formating as well as calculations for energy management. Additional features include: real-time clock; power fail/restart; I/O interrupts; direct addressing of words, bytes and bits; memory management; expansion capability to 128K words; memory byte parity error detection; and operating panel. The single reliable link has 80 MB of storage for formatted data, operator communications and display formats, and program storage. To reduce downtime if the disk fails, the 80 MB may be divided between two discs. The system default I/O will be the programmers CRT with keyboard, that will also allow program maintenance and may include EPROM programming hardware for DPU maintenance.

The major I/O devices of the CPU, outside of the operator console, are the magnetic tape drive, the line printer and the card reader. The nine-track magnetic tape drive will handle 2400-foot reels at either 1600 or 800 BPI. It will be useful for large program input and data output. The density is selectable so that the capability to match the BPI rate of other facilities where detailed data analysis is to be pursued. The card reader is an easy, reliable input device for small amounts of data or control and provides backup to the magnetic tape input. The medium speed line printer provides hard copy output as the system demands. It will be used for program maintenance, selected data output, and hard copy of sequence of alarms.

Distributed Processing Unit (DPU)

The DPU hardware is purposely unspecified so as not to limit the design to match a certain vendors products. The functional requirements of local control and data gatherings however are specified. Each DPU is envisioned as a micro-computer containing control algorithms and data storage areas. The DPU has complete local control over its assigned subsystem and responsibility for monitoring its instrumentation. It will accept and implement commands from the CPU specifying the mode of subsystem automatic operation and specific component operation. When polled it will provide the CPU with current data from its instrumentation.

CONTROL CONSOLE

The Control Console is located in the main control room of the STES building. Panel meters, system status lights, and alarms that are hard-wired from the field locations are mounted on the Control Console. The Control Console also contains two CRTs with interactive keyboards for operator use. One of the CRT units is dedicated for display of alarm functions while the second is for general use to the operator for display of all data system parameters. Space is also provided for digital meters for continuous display of selected system data. These digital meters are driven by the CPU I/O system. The ten foot Control Console and the dedicated recorders and displays are incorporated into a typical control room layout shown in Figure 3.6-82.

Input/Output Channels and Signal Conditioners

The I/O ports for the DPUs are shown on Drawing 102E145 of Volume III. Although the input and output signals of each DPU varies, a description of the signal types is presented. The I/O ports and the microprocessors are part of the overall DPU.

1. CRT & Keyboard
2. Card Reader
3. Central Process Unit
4. Disk
5. Magnetic Tape Unit
6. Line Printer
7. Controls, Indicators, Alarms
8. 2 CRT's with Keyboards
9. Recorders and Displays, Logic
10. Storage for Manuals, Drawings, Tape, etc.

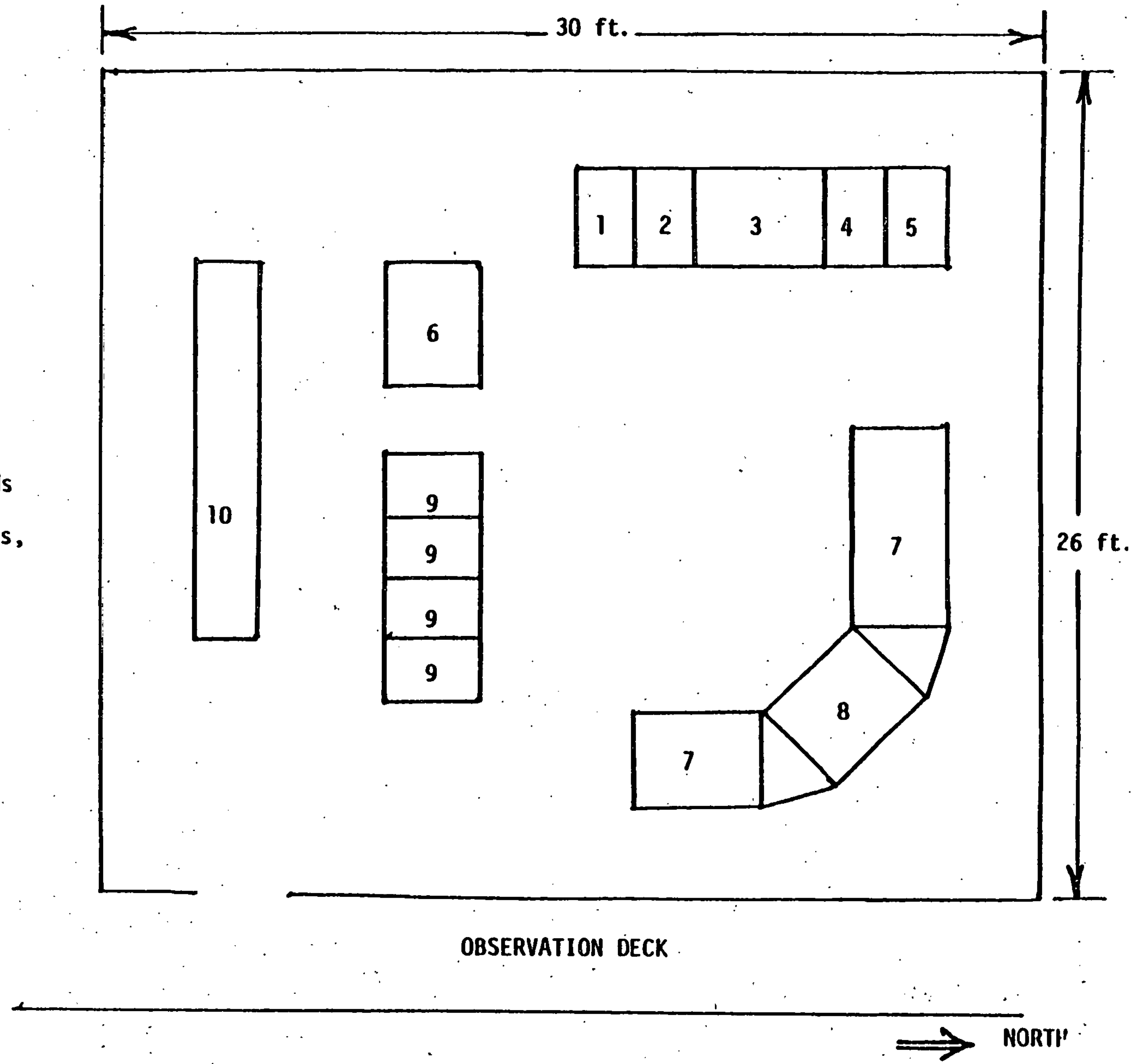


Figure 3.6-82. Control Room Layout

Two types of analog signals are transmitted to the I/O ports. One of these is a low-level signal from the thermocouple sensors; the other is from field transmitters that have an output of 4 to 20 milliamps. The low-level thermocouple signals are initially received at the input port at a thermocouple reference unit which establishes a reference temperature from which input signals are derived. These signals are then multiplexed (scanned) by the low-level multiplexer, amplified and transmitted to the A/D converter. The A/D converter changes the analog signal to a digital format that is available to the microprocessor data bus. Transmitter current signals terminate at dropping resistors at the input to the multiplexer. These current signals are interpreted as high voltage input signals of one to five volts. Since no amplification is required, these signals go directly to the A/D converter from the high-level multiplexer and are handled in the same manner as described above.

Analog output signals are provided by the output ports of the I/O system. Digital signals from the microprocessor are converted to 4 to 20 milliamp signals by the D/A converter. These signals are distributed to the respective control channels by the de-multiplexer where they are used for analog set point control, direct valve position control, or converted to pneumatic signals for valve control purposes.

Contact closure input ports as well as digital input ports from position encoders are provided at the I/O ports. These signals are basically the same and are handled as single bits of information. These digital bits are transmitted to the microprocessor bus directly.

Contact closure output ports are provided and the digital signals are buffered by relay drivers that energize control relays. Contacts from the relays are then used for power ON/OFF controls, solenoid and circuit breaker control, pump motor and fan motor controls. Optional power driving outputs from triac devices may be utilized as required.

3.6.4.4 INSTRUMENTATION

Instrumentation descriptions as a component of the overall I&C are given in detail in each subsystem description and are not repeated here. However, included in this section is the MRL summary. In the preceding description, all instruments that are required to monitor and/or measure selected parameters for control were discussed and are listed in the Measurement Requirement List. The details are given in Section 3.6.6. Instruments are classified by function and are arranged by subsystem. Various subsystem control loops are identified by channel numbers. All instruments carry a channel number and those instruments belonging to a given control loop can be identified. Table 3.6-4 summarizes the type and number of instruments required to control the STES at Fort Hood.

3.6.4.5 POWER SUPPLIES

Various power supplies required by the computer system are provided by the computer equipment supplier. Separate 45 Vdc power supplies are provided for use with the instrumentation transmitters. Sufficient voltage is provided by the instrumentation power supply to drive separate loads such as local and remote readout devices as well as the input to the DPU. In addition, capability for driving optional bistables for alarm functions is also provided.

3.6.4.6 AUXILIARY SYSTEMS

To insure that hard to detect fluctuations and interruptions in commercial AC power do not affect the computer systems operation, a reverse transfer static UPS is provided. Transient power line disturbances often affect memory contents such that computation errors, an inability to breakout of a command loop, an unexpected branch or jump, an unexpected program halt, a reduced throughput rate, or an inability to read data previously recorded on disk or tspe can occur.

Although some minicomputers have circuits which initiate a power-down sequence when the supplied DC voltage moves out of tolerance for more than a few milliseconds, to protect against these distortions of data stored in memory, there are many cases when these voltage detection circuits command a power-down sequence for a transient that poses no threat to the computer system, causing an unnecessary interruption in service.

The reverse transfer static UPS insures continuous computer operation without frequent manual or automatic restart by providing protection against common-mode noise, normal mode noise, voltage fluctuations, varying line frequency, blackout and brownout conditions. The UPS will be rated at 20 KW at a minimum and 28 KW at a maximum and will regulate the operating voltage and frequency to 120 VAC ± 10% @ 60 Hz ± 1 Hz.

3.6.5 INSTRUMENTATION AND CONTROL OPERATION

The Instrumentation and Control Subsystem (ICS) improves overall plant performance by maximum utilization of available solar energy and the efficient conversion of solar energy to thermal and electrical power.

The Energy Management and Control (EMAC) program is a software controller that contains necessary calculations to determine heat balances, energy availability, energy load demands and energy forecasting on a subsystem and total system basis. The energy management and plant control interface provided by the ICS is composed of both hardware and software control functions.

TABLE 3.6-4

MEASUREMENT REQUIREMENT LIST SUMMARY

Subsystem	Temperature	Pressure	Flow	Level	Control Valves	On/Off Valves	Motor Commands	Other
Solar Collector:								
-Collector Field	107(TE)		12(FT) 84(FS)		5(TCV):D 5(ZSL) 5(ZSH)	3(3WAY) 5(2WAY) 5(ZSH) 5(ZSL)		168 (10 Bit Position Indication)
-Auxiliary Heater	2(TS) 2(TI) 1(TSH) 1(TC)	1(PT) 1(PS) 9(PI) 1(PSH) 1(PSL)	1(FI) 1(FSL) 2(FC)	1(LG) 1(LS) 1(LAHL)	2(TCV):A 2(FCV):A 2(PCV):A			1 (BA) 1 (BC)
Thermal Storage	32(TE)	10(PT) 3(PAHL)	2(FT)	3(LT) 3(LI) 3(LAHL)		19(2WAY) 19(ZSH) 19(ZSL)		1 (CC)
Power Conversion	16(TI) 13(TE) 13(TT) 1(TC)	7(PI) 7(PT) 1(PDI)	2(FI) 2(FT) 1(FIT)	1(LS) 4(LT) 1(LSH) 1(LSL) 4(LG) 4(LC)	1(CCV):A 4(LCV):A 1(PCV):A 2(TCV):D 1(TCV):A 1(PCV):D 7(ZSH) 7(ZSL)		6(IY) 5(ZY)	1 (CT) 1 Voltmeter 4 Watt Hour Meters 20 (IY) Elect. Distribution 1 Volt/amp Regulator
Hot Water Heating	15(TE) 15(TT) 8(TI) 16(TE)	7(PT)	4(FT)	1(LT)			3(IY) 3(ZY)	
Chilled Water Cooling	16(TT) 5(TI) 5(TE)	10(PT) 1(PI)	5(FT) 2(FS)	1(LT)	1(PCV):A 1(PCV):D		8(IY) 10(ZY)	
Domestic Hot Water	5(TT) 1(TI)	2(PT)			1(TCV):D		2(IY) 2(ZY)	
TOTAL	139(TE) 49(TE/TT) 2(TS) 32(TI) 2(TC)	37(PT) 3(PS) 17(PI) 1(PDI)	26(FT) 4(FI) 87(FS) 2(FC)	9(LT) 3(LI) 5(LG) 4(LS) 4(LAHL) 4(LC)		24(2WAY) 3(3WAY) 24 Valve Positions (ZSH/ZSL)	19(IY) Command Outputs 20(EY) Status Inputs	168 Encoder Outputs 20 Elect. Distribution 1 Voltmeter 4 Watt Hour Meters

3.6.5.1 NORMAL OPERATION

The computer based control system relies on both serial and parallel control operation in real time by allowing non-critical calculations to proceed in the serial fashion of computer logic and in parallel fashion with the control loops. The series program execution consist of logic control, energy calculation, control algorithms, set points, data calculations and data input/output. The parallel execution of the program is based on interrupts generated by either the real time clock (internal), one of the process interrupts (external), or a software controlled interrupt (program logic). The interrupt capability of the system provides the function of allowing the system to change from series to "parallel" operation. The interrupt process causes the normal sequence of program/control instructions to be temporarily suspended while a higher priority calculation, data transfer or control function can be performed.

Figure 3.6-83 shows the functional operations of EMAC. Proceeding from left to right of the diagram defines the serial operation of the control program. The upper to lower vertical levels are divided into: level (1), overall system energy management and control; level (2), measurements; and level (3), subsystem control. The interconnecting lines between blocks and levels show flow path of control, measurement or data information. Also, several blocks are shown that generate program interrupts such as the real time clock, operator control console, and alarm indicators.

The EMAC level divisions are defined as follows:

Level (1) - Overall System Control (Main CPU)

- Input/output data, operator information
- CPU peripheral I/O control
- System on/off procedures
- Data acquisition
- Support programs and calculations
- Control algorithms and strategy

- Monitoring systems, alarms, etc.
- Diagnostics (plant)
- Auxiliary component control functions
- Energy management
- Local manual control selection
- System clock

Level (2) - Instruments and Measurements (Hardware)

- Computer peripheral diagnostics
- System clock
- Interrupt control
- Input/output device control
- Input/output data transfer control (Micro to main CPU)

Level (3) - Subsystem Controllers (Microprocessors)

- Microprocessor I/O device control
- Output command to subsystem actuator
- Input feedback measurement
- Input subsystem measurement
- Input subsystem alarms
- Input subsystem status
- Calculate control system errors and check against limits
- Store measurement data
- Transfer control data
- On-line diagnostic (when able)

3.6.5.2 STARTUP AND SHUTDOWN

The ICS contains an "automatic controller" that sequences subsystem startup/shutdown procedures through initiation of on/off commands and set points to the distributive processing units (DPU) which in turn transmit signals to the subsystem actuators, motors and component analog controllers. Based on operator mode selection, the automatic controller will sequence appropriate valving and system flow rates. During the startup/shutdown sequence, key system parameters are monitored to determine if plant capability will be inhibited by the subsystems as they come "on-line" or go "off-line." If so, it initiates plant protective functions and alarms the operator.

The ICS also contains a "master control logic program" that monitors the various subsystems and determines the operating mode of each subsystem, rate of change of key parameters, and operating levels. The "controller" also contains a series of interlocking functions such that in case of failures, or when rate limits are exceeded, an automatic trip function would be initiated. The interlock function would only permit return to normal startup mode by operator action.

3.6.5.3 ABNORMAL OPERATION

To allow for safe operation and subsystem component protection, certain key features are provided for in the ICS for plant control in the event of loss of electrical power, loss of a DPU, or loss of the central processing unit.

LOSS OF ELECTRICAL POWER

The ICS is designed such that in case of electrical power failure (loss of grid; turbine generator unoperational) all control valves, pumps and major subsystem components will go to a fail-safe position and the plant will coast to an unaccessed shutdown.

The fail-safe position features include:

- Automatic turbine - generator trip
- Valves (both pneumatic and electric) going to predefined states that yield the fail-safe shutdown configuration

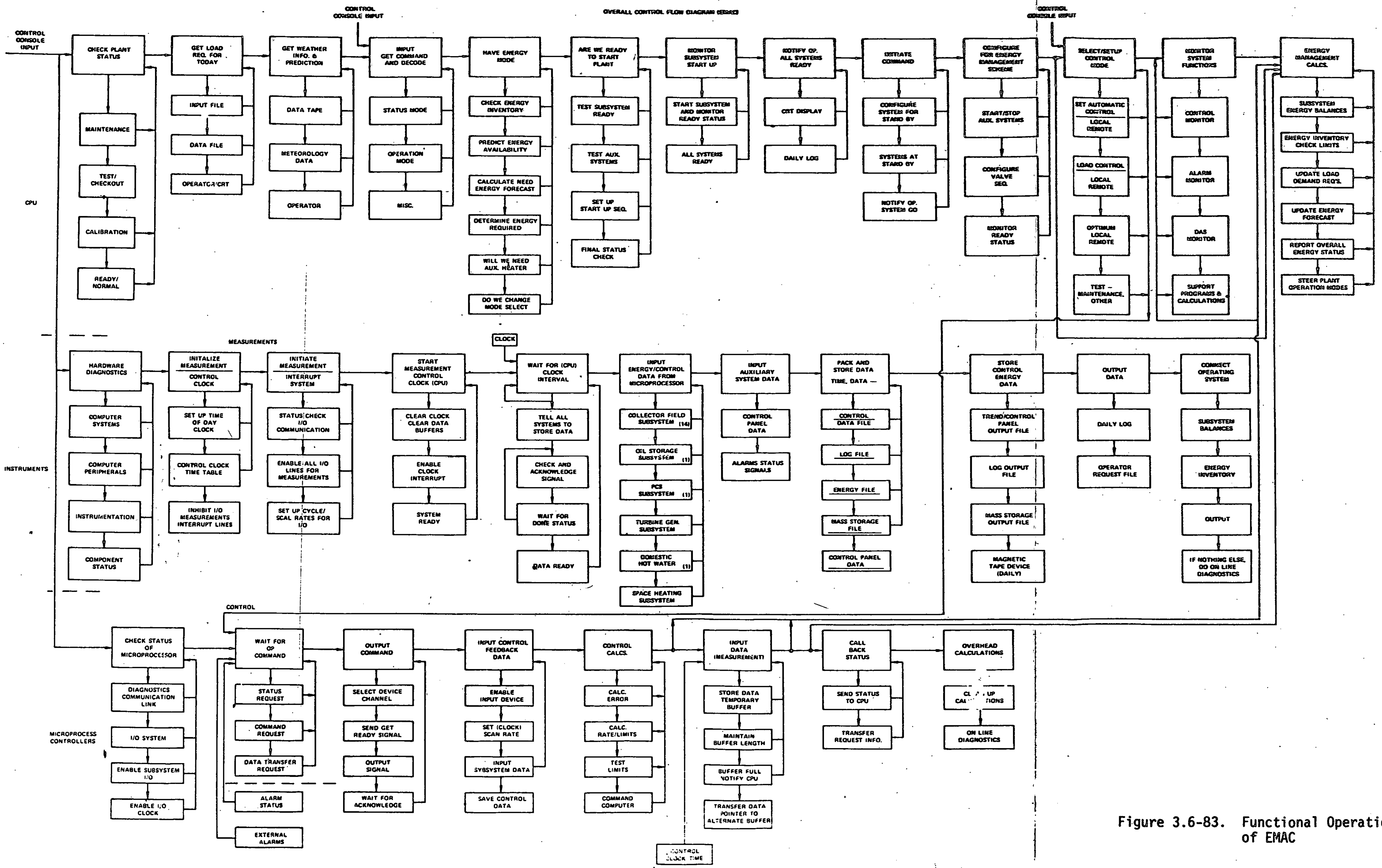


Figure 3.6-83. Functional Operations of EMAC

- All pumps tripping
- Stowage of the collectors

DPU OUT-OF-SERVICE

In the event of a failure in a distributed process unit, the system I/O and instrumentation will latch on the last commanded output (set point conditions) and the operator will be alerted. The subsystem will remain in this state until the malfunction is corrected or until the operator takes appropriate action (i.e., places the subsystem under local analog control if provided).

CENTRAL PROCESSOR OUT-OF-SERVICE

A minimum amount of redundant measurements will appear on the operator control panel for monitoring system operation and performance. In the event of the CPU failing or being out-of-service, the system will be configured to operate in the defined fail-safe operating mode.

3.6.6 OVERALL INSTRUMENTATION AND CONTROL INTERFACES

All of the Fort Hood STE-LSE subsystem instrumentation and controls interface with the Overall Instrumentation and Control Subsystem at the local DPU's. The following subparagraphs define the interfaces.

3.6.6.1 SUBSYSTEM INTERFACES - MEASUREMENTS REQUIREMENTS

The measurement requirements for each of the subsystems are identified in the following tables. Abbreviations used in the MRL tables are defined in Table 3.6-11.

SOLAR COLLECTOR SUBSYSTEM

The Solar Collector Subsystem (SCS) measurement requirements are identified in Table 3.6-5.

THERMAL STORAGE SUBSYSTEM

The Thermal Storage Subsystem (TSS) measurement requirements are identified in Table 3.6-6.

POWER CONVERSION SUBSYSTEM

The Power Conversion Subsystem (PCS) measurement requirements are identified in Table 3.6-7.

HEATING/COOLING AND DOMESTIC HOT WATER SUBSYSTEMS

The measurement requirements for the water systems are separately divided and are identified as follows:

- Hot Water System - Table 3.6- 8
- Chilled Water System - Table 3.6-9
- Domestic Hot Water System - Table 3.6-10

AUXILIARY SYSTEMS

Provisions for various auxiliary systems have been provided in the main control room. Space for the system fire alarm annunciation as well as display for heating, ventilation, and air conditioning parameters within the STES building are provided within the main control console and vertical equipment racks. In addition, space is provided for communications systems such as telephones, intercoms and public address systems. Radio communications will also be provided as a backup communications system by means of walkie-talkies. These hand-held radio devices will be required during inspections and maintenance of the Solar Collector Subsystem and Thermal Storage Subsystem, and at various facility locations as needed. It is expected that frequencies or channels will be dedicated for use by the STES facility without interference from other Fort Hood systems.

INSTRUMENT AND CONTROL INTERFACES

The ICS interfaces electrically and mechanically with the solar collector subsystem, thermal storage subsystem, power conversion subsystem, domestic hot water subsystem, chilled/hot water subsystem, makeup subsystem, and meteorological station subsystem. The ICS also interfaces with the TP&L grid through an Uninterruptible Power Supply.

TABLE 3.6-5

SOLAR COLLECTOR SUBSYSTEM MEASUREMENT REQUIREMENT LIST

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
TE1000	SENSOR-TEMPERATURE	INLET OIL FIELD1	SCS	F
TE1001	SENSOR-TEMPERATURE	OUTLET OIL FIELD1	SCS	F
NV1002	ON/OFF VALVE - 3 WAY	EXIT OIL FIELD 1	SCS	F
TE1002	SENSOR-TEMPERATURE	OUTLET OIL FIELD1	SCS	F
TE1004	SENSOR-TEMPERATURE	FDFWD, INLET OILFIELD2	SCS	F
TE1005	SENSOR-TEMPERATURE	INLET OIL FIELD2	SCS	F
TE1006	SENSOR-TEMPERATURE	INLET OIL FIELD2	SCS	F
TE1007	SENSOR-TEMPERATURE	OUTLET OIL FIELD2	SCS	F
NV1008	ON/OFF VALVE - 3 WAY	EXIT OIL FIELD 2	SCS	F
TE1008	SENSOR-TEMPERATURE	OUTLET OIL FIELD2	SCS	F
TE1009	SENSOR-TEMPERATURE	FDFWD INLET OIL FIELD3	SCS	F
TE1010	SENSOR-TEMPERATURE	INLET OIL FIELD3	SCS	F
TE1011	SENSOR-TEMPERATURE	INLET OIL FIELD3	SCS	F
NV1012	ON/OFF VALVE - 3 WAY	EXIT OIL FIELD 3	SCS	F
TE1012	SENSOR-TEMPERATURE	OUTLET OIL FIELD3	SCS	F
FT1013	TRANSMITTER-FLOW	INLET OIL FIELD 1	SCS	F
FT1014	TRANSMITTER-FLOW	EXIT OIL FIELD 1	SCS	F
FT1015	TRANSMITTER-FLOW	INLET OIL FIELD 2	SCS	F
FT1016	TRANSMITTER-FLOW	EXIT OIL FIELD 2	SCS	F
FT1017	TRANSMITTER-FLOW	INLET OIL FIELD 3	SCS	F
TCV1018	CONTROL VALVE - FLOW	INLET OIL FIELD 1	SCS	F
ZSH1018	SWITCH -HIGH POSITION	PROPORTIONAL FCV POS.	SCS	F
ZSL1018	SWITCH -LOW POSITION	PROPORTIONAL FCV POS.	SCS	F
TCV1019	CONTROL VALVE-FLOW	EXIT OIL FIELD 1	SCS	F
ZSH1019	SWITCH -HIGH POSITION	PROPORTIONAL FCV POS.	SCS	F
ZSL1019	SWITCH -LOW POSITION	PROPORTIONAL FCV POS.	SCS	F
TCV1020	CONTROL VALVF-FLOW	INLET OIL FIELD 2	SCS	F
ZSH1020	SWITCH -HIGH POSITION	PROPORTIONAL FCV POS.	SCS	F
ZSL1020	SWITCH -LOW POSITION	PROPORTIONAL FCV POS.	SCS	F
TCV1021	CONTROL VALVE - FLOW	EXIT OIL FIELD 2	SCS	F
ZSH1021	SWITCH -HIGH POSITION	PROPORTIONAL FCV POS.	SCS	F
ZSL1021	SWITCH -LOW POSITION	PROPORTIONAL FCV POS.	SCS	F
TCV1022	CONTROL VALVE - FLOW	INLET OIL FIELD 3	SCS	F
ZSH1022	SWITCH -HIGH POSITION	PROPORTIONAL FCV POS.	SCS	F
ZSL1022	SWITCH -LOW POSITION	PROPORTIONAL FCV POS.	SCS	F
FT1023	TRANSMITTER-FLOW	FDFWD INLET-FIELD 2		
FT1024	TRANSMITTER-FLOW	FDFWD INLET-FIELD3	SCS	F
FT1025	TRANSMITTER-FLOW	OUTLET OIL - FIELDS	SCS	F
FT1026	TRANSMITTER-FLOW	INLET OIL-PUMP/TANKS	SCS	F
TE1027	SENSOR-TEMPERATURE	OUTLET OIL-FIELDS	SCS	F
TE1028	SENSOR-TEMPERATURE	INLET OIL-PUMP/TANKS	SCS	F
ZT1030	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F 1A
ZT1031	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F 1B
ZT1032	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F 1C
ZT1033	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F 1D
ZT1034	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F 1E
ZT1035	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F 1F
ZT1037	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F 2A

TABLE 3.6-5 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE	VARIABLE	SERVICE DESCRIPTION	SYS	LOC
ZT1038	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 2B
ZT1039	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 2C
ZT1040	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 2D
ZT1041	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 2E
ZT1042	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 2F
ZT1044	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 3A
ZT1045	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 3B
ZT1046	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 3C
ZT1047	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 3D
ZT1048	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 3E
ZT1049	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 3F
ZT1051	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 4A
ZT1052	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 4B
ZT1053	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 4C
ZT1054	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 4D
ZT1055	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 4E
ZT1056	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 4F
ZT1058	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 5A
ZT1059	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 5B
ZT1060	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 5C
ZT1061	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 5D
ZT1062	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 5E
ZT1063	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 5F
ZT1065	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 6A
ZT1066	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 6B
ZT1067	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 6C
ZT1068	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 6D
ZT1069	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 6E
ZT1070	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 6F
ZT1072	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 7A
ZT1073	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 7B
ZT1074	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 7C
ZT1075	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 7D
ZT1076	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 7E
ZT1077	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 7F
ZT1079	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 8A
ZT1080	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 8B
ZT1081	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 8C
ZT1082	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 8D
ZT1083	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 8E
ZT1084	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 8F
ZT1086	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 9A
ZT1087	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 9B
ZT1088	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 9C
ZT1089	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 9D
ZT1090	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 9E
ZT1091	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F 9F
ZT1093	ENCODER	POSITION	COLLECTOR ANGLE	SCS	F10A

TABLE 3.6-5 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
ZT1094	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F10B
ZT1095	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F10C
ZT1096	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F10D
ZT1097	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F10E
ZT1098	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F10F
ZT1100	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F11A
ZT1101	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F11B
ZT1102	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F11C
ZT1103	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F11D
ZT1104	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F11E
ZT1105	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F11F
ZT1107	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F12A
ZT1108	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F12B
ZT1109	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F12C
ZT1110	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F12D
ZT1111	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F12E
ZT1112	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F12F
ZT1114	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F13A
ZT1115	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F13B
ZT1116	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F13C
ZT1117	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F13D
ZT1118	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F13E
ZT1119	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F13F
ZT1121	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F14A
ZT1122	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F14B
ZT1123	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F14C
ZT1124	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F14D
ZT1125	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F14E
ZT1126	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F14F
ZT1128	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F15A
ZT1129	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F15B
ZT1130	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F15C
ZT1131	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F15D
ZT1132	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F15E
ZT1133	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F15F
ZT1135	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F16A
ZT1136	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F16B
ZT1137	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F16C
ZT1138	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F16D
ZT1139	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F16E
ZT1140	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F16F
ZT1142	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F17A
ZT1143	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F17B
ZT1144	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F17C
ZT1145	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F17D
ZT1146	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F17E
ZT1147	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F17F
ZT1149	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F18A

TABLE 3.6-5 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
ZT1150	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F18B
ZT1151	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F18C
ZT1152	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F18D
ZT1153	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F18E
ZT1154	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F18F
ZT1156	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F19A
ZT1157	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F19B
ZT1158	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F19C
ZT1159	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F19D
ZT1160	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F19E
ZT1161	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F19F
ZT1163	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F20A
ZT1164	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F20B
ZT1165	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F20C
ZT1166	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F20D
ZT1167	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F20E
ZT1168	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F20F
ZT1170	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F21A
ZT1171	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F21B
ZT1172	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F21C
ZT1173	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F21D
ZT1174	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F21E
ZT1175	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F21F
ZT1177	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F22A
ZT1178	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F22B
ZT1179	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F22C
ZT1180	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F22D
ZT1181	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F22E
ZT1182	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F22F
ZT1184	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F23A
ZT1185	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F23B
ZT1186	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F23C
ZT1187	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F23D
ZT1188	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F23E
ZT1189	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F23F
ZT1191	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F24A
ZT1192	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F24B
ZT1193	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F24C
ZT1194	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F24D
ZT1195	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F24E
ZT1196	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F24F
ZT1198	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F25A
ZT1199	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F25B
ZT1200	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F25C
ZT1201	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F25D
ZT1202	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F25E
ZT1203	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F25F
ZT1205	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F26A

TABLE 3.6-5 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
ZT1206	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F26B
ZT1207	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F26C
ZT1208	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F26D
ZT1209	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F26E
ZT1210	ENCODER - POSITION	COLLECTOR ANGLE	SCS	F26F
ZT1212	ENCODER-POSITION	COLLECTOR ANGLE	SCS	F27A
ZT1213	ENCODER-POSITION	COLLECTOR ANGLE	SCS	F27B
ZT1214	ENCODER-POSITION	COLLECTOR ANGLE	SCS	F27C
ZT1215	ENCODER-POSITION	COLLECTOR ANGLE	SCS	F27D
ZT1216	ENCODER-POSITION	COLLECTOR ANGLE	SCS	F27E
ZT1217	ENCODER-POSITION	COLLECTOR ANGLE	SCS	F27F
ZT1219	ENCODER-POSITION	COLLECTOR ANGLE	SCS	F28A
ZT1220	ENCODER-POSITION	COLLECTOR ANGLE	SCS	F28B
ZT1221	ENCODER-POSITION	COLLECTOR ANGLE	SCS	F28C
ZT1222	ENCODER-POSITION	COLLECTOR ANGLE	SCS	F28D
ZT1223	ENCODER-POSITION	COLLECTOR ANGLE	SCS	F28E
ZT1224	ENCODER-POSITION	COLLECTOR ANGLE	SCS	F28F
TE1225	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 1C
TE1226	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 2C
TE1227	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 3C
TE1228	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 4C
TE1229	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 5C
TE1230	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 6C
TE1231	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 7C
TE1232	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 8C
TE1233	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 9C
TE1234	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F10C
TE1235	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F11C
TE1236	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F12C
TE1237	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F13C
TE1238	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 14
TE1239	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F15C
TE1240	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F16C
TE1241	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F17C
TE1242	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F18C
TE1243	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F19C
TE1244	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F20C
TE1245	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F21C
TE1246	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F22C
TE1247	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F23C
TE1248	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F24C
TE1249	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F25C
TE1250	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F26C
TE1251	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F27C
TE1252	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F28C
TE1253	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 1E
TE1254	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 2E
TE1255	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 3F

TABLE 3.6- 5 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
TE1256	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 4E
TE1257	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 5E
TE1258	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 6E
TE1259	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 7E
TE1260	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 8E
TE1261	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 9E
TE1262	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F10E
TE1263	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F11E
TE1264	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F12E
TE1265	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F13E
TE1266	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F14E
TE1267	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F15E
TE1268	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F16E
TE1269	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F17E
TE1270	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F18E
TE1271	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F19E
TE1272	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F20E
TE1273	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F21E
TE1274	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F22E
TE1275	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F23E
TE1276	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F24E
TE1277	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F25E
TE1278	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F26E
TE1279	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F27E
TE1280	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F28E
TE1281	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 1F
TE1282	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 2F
TE1283	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 3F
TE1284	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 4F
TE1285	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 5F
TE1286	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 6F
TE1287	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 7F
TE1288	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 8F
TE1289	SENSOR - TEMPERATURE	STRING OUTLET TEMP	SCS	F 9F
TE1291	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F10F
TE1292	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F11F
TE1293	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F12F
TE1294	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F13F
TE1295	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F14F
TE1296	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F15F
TE1297	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F16F
TE1298	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F17F
TE1299	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F18F
TE1300	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F19F
TE1301	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F20F
TE1302	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F21F
TE1303	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F22F
TE1304	SENSOR TEMPERATURE	STRING OUTLET TEMP	SCS	F23F

TABLE 3.6-5 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE	VARIABLE	SERVICE DESCRIPTION	SYS	LOC
TE1305	SENSOR	TEMPERATURE	STRING OUTLET TEMP	SCS	F24F
TE1306	SENSOR	TEMPERATURE	STRING OUTLET TEMP	SCS	F25F
TE1307	SENSOR	TEMPERATURE	STRING OUTLET TEMP	SCS	F26F
TE1308	SENSOR	TEMPERATURE	STRING OUTLET TEMP	SCS	F27F
TE1309	SENSOR	TEMPERATURE	STRING OUTLET TEMP	SCS	F28F
FS1310	SWITCH - FLOW		STRING FLOW	SCS	F
FS1311	SWITCH - FLOW		STRING FLOW	SCS	F
FS1312	SWITCH - FLOW		STRING FLOW	SCS	F
FS1313	SWITCH - FLOW		STRING FLOW	SCS	F
FS1314	SWITCH - FLOW		STRING FLOW	SCS	F
FS1315	SWITCH - FLOW		STRING FLOW	SCS	F
FS1316	SWITCH - FLOW		STRING FLOW	SCS	F
FS1317	SWITCH - FLOW		STRING FLOW	SCS	F
FS1318	SWITCH - FLOW		STRING FLOW	SCS	F
FS1319	SWITCH - FLOW		STRING FLOW	SCS	F
FS1320	SWITCH - FLOW		STRING FLOW	SCS	F
FS1321	SWITCH - FLOW		STRING FLOW	SCS	F
FS1322	SWITCH - FLOW		STRING FLOW	SCS	F
FS1323	SWITCH - FLOW		STRING FLOW	SCS	F
FS1324	SWITCH - FLOW		STRING FLOW	SCS	F
FS1325	SWITCH - FLOW		STRING FLOW	SCS	F
FS1326	SWITCH - FLOW		STRING FLOW	SCS	F
FS1327	SWITCH - FLOW		STRING FLOW	SCS	F
FS1328	SWITCH - FLOW		STRING FLOW	SCS	F
FS1329	SWITCH - FLOW		STRING FLOW	SCS	F
FS1330	SWITCH - FLOW		STRING FLOW	SCS	F
FS1331	SWITCH - FLOW		STRING FLOW	SCS	F
FS1332	SWITCH - FLOW		STRING FLOW	SCS	F
FS1333	SWITCH - FLOW		STRING FLOW	SCS	F
FS1334	SWITCH - FLOW		STRING FLOW	SCS	F
FS1335	SWITCH - FLOW		STRING FLOW	SCS	F
FS1336	SWITCH - FLOW		STRING FLOW	SCS	F
FS1337	SWITCH - FLOW		STRING FLOW	SCS	F
FS1338	SWITCH - FLOW		STRING FLOW	SCS	F
FS1339	SWITCH - FLOW		STRING FLOW	SCS	F
FS1340	SWITCH - FLOW		STRING FLOW	SCS	F
FS1341	SWITCH - FLOW		STRING FLOW	SCS	F
FS1342	SWITCH - FLOW		STRING FLOW	SCS	F
FS1343	SWITCH - FLOW		STRING FLOW	SCS	F
FS1344	SWITCH - FLOW		STRING FLOW	SCS	F
FS1345	SWITCH - FLOW		STRING FLOW	SCS	F
FS1346	SWITCH - FLOW		STRING FLOW	SCS	F
FS1347	SWITCH - FLOW		STRING FLOW	SCS	F
FS1348	SWITCH - FLOW		STRING FLOW	SCS	F
FS1349	SWITCH - FLOW		STRING FLOW	SCS	F
FS1350	SWITCH - FLOW		STRING FLOW	SCS	F
FS1351	SWITCH - FLOW		STRING FLOW	SCS	F
FS1352	SWITCH - FLOW		STRING FLOW	SCS	F

TABLE 3.6-5 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
FS1353	SWITCH - FLOW	STRING FLOW	SCS	F
FS1354	SWITCH - FLOW	STRING FLOW	SCS	F
FS1355	SWITCH - FLOW	STRING FLOW	SCS	F
FS1356	SWITCH - FLOW	STRING FLOW	SCS	F
FS1357	SWITCH - FLOW	STRING FLOW	SCS	F
FS1358	SWITCH - FLOW	STRING FLOW	SCS	F
FS1359	SWITCH - FLOW	STRING FLOW	SCS	F
FS1360	SWITCH - FLOW	STRING FLOW	SCS	F
FS1361	SWITCH - FLOW	STRING FLOW	SCS	F
FS1362	SWITCH - FLOW	STRING FLOW	SCS	F
FS1363	SWITCH - FLOW	STRING FLOW	SCS	F
FS1364	SWITCH - FLOW	STRING FLOW	SCS	F
FS1365	SWITCH - FLOW	STRING FLOW	SCS	F
FS1366	SWITCH - FLOW	STRING FLOW	SCS	F
FS1367	SWITCH - FLOW	STRING FLOW	SCS	F
FS1368	SWITCH - FLOW	STRING FLOW	SCS	F
FS1369	SWITCH-FLOW	STRING FLOW	SCS	F
FS1370	SWITCH-FLOW	STRING FLOW	SCS	F
FS1371	SWITCH-FLOW	STRING FLOW	SCS	F
FS1372	SWITCH-FLOW	STRING FLOW	SCS	F
FS1373	SWITCH-FLOW	STRING FLOW	SCS	F
FS1374	SWITCH-FLOW	STRING FLOW	SCS	F
FS1375	SWITCH-FLOW	STRING FLOW	SCS	F
FS1376	SWITCH-FLOW	STRING FLOW	SCS	F
FS1377	SWITCH-FLOW	STRING FLOW	SCS	F
FS1378	SWITCH-FLOW	STRING FLOW	SCS	F
FS1379	SWITCH-FLOW	STRING FLOW	SCS	F
FS1380	SWITCH-FLOW	STRING FLOW	SCS	F
FS1381	SWITCH-FLOW	STRING FLOW	SCS	F
FS1382	SWITCH-FLOW	STRING FLOW	SCS	F
FS1383	SWITCH-FLOW	STRING FLOW	SCS	F
FS1384	SWITCH-FLOW	STRING FLOW	SCS	F
FS1385	SWITCH-FLOW	STRING FLOW	SCS	F
FS1386	SWITCH-FLOW	STRING FLOW	SCS	F
FS1387	SWITCH-FLOW	STRING FLOW	SCS	F
FS1388	SWITCH-FLOW	STRING FLOW	SCS	F
FS1389	SWITCH-FLOW	STRING FLOW	SCS	F
FS1390	SWITCH-FLOW	STRING FLOW	SCS	F
FS1391	SWITCH-FLOW	STRING FLOW	SCS	F
FS1392	SWITCH-FLOW	STRING FLOW	SCS	F
FS1393	SWITCH-FLOW	STRING FLOW	SCS	F
TE1400	SENSOR-TEMPERATURE	STRING PROFILE	SCS	F 2A
TE1401	SENSOR-TEMPERATURE	STRING PROFILE	SCS	F 2B
TE1402	SENSOR-TEMPERATURE	STRING PROFILE	SCS	F 2C
TE1403	SENSOR-TEMPERATURE	STRING PROFILE	SCS	F14A
TE1404	SENSOR-TEMPERATURE	STRING PROFILE	SCS	F14B
TE1405	SENSOR-TEMPERATURE	STRING PROFILE	SCS	F14C
TE1406	SENSOR-TEMPERATURE	STRING PROFILE	SCS	F27A

TABLE 3.6-5 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC	
TE1407	SENSOR-TEMPERATURE	STRING PROFILE	SCS	F27B	
TE1408	SENSOR-TEMPERATURE	STRING PROFILE	SCS	F27C	
FT1410	TRANSMITTER-FLOW	STRING FLOW-FIELD1	SCS	F 2	
FT1411	TRANSMITTER-FLOW	STRING FLOW-FIELD 1	SCS	F 14	
FT1412	TRANSMITTER-FLOW	STRING FLOW-FIELD1	SCS	F27	
NV1501	ON-OFF VALVE	INLET OIL-FIELD1	SCS	F	
NV1505	ON-OFF VALVE	EXIT OIL-FIELD3	SCS	F	
NV1506	ON-OFF VALVE	EXIT OIL-AUX HTR	SCS	F	
NV1507	ON-OFF VALVE	EXIT OIL-AUX HTR	SCS	F	
NV1508	ON-OFF VALVE	INLET OIL-AUX HTR	SCS	F	
PI1700	INDICATOR - PRESSURE	INLET OIL-AUX HTR PUMP	SCS	L	BY VENDOR
PI1701	INDICATOR - PRESSURE	EXIT OIL-AUX HTR PUMP	SCS	L	BY VENDOR
PI1702	INDICATOR - PRESSURE	CW FOR AUX HTR PUMP	SCS	L	BY VENDOR
PT1703	TRANSMITTER - PRESSURE	CW FOR AUX HTR PUMP	SCS	L	BY VENDOR
FI1704	INDICATOR - FLOW	AUX HTR PUMP BYPASS	SCS	L	BY VENDOR
TI1705	INDICATOR - TEMP	AUX HTR PUMP BYPASS	SCS	L	BY VENDOR
TS1706	SWITCH - TEMP	AUX HTR	SCS	L	BY VENDOR
TC1707	CONTROLLER - TEMP	EXIT OIL-AUX HTR	SCS	L	BY VENDOR
TCV1707B	CONTROL VALVE - TEMP	NATURAL GAS-FUEL LINE	SCS	L	BY VENDOR
TCV1707A	CONTROL VALVE - TEMP	INLET FUEL OIL	SCS	L	BY VENDOR
TS1708	SWITCH - TEMP	EXIT OIL-AUX HTR	SCS	L	BY VENDOR
FC1709	CONTROLLER - FLOW	EXIT OIL-AUX HTR	SCS	L	BY VENDOR
FCV1709	CONTROL VALVE - FLOW	RECIRC LINE-AUX HTR	SCS	L	BY VENDOR
FSL1709	SWITCH - LOW - FLOW	EXIT OIL-AUX HTR	SCS	L	BY VENDOR
TI1711	INDICATOR - TEMP	EXIT OIL-AUX HTR	SCS	L	BY VENDOR
FC1712	CONTROLLER - FLOW	AIR-FORCED DRAFT FAN	SCS	L	BY VENDOR
FCV1712	CONTROL VALVE - FLOW	AIR-FORCED DRAFT FAN	SCS	L	BY VENDOR
PI1713	INDICATOR - PRESSURE	COMP AIR INLET-AUX HTR	SCS	L	BY VENDOR
PS1714	SWITCH - PRESSURE	COMP AIR INLET-AUX HTR	SCS	L	BY VENDOR
PI1715	INDICATOR - PRESSURE	INLET FUEL OIL	SCS	L	BY VENDOR
PI1716	INDICATOR - PRESSURE	INLET FUEL OIL	SCS	L	BY VENDOR
PI1717	INDICATOR - PRESSURE	INLET FUEL OIL	SCS	L	BY VENDOR
PCV1718	CONTROL VALVE-PRESSURE	NATURAL GAS-FUEL LINE	SCS	L	BY VENDOR
PSL1719	SWITCH-LOW-PRESSURE	NATURAL GAS-FUEL LINE	SCS	L	BY VENDOR
PI1720	INDICATOR - PRESSURE	NATURAL GAS-FUEL LINE	SCS	L	BY VENDOR
PSH1721	SWITCH-HIGH-PRESSURE	NATURAL GAS-FUEL LINE	SCS	L	BY VENDOR
PCV1722	CONTROL VALVE-PRESSURE	NATURAL GAS INLET	SCS	L	BY VENDOR
PI1723	INDICATOR - PRESSURE	NATURAL GAS INLET	SCS	L	BY VENDOR
BA1724	ALARM - BURN	AUX HTR UNIT	SCS	L	BY VENDOR
BC1724	CONTROLLER - BURN	AUX HTR UNIT	SCS	L	BY VENDOR
BE1724	ELEMENT - BURN	AUX HTR UNIT	SCS	L	BY VENDOR
TSH1725	SWITCH - HIGH - TEMP	EXHAUST-AUX HTR	SCS	L	BY VENDOR
LG1726	GAUGE - LEVEL	EXPANSION TANK	SCS	L	BY VENDOR
LAHL1727	ALARM - HIGH - LEVEL	EXPANSION TANK	SCS	L	BY VENDOR
LS1728	SWITCH - LEVEL	EXPANSION TANK	SCS	L	BY VENDOR
COUNT	429				

TABLE 3.6-6

THERMAL STORAGE SUBSYSTEM MEASUREMENT REQUIREMENT LIST

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
TE2100	SENSOR-TEMPERATURE	INLET OIL-HTT		
TE2101	TEMPERATURE SENSOR	TEMP OF TANK T 1	TSS	F
TE2102	TEMPERATURE SENSOR	TEMP OF TANK T 1	TSS	F
TE2103	TEMPERATURE SENSOR	TEMP OF TANK T 1	TSS	F
TE2104	TEMPERATURE SENSOR	TEMP OF TANK T 1	TSS	F
TE2105	TEMPERATURE SENSOR	TEMP OF TANK T 1	TSS	F
TE2106	TEMPERATURE SENSOR	TEMP OF TANK T 1	TSS	F
TE2107	TEMPERATURE SENSOR	TEMP OF TANK T 1	TSS	F
LI2115	INDICATOR-LEVEL	LIQUID LEVEL HTT		
LT2115	TRANSMITTER-LEVEL	LIQUID LEVEL TANK 1	TSS	F
LAHL2115	ALARM-LEVEL HIGH/LOW	LIQUID LEVEL HTT		
ZSH2170	SWITCH-OPEN VALVE POS	INLET OIL SCS-HTT	TSS	F
ZSL2170	SWITCH-CLOSE VALVE POS	INLET OIL SCS-HTT	TSS	F
ZSH2172	SWITCH-OPEN VALVE POS	EXIT OIL HTT-PCS	TSS	F
ZSL2172	SWITCH-CLOSE VALVE POS	EXIT OIL HTT-PCS	TSS	F
ZSH2174	SWITCH-OPEN VALVE POS	NITROGEN COVER GAS	TSS	F
ZSL2174	SWITCH-CLOSE VALVE POS	NITROGEN COVER GAS	TSS	F
ZSH2176	SWITCH-OPEN VALVE POS	BDV-HTT	TSS	F
ZSL2176	SWITCH-CLOSE VALVE POS	BDV-HTT	TSS	F
PAHL2190	ALARM-PRES-HIGH/LOW	HTT		
TE2200	SENSOR-TEMPERATURE	INLET OIL-ITT		
TE2201	TEMPERATURE SENSOR	TEMP OF TANK 2	TSS	F
TE2202	TEMPERATURE SENSOR	TEMP OF TANK 2	TSS	F
TE2203	TEMPERATURE SENSOR	TEMP OF TANK 2	TSS	F
TE2204	TEMPERATURE SENSOR	TEMP OF TANK 2	TSS	F
TE2205	TEMPERATURE SENSOR	TEMP OF TANK 2	TSS	F
TE2206	TEMPERATURE SENSOR	TEMP OF TANK 2	TSS	F
TE2207	TEMPERATURE SENSOR	TEMP OF TANK 2	TSS	F
LI2215	INDICATOR-LEVEL	LIQUID LEVEL ITT		
LT2215	TRANSMITTER-LEVEL	LIQUID LEVEL TANK 2	TSS	F
LAHL2215	ALARM-LEVEL HIGH/LOW	LIQUID LEVEL ITT		
ZSH2270	SWITCH-OPEN VALVE POS	EXIT OIL ITT-PCS	TSS	F
ZSL2270	SWITCH-CLOSE VALVE POS	EXIT OIL ITT-PCS	TSS	F
ZSH2272	SWITCH-OPEN VALVE POS	INLET OIL SCS-ITT		
ZSL2272	SWITCH-CLOSE VALVE POS	INLET OIL SCS-ITT	TSS	F
ZSH2274	SWITCH-OPEN VALVE POS	INLET OIL PCS-ITT	TSS	F
ZSL2274	SWITCH-CLOSE VALVE POS	INLET OIL PCS-ITT	TSS	F
ZSH2276	SWITCH-OPEN VALVE POS	NITROGEN COVER GAS	TSS	F
ZSL2276	SWITCH-CLOSE VALVE POS	NITROGEN COVER GAS	TSS	F
ZSH2278	SWITCH-OPEN VALVE POS	BDV-ITT	TSS	F
ZSL2278	SWITCH-CLOSE VALVE POS	BDV-ITT	TSS	F
ZSH2280	SWITCH-OPEN VALVE POS	EXIT OIL ITT-SCS	TSS	F
ZSL2280	SWITCH-CLOSE VALVE POS	EXIT OIL ITT-SCS	TSS	F
PAHL2290	ALARM-PRES-HIGH/LOW	ITT		
TE2300	SENSOR-TEMPERATURE	INLET OIL-LTT		
TE2301	TEMPERATURE SENSOR	TEMP OF TANK T 3	TSS	F
TE2302	TEMPERATURE SENSOR	TEMP OF TANK T 3	TSS	F
TE2303	TEMPERATURE SENSOR	TEMP OF TANK T 3	TSS	F

TABLE 3.6-6 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
TE2304	TEMPERATURE SENSOR	TEMP OF TANK T 3	TSS	F
TE2305	TEMPERATURE SENSOR	TEMP OF TANK T 3	TSS	F
TE2306	TEMPERATURE SENSOR	TEMP OF TANK T 3	TSS	F
TE2307	TEMPERATURE SENSOR	TEMP OF TANK T 3	TSS	F
PT2310	TRANSMITTER-PRESSURE	LINE PRESSURE FROM NIT	TSS	F
PT2311	TRANSMITTER-PRESSURE	NITROGEN SYSTEM PRESSU	TSS	F
LI2315	INDICATOR-LEVEL	LIQUID LEVEL LTT		
LT2315	TRANSMITTER-LEVEL	LIQUID LEVEL TANK 3	TSS	F
LAHL2315	ALARM-LEVEL HIGH/LOW	LIQUID LEVEL LTT		
ZSH2370	SWITCH-OPEN VALVE POS	BDV-LTT	TSS	F
ZSL2370	SWITCH-CLOSE VALVE POS	BDV-LTT	TSS	F
ZSH2372	SWITCH-OPEN VALVE POS	NITROGEN COVER GAS	TSS	F
ZSL2372	SWITCH-CLOSE VALVE POS	NITROGEN COVER GAS	TSS	F
ZSH2374	SWITCH-OPEN VALVE POS	INLET OIL SCS-LTT	TSS	F
ZSL2374	SWITCH-CLOSE VALVE POS	INLET OIL SCS-LTT	TSS	F
ZSH2376	SWITCH-OPEN VALVE POS	INLET OIL PCS-LTT	TSS	F
ZSL2376	SWITCH-CLOSE VALVE POS	INLET OIL PCS-LTT	TSS	F
ZSH2378	SWITCH-OPEN VALVE POS	EXIT OIL LTT-SCS	TSS	F
ZSL2378	SWITCH-CLOSE VALVE POS	EXIT OIL LTT-SCS	TSS	F
PAHL2390	ALARM-PRES-HIGH/LOW	LTT		
TE2401	TEMPERATURE SENSOR	BY-PASS OIL TEMP TANK	TSS	F
TE2402	TEMPERATURE SENSOR	COLD PUMP TEMP A	TSS	F
TE2403	TEMPERATURE SENSOR	COLD PUMP TEMP B	TSS	F
PT2405	TRANSMITTER-PRESSURE	PUMP INLET PRESSURE LO	TSS	F
PT2406	TRANSMITTER-PRESSURE	PUMP OUTLET PRESSURE L	TSS	F
TE2407	SENSOR-TEMPERATURE	EXIT OIL PUMP-SCS		
FE2410	SENSOR-FLOW	LOW TEMP OIL FLOW	TSS	F
FT2410	TRANSMITTER-FLOW	LOW TEMP OIL FLOW	TSS	F
ZSH2474	SWITCH-OPEN VALVE POS	LOW TEMP PUMP BY-PASS		
ZSL2474	SWITCH-CLOSE VALVE POS	LOW TEMP PUMP BY-PASS		
ZSH2476	SWITCH-OPEN VALVE POS	INLET FLOW SCS-PUMPS		
ZSL2476	SWITCH-CLOSE VALVE POS	INLET FLOW SCS-PUMPS		
TE2501	TEMPERATURE SENSOR	BY-PASS OIL TEMP TANK	TSS	F
TE2502	TEMPERATURE SENSOR	HOT PUMP TEMP A	TSS	F
TE2503	TEMPERATURE SENSOR	HOT PUMP TEMP B	TSS	F
PT2505	TRANSMITTER-PRESSURE	PUMP INLET PRESSURE HI	TSS	F
PT2506	TRANSMITTER-PRESSURE	PUMP DISCHARGE PRESSUR	TSS	F
TE2507	SENSOR-TEMPERATURE	EXIT OIL TSS-PCS		
FE2510	SENSOR-FLOW	EXIT OIL TSS-PCS		
FT2510	TRANSMITTER-FLOW	EXIT OIL TSS-PCS		
PT2555	TRANSMITTER-PRESSURE	SEAL WATER PRESSURE	TSS	F
PT2556	TRANSMITTER-PRESSURE	SEAL WATER PRESSURE	TSS	F
ZSH2574	SWITCH-OPEN VALVE POS	HIGH TEMP PUMP BY-PASS		
ZSL2574	SWITCH-CLOSE VALVE POS	HIGH TEMP PUMP BY-PASS		
ZSH2576	SWITCH-OPEN VALVE POS	EXIT OIL PUMPS-HTT		
ZSL2576	SWITCH-CLOSE VALVE POS	EXIT OIL PUMPS-HTT		
PT2655	TRANSMITTER-PRESSURE	SEAL WATER PRESSURE	TSS	F
PT2656	TRANSMITTER-PRESSURE	SEAL WATER PRESSURE	TSS	F

COUNT = 96

TABLE 3.6-7

POWER CONVERSION SUBSYSTEM MEASUREMENT REQUIREMENT LIST

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
TT3100	TRANSMITTER-TEMP	OIL INLET TO PCS	PCS	L
TI3101	INDICATOR-TEMP	OIL INLET TO PCS	PCS	L
PI3102	INDICATOR-PRESSURE	OIL INLET TO PCS	PCS	L
TT3103	TRANSMITTER-TEMP	EXIT OIL-SPHTR	PCS	L
TI3104	INDICATOR-TEMP	EXIT OIL-SPHTR	PCS	L
TT3105	TRANSMITTER-TEMP	INLET OIL-BOILER	PCS	L
TI3106	INDICATOR-TEMP	INLET OIL-BOILER	PCS	L
TT3107	TRANSMITTER-TEMP	EXITOIL-BOILER	PCS	L
TI3108	INDICATOR-TEMP	EXIT OIL-BOILER	PCS	L
TT3109	TRANSMITTER-TEMP	INLET OIL-PRHTR	PCS	L
TI3110	INDICATOR-TEMP	INLET OIL-PRHTR	PCS	L
TT3111	TRANSMITTER-TEMP	EXIT OIL-PRHTR	PCS	L
TI3112	INDICATOR-TEMP	EXIT OIL-PRHTR	PCS	L
TT3113	TRANSMITTER-TEMP	EXIT OIL-LAST VALVE	PCS	L
TI3114	INDICATOR-TEMP	EXIT OIL-LAST VALVE	PCS	L
PI3115	INDICATOR-PRESSURE	EXIT OIL-PCS	PCS	L
TT3116	TRANSMITTER-TEMP	EXIT FDWTR-PRHTR	PCS	L
TCV3116	CONTROL VALVE-TEMP	EXIT OIL PRHTR-3WAY	PCS	L
ZSH3116	SWITCH-HIGH POSITION	EXIT OIL PRHTR-3WAY	PCS	L
ZSL3116	SWITCH-LOW POSITION	EXIT OIL PRHTR-3WAY	PCS	L
TI3117	INDICATOR-TEMP	EXIT FDWTR-PRHTR	PCS	L
LG3118	GAUGE-LEVEL	BOILER FDWTR LEVEL	PCS	L
LC3119	CONTROLLER-LEVEL	BOILER FDWTR LEVEL	PCS	L
LT3119	TRANSMITTER-LEVEL	BOILER FDWTR LEVEL	PCS	L
LCV3119	CONTROL VALVE-LEVEL	INLET TO PRHTR	PCS	L
TT3120	TRANSMITTER-TEMP	EXIT STEAM	PCS	L
TCV3120	CONTROL VALVE-TEMP	EXIT OIL SPHTR-3WAY	PCS	L
ZSH3120	SWITCH-HIGH POSITION	EXIT OIL SPHTR-3WAY	PCS	L
ZSL3120	SWITCH-LOW POSITION	EXIT OIL SPHTR-3WAY	PCS	L
TI3121	INDICATOR-TEMP	EXIT STEAM	PCS	L
PT3122	TRANSMITTER-PRESS	EXIT STEAM	PCS	L
PCV3122	CONTROL VALVE-PRESS	EXIT OIL PCS	PCS	F
ZSH3122	SWITCH-OPEN VALVE POS	PCV-EXIT OIL PCS	PCS	F
ZSL3122	SWITCH-CLOSE VALVE POS	PCV-EXIT OIL PCS	PCS	F
PI3123	INDICATOR-PRESS	EXIT STEAM	PCS	L
FT3124	TRANSMITTER-FLOW	EXIT STEAM	PCS	L
PI3200	INDICATOR-PRESSURE	INLET OIL-PCS	PCS	F
PDI3201	INDICATOR-DIF PRESS	ACROSS STMGENERATOR	PCS	F
PI3202	INDICATOR-PRESSURE	BEFORE EXIT PCV	PCS	F
FT3203	TRANSMITTER-FLOW	BEFORE EXIT PCV	PCS	F
TI3204	INDICATOR-TEMP	INLET FDWTR TO PRHTR	PCS	F
CC3205	CONTROLLER-CONDUCT	BOILER BLOWDOWN	PCS	F
CE3205	ELEMENT-CONDUCTIVITY	BOILER BLOWDOWN	PCS	F
CT3205	TRANSMITTER-CONDUCT	BOILER BLOWDOWN	PCS	F
CCV3205	CONTROL VALVE-CONDUCT	BOILER BLOWDOWN	PCS	F
FI3300	INDICATOR-FLOW	INLET STM-T/G	PCS	F
TI3301	INDICATOR-TEMP	INLET STM-T/G	PCS	F
PI3302	TRANSMITTER-PRESSURE	BYPASS H.P. T/G	PCS	F

TABLE 3.6-7 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC	
PI3304	INDICATOR-PRESSURE	BYPASS T/G	PCS	F	
TI3305	INDICATOR-TEMP	BYPASS T/G	PCS	F	
TT3400	TRANSMITTER-TEMP	INLET STM-CONDECSER	PCS	L	
TI3401	INDICATOR-TEMP	INLET STM-CONDECSER	PCS	L	
PT3402	TRANSMITTER-PRESSURE	VACUUM IN CONDENSER	PCS	L	
ZY3403	RELAY-CONTACT POSITION	AIR EJECT VACUUM PUMP	PCS	L	
LG3405	INDICATOR-LEVEL	WATER-HOTWELL	PCS	L	
IY3406	CONTROL RELAY	RUN CONDENSATE PUMP1	PCS	L	
LS3406	SWITCH-LEVEL	WATER-HOTWELL	PCS	L	
ZY3406	RELAY-CONTACT POSITION	RUN CONDENSATE PUMP1	PCS	L	
LC3407	CONTROLLER-LEVEL	WATER-HOTWELL	PCS	F	
LT3407	TRANSMITTER-LEVEL	WATER-HOTWELL	PCS	L	
LCV3407	CONTROL VALVE-LEVEL	INLET COND-DEAERATOR	PCS	F	
IY3408	CONTROL RELAY	RUN CONDERSATE PUMP2	PCS	L	
ZY3408	RELAY-CONTACT POSITION	RUN CONDENSATE PUMP2	PCS	L	
TT3409	TRANSMITTER-TEMP	EXIT WATER-HOTWELL	PCS	F	
TI3500	INDICATOR-TEMP	STEAM-DEARATOR	PCS	L	
PT3501	TRANSMITTER-PRESSURE	STM - DEAERATOR	PCS	L	
PCV3501	CONTROL VALVE-PRESS	INLET STM-DEAERATOR	PCS	F	
ZSH3501	SWITCH-OPEN VALVE POS	STM VALVE-DEAERATOR	PCS	F	
ZSL3501	SWITCH-CLOSE VALVE POS	STM VALVE-DEAERATOR	PCS	F	
PI3502	INDICATOR-PRESSURE	STEAM-DEAERATOR	PCS	L	
TT3503	TRANSMITTER-TEMP	WATER-DEAERATOR	PCS	L	
TI3504	INDICATOR-TEMP	WATER-DEAERATOR	PCS	L	
LG3505	INDICATOR-LEVEL	WATER-DEAERATOR	PCS	L	
LC3506	CONTROLLER-LEVEL	WATER-DEAERATOR	PCS	F	
LT3506	TRANSMITTER-LEVEL	WATER-DEAERATOR	PCS	L	
LCV3506	CONTROL VALVE-LEVEL	INLET MK-UP WTR-CRU	PCS	F	
ZSH3506	SWITCH-OPEN VALVE POS	MK-UP WTR VALVE-CRU	PCS	F	
ZSL3506	SWITCH-CLOSE VALVE POS	MK-UP WTR VALVE-CRU	PCS	F	
FIT3600	THANS/IND-FLOW	INLET FDWTR-FDWTR HTR	PCS	F	
TI3601	INDICATOR-TEMP	INLET FDWTR-FDWTR HTR	PCS	F	
PT3602	TRANSMITTER-PRESSURE	INLET FDWTR-FDWTR HTR	PCS	F	
PI3603	INDICATOR-PRESSURE	INLET FDWTR-FDWTR HTR	PCS	F	
TC3604	CONTROLLER-TEMP	INLET STEAM-FDWTR HTR	PCS	F	
TT3604	TRANSMITTER-TEMP	EXIT FDWTR-FDWTR HTR	PCS	F	
TCV3604	CONTROL VALVE-TEMP	STEAM VALVE-FDWTR HTR	PCS	F	
ZSH3604	SWITCH-OPEN VALVE POS	STM VALVE-FDWTR HTR	PCS	F	
ZSL3604	SWITCH-CLOSE VALVE POS	STM VALVE-FDWTR HTR	PCS	F	
IY3605	CONTROL RELAY	FDWTR PUMP1	PCS	L	
ZY3605	RELAY-CONTACT POSITION	FDWTR PUMP1	PCS	L	
IY3606	CONTROL RELAY	FDWTR PUMP2	PCS	L	
ZY3606	RELAY-CONTACT POSITION	FDWTR PUMP2	PCS	L	
PT3610	TRANSMITTER-PRESSURE	STEAM IN FDWTR HTR	PCS	L	
IY3700	LOCK OUT RELAY	TRIPS ACB A-ACB B	PCS	L	
IY3701	T.O. OVERCURRENT RELAY	GEN GROUND FAULT	PCS	L	
IY3702	GROUND FAULT RELAY	GEN GROUND FAULT	PCS	L	
EI3703	VOLT METER	GEN VOLTAGE	PCS	L	BY VENDOR

TABLE 3.6-7 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC	
JQI3706	WATTHOUR METER	GEN POWER	PCS	L	BY VENDOR
EIC3707	VOLT/AMP REGULATOR	REACTANCE ADJUSTMENT	PCS	L	BY VENDOR
IY3708	OVERCURRENT RELAY	TRIPS ACB B	PCS	L	BY VENDOR
IY3709	REVERSE POWER RELAY	TRIPS ACB B	PCS	L	BY VENDOR
IY3710	REVERSE PHASE RELAY	TRIPS ACB B	PCS	L	BY VENDOR
IY3711	OVERVOLTAGE RELAY	TRIPS ACB B	PCS	L	BY VENDOR
IY3712	UNIT DIFF PHASE RELAY	TRIPS ACB B	PCS	L	
IY3713	T.D. OVERCURRENT RELAY	GEN GROUND FAULT-BUS	PCS	L	
JQI3714	WATTHOUR METER	POWER OUT GEN BUS TIE	PCS	L	
IY3717	OVER/UNDER VOLT RELAY	TRIPS ACBA-ACB B	PCS	L	
IY3718	OVER/UNDER FREQ RELAY	TRIPS ACBA-ACB B	PCS	L	
IY3719	GROUND FAULT RELAY	TRIPS ACB B	PCS	L	
IY3720	TRIP COIL RELAY	TRIPS 351	PCS	L	
IY3721	REVERSE POWER RELAY	BASE SOURCE TRIPS 351G	PCS	L	
IY3722	LOCK-OUT RELAY	TRIPS 251 AND ACB A	PCS	L	
IY3723	OVERVOLTAGE RELAY	TRIPS ACB A	PCS	L	
IY3724	T.D.OVERCURRENT RELAY	GROUND FAULT	PCS	L	
JQI3727	WATTHOUR METER	POWER IN	PCS	L	
JQI3728	WATTHOUR METER	POWER OUT	PCS	L	
IY3730	TRIP COIL RELAY	TRIPS ACB A	PCS	L	
IY3731	GROUND FAULT RELAY	TRIPS ACB A	PCS	L	
IY3732	CONTROL RELAY	TRIPS 351 AND ACB B	PCS	L	
LG3810	INDICATOR-LEVEL	COND IN CRU	PCS	L	
IY3811	CONTROL RELAY	COND RETURN PUMP1	PCS	L	
LSH3811	LIMIT SWITCH-HIGH	COND IN CRU	PCS	L	
LSL3811	LIMIT SWITCH-LOW	COND IN CRU	PCS	L	
LC3812	CONTROLLER-LEVEL	COND TO DEAERATOR	PCS	F	
LT3812	TRANSMITTER-LEVEL	COND IN CRU	PCS	L	
LCV3812	CONTROL VALVE-LEVEL	COND TO DEAERATOR	PCS	F	
ZSH3812	SWITCH-OPEN VALVE POS	LCV-COND TO DEAERATOR	PCS	F	
ZSL3812	SWITCH-CLOSE VALVE POS	LCV-COND TO DEAERATOR	PCS	F	
IY3813	CONTROL RELAY	COND RETURN PUMP2	PCS	L	

COUNT = 128

TABLE 3.6-8

HOT WATER SUBSYSTEM MEASUREMENT REQUIREMENT LIST

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
TE4000	ELEMENT - TEMP	HOT WTR TANK - HL	HWS	
TI4000	INDICATOR - TEMP	HOT WTR TANK - HL		
TT4000	TRANSMITTER - TEMP	HOT WTR TANK - HL	HWS	
PE4001	SENSOR - PRESSURE	HOT WTR TANK - HL		
PT4001	TRANSMITTER - PRESSURE	HOT WTR TANK - HL		
TE4002	ELEMENT - TEMP	HOT WTR TANK - HIL		
TI4002	INDICATOR - TEMP	HOT WTR TANK - HIL		
TT4002	TRANSMITTER - TEMP	HOT WTR TANK - HIL		
TE4003	ELEMENT - TEMP	HOT WTR TANK - IL		
TI4003	INDICATOR - TEMP	HOT WTR TANK - IL		
TT4003	TRANSMITTER - TEMP	HOT WTR TANK - IL		
TE4004	ELEMENT - TEMP	HOT WTR TANK - LIL		
TI4004	INDICATOR - TEMP	HOT WTR TANK - LIL		
TT4004	TRANSMITTER - TEMP	HOT WTR TANK - LIL		
TE4005	ELEMENT - TEMP	HOT WTR TANK - LL		
TI4005	INDICATOR - TEMP	HOT WTR TANK - LL		
TT4005	TRANSMITTER - TEMP	HOT WTR TANK - LL		
PE4006	SENSOR - PRESSURE	HOT WTR TANK - LL		
PT4006	TRANSMITTER - PRESSURE	HOT WTR TANK - LL		
LT4007	TRANSMITTER - LEVEL	HOT WTR TANK - LL		
FE4008	SENSOR - FLOW	INLET HOT WTR TANK		
FT4008	TRANSMITTER - FLOW	INLET HOT WTR TANK		
FE4009	SENSOR - FLOW	HOT WTR FROM COND		
FT4009	TRANSMITTER - FLOW	HOT WTR FROM COND		
TE4010	ELEMENT - TEMP	INLET COND WTR-HT EXC		
TT4010	TRANSMITTER - TEMP	INLET COND WTR-HT EXC		
TE4011	ELEMENT - TEMP	INLET LINE TO PUMP		
TT4011	TRANSMITTER - TEMP	INLET LINE TO PUMP		
TE4012	ELEMENT - TEMP	EXIT COND WTR-HT EXC		
TT4012	TRANSMITTER - TEMP	EXIT COND WTR-HT EXC		
PE4013	SENSOR - PRESSURE	EXIT CW - HT EXC		
PT4013	TRANSMITTER - PRESSURE	EXIT CW - HT EXC		
TE4014	ELEMENT - TEMP	EXIT CW - HT EXC		
TT4014	TRANSMITTER - TEMP	EXIT CW - HT EXC		
PE4015	SENSOR - PRESSURE	INLET CW - HT EXC		
PT4015	TRANSMITTER - PRESSURE	INLET CW - HT EXC		
TE4016	ELEMENT - TEMP	INLET CW - HT EXC		
TT4016	TRANSMITTER - TEMP	INLET CW - HT EXC		
TE4017	ELEMENT - TEMP	HOT WTR AHEAD DHWL		
TT4017	TRANSMITTER - TEMP	HOT WTR AHEAD DHWL		
FE4018	SENSOR - FLOW	HOT WTR TANK INLET		
FT4018	TRANSMITTER - FLOW	HOT WTR TANK INLET		
TE4019	ELEMENT - TEMP	EXIT HOT WTR - COND		
TI4019	INDICATOR - TEMP	EXIT HOT WTR - COND		
TT4019	TRANSMITTER - TEMP	EXIT HOT WTR - COND		
PE4020	SENSOR - PRESSURE	EXIT HOT WTR - COND		
PT4020	TRANSMITTER - PRESSURE	EXIT HOT WTR - COND		
TE4021	ELEMENT - TEMP	LINE AFTER PUMP		

TABLE 3.6-8 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
TI4021	INDICATOR - TEMP	LINE AFTER PHWP	HWS	
TT4021	TRANSMITTER - TEMP	LINE AFTER PHWP		
IY4022	CONTROL RELAY	PHWP - STARTER		
ZY4022	RELAY-CONTACT POSITION	PHWP - STARTER		
TE4023	ELEMENT - TEMP	HOT WTR SUPPLY LINE		
TI4023	INDICATOR - TEMP	HOT WTR SUPPLY LINE		
TT4023	TRANSMITTER - TEMP	HOT WTR SUPPLY LINE		
IY4024	CONTROL RELAY	SHWP STARTER		
ZY4024	RELAY-CONTACT POSITION	SHWP STARTER		
PE4025	SENSOR - PRESSURE	HOT WTR RETURN LINE		
PT4025	TRANSMITTER - PRESSURE	HOT WTR RETURN LINE		
IY4026	CONTROL RELAY	COND WTR PUMP STARTER		
TE4026	ELEMENT - TEMP	HOT WTR RETURN LINE		
TT4026	TRANSMITTER - TEMP	HOT WTR RETURN LINE		
ZY4026	RELAY-CONTACT POSITION	COND WTR PUMP STARTER		
PE4027	SENSOR - PRESSURE	HOT WTR SUPPLY LINE		
PT4027	TRANSMITTER - PRESSURE	HOT WTR SUPPLY LINE		
FE4028	SENSOR - FLOW	HOT WTR SUPPLY LINE		
FT4028	TRANSMITTER - FLOW	HOT WTR SUPPLY LINE		

COUNT = 67

TABLE 3.6-9

CHILLED WATER SUBSYSTEM MEASUREMENT REQUIREMENT LIST

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
TT5100	TRANSMITTER - TEMP	CH WTR SUPPLY LINE	CWS	
TT5101	TRANSMITTER - TEMP	CH WTR RETURN LINE		
TT5103	TRANSMITTER-TEMP	CHANGE OVER CONTROLS		
FT5104	TRANSMITTER - FLOW	CH WTR SUPPLY LINE		
PT5105	TRANSMITTER - PRESSURE	CH WTR SUPPLY LINE		
LT5106	TRANSMITTER - LEVEL	CH WTR TANK - LL		
FT5107	TRANSMITTER - FLOW	CH WTR TANK S/R		
TE5108	ELEMENT - TEMP	CH WTR LINE - PCWP		
TT5108	TRANSMITTER - TEMP	CH WTR LINE - PCWP		
PE5110	SENSOR - PRESSURE	EXIT CH WTR LINE		
PI5110	INDICATOR - PRESSURE	EXIT CH WTR LINE		
PT5110	TRANSMITTER - PRESSURE	EXIT CH WTR LINE		
PCV5110	CONTROL VALVE-PRESSURE	CH WTR LOOP		
IY5111	CONTROL RELAY	PCWP STARTER		
ZY5111	RELAY-CONTACT POSITION	PCWP STARTER		
TE5112	ELEMENT - TEMP	INLET CH WTR - AB CH		
TT5112	TRANSMITTER - TEMP	INLET CH WTR - AB CH		
PE5113	SENSOR - PRESSURE	INLET CH WTR - AB CH		
PT5113	TRANSMITTER - PRESSURE	INLET CH WTR - AB CH		
FS5114	SWITCH - FLOW	EXIT CH WTR - AB CH		
PE5115	SENSOR - PRESSURE	EXIT CH WTR - AB CH		
PT5115	TRANSMITTER - PRESSURE	EXIT CH WTR - AB CH		
TE5116	ELEMENT - TEMP	EXIT CH WTR - AB CH		
TT5116	TRANSMITTER - TEMP	EXIT CH WTR - AB CH		
IY5117	CONTROL RELAY	SCWP STARTER		
ZY5117	RELAY-CONTACT POSITION	SCWP STARTER		
PE5118	SENSOR - PRESSURE	CH WTR SUPPLY LINE		
PT5118	TRANSMITTER - PRESSURE	CH WTR SUPPLY LINE		
TE5119	ELEMENT - TEMP	INLET COND WTR-AB CH		
TT5119	TRANSMITTER - TEMP	INLET COND WTR-AB CH		
PE5120	SENSOR - PRESSURE	INLET COND WTR-AB CH		
PT5120	TRANSMITTER - PRESSURE	INLET COND WTR-AB CH		
TE5121	ELEMENT - TEMP	EXIT COND WTR-AB CH		
TT5121	TRANSMITTER - TEMP	EXIT COND WTR-AB CH		
PE5122	SENSOR - PRESSURE	EXIT COND WTR-AB CH		
PT5122	TRANSMITTER - PRESSURE	EXIT COND WTR-AB CH		
FS5123	SWITCH - FLOW	EXIT COND WTR-AB CH		
ZY5123	RELAY-CONTACT POS	AB CH LOW TEMP ALARM		
TE5124	ELEMENT - TEMP	EXIT CH WTR - AB CH		
TT5124	TRANSMITTER - TEMP	EXIT CH WTR - AB CH		
TE5125	ELEMENT - TEMP	MIXED COND WTR LINE		
TT5125	TRANSMITTER - TEMP	MIXED COND WTR LINE		
IY5127B	CONTROL RELAY	CT FAN HIGH SPEED		
IY5127A	CONTROL RELAY	CT FAN LOW SPEED		
ZY5127B	RELAY-CONTACT POSITION	CT FAN HIGH SPEED		
ZY5127A	RELAY-CONTACT POSITION	CT FAN LOW SPEED		
IY5128	CONTROL RELAY	CWP TO CH UNIT		
ZY5128	RELAY-CONTACT POSITION	CWP TO CH UNIT		

TABLE 3.6-9 (Continued)

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
TE5129	ELEMENT - TEMP	CH WTR TANK HL	CWS	
TI5129	INDICATOR-TEMP	CH WTR TANK HL		
TT5129	TRANSMITTER - TEMP	CH WTR TANK HL		
PE5130	SENSOR - PRESSURE	CH WTR TANK HL		
PT5130	TRANSMITTER - PRESSURE	CH WTR TANK HL		
TE5131	ELEMENT - TEMP	CH WTR TANK - HIL		
TI5131	INDICATOR - TEMP	CH WTR TANK - HIL		
TT5131	TRANSMITTER - TEMP	CH WTR TANK - HIL		
TE5132	ELEMENT - TEMP	CH WTR TANK - IL		
TI5132	INDICATOR - TEMP	CH WTR TANK - IL		
TT5132	TRANSMITTER - TEMP	CH WTR TANK - IL		
TE5133	ELEMENT - TEMP	CH WTR TANK - LIL		
TI5133	INDICATOR - TEMP	CH WTR TANK - LIL		
TT5133	TRANSMITTER - TEMP	CH WTR TANK - LIL		
PE5134	SENSOR - PRESSURE	CH WTR TANK - LL		
PT5134	TRANSMITTER - PRESSURE	CH WTR TANK - LL		
TE5135	ELEMENT - TEMP	CH WTR TANK - LL		
TI5135	INDICATOR - TEMP	CH WTR TANK - LL		
TT5135	TRANSMITTER - TEMP	CH WTR TANK - LL		
TE5136	ELEMENT - TEMP	CH WTR TANK - S/R		
TT5136	TRANSMITTER - TEMP	CH WTR TANK - S/R		
FE5137	SENSOR - FLOW	EXIT CH WTR - AB CH		
FT5137	TRANSMITTER - FLOW	EXIT CH WTR - AB CH		
FE5138	TRANSMITTER - FLOW	AB CH LOOP LINE		
FT5138	TRANSMITTER - FLOW	AB CH LOOP LINE		
FE5139	SENSOR - FLOW	INLET COND WTR-AB CH		
FT5139	TRANSMITTER - FLOW	INLET COND WTR-AB CH		
FY5140	CONTROL RELAY	AB CH UNIT		
ZY5140	RELAY-CONTACT POS	AB CH UNIT		
IY5141	CONTROL RELAY	PURGE PUMP		
ZY5141	RELAY-CONTACT POS	PURGE PUMP		
IY5142	CONTROL RELAY	AB CH UNIT PUMP		
ZY5142	RELAY-CONTACT POS	AB CH UNIT PUMP		
ZY5144	RELAY-CONTACT POS	AB CH LOW REF ALARM		
PC5501	CONTROLLER-PRESSURE	INLET STEAM-DEAERATOR		
PT5501	TRANSMITTER-PRESSURE	STEAM-DEAERATOR		
PCV5501	CONTROL VALVE-PRESS	INLET STEAM-DEAERATOR		
COUNT -	85			

TABLE 3.6-10

DOMESTIC HOT WATER SUBSYSTEM MEASUREMENT REQUIREMENT LIST

INSTRUMENT NUMBER	INSTRUMENT DESCRIPTION DEVICE VARIABLE	SERVICE DESCRIPTION	SYS	LOC
TE6000	ELEMENT - TEMP	EXIT HOT WTR-HT EXC	DHS	
TT6000	TRANSMITTER - TEMP	EXIT HOT WTR-HT EXC		
TE6001	TRANSMITTER - TEMP	INLET HOT WTR-HT EXC		
TT6001	TRANSMITTER - TEMP	INLET HOT WTR-HT EXC		
PE6002	SENSOR - PRESSURE	COLD WTR TO DHS		
PT6002	TRANSMITTER - PRESSURE	COLD WTR TO DHS		
TY6003	CONTROL RELAY	DHS HOT WTR PUMP		
ZY6003	RELAY-CONTACT POS	DHS HOT WTR PUMP		
TE6004	ELEMENT - TEMP	EXIT DHW HT EXC		
TI6004	INDICATOR - TEMP	EXIT DHW HT EXC		
TT6004	TRANSMITTER - TEMP	EXIT DHW HT EXC		
TCV6004	CONTROL VALVE - TEMP	EXIT DHW HT EXC		
TE6005	ELEMENT - TEMP	COLD WTR TO DHS		
TT6005	TRANSMITTER - TEMP	COLD WTR TO DHS		
PE6006	SENSOR - PRESSURE	DHW SUPPLY LINE		
PT6006	TRANSMITTER - PRESSURE	DHW SUPPLY LINE		
TE6007	ELEMENT - TEMP	DHS RETURN LINE		
TT6007	TRANSMITTER - TEMP	DHS RETURN LINE		
IY6008	CONTROL RELAY	DHS RETURN PUMP		
ZY6008	RELAY-CONTACT POS	DHS RETURN PUMP		

COUNT = 20

COUNT = 825

TABLE 3.6-11

MRL ABBREVIATION DEFINITIONS

AB CH	Absorption Chiller
ALT	Alternate
AUX	Auxiliary
BDV	Blowdown Valve
CH WTR	Chilled Water
COND	Condensate
CRU	Condensate Return Unit
CW	Cooling Water
FDFWD	Feed Forward
FDWTR	Feedwater
GEN	Generator
HIL	High Intermediate Level
HTT	High Temperature Tank
HL	High Level
HT EXC	Heat Exchanger
HTR	Heater
HW	Hot Water
IL	Intermediate Level
ITT	Intermediate Temperature Tank
LIL	Low Intermediate Level
LIT	Low Temperature Tank
LL	Low Level
MK-UP WTR	Make-Up Water
PCWP	Primary Chilled Water Pump
PHWP	Primary Hot Water Pump
POS	Position
PRHTR	Preheater
SCWP	Secondary Chilled Water Pump
SPHRT	Superheater
S/R	Supply/Return
STM	Steam
STM GEN	Steam Generator
T/G	Turbine Generator

The control system interfaces electrically with the above subsystems instrumentation via electrical signals that terminate at the I/O terminal boards of the distributed process unit (DPU) or the I/O racks behind the operator control panel/console. The I/O terminal board connectors and transmission cables are the mechanical interfaces between subsystem instrumentation cabling and the computer based control system.

3.6.6.2 ELECTRICAL POWER

Power for the computer control system critical load is derived from a reverse transfer static UPS. Under normal operation, the critical load receives AC power from the UPS ferroresonant inverter in order that AC filtering is provided to protect against short term voltage transients and frequency deviations. Should the UPS fail or a large amount of current be necessary for clearing faults, a static transfer switch is provided to automatically switchover to commercial AC power, unput power to drive the UPS is provided by the facility utility 230 VAC, 3 phase, 60 Hz source that is connected to a common distribution system. The UPS system shall be located in an area outside the main control room.

3.6.7 SYSTEM SOFTWARE

The ICS control is implemented as operating system and control system software in the CPU, and as control system software or hardware in the DPUs. The operating system software will be supplied and maintained by the computer hardware supplier as a standard item. This operating system provides the software base and tools required to implement the unique Fort Hood STES control system software that will be developed during Phase IV.

3.6.7.1 OPERATING SYSTEM SOFTWARE REQUIREMENTS

System software will be modularly constructed and controlled by a priority oriented real time multiprogramming executive.

All units of software furnished as part of this system will have been successfully used in at least two documented prior applications.

- The software will support high-level language program development and maintenance for the host computer and the DPU's including a text editing and a debugging capability

- The software will be capable of generating an operating system based on combinations of routines from a library of basic facilities
- The software will provide program assembly capability for the host computer and the DPU's
- The software will provide capability to download data and commands to the DPU's from the host computer
- The software will provide input/output task scheduling, file management, task swapping memory allocation, overlay capability, and memory protection
- The software will provide interrupt handling capability and support at least four levels of priority for task execution. The priority level of any task may be altered by operator or programmer intervention
- The software will provide for the control of disc to tape and tape to disc transfers, and other such utility routines, including I/O with peripherals such as CRT terminals, card reader, etc.
- The executive will control all application programs and execute them at frequencies and priorities to be specified by the purchaser
- The software will support interactive communication with the operator through his CRTs and keyboard
- A compiler for ANSI Standard FORTRAN IV (ANSI X3.9) will be provided, including the real time extensions of ISA S61.1. The FORTRAN language will be capable of on-line assembly language coding and bit and byte manipulation. A run time diagnostic package will be included.
- Mathematical and utility program libraries will be provided for both the CPU and DPU's.
- Device independent input/output capability will be provided and specific software drivers will be provided for all hardware furnished with the computer system including all peripherals and CPU options such as the real time clock, fail/restart function, direct digital control.
- Full diagnostic routines will be provided for the host computer and all options and peripherals furnished. The diagnostics will provide an exercise of all functions of each specific piece of hardware as well as serve to locate hardware malfunctions in detail.

- Real time, run time and diagnostic routines will be provided for the host computer and the DPU's that will detect errors and failures in all peripherals to the host computer especially the data link and DPUs.
- Software modules to program and check DPU software will be provided

3.6.7.2 CONTROL SYSTEM SOFTWARE

The control software in the CPU will be modularly built and implemented to fulfill the functions below.

ENERGY MANAGEMENT

The energy supply and load demand will be predicted periodically during daily plant operation to provide daily and longer range input to the mode selection to efficiently meet immediate and projected energy needs. The weather station and the instrumentation of each subsystem provide the current data. Also the operator may provide current data as well as inputing special information to the predictions.

OPERATOR COMMUNICATIONS

Through the CPU the operator has complete control. The CPU will provide command data to facilitate operator commands and reduce operator input error. The operator may override automatic mode selection with his own choice or even control individual component operation. The CPU will provide the operator with warning alarms as well as limit alarms and notice of automatic actions. The operator may display on his CRT data about the overall system or about a detailed selected area. In addition, the operator can request data trending of key system parameters.

The alarm handler will keep the alarm CRT up to date; flashing new alarms and showing cleared alarms as space allows. A hard copy of the sequence of the alarms will also be output.

STES MODE SELECTION, ALARM AND PROTECTION LOGIC

This software module will govern automatic mode selection and provide interlock and protection logic for operator action and individual DPU action. The energy supply and demand modules outputs will be used here to automatically select the system mode of operation. The selection logic will account for current status including operator imposed conditions and any hardware that is out of service, and demand and load predictions to select the mode for best overall system efficiency. The operators commands for mode selection will override the automatic selection but individual component commands must pass through the interlock logic which, for safety reasons, may trigger additional commands and/or alarms. Individual DPU actions and alarms will also pass through the interlock logic to provide system wide response.

STES MODE CONTROL INCLUDING MODE TRANSITION CONTROL

Each of the DPU's down-loaded commands and software will be formatted and will reside in a software module. Triggered by automatic actions and operator commands that come through the interlock logic, the overall control program will assemble and transmit the appropriate DPU communications. Ordered mode changes may require a special timing of commands including intermediate steps, that will be timed, assembled and transmitted by this module.

3.6.8 MAINTENANCE

Typically the instrumentation and control system is designed with solid state electronic equipment. This equipment includes the Central Processor Unit, Distributed Process Units (which includes the microprocessors and input/output channels), components within the control console, and power supplies. It is expected that specific "plug in" units may fail over the life of the equipment, the design mean-time-to-repair will be two hours. All parts that may require servicing, repair or replacement during the life of the equipment are accessible for replacement or repair. Access to these parts, with a drawer withdrawn or access doors open, is from the front or back of cabinets or consoles. Sufficient clearance is provided for maintenance access to any panel.

Spare parts for failed components will be made available per the recommended spare parts list from the various equipment suppliers. All items removable from the equipment, such as assemblies or subassemblies, electrical parts, and hardware, will be physically and electrically interchangeable with corresponding items. The replacement of any part will not cause the equipment to depart from its specified performance. It is expected that periodic diagnostics will be performed at appropriately convenient times on specific components and systems to insure that system operation is within required specifications. All maintenance functions may be fulfilled by the computer maintenance contract. Two types of hardware maintenance contracts are normally available, daily maintenance service and on-call service. Service coverage will be provided to allow the best service plan for each application.

For the maintenance program for the instruments located in the various subsystems refer to each subsystems dedicated section.

Maintenance of the auxiliary systems will be performed at the intervals prescribed by the various equipment suppliers. Rechargeable batteries will be available for equipment as needed. Filters on equipment racks and consoles will be replaced or cleaned at frequent intervals to insure adequate flow of cooling air to operating equipment. Maintenance on rotating machinery will be performed as prescribed by the equipment manufacturer. Maintenance records will be kept on all I&C equipment to insure that maintenance has been performed at the prescribed intervals as required.

3.6.9 TRANSIENT MODEL DEVELOPMENT

3.6.9.1 SOLAR COLLECTOR FIELD DYNAMIC MODEL DESCRIPTION

INTRODUCTION

A digital computer model of the Fort Hood collector field has been developed to study transient reponse and field controllability. This model includes simulation of the hydraulic piping network that connects the fields and various field bypasses, including pressure drop, flow, and energy transport calculations. A nodalized model of the solar collectors is included to represent the collector field. Finally, a field flow and temperature controller that adjusts valve positions to control flowrates is included.

The model is used in this report to describe field transient response to various basic transients. It will be used to future studies to develop a more defined field control algorithm.

MODEL DESCRIPTION

The collector field model shown in Figure 3.6-84 is composed of several basic parts. The first part is the flow network. The flow network consists of flow paths, junction nodes and control valves. A flow path is represented by a mass flowrate, W, a path temperature, PT, and a pressure drop. A path junction is represented by a temperature, TJ, and a pressure, P. Flow control valves are represented at various places in the flow network. There are two types of valves – control valves that introduce a variable flow resistance in a flow path, and two-position valves that switch flow on or off in a particluar flow path.

The second part of the field simulation is the solar receiver simulation. This consists of nodes that represent the active solar collectors and absorb heat from the sun, lose heat to ambient, and transport energy to the next node in the string. Other components in the model are the thermal storage tanks, which supply cold fluid and absorb heated fluid, and the pump that circulates the fluid.

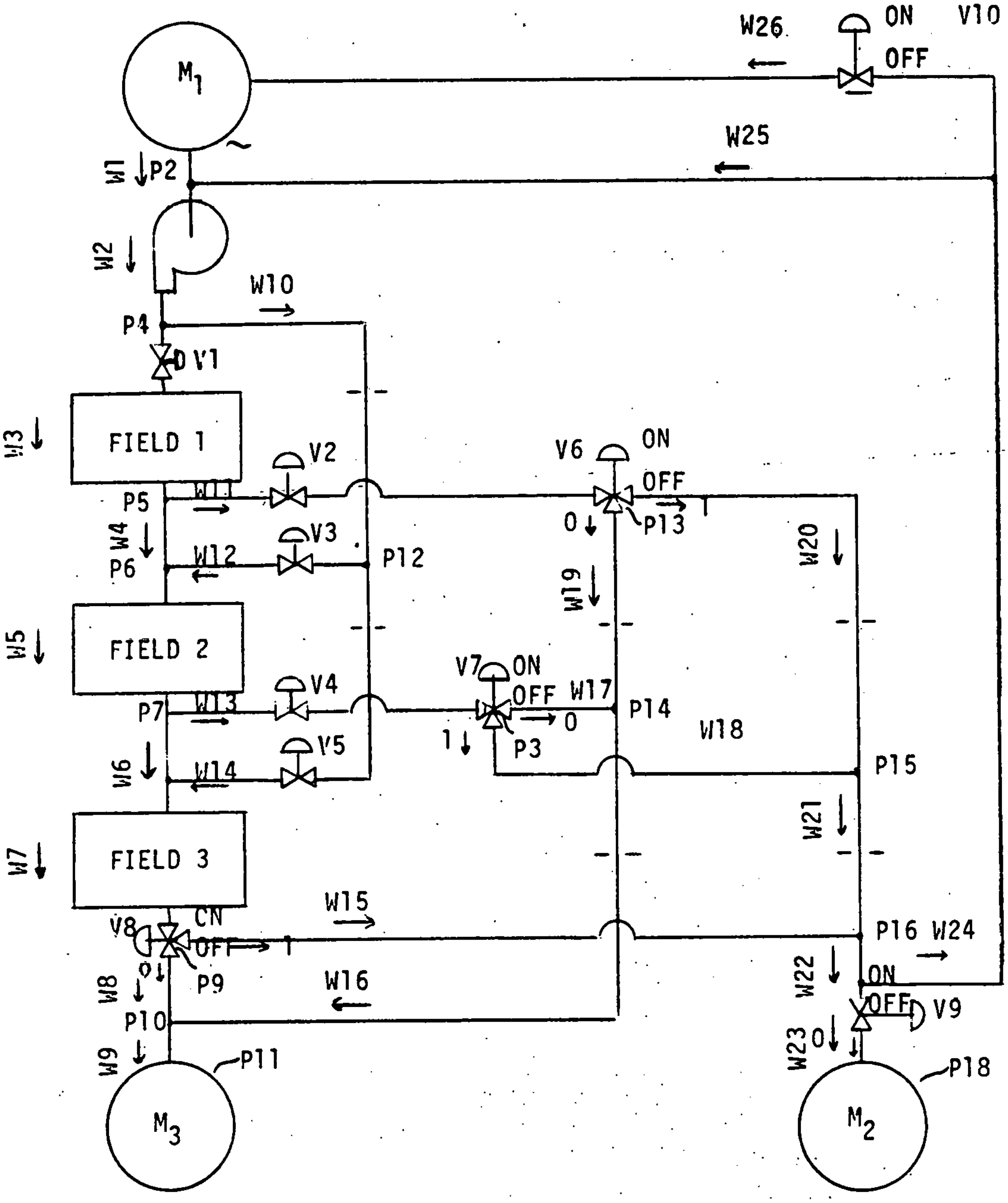


Figure 3.6-84. Collector Field Geometry

The collector field nodel equations are solved by a Westinghouse Electric Corporation program called TAF (Time and Frequency). TAF is a general purpose program for solving ordinary differential equations. The differential equations are written to provide a value for the first derivative of each variable in terms of the values of the other variables, time and other program values. TAF provides steady state solutions, time transients, and frequency responses.

FLOW NETWORK FLOW SOLUTION

The flow network has 26 flow paths that are joined at 19 junctions. It includes five control valves and five on/off valves; three of the latter are three-way valves. There is a flow, W, associated with each flow path and a pressure associated with each node. A flow continuity equation is written at each node.

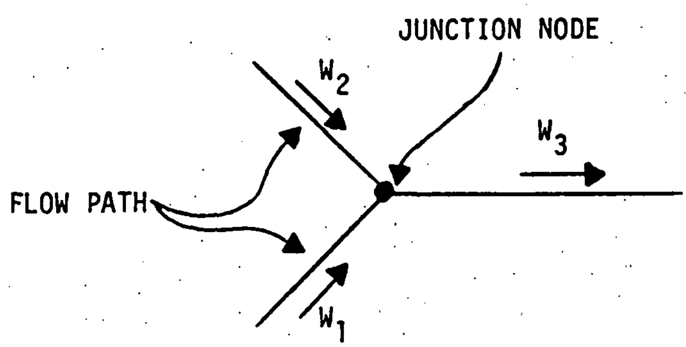
$$\sum_i X_i W_i = 0$$

where:

i = All flow paths that meet at the junction

W_i = Flow in flow path i

X_i = +1 if postive flow (as defined on Figure 3.6-84) is toward the node for flow path i; -1 otherwise



$$W_1 + W_2 - W_3 = 0$$

One equation of this type is written for each of the 19 nodes, except for the nodes at the three storage tanks that may accumulate or lose mass. For these three nodes, an equation relating the node pressure to an assigned constant value is given:

$$P_1 = P1REF$$

$$P_{11} = P11REF$$

$$P_{18} = P18REF$$

An equation is written for each flow path relating the difference in pressure at the junctions at the ends of the paths to the flow and hydraulic resistance:

$$P_i - P_j = \left[f\left(RE_k, ED_k\right)\left(\frac{L}{D_e}\right)_k + PIPEK_k + VALVEK\left(VP_k\right)\right] \frac{\left|WOLD_k\right| \times W_k}{\rho\,(PT_k) \times AREA_k^2 \times 2G}$$

where:

P_i = Upstream node pressure

P_j = Downstream node pressure

f = Friction factor as a function of the Reynold's number, RE, and roughness to diameter ratio, ED, for flow path k

$\left(\frac{L}{D_e}\right)_k$ = Ratio of length to equivalent diameter

$PIPEK_k$ = K-loss factor for path k

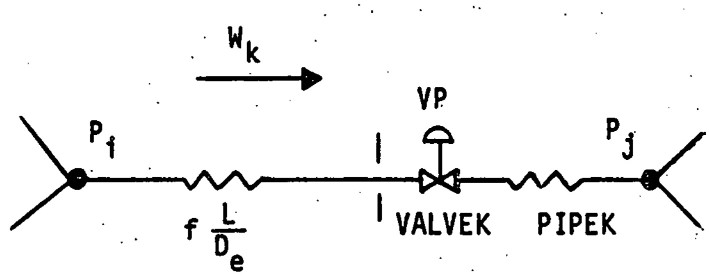
VALVEK = K-loss factor for path k as a function of valve position, VP, if applicable

$\left|WOLD_k\right|$ = Absolute value of flow from previous flow iteration, W_k, for path k

ρ = Fluid density as a function of path temperature, PT, for path k

$AREA_k$ = Flow path area

G = Gravitational constant



Other Path Properties: Area; Roughness; Temperature; Density

The flow paths with on/off valves have no flow when the valve is shut, so the equation is modified to

$$W_k = 0$$

To solve the 19 continuity equations and the 26 flow/pressure drop equations, a matrix solution method is used. The 45 unknowns (19 pressures and 26 flows) are assigned positions in the column vector $\overline{X}$. Each equation becomes one row in the coefficient matrix B of the form

$$B_{1,j}X_1 + B_{2,j}X_2 \;\ldots\ldots + B_{n,j}X_n = D_j$$

where:

n = Number of unknowns, 45

D_j = Any constant in the equation

For instance, Equation (2) (j = 2) for continuity at node 2 is:

$$W_1 - W_2 + W_{25} = 0$$

W_1 occupies postion 20 in the $\overline{X}$ vector, similarly:

$$W_2 = X_{21} \text{ and } W_{25} = X_{44}$$

The equation then becomes:

$$0 \times X_1 + 0 \times X_2 + \ldots + (+1) \times X_{20} + (-1) \times X_{21} + \ldots + (+1) \times X_{44} + 0 \times X_{45} = 0$$

The elements of row j = 2 are all zero except $B_{20,2} = +1$, $B_{21,2} = -1$ and $B_{44,2} = \underline{+}1$. Also, $D_2 = 0$. The form of the matrix equations is $B\overline{X} = \overline{D}$. To solve this matrix using standard techniques requires that the coefficients be known. The pressure drop equation that normally contains a term W^2 is revised to $|WOLD| x W$, where $|WOLD|$ is the value of W from the previous solution. After a solution, the value of $|WOLD|$ is updated using an under-relaxation method:

$$WOLD_{new} = WOLD_{old} + \left(W - WOLD_{old}\right) \times RELAX$$

where RELAX is the relaxation parameter that can range from $0 < RELAX < 2$. Good results have been obtained using RELAX = 0.6, even when the sign of the initial guess of WOLD was incorrect.

The matrix is solved by a standard matrix solution available in the Westinghouse computer library.

The friction factor, f, is calculated from an equation that is a curve fit to the Moody diagram published in Chemical Engineering, November 7, 1977, by Stuart W. Churchill.

$$f = 8\left[\left(\frac{8}{RE}\right)^{12} + \left(\frac{1}{A + B}\right)^{3/2}\right]^{1/12}$$

$$A = \left\{2.457 \ln\left[\frac{1}{\left(\frac{7}{RE}\right)^{0.9} + 0.27 \frac{\varepsilon}{D}}\right]\right\}^{16}$$

$$B = \frac{37,530}{RE}^{16}$$

This equation was modified to avoid unreasonably large numbers for the computer by adding 180 to the RE and setting "B" to "0" for RE less than 10^6. These modifications result in a negligible change in the resulting friction factor.

The valve characteristics have not yet been determined. At this time the valve k-loss is calculated as:

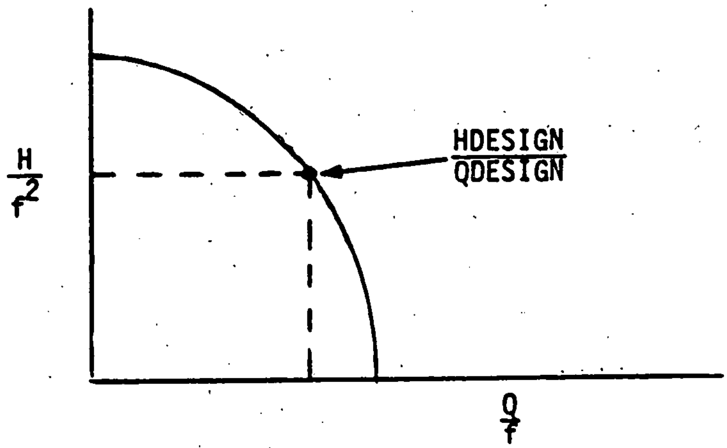
$$VALVEK = \left(\frac{KOPEN}{VP^2}\right)$$

with a maximum value of 100 KOPEN at 10 percent valve opening (VP).

PUMP HEAD FLOW CHARACTERISTICS

The preliminary design head and flow have been developed by GIT but the slope of the head flow curve is not established. For the current study, it was assumed that the curve is parabolic in shape with a slope of zero at the shut-off head point (zero flow), and that the shut-off head is 1.25 times the design head. The resulting curve, including the pump affinity laws for speed variation (f), is:

$$HP = f^2 \times 1.25\ HDESIGN - \frac{0.25\ HDESIGN}{(QDESIGN)^2} \times \left(\frac{Q}{F}\right)^2$$



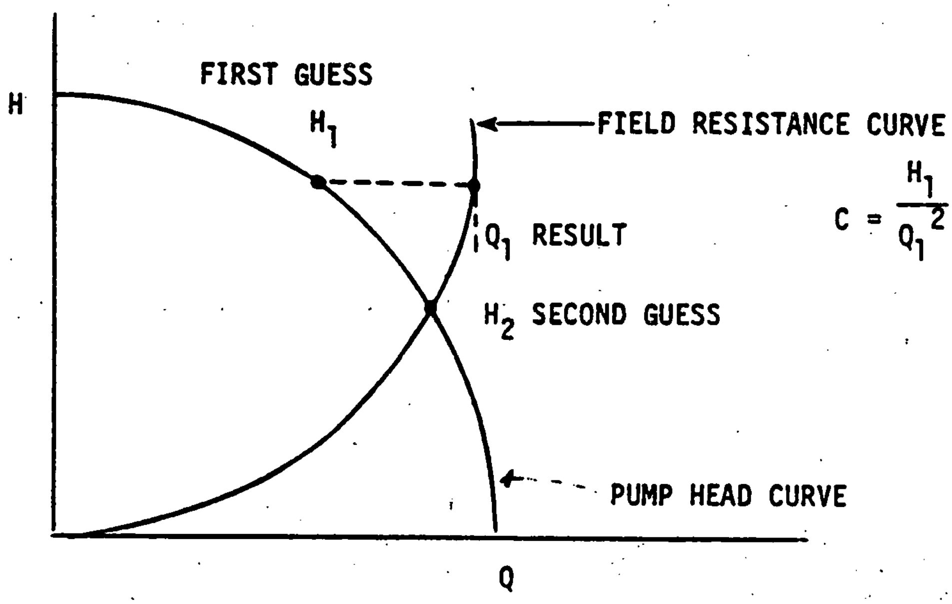
ASSUMED HEAD FLOW CURVE

For rapid convergence on hydraulic iterations it is assumed that the entire collector field resistance curve is parabolic.

$$HF = C\ QF^2$$

where the constant, C, is found from the first flow result, QF_1, that results from the guess, HF_1. The next guess for pump head, HF_2, is obtained by equating pump flow and field flow, and solving for head. This results in a new head guess:

$$HF = \frac{1.25\ f^2\ HDESIGN \times C}{C + 0.25\ \frac{H_2}{Q_2^{\ 2}}}$$



FLOW PATH TEMPERATURE CALCULATION

There is a temperature associated with each flow path in the collector field. Since there is a large volume of fluid in many of the pipes, the pipe temperature is modeled as a node that contains the heat capacity of both the fluid and the pipe. The energy conservation equation is written for the path temperature node:

$$[EPC_k + VOLPTH_k \times RHO\ (PT_k) \times SCP\ (PT_k)]\ \frac{d\ PT_k}{dt} = W_k\ (TJ_i - PT_k) \times SCP\ (PT_k)$$

where:

EPC_k = Total pipe heat capacity for k

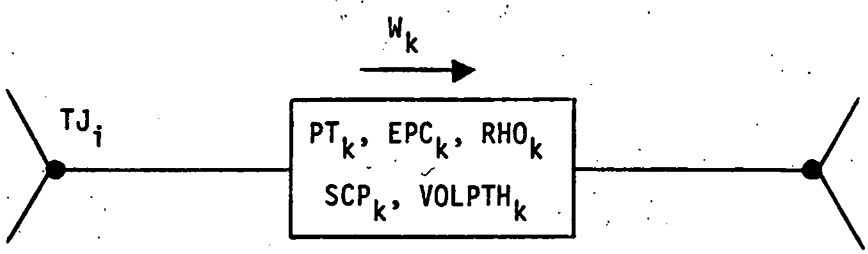
RHO = Fluid density as a function of path temperature in path k, PT_k

SCP = Fluid heat capacity as a function of path temperature in path k, PT_k

$VOLPTH_k$ = Fluid volume in path k

W_k = Flow in path k

TJ_i = Temperature of junction upstream of path k (downstream for negative W_k)

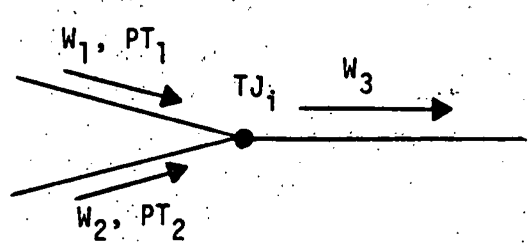


The equation is solved for $\frac{d\,PT_k}{dt}$ and TAF solves for PT.

The junction temperature is solved by taking an instantaneous energy balance of the flows entering the junction.

$$TJ_i = \frac{\sum_j W_j PT_j}{\sum_j W_j}$$

where j is all flow paths flowing <u>into</u> the junction. The equation can be written in this simplified form because fluid enthalpy is approximately linear with temperature over the temperature range of interest.



$$TJ_i = \frac{W_1 PT_1 + W_2 PT_2}{W_1 + W_2}$$

For flow paths that include a collector subfield, these equations are modified. The temperature of the fluid in the receivers is calculated by the receiver equations. The path temperature then represents only the piping from the exit of the collector to the junction. The field outlet temperature is used in place of upstream junction temperature to calculate the path temperature.

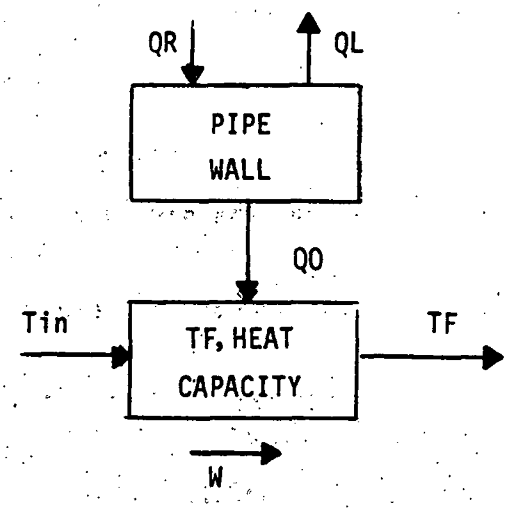
SOLAR RECEIVER CALCULATIONS

The collector subfield model is based upon a design using Accurex collectors. This assumption was made to obtain representative results for the current studies. When the collector vendor is selected, the model can easily be revised to incorporate the actual geometry.

The subfield are arranged with 28 parallel strings of collectors in each subfield. Subfield 1 has 36 modules per string; Subfield 2 has 26 modules per string; and Subfield 3 has 12 modules per string. Each subfield is modeled as a single string of nodes. There are eight, four and two nodes in Subfields 1, 2 and 3, respectively. The model is flexible in that the number of nodes in a string and the number of strings in a subfield can be changed relatively easily. The total number of nodes may be increased as required.

Each node in the subfield represents the receiver for one module width and is an incremental length (i.e., the properties are in terms of X per meter). When multiplied by the number of strings and a length, the node represents a finite part of the subfield.

The model of a receiver node is shown in the following diagram.



The model consists basically of a pipe wall temperature solution point that receives net solar insolation, QR, loses heat to ambient, QL, and transfers heat to the heat transfer oil, QO, and a fluid node that has a volume filled with oil that receives heat from the pipe wall and gains or loses energy by mass transport down the pipe.

The receiver model incorporates several assumptions. It is assumed that axial conduction of heat along the length of the pipe is negligible. It is assumed that the glass envelope around the receiver can be neglected as long as its net affect on the heat transfer to the receiver tube is correctly accounted for. The main reason for this assumption is that the glass temperature variation is relatively small during normal collector operation. It is also assumed that the emissivity and absorbtivity of the pipe surface are independent of pipe wall temperature. It is assumed that the conduction and convection heat losses from the receiver are a linear function of the pipe wall to ambient temperature difference. Node temperature is calculated using a mixing tank model and thus represents the outlet temperature of the pipe section. Heat losses are based on the average between the node temperature (which represents the outlet) and the node inlet temperature.

The net heat received from insolation for node i, QR_i, is calculated from:

$$QR_i = QNIP \times TOD \times ANGLE \times Q_i \times WDMOD \times OC$$

where:

QNIP = Maximum value of normal incident radiation

TOD = Multiplier that varies through the day to reflect the changing incidence

ANGLE = Multiplier that depends on the angle between the collector normal and the sun

Q_i = Multiplier that can be varied for different nodes to simulate partial or varying cloud cover or defocusing a portion of a field

WDMOD = Aperture width of a collector module

OC = Optical constant for reflector type; ratio between insolation incident on the collector to that incident on the receiver tube

The heat losses are divided between convective, QL1, and radiative losses, QL4.

$$QL = QL1 + QL4$$

The convective losses are calculated to match the manufacturers performance data. The constant, C1, is fit to that data after the other parameters have been calculated. The convective heat loss term is proportional to the wall to ambient temperature difference for node i. The loss is calculated on a per unit length basis and for a single module width.

$$QL1_i = C1 \left(TW_i - TA\right)$$

The radiative loss term, QL4, is calculated using a typical emissivity for black chrome of 0.12. A view factor of 1.0 is assumed and the surrounding temperature is assumed to be ambient (these assumptions are not quite correct, but they lead to small and acceptable errors at this stage of analysis).

$$QL4_i = 0.12 \times STBOLT \times APG \left[\left(TW_i + 273.15\right)^4 - (TA + 273.15)^4\right]$$

where:

STBOLT = Stefan-Boltzmann constant

APG = Outer circumferential surface area of the pipe

TW = Effective wall temperature of the pipe that is the average wall temperature

TA = Ambient temperature

Heat transfer from the pipe to the oil is calculated using the fluid film temperature drop. The temperature drop through the pipe wall is on the order of 2.0°C and is therefore neglected as it only affects the heat loss terms. The heat transfer coefficient is based upon a vendor supplied value of 1.629 kW/m^2-°C at a flow of 0.2016 kg/s. This value is assumed to vary as the 0.8 power of the flow rate per the Dittus-Boelter equation with an arbitrary minimum of 10 percent of the reference values. This relation will be improved for future analysis.

$$UARF = 1.629 \frac{kW}{m^2\text{-}°C}$$

$$WRF = 0.2016 \frac{kg}{sec}$$

$$UA_i = 0.9 \left(\frac{W_i}{WRF}\right)^{0.8} + 0.1 \times UARF$$

Finally:

$$QO_i = UA_i \times AREA_i \times \left(TW_i - TF_i\right)$$

Preliminary studies were performed with the pipe node temperature being the result of a differential equation solution involving the pipe heat capacity. It became quickly apparent that the time constant of conduction of heat from the pipe wall to the fluid was an order of magnitude less than that of fluid transport through a fluid axial node. Therefore, after some confirmatory studies reported in DRM: DA-0568 dated September 11, 1978, the pipe wall node was eliminated and its heat capacity combined with that of the fluid.

The wall temperature was obtained by setting the sum of the heat flows into and out of the pipe wall to zero

$$QR - QL4 - QL1 - QO = 0$$

The solution of the preceeding heat balance equation for TW_i is complicated by the fourth order term due to radiation heat losses. Since TW does not change rapidly and since QL4 is a relatively small term, the radiation heat loss term is approximated using the derivative of the loss term with respect to TW evaluated at the previous time step.

$$QL4(TW) = QL4\ (TWOLD) + \left.\frac{d\ QL4}{d\ TW}\right|_{TWOLD} (TW - TWOLD)$$

The resulting linear equation is then solved for TW. Then QO is obtained from knowledge of TW and solution for TF can proceed.

The conservation of energy equation is written for the fluid node incorporating the pipe heat capacity, CPP.

$$(CPP + RHOO \times CPO \times VOLO) \frac{d\ TF_i}{dt} = QO + \frac{W_i \times COP \left(T_{in} - TF_i\right)}{ALONG}$$

where:

CPP = Heat capacity of the pipe

RHOO = Density of oil

CPO = Specific heat capacity of oil

VOLO = Volume of oil in pipe node

ALONG = Length of pipe node

(Note: CPP and VOLO are on a "per unit length" basis)

This equation neglects the change in mass inventory in the fluid due to changes in density so the mass flow in equals the mass flow out. This is judged to be a reasonable assumption.

HYDRAULIC SYSTEMS DESIGN

It is important to design proper hydraulic resistances in the bypass flow paths to allow the control valves to operate in a reasonable range of valve positions. Additional fixed resistance is required in the flow paths that are parallel with the collector subfields to approximately match the relatively large pressure drop through the subfields.

The architect-engineer, Heery & Heery, provided preliminary estimates of hydraulic parameters for the main flow path through the field; paths two through nine. Characteristics of the collector subfields were obtained from vendor data. The pressure drop term for the collectors was considered to be entirely frictional pressure drop; shock loss pressure drop was assumed to be negligible. Additional affects due to flexible hoses, connectors or isolation valves were neglected. The equivalent k-factor for the first subfield is 725 based upon the actual receiver flow area.

The flow rate is determined by the flows in the bypass paths,

$$W_5 = W_3 + W_{12} - W_{11} \qquad \text{Eqn B}$$

The temperature at the inlet to field 2, TJ_6, is approximated by an energy balance as

$$W_5 TJ_6 = (W_3 - W_{11}) PT_4 + W_{12} PT_{12} \qquad \text{Eqn C}$$

Equations A and C are solved for TJ_6 and set equal to each other, also W_5 is eliminated using equation B.

Hydraulic studies were conducted by extracting the hydraulic solution subroutine from the main program and running this as a separate program. Various flow conditions were evaluated and valve and pipe k-factors were modified to obtain these flowrates. Then the range of k-factors required to satisfy the various flow conditions in a particular path was found and these factors were entered into the main program.

SOLAR COLLECTOR FIELD CONTROLLER

Subfield #1

The steady state temperature rise through subfield #1 can be approximated to a first order in the normal operating range as

$$\Delta T = \frac{792°C/kg/sec \times Q}{W_3}$$

where:

Q is fraction of maximum insolation (0.806 kW/m^2)

W is total subfield flow rate in kg/sec

Assuming that Q is specified and the desired outlet temperature is 302° (575°F), the required flow can be calculated (use Q = 1.0 for now)

$$W_3 = \frac{792}{302 - TJ_4}$$

The controller for valve V1 will control to this flow rate.

Subfield #2

Similarly, the steady state temperature rise in subfield #2 is approximated as

$$T = \frac{572\,Q}{W_5}$$

Thus, for Q = 1.0 and for a desired outlet temperature of 302°C, the desired flow rate is

$$W_5 = \frac{572}{302 - TJ_6} \qquad \text{Eqn A}$$

$$302 - \frac{572}{W_3 + W_{12} - W_{11}} = \frac{(W_3 - W_{11})\,PT_4 + W_{12}\,PT_{12}}{W_3 + W_{12} - W_{11}} \qquad \text{Eqn D}$$

This is an equation in the two unknows W_{11} and W_{12}. The further relation is added that the inlet temperature should be the maximum attainable without violating equation D with both W_{11} and W_{12} being positive or zero.

By examination of equations C and D it is determined that this relation is satisfied when only one of W_{11} and W_{12} is positive and the other is zero.

If W_{12} is zero, equation D reduces to

$$W_{11} = W_3 - \frac{572}{302 - PT_4} \qquad \text{Eqn E}$$

If W_{11} is zero, equation D reduces to:

$$W_{12} = \frac{572 - W_3 (302 - PT_4)}{302 - PT_{12}} \qquad \text{Eqn F}$$

It turns out that both W_{11} and W_{12} are zero at

$$W_3 (302 - PT_4) - 572 = 0 \qquad \text{Eqn G}$$

If equation G is greater than zero, W_{11} is greater than zero per equation E and W_{12} is less than zero per equation F so W_{12} is set to zero. The inverse of this also applies.

Thus the equations E and F provide desired values for W_{11} and W_{12} which are limited to positive values or zero.

Subfield #3

The desired flows for subfield #3 are determined in the same manner as for subfield #2. The temperature rise is

$$\Delta T = \frac{264\,Q}{W_7}$$

The resulting relations for W_{13} and W_{14} are

$$W_{13} = W_5 - \frac{264}{302 - PT_6}$$

$$W_{14} = \frac{264 - W_5 (302 - PT_6)}{302 - PT_{14}}$$

Recirculation Valves V6, V7, and V8

These are two position valves. In position 0 the fluid is sent to the hot tank. In position 1 the fluid is sent to the recirculation line or to the intermediate or cold tank.

It is assumed (arbitrarily at this time) that above 265°C (509°F) the fluid is sent to the hot tank and below 255°C (491°F) the fluid is sent to the recirculation path. Between these temperatures the valve position does not change.

Intermediate and Cold Temperature Tanks, V9 and V10

These valves are inactive in the shut position at present but will be programmed with hysteresis as Valves 6, 7, and 8.

Valve Positioning Model

The modulating control valves in the collector field, valves V1 through V5 on Figure 3.6-84 are to control flow in the paths in which the valves reside. The flow is determined from the valve position and the resulting valve K-factor and the system hydraulics. The input to the valve position controller is the desired flow and the output is valve position. For the current analysis, no attempt was made to develop a realistic model of the valve controller; the objective was to model a stable field controller. Future analysis will be conducted to determine the characteristics of an actual valve position controller. This analysis should consider other effects such as fluid inertia which are neglected in the current model. The objective of the current model is to demonstrate the acceptability of collector field temperature control. The effects of valve positioning dynamics are so much faster than temperature change dynamics as not to affect the temperature transients. Therefore, the valve positioning dynamics are not discussed further.

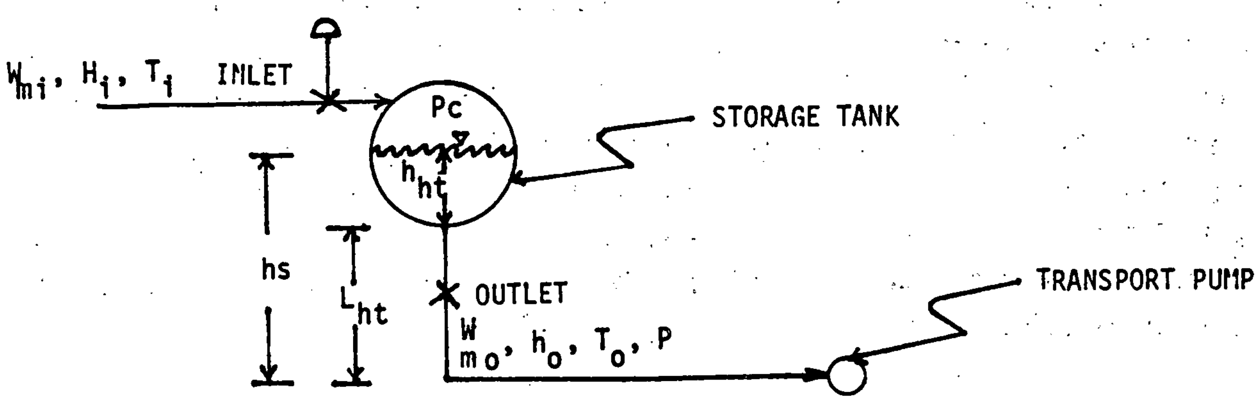
3.6.9.2 THERMAL STORAGE SUBSYSTEM

The thermal storage subsystem provides two basic functions. First, the subsystem transfers the thermal energy collected in the solar collector field to the power conversion capability of Sun 21 oil.

The following equations define the mass storage and energy inventory of mass storage tanks as well as tank outlet conditions.

HIGH TEMPERATURE TANK

- Assumes all fluid from solar field and auxiliary heater charge storage tank
- No heat loss in piping
- Tank heat loss - fraction of total available heat
- No recirculation flow
- Incompressible flow
- Pipe hydraulic losses (form and friction) proportional to flow square
- Constant cover gas pressure
- Tanks cylindrical (vertical)
- Discharge valve at bottom of tank
- Assume perfectly mixed fluid



Mass Balance

$$\frac{d}{dt} M_{ht} = (W_{mi} - W_{mo})$$

where:

M_{ht} = Mass of oil in high storage tank (lb)

W_{mi} = Mass flow into tank (lb/sec)

W_{mo} = Mass flow out of tank (lb/sec)

$$\frac{d\,H_{ht}}{dt} = \frac{\left(\frac{W_{mi}}{\rho_{hi}} - \frac{W_{mo}}{\rho_{ho}}\right)}{A_{ht}}$$

where:

A_{ht} = Cross section area of tank = $f(H_{ht})$

ρ_{hi} = Density of oil (lb/ft^3) in

ρ_{ho} = Density of oil (lb/ft^3) out

H_{ht} = Tank Liquid Level (ft)

Energy Balance

$$\frac{dE_t}{dt} = M_i H_i - M_o H_o - q_{loss}$$

where:

E_t = Stored energy in Tank (Btu/sec)

H_i = Enthalpy of fluid into tank (Btu/sec)

H_o = Enthalpy of fluid out of tank (Btu/lb)

Tank Outlet Pressure

$$P_{ht} = \frac{\rho \cdot h_s}{144} + P_c$$

where:

P_c = Nitrogen cover gas pressure (psia)

h_s = H_{ht} + L_{ht} elevation

ρ = Oil density (lb/ft^3)

Intermediate tank and low temperature storage tanks are defined with similar equations.

Nomenclature:

ht = High temperature tank

mt = Intermediate temperature tank

lt = Low temperature tank

Total Oil Flow

$$\frac{gA}{L}\frac{d\,W_{sfo}}{dt} = P_{sfo} - P_{sfv} - K\,W_{sfo}^2 + \Sigma\rho_i\,\Delta h$$

where:

$\frac{gA}{L}$ = Lumped fluid inheritance coefficient

$= g\Sigma\,\frac{A_i}{L_i}$ (where i is the discrete nodal pipe areas and lengths dependent upon flow path)

K = Lumped pressure drop coefficient

= Sum of friction, form and value loss factors

$\Sigma\rho_i\Delta h_i$ = Static head due to elevation changes

$K = K_1 + K_2 + K_3 + K_4$ = Sum of equivalent pipe loop losses and value loss coefficients

Pump Exit Pressure

$$P_{sfo} = P_{sfi} + \Delta P \text{ Pump}$$

$$\Delta P \text{ Pump} = \text{Pump Head} = H_d = AN^2 - BW_{sfo}^2$$

A and B Pump Performance Coefficient

where:

A = Shut-off head/design head = $\frac{HDC}{HD}$

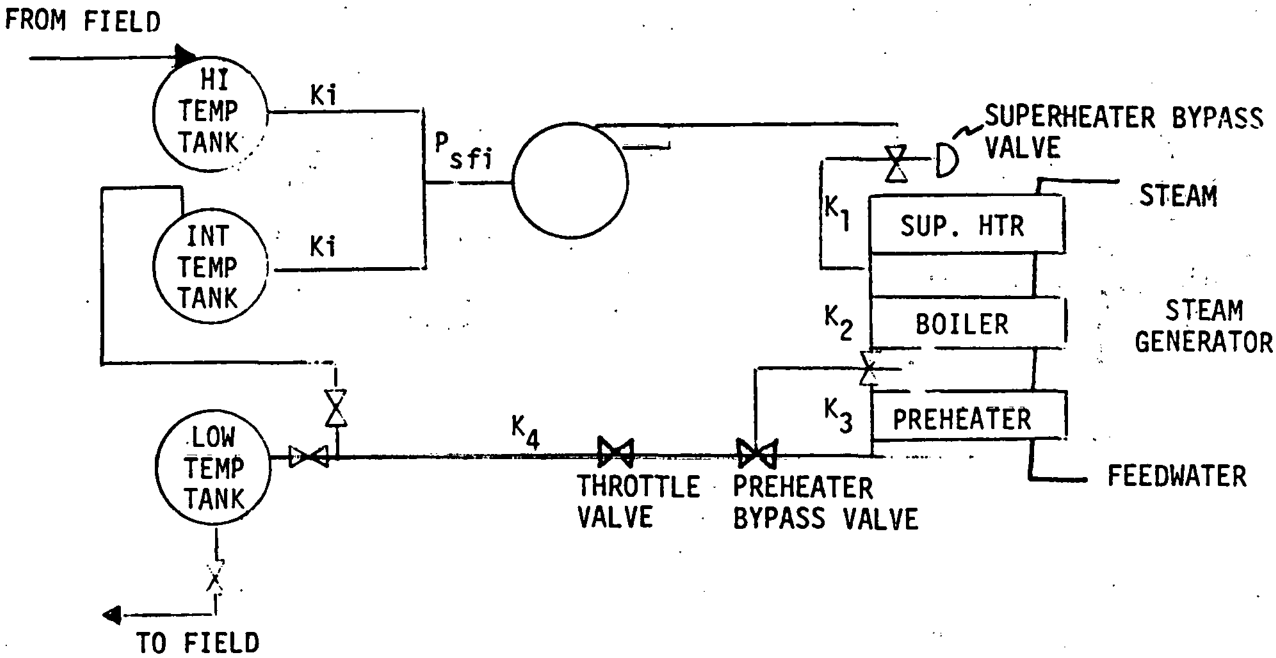
$B = A - 1 = \frac{HDC - HD}{HD}$

N = Pump Speed = Constant

Pump Suction Pressure

$$P_{sfi} = P_{sfi} - P_{sb} - K_i\,W_{sfo}^2$$

Ki Valve and Line Loss Coefficient

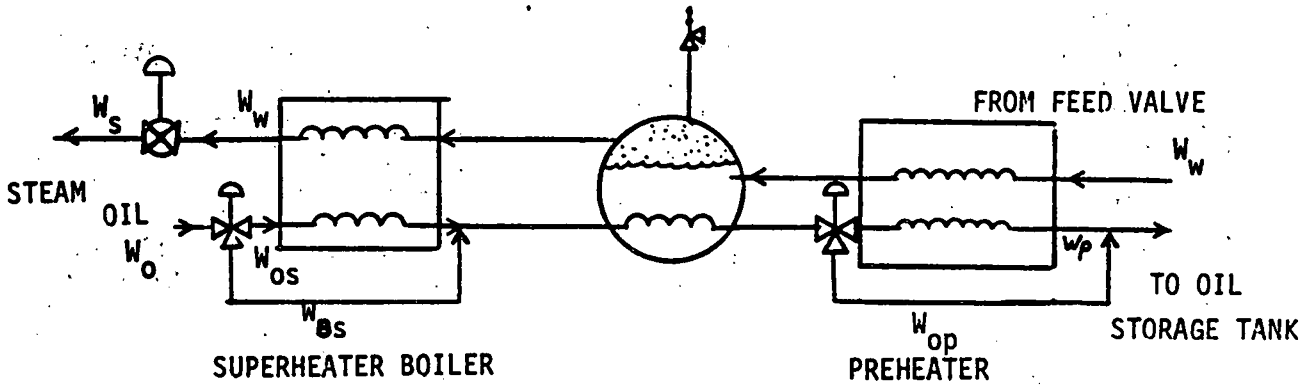


3.6.9.3 POWER CONVERSION SUBSYSTEM

As shown in the model schematic below, the power conversion subsystem converts the thermal energy collected and stored in the thermal storage subsystem into useful electrical energy, into process steam or hot water that can be utilized for space heating and cooling, and domestic hot water for the Fort Hood complex. The power conversion model subsystem is composed of the following components: preheater, boiler, superheater, high pressure turbine, low pressure turbine, condenser, condensate pump, deaerator, boiler feed pump and feedwater heater.

STEAM GENERATOR

- Includes preheater, boiler and superheater
- Assumes single-phase flow except in boiler and deaerator
- Neglect fluid dynamics in superheater steam region
- As a first estimate two steam/water nodes and two oil nodes per superheater and preheater is assumed adequate for heat transfer calculations
- Neglect tube wall temperature, assume linear Δt across wall



<u>Preheater</u>

Flow - Oil Side:

$$W_p = 20.79\ (VPRE)$$

Where:

VPRE = Position of Preheater Bypass Valve

Temperature - Oil Side:

To_1 = oil side inlet (from drum exit) = TB3

TRET = oil to storage = $(W_p To_3 + W_{op}\ To_1)/Wo$

$$MC_{po} \frac{dTo_2}{dt} = WpCp_2\ (To_1 - To_2) - UA_{12}\left(\frac{To_1 + To_2}{2} - \left(\frac{Tw_1 + Tw_2}{2}\right)\right)$$

$$MC_{po} \frac{dTo_3}{dt} = WpCp_3\ (To_2 - To_3) - UA_{23}\left(\frac{To_2 + To_3}{2} - \left(\frac{Tw_2 + Tw_3}{2}\right)\right)$$

Temperature — Water Side:

Tw_3 = Feedwater Temperature

$$MC_{pw}\ \frac{dTw_1}{dt} = W_w\ C_{pw}\ (TW_2)\ (Tw_2 - Tw_1) + UA_{12}\ \frac{To_1 + To_2}{2} - \frac{Tw_1 + Tw_2}{2}$$

$$MC_{pw}\ \frac{dTw_2}{dt} = W_w C_{pw}\ (TW_3)\ (Tw_3 - Tw_2) + UA_{23}\ \frac{To_2 + To_3}{2} - \frac{Tw_2 + Tw_3}{2}$$

Node Definition:

Oil i = O_i (i = 1, 2, 3 inlet to exit)

Water i = W_i (i = 1, 2, 3 exit to inlet)

UA_{12} = Overall heat transfer coefficient

UA_{23} = Overall heat transfer coefficient

$UA_{12} = UA_{23} = UAP\ (W_p)^{0.8}$

UAP = Heat transfer coefficient of oil

MC_{po} = Effective heat conductance (oil side)

MC_{pw} = Effective heat conductance (water side)

C_{pw} = Specific heat of water

C_{po} = Specific heat of oil

Cp_2, Cp_3 = Specific heat of oil

$Cp_2 = Cpo\ (To_2)$

$Cp_3 = Cpo\ (To_3)$

Ww = Feedwater flow (lb/sec)

Pw_3 = Feedwater pressure

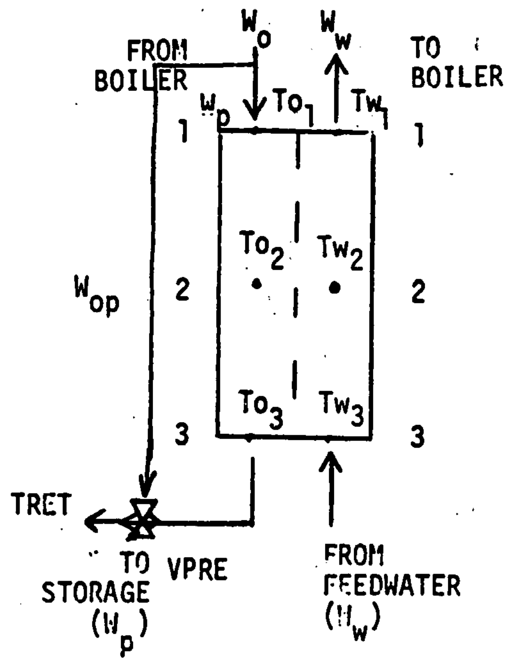
$Pw_1 = Pw_3 - K_w\ W_w^{\ 2}$

$Po_3 = Po_1 - KoWo^2$

Wo = Heat transport oil flow rate

Ko = Effective pressure loss coefficient (oil side)

Kw = Effective pressure loss coefficient (water side)



PREHEATER NODAL DIAGRAM

Boiler

Steam drum energy valance assume constant volume.

Volume:

$$V_{Drum} = MuaV_L + Mvap\ Vs = Constant$$

Mass in Drum:

$$M_{DR} = M_{liq} + M_{vap}$$

where:

$W_s = \dot{M}_{vap}$ (Steam flow)

$W_w = \dot{M}_{liq}$ (Feed flow)

V_L = Water specific volume

V_s = Steam specific volume

Energy Balance (Water Side):

$$\frac{d}{dt} E_{dR} = W_w Hw - W_s H_G + QOW$$

$$\frac{d}{dt} M_{DR} = W_w - W_s$$

$$Q_{fi} \cong \sum_{i=1}^{n} UA \ \Delta T$$

$$Q1 = UAB1 \left(\frac{Tb1 + Tb2}{2} - Tsat\right)$$

$$Q2 = UAB2 \left(\frac{Tb2 + Tb3}{2} - \frac{Tsat + Twl}{2}\right)$$

$$QOW = Q1 + Q2 \quad MC_p \frac{d}{dt} TB_2 = WoC_p (Tb_1 - Tb_2) - UAB_1 \frac{Tb_1 + Tb_2}{2} - T_{sat}$$

$$MC_p \frac{d}{dt} Tb_3 = WoC_p (Tb_2 - Tb_3) - UAB \frac{Tb_2 + Tb_3}{2} - \frac{Tsat + Twl}{2}$$

where:

$n = 2$

Q_{fi} = Heat flux (Btu/sec-ft^2)

ΔT = Average temperature difference between saturated water and oil in tubes

Tb_1 = Exit from superheater = W_{BS} (Tsol) + Wos (Tso3)/Wo

$UA_{12}^{B1} = UA_{23}^{B2}$ = Overall heat transfer coefficient (Btu/°F-sec) = $UAB\,(wo)^{0.8}$

MC_p = Overall heat conductance coefficient (Btu/°F-sec)

Energy Balance (Oil Side):

$$Hw_1 = 0.94 + Tw_1$$

$$V_{DR} = VDRUM/_{MDR}$$

$$U_{DR} = E_{DR}/M_{DR}$$

Where:

U_{DR} = Internal Energy (BTU/lb)

Drum Pressure: (from ASME Steam Tables):

$$PDR = PSAT = f\,(UDR)$$

for UDR > 392.79

$$PDR = 300 + (U_{DR} - 392.8) / K\,PDR$$

for 298.08 < UDR < 392.79

$$PDR = 2.111\,(UDR) - 529.2$$

for UDR < 298.08

$$PDR = 1.0384\,(UDR) - 209.52$$

Where:

kPDR =

Drum Temperature: (from ASME Steam Tables)

$$TDR = T\,sat = f\,(P\,sat)$$

Steam Enthalpy: (from ASME Steam Tables)

$$H_G = f\,(P\,sat)$$

for PDR > 100

$$H_G = 1168.36 + 1.8833\,(PDR)^{.5}$$

for PDR < 100

$$H_G = 1164.09 + 0.2314\,(PDR)$$

Liquid Enthalpy:

$$H_{DRUM} = U_{DR} + P_{DR}\,(V_{DR})\,0.185$$

Superheater

Oil Side:

$$MC_{pso}\frac{dTso_2}{dt} = W_{os}C_p(Tso_1 - Tso_2) - UAS_1\left(\frac{Tso_2 + Tso_1}{2} - \frac{(Tsw_2 + Tsw_1)}{2}\right)$$

$$MC_{pso}\frac{dTso_3}{dt} = W_{os}C_p(Tso_2 - Tso_3) - UAS_2\left(\frac{Tso_3 + Tso_2}{2} - \frac{(Tsw_3 + Tsw_2)}{2}\right)$$

where:

MC_{pso} = Overall heat conductance coefficient (Btu/°F-sec)

UAS_2 = UAS_2 = Overall heat transfer coefficient (Btu/°F-sec) = $UAS\,(Wos)^{0.8}$

Cp = Specific heat of oil (Btu/lb-°F)

Steam Side:

$$MC_{ps}\frac{dTsw_1}{dt} = W_sC_{ps}\,(Tsw_2 - Tsw_1) + UAS_1\left(\frac{Tso_1 + Tso_2}{2} - \frac{(Tsw_2 + Tsw_1)}{2}\right)$$

$$MC_{ps}\frac{dTsw_2}{dt} = W_sC_{ps}\,(Tsw_3 - Tsw_2) + UAS_2\,\frac{Tso_2 + Tso_3}{2} - \frac{(Tsw_3 + Tsw_2)}{2}$$

where:

MC_{ps} = Overall heat conductance (Btu/°F-sec)

C_{ps} = Specific heat of steam (Btu/lb-°F)

Oil Side Pressure Drop:

$$\Delta P_{so} = K_{so}W_o^{\,2}$$

where:

K_{so} = Pressure loss coefficient (oil)

K_{sw} = Pressure loss coefficient (steam)

Water Side:

$$\Delta P_{sw} = K_{sw} W_s^{\,2}$$

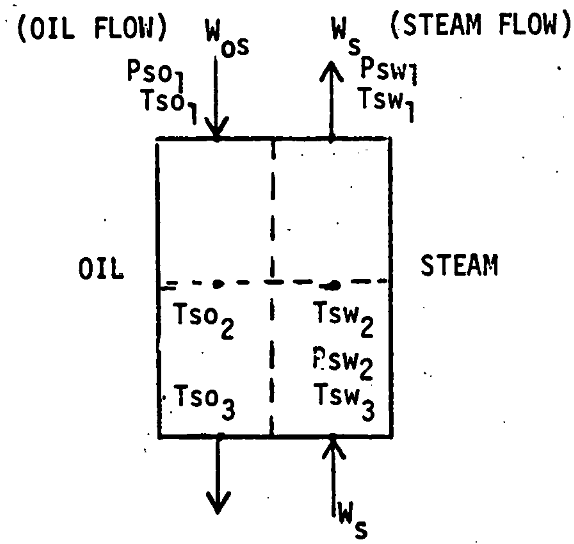
$$Psw2 = Psw3 - 0.5\ (Ksw)\ (Ws)^2$$

$$Psw_1 = Psw2 - 0.5\ (Ksw)\ (Ws)^2$$

Nomenclature:

Tso_1 = Oil Temperature

Tsw_1 = Steam Temperature



SUPERHEATER NODAL DIAGRAM

STEAM TURBINE

Equations apply for high and low pressure turbines.

Turbine Flow:

$$W_{ti} = K_v S_v \frac{P_{ti}}{\sqrt{T_{ti}}}$$

where:

$S_v = \frac{n}{N}$ Ratio of valves open/total number of valves

K_v = Flow coefficient

T_{ti} = Tsw_1 + 460°F

Exit Pressure:

$$P_{to} = K_{to} W_{ti}$$

Inlet Pressure:

$$P_{ti} = K_{tv} \cdot P_{so} = P_{TV}$$

where:

K_{tv} = Turbine valve flow coefficient

Power Extracted from Steam:

$$P_{wrt} = W_{ti} N_t (H_{ti} - H_{ts})$$

where:

H_{ts} = Enthalpy of isentropic expansion of inlet to turbine outlet pressure

H_{ti} = $F(Tsw_1, P_{ti})$ Turbine inlet enthalpy

Efficiency:

$$N_t = N_r N_b$$

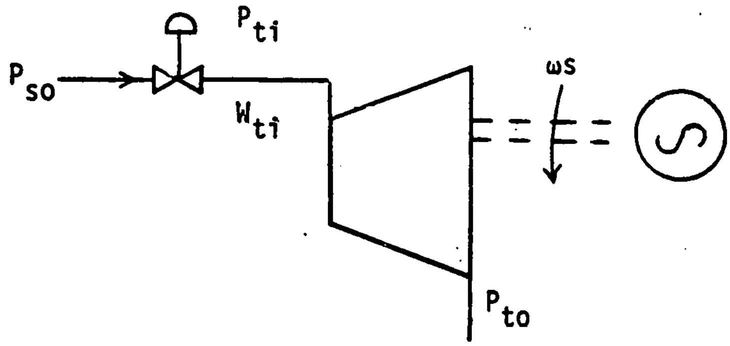
where:

N_r = 0.85 (nominal value)

N_b = Generator and mechanical losses

= $K_{tg} \cdot \omega s$ or constant

ωs = Shaft velocity



STEAM TURBINE MODEL FLOW SCHEMATIC

CONDENSER

Condenser Inlet Steam Pressure:

$$Tc_2 = T_{TE}$$

Where:

T_{TE} = Exit Steam Temperature from Low Pressure Turbine

Condenser Exit Enthalpy:

$$H_{co} = H_{ci} - UAC\ (THEACM)/W_{sc}$$

Where

H_{ci} = Inlet Steam Enthalpy

UAC = Overall Heat Transfer Coefficient

W_{sc} = Steam Flow Rate to condenser

THEACM = Log mean temperature difference

$= T_{ci} + T_{c3} - T_{c2} - T_{c4}\ /\ 2.0$

Water Side Exit Temperature:

$$MCpc \frac{dTc_4}{dt} = WcCpc\ (Tc_2 - Tc_4) + UAC\ (THEACM)$$

Where

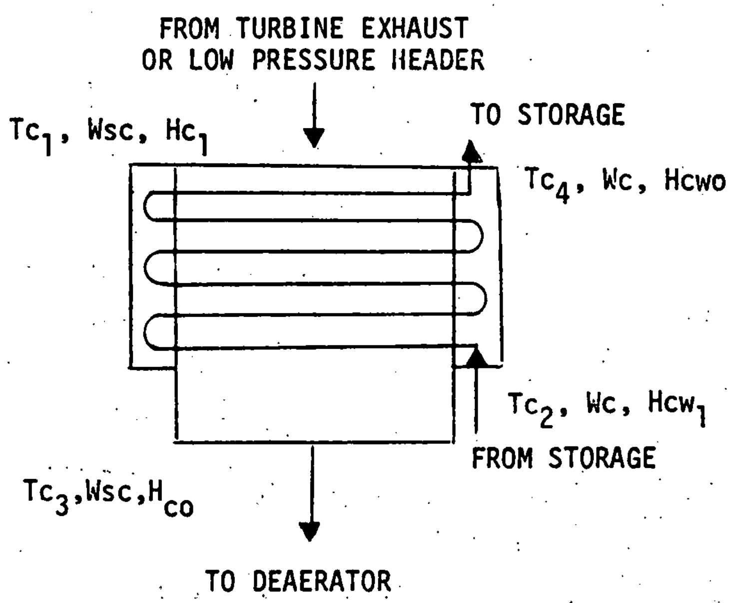
MCpc = Effective conductance coefficient

Wc = Coolant Water Flow Rate

Tc_2 = Condenser Inlet Coolant Temperature

Condensate Exit Temperature:

$$Tc_3 = 32.1 + H_{co}$$



CONDENSER MODEL FLOW SCHEMATIC

DEAERATOR

Energy Balance:

$$\frac{DE_{dea}}{dt} = Hco\ (WTLP) + Wfs\ (HCFHM) + Vsd\ (Hso)$$

Steam Flow Rate:

$$WDEA = WTLP + Wfs + Wsd$$

Where:

$$Wfs = 0.1092 (Vfs)$$
$$Wsd = 0.1028 (Vsd)$$

Enthalpy:

$$HDEA = \frac{W\ TLP\ (Hco) + Wfs\ (H_{cfhm}) + Wsd\ (Hsd)}{(W\ TLP + Wfs + Wsd)}$$

Where:

$Wsd\ (Hsd)$ = Energy entering deaerator from condenser

$Wfs\ (H_{cfhm})$ = Energy entering deaerator from condensate return unit

$W\ TLP\ (H_{co})$ = Energy entering deaerator from turbine

Ww = Feedwater flow

Temperature:

$$TDEA = 33.826 + 0.9896 (HDEA)$$

Where:

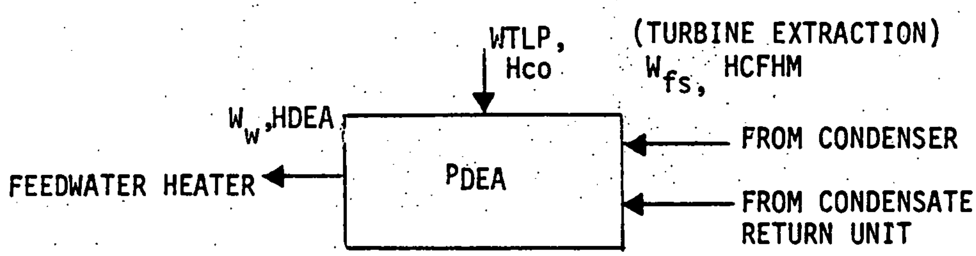
TDEA = Saturated Temperature of f (HDEA) [Steam Tables]

Pressure:

$$PDEA = 0.41275 (TDEA) - 74.091$$

Where

PDEA = f (TDEA) [Steam Tables]



DEAERATOR MODEL FLOW SCHEMATIC

FEEDWATER HEATERS

Water Side

$$MC_{pf} \frac{dT_{fo}}{dt} = W_w C_{pf}(T_{fi} - T_{fo}) + UAFH\ (\theta M)$$

where:

C_{pf} = Specific heat (Btu/lb-°F) = 1.0

ΘM = Log mean temperature difference (°F) = $\frac{T_{sf} + T_{cfm}}{2.0} - T_{fi} - T_{fo}$

MC_{pf} = Effective heat conductance (Btu/°F-sec)

Overall Heat Transfer Coefficient:

$$UAFH = f(T_{sat}, T_{sf}, \Theta M)$$

Average Film Temperature:

$$T_{sat} = T_{sf} - 0.8\ \Theta M$$

where:

T_{sat} = Saturated steam temperature

Steam Side

Condensate Exit Conditions:

$$H_{cfh} = H_{to} - \frac{(UAFM)\ \theta M}{W_{fs}}$$

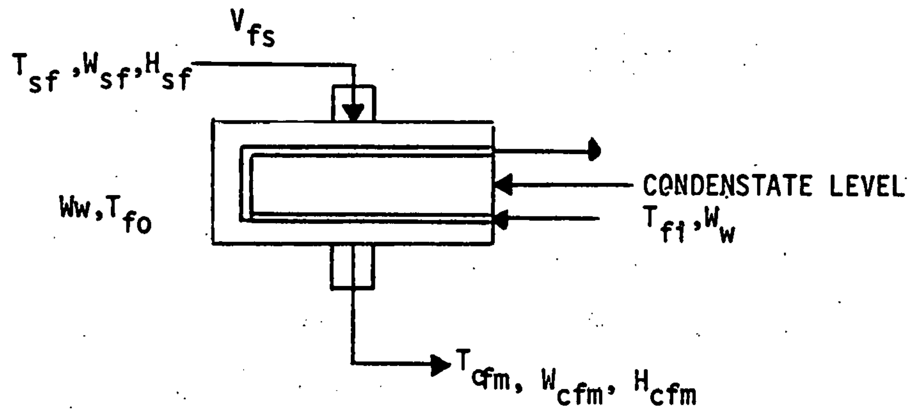
where:

$H_{to} = f(T_{sf}, P_{sf})$ Steam inlet [ASME Steam Tables]

$T_{cfh} = f(H_{cfh})$ Condensate Exit [ASME Steam Tables]

$T_{cfh} = 37.75 + 0.9729\ (H_{cfh})$

$P_{cfh} = 0.76864\ (T_{cfm}) - 164.4$



FEEDWATER HEATER MODEL FLOW SCHEMATIC

3.6.9.4 DOMESTIC HOT WATER SUBSYSTEM

The domestic hot water subsystem model is comprised of the condenser, domestic (hot) water storage tank, domestic water circulating pump, domestic water pump, associated piping, and control and isolation valves. This subsystem is connected to a city water makeup line that provides a supply of water to the tank and condenser to fulfill the domestic hot water requirements.

STORAGE WATER SIDE EXIT TEMPERATURE

$$MC_{pd} \frac{d}{dt} T_{do} = W_{dhe} C_p (T_{di} - T_{do}) - UA\Theta M$$

DOMESTIC WATER SIDE EXIT TEMPERATURE

$$MC_{pdh} \frac{d}{dt} T_{dhi} = W_{dh} C_p (T_{dhr} - T_{dhi}) + UA\Theta M$$

$$\Theta M = \left(\frac{T_{di} + T_{do}}{2}\right) - \left(\frac{T_{dhr} - T_{dhi}}{2}\right)$$

where:

ΘM = Average temperature difference (°F)

UA = Effective heat transfer coefficient (Btu/°F-sec)

MC_{pdh} = Effective heat conductance domestic water side (Btu/°F-sec)

MC_{pd} = Effective heat conductance storage water side (Btu/°F-sec)

Total Q to Domestic Hot Water:

$$Q = W_{dh} + C_p \,(T_{dhr} - T_{dhi})$$

$$T_{di} = T_{cwo} + Q_{pump}$$

where:

Q_{pump} = $W_{dhe} \cdot (H_{pi} - H_{po})$ Pump flow work

T_{cwo} = Condenser coolant water exit temperature (°F)

W_{dhe} = Storage system water flow (lb/sec)

W_{dh} = Domestic water flow (lb/sec)

DOMESTIC HOT WATER STORAGE TANK

Hot Water Storage Tank Energy:

$$\frac{d}{dt} E_{hw} = W_{hwi} H_{hwi} - W_{hwo} + H_{cwo}$$

Flow Into Tank:

$$W_{hwi} = W_{cd} - W_{cde} - W_{sp} - W_{dhe}$$

$$W_{hwo} = W_{cd} - W_{sp}$$

Tank Inlet Enthalpy:

$$H_{hwi} = F(T_{dwo})$$

Tank Exit Enthalpy:

$$H_{hwo} = E_{sh}/M_{hw}$$

$$\frac{dM_{hw}}{dt} = W_{hwi} - W_{hwo}$$

where:

W_{dhe} = Flow to domestic hot water heat exchanger

W_{sp} = Net flow to space heating

W_{cd} = Condenser coolant water flow

W_{cde} = Condenser flow to cooling tower heat exchanger

3.6.9.5 HOT/CHILLED WATER SUBSYSTEM

The chilled water cooling subsystem provides cooling (air conditioning) to the Fort Hood complex. The subsystem model is comprised of the following components: two-stage absorption chiller; hot (or chilled) water storage tank; heating (or chilled) water circulating pump; hot/chilled water storage tank; cooling water pump; cooling tower and chiller condenser pump.

COOLING TOWER

$$QH_2O = F(T_{cti}, W_{ct})$$

where:

QH_2O = Heat rejected to air

Air Flow Required in Cooling Tower:

$$W_a = \frac{QH_2O}{H_{85} - H_{wet\ bulb}}$$

Air Enthalpy Inlet to Tower:

$$H_{85} = 49.455 \text{ Btu/lb}$$

where:

H_{85} = Air exit enthalpy

Cooling Tower Exit Water Temperature:

$$T_{ct} = T_{cti} - \frac{QH_2O}{500\ W_{ct}}$$

Air Wet Bulb Temperature:

$$H_{wet\ bulb} = K_{air} \cdot (T_{air} - 78)$$

where:

T_{air} = Ambient air temperature

K_{air} = 1.125 (from properties table fit)

Cooling Tower Water Inlet Temperature:

$$T_{cti} = \frac{W_{cta} \cdot T_{cta} + W_{cte} \cdot T_{eo}}{W_{ct}}$$

where:

W_{ct} = Total cooling tower flow

$W_{ct} = W_{cta} + W_{cte}$

W_{cta} = Flow from chiller

W_{cte} = Flow from condenser/tower heat exchanger

COOLING TOWER HEAT EXCHANGER

Cooling Side Fluid Exit Temperature:

$$MC_{pe} \frac{d}{dt} T_{eo} = W_{cte} \cdot C_p \left(T_{ei} - T_{eo}\right) - UA_{ct} \Theta M$$

Condenser Side Fluid Exit Temperature:

$$MC_{pcd} \frac{d}{dt} T_{cdo} = W_{cde} \cdot C_p \left(T_{cdi} - T_{cdo}\right) + UA_{cg} \Theta M$$

where:

ΘM = Log mean temperature difference

W_{cte} = Cooling tower water flow rate

C_p = Specific heat of H_2O

MC_{pe} = Effective conductance cooling side

MC_{ped} = Effective conductance hot side

UA_{ct} = Overall heat transfer coefficient

W_{cde} = Condenser side flow rate

CHILLED/HOT WATER STORAGE TANKS

$$\frac{d}{dt} E_{ch} = W_{sti} H_{sti} - W_{sto} H_{sto} - Q_{so}$$

where:

Q_{so} = Thermal losses

Inlet Flow:

$$\left.\begin{array}{l} W_{sti} = W_{spi} - W_{spr} \\ W_{sti} = W_{chr} - W_{chi} \end{array}\right\} \begin{array}{l} \text{Heating Season} \\ \text{Cooling Season} \end{array}$$

Exit Flow:

$$\left.\begin{array}{l} W_{sto} = K_a \sqrt{P_{sto} - P_{si}} \\ W_{sto} = K_c \sqrt{P_{sto} - P_{co}} \end{array}\right\} \begin{array}{l} \text{Heating Season} \\ \text{Cooling Season} \end{array}$$

$$\left.\begin{array}{l} \quad = 0 \\ K_h = F(\ _{nh}) \\ K_c = f(\ _{nc}) \\ \quad = 0 \end{array}\right\} \begin{array}{l} \text{Cooling Season} \\ \text{Heating Season} \\ \text{Cooling Season} \\ \text{Heating Season} \end{array}$$

STORAGE TANK EXIT WATER CONDITIONS

$$H_{sto} = E_{ch}/M_{ch} \quad \text{[ASME Steam Tables]}$$

$$T_{sto} = F(H_{sto}) \quad \text{[ASME Steam Tables]}$$

Storage Tank Mass:

$$\frac{d}{dt} M_{ch} = W_{sti} - W_{sto}$$

ABSORPTION CHILLER

Required Cooling (tons):

$$Q_{avail} = Q_r \times C_{op}$$

where:

C_{op} = Coefficient performance

__Steam Rate__:

$$W_{sa} = F_1\ (Q_r) \quad \text{[from Table 3.6-12]}$$

__Condensate Temperature__:

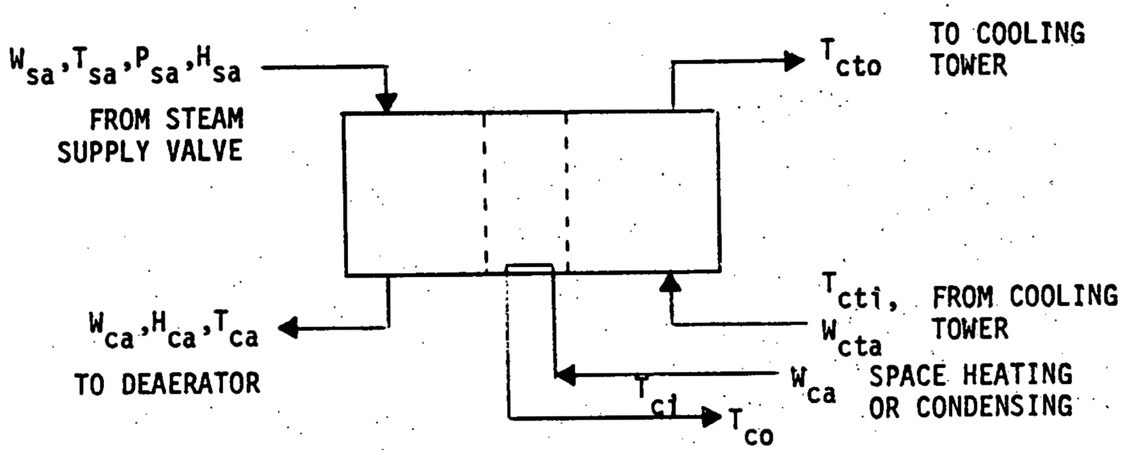
$$T_{ca} = F_2\ (Q_r) \quad \text{[from Table 3.6-13]}$$

where:

$H_{sa} = F(P_{sa}, T_{sa})$ [ASME Steam Tables)

$H_{ca} = F(P_{ca}, T_{ca})$ [ASME Steam Tables]

$$T_{cto} = T_{cti} + \frac{Q_{ct}}{W_{cta}} \cdot C_p$$



ABSORPTION CHILLER MODEL SCHEMATIC

TABLE 3.6-12

ABSORPTION CHILLER - STEAM RATE

Steam Rate (lb/hr-ton)	Load (Q_r) (ton)
11.45	174
11.50	157
11.83	139
12.15	122
12.47	104
12.78	87
13.57	70
15.15	52
17.07	38

TABLE 3.6-13

ABSORPTION CHILLER - CONDENSATE TEMPERATURE

Condensate Temperature (Btu/°F)	Load (Q_r) (ton)
182.0	174
178.4	157
174.8	139
171.2	122
167.6	104
164.0	87
160.4	70
158.0	52
156.0	38

3.6.9.6 POWER CONVERSION SUBSYSTEM CONTROLLERS

Boiler Pressure Control

The oil throttle valve in the power conversion subsystem is provided for the control of steam boiler pressure.

The control algorithm (Figure 3.6-85) developed from the preliminary step response data contained in Section 3.6.4.2.1 is a proportional-integral (P & I) type controller for the high temperature operating mode.

$$\frac{\Delta W_o}{\Delta P} = K_c \left(\frac{1}{\tau_i S} + 1 \right)$$

K_c = 2.158

τ_i = 13.787

ΔP = Pressure Error

ΔP = $P_{demand} - P_{boiler}$

W_o = oil flow rate

P_{demand} = 365 psia

S - operator variable

Superheater Oil Flow Control

Superheater oil modulating valve (Figure 3.6-86) is provided for the control of superheater exit temperature. Step response data contained in Section 3.6.4.2.1 was used to develop preliminary control algorithm.

The P & I control algorithm is as follows:

$$\frac{\Delta W_o}{\Delta T} = K_c \left(\frac{1}{\tau_i S} + 1 \right)$$

K_c = 0.0471 $\frac{lb}{^oF}$

τ_i = 8.15 sec.

ΔT = Temperature Error = $T_{demand} - T_{swi}$

S - operator variable

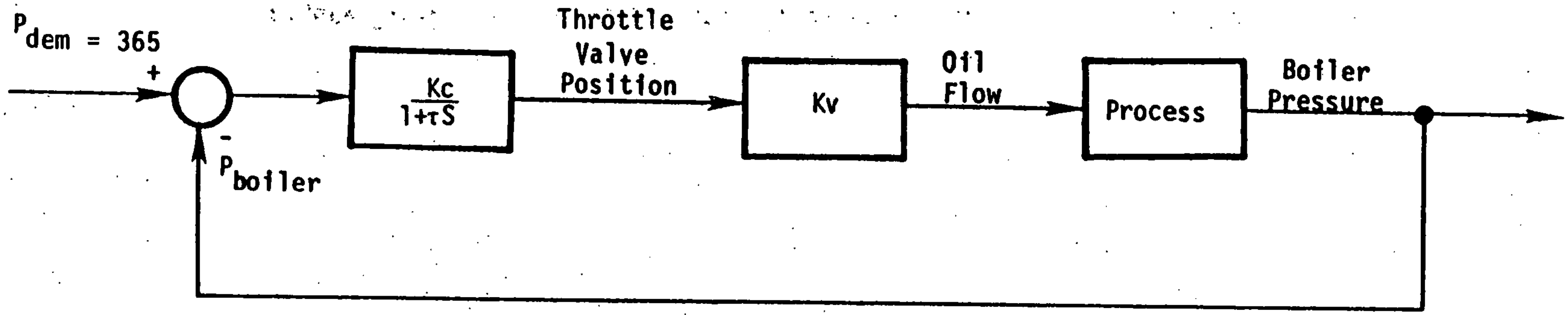


Figure 3.6-85 Power Conversion Subsystem Boiler Pressure Controller Block Diagram

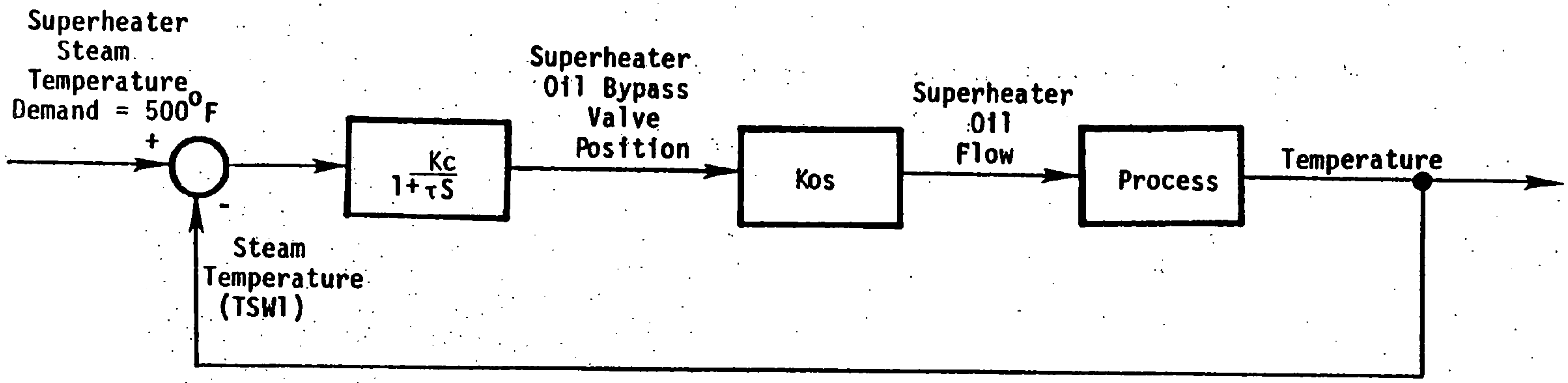


Figure 3.6-86 Superheater Steam Temperature Control Block Diagram

Preheater Exit Water Temperature Control

Preheater exit water temperature control (Figure 3.6-87) is provided to maintain boiler inlet water temperature to $\sim 5^{\circ}F$ subcooled of the boiler saturation temperature by control of the oil flow valve.

The P & I control algorithm derived from step response data for steady state control is:

$$\frac{\Delta W_0}{\Delta T_e} = K_c\left(\frac{1}{\tau S} + 1\right)$$

K_c = 0.84 lb/$^{\circ}$F

τ_i = 3.5 sec.

$\Delta T_e = T_{demand} - T_{wi}$

$T_{demand} = T_{sat} - 5^{\circ}F$

S = operator variable

High and Low Pressure Turbine Steam Hand Valve Control

The high and low pressure turbine power generation is controlled via steam flow control with use of hand valves either manually controlled or with turbine governor control.

The P & I control algorithm (Figure 3.6-88 and 3.6-89) for the turbine valve is:

$$\frac{\theta_v}{\Delta W_e} = K_c\left(\frac{1}{\tau_i S} + 1\right)$$

K_c = 0.0985 %/lb/sec

τ_i = 6.396 sec

θ_v is valve position

$\Delta W_e = W_{demand} - W_{tlp}$

S - operator variable

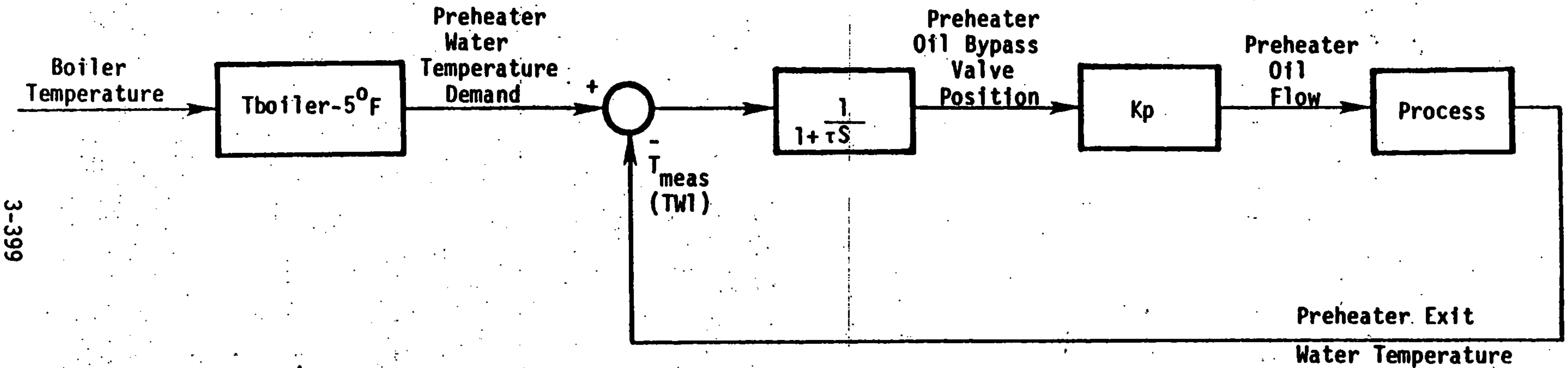


Figure 3.6- 87 Preheater Water Temperature Control Block Diagram

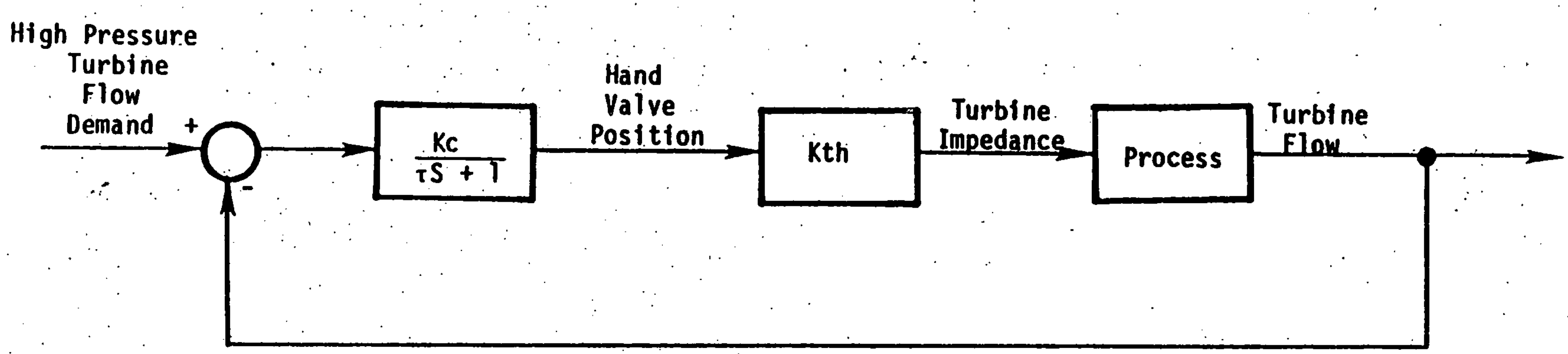


Figure 3.6-88. High Pressure Turbine Position Control Block Diagram

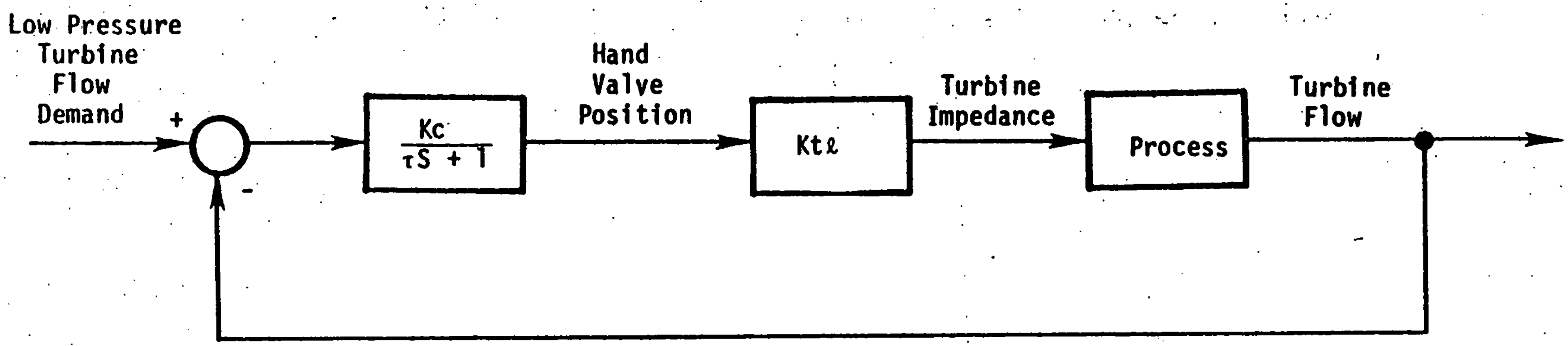


Figure 3.6-89. Low Pressure Turbine Control Block Diagram

Turbine Steam Bypass Valve

Turbine bypass valve is provided to control the pressure in the low pressure steam header. The P & I control algorithm (Figure 3.6-90) is pressure feedback and is:

$$\frac{\theta_v}{\Delta P_e} = K_c\left(\frac{1}{\tau S} + 1\right)$$

K_c = 0.573 %/psia

τ_i = 37.16 sec.

θv valve position

ΔP_e = Pto_{demand} - Pto

Pto_{demand} = 65 psia

S - operator variable

Condenser Pressure Control

Condenser pressure control is provided by throttle of the condenser coolant flow.

The control algorithm (Figure 3.6-91) is an integral type controller until further analysis can be completed.

$$\frac{W_{cc}}{\Delta P_e} = \frac{-K_c}{\tau_i S}$$

K_c = 1 psi/lb/sec.

τ_i = 10 sec.

ΔP_e = Pc_{demand} - P_e

Pc_{demand} = 4.9 psia

P_e - condensor pressure

S - operator variable

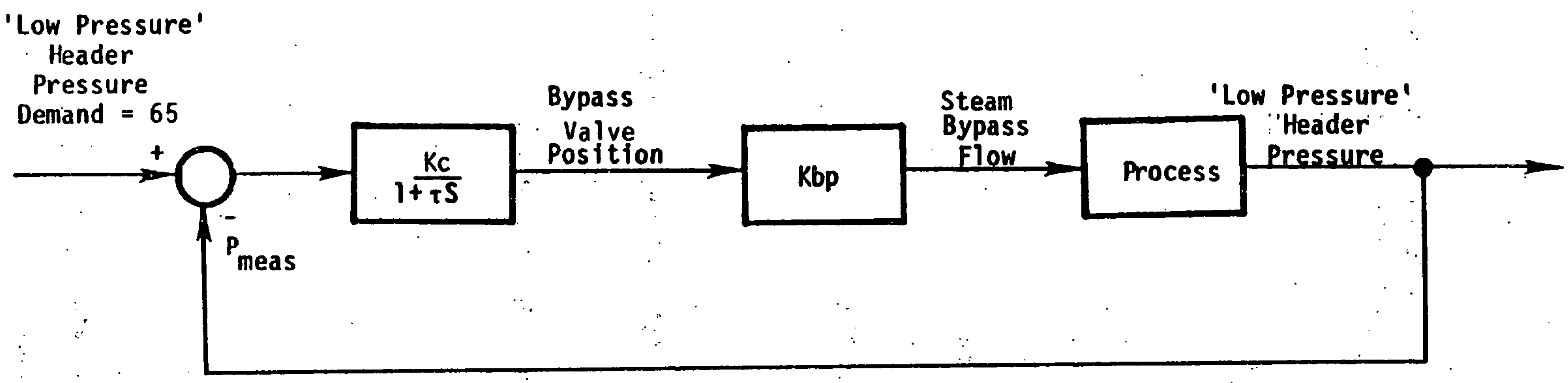


Figure 3.6-90. High Pressure Turbine Back Pressure Controller Block Diagram

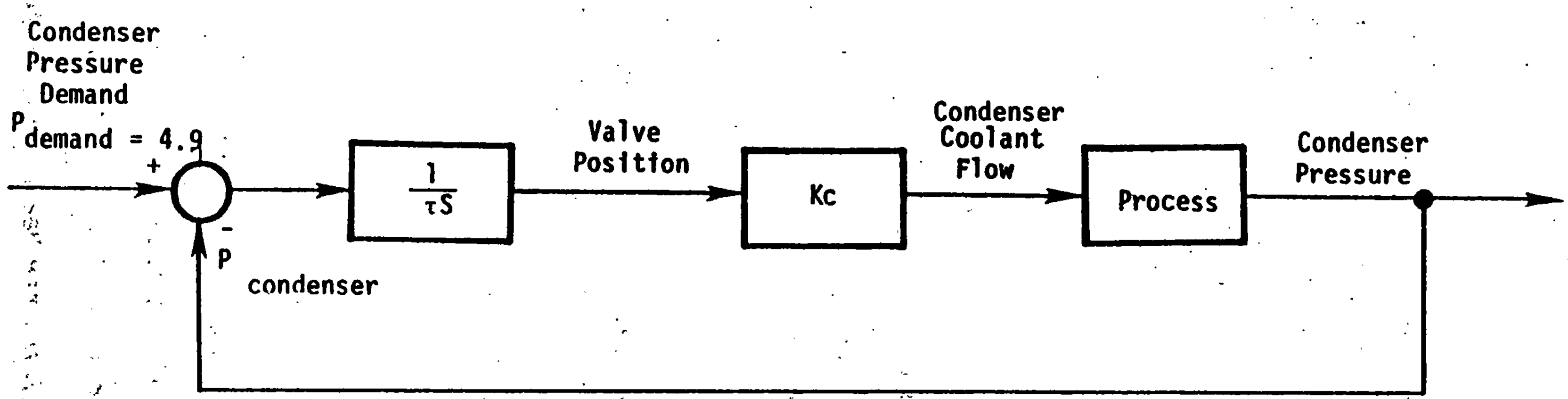


Figure 3.6-91. Condenser Pressure Controller Block Diagram

Deaerator Pressure Control

Flow control of steam flow to the deaerator is provided to maintain control of deaerator pressure and condensate temperature. The integral control algorithm (Figure 3.6-92) is preliminary until further analysis can be completed.

$$\frac{\theta_{sd}}{\Delta P_e} = \frac{1}{\tau_i S} \qquad \left(\frac{\text{lb/sec}}{\text{psia}}\right)$$

ΔP_e = P_{demand} - P_{dea}

P_{demand} = 22.0 psia

τ_i = 50 sec.

θ_{sd} valve position (% of design)

W_{sd} = K_{sd} θ_{sd} (Deaerator Steam Flow)

K_{sd} = 0.1092 lb/sec-%

S - operator variable

Feedwater Heater Temperature Control

Control of feedwater steam flow to maintain feedwater temperature is provided via control of the modulating steam valve in the low pressure header.

The integral control algorithm (Figure 3.6-93) is preliminary until further analysis is completed.

$$\frac{\theta_{sf}}{\Delta T_e} = \frac{1}{\tau_i S}$$

ΔT_e = T_{fod} - T_{fo}

T_{fod} = Temperature demand = 290.1°F

T_{fo} = Feedheater exit temperature

θ_{sf} = Steam valve position (% of design)

W_{sf} = K_{sf} θ_{sf} (Feedwater Heater Steam Flow)

K_{sf} = .1098 $\frac{\text{lb}}{\text{sec - \%}}$

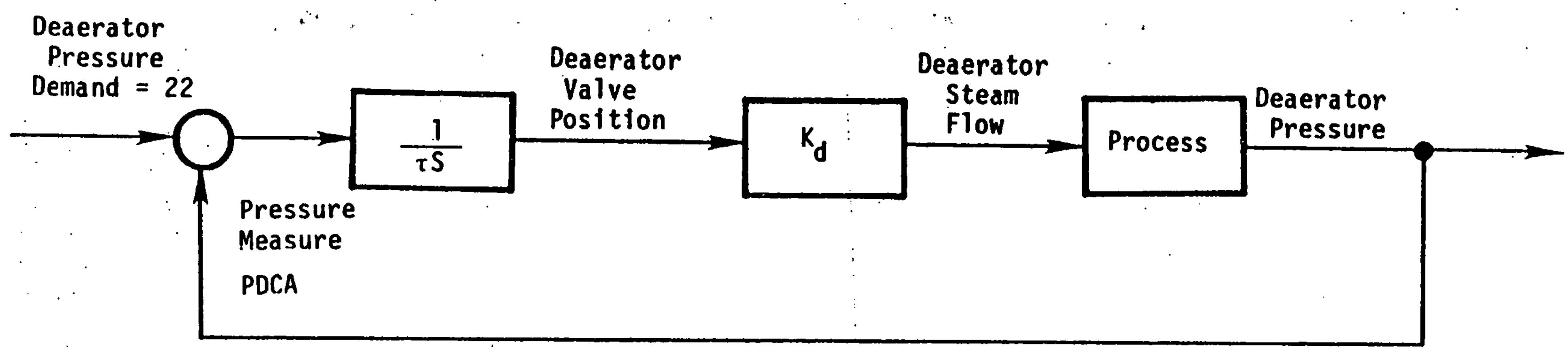


Figure 3.6-92. Deaerator Pressure Controller Block Diagram

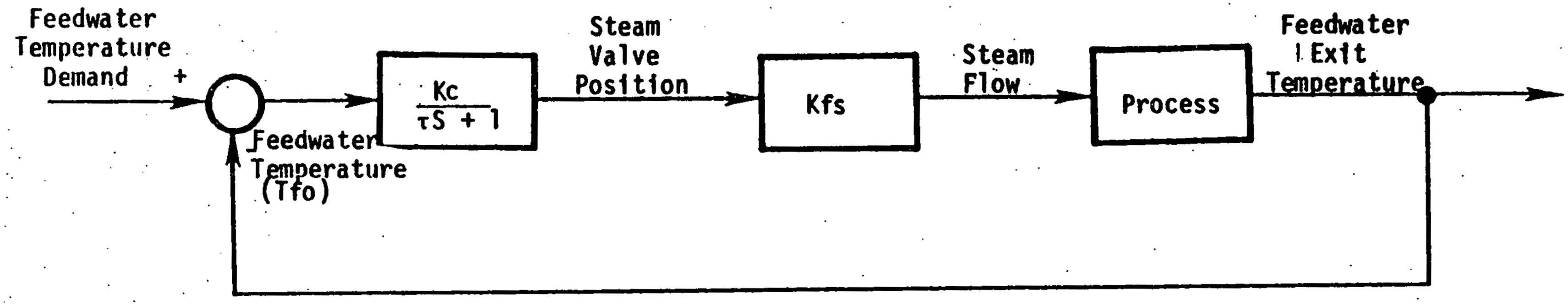


Figure 3.6-93. Feedwater Heater Temperature Control Block Diagram

Condenser Coolant Water Exit Temperature

The condenser coolant water temperature is controlled by a valve which mixes chilled water with the condenser flow, (Figure 3.6-94).

The preliminary model uses integral control of valve position.

$$\frac{\theta\ cw}{\Delta\ tc} = \frac{1}{\gamma i s}$$

$\theta\ cw$ = chilled water valve position

$\Delta\ tc$ = exit temperature error

τi = time constant of integrator

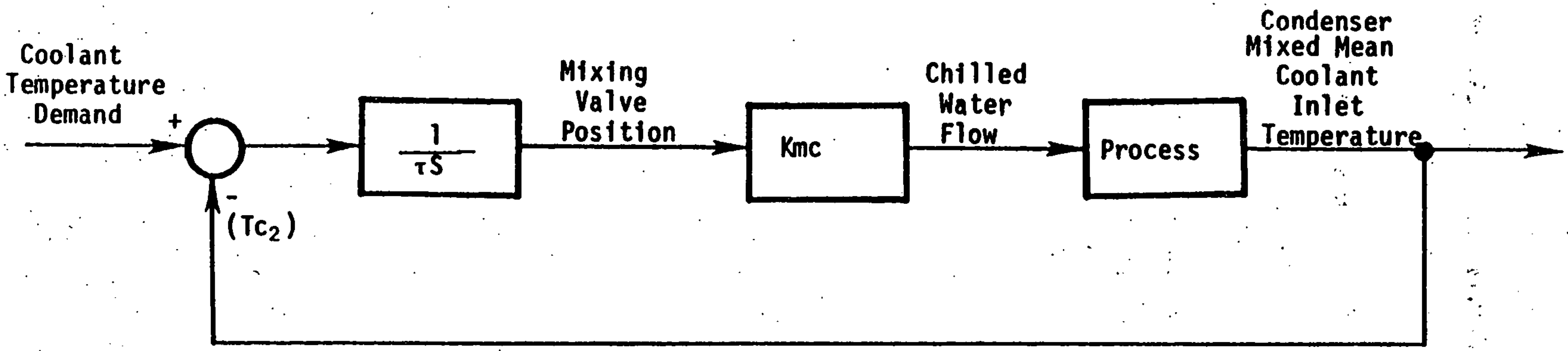


Figure 3.6-94. Condenser Coolant Water Exit Temperature Controller Block Diagram

Boiler Level Control

The feedwater flow rate is controlled via a feedwater throttle valve to maintain boiler water level.

For the present analysis the controller is assumed to lag steam flow or:

$$\frac{W_w}{W_s} = \frac{1}{1 + \tau_i S}$$

$$\tau_i = 50 \text{ sec.}$$

Table 3.6-14 summarizes the controller parameters.

TABLE 3.6-14

CONTROLLERS GAINS, TIME CONSTANTS AND VALVE COEFFICIENTS

		K_c Proportional Constant	τ_i Time Constant	K_v Valve Constant $\frac{lb/sec}{100\%}$
1.)	Superheater steam temperature	.047	81.3	20.8
2.)	Boiler pressure	2.158	13.8	20.8
3.)	Preheater water temperature	0.84	34.9	20.8
4.)	Turbine bypass valve	15.4	3.71	.1721
5.)	H.P. turbine hand valves	.063	6.4 sec	.1721
6.)	L.P. turbine hand valves	.063	6.4 sec	.616
7.)	Condenser pressure	---	10 sec	30.
8.)	Condenser exit temperature	---	10 sec	1.
9.)	Deaerator pressure	---	50 sec	.1023
10.)	Feedwater temperature	---	50 sec	.1092
11.)	Boiler Level Control	---	50 sec	---

3.7 OPERATION AND MAINTENANCE

3.7.1 SUMMARY DESCRIPTION

The facility is a highly automated energy process system relying on extensive parameter sensing, closed loop analog and digital controls, programmed microprocessors and a master computer to operate the system efficiently in many different operating modes, each appropriate to a set of energy supply and demand conditions. The facility is, therefore, largely automatic and dependent on a few skilled operators.

During the initial two-year period, engineers will be present to assist in operating, trouble shooting, and correcting the inevitable electrical, control, hydraulic, mechanical and logic problems. This will produce a body of knowledge and a smooth operating system for the trained operators.

The facility will operate on a 24-hours/day basis. Most of the effort required by operators, particularly in the control room, consists of monitoring the system and seeing that the appropriate mode of operating is selected and enacted.

While the amount of mechanical equipment is not extensive, it will require maintenance by skilled personnel. Equipment such as the turbine-generator and components such as mechanical pump seals, will require care and skill to run properly. Having the proper maintenance, these components will show a good productive life.

3.7.2 OPERATIONAL REQUIREMENTS

The basic aim of the STES is to collect and use as much solar energy as possible to produce thermal and electrical energy for the 87,000 barracks complex. Operation is to achieve the greatest thermal efficiency possible relative to other energy sources. To this end, co-generation, the production of electrical energy and the use of its rejected heat for thermal energy, is to be maximized for a fixed field size of 125,000 square feet aperture.

Operations are conducted according to the following priorities:

- Satisfy thermal loads
- Maximize the use of solar energy to satisfy thermal loads and minimize fossil fuel consumption
- Provide electrical power peak shaving capability
- Maximize electrical energy production

System operation is intended to by highly automated. The energy management program is required to use the collected energy effectively. A side benefit of this automation is reduced manpower requirements. The control room operator will perform a management function for the system. The operators' activities are described in Section 3.7.7.1.

The staffing requirements for operation (not including curative maintenance) may be derived from the following shift breakdown.

Shift	Control Room Operator	Outside Operator	Supervisor
Day (8:00 a.m. - 4:00 p.m.)	1	2	1
Evening (4:00 p.m. - 12:00 p.m.)	1	1	
Night (12:00 p.m. - 8:00 a.m.)	1	1	

The facility will run 24 hours/day, 365 day/year. Day shift activities for outside operators will include equipment attention as well as assisting the control room operator (see Section 3.7.7.2). The outside operator for the evening and night shift will also have outside duties, but will tend to remain closer to the control room than during the day. During day operation, two outside operators are not necessary for operation alone. However, to respond quickly to problems and to provide safety for the single necessary operator, a second operator is recommended.

3.7.3 NORMAL OPERATION

There are two general situations covered by Section 3.7 concerning operation. The hour-to-hour steady-state operation is described in this section and the transitional operation such as startup, shutdown, and changing from one defined operating mode to another is described in Section 3.7.4.

During steady-state normal operation, the STES in any of the defined modes requires the operator to act as a monitor only, since system control is almost entirely automatic. Once the mode is specified the computer system will maintain control by monitoring process conditions and making adjustments according to the requirements specified under the given mode. When operation is no longer within the limits defined for a given operating mode the system's configuration will automatically change to a mode that optimizes energy utilization.

3.7.3.1 OPERATING MODES

The STES has a number of defined operating modes which are listed below:

- High Temperature Part-Power
- High Temperature Peaking
- Intermediate Temperature Part-Power
- Intermediate Temperature Peaking
- Electrical Generation
- Hot Standby

These modes are defined for each subsystem in their corresponding section. The greatest difference among the defined operating modes is the variation in flow paths between the various subsystem components.

Since the STES operates on a 24hr/day basis the selection of the desired operating mode is based upon the predicted insolation for the day, the predicted thermal load for the day and the predicted solar insolation for the following day. Typical examples of daily operation based on predicted insolation are given in the sections that follow.

It is understood that only by operating the facility under various conditions, will the knowledge that is required to make a selection among the various operating modes, for optimum energy utilization be gained.

3.7.3.2 SUNNY DAY OPERATION

Sunny day insolation is defined to deliver more than 100 million Btu to the hot oil storage for use in supplying the required loads. The rate of delivery, except in early morning and late afternoon, is sufficient to operate the PCS in the high temperature peaking mode and store any excess amount of high temperature (550°F) oil.

The Power Conversion Subsystem is switched to the high temperature peaking mode as soon as a minimum level in the high temperature storage tank is achieved. Water storage tanks are filled as rapidly as possible, keeping a minimum level in the high temperature oil tank. When oil flow from the collector field exceeds the design oil flow rate to the steam generator, the excess is stored in the high temperature tank. If the high temperature tank becomes filled while operating in the peaking mode, a portion of the solar collector field must be stowed or desteered to reduce collector flow to equal the design flow to the steam generator.

When the water tanks reach thermal capacity the cooling tower is placed in operation to continue turbine generating operation. As water is drawn from the tanks to satisfy thermal loads, they are periodically refilled throughout the day. Near the end of the solar day, if any of the collectors have been stowed or desteered, they are again brought into focus to maintain design flow to the steam generator and keep the high temperature tank filled.

The weather forecast for the following day is used to decide the mode of operation for the night. If a good insolation day is forecast, high temperature peaking is continued until the high temperature tank is empty and then the intermediate temperature peaking mode is continued throughout the night. If poor or no solar insolation is forecast, the water storage tanks are fully charged and the PCS is switched to hot standby. The PCS operation is then intermittent while continuing to supply thermal loads.

3.7.3.3 PARTLY CLOUDY OR HAZY DAY OPERATION

For plant operating purposes, a partly cloudy or hazy day is defined as having insolation of between 5 million and 100 million Btu's of collected energy. Below

5 million Btu's the day is considered cloudy, that is, too cloudy to warrant operation of the solar collectors.

During a partly cloudy day, the Solar Collector Subsystem is in its most variable state. The percent coverage may vary from one field segment to another in a relatively unpredictable manner. Collectors which are in cloud shade will produce no energy while those in the sun can produce at a rate equivalent to a clear day. The control system configures the flow path through the subfields and adjusts the flow rates to produce acceptable field exit temperature.

If, at the start of the solar day, collection is predicted to be less than 100 million Btu and collection on the following day is predicted to be good, high temperature part-power operation is started. If the collected energy exceeds that required to meet PCS thermal demand, the excess hot oil is stored in the high temperature tank. During periods of peak electrical demand, flow rates within the PCS are increased to their design value (the peaking mode) so additional electricity can be produced. Oil flow from the high temperature tank must be available to supplement that from the collector field during this period. When the electrical demand drops to normal, power conversion is again reduced to the level required to meet thermal loads only and the hot oil storage tank is replenished for the next peak in electrical demand. This procedure is repeated until all of the 550°F oil has been expended, at which time intermediate temperature part-power operation is started.

At the end of the solar day, the overnight thermal load prediction and the weather forecast for the following day are used to determine the operating mode to be used during the night. If the load is expected to be high, a load following operation would be selected. If the load is light and a good day is forecast for the next day, intermediate temperature peaking operation would be used to the extent necesary to empty the intermediate temperature tank before the start of the next solar day. If the load is light but no solar collection is forecast for the next day, a load following operation would be used to conserve the stored energy for use in meeting the next day's thermal loads. If, at any time, the high and intermediate tanks are emptied and the water storage tanks are forecast to reach a low limit, the auxiliary heater is placed in operation to generate intermediate temperature oil for meeting the thermal loads.

3.7.3.4 CLOUDY DAY OPERATION

Cloudy days are those with less than 5 million Btu/day of collected heat available. In essence, the heat losses and the power required to operate the field would exceed the collected energy. Therefore, the solar collector field is not operated on cloudy days.

On these cloudy days, the energy contained in the storage system will be utilized until the water storage tanks are depleted. The auxiliary oil fired heater is then placed in operation to generate intermediate temperature (438°F) oil. This oil is used by the PCS in the intermediate temperature operation mode as required to satisfy thermal loads.

3.7.4 TRANSITIONAL OPERATION

Transitional operation includes startup, shutdown, and changing modes of operation. Changing of rates within a defined limit during a given mode of operation is not considered a transition.

3.7.4.1 STARTUP

Startup is defined as the routine startup which would occur on a daily basis. Initial facility startup (or startup after a prolonged shutdown) is discussed in Section 3.7.4.5.

SOLAR COLLECTOR SUBSYSTEM

The Thermal Storage Subsystem acts as a buffer between the collection and use of energy in the STES. Thus, operation of the Solar Collector Subsystem is dependent on the TSS conditions and solar insolation and operated in a way so as to maximize the collection of useful energy. Operation of the Solar Collector Field, however, is independent of the PCS since its startup and shutdown are determined on the basis of available solar insolation, not upon thermal loads.

Startup of the SCS is contingent upon two conditions:

- There is sufficient solar insolation for useful collection.
- The inventory of oil in the TSS is such that the SCS can be operated for one hour.

With the control system in operation, startup of the collector field is accomplished by closing the recirculation valve to the pump suction and starting the collector field circulating pump. The valve alignment at this time will direct the oil flow through the three subfields in series and return it to the low temperature storage tank. Once flow has been established, the collectors can be unstowed and oil heating begun. As the inlet temperature setpoints are reached in the second and third subfields, the control system responds in its normal fashion to blend flows and maintain the proper subfield inlet temperatures. When any subfield outlet temperature reaches 525°F, the control system directs the oil to the high temperature storage tank. At this time the flow path to the intermediate tank is closed and the recirculation valve logic is activated. The system is now in its normal operation configuration.

THERMAL STORAGE SUBSYSTEM

The TSS, by its nature, is not started and stopped on a daily basis but is in continuous operation after initialization basis. Its pumps are started and stopped in response to the demands of the SCS and the PCS and the subsystem has been designed to accept these starts and stops as normal operation.

POWER CONVERSION SUBSYSTEM

Like the TSS, the PCS does not go through a daily startup and shutdown. Rather, during those periods of when thermal loads are satisfied, the subsystem is placed in a "Hot Standby" condition. In this mode, pumps are run only as required to keep fluid levels within limits, steam flow is reduced to only that required to maintain condenser and deaerator pressure, and no electricity is generated. In this manner, parasitic power comsumption is minimized.

Transition of the PCS from hot standby to the intermediate temperature part-power operating mode is defined as a startup of the PCS and is accomplished as follows:

- Start condensate, condensate return and small boiler feed pumps to establish proper water levels in the PCS.
- Start primary hot water pump in the hot water subsystem.
- With steam pressure controller set at 65 psia, start intermediate temperature oil flow through the steam generator. Establish 65 psia in the steam header. The turbine bypass is in pressure control to maintain 4.9 psia condenser pressure.
- Issue "start" command to low-pressure turbine. Second stage automatically comes up to operating speed in speed control.
- Issue "synchronize" command to second stage control system. System will automatically synchronize and connect to grid. Low pressure turbine throttle valve will adjust to a preset position.

The PCS is now in intermediate temperature part-power operating configuration. Steam is available for the operation of the absorption chiller and/or the L.P. turbine as the thermal loads dictate.

HOT WATER SUBSYSTEM

The hot water subsystem, in the heating season, operates continuously to satisfy the heating load of the five selected buildings and the STES building. Thus there is no daily startup and shutdown of the hot water subsystem; however, the periodic production of hot water by the condenser requires a starting and stopping of the primary circulating pump upon demand.

In the cooling season the hot water subsystem supplies energy for domestic hot water. Again, operation of the primary hot water pump is start-and-stop in response to condenser operation.

CHILLED WATER SUBSYSTEM

Operation of the chilled water subsystem, like the hot water subsystem, is on and off in response to the thermal demands of the buildings. In this case the "on" and "off" commands are sent to the primary chilled water pump, chiller condenser water pump and the absorption chiller. Startup of these units occurs automatically upon receipt of the "on" command from the control system.

Unlike the hot water subsystem, the chilled water subsystem requires a seasonal startup and shutdown.

The seasonal start-up involves converting the secondary thermal distribution system (the underground distribution system to the five project buildings) and one of the thermal storage tanks to chilled water usage.

The distribution system is converted by changing three-way isolation valves in each building as explained in Section 3.5. These valves have automatic positioners so that the system can be changed from the control room.

The storage tank is also converted from Heating Water Subsystem use to the Chilled Water Subsystem by realigning automatic isolation valves from the control room.

Since the same water and same piping will be used in the Chilled Water Subsystem as in the Heating Water Subsystem, no special system cleanouts or precautions are required. However, the seasonal startup of the absorption chiller should include a maintenance check to assure that it is in proper operating condition.

3.7.4.2 SHUTDOWN

Daily shutdown is, in general, the reverse of normal daily startup. Note that startup of the Thermal Storage and Hot/Chilled Water Subsystems is discussed in Section 3.7.4.1.

SOLAR COLLECTOR SUBSYSTEM

Shutdown of the SCS will normally occur when solar insolation has fallen to the point where collection is no longer practical or the thermal storage subsystem has become fully charged and can no longer supply low temperature oil to the SCS.

If the reason for shutdown is low insolation, the control system is recirculating a large percentage of the field flow to maintain the desired outlet temperature. When insolation drops to a point where the required outlet temperature reaches a shutdown limit, the recirculation valve is commanded to close. This drops the field inlet temperature to 316°F. The control system will then direct the flow to the appropriate storage tank as field outlet temperatures decrease. Once the outlet temperature drops below 300°F the collectors are stowed and flow is stopped.

If the reason for shutdown is a fully charged storage system, the shutdown is accomplished by stowing the collectors and stopping the collector field circulating pump. In this case, recovery of the energy in the field at shutdown is not justified.

POWER CONVERSION SUBSYSTEM

Transition of the PCS to hot standby is defined as the shutdown for the subsystem. It is accomplished by stopping the turbine generator and/or absorption chiller As the steam demand drops, the control system reduces oil flow to the steam generator and the level controller reduces feedwater flow. The various component controllers continue in their normal function until the system stabilizes in a no load condition. At this time the oil pump in the TSS, the feedwater pump, the condensate pump, and the condensate return pump are stopped. The subsystem is now in hot standby. Only if steam pressure or water level in one of the components reaches a prescribed limit will a pump be restarted to maintain the hot standby status. In this manner, parasitic loads are kept to a minimum while maintaining the subsystem in a ready condition.

3.7.4.3 MODE CHANGING

Mode changing reconfigures the Thermal Storage, Power Conversion, and Hot/Chilled Water Subsystems. There are two basic operating modes that configure the STES: the high temperature operating mode and the intermediate temperature operating mode. Additional operating modes have been defined to identify special subsystem configurations that can occur in either the high or intermediate temperature mode. "Peaking" and "Part-Power" identify separate power levels of the

Power Conversion Subsystem that are a result of whether the subsystem is operating at or below rated capacity respectively. Electrical generation identifies a particular configuration of the Hot/Chilled Water Subsystems. The transition from one operating mode to another results in a system reconfiguration. System reconfigurations are identified below for each possible operating mode transition.

INTERMEDIATE-TO-HIGH TEMPERATURE MODE

This mode change is initiated by five command signals from the control system:

- Oil supply to the steam generator is switched from the intermediate temperature tank to the high temperature tank.
- Oil return from the steam generator is switched from the low temperature tank to the intermediate tank.
- Steam pressure demand is switched from 65 psia to 315 psia.
- The steam outlet temperature control is activated with a setpoint of 500°F.
- The low pressure boiler feed pump is turned off and the high pressure pump is turned on.

Once these commands are issued, steam pressure starts to rise with steam flow being controlled by the high pressure turbine bypass. When it reaches 100 psia, a start command is issued to the high pressure turbine. This command starts the turbine, brings it up to speed, and engages the clutch to the reducing gear, which connects it to the load. The turbine is then switched into back pressure control and the turbine bypass is closed. The subsystem is then in the high temperature mode. Note, this mode change does not require any change in the Hot/Chilled Water Subsystem.

HIGH-TO-INTERMEDIATE TEMPERATURE MODE

This mode change is initiated by four command signals from the control system:

- Oil supply to the steam generator is switched from the high temperature tank to the intermediate tank.
- Oil discharge from the steam generator is switched from the intermediate temperature tank to the low temperature tank.

- Steam pressure demand is switched from 315 psia to 65 psia.
- Steam outlet temperature control is deactivated.

When the steam pressure has decayed to 100 psia, the high pressure turbine bypass is opened and the high pressure turbine isolation valve is closed.

When 65 psia is reached, the low pressure boiler feed pump is started and the high pressure boiler feed pump is stopped. The system is now in the intermediate temperature mode.

CHANGING TO ELECTRICAL GENERATION MODE

This mode change requires only a change in the Hot/Chilled Water Subsystem as follows:

- Start the cooling tower with a sump temperature setting of 60°F.
- Start circulation of cooling tower water through the cooling tower heat exchanger.
- Switch condenser cooling water flow from the hot water storage loop to the cooling tower heat exchanger loop. This removes the condenser discharge temperature controller from the system and allows condenser temperature (and pressure) to drop to a value which can be maintained by the heat removal capacity of the cooling tower. The actual condenser pressure attained is dependent upon ambient wet bulb temperature.

The system is now in the electrical generation mode. The amount of electricity generated is controlled by the position setting of the governor valve of the low pressure turbine. When this valve is wide open, electrical generation is maximum.

CHANGING FROM ELECTRICAL GENERATION

This mode change is the reverse of the peaking to electrical generation mode change described previously.

3.7.5 INITIAL FACILITY START-UP

A thorough plan will be developed for the system's initial start-up in order to reduce hazards or possible equipment damange. This plan will include a component by component check out in which many of the particulars will be prescribed by equipment manufacturers. A general list of check items is given below for selected system components.

PUMPS

- Ensure pump and driver are mechanically secure.
- Lubricate.
- Check alignment and drive coupling.
- Check mechanical seals.
- Rotate by hand to assure free turning.
- Check motor wiring and supply voltage.
- Check rotation. Bump, do not run dry.
- Check cooling water on high temperature oil pumps.
- When oil is available, start pump in the field and check discharge pressure and for leaks.
- Check remote starting.
- Check bearing temperature periodically during first few hours of operation.

CONTROL VALVES

A. Stroke valves in field
B. Check valve packing
C. Stroke valves from control room with field observation

PIPING

- Oil Piping

  Prior to installing insulation:

  - Secure all flange bolts to proper torque.

- Remove any debris or dirt from tanks and vessels.
- Block in pipe segments and pressure test with air. Locate leaks with halide, ammonia, ultrasonic detectors. Repair.
- Be sure line strainers are installed; clean as necessary.
- Charge cold oil and pump through system.
- Check for leaks. Fix.
- Install insulation.
- When hot oil is available (produced by the auxiliary heater) pump oil through the system at elevated pressures. It would be helpful to raise the oil temperature in steps so that the thermal expansion of piping can be observed.
- Check for leaks. Fix.
- Install flange insulation.

- Water Piping

  The checkout can be similar to the oil piping. Air pressure tests can be omitted except where water leaks would be a problem. Underground lines are to be tested prior to covering.

- Air and Nitrogen Piping
  - Blow lines out with compressed air.
  - Block in segments and pressure test with air.
  - Locate leaks. Fix.

- Steam and Condensate Piping

  The checkout can be similar to that used for oil piping.

TANKS

This includes the oil storage, water storage, fuel oil, auxiliary heater expansion tank, condensate pumps, and cooling tower pump.

- Enter all tanks, visually inspect, and remove all debris and dirt, sand, string, paper, cigarette butts, etc.

- Charge the tanks with the appropriate cold fluid (oil or water). See HEAT TRANSFER FLUID INITIAL FILL for charging the oil tanks. This should be done prior to insulating if possible so that any leaks are immediately obvious. This is particularly important for the oil tanks where a tiny oil leak will develop into a serious fire hazard after several months of seepage.

- On tanks with venting valves and emergency relief valves, block in the tank and pressure with compressed air to test the valves. Adjust or repair as necessary.

SOLAR COLLECTORS

- Visually inspect each collector module and string after installation for mechanical soundness.

- With motor mechanically disconnected, check motor operation and tracking controls.

- With motor connected, operate each collector string through full tracking movement and other collector movements. Field observation (and operation, if possible) is necessary to assure proper performance and to interrupt operation if a problem occurs.

The collectors should be tested hydraulically along with the oil piping.

AUXILIARY HEATER

- Check out combustion controls.

- Check out fuel oil and circulating oil pumps as outlined in PUMPS, Page .

- Check out forced draft fan.

- Check that fan and driver are mechanically secure.
- Check fan and driver alignment and belt tension.
- Lubricate.
- Rotate fan by hand to assure free turning.
- Check motor wiring and voltage.
- Check fan rotation by turning fan on.

- Check out the hydraulic side by methods used to check out oil piping.
- Assure that the CO_2 extinguishing system is operational.
- Once the rest of the oil system (piping, pumps, tanks, controls) is hydraulically ready, start-up the heater and checkout the oil firing model.

COOLING TOWER

- Pumps. See Page 3-424.
- Fan
  - Check that fan and driver are mechanically secure.
  - Check fan and driver for alignment and proper adjustment.
  - Lubricate.
  - Rotate fan by hand to assure free turning.
  - Check motor wiring and voltage.
  - Check fan rotation by turning on.
  - Check that two-speed operation is available.

HEAT TRANSFER FLUID INITIAL FILL

The introduction of the heat transfer oil into the Thermal Storage Subsystem must be done with care to avoid contamination or promoting of oxidation. In addition, two additional objectives must be accomplished during charging. These are:

- The fluid must be "degassed" while the transfer is taking place.
- The entry of the fluid must be controlled such that the maximum amount of residual oxygen in the vessels is bled to the outside of the vessels.

To accomplish the required objectives, and to install the subsystem storage fluid, the actual procedures would follow the general approach as outlined below.

- Initial Conditions:
  - Vessels empty and clean.
  - All remote valves verified for remote and field function.
  - All valves leading from vessels are open.
  - Nitrogen supply system full and prepared to deliver nitrogen at 4-inch water column.
  - Storage fluid available from "at site" truck tankers or from "at site" rail tankers using truck tanker transfer unit.
  - Vacuum degassing unit set-up and operational.
- Procedure:

  The fluid is placed into the intermediate temperature vessel first by pumping the fluid from the connected truck tanker through the vacuum degassing unit and into the vessel using the tanker pumping system.

  - Close all line valves adjacent to the intermediate temperature vessel except for the atmospheric blowdown valve.
  - Connect delivery tanker to special API fitting.

- Pump fluid from truck tanker through vacuum degassing unit, and into vessel until vessel is filled to top of cylindrical body section, or all of fluid charge is added.

- Close atmospheric blow-down valve and simultaneously, open vessel to nitrogen flow, bringing ullage pressure to 4 inch water column.

- Flush ullage space until oxygen content is below one percent.

- Pump fluid from intermediate temperature vessel into low temperature vessel using system pumps and bypassing the Solar Collector Subsystem and the auxiliary heater, while simultaneously allowing the air in the low temperature vessel to blow to atmosphere, until the low temperature vessel is filled to the top of the cylindrical body section or all fluid that can be transferred is in the low temperature vessel.

- Simultaneously close the atmospheric blow-down valve and open the vessel to the nitrogen system. Allow ullage pressure to reach 4 inches of water column.

- Flush ullage space until oxygen content is below one percent.

- Pump fluid from the low temperature vessel to the high temperature vessel while simultaneously venting the air from the high temperature vessel.

- When fluid level reaches the top of the cylindrical vessel section (if vessel is an API 650 vessel), or the top-most level in the vessel head (if vessel is an ASME Section VIII vessel), stop oil flow into the vessel.

- Simultaneously close the vessel to the atmospheric vent and open the ullage to the nitrogen system. Allow the ullage pressure to reach 4 inches of water column.

- Flush ullage space with nitrogen until oxygen content is below one percent.

- Pump the oil in the high temperature vessel into the low temperature vessel.

- Serially open flow paths from the full low temperature vessel to the Steam Generation Subsystem, the Collector Subsystem, and the auxiliary heater to fill all fluid channels and spaces by venting "high points" to atmosphere.

- System is now prepared for initial oil heat up.

- Initial System Startup

  The appropriate procedures for initial system startup are best accomplished using the auxiliary heater rather than the Solar Collector Subsystem since the auxiliary heater can be modulated to a low output level which allows for careful and cautious initial system heating.

The initial heating approach would follow a relatively slow schedule where not more than 50°F temperature increments are imposed on the system for each "oil pass." This would be accomplished along the following procedural lines:

- Oil would be pumped from the low temperature vessel at a specified rate through the auxiliary heater where it would be heated by 50°F, and would flow into the high temperature vessel.
- Simultaneously, but at a lower rate, the oil would be pumped from the high temperature vessel through the Steam Generation Subsystem (no steam generation but filled with water), and into the intermediate temperature vessel.
- When the high temperature vessel is filled to maximum level, the fluid discharge rate would be increased to the inlet level.
- The balanced flow would continue until all of the fluid was extracted from the low temperature vessel, heated by 50°F, passed through the high temperature vessel and into the intermediate temperature vessel until all of the fluid is transferred to the intermediate temperature vessel.
- At this point, the temperatures of the high temperature and intermediate temperature vessels are approximately 50°F above the low temperature vessel. The fluid is then pumped from the intermediate temperature vessel through the Solar Collector Subsystem and into the low temperature vessel.
- The cycle is repeated (approximately six times) until all three vessels are approximately 316°F.
- At this point the low temperature vessel is eliminated from further heating and the fluid is circulated in a similar manner through the high and intermediate temperature vessels until both vessels, the Solar Collector Subsystem and the steam generator, are approximately 438°F.

- Next, the fluid is pumped at a specified rate from the intermediate temperature vessel and through the auxiliary heater, heated to approximately 500°F, and placed in the high temperature vessel until it is filled to maximum level.
- When the high temperature vessel is filled to maximum level, flow from the high temperature vessel is initiated through the steam generator where superheated steam is generated at a controlled rate such that the returned fluid to the intermediate temperature vessel is approximately 438°F. This is continued until all of the fluid charge has passed through the auxiliary heater.
- Next, the fluid is heated to 550°F using the auxiliary heater (438°F and 550°F) and again, when the high temperature vessel is filled, superheated steam is generated and the fluid is returned to the intermediate temperature vessel at 438°F.
- When all of the fluid has been heated to 550°F and has been used to generate superheated steam, and returned to the intermedaite temperature vessel, the fluid is then pumped from the intermediate temperature vessel through the steam generator where saturated steam is generated and the fluid is returned to the low temperature vessel ay 316°F.
- At this point the TSS is completely preheated to normal operating conditions, the collector field has been heated initially to about 438°F, the auxiliary heater performance has been verified, the steam generator has operated through two complete cycles (high and low pressure generation) and the TSS is ready to perform the normal operations.

Additional check items for components not mentioned will be specified by the selected manufacturers and a thorough checkout of all components will be performed prior to and following installation. A checkout will also be performed on a system level for the Computer Control System, the Nitrogen Cover Gas System, the Water Makeup System, and the Compressed Air Supply System.

3.7.6 ABNORMAL OPERATION

Abnormal Operation of the plant is defined to be operation under two conditions; loss of electrical power and loss of the computer system. If the computer system fails or is not operational, operation of the plant switches to the intermediate temperature part-power mode with the auxiliary heater supplying the thermal input (the Solar Collector Subsystem is already in the stowed position or will be put there). This is abnormal operation since the necessary components which are normally controlled by remote digital control are now operated by local analog controllers (additional operator interface in the field being required).

When electrical power from the utility is lost, the plant is operated in the same way provided the low pressure turbine is on line to supply the necessary power required for system operation. If the low pressure turbine is unable to supply the required parasitic loads, the system will coast down to a fail safe shutdown configuration, (more detailed information is given in Section 3.6.4).

3.7.7 OPERATOR INTERFACES

The entire system will be largely automated to operate in a variety of modes (or mixtures of subsystem modes). Ideally, the operator is a monitor checking the system, looking for mechanical, electrical, process and control problems before they jeopardize system operation. With any system, particulary a newly designed, development facility, the role of the operator will be much more demanding due to system "bugs" and lack of operating knowledge and experience. Although many aids will be available, one of the most critical operating demands will be to decide upon the mix of operating modes which is the most appropriate for any given day or portion of a day. Much of the time the decision will be clear cut. For example, sunny days in midsummer require cooling and have energy available for producing electrical power. However, partly cloudy days introduce the problems of how to best use the available energy and whether to augment the solar energy with the auxiliary heater. These decisions are first made by the automatic control system with the operator as backup.

3.7.7.1 CONTROL ROOM ACTIVITIES

Control room activities will involve:

Monitoring system displays.

Observing the mechanical areas.

Adjusting process conditions if required.

Changing operating modes.

Diagnosing process or system problems.

Occasionally, operating portions of the system manually.

Starting up and shutting down subsystems and equipment.

Recording selected data.

Developing operating strategies for periods later in the day or for the next day.

Communicating with field operators.

3.7.7.2 FIELD ACTIVITIES

Like the control room operator, operators assigned to the field (and outside area) are primarily interested in monitoring the system to ensure that it is operating properly. Activities will include:

- Listening to and observing rotating equipment (compressors, pumps and fans) for unusual sounds, vibrations, leaks and other signs of failure.
- Observing smoothness of collector tracking and operation.
- Noting leaks (particularly in the oil system) especially at flanges, flexible bellows, connections, pumps, valve stems, etc.
- Checking fluid levels (e.g., condensate sumps, nitrogen tank, lubrication eyes and bottles, etc.).
- Checking proper sequencing and operation of the compressor and air dryer equipment; check relative humidity of compressed air.
- Observing temperature and pressure gauges; record selected variables.
- Observing cooling water flow to pumps.
- Checking compressor safety valve.
- Draining compressed air drip legs; blowing down filters.
- Changing air filters, desiccants,recording charts, etc.

- Checking belt drivers for wear and tension.
- Checking field set points.
- In conjunction with control room operator, checking operation of equipment, limit switches, controls, etc.
- In conjunction with control room operating, diagnosing system problems.
- Adding chemicals (e.g., water treatment).
- Lubricating equipment, couplings, etc.
- General cleanup.
- Obtaining fluid samples (e.g., oil to check contamination).
- Observing auxiliary heater tubes for soot formation.
- Observing condition of insulation (e.g., for breaks, etc.). particularly at flanges and slide points for thermal expansion.
- Inspecting pump/motor couplings, vibration insolators, equipment mounts and supports.
- Venting non-condensables from the chiller once/week.

3.7.8 MAINTENANCE

The objective of this section is to provide an overview of the maintenance approach and leave the particular maintenance details for each subsystem to be covered in those sections (3.2 through 3.6).

During the initial shakedown of the system considerable maintenance type activities will be required by the contractors and the operating crew as part of their training. After the shakedown, maintenance activities are expected to be minimum and comparable to a normal power plant. The one exception is the solar collectors and the need for reflective surface cleaning.

The on-site maintenance crew will require skills in mechanical components, piping, electrical, instrumentation, control, and fluid chemistry areas.

The maintenance activities can be considred in three parts namely, inspection, preventive and curative. The inspection and preventive maintenance activities will be done by the site crew with the possible exception of the computers. Much of the curative maintenance will be done by the component suppliers under warranty or contract.

3.7.8.1 INSPECTION MAINTENANCE

Inspection is very important and the most cost effective maintenance activity. It involves observation (visual and audio) of the physical features of the plant and components for trends towards abnormality. This is done by the operating crew as they walk through the plant including planned routes and points for observation.

Evaluation of performance data for degradation trends is another important source of inspection. The data acquisition system can be used to correlate and display selected parameters for trend observation such as heat exchanger effecitveness for fouling, solar collector efficiency for reflective surface soiling, energy storage vessel performance for insulation deterioriation, etc. These observations can be made in situ.

3.7.8.2 PREVENTIVE MAINTENANCE

Preventive maintenance are those planned periodic activities resulting from recommendations from component suppliers and similar plant operating experiences. Such items as lubrication, changing oil and filters, cleaning solar collectors, calibrating instruments, adjusting electronic circuits, checking and adjusting fluid chemistry and responding to special situations uncovered by the inspection maintenance (3.7.8.1) are typical of preventive maintenance.

The preventive maintenance plan (items and frequency) will initially be conservative and with experience be improved to reflect the true preventive maintenance required; i.e., an expected reduction in effort.

3.7.8.3 CURATIVE MAINTENANCE

Curative maintenance are those activities involving significant repair and/or replacement of components principally due to wear, failure or accident. These activities will be the most costly per incident. To the extent that inspection and preventive maintenance foretell of curative maintenance, they can be scheduled to minimize the cost. Such items as replacing pump seals and valve packing, decoking auxiliary heater tubes in case of serious overheat, repair to insulation and refractory liners, replacement of rotating equipment bearings, replacement of solar collector drive components, replacement of valves, etc., are typical of this level of maintenance.

Typical of maintenance to be done by the component suppliers involve computers, and, possibly, major repairs to the tubine generator, solar collectors, and chiller.

3.8 FACILITY AND BUILDING DESIGN

3.8.1 SUMMARY DESCRIPTION

There are a number of points that must be examined in the development of the STES facility design. Because this facility is an experimental project in solar energy, it is important that it functions correctly from an engineering standpoint. It is also of great importance that this type of facility gain acceptance from the general public and from the surrounding community. If solar energy is to be accepted as a potential primary energy source, then one acceptance criterion is that a facility of this type be exhibited as a pleasant asset to the surrounding community — a facility that a residential community would not object to as a close neighbor. A differentiation must be made between this type of facility and the widely accepted image of energy generation facilities or fuel storage facilities.

Because of the potential for public exhibition of this facility, it is important to integrate the visitor into the system as much as possible, to demonstrate not only functional aspects, but also the pleasant, safe qualities of the system. The major effort to integrate the visitor into the system has been to allow the visitor to walk near the equipment, view equipment from various observation points, walk under piping runs, and observe presentation material that explains the more detailed aspects of the engineering design.

3.8.2 FUNCTIONAL OBJECTIVES

The overall site arrangement shown in Drawing 1-1 in Volume III is largely dictated by the position of the solar collector field. The heated oil storage system tanks are logically located between the collector field and the 87000 Building Complex, near the midpoint of the collector field in order to minimize length of pipe and pipe sizes, thereby minimizing energy losses.

The STES Building is located close to the Thermal Storage Subsystem tanks, since steam is piped to the equipment within the building. A parking lot for visitors and employees is located to the north of the STES Building and is accessible from Fifteenth Street.

The water storage tanks and the cooling tower are located to the north of the STES Building close to the equipment inside the building associated with each.

The dike surrounding the oil storage tanks has sufficient volume to contain the oil in case of a tank rupture. The berm to the east and south of the collector field will contain any oil spill in case of a rupture in the solar collector field.

The STES building has been located in a position between the Thermal Storage Subsystem and the water storage tanks and adjacent to the solar collector field. The building is approached by a walkway between the water storage tanks and heat exchangers. The mechanical equipment inside is visible through the glass north wall. The ground level contains the Control Room office, Training/Conference Room, Public Toilets and a Vending Area; all of which require direct access for both visitors and employees from the ground level entrance.

When proceeding up the ramp eastward, the expanse of solar collectors and associated piping can be viewed; and by continuing up the ramp westward, entrance to the upper level of the building is gained. The upper level contains the Visitor's Area (display/observation) and the Control Room. The upper level location allows a better view of the surrounding site for the visitors and Control Room operators. The exterior wall of the observation level is clear glass to provide an unobstructed view. Visual observation of the collector field and the Thermal Storage Subsystem equipment by the Control Room operators is necessary (is provided) at all times.

3.8.3 STES BUILDING DESIGN

The Energy Conversion Equipment Control Room and Office, Training Classroom/Conference Room, Visitors Center/Observation Area must be housed. The building is divided into two distinct sections. One section will house energy conversion equipment and will serve as a mechanical equipment room. The other section of the building contains the public portion, which will be accessible to both visitors and employees.

The exterior materials have been selected to respond to the general appearance and visibility requirements. A combination of brick and glass will be used. The south and north walls of the mechanical area will be a combination of solid glass, operable windows and louvers at the base of the walls. The west wall will be constructed of brick. The glass was selected primarily for the maximum visibility both into and out of the mechanical room. Because the mechanical room is not cooled or heated (except by equipment), 1/8 inch and 3/16-inch thick glass is used, which is much less expensive per square foot than is a masonry wall.

The habitable section of the building has an exterior wall constructed of a combination of 5/8-inch insulating glass and masonry. The upper level is surrounded by this insulating glass while the lower level is mostly masonry construction with some operable windows.

The floor plan layout of the STES Building has been carried out in a response to the intended functions of the building. Spaces provided are summarized below:

LOWER LEVEL

- Mechanical Room . . . . 3030 sq-ft
- Training/Conference Room . . . . 362 sq-ft
- Control Room Office . . . . 120 sq-ft
- Men's Toilet Room . . . . 104 sq-ft
- Women's Toilet Room . . . . 104 sq-ft
- Vending/Break Room . . . . 64 sq-ft

SUB-TOTAL (NET) . . . . 3784 sq-ft

SUB-TOTAL (GROSS) . . . . 4449 sq-ft

UPPER LEVEL

- Control Room . . . . 780 sq-ft
- Observation/Display Room . . . . 828 sq-ft

  SUB-TOTAL (NET) .1608 sq-ft

  SUB-TOTAL (GROSS) . . . . 1664 sq-ft

- TOTAL Building Gross sq-ft . . . . 6113 sq-ft
- TOTAL Building Net sq-ft . . . . 5392 sq-ft

  Circulation Space, Interior Partitions,
  Exterior Walls . . . . 721 sq-ft

The square footage allocated to the various spaces in the building have been based on a combination of code requirements and sound architectural judgments.

There are a number of code requirements that have had an effect on the design of the STES Building. The Uniform Building Code 1976, the Uniform Plumbing Code 1976, and the ANSI A117.1 - 1961 Code have been the main influences on the design requirements. The Uniform Plumbing Code and the ANSI A117.1 - 1961 Code have established critiera for the toilet room design.

The Uniform Building Code requires that an assembly room (Observation/Display Room) on a second floor with an occupant load of 10 or more people must have two separate and remote means of egress. The Uniform Building Code also requires that an upper level assembly room in a public use building be accessible to handicapped persons by means of a ramp or an elevator. Given the requirements by the building code for two means of egress and accessibility by physically handicapped people, an exterior ramp has been devised to respond to those requirements. The ANSI A117.1 - 1961 Code states certain criteria governing slopes and landings of ramps making them usable by the physically handicapped. This has determined the length and width of the ramp.

3.8.3.1 CONTROL ROOM/OFFICE

The Control Room is designed to accommodate monitoring and computer equipment. The space designated is required to accommodate the computer equipment and allow circulation around the various pieces of equipment. A stair is provided to maintain access from this room to the mechanical room, the control room office, and the exterior mechanical areas.

The Control Room Office is to accommodate the supervisory and access to the mechanical room, the exterior functions and the control room upstairs. The Control Room Office is located in a position that allows easy access to each of these areas. An office of this nature requires a space of between 120 ft^2 and 150 ft^2.

3.8.3.2 TRAINING ROOM/CONFERENCE ROOM

The Training Room/Conference Room is designed to accommodate 10 to 12 personnel in training for the operation of the STES facility, and to also function as a conference room for visiting professionals. The room may also be used as a space to show slide presentations or films as a part of the information dissemination function of the Visitors' Center. Rooms of this type generally require a minimum square footage allotment of about 15 square-feet per person, which means the room as designed could accommodate up to 20 people in a classroom seating arrangement.

3.8.3.3 MECHANICAL SPACE LAYOUT

The mechanical equipment room layout is designed to provide the most efficient arrangement of equipment with adequate access for maintenance and service.

Access aisles are located to provide capability to move all components of the mechanical system within and out of the building without disturbing any other components in the equipment room.

Access space required for equipment service, heat exchanger, tube pull, control panel observation, and safety clearances is provided in accordance with equipment manufacturers' recommendations, code authorities and good engineering practice.

Access is provided to all operating control valves, panels, electrical switches and safety devices to ensure operator quick and safe access to all operating controls.

The mechanical equipment room will be cooled by a ventilating exhaust fan for warm weather and will be provided with minimum heating equipment to prevent freezing of components if the system is down during severe weather.

3.8.3.4 VISITOR CENTER

The Visitor Center provides space for display of solar energy descriptive materials. Graphic presentations of the overall STES operation and design considerations will be an important aspect of the Visitor Center. The use of flow diagrams, charts, verbal presentations, recorded presentations, slides, models of various functions, etc., are anticipated.

The Observation/Display Room is designed to accommodate visitors in groups of from 20 to 30 people. The size of the group of people expected (20 to 30) is based on having a bus-load of people come to the site from a distant location. Local schools and area colleges and universities may also bring bus loads of students on field trips to this type of facility.

A Vending/Break Room area has been provided to accommodate a soft-drink vending machine and coffee-making appliances. This area is intended to serve employees, both field personnel and control room operators, as well as visiting public using either the display area or the conference room.

The Mens and Womens Restrooms have been designed in accordance with applicable codes to make these facilities accessible to handicapped employees or visitors. The square footage of both rooms has been determined by the space required for the plumbing fixtures, as outlined in the Uniform Building Code, and the space required to make those fixtures accessible to the physically handicapped.

3.8.3.5 HEATING, VENTILATION AND AIR CONDITIONING

All occupied spaces of the STES Building will be provided with mechanical space heating and cooling systems. Design conditions are:

	Summer	Winter
• Outside	99°F D.B. 77°F W.B.	25°F D.B.
• Inside		
- All occupied areas except Control Room	78°F D.B. 50% R.H.	68°F D.B.
- Control Room	75°F D.B. 55% R.H.	75°F D.B. 55% R.H.

Two separate H.V.A.C. systems will be provided; one for each of the two occupied floors.

The H.V.A.C. system serving the first floor will be a single-zone fan coil unit with chilled water and heating hot water supplied from the STES system. Supplementary electric heat, with power from the Fort Hood grid, will be provided to prevent freezing and subsequent damage during the heating season should the STES be shut down for an extended period of time.

The H.V.A.C. system serving the second floor, which includes the Control Room, will also be a single-zone unit with a direct expansion refrigerant coil and hot water heating coil, and a remote-mounted chilled water coil. Chilled water and heating water will be supplied from the STES system. The direct expansion refrigerant cooling coil will be used as back-up when chilled water is not available. The condensing unit will be connected to the existing Fort Hood power grid and will be used only when power from the STES is not available. An electric heater, also connected to the existing Fort Hood grid, will be installed to prevent freezing.

Both H.V.A.C. systems will have 100 percent outside air capabilities to provide an air-side economizer for free cooling when ambient conditions are below 55°F.

An exhaust system will be provided to exhaust toilets, lockers and the janitor's closet.

Although the STES Building does not fall under the jurisdiction of ASHRAE 90-75, the building will be designed to meet this standard whenever possible.

The H.V.A.C. controls will consist of the following:

- Space thermostat to modulate the heating/chilled water valve
- Outdoor air sensor to activate economizer provisions
- Interlock to activate emergency power connection from existing power grid to operate emergency heat and backup electrical air conditioner

3.8.3.6 LIGHTING AND ELECTRICAL

Lighting within the STES Building will utilize high-intensity discharge lamp sources wherever possible for maximum energy efficiency and lowest maintenance costs. High-bay lighting within the mechanical room will be open bottom, prismatic glass reflector-type fixtures. Indirect lighting sources will be used within the control room. Exterior lighting will be by means of high-intensity discharge fixtures utilizing a type five distribution pattern for greatest spacing ratios with a sharp cut-off angle to avoid glare. An emergency battery powered back-up lighting system will be integrated into the normal lighting system for times of power outages.

Power distribution within the STES Building will utilize 277/480 volts for lighting and heavy mechanical loads, and 120/208 volts for miscellaneous power requirements.

3.8.3.7 STRUCTURAL

Applicable Building Codes for the STES Building are: Uniform Building Code, 1976 Edition, and Building Code Requirements for Minimum Design Loads in Buildings and Other Structures (ANSI A58.1 - 1972).

Design Loads

- Live Load on Roof . . . . 20 psf
- Piping Load on Roof . . . . 20 psf
- Live Load on Mezzanine . . . . 100 psf
- Wind Load on Horizontal Projection . . . . 20 psf

The building foundation will be spread footings bearing on the fractured limestone underlying parent material, which occurs approximately three feet below existing grade. Design pressure for the foundation is 5 ksf.

The site is located in Seismic Risk Zone 1, as defined by ANSI A58.1 - 1972.

Framing systems for the STES Building are as follows:

- Roof - Metal deck on bar joists that span between joist girders. Joist girders are supported by pipe collums.
- Mezzanines - Cast-in-place concrete slab (2-1/2 inches thick) on corrugated metal centering spanning between bar joists that span in turn to steel beams. Beams are supported by pipe columns.
- Lateral Loads - Diagonal bracing and moment resistive frames

3.8.4 FACILITIES DESIGN

3.8.4.1 SOLAR COLLECTOR FIELD

The design features concerning the layout of the collectors, and the field segments are covered in Section 3.2, Solar Collector Subsystem. Other features (e.g., piping layout, grading, access, erosion control, etc.) are covered in the following paragraphs.

Supply and return piping in the field area will be supported approximately one foot above the ground level except at road crossings where a 12-foot clearance will be maintained. The collector headers will be placed subgrade in a shallow concrete ditch or trough. Vehicles will cross the trough on fabricated decks.

The field will be graded to slope evenly to the east and south, as shown on Drawing 1.4 (Volume III). In accordance with recommendations from the American Technological University, erosion protection and oil spill protection will be provided by a field surface treatment consisting of compacted subgrade, 4- to 5-inch base course material (e.g., crushed limestone), topped by a single penetration course (oil and aggregate).

Runoff protection will consist of an earth berm on the north, east and south sides to contain runoff and a weir structure that restricts the outflow to conform to preconstruction flow rates. The outfall structure will be constructed so as to prevent oil spills or floating oil films from escaping. Oil skimming apparatus will also be installed.

Access to the collector field for maintenance is provided by perimeter roads on the south, west and north sides, and an east-west road through the field middle. Collectors are spaced so that when the collectors are stowed, a vehicle can drive between the collector rows.

Security will be provided by a chain link fence around the entire field. The fence will run along the top of the earth berm of the north and south sides of the collector field. Landscaping in the form of a low ground cover will be necessary to stabilize the soil of the sloped berm. A possible ground cover is honeysuckle, which would stabilize the berm with its vine-like quality and form a pleasing landscaped perimeter edge to the entire collector field.

3.8.4.2 THERMAL STORAGE AREA

This area contains the Thermal Storage Subsystem equipment, the auxiliary heater (Solar Collector Subsystem), and the steam generator (Power Conversion Subsystem). Many design constraints combined to produce the layout and design indicated on Drawing 1-1 and 3-1 in Volume III.

Since tank ruptures are a possibility, the storage tanks are placed inside a diked area. The area is divided into two parts: a circular area around the storage tanks (depth about 2-feet) and a rectangular basin (depth about 4-feet) to the south. The basin will hold the contents of the largest tank while leaving the circular area unflooded. Should all the oil in the system be released, the safety margin on the dikes is about 1-1/2 feet of free board above the floor level.

The storm drain for the entire area is placed in the southwest corner of the rectangular basin. It is equipped with automatic devices to allow water, but not oil to pass. The floor of the diked area is sloped to drain to the storm drain.

The fuel oil tank outside the diked area will be buried.

Fire safety as enforced by codes influenced the design. Although the heat transfer oil is a Class III-B liquid when cold, it is handled and stored above its flash point when termed hot (550°F) or intermediate (438°F). (The flash point is between 415° and 445°F according to manufacturers' data.) As a consequence, the fluid is classed as more flammable. According to NFPA 30-76, Section 5-7 (Electrical Equipment) applies to Class III liquids when stored or handled above the flash point. (At ambient temperatures, this Section applies to Class I liquids.) Consequently, electrical design will follow Section 5-7.

The Uniform Building Code indicates that a Class III liquid handled and stored above the flash point will be treated as a Class II liquid. For storage design purposes it will be considered Class II and meet code requirements in NFPA 30-76, Section 2-2. Tank spacing, distances from public areas and buildings, and drainage (in case of rupture) all meet code requirements. In addition, the tanks will be placed on two-foot high crushed stone/earth pads to protect the base from possible fires. These raised areas also permit possible access to valves during a spill incident. The pumps are also raised slightly above the floor.

The auxiliary oil-fired heater is placed outside the diked area and set back far enough to satisfy Code requirements. Its site is graded to drain to the diked area in case of a spill.

The storage tanks are placed as far west from the collector field as possible to reduce late afternoon shadowing. However, the tanks are not lined up north-south along 15th Street (Redbud Avenue) since this would greatly extend piping runs and reduce visibility greatly.

Visual access or visibility of all components in the storage area is important for operation, maintenance and public viewing. All pumps and the "working end" of equipment are located and oriented to achieve maximum visibility. Consequently, the control room operator has full visibility of the area, allowing observation of equipment and personnel, an important safety consideration.

Equipment is laid out to assure accessibility by personnel and equipment (e.g., vehicles and lifting equipment). Piping is about chest-high where possible to reduce support costs and increase accessibility. Location of equipment and tanks attempts to reduce total piping length and hot piping length particularly.

The earth berm enclosed oil retention area is landscaped with a ground cover to stabilize the soil of the sloped surface. The ground cover material used will add a texture to the perimeter surface of the slope which will define the circular form of the retention area. The circular form was generated as a simple geometric shape that would visually contain the complexity of the oil storage tanks, piping runs and pump equipment. The light color of the crushed stone base of the retention area will also contrast with the textured landscaped edge further emphasizing the enclosure area.

3.8.5 FACILITY INTERFACES AND SITE PREPARATION

The site preparation that will be necessary to construct the STES will occur in two phases. The first phase will consist of the relocation of the existing parking facilities, park and power lines to the south side of Battalian Avenue, and site preparation in the area of the oil storage tanks. This work will consist of some minor grading that will be necessary to construct the parking in the new location, and finish grading in the oil storage tanks. The recommended soil cement subbase and asphaltic concrete paving and curbing can then be installed.

The power lines are to be completely rerouted by Fort Hood and should not be a constraint to the construction program.

Once the parking has been relocated, construction can proceed by the installation of erosion control measures and the stripping of the grass and vegetation from the site.

3.8.5.1 DEMOLITION, STAKING AND GRADING

After construction of relocated parking lots, the demolition of the existing parking lots will be done in phases to allow the contractor access to the site and provide him with a paved surface from which to work. The initial paving to be removed will be in the area of the building and underground utility lines.

The soils existing on the site are mostly of the Denton Association of the Soil Conservation Service system of classification. Soils in this classification have a surface layer, usually about 18 inches thick, of dark grey/brown silty clay and a secondary layer of dark brown silty clay, extending normally to about 36-inch depth. The parent material underlying the soil is fractured limestone. In five borings performed by American Soils, Limited of Houston, Texas, and recorded in their report dated October 26, 1977, the layer of soil covering the weathered limestone was found to be from two to three feet thick. The underlying limestone layer was found to be from three to five feet thick. These two layers are underlain by alternating layers of clay and limestone and exist in all the borings within the 25-foot depth examined.

Grading for the solar collector field can proceed immediately as soon as the vegetation is stripped. Due to the shallow nature of the surface soils, grading has been held to a minimum and consists of shaping the field to a true plane which slopes toward the southeast corner of the site and construction of storm water ditches for the handling of storm water on and off the site.

The drainage for the proposed STES will follow the same general pattern.

Three 24-inch equivalent concrete pipe arches have recently been installed under Park Avenue to the north of the site and conduct off-site water onto the site. This water flows across the site and finds its way through the 30-inch culvert to the South Fork of Nolan Creek. Drainage for the 87000 Complex has been handled by means of a storm water piping system that conducts the water along Battalion Avenue to under Martin Drive to the South Fork of Nolan Creek. The drainage from two existing paved parking lots is handled by this system.

The drainage for the proposed STES will follow the same pattern. The off-site water is to be conducted via a swale to the 30-inch culvert separately from the runoff of the solar field. The runoff from the proposed visitor parking area, building and storage area will be handled by the storm drainage system handling the existing paved parking area. The runoff from the solar collector field will be diverted along the south and east boundaries to the existing culvert location. At this point, a flow regulating weir will be constructed so that the maximum rate of runoff from the proposed field approximates the maximum rate of runoff from the existing open field.

As soon as the plane is shaped and foundations installed, the permanent erosion control consisting of four to five inches of crushed limestone base course material and a single oil penetration course, as recommended by American Technological University, should be installed to minimize erosion from the site.

3.8.5.2 CONSTRUCTION ACCESS AND FACILITIES

Construction access can easily be accommodated by means of the existing parking areas and driveways. Removal of these should only occur as necessary to install new facilities. The existing paving will provide a convenient location for construction trailers, as well as the staging of equipment and supplies.

3.8.5.3 STES INTERFACES

WATER

A new connection will be made to the existing underground water main west of Fifteenth St., north of the STES facility. From this point, the new underground water line passes under Redbud Drive, turns south and enters the northwest corner of the STES building. (See Drawings 1-6 and 1-7 in Volume III.)

SANITARY SEWER

A new connection will be made to the existing manhole near the southeast corner of the existing Feed Service Facility. The existing manhole will receive a new sanitary line from the new STES facility, which will be routed under Redbud Drive.

NATURAL GAS

A new connection will be made to the existing underground natural gas line west of 15th Street (Redbud Drive) approximately in line with the south end of the existing Central Energy Facility. From this point, the new underground natural gas line passes under 15th Street turns north, then south to the STES for use at the flare. (See Drawings 1-6 and 1-7 in Volume III.)

ELECTRIC POWER

The new STES facility will receive power from the new transformer (T-11) located adjacent to the new STES building. T-11 will be fed from the power grid at the existing transformer, T-4, by new underground lines. (See Drawing 8-13 in Volume III.)

COMMUNICATIONS

Interface will occur with the existing Fort Hood telephone and fire alarm system.

The prime components of the existing energy systems in the five selected buildings being served by the STE-LSE at Fort Hood are effectively utilized. These components include the heating and chilled water piping, air handling units with heating and/or cooling costs, the domestic hot water system, and the electrical system. Where the existing chilled water and steam system is not directly utilized, it is used as an emergency back-up system.

The existing underground steam and chilled water piping will be used in the operation of the STES. The existing chilled water, steam and condensate piping will become a back-up system. This would be accomplished by installing a two-way/two-position shutoff valve in the existing steam and a check valve in the condensate line, as indicated in Figure 3.8-1.. The closing of this valve will isolate the existing steam piping to the five buildings served by STES from the balance of the existing steam piping systems. The existing chilled water supply lines will have a new by-pass connection to the existing chilled water return lines, with new two-position automatic by-pass valves. In addition, the existing chilled water supply and return lines will have new two-position automatic three-way valves installed on the building side of the new by-pass connection at each building. These valves allow isolation of the existing chilled water piping system without disturbing the operating characteristics of the 87018 central energy facility chilled water pumping system. The new chilled/heating water piping from the STES will connect to the existing chilled water piping at each of the five selected buildings, as indicated in Figures 3.8-2 and 3.8-3. The valves will be remotely controlled by the STES control/monitoring.

New hot water unit heaters will be provided in the Three Company Administration and Supply Building and the Five Company Administration and Supply Building. The new unit heater piping will be connected to the existing chilled/heating water piping with a new two-position/three-way valve that will allow flow to the unit heaters during heating months, and will stop flow to the unit heaters during cooling months. This arrangement is illustrated in Figure 3.8-3.

Domestic hot water for the three buildings to be served will be transported to the buildings in a new underground pipe system. The new piping system, as shown in Figure 3.8-4, will follow the route of the new chilled hot water underground distribution system. The existing domestic hot water generators will be used as hot water storage spaces. Figure 3.8-5 shows the proposed new piping arrangement for the existing domestic hot water generators. This figure also indicates that the steam piping will be left intact to provide standby.

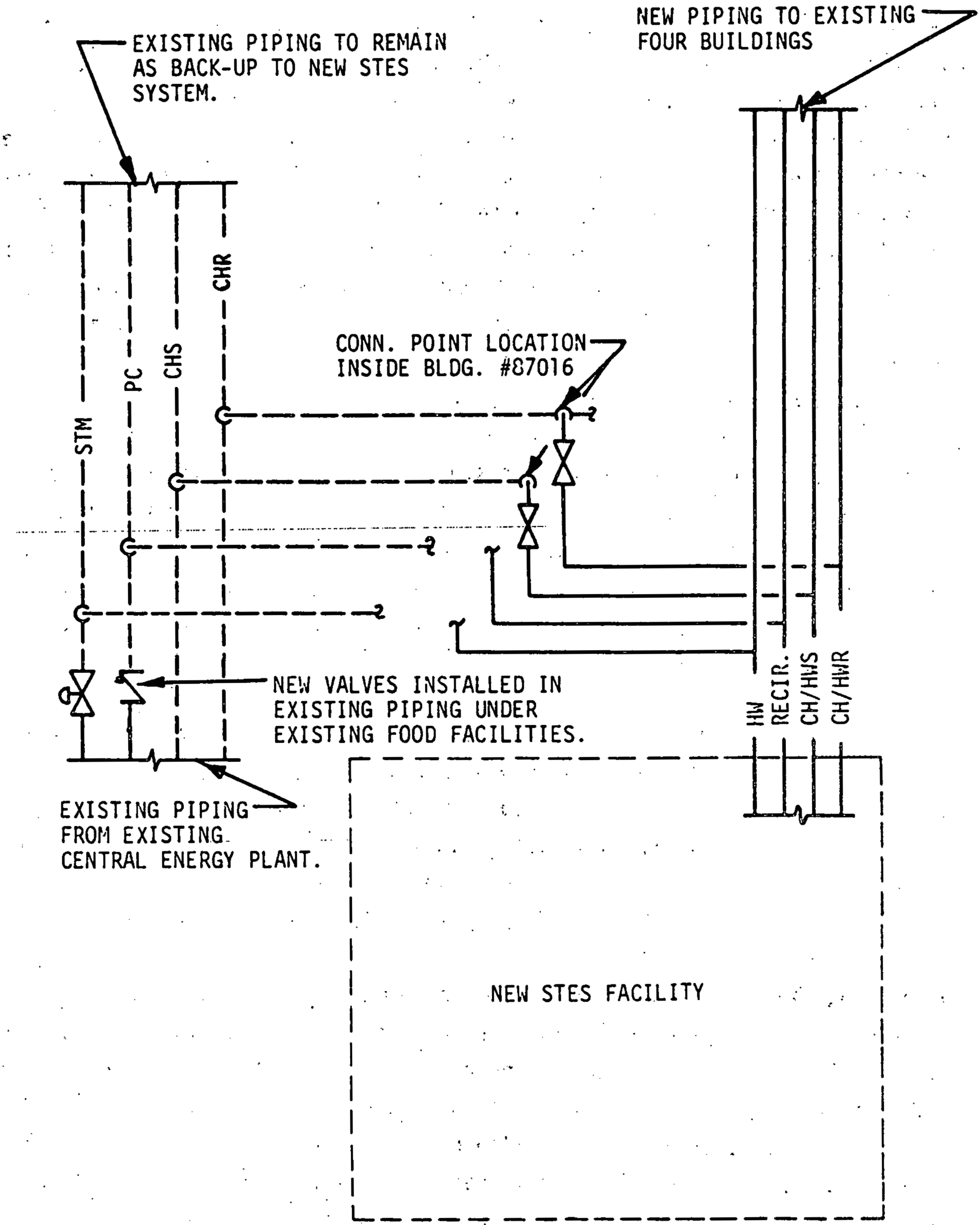
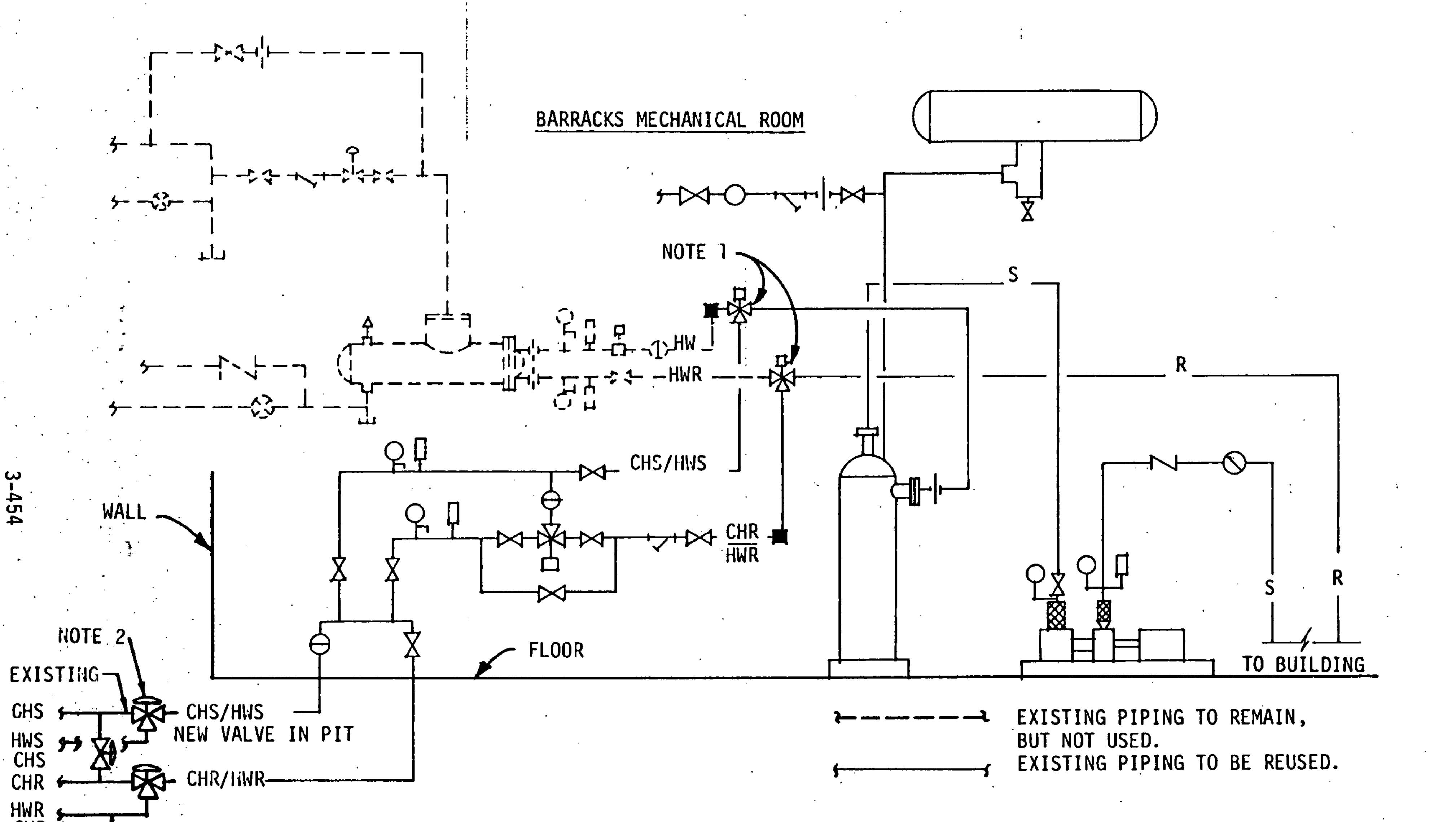


Figure 3.8-1. Piping Modifications



NOTE 1: MINOR MODIFICATIONS TO THE PIPING AND CONTROLS IN THIS AREA SHALL BE REQUIRED TO PRODUCE SATISFACTORY PERFORMANCE.

2: CONNECTION POINT FOR NEW CHILLED/HEATING SUPPLY & RETURN PIPING TO EXISTING CHILLED WATER SUPPLY & RETURN SHALL BE ADJACENT TO BARRACKS MECHANICAL ROOM WALL IN NEW VALVE PIT.

Figure 3.8-2. Piping Diagram - Barracks Building

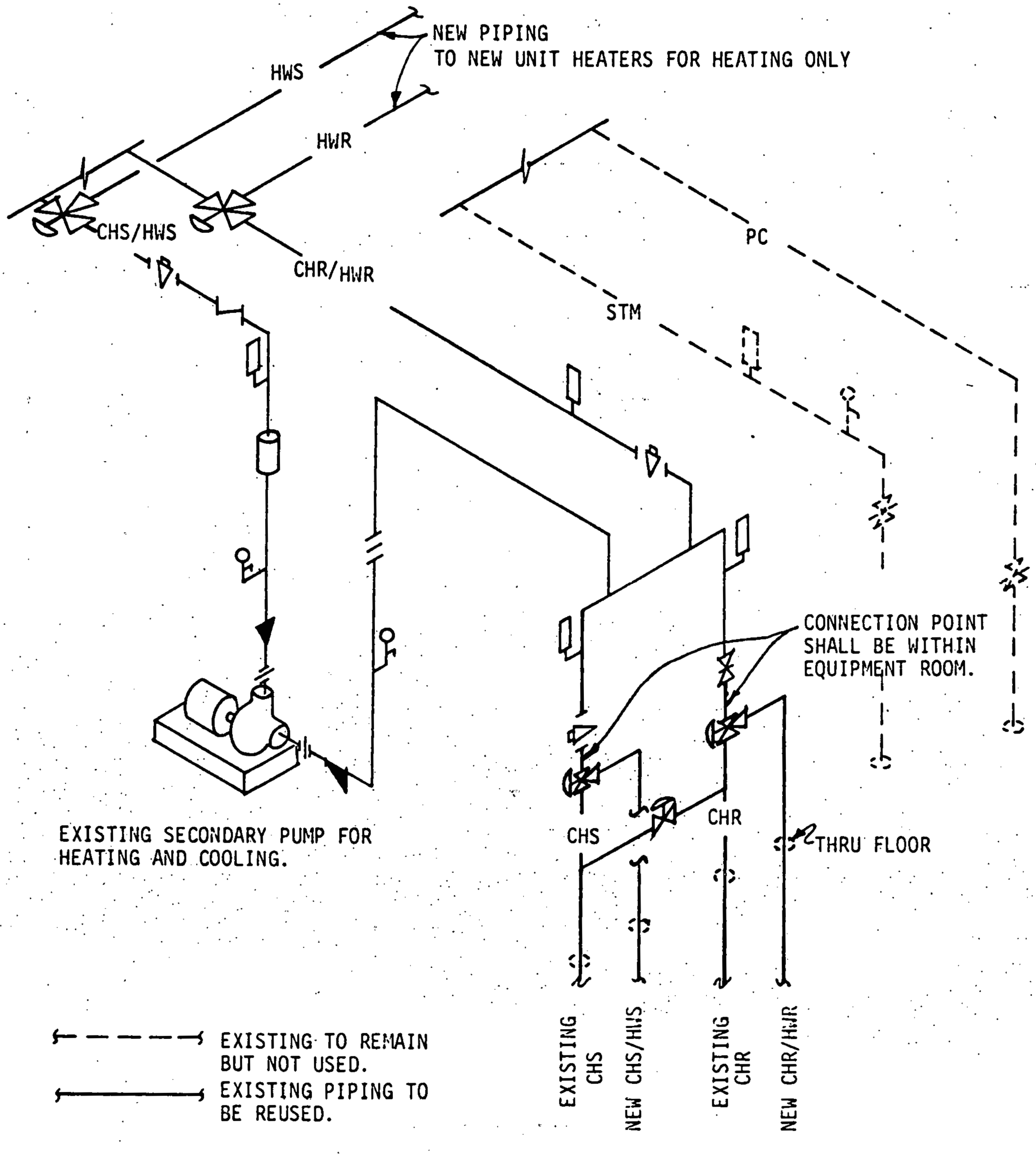


Figure 3.8-3. Company Administration and Supply Equipment Room Modifications

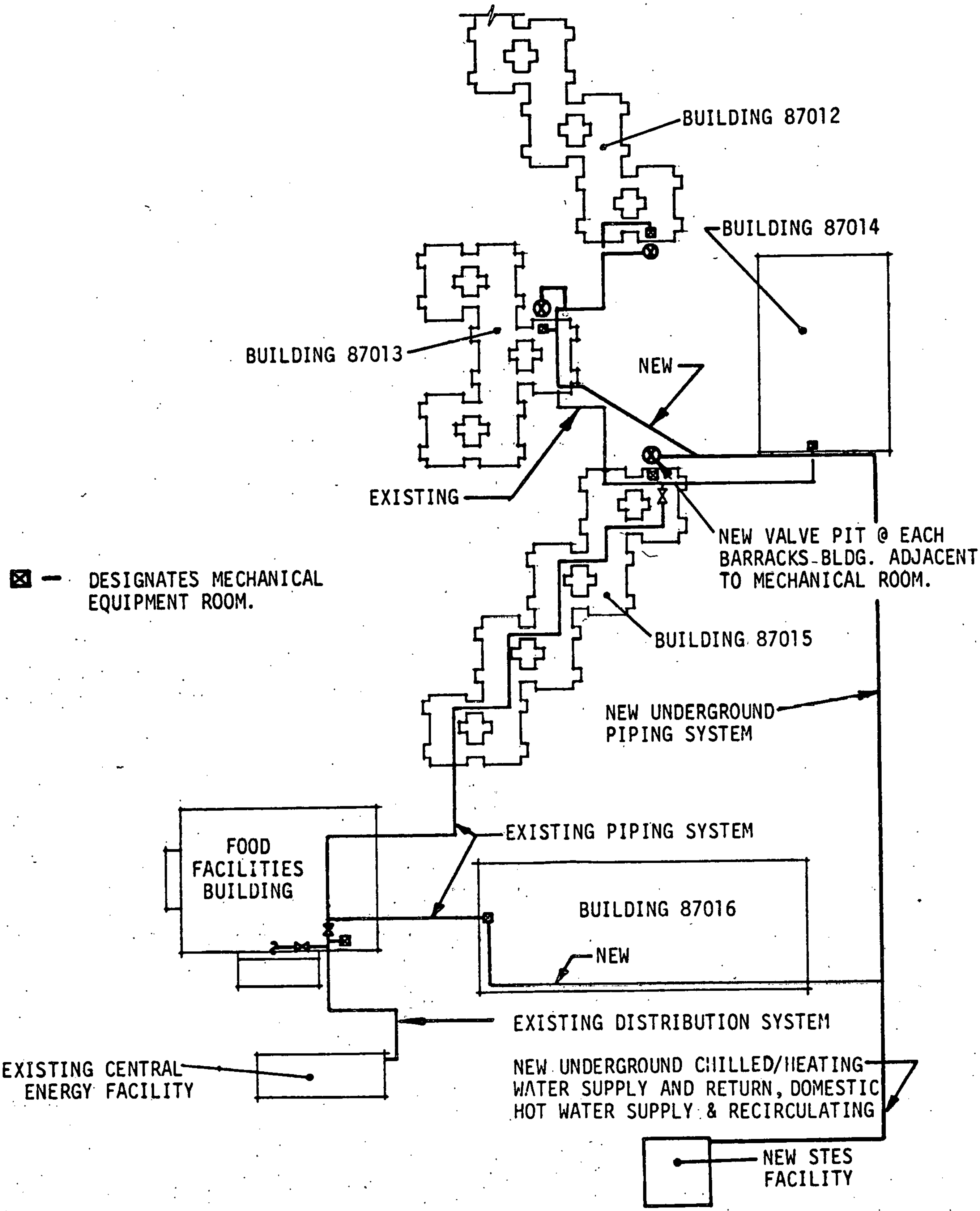
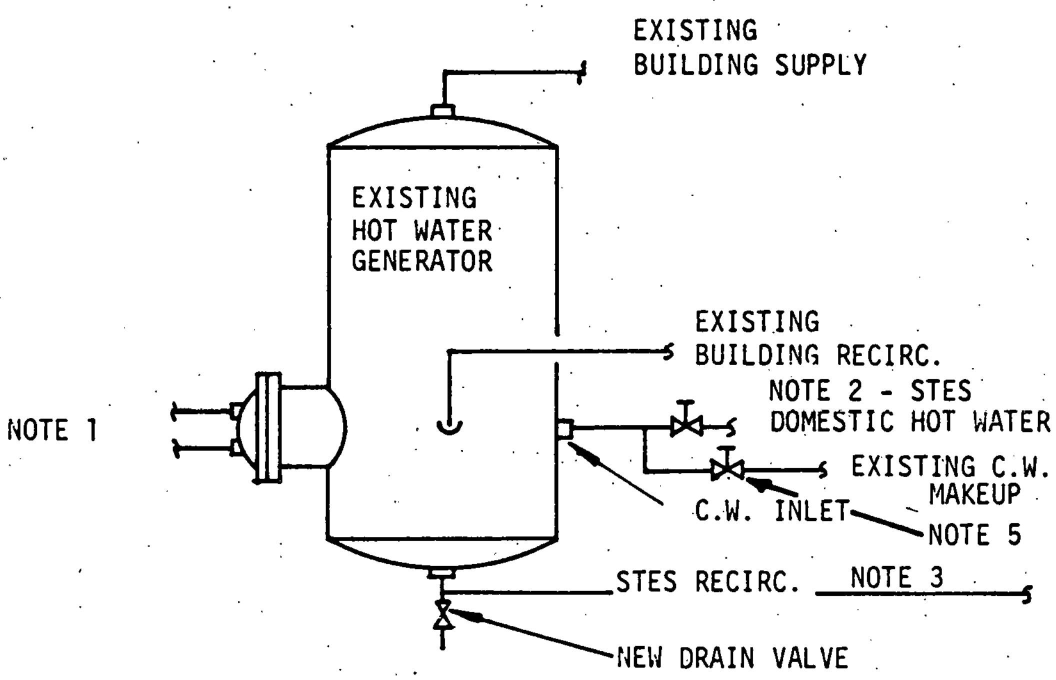
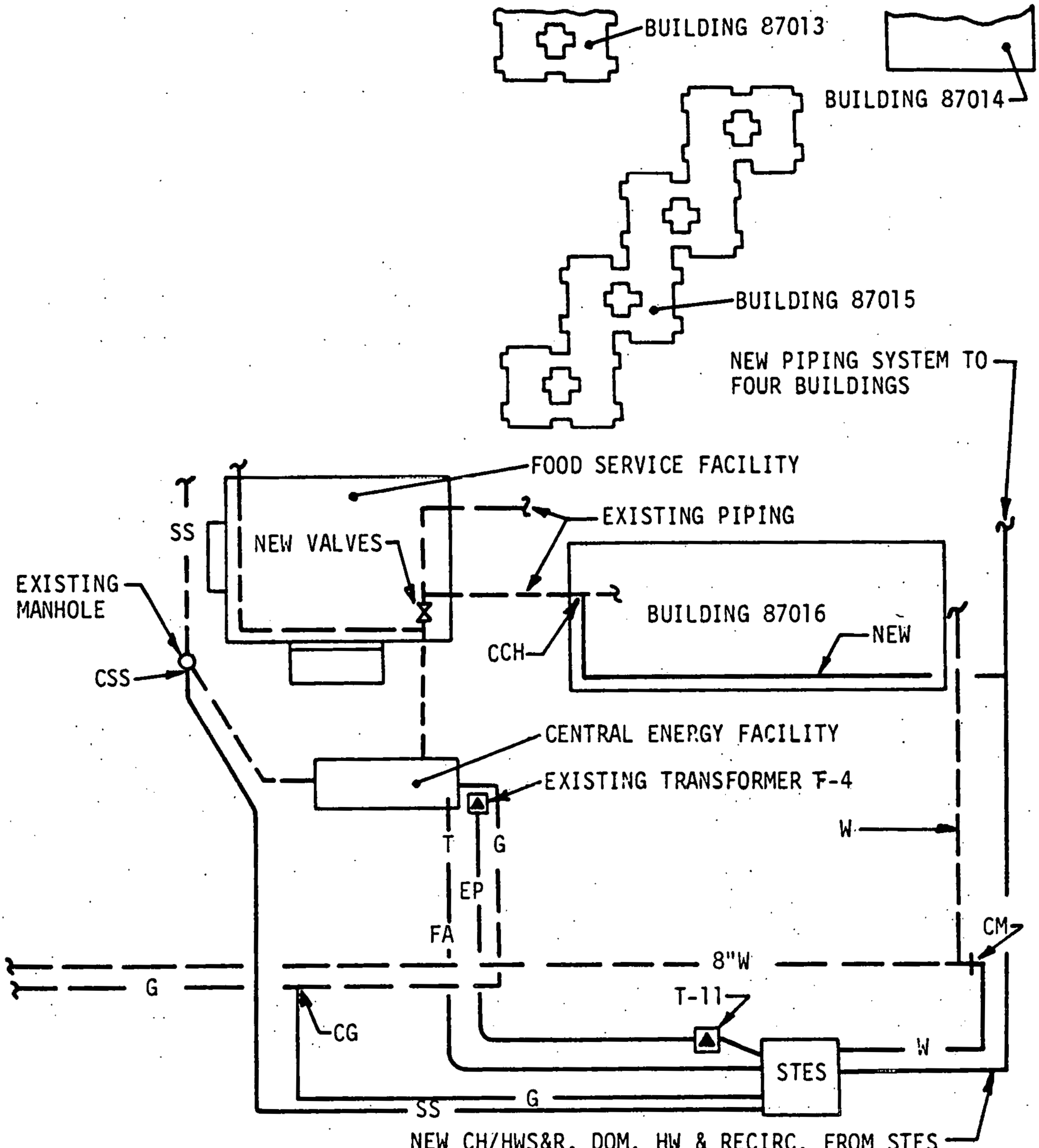


Figure 3.8-4. New Piping System



1. EXISTING STEAM PIPE TO REMAIN IN PLACE FOR STANDBY ONLY.
2. EXTEND STES-DOMESTIC HOT WATER PIPE TO COLD WATER INLET AND CONNECT TO HOT WATER GENERATOR TANK.
3. EXTEND STES DOMESTIC WATER RECIRCULATING PIPE TO EXISTING HOT WATER GENERATOR DRAIN AND CONNECT. ADD DRAIN VALVE.
4. THIS UTILIZATION OF THE EXISTING TANK ACTUALLY INCREASES THE STORAGE FACTOR OF THE STES STORAGE/GENERATOR SYSTEM.
5. VALVE NORMALLY CLOSED. OPENS ONLY IF EXISTING STEAM COIL ACTIVATED.

Figure 3.8-5. Barracks Domestic Water System



NOTES

1. ALL TOPOGRAPHIC INFORMATION TAKEN FROM DRAWING "FT. HOOD SOLAR TOTAL ENERGY TOPOGRAPHIC & SITE SURVEY" AND PREPARED BY DUNLAP & ASSOCIATES, CONSULTING ENGINEERS, KILLEEN, TEXAS FILE NO. K-78101, SHT. NO'S. 1 THRU 4, DATED JUNE 1978 AND CERTIFIED BY JAMES D. LEE, TEXAS R.L.S. #1467 ON JUNE 30, 1978.
2. SEE FIGURE 3.8-6A FOR LEGEND.

Figure 3.8-6. Utility Interface Points

LEGEND

— — — — —	=	EXISTING PIPE TO REMAIN IN SERVICE
————————	=	NEW PIPING
SS	=	SANITARY SEWER
G	=	GAS
W	=	CITY WATER SUPPLY
CH/HWS	=	CHILLED WATER/HEATING WATER SUPPLY
CH/HWR	=	CHILLED WATER/HEATING WATER RETURN
CW	=	COLD WATER (DOMESTIC)
HW&R	=	HOT WATER SUPPLY & RECIRCULATING (DOMESTIC)
CSS	=	CONNECTION POINT NEW SANITARY SEWER TO EXISTING
CG	=	CONNECTION POINT NEW GAS LINE TO EXISTING
CM	=	CONNECTION POINT NEW MAKE-UP WATER TO EXISTING CITY WATER
CCH	=	CONN. PT. NEW CHILLED/HEATING WATER SUPPLY & RET. TO EXISTING
T	=	TELEPHONE
FA	=	FIRE ALARM
EP	=	ELECTRICAL PRIMARY 12,470 VOLTS
ES	=	ELECTRICAL SECONDARY 480/277 VOLTS 3Ø, 4W

Figure 3.8-6a. Legend for Figure 3.8-6

3.8.6 FACILITY SUPPORT INSTRUMENTATION

Smoke and fire detection and alarm systems will be consistent with Base requirements and applicable codes, and tied into Base Systems at appropriate points.

3.8.7 MAINTENANCE

3.8.7.1 FIELD ACCESS AND BERMS

Maintenance of the access roads would be minimal. The only maintenance that would be required would be the addition of a topping layer of asphaltic concrete paving material approximately 10 to 15 years after construction. This additional paving would be more than sufficient to replace material that has failed due to fatigue.

Maintenance of the berms will be quite simple. The ground cover on the berms will require a fertilization program coupled with a disease and insect control program which could vary from year to year. Irrigation will also be necessary.

3.8.7.2 STES BUILDING

Maintenance of the STES Building would be minimal. Other than the normal janitorial services, the only maintenance that would be required for the building will be repainting of the interior partitions after four or five years (depending on use).

The HVAC system must be periodically inspected and lubricated in accordance with manufacturers' recommendations. These recommendations will be included in the STES operator's manual.

3.8.8 SPECIAL FEATURES AND PRECAUTIONS

The design of the STES building has taken into account the desire to have the building totally accessible to handicapped persons - both employees and public visitors. This has been accomplished through the use of a ramp for access to the upper level observation/display room and through the design of the toilet facilities making them usable by the physically handicapped. The design requirements for access by physically handicapped persons have been based on requirements of the Uniform Building Code 1976, and the ANSI A117.1 - 1961 Code.

3.8.8.1 HEALTH AND SAFETY

Health and safety is assured by meeting the design codes specified for the STES Building. Of special concern is access to the equipment in the mechanical room. However, for the safety of visitors, the mechanical room is separated from the habitable portion of the building.

3.8.8.2 ENVIRONMENT

There are a number of features in the design of the STES complex that have addressed environmental concerns. Earth berms have been incorporated to retain oil in the event of a rupture of either an oil storage tank or piping carrying oil. The earth berms contain the oil on the site until it can be cleaned up. The surface treatment of the ground around any equipment using oil or containing oil has been selected to prevent any long-term damage to surrounding soil areas.

Landscaping has also been incorporated to aid in the stabilization of bermed areas and to visually enhance the surrounding community. The use of landscape materials will soften the harsh, flat character of the surrounding site.

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