1359

DOCUMENT NO. 78SDS4235
DATE: DECEMBER 10, 1979
REVISION 1

SOLAR TOTAL ENERGY PROJECT, SHENANDOAH

OPERATING PLAN

DEPARTMENT OF ENERGY

CONTRACT NUMBER DE-AC04-77ET20260

GENERAL ELECTRIC

space division

DOCUMENT NO. 78SDS4235
DATE: DECEMBER 10, 1979
REVISION 1

SOLAR TOTAL ENERGY PROJECT, SHENANDOAH

OPERATING PLAN

DEPARTMENT OF ENERGY

CONTRACT NUMBER DE-AC04-77ET20260

TABLE OF CONTENTS

Section		Page
1	INTRODUCTION	1-1
	1.1 Purpose	1-1
	1.2 Document Format	1-1
	1.2.1 Operating Plan	1-1
	1.2.2 Final Test And Evaluation Plan	1-2
	1.2.3 Final Test Data Management Plan	1-2
2	SYSTEM DESCRIPTION	2-1
	2.1 Solar Collection Subsystem (SCS)	2-7
	2.1.1 Collector Field Subsystem	
	2.1.1.1 Collector Tracking Control	2-10
	2.1.1.2 Hydraulic Loop Temperature/Flow Control	2-13
	2.1.2 High Temperature Storage Subsystem (HTS)	2-10
	2.1.2.1 High Temperature Storage Tank Control	2-21
	2.1.2.2 Fluid Inventory Management	2-23
	2.1.3 Steam Generator Supply Subsystem (SGS)	2-24
	2.1.3.1 Fossil Fired Heater Control	2-24
	2.1.3.2 SGS Valve and Pump Control	2-26
	2.2 Power Conversion Subsystem (PCS)	2-26
	2.3 Thermal Utilization Subsystem (TUS)	2-42
	2.4 Control and Instrumentation Subsystem (CAIS)	2-47
3	OPERATOR RESPONSIBILITIES	3-1
4	SYSTEM OPERATIONS	4-1
	4-1 System Operation Timelines	4-1
APPENDIX A:	SUBSYSTEM OPERATING MODES	
A.1	WEEKDAY SYSTEM OPERATION	A-1
	A.1.1 Solar Collection Subsystem Operation	A-1
	A.1.1.1 Startup/Storage Depleted	A-1
	A.1.1.1.1 Fossil Heater Steam Generator Supply/Plant Cooling	A-1
	A.1.1.1.2 Threshold Insolation/Field Activation/ By-Pass Warmup	A-2
	A.1.1.1.3 Approach to Operation Temperature	A-4
	A.1.1.1.4 Series Transfer to Charge Tank Fully	A-6
	A.1.1.1.5 Fossil to Solar Transition	A-6
	A.1.1.2 Startup/Storage Charged	A-7

TABLE OF CONTENTS (Cont)

Section		Page
	A.1.1.2.2 Threshold Insolation/Activation	A-7
	A.1.1.2.3 Approach to Operating Temperature	A-8
	A.1.1.3	
	A.1.1.3.1 Collection/Charge Storage/PCS Direct Supply	A-8
	A.1.1.3.2 Collection/Discharge Storage/ Direct PCS Supply	A-10
	A.1.1.3.3 Storage Operation	A-12
	A.1.1.4 Shutdown	A-12
	A.1.1.4.1 Collector Field Shutdown	A-12
	A.1.1.4.2 Solar to Fossil Transition	A-13
	A.1.1.4.3 Nighttime Idle/Shutdown Heating	A-14
	A.1.2 Power Conversion Subsystem Operation	A-14
	A.1.2.1 PCS Startup	A-14
	A.1.2.2 Electric Load Following Total Energy Operation	A-15
	A.1.2.3 Shutdown	A-16
	A.1.3 Thermal Utilization Subsystem Operation	A-16
	A.1.3.1 Absorption Air Conditioning	A-16
	A.1.3.2 Heating	A-17
	A.1.3.3 Absorption Air Conditioning and Heating	A-17
	A.1.3.4 Excess Heat Dissipation	A-17
A.2	WEEKEND OPERATION	A-17
	A.2.1 Solar Collection Subsystem	A-17
	A.2.1.1 Startup	A-17
	A.2.1.2 Charge Storage	A-18
	A.2.1.3 Shutdown	A-18
	A.2.2 Thermal Utilization Subsystem Operation	A-18
	A.2.3.1 Absorption Air Conditioning	A-18
	A.2.3.2 Heating	A-18
A.3	DUAL MEDIA OPERATION	A-19
	A.3.1 Series Discharge/Dual Media Operation	A-19
	A.3.2 Level Control/Dual Media	A-19
A.4	EXPERIMENTAL MODES	A-19
	A.4.1 Turbine Bypass	A-19
	A.4.2 Series Fossil Fired Heater	A-19
APPENDIX B:	TEST AND EVALUATION PLAN	
B.1	OVERALL EXPERIMENT OBJECTIVES	B-1
B.2	SCHEDULE OF TEST ACTIVITIES	B-2
B.3	SYSTEM PERFORMANCE EVALUATION TEST	B-5
	B.3.1 System Data Set	B-5
	B.3.2 System Experimental Operation	B-6

TABLE OF CONTENTS (CONT)

Section		Page
	B.3.2.1 Electrical Power Variation	B-6
	B.3.2.1.1 Stand Alone Operation	B-6
	B.3.2.2 Constant Power Output	B-7
	B.3.2.3 Variable Utility Baseload	B-7
	B.3.3 Thermal Power Variations	B-7
	B.3.3.1 Turbine Bypass	B-7
	B.3.3.2 Series Fossil Fired Heater Mode	B-8
B.4	SUBSYSTEM AND COMPONENT TESTS	B-8
APPENDIX C:	TEST DATA MANAGEMENT PLAN	C-1
C.1	APPROACH	C-1
C.2	DATA ANALYSIS PLAN	C-2
	C.2.1 Data Processing	C-2
	C.2.2 Output Format	C-5

LIST OF ILLUSTRATIONS

Figure		Page
2-1	STES System Schematic	2-3
2-2	Site Layout	2-5
2-3	Layout, Mechanical Building and Area	2-6
2-4	LSE 7 Meter Diameter Parabolic Dish Solar Collector	2-9
2-5	Shenandoah CCU Interfaces	2-11
2-6	Collector Field Subsystem P&ID	2-15
2-7	High Temperature Storage Subsystem P&ID	2-17
2-8	Power Conversion Subsystem P&ID	2-27
2-9	Steam Turbine Generator Interface P&ID Requirements	2-31
2-10	Electrical System Instrumentation	2-35
2-11	Thermal Utilization Subsystem P&ID Requirements	2-43
2-12	CAIS Block Diagram	2-47
2-13	CAIS System Block Diagram	2-49
2-14	Solar Total Energy System Control Room Layout	2-50
2-15	Outline - Operators Console	2-51
2-16	Energy Management Panel (Upper)	2-52
2-17	Energy Management Panel (Lower)	2-53
4-1	Weekday STES Operating Timeline Case: April 13th SSMY	4-3
4-2	Weekday Solar Collector Field Timeline Case: April 13th SSMY	4-4
4-3	Weekday STES Operating Timeline Case: March 20th SSMY.	4-5
4-4	Weekday Solar Collector Field Timeline Case: March 20th SSMY	4-6
A-1	Fossil Heater Steam Generator Supply (Plant Cooling)	A-21
A-2	Threshold Insolation/Field Activation/Bypass Warmup	A-23
A-3	Approach to Operating Temperature	A-25
A-4	Series Transfer to Charge Tank Fully	A-27
A-5	Fossil to Solar Transition	A-29
A-6	Storage Steam Generator Supply	A-31
A-7	Threshold Insolation/Activation	A-33
A-8	Approach to Operating Temperature	A-35
A-9	Collection/Charge Storage/PCS Direct Supply	A-37
A-10	Collection/Discharge Storage/Direct PCS Supply	A-39
A-11	Storage Operation	A-41
A-12	Solar to Fossil Transition	A-43
A-13	Shutdown Heating	A-45
A-14	PCS Startup	A-47
A-15	Shutdown	A-49
A-16	Absorption Air Conditioning	A-51
A-17	Heating	A-53
A-18	Absorption Air Conditioning and Heating	A-55
A-19	Excess Heat Dissipation	A-57
A-20	Startup	A-59

LIST OF ILLUSTRATIONS (Cont)

Figure		Page
A-21	Charge Storage	A-61
A-22	Heating	A-63
A-23	Series Discharge/Dual Media	A-65
A-24	Level Control/Dual Media	A-67
A-25	Solar Boost	A-69
A-26	Turbine Bypass	A-71
B-1	System Operation - Preliminary Activities Schedule	B-4
B-2	Test Procedure	B-12
C-1	Test Data Management Plan	C-2

LIST OF TABLES

Table		Page
2-1	Command Table	2-11
2-2	Collector Field Tracking Control Loops	2-12
B-1	Weekday System Operating Modes	B-3
B-2	Weekend System Operating Modes	B-4
B-3	System Operational Data Set Details	B-9
B-4	Subsystem and Component Tests	B-11
C-1	Test Data Processing	C-6

LIST OF ACRONYMS

Acronym		First Section
AAC	Absorption Air Conditioning	2.3
CFS	Collector Field Subsystem	2.0
DOE	U.S. Department of Energy	Preface
GFE	Government Furnished Equipment	2.2
GPC	Georgia Power Company	1.2.2
HTS	High Temperature Storage	2.0
MTI	Mechanical Technology Incorporated	2.2
PCS	Power Conversion System	2.0
SCS	Solar Collector Subsystem	2.0
SGS	Steam Generator Supply	2.0
STEP	Solar Total Energy Program	Preface
STES	Solar Total Energy System	1.0
TUS	Thermal Utilization Subsystem	2.0
CAIS	Control and Instrumentation Subsystem	2.0
ES	Electrical System	2.0

PREFACE

The Solar Total Energy Program (STEP) is a separate activity of the National Solar Electric Applications Program and is supported by the U. S. Department of Energy. During the program, solar total energy systems will be designed, constructed, and operated to provide electricity and thermal energy to localized users such as Government and institutional facilities, apartment houses, shopping centers, and industrial and commercial plants, buildings, and complexes. The overall purpose of these energy systems is to demonstrate the high potential that solar energy offers for total energy systems, to develop a solar-oriented technology compatible with the high temperature demands of electric power conversion via thermodynamic cycles, and to provide the stimulus required so that private industry will agressively participate, both as manufacturers and users.

The Solar Total Energy Project, Shenandoah consists of the design, construction, operation, and technical evaluation of a solar total energy system providing power to a knitwear factory operated by Bleyle of America, Inc. The preliminary design phase of the project was completed in August, 1978, with the final design to be completed in the fourth quarter of 1979. The factory, initially equipped with its own independent (convertional) energy source, will derive greater than 50 percent of its annual energy needs from the sun when the solar energy system becomes operational in the first quarter of 1981.

The site for the STEP is located in the industrial park of Shenandoah, Georgia, which is about 25 miles south of the Atlanta airport on U.S. highway I-85.

The objective of the Project at Shenandoah is to design, construct, test, evaluate and operate a solar total energy system to obtain experience with large-scale hardware systems, narrow the uncertainty of cost and performance predictions, and establish an industrial engineering capability for subsequent demonstrations. The Project will be large enough to encounter problems typical of a full-scale demonstration and commercial application, and will utilize collected energy in a cost effective manner.

SECTION 1

INTRODUCTION

SECTION 1
INTRODUCTION

1.1 PURPOSE

The Solar Total Energy System (STES) being developed for the Solar Total Energy Project (STEP) at Shenandoah, Georgia will provide process heat, electric power, and space heating and cooling for the Bleyle Knitwear Plant. The plant will derive greater than 50 percent of its annual total energy requirements from the sun when the STES becomes operational. This document is the Operating Plan for the STES. Primarily, it will serve as an orientation handbook and reference guide for personnel (operating engineers, operators, technicians, system evaluation engineers, etc.) who will participate in the operation of the STES. In addition, it provides guidelines and definition for development of the plant operating and control system.

1.2 DOCUMENT FORMAT

1.2.1 OPERATING PLAN

The STES Operating Plan provides in Section 2 a description of the system and the major subsystems including: Solar Collection, Power Conversion, and Thermal Utilization. The locations of subsystems and principal components on the site, and within the Mechanical Building and Mechanical Equipment Area are provided; as is a description of the subsystem control elements, functions and interactions. To complete the facility description, the control room layout and a description of the primary control system equipment is provided.

Operator responsibilities are provided in Section 3. It identifies responsibilities for STES daily operation and maintenance, and provides a staffing plan.

Systems Operations, as described in Section 4, presents daily system timelines for automatic operation. These timelines reference descriptions of the system/subsystem operating modes selected during the day by the automatic control system, as provided in Appendix A.

In addition to describing the automatically selected operating modes, Appendix A provides a description of the system major experimental modes and control options which are operator initiated.

Appendices B and C provide the preliminary STEP Test and Evaluation Plan and Test Data Management Plan, respectively. The Preliminary Test and Evaluation Plan identifies the system test objectives, approach, and data set for performance evaluation, as well as the system experimentation and testing capabilities. The Preliminary Test Data Management Plan identifies the data requirements, data processing plan and candidate output formats. Both of the documents will be expanded during the STEP Construction Phase V into complete, separate documents suitable for use by all parties.

1.2.2 FINAL TEST AND EVALUATION PLAN

In the Final Issue of the Test and Evaluation Plan the system test description and data set will be updated to reflect the finalized CAIS. Similar test plans and data requirements will be provided for system experiments and subsystem tests.

In addition to the test objectives and descriptions, the milestone schedule for test operations at the site will be updated. Implementation of the tests in accordance with the schedule, and a facilities description directed toward test implementation will complete the plan.

1.2.3 FINAL TEST DATA MANAGEMENT PLAN

The finalized Test Data Management Plan will be based on the data format and content as determined by the Test and Evaluation Plan. The Management Plan primarily will provide requirements for processing data via an off-site computer system into clear, consise, meaningful formats for use in both system evaluation as well as design modification and refinement.

Additionally, the plan will identify procedures for handling and transmitting data from the site to the off-site processing center, and will describe the equipment associated with the handling. Personnel requirements, and the processing timetable to support the site operations schedule will also be provided.

SECTION 2

SYSTEM DESCRIPTION

SECTION 2

SYSTEM DESCRIPTION

The Shenandoah Project is a total energy system design featuring high temperature paraboloidal dish solar collectors with a 235 concentration ratio, a steam Rankine cycle power conversion system capable of supplying 100 - 400 kW(e) output with an intermediate process steam takeoff point, and a back pressure condenser to provide hot water for heating and cooling, thus providing a fully cascaded thermal energy utilization system. The design also includes an integrated control system employing the supervisory control concept to allow maximum experimental flexibility. The supervisory control concept provides the capability for the operator to exercise manual control over selected subsystems and components in addition to the automatic control functions.

Functionally, the Solar Total Energy System (STES) consists of three major hydraulic subsystems: the Solar Collection Subsystem (SCS), the Power Conversion Subsystem (PCS), and the Thermal Utilization Subsystem (TUS), as shown in Figure 2-1.

The SCS itself consists of three hydraulic subsystems: The Collector Field Subsystem (CFS), the High Temperature Storage Subsystem (HTS), and the Steam Generator Supply (SGS). These function to collect, store, and supply solar or auxiliary energy to the PCS.

The PCS converts a portion of the supplied energy to electricity, provides another portion of the energy as process steam, and transfers the remaining energy to the TUS to provide absorption air conditioning and heating.

Electrical power generation itself is provided via a steam driven Turbine-Generator (T-G) and electricity distributed via the Electrical Subsystem (ES).

System and subsystem automatic and manual control, monitoring, and safeguarding is provided via the Control and Instrumentation Subsystem (CAIS).

The STEP is located at the Shenandoah site, which as shown in Figure 2-2, covers an area of approximately 23,150 square meters (5.72 acres) of gently sloping land. As shown, the site includes the Solar Collector Field, the Mechanical Building and Area, a yard area, and an access way and parking area. Fencing is provided around the perimeter of the Collector Field and Mechanical Area.

The Solar Collector Field itself is piped with the main headers in an East/West direction, and the branches running North to South. Twelve branches, each with ten collectors, comprise the 120 dish field. The individual collectors are arranged in a repeating diamond pattern.

To the west of the collector field is the Mechanical Building and Area; a layout is provided as Figure 2-3. As shown, it consists of an enclosed building which houses primarily control equipment, electrical equipment, the turbine-generator and associated auxiliaries, the absorption air conditioner, and the site Visitors Center. The control room provides a specially conditioned environment for the control equipment located within.

As shown, the majority of the STEP mechanical equipment is located in the mechanical area, essentially a concrete pad surrounded by a retaining wall for spill containment, and is therefore exposed to the ambient environment. A second story observation deck, provided on the East/center of the area, contains the STEP meteorological instruments, in addition to providing a view of the site for visitors. As indicated the overall Mechanical Building and Area was designed to provide environmental protection only when deemed necessary by equipment and/or personnel requirements, and as a result most equipment is designed and located in an outdoor environment.

Functional descriptions of the STEP subsystems, directed primarily at operation and control are provided in the following subsections. A complete STEP design summary and specification is provided in the System Description, Document No. 78SDS4234.

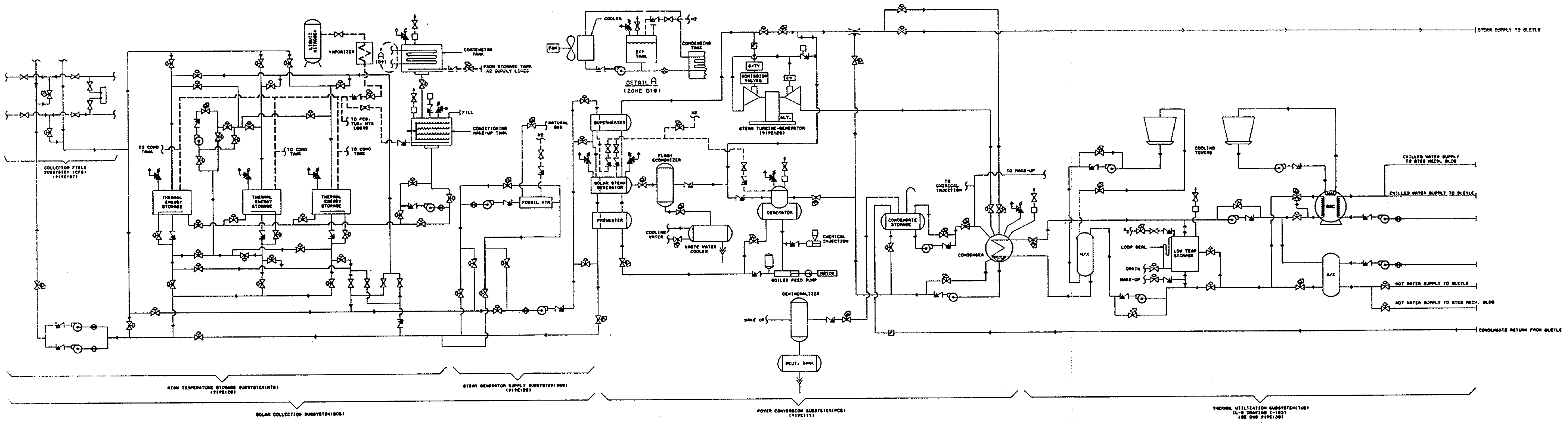


Figure 2-1. STES System Schematic

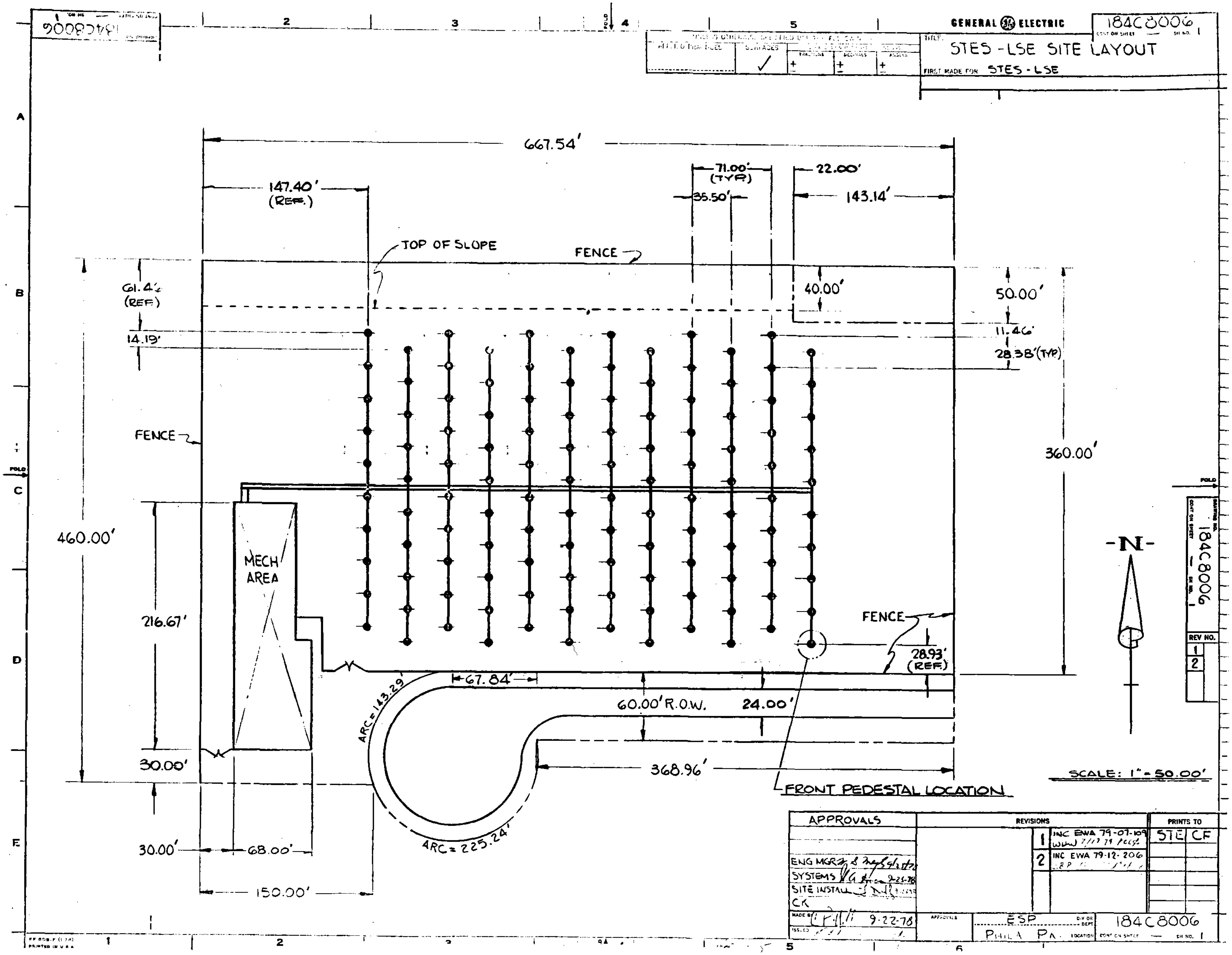
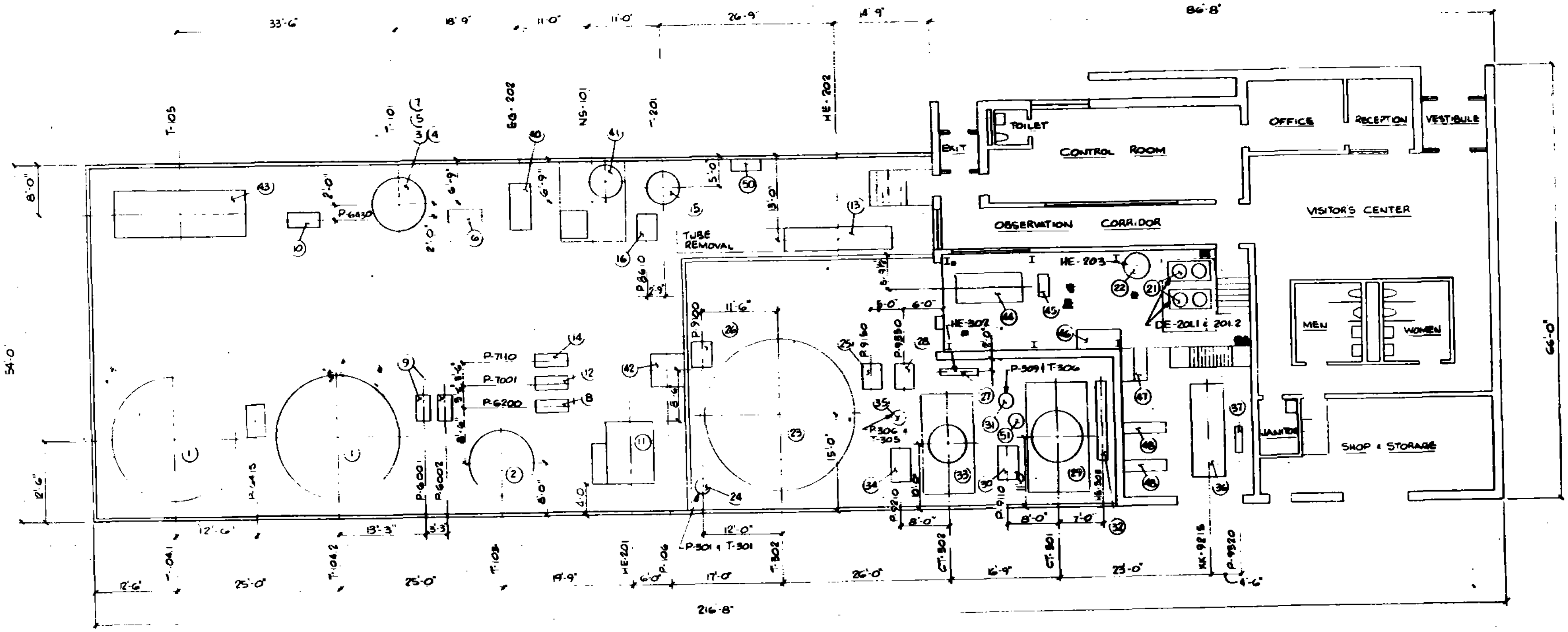
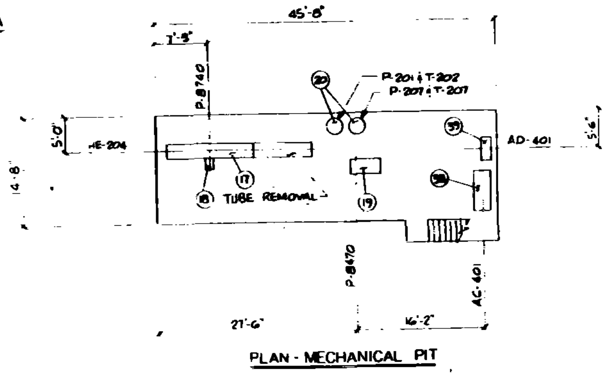


Figure 2-2. SITE LAYOUT





REF. NO.	EQUIPMENT NO.	EQUIPMENT NAME
1	T-104.1 & 104.2	Large Thermal Energy Storage Tank
2	T-103	Small Thermal Energy Storage Tank
3	T-101	Syltherm™ Make-up/Conditioning Tank
4	HE-102	Syltherm™ Vapor Condenser
5	HE-103	Syltherm™ Field Cooler
6	[illegible]	Syltherm™ Condenser Recirculation Pump
7	T-1[illegible]	Syltherm™ Cooler Expansion Tank
8	P-6200	HTS Transfer Pump
9	P-6001 & 6002	Collector Field Circulation Pumps
10	P-6430	Syltherm™ Fill Pump
11	HE-201	Fossil Fired Syltherm™ Heater
12	P-7001	Fossil Heater Circulation Pump
13	HE-202	Solar Steam Generator
14	P-7110	Steam Generator Supply Pump
15	T-201	Condensate Storage Tank
16	P-8610	Condensate Storage Pump
17	HE-204	Steam Condenser
18	P-8740	Condensate Pump
19	P-8470	Boiler Feed Pump
20	P-201, T-202, P-207 & T-207	Boiler Feedwater Chemical Injection Pumps & Tanks
21	DE-201.1 & 201.2	Demineralizer
22	HE-203	Deaerator
23	T-302	Low Temperature Storage Tank
24	P-301 & T-301	TUS Chemical Injection Pump & Tank
25	P-9160	Thermal Load Supply Pump
26	P-9100	Cooling Water Pump
27	HE-302	Bleyle Heating Heat Exchanger
28	P-9550	Heating Water Pump
29	CT-301	Excess Heat Cooling Tower
30	P-9110	Excess Heat Cooling Tower Pump
31	P-309 & T-306	Excess Heat Cooling Tower Chemical Injection Pump & Tank
32	HE-303	Excess Heat Cooling Tower Heat Exchanger
33	CT-302	AAC Cooling Tower
34	P-9210	AAC Cooling Tower Pump
35	P-306 & T-305	AAC Cooling Tower Chem Injection Pump & Tank
36	XK-9215	Absorption Air Conditioner
37	P-9320	A/C Chilled Water Pump
38	AC-401	Air Compressor
39	AD-401	Compressed Air Dryer
40	GG-202	Natural Gas Fired Generator
41	NS-101	Nitrogen System
42	P-106	Oily Waste Pump
43	T-105	Oily/Water Separator
44	-----	Turbine Generator Set
45	-----	Vacuum Pump
46	-----	Transformer
47	-----	Circuit Breaker
48	-----	Motor Control Center
49		[illegible]

Figure 2-3. Layout, Mechanical Building and Area

2.1 SOLAR COLLECTION SUBSYSTEM (SCS)

The three subsystem of the SCS (i.e. the CFS, the HTS, and the SGS) are shown in Figure 2-1. They circulate a common heat transfer fluid, Syltherm™800*. Discussion of the individual subsystems follows.

2.1.1 COLLECTOR FIELD SUBSYSTEM

The collector field subsystem includes 120 point focus parabolic dish collectors laid out in a repeating diamond pattern having North-South and East-West spacing as shown on the Site Layout Drawing Figure 2-2. The CFS will be capable of operating at collector outlet temperatures of up 672°K (750°F) using Syltherm™ 800 heat transfer fluid. The subsystem will operate with incident direct normal insolation values of 158 Watts/m^2 (50 BTU/hr-ft^2) to 1024-watts/m^2 (325 BTU/hr-ft^2). Fluid flow will be controlled to provide the design field temperature rise under conditions of varying direct normal insolation. The collector field is piped in an overall paralled flow configuration such that the full field temperature rise is achieved through each collector. The main field supply and return lines run in the East-West direction with branch collector supply and return lines in the North-South direction. The field is configured to recirculate fluid during warmup before delivering proper temperature fluid to the remainder of the system.

The main field manifolds are located in a trough, with bridges provided to allow access to the collectors by maintenance vehicles. Main manifolds and branches are tapered after branch and individual collector take offs; this is permissible due to reduced flow requirements. Branches are raised to reduce the length of up and down tubes. The interface with the main manifolds is designed to allow for thermal expansion of the junction of branch and mains.

*Registered Trademark of the Dow-Corning Corporation.

To reduce thermal losses the branch and collector lines are insulated in such a manner that the supply and return fluid lines are enclosed in a common insulation system.

The collector itself is a seven meter diameter parabolic dish, as shown in Figure 2-4. Principal components are the 21 stamped aluminum petals, a cavity receiver, the structural support assembly, and the collector driving mechanism.

Control of the collector field, as is typical of the STES subsystems, is achieved via a combination of local controllers and the central or supervisory controller. The local controller, in the case of the collector field, is designated as a Collector Control Unit. This is a specialized unit; one is provided and mounted on each of the 120 dishes. Each CCU contains functions as follows:

Sun tracking electronics
2 RTD signal conditioners
4 sun energy tracking sensors
2 potentiometer position signal conditioners
Control electronics and relays for 3 collector movement motors
Serial communications station and associated control functions
2 limit switch signal conditioners
Manual Control Panel
Power supplies
One 4-20MA current driver
One 0 to -10VDC Universal input signal conditioner

Two primary control functions are primed for the CFS; collector tracking control, and hydraulic loop temperature/flow control. Tracting control is via a combination of the CCU and central processor, while hydraulic control is essentially via the central processor. Discussion of the control functions (and associated alarms) and the instrument signal inputs and outputs to/from the controller to provide the functions will follow for both tracking and hydraulic control. However, it should be first noted that all signal inputs and outputs within the collector field are via the CCU, which interfaces with

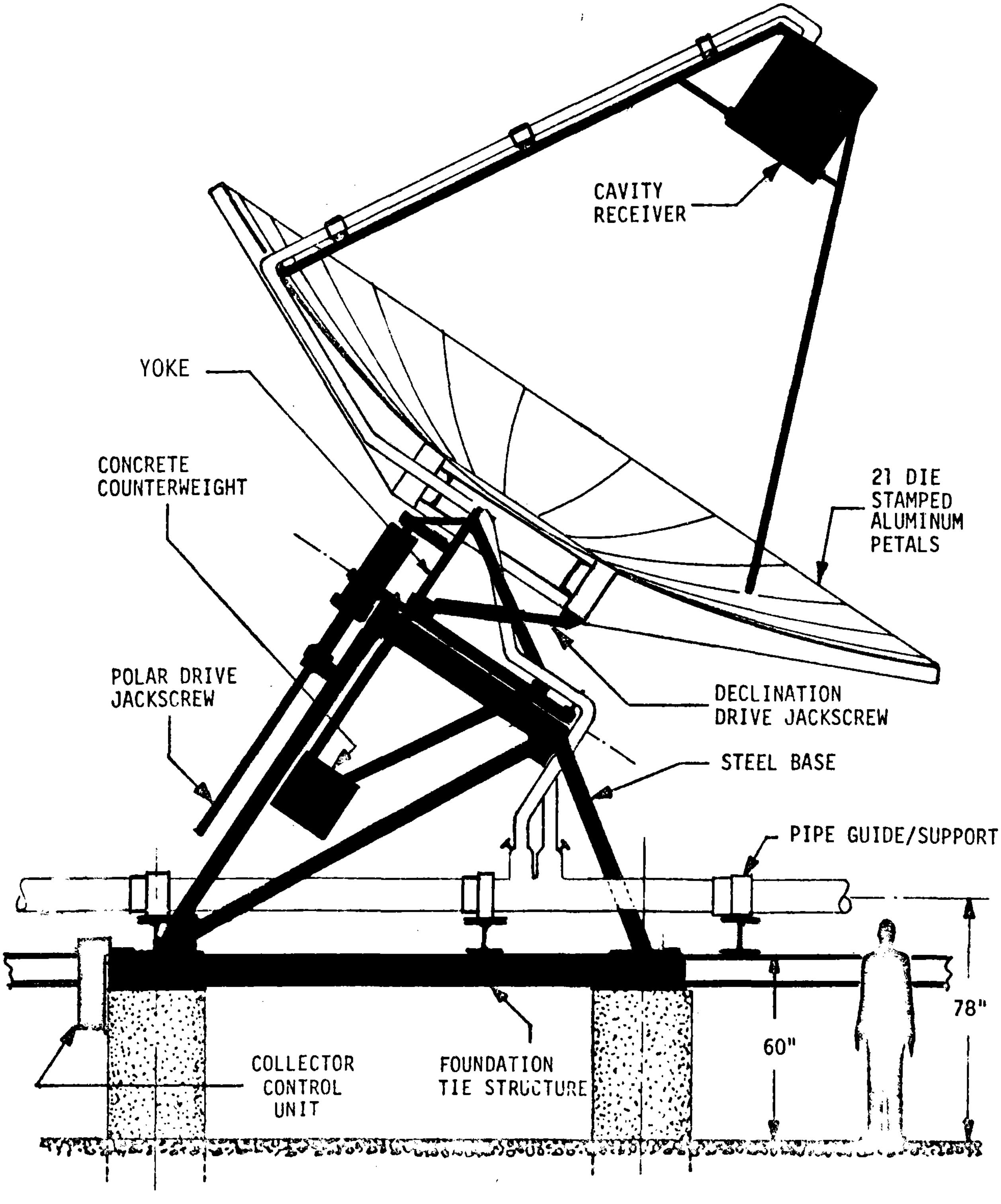


Figure 2-4. LSE 7 Meter Diameter Parabolic Dish Solar Collector

a serial data link, a Buffer Control Unit (BCU), which controls signal exchange, and then the central processor, as is discussed in Section 2.4. Figure 2-5 depicts the normal signal input/output interface with the CCU.

2.1.1.1 Collector Tracking Control

Collector tracking control is provided via a hybrid system utilizing both central computer position tracking and CCU (local controller) OPTO-Electronic tracking.

The computer control provides logic for collector positioning during acquisition and stow and during periods of intermittant cloudiness when the insolation level is inadequate for optical tracking. It positions the collector to within ±.2° (as sensed via the polar and declination position pots) of the computed sun position for optical tracking enable, and resumes collector positioning should the sensed position error exceed ±1.1, as a result of cloudiness or another transient. Table 2-1 lists the computer output commands for collector tracking control. These are controlled by the BCU, decoded by the CCU, and via control electronics and relays with the CCU, provide the desired collector motor activation.

OPTO-electronic tracking, when enabled, utilizes receiver mounted fibre optics and CCU internal electronics to sense sun position and command motor activation as is necessary to maintain a ±.17° absolute position error.

A specialized tracking command, defocus, is also provided to activate all three collector motors in a predetermined direction to minimize the amount of time that the sun's focused energy will be incident upon the receiver, in the event of a potentially hazardous transient. This command can originate from either the CCU or certral control. The CCU generated defocus results if the temperature sensed by either receiver RTD exceeds the predetermined setpoint, as discussed in Section 2.1.1.2. A reset is

Table 2-1. Command Table

COMPUTER COMMAND	BINARY MBS			LSB	HEX EQUIV.
POLAR DRIVE 1 EAST	1	0	0	1	9
POLAR DRIVE 2 EAST	0	1	0	1	5
BOTH POLAR DRIVES EAST	1	1	0	1	D
POLAR DRIVE 1 WEST	1	0	0	0	8
POLAR DRIVE 2 WEST	0	1	0	0	4
BOTH POLAR DRIVES WEST	1	1	0	0	C
DECLINATION SOUTH	0	0	1	1	3
DECLINATION NORTH	0	0	1	0	2
BOTH POLAR WEST & DECLINATION NORTH	1	1	1	0	E
NORMAL OR CLEAR	0	0	0	0	0
AUTOTRACK ENABLE	0	0	0	1	1
DEFOCUS	1	1	1	1	F
DEFOCUS RESET	0	1	1	1	7

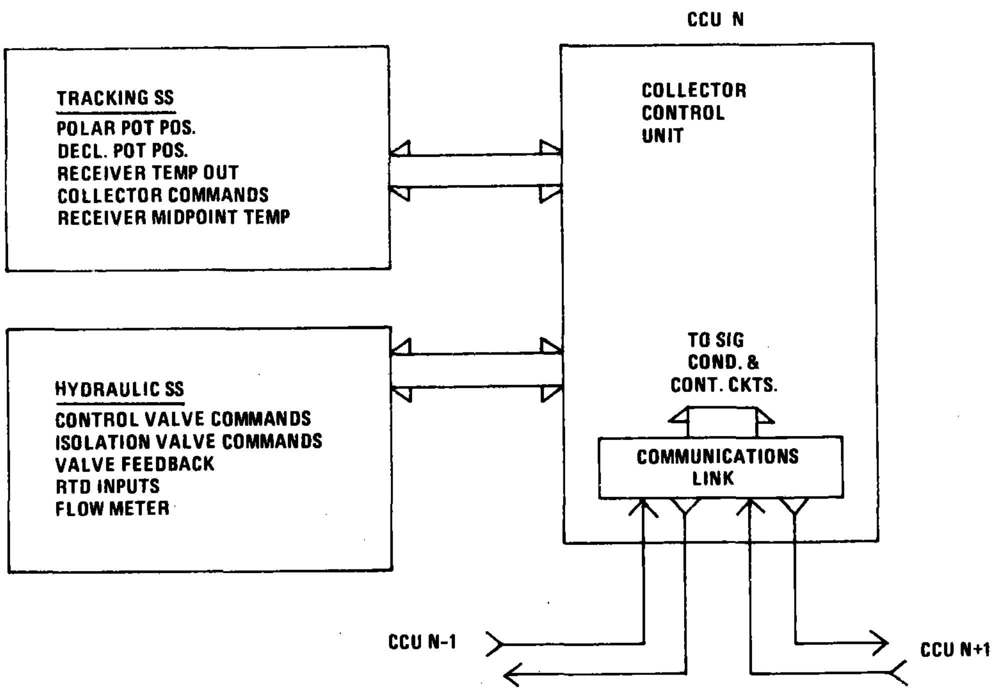


Figure 2-5. Shenandoah CCU Interfaces

required following a defocus; this is provided via the computer, as is indicated in Table 2-1 or via the local manual panel. The command signal input capabilities available in the manual control panel provided in the CCU are as follows:

1. Polar Motor 1 East and West
2. Polar Motor 2 East and West
3. Declination Motor North and South
4. Defocus Reset
5. DC Power On-Off
6. Computer Inhibit - All computer commands except Defocus, Defocus Reset, and Clear
7. Declination Defocus Direction
8. Manual Clear

Collector field tracking control loops are summarized in Table 2-2 below, in addition to control functions, these loops describe alarm functions, and reference interfaces, with the Energy Management Panel (EMP) on the operator console. The EMP interfaces are discussed in detail in Section 2.4. Alarm levels are also provided in the loop descriptions. Three alarm levels exist within the STES; Level 1 alarms have an audible alarm and dedicated indicators on the EMP; Level 2 alarms have an audible alarm and are logged on the page printer; Level 3 alarms are local audible and/or visible only. Additionally, the loops identify the software algorithms which provide the logic for loop implementation. The algorithms are described in Appendix A in the mode descriptions.

Table 2-2. Collector Field Tacking Control Loops

Computer Position - Polar and declination position pots mounted on the collector provide signals via the CCU/SERIAL DATA LINK to the central processor. Based on the tracking algorithms, the central computer generates appropriate position commands. Position pots, and the computer command status, are used to reflect the collector status on the EMP.

Table 2-2. Collector Field Tracking Control Loops (Cont)

OPTO-Electronic Tracking - Four receiver mounted fibre optics sensors provide signals to the CCU, which in turn, based on internal electronics, generates commands for collector movement. Optics signals are CCU internal only.
DEFOCUS - Defocus is a CCU internal generated command based on receiver temperature sensors and electronics, or is a computer command as is discussed in Computer Positioning above.

2.1.1.2 Hydraulic Loop Temperature/Flow Control

The hydraulic control for the collector field is provided via the central computer, which based on signal inputs from the field, and control algorithms in the CAIS software, directs final control elements within the field to provide the desired control action. The primary control function within the field is to control flow during startup and normal operation to provide the desired dish outlet temperature. Alarm and safeguarding functions are also provided.

The instruments and control elements within the collector field which provide the hydraulic control are shown in Figure 2-6, Collector Field Subsystem Piping and Instrument Diagram (P&ID), with the exception of the field pumps, main flow valves, and instruments, which are shown in Figure 2-7, High Temperature Storage P&ID. Signal inputs and outputs within the field are via the serial data link and the BCU, as in the case for the tracking control. Signal inputs and output for the equipment shown in Figure 2-7 are, however, via the Energy Utilization Processor (EUP) to the central processor, as will be discussed in Section 2.4. As shown in the Figures, the control elements include: a flow control and flow isolation valve for each of the 12 branches, a special shadowing flow control valve for seven of the dishes which are shadowed less than the others, a main field flow control valve and two pumps. Signal inputs for control are as follows: two receiver temperatures for each dish (although only one is shown in Figure 2-6), branch outlet temperature for each branch, field inlet and outlet temperature, field inlet and outlet flow, pump on/off and isolation valve open/closed status for each pump or valve, and position feedback for each of the flow control valves (branch, shadow, and main). The control loops, which also include identification of alarms and EMP interfaces, are as follows:

1. Receiver Outlet Temperature - Two temperature sensors mounted on each dish provide signals via the CCU/SERIAL Data Link to the central processor. Temperature control within the processor is by branch. The highest temperature and the average temperature are considered. Based on the startup and normal operation receiver setpoint algorithm, and an appropriate PID algorithm, the computer generates a valve position command to provide the desired outlet temperature, for the hot dish. Shadowing valves are positioned in the same manner, except only the one dish, and not an entire barnch, is considered. If the hot dish temperature exceeds the average temperature by the operator selectable setpoint, the computer defocuses the dish via the command table (as discussed in 2.1.1.1), and this is indicated via the collector status on the EMP. The temperature of the hot (controlling) dish is also indicated on the EMP.

   Should either temperature signal from a receiver exceed the defocus setpoint, the CCU generates an internal defocus command, (as disucssed in 2.1.1.1), and a level 1 alarm is generated.

2. Main Flow Control - Branch flow valve positions are provided via the serial data link to the processor. Based on the positioning algorithm the main valve is set to maintain the branch valve settings within the desired span. Branch and shadow valve positions are indicated on the EMP.

3. Pump Control - Main valve position is provided via the EUP to the central processor. Based on the pump control algorithm, the two pumps are turned on/off via a computer signal to the pumps relay (as will be discussed in Section 2.3). Pump on/off status is provided via the EUP to central; status is indicated on the EMP; and status failure results in a level 1 alarm, signaling transition to second pump and/or field defocus.

   During startup an alternate loop is employed. Field flow is provided via the EUP to central. An algorithm activates one or both pumps to provide an adequate flow. Failure to provide adequate flow results in a level 2 alarm and a call for heating. Continued failure results in field stow.

4. Branch Temperature Monitoring - Branch outlet temperatures are provided via the serial link to the processor. If the branch temperature drops below the minimum, a level 2 alarm is given, and the branch defocused. Branch temperatures are also indicated on the EMP.

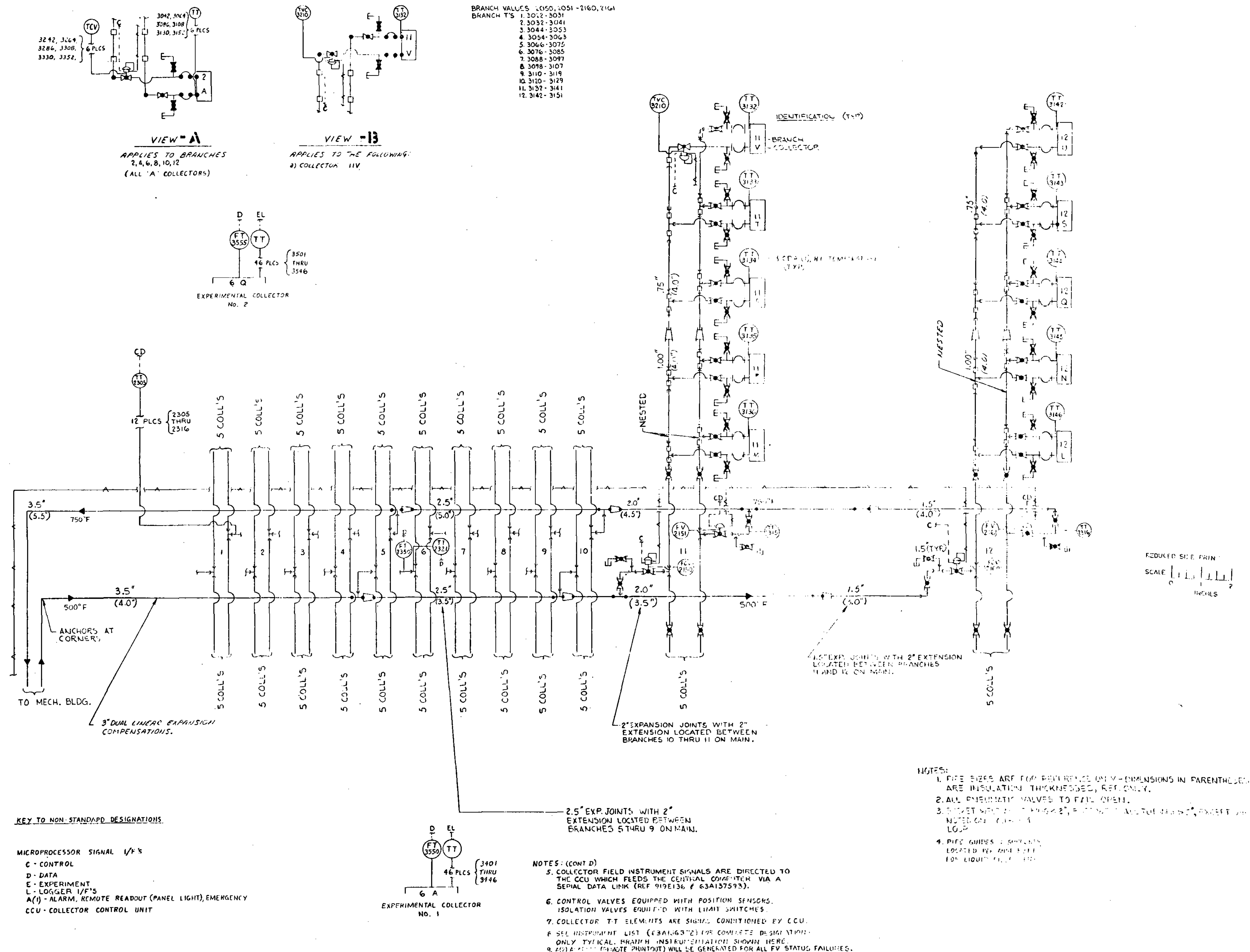


Figure 2-6. Collector Field Subsystem P&ID

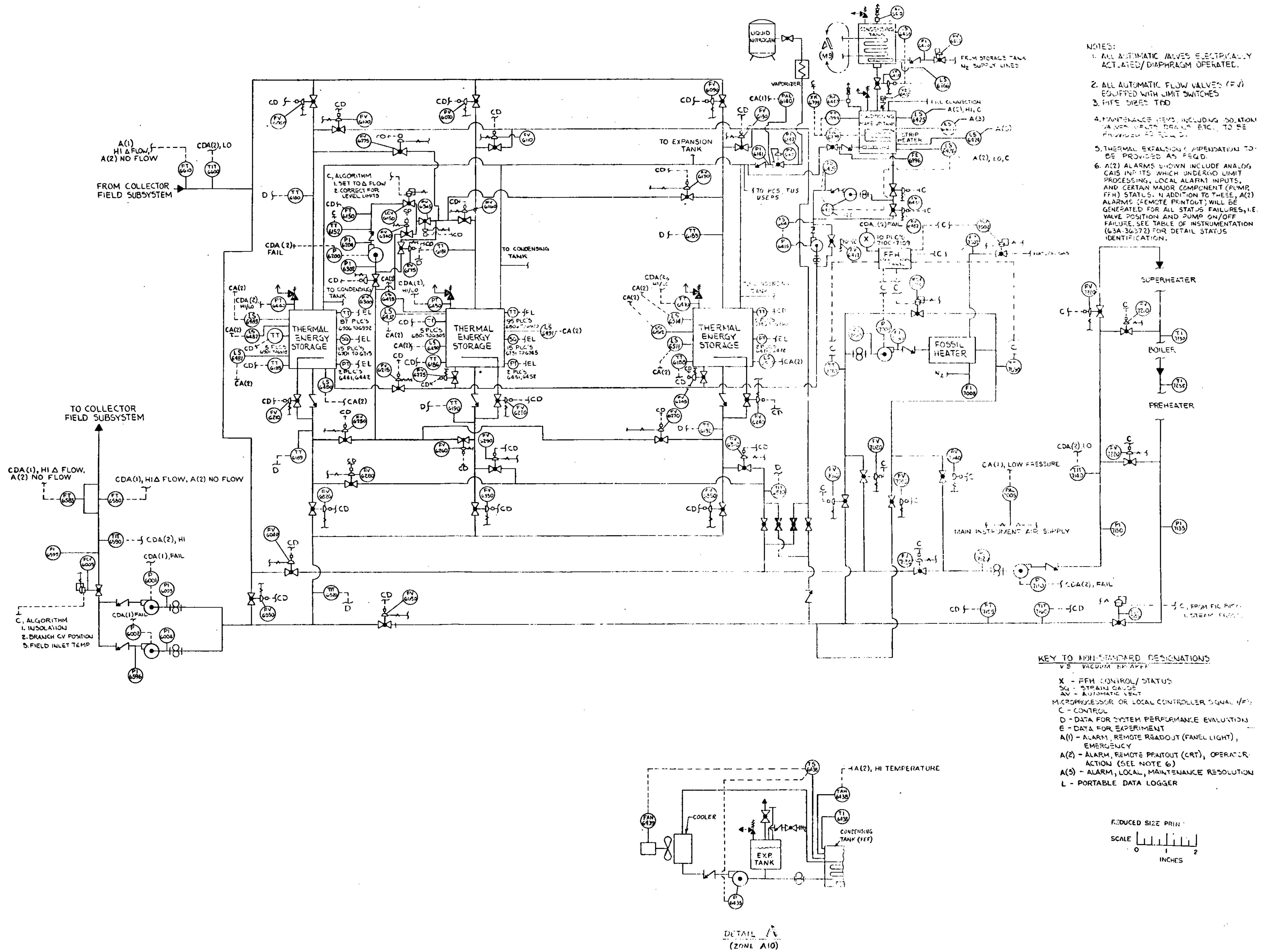


Figure 2-7. High Temperature Storage Subsystem P&ID

5. Field Temperature Monitoring - Field inlet and outlet temperatures are provided via the EUP to the processor. Field inlet temperature is used to determine to proper dish setpoint during startup (as discussed in Receiver Outlet Temperature above); triggers a level 2 alarm if the temperature exceeds the maximum inlet setpoint, resulting in field defocus; is used for temperature correction for the field inlet flow and is indicated on the EMP. Field outlet temperature is used to control selected field mode; i.e. recirculating, storage supply, direct SGS supply, and shutdown, as discussed in Appendix A. Low temperature triggers a level 2 alarm, and mode shift. Field outlet temperature is used for temperature correction of the field outlet flow, and is also indicated on the EMP.

6. Field Flow Monitoring - Field inlet and outlet flows are provided via the EUP to the central processor. Field inlet flow is used to provide pump control during startup (see above), and to set series transfer flow as discussed in 2.1.2. Field inlet and outlet flows are compared, if the outlet is less than the inlet by the setpoint, a level 1 alarm is given and defocus initiated. If either sensor senses "No" (minimal) flow a level 2 alarm is initiated and defocus occurs, and the pumps are turned off.

7. Flow Isolation Valve Status - Isolation valve open/closed status is provided via the Serial Data Link to the processor. A status failure generates a level 2 alarm, resulting in the processor signalling branch defocus. Branch valve status is indicated on the EMP.

2.1.2 HIGH TEMPERATURE STORAGE SUBSYSTEM (HTS)

The High Temperature Storage Subsystem (HTS) consists of three storage tanks (one small and two large), a storage transfer pump, a fluid conditioning and makeup tank, two fluid transfer pumps, a vapor condensing tank and cooler, a nitrogen supply subsystem, interconnecting piping and valves, and process instrumentation, as shown in Figure 2-7. The HTS provides storage of thermal energy when the solar collected energy exceeds the PCS demands, and supplies stored thermal energy when the PCS demands exceed the collector field output. Thermal energy is stored at temperatures up to 400^{o}C, (750^{o}F). This is achieved via a combination of a solid sensible heat storage media (iron ore pellets) which fills the tanks, and the circulating Syltherm^{TM}800 heat transfer fluid, which either trickles through or fills the storage bed, depending on the operating mode as discussed below. Mechanical equipment within the subsystem, excepting the tanks, either provides circulation of the fluid, or fluid inventory management (i.e. conditioning/make-up, off-gas-recondensing, inert gas overpressure, etc.).

The HTS tanks are designed for a total iron ore volumetric capacity of 264 cubic meters (9323 cubic feet), distributed among three tanks as follows: two tanks have a capacity of 120 cubic meters (4254 cubic feet), and one has a capacity of 23 cubic feet (815 cubic feet). Storage operation may be in either the trickle or dual media mode with trickle being the primary mode.

In the trickle mode, fluid is pumped into the tank through an upper distribution mainfold and allowed to trickle down through the solid storage media, either extracting or providing heat to the media, depending on mode. In the dual media mode, the tanks are filled with fluid, and flow is in either direction, up for discharging and down for charging. In the trickle mode, which is the limiting case, the HTS tankage is allocated 31300 liters (8266 gallons) of Syltherm^{TM} 800, and provides 63.36 kilojoules (60 million BTU's) of energy over a nominal charge/discharge cycle. During the charging and discharging cycles, for either mode of operation, fluid is passed from tank to tank in a series mode; this allows full utilization of the storage energy of each tank.

The make-up/conditioning tank holds new charges of heat transfer fluid to provide make-up. Prior to use, the fluid is subjected to a conditioning process which consists of heating and a bubbling nitrogen scrub. Pumps are provided to supply makeup to the HTS tanks and back.

Exhaust vapors from the HTS tanks contain reusable fractions, these are condensed in the vapor conditioning tank and returned to the make-up conditioning tank. To promote fluid condensation, the condenser includes an internal heat exchanger and external air cooled oil cooler.

A self-contained nitrogen system is provided, which primarily supplies the HTS, but also provides N_2 to SGS, PCS, and TUS users. The nitrogen subsystem provides an inert blanket for the HTS tanks and the condenser cooler expansion tank, and also bubbling N_2 for the conditioning/make-up tank.

Control of the HTS is primarily via the central processor, with some local control. All processor input/output signals interface via the EUP. The principal processor control function is to line up the tanks and transfer pump as is appropriate to provide required charging and discharging.

Monitoring tanks status, and alarming/failsafing is provided in support of this, including fluid level control (dual media only), to assure the proper tank is safely on line. Local control functions provide conditioning tank temperature control, condensing tank temperature and level control, and pump No-flow lockouts. The N_2 system is essentially self-contained. Discussion of the control instruments, elements and loops will follow, these will be structured by principal control functions.

2.1.2.1 High Temperature Storage Tank Control

The instruments and control elements for the HTS tanks are as shows in Figure 2-7. Elements for each tank include the following: charging on/off valves (two), discharging on/off valves (two), series transfer top or bottom (two) on/off valves, and one expansion compensation valve. Instruments for each tank are as follows: bed temperature sensors (seven), sump temperature sensor, dual medial level switches (two), and tank overpressure. Control loops for the HTS tanks are summarized below:

1. Valve Position - Based on system requirements for storage tanks, i.e. charging, discharging, expansion, etc. and tank status, i.e. charged, discharged, partially charged, etc, the central computer positions the HTS valves according to the control algorithms to provide the desired function. Valve open/closed status is provided to the processor; status failures result in level 2 alarms, and tank nonavailability. Tank status is indicated on the EMP.
2. Temperature Profile - Bed and sump temperatures are provided via the CUP to the processor. Via algorithm, the processor determines tank status, and also if a tank mode shift is required. If so, valves are repositioned as described above. Temperature status (charged/discharged) and temperature indication for a selected sensor is provided on the EMP.

3. Level - High and low level switches for both dual and trickle mode are provided to the processor.

   In the trickle mode the high level switch generates a level 2 alarm, and the alarming tank is rendered unavailable via the processor for manually initiated maintenance The low level switch generates a level 1 alarm, with the same action taken.

   In dual media, alarm codes are similar, however the alarms trigger make-up feed/bleed operation as discussed below for the conditioning make-up tank.

4. Pressure - Tank N_2 pressure is provided to the processor. High or low pressure results in a level 1 alarm, and the tank status rendered unavailable.

Associated with the HTS tanks is the series transfer pump. Elements and instruments for series transfer pump control, as shown in Figure 2-7, include: the flow control valve, the flow direction valves (four), and a flow and temperature sensor. Control loops are summarized as follows:

1. Flow Rate - Series transfer flowrate is provided to the processor via the EUP, as is flow temperature for temperature compensation. A PID algorithm is used to generate the flow control valve setting to provide the desired setpoint, and valve position feedback provided. The setting is the difference between the field and SGS flows, as discussed in Appendix A. A no-flow condition results in turning off the transfer pump.

2. Flow Direction Valve - Based on mode, the processor position valves to provide bottom to top (trickle or dual media) or top to bottom (dual media only) flow direction. Valve open/closed status is provided to the processor; status failures result in series transfer unavailability.

3. Pump Control - Based on mode, the processor activates the series transfer pump. Pump status is provided, failure results in a level 2 alarm, and inhibits series transfer.

2.1.2.2 Fluid Inventory Management

Control of the inventory management equipment is via a combination of local and processor control. Control elements, instruments, and loops for this equipment are summarized as follows:

Conditioning Make-up Tank

1. Temperature - Temperature control during the conditioning process is provided via a local senser and indicating controller which adjusts the heat input to the tank to provide the desired temperature. The heater on/off status is provided to the processor, to inhibit use of the tank while conditioning is underway. The status is indicated on the EMP.
2. Level - Four level switches/alarms are provided for the tank. The uppermost generates a level 1 alarm; indicating the tank level in the hot condition is too high; and resulting in maintenance dispatch.

   The second level switch generates a level 3 (local only) alarm, and indicates to maintenance personnel that the tank is full during the cold fill operation.

   The third level switch provides a level 3 alarm, and locks out use of the strip heaters when they aren't totally submerged.

   The fourth switch provides a level 1 alarm, and inhibits use of the makeup pump.
3. Flow - The makeup supply and return pumps (two), and the flow direction valves (three), are positioned via the processor (just as the tank valves are) to provide the desired flow. Note, however that the pumps are positioned automatically only during dual media level control, trickle level control is operator initiated. Valve and pump status are provided to the processor, failures result in level 2 alarms and mode inhibit. Local flow switches provide local lockout of the pump, if a no flow condition is sensed.

Condensing Tank

1. Level - A high and low level switch are provided, via local interlock they open and close the tank exit valve.
2. Temperature - A local temperature indicator and switch are provided; they activate via local relays the cooler circulating pump and fan. A level 2 high temperature alarm is provided indicating cooler malfunction and resulting in maintenance dispatch.

Nitrogen System

1. Pressure - The nitrogen system is provided with self-contained pressure regulators and automatic vents which control N_2 flow for the users. Local pressure indicators, and flow indicators are provided where applicable. A level 1 alarm is provided for low pressure which triggers system shutdown.

2.1.3 STEAM GENERATOR SUPPLY SUBSYSTEM (SGS)

The Steam Generator Supply Subsystem contains the SGS pump, SGS mode selection valves, (three) the Fossil Fired Heater (FFH), and the FFH mode selection valves (five), as shown on Figure 2-7. The SGS provides heated Syltherm™ 800 to the steam generator, and positions the supply valves to provide either superheated, saturated, or bypass steam generator operation as determined by system requirements. Based on solar availability, the FFH is activated, and valves positioned to provide backup heat supply. The fossil heater is a horizontal radiant-convection type natural gas fired heater. It is provided as a packaged unit, complete with local control panel and safety interlocks. A circulating pump and bypass line are also provided to maintain a continuous, minimum flow through the heater.

Control of the SGS, as is typical of the STES subsystems, is achieved via bith the processor and local controllers. Valve and pump control and associated failsafing is via the processor only, FFH control is provided via a combination; these are discussed below.

2.1.3.1 Fossil Fired Heater Control

Control on the FFH is achieved via input commands from the central processor to the heater local control panel; the commands are based on system requirements for heater operation. These commands are decoded/interpreted by the FFH panel, and it in turn directs/activates the heater and associated equipment (pumps, valves, etc.) to provide the desired operation. Heater status is then provided via the panel interface back to the central processor, and indicated on the EMP.

The heater unit itself is provided with alarms and failsafe devices, which automatically shut down the unit, and indicate via a level 2 alarm, as well as change in heater status, the shutdown condition.

The alarms are as follows:

1. Flame failure
2. Electric failure at the panel
3. High tubewall temperature
4. Instrument air failure
5. High temperature or pressure of the heating medium
6. High pressure
7. Low oil flow
8. Low oil pressure
9. Low oil temperature

The heater outlet temperature is provided to the processor, as is a capability for the operator, via the CRT and keyboard (as discussed in Section 2.4), to ramp/adjust the heater setpoint. This capability is not required during normal (automatic operation) as the processor provides ramping as is necessary, but is used during off-normal heater operation (conditioning, subsystem temperature maintenance, etc) as well as initial system operation, to enhance system control flexibility.

2.1.3.2 SGS Valve and Pump Control

Valve and pump control for the SGS is typical for the SCS in general; based on desired mode, as determined by the processors, position or on/off signals are provided to the appropriate elements. Status feedback is provided; failures result in level two alarms, and system mode shift or shutdown as is determined via the software algorithms. Additional control associated with the SGS is as follows:

1. Flow - Steam generator flow (and corresponding temperature for temperature correction) is provided to the processor. This is used to determine the series transfer flow rate setpoint, as discussed in Section 2.1.2.1.

2. Temperature - Steam generator inlet temperature is provided to the processor. The temperature is used in control of mode shifts (solar to fossil, etc.) and a low temperature triggers a level two alarm and SGS shutdown after an appropriate time delay.

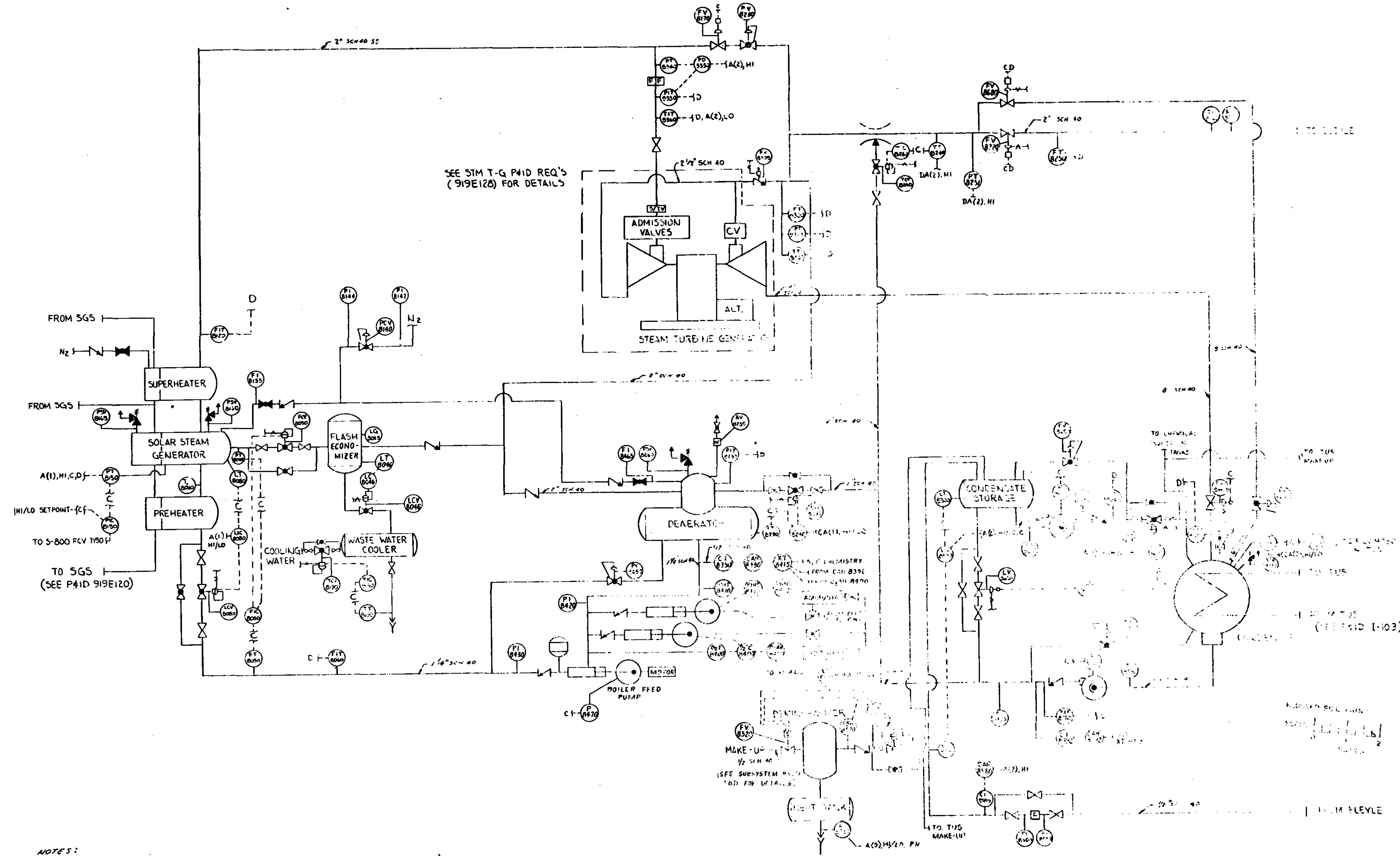
3. Pressure - A low instrument air pressure triggers a level 1 alarm and STES shutdown. This critical alarm, although not necessarily associated with the SGS as all STES automatic valves are air operated, is discussed here due to P&ID location.

   Local pressure indicators are provided at the steam generator inlet/outlet and at the pump suctions/discharges for startup and maintenance operation.

2.2 POWER CONVERSION SUBSYSTEM (PCS)

The Power Conversion Subsystem consists of the following principal mechanical components: steam generator, steam driven turbine-generator, condenser, condensate storage tank, condensate storage pump, condensate pump, boiled feedwater pump, demineralizer, chemical injection subsystem, desuperheater and the Bleyle steam supply equipment, as shown in Figure 2-8. The PCS and its components function to startup and operate in the desired mode, as determined by the processor or operator, and to shift mode and shutdown as is directed by either processor/operator or subsystem internal alarms. PCS modes are as follows:

1. Turbine-generator, with process steam, and heat provided to the TUS for cooling and heating.



NOTES:

1- LOCAL CONTROL COMPONENTS (TRANSMITTERS, CONTROLLERS, CONTROL VALVES) SHOWN AS ELECTRICAL CONTROL/PNEUMATIC OPERATION TO INDICATE FUNCTIONS. SPECIFIED LOCAL CONTROLS MAY BE OTHERS, HOWEVER TRANSMITTER INTERFACE WITH PCS MICROPROCESSOR IS TO BE ELECTRICAL (4-20 mA)
2- MODE SELECTION VALVES (POSITIONED via PCS μP) TO BE ELECTRICAL CONTROL/PNEUMATIC OPERATION. VALVES TO BE EQUIPPED WITH POSITION SWITCHES
3- VENT, DRAIN, SMALL PIPE SIZES, AND ADDITIONAL PV'S AND OTHER SPECIALTIES NOT SHOWN. STANDARD ENGINEERING PRACTICE TO BE EMPLOYED.
4- ADDITIONAL COOLING WATER CONNECTIONS NOT SHOWN
5- ELECTRICAL SYSTEM/INSTRUMENTATION SHOWN ON SAC INTERFACE DRAWING C3.
6- COMPONENT LOCAL CONTROL/PANEL INTERFACE TBD. REFER TO COMPONENT SPECIFICATIONS
7- SEE INSTRUMENTATION LIST (63A136372) FOR DETAILS.

KEY TO NON-STANDARD DESIGNATIONS
AV - AUTO VENT
X - COMPONENT CONTROL/STATUS
MICROPROCESSOR (μP) OR LOCAL CONTROLLER SIGNAL I/F'S
C - CONTROL
D - DATA FOR SYSTEM PERFORMANCE EVALUATION
E - DATA FOR EXPERIMENT
A(1) - ALARM, REMOTE READOUT (PANEL LIGHT), EMERGENCY
A(2) - ALARM, REMOTE READOUT (CRT), OPERATOR ACTION
A(3) - ALARM, LOCAL, MAINTENANCE RESOLUTION

Figure 2-8. Power Conversion Subsystem P&ID

2. Turbine-generator, and heat to the TUS for heating and cooling.
3. Process steam and heat to the TUS for cooling and heating.
4. Process steam only.
5. Heat to the TUS only.

More descriptions are provided in Appendix A.

Control of the PCS operation is achieved via a combination of local and processor control. The local controllers provide for steady state maintenance of system operating variables (temperature, pressure, level, etc), and alarming, while the processor provides for mode control. Discussion of the PCS components and their control, both processor and local, follows:

Steam Generator

The Steam Generator provides superheated steam to the steam turbine-generator using heat transferred from the recirculating heat transfer fluid in the Solar Collection Subsystem, Syltherm^{TM}800.

The Steam Generator also provides low pressure saturated steam for process and thermal use during turbine outage. The Steam Generator employs controlled blowdown to limit contaiminant levels. A flash tank flashes a portion of the blowdown flow to steam for reuse via supply to the deaerator, and the remainder is passed through the waste water cooler to drain. A nitrogen blanket is provided to the steam generator during extended shutdown to prevent O_2 contamination. Control loops associated with the steam generator include:

a. Pressure - A local controller sets the Syltherm ^{TM}800 flow valve (heat input) to maintain the desired steam pressure; the measured pressure is also transmitted via the EUP to the processor for a Level 2 alarm function (turbine trip/subsystem shutdown) on high pressure. Local and EMP indication of pressure is also provided. The steam pressure setpoint (superheated or saturated) is provided via the processor to the local controller.

b. Level - A local controller sets the feedwater flow valve to maintain desired boiler level; high and low level alarm discretes generated by the controller are transmitted to CAIS for a Level 1 alarm function (turbine trip subsystem shutdown). Local indication of level is also provided.

c. Blowdown - A local controller sets the blowdown flow valve to maintain blowdown flow as a desired percentage of feedwater flow. Feedwater is indicated locally.

d. Waste Water Temperature - a local controller sets the cooling water flow valve to maintain desired waste discharge temperature. Local indicator also provided.

Main Steam Filter

The main steam filter removes particulate contaminants in the entering steam at a maximum 1 PPM to a level of .1 PPM, with 95% of the particles less than 4 microns.

Instrumentation associated with the filter includes:

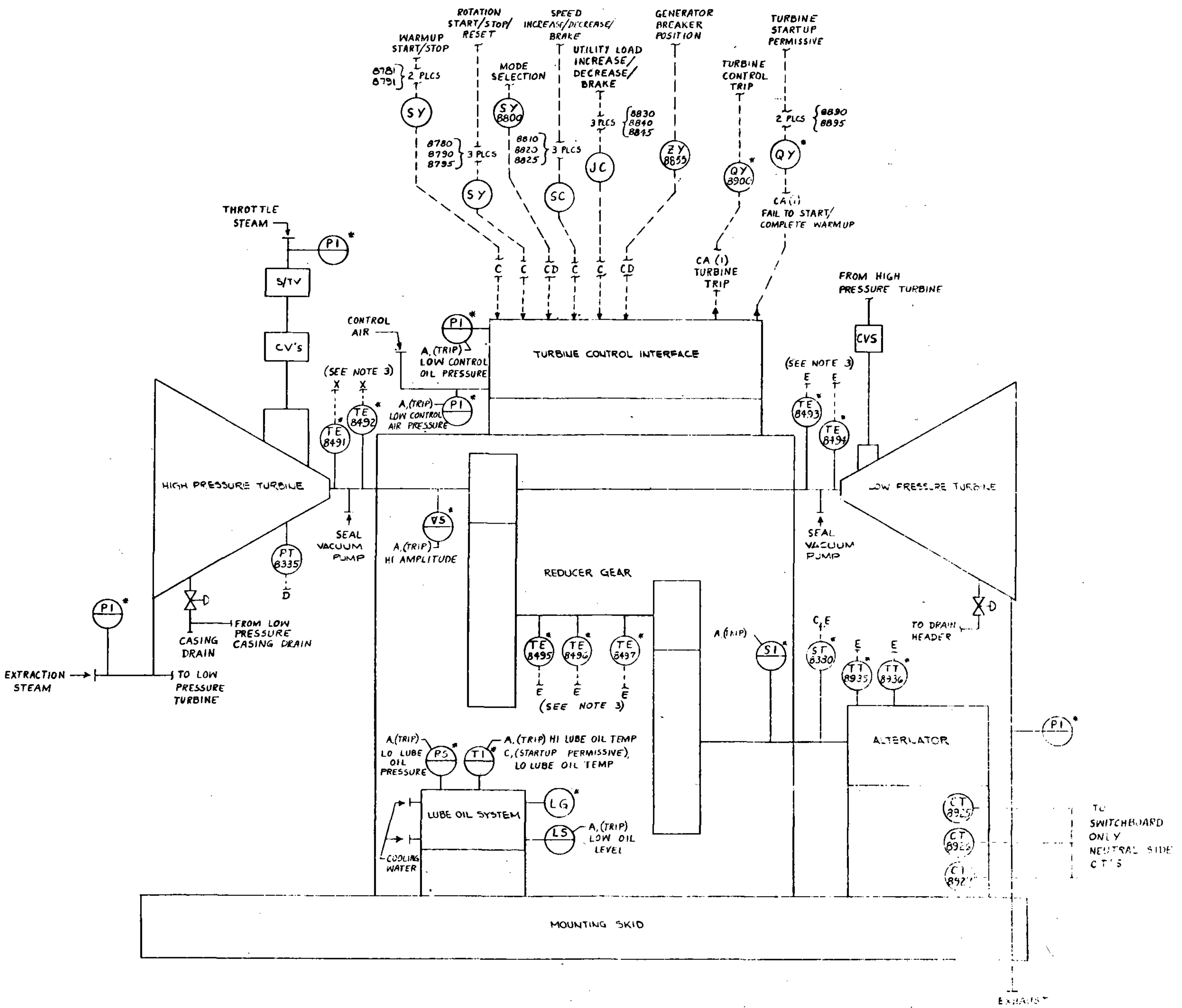
a. Steam Pressure - Upstream and downstream pressure indicators/transmitters indicate ΔP for maintenance; a high ΔP Alarm transmits a discrete to CAIS for a Level 2 alarm function (turbine bypass mode).

b. Steam Temperature - The Filter downstream temperature is transmitted to CAIS to initiate a low temperature Level 2 alarm function (turbine bypass mode). Local indication is also provided.

Steam Turbine-Generator

The steam turbine-generator (T-G) generates 480 volt, 3 ϕ , 60 Hz electric power in the range of 100-400 KW_e while operating in parallel or independent from the utility (GPC). (100 KW_e independent operation to be verified.) The turbine provides superheated steam from a controlled extraction port for supply to the Bleyle Plant and deaerator. Exhaust steam from the turbine passes to the condensor for thermal utilization. Also provided with the turbine is a vacuum pump subsystem which provides a vacuum at high and low pressure shaft seal discharge ports.

The turbine-generator is provided as a complete and integrated unit, including a local control panel and system. Control of the T-G is similar to the FFH. Input commands from the processor are provided to the T-G local panel based on system requirements. The commands are interpreted by the T-G panel, which in turn directs T-G operation. T-G status is then provided back to the processor. T-G input and status output commands are shown in Figure 2-9, the Turbine-Generator P&ID requirements.



NOTES:

1. ALL MECHANICAL EQUIPMENT SHOWN PROVIDED GFE (MTI), SEE STES/STM T-G ICD FOR DETAILS
2. ⊖* STANDARD DESIGNATOR INDICATES GFE (MTI) ORIGINAL EQUIPMENT/INSTRUMENT LOCATED ON LOCAL (TURBINE GENERATOR) CONTROL PANEL.
3. TURBINE BEARING RTD'S (TE 8491 - 8497) AVAILABLE FOR USE ONLY (NOT WIRED UP). IF USED, TT 8935 & 8936 WILL PROVIDE TRANSMITTER/CHANNEL.
4. VACUUM PUMP SUB-SYSTEM NOT SHOWN, SEE STES/STM T-G ICD FOR DETAIL.

KEY TO NON-STANDARD [illegible]

VS - VIBRATION SWITCH

MICROPROCESSOR (μP) OR LOCAL TURBINE GENERATOR SIGNAL I/F'S

C - CONTROL

D - DATA FOR SYSTEM PERFORMANCE EVALUATION

E - DATA FOR EXPERIMENT

A (I) - ALARM, REMOTE READOUT (PANEL LIGHT) EMERGENCY

A (TRIP) - ALARM, LOCAL TURBINE GENERATOR TRIP, LOCAL ANNUNCIATOR LIGHT

Figure 2-9. Steam Turbine Generator Interface P & ID Requirements

Also shown in the Figure are the local indicators and alarms provided with the T-G, and mounted on the local panel. These function to failsafe the unit, and send a trip signal back to the processor as a Level 1 alarm.

In addition to the automatic processor interface, a complete set of commands inputs and status indicators are provided on the EMP (as shown in Section 2.4) to allow the operator to startup, synchronize, and operate the T-G manually from the control console. Figure 2-10 depicts the Electrical System and Instruments, including the T-G circuit breaker, voltage regulator, and synchronizing equipment which is provided to allow T-G operation in parellel and isolated from the utility (GPC). The T-G may also be operated in an unloaded condition from its own local panel.

Turbine Bypass

The turbine bypass provides a steam flowpath to the Bleyle process steam line, the deaerator, and the condenser in the event of a turbine outage. The turbine bypass is provided with low pressure saturated steam from the steam generator during extended T-G outage but also receives high pressure steam immediately following a turbine trip. The turbine bypass includes four on/off control valves: one isolates the overall bypass, one isolates the process steam line to the Bleyle plant, one isolates the bypass line to the condenser, and one isolates the condenser. A pressure regulator is provided downstream of the main isolation valve to control steam pressure to the deaerator and the Bleyle plant, and another regulator is provided on the condenser bypass line to reduce the pressure prior to the condensor. The processor/EUP provides on/off position signals to the automatic isolation valves based on required mode. The valves are equipped with open and closed limit switches which provide the valve status to the processor. Status failures generate Level 2 alarms and mode shifts.

Desuperheater and Bleyle Steam Supply

The desuperheater reduces the temperature of the steam provided from the turbine extraction port or the bypass line from superheated to saturated before supply to the Bleyle plant and condenser bypass. This is achieved by spraying condensate into the superheated steam. The resultant saturated steam is supplied to the Bleyle piping interface.

Control loops for the desuperheater and steam supply are as follows:

Temperature - A local indicating controller sets the spray water valve to maintain the desired steam temperature; the steam temperature is transmitted to the processor for a Level 2 alarm function (steam inhibit) and local indication provided.

Pressure - Turbine extraction pressure is transmitted to the processor for EMP indication; Bleyle supply pressure is indicated and transmitted to the processor for a Level 2 high pressure alarm function (STES Bleyle steam supply discontinued, Bleyle backup actuated).

NOTES:

1. SEE DWG. 147D9659 (SINGLE LINE DIAGRAM) FOR MOTOR AND DEVICE RATINGS.

2. SEE DWG. 63A136372 (INSTRUMENTATION LIST) FOR DETAILS.

3. NON-STANDARD SYMBOL USE :
   - C - CONTROL
   - D - DATA FOR SYSTEM PERFORMANCE EVALUATION.
   - A(1) - ALARM, REMOTE READOUT (PANEL LIGHT), EMERGENCY.
   - A(2) - ALARM, REMOTE READOUT, OPERATOR ACTION.

4. ONLY DEVICES HAVING C.A.I.S (CONTROL AND INSTRUMENTATION SUBSYSTEM) INTERFACES SHOWN. LOCAL CONTROLLER INTERFACES ARE SHOWN ON SUBSYSTEM P & ID REQUIREMENTS DWG. NOS 919E107, 919E111, 919E120, 919E128 & 919E130.

5. MOTORS CAN BE CONTROLLED MANUALLY VIA SWITCHING NEAR EACH MOTOR AFTER MANUAL TRANSFER FROM AUTOMATIC TO MANUAL MODE AT THE MOTOR CONTROL CENTER AS DESCRIBED IN 295A8054 (POWER DISTRIBUTION REQUIREMENTS). IN MANUAL MODE, THE FY OUTPUT HAS NO EFFECT ON THE MOTOR CONTACTOR, THE YZ INPUT STILL SHOWS CONTACTOR POSITION & THE HS INICATES MODE LOCALLY.

6. LOCAL CONTROLLERS WITHOUT C.A.I.S. ARE POWERED FROM A MANUALLY SWITCHED PANELBOARD, NOT SHOWN HERE. THESE DEVICES PROVIDE ALARM & ANALOG SIGNALS TO THE C.A.I.S. & MAY START & STOP MOTORS & MODULATOR VALVES AS PART OF THEIR FUNCTIONS. SUCH DEVICES ARE TYPICALLY VENDOR SUPPLIED:

   - CONDITIONING TANK LEVEL, TEMPERATURE
   - FOSSIL FIRED HEATER UNIT
   - CONDENSING TANK LEVEL, TEMPERATURE, COOLER FAN & PUMP.
   - VACUUM PUMP S/S
   - INSTRUMENT AIR COMPRESSOR.
   - STEAM GENERATOR LEVEL & PRESSURE CONTROLS
   - WASTE WATER TEMPERATURE CONTROL
   - FLASH ECONOMIZER LEVEL CONTROL
   - FEEDWATER CHEMISTRY CONTROLS
   - DEAERATOR LEVEL CONTROL
   - DESUPERHEATER TEMPERATURE/FLOW CONTROL
   - CONDENSATE STORAGE LEVEL CONTROL
   - DEMINERALIZER CONTROL
   - CONDENSOR LEVEL & PRESSURE CONTROLS
   - COOLING TOWER FAN/TEMPERATURE CONTROLS
   - AAC CONTROL INCLUDING COOLING TOWER FLOW
   - TURBINE GENERATOR CONTROL
   - HOT WATER HEAT EXCHANGER TEMPERATURE CONTROL
   - CONDENSOR COOLING TEMPERATURE CONTROL

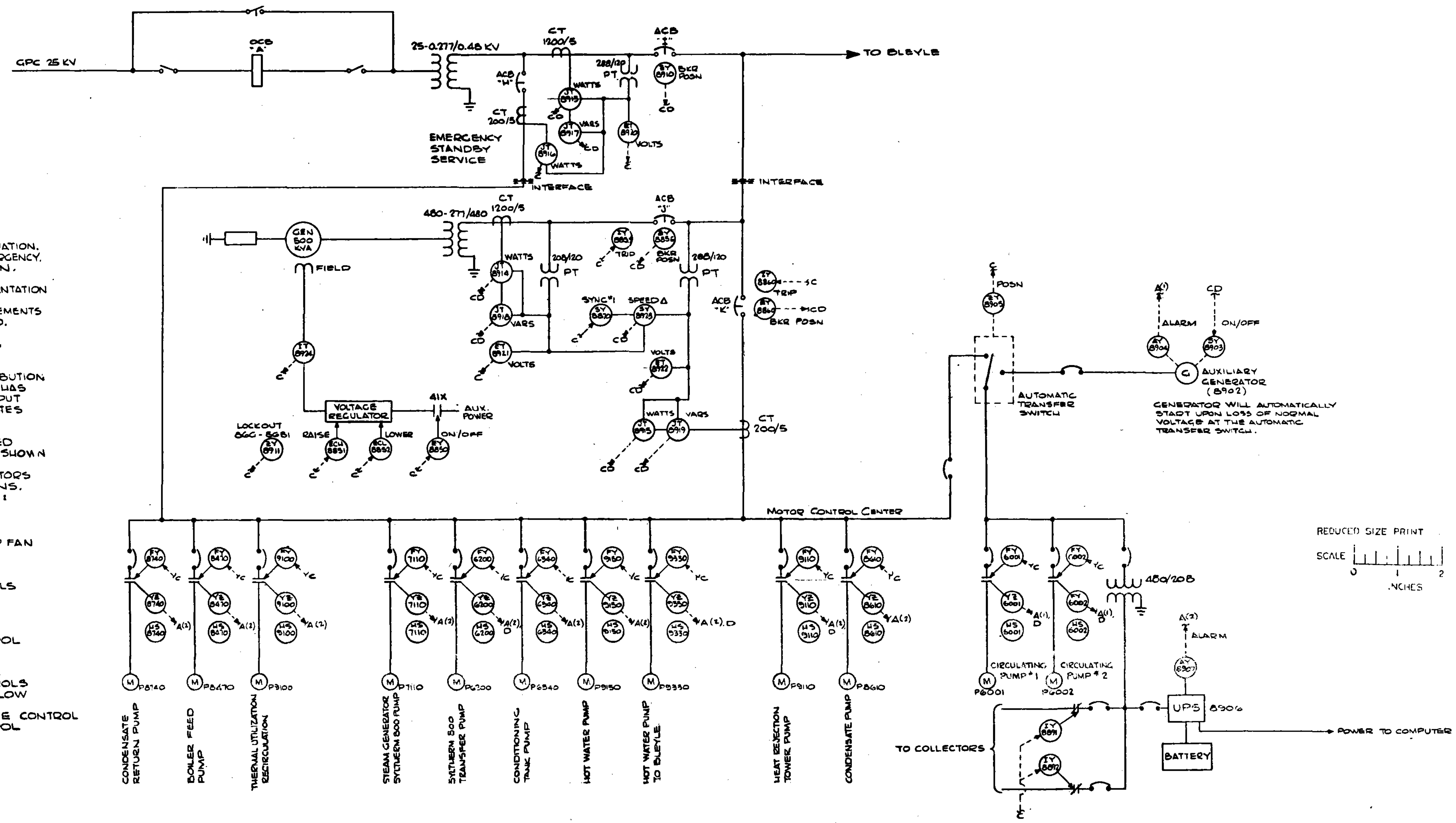


Figure 2-10. Electrical System Instrumentation

Bleyle Condensate Return

The Bleyle condensate return equipment includes a filter to remove any particulate contaminants and manual isolation valves to prevent reuse of chemically impure condensate.

Control loops associated with the Bleyle Condensate Return include:

1. Pressure - Filter upstream and downstream pressure indicators are provided to signal cartridge replacement maintenance.
2. Conductivity - Conductivity indicator and high conductivity Level 2 alarm for maintenance dispatch.

Make-up Demineralizer

The makeup demineralizer unit includes a filter, cation and anion exchangers, and regeneration equipment to process raw makeup water prior to admission to the condensate storage tank. The unit requires a maintenance person to perform the semi-automatic regeneration process and replace filter cartridges, but operates and shuts down automatically between regenerations.

Control loops are as follows:

1. Flow - A local flow alarm automatically shuts down the unit on total gallons processed between regenerations.
2. Conductivity - A local conductivity alarm automatically shuts down the unit on high effluent conductivity.
3. Alarm Status - A status signal indicating unit shutdown for either 1 or 2 above is transmitted to the processor as a Level 2 alarm.
4. pH - A Level 3 high/low pH alarm is provided on the neutralization tank to alert maintenance personnel to avoid discharge of hazardous waste.

Condensate Storage Tank

Demineralized make-up water and Bleyle condensate return are fed to the condensate storage tank for storage prior to admission to the PCS fluid loop via the condensate storage pump. The tank is open to the atmosphere via a static vent, and is sized to provide the PCS demands for make-up for a full day with both demineralized make-up and Bleyle condensate flows discontinued.

The tank is provided with a level transmitter/level indicating controller to regulate demineralized make-up flow to maintain the desired tank level. The local controller also transmits Level 2 high or low level alarms to the processor for maintenance resolution. The Bleyle condensate return flow into the tank is unrestricted, excepting the conductivity valve. Condensate excess from the condenser is also supplied to the tank.

Condensate Storage Pump

The condensate storage pump supplies PCS make-up from the condensate storage tank to the condenser. The pump is provided with a recirculation loop and self-contained pressure regulator to allow continued operation under all flow conditions. The pump has control provisions to allow remote processor start/stop functions, and provides on/off status signals to the processor.

The pump is provided with inlet and discharge pressure indicators.

Condenser

Turbine exhaust or turbine bypass steam is condensed in the condenser. The heat is transferred to the condenser cooling water for thermal utilization. PCS make-up water is sprayed into the steam flow entering the condenser. This preheats the make-up flow to the hotwell saturation temperature and also deaerates it. An automatic vent removes noncondensible gases from the condenser. Control loops associated with the condenser include:

1. Pressure - A local controller sets the cooling water flow valve to maintain desired pressure; the pressure is transmitted to the processor for generation of Level 2 high and low pressure alarms, resulting in turbine trip/bypass operation, Bleyle steam only. Condenser pressured is indicated on the EMP.
2. Level - A local controller sets the make-up flow valve to maintain desired level; the controller positions the condensate excess valve to the condensate storage tank; the controller generates Level 2 alarms for high and low level, resulting in turbine trip/subsystem shutdown.

Condensate Pump

The condensate pump principally transfers condensate from the condenser to the deaerator. It also provides condensate to the desuperheater for use as spray and intermittantly pumps condensate into the condensate storage tank to control the condenser high level. The condensate pump is provided with a bypass loop with a self contained pressure regulator to allow continued operation under all flow conditions. The pump has control provisions to allow remote processor start/stop functions, and also provides on/off status signals to the processor.

The condensate pump is provided with inlet and discharge pressure indicators, and a local conductivity indicator which generates a HI alarm and transmits it to the chemistry annunciator.

Deaerator

The deaerator removes noncondensable gasses and preheats the boiler feedwater using the energy available in condensing steam. During turbine operation, turbine extraction steam combined with boiler blowdown flash steam provide the heat source. During turbine outage bypass steam is provided. The deaerator is equipped with an automatic vent to remove noncondensables. Nitrogen is supplied to the deaerator during prolonged shutdown to prevent oxygen contamination.

Control loops for the deaerator are as follows:

1. Level - A local controller sets the feedwater flow valve to maintain the desired level; the controller generates Level 1 high and low level alarms and transmits them to the processor to initiate turbine trip/subsystem shutdown.

Chemical Injection Subsystem

The chemical injection subsystem includes ammonia and hydrazine storage tanks, metering pumps and controls. The subsystem automatically meters addition of ammonia and hydrazine into the boiler feedwater to maintain pH and 0_2 concentration, respectively.

The system controls include:

1. Oxygen - An oxygen transmitter/local indicating controller sets the hydrazine metering pump to control oxygen concentration to less than .005 PPM; the controller generates a high concentration alarm, and transmits it to the local alarm annunciator.
2. pH - A pH transmitter/local indicating controller sets the ammonia metering pump to maintain normal 9.5 pH, the controller generates HI/LO pH alarms and transmits it to the local alarm annunciator.
3. Conductivity - A conductivity indicator/alarm is provided. It transmits an alarm status to the local alarm annunciator on high conductivity.
4. Alarm Annunciator - 0_2, pH and conductivity alarms are transmitted to the alarm annunciator; the annunciator provides local visual indication, and transmits a single chemistry Level 2 alarm to the processor for maintenance resolution.

Boiler Feed Pump

The boiler feed pump supplies feedwater from the deaerator to the steam generator. The positive displacement pump is equipped with a pulsation dampener and a recirculation loop with self contained pressure regulation valve to provide continuous and constant pressure flow under all flow conditions.

Instrumentation associated with the boiler feed pump includes inlet and outlet pressure indicators.

Extraction Non-Return Valve

The extraction non-return valve (NRV) is a pneumatic spring loaded angle valve. It will be located as close as possible to the T-G extraction port, and will close on turbine trip or shutdown to prevent overspeed.

The NRV is controlled by the turbine panel. The turbine trip pneumatic signal is transmitted to the pilot port of a 3-way pilot-operated valve, also provided with the NRV. Instrument air is also supplied to the pilot valve.

2.3 THERMAL UTILIZATION SUBSYSTEM (TUS)

The Thermal Utilization Subsystem consists of the following principal components: Low Temperature Storage Tank (LTS), Absorption Air Conditioner (AAC) and Cooling Tower, Heating Heat Exchanger, Chilled and Hot Water Pumps, Condenser Cooling Water Pump, Thermal Load Supply Pump, and the Excess Heat Dissipation Heat Exchanger and Cooling Tower. Figure 2-11 provides the P&ID for the TUS. The TUS provides cooling water to the condenser; the transferred heat is utilized to drive an absorption air conditioner or hot water heating system to meet Bleyle plant as well as STEP Mechanical Building needs. Energy is stored in the LTS tank to extend operation beyond PCS shutdown, and a heat exchanger/cooling tower is provided to dissipate energy in excess of the thermal load demands.

The TUS is controlled via both the central processor and local controller. Control loops are provided below by principal mechanical components. All processor interfaces are via the EUP.

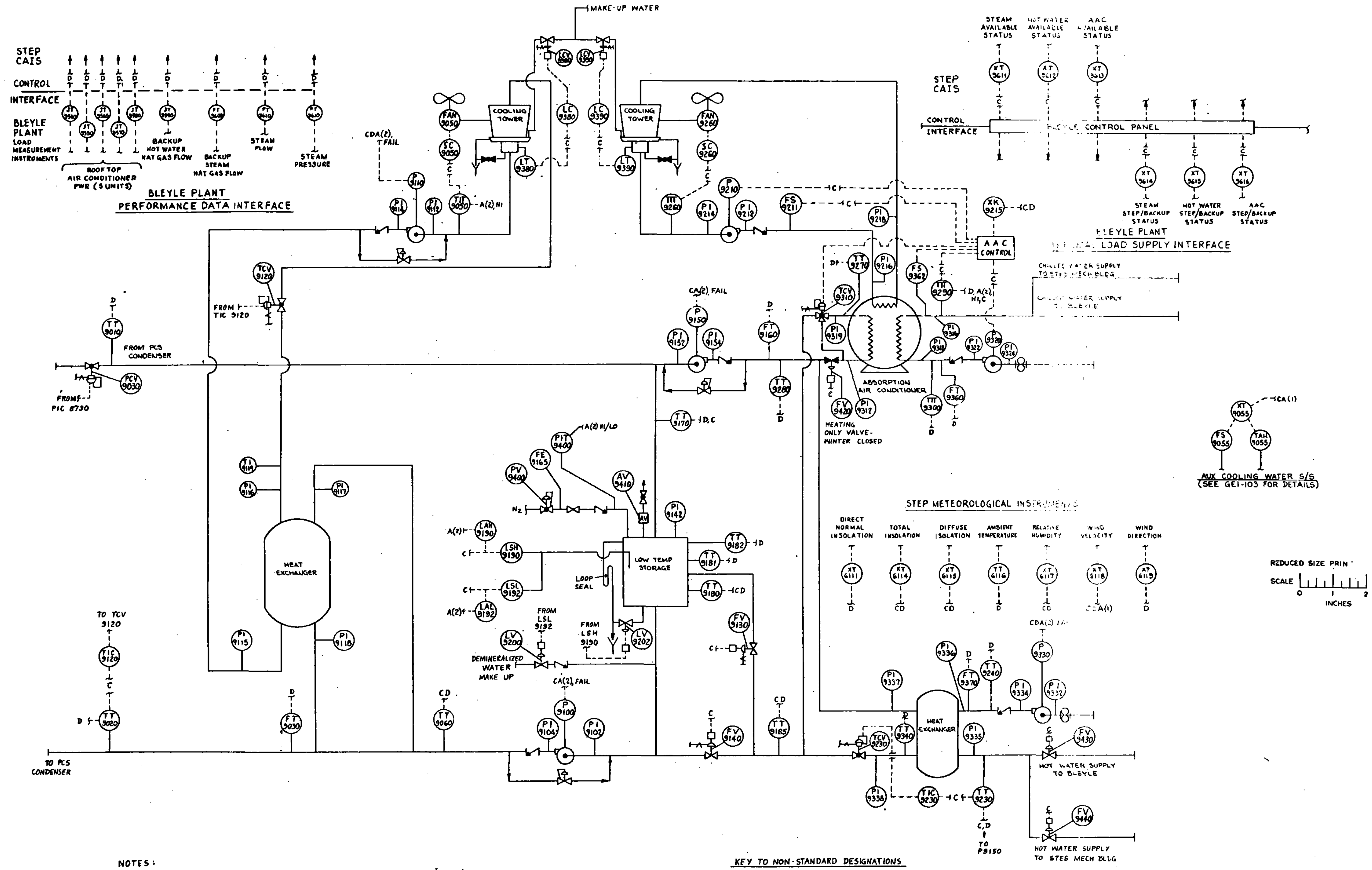
Cooling Water Pump

The pump is activated by the processor as required by system mode. Status is provided; failure results in a Level 2 alarm triggering PCS trip to mode D.

Excess Heat Dissipation Equipment

Flow temperature entering the Excess Heat Heat Excahnger is provided via the ELP to the processor. If the temperature exceeds the setpoint, the Excess Heat Cooling Tower and Pump are activated. Tower fan control is via a temperature sensor and local controller which controls the fan to provide the desired cooling water temperature. A Level 2 alarm is generated if the temperature exceeds the setpoint resulting in PCS trip to mode D.

Pump control is via the processor; status feedback is provided; status failure results in PCS trip to mode D.



NOTES:

1. LOCAL CONTROL COMPONENTS (TRANSMITTERS, CONTROLLERS, CONTROL VALVES) SHOWN AS ELECTRICAL CONTROL/PNEUMATIC OPERATION TO INDICATE FUNCTIONS. SPECIFIED LOCAL CONTROLS MAY BE OTHERS, HOWEVER TRANSMITTER INTERFACE WITH PCS MICROPROCESSOR IS TO BE ELECTRICAL (4-20 mA)
2. MODE SELECTION VALVES (POSITIONED VIA μP) TO BE ELECTRICAL CONTROL/PNEUMATIC OPERATION. VALVES TO BE EQUIPPED WITH POSITION SENSORS.
3. VENT, DRAIN, PIPE SIZES, AND ADDITIONAL SPECIALTIES NOT SHOWN. STANDARD ENGINEERING PRACTICE TO BE EMPLOYED.
4. ADDITIONAL COOLING WATER CONNECTIONS NOT SHOWN.
5. COMPONENT LOCAL CONTROL/PANEL INTERFACE TBD. REFER TO COMPONENT SPECIFICATIONS.
6. SEE INSTRUMENTATION LIST (63A136372) FOR DETAILS.

KEY TO NON-STANDARD DESIGNATIONS

AV - AUTO VENT
VB - VACUUM BREAKER
X - COMPONENT CONTROL/ STATUS
MICROPROCESSOR (μP) OR LOCAL CONTROLLER SIGNAL I/F'S
C - CONTROL
D - DATA FOR SYSTEM PERFORMANCE EVALUATION
E - DATA FOR EXPERIMENT
A(1) - ALARM, REMOTE READOUT (PANEL LIGHT), EMERGENCY
A(2) - ALARM, REMOTE PRINTOUT (CRT) OPERATOR ACTION
A(3) - ALARM, LOCAL, MAINTENANCE RESOLUTION

Figure 2-11. Thermal Utilization Subsystem P & ID Requirements

Cooling water temperature entering the condenser is provided to a local indicating controller; flow through the heat exchanger is controlled to provide the desired value. A local level controller controls tower makeup for the excess heat tower, as well as the AAC tower.

Thermal Load Supply Pump

The pump is activated by the processor as is required to provide heating/cooling needs. Status is provided; failure generates a Level 2 alarm and heating and cooling inhibits.

Absorbtion Air Conditioner

The AAC is controlled via the processor and a local control panel/system provided with the unit. The processor activates the unit, which in turn provides local control and returns status indication of operation. Local control provides for activation of chilled water, cooling tower and solution pumps, chilled water temperature control, and failsafing to shutdown. In addition, high chilled water temperature results in a Level 2 alarm, and is indicated on the EMP.

Heating Supply

Heating water supply temperature is provided to a local indicating controller which positions the temperature control valve to provide the desired temperature. Excessive temperature results in shutoff of the thermal load supply pump.

LTS Tank

Make-up and drain (level management) for the HTS tanks is provided via local level switches which activate on/off valves. Level transients exceeding 5 minutes results in Level 2 alarms for maintenance dispatch.

Temperature at the bottom of the tank and exciting the thermal load equipment is provided to the processor. Tank flow valves are positioned accordingly, to provide the coolest flow to the condenser, and valve status returned. Tank top and bottom temperatures are provided to the processor to indicate storage status for mode selection.

Nitrogen is provided to the tank, high or low N_2 pressure results in a Level 2 alarm and TUS shutdown.

Bleyle Plant Load Supply Interface

STEP thermal load supply status information (i.e., AAC status and temperature, heating pump status and temperature, steam supply status and pressure) is provided to the processor. Based on availability, the processor provides a status signal to the Bleyle control panel. The Bleyle panel then positions its mechanical equipment, automatically, to receive STEP steam, AAC, and Heating, or any combination of the three. This results in a status return to the processor. Flow to Bleyle is then initiated. Termination of supply normally occurs a at the STEP as the operating day ends; termination may occur at Bleyle via status change, or abnormally at the STEP via alarm/failure.

Meteoroligical Control

Meteorological instruments are used to determine the requirement for AAC in the winter, as well as to provide collector operation permissives.

Ambient temperature and relative humidity are provided to the processor and based on an algorithm AAC operation is determined.

Isolation and windspeed are provided to the processor, insufficient isolation inhibits automatic field start-up while excessive windspeed results in a Level 1 alarm and collector field stow.

2.4 CONTROL AND INSTRUMENTATION SUBSYSTEM (CAIS)

The Step CAIS consists of four major subsystems as follows:

1. Energy Collection Subsystem
2. Energy Utilization Subsystem
3. Archiving Subsystem
4. Man/Machine Interface Subsystem

Figure 2-12 provides a block diagram showing the allocation of major CAIS components within the various subsystems.

As shown, the energy collection subsystem contains the BCU, the 120 CCU's, and the Serial Data Link. As discussed in Section 2.1, this equipment provides for signal input/output control between the solar collector field and the processor, as well as the specialty features of the CCU.

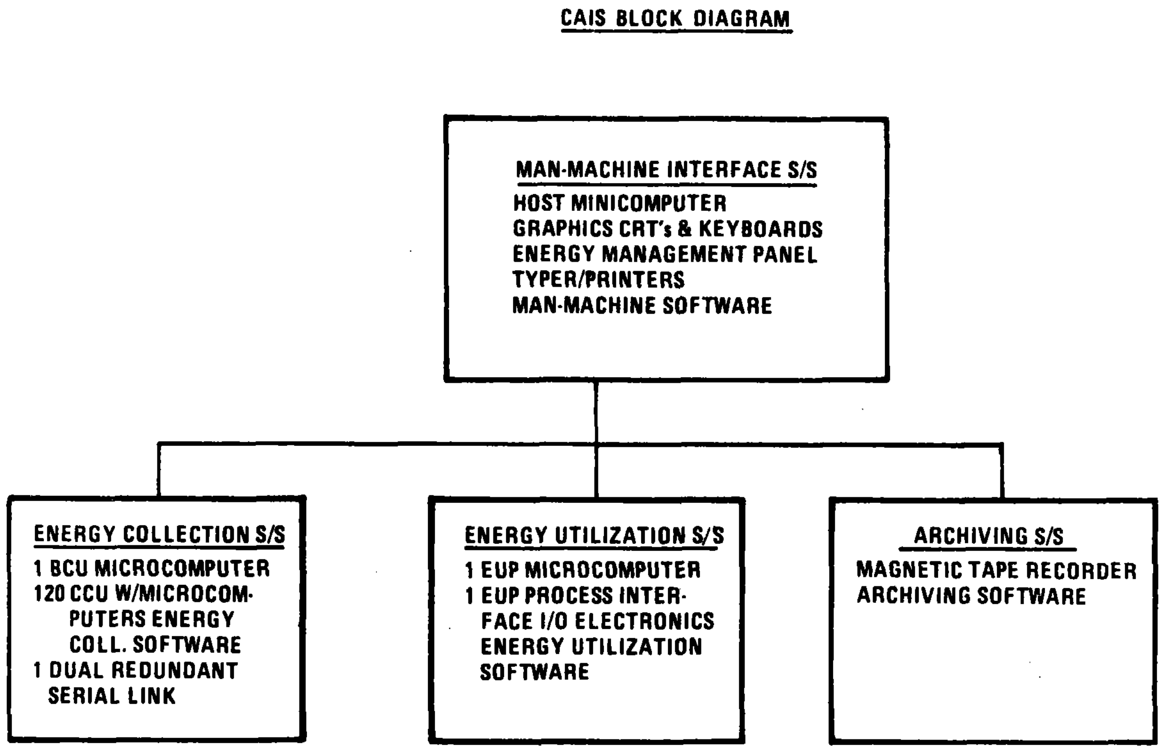


Figure 2-12. CAIS Block Diagram

The Energy Utilization Subsystem contains the EUP and associated interface electronics. This equipment, as discussed previously, provides for all interfacing control between the balance of the plant (i.e., HTS, SGS, PCS, TUS, ES) and the processor. Signals which do not interface with either of these subsystems are deemed local control.

The man-machine interface and the archiving subsystems, and their location within the control room, are of particular interest to system operation, and will be further discussed. A top level wiring schematic of the CAIS is provided as Figure 2-13, the System Description, Document No. 78SDS4234 provides further definition.

Control Room

Figure 2-14 provides the equipment locations within the STES Control Room. As indicated, all CAIS equipment, with the exception of the CCU's and Serial Data Link, is located within the control room. The internal environment is maintained at approximately 21°C (70°F) and 45 to 70 percent RH.

The Operator's Console is located centrally within the room, and is visible through the observation window. Figure 2-15 provides an outline drawing of the Operator's Console. The console provides centralized system status, alarm monitoring, and the capability for centralized remote control of the STES. The console is designed for operation by one person, and accommodates two. Principal components are the Energy Management Panel (EMP) which provides primarily system status/alarms as well as some active remote controls, and the two color graphics terminals which provide the primary operator/system interface. To the right are the page printer and tape drive. There as discussed below.

Energy Management Panel

The Energy Management Panel of the operators console primarily provides a mimic board representation, of the STES and its subsystems. The panel layout, including indicator lamp selection as well as color has been designed with consideration of human factors engineering, so that the operator can easily monitor status of the system during normal operation, and at a glance determine alarm status for intervention if desired, although not necessary. Figure 2-16 and 2-17 depict the upper and lower portions of the EMP.

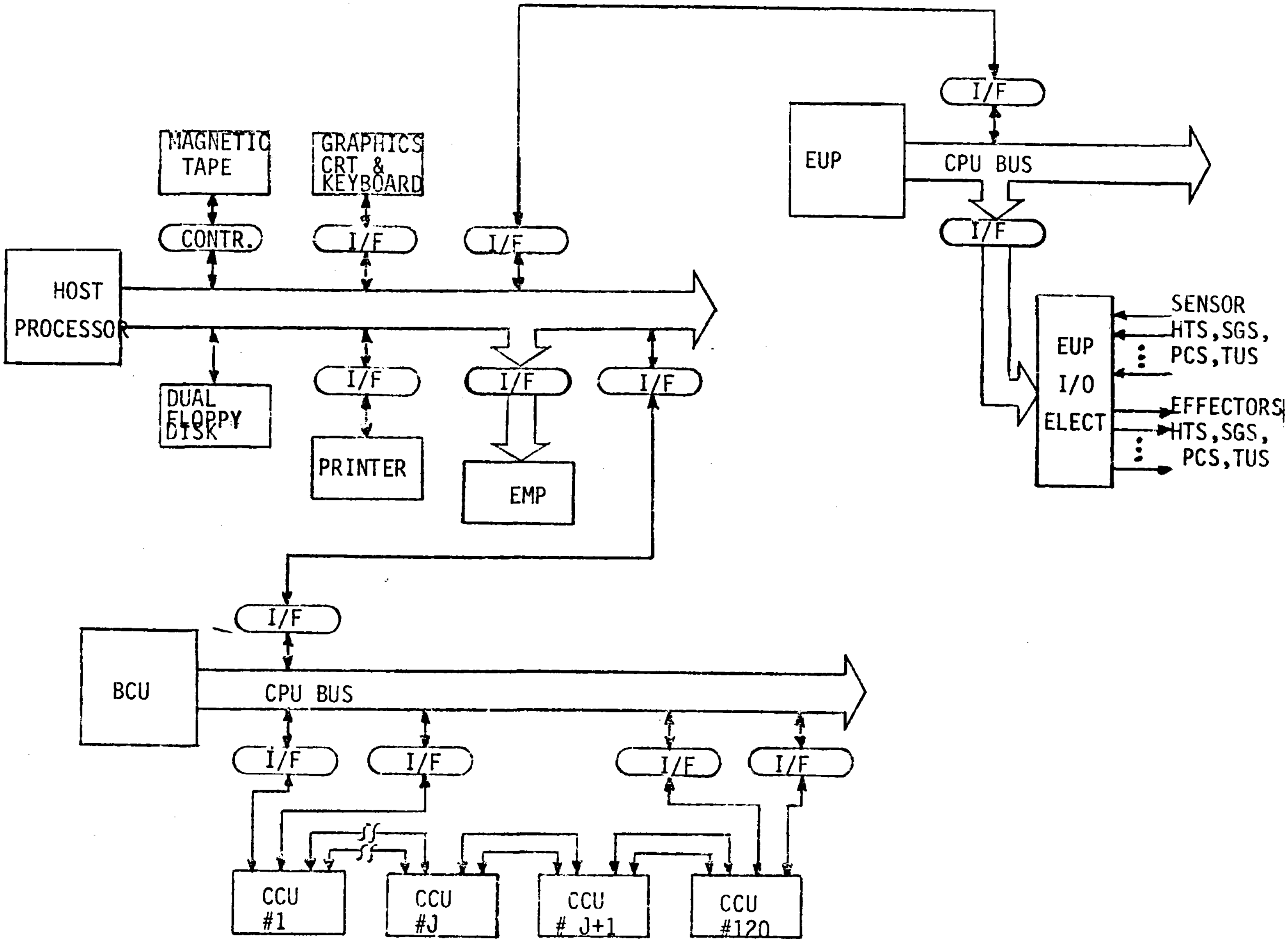


Figure 2-13. CAIS System Block Diagram

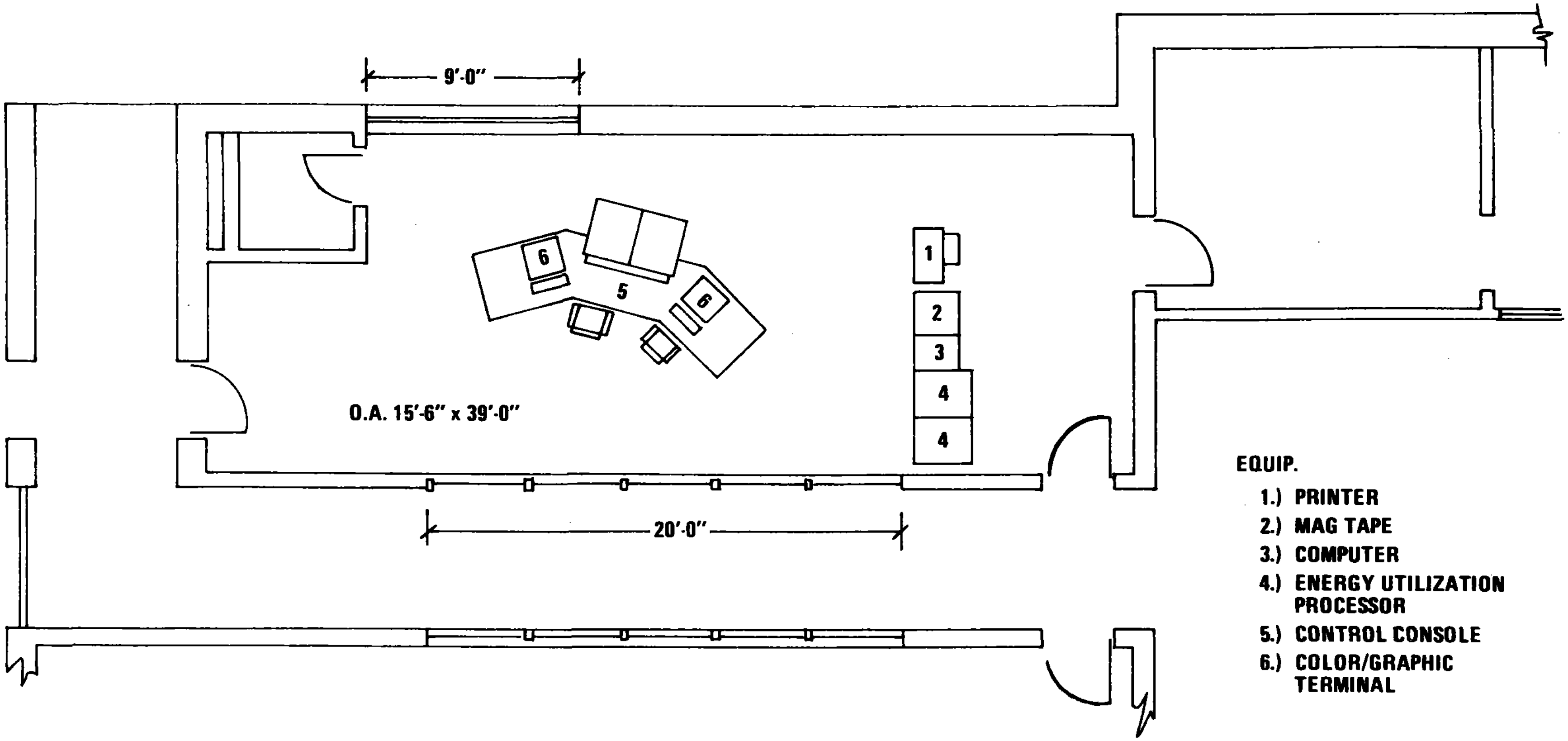


Figure 2-14. Solar Total Energy System Control Room Layout

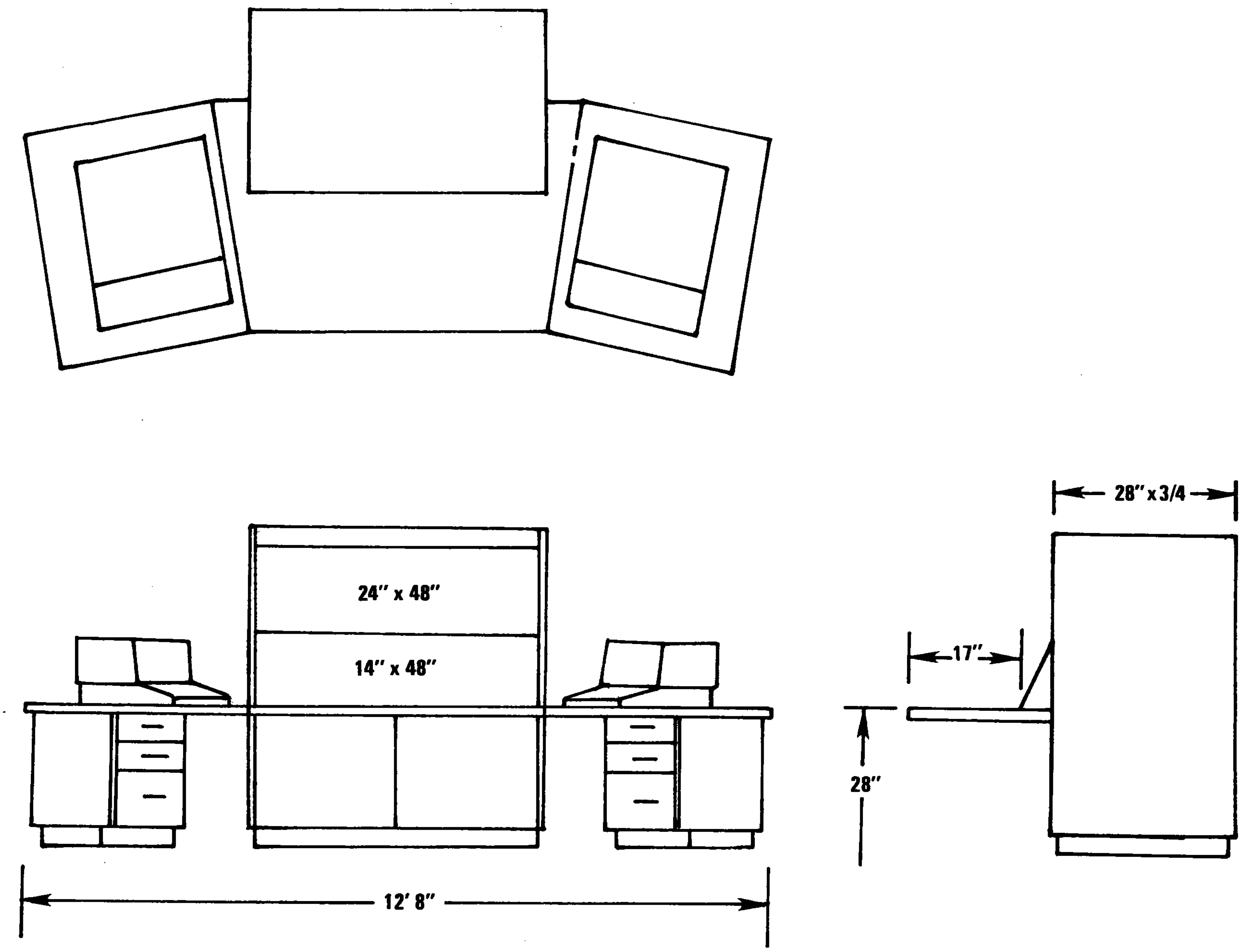


Figure 2-15. Outline - Operators Console

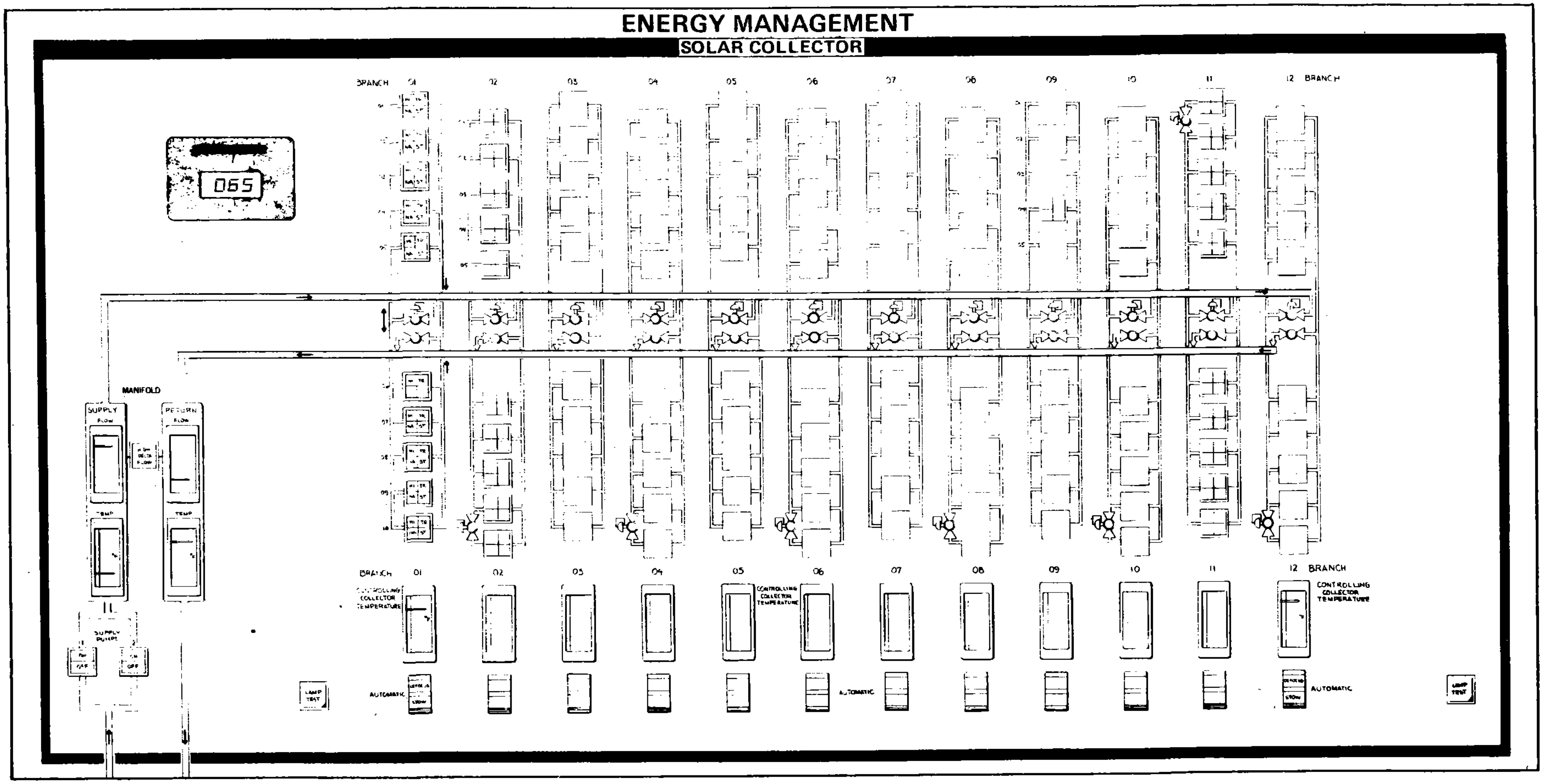


Figure 2-16. Energy Management Panel (Upper)

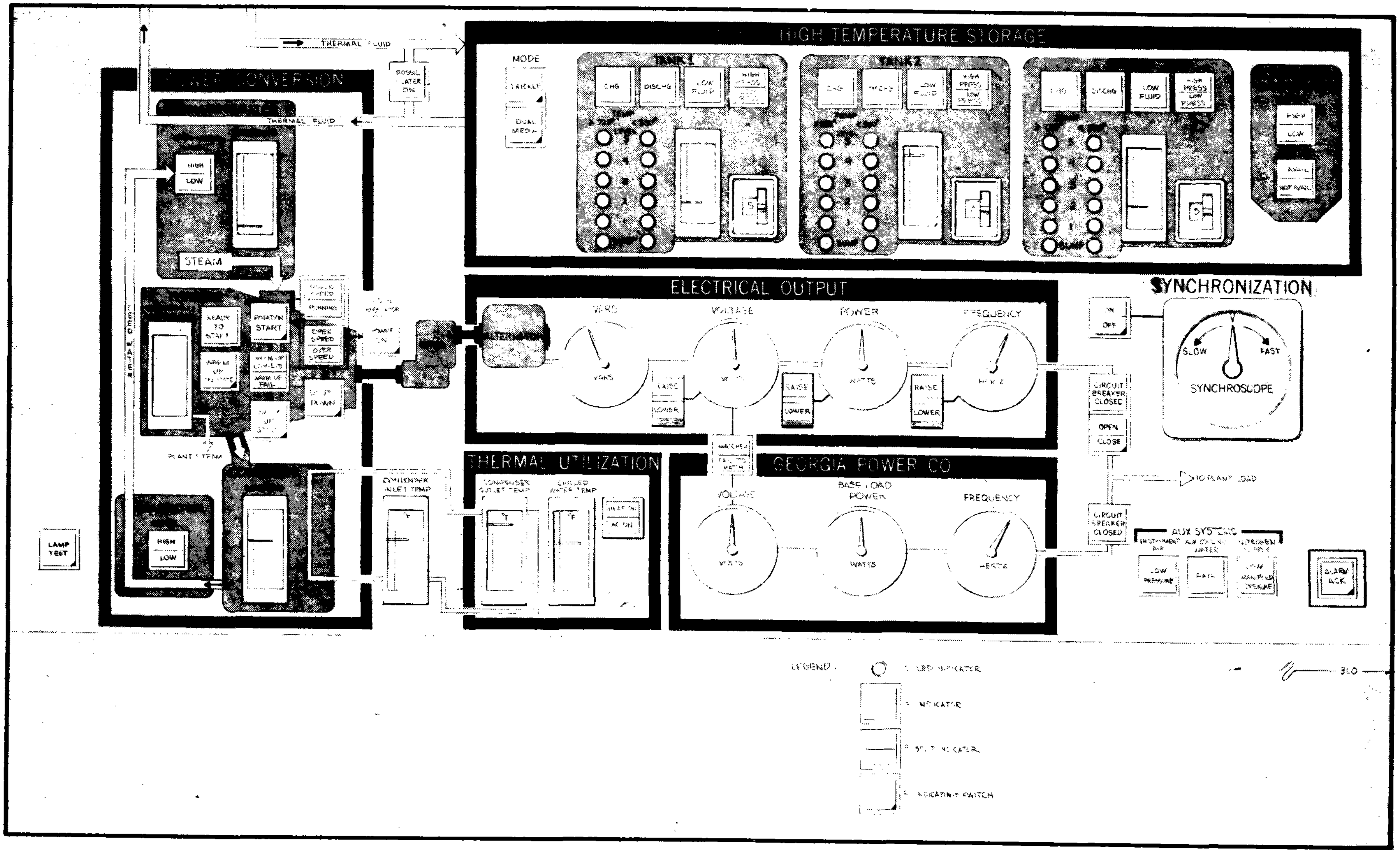


Figure 2-17. Energy Management Panel (Lower)

The upper panel displays in a mimic presentation, the Solar Collector Field, and includes:

1. Collector Status (i.e. tracking, stowed, not available, and over-temperature)
2. Branch flow and isolation valve status
3. Shadowing valve status
4. Manifold supply and return (field) flow rate and temperature
5. Supply pump No. 1 and No. 2 status.

In addition, a meter to display solar insolation, wind alarm status, and a meter to display the controlling collector receiver temperature in each branch will be provided. Remote controls provided on the EUP panel for the CFS are:

1. Defocus (any entire branch of collectors)
2. Stow (any entire branch of collectors).

These controls override the automatic collector tracking mode.

The lower panel of the EMP provides status, alarm monitoring, and remote control for the critical functions for the balance of the STES.

Indications provided on the lower panel are:

1. HTS tank status (i.e. charging, low level, hi/lo pressure, discharging)
2. HTS tank temperature and status profile
3. Conditioning make-up tank level and status
4. Fossil heater status
5. Steam generator pressure and level
6. Turbine status signals (a complete T-G startup/operation capability is provided)
7. Extraction steam pressure
8. Turbine-generator electrical output (vars, power, voltage, frequency)
9. Generator breaker position

10. Condenser pressure
11. Deaerator level
12. Condenser cooling water inlet and outlet temperature
13. AAC chilled water temperature
14. Georgia Power Company electrical meters (power,voltage, frequency)

Remote controls provided on this panel for the EUS are:

1. Turbine startup/shutdown
2. Synchronization of the electrical output of the system to Georgia Power Co.

Hardwired instruments on the panel include the electrical power meters and the synchroscope.

Each of these controls will override the automatic controls of the system. Also provided are a telephone and plant intercom system, to the right of the mimic board.

Color Graphic Terminals

The Operator Console will be provided with two independent alphanumeric displays. These displays will have the capability of displaying data for any sensor (measurement, status or alarm), and effector signal with which the control system interfaces.

The keyboard of the A/N displays provides remote centralized control capability for the entire system. The operator is provided with the capability of entering commands from the keyboard of the A/N displays. These commands override the automatic controls of the system when they do not violate safe system operation (i.e. a CCU defocus command can not be overridden). The A/N displays are independent in their display mode but not in the control mode. When an operator enters the control mode at one display the software will lockout the control mode of the other display. Formats for displaying data and alarms and entering commands for the system include the following:

1. Subsystem schematics
2. Weather status
3. Mode selection (including manual)
4. Branch temperature profile
5. Others, TBD

Archiving Subsystem

The Archiving Subsystem of the CAIS shall contain the hardware, software and documentation for recording of binary data directly from computer analog and digital input electronics for periods of time lasting up to one week onto a single record. The purpose for the archiving subsystem is to generate a magnetic tape of data to be used at facilities other than the STEP site for analyzing STEP performance as part of the test data management plan.

The hardware complement of the Archiving Subsystem shall consist of a nine track, large reel digital magnetic tape recorder with recording density capability of 800 bits per inch and recording speed of 45 inches per second.

The archiving documentation shall consist of an archive Directory which shall define the content of the magnetic tape recording with the detail of data format, time of samples, scale factors, correction factors, and Archive Directory revision numbers to permit the archive tape data to be reduced and analyzed at other facilities.

Description of this equipment will be expanded, as applicable, in the Test and Evaluation and Test Data Management Plans.

Page Printer

The page printer is provided primarily to log STEP system Level 1 and 2 alarms. The printer receives alarm data from the central processor, and logs with a sufficient speed each alarm as it occurs. The alarm log will be used in onsite evaluation, as well as provided for use in the Test and Evaluation Plan.

A keyboard is also provided with the logger for software interfacing/modification. The printer will provide a hard copy of this activity.

Description of the page printer will be expanded, as applicable, in the Test and Evaluation and Test Data Management plans.

SECTION 3

OPERATOR RESPONSIBILITIES

SECTION 3

OPERATOR RESPONSIBILITIES

The Solar Total Energy System, although capable of fully automatic operation, will be provided with a dedicated staff to support system operation and experiment implementation, site data recording and transfer, system operating modifications, and system maintenance.

As discussed in Section 2.4, the Step Operators Console is designed for a single operator, and accommodates two. It is anticipated that two console operators will be on site during operation to provide the support necessary to fulfill the experiment objectives. Additionally, an operator rotation is likely to be implemented to allow maximum exposure of operating personnel to the STES for the purpose of familiarization and training.

Maintenance personnel requirements for the plant are based on the selected equipment requirements, and also the degree to which the operators themselves can perform maintenance. It is anticipated that a single maintenance engineer, supported by vendor field service technicians and part-time contractors will comprise the maintenance crew. In addition to the dedicated staff, numerous technical observers and support personnel from throughout the solar power industry will contribute to the STES operation.

SECTION 4

SYSTEM OPERATIONS

SECTION 4

SYSTEM OPERATIONS

The Solar Total Energy System is designed as a fully automatic system, capable of starting up, operating, monitoring status and alarms, and shutting down, independent of operator intervention. The capability to operate the mechanical components in this manner is provided via the integrated control system which consists of both local and central control hardware and software. Operator intervention is not typically required, however, to both enhance system experimental flexibility and normal operations, this capability is provided. The primary operator control is via the Color Graphic Terminals, with some functions (primarily T-G startup) provided via the Energy Management Panel.

STES timelines, which identify operation of the system in the automatic mode relative to the Bleyle plant and local climatology are provided below. These timelines provide an introduction to the system automatic mode descriptions provided in Appendix A. The modes descriptions reflect the software algorithms which provide the STES automatic capability. Descriptions of major experimental modes and operational options are also provided in Appendix A.

Appendix B and C provide the Test and Evaluation and Test Data Management Plans, respectively. Appendix B describes the test objectives, milestone schedule, and system/subsystem data capability. Appendix C identifies on and off site data processing capabilities and requirements.

4.1 SYSTEM OPERATION TIMELINES

The STES, when operating in the automatic mode, will startup and operate based on a real time clock to provide electrical and thermal needs of the Bleyle plant in accordance with their shift needs.

The solar collector field operates independantly of the electrical and thermal load supply equipment; it is activated via a solar clock (with a measured insolation permissive) to startup, and operates through the day as long as sufficient insulation is available. Based on solar availability, a backup fossil heater is activated, so that the Bleyle plant loads are always supplied.

Figures 4-1 and 4-2 depict daily timelines for the overall STES and the Solar Collector Field. For this simulated case, which was abstracted from an annual system simulation using Shennandoah Solar Model Year climatology, the sorage tanks were depleted in the early morning. As shown in Figure 4-1 the fossil heater was activated; the PCS and TUS were started; and the turbine-generator synchronized with the utility. All this occurred prior to the Bleyle 1st shift startup.

The collector field started up somewhat after six. As shown in Figure 4-2, it performed its acquisition sequence, operated through the solar hours and stowed.

Returning to Figure 4-1, solar power operation was initiated a few minutes past 8 o'clock. Solar storage was sufficient during the day to extend the system operation on solar power through the night-time second shift.

Figures 4-3 and 4-4 depict similar STES and Solar Collector Field timelines. However, for this case, a Monday morning, the High Temperature Storage was charged. System startup and operation was, therefore, entirely under solar power.

The collector field startup and acquisition sequence for this day was similar to the previous. At noon, though, a cloud transient resulted in assumption of computer tracking. The duration was not long enough to trigger field shutdown, and optical tracking resumed. For this case, the combination of stored and the daily collected energy was sufficient to power the system on solar throughout the two shift Bleyle plant operation.

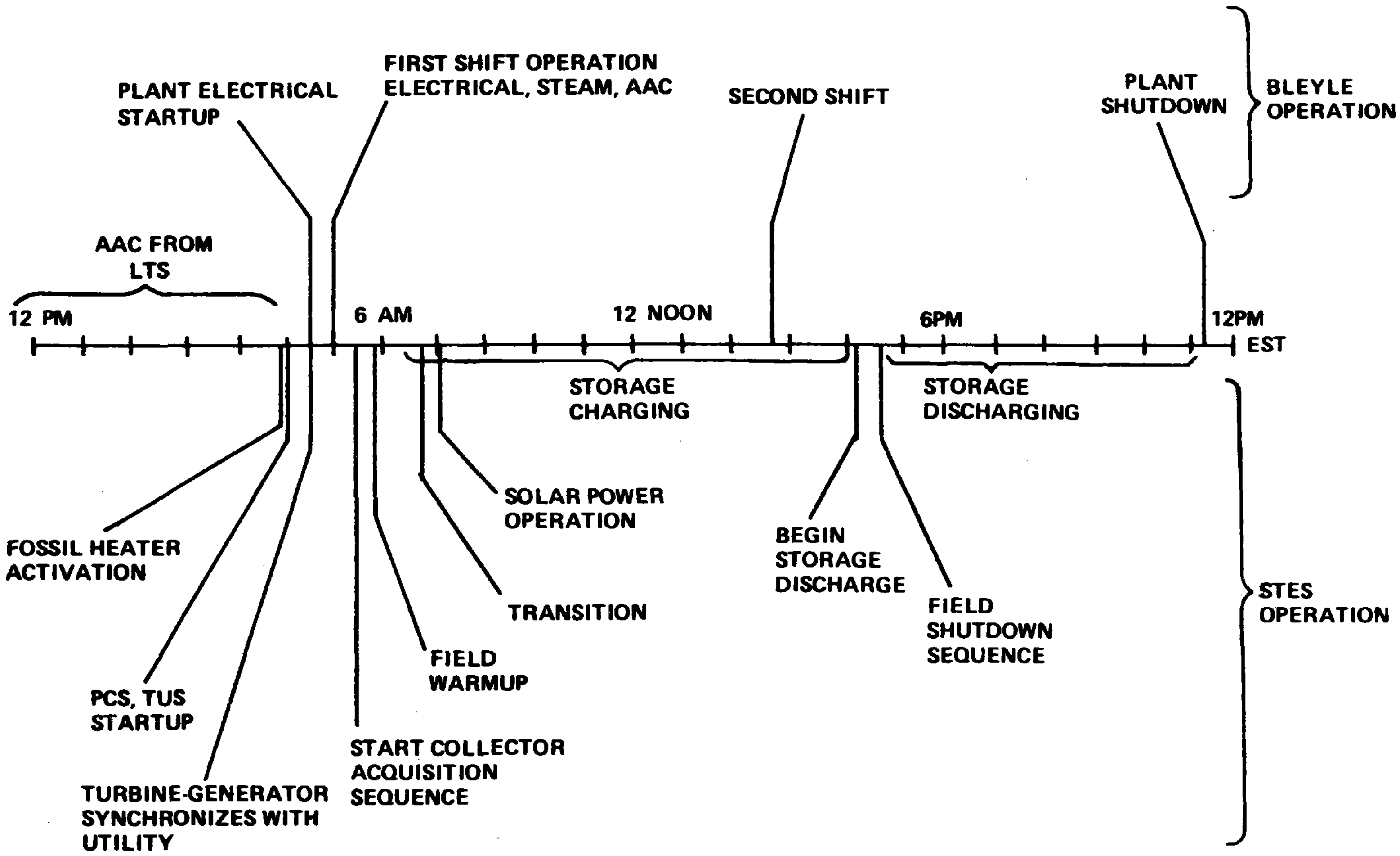


Figure 4-1. Weekday STES Operating Timeline Case: April 13th SSMY

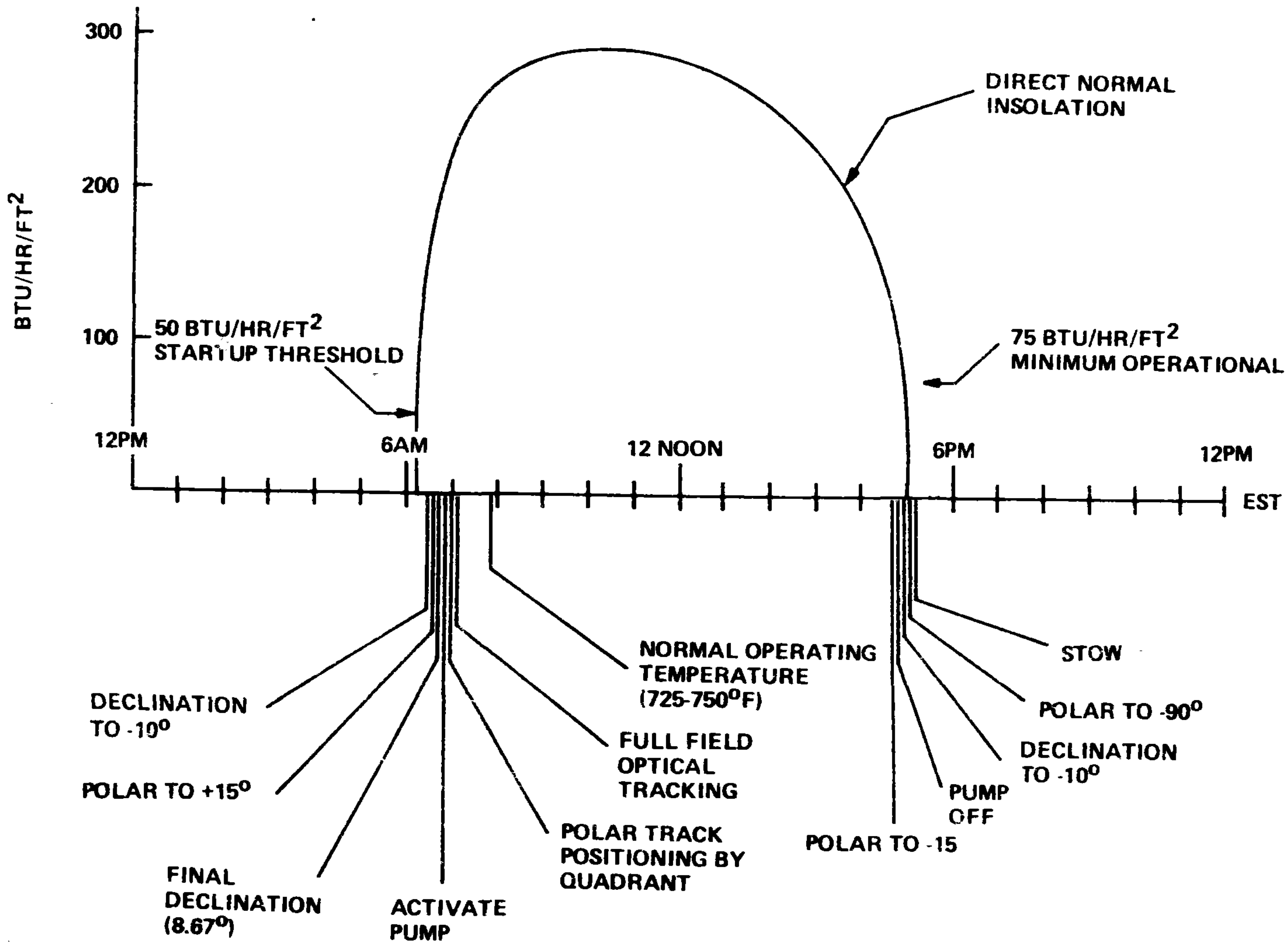


Figure 4-2. Weekday Solar Collector Field Timeline Case: April 13th SSMY

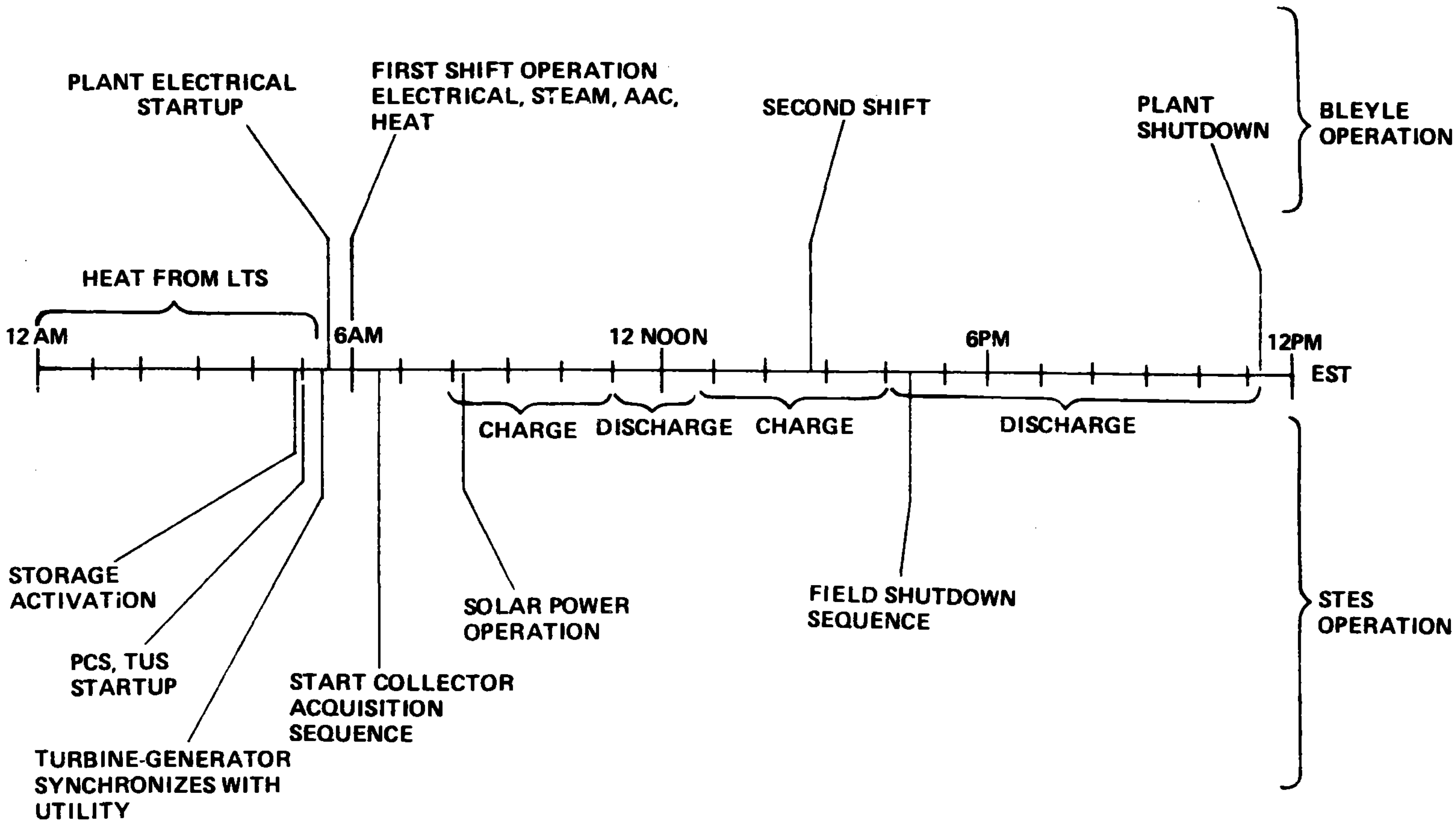


Figure 4-3. Weekday STES Operating Timeline Case: March 20th SSMY.

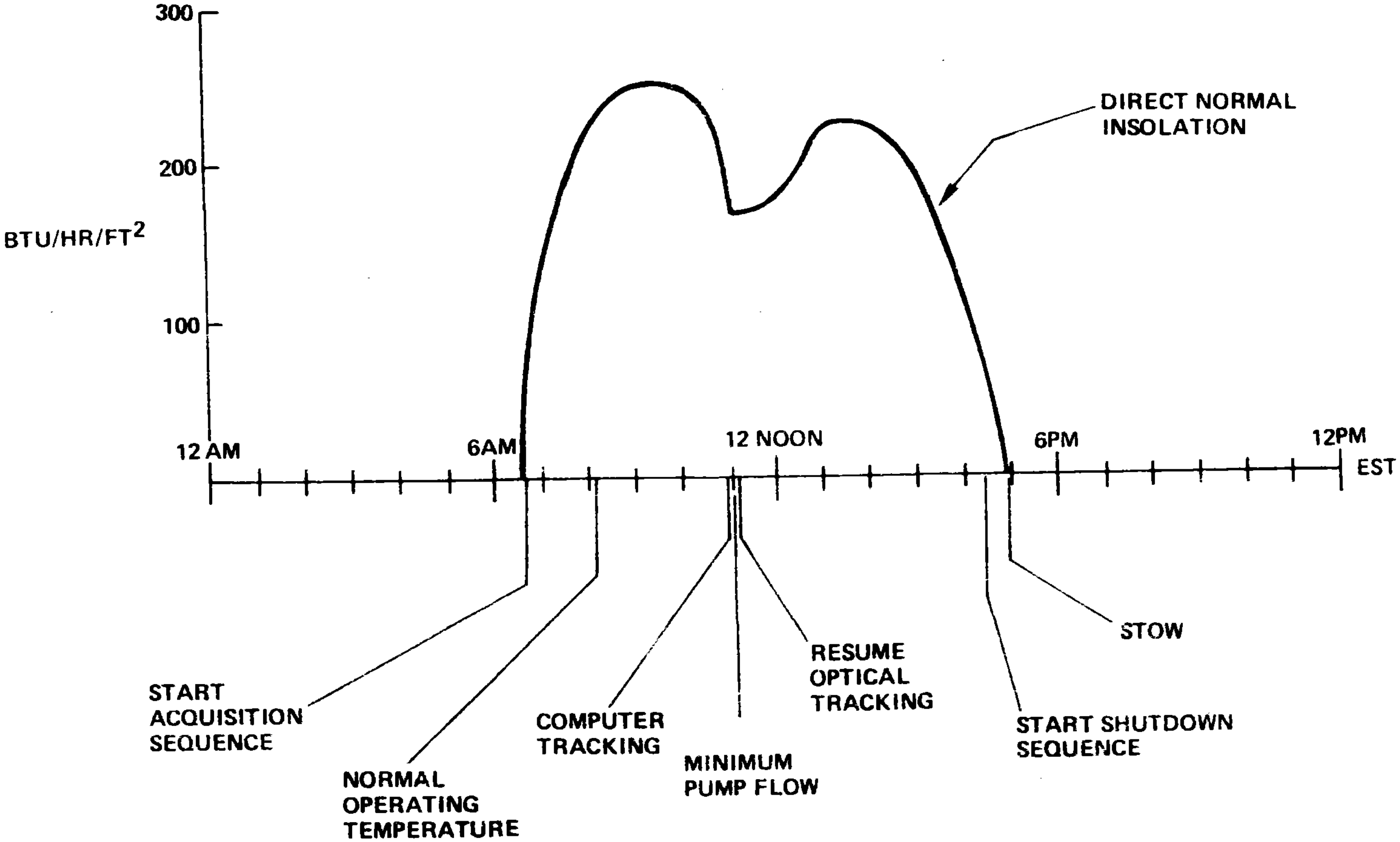


Figure 4-4. Weekday Solar Collector Field Timeline Case: March 20th SSMY.

These figures provide temporal orientation for the mode and mode sequencing discussions in Appendix A. It is important to note that the actual real time setpoints, as well as all system operating setpoints, are operator adjustable.

As a result, the STEP operation may be easily adjusted to accommodate the Bleyle plant shift schedule in effect at the time of the experiment.

APPENDIX A

SUBSYSTEM OPERATING MODES

APPENDIX A

SUBSYSTEM OPERATING MODES

A.1 <u>WEEKDAY SYSTEM OPERATION</u>

A.1.1 SOLAR COLLECTION SUBSYSTEM OPERATION

A.1.1.1 <u>Startup/Storage Depleted</u>

A.1.1.1.1 Fossil Heater Steam Generator Supply/Plant Cooling (Figure A-1)

Startup of the Solar Collection Subsystem with the storage depleted begins with ignition of the fossil fired Syltherm 800 heater to provide startup and normal operating energy for the PCS/TUS. At approximately 5:15 AM, the fossil heater steam generator supply will receive an actuation signal from the control system. The heater will undergo automatic warmup and activation of its circulation pump and recirculation loop to begin supplying Syltherm 800 at the desired temperature to the suction of the steam generator supply pump, which in turn supplies flow to the steam generator. The Syltherm 800 flow to the steam generator is controlled via the steam generator supply valve which receives its flow setting from the PCS control subsystem. Startup of the PCS itself, which is discussed in Section A.1.2.1, will be completed at approximately 5:45 AM, at which time the PCS begins supplying Bleyle Plant startup loads in anticipation of the 6 AM Bleyle Plant work shift. Figure A-1 shows the Solar Collection Subsystem in the Fossil Heater Steam Generator Supply mode. It shows the PCS and TUS in their normal total energy mode, assuming PCS startup is completed. As indicated by the figure, the fossil heater package functions to provide proper temperature fluid to the steam generator supply pump. This pump, in turn, provides flow to the steam generator with flow controlled by the steam generator control valve. Also, the fossil heater mode selection valves are set to isolate the Steam Generator Supply subsystem from the collector field and to allow fluid expansion into a storage tank to provide expansion compensation and net pump suction head.

A. 1. 1. 1. 2 Threshold Insolation/Field Activation/By-Pass Warmup (Figure A-2)

Activation of the solar collector field includes both initiation of the parabolic dish tracking mechanism as well as start-up of the field pump and power initiation to the flow control valves. The acquisition sequence is based on the following requirements:

1. The sequence is initiated on reaching a threshold insolation. A pre-acquisition tracking insolation threshold is based on achieving turbulent flow in the receivers and allowing net positive collection to offset field losses. A tracking and collection insolation threshold is based on offsetting pipefield thermal losses to deliver in-spec fluid to the HTS or solar steam generator.
2. To prevent receiver damage, there is no gradual solar acquisition.
3. The sequence considers operational constraints to prevent sun glint reflections outside of controlled areas.
4. Collector dish start-up is sequenced to avoid a simultaneous start-up power spike.

The following start-up options will be available:

1. Automatic timed start-up with Pyrheliometer Override
2. Timed Start-up with manual Override.
3. Manual Start-up Override.

If start-up is not accomplished, the collector field shall remain in the stow position which is the 6:00 AM Winter Solstice, polar declination attitude. This will cause the collector to point toward the ground to protect the reflector in adverse weather conditions and prevent reflected concentrated sunlight from occurring outside of the protected field area.

In the automatic start-up sequence, the activation signal for the collector field is provided by a timer programmed to predict when the integrated direct normal insolation level adjusted for field shading factors reaches start-up threshold. A maximum windspeed permissive is also provided. However, if the measured integrated direct normal insolaation does not exceed the start-up threshold for pre-acquisition tracking (approximately 157 W/m^2 or 50 $BTU/hr\text{-}ft^2$), or the windspeed permissive is not met, the tracking acquisition sequence shall be inhibited until it does. Manual override can be excercised by the operator if the weather forecast is not favorable. To acquire the sun, declination drive motors shall first move the dishes to a position ten degrees from the solar declination, (if the solar declination is $> -13^{o}$, otherwise the dishes remain in stow). If the time is before 7:00 AM solar time, the polar axis shall be moved to a position fifteen degrees ahead of the sun. For solar times after 7:00 AM a polar position fifteen degrees behind the sun is assumed. Also, if no declination adjustment was made, the dishes continue to remain in stow. Then the declination shall be changed to that of the sun while the polar tracking continues at fifteen degrees ahead or behind the sun, or in the case where no polar adjustment was yet made, a position fifteen degrees behind the sun is assumed. The collectors continue in this pre-acquisition tracking mode while the field pumps are turned on, unless the tracking and collection insolation threshold of approximately 236 W/m^2 (75 $BTU/hr\text{-}ft^2$) is not reached. If the threshold is not reached by 1:00 o'clock the field is stowed. Alternately, the weather forecast for the day may be checked and the field stowed by operator override command if adequate insolation is not likely to occur.

After the threshold is reached, the field pump(s) shall be activated, and adequate flow checked. The adequate flow determination considers the measured flow, and a calculated flow required to keep the field ΔT during startup less then 222°k (400°F). If this is not provided by one pump, the second is activated. If the flow is still not adequate, autotrack is inhibited, and 5 minutes are allotted to allow fluid heatup via routing through a discharged tank (as described in A.1.1.1.3). On verification of adequate flow within the field, the collector polar positions shall be changed, by thirds, to that of the sun. Automatic initiation of optical tracking by the individual collector sun sensors shall occur. After close tracking is achieved by all branches, the field shall proceed in the normal tracking mode with computer sequenced tracking updates.

After the field is started and normal tracking is initiated, the Syltherm ™ 800 fluid is recirculated through the field until it reaches operating temperature. Meanwhile, the fossil heater, PCS, and TUS continue to function to provide site thermal and electric loads.

During warmup, the flow valves are initially wide open, and one or two pumps running. After one minute, the valve and pump loops are activated. The flow settings for the main and branch flow control valves and the field pumps, as discussed later, are the same as that for normal operation, except that the dish outlet setpoint is not the normal 400^{O}C (750^{O}F), but instead is equal to the field inlet temperature plus the receiver ΔT [139^{O}k, + 83^{O}k, -28^{O}k (250^{O}F + 150^{O}F, -50^{O}F)]. Thus, a variable increasing setpoint ramp is used during warmup.

This mode of recirculation shall continue until the fluid output from the collector field, which is also the input to the field during recirculation, exceeds the selected discharged tank temperature, approximately 533^{O}K (500^{O}F).

A.1.1.1.3 Approach to Operation Temperature (Figure A-7)

When the temperature from the collector field reaches a storage discharge temperature of approximately 533^{O}K (500^{O}F), the by-pass mode shall be discontinued. Field fluid flow shall be directed to the selected discharged tank, typically the smaller (1 hour) storage tank which, in turn, shall supply return flow to the field from its cold or discharged sump. This mode provides a relatively constant inlet temperature to the collector field during startup rather than an increasing one which would occur if recirculation were allowed to continue. This constant inlet temperature stabilizes the approach to the desired outlet temperature.

Also, by directing inlet flow to the collector field from the storage tank rather than through by-pass recirculation, the maximum temperature of the collector field inlet piping is limited to 525^{O}F during startup which is the storage breakthrough temperature.

During this mode, the field outlet temperature increases. When the hottest temperature in each branch reaches 363^{O}k (685^{O}F), the variable ΔT setpoint control is deleted, and normal dish outlet setpoint control initiated. The setpoint is ramped up to 671^{O}k (745^{O}F) in 5 minutes. As mentioned previously, the field fluid flow is controlled by a combination of a main flow control (course), and individual branch control (fine) to provide the desired outlet temperature under condition of varying direct normal insolation. The main flow control is via a series throttling valve and one or two pumps. The series valve setting is determined by feedback from the active branch modulating valves and pump control is determined by the main valve position feedback as follows:

1. If any active branch valve is more than 90% of full flow, open the main valve until a return to 90% $\pm$ TBD
2. If any active branch valve is less than 15% of full flow, close the main valve until a return to 15% $\pm$ TBD
3. If the main valve is at more than 80% of full flow, turn on 2nd pump.
4. If the main valve is at less than 25% of full flow, turn off 2nd pump.

During initiation of the valve and pump control, pump control is inhibited for 1 minute to allow valve stabilization. The branch control valves are set by a position signal from the control system which scans the outlet temperature for each collector in a given row. The control system shall select the highest temperature collector in the row and generate a valve position signal to control the setpoint temperature to approximately 671 $\pm$ 3^{O} K (745 $\pm$ 5^{O}F). The control system shall compare the hottest, or control, collector temperature to the average collector temperature for the row. If the difference is >15^{O}F, indicating the row has a hot collector, that collector shall be defocussed, and the second hottest collector shall become the control. If many dishes in a row are defocussed, resulting in an average branch outlet temperature less than 644^{O}K (700^{O}F), the branch shall be defocussed and isolated. This approach keeps the average field outlet temperature within an acceptable normal operating range of 685-750^{O}F.

Figure A-3 shows the collector field in this mode, with the PCS and TUS continuting to operate under fossil heater power. This mode will continue until the sump temperature in the small (1 hour) storage tank indicates breakthrough, i.e., reaches 561^{O}K (550^{O}F). The series transfer mode is then initiated to prevent exceeding the 561^{O}K (550^{O}F) collector field inlet temperature limit.

A. 1. 1. 1. 4 Series Transfer to Charge Tank Fully (Figure A-4)

In the series transfer mode, hot Syltherm 800 fluid (@533°K or 500°F) from the sump of the charging one-hour tank is no longer directed back to the field. Instead, as shown in Figure A-4, the storage transfer pump is activated and the storage isolation valves are positioned so that the next uncharged large storage tank now receives the one-hour tank sump flow, and the large tank now provides return flow for the field from its sump at a reduced temperature. This mode allows the one-hour tank to charge fully without raising the maximum temperature of the field inlet piping above 561°K (550°F) even though the sump temperature of the one-hour tank will approach 658 - 672°K (725 - 750°F) during charging. When the sump temperature of the one-hour tank reaches the fully charged state which is essentially the collector field outlet temperature ± 3°K (± 5°F), the fossil-to-solar transition mode is initiated.

A. 1. 1. 1. 5 Fossil to Solar Transition (Figure A-5)

When the one-hour tank is fully charged, its isolation valves are repositioned from the charge to the discharge mode so that the tank is available, if necessary, to supply energy to the PCS. The storage transfer pump is turned off, and the large tank which was being charged during the series transfer mode is now the charging tank for the field. Thus, any flow from the field in excess of the flow going to the steam generator will be available to charge the tank.

The bulk of the field flow will go directly to supply the steam generator load. However, the hot output from the collector field is directed first through the fossil heater and then to the steam generator. This is achieved by repositioning the Stem Generator Supply Subsystem isolation valves as shown in Figure A-5. The fossil heater operation is continued in order to heat the mass of cold Syltherm 800 fluid existing in the piping.

Syltherm 800 fluid from the steam generator flows back to the field until all cold fluid is eliminated from the pipe. The fossil heater will be turned off and isolated, and solar heated fluid will be supplied directly to the steam generator supply pump and the steam generator. The SCS is now in normal solar power operation as discussed in Section A. 1. 1. 1. 3.

A. 1. 1. 2 Startup/Storage Charged

A. 1. 1. 2. 1 Storage Steam Generator Supply (Figure A-6)

Startup of the Solar Collection Subsystem with the storage charged is identical to the case with the storage discharged. The control system monitors the storage subsystem status at 5:15 AM to determine energy availability. With stored energy available, instead of the fossil fired heater being activated, the storage subsystem is placed on line to supply the PCS startup and operating energy.

The storage tank placed on line by the storage subsystem microprocessor to supply the energy depends on multi-tank storage subsystem logic. First, if the one-hour storage tank is charged, it is preferentially discharged. This assures that the one-hour tank will be empty when the approach to operating temperature mode is begun. If the one-hour tank is discharged, the next partially discharged or fully charged large tank is placed on line to supply the steam generator. Figure A-6 shows the SCS in this mode, with the one-hour tank charged and on line for discharge and the third (from left to right) tank supplying net pump suction head and expansion compensation for the imminent collector field startup.

As in the fossil-heater-steam-generator-supply mode (Section A. 1. 1. 1. 1), the SCS will provide first startup and then normal operating energy demands to the PCS. In Figure A-6 the PCS and TUS are shown in normal operation. If the storage is fully charged, this condition will be sensed by the controls during scan of the storage. The T-G mode is then shifted to contant (400 fuse) power content as discussed in Section A. 1. 2. 2. This essentially increases the solar heat requirements for the PCS and accelerates the use of storage energy so that discharged tanks become available for start-up.

A. 1. 1. 2. 2 Threshold Insolation/Activation (Figure A-7)

As discussed in Section A. 1. 1. 1. 2, for SCS startup with storage depleted, startup of the field pumps and close tracking of the dish collectors occurs as timed. The same is true for startup with the storage charged.

The collector field startup is as discussed in Section A. 1. 1. 1. 2, with the sequence including pump activation, close tracking, and recirculation while warmup occurs. Figure A-7 shows the SCS in this mode. As shown, the one-hour tank is not quite discharged when activation occurs so that it continues to supply the load. (This situation could result only on a Monday morning following a weekend during which the storage was fully charged coupled with a 6:00 AM or soon thereafter threshold insolation).

The third tank supplies expansion compensation and net pump suction head for the field. During this warmup mode, the one-hour tank will fully discharge, and it will become the expansion and net pump suction head tank prior to the approach to normal operation mode. Due to the plant location and daylight savings time, adequate time exists in all seasons during which the tank is supplying PCS demands to assure that this occurs. The next or second large tank, which is taken to be charged, is now the steam generator supply tank.

A. 1. 1. 2. 3 Approach to Operating Temperature (Figure A-8)

As in the approach-to-operating-temperature mode with storage depleted (Section A. 1. 1. 1. 3), when the output from the collector field reaches approximately 533°K (500°F), flow is directed to the one-hour tank to provide a relatively constant inlet temperature to the collector field as the outlet temperature approaches the normal operating value. Figure A-8 shows the SCS in this mode. However, once the outlet temperature reaches its normal value, operating flow is directed to the steam generator, and normal operation is assumed. The second tank, which was supplying the steam generator, is still on line to supply as necessary. The one-hour tank is still in the charge mode to receive field flow, if any, in excess of the steam generator demands. As mentioned previously, the PCS may be operating at an increased power level.

A. 1. 1. 3

A. 1. 1. 3. 1 Collection/Charge Storage/PCS Direct Supply (Figure A-9)

When the Solar Collection Subsystem is in this solar power operating mode, heated Syltherm 800 flow from the collector field is supplied directly to the steam generator supply pump, then to the steam generator, and finally back to the field. Flow from the collector field which is in excess of the PCS demand flows through the charging storage tank and then back to the field. Thus, in this mode, the SCS supplies energy to the load directly, with excess energy being stored, as shown in Figure A-9. The storage tank being charged during this mode depends on the storage subsystem charging logic and the state of the tanks. As mentioned in the fossil-to-solar-transition mode (Section A.1.1.1.5), following the startup with storage depleted, the one-hour tank has just been charged and placed on discharge, and the first of the two discharged large storage tanks is placed on charge. The storage tanks are shown in this state in Figure A-9. This mode will continue until either (1), charging is discontinued because the fluid flow due to an insolation drop is less than the PCS demands as covered in A.1.1.3.2, or (2), the charging tank reaches breakthrough. If the charging tank reaches breakthrough, meaning its sump temperature has reached 561°K (550°F), the storage transfer pump is activated.

The next discharged tank begins to be charged with the 561°K (550°F) pump fluid, and this tank now supplies return flow to the field. This series transfer mode is identical to that discussed in Section A.1.1.1.4 and terminates when the breakthrough tank becomes fully charged, at which point it becomes available for discharge, and the tank which was being series charged now is directly charged by the field. This charging (and series charging) will continue until either all the tanks are fully charged (i.e., 95%), as discussed in Section A.2.1.2, or discharging occurs.

As mentioned in the approach-to-operating-temperature mode with storage charged (Section A.1.1.2.3), the one-hour tank is being discharged when the collector field outlet temperature reaches 658 - 672°K (725 - 570°F), and flow is sent directly to the steam generator. Thus, for the startup-with-storage-charged mode, the one-hour tank will continue to be the selected charging tank. However, when the one-hour tank reaches breakthrough and the control system scans for the next discharged tank, the tank selected may not be the second but rather the third, depending on the storage charge/discharge history. In this case, the control system will set the storage valves and activate the storage transfer pump to series charge the appropriate tank. However, a discharged tank will always be available because, as mentioned in A.1.1.2.2, if the possibility for a discharged tank not being available exists, the constant power output mode is selected.

A.1.1.3.2 Collection/Discharge Storage/Direct PCS Supply (Figure A-10)

When the Syltherm 800 flow from the field which is being supplied directly to the steam generator supply pump is less than the PCS demand, the deficit flow will be made up by discharging a charged storage tank. No valve changes are required immediately from those given in the collection/charge-storage/PCS-direct-supply mode (Section A.1.1.3.1) during which a tank is on line to be charged and another on line to be discharged instead. The discharge flow is drawn and returned to the discharging tank by the steam generator supply pump to supplement the direct flow from the field.

As in the collection/charge-storage/PCS-direct-supply mode (Section A.1.1.3.1), the tank being discharged depends on the storage subsystem discharge logic and the state of the tanks. The storage discharge logic is essentially the same as charging. It directs discharge of the small tank first and then the large tanks in sequence. Also, only those tanks which have been fully charged or have charged lower portions, due to inversion, etc., are directed to be discharged. Numerous states of charge or discharge for the tanks are possible.

Figure A-10 shows the SCS operating in the mode of discharging the one-hour tank. The first tank is shown charged, and the second large tank is shown ready for charge by the field flow should a higher insolation level return. Fluid does not charge the second large tank because the height of the fluid column in the charging header will rise only to that level which corresponds to the sump level in the discharging tank plus a minimal pressure drop in the piping. Essentiallly, the discharging storage tank sets the steam generator supply pump suction head. This mode will continue until the sump temperature in the discharging one-hour tank reaches the minimum steam generator supply temperature. At this point, because a charged large storage tank is available, the storage transfer pump is activated, and series discharge is initiated.

The mode is similar to series charge, however just prior to initiation, flow is flop-flopped back and forth between the two tanks to eliminate any cold slugs in the piping below the sump of the charged tank. Then, the hot fluid exiting from the one-hour tank sump at a temperature somewhat below the steam generator supply temperature is directed via the storage transfer pump and valves to the top of the available charged large tank. The fluid passes through the tank, is heated to the proper temperature, and then, due to a valve position change for the large tank, is directed to the steam generator supply pump suction. This operation will continue until the one-hour storage tank temperature sensors indicate no more extractable energy in the one-hour tank. Then the one-hour tank is positioned to receive any charged flow from the field, or the second large tank will continue to be kept on line to receive charging flow.

The tank selected for charging is the one which can achieve the earliest fully charged status. Thus, if the large tank is almost fully charged, it will continue to receive the flow, but if it is less than, say, 60% charged, the one-hour tank will receive the charging flow. This decision will be made again the following morning. If temperature degradation in the partially charged tank has occurred, it may preclude its use and result in the selection of the one-hour tank for charging.

Returning to the series discharge operation, the first large tank, which was being series discharged, is now being discharged by the steam generator supply pump, just as the one-hour tank was, and the series transfer pump is turned off. This mode will continue, and eventually either the insolation level will drop and the field shutdown will occur as discussed in Section A.1.1.4 or the energy of the discharging large tank, which is determined by the tank temperature sensor, becomes equal to the amount of energy that the PCS will consume during the warmup of the fossil fired heater. If the former occurs (i.e., the field flow is off before the storage is fully discharged), the storage-operation mode (Section A.1.1.3.3) is effected. If the latter occurs (i.e., the stored solar energy is just adequate to keep the STES running until the fossil heater can reach the desired supply temperature), the solar-to-fossil-transition mode (Section A.1.1.4.2) is effected. However, because the field is still operational in this case (unlike that in the discussion of the solar-to-fossil-transition mode), the decision as to which tank to charge is made as mentioned above, and solar energy is supplied only to that tank; the discharging large tank continues to supply the PCS. This mode is similar to the approach-to-operating temperature mode with storage charged (Section A.1.1.2.3) except that the field outlet flow is already at operating temperature.

A.1.1.3.3 Storage Operation (Figure A-11)

In this mode, the storage supplies energy to the steam generator to meet PCS needs in an identical manner to that of the storage-steam-generator-supply mode (Section A.1.1.2.1) The solar collector field is not supplied flow, and it is isolated from the HTS and SGS except for a discharged storage tank which provides net pump suction head and expansion compensation for the forthcoming field startup. Typically, this mode will occur in the evening following a solar power operation day; or, as discussed in Section A.1.1.2.1, it can occur also on a morning following a weekend or sunny weekday. As mentioned in the threshold-insolation/activation mode (Section A.1.1.2.2), the storage transfer pump is activated to bring a charged tank into series discharge when a discharging tank can no longer supply flow above the minimum steam generator supply temperature, with tank flip-flopping occurring just prior to this to eliminate cold slugs. The system is shown in this mode in Figure A-11. This type of operation continues until either the PCS shuts down due to Bicyle Plant shutdown (discussed in the PCS shutdown mode, Section A.1.2.3) or the situation mentioned in the collection/discharge-storage/direct-PCS-supply mode (Section A.1.1.3.2) occurs, that being that the available storage energy is only adequate to meet the steam generator requirements for that amount of time required to activate the fossil fired heater.

A.1.1.4 <u>Shutdown</u>

A.1.1.4.1 Collector Field Shutdown

Shutdown of the solar collector field may occur during attempted field startup modes, or it may occur during operation. During start-up, numerous automatic failure-to-start signals may trigger a shutdown. In addition manual shutdown override is also possible. The first automatic shutdown occurs when the field is in pre-acquisition tracking in anticipation of increased insolation. If pre-acquisition tracking occurs for a duration greater than a predetermined time (1 hour) before the threshold insolation is reached, the collectors shall be stowed, but possibly manually retracted. Second, once the insolation signal exceeds the minimum operating level, but the field outlet temperature does not exceed 685°F for a duration of one and one-half hours, the collectors shall be stowed and the field pump shut off.

The durations specified are preliminary and shall remain so until further analysis definitizes them. Once the field outlet temperature enters the 685-750^{o}F range, indicating normal operation, another set of requirements governs shutdown.

Field outlet temperature is the primary signal for shutdown. After each branch has reached 671^{o}K (745^{o}F), if the field outlet temperature drops below 636^{o}K (685^{o}F), the approach to operational temperature mode is selected, isolating the fluid flow from the steam generator. At this point the field assumes its normal offset track to shutdown if it is later than 3 PM, or if the isolation is greater than 75BN/hr ft^{2}. If these conditions are not met, the field stays in offset track, with the pumps off for 1 hour awaiting increased insolation.

A.1.1.4.2 Solar to Fossil Transition (Figure A-12)

When the STES is operating in the storage steam generator supply mode and the storage tank sensor indicates that stored energy has reached a minimum level which is adequate to meet PCS demands only for the time that it takes to bring the fossil fired heater on line, the solar to fossil transition mode is begun. During this mode, the last discharging storage tank continues to supply the steam generator while the fossil fired heater begins heating and recirculating Syltherm 800 in its heatup mode from the standby temperature to normal operating temperature. During this mode the discharge from the fossil fired heater is isolated from the steam generator supply pump so that all flow is recirculated. The inlet valve from the storage is open to allow for expansion. The system is shown in this mode in Figure A-12. When the fossil fired heater recirculation temperature reaches the steam generation supply temperature from the sump of the discharging storage tank, the steam generator supply valves are repositioned so that flow from the storage goes first through the fossil heater and then to the suction of the steam generator supply pump. The fossil heat input gradually increases as the discharging storage tank sump temperature, which is the inlet temperature to the fossil fired heater, gradually decreases and the fossil heater discharge temperature is increased to 672^{o}K (750^{o}F). When the storage tank sump temperature drops below the minimum supply temperature, the mode is shifted to fossil-heater-steam-generator supply as discussed in Section A.1.1.1.1.

As mentioned above, the fossil heater may be kept in a hot standby mode when it is idle. In this mode the steam generator supply valves are positioned to direct discharge flow from the steam generator through the fossil fired heater before returning to the field. The frequency of occurrence and duration of this mode will be further defined as details of fossil fired heater operation are provided by the manufacturer.

A.1.1.4.3 Nightime Idle/Shutdown Heating (Figure A-13)

When the PCS shuts down following completion of the Bleyle Plant second shift operation, heat input to the solar steam generator either from the fossil fired heater or from storage will be discontinued. System valves will be set in the morning startup position as discussed in Section A.1.1.1.1 or A.1.1.2.1; the essential operating requirements will be expansion compensation, prevention of fluid migration, and continued N_2 overpressure. Should the system fluid inventory in any of the SCS subsystems cool below the allowed operating range, during extended shutdown, the SCS will be actuated to provide shutdown heating. Primarily, shutdown heating may be required to re-establish proper temperature levels in the HTS tanks.

The fossil fired heater or storage energy, if available, will provide the heat source. If the fossil fired heater is the heat source, its circulating pump will continue to provide outlet temperature control. The steam generator supply bypass valve will be opened to avoid the associated ΔP and heat loss. The storage transfer pump may be activated to re-initialize storage temperatures. This mode is manually (operator) initiated.

A.1.2 POWER CONVERSION SUBSYSTEM OPERATION

A.1.2.1 PCS Startup (Figure A-14)

PCS startup sequence is initiated far enough in advance of Bleyle Plant first shift startup so that the turbine-generator set is synchronized with the utility and ready to supply electrical and process steam. Exhaust heat will also be supplied to the TUS; however, as discussed in Section A.2.3, the TUS will operate on storage energy when the PCS is not operational.

The PCS startup is also coordinated with the SGS to assure that hot Syltherm 800 is available upon demand. First, the PCS pumps are activated and component fluid levels established. The steam pressure is then brought up to normal operation.

Via the T-G activation sequence, the turbine is rolled, voltage and frequency established, and synchronization with the utility achieved. PCS startup is then complete.

A. 1. 2. 2 Electric Load Following Total Energy Operation (Refer to Figure A-9)

Following startup, the PCS turbine-generator set begins to supply electric power in a load following manner in parallel with the utility baseload which is controlled to a constant value of (50-75 kWe). Heat energy input to the PCS is supplied through a flow of liquid Syltherm 800 at a temperature of 672^{o}K (750^{o}F) from the Solar Collection Subsystem. This flow passes through the tube side of the steam generator heat exchanger units in which superheated steam at 4.83×10^{6} N/m^{2} (700 psig), 655^{o}K (720^{o}F) is produced. The steam pressure is controlled by variation of the Syltherm 800 flow rate. A small variation of superheat temperature of $\pm$ 6^{o}K ($\pm$ 10^{o}F) occurs over the full range of discharge steam flow.

During normal operation, steam is admitted to the turbine through the control valves. Combined function stop valve/throttle valves are located upstream of the control valves for startup/shutdown and emergency shutdown. The 700 rev/s (42,000 rpm) turbine drives a 30 rev/s (1800 rpm) synchronous generator through a reduction gear.

At a midpoint in the turbine expansion, steam is extracted for process use and also for feedwater deaeration/heating. The extraction port pressure is maintained at or above the required process steam delivery pressure throughout the kWe/process steam load range. The extracted steam, which has a substantial superheat, is conditioned to the process requirement of 7.24×10^{5} N/m^{2} (105 psig), saturated, through controlled throttling and desuperheating by spray injection of condensate out of the condenser hot well.

At the turbine, discharge steam flows to the condenser through a short makeup water preheating passage into which the makeup water from the condensate storage tank is sprayed. The major portion of the condenser thermal load is delivered to the Thermal Utilization Subsystem through a flow of circulating water. This flow is controlled so as to maintain a constant condenser pressure. The design provides for minimum hot well condensate subcooling in order to minimize heat input requirement. Hot well level is controlled by a float actuated valve in the makeup injection line. There is also an on-off valve through which condensate can be delivered to the condensate storage tank from the condensate pump discharge. The hot well storage capacity is sufficient for four minutes operation at full load. Makeup water needed to replace the process steam flow is admitted to the makeup demineralizer from the plant water supply at a rate controlled by the condensate storage tank level control.

From the condenser hot well, condensate is pumped by the condensate pump to the deaerator. The deaerator has a storage capacity sufficient for six minutes of operation at full load. The deaerator incorporates a storage level control which regulates condensate in-flow. In the deaerator, entering condensate is mixed with extraction steam from the turbine, and the heated condensate leaves in a saturated condition at deaerator pressure.

From the deaerator, the heated condensate passes to the boiler feed pump. Near the suction of this pump, hydrazine and ammonia are injected into the feedwater by means of metering pumps from which flow is controlled in response to inputs from sensors of dissolved O_2 (hydrazine control) and pH (ammonia control). The boiler feedwater pump discharge pressure is controlled by a recirculation valve which maintains a constant pressure at the steam generator control valve inlet.

A.1.2.3 Shutdown (Figure A-15)

The shutdown of the PCS occurs when the Bleyle Plant electrical load drops to typical nighttime levels following shutdown of second shift operations. The T-G load is ramped down, the turbine tripped to shutdown, and system pumps deactivated.

A.1.3 THERMAL UTILIZATION SUBSYSTEM OPERATION

A.1.3.1 Absorption Air Conditioning (Figure A-16)

During this mode, a controlled flow of TUS cooling water is supplied to the condenser to maintain the desired 41920 N/m^2 (6.08 psig) pressure. The heated cooling water exiting from the condenser is supplied directly to the termal load supply pump suction. The thermal load supply valves are positioned, and the pump provides a controlled flow to the AAC to meet cooling demands. Exhaust flow from the AAC is then either supplied to a centrally located inlet to the low temperature storage tank or directed back to the cooling water pump suction.

The storage return valves are positioned to control the flow, with the AAC exhaust flowing through the tank if its temperature is hotter than the tank's coldest temperature (typically in the morning) or flowing directly to the pump if colder (typically in the afternoon). Cooling water flow in excess of the AAC demand passes through the storage tank from the top to bottom and then back to the cooling water pump suction.

A.1.3.2 Heating (Figure A-17)

Operation of the TUS in the heating mode is identical to that of the AAC discussed in Section A.1.3.1 except that the thermal load supply valves are positioned to supply heating rather than AAC.

A.1.3.3 Absorption Air Conditioning and Heating (Figure A-18)

Operation of the TUS in this mode is identical to that in Section A.1.3.1 except that the thermal load supply valves are positioned to supply both heating and AAC, and the thermal load supply pump flow is controlled to meet both demands.

A.1.3.4 Excess Heat Dissipation (Figure A-19)

During any of the TUS modes, if the cooling water flow temperature entering the condenser exceeds $364^{O}K$ ($195^{O}F$), the maximum inlet temperature, the excess heat cooling tower is activated. The cooling tower heat exchanger valves are positioned so that discharge flow from the cooling water pump now flows through the excess heat dissipation heat exchanger where it is cooled to $361^{O}K$ ($190^{O}F$) before entering the condenser. In this way, excess heat is dissipated at the coldest part of the TUS subsystem, the condenser inlet, allowing the storage tank to remain hot.

A.2 WEEKEND OPERATION

A.2.1 SOLAR COLLECTION SUBSYSTEM

A.2.1.1 Startup (Figure A-20)

The startup sequence for the Solar Collection Subsystem is identical to that presented in Sections A.1.1.1 and A.1.1.2 except that the PCS will not be operating due to the Bleyle Plant shutdown. Therefore, the weekend startup sequence does not include fossil or storage steam generator supply or fossil-to-solar transition. Instead, the SGS is isolated from the CFS and HTS except for connection to a storage tank for expansion compensation.

A.2.1.2 Charge Storage (Figure A-21)

In this mode, operation is similar to that in the collection/charge-storage/PCS-direct-supply mode (Section A.1.1.3.1) except the SGS supply and return valves are closed. The SGS is isolated and non-operational except for expansion compensation.

The solar collector fluid supplies all flow to the charging storage tanks. Series charging is employed, and the first two tanks are fully charged if adequate insolation is present. The third tank is not fully charged because no additional tanks are available for series charge once breakthrough is reached. Instead, this tank is fully charged on Monday before or after the one-hour tank, depending on its temperature state on Monday morning.

A.2.1.3 Shutdown

Same as Section A.1.1.4.1

A.2.2 POWER CONVERSION SUBSYSTEM OPERATION

The PCS is shutdown on the weekend as discussed in Section A.1.2.3.

A.2.3 THERMAL UTILIZATION SUBSYSTEM OPERATION

A.2.3.1 Absorption Air Conditioning (Refer to Figure A-22)

During this mode, the cooling water pump is off, and no cooling water is supplied to the condenser, for the PCS is shutdown. The thermal load supply pump takes suction flow from the top connection of the storage tank and supplies a controlled flow to the AAC to meet cooling demands. The return flow is directed to the bottom or middle connection on the tank, depending on its temperature relative to the tank. This mode also applies to early weekday cooling before the Bleyle Plant has started up.

A.2.3.2 Heating (Figure A-22)

This mode is identical to Section A.2.3.1 except the thermal load supply valves are positioned to supply heating rather than AAC.

A. 3 DUAL MEDIA OPERATION

A. 3. 1 Series Discharge/Dual Media

The dual media storage operation as described in Section 2, is provided as a backup operation capability. Automatic operation in the dual media more is provided, operation is essentially the same as the trickle mode, except that flow is reversed during discharge and series discharge. Figure A-23 depicts the steps in the dual media series discharge mode.

A. 3. 2 Level Control/Dual Media

To accommodate level changes in the dual media mode due to temperature/expansion effects, an automatically activates level control system is provided. Figure A-24 shows the STES employing level maintenance in the dual media mode.

A. 4 EXPERIMENTAL MODES

A. 4. 1 Turbine Bypass

In this experiment the turbine-generator set is isolated, and all electrical loads are provided by the utility. The turbine bypass valves are opened, and steam exiting from the steam generator goes directly to the steam presses and to the condenser for thermal utilization. This operation allows a substantial reduction in steam supply pressure, 7.58×10^5 N/m^2 vs. 4.83×10^6 N/m^2 (110 psig vs 700 psig) for turbine operation. The pressure reduction allows for use of lower temperature solar energy to meet the thermal loads, and the direct supply without a variable electric load being generated allows for an increased and completely matched supply of solar energy to the thermal loads. This mode is shown in Figure A-25.

A. 4. 2 Series Fossil Fired Heater

In this mode the steam generator supply valves are positioned as they are in the fossil to solar transition mode covered in Section A. 1. 1. 5 of Appendix A. Solar heated fluid from either the collector field or storage passes through the fossil fired heater before entering the steam generator. Thus, fluid from the SCS which is at a temperature lower than the minimum required by the PCS can be used because it is boosted to temperature by the fossil fired heater. This operation allows the collector field to operate at reduced outlet temperature, increasing the collected energy, and also allows for complete discharge of all storage tanks. This is shown in Figure A-26.

LEGEND FOR FIGURES A-1 THRU A-26

LEGEND	
	GATE VALVE (MANUAL)
	GLOBE VALVE (MANUAL)
	CHECK VALVE
	SAFETY RELIEF VALVE
	SELF ACTUATED PRESSURE REGULATION VALVE
	ISOLATION VALVE , GATE TYPE (ELECTRICALLY ACTUATED,DIAPHRAGM OPERATED)
	THREE WAY VALVE (ELECTRICALLY ACTUATED, DIAPHRAGM OPERATED)
	MODULATING VALVE (ELECTRICALLY ACTUATED, DIAPHRAGM OPERATED)
	DESUPERHEATER
	STRAINER
	STRAINER (DUPLEX)
	FILTER
	DRAIN
	ISOLATION VALVE , GLOBE TYPE (ELECTRICALLY ACTUATED,DIAPHRAGM OPERATED)

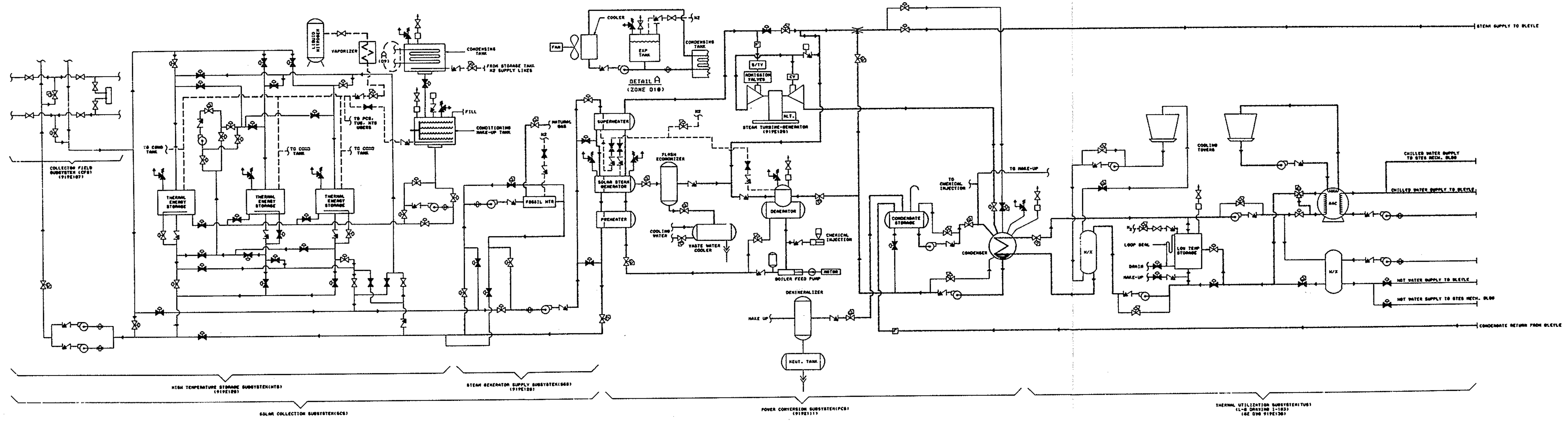


Figure A-1. Fossil Heater Steam Generator Supply (Plant Cooling)

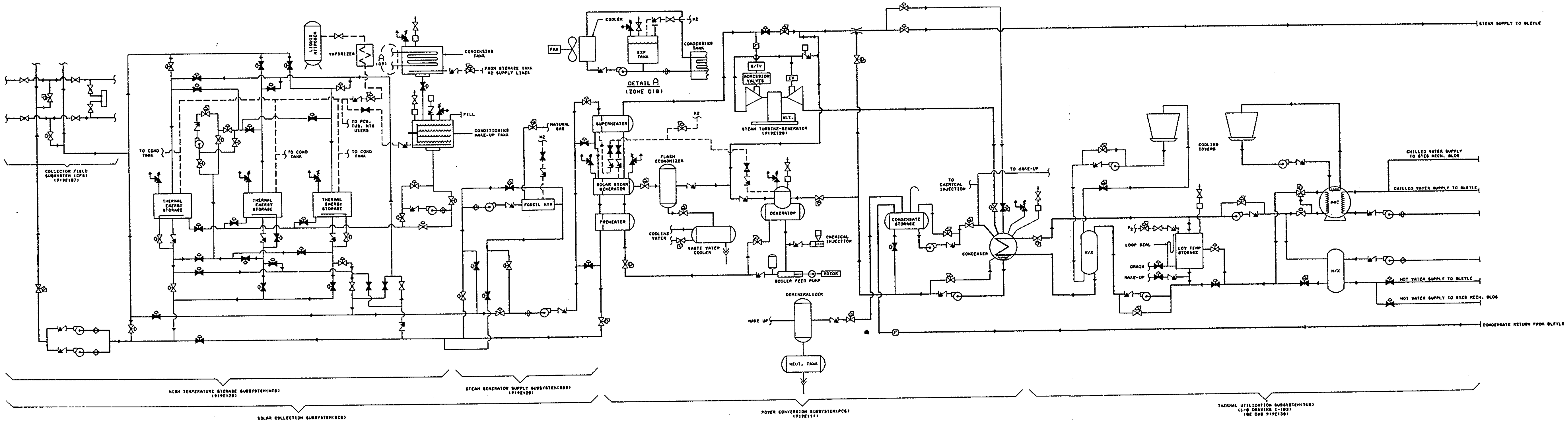


Figure A-2. Threshold Insolation/Field Activation/Bypass Warmup

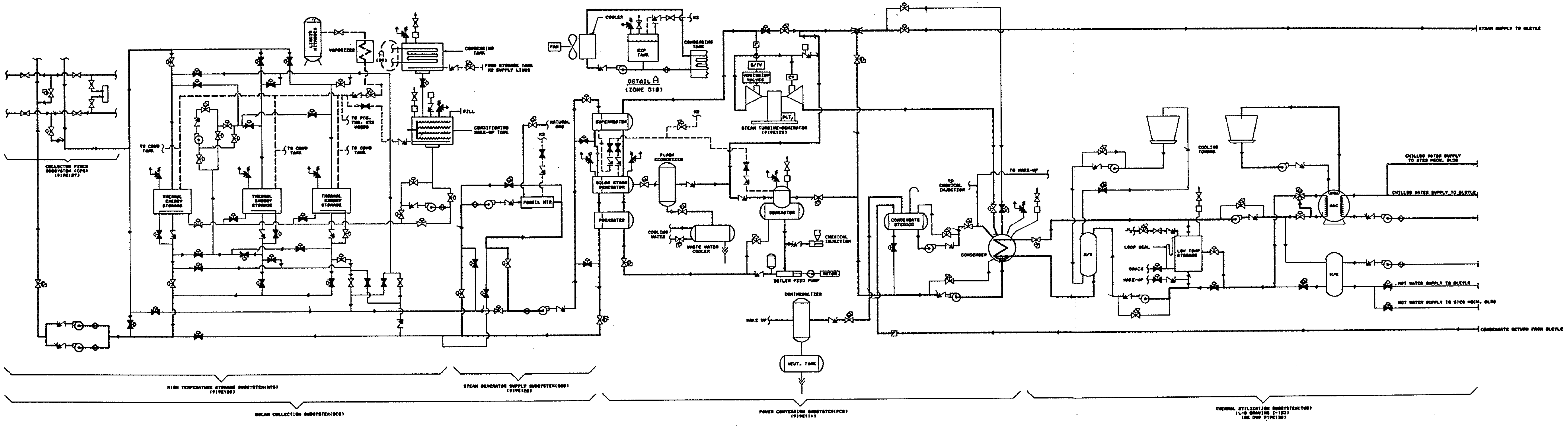


Figure A-3. Approach to Operating Temperature

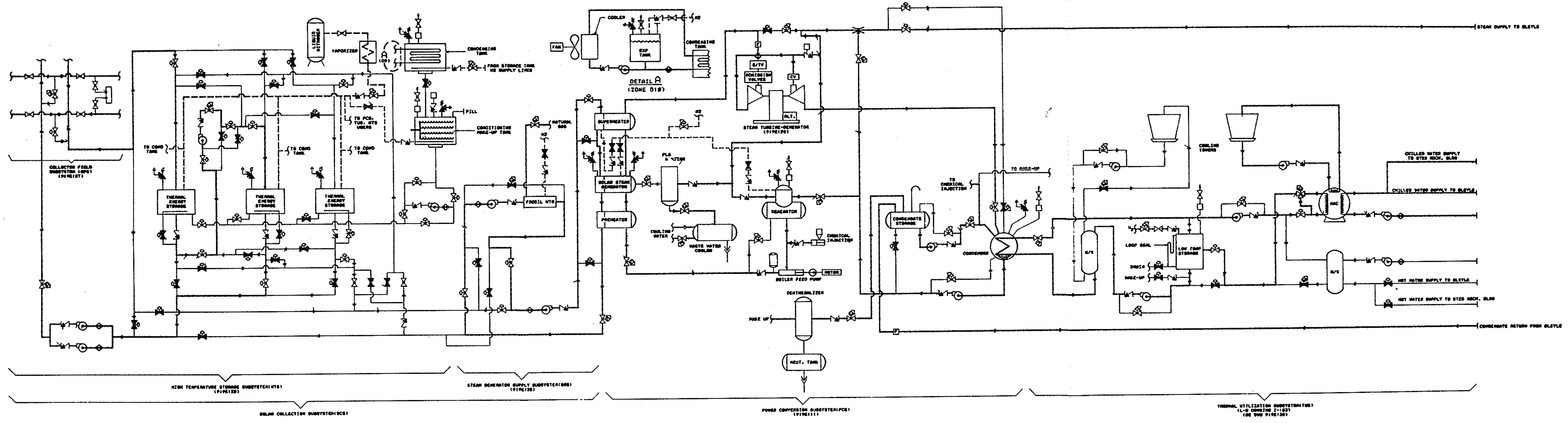


Figure A-4. Series Transfer to Charge Tank Fully

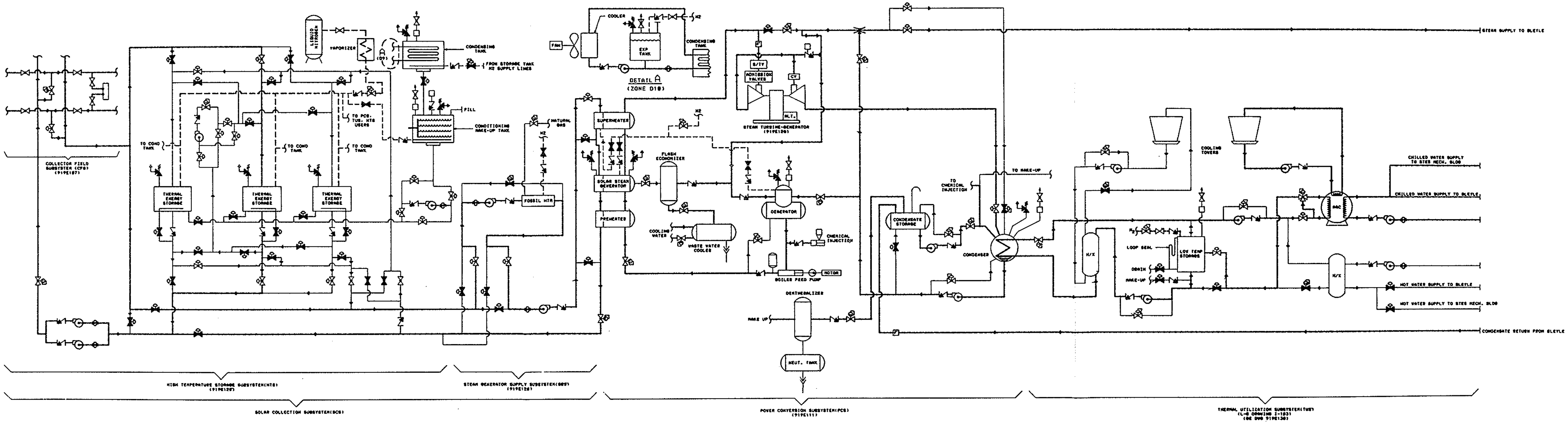


Figure A-5. Fossil to Solar Transition

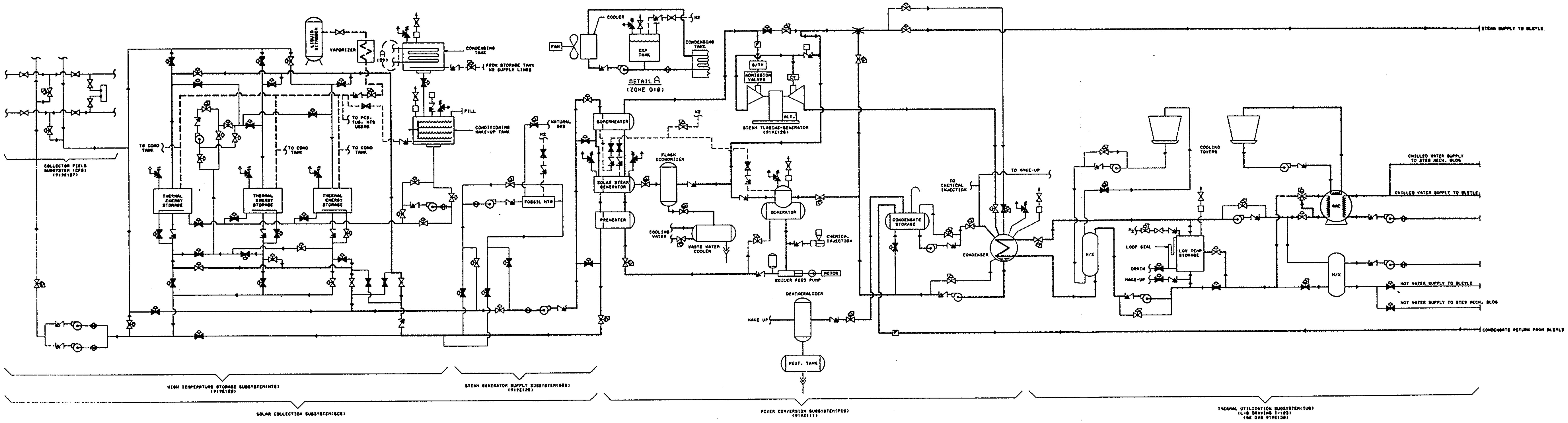


Figure A-6. Storage Steam Generator Supply

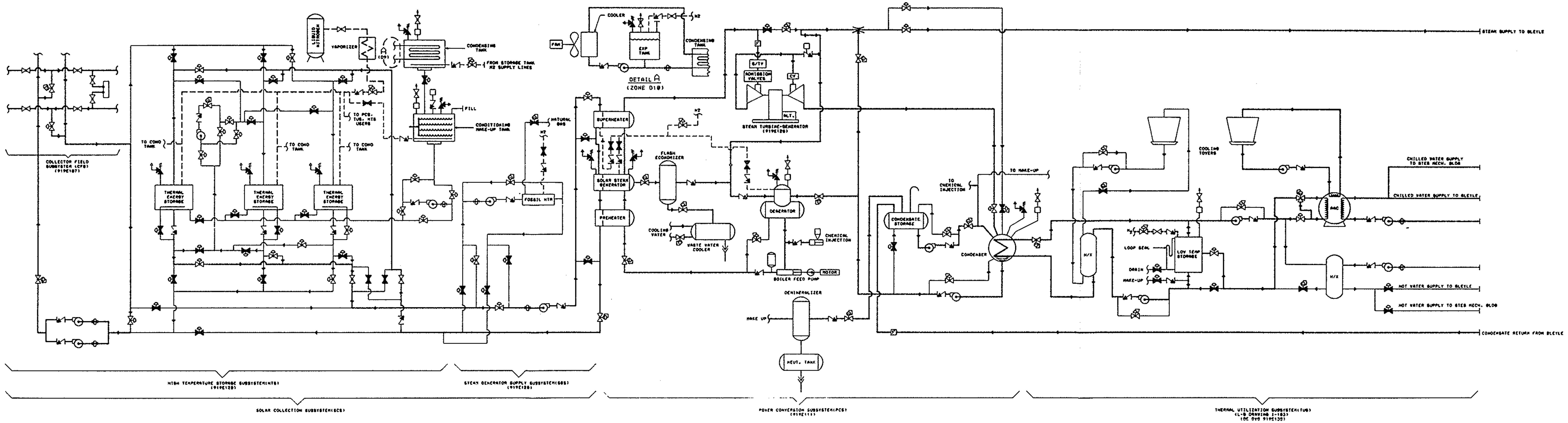


Figure A-7. Threshold Insolation/Activation

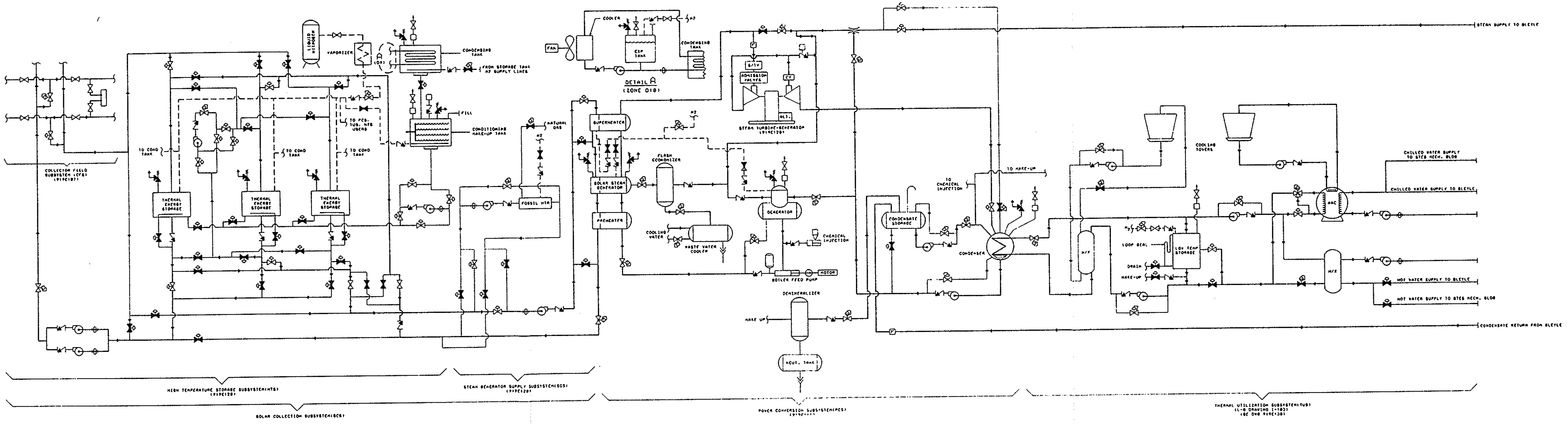


Figure A-8. Approach to Operating Temperature

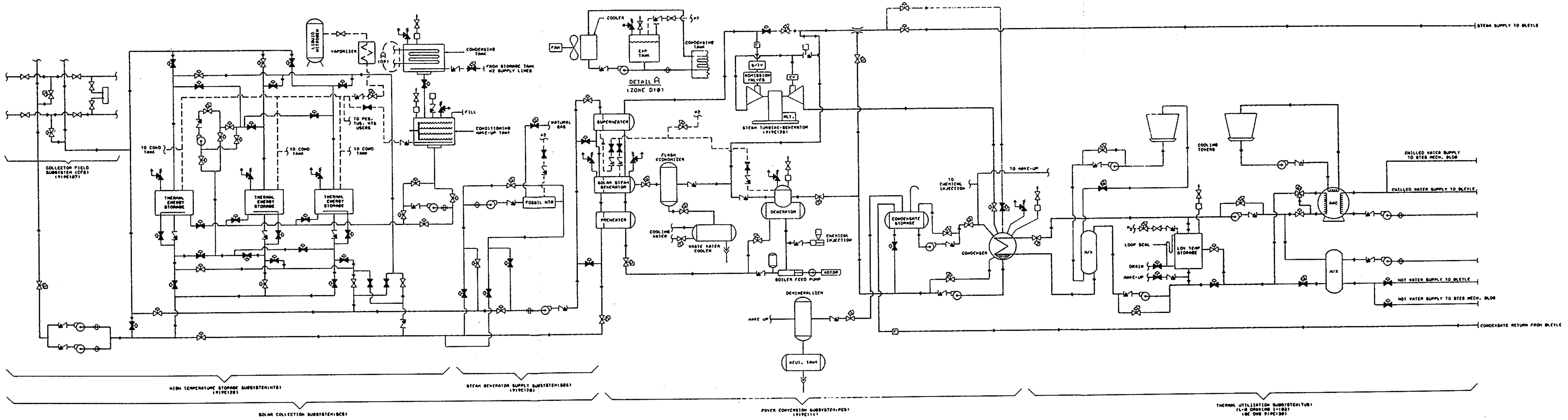


Figure A-9. Collection/Charge Storage/
PCS Direct Supply

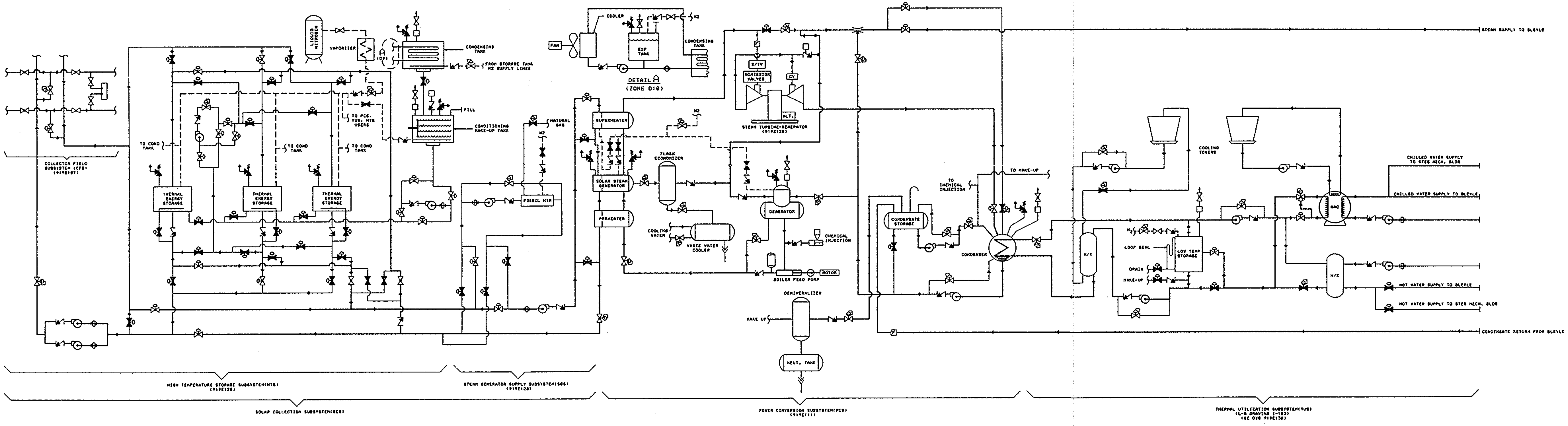


Figure A-10. Collection/Discharge Storage/ Direct PCS Supply

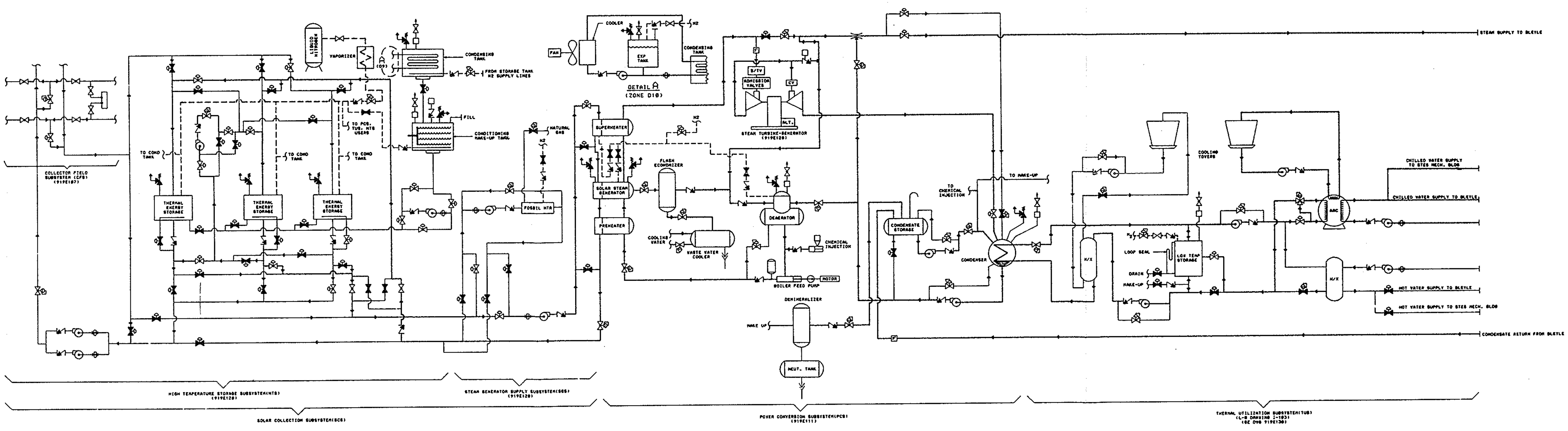


Figure A-11. Storage Operation

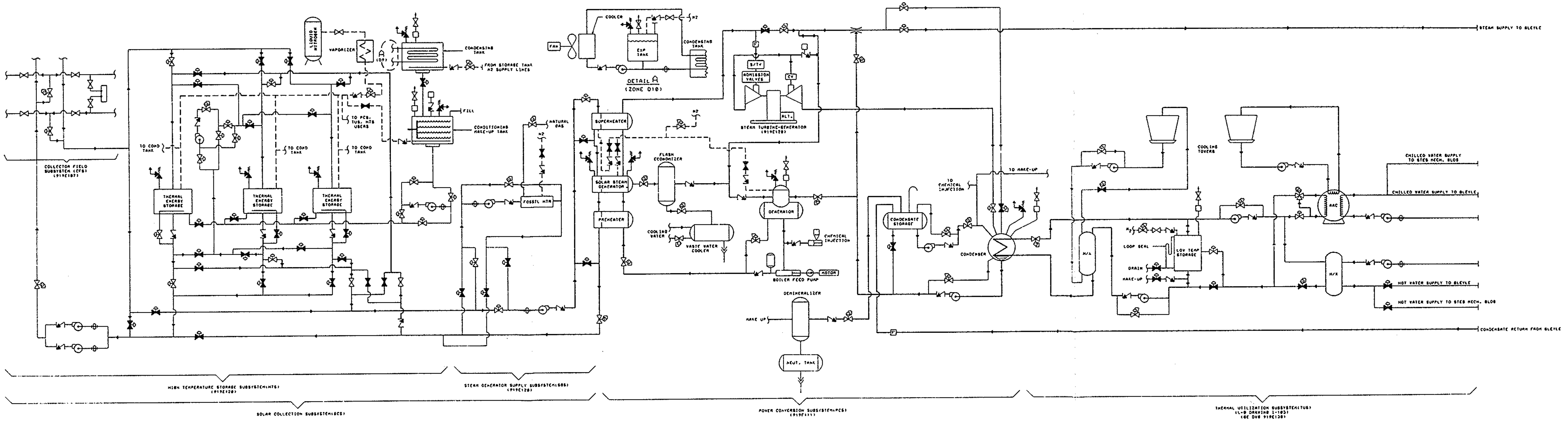


Figure A-12. Solar to Fossil Transition

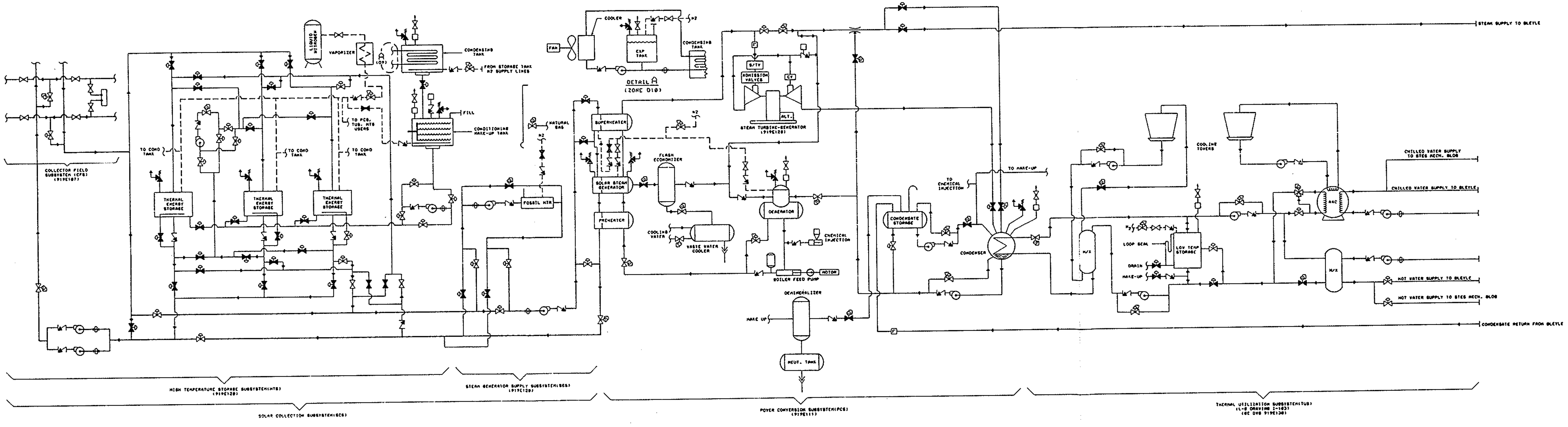


Figure A-13. Shutdown Heating

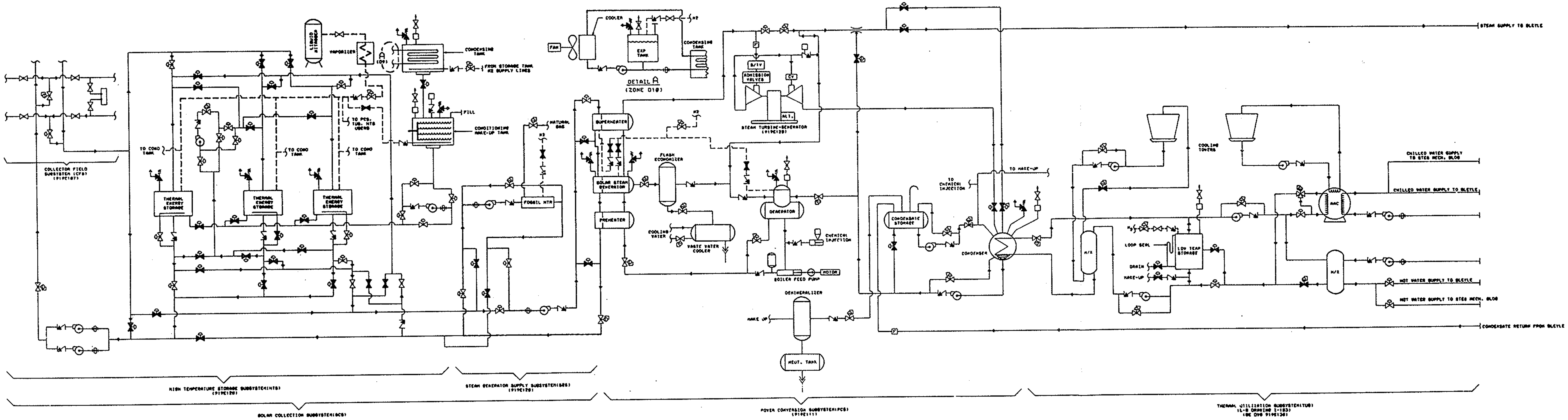


Figure A-14. PCS Startup

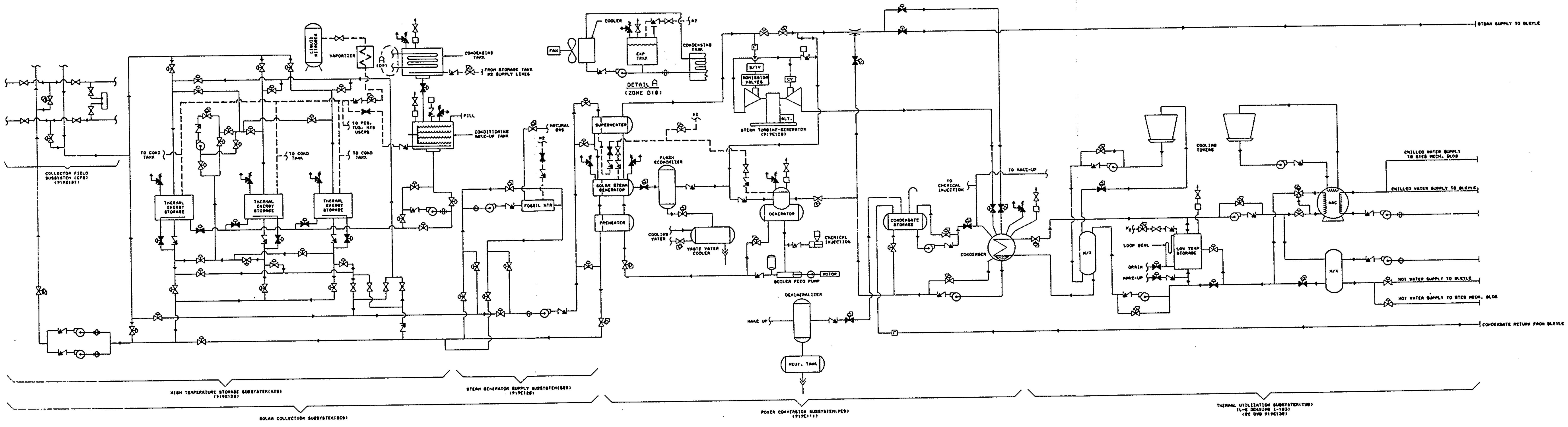


Figure A-15. Shutdown

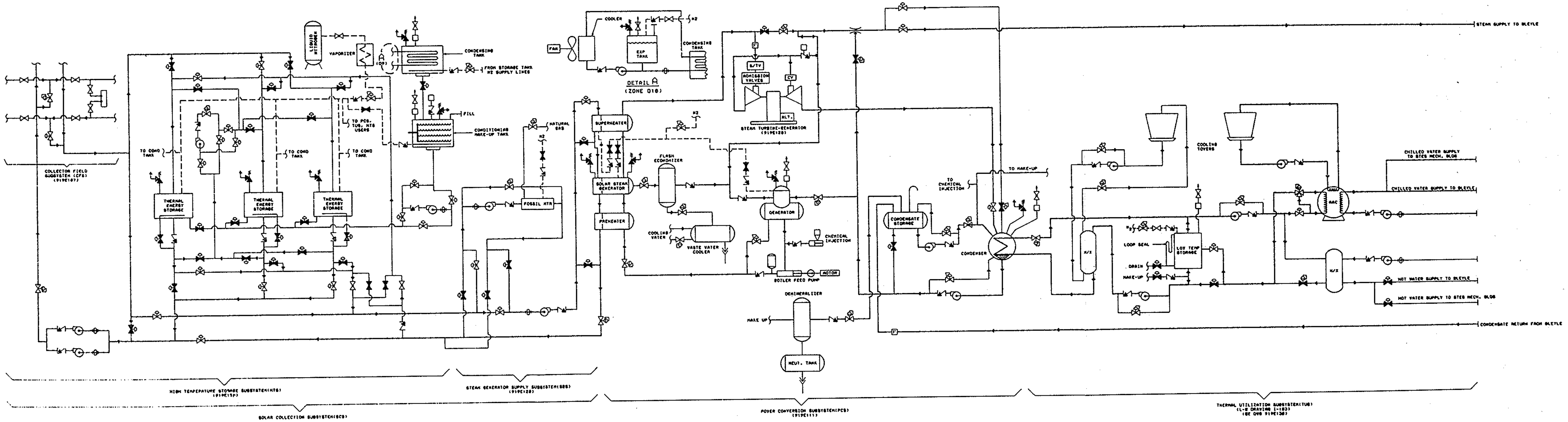


Figure A-16. Absorption Air Conditioning

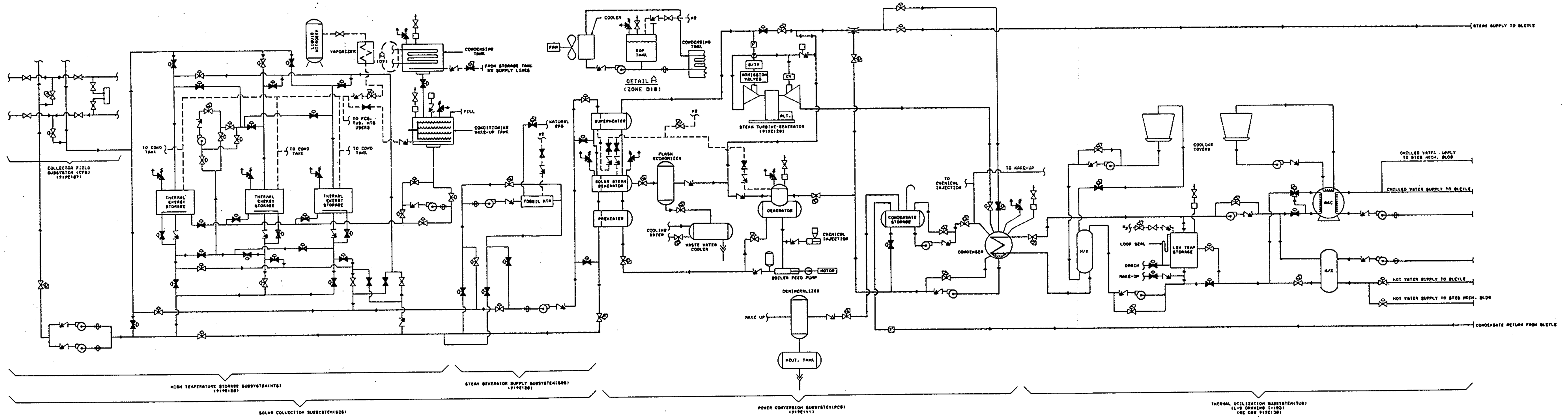


Figure A-17. Heating

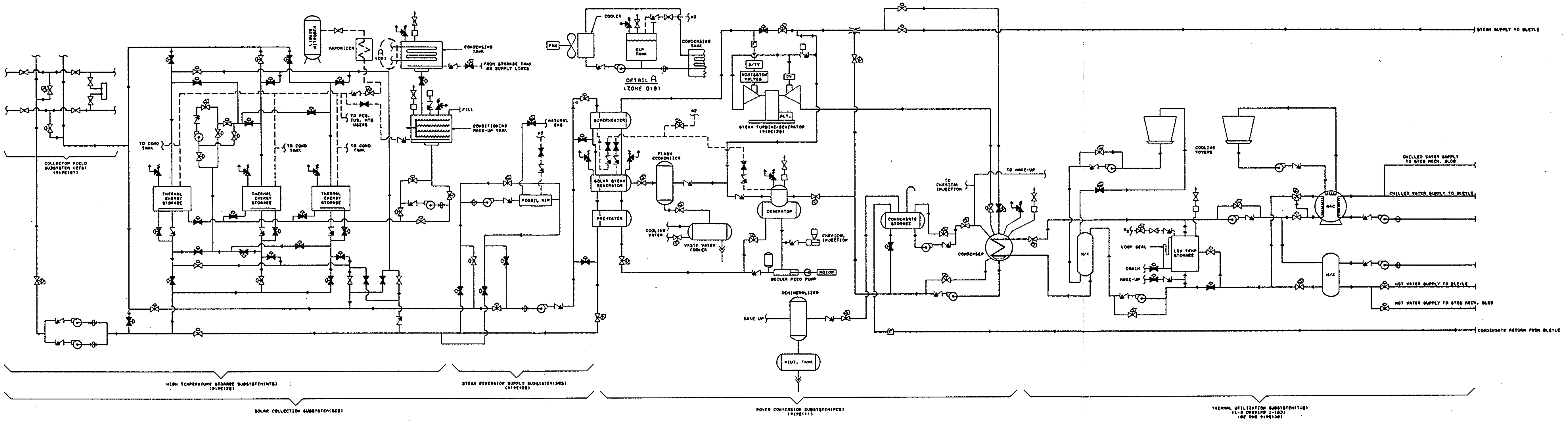


Figure A-18. Absorption Air Conditioning and Heating

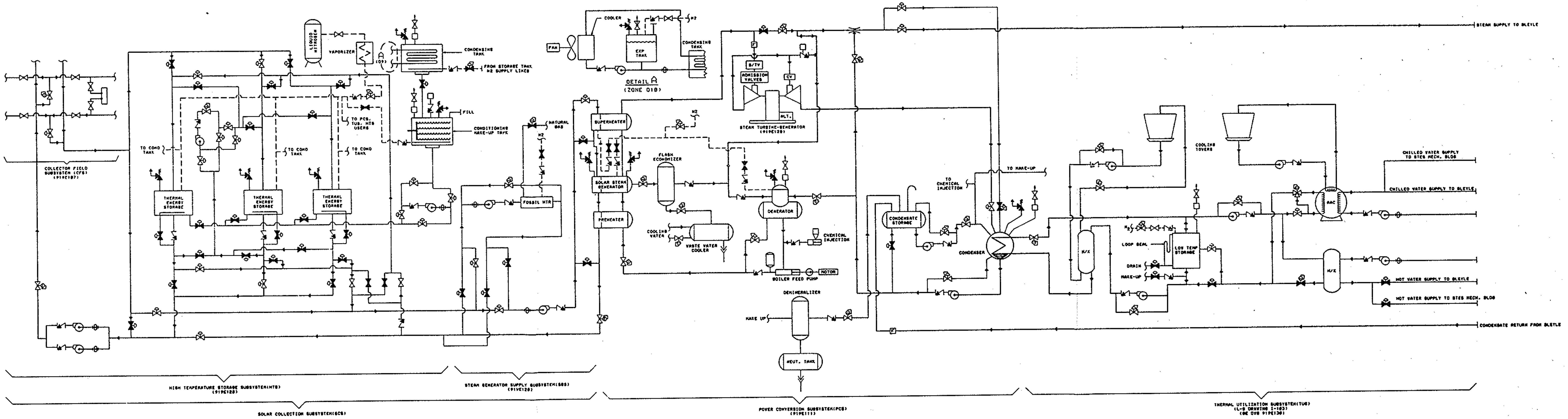


Figure A-19. Excess Heat Dissipation

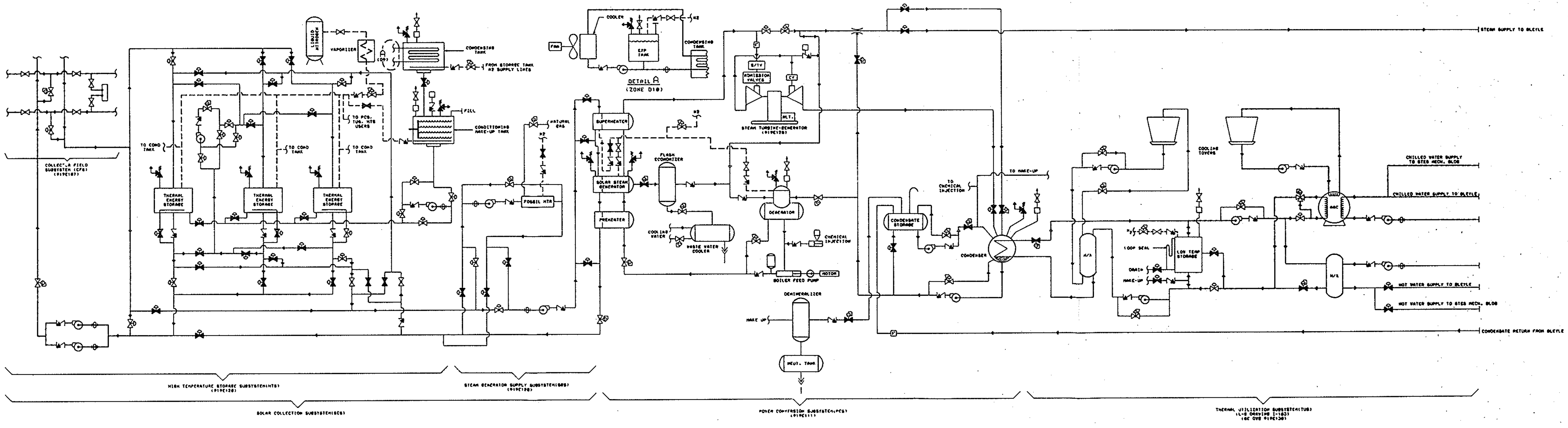


Figure A-20. Startup

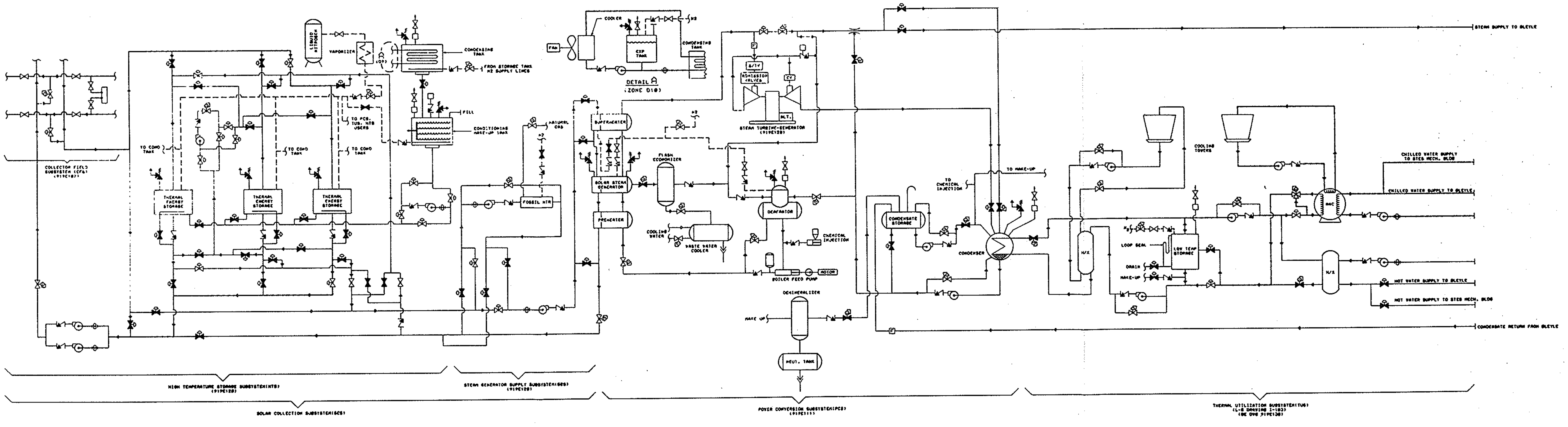


Figure A-21. Charge Storage

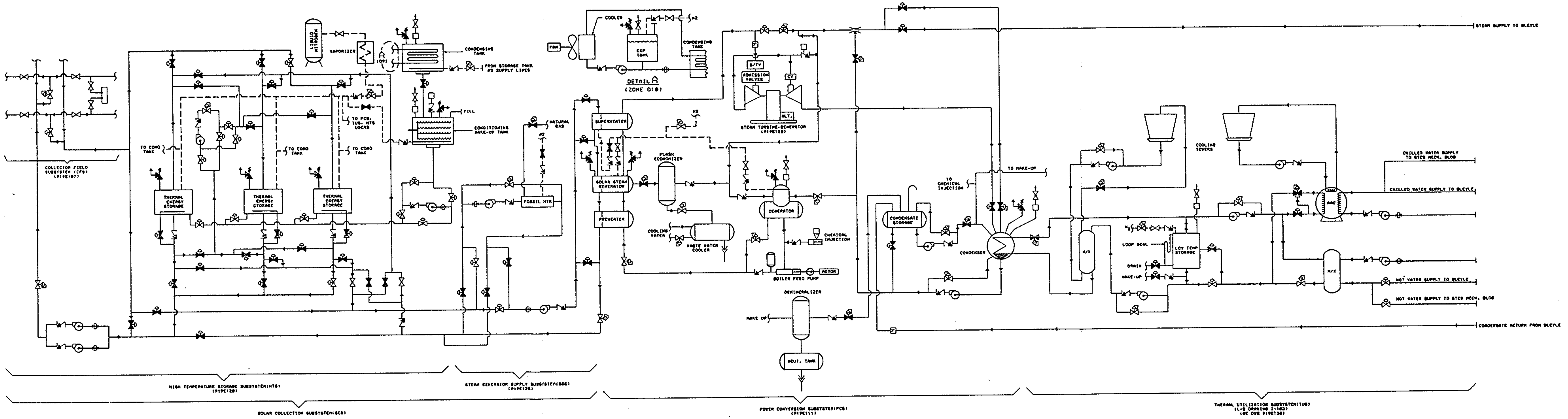


Figure A-22. Heating

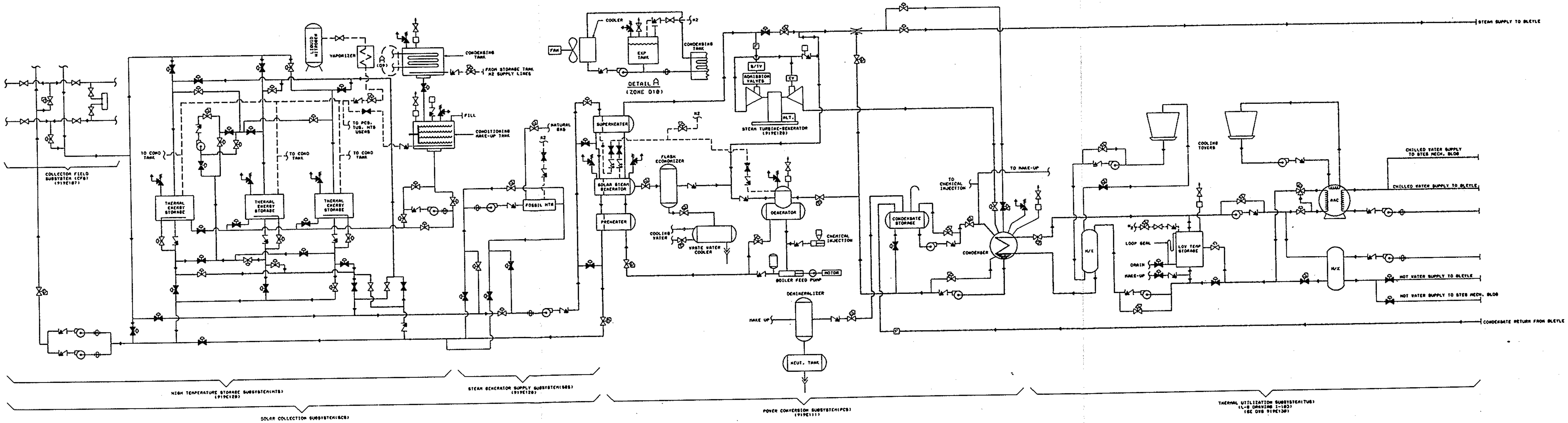


Figure A-23. Series Discharge/Dual Media

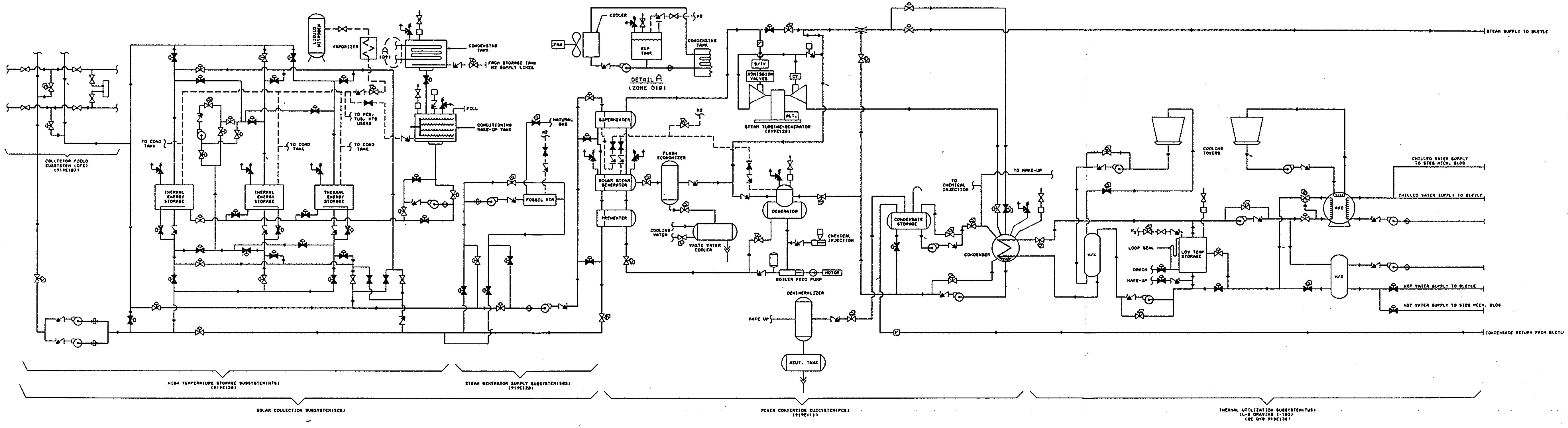


Figure A-24. Level Control/Dual Media

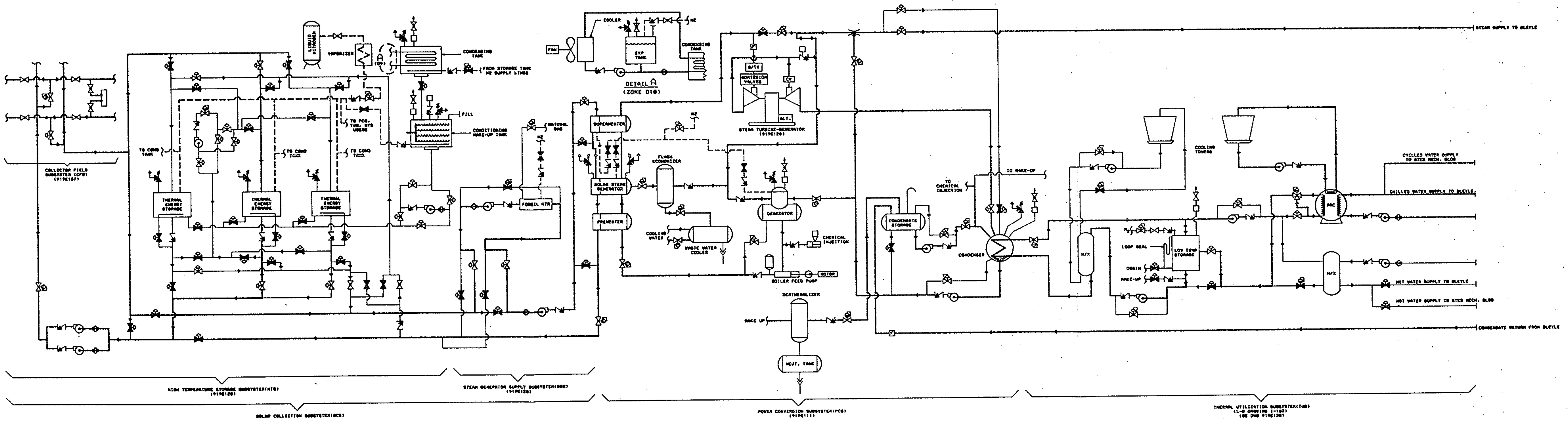


Figure A-25. Solar Boost

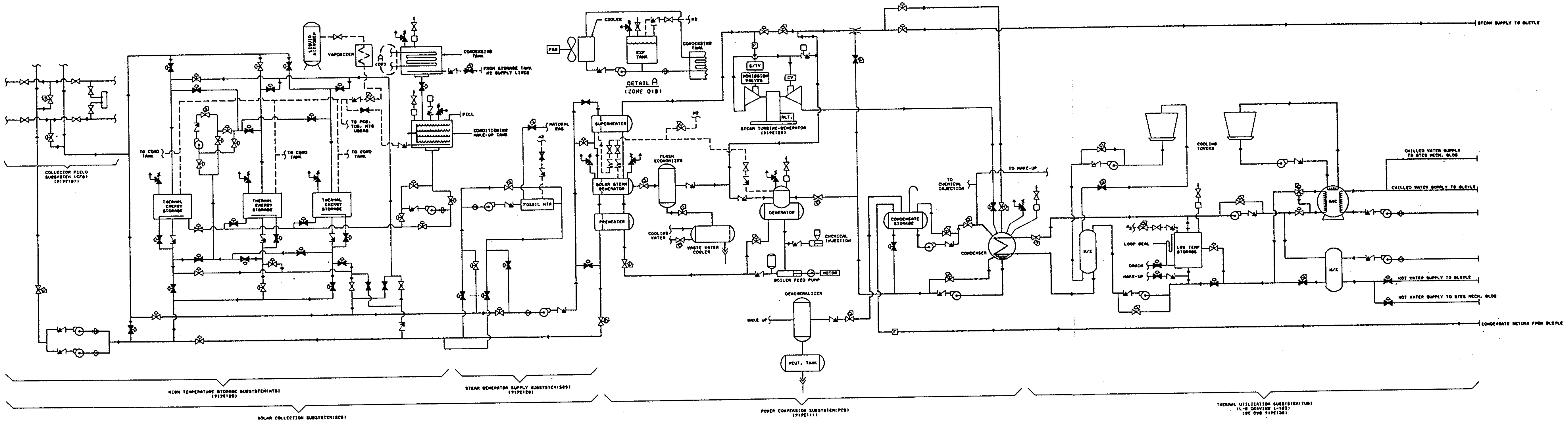


Figure A-26. Turbine Bypass

APPENDIX B

TEST AND EVALUATION PLAN

APPENDIX B

TEST AND EVALUATION PLAN

This preliminary test and evaluation plan presents the general approach for operation of the STES over the duration of the experiment at Shenandoah. First the objectives of the experiment are defined. The schedule of test activities is next discussed which includes both normal operation and the operation of the system in the experimental modes. A description of the System Performance Evaluation Test and associated data set for each of the subsystems is then provided, and the system experimental variation described. In the final section, subsystem test capabilities and speciality instruments are defined.

This preliminary test and evaluation plan will be updated during the Program Phase V into a complete and separate document for use during the Shenandoah operations.

B.1 OVERALL EXPERIMENT OBJECTIVES

The primary objectives of the Solar Total Energy-Program at Shenandoah include the following:

1. To determine the technical and economic viability of a large scale solar total energy system through the collection of a quantitative set of engineering data (in an actual environment) to allow evaluation of the design, performance, and operational characteristics of the system.
2. To determine the performance of each of the subsystems and to establish the impact on performance due to interactions among subsystems.
3. To evaluate the performance of the major experimental components and to determine their suitability and modifications for use in future systems.
4. To examine the operational relationship between the STES and the utility, Georgia Power Company.
5. To evaluate the suitability of load supplying service provided by the STES to the Bleyle plant.
6. To determine the impact on performance of variations between actual loads and solar insolation experienced at the site and those utilized in establishing the STES design.

7. To provide information and experience for establishing the appropriateness of the control system.

8. To determine requirements for improvement in STES design prior to commercialization.

9. To validate operational and maintenance procedures.

10. To evaluate different operational modes such as Stand-Alone Operation, Constant Power Output, and Variable Utility Baseload.

B.2 SCHEDULE OF TEST ACTIVITIES

The preliminary activities schedule for STES operation at Shenandoah is shown in Figure B-1. The schedule begins following completion of system acceptance and pre-operational testing.

Two testing activities will continue throughout the planned two-year operations phases. First, the required maintenance of all system components will be recorded. Maintenance will be identified as either planned or routine or abnormal resulting from component or subsystem malfunction or failure. Second, the degradation of the Syltherm 800 will be continuously monitored via fluid sampling and analysis. All fluid additions and subtractions from the system will be tabulated to maintain a mass balance on the fluid inventory.

As the test operations begin, the system will operate in the normal total energy system modes as described by subsystem in Appendix A. Tables B-1 and B-2 list the various subsystem modes for weekday and weekend operation, respectively. The first operation phase will provide verification checkout of the system control hardware and software to finalize the modes, sequencing, and setpoints. Subsystem tests as discussed in Section B-4 will be performed to support the activity, and the system design data collected in this verification period will be compared. This verification operation will result in a refinement of the STES normal operation, and a period of six to eight months is reserved for normal operation and collection of system data for performance analysis. This period will span summer, winter, and spring or fall to evaluate the effect of cooling, heating, and both on the STES as well as Bleyle and GPC operation.

Table B-1. Weekday System Operating Modes

<u>Solar Collection Subsystem Operation</u>

1. Startup with Storage Depleted
   a. Fossil Heater Steam Generator Supply
   b. Threshold Insolation/Field Activation/Bypass Warmup
   c. Approach to Operating Temperature
   d. Series Transfer to Charge Tank Fully
   e. Fossil to Solar Transition
2. Startup with Storage Charged
   a. Storage Steam Generator Supply
   b. Threshold Insolation/Activation
   c. Approach to Operating Temperature
3. Solar Power Operation
   a. Collection/Charge Storage/PCS Direct Supply
   b. Collection/Discharge Storage/Direct PCS Supply
   c. Storage Operation
4. Shutdown
   a. Solar Collector Field
   b. Solar to Fossil Transition
   c. Nightime Idle/Shutdown Heating

<u>Power Conversion System Operation</u>

1. PCS Startup
2. Total Energy Operation with Electric Load Following
3. Shutdown

<u>Thermal Utilization Subsystem Operation</u>

1. Absorption Air Conditioning
2. Heating
3. Absorption Air Conditioning and Heating
4. Excess Heat Dissipation

Table B-2. Weekend System Operating Modes

<u>Solar Collection Subsystem Operation</u>

1. Startup
2. Charge Storage
3. Shutdown

<u>Power Conversion Subsystem (Non-operating)</u>

<u>Thermal Utilization Subsystem Operation</u>

1. Absorption Air Conditioning
2. Heating

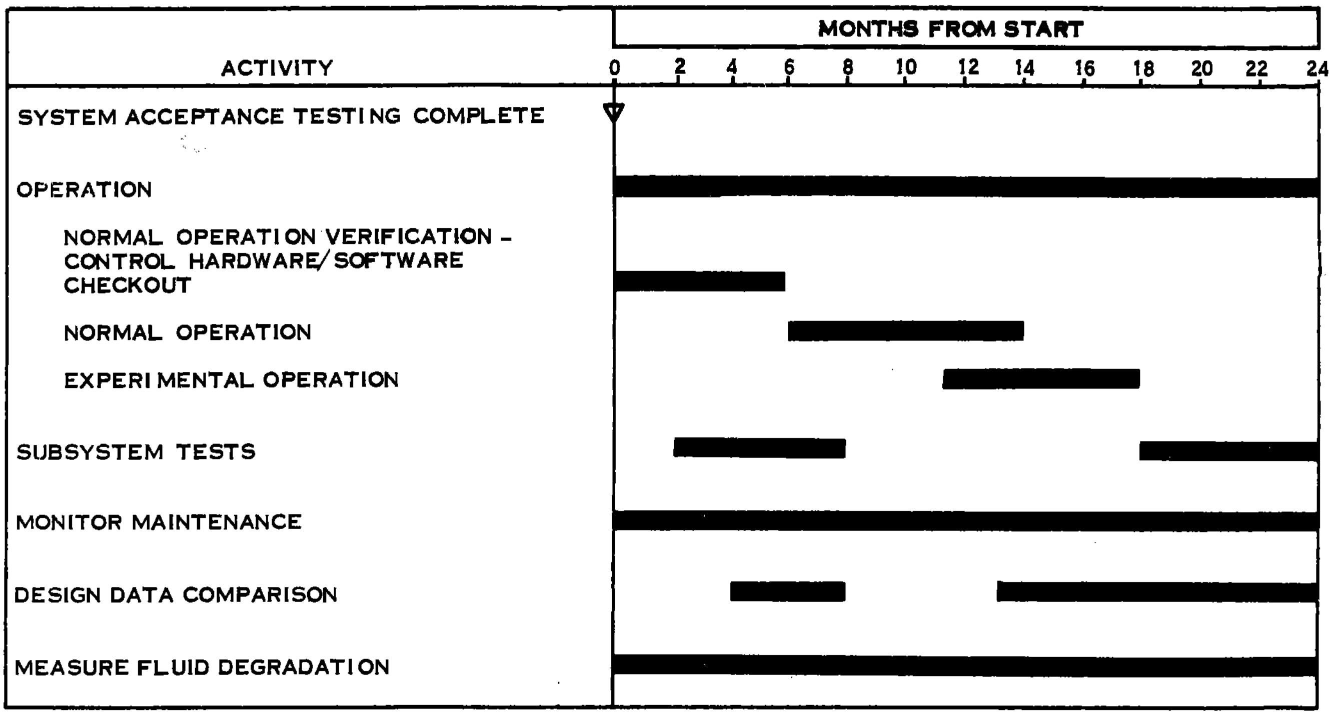


Figure B-1. System Operation - Preliminary Activities Schedule

System experimental operation as discussed in Section B. 3 will begin toward the completion of the normal operating period when it is determined that sufficient data to characterize the normal operation has been collected. This operation includes variations in the electrical power interface with the utility and thermal input of the Collector Field Subsystem. Subsequently, detailed subsystem tests to characterize their operation and interaction as well as to concentrate on the major experimental components will complete the planned operation phase. Test data analysis will continue to support this activity.

B. 3 SYSTEM PERFORMANCE EVALUATION TEST

The System Performance Evaluation Test is the top level test to be performed at the Shenandoah site. The system data set, which is identified in Section B. 3. 1 by subsystems, forms the evaluation data base. This data is continually archived during site operation as described in the Test Data Management Plan provided in Appendix C.

The Test Data Base will be utilized to generate system, subsystem, and component energy balances. These in turn will be converted into efficiencies. Additionally, the solar utility and fossil contributions to the Bleyle Plant loads will be determined.

The System Performance Evaluation Test will be conducted according to the test schedule for the baseline or normal solar total energy mode (electric load following utility baseload), and also the principal system experimental modes as described in Section B. 3. 2.

This test will allow comparative analysis of the various system modes. It will identify the most viable operating options for both electric and thermal displacement for use in future systems. Also, comparative performance analysis of the component and subsystem to determine their optimum configuration and configuration sensitivities will be provided.

B. 3. 1 System Data Set

The System Data Set provides the data base for the system performance test, and also identifies measurements available via the archive tape for subsystem and component tests. Subsystem piping and instrument drawings provided in Section 2 (Figures 2-6 thru 2-11) identify the system data set instruments and their plant location.

The instruments are designated "D" for their CIAS interface. These measurements are provided to the central processor just as control signals are (and many are used for control), i.e., via either the serial data link and BCU for the collector field or via the EμP for the rest of the plant. Table B-3 lists the instruments, types, and their functions for the system data set.

In addition to the data set, subsystem status information derived from the values, pumps, and and other mechanical component status signals will be provided on the tape.

To supplement the system data set above and to facilitate its interpretation relative to overall STES evaluation, certain site operational data will also be provided. Some of the operational data which may be included are:

1. Bleyle Plant operating status
2. STES operating costs
3. Fossil Fuel and utility costs and rates
4. Scheduled and unscheduled maintenance
5. Heat transfer fluid replacement

B. 3. 1 SYSTEM EXPERIMENTAL OPERATION

System experimental operation includes normal STES operation as discussed in Appendix A as well as electrical and thermal power variation as discussed below. During the experiments, system performance evaluation data will be continuously monitored and recorded to characterize the system performance fully in terms of Bleyle plant loads, solar, utility and fossil contributions; and climatology as it affects system operation.

B. 3. 2. 1 <u>Electrical Power Variation</u>

B. 3. 2. 1. 1 Stand Alone Operation

During this experimental mode, the turbine generator will not operate in parallel with the utility but instead will operate independently to provide its own speed/load control to meet the varying Bleyle Plant load. The stand alone mode will provide operational experience typical of a remote application which is isolated from the utility network. (In this situation, however, an auxiliary power source would be required for start-up.)

The stand-alone mode will be initiated after STES startup in the normal interconnected mode with the utility. This simulates remote condition start-up with a backup generator.

B.3.2.2 Constant Power Output

During this experiment, the turbine-generator continues to operate in parallel with the utility; however, the turbine-generator output is maintained constant, and the utility contribution is variable to follow the load. This is typical of STES operation at a fixed level when solar energy is available. This mode allows the turbine-generator to operate at or near its maximum rating which typically is its maximum efficiency operating point. It will allow detailed characterization of the turbine-generator design performance.

B.3.2.3 Variable Utility Baseload

During this mode operation is identical to the normal STES operation presented in Appendix A except the fixed 75 kWe utility baseload is now a variable. This mode allows the utility to increase its power output during offpeak hours such as early morning and evening when it has potentially idle capacity and to decrease its baseload during peak daytime hours when solar power is typically available. This operation allows the STES to serve as a peak shaving system.

B.3.3 THERMAL POWER VARIATIONS

B.3.3.1 Turbine Bypass

In this experiment the turbine-generator set is isolated, and all electrical loads are provided by the utility. The turbine bypass valves are opened, and steam exiting from the steam generator goes directly to the steam presses and to the condenser for thermal utilization. This operation allows a substantial reduction in steam supply pressure, 7.58×10^5 N/m^2 vs. 4.83×10^6 N/m^2 (110 psig vs 700 psig) for turbine operation. The pressure reduction allows for use of lower temperature solar energy to meet the thermal loads, and the direct supply without a variable electric load being generated allows for an increased and completely matched supply of solar energy to the thermal loads.

B. 3. 3. 2 Series Fossil Fired Heater Mode

In this mode the steam generator supply valves are positioned as they are in the fossil to solar transition mode covered in Section A. 1. 1. 5 of Appendix A. Solar heated fluid from either the collector field or storage passes through the fossil fired heater before entering the steam generator. Thus, fluid from the SCS which is at a temperature lower than the minimum required by the PCS can be used because it is boosted to temperature by the fossil fired heater. This operation allows the collector field to operate at reduced outlet temperature, increasing the collected energy, and also allows for complete discharge of all three storage tanks.

B. 4 SUBSYSTEM AND COMPONENT TESTS

Subsystem and component tests will be performed according to the site operations schedule to characterize component performance related to predictions, and to evaluate component performance sensitivities to operating configuration and operational life. Table B-4 summarizes the planned subsystem and component tests for each STES subsystem.

To support detailed component tests, specialty instruments are provided for two of the solar collectors, and for the small and one large high temperature storage tank. These instruments are shown in Figures 2-6 and 2-7, respectively, and include extensive thermocouple-provisions for two collectors in branch six, and profile thermocouples and strain gages for the tank. Data outputs from these instuments will interface with a portable data logger rather than the central processor to provide experimental flexibilities and on line processing capability.

Subsystem and component tests will be initiated via the operating console; a test procedure is summarized in Figure B-2.

Table B-3. System Operational Data Set Details

Subsystem	Measurement	Number of Measurements/Location
Collector Field	Flow	1 Collector Field Supply Line
	Pressure	1 Collector Field Return Line
		1 Branch 6 Flow
		2 Experiment Dish (2) Flows
	Temperature	1 Collector Field Inlet
		1 Collector Field Outlet
		12 Branch Outlets (averages)
		1 Branch Inlet
		240 Receiver Outlet
		240 Polar and Declination
Thermal Energy Storage	Pressure	3 Tanks (top)
	Temperature	3 Tank Inlet
		3 Tank Outlet
		18 Tank Profile (3 tanks)
		1 Return Line (to CFS)
		1 Supply Line (to SGS)
	Valve	40 Tank Valves (On/Off - mode determination)
Steam Generator Supply	Flow	1 Syltherm Line
	Temperature	1 Fossil Heater Outlet
		1 Steam Generator Inlet
		1 Steam Generator Outlet (On Syltherm Side)
Power Conversion	Flow	1 Steam Generator Outlet
		1 Total Extraction (Turbine)
		1 Process Steam (to Bleyle)
	Pressure	1 Steam Generator
		1 Turbine Inlet (Throttle)
		1 Turbine Extraction
		1 Turbine Exhaust
		1 1st Turbine
		1 Deaerator Tank
		1 Process Steam (to Bleyle)
	Temperature	1 Preheater Inlet
		1 Turbine Throttle
		1 Turbine Extraction
		1 Turbine Exhaust
		1 Turbine Desuperheater
		1 Condensate
		1 Process Steam (to Bleyle)
	Valve	1 Turbine Speed
	Frequency	

Table B-3. System Operational Data Set Details (Continued)

Subsystem	Measurement	Number of Measurements/Location
Electrical Subsystem	Frequency	1 Alternator Speed
	Power	4 Real
		4 Reactive
	Voltage	1 STES Generator
		1 GPC Feed
		1 Aux. GPC Feed
		1 Aux. STES Feed
	Position	6 Discretes (TBD)
		- Mode Selection
		- Breaker Position
		- Synchronization
Thermal Utilization Subsystem	Flow	1 Chilled Water Supply
		1 Hot Water Supply
		1 TUS Delivery Flow (to AAC or HX)
		1 Condenser Return
	Temperature	1 Condenser Inlet
		1 Condenser Outlet
		1 Storage Tank Inlet
		1 Storage Tank Outlet
		3 Storage Tank Profile
		1 AAC Inlet
		1 AAC Outlet
		1 Chilled Water Inlet
		1 Chilled Water Outlet
		1 Heating Water Inlet
		1 Heating Water Outlet
		1 Bleyle Heating HX Outlet
Bleyle Plant	Flow	1 Steam Supply
		1 Aux. Fuel (Steam Boiler)
		1 Aux. Fuel (Hot Water Boiler)
	Pressure	1 Steam
	Electrical	5 Roof Top Air Conditioner Power
Weather	Insolation	1 Pyrheliometers
		2 Pyranometers
	Temperature	1 (Dry Bulb)
	Humidity	1 (Relative)
	Wind	1 Velocity
		1 Direction

Table B-4. Subsystem and Component Tests

SOLAR COLLECTOR FIELD (SCF) TESTS

- COLLECTOR EFFICIENCY
- FIELD S/S HEAT LOSS
- FIELD WARMUP
- CLEANING CYCLE
- IMAGE PROFILE
- SETPOINT VARIATIONS
  - STARTUP/SHUTDOWN INSOLATION
  - PARTIAL FIELD STARTUP
  - OPERATING TEMPERATURE
  - TEMPERATURE ERROR CONTROL BAND

HIGH TEMPERATURE STORAGE (HTS) TESTS

- EFFICIENCY
- TEMPERATURE DEGRADATION
- THERMAL LOSSES
- TEMPERATURE PROFILE
- PRESSURE GRADIENT
- STRESS/STRAIN

STEAM GENERATOR SUPPLY (SGS) SUBSYS. TESTS

- FOSSIL FIRED HEATER EFFICIENT
- SUPPLY TEMPERATURE SETPOINT

POWER CONVERSION SUBSYS. (PCS) TESTS

- TURBINE EFFICIENCY
- TRANSIENT RESPONSE
- THERMAL LOSS
- SETPOINT VARIATIONS

THERMAL UTILIZATION SUBSYS. (TUS) TESTS

- AAC PERFORMANCE
- STORAGE EFFICIENCY
- STORAGE TEMPERATURE PROFILE
- SETPOINT VARIATIONS

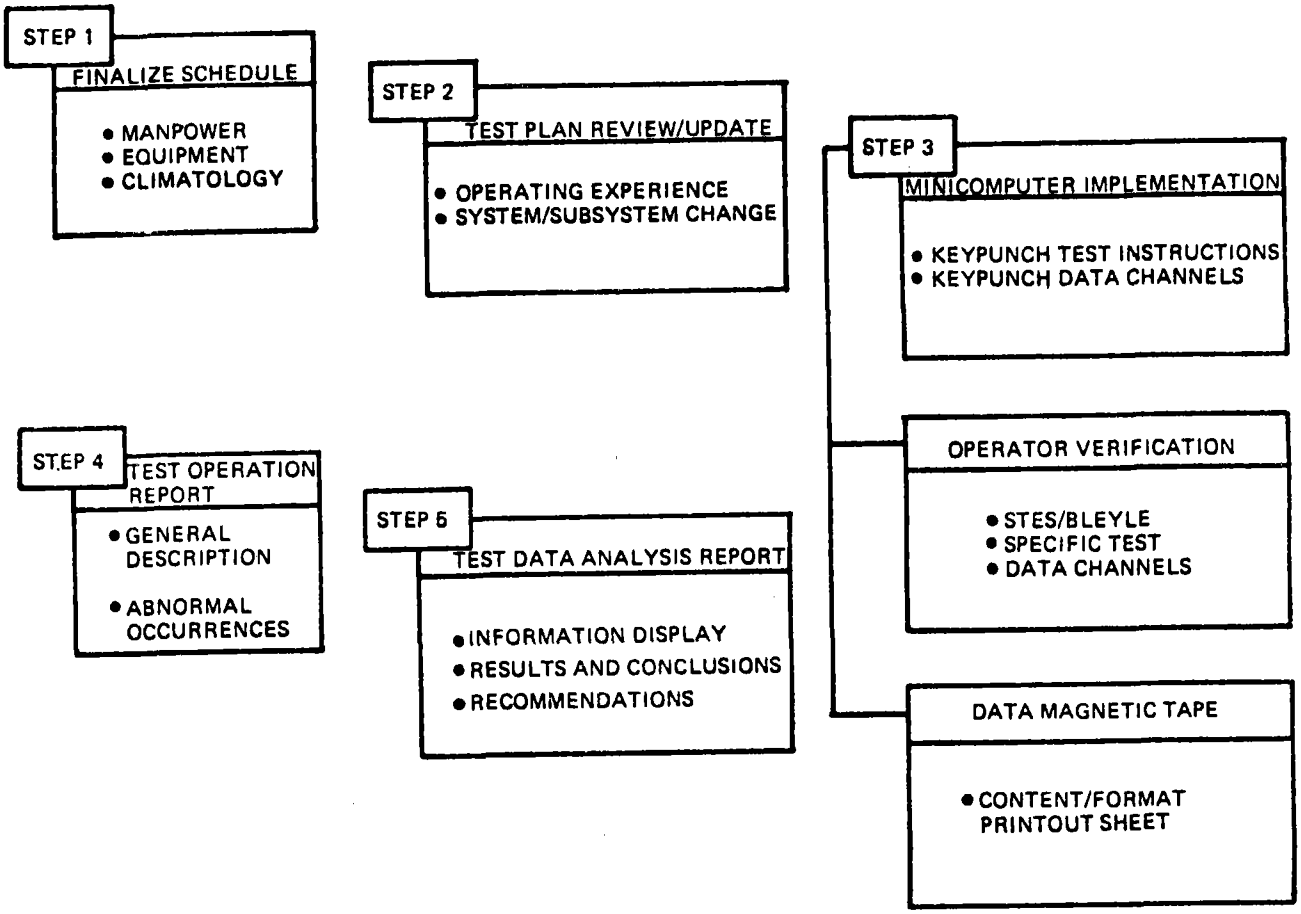


Figure B-2. Test Procedure

APPENDIX C

TEST DATA MANAGEMENT PLAN

APPENDIX C

TEST DATA MANAGEMENT PLAN

To support the experimental objectives of the Shenandoah Program, the system will be extensively instrumented to obtain data both for on-site system operation and for off-site system and subsystem evaluation. The use of the central mini-processor to collect and archive the data facilitates the accumulation of significant amounts of data, and thus it becomes imperative to develop a test data management plan which will allow the most meaningful use of the available data and to insure that useless data is not generated. This preliminary plan identifies the approach to be utilized for data management, and provide a data analysis plan.

C.1 APPROACH

During the two-year system operational period, three basic types of data outputs will be provided. These include digital data taken at specified time intervals for performance analysis, site operational data reports, and site summary reports, as discussed in Appendix B.

The Instrument measurements will be processed and converted to engineering units, and subsequently transferred onto magnetic tape. The system data set would normally be archieved until one month of data is available on a single magnetic tape. This tape would then be shipped to GE/Valley Forge for analysis, along with the site operational data reports and monthly summary. The site report will also contain the printed alarm log generated during the recording period.

The data will then be processed at GE/Valley Forge, (although, via tape duplication, the is available for use at any selected location), and periodic performance analysis reports generated. Figure C-1 summarizes the Test Data Management Approach. The following provide the offsite analysis plan.

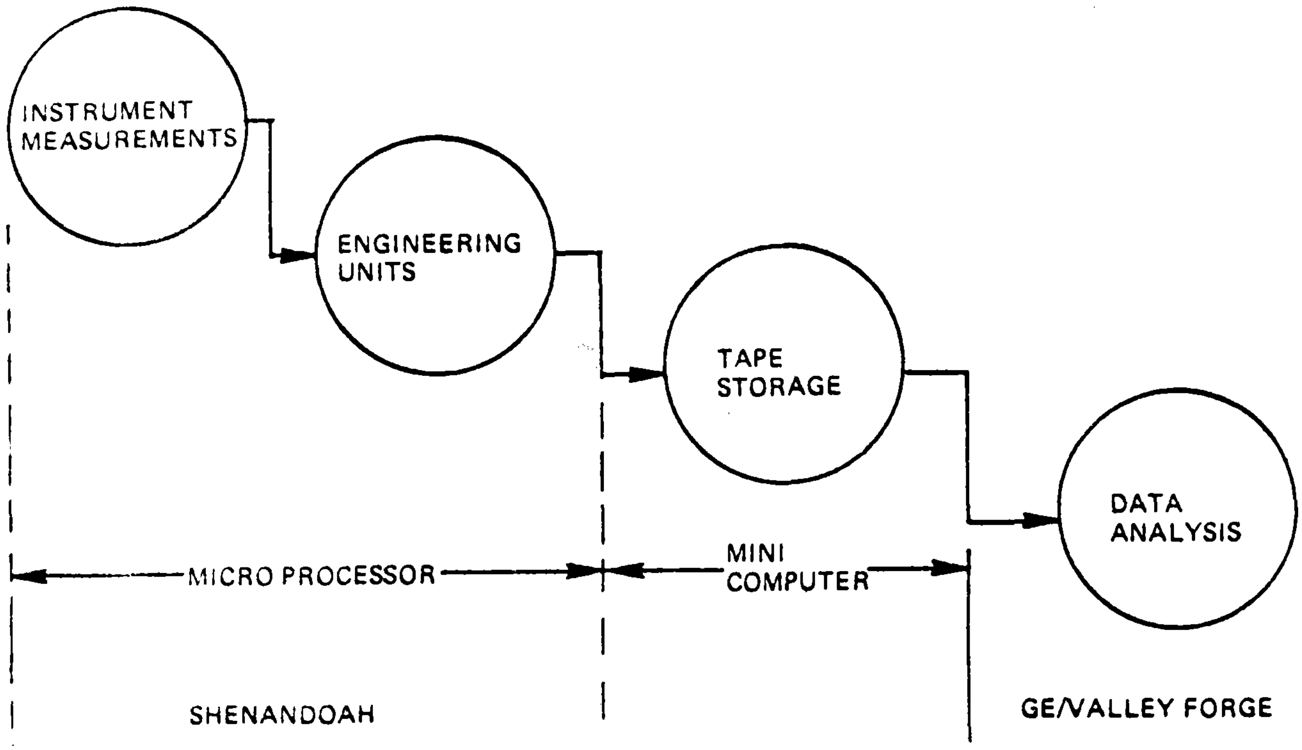


Figure C-1. Test Data Management Plan

C.2 DATA ANALYSIS PLAN

The purpose of the Data Analysis Plan is to identify data collection points provided, to describe any necessary data processing, and to provide for a standard results reporting format.

C.2.1 DATA PROCESSING

Table C-1 shows the instruments which will be used in collecting data for system Test and Evaluation. Also shown in the table is the final, derived parameter which is desired for evaluation, a description of the derivation, each type of measurement made using the corresponding instruments, and the time interval over which to integrate to obtain a value for the desired parameter. In many cases an alternate method of measurement, or backup instrumentation, is also listed.

Computations fall mainly into two catagories: energy balances and efficiency calculations.

The energy balances will be done as follows:

For fluid flow systems, if Syltherm 800 is the medium $Q = \dot{m}\ Cp\ |\Delta T|$ or if water is the medium $Q = \dot{m}\Delta h$

where,

$$Q = \text{heat transfered}$$

$$\dot{m} = \text{mass flow rate}$$

$$Cp = \text{specific heat}$$

$$|\Delta T| = |T_{in} - T_{out}|$$

$$\Delta h = h_{in} - h_{out}$$

and Cp and Δh are available from tables $[Cp = F(T_{avg}),\ h = F(T, P)]$

For solar energy directed at the collector field:

$$Q = \text{Insolation x A effective}$$

where,

A eff. = (A eff/collector) x Number of operating collectors

For isolated HTS tanks

$$Q = C\,\Delta T$$

where,

C = constant

ΔT = Temperature initial - Temp final

Efficiencies will be calculated according to the following procedure. First, used energy is defined as the sum of STES gross electrical output, process steam directed to Bleyle and the STES mechanical building, the AAC cooling load, and hot water sent to Bleyle and the STES mechanical building. Residual energy is equal to the stored energy at the end of the time interval under consideration, and is calculated for the high and low temperature storage tanks as a function of temperature.

Then,

$$\eta \text{ overall based on total direct insol} = \frac{\text{Used energy}}{\left[\begin{array}{l}\text{Total direct insol. after shading}\\ \text{minus residual energy}\end{array}\right]}$$

$$\eta \text{ overall based on total collected energy} = \frac{\text{Used Energy}}{\left[\begin{array}{l}\text{Total collected energy}\\ \text{minus residual energy}\end{array}\right]}$$

$$\eta \text{ solar to electr. based on total direct insol.} = \frac{\text{Gross Elect. Output}}{\left[\begin{array}{l}\text{Total direct insol, after shading}\\ \text{minus residual energy}\end{array}\right]}$$

$$\eta \text{ solar to electr. based on collected energy} = \frac{\text{Gross elect. Output}}{\left[\begin{array}{l}\text{Total collected energy}\\ \text{minus residual energy}\end{array}\right]}$$

$$\eta \text{ collector} = \frac{\text{Total solar energy collected}}{\left[\text{total direct insol, after shading}\right]}$$

$$\eta \text{ hi temp ST tank} = \frac{\text{Solar energy supplied by HTS}}{\left[\begin{array}{l}\text{Solar energy stored minus}\\ \text{residual stored energy}\end{array}\right]}$$

C.2.2 OUTPUT FORMAT

The format for computer output is listed below. Quantities are derived as explained in Table C-1.

System Energy Balance (Solar Heat only)

Total Direct Insolation during SCF op. hours
Total Direct Insolation, after shading effects
Total Solar Energy collected

Collector Efficiency

Solar Coll. Subsyst. Heat losses

Start Up
Field Piping during Steady State Op.
HTS Tanks

Residual HTS Stored Energy

Solar Energy transferred to PCS

Gross Electrical Power output, w/solar heat source.

Process Steam to Bleyle

Heat to TUS

Energy to AAC

Hot Water to Bleyle

Residual Low Temp. Stored Energy

Excess Energy

Heat Rejected to the Atmosphere

System Efficiency (Solar)

Overall Efficiency based on Total direct insolation
Overall Efficiency based on Total collected
Efficiency of Total direct insolation to electricity
Efficiency of Total collected energy to electricity
HTS tank efficiency

Table C-1. Test Data Processing

Parameter	Derivation	Measurement	Instrument Tag No.	Alternate Method	Time Interval
Total Direct Insolation	Total direct insolation will be derived using readings from the two pyranometers XT6114 & XT6115 & a sun position algorithm, then the total direct incident radiation is calculated, as a function of the number of operational (tracking) collection.	Insolation Diffuse Insolation A effective (FT^2)	XT6114 XT6115 Collector Status		When P6001 or P6002, the SCF supply pumps, are running Motor switches YZ 6001 or 6002 may be used to monitor pump status.
Total Insolation after Shading	Same as above except a shading correction factor is included.	Same as above plus Shading.			Same as above
Solar Energy Collected	An energy balance is done using the average value of the operating branch outlet temperatures. If the alternate Thot instrument is used, field return losses will not be calculated. Alternate instruments TT6520 & TIT7160 for T_{COLD} measurement can only be used if recircling the SCF fluid through the HTS (TT6520) or the SGS (TT7160)	$\dot{m}$ T_{HOT} T_{COLD}	FT6580 w/TT6590 TT2305 through TT2316 TIT 6590	FT6585 w/TIT6590 TIT6600 TT6520 or TT7160 or TT2321	Same as above.
SCS Startup Loss	Same as above	Same as above	Same as above	Same as above	P6001 or P6002 running and FV6040, FV6060, FV6070, FV6090 closed. (i.e., SCF on recirc. through field)
SCS Field Piping Losses	An energy balance is done using	$\dot{m}$ T_{COLD} T_{HOT}	FT6580 w/TIT6590 TIT6600 TT2305 through TT2316	FT6585 w/TIT6590	When P6001 or P6002 are running and the SCF is not isolated.

Table C-1. Test Data Processing (Continued)

Parameter	Derivation	Measurement	Instrument Tag No.	Alternate Method	Time Interval
Energy Stored	Using the instruments associated with the tank being charged, an energy balance is calculated. Flow rate is the difference between indications from the two flow transmitters and equals flow to the HTS minus flow to the SGS.	$\dot{m}$ T_{HOT} T_{COLD}	FT6580 w/TIT6590 and FT7155 w/TIT7160 (1) TT6180 (2) TT6181 (3) TT6183 (1) TT6189 (2) TT6190 (3) TT6192	TIT6600 TIT6520	When a recirc. path from the SCF through a HTS tank is open as indicated by these valve positions Tk 1 - FV6060 FV6320 Tk 2 - FV6070 FV6330 Tk 3 - FV6090 FV6350
Energy Supplied by the HTS to the SGS		$\dot{m}$ T_{HOT} T_{COLD}	FT7155 w/TIT7160 TIT7140 TIT7160		When a recirc. path from the HTS through the SGS is open and the SCF is isolated from the SGS. (SCF isolation valve FV6040 is closed). Valves in the HTS recirc. path through the SGS are: Tk 1 - FV6100 FV6280 Tk 2 - FV6110 FV6290 Tk 3 - FV6130 FV6310
HTS Tank Losses	Heat loss is calculated using the temperature drop which occurs when the tank is isolated and a constant value which relates tank temperature to the amount of stored energy present.	T_{HOT} & T_{COLD}	(1) TT6185 (2) TT6186 (3) TT6188	(1) TT6901 through TT6905 (2) TT6801 through TT6805 (3) TT6756 through TT6760	From when the HTS tank inlet & outlet isolation values are open to when either isolation valves are closed. (Each tank is considered individually). Isolation valves are: (1) FV6060 FV6320 FV6100 FV6280 FV6250 FV6215 (2) FV6070 FV6330 FV6290 FV6110 FV6260 FV6225 (3) FV6090 FV6350 FV6130 FV6310 FV6270 FV6245

Table C-1. Test Data Processing (Continued)

Parameter	Derivation	Measurement	Instrument Tag No.	Alternate Method	Time Interval
Residual HTS Energy	Residual Stored energy is calculated using a constant value as mentioned in the derivation above and tank temperature at the end of the time interval.	T	Same as above.	Same as above.	This is a point (not interval) at the end of the total time interval under consideration.
Solar Energy Transfer to the PCS via the SGS	A heat balance during the specified time interval is used to determine energy transfer.	$\dot{m}$ T_{HOT} T_{COLD}	FT7155 w/TIT7160 TIT7140 TIT7160		When the SGS is being supplied by either the HTS or SCF that is when either of these pairs of valves is open. (1) FV6280 & FV6100 (2) FV6290 & FV6110 (3) FV6310 & FV6130 (4) FV6040 & FV6050
Gross Electric Power Output derived from Solar Energy	Power is integrated over the specified time interval.	Electrical Power	JT8914		Same as above.
Process Steam to Bleyle	Energy in the returning condensate is considered to be negligable and only the supply energy is accounted for here.	$\dot{m}$ T_{HOT} P	FT8250 w/TT8240 TT8240 PT8251		Same as above.
Heat to the TUS	Heat transfer is calculated over the given time interval.	$\dot{m}$ T_{HOT} T_{COLD}	FT9030 w/TT9020 TT9010 TT9020		When the SGS recirc. through either the HTS or SCF is open. (as detailed above)
Energy to the AAC	Mass flow rate is derived by subtracting flow to the hot water heat exchanger from the flow measured by FT9160. Flow to the hot water heater is calculated by doing a heat balance around the heater. Total energy is then calculated.	$\dot{m}$ T_{HOT} T_{COLD}	FT9160 w/TT9280 FT9370 w/TT9240 TT9240 TT9230 TT9280 TT9340 TT9280 TT9270		Same as above.

Table C-1. Test Data Processing (Continued)

Parameter	Derivation	Measurement	Instrument Tag No.	Alternate Method	Time Interval
Hot Water supplied to Bleyle & the STES Mechanical Bldg.	Energy transfer is integrated over the given interval.	$\dot{m}$ T_{HOT} T_{COLD}	FT9370 w/TT9240 TT9230 TT9240		Same as above.
Residual Low Temperature Energy	Energy left in the tank is calculated as a function of the tanks average temperature.	T	TT9182 TT9181 TT9180		This is a point, not an interval, at the end of the entire interval under consideration.
Excess Energy-High Temperature	Available Energy is defined as the total direct insolation times the average collector efficiency minus SCF field losses. The HT excess energy equals the available energy minus energy to the HTS minus energy to the PCS.	Required Measurements are available from previously listed instruments.			The entire test and evaluation interval is considered (during which the energy source is solar).
Excess Energy-Low Temperature	Excess LT energy is equal to the energy content of fluid directed to the LT storage tank after "full charge" had been achieved. Flow is equal to the difference of the two flow indications.	$\dot{m}$ T	FT9030 w/TT9020 FT9160 TT9170		Same as above.
Heat Rejected to the Atmosphere via the AAC Cooling Tower	An energy balance is done around the AAC unit.	$\dot{m}_{HOT}$ $T_{HOT\ IN}$ $T_{HOT\ OUT}$ $\dot{m}_{COLD}$ $T_{COLD\ IN}$ $T_{COLD\ OUT}$	FT9160 w/TT9280 TT9280 TT9270 FT9360 w/TT9300 TT9300 TT9290		When the SGS recirc. through the HTS or SCF is open.

Table C-1. Test Data Processing (Continued)

Parameter	Derivation	Measurement	Instrument Tag No.	Alternate Method	Time Interval
Heat Rejected to the Atmosphere via the Condenser Cooling Tower	A heat balance is done around the cooling tower heat exchanger since direct measurements on the cooling tower loop are not available.	$\dot{m}$ T_{HOT} T_{COLD}	FT9030 w/TT9020 TT9020 TT9060		Same as above.
Electric Power					
Bleyle Demand	The STES supplied and GPC supplied energy are summed.	Power	JT8913 JT8914		The entire test & evaluation interval whether or not solar energy is available.
Solar Supply	The solar supply equals the difference between gross generation and station service.	Power	JT8914 JT8915		When the SGS is being supplied by either the HTS or the SCF.
Process Steam					
Bleyle Demand	Process steam produced at Bleyle is metered. The steam is assumed to be saturated but temperature measurement is available as a check. This is added to the solar & fossil supplied steam.	$\dot{m}$ P	FT9610 PT9610		The entire test & evaluation interval.
Solar Supply	This measurement is done as mentioned in section 1 of this table.	$\dot{m}$ T P	FT8250 w/TT8240 TT8240 PT8251		When the SCS is on recirc. to either the HTS or SCF.

Table C-1. Test Data Processing (Continued)

Parameter	Derivation	Measurement	Instrument Tag No.	Alternate Method	Time Interval
Cooling Load					
Bleyle Demand	As for process steam the demand equals Bleyle produced plus solar & fossil produced cooling. Bleyle produced is measured using the air conditioning unit COP and the units electrical power consumption.	Electric Power	JT9540 JT9550 JT9560 JT9570 JT9580		The entire test & evaluation interval.
Solar Supply	The heat loss from the chilled water supply is calculated for the given time interval.	$\dot{m}$ T_{HOT} T_{COLD}	FT9360 w/TT9300 TT9300 TT9290		When the SGS is on recirc. through either the HTS or the SCF.
Heating Load					
Bleyle Demand	The demand equals solar/fossil produced plus Bleyle produced. Bleyle produced is calculated using the water heater gas flow & the heater efficiency.	$\dot{m}_{gas}$	FT9600		During the test & evaluation interval.
Solar Supply	The heat transfer is calculated during the given interval.	$\dot{m}$ T_{HOT} T_{COLD}	FT9370 w/TT9240 TT9230 TT9240		When the SGS is on recirc. through either the HTS or the SCF.

Note: The "solar supplied" hot and chilled water (heating & cooling) includes a portion directed to the STES Mechanical Bldg. The quantity may be estimated later & a correction factor applied.

Table C-1. Test Data Processing (Continued)

Parameter	Derivation	Measurement	Instrument Tag. No.	Alternate Method	Time Interval
Solar Operating Hours	Computation required involves the summation of the incremental time elements during the time intervals described.	Time	See valve positions required under time interval.		When the SGS is on recirc. through the SGS or HTS as indicated by the proper valve lineup & P7110, the SGS pump running or tank charging or SCF warmup is in progress. Where tank changing is indicated by either of the following pairs of valves being open & a SCF pump running. (1) FV6060 FV6320 (2) FV6070 FV6330 (3) FV6090 FV6350
Fossil Operating Hours	Same as above.	Time			When the fossil heater is running and the supply path to the SGS from both the HTS & SCF is closed.
Gross Electrical Output		Power (kW)	JT8914		The entire test & evaluation interval.
Total STES supplied Energy (fossil plus solar)	The heat transfer is calculated as in section 1 of this table under solar energy supplied to the PCS.	$\dot{m}$ T_{HOT} T_{COLD}	The same instruments as those listed to determine solar energy supplied to the PCS, in section 1 of this table.		The test & evaluation interval.
Total STES supplied Electric Energy	See above.	Power	See above.		Same as above.
Solar Parasite Power	The normal station service plus emergency standby power are integrated over the given interval.	Power	JT8915 JT8916		When the SGS is being supplied by either the HTS or SCF.

Table C-1. Test Data Processing (Continued)

Parameter	Derivation	Measurement	Instrument Tag No.	Alternate Method	Time Interval
Fossil Parasitic Power	Same as above.	Same as above.	Same as above.		When the fossil heater is running & the SGS supply lines from the HTS and SCF are closed.
STES Operating Power supplied by GPC	Power is integrated over the specified time interval.	Power	JT8915		When breaker ACB J is open.
PCS Operating Hours	This includes only the time when the turbine generator is on line. Time increments are summed over the specified interval.	ΔTime			When breaker ACB J is closed.

Solar Energy Supply vs. Bleyle Demand

	Electr.	Thermal			Total
		Process Stm	Cooling	Heat	
Bleyle Demand Solar Supplied (NET) % Sol. Supplied of Demand					

System Operations Summary

Operating Hours

Solar
Fossil

Avg. Daily Op. Hours (Total)

Total Gross Electr. Output
Total STES Supplied (Used) Energy
Operating Power (MW Hrs.)

Solar
Fossil

GPC Supplied/STES Consumed Electr. Energy (MW Hrs.)

SOLAR TOTAL ENERGY PROJECT

SHENANDOAH