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TEXTILE DRYING USING SOLARIZED CYLINDRICAL CAN DRYERS  
TO DEMONSTRATE THE APPLICATION OF SOLAR ENERGY TO  
INDUSTRIAL DRYING OR DEHYDRATION PROCESSES

Phase I. Final Report

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Honeywell, Incorporated  
Minneapolis, Minnesota



**MASTER**

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## ABSTRACT

This Phase I ERDA program has resulted in the detailed design of a solar energy collection system for providing process heat to a textile drying process. The solar collection subsystem uses 773 square meters (8313 square feet) of parabolic trough, single axis tracking, concentrating collectors to heat water in a high temperature water (HTW) loop. At the 2:00 pm September 21 time point (clear day) the solar collectors nominally generate 198°C (389°F) water with the HTW loop at  $1.59 \times 10^6$  Pa (230 psi). A steam generator is fueled with the HTW and produces 544.3 kg/hr (1200 lbs. per hour) of process steam at the nominal design point conditions. The generated process steam is at  $0.524 \times 10^6$  Pa (76 psi) and 160°C (321°F). The solar system will provide  $1.3 \times 10^6$  MJ/yr ( $1.2 \times 10^9$  BTU/year) to the process. This is 46 percent of the direct isolation available to the collector field during the operational hours (300 days/year) of the Fairfax mill. The process being solarized is textile drying using cylindrical can dryers. The can dryers are part of a "slashing" operation in a WestPoint Pepperell mill in Fairfax, Alabama. Over 50% of all woven goods are processed through slashers and dried on cylindrical can dryers. Furthermore, since can dryers are also used in other drying processes, this application of solar energy to process heat is one that shows high potential for having a significant impact on displacing conventional fuels. An economic analysis of the solar system was conducted for three locations; Albuquerque and Omaha for two "fiducial" locations, and Fairfax, Alabama for the analysis at the specific site. Upon completion of the design, Specifications and Drawings were developed. All subsystems and components of the specified system are available for fabrication and installation at the proposed site. The specifications and drawings have been issued to several general contractors for receipt of firm bids for the second phase of the program.

## ACKNOWLEDGEMENT

This document reports the activity of Honeywell Inc. and WestPoint Pepperell during Phase I of the subject program. The overall program was under the direction of E. G. Zoerb of Honeywell. From WestPoint Pepperell, the support was provided by R. I. Uhl and C. Summers.

The support of this program by the Agricultural and Industrial Process Heat Branch, Division of Solar Energy, U.S. Energy Research and Development Administration, and the help provided by William W. Auer, Technical Project Officer, and the Program Consultants, J. R. Blevins, W. C. Dickenson, A. Clark, D.E. Randall, and G. W. Treadwell is acknowledged with sincere thanks.

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SECTION I  
INTRODUCTION

1.1 PROGRAM OBJECTIVE

The overall objective of the Industrial Drying or Dehydration Processes program, under which this Textile Drying project is funded, is to stimulate and give impetus to the growth of industry in areas capable of supplying significant amounts of industrial process heat through the use of solar energy.

The specific objective of the Textile Drying project is to design, build, install, and evaluate the application of solar energy to textile drying and to provide an analysis of the economic benefits to be gained by such application.

1.2 PHASES OF PROGRAM

This document is the Final Report for Phase I of the Textile Drying project. Phase I included the process definition, detailed design of the solar system, development of specifications and installation blueprints for the system, and an economic analysis of the solar application.

The future Phase II includes the procurement and assembly of the system components and subsystems, the installation of the system at the MARTEX\* towel mill of WestPoint Pepperell at Fairfax, Alabama, the system start-up and check-out, and the development of a test plan for tests to be conducted in Phase III.

---

\* Brand name

Phase III will include the operation of the system for a twelve month period supplying process heat to the drying application, the collection of system operating data during that period, and the evaluation of system performance and system economics based on the data collected.

### 1.3 FORMAT OF REPORT

This report is organized to facilitate evaluation using the criteria set forth by ERDA during Phase I. Section II of this report, Process Description, documents the drying operation analysis and lists the solar integration requirements as the basis for the solar system design. This section is concluded by explaining that no process modifications are required for utilization of the solar system.

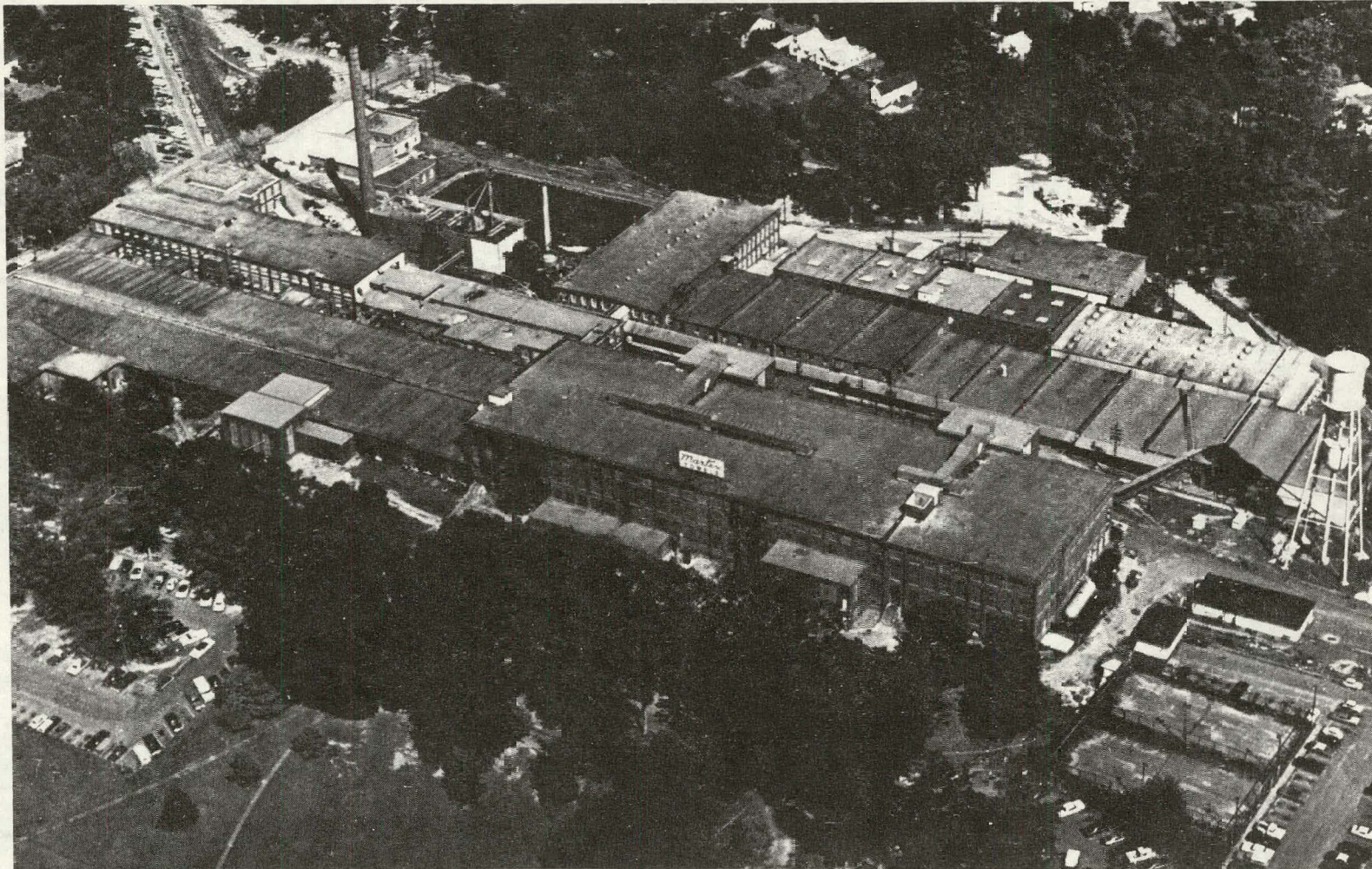
Section III is the Technical Discussion that includes the solar energy system description. All system components are listed, along with the manufacturer of each component, to prove the state of the art of the components that make up the solar process heat system. The System Design Subsection describes in detail the solar energy system proposed for Phase II of the program; the Design Considerations Subsection addresses the design decisions and the trade-offs that led to this design. System operation, control, and performance are also covered in the technical discussions of Section III.

Section IV describes the Economic Analysis including the methodology used, the energy demanded by the process, and the solar contribution to the process. The Lawrence Livermore Laboratory (LLL) format is used for the analysis based on the two "fiducial" locations, Albuquerque, New Mexico and Omaha, Nebraska. The site specific economic analysis is based on the LLL format but uses Fairfax, Alabama costs and weather.

#### 1.4 PROGRAM ACCOMPLISHMENTS

During this program, the following major accomplishments were achieved,

- Detailed analysis of the selected textile drying process (slashers)
- Selection of the WestPoint Pepperell, Fairfax, Alabama towel mill as the site for the demonstration. Figure 1-1 is an aerial photograph of this mill.
- Design of a solar energy system of state of the art components to interface with this process and displace fossil fuel process heat.
- Evaluation of the expected performance of this system at the Fairfax, Alabama site.
- Development of Specifications and Drawings for system fabrication and installation.
- Industry partner approval of the system design and the Specifications and Drawings.
- Issuance of these Specifications and Drawings to General Contractors for firm bids.
- Conduct of an economic analysis of the solar energy system.



1-4

Figure 1-1. Photo of WestPoint Fefferell Mill at Fairfax, Alabama

SECTION II  
PROCESS DESCRIPTION

2.1 DRYING OPERATION ANALYSIS

2.1.1 Introduction

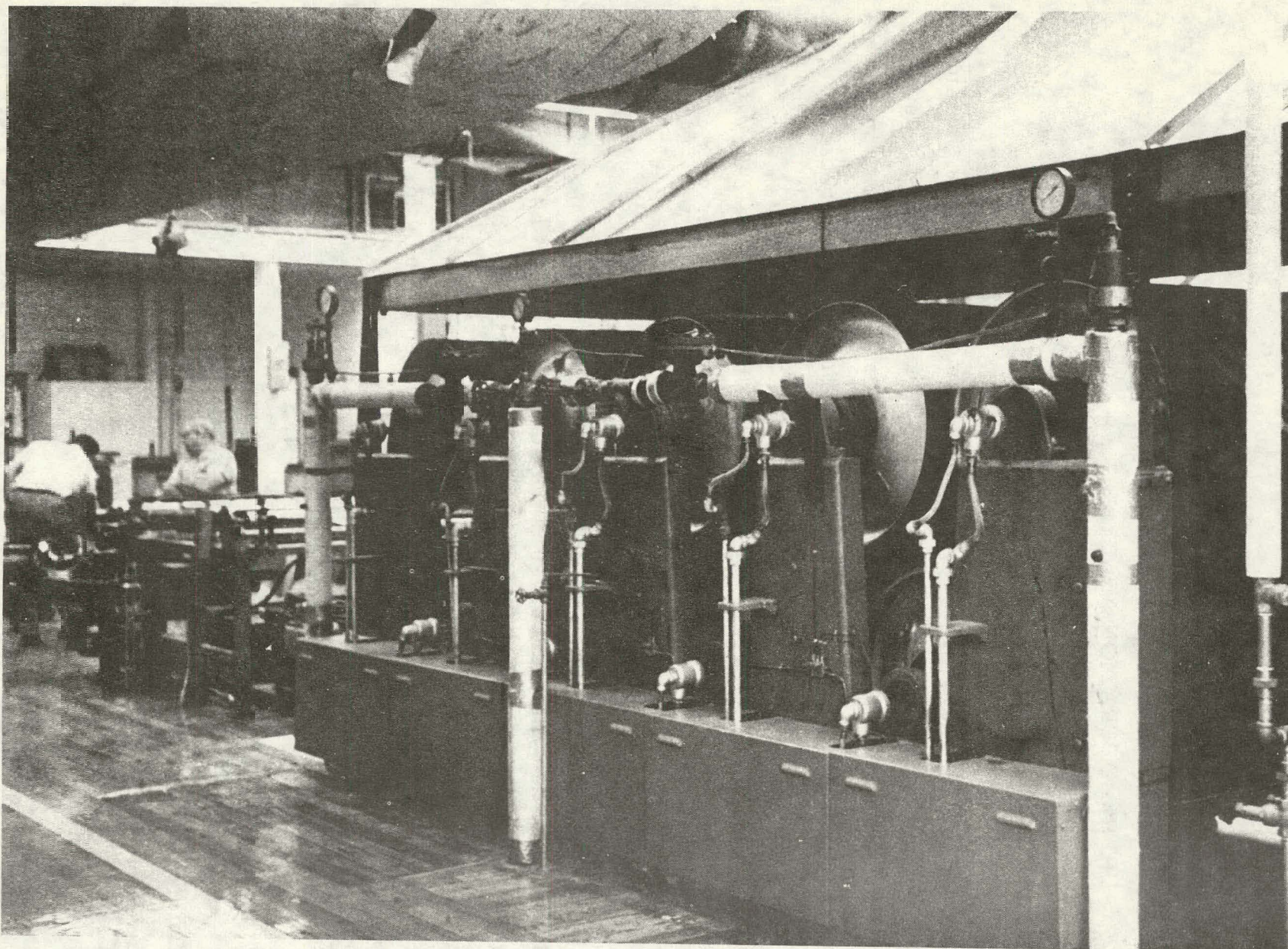
The textile industry, which is heavily dependent on natural gas, is ranked tenth on the Federal Energy Agency's list of the most energy-intensive industries, with an annual consumption of 383 trillion BTU's. Approximately 30% of this energy is consumed in drying related operations.

Our industry partner, WestPoint Pepperell, is one of the largest U.S. textile manufacturers, and consumes 8.7 trillion BTU's per year in its 32 plants.

The cylindrical can dryer is a major drying mechanization in the textile industry. The cylindrical dryer in the slashing process was chosen as typical of the operational regime of this family of dryers. Furthermore, this specific dryer exists in all textile weaving plants and approximately 50% of the national textile production is processed through this kind of dryer. Figure 2-1 is a photograph of a slasher at the WestPoint Pepperell Fairfax, Alabama mill.

2.1.2 Glossary

Before describing the details of the drying operation, it will be helpful to define a set of terms common to the textile industry.



2-2

Figure 2-1. Photo of a Slasher Unit

- Beam - a large spool containing hundreds or thousands of different threads accurately wound to form a sheet of yarn that can be used in weaving (and other operations).
- Beamer - a machine that forms the beam by simultaneously combining and winding the hundreds or thousands of threads.
- Warp - the sheet of yarn that runs in a continuous straight line through the weaving machine. It may contain hundreds or thousands of threads. The warp is created on the beamer and runs through the slasher before being used in the weaving operation.
- Fill - the yarn that is carried by the shuttle and runs back and forth across (through) the warp in the weaving operation.
- Size - a substance that is applied to the warp yarn to provide lubrication and protection from the abrasion of the weaving process. Size is predominately cornstarch with a small percentage of other ingredients such as wax.
- Slasher - a machine that applies size to textile yarn. Since applying size wets the yarn, slashers also include a drying operation.

### 2.1.3 Selected Slasher Drying Operation

The WestPoint Pepperell plant in Fairfax, Alabama contains eight slashers which process 70% of the yarn used in the weaving of MARTEX\* towels.\*\* Figure 2-2 is a schematic of a slasher which is useful in describing the slashing operation. Dry yarn on one or more beams is located at the rear of the slasher (Section A in Figure 2-2). Four beams are shown in the illustration. The yarn is pulled from the beams and drawn through a tank containing the hot liquid size (shown as Section B in Figure 2-2) where the individual threads are coated. Rollers squeeze off the excess size. To remove the moisture absorbed from the size, the warp passes over the cylindrical can dryers as shown in Section C of Figure 2-2 (nine can dryers shown). The hollow can dryers are heated with saturated steam and are maintained at a temperature which vaporizes the moisture in the yarn during the time yarn is in contact with the metal can. A large hood above the slasher carries off the humid air and other chemicals.

The dry warp then travels through rollers that separate the threads that have stuck together and is rewound on the beam as shown in Section D of Figure 2-2. Since multiple beams typically feed one beam as shown, the output beam fills quickly and must be replaced more often than the input beams. These machines operate continuously, 24 hours a day, with the exception of the time taken to unload full beams, set-up and load new input beams, and change the size. At the Fairfax plant, the slashers have the following average duty cycle;

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\*brand name

\*\*whereas most weaving is 50% fill and 50% warp, towels are woven with 30% fill and 70% warp as an extra layer of warp forms the tiny absorbing loops on the towels.

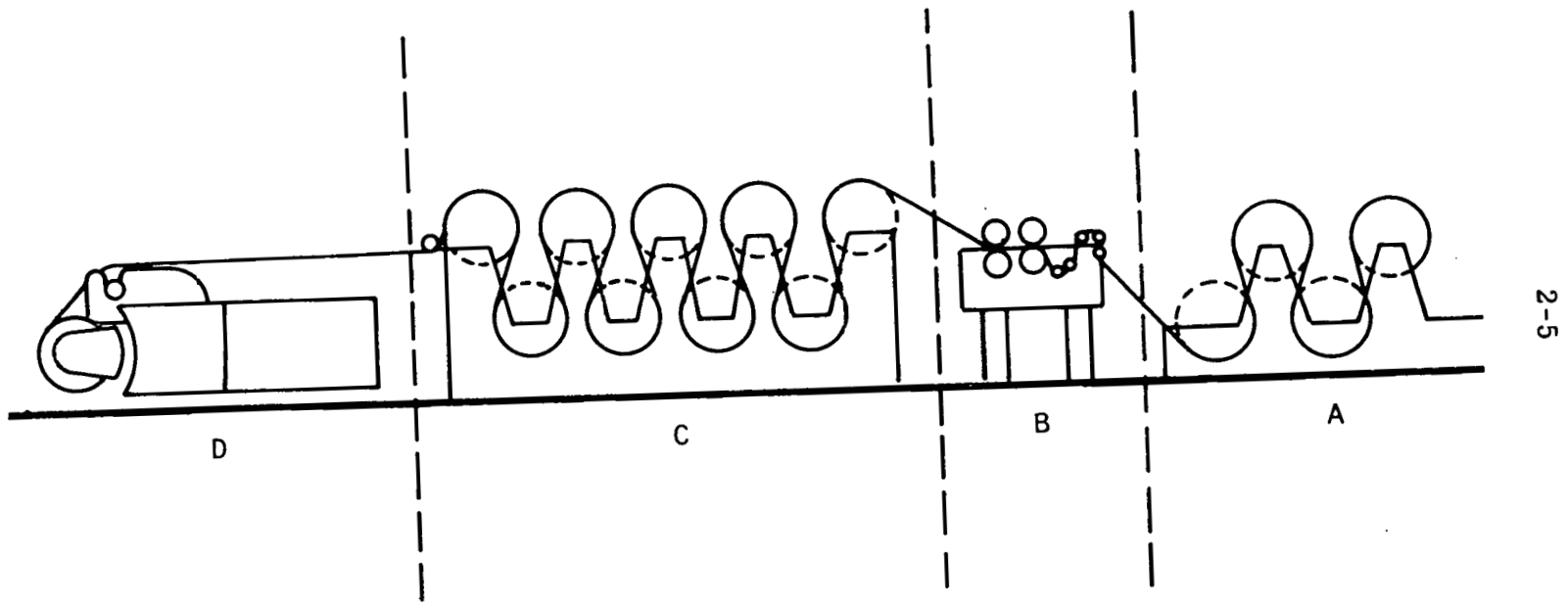
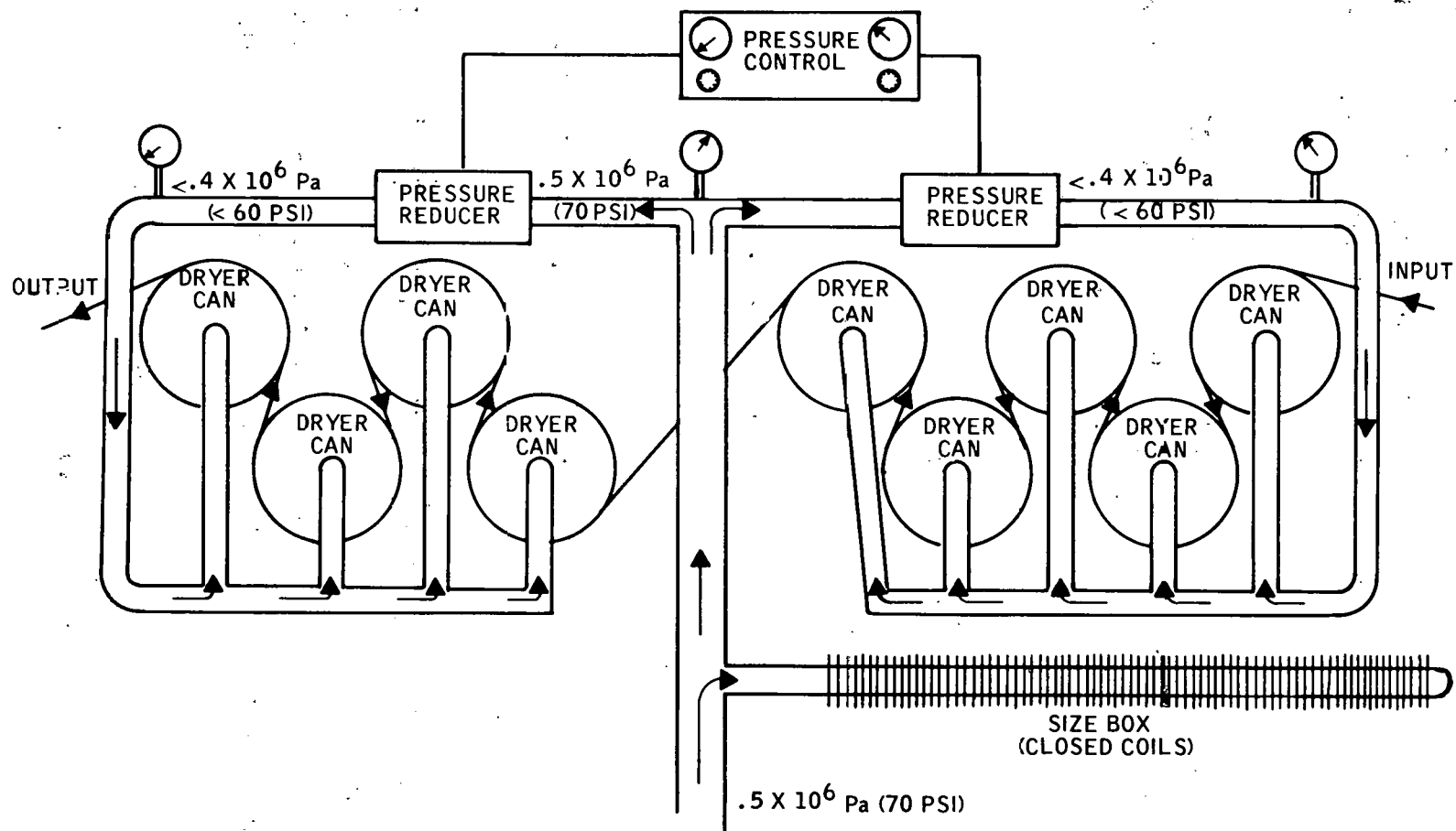


Figure 2-2. SCHEMATIC OF A SLASHER

operating - 30 to 40% of the time  
loading/unloading/setup - 60 to 70% of the time

During the slashing operation, sensors and instrumentation continuously monitor and record the stretch of the yarn and the moisture in the yarn. The drying process is controlled by the steam pressure in the cans (latent heat given away during condensation) and the rate of movement of the yarn through the slasher (time in contact with the cans). The appropriate steam pressure is selected by the operator based on the amount of yarn being processed (number of threads and type of thread). The slashers at the Fairfax Plant are divided into two drying sections that allow individual control of sets of three, four or five cans. The rate at which the yarn is processed is then adjusted to obtain the proper moisture content at the output. Thus the can pressure is a coarse control and the yarn velocity is a fine control.

Figure 2-3 is a schematic illustration of the steam lines on a single slasher (with 9 dryer cans). Steam at  $0.5 \times 10^6$  Pascals (70 psi) is input at the central pipe, split between the two sections of the slasher, and regulated to obtain the desired drying rate. The steam pressure in each set of cans is set manually with the knob and meter shown on the control box. The controls automatically adjust the steam flow to maintain the set pressure as conditions change or when the movement is stopped to change beams. Typically the first set of cans (the five cans on the right of Figure 2-3) will have a higher pressure than the latter set to achieve higher rates of vaporization with the wetter yarn.



2-7

Figure 2-3. TYPICAL SLASHER STEAM LINES (condensate lines not shown)

Steam enters the dryer cans through a rotary steam joint at the bearing as shown in Figure 2-4. The condensate line exits through the steam line. The stationary condensate tube is directed to the bottom of the can where it "sucks" up the condensate.

The slashers at the WestPoint Pepperell plant in Fairfax, Alabama are located on the second floor\* of building number 2, as shown in Figure 2-5. The eight slashers have the following characteristics:

- No. 1 Seven drying cans
- No. 2 Seven drying cans on slasher,  
Six drying cans on predryer\*\*
- No. 3 Seven drying cans
- No. 4 Seven drying cans
- No. 5 Seven drying cans
- No. 6 Nine drying cans (as in Figures 2-2 and 2-3)
- No. 7 Seven drying cans
- No. 8 Nine drying cans (as in Figures 2-2 and 2-3)

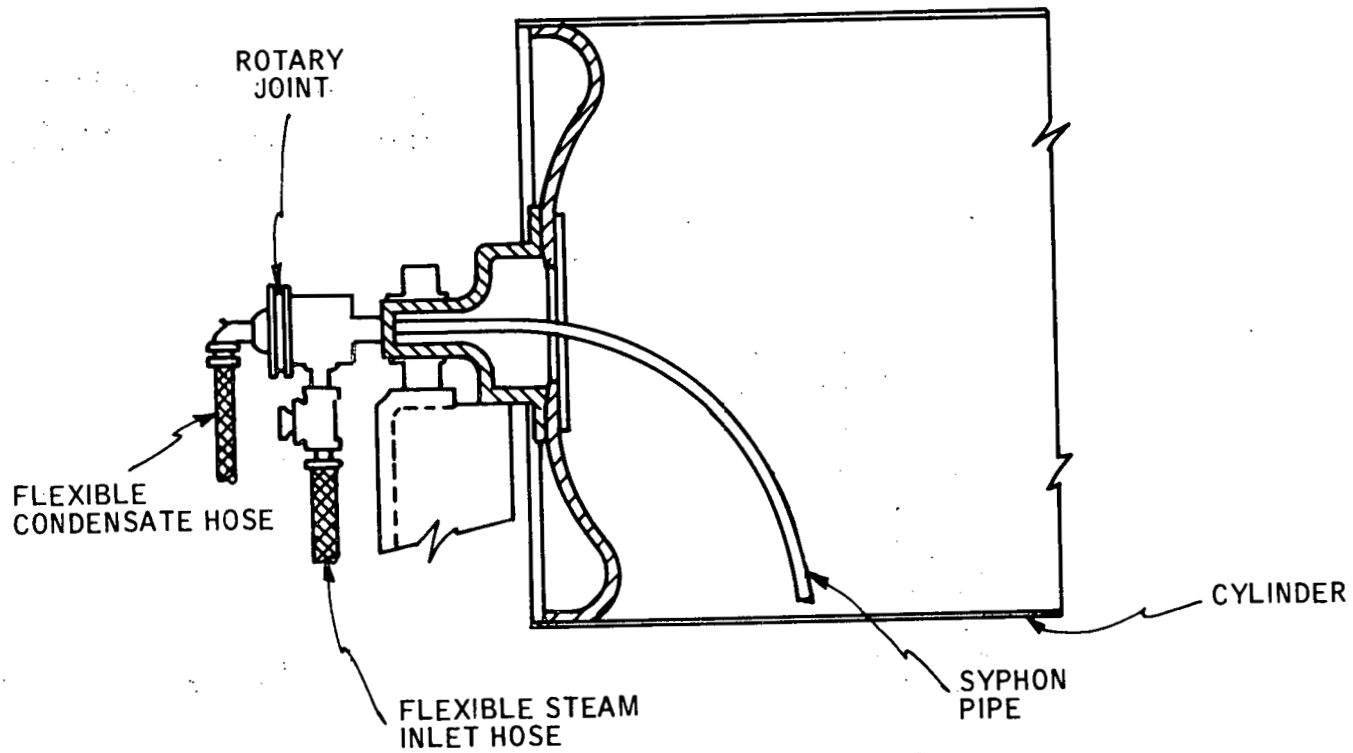
The steam supplied to the slasher room is also used to heat the size in the slasher size box (Figure 2-3).

Figure 2-6 is a schematic of the steam lines that serve the slasher drying cans. The steam originates at a main line of  $1.2 \times 10^6$  Pa (175 psi) steam from the plant boiler. Two redundant pressure regulators reduce the steam pressure to  $0.5 \times 10^6$  Pa (70 psi). The  $0.5 \times 10^6$  Pa (70 psi) manifold

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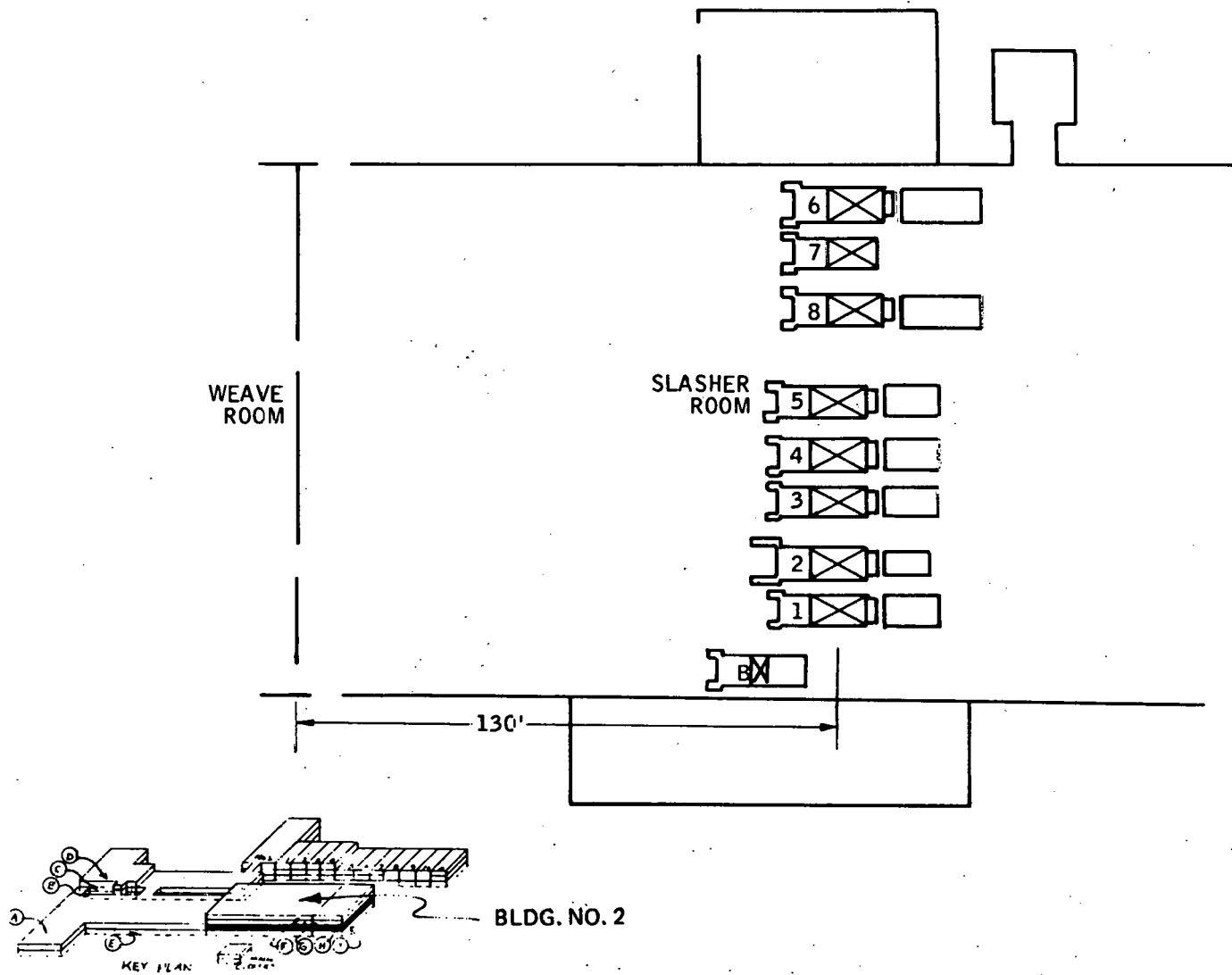
\*counting the basement floor as the first floor of the four floor building.

\*\*predryer is used on yarn that is moist from dyeing process.



2-9

Figure 2-4. CYLINDRICAL DRYING CAN (SLASHER)



2-10

Figure 2-5. SLASHER LOCATION

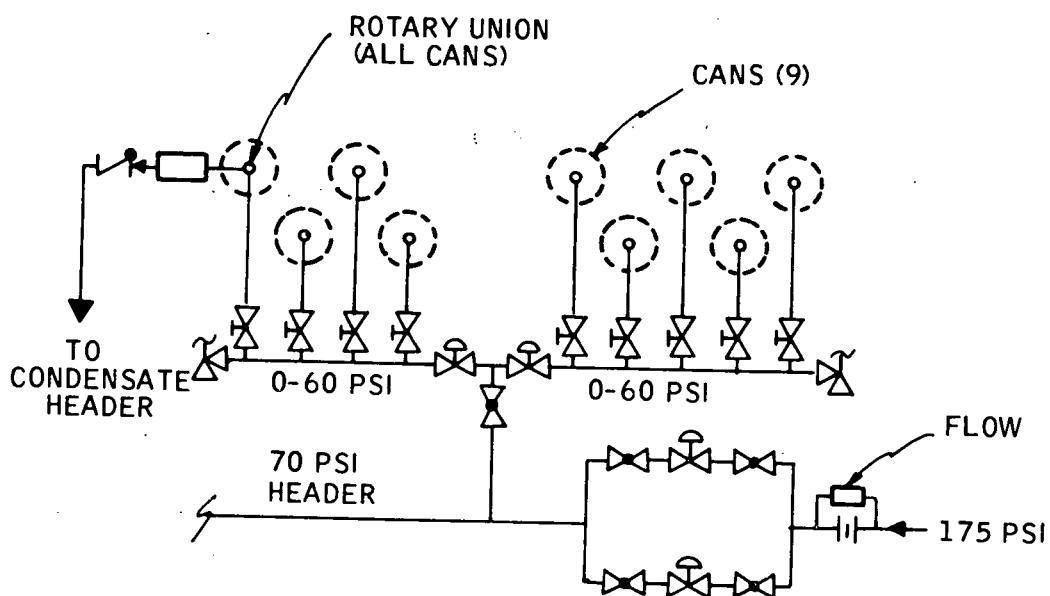


Figure 2-6. SCHEMATIC OF EXISTING STEAM LINES

serves the eight slashers and additional equipment. A flow meter measures the amount of steam used and records it on a 24 hour chart recorder. Two more pressure regulators on each slasher reduce the steam pressure to the desired pressure in the cans. The additional equipment on this  $0.5 \times 10^6$  Pa (70 psi) steam line includes:

- six drying cans on a beamer
- one size cooker (open steam coils)
- eight size storage vats (open steam coils)

Therefore, the steam line associated with the slasher operation provides the steam for 72 drying cans, 8 size boxes, 8 size storage vats, and 1 size cooker.

#### 2.1.4 Historical Data

Slasher room steam usage data were extracted from the available chart records. As the year 1975 was an atypical year in the textile industry, 1974 and 1976 have been evaluated. Figure 2-7 shows examples of the average slasher room steam usage (pounds per hour) for two working days. Although considerable variation occurs hour-to-hour, usage is usually in the 1361 to 2268 kg/hr (3000 to 5000 lb. per hour) range. The lowest demand occurring during daylight hours was 908 kg/hr (2000 lb. per hour).

Figure 2-8 shows the slasher room steam usage by week over the years 1974 and 1976. Each week is a 6 day week unless noted otherwise by number. Steam usage remains relatively constant. This slasher room steam usage represents about 10% of the total plant steam usage. This

2-13

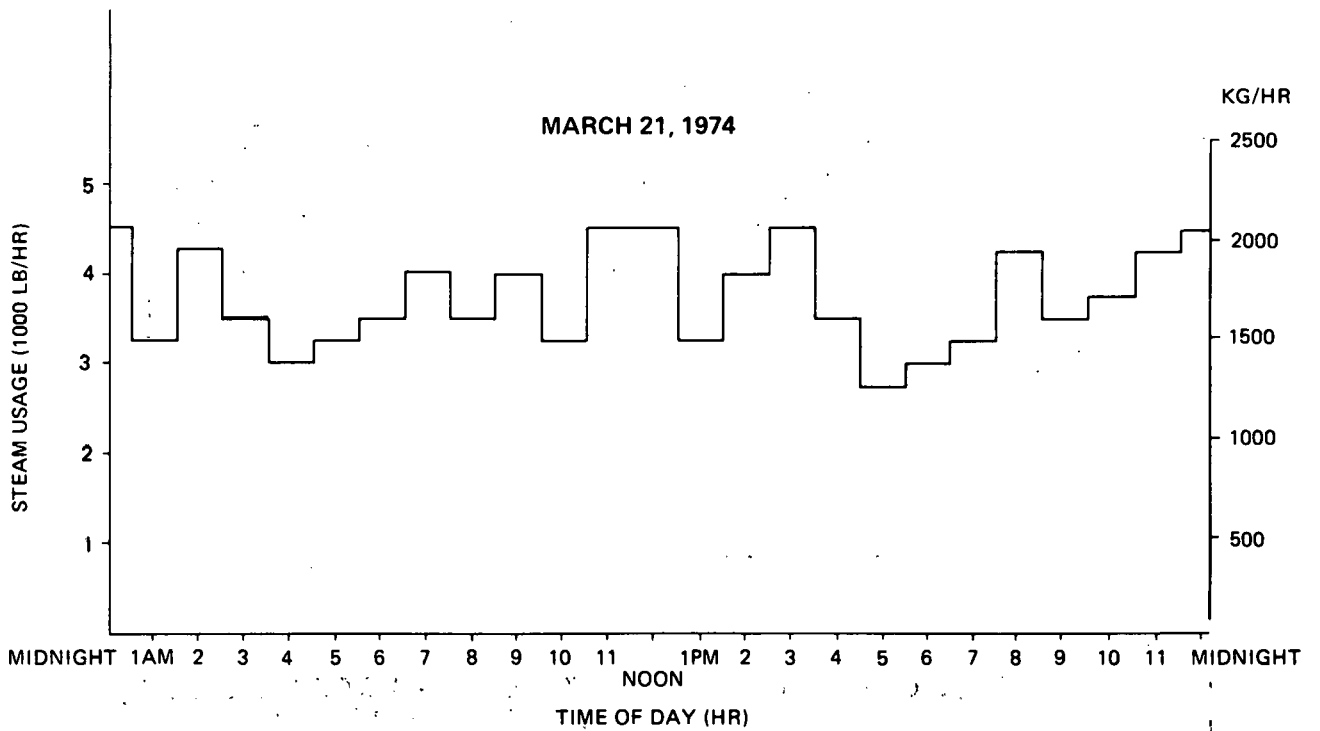
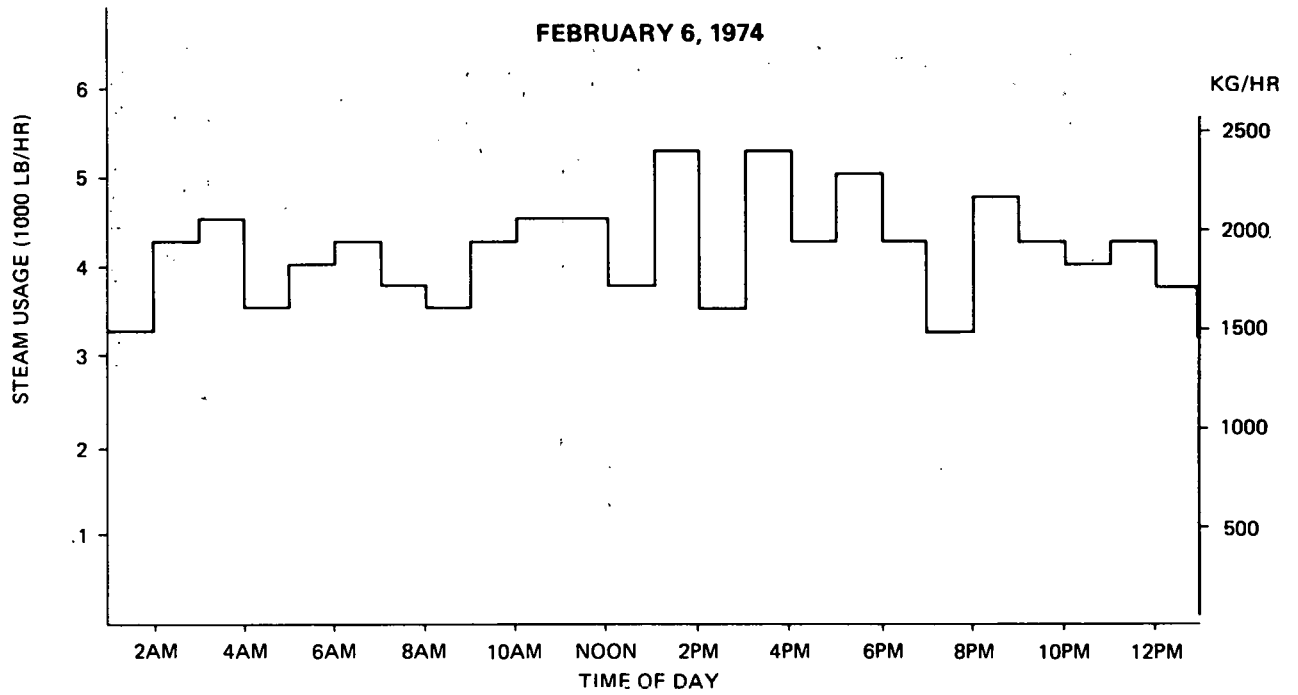


Figure 2-7. SLASHER ROOM STEAM USAGE, TWO TYPICAL EXAMPLES

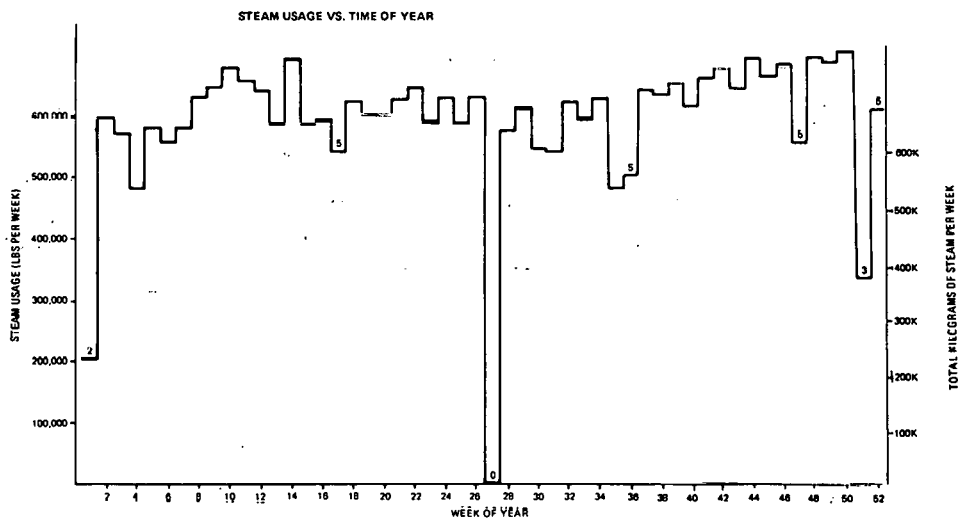
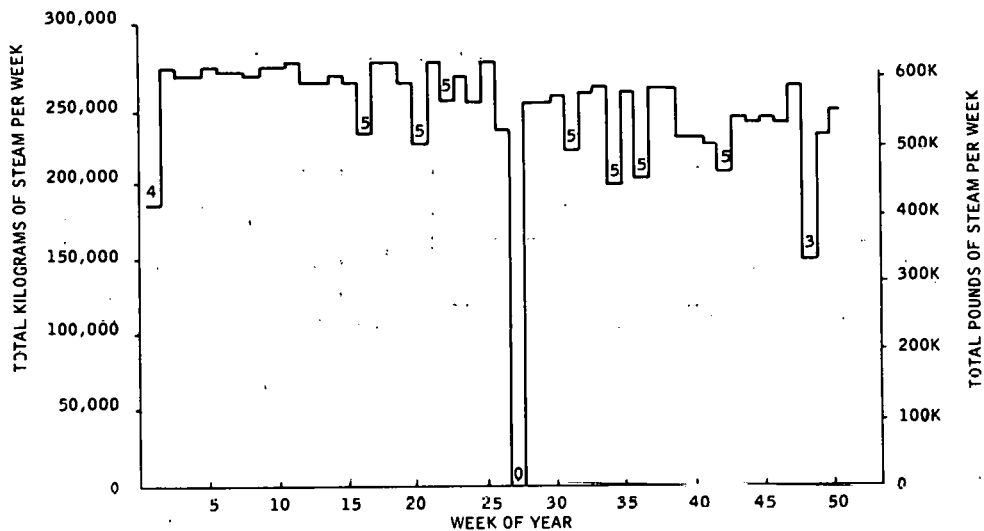


Figure 2-8. TOTAL SLASHER ROOM STEAM USAGE, 1974 (TOP) AND 1976 (BOTTOM)

data shown in Figures 2-7 and 2-8 for 1974 and 1976, represent a plant that is operating at capacity. There are no unusual characteristics in the usage data and future usage predictions can be made accurately.

Records of the amount of yarn processed during these periods has been compared with the steam usage data. Figure 2-9 plots the pounds of yarn processed during each week in 1976 versus the steam usage data. A correlation exists between pounds of steam used and pounds of yarn produced and can be approximated with the relationship 2 lb. steam per lb. yarn.

#### 2.1.5 Future Projections

After a significant production slump in 1975, the textile industry has recovered its earlier gains and is continuing to expand its production. Therefore, the WestPoint Pepperell mill at Fairfax, Alabama will continue to operate at full capacity. Over the years 1977 and 1978, WestPoint Pepperell is projecting steam usage and yarn production at a rate similar to that shown in Figures 2-7 through 2-9.

Based on these predictions, steam usage in the slasher line can be expected to be about 1905 kg/hr (4200 pounds per hour) on the average, and the same during the day shift when solar generated steam is available.

## 2.2 SOLAR INTEGRATION REQUIREMENTS

### 2.2.1 Objective

The integration of the solar drying capability into the WestPoint Pepperell

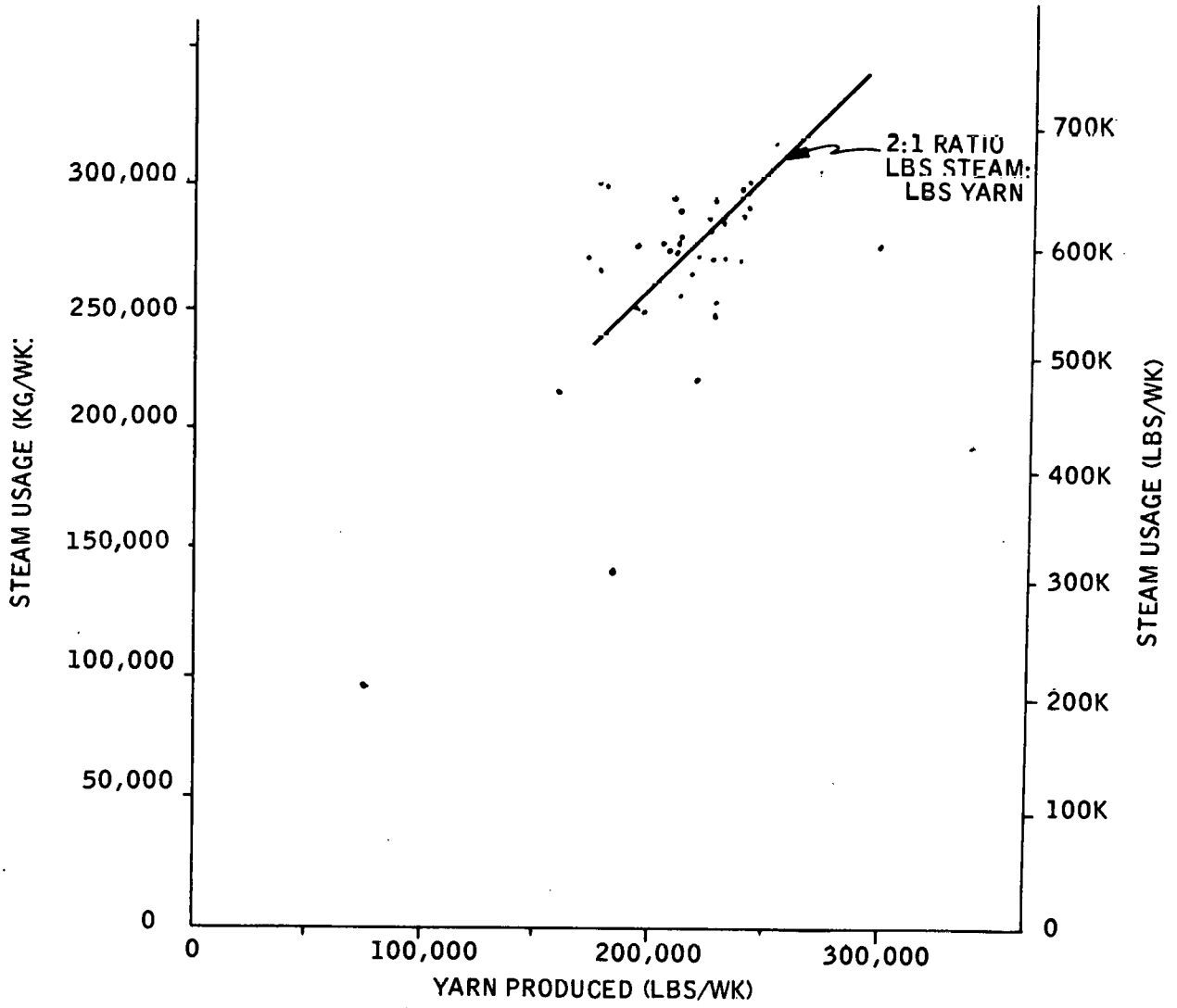


Figure 2-9. STEAM USAGE VS. YARN PRODUCTION

Fairfax, Alabama facility must take place with minimal disturbance to normal production facilities. The slashers in this plant operate 24 hours a day, 6 days a week. Our objective is to integrate the solar energy system in a manner so as to enable the slashing operations to proceed unaffected by the solar demonstration.

### 2.2.2 Constraints

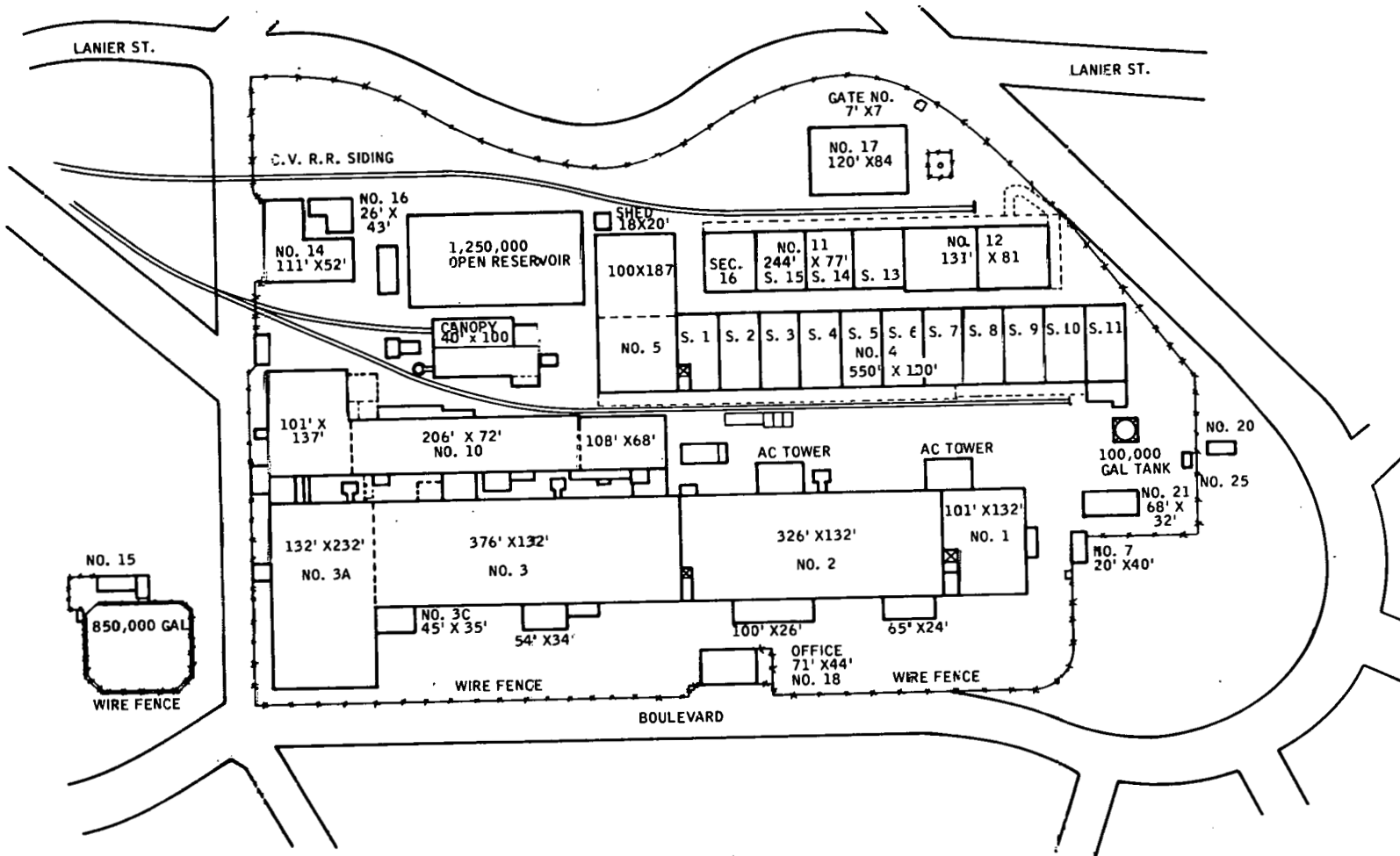
The existing drying equipment and facility impose constraints on the solar design. The following paragraphs discuss the existing constraints.

The main manifold in the slashing operation is maintained at  $0.5 \times 10^6$  Pa (70 psi). Therefore, the solar generated steam must be at a higher pressure to provide for its introduction into the existing system. Since solar steam is generated only in daylight, and the slashing operation continues 24 hours a day, the usage of solar steam must be automatic and should not affect the slasher department. Furthermore, even at peak solar input, the solar steam system will supply only a fraction of the steam needed, so automatic proportioning is required.

The control of the solar system should have sufficient flexibility so that on Sunday (and Holidays) when the plant is closed, it can be shut down or operated in a test mode.

Furthermore, installation of the solar system and its interface must not affect the operation of the slasher department.

Figure 2-10 shows the size of the various buildings at the Fairfax plant. The slashers are located in building number 2. The roof of building



2-18

Figure 2-10. WESTPOINT PEPPERELL FAIRFAX, ALABAMA MILL

number 2 contains two large air conditioning ducts that make it undesirable as a location for the solar collectors. The building number 3 roof is relatively free from obstructions. However, it is two stories lower than building number 2 and therefore suffers some shadowing in the afternoon.

In spite of the shadowing, the roof of building number 3 is sufficiently large to provide ample room for the necessary collectors (one-half of the roof of building 3A is also available). In all, there are 7436 m<sup>2</sup> (80,000 square feet) of roof available with less than 930 m<sup>2</sup> (10,000 square feet) shadowed. In addition to the shadowing, the only obstructions on the roof of building number 3 are a small air conditioning duct (< 279 m<sup>2</sup>) (< 3000 square feet) and a radio antenna.

This roof and support structure is adequate to support the static load of the solar collector field. However, special attention must be paid to the dynamic loading of the collector support structure and the method by which the dynamic loads are transmitted to the roof structure. The floor directly beneath the roof of the building number 3 is the weave room. It is critical that the solar collector installation cause no roof leaks onto the weaving operation.

The solar boiler also should be located on the weave room roof, against the building number 2 wall (in the shadowed area). It should have automatic controls so that no operator is necessary. From the solar boiler, the process steam line should enter building number 2 and travel across the ceiling of the first floor to the slasher manifold which runs across the ceiling of the first floor (below the slashers on the second floor).

Solar boiler feedwater will come from an existing condensate receiver. Therefore, no make-up water treatment plant will be needed. The existing condensate receiver is associated with a finishing process in building no. 10 and a feedwater line to the solar boiler is necessary.

### 2.2.3 Requirements

Based on the constraints described above the following requirements are defined.

#### Steam Loop

- Solar steam boiler
  - automatic controls
  - pressure relief valve
- $.5 \times 10^6$  Pa (71 psi) saturated steam at existing manifold with saturation temperature of  $158^{\circ}\text{C}$  ( $317^{\circ}\text{F}$ )
- $.524 \times 10^6$  Pa (76 psi) saturated steam at solar boiler, temperature of  $160^{\circ}\text{C}$  ( $321^{\circ}\text{F}$ )
- check valve at interface
- flow meter in steam line with recorder and integrator
- boiler feedwater pump and line from existing condensate receiver

### 2.3 PROCESS MODIFICATIONS REQUIRED

No modifications to the process are required to allow demonstration of the solar process heat system. Solar steam will be introduced automatically into the existing steam manifold at the same characteristics (temperature, pressure) as existing steam. The textile drying process will continue, insensitive to the source of process steam. The existing plant steam boiler

will automatically throttle back when solar steam is available because the demand will be reduced. Thus, the solar system will displace conventional fuel when solar energy is available.

SECTION III  
TECHNICAL DISCUSSION

### 3.1 SYSTEM DESCRIPTION

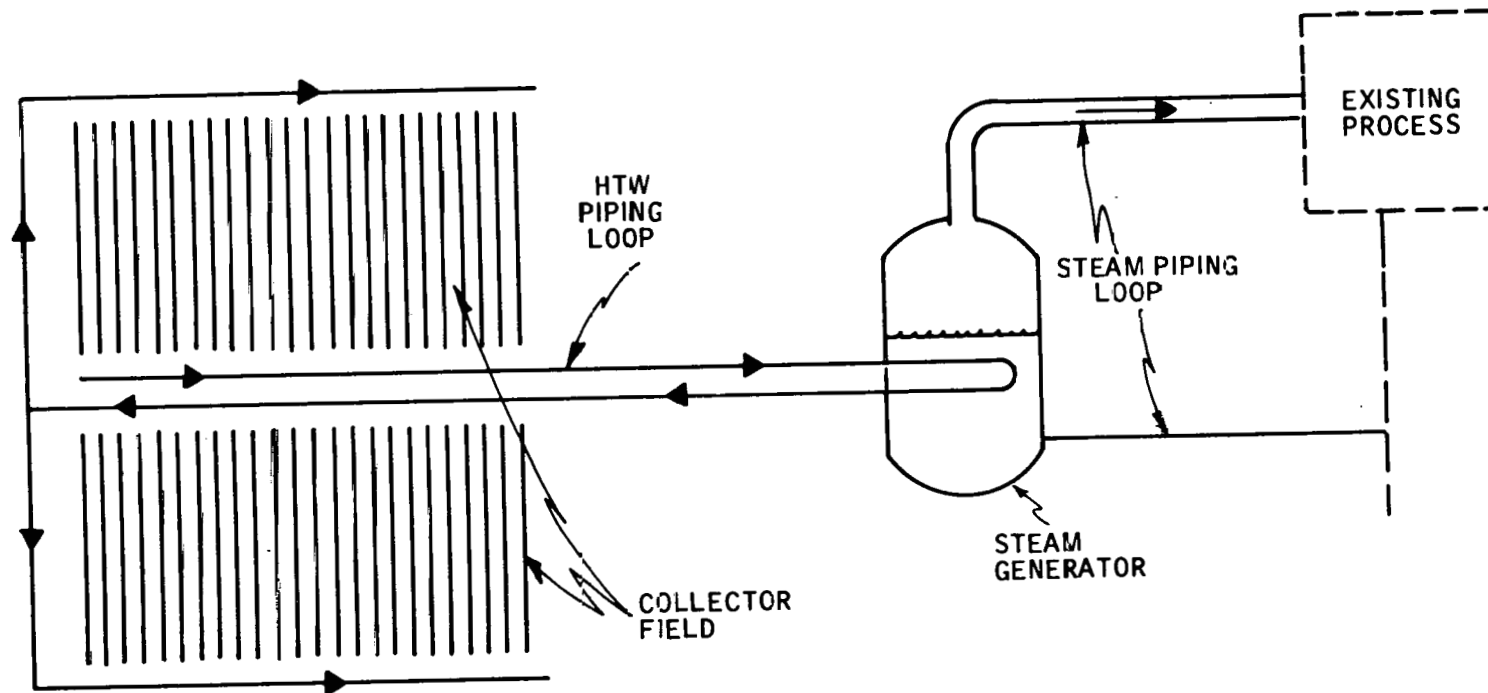
#### 3.1.1 General

The solar system designed to provide process heat for textile drying consists of five major subsystems:

1. the collector field
2. the high temperature water (HTW) pipe loop
3. the steam generator
4. the steam pipe loop
5. the process

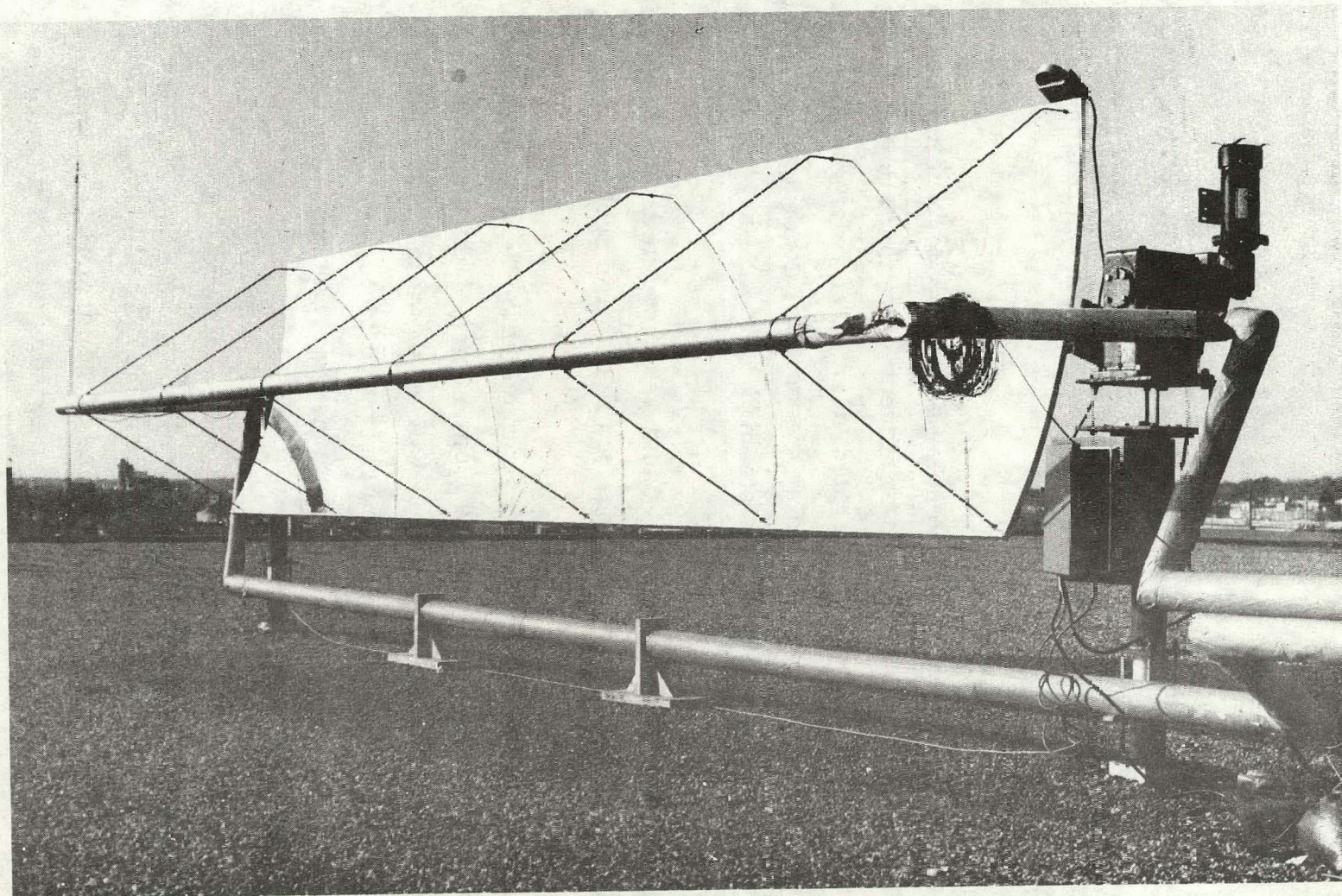
Figure 3-1 is a simplified system schematic showing these five major subsystems. The collector field contains 48 concentrating collectors which utilize parabolic trough shaped mirrors and tubular receivers, and follow the sun by means of single axis tracking. Figure 3-2 is a photo of the engineering model of the concentrating collector which has 1/2 the mirror area. Section 3.4.6 describes the collector in detail.

The HTW loop transports the collected energy to the steam generator in the form of  $193^{\circ}\text{C}$  ( $380^{\circ}\text{F}$ ) water. It is a closed loop system pressurized to  $1.59 \times 10^6$  Pa (230 psig). Figure 3-1 illustrates how the HTW loop connects the 48 collectors, transports the high temperature water to the steam generator, and returns the cooled water back to the collector field.



3-2

Figure 3-1. SIMPLIFIED SYSTEM SCHEMATIC



3-3

Figure 3-2. Photo of Engineering Model of Concentrating Collector (One-half of mirror area)

The HTW loop includes the expansion tank, air separator, and field flow pump.

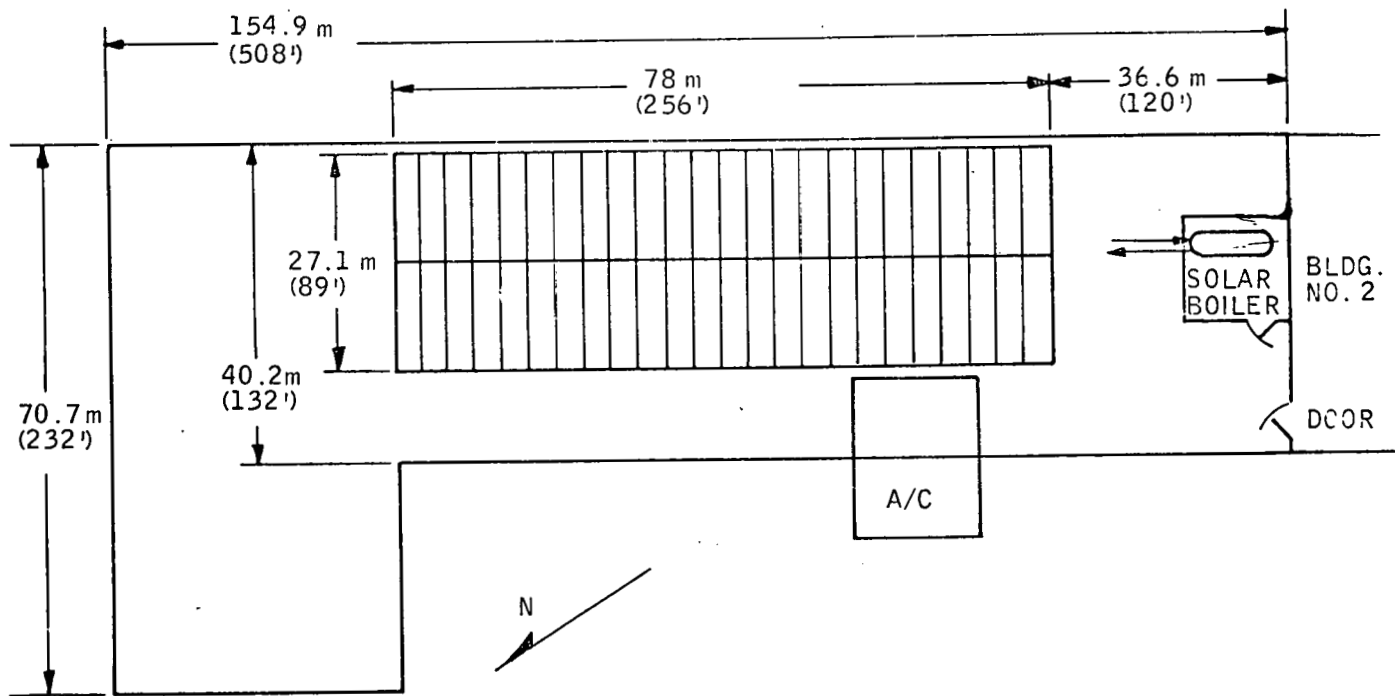
The steam generator is an unfired package boiler that generates  $0.524 \times 10^6$  Pa (76 psig) process steam when fueled by the  $193^{\circ}\text{C}$  ( $380^{\circ}\text{F}$ ) water from the HTW loop. Feedwater for the steam generation is taken from a steam condensate tank.

The steam pipe loop transports the solar generated steam to the textile process. Steam flow is controlled by a check valve that allows the solar system to displace fossil fuel generated steam when solar generated steam is available. Conversely, when solar steam is not generated, the existing steam system supplies the process steam.

The process consists of cylindrical can dryers used in drying textiles in a slasher line. The process was described in detail in Section II.

Figure 3-3 shows the location of the solar collector field on the weave room roof (building number 3). The HTW loop is completed with the solar boiler located against the building number 2 wall as shown in Figure 3-3. A small building will house the boiler, the automatic controls, and test equipment. A door to the weave room roof will be constructed as shown next to an existing landing.

Figure 3-4 shows the general routing of the steam lines in the steam loop. From the solar boiler, the line will go into building number 2, down to the first floor ceiling and across this ceiling to the manifold. Completing the steam loop is the feedwater line from an existing condensate receiver. The



3-5

Figure 3-3. LOCATION OF COLLECTOR FIELD ON WEAWE ROOM ROOF

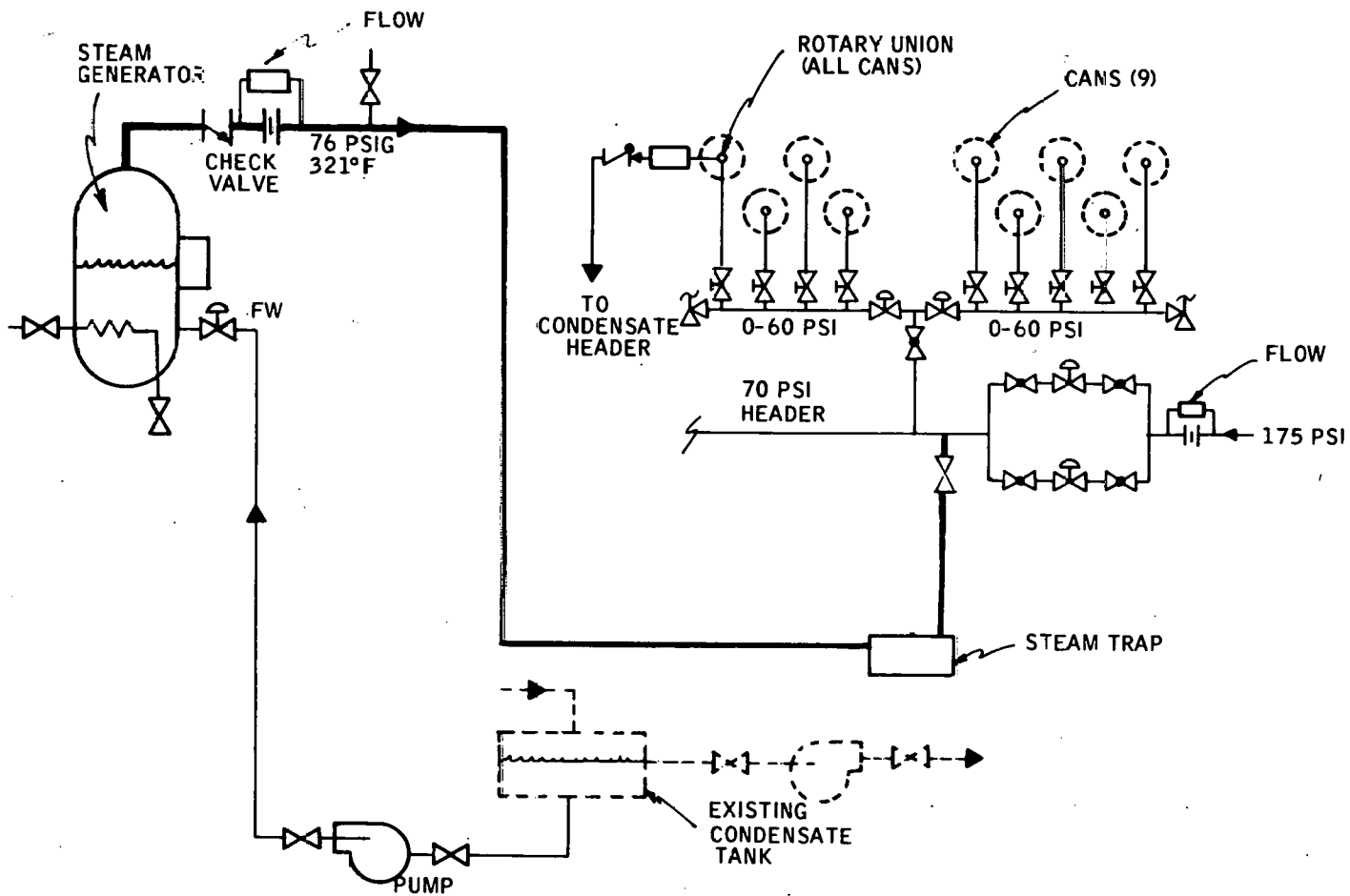


Figure 3-4. SOLAR STEAM LINE

feedwater pump will be located in building no. 10 at an existing receiver.

Figure 3-4 also shows the solar steam/conventional steam interface. The "T" which connects the solar steam line to the existing steam system is located on the  $0.5 \times 10^6$  Pa (70 psi) main manifold line. A flow meter in the solar line monitors the contribution from the solar system. The check valve is completely automatic in its acceptance of solar steam when available and use of conventional steam when necessary. A manual valve is included on the solar line for redundant shut-off of the solar system.

Solar steam condensate is combined with the conventional steam condensate and carried to an existing condensate receiver. Solar boiler feedwater is taken from an existing condensate receiver.

### 3.1.2 Interface with Existing Line

The solar system described above is completely responsive to the requirement for integration of the solar system with the slasher operation without disturbing the normal operation of the dryers, the slashers, or the plant. The "T" and manual steam valve (shown in Figure 3-4) can easily be installed at a time when the facility is not in operation (Sunday). Connections to the condensate lines can also be made at this time. The feedwater system, controlled by the boiler level controller, operates automatically by switching on a pump when the solar boiler needs water. Therefore, the complete solar system can be installed, tested and hooked up to the existing steam line with no effect on normal operations. Once the system is tested and operational, the manual steam valve can be opened and the slashers will automatically use solar steam when it is available. The solar system can be completely isolated manually at any time using the manual valves.

Other solar equipment integrated into the Fairfax, Alabama facility will not disturb the normal operation of the plant. This equipment includes an additional flow meter and other instrumentation, chart recorders, and a recording pyroheliometer. Most of this equipment will be located on the roof in the solar boiler building, where it will not disturb normal plant operations. An annunciator panel with a master switch, warning lights, alarm, temperature readout, and flow meter recorder will be located in the machine shop with other existing alarms.

## 3.2 STATE OF THE ART

The solar energy system design consists of an integration of existing or well developed components that are combined to provide process heat for textile drying. This subsection details these components to prove the state of the art of this solar system design.

### 3.2.1 Components List

Table 3-1 is a component list for the solar energy system summarizing all items required for the Phase II installation including the instrumentation for data gathering. All items on this list are commercial products which may be purchased from the manufacturer and are usually used for other applications, except for the parabolic trough solar collector. Each of the items in Table 3-1 is briefly described below. A more detailed description of the collector elements is included in Subsysection 3.2.2.

3.2.1.1 Collector Support Structure -- This structure is formed out of standard welded pipe that forms the three support posts per collector and the braces for the posts. The center support carries the motor drive and therefore is larger to withstand the wind loading.

3.2.1.2 Steam Generator -- One Patterson-Kelly Series 380 Unfired Steam Generator, Model H307. This steam generator is typical of unfired package boilers which range in size from 250 lbs. per hour to 15,000 lbs. per hour of steam output. No unusual options are required for its use in the solar energy system. The Specifications include the following conditions:

for 48 GPM of 389°F HTW and 200°F feedwater supplied, the outlet temperature shall be 333°F and greater than 1000 lb/hr of 76 psig saturated steam will be produced.

Table 3-1. Components List

Solar Collector	Honeywell HSCC-1	
Collector Support Structure	Welded Pipe 3-1/2" and 5" std.	
Steam Generator	Patterson-Kelly H307	
Expansion Tank	200 gallon, 400 psig, N <sub>2</sub> charged	
Field Flow Pump	Buffalo HCR H66058	
Feedwater Pump	Skidmore TP 212-1/2	
<b>Valves</b>		
gate (18)	Powell no. 375, no. 1503	
ball (96)	Imperial Eastman Model 263	
globe (2)	Powell no. 1531	
check (2)	Powell no. 560	
stop & check (1)	Powell no. 2475	
relief (2)	Bell & Gossett	
manual vent (2)	Worchester no. 466-300	
<b>Traps</b>		
steam (2)	Armstrong F&T no. 125-A3	
air (2)	Armstrong no. 11 AV	
<b>Piping</b>		
3" schedule 40 (welded)	Process steam	180 ft
2-1/2" schedule 40 (welded)	HTW	750 ft
2" schedule 40 (welded)	HTW	600 ft
2" schedule 40	Waste/drain	150 ft
1" schedule 40	Domestic water	500 ft
1" schedule 40	Condensate return	180 ft
3/4" schedule 40	Feedwater	300 ft
pipe hangers as required	Grinnell no. 173	
ball joint expansion joints(2)	Chiksan	
<b>Insulation</b>		
fiberglass pipe insulation	Johns-Manville	
PVC insulated fitting covers	Johns-Manville	
<b>System Controller</b>		
Honeywell		
<b>Sensors</b>		
temperature (8)	Minco, S53-P	
pressure (2)	Robinson-Halpern, 144C	
flow (3)	Hayes, Republic	
radiation (3)	Eppley, Solar Systems Inc.	
wind (1)	WeatherMeasure, W161	
watt hour (1)	Westinghouse	
Penthouse	Armco	
Emergency Generator	Onan	

3.2.1.3 Expansion Tank -- The expansion tank is specified to be of ASME construction and rated at 400 psig. Capacity is 200 gallons. All required support structure is included as a part of the expansion tank. The tank will include standard accessories and fittings.

3.2.1.4 Field Flow Pump -- One Buffalo Can-O-Matic Model No. HCR H66058. This pump is typical of "canned" pumps which are used for process heating and industrial HTW applications. It eliminates the need for mechanical seals and seal cooling by hermetically sealing the complete pump/motor unit inside the case. The Buffalo Forge Company has built and sold Can-O-Matic pumps in sizes ranging from 6gpm to 800 gpm, 10 to 140 foot head, 180 to 430°F, and operating at pressures up to 400 psi. The Specifications state the following operating conditions:

430°F maximum  
300 psig maximum  
48 gpm at 50 foot head  
5hp motor  
1750 RPM, 600V, 3 phase

3.2.1.5 Feedwater Pump -- One Skidmore turbine pump model no. TP 212-1/2. This pump is typical of turbine pumps for boiler feed which range in size from 1.5 to 150 gpm and 20 to 200 psig at 1750 RPM. The Specifications state the following operating conditions:

1-1/2 hp motor  
600V, 3 phase, 60 cycle  
3 gpm at 125 psig head  
210°F inlet water at approx. 2 foot suction pressure.

3.2.1.6 Valves -- The solar process heat system uses all standard valves available for HTW, steam, feedwater, or condensate applications. Each valve type is briefly discussed below.

Gate valves -- there are 18 gate valves in the solar energy system. These valves are used for isolation of the steam,  $N_2$ , condensate, feedwater, and HTW subsystems. Either Powell, Crane, or Lunkenheimer valves are specified.

Ball valves -- there are 96 ball valves in the HTW loop to balance the fluid flow in the collectors and isolate collectors. Imperial Eastman Model 263 valves with 1/2" orifice are specified.

Globe valves -- two globe valves are specified, 1) the outlet on the process steam line during start-up and 2) the HTW loop balance valve to control the flow rate. Powell no. 1531 valves are specified.

Check valves -- two check valves are specified, one for the feedwater line and one for the make-up water line. Powell no. 560 valves are specified.

Stop and check -- a stop and check valve is used to control the process steam flow. A Powell no. 2475 valve is specified.

Relief -- the HTW loop and the steam generator each have relief valves for safety reasons. The steam generator relief valve is specified as a steam generator accessory as described earlier in this subsection. A Bell & Gossett HTW loop relief valve is specified.

Manual vent -- two manual vent valves are used to bleed the system of air during the filling operation. Additional bleeding at periodic intervals will eliminate air trapped in the supply headers. Worchester model no. 466-300 valves are specified.

3.2.1.7 Traps -- Two steam traps and two air traps are specified in the solar process heat system.

Steam Traps -- two traps in the process steam line are used to improve the quality of the steam and reduce potential for water hammer. Armstrong F&T no. 125-A3 steam traps are specified.

Air traps -- two traps are included in the HTW line to eliminate air ( $N_2$ ) in the system. One is a basic air trap constructed in the piping. The other is an Armstrong no. 11AV automatic air vent on an air chamber rated for 400 psig at 500°F.

3.2.1.8 Piping -- Piping includes schedule 40 welded 2", 2-1/2", and 3" steel pipe and schedule 40 threaded 3/4", 1", and 2" steel pipe. All pipe and installation will be standard and typical of existing installations with provision for expansion and air removal. Table 3-1 lists the pipe lengths.

Also specified are pipe hangers and saddles, and ball joint expansion joints. Hangers are Grinnell no. 173. Ball joints are Chiksan.

3.2.1.9 Insulation -- Piping insulation is Johns-Manville Flame Safe Pipe insulation, AP jacket, 4-1/2 lbs. density and 650°F. Fittings will be covered with Johns-Manville Uni-Fit PVC covers. All insulation will be of standard materials and typical installation.

3.2.1.10 System Controller -- The system controller is a logic box that takes the signals from eight sensors and provides signals to three components and an alarm. The controller uses standard components arranged in a custom design for this application. System control is described in detail in Subsections 3.4.5, 3.5.2, and 3.6. The controller will be supplied by Honeywell.

3.2.1.11 Sensors -- A variety of sensors are used to control the system and provide data on the system. These sensors are all existing available sensors and most are on ERDA's list of acceptable sensors.

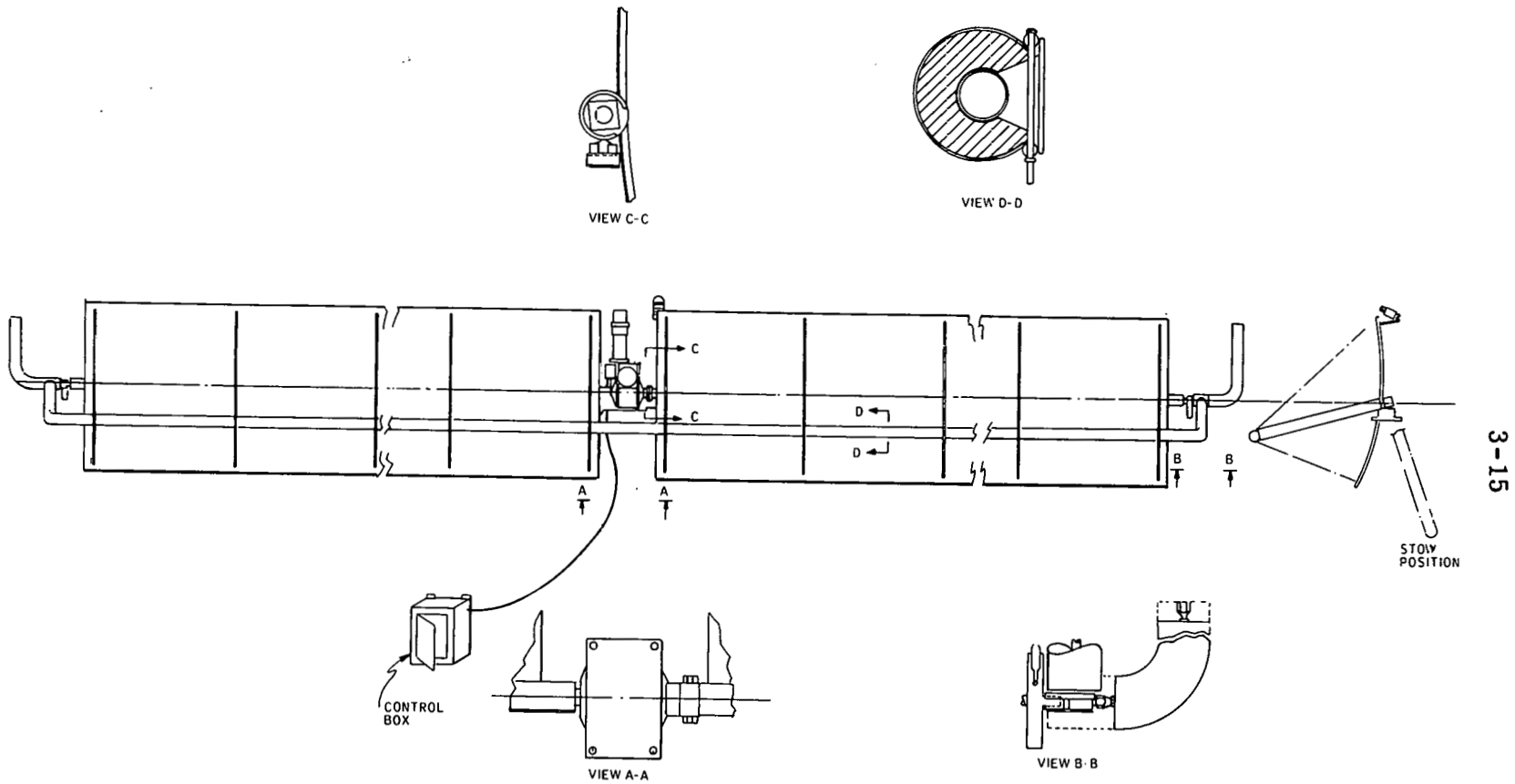
3.2.1.12 Penthouse -- A metal building atop the weave room roof will house the solar system equipment. This 21' x 26' building is of standard materials and construction.

3.2.1.13 Emergency Generator -- A 12 kw diesel powered electrical generator will provide 110V three phase power to the solar collector system in times of power outage. An Onan model is specified.

### 3.2.2 Collector Components

The concentrating solar collector to be used for the WestPoint Pepperell application includes approximately forty linear feet of curved honeycomb reflector and uses a closed loop hot water system for the thermal transport. Figure 3-5 shows the top assembly drawing of this unit and the absorber detail. This drawing reflects the location of the more important components of the assembly. The main subassemblies of the collector are,

Reflector assembly



3-15

Figure 3-5. TOP ASSEMBLY DRAWING

Torque tube and adapter assembly  
Absorber support assembly  
Absorber assembly  
Swivel joint holder

The following text discusses the important parts of each of these sub-assemblies.

3.2.2.1 Reflector Assembly -- The reflector assembly is a curved piece of aluminum honeycomb sandwich. The standard assembly is purchased from Hexcel and is preformed, supplied with a 3M reflective surface (Scotchcal), screw inserts, and an interface hole pattern. Five parts (all standard) are required for each assembly. Four reflector assemblies are required for each collector.

3.2.2.2 Torque Tube and Adapter Assembly -- The torque tube is a standard hollow, square aluminum beam trimmed to fit each pair of reflector assemblies. The bearing adapter of one end and the coupling adapter of the other end are fabricated from standard stock material to interface with the pillow block support bearing and with the gear drive. Six piece parts are required for each assembly. Two of these assemblies are required for each collector.

3.2.2.3 Absorber Support Assembly -- The absorber support assembly consists of two pieces of rod (legs) joined by a circular strip. All pieces are standard aluminum stock material. Twelve of these assemblies are required for each collector.

3.2.2.4 Absorber Assembly -- The absorber assembly consists of an insulated copper tube with a segment of insulation removed to provide a window for the reflected sunlight. All of the absorber components are made of standard stock materials with the necessary modifications to fit

this application. The copper tube is selectively coated with black chrome after purchase. Similarly, the window glass is treated to enhance the transmission. The pipe insulation is of standard fiberglass type and is covered with a single ply of high temperature fabric marketed by ARMCO. The riser portions of the absorber assembly are made from standard pipe, pipe insulation, and fittings. The two absorber ends are terminated with standard Aeroquip swivel joints.

Fifteen components are required to fabricate each absorber. One absorber assembly is required for each 40-ft collector.

3.2.2.5 Drive Assembly -- Each collector has its own drive assembly. It consists of an electric motor and gear reducer. The gear reducer is a standard Winsmith Model 8MCTT that is purchased with a minimum backlash option for improved collector tracking accuracy. The required output speeds are achieved with a 7500-to-1, triple reduction, worm gear train.

The drive motor is a standard 1/2 hp General Electric dc shunt wound motor, 1/2 GE-17-56N-90-TE-C. This model is a non-ventilated, totally enclosed, 1750 rpm motor with a 90 vdc armature and a single NEMA type "C" face.

3.2.2.6 Sun Tracking and Control -- Solar tracking is provided by a modified Delevan Electronics SUN LOC-1 sun tracking system. The operation of this device is described in Sections 3.4.7 and 3.5.4, as it pertains to the collector unit controller. The unit requires 110 vac and is designed to provide  $\pm 0.25$ -degree tracking accuracy. Tracker electronics are mounted within the unit controller enclosure to facilitate interface with the unit controller.

The unit controller contains the sun tracking electronics (SUN LOC-1), motor control electronics (SECO Model 8503A), and hardwired unit control electronics.

3.2.2.7 Miscellaneous Parts -- The other important parts not included in the above paragraphs include the bearings, the swivel joint holders, and the flexible hose. Standard Dodge pillow block bearings are installed on the two outside posts of each collector module. Two swivel joint holders fabricated from standard aluminum hold the rotating joints at the ends.

Two flexible hose assemblies made by Parker will provide the interface between the collector and the supply and return headers.

### 3.3 INSTRUMENTATION

Instrumentation in the form of sensors is used in this project for data collection and for system control. Some sensors serve both purposes. This subsection describes the data collection instrumentation in detail, then lists the control sensors for completeness. Details of the control functions are given in Subsections 3.4.5 and 3.5.2.

#### 3.3.1 Data Collection Instrumentation

Instrumentation is provided for collection of data during the Phase II checkout and the Phase III operation and test. Figure 3-6, a schematic of this instrumentation, includes data from the control sensors. Table 3-2 lists data collection instrumentation and summarizes the purpose of each sensor. This data will be collected on a 14-channel recorder or data logger for analysis and determination of system performance. All sensor inputs are compatible with the Solar Data Acquisition System (SDAS). The data analysis methodology is described in Section 3.11, titled Test Plan.

#### 3.2.2 Control Instrumentation

The solar energy system is controlled by a system controller that performs logic functions based on control sensor inputs. Unit controllers at each collector control the individual collectors when permitted by the system controller. Figure 3-7 shows the system controller, the control sensors, and the control outputs schematically. Table 3-3 lists the control sensors and the control functions each sensor commands. The primary sensors in normal operation are I-1, the illumination sensor, and W-1 the wind sensor. The illumination sensor turns the system on and off each day as a function of the light level, and the wind sensor serves to protect the tracking collectors from high winds by stowing the system if the winds go above 30 mph. The other sensors protect the system from damage due

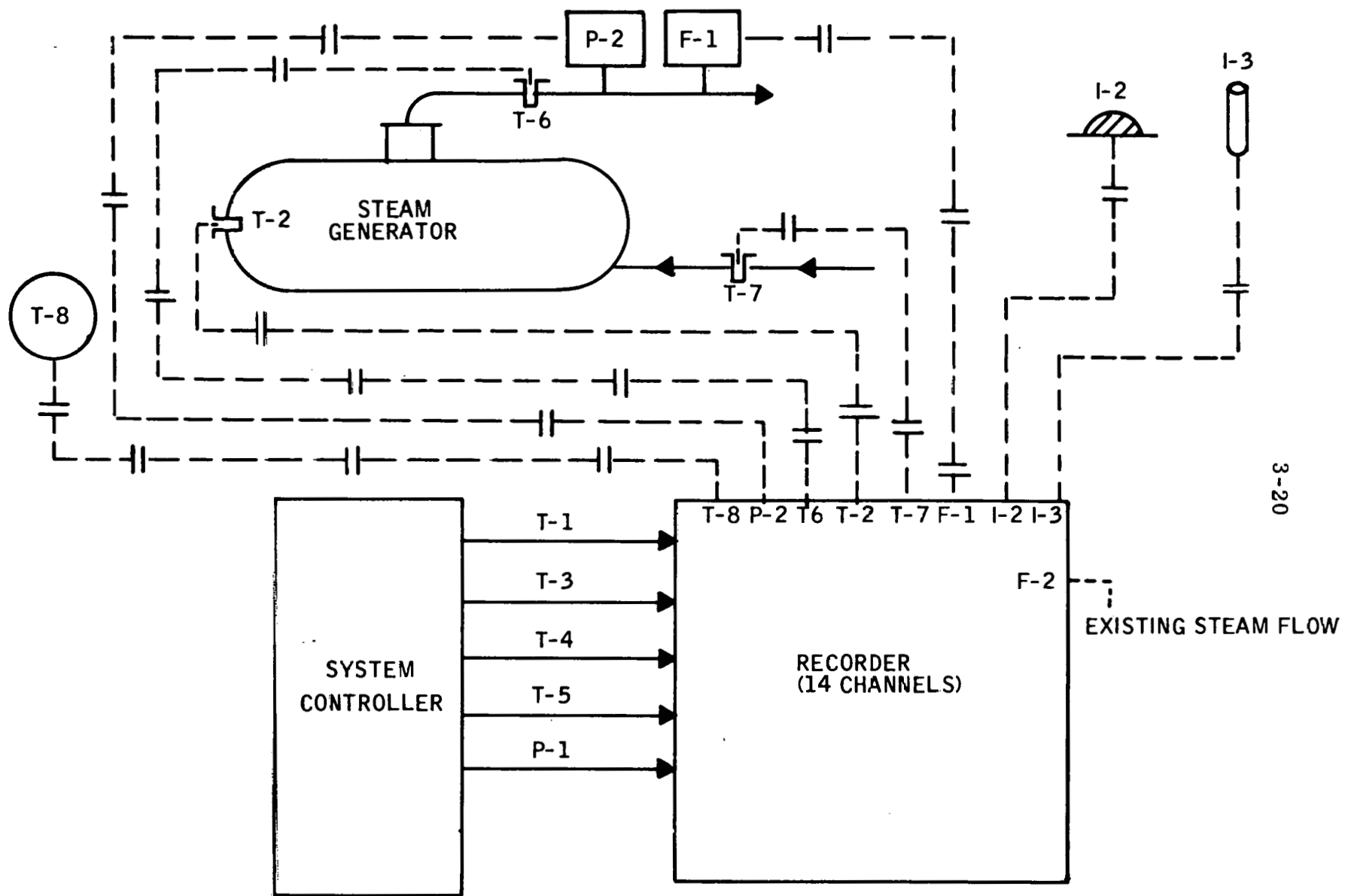


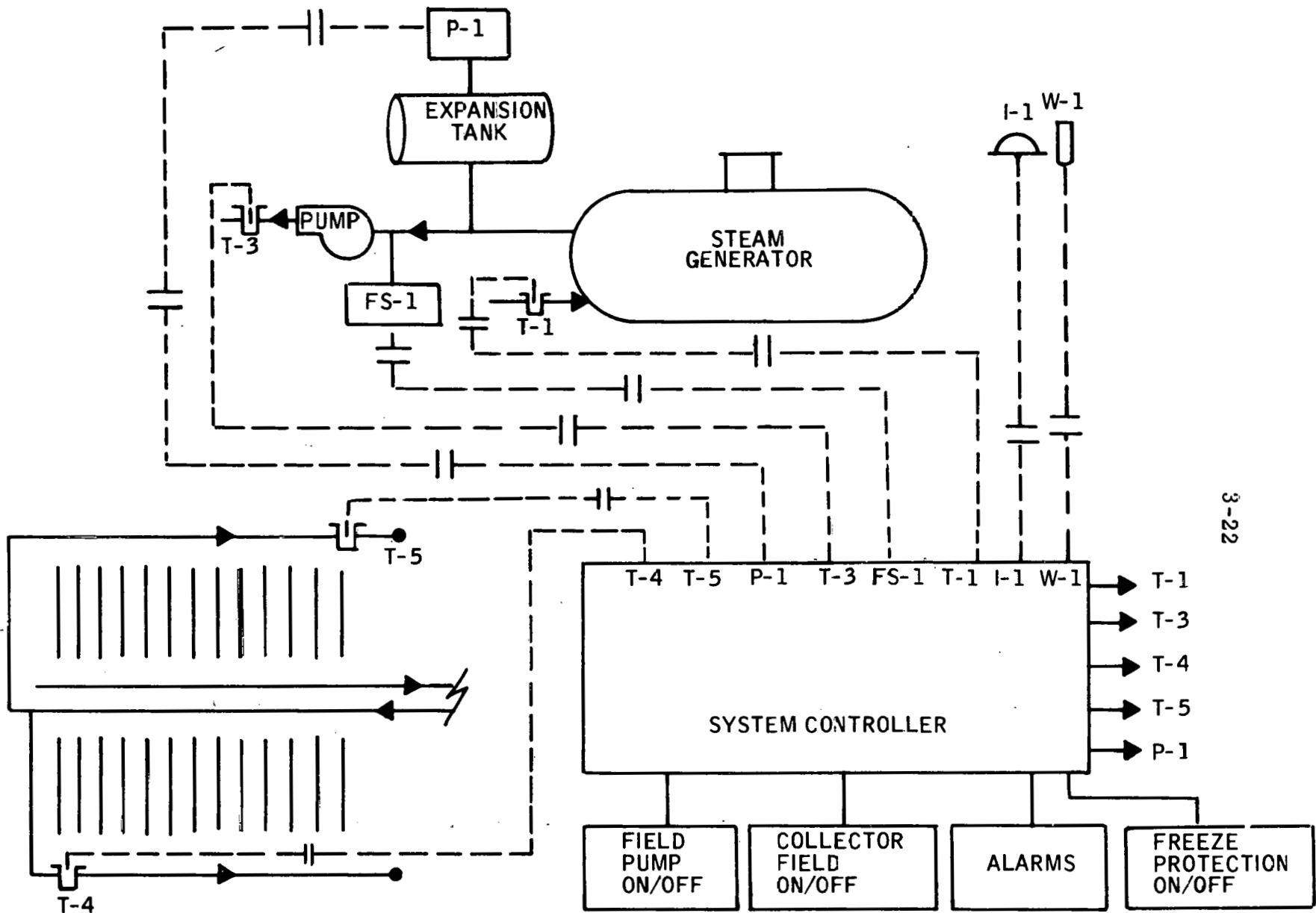
Figure 3-6. DATA COLLECTION INSTRUMENTATION SCHEMATIC

Table 3-2. Data Collection Instrumentation

Abbreviation	Sensor	Manufacturer	Units	Range	Accuracy	Function
T-1*	steam generator inlet temperature	Minco S53-P	ohms	100-190	+ .05%	<ul style="list-style-type: none"> <li>• Monitor system characteristics as a function of time</li> <li>• Calculate system performance</li> </ul>
T-2	steam generator fluid temperature	Minco S53-P	ohms	100-170	+ .05%	
T-3*	steam generator outlet temperature	Minco S53-P	ohms	100-170	+ .05%	
T-4*	HTW fluid temperature in field	Minco S53-P	ohms	100-170	+ .05%	
T-5*	HTW fluid temperature in field	Minco S53-P	ohms	100-170	+ .05%	
T-6	process steam temperature	Minco S53-P	ohms	100-170	+ .05%	
T-7	feedwater temperature	Minco S53-P	ohms	100-140	+ .05%	
T-8	ambient temperature	Minco S53-P	ohms	100-115	+ .05%	
P-1*	HTW loop pressure	Robinson-Halpern Model 144C-230-E-P42-T	ma	4-20	±0.10%FS	<ul style="list-style-type: none"> <li>• Monitor system characteristics</li> <li>• Calculate system performance</li> </ul>
P-2	process steam pressure	Robinson-Halpern Model 144C-210-E-P42-T	ma	4-20	±0.10%FS	
F-1	process steam flow	Hayes	ma	4-20	0.5%	<ul style="list-style-type: none"> <li>• Calculate system performance</li> <li>• Calculate process demand</li> </ul>
F-2	existing steam flow to process	Republic				
I-2	pyronometer	Eppley Model no. 2	mv	0-10	±2%	<ul style="list-style-type: none"> <li>• Monitor total radiation level</li> <li>• Monitor direct radiation level</li> <li>• Calculate system performance</li> </ul>
I-3	pyroheliometer (tracking)	Eppley	mv	0-10	±2%	
E-1	watthour meter	Westinghouse	kwh		3.5%	<ul style="list-style-type: none"> <li>• Monitor electrical power usage</li> </ul>

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\*also used for control (see Figure 3-7 and Table 3-4).



3-22

Figure 3-7. SENSOR AND CONTROL SCHEMATIC

Table 3-3. Control Sensors

<u>Abbreviation</u>	<u>Sensor</u>	<u>Manufacturer</u>	<u>Function</u>
I-1	photocell	Solar Systems Inc. SS-300-1	sense illumination level to turn system on and off
W-1	anemometer	WeatherMeasure SkyVane W161	sense wind to protect collectors (stow in high winds)
FS-1	flow switch		senses flow/no flow in field HTW loop (no flow stows collectors)
P-1	pressure sensor	Robinson-Halpern Model - 144C-230-E-P42-T	senses pressure in HTW loop* high pressure shuts system off low pressure indicates fluid loss and inhibits system operation
T-1	steam generator inlet temperature	Minco S53-P	senses overtemperature* senses freeze threat
T-3	steam generator outlet temperature	Minco S53-P	senses overtemperature* senses feedwater failure senses freeze threat
T-4, T-5	temperature of fluid in field	Minco S53-P	senses freeze threat*

3-23

\*sensor also used for data collection.

to component failures or temperature extremes. The flow switch and pressure sensor are standard control sensors that serve to inhibit system operation if either the HTW loop flow or pressure is too low. The temperature sensors monitor various locations for overtemperature protection and freeze protection.

## 3.4 SYSTEM DESIGN

### 3.4.1 Introduction

This section describes the system designed for installation on the WestPoint Pepperell mill at Fairfax, Alabama. In this section, the system is described in terms of its major elements, the collector field, the high temperature water (HTW) loop, the steam and feedwater loop, and the system controller. Following the design description of these major elements, a description of the major components is given to facilitate understanding of the operation of these components. Additional design detail is included in Section 3.5, along with the important design considerations that led to the overall system design.

### 3.4.2 Collector/Field Design

3.4.2.1 Physical Arrangement -- The collector field consists of 48 collectors arranged in two rows of 24 collectors aligned along the weave room roof so that the collector axis is parallel to the roof beam structure. The field has  $773 \text{ m}^2$  ( $8313 \text{ ft}^2$ ) of collector aperture. Figure 3-3 shows the field location on the roof with the significant dimensions. As shown by the arrow pointing north, the building itself is not aligned north-south or east-west. Since the collector axes are aligned with the building rather than N-S or E-W, the plane normal to the tracking axis is 40 degrees east of north (the axis points  $40^\circ$  south of east and  $40^\circ$  north of west). Although this orientation affects the tracking operation, performance predictions show that there is no adverse effect on the overall system performance. The performance analysis results are discussed in Section 3.7.

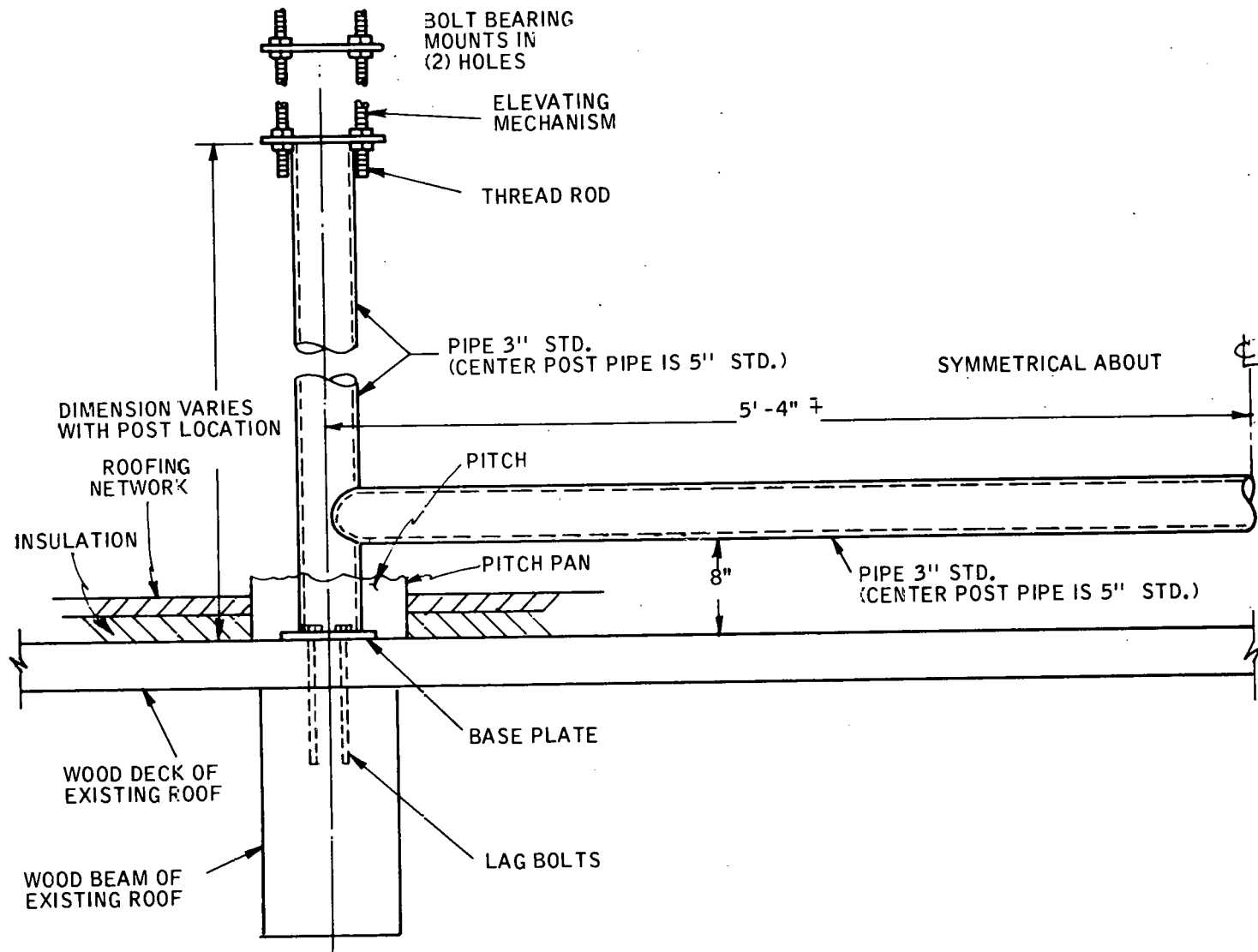
The collector supports are positioned directly above the existing roof support beams. This 3.25 m (10' 8") spacing results in a 36% ground cover and eliminates shadowing from adjacent collectors unless the sun is below 22° elevation. For lower elevations part of the collector aperture will be shadowed, increasing to 50 percent for 11 degrees sun elevation. Therefore, shadowing of the collectors occurs only for a short period at the beginning and end of the day when the sun elevation is very small.

The collectors are located as close to the roof as possible. Since the roof slopes, the "eastern" row of collectors is .2m (8") lower than the "western" row. Analysis has shown this to have no significant affect on system performance.

The wall of building number 2 shadows the weave room roof on winter afternoons. The worst shadows occur on December 21. Sun position data has been used to calculate the length of this shadow at various times of the day. These results have been confirmed by direct observation on 22 December 1976. The solar collector field is located 36.6m (120 feet) from the building number 2 wall so that the shadow does not fall on any part of the collector field until after 4:00 p.m. local time (EST) on 21 December. At this time the sun is below 15 degrees in elevation.

In summary, the collector field is arranged in a manner to optimize the sun's energy collection with minimal modification to the existing structure. The alignment of the collector field squarely with the building is also desirable for aesthetic considerations.

**3.4.2.2 Support Structure** -- Each 40-foot collector assembly is mounted on three vertical posts. Figure 3-8 illustrates the post structure. The drive assembly is mounted on the center line post and the two end posts support pillow block bearings. Each of the posts is topped by an adjustable



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Figure 3-8. TYPICAL COLUMN DETAIL AT END POST

elevating mechanism to provide for fine tuning of the local collector elevations. Each elevating mechanism consists of two parallel, horizontal plates, which are separated by four threaded rods and nuts for locking the mechanism in its final position. The top plates of each center post elevating mechanism are slotted to provide for alignment flexibility of the gear box. The plates of the end posts are not slotted because of the flexible design of the standard pillow block bearing.

The column of the center post is made from a standard 5-inch, SCH 40 steel pipe while the column of the end posts is made from a standard 3-inch SCH 40 steel pipe. The center post requires greater strength because it supports the gearbox and absorbs the majority of the loads exerted on the collector.

Each of the three support posts are centered on a rectangular wooden beam of the existing roof structure. The location of the beams on 3.25m (10'8") centers is used to locate the adjacent rows of the collector field. The beam-post interface is made with two 1/2 x 8-inch lag bolts which fasten the post to the beam. Pitch pans are installed at each of the posts to weather seal the interface.

Since one row of collectors straddles the roof apex, and the other row of collectors is positioned down the sloping roof, each of the six support posts have different lengths and the pivot axis of the two adjacent collectors differ in elevation by 0.2 m (8 inches). The lengths of the column above the roof line are as follows,

<u>Post Location</u>	<u>Column Length</u>
D	4'3"
E	5'2"
F	6'

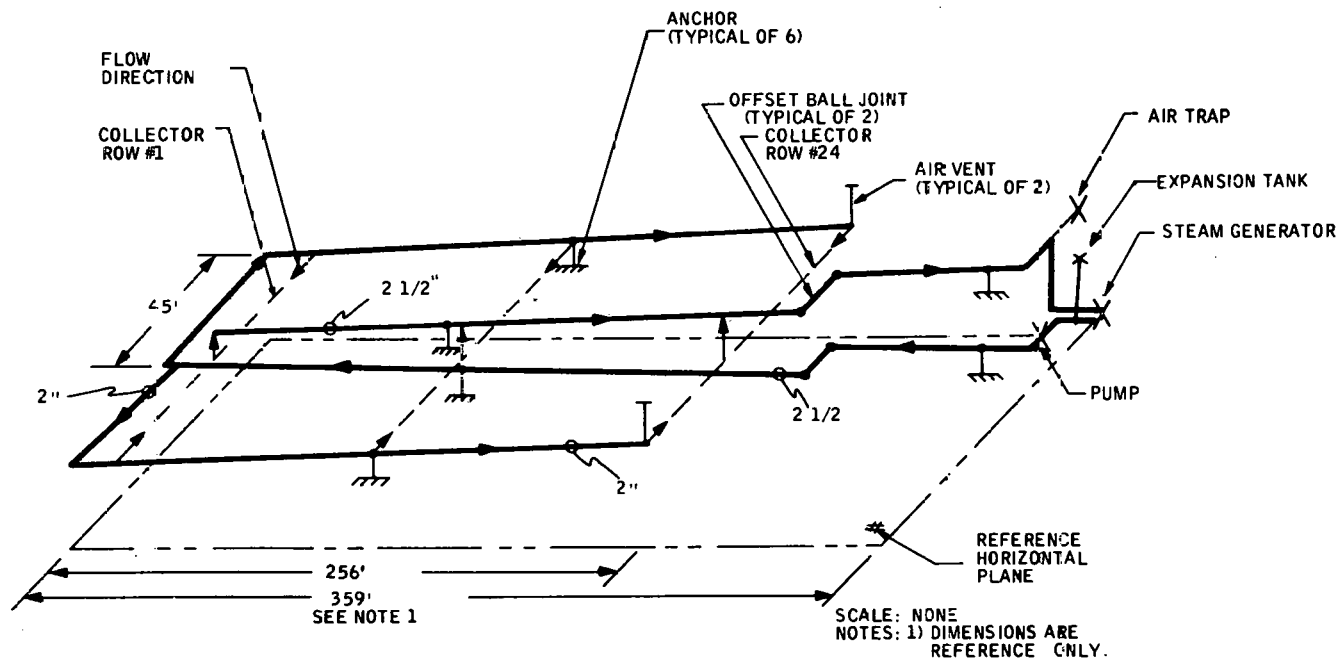
The collector elevations which result from these column lengths are sufficient to allow the collector assembly to be stowed with the chord of the reflector honeycomb positioned horizontally.

The support posts are interconnected to provide stiffness and resistance to the air load exerted on the posts through the collector. Subsection 3.5.3 discusses the wind loads in detail.

### 3.4.3 High Temperature Water Loop Design

The high temperature water (HTW) loop includes several key components including the absorber of the concentrating collectors, the steam generator, and the interconnecting piping, as well as accessory components such as valves, circulation pump, expansion tank, and air elimination devices. These components are discussed in general below and in Section 3.4.8. Further details are included in Section 3.5, Design Considerations.

3.4.3.1 Piping -- The piping of the HTW loop, shown schematically in Figure 3-9, consists of 750 feet of 2-1/2 inch pipe and 600 feet of 2 inch pipe. The former is used for the supply and return mains which have a design flow rate of 48 gpm. The latter is used for the pipe runs from the supply main, and for the supply headers to the field of collectors. These pipe runs have design flow rates of 24 gpm or 1 gpm per collector branch.



3-30

Figure 3-9. HTW RECIRCULATION LOOP PIPING

Standard pipe material and standard sizes are used for the system conduits. The HTW loop piping will be of welded construction, Schedule 40, seamless, black steel pipe as described by ASME SA-53 (specification for welded and seamless pipe). In accordance with standard practice the piping of the HTW loop is sloped upward in the flow direction by approximately 1/4 inch per 10 feet of length wherever possible. This provides for the migration of vapor bubbles toward the standpipes located at several points in the loop. Periodically, the accumulation of vapor is bled from the system through the manual valves located at the vapor collection points.

At certain tracking angles, the collector absorber elevation will be greater than the return header elevation. In this design the return header is fixed at an elevation which allows vapor bubbles to migrate to the return header when the collector is stowed. This automatic purge operation takes place when the collector absorber is positioned below the return header while the pump is operating. Any vapor bubbles which collect in the HTW loop close to the steam generator are removed by either of two loop components. The first is the "air trap" located at the highest point in the loop, just before the inlet to the steam generator. The second is the "air eliminator" located downstream of the steam generator and just before the field flow pump. These two devices are purged automatically by ducting each to the expansion tank.

3.4.3.2 Insulation -- Standard fiberglass pipe insulation is used to control the heat loss in the HTW loop. The insulation includes an aluminum outer jacket which protects the material from adverse weather conditions. Based upon manufacturer's data on "economic thickness", an insulation thickness of four inches was selected for the 2-inch and 2-1/2 inch pipes of the HTW loop.

3.4.3.3 Interfaces -- The piping of the HTW loop interfaces with two major components, the collector and the steam generator.

A typical header/collector interface is shown in Figure 3-10. The supply header pipes are drilled at forty-eight locations on 10 ft. 8-inch centers to accept a single 1/2-inch, schedule 80 pipe nipple. The threaded end of the nipple interfaces with the thread of the ball valve. The valve in turn connects to the flexible hose of the collector assembly. The size of these interface parts is more than adequate to handle the collector branch design flow rate of 1.0 GPM without causing an excessive pressure drop or violating pressure piping code requirements. Using 1/2-inch valves minimize the piece part costs.

The interface at the return header is similar to that at the supply header except that two half-inch nipples are installed at each of 24 locations to accept return fluid from two collectors on either side of the header. The two pipe nipples, which are offset along the header, accept return flow from two adjacent collectors - one to the left of the return header and one to the right of the return header.

The flexible hose allows for the thermal expansion and contraction of the headers. In addition it compensates for normal variations of the hard point locations which might occur during the installation of the header pipes and the collector assemblies.

The interface between the HTW piping and the steam generator is accomplished with a standard ASA 300 pound flanged nozzle.

3.4.3.4 Circulation Pump -- Fluid transport between the solar collectors and the steam generator is accomplished with a standard centrifugal pump. A hermetically sealed, Can-O-Matic pump manufactured by Buffalo Forge Co. performs this function at HTW temperatures to 430<sup>o</sup>F without the need

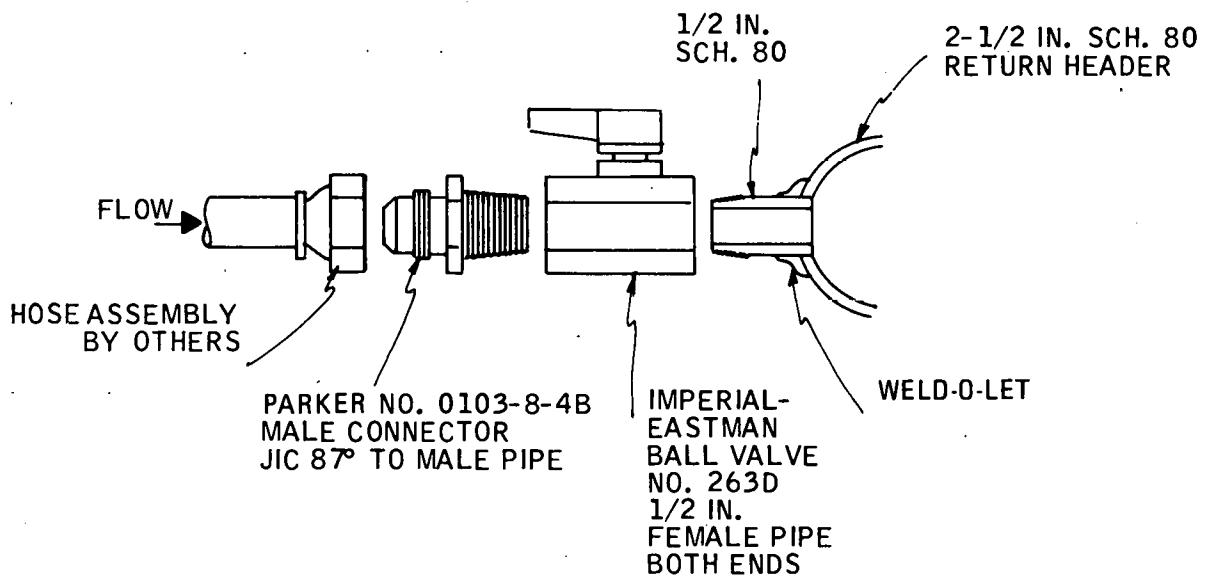


Figure 3-10. TYPICAL HEADER/COLLECTOR INTERFACE

for external cooling of stuffing boxes and bearings required for many other candidate pumps. The canned pump maximizes safety because it has no exposed rotating parts.

The selected HTW circulation pump is a model H66-058. Its 5 hp motor drives a 7-1/2 inch diameter impeller at 1750 RPM providing 48 gpm at 50 feet of head.

3.4.3.5 Expansion Tank -- A 200 gallon expansion tank is located in the HTW loop to accommodate the thermal expansion of the water in the HTW loop. The tank, a standard pressure vessel, contains the fittings necessary to accept a charge of nitrogen from an external bottle supply. The nitrogen, which is used to pressurize the fluid of the HTW loop, is introduced manually in accordance with a predetermined pressure - temperature schedule. The schedule is designed to prevent boiling in the HTW loop under all normal operating conditions.

The maximum pressure in the HTW loop is controlled by a relief valve located just downstream of the circulation pump at the highest pressure point of the system.

3.4.3.6 Valves -- An addition to the major HTW loop components discussed above, a variety of valves are included in the HTW loop. All of the valves are standard, readily available items and only one bears further mention here. Ball valves were selected for the inlet and outlet of each collector branch. They represent a compromise between the high cost modulating types (needle valves and globe valves) and the lower cost shut off types (gate valve etc.).

During the initial checkout of the collector field, the valves are manually adjusted to provide equal flow rates of 1.0 gpm in each of the 48 collector branches. It is anticipated that branch-to-branch flow variations of  $\pm 15\%$  would not adversely affect the system performance.

3.4.3.7 Freeze Protection -- On occasion, despite the Alabama location of the textile mill, it is expected that freezing temperatures will be experienced by the system. The freeze protection is accomplished by the addition of 7000 watts of immersion heating capacity to the HTW loop. The heaters are installed at two locations in the loop, and fit inside the piping of the loop as shown in Figure 3-11. The heaters are standard devices and are selected to operate on the stand-by 120 volt power supply in case of an emergency.

The operation of the HTW loop during the onset of freezing temperatures is as follows. As the fluid temperature drops below the setpoint temperature, an electric signal is generated which activates the electric heaters and the recirculation pump. This thermostatic control is designed to maintain a minimum fluid temperature of  $35^{\circ}\text{F}$ .

If severe freezing conditions are encountered, and the fluid temperature drops below  $35^{\circ}\text{F}$ , an alarm is triggered by the fluid temperature sensor signal. In response to the alarm the HTW fluid is drained manually with the gate valve located at the low point of the loop.

3.4.3.8 System Initial Fill and Makeup -- The initial fill and any subsequent water makeup is accomplished by tapping the feedwater supply line of the steam generator. The gate valve in the branch leading to the shell side of the steam generator is closed and the gate valve in the branch leading to the HTW loop is opened. The feedwater pump is then used to fill the HTW loop. After the filling operation is complete, as indicated in the expansion tank gauge glass, the gate valves are returned to their normal positions

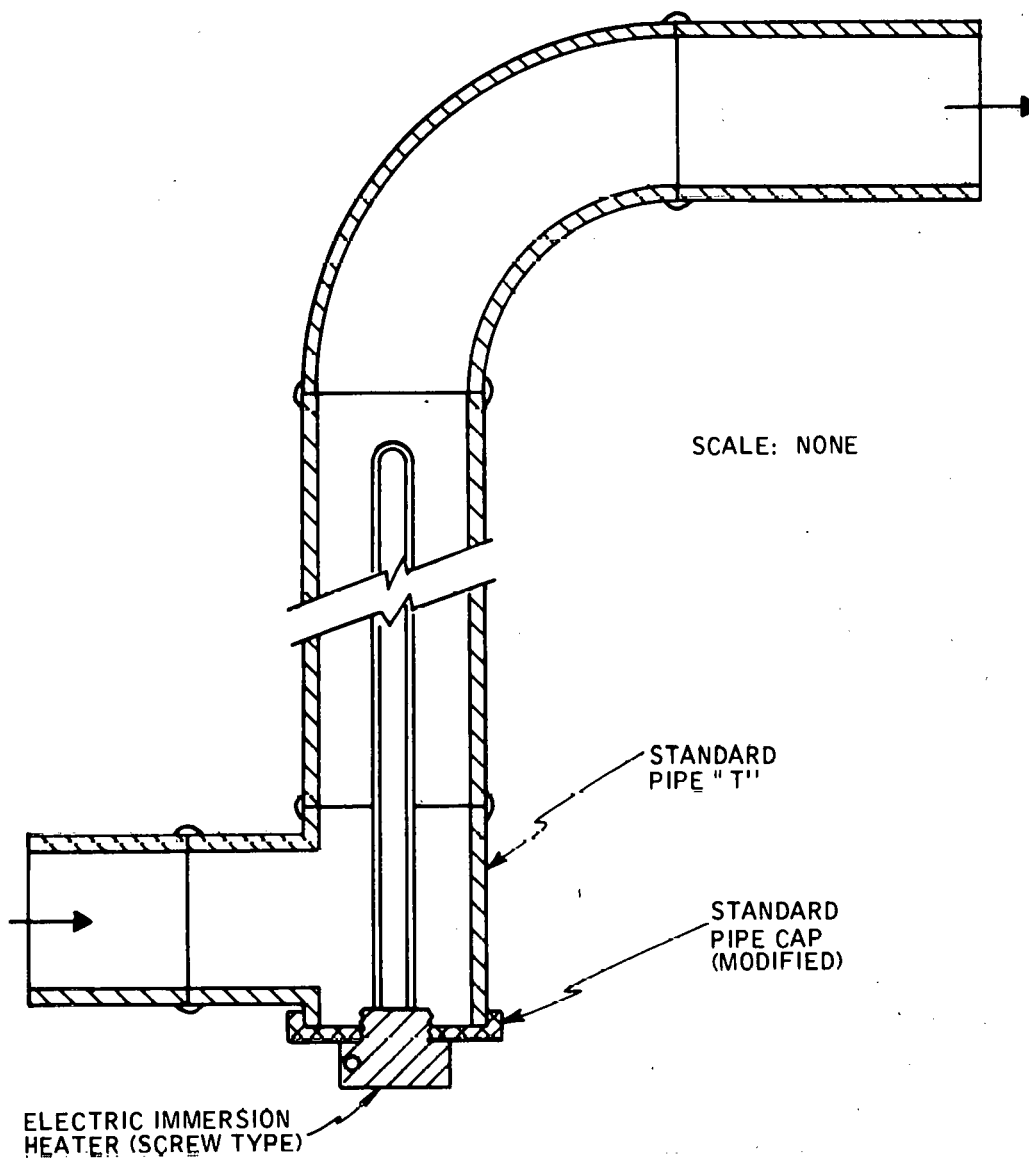


Figure 3-11. TYPICAL INSTALLATION OF IMMERSION HEATER

and the HTW loop is repressurized with nitrogen. Liquid level decrease caused by lost fluid is made up with the same procedure. It is anticipated that once filled, the system will operate with minimal refill and make-up water requirement.

3.4.3.9 Thermal Expansion of Pipes -- Thermal expansion provision in the HTW loop piping has been provided because of long pipe runs. Two anchor point locations exist in the supply and return lines. One is at the center of the collector field and one is at the entrance to the penthouse. All 2-inch and 2-1/2 inch piping which runs the length of the field is anchored between collector row numbers 12 and 13. Thus thermal expansion is allowed toward the ends of the field. The relative pipe motion between the anchors is absorbed by a pair of standard flexible off-set joints. Each joint consists of two ball joints connected by a piece of rigid pipe. Figure 3-12 shows a typical off-set expansion joint.

For a pipe wall temperature variation of  $400^{\circ}\text{F}$ , the linear expansion will cause a growth in pipe length of approximately 4 inches on either side of the mid-field anchor location. Similarly, the pipe length between the ball joint and the penthouse anchor will increase by approximately 3 inches.

#### 3.4.4 Steam and Feedwater Loop Design

The heat content of the high temperature water of the HTW loop is used to convert feedwater to steam in the steam loop of the solar system.

The steam loop is the second of the two fluid loops of the system. It is shown schematically in Figure 3-13, and for discussion purposes, includes a "steam side" and a "feedwater side". The figure shows the layout of the steam loop between the penthouse, which houses the steam generator, and the interface connection with the existing steam line in WestPoint Pepperell building number 2. Figure 3-4 shows the plumbing details of the

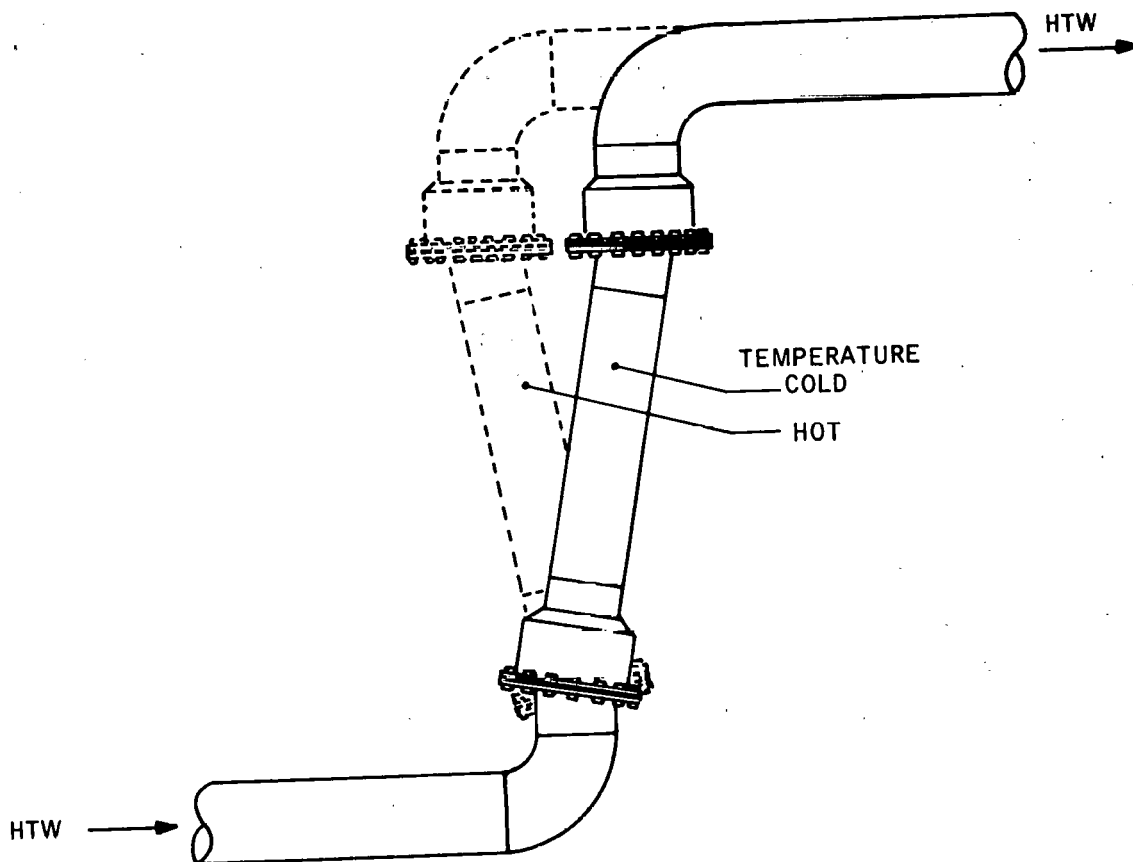
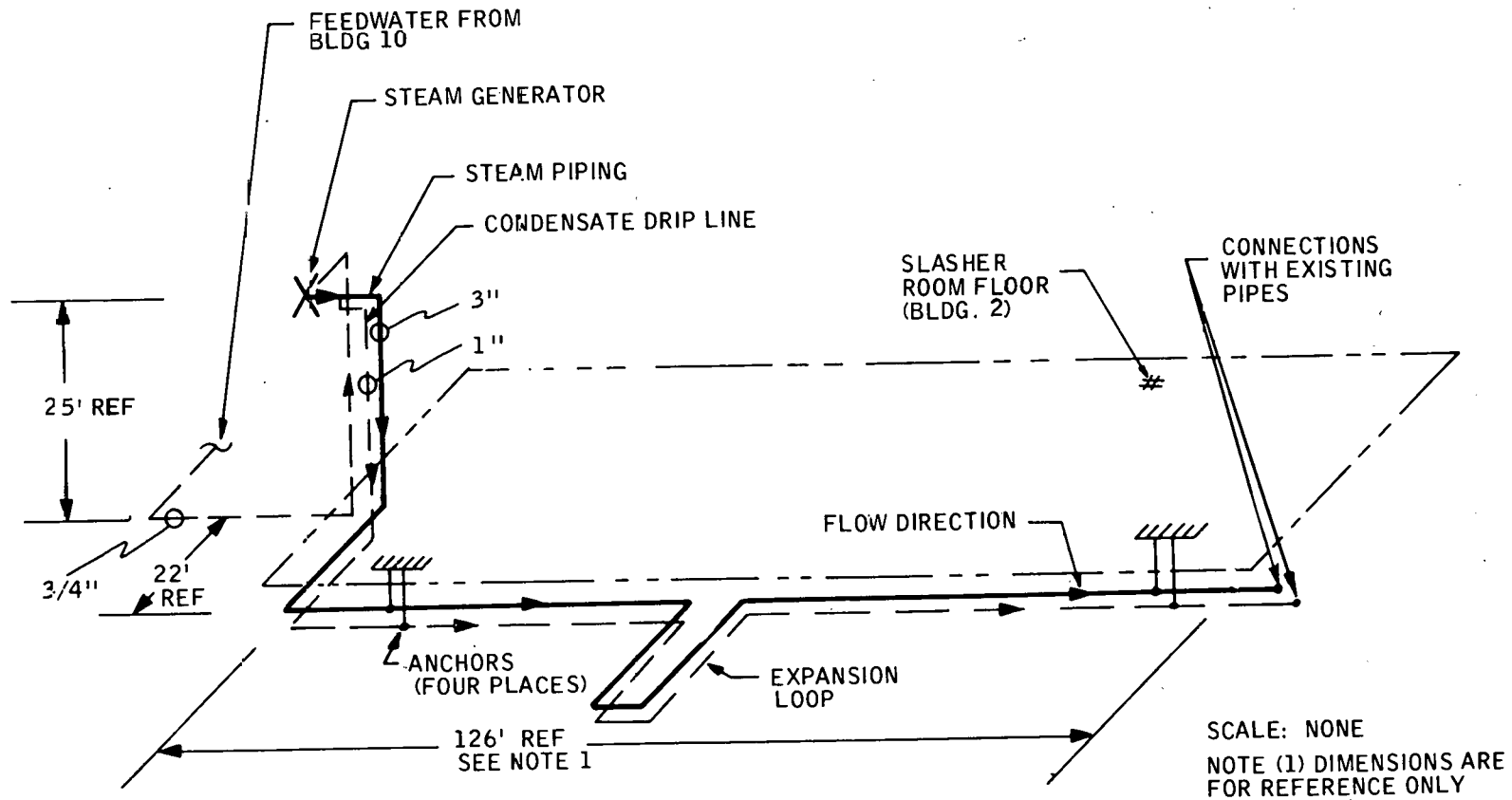


Figure 3-12. TYPICAL OFFSET BALL JOINT



3-39

Figure 3-13. STEAM LOOP SCHEMATIC

steam loop including various valves, condensate tank, feedwater pump and interconnecting pipes.

3.4.4.1 Steam Loop -- Steam at 76 psig and 321<sup>o</sup>F is generated at the design operating point of the steam generator. This steam is delivered to an existing steam-load supply line. The existing steam line is at a regulated 70 psig condition. Therefore, to insure positive steam flow from the solar system, the design delivery pressure will be greater than 70 psig at the junction of the two steam branches. To meet this requirement, a standard three-inch diameter, schedule 40 black steel pipe is used. This diameter pipe results in a very small pressure drop in the 190 foot pipe run needed to deliver steam from the steam generator to the slasher room supply header.

Standard fiberglass pipe insulation is used to control the heat lost from the steam pipe run. A wall thickness of three inches was selected based upon manufacturer's economic thickness data. The resulting heat loss from the steam line is expected to condense a small amount (17.7 lbs/hr) of liquid at a steam flow rate of 1200 lb/hr, which drops the steam temperature to 317<sup>o</sup>F at the point of delivery to the existing steam line in the slasher area.

The condensing water is collected, strained, trapped, and routed to the existing condensate return system at the textile mill. The condensate piping on the steam side is one inch, standard weight yolo pipe.

Provision for the thermal expansion of the pipe on the steam side is accomplished with a loop of piping located at the middle of the pipe run as indicated in Figure 3-13.

3.4.4.2 Feedwater Side -- The feedwater for the steam loop of the solar system is obtained from an existing condensate supply tank at the mill. The feedwater loop includes a feedwater pump and the necessary piping to transport the condensate from the receiver to the feedwater supply port of the steam generator. The conduit for this pipe run is 3/4-inch, standard weight yoyo pipe. The design temperature of the feedwater at the inlet to the steam generator is 200°F. Feedwater is available at this temperature and hence no additional water treatment plant or preheaters are needed.

The feedwater pump chosen for this application is a standard Skidmore Model TP (Turbine Pump) 212-1/2 with a 1-1/2 hp motor. This unit is designed to run at 1750 RPM and to deliver 3 gpm at 125 psig when supplied with feedwater at 210°F and approximately two feet of suction pressure. The turbine pump was chosen for this application because it develops higher pressures at low flow rates with more efficiency than centrifugal pumps. The presence of the existing condensate receiver eliminates the need for a separate receiver. The feedwater pump is operated by the liquid level control on the steam generator.

3.4.4.3 Interfaces -- Three interface connections are required. First, the three-inch solar steam supply line must be connected to the existing five-inch steam supply line for the slashers. Second, the one-inch condensate line must be connected to an existing condensate line in the mill. Finally, the 3/4-inch feedwater supply line must be connected to the existing condensate receiver. All three connections can be accomplished with standard pipe fittings and plumbing techniques.

### 3.4.5 System Controller

The purpose of the system controller is to provide a central control and display station for the collector field of 48 collectors. The collector field is divided into four quadrants. The system controller will completely control the direction of travel of the entire field of collectors on a quadrant-by-quadrant basis, will act as a status monitoring station at the penthouse, and will provide remote field status indication to the basement and control room. The system controller operates in three modes, manual, automatic, and emergency control mode. The field is controlled on a quadrant-by-quadrant basis to minimize the hardware requirements for the power distribution system. The quadrants are commanded sequentially to follow manual commands and automatic commands. In addition to sequencing commands, the system controller is also capable of sequencing power distribution to each of the quadrants. The field uses 28 volt dc power for the control electronics and 110 volt ac power for the drive motors. There is a stand-by power generator which supplies power through an automatic transfer switch. Upon loss of primary power the transfer switch enables a 12 Kw diesel generator to begin operation to supply stand-by power which is then used to stow the field in a sequential manner such that the motor surge current requirements are within the capability of the stand-by generator.

3.4.5.1 Requirements -- The requirements placed on the system controller are 1) to insure safe operating conditions before the system is enabled, 2) to provide self protection functions for the field, and 3) to provide the manual intervention capability for collector orientation, feedwater pump, field pump, freeze protection heater, power distribution during maintenance, and under an emergency situation.

3.4.5.2 Functions -- The functions of the system controller are 1) command/control function, and 2) the status indication function. In the command and control mode, there are three submodes, the automatic mode, the manual mode, and the emergency power mode.

Automatic Mode -- In its day-to-day operation the system controller is typically operating in the automatic mode. In this mode it responds to control sensor input and commands system components. Figure 3-13 is a schematic of the sensors, the system controller, and the controlled components.

To initiate operation of the solar energy system, three of the sensors must provide a positive response to the controller,

- HTW loop pressure above limit
- wind below limit
- illumination above limit

The initial control response is to turn the field flow pump on. When the flow switch signals flow has commenced, the collector field is commanded to the "acquire" mode. If either the illumination or wind sensors provides a negative signal, the system controller commands a "stow" after a set time delay. If the loop pressure or fluid temperatures depart from their nominal ranges, the system controller will stow the field and manual reset of the controller is required before automatic operation is re-initiated. Furthermore, the controller commands the freeze protection system (immersion heaters and field flow pump) based on fluid temperature inputs and monitors the collector state through stow switches and overtravel switches.

Manual Mode -- In the manual mode, power distribution can be supplied on a quadrant-by-quadrant basis for maintenance and inspection. Key lock switches are used so that the operator is assured that the selected quadrants are without electrical power. The capability exists at the system controller panel for the operator to remove power to the entire field through the use of an emergency power panic button with a key lock reset.

The operator may manually command the field of collectors to rotate in the forward or reverse direction or to maintain a position selected by the operator. These commands are generated through the system controller in a sequential fashion so that motor surge currents are kept within acceptable limits to the power distribution system. The forward and reverse directions for collector rotations are selected by two manual push-buttons on the system controller panel. The operator may enable both the feedwater pump and the field pump using manual push buttons on the system controller panel. Freeze protection in the form of immersion heaters may also be enabled from the system controller panel.

Emergency mode -- In the event that emergency power is required due to loss of primary power, the system controller's primary function is to stow the field, quadrant-by-quadrant using the backup power generator. Two minute quadrant sequencing is used to keep power consumption within the limits of the emergency power source. The emergency power generator will continue to operate to provide power for the system controller so that temperatures in the field may be monitored for freeze protection information. After the loss of primary power,

manual reinstatement to normal operation is required before the system can be operated in the automatic mode. The emergency power generator operates until normal power is restored or its fuel supply is exhausted.

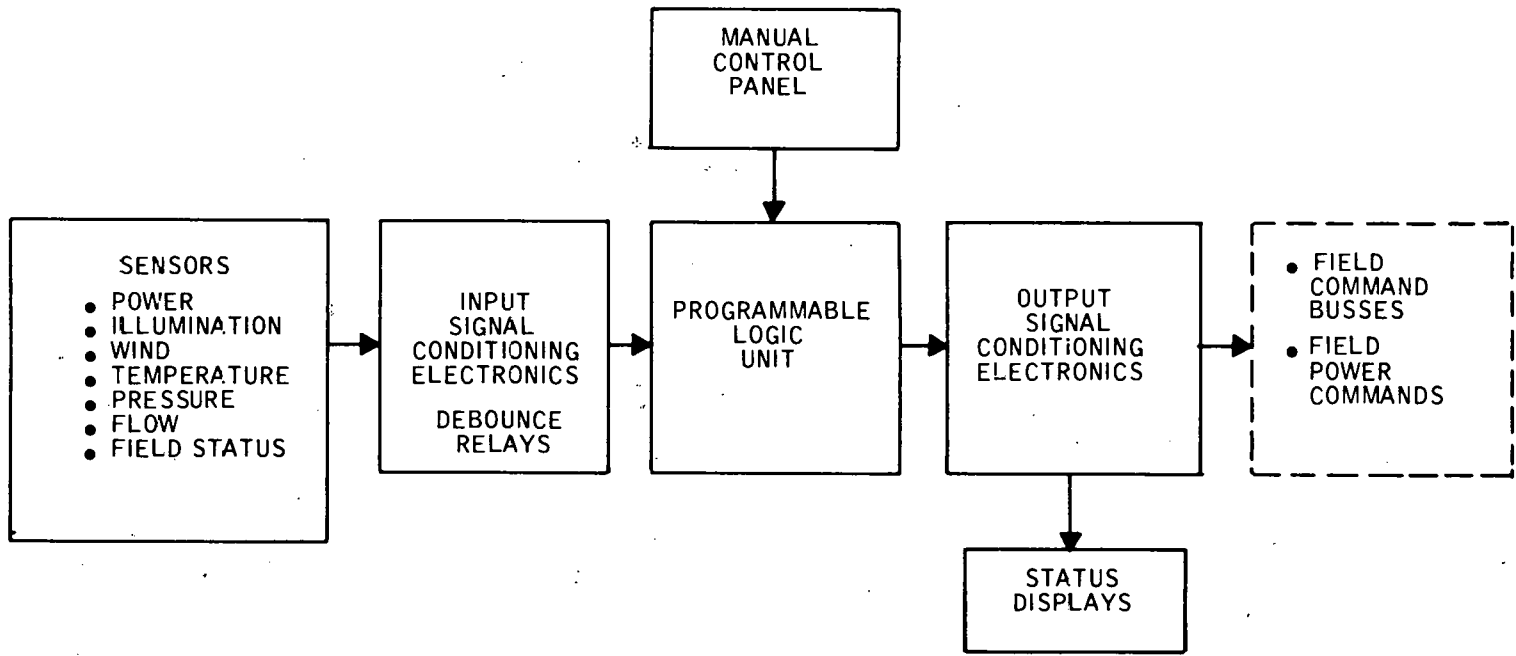
Status indication -- The system controller provides collector field status indication. Stow parity is indicated; a signal is generated if all of the collectors are not in the same state (either stowed or not stowed). If any of the collectors have exceeded the safety limit switch indicating some malfunction at a unit controller, a status lamp is lighted. Other status indications are: 1) loss of the loop pressure, 2) feedwater pump failure, 3) field pump failure, 4) freeze protection required and 5) the condition of having a wind greater than 30 mph persisting for more than one minute and a no-stow condition in the field. This no-stow condition could be caused by as few as one collector remaining unstowed.

3.4.5.3 Implementation -- The system controller is implemented subject to certain constraints. One such constraint is the requirement for power sequencing. The field is divided into four quadrants such that each quadrant may be sequentially brought into its normal operating state by the system controller. In normal operation, each quadrant is enabled at 5 second intervals; the reason for this is to keep surge currents within reasonable limits to ensure an economic utilization of field wiring. When the emergency power generator is being used and the field is sequenced into the stow mode to protect the collectors, this sequencing is done at two-minute intervals. This allows the use of a smaller emergency power generator than would be necessary if all quadrants were required to stow at the same time.

3.4.5.4 System Block Diagram -- Figure 3-14 is a functional block diagram of the system controller. The system controller obtains information from a number of sensors; illumination, wind velocity, temperature, pressure, field flow, field status, and a signal which informs the controller whether the power being supplied is from the stand-by generator. The signals from these sensors are fed into the input signal conditioning electronics. Basically these electronics perform thresholding functions and de-bouncing functions to condition the signals for input to the programmable logic unit. This programmable logic unit also accepts inputs from the manual control panel of the system controller. The programmable logic unit is a custom microprogrammable controller utilizing MSI and LSI devices. This system controller algorithm is programmed into two eight bit PROM's which are addressed by a pair of 54 LS 163 binary counters. This algorithm performs the control functions necessary to enable the collector field to operate as required. Outputs from the programmable logic units are fed into the output signal condition electronics. Basically transistor switching devices, they pull in 28 volt relays to supply signals to the field command busses and to the field power commands. These same signal conditioning electronics also supply output to the status displays in both the penthouse and the remote basement control room. A detailed discussion of the elements of the system controller follows in Section 3.5.2.

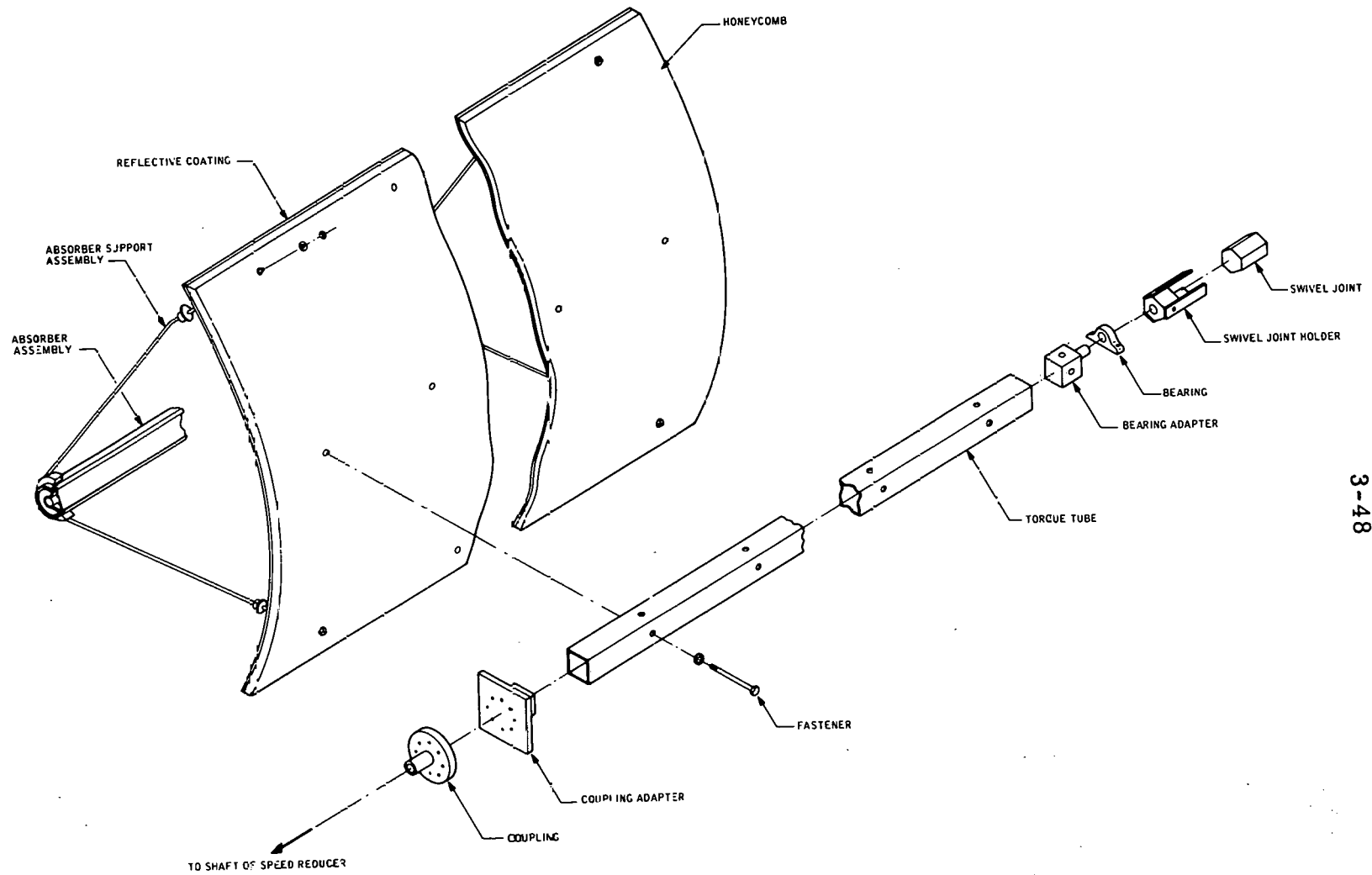
#### 3.4.6 Collector Design

The concentrating solar collector used for the WestPoint Pepperell application is an assembly of standard piece parts as well as adapters and interface parts. For discussion purposes, the mechanical components of the collector assembly comprise five main subassemblies and interface parts. These subassemblies include the drive assembly, the absorber assembly, the reflector assembly, the torque tube/adaptor assembly, and the absorber support assembly. An exploded view of a 20-foot mirror subassembly (one-half of a 40-foot collector) is shown in Figure 3-15. The



3-47

Figure 3-14. SYSTEM CONTROLLER FUNCTIONAL BLOCK DIAGRAM



3-48

Figure 3-15. MIRROR SUBASSEMBLY (20 foot section) WITH ABSORBER ATTACHED

The drive assembly is composed of an electric motor drive and a reduction gearbox. The motor is a standard 1/2 hp unit compatible with the electrical controls of the solar system. The gearbox is a standard Winsmith triple reduction (7500 to 1) worm gear unit assembled with a "minimum backlash" option to provide maximum tracking accuracy and has a double ended output shaft to interface with the left and right halves of the collector assembly.

The drive system was selected to provide a tracking speed of 0.36 degrees per second. In addition, the selected drive system has the torque capability necessary to drive the 40-foot collector assembly in a free stream, 30 mph wind. Aerodynamic analysis of the collector assembly indicates that at the 30 mph design wind condition, the torque load on the gearbox caused by inertial and air loads would be approximately 806 foot pounds.

The half-parabola reflector assembly consists of a one-inch thick, aluminum honeycomb sandwich with a 3M aluminized acrylic, reflective surface adhered to the concave side. The honeycomb is formed to fit the parabola represented by the equation  $X^2 = 144Y$  where X and Y are in inches. The half-parabola reflector, available from Hexcel, has a 3 foot focal length and an aperture width of 4.327 feet.

The drive system output loads are transferred to the reflector assembly through the torque tube/adaptor assembly. The torque tube is a standard 3 inch square, 1/8 inch wall aluminum extruded section. Adaptors are installed in both ends of the torque tube to interface with a rigid coupling on the drive end and with a pillow block bearing on the other end. During the final assembly process, the torque tube/adaptor assembly is attached to the back side of the honeycomb at locations where inserts are provided in the honeycomb. The inserts allow absorption of the compressive loads of the torque tube mounting screws.

The absorber assembly consists of standard materials, some of which are treated, after purchase, to enhance the thermal performance. The assembly, shown in Figure 3-16, includes a 0.065 inch wall, 1-1/4 inch diameter copper tube with a selective black chrome coating on the outside surface. The tube is centered in pipe insulation which has been notched along its length to provide the optical window. The exposed edges of the insulation are covered with a strip of textile form refractory silica insulation. This composite is enclosed in an aluminum skin which is formed to accept an etched glass window. The assembly is held together with bolts located periodically along the absorber length.

Experimental tests show that the refractory silica insulation will withstand direct concentrated sun's energy. During normal operation the direct energy will not fall on the insulation. The resistance to high temperatures is due, for the most part, to the protective silica fabric which is rated to 1800°F. The fabric also performs a secondary function of providing finished edges for the fiberglass insulation.

A length of riser tube and pipe insulation is used on both ends of the absorber to complete the flow path. One end of each riser is attached to the end of the horizontal absorber. The other end is attached to a rotary joint mounted on the pivot axis of the collector. Additional absorber support is obtained by spacing absorber support legs along the length of the assembly. These supports connect the absorber to the reflector assembly.

The interface between the absorber assembly and the torque tube assembly is accomplished with a "swivel joint holder". This is a forked piece designed to permit relative longitudinal displacement of the hexagonally shaped swivel joint due to the thermal expansion of the absorber tube. At the installation time the longitudinal clearance between the swivel joint and the holder is set to accommodate the hot and cold temperature positions. Total travel for the swivel joint within the holder is expected to be a maximum of 0.7 inches.

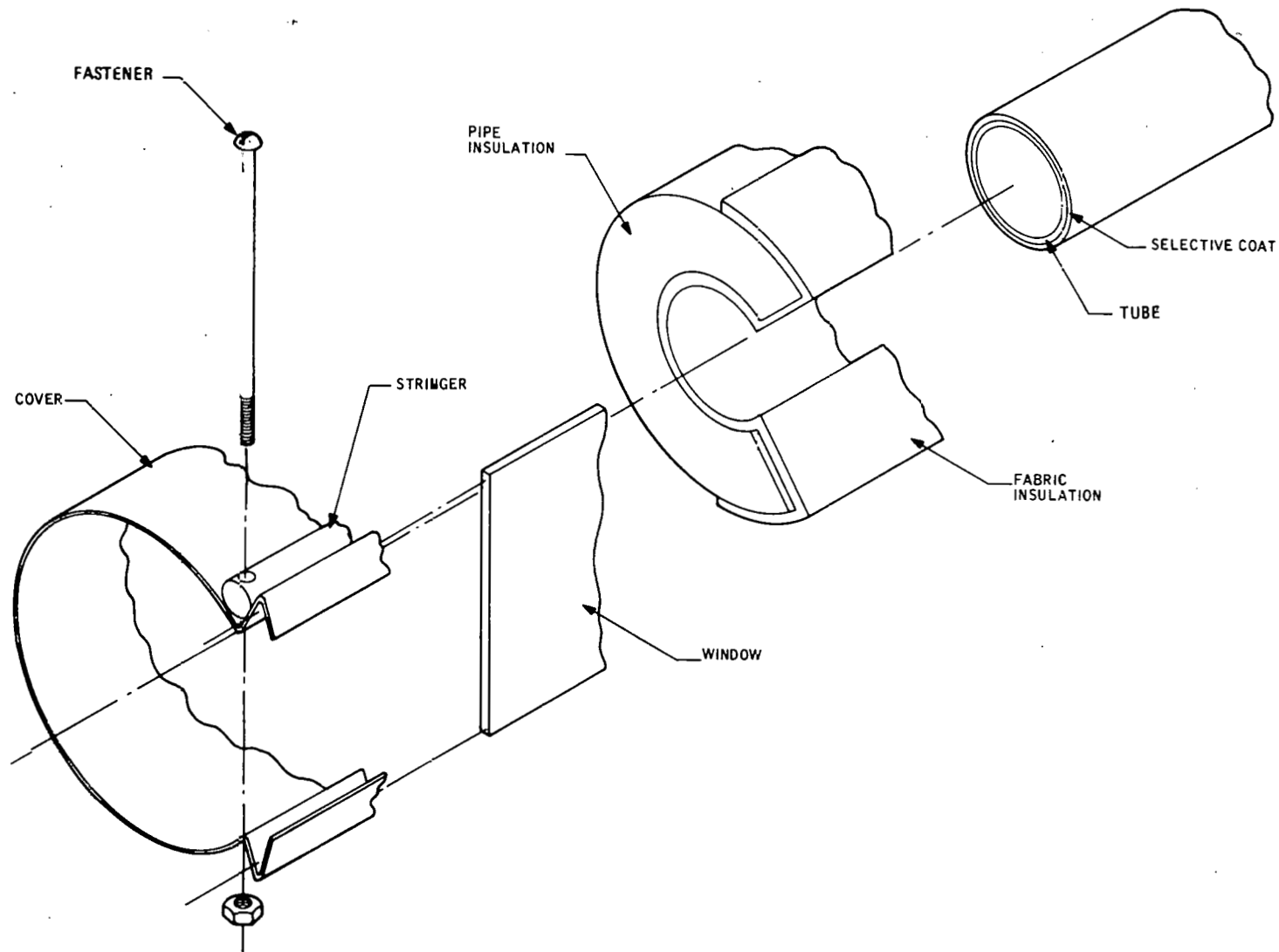


Figure 3-16. ABSORBER ASSEMBLY (EXPLODED VIEW)

### 3.4.7 Unit Controller

3.4.7.1 General -- The Unit Controller is the device which controls each collector. There are 48 unit controllers, one for each collector, and they accept control inputs from either the system controller located in the penthouse or the manual control panel at the unit controller. The unit controller must enable the collector to track the sun's image to within  $\pm 1/4$  degree in wind conditions up to 30 mph; be capable of stowing in two minutes; and provide a self protect function.

The Unit Controller performs the following functions:

- 1) acquire
- 2) track
- 3) stow
- 4) self protect
- 5) respond to local and remote manual mode commands
- 6) respond to remote automatic mode commands
- 7) inform system controller of the unit controller state.

"Acquire" is the act of finding the sun's image and focusing it on the absorber tube within the limits of the solar sensing device. "Track" is the act of maintaining the focused image of the sun on the absorber tube. "Stow" is the act of stowing or condition of being stowed, i.e., being oriented in the "off-duty" position of the collector. The stowed orientation is a protective orientation in which the chord of the parabola is horizontal and the mirror surface points downward. The "self protect" function of the unit controller

ensures that the collector cannot damage itself by rotational over-travel. The unit controller has the capability to respond to remote (from penthouse) and local (at the collector module) manual commands to effect changes in the collector orientation. It is also required that the unit controller transmit the status (stow or not-stow) to the system controller. In addition, the unit controller must inform the system controller if the collector orientation limits have been exceeded.

Figure 3-17 is a conceptual block diagram of the unit controller showing its relation to the system controller and the collector. The unit controller consists of four functional blocks; sensors (sun sensor and position limit switches), manual control panel, controller electronics, and the actuator composed of a motor-gear train combination.

**3.4.7.2 Sensors** -- The sun sensor is a null type of device which provides switch closure information relating to solar image position on two phototransistors mounted on the sensor head. The sun sensor and its electronics are described in detail in Section 3.5.4. The limit switches ("stow" and "max. travel") are positioned such that the collector assembly will activate them at the design limits of desired collector angular excursion. Their activation signals the control electronics to modify its command signals to the actuator according to the mode of operation at that time. The safety limit switches provide the self-protect function. They are mounted at the extremes of safe collector orientation (outboard of the "stow" and "max. travel" limit switches). When these switches are activated, they interrupt the motor armature circuit and prevent collector rotation.

**3.4.7.3 Manual Control** -- The manual control panel allows an operator to command five functions: mode select, automatic/manual; forward rotation; reverse rotation; stow; stow-reset, and manual override of safety limit switch.

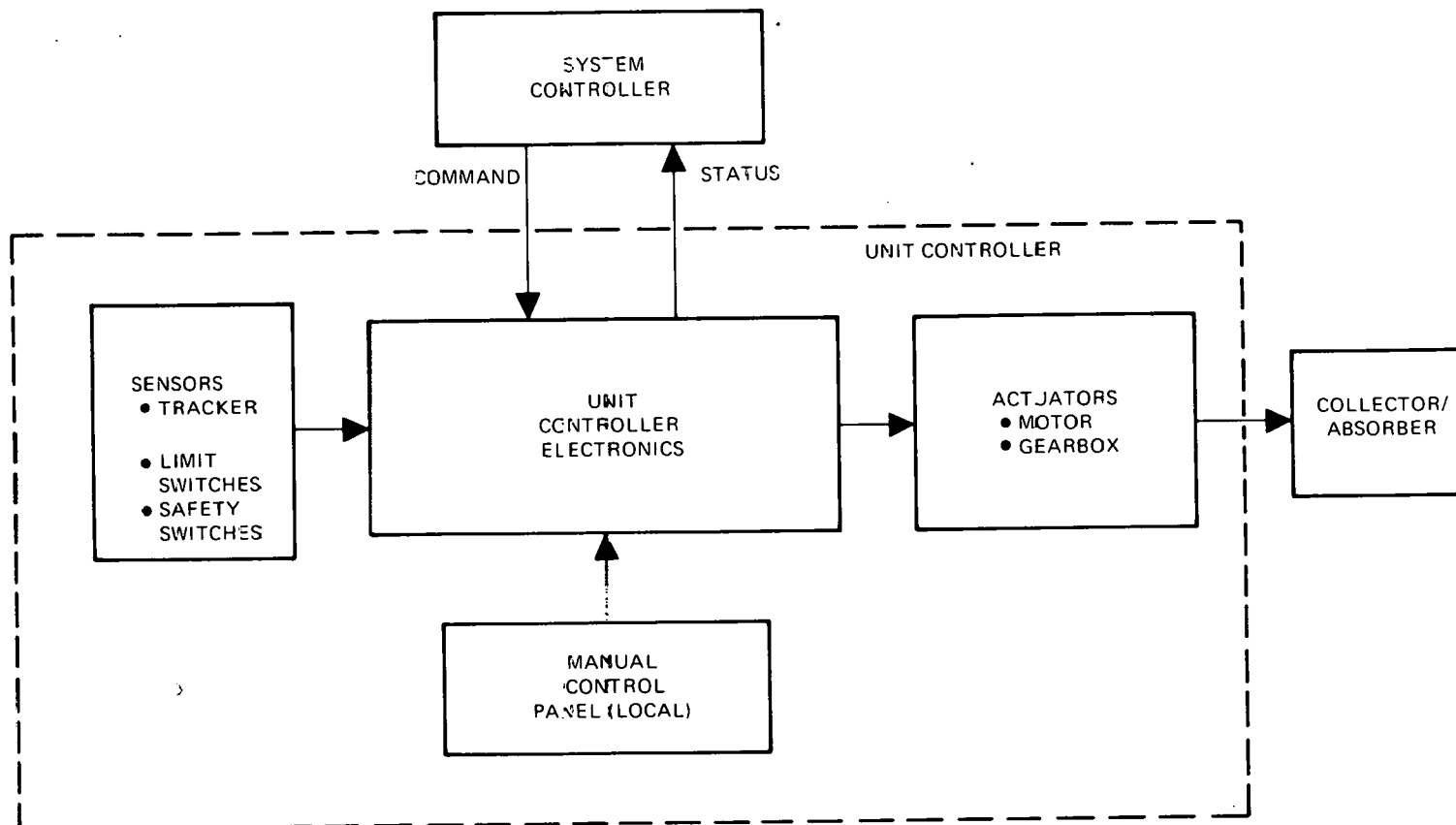


Figure 3-17. UNIT CONTROLLER CONCEPTUAL BLOCK DIAGRAM

Upon selecting manual mode at the unit controller, all commands from the system controller are disabled and the operator has complete control at the local unit controller.

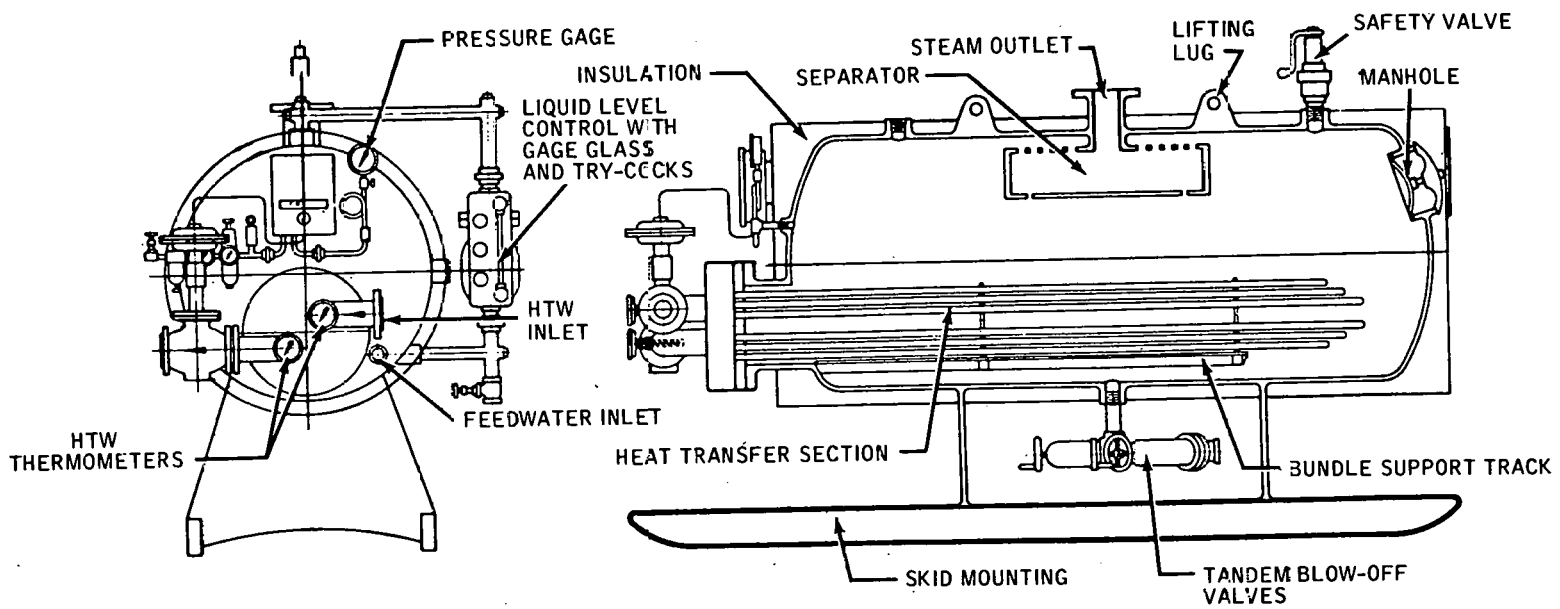
3.4.7.4 Electronics -- The unit controller electronics provide the interface, signal conditioning and mode logic required to make the unit controller function in the automatic and manual modes. These electronics accept local manual commands, remote system controller commands and respond to local limit switch signals.

3.4.7.5 Actuator -- The actuator consists of a 1/2 hp, variable-speed dc motor, associated control electronics, and a 7500:1 gear train. The combination of these elements was selected to satisfy jointly the requirements for tracking accuracy, stow speed capability, and collector wind-induced torque balance requirement.

#### 3.4.8 Steam Generator

A key component of the solar drying system is the steam generator. It acts as the interface between the two flow loops of the system - the HTW loop, and the steam and feedwater loop.

It is standard industry practice to configure a steam generator to fit the application by assembling a set of standard components which best fit the immediate requirements. To meet our requirements a Patterson-Kelley unfired, Model H307 has been selected. It is comprised of components including a standard pressure vessel, liquid level control, fittings, and safety valves. Periodic maintenance is enhanced by the inclusion of a removeable tube bundle. To maximize safety the generator is constructed in accordance with ASME codes. A typical model of this manufacturer is shown in Figure 3-18.



3-56

Figure 3-18. A TYPICAL SERIES 380 UNFIRED STEAM GENERATOR WITH STANDARD CONTROLS

The operating requirements of the steam generator are specified for a nominal operating time point. Because of the necessity for matching the temperature rise across the collectors with the temperature drop across the remaining hardware of the HTW loop, the temperature drop across the steam generator is specified rather than the usual steam flow rate. Therefore the steam generator performance requirements include the following:

steam output:	1000 lbs/hr minimum, 76 psig, 321 <sup>o</sup> F
condensate input:	200 <sup>o</sup> F
HTW input:	48 gpm, 389 <sup>o</sup> F, 218 psig
HTW output:	333 <sup>o</sup> F

The unfired steam generator is inherently safe and relatively simple. No damage is done if the HTW is admitted to the heat transfer section without any feedwater in the shell. This eliminates the need for the presence of a qualified attendant, highly accurate low-water controls, and/or back-up sensors and controls.

Shell side level control is performed with a standard Magnetrol Model W-251 water column control which activates the feedwater pump as the level falls below the low-water set point. Similarly, pump deactivation occurs as the level rises to the high water set point. This control utilizes a magnetic field as the only "link" between a float movement and mercury switch actuation. This combination provides a high degree of safety and reliability since magnetism is immune to pressure fluctuations, high temperatures, and metal fatigue which cause failures in other types of controls.

### 3.5 ADDITIONAL DESIGN DETAILS AND DESIGN CONSIDERATIONS

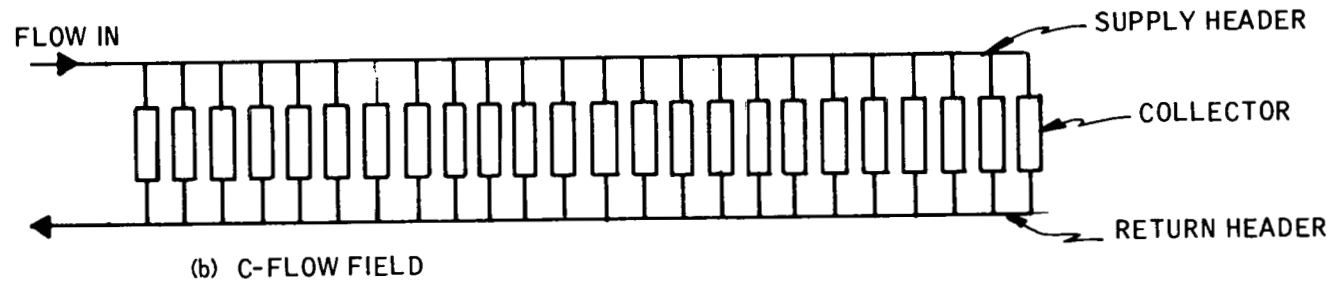
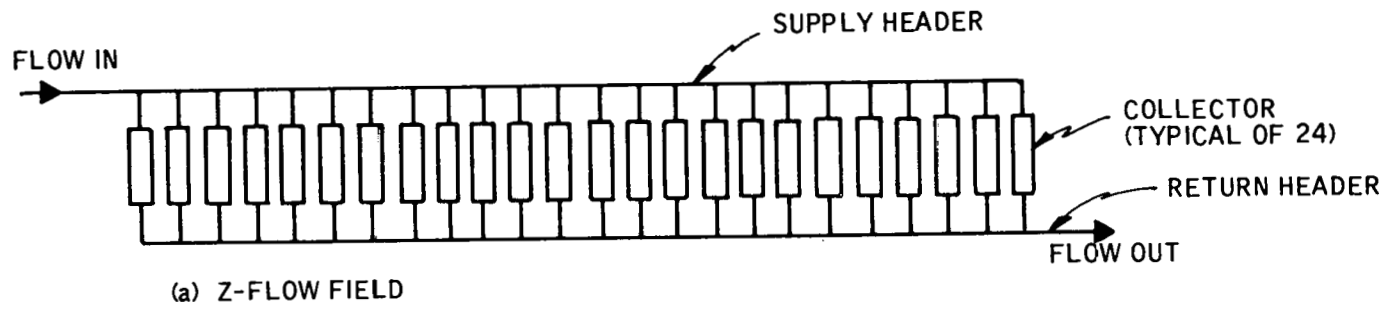
The text of this section includes a discussion of some of the design considerations that led to the final design discussed previously in Section 3.4. The discussion includes design trade-off results and design details to substantiate the final system design. Included are design topics relative to the collector assembly, HTW loop hardware, steam generator, and system controller.

#### 3.5.1 High Temperature Water Loop

This section discusses some of the design considerations and design details of the HTW loop hardware. Included are discussions of the collector field design, pipe assembly techniques, pipe support details, and ball valve characteristics.

3.5.1.1 Loop Design -- Computer simulation studies were conducted to evaluate the performance of several collector field piping loop designs. Two basic designs were investigated. They included the Z-flow networks and C-flow networks as shown in Figure 3-19. The results of the study are briefly discussed in this section.

With a branch flow criterion of + 15 percent maximum flow deviation in the collector branches and no valve control, simulation results showed that the maximum number of parallel branches in the field could be 21 and 16 for the Z and C configurations respectively when the header was 6-inch diameter. Eight inch constant diameter header was required before the flow criterion could be met with 24 parallel branches.



3-59

Figure 3-19. COLLECTOR FIELD NETWORK DESIGNS

Subsequent investigations of configurations with variable header diameter i.e., stepped down by decreasing standard pipe sizes in the direction of decreasing flow and visa versa, indicated that valves were necessary to provide "uniform" flow rates in the field branches.

The computer simulation results also indicated that the low fluid resistance of the collector caused the shorting of most of field inlet flow through the first few collectors of a C-flow field and that a more uniform flow can be obtained with a Z-flow field if the pipe sizes are held constant.

The results of the field design simulation studies indicated that the addition of valves to each collector branch permitted a large reduction in pipe sizes, i.e., from 8-inch to 2-inch diameter, which in turn reduces pipe and insulation costs, structural support requirements, fluid volume, pumping power and heat losses.

Because of improved flow uniformity, a Z-field design was selected for the collector network of the HTW loop. Anticipated flow and pressure distributions, as output computer data for the selected configuration, are shown in Figure 3-20. These data were used in part to size the circulation pump of the HTW loop as well as to establish the branch valve pressure drops required for a uniform flow field.

**3.5.1.2 Piping Design** -- A cost trade-off study was conducted to determine the effects of two designs permitted by the code for the HTW loop. The two configurations include the use of welded, schedule 40 pipe or threaded, schedule 80 pipe. The costs of the two designs differed by less than one percent. Therefore, the design specified is the one preferred by WestPoint

PIPING NETWORK SUMMARY

NO.	PRESSURES (PSI)		COLLECTOR	VELOCITY HEAD (PSI)		COLLECTOR	BRANCH FLOW VARIATION		
	SHDR.	RHDR.		SHDR.	RHDR.		COL.FLW	BC/CAVG	VAR.(PCT)
1	.0000	-.3129	.3129	.03350	.00006	.01154	1.0000	1.000	.000
2	-.0350	-.3130	.2700	.02985	.00022	.01154	1.0000	1.000	.000
3	-.0672	-.3136	.2464	.02731	.00030	.01154	1.0000	1.000	.000
4	-.0965	-.3149	.2183	.02488	.00083	.01154	1.0000	1.000	.000
5	-.1235	-.3170	.1935	.02257	.00138	.01154	1.0000	1.000	.000
6	-.1479	-.3200	.1721	.02037	.00199	.01154	1.0000	1.000	.000
7	-.1699	-.3240	.1542	.01828	.00270	.01154	1.0000	1.000	.000
8	-.1895	-.3293	.1397	.01631	.00353	.01154	1.0000	1.000	.000
9	-.2071	-.3359	.1277	.01444	.00447	.01154	1.0000	1.000	.000
10	-.2227	-.3438	.1182	.01270	.00552	.01154	1.0000	1.000	.000
11	-.2363	-.3534	.1111	.01100	.00667	.01154	1.0000	1.000	.000
12	-.2480	-.3645	.1055	.00954	.00794	.01154	1.0000	1.000	.000
13	-.2581	-.3775	.1013	.00813	.00932	.01154	1.0000	1.000	.000
14	-.2666	-.3923	.0980	.00683	.01081	.01154	1.0000	1.000	.000
15	-.2737	-.4090	.0953	.00564	.01241	.01154	1.0000	1.000	.000
16	-.2794	-.4279	.0935	.00457	.01412	.01154	1.0000	1.000	.000
17	-.2840	-.4489	.0920	.00361	.01594	.01154	1.0000	1.000	.000
18	-.2874	-.4723	.0908	.00276	.01787	.01154	1.0000	1.000	.000
19	-.2900	-.4980	.0900	.00203	.01991	.01154	1.0000	1.000	.000
20	-.2917	-.5262	.0895	.00141	.02207	.01154	1.0000	1.000	.000
21	-.2927	-.5570	.0893	.00090	.02433	.01154	1.0000	1.000	.000
22	-.2933	-.5905	.0892	.00051	.02670	.01154	1.0000	1.000	.000
23	-.2935	-.6268	.0893	.00023	.02918	.01154	1.0000	1.000	.000
24	-.2934	-.6659	.0895	.00006	.03177	.01154	1.0000	1.000	.000

NOMINAL SIZE (IN.)	
SUPPLY HEADER	2.000
RETURN HEADER	2.000
BRANCH	.500
PRESSURE CHANGE (PSI)	
TOTAL	.6659
SUPPLY HEADER	.2934
RETURN HEADER	.3030
Avg. across BRANCH	.1995
CONVERGENCE CRITERIA	
ITERATIONS	1
OLD PRESSURE SUM	9.6506
NEW PRESSURE SUM	4.7049

Figure 3-20. COMPUTER SIMULATION OUTPUT DATA FOR A TYPICAL COLLECTOR FIELD DESIGN

Pepperell which includes welded Scheduled 40 pipe with flanged connections.

3.5.1.3. Piping Supports -- As discussed previously, supply and return piping divides the collector field into two halves. Each half contains 24 parallel collector branches, i. e., each half is one column of 24 rows. Figure 3-21(a) shows the support for the 2-1/2 inch supply pipe and the 2-1/2 inch return pipe which consists of a horizontal 3 x 3 x 1/4 angle iron which spans the two inside "end" posts of adjacent collectors in the same row. Fastened to the angle iron assembly are two standard, adjustable pipe hangers for setting the desired local pipe elevations.

The support used for the 2-inch supply header is also shown in Figure 3-21(b). A cantilever truss of 2 x 2 x 1/4 angle iron is welded to each outside end post. An adjustable, roller type pipe hanger is mounted to the horizontal truss member to allow adjustment of the pitch and expansion of the pipe.

The roller type pipe hangers accommodate the thermal expansion of the pipe over the anticipated range of environmental conditions. To prevent damage to the pipe insulation, saddles are installed at all support locations.

3.5.1.4 Ball Valve Characteristics -- The relationship between the handle position and the flow characteristics of the Imperial Eastman valve will be used for controlling the collector branch flow rates. From the available information it was determined that at the design point, a handle position of 28 degrees (from full open) would generate a 5.0 PSI pressure drop at a 1.0 GPM flow rate. At this operating point the estimated pressure and flow sensitivities to handle position are:

0.032 GPM per degree

0.286 PSID per degree

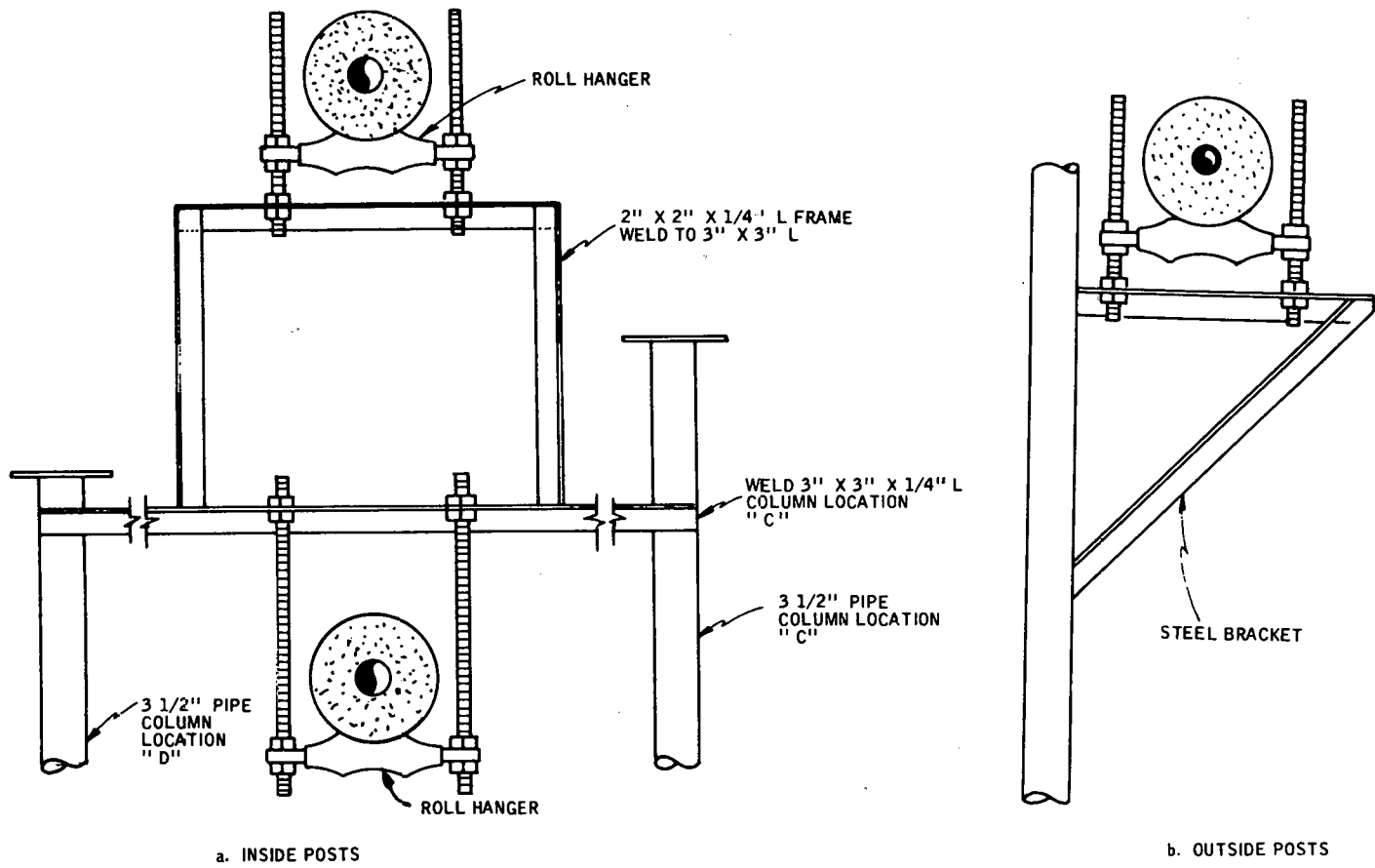


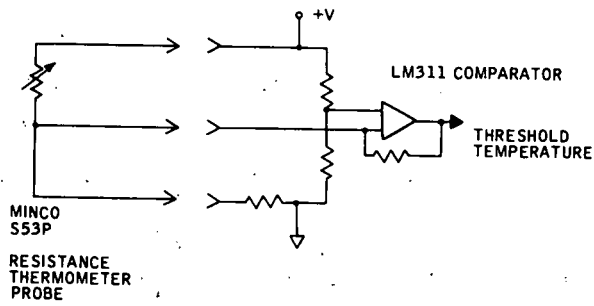
Figure 3-21. Typical Pipe Supports

### 3. 5. 2 System Controller

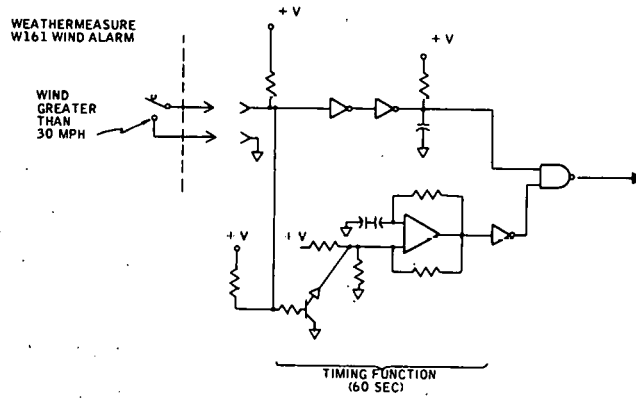
This section discusses details of the System Controller elements: sensors, programmable logic unit, input signal conditioning electronics, output signal conditioning electronics, control panel, and mechanical design. Representative generic circuitry for each of the system controller functions are presented below.

3. 5. 2. 1 Sensors and Input Signal Conditioning -- Figure 3-22(a) is a representation of the temperature signal conditioning electronics. It is typical of the thresholding devices used to generate logic signals informing the system controller if the field temperature exceeds normal operating limits, either too high a temperature or too low a temperature (as in the case of the freeze protection circuits). The temperature sensing device is a Minco Incorporated Model S53P thermometer probe. It is a three lead device and is suitable for use in a Wheatstone bridge configuration. Three leads are used on the probe to cancel the effects of the long lead length necessary when the temperature probes are placed at great distance from the conditioning electronics. The active device in the temperature signal conditioning electronics is a LM311 comparator, a standard integrated circuit.

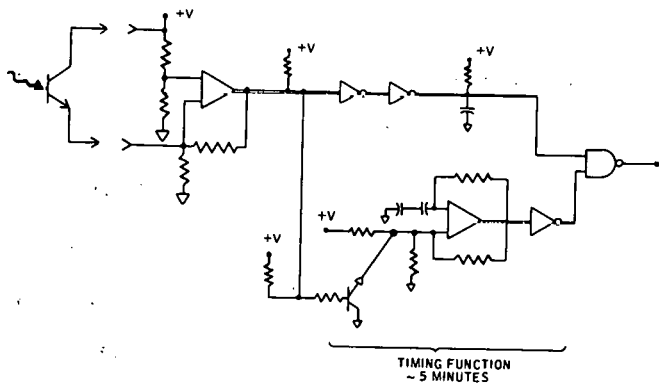
The field freeze protection logic implementation is based on the signals from each of the four freeze protection sensors. They are combined into a logical function by means of a quad-inverting NOR circuit such that if any one of the temperature signals exceeds the freezing threshold, the circuit will generate a signal used by the system controller to take appropriate action. Similarly, a field over-temperature condition is generated by a combination of the temperatures as sensed by the resistance thermometers at the inlet to the steam generator and at the outlet of the steam generator. Should either of these signals exceed their predetermined threshold, a signal will be generated which is interpreted by the system controller as a signal to stow the collector field and await manual intervention.



(a). GENERIC TEMPERATURE SIGNAL CONDITIONING



(b). WIND VELOCITY SIGNAL CONDITIONING



(c). ILLUMINATION SIGNAL CONDITIONING

Figure 3-22. INPUT SIGNAL CONDITIONING ELECTRONICS

Figure 3-22(b) is a generic diagram of the wind velocity measuring instrument. It is a WeatherMeasure W161 Wind Alarm which provides a relay closure if the wind velocities are greater than a preset amount. In this case we have chosen 30 miles an hour. The signal generated by the switch closure provides a ground signal at the input to the signal conditioning electronics. A timing circuit, composed of an operational amplifier and an RC network, generates a timing pulse of approximately 60 seconds duration. The ground signal is combined logically with the delayed signal and an output is generated if the wind velocity is greater than 30 mph for longer than 60 seconds. This signal informs the system controller to stow the collector field.

Figure 3-22(c) is a schematic representation of the illumination signal conditioning electronics. A phototransistor is used as the sensing element and is placed in one leg of a Wheatstone bridge. The LM311 operational amplifier is used to sense when the illumination is above a preset level. The comparator output is fed into the same kind of timing function electronics as used in the wind velocity signal conditioning. When the absence of illumination above the preset level persists for greater than 5 minutes the signal is sent to the system controller and the field is commanded to stow.

The field loop pressure sensor is a Robinson-Halpern Pressure Transducer which is comprised of a linear variable differential transformer whose outputs are then conditioned using similar thresholding techniques as have been discussed in the temperature sensing electronics. The field flow sensor is a pressure switch which is activated when the field pump is in operation. This switch provides a ground signal to the conditioning electronics and it is also debounced and fed to the programmable logic unit in the system controller. The field status sensors are the safety limit switches and the maximum travel and stow limit switches. These signals are also debounced and fed to the programmable logic unit.

3.5.2.2 Programmable Logic Unit -- This device provides the control algorithm for the four-quadrant collector field. To accomplish this, inputs are required from the sensors and the manual control panel. Output signals from the logic unit are converted into actuator commands by the output signal conditioning electronics.

A set of state diagrams have been constructed for the required modes of operation and are illustrated in Figures 3-23, 3-24, and 3-25. The modes for automatic operation and emergency power operation are illustrated in Figure 3-23. Each circle in the figure represents one state of the controller. The alphanumeric symbols in the upper half of the circle identify the state, and any outputs that are required are identified in the lower half of the circle. Directed line segments emanating from the state circles indicate transitions to other states or to the same state depending upon the values of input parameters which are sampled prior to making the state transition decision.

When power is first applied to the controller, operation starts in state AA but proceeds immediately to state A assuming that operation is not under emergency power. If the manual/automatic mode switch is in the automatic position the controller sequences the system into operation under the automatic mode. Condition C1 is tested first to see if wind and illumination values are both within range, and if they are, state C is entered starting the field pump. Field pump operation, field pressure and field temperature are checked as part of condition C2 and when they are all at the proper values, state F is entered. A GO signal is sent to the first quadrant initiating automatic operation in this quadrant of the field and the timing counter is reset to start timing for initiation of the second quadrant. The controller goes to State G and remains there until five seconds have elapsed at which time it proceeds to State H and initiates automatic operation of the second quadrant.

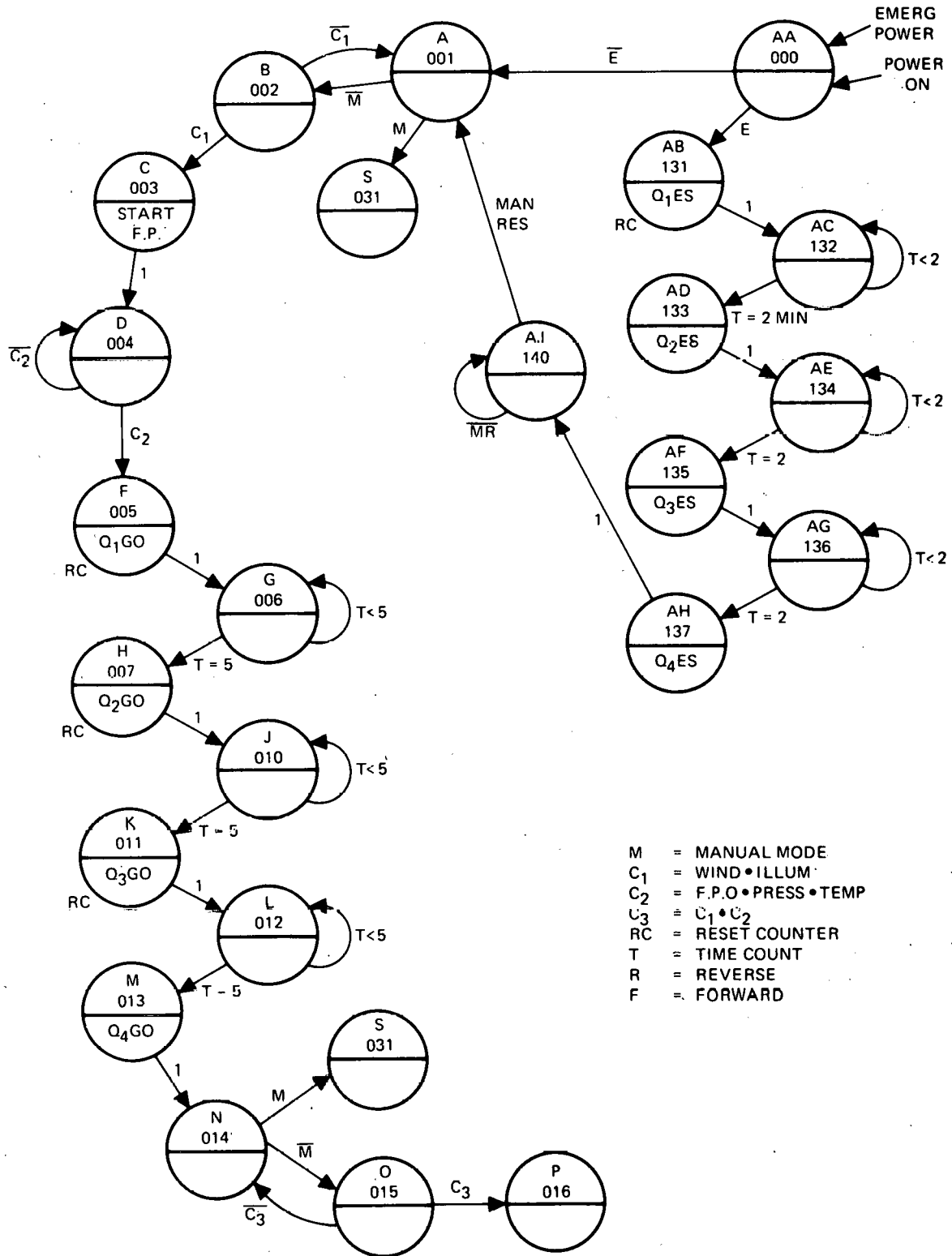


Figure 3-23. STATE DIAGRAM - AUTOMATIC AND EMERGENCY POWER MODES

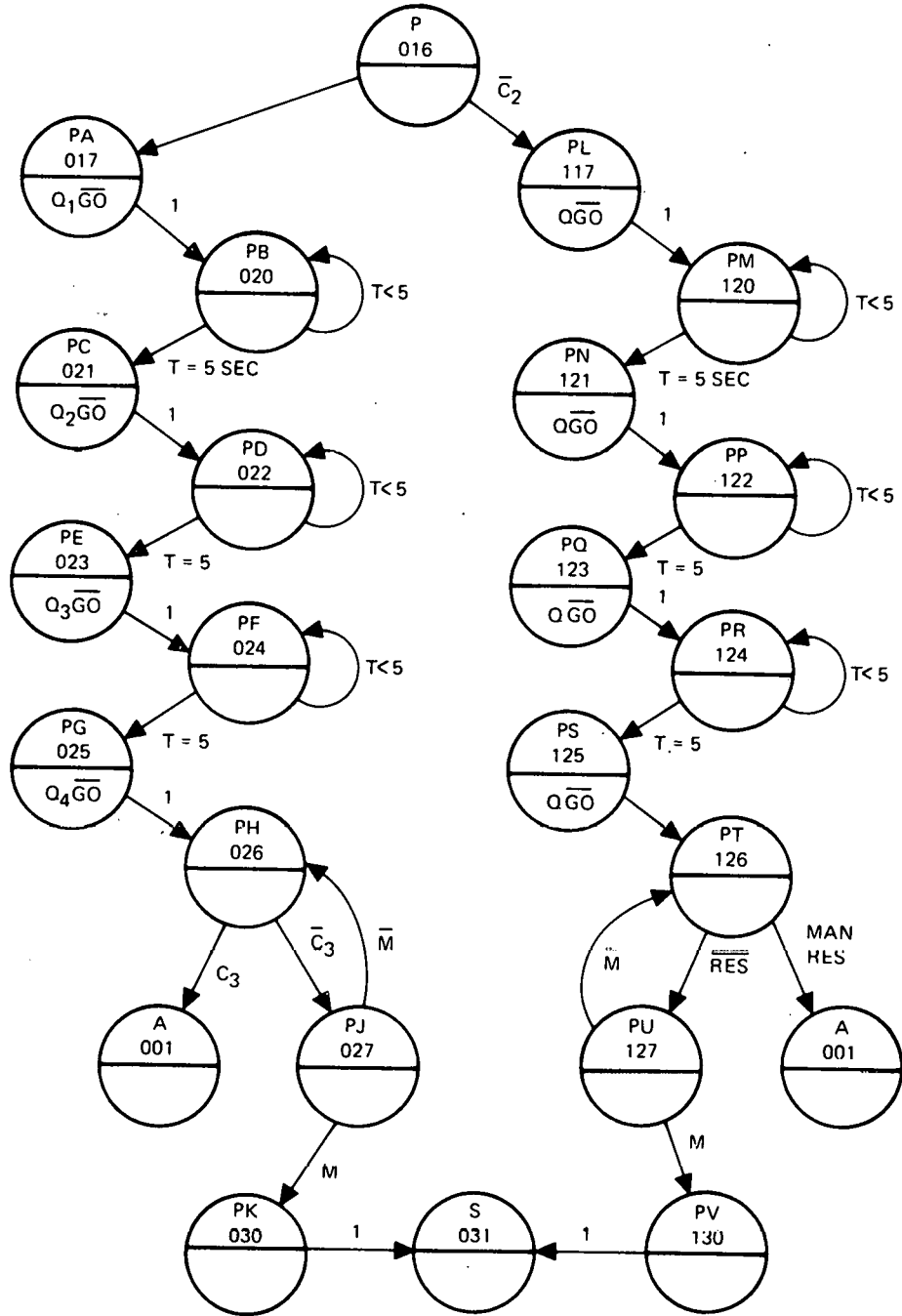


Figure 3-24. STATE DIAGRAM - STOW MODE

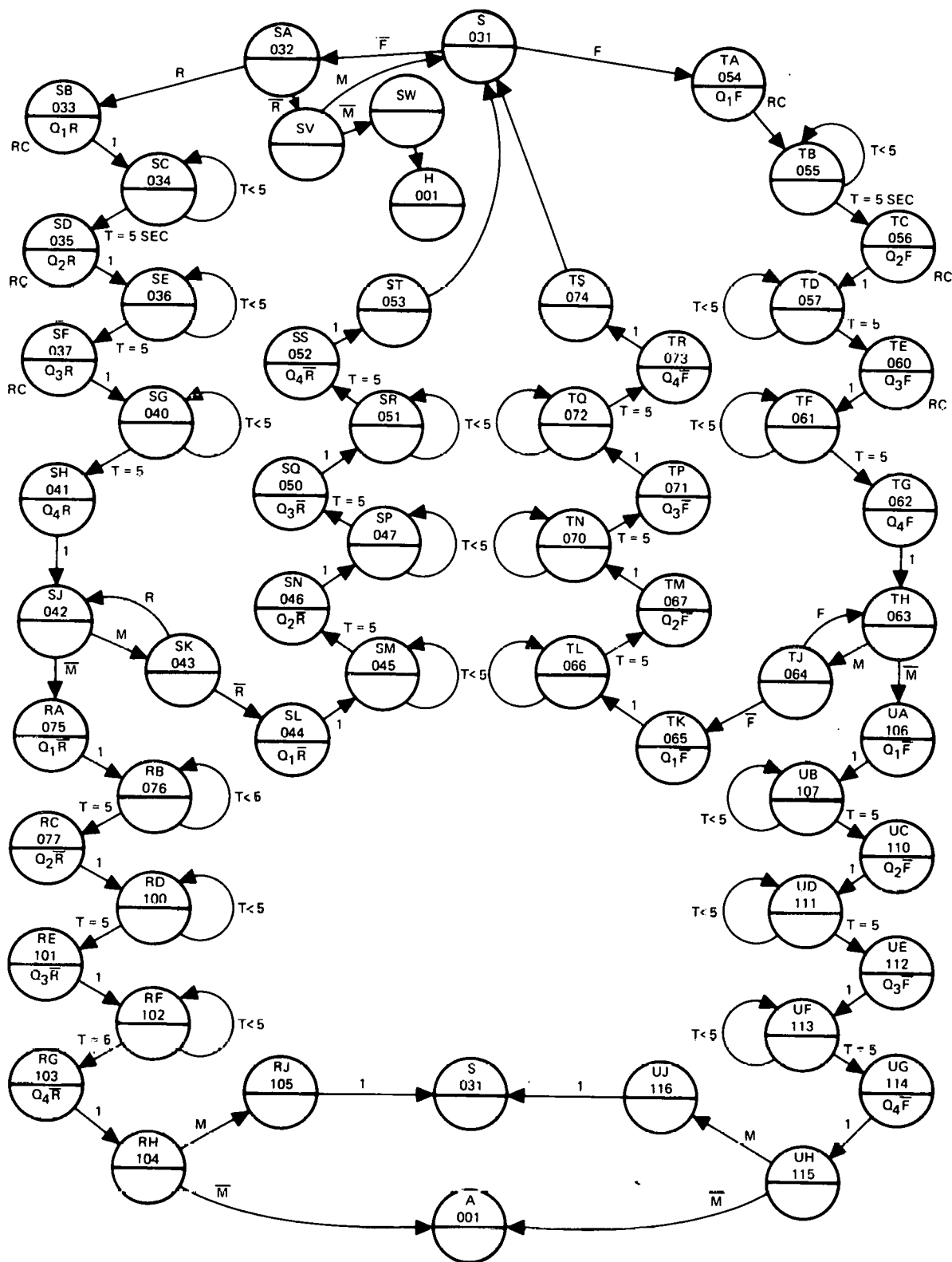


Figure 3-25. STATE DIAGRAM MANUAL MODES

This procedure continues until, at State M, automatic mode operation has been initiated in all four quadrants. The controller then proceeds to the state group consisting of states N, O, P and S constantly monitoring the manual/automatic mode switch and Condition C3. Condition C3 is the logical "and" of conditions C1 and C2 and as long as it remains true and the manual/automatic mode switch is in the automatic position the controller sequences between states N and O but goes to state S if manual mode is selected or to state P if condition C3 is not satisfied.

Emergency power cycling is also illustrated in Figure 3-23. Switch-over to emergency power is essentially an interrupt to the controller and causes an immediate transition to state AA. In State AB an emergency stow signal is sent to the first quadrant. The timing counter is reset and after a two minute wait in state AC the controller advances to state AD at which time the emergency stow signal is sent to the second quadrant. This procedure continues until all four quadrants have received emergency stow signal at which time the controller waits in state AJ for a manual reset before normal operation can continue.

The state diagram for stow mode operation is illustrated in Figure 3-24. Two paths are shown; each of them resulting in transmission of the GO (not go) signal to the four quadrants in sequence separated by five seconds each. The path on the left is entered if out-of-range wind or illumination values are the cause of the stow command. Upon resumption of in-range wind and illumination values the automatic mode is reentered and normal operation resumes. The right hand path is entered if the stow command is the result of improper field pump operation or out-of-range field pressure or temperature. In this case a manual reset is required before normal automatic operation can commence.

Manual mode operation is illustrated in Figure 3-25. Starting in state S at the top of the figure the forward/reverse switch is checked and the extreme left or right hand paths are selected if either forward or reverse manual operation has been selected by the operator. The forward/reverse switch has a center off position. When it is in this position the controller sequences through states S, SA, and SV, continuously checking for any change in the switch position. At all times except when an actual sequencing of the quadrant signals is taking place the manual mode selector switch is monitored and appropriate actions are taken. If reverse manual movement of the collector has been selected, the sequence of states on the upper left of Figure 3-25 causes a reverse command signal to be sequentially transmitted to the four quadrants. When it is desired to stop reverse movement of the collectors, the switch is moved to the center off position and the reverse command signals are removed from the four quadrants in the same order in which they were transmitted, by the sequence of states immediately to the right of those previously mentioned. A similar sequence for forward movement of the collectors is illustrated at the upper right part of Figure 3-25. If forward or reverse command signals have been sent to the 4 quadrants and the manual/automatic switch is moved to the automatic position, the forward or reverse signals must be sequentially removed in the same manner as if the forward/reverse switch had been moved to the center off position. The sequence of states for accomplishing this are illustrated at the bottom of Figure 3-25.

Control functions such as those required in this application have traditionally been implemented with hardwired, fixed-design, sequential circuits implemented with flip flops and gates. For this application, a controller designed in this manner would require a large amount of logic due to the number of states that are required, the number of input parameters that must be checked, and the number of latched output signals required. Fixed design controllers of this type also require a relatively large amount of design time, are difficult to debug and are extremely difficult to modify if changes to the controller algorithm are required.

In contrast, current MSI and LSI technology have made possible the design of simple programmable controllers which are easy to design and debug and extremely easy to modify to accommodate control program changes. Two types are currently in use. The first utilizes standard MSI and LSI devices to implement a microprogrammable controller sized and structured to fit the intended application. The second uses microcomputers to implement control functions of this type although they often contain additional capability which is not needed.

Based on these considerations, a custom microprogrammable controller utilizing currently available MSI and LSI devices has been designed to perform the control functions illustrated in the state diagrams of Figures 3-23, 3-24, and 3-25. It has built-in memory and address capabilities to handle approximately two times the number of states presently anticipated, to sample and test five additional input parameters, and to output five additional latched logic signals.

A 16-bit instruction word is stored in two programmable read only memory (PROM) arrays which are addressed by a pair of 54LS163 binary counters. Each instruction word provides bits for selecting an input parameter to be tested and for providing instructions to the address counter for sequencing the control program. In addition, the timing counter can be reset and an 8-bit field is available for use either as a jump address or an output address depending on which of these two functions is enabled. The instruction word format is illustrated in Figure 3-26. A description of the controller follows.

Two 54LS251 multiplexers are used to select one of up to 16 input parameters to be tested by the program control logic in order to select between an increment or hold operation or a jump and increment operation. This provides considerable flexibility for controlling the sequencing of the microprogram. A four stage timing counter provides for timing intervals of up to 17 seconds. Decoded outputs of this counter can be tested via the input multiplexers and used to modify the sequencing of the microprogram. A set of three 8-bit output latches is available for holding output parameters and permitting them to be selectively set or reset by the microprogram. The only restriction is that an output parameter cannot be modified during a jump instruction.

Programming is very straightforward due to the single instruction format and relatively small number of variations in the use of each of the instruction fields. The format is illustrated in Figure 3-26 along with several lines of program code to illustrate its utilization. Bit 0 is the count/load select bit. A logic 0 causes the program counter to increment if the selected condition is satisfied or to hold the present count if it is not satisfied. A logic 1 causes the program to jump to the address specified by bits 8 through 15 if the condition is satisfied or to increment the counter if the condition is not satisfied. Bits 1 through 4 select the input condition to be tested. If these bits are all 0's, the output of the multiplexer is a logic 1 and the

Figure 3-26. MICROINSTRUCTION FORMAT

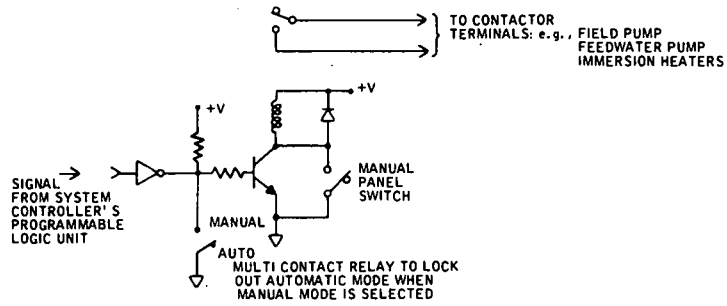
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	CT/ LD	MUX ADDR. (CONDIT. CODE)				COMPLEMENT MUX OUTP.	RESET CTR.	JUMP/OUTPUT	JUMP/OUTPUT ADDRESS								
PROM ADDRESS (OCTAL)	MICROINSTRUCTION CODE															COMMENT	
000	1	0	1	1	1	1	0	0	0	1	0	1	1	0	0	1	TEST E
001	1	0	1	0	0	1	0	0	0	0	0	1	1	0	0	1	TEST M
002	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	TEST C <sub>1</sub>
003	0	0	0	0	0	1	0	1	1	X	X	0	1	0	0	0	START FIELD PUMP
004	0	0	0	1	0	1	0	0	X	X	X	X	X	X	X	X	TEST C <sub>2</sub>
005	0	0	0	0	0	1	1	1	1	X	X	0	0	0	0	0	SET Q <sub>1</sub> GO = 1
006	0	1	0	0	1	1	0	0	X	X	X	X	X	X	X	X	WAIT 5 SEC.

X = DON'T CARE

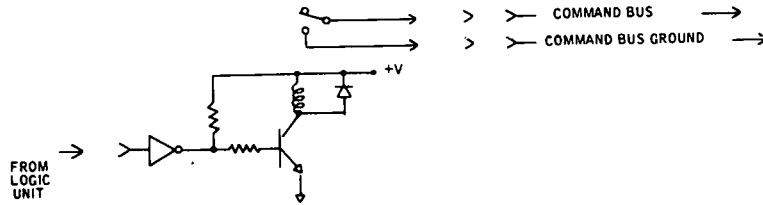
program increment or jump will occur unconditionally. The remaining codes permit the selection of one of 15 input conditions to be tested. Bit 5 in the instruction word is used to complement the output of the condition multiplexer and thereby implement a program change based on a 0 state rather than a 1 state out of the multiplexer. A 1 in bit 6 causes the timing counter to be cleared such that a new timing sequence can begin. Bit 7 is used to define the function of bits 8 through 15. A logic 1 implies that these bits will be used to set or reset an output latch based on data contained in bit 8 and an address contained in bits 11 through 15. A logic 0 in bit 8 and an address contained in bits 11 through 15. A logic 0 in bit 7 signifies that bits 8 through 15 contain a jump address to be loaded into the program counter if the input conditions are satisfied.

3.5.2.3 Output Signal Conditioning Electronics -- The purpose of the output signal conditioning electronics is to amplify the control commands from the programmable logic unit. The logic unit itself cannot provide the switching capability needed to actuate the devices (i.e., contactors, etc.) which control the field motors, unit controllers, pumps, etc.

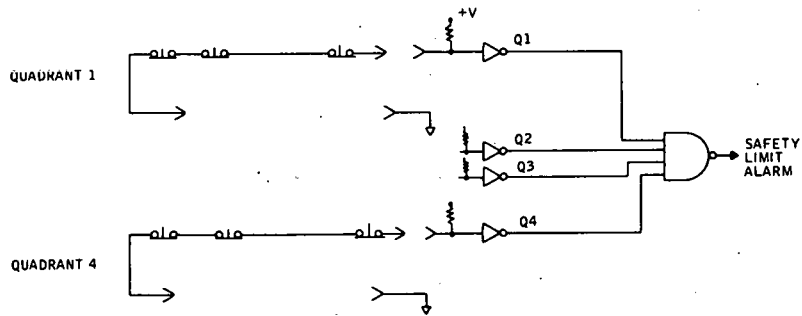
Figure 3-27(a) shows a typical arrangement for the output signal conditioning for the field pump, the feedwater pump, and immersion heater command signals. The circuit consists of an analog transistor switch in parallel with the manual control switch on the panel of the system controller. The analog switch is driven from the system controller's programmable logic unit through an inverter which will switch the transistor on and off. A multicontact relay is used to lock out the automatic mode when the manual mode is selected; this is done by grounding the base of the transistor analog switch. When the switch is activated, the relay is pulled in and the relay contacts then provide signal closure to a contactor which enables the pumps or the immersion heaters. Figure 3-27(b) describes the output signal conditioning switches for the sequenced field signals typical of the command bus.



(a). OUTPUT SIGNAL CONDITIONING FOR FIELD, FEEDWATER PUMPS AND IMMERSION HEATERS



(b). OUTPUT SIGNAL CONDITIONING FOR SEQUENCED SIGNALS



EACH QUADRANT'S SAFETY LIMIT SWITCHES ARE CONNECTED IN SERIES AND SUPPLY A GROUND TO AN INVERTER. IF ANY COLLECTOR IN ANY QUADRANT VIOLATES THE SAFETY LIMIT, THE ALARM IS GENERATED VIA THE "NAND" GATE.

(c). DETAIL OF SAFETY LIMIT VIOLATION ALARM

Figure 3-27. OUTPUT SIGNAL CONDITIONING ELECTRONICS

The programmable logic unit output is inverted into a transistor switch which pulls in a relay to switch the appropriate command bus to the command bus ground. Collector parity logic is used to indicate to the system controller that all collectors in the field are not in the same state. This is done using LSI logic which accepts inputs from the limit switches from the field collectors. Figure 3-27(c) is a detail of the safety limit violation alarm and it is implemented on a quadrant-by-quadrant basis by the series connection of the safety limit switches of all of the collectors in each quadrant. This circuit, when complete, locks out the safety alarm. Should any of the safety limit switches be interrupted due to collector overtravel the safety alarm is set through the four input "NAND" gates.

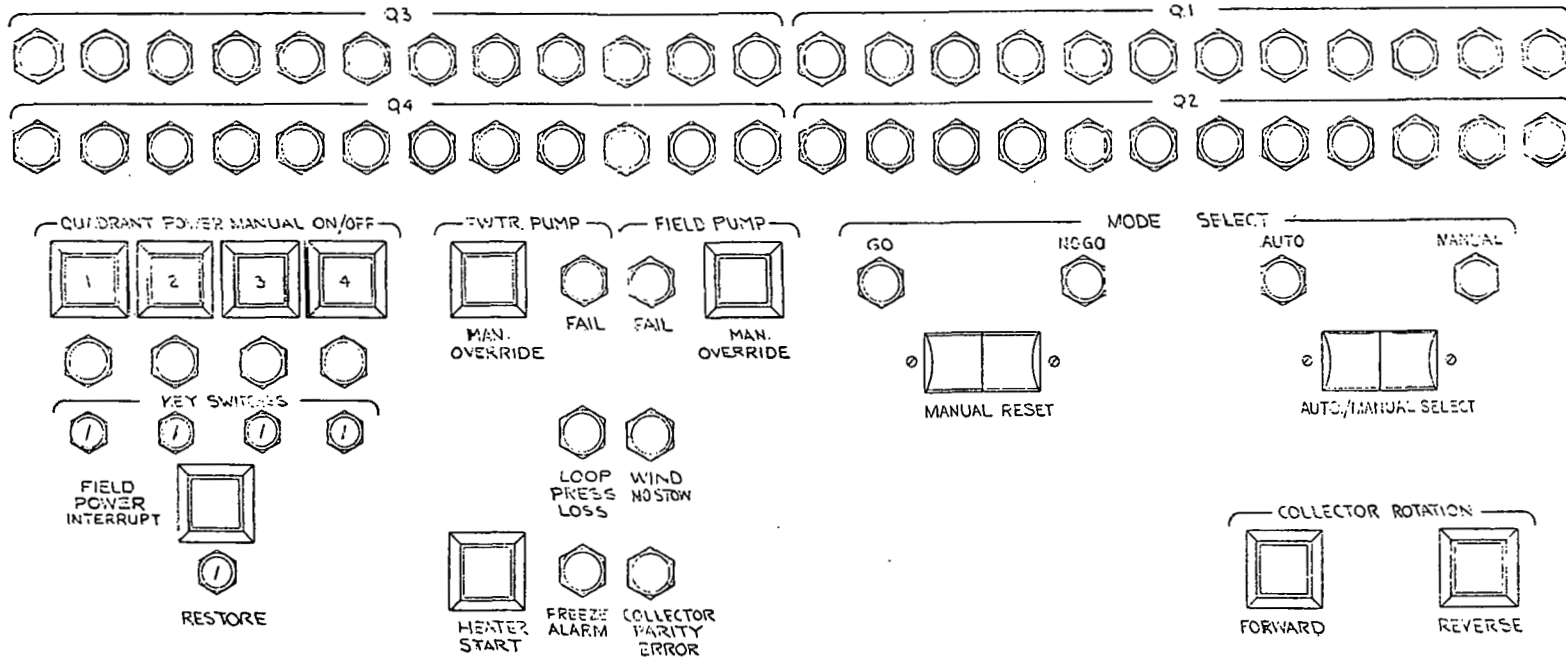
3.5.2.4 System Controller Manual Control Panel -- The manual control panel has a number of status indicators and manual control switches which are used to control the field and display field status information to the operator. An array of 48 lights displays to the operator which of the 48 modules are in the stowed or unstowed status. There are two lights which indicate failure of the feedwater pump and the field pump. Beside each of these status indicating lights is a manual override switch which allows the operator to command the feedwater pump or the field pump to begin operation. There is a freeze indicator lamp which informs the operator that the temperature in the field is approaching 32<sup>o</sup>F. Near this freeze indicator is a manual pushbutton which allows the operator to start the immersion heaters to prevent the field from freezing. There are also indicator lamps which tell the operator that the field loop pressure has been lost, that there is a condition of high winds with the field unstowed and a status indication that not all of the collectors are in the same state (which would usually indicate some type of unit controller malfunction). The mode switch allows the operator to select the automatic mode or the manual mode. In the manual mode the operator may select collector rotations by means of two

pushbuttons near the automatic/manual mode switch. These pushbuttons then allow the operator to command the entire field of collectors to rotate either in the forward or in the reverse direction. If neither forward nor reverse is selected the collectors remain stationary. There are series of four toggle type pushbuttons and four key lock switches whereby the operator may disable any or all quadrants' power by these switches. In the event that maintenance is required on a given quadrant, the operator may remove power to that quadrant by means of the appropriate key switch and therefore insure him that power will be disabled while he is in that quadrant performing maintenance or inspection. There is an emergency power disable switch (or panic button) which allows the operator to remove all power to the field in a single stroke. Once this has been done, it is required that the operator use a key to return power to the field. Certain conditions exist under which the field must be manually reset in order to restore power to the field. Those conditions are 1) if the feedwater pump fails, 2) if the loop pressure becomes excessive, or 3) if temperature conditions in the field violate certain extremes as were discussed in the previous sections of this report.

3.5.2.5 System Controller Mechanical Design -- The system control panel is fabricated from a standard 19" wide panel and will be mounted over a standard electrical enclosure hung on the wall in the penthouse.

The system controller electronics cards will be mounted on standoffs to the back of the system controller panel to aid in maintenance, checkout and operation. The system controller electronics will consist of four electronics cards; two cards will contain the relay and relay drivers and the other two cards will contain integrated circuits and the input signal conditioning electronics. Signal and power cabling will enter through the bottom of the standard breaker box and be distributed to the various cards by means of pin connectors. Figure 3-28 describes the system controller Manual Control Panel.

SYSTEM CONTROL PANEL  
HONEYWELL IIIIC.



3-80

Figure 3-28. Manual Control Panel

### 3.5.3 Collector

The solar collector assembly is a key component in the solar drying system. The design was formulated under a Honeywell funded development program. For completeness, this section discusses the more important collector design considerations. They include a discussion of the design wind requirements, pivot location and stow position. Also included are the critical design loads and absorber tube design details.

3.5.3.1 Wind Conditions -- Design loads for the solar collector assembly were established at a 30 MPH wind condition for the operational mode and at a 100 MPH wind condition for the nonoperational mode. The latter condition was established based upon the data of "Wind Gust Statistics for Structure Designs", a Sandia Lab memo by J.W. Reed dated January 21, 1975. The data contained in this document suggest that the probability of a wind condition exceeding 100 MPH in a 20 year return interval is approximately  $10^{-7}$ . Recorded winds have never exceeded 55 mph in the Columbus, Georgia area and recorded wind gusts have never exceeded 70 knots. The 30 MPH wind condition was selected considering the wind characteristics as described in Marks' Mechanical Engineering Design Handbook. According to this reference a 30 MPH wind, labeled "strong" by weather bureaus, is accompanied by the motion of large tree branches. A 32 MPH wind is also "strong" but is accompanied by the motion of whole trees. A 39 MPH wind is classified as a "gale" and is accompanied by broken tree twigs. The collector would be stowed for winds above 30 MPH to protect its components, especially the reflective surface and the absorber, from flying objects.

3.5.3.2 Collector Pivot Location -- Design studies were conducted to investigate the trade-offs of alternate collector pivot locations. These included the configuration with the pivot at one end of the reflector honeycomb, an absorber-pivot configuration, and configurations with the pivot positioned at different locations along the back side of the reflector honeycomb. The analysis included the inertial loads and the free stream air loads which act on the collector assembly. In addition, angle-of-attack effects on the aerodynamic forces and moments were considered as well as the effect of resultant wind direction and collector orientation.

The results indicated that the key design parameter was the hinge-line torque and that substantial reductions in its magnitude could be obtained by locating the collector pivot at or near the mid-chord position of the reflector. Therefore, the torque-tube assembly was located midway between the ends and on back side of the curved reflector.

3.5.3.3 Collector Stow Position -- The collector is stowed at night and when wind speed exceeds 30 MPH. In the stow position, the chord line across the ends of the honeycomb is horizontal. This orientation presents a low profile and reduces the wind loads on the collector assembly and on the support structure. This orientation also protects the reflective surface from night time condensation and from adverse atmospheric conditions including rain and hail. It is noted that because of the non-symmetric airfoil shaped nature of the collector profile, the stow position is not one of zero aerodynamic lift. Further force and torque reduction could in theory be obtained by stowing at the zero-lift position, however, this is only true for the condition when the wind direction stays at a constant azimuth.

3.5.3.4 Collector Design Loads -- The estimated design loads for the 40-foot collector assembly of the design discussed in this report are summarized in Table 3-4. They include the aerodynamic loads resulting from 30 MPH and 100 MPH design wind conditions and weight of the collector assembly hardware. The sign convention for these loads is shown in Figure 3-29.

TABLE 3-4. COLLECTOR DESIGN LOADS

Load	Unit	End Post <sup>(1)</sup>		Center Post	
		30 MPH	100 MPH	30 MPH	100 MPH
Lift	lb	126	470	252	939
Drag	lb	130	44	260	87
Weight	lb	56	56	383	383
Torque <sup>(2)</sup>	ft-lb	0		806	2486

(1) typical of two

(2) torque is about pivot axis

Using the support structure design described in Section 3.4.2.2, at the collector support/roof interface, these loads result in a 1120 lbs. upward load at the center post when operating in a 30 MPH wind, and a 560 lbs. downward load when stowed in a 100 MPH wind. Accompanying shear values within the structure and moments around the welded joints are well within the structure design limits.

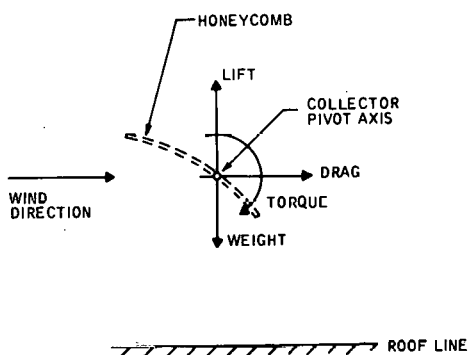


Figure 3-29. SIGN CONVENTION FOR COLLECTOR DESIGN LOADS

3.5.3.5 Absorber Tubing -- Copper tubing is one of the piping materials permitted by the pressure piping code (ASAB 31.1). It can be used up to temperatures of 406<sup>o</sup>F and the corresponding saturation pressure of 250 psig. Based upon the hoop stress design equation of the seamless copper tube specification limit (ASTM SB-75), fluid pressures for various standard wall thickness were established as follows:

Standard Wall Thickness (inches)	Limit Pressure	
	(PSIG)	(PSIA)
.040	149	164
.049	183	198
.065	246	261

These limits were established using the relation:

$$P = 2St / (O.D. - 0.8 t)$$

where

P = pressure (psig)

S = allowable hoop stress  
(2500 psi at  $T \leq 400^{\circ}F$ )

t = wall thickness (inches)

O.D. = outside tube diameter (inches)

Based on these data a 0.065 inch wall was selected for this application.

3.5.3.6 Motor/Gear Drive -- This section presents the considerations which led to the selection of the motor gearbox and motor controller for the collector modules to be used in the WestPoint Pepperell concentrating collector field. The selection of these three items is based on three main constraints, 1) the collector must stow in three minutes from any position; 2) the motor and gear train must be capable of driving the collector against a wind load torque of 806 ft. lbs.; and 3) the motor/gearbox and controller

configuration should maintain a quarter of a degree tracking accuracy. Along with these criteria are certain economic considerations and mechanical limitations.

To stow in three minutes the collector stow speed must be 1/4 rpm or higher. Tracking speed was selected to be 25% of the full speed capability of the motor. Thus, track speed is 1/16 rpm and specifying an 1800 rpm motor, the motor speed during tracking is 450 rpm or 7.5 revolutions per second.

A bang-bang or on-off controller is the most simple and economical type to be used. Popular reversible and variable speed motors are typically of the permanent magnet variety or the shunt wound variety requiring dc power. An important consideration in these types of motors, especially when used in a reversing scenario, is that the armature current be allowed to extinguish in one direction before reverse polarity voltage is applied to the armature. Typically, it takes about 500 milliseconds for this to occur. Computing the amount of armature rotation which is possible under the constraint of the 500 millisecond armature extinction, the equation is:

$$\begin{aligned}\Delta\theta_{\min} &= 0.5 \text{ sec} \times 7.5 \text{ rev/sec} \times 360^\circ/\text{rev} \\ \Delta\theta_{\min} &= 1350^\circ\end{aligned}$$

Therefore the required gear ratio =  $1350^\circ$  input divided by  $0.25^\circ$  output = 5400.

Thus we can see that at least a 5400:1 gear reduction is necessary if the required tracking accuracy is to be obtained.

Considering the horsepower requirements for the motor, it is required that the motor be able to stow the collector in 3 minutes. This is to allow for stowing of collectors under adverse weather conditions. The collector

has a total possible angular rotation of  $270^{\circ}$ . The 3 minutes and  $270^{\circ}$  constraint yields  $1/4$  of an rpm as the required stow speed. A further requirement is that the motor be able to stow the collector in the 30 mph wind. It has been shown by aerodynamic considerations that the maximum torque which the motor must overcome with the collector in a 30 mph wind is 806 ft. lbs. Therefore there is approximately 0.057 horsepower required at the output shaft of the gear reducer in order to stow the collector in the 30 mph wind. This output shaft horsepower may be converted to input shaft horsepower by consideration of the efficiency of the gear reducer; this efficiency is between 12-20% depending upon the gear reduction chosen. Figure 3-30 shows the efficiency of gearboxes with several gear reductions. The basis for this graph is manufacturers data on gearboxes in which input horsepower is given for a specified input shaft speed and output torque speed are also given. From the graph, it can be seen that in the range of gear reductions from about 5000-7500:1, the efficiency is approximately 13-16 percent. Combining this efficiency with our required output shaft horsepower of 0.057 horsepower we see that the required input horsepower is on the order of 0.44 horsepower for the 7500:1 reduction. It is on this basis that the  $1/2$  horsepower motor was selected for this application.

Another important consideration in the selection of the gearbox is the required output shaft size to sustain the design torque loads of 800 ft. lbs. of torque under a 30 mph wind condition. Under the assumption that the gearbox output shaft is of solid steel construction, the required output shaft diameter needed to accommodate the 800 ft. lbs. torsional load without failure of the shaft has been calculated. This calculation is shown in Table 3-5.

Therefore, to sustain a pure torsional load of 800 ft. lbs., the required diameter of the output shaft is about  $1-3/4$ ". If the ultimate shear stress of steel (12000 psi) is substituted for the 9000 psi and the calculations are repeated for the 30 mph wind requirement, a shaft diameter of 0.92 inches

Table 3-5. Sample Calculation

Sample Calculation

Compute shaft diameter needed to sustain 800 ft-lb torsional load.

Variable:  $S_s$ : shearing stress, psi  
 $T$ : applied torque, in-lb = 800 x 12  
 $D$ : shaft diameter, in.  
 $C$ : shaft radius, in. =  $D/2$   
 $J$ : shaft sectional moment of inertia (in)<sup>4</sup>

$$S_s = \frac{T \cdot C}{J}$$

For a solid shaft  $J = (\pi/32) D^4$

$(S_s)_{\max}$  for steel is between 9000 psi - 12000 psi. Using  $S_s = 9000$  psi we find

$$9000 = \frac{(800 \times 12) (D/2)}{(\pi/32) D^4}$$

or

$$D = 1.76 \text{ inches}$$

This is the required shaft size to sustain 800 ft-lb of torsional load with 9000 psi shearing stress.

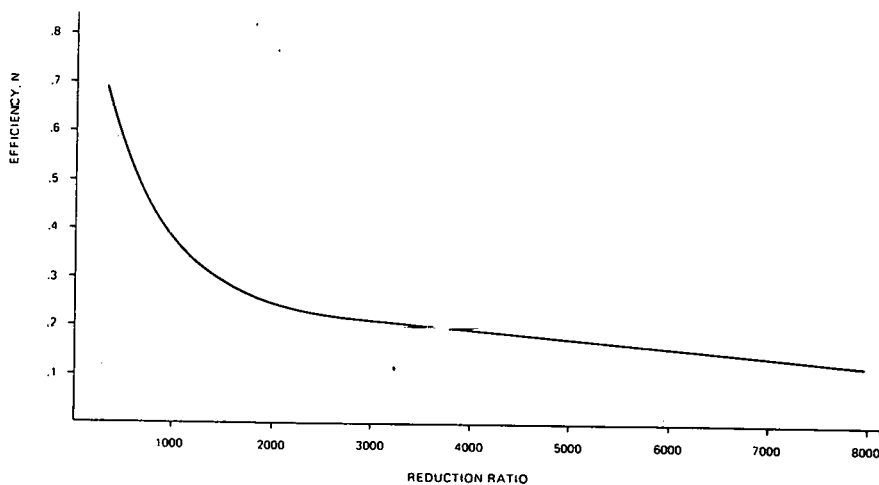


Figure 3-30. GEARBOX EFFICIENCY VS. GEAR REDUCTION RATIO

is required. These two values define the design limits for the output shaft size. The chosen gearbox has an output shaft diameter which meets the design constraints.

### 3.5.4 Unit Controller

This section describes the constituents of the unit controller. Four principal subelements comprise the unit controller; sensors, manual control panel, the motor-gearbox actuator, and the controller electronics.

3.5.4.1 Sensors -- The sun sensor is a null type of device which provides switch closure information relating to the relative solar image position on two phototransistors mounted on the sensor head. The sensor is mounted above the collector in a plane perpendicular to the collector aperture plane. This sensor gives relative position information with respect to the sun by varying the shading of the two phototransistors. The control translates this position information (see Figure 3-31) into relay outputs that drive the motor until a balance condition exists.

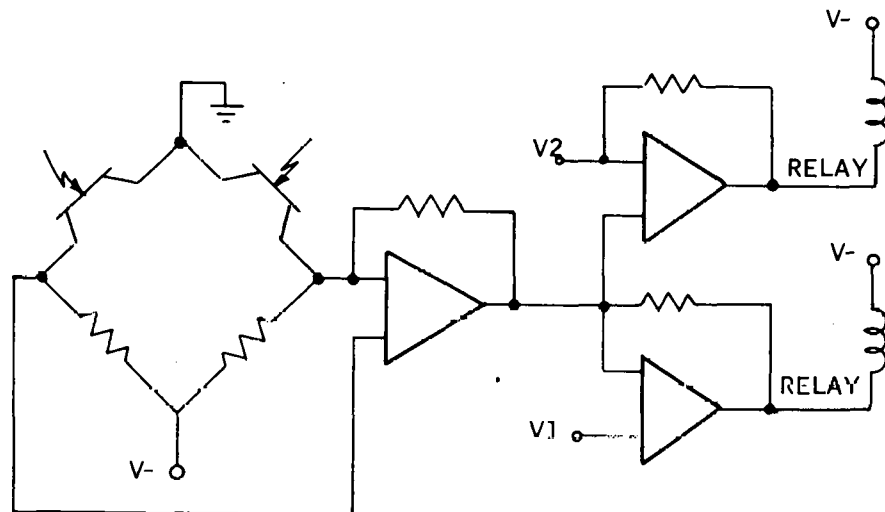


Figure 3-31. SIMPLIFIED TRACKER CIRCUIT DIAGRAM

The sensor box is mounted by three screws arranged in the tripod configuration. This allows for alignment of the sensor with the solar collecting system. Relay contact ratings are 115 VSC at 5 amperes.

The two phototransistors in the sensor box (see Figure 3-31) are in a bridge circuit. The impedance of the phototransistors varies as the amount of sunlight on them varies. The shade mounted above the sensor box is a half circle with concave sides that allow the phototransistor chip to be mounted directly below the outside edge of the shade. The shadow line is not an on/off condition but follows the Cornu spiral, where the change from light to shadow occurs in about 20 thousandths of an inch. If the phototransistors are placed such that they are both exposed to the sun when in the balanced condition, there is a deadband in the output of the summing amplifier. If the transistors are placed such that they are both entirely shaded when the system is balanced, then again a deadband appears in the output of the summing amplifier. Therefore, it is necessary to place the phototransistors such that the proper response time in the output will occur when a desired accuracy is needed. Thus, it is imperative that the phototransistors are properly positioned in order to give the user the ability to select the desired accuracy, within a given range, with the deadband control in the control box.

Also, the phototransistors have a wide angle of response that allows the same system accuracy to be generated in the bridge circuit for any complete solar day that will give a shadow on the phototransistors. This system responds to the infrared frequencies from the sun. Thus, the system will function on lightly overcast days.

The output of the summing amplifier is put into an adjustable delay. The delay will be set such that it will allow the system to overlook any temporary fluctuations in sunlight intensity, but yet fast enough to give desired response

in the servo loop. Too long a delay will result in hunting of the control, given that all other mechanical parameters are correct. The delay also avoids having both relays being energized simultaneously.

The deadband control is the parameter used to adjust the accuracy of the system. By decreasing the deadband the accuracy of the system is increased. When the voltage from the delay circuit is out of the deadband area, it either turns one or the other of the relays on, depending on the voltage present at the comparators.

The limit switches ("stow" and "max. travel") are positioned such that the collector assembly will activate them at the design limits of desired collector angular excursion. Their activation signals the control electronics to modify its command signals to the actuator according to the mode of operation at that time. In the case of "acquire" command, the maximum travel limit switch will cause the collector controller to reverse the motor. In the case of a "stow" command the stow limit switch activation will cause the controller to cease motor operation. If the system is not called upon to stow, the stow limit switch activation will be interpreted as a signal to cause the motor to drive forward, seeking the sun. This case could be caused by a cloud passing over the face of the sun while the system is acquiring.

The safety limit switches provide the self-protect function. They are mounted at the extremes of safe collector orientation (outboard of the "stow" and "max. travel" limit switches). When these switches are activated, they interrupt the motor armature circuit and disable a latched relay which is

also in series with the motor armature. Manual correction and reset of this latching relay is then required to permit resumption of operation. Figure 3-32 describes the electrical circuitry involved in the safety limit switch arrangement.

**3.5.4.2 Manual Control Panel** -- The manual control panel allows an operator to command five functions:

- 1) mode select: automatic/manual
- 2) forward
- 3) reverse
- 4) stow
- 5) stow-reset
- 6) manual override of safety limit switch

Upon selecting manual mode at the unit controller, all commands from the system controller are disabled and the operator has complete control at the local unit controller. Once in the manual mode, the operator may request forward or reverse rotation of the collector. This rotation is at the highest speed available (stow speed). The forward-reverse switch is a 3 position, center off, spring return type so that the operator is required to hold the switch in the "forward" or "reverse" position until the collector attains the desired orientation. Release of the switch stops the collector motion. Through the activation of the "stow" switch the operator may cause the collector to stow. The collector will continue to drive toward the stow position until the stow position is attained or the operator activates "stow-reset".

The "stow"/"stow-reset" switch is a center-off position, spring switch also. Stow commands are executed at stow speed (3/8 rpm). Figure 3-33 describes the manual control panel at the unit controller. The manual override switch

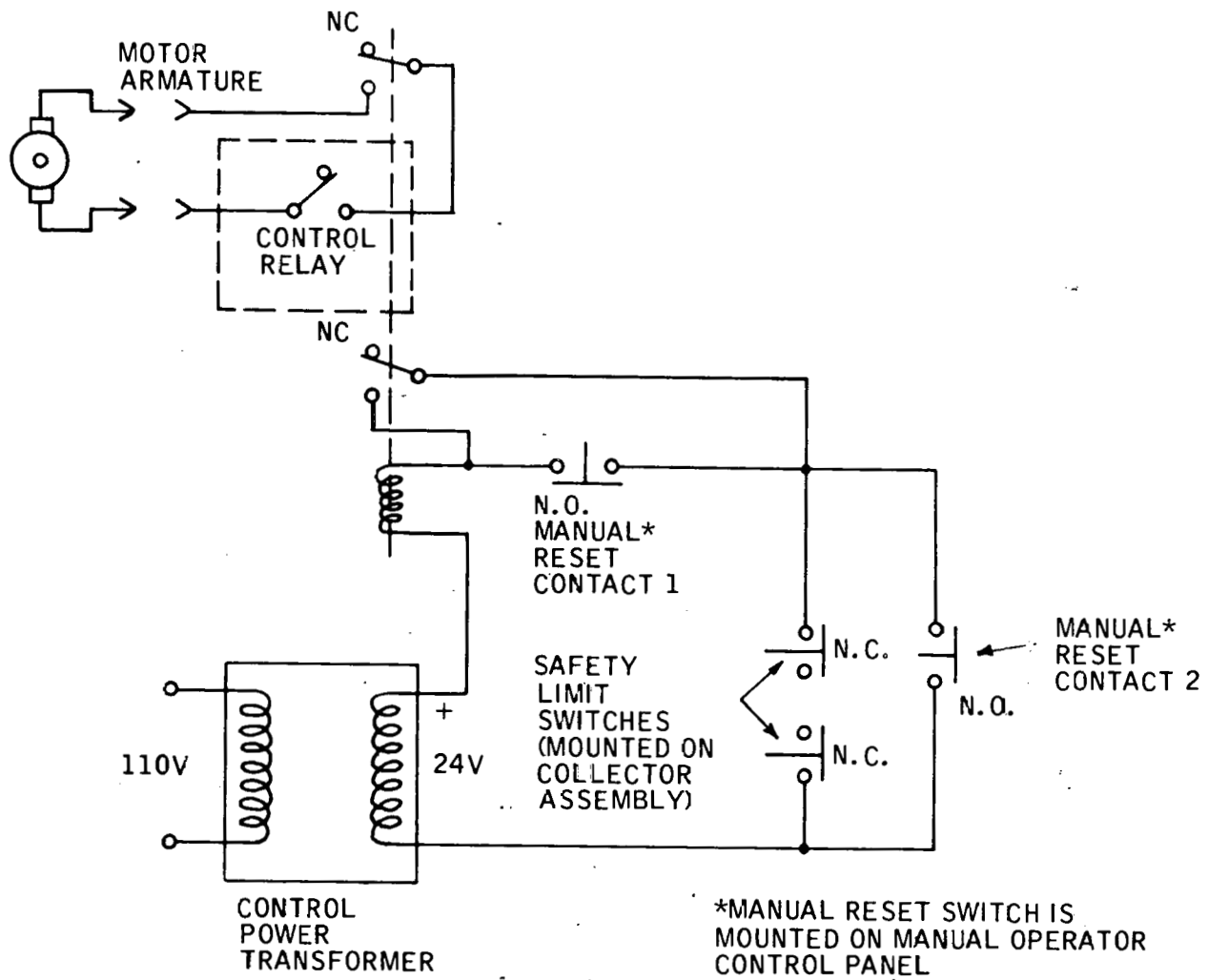
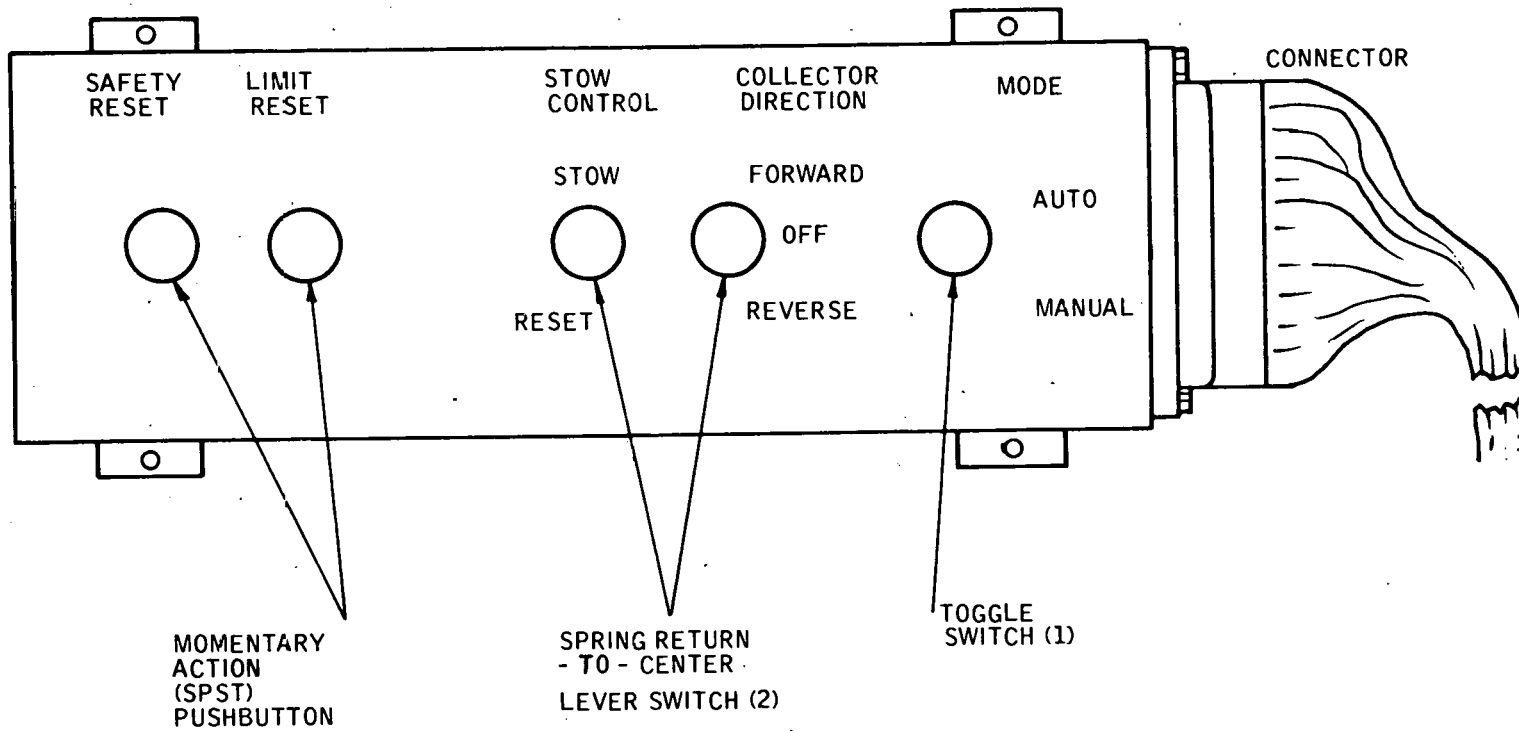


Figure 3-32. SAFETY LIMIT SWITCH ARRANGEMENT



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Figure 3-33. UNIT CONTROLLER MANUAL OPERATOR PANEL

allows the operator to reinstate the motor or armature circuit and back the collector off of the safety limit switches. Once the safety limit switches are in their normal state, the latching relay holds the armature circuit intact.

3.5.4.3 Actuator -- The actuator consists of a 1/2 hp, variable-speed dc motor, associated control electronics, and a 7500:1 gear train. The combination of these elements was selected to satisfy jointly the requirements for tracking accuracy, stow speed capability, and collector wind-induced torque balance requirement.

The motor is a shunt field, 1/2 hp, motor rated at 90 vdc armature and 100 vdc field voltages. Control electronics for the motor provide variable speed and reversing capability. Dynamic armature braking and armature current protection are provided by the motor control electronics. A standard SCR full wave bridge technique is used to provide speed control. An auxiliary circuit is incorporated to ensure that plugged rotor conditions do not occur due to too rapid armature current reversal attempts on the part of the controller.

3.5.4.4 Unit Controller Electronics -- The unit controller controls the collector drive via signals from the sun tracker and commands from either the manual control panel or the system controller. The inputs from the system controller are interrupted by a relay which is energized when the manual mode is selected at the unit controller. The inputs from the system controller are parallel signals to the manual mode switches at the unit controller. Manual mode functions are manual/automatic mode select, forward/reverse collector rotation, stow control and motor control. There is also a manual reset for the start lock-out latch. The function of the start lock-out latch is to inhibit collector rotation in the event that the collector is on the maximum limit switch. The System Controller Enable

input is a control signal which allows the unit controller to assume control and perform the "acquire" function. The System Control Enable signal generates a pulse which resets the stow command latch and generates a power on signal which is used to set the track mode latch. The function of the track mode latch is to change the speed from the acquire speed (1/4 rpm), which is the top speed of the collector, to the slower tracking speed (1/16 rpm) required for maintaining tracking accuracy. The inputs to the unit controller electronics from the tracker electronics have the following functions:

- 1) determine the direction of rotation of the collector
- 2) generate a signal to trip the track mode latch which indicates to the unit controller that the sensor has acquired the sun and that the speed should be shifted from acquired speed to the track speed.

Tracker electronics are also used to generate forward and reverse commands and power on-off commands, that is power on or off to the motor. Motor control relays, that is the power on-off relay and the forward-reverse relay are connected such that when the tracker has achieved a null state the power on-off relay is switched so that no power is available to the motor. The forward-reverse relay is then dropped into the reverse direction so that in case of component failure of the system will return to the stow mode. If the maximum limit switch is activated, "Max Travel Limit Switch" circuit is interrupted causing the power on-off relay to be disengaged. The second function of the "max. limit" switch is to reset the stow initiate latch which then pulls in the stow relay which subsequently pulls in the power on-off relay. There is a twenty-second delay circuit between the stow initiate latch and the power on-off relay to allow sufficient time for armature current extinction in the motor. Subsequent to this action, logic has been engaged to put the system in the reverse mode so that the collector will

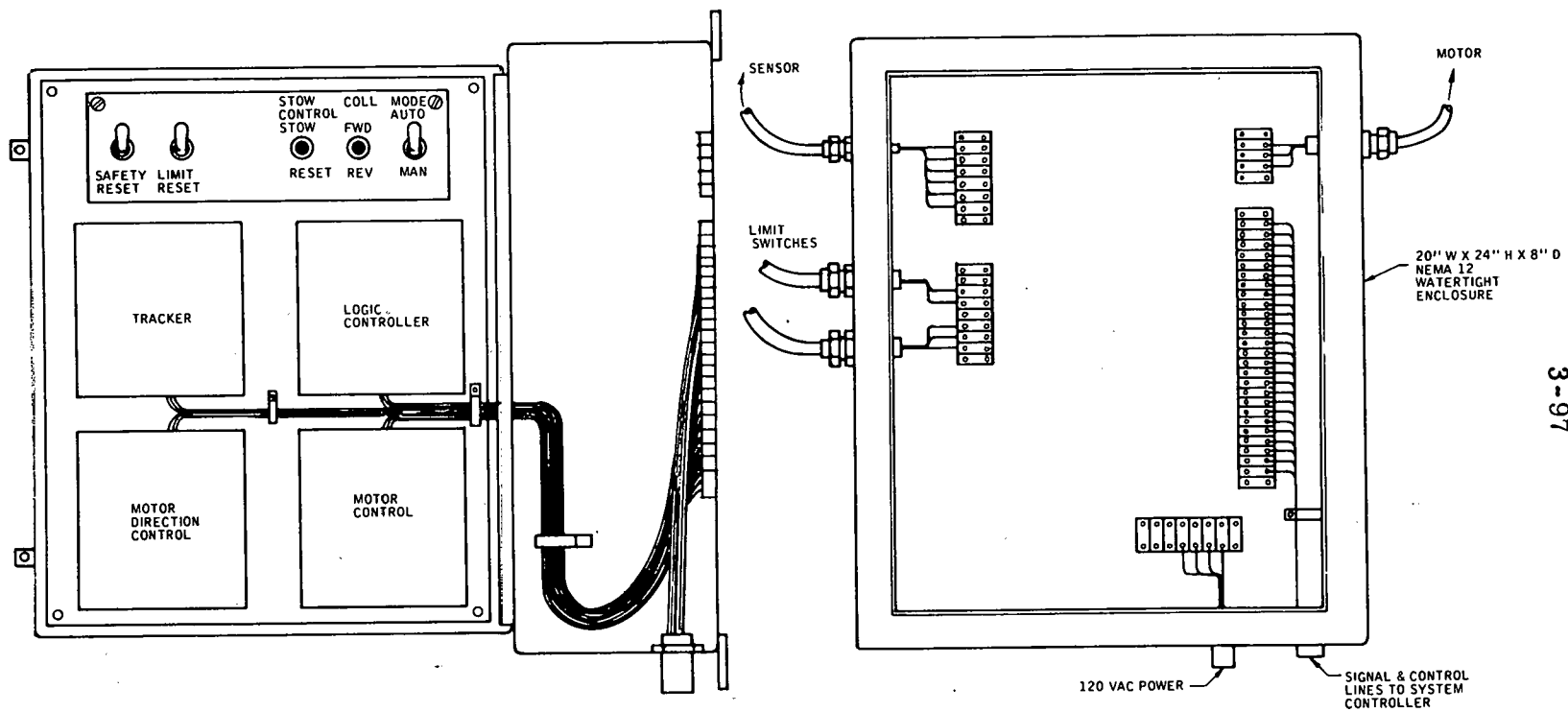
return to the stow position at the stow speed. Speed control is selected by the stow speed relay. The motor speed control is effected by the stow speed relay and switches two combinations of resistors into the motor controller circuitry by means of the stow speed relay.

3.5.4.5 Voltage Requirements -- Unit controller voltage requirements are:

- 1) 110 vac for motor and motor controller
- 2) +5 vdc digital logic electronics
- 3) +28 vdc for relay logic/switching

The 110 vac and 28 vdc power is bussed to the unit controller via field wiring. The +5 vdc is generated internal to the unit controller, from +28 vdc, using a standard logic power regulator.

3.5.4.6 Unit Controller Mechanical Design -- The unit controller electronics is housed in a NEMA 12 water-tight enclosure measuring 20"W x 24"H x 8"D. The manual control panel and the required electronics cards for the unit controller are mounted on the door of the water tight enclosure to facilitate maintenance and operation. Terminal strips are mounted on the rear portion of the water tight enclosure to facilitate cabling and electrical wiring between the motor, sensors, limit switches, signal busses from the system controller and the field power distribution system. The field power and system controller signal bus entries into the enclosure will be made by means of conduit as specified on the overall electrical installation drawing of the field. Inputs from the sensor, limit switches and the motor control outputs are passed out through the enclosure by means of water-tight strain relief couplings. Figure 3-34 depicts the mechanical housing of the unit controller.



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Figure 3-34. COLLECTOR UNIT CONTROLLER

## 3.6 SYSTEM OPERATION AND MAINTENANCE

### 3.6.1 Sequence of Operation

For purposes of this discussion the operational sequence is divided into two parts; 1) normal operation and 2) abnormal operation. In the normal operational mode we will consider day and night operational status. During the night, the system controller will be in the automatic mode, the collectors will be stowed and all pumps will be off. The 110 vac supply voltage and 28 vdc supply voltages will be present at the unit controllers. The sensors will be activated for control and data acquisition, but because of the lack of an "enable" signal, the unit controllers will remain dormant.

After sun-up when the illumination exceeds the preset limit and the wind is below 25 miles per hour, the system controller checks the status of the field pressure. If field pressure is between specified limits, then the field pump is enabled. When field flow is verified, the collector field is enabled on a quadrant-by-quadrant basis. The enable command to the collector field then causes the collectors to unstow (on a quadrant to quadrant basis). Subsequent to the unstow of the collectors the unit controllers will take over control from the system controller to acquire the sun. When the sun has been acquired by the tracking sensor the unstow operation ceases and the unit controller changes to the track mode. Under normal conditions the sensors will cause the collector to track the sun as it rises towards the zenith and through the day until sunset. During the time that the collectors are tracking, fluid in the high temperature water loop is heated in the absorber tubes. The field flow pump transfers the water through the collector loop to the steam generator. Heat is extracted from the collector loop and

transferred to water in the steam generator. Steam is generated at process conditions and piped into the slasher manifold.

The feedwater pump maintains liquid level with feedwater and this operation continues throughout the day with the high temperature water loop collecting solar energy and transporting it to the steam generator for the production of the process steam. At sundown, which is determined when the illumination drops below a preset threshold, a stow command is sent from the system controller causing the collectors to stow. The system controller also disables the field pump and returns the collector field to the nighttime status as described earlier.

Certain abnormal conditions may exist in which the system controller is required to protect the collector field from possible damage due to high winds, high temperatures, high pressure, field pump failure, freezing conditions in the field, and combinations of these events coupled with the possibility of loss of primary power. When the wind rises to over 30 miles an hour and wind velocities of this magnitude persist for more than 60 seconds, the system controller automatically stows the field. When the winds diminish, the field will again unstow. If the water loop temperature rises above a preset threshold, or there are pressure excursions beyond the normal limits, or a field pump failure occurs, the system controller will command the collector field to stow. Any of these latter conditions will require a manual reset of the system controller at the system controller manual control panel in order to reinstate normal field operating conditions.

In the event that freezing conditions occur in the field the system controller enables two immersion heaters located at the extreme ends of the field to

operate and provide heat to prevent the field loop from freezing. In the event that normal primary power is interrupted, the stand-by generator is activated. Power from the stand-by generator activates the system controller and causes the collector field to stow. The system controller is maintained in an active state by power from the stand-by generator until such time as the normal primary power comes back on line. After the normal primary power is reinstated a manual reset is required to restore normal operating conditions at the system controller. The operational sequence is summarized in Table 3-6.

### 3.6.2 Maintenance

The maintenance requirements of the textile drying solar system are expected to be minimal based upon the past experience of Honeywell with other solar systems. The maintenance schedule for the WestPoint Pepperell application is planned to include brief visual inspections and more thorough quarterly maintenance programs. The anticipated maintenance requirements are discussed in the following text, and a more detailed maintenance schedule will be developed during Phases II and III of the program as no system of this type currently exists.

3.6.2.1 Visual Inspection -- During the first year of operation a daily visual inspection of the system is anticipated. This will consist of a walk-through tour observing the hardware for damage, wear, and/or malfunction. Particular attention will be given to those components with moving parts, bearings, and seals. Unusual vibration and noise would indicate potential pump problems. Similarly any fluid leaks through valves, swivel joints, and flexible hoses would indicate that the seals or other elastomeric parts need replacement. The pipe insulation will also be inspected. If any area of the insulation is damaged it will be repaired during this daily maintenance program.

TABLE 3-6. SYSTEM OPERATIONAL SEQUENCE

A. <u>Nighttime Status</u>	<ul style="list-style-type: none"> <li>● Control in automatic</li> <li>● Collectors stowed</li> <li>● Pumps off</li> <li>● 110v supply on</li> <li>● 28v control supply on</li> <li>● Sensors active for control and data collection.</li> </ul>
B. <u>Sun-Up</u>	<ul style="list-style-type: none"> <li>● When illumination is above preset level, and wind is below preset level, and system pressure is within limits; TURN ON FIELD PUMP.</li> <li>● When field flow is verified; TURN ON COLLECTOR FIELD.</li> </ul>
C. <u>Unstow (Acquire)</u>	<ul style="list-style-type: none"> <li>● Collector control transferred to unit controller</li> <li>● Collectors rotate to unstow</li> <li>● Tracking sensor monitors sun position</li> <li>● Unstow ceases when tracking sensor nulls.</li> </ul>
D. <u>Tracking</u>	<ul style="list-style-type: none"> <li>● Collector tracks forward and/or reverse with control from tracker</li> <li>● Fluid in HTW loop is heated in receiver tube</li> <li>● Field flow pump transfers water around collector loop and to steam generator</li> <li>● Heat is transferred to water in steam generator</li> <li>● Steam is generated at process conditions and piped to slasher manifold</li> <li>● Feedwater pump maintains liquid level with feedwater</li> <li>● Operation continues throughout day with HTW loop collecting solar energy and transporting it to steam generator for production of process steam.</li> </ul>
E. <u>Stow (Sun-down)</u>	<ul style="list-style-type: none"> <li>● Illumination drops below preset level</li> <li>● Stow command sent from system controller</li> <li>● Collectors stow</li> <li>● Field flow pump turns off</li> <li>● System in Nighttime status (A).</li> </ul>

Instruments such as pressure gauges, temperature gauges, and liquid level indicators will be observed to verify that the entire solar system is operating normally. The reflective surface of each collector will be inspected to check for excessive dust deposits or spotting which tend to reduce the performance of the collectors. This condition will be corrected initially by washing the surface on an as-needed basis and later on a defined schedule. The collector reflector surface will be inspected for any structural damage such as that caused by flying objects (stones, etc.).

3.6.2.2 Quarterly Maintenance -- In addition to the regular visual inspection of the solar system a quarterly preventive maintenance program is anticipated. For this program, maintenance will be conducted when the system is not operating such as during the normal weekly shut-down period (Sunday). At this time the steam generator will be drained and refilled to remove the non-circulating portion of the fluid reservoir. Once a year a thorough inspection of the steam generator may be needed.

Collector drive system gearbox lubrication, the drive motor, the HTW circulation pump, and the feedwater pump would be serviced at the interval recommended by the manufacturer. This includes inspection and lubrication on an as-required basis.

Those components with elastomeric parts will be checked at this time. This is particularly applicable to the flexible hose assemblies which join the collectors to the supply and return headers, and the rotary joints. Those hoses or joint seals with noticeable deterioration will be replaced with new assemblies.

### 3.7 SYSTEM PERFORMANCE

#### 3.7.1 Energy Collected from the Solar Field

To predict the performance of the solar system the following information is necessary.

- Solar insolation at location (both instantaneous and integrated)
- Direct component of insolation
- Solar collector performance
- System thermal losses

Typically, the insolation data from the actual location of the solar system is not available. Moreover, if the total insolation data were available the direct and diffuse components of the available insolation need to be determined for which only a few models exist and these give differing results. For the purpose of this project, a simulation approach is used in which a clear air model is modified by the weather data. The simulation technique, developed earlier at Honeywell under ERDA Contract No. W-7405-ENG-92 (SUNSIM) is based on the ASHRAE procedure, and uses the weather data provided by the National Climatic Center and the radiation model due to Kimura and Stephenson to modify the clear air predicted insolation. The output of the simulation is the direct component of the solar energy available for use by the concentrating collectors.

The single axis tracking collector used in this design, continues to undergo

testing under an internally funded Honeywell program. Based on the test data taken on the collector and the design of the collector for installation at the WestPoint Pepperell facility, Figure 3-35 displays the expected efficiency against operating temperature. The various optical component efficiencies reduce the amount of energy at the receiver wall to 70 percent of that intercepted by the collector aperture. A further reduction in collector efficiency is experienced due to the thermal losses from the collector absorber. A detailed description of the thermal loss analysis is given later in this section. At the design point of 380°F, a peak collector efficiency of 64 percent is expected. Equation 3-1 defines the collector performance on an instantaneous basis and incorporates the effect of receiver thermal losses and end losses due to single axis tracking.

$$\eta = C_{op} \left( 1 - \frac{f \tan \alpha}{L} \right) - \frac{Q/L}{Q_{DIR} \times H} \quad (3-1)$$

where

- $\eta$  = collector efficiency
- $C_{op}$  = optical constant
- $f$  = focal length
- $\alpha$  = sun angle with normal to collector aperture
- $L$  = length of the collector
- $H$  = width of the collector aperture
- $Q/L$  = heat loss per unit length of absorber length
- $Q_{DIR}$  = direct component of solar flux intercepted by collector aperture

A detailed time point by time point thermal analysis of the solar system transport loop was also performed.

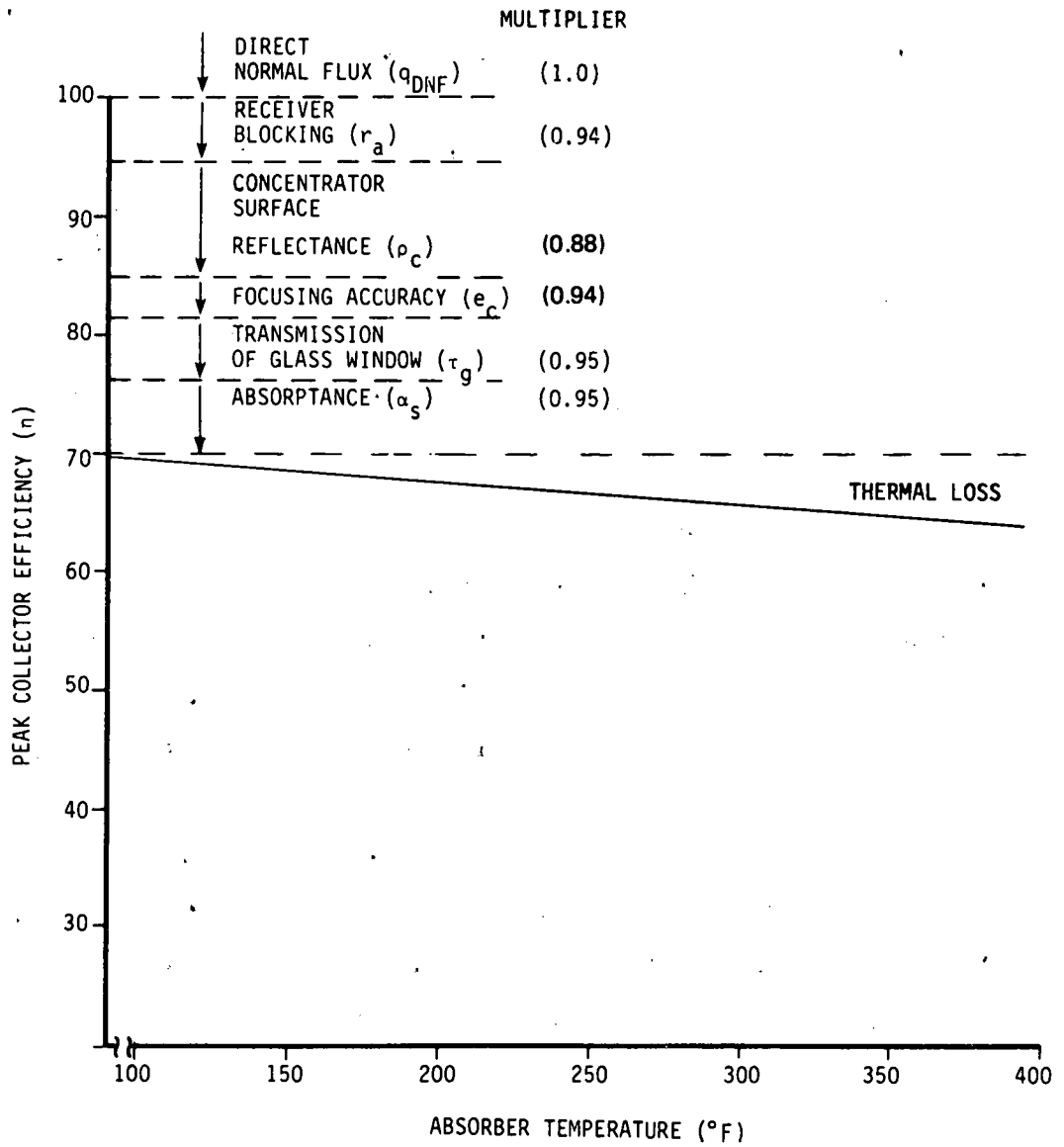


Figure 3-35. EXPECTED COLLECTOR EFFICIENCY

The collector efficiency defined by equation 3-1 was included in the simulation. The system thermal losses were then included in the analysis to determine the amount of steam that can be generated at the installation site. At the chosen design point of 2 p.m. on September 21, the solar system is expected to provide 544 kg/hr (1200 lb/hr) of steam. On the basis of the computation of the energy collected over the entire year,  $1.3 \times 10^6$  MJ ( $1.2 \times 10^9$  BTU's) of steam is expected at the process. Table 3-7 summarizes the solar field performance data for Fairfax, Alabama.

### 3.7.2 Verification of the Simulation Approach

For conducting the economic analysis, data were provided by ERDA for the measured insolation at two locations, namely, Albuquerque, New Mexico and Omaha, Nebraska. The tabulation provided included the total radiation and also the direct component available to an East-West axis horizontal tracking concentrating collector. Also, weather data tapes of the type used in our simulation approach are available for these two locations.

Table 3-8 shows the insolation available in BTU's per square feet per year at the collector aperture aligned East-West obtained by our simulation approach. Included in Table 3-8 is the insolation available as calculated from the data provided by ERDA. It is seen that for the two cities mentioned the data matches quite closely. This comparison is a verification of the simulation used to obtain the direct component at Fairfax, Alabama based on an Atlanta 1952 weather tape.

Table 3-7.

Solar Energy Available and Delivered to  
Process in the Form of Steam, Fairfax, Alabama

	Peak BTU/sq.ft./hr.	BTU/sq.ft./yr.	Total BTU/yr. (8313 sq.ft.)
QAVAIL (365 days)	282	394,900	$3.3 \times 10^9$
QAVAIL (300 operating days)	282	324,600	$2.7 \times 10^9$
QPROCESS (In form of steam)	130	149,300	$1.2 \times 10^9$

Table 3-8. Solar Flux Available at Collector Aperture,  
BTU/square foot/year

Location →	Fairfax (Alabama)	Omaha (Nebraska)	Albuquerque (New Mexico)
Qavail by simulation	372,400	410,600	639,300
Qavail from ERDA data	N. A.	401,200	629,500

### 3.7.3 Effect of Collector Orientation North 40° East

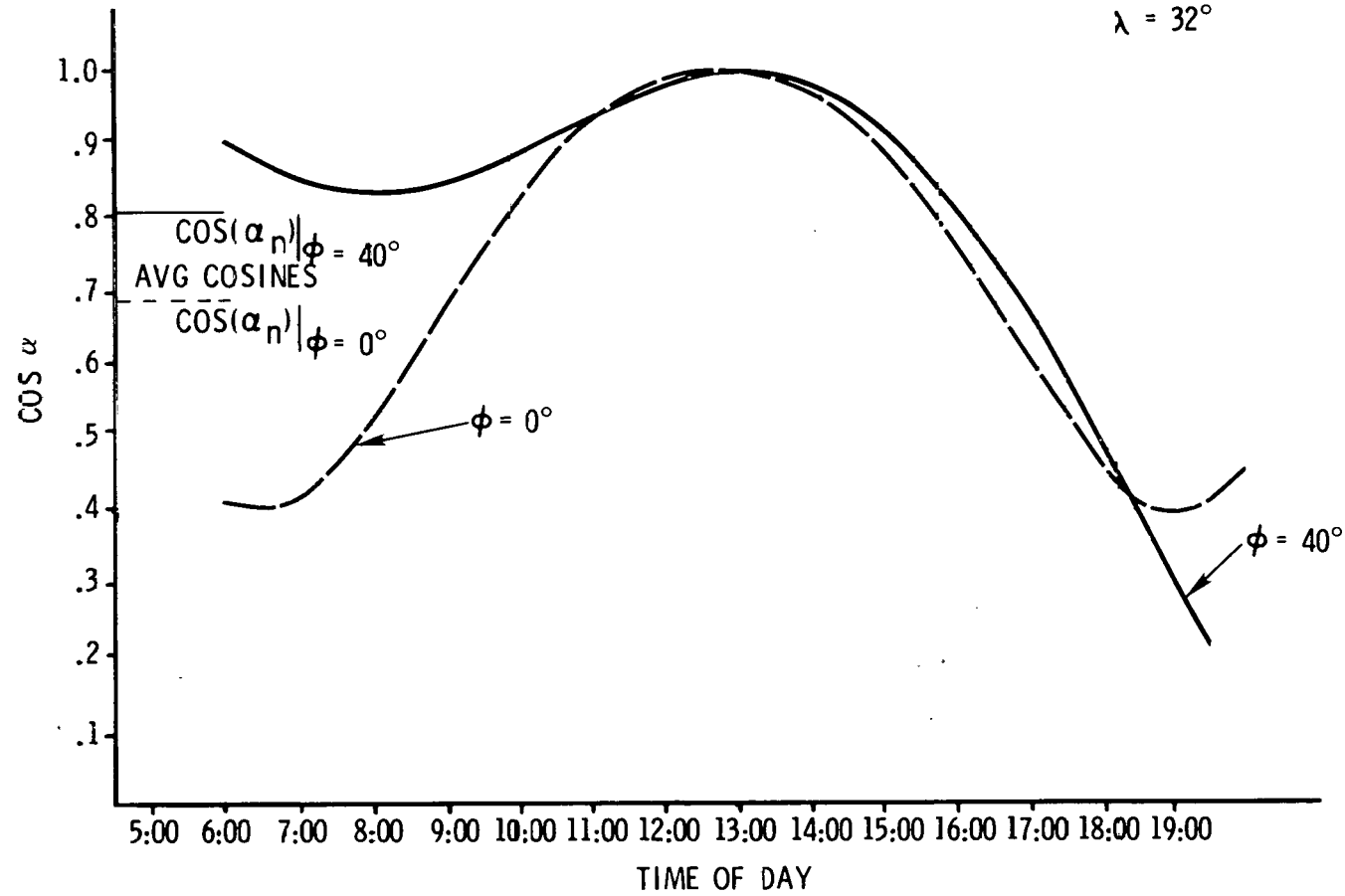
The collector field of the WestPoint Pepperell installation will be aligned square with the building number 3 roof. This building is oriented with its longest wall at an angle 40° east of north. With the collectors mounted in line with the roof, the axis of rotation of the collectors will be oriented 40° north of west. The predicted performance of the collector field was examined with the collectors in this orientation and was compared with truly E-W oriented collectors. Figure 3-36 presents a performance measure for day 173 (June 21) for the Fairfax, Alabama latitude. This performance measure is the cosine alpha functions (effect of the angle the sun makes with the normal to collector aperture) over the solar day. Included on the axis is the average cosine  $\alpha$  value for the day. Cosine alpha is the measure of orthogonality of the collector system with respect to the sun line-of-sight with the collector location. In all, three days were investigated; 3/21, 6/21, and 12/21. For 3/21 and 6/21, the average cosine  $\alpha$  value is greater for the 40° orientation than the east-west orientation. On 12/21 the 40° orientation gives a smaller average cosine  $\alpha$ .

This effect can be seen in Figure 3-37, a plot of the energy collected per collector for each of the two field orientation cases. This graph, obtained by integrating the daily energy collected per collector, shows that the two orientations collect almost equivalent amounts of energy over the year. This can be seen by the average values of these curves which are shown on the ordinate of the graph. The 40° north-of-west orientation shows somewhat more variability during the year than the east-west orientation. This investigation was conducted through the use of the simulation program which uses the clear air model for the insolation to eliminate the affect of weather variability.

Figure 3-38 is a yearly plot of the end loss measure of the concentrating collector for the two orientations, E-W and aligned with the building (40°

DAY 173  
(June 21)

$\lambda = 32^\circ$



3-110

Figure 3-36. COSINE ALPHA VS. TIME OF DAY FOR DAY 173

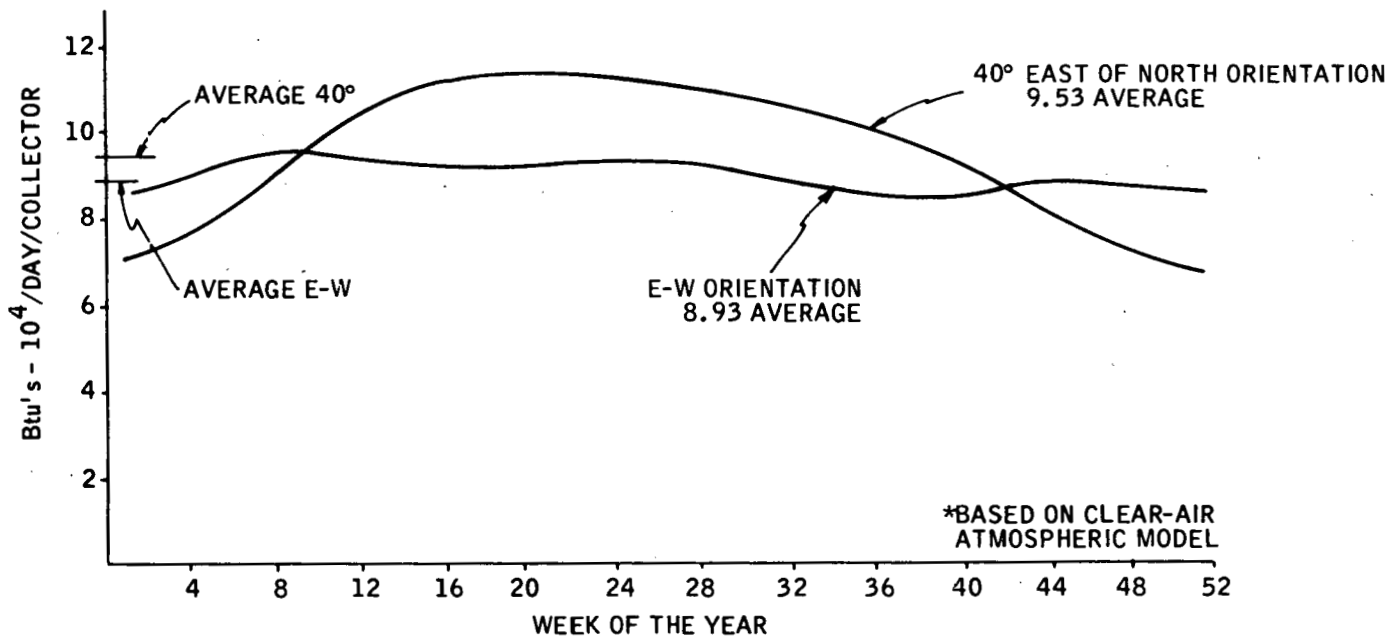


Figure 3-37. ENERGY COLLECTED VS. TIME OF YEAR\* (Single Collector)

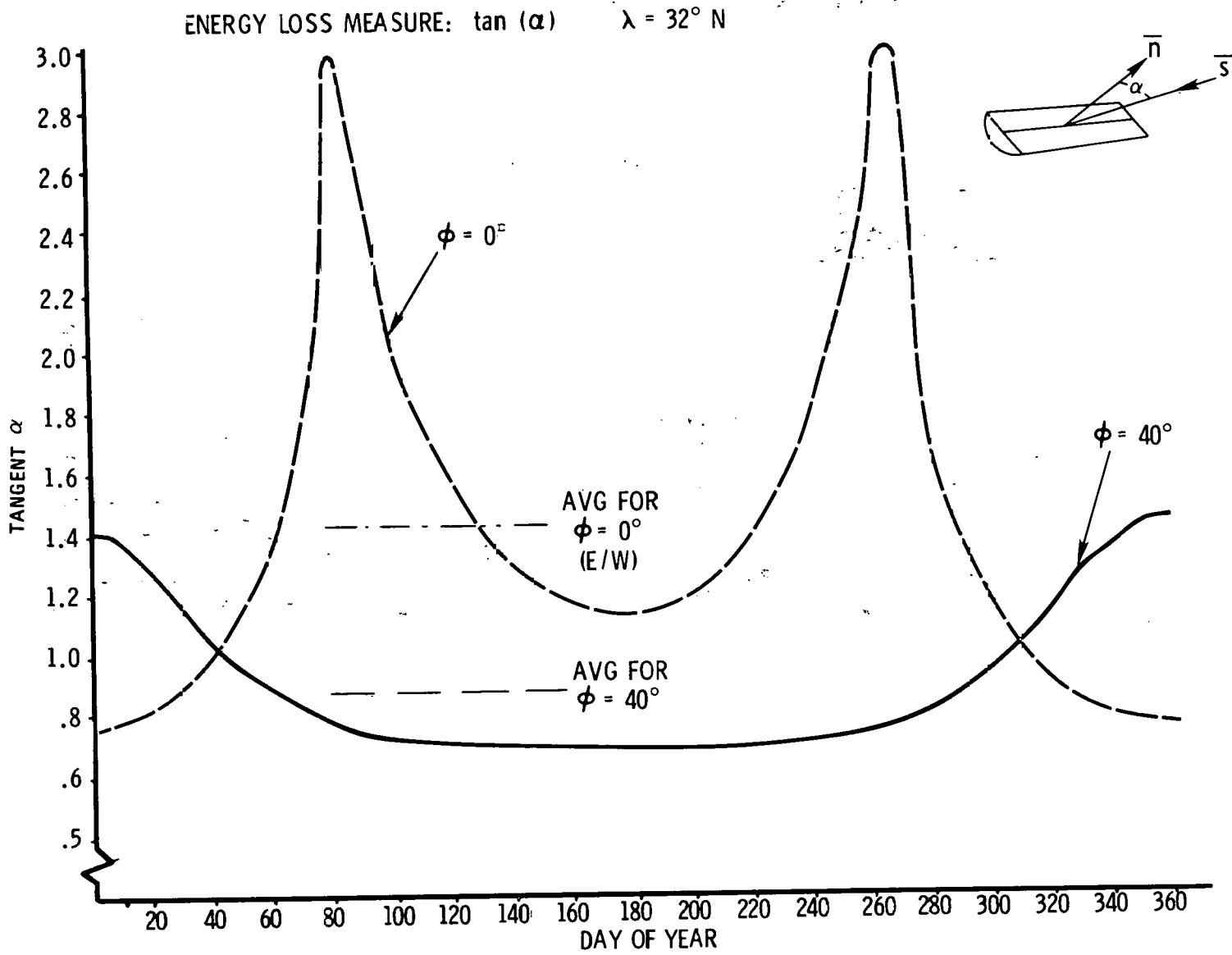


Figure 3-38. AVERAGE ENERGY LOSS MEASURE VS. DAY OF YEAR

north of west). Average values of the curves are shown on the ordinate. It is seen that the average end loss is less for the 40° north of west orientation.

#### 3.7.4 Thermal Losses from the Collector Receiver

The heat losses from the receiver can be divided into three components; a) conduction through the insulation, b) convection in the aperture opening, and c) radiation from the aperture. To estimate the heat losses the following assumptions were made;

- a) the surface of the absorber is at a uniform temperature  $T_1$ ,
- b) the outer surface of the receiver is at a uniform temperature  $T_2$ ,
- c) the heat transfer is one dimensional, and
- d) the aperture window is black in the infrared.

Conduction through the insulation -- The heat transfer by conduction from a circular tube completely surrounded by insulation is given by

$$\frac{Q_c}{L} = \frac{2\pi k_I (T_1 - T_2)}{\ln (r_2/r_1)} \quad (3-2)$$

where

$k_I$  = thermal conductivity of the insulation

$L$  = length of the tube

$Q_c$  = heat loss by conduction

$r_1$  = inner radius of the insulation  
(or absorber tube radius)

$r_2$  = outer radius of the insulation

$T_1$  = temperature at the inner surface of the insulation (or absorber tube temperature)

$T_2$  = temperature at the outer surface of the insulation.

For the receiver design described herein, approximately 78 percent of the circumference of the tube is insulated.

Therefore the conduction heat loss,  $Q_{\text{cond}}$ , is given by

$$\frac{Q_{\text{cond}}}{L} = \frac{0.78 (2\pi) k_I (T_1 - T_2)}{\ln (r_2/r_1)} \quad (3-3)$$

Convection in the aperture region -- The heat transfer mechanism in the aperture region is free convection. However, the convection process can be expressed in the same form as conduction by the introduction of an "effective thermal conductivity",  $k_e$ . Using this procedure and observing that approximately 22 percent of the total circumference is aperture, the heat loss by convection in the aperture,  $Q_{\text{conv}}$ , can be expressed as

$$\frac{Q_{\text{conv}}}{L} = \frac{0.22 (2\pi) k_e (T_1 - T_2)}{\ln (r_2/r_1)} \quad (3-4)$$

The equivalent thermal conductivity is a function of temperatures, air properties, aperture dimensions and the orientation of the warmer and cooler surfaces. For example, when the receiver aperture faces downward (i.e., the hotter absorber tube is directly above the horizontally oriented window) the air in the aperture region is relatively stable.

Therefore, in this case the equivalent thermal conductivity is approximately equal to that of still air.

If the receiver is rotated from this position, such that the hottest surface is not at the extreme top of the enclosed air space, free convection begins to occur and the equivalent thermal conductivity increases.

This variation due to orientation can be approximated by equation 3-5 from Reference 2,

$$\frac{k_e}{k_{air}} = 1 + \left( \frac{k_{e, (\theta=0)}}{k_{air}} - 1 \right) \cos \theta \quad (3-5)$$

$$0 \leq \theta \leq \pi/2$$

where

$k_{air}$  = thermal conductivity of air

$\theta$  = angle between the normal to the aperture and the horizontal (see Figure 3-39)

Based on the current design and information presented in Reference 3, it is estimated that

$$\frac{k_{e, (\theta = 0)}}{k_{air}} \cong 3.5 \quad (3-6)$$

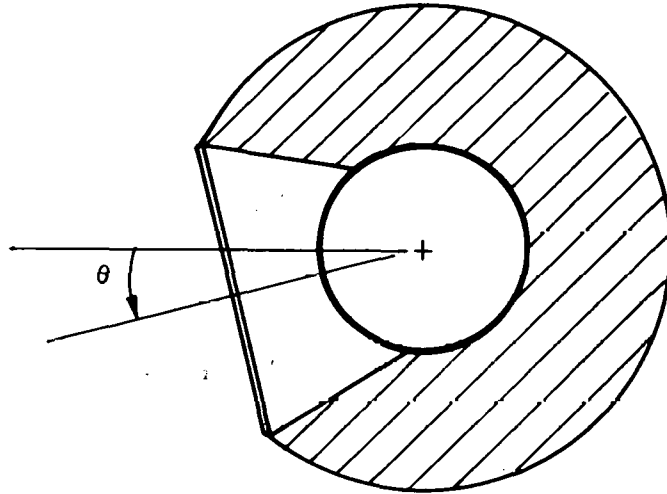


Figure 3-39. Definition of Angular Orientation  $\theta$

Substituting this value into equation (3-5) results in an estimate of the effective thermal conductivity

$$\frac{k_e}{k_{\text{air}}} = 1 + 2.5 \cos \theta \quad (3-7)$$

This value is then used in equation (3-4) to predict the convection heat loss.

Radiation heat loss -- The net radiation heat loss was calculated using the radiosity approach, taken from Reference (4). The glass aperture cover was assumed to

be black at the wavelengths in which the radiant heat exchange occurs. The edges or surfaces of the insulation, which form the side walls of the aperture, were included in the radiation calculation. The temperature of these surfaces was treated as constant but unknown and they were assumed to be black. The radiation heat loss,  $Q_r$ , was calculated to be given by

$$Q_r = \frac{A_r \epsilon \sigma (T_1^4 - T_2^4)}{1 + 0.25\epsilon} \quad (3-8)$$

where

- $A_r$  = uninsulated area of the absorber tube
- $\epsilon$  = infrared emittance of the absorber tube
- $\sigma$  = Stefan-Boltzmann constant

The denominator of the right hand side of equation (3-8) (i. e.,  $1 + 0.25\epsilon$ ) results from the inclusion of the side walls of the aperture in the analysis. If they had been neglected, the denominator would have been unity. For the current configuration the uninsulated area,  $A_r$ , is

$$A_r = 0.3 (2\pi r_1) L \quad (3-9)$$

Therefore

$$\frac{Q_r}{L} = \frac{0.3 (2\pi r_1) \epsilon \sigma (T_1^4 - T_2^4)}{1 + 0.25 \epsilon} \quad (3-10)$$

Total heat transfer -- The total heat loss,  $Q$ , from the receiver is given by the sum of the conduction, convection and radiation losses expressed by equations (3-3), (3-4) and (3-10) respectively. That is,

$$\frac{Q}{L} = \frac{2\pi (0.78 k_I + 0.22 k_e) (T_1 - T_2)}{\ln (r_2/r_1)} + \frac{2\pi r_1 (0.3) \epsilon \sigma (T_1^4 - T_2^4)}{1 + 0.25 \epsilon} \quad (3-11)$$

and

$$k_e = k_{\text{air}} (1 + 2.5 \cos \theta) \quad (3-7)$$

The outer surface temperature of the insulation,  $T_2$ , will be very close to, but slightly above, ambient temperature. The maximum heat loss will be predicted by assuming that the temperature  $T_2$  is equal to ambient temperature. The outer surface temperature can be corrected by assuming the receiver to be a cylinder in cross flow with the air velocity equal to the wind speed. However, doing this correction for a minimal wind speed of 15 mph only reduces the predicted heat loss by 5 percent. Increasing the wind speed reduces the correction. Equation (3-11) along with the equation (3-1) and (3-6) were included in the simulation to arrive at the best possible estimate of yearly energy collected by the solar system.

### 3.8 IMPACT OF SYSTEM ON PROCESS ENERGY REQUIREMENTS

#### 3.8.1 At the WestPoint Pepperell, Fairfax, Alabama Mill

As discussed in detail in Section II, the cylindrical can dryer operation at the Fairfax, Alabama mill averages 1905 kg/hr (4200 lbs per hour) of  $0.5 \times 10^6$  Pa (70 psig) steam usage for 72 dry cans. For three slashers (21 drying cans) this represents a requirement for 1162 MJ/hr ( $1.1 \times 10^6$  BTU/hr). The proposed solar system is expected to supply 1200 lbs. per hour peak (every clear day) to the process. This represents 1138 MJ/hr ( $1.08 \times 10^6$  BTU/hr) supplied or 98% of the three slasher demand during peak solar conditions (and 29% of the total average slasher room demand).

Over an eight hour day, the three slasher process requirement is 9296 MJ ( $8.8 \times 10^6$  BTU). At the equinoxes, the solar system is expected to supply 7,968 MJ ( $7.56 \times 10^6$  BTU) which is 86% of the average demand during that 8 hour period (and 25% of the total slasher room demand).

Using WestPoint Pepperell data for 1976, the day shift requirements for process energy for three slashers over a complete year is  $2.8 \times 10^6$  MJ ( $2.65 \times 10^9$  BTU). Based on the Atlanta weather data as described in Section 3.7, the proposed solar system will supply  $1.3 \times 10^6$  MJ ( $1.2 \times 10^9$  BTU) over a year's period. This represents 46% of the three-slasher demand and 14% of the total slasher room process energy requirement at the Fairfax, Alabama mill.

The total annual demand for steam at the WestPoint Pepperell Fairfax, Alabama mill was  $5 \times 10^9$  lbs. steam (in 1976) or  $4.5 \times 10^{12}$  BTU/year ( $4.6 \times 10^9$  MJ). Steam usage at  $0.5 \times 10^6$  Pa (70 psig) or less is  $2.3 \times 10^9$  MJ/yr. ( $2.2 \times 10^{12}$  BTU/yr.). The solar demonstration project is expected to provide 0.1% of this latter demand.

### 3.8.2 Industry Wide Impact

The U.S. textile industry consumes 115 trillion BTU's annually in textile drying-related operations. Over 50% of the material used in weaving goods is dried on slashers using cylindrical can dryers. The U.S. Department of Commerce Report No. MC-72 contains statistics under the heading "Textile Machinery in Place as of December 31, 1973" that state that 1056 Slashing and Sizing machines were in place on that date. Furthermore, statistics from the Department of Commerce Bureau of Census state that the average production of broad woven goods over the period 1971 to 1975 was  $10,800 \times 10^6$  yards. At 2.31 yards per pound, the production was  $4700 \times 10^6$  lbs. of yarn. Since approximately 60% of this yarn is processed on a slasher,  $2800 \times 10^6$  lbs. was dried on cylindrical can dryers. Using the ratio of 2.0 lbs. of steam per lb. of yarn (from Figure 2-9),  $5.6 \times 10^9$  lbs. of steam or  $5 \times 10^{12}$  BTU per year were consumed in the slashing process. Therefore, the selected process, slashing, represents a use of process heat that consumes a significant amount of energy.

### 3.9 MODIFICATION TO BUILDING REQUIRED

Modifications to the WestPoint Pepperell mill at Fairfax, Alabama in the installation of the solar system will be minor. They are summarized thusly:

- access door between landing and weave room roof
- passage of pipes (steam, condensate, conduit) through wall between penthouse and building no. 2
- passage of waste drain pipe through weave room roof and first floor
- passage of emergency generator exhaust pipe through outside wall
- passage of feedwater pipe out of existing building to penthouse

The access door will be a 3'6" by 7'0" fire door. The opening in the existing masonry will be placed at a previously bricked-in window. Details of the specifications for this modification are given in Division 4, Masonry and Division 8, Doors, in the Specifications and Drawings.

Specifications for the passage of pipes through floors, walls, and roofs are given in Division 15, Mechanical, (Section 1510.05) and Division 16, Electrical, (Section 1601.14).

The addition of the solar collector field supports atop the weave room roof is not considered a modification to the building. The support structure is

designed to support the loads without modification to the building and without requiring cutting holes through the roof. The detailed description of this addition is in Section 3.4.

Similarly, the penthouse on the weave room roof, the steam and feedwater pipes in the building, and the annunciator panel in the machine shop are considered additions to the existing capital equipment and not as modifications to the building. These additions are discussed in detail elsewhere in Section III.

### 3.10 INTERRUPTION TO PROCESS FOR INSTALLATION

No interrupt to the textile drying process will occur due to the installation of the solar system. The critical nature of the drying process within any textile mill demands that no interruption occur. Therefore, the solar system was designed to feature a simple interface between the solar system and the existing system and thereby eliminate any interruption to the process.

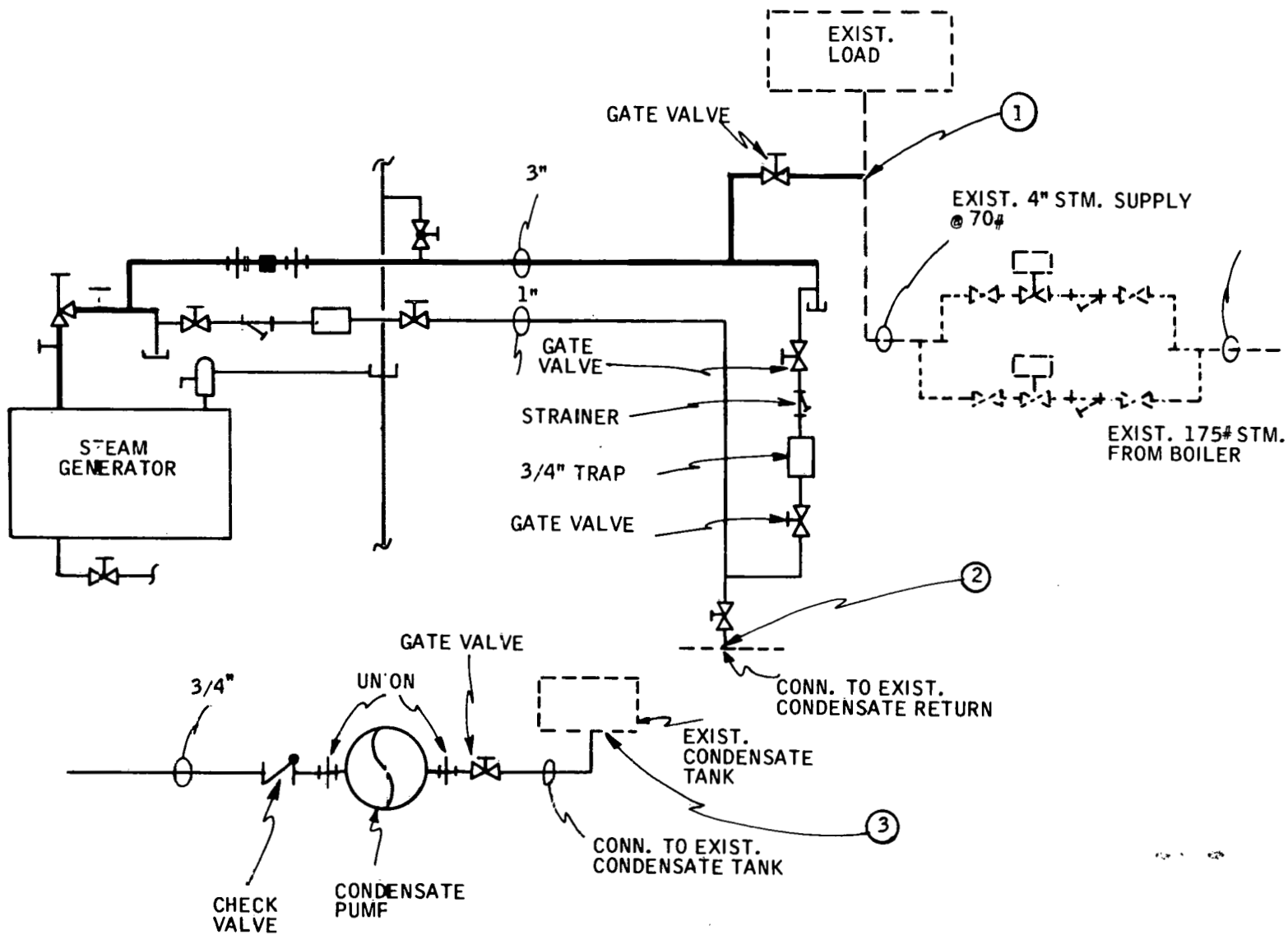
The textile drying process in the slasher room is a continuous, 24 hour a day, six days a week operation. On Sunday, the mill shuts down and the interface points can be modified. The main connection is at the 5-inch steam line that acts as the manifold for the slashers. This steam line runs along the ceiling of the basement floor under the slashers. Under WestPoint Pepperell supervision, this line can be cut and a "T", with a valve, installed on a Sunday. With the valve closed the drying process will continue uninterrupted as the remainder of the solar steam line is installed during weekday working hours.

Similarly, a condensate line connection will be made with a "T" and a valve in the same area of the ceiling. This work will also be conducted on Sunday.

The feedwater pump fitting will also be added to the existing receiver on a Sunday when the mill is not in operation. This work is minimal and will not interrupt the drying process or any other process in the mill.

Figure 3-40 illustrates these three interface points.

The electrical connection to the WestPoint Pepperell power line are designed to isolate the solar system for data analysis purposes. This connection will also be done on Sunday and no interruption to the process or the mill will occur.



3-124

Figure 3-40. INTERFACE POINTS - SOLAR TO EXISTING

During the installation of the solar system at the WestPoint Pepperell facility, employees of the General Contractor will be on and around the building, in the halls, and using the access to the building. Additional equipment will be on the grounds. However, any minor disruptions that occur will be typical of this general type of work (i. e., installation of another steam line, additions to a roof) and not be aggravated by the inclusion of a solar system.

### 3.11 TEST PLAN

A preliminary test plan was developed in this study for use in defining the instrumentation requirements. This test plan is described briefly below.

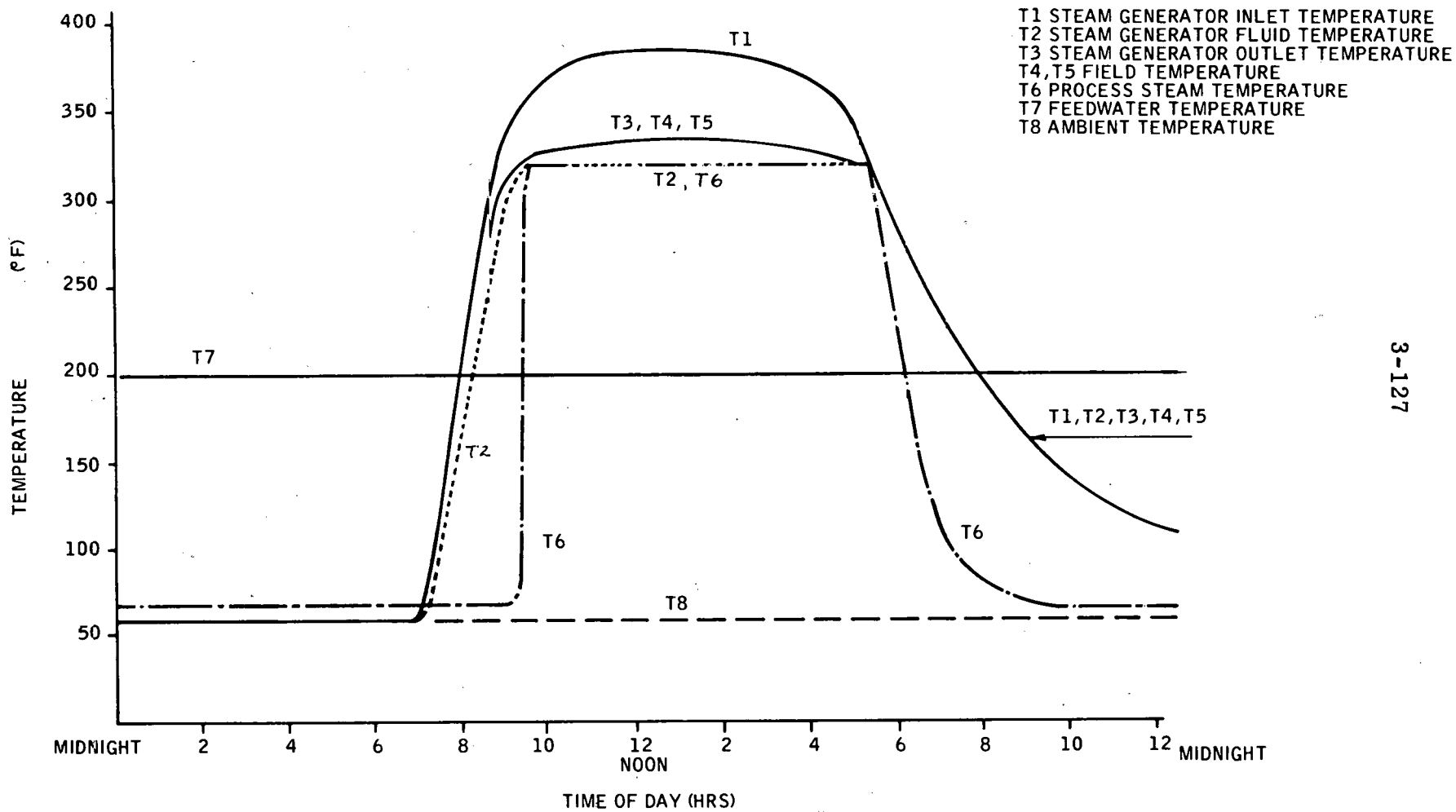
The Phase III operation and test will be directed to two objectives:

- provide solar produced steam to the process
- monitor performance of the system

The system will be adjusted and "tuned" during the set-up and checkout period in Phase II. This will include balancing the collector flows and setting the field flow. Further adjustment of the operating parameters will not be scheduled during Phase III but can be conducted if necessitated by the change in solar insolation with season. Phase III will emphasize steam production and data collection rather than experimentation and modifications.

System performance is monitored by fourteen sensors as described in Section 3.3, Instrumentation. The function of each sensor in the test plan and the data analysis is described in the following paragraphs.

Temperature Sensors -- The temperature sensor data will be plotted versus time (eight sensors, eight curves) for each day of operation to allow visual inspection of the system warm-up, operation, and cool-down, and for comparison with similar plots of illumination versus time. Figure 3-41 is an example of how the temperature data is expected to look.



3-127

Figure 3-41. SYSTEM TEMPERATURE PROFILE DESIGN POINT (SEPTEMBER 21) - EXAMPLE

The solar collector field input and output temperature (T1 and T3) will be used in calculating the performance of the solar collector field subsystem. The rate of energy collection by the field,  $Q_c$ , will be determined as a function of time using the following relationship,

$$Q_c = \dot{M}(C_p) \Delta T_c \quad (3-12)$$

where

$Q_c$  = rate of energy collection by the collector field  
(MJ/hr) or (BTU/hr)

$\dot{M}$  = HTW flow rate (kg/hr) or (lbs/hr) or (GPM)

$C_p$  = the specific heat of the fluid

$$= 2.4 \times 10^{-4} \frac{\text{MJ}}{\text{kg} \cdot ^\circ\text{C}}$$

$$= (1.0 \frac{\text{BTU}}{\text{lb} \cdot ^\circ\text{F}})$$

$\Delta T_c$  = temperature differential ( $^\circ\text{C}$ ) or ( $^\circ\text{F}$ )

$$= T1 - T3$$

The solar steam line temperature (T6), and the feedwater temperature (T7), will be used in calculating the overall performance of the system in terms of the rate of energy delivered to the process.

$$Q_p = \dot{m}(C_p \Delta T_p + h_{fg}) \quad (3-13)$$

where

$Q_p$  = rate of energy delivery to the process  
(MJ/hr) or (BTU/hr)

$\dot{m}$  = steam flow to process (kg/hr) or (lbs/hr)

$\Delta T_p$  = the temperature differential ( $^\circ\text{C}$ ) or ( $^\circ\text{F}$ )

$$= T7 - T6$$

$h_{fg}$  = heat of vaporization (MJ/kg) or (BTU/lb)

The value  $\Delta T_p$  will be relatively constant and the flow rate  $m$  will be integrated to determine the total amount of energy delivered per day.

$$E_p = m (C_p \Delta T_p + h_{fg}) \quad (3-14)$$

where

$m$  = the amount of steam delivered to the process per day (kg) or (lbs) as determined by the flow meter integrator.

These performance values will be plotted versus time,  $Q_c$  and  $Q_p$  on an hourly basis and  $E_p$  on a daily scale. Figure 3-42 is an example of  $Q_p$  vs. time taken from the performance prediction.

Pressure Sensors -- The pressure sensor data will be plotted versus time (two sensors, two curves) for each day of operation to allow visual inspection of the system changes in pressure with temperature change and time. Figure 3-43 is an illustration of representative plots. The solar steam pressure,  $P_2$ , will be used in calculating the performance of the system. The value of the heat of vaporization,  $h_{fg}$ , in equations (2) and (3) will be determined by the pressure from sensor  $P_2$ .

Flow Sensors -- The flow sensor data will be plotted versus time (two meters, two curves) for each day of operation to allow visual inspection of the system performance in terms of steam flow provided to the process. The flow in the existing steam line, taken from the existing sensor  $F_2$  will be recorded on the solar data collection system in addition to its existing recorder at the mill. The solar steam flow,  $F_1$  will be used in calculating the performance of the system. The value of  $\dot{m}$ , the steam flow in lbs. per hour will come directly from sensor  $F_1$ .

Figure 3-44 shows one example of a) existing flow taken from WestPoint

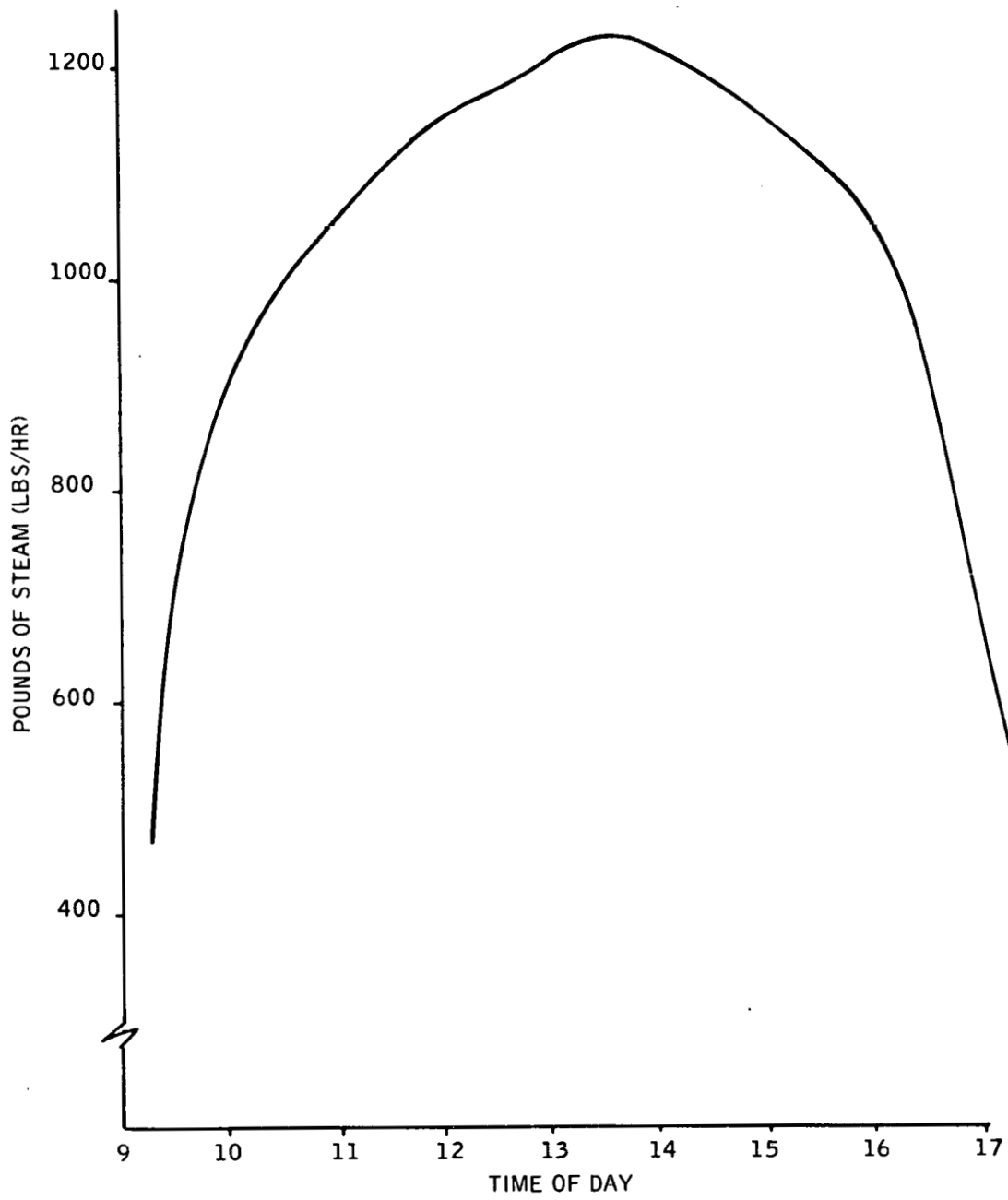
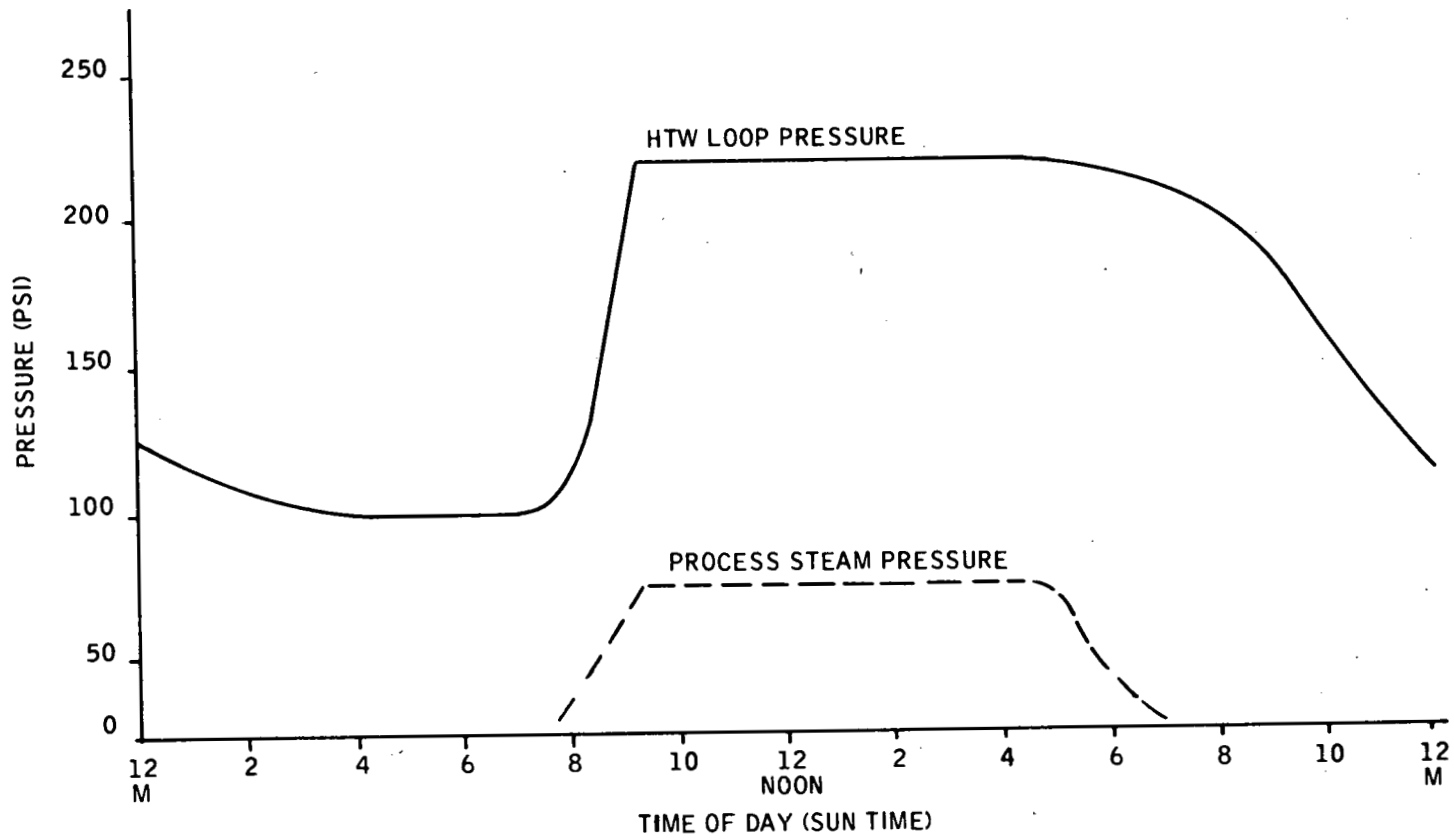
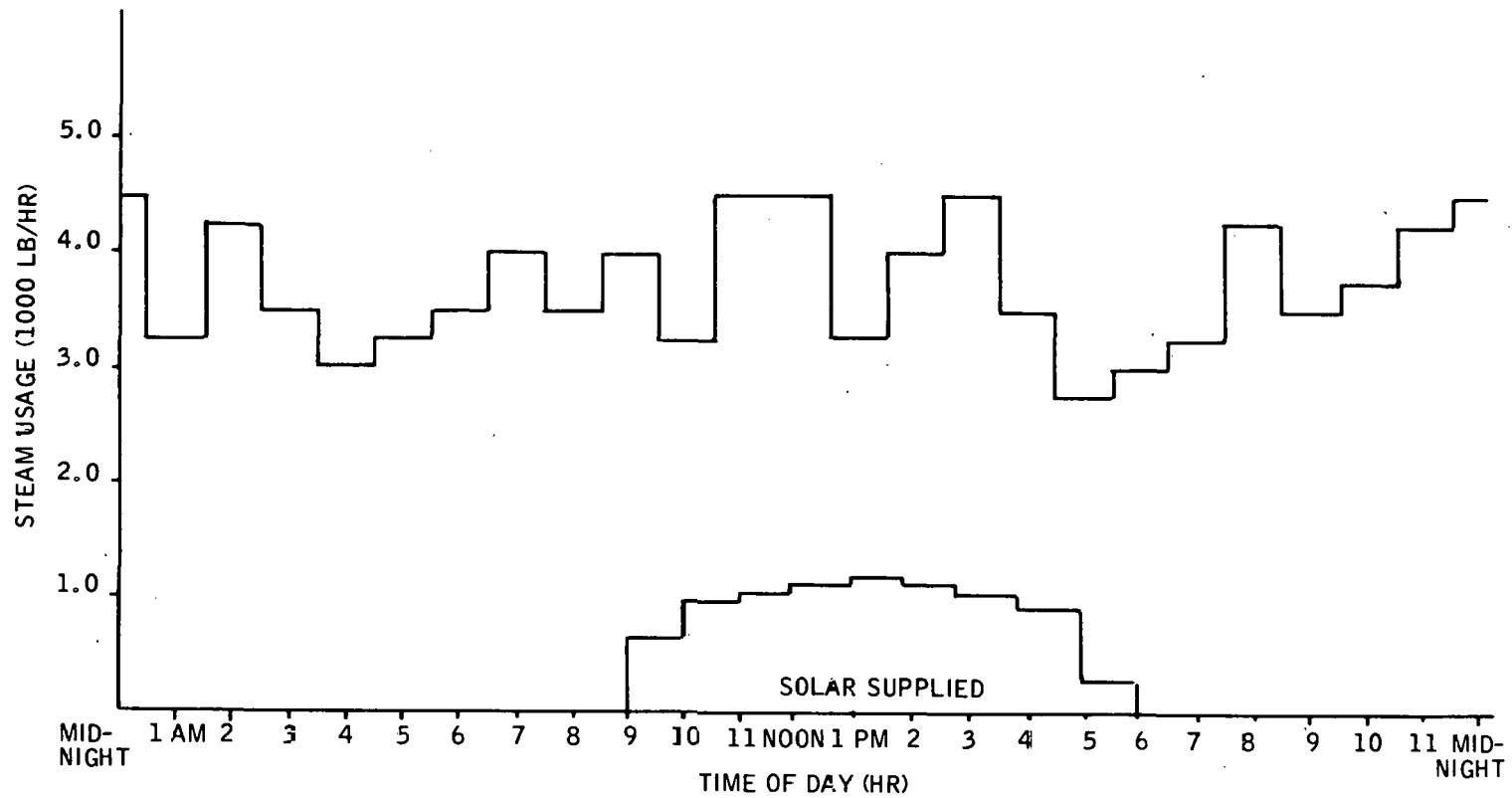


Figure 3-42. POUNDS OF STEAM PRODUCED VS. TIME OF DAY  
DESIGN POINT - 21 SEPTEMBER - EXAMPLE



3-131

Figure 3-43. EXAMPLE OF SYSTEM PRESSURE PLOTS



3-132

Figure 3-44. STEAM USAGE BY HOUR (DEMAND) MARCH 21, 1974 AND PREDICTED SOLAR STEAM SUPPLY

Pepperell data and b) predicted solar steam flow as determined in the performance analysis.

Radiation Sensors -- The radiation sensor data will be plotted versus time (two sensors, two curves) for each day of operation to allow visual inspection of the illumination levels and comparisons with other data. This data will provide a data base of total and direct normal incident radiation not currently available for the Alabama-Georgia locality.

The direct solar insolation on the collector plane,  $I_d$ , will be calculated from the direct normal data,  $I_2$ , using cosine  $\alpha$  factors calculated from the known positions of the sun and the collector field. This parameter ( $I_d$ ) will be plotted versus time.

The solar collector field efficiency at given points in time will be calculated from

$$\eta_c = \frac{Q_c}{A_c I_d} \quad (3-15)$$

where

$\eta_c$  = the efficiency

$Q_c$  = the rate of energy collected as calculated in equation (3-12) (MJ/hr) or (BTU/hr)

$A_c$  = the area of the collector field  
( $m^2$ ) or ( $ft^2$ )

$I_d$  = the direct solar insolation on the collector plane (MJ/hr· $m^2$ ) or (BTU/hr· $ft^2$ )

The total solar system efficiency, at given points in time,  $\eta_{syst}$ , will

be calculated from

$$\eta_{\text{syst}} = \frac{Q_p}{A_c I_d}$$

where

$\eta_{\text{syst}}$  = the energy available-to-energy provided to the process ratio

$Q_p$  = the rate of energy delivered to the process as calculated in equation (3-13) (MJ/hr) or (BTU/hr)

Using data from the pyroheliometer integrator and the process steam integrator, average values of efficiency over a days time will also be calculated.

Solar system efficiency as a function of the total incident radiation may also be calculated using the data from sensor I-1.

Graphs of solar system efficiency versus the operating parameter OP will be generated where

$$OP = \frac{\left( \frac{T1-T3}{2} \right) - T8}{I_d}$$

and T8 is the ambient temperature. This plot is expected to be a family of curves forming a band of expected performance. Figure 3-45 is an illustration of the form this curve will take.

Recorder -- The data collection system is designed for complete compatibility with the Solar Data Acquisition System (SDAS) currently being developed by ERDA. This system will be used for data collection

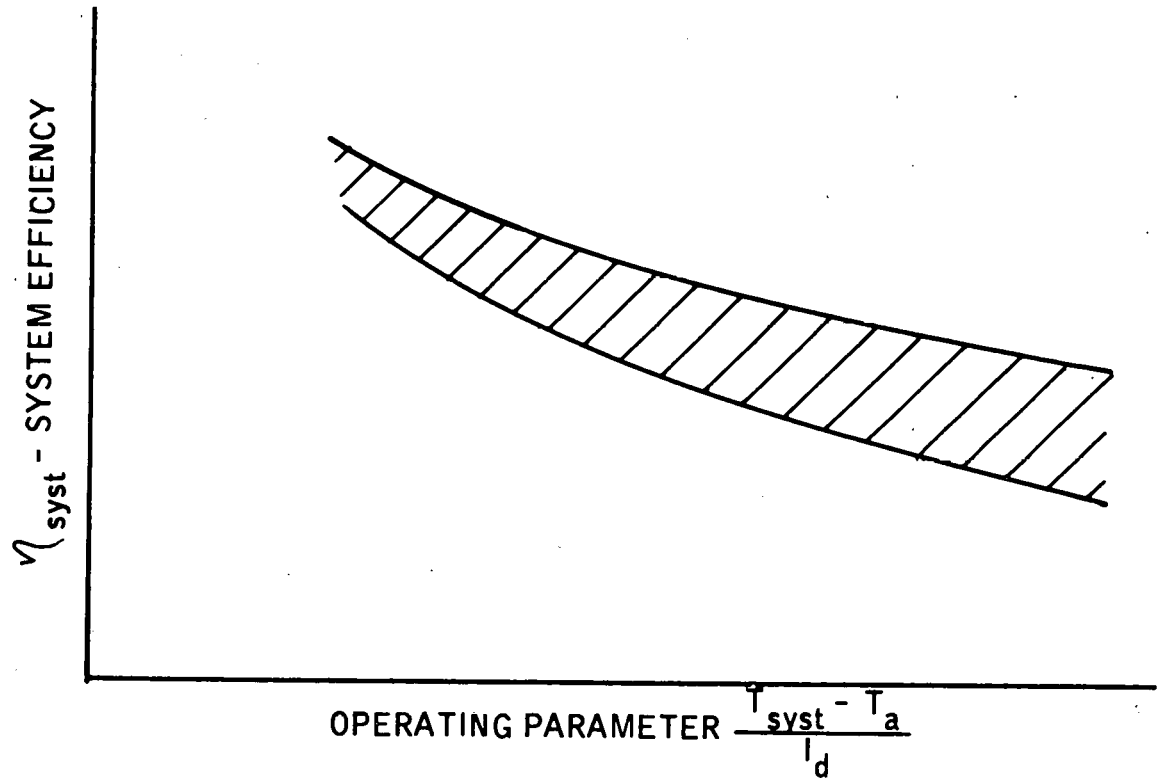


Figure 3-45. EXAMPLE OF EFFICIENCY VERSUS OPERATING PARAMETER CURVE

if it is available when needed. If the SDAS is not available, Honeywell will provide a data logger or recorder from its capital equipment. The data can be recorded continuously or at specific time intervals. Process steam flow and direct radiation will also be integrated due to the critical nature of these parameter in the data analysis and their variability.

SECTION IV  
ECONOMIC ANALYSIS

#### 4.1 INTRODUCTION

The economic analysis conducted in this program involves two approaches. The first is the Lawrence Livermore Laboratories format developed by Dickenson and Shearer which uses two "fiducial" locations so that various solar systems may be compared on a common basis. The second is the industry-specific analysis that uses the specific unique process location to demonstrate the economic viability of the project. This introduction describes these two methodologies briefly, summarizes the performance information used in the economic analysis (performance details are described in Section 3.7), and details the costs used in this analysis. The following subsections describe the results of the analysis.

##### 4.1.1 Methodology

4.1.1.1 Lawrence Livermore Lab Format -- The LLL format, described in detail in Reference 1, is summarized below. Much of this summary is a paraphrasing of Reference 1.

The purpose of this economic analysis is to assist ERDA in evaluating the economic viability of the textile drying solar system that is described in this report. The standard conditions defined herein allow this to be done in a way that is both meaningful to ERDA and equitable for other solar energy systems.

In some ways this analysis imposes conditions that are different from those expected in the textile industry in the Southeast. For example, to avoid the influence of different amounts of insolation in different parts of the country,

this economic analysis is conducted for two "fiducial" locations, Albuquerque, N.M. and Omaha, Neb. Likewise, the fuel oil at \$15 per bbl has been chosen as the standard fossil fuel energy source. These conditions are used for the purposes of this economic analysis even though the proposed textile mill is in Fairfax, Ala. and uses natural gas and coal rather than oil. Likewise, it is necessary to standardize assumed lifetimes, income tax, rate of return on investment, and other factors which in reality will vary from one location to another or from one industry to another.

Four sets of calculations are conducted in this economic analysis:

Plan A - Annual Energy Cost Calculation for Conventional  
Process Heat System using Fuel Oil

Plan B - Annual Energy Cost Calculation for a Combined  
Solar/Fuel Oil System

Plan C - Annual Energy Cost Calculation for Solar Energy Alone

Payback - Calculation of the Payback Period for Plan B

The results of the cost calculations are expressed in \$/MBtu. The payback results are in terms of years.

To simplify the analysis the method of "equivalent uniform annual net disbursements", usually referred to as the "annual cost method" is used. No energy conservation or energy recovery system are included in the analysis. The costs used are in 1977 dollars and include those costs as estimated by a General Contractor based on the Specifications and Installation Drawings developed during Honeywell's Phase I program.

The methodology described by Dickenson in Reference 1 has been coded into a computer program for continuing use in this project. To verify the coding, the example in Reference 1 was run. Figure 4-1 is a reproduction of the output from the program showing identical results to those described in Reference 1.

For the analysis of the solar textile drying system at the "fiducial" locations, the following assumptions are made:

- Lifetime for boilers and solar energy system is 20 years.
- Straight line depreciation on solar energy system
- Federal plus state income tax is 50%
- Initial investment tax credit is 10%
- Inflation rate is zero
- Real after tax rate of return is 10%
- Fuel oil delivered price is \$15 per barrel
- One barrel equals 5.8 MBtu of energy
- Fuel oil conversion efficiency is 70%
- Conventional boiler cost is \$0.20/MBtu
- Salvage value after 20 years is zero
- Local labor rate is \$15/hr.

Furthermore, the analysis is carried out for the case of NO FUEL ESCALATION, and for the case of 5% of ESCALATION IN PRICE OF FUEL OIL. A "levelized" fuel cost technique is used to incorporate this fuel price escalation in the analysis.

PLAN A - ANNUAL ENERGY COST CALCULATION

COST OF FUEL OIL ENERGY:	778916.37
BOILERS:	40000.00
DEDUCTIBLE EXPENSES:	
FUEL OIL:	778916.37
BOILERS:	40000.00
TOTAL:	778916.37
EFFECT OF EXPENDITURES:	-389458.19
AFTER TAX ENERGY COST:	389458.19
BEFORE TAX ENERGY COST:	778916.37
COST PER MILLION BTU:	
(BEFORE TAX)	3.99

PLAN B ANNUAL ENERGY COST CALCULATION

REPAIRMENT TO EQUITY FOR SOLAR FACILITY:	409324.62
10 PERCENT INVESTMENT TAX CREDIT:	-40932.46
COST OF FUEL OIL ENERGY:	389458.19
BOILERS:	40000.00
DEDUCTIBLE EXPENSES:	
FUEL OIL-	389458.19
BOILERS-	40000.00
DMRI-	30000.00
DEPRECIATION-	174340.00
TOTAL	613898.25
EFFECT OF EXPENDITURES:	-389349.12
AFTER TAX ENERGY COST:	501091.19
BEFORE TAX ENERGY COST:	1002492.37
COST PER MILLION BTU:	
(BEFORE TAX)	5.01

ANNUAL COST CALCULATION FOR SOLAR ENERGY ALONE

REPAIRMENT TO EQUITY FOR SOLAR FACILITY:	409324.62
10 PERCENT INVESTMENT TAX CREDIT:	-40932.46
SOLAR OIL REPLACEMENT AND INSURANCE:	30000.00
DEDUCTIBLE EXPENSES:	
DMRI-	30000.00
DEPRECIATION-	174340.00
TOTAL	204340.00
EFFECT OF EXPENDITURES:	-101120.00
AFTER TAX COST:	528544.68
BEFORE TAX COST:	528544.68
RATE PER MILLION BTU:	
(BEFORE TAX)	5.93

CALCULATION OF PAYBACK PERIOD FOR PLAN B

ANNUAL PLAN B CASH SAVINGS:	217433.19
ADDED INCOME BEFORE TAX:	165212.19
ADDED INCOME TAX:	32609.09
NET ANNUAL INCREMENTAL CASHFLOW:	256349.09
PAYBACK PERIOD:	12.21 YEARS
STOP:	

4-4

Figure 4-1. EXAMPLE, ECONOMICS PROGRAM OUTPUT, REFERENCE 1 SAMPLE

4.1.1.2 Industry Format -- The site specific economic analysis utilizes the LLL format as its basis. The variations include:

Fuel costs

Fuel escalation rate

Labor rates

Electricity rates

The WestPoint Pepperell Fairfax, Alabama mill uses natural gas as its primary fuel and coal as the backup. Its average fuel cost for 1978 is estimated to be \$1.68 per MBtu (40% natural gas at \$1.65 per MBtu and 60% coal at \$1.70 per MBtu). Thus fuel costs at the site are considerably cheaper than those assumed for the comparative analysis.

WestPoint Pepperell has estimated that their fuel costs will escalate at a rate of 7% per year over the three year period of 1978 to 1981. This escalation rate is taken over 20 years in the analysis. This escalation rate, combined with a return on investment of 0.1 gives a Multiplying Factor (MF) of 1.66. The resulting "levelized" fuel cost is \$2.68 per MBtu.

Maintenance labor rates in the Fairfax, Alabama area are \$6 per hour. This cost affects the Operation, Maintenance, Replacement, and Insurance (OMRI) costs. Subsection 4.4 describes the calculation of OMRI cost in detail.

Electricity rates at Fairfax, Alabama are \$0.02/Kw Hr. This cost affects the operation portion of the OMRI cost as detailed in Subsection 4.4.

Of course the industry format uses performance data representative of Fairfax, Alabama. This data was described in detail in Section 3.7 and is summarized in this subsection below.

**4.1.2 Performance** -- This subsection describes the energy demand for the process and the solar contribution to that demand - two inputs to the economic analysis.

**4.1.2.1 Energy demand** -- The solar system has been designed to supply the day shift energy demand of three slashers with 21 cylindrical drying cans (seven cans/dryer). Based on the data provided by WestPoint Pepperell, these three slashers have a demand of  $2.8 \times 10^6$  MJ per year ( $2.65 \times 10^9$  Btu/yr). It is this demand that is used in the economic analysis.

**4.1.2.2 Solar contribution** -- the solar contribution is defined for three locations - Albuquerque, NM, Omaha, Nebraska, and Fairfax, Alabama. For the "fiducial" locations Albuquerque and Omaha, the data for radiation available is taken from reference 1, "Average direct radiation on a surface tracking about an east-west axis,"

Season	Radiation (MJ/m <sup>2</sup> )	
	Albuq.	Omaha
Spring	16.3	9.7
Summer	22.7	14.7
Fall	17.1	13.1
Winter	22.2	12.4

The yearly radiation is calculated as recommended - the sum of the seasonal values x 365/4.

The radiation available at Albuquerque is

$$7145 \text{ MJ/m}^2 \text{ (629,463 Btu/ft}^2\text{)}$$

The radiation available at Omaha is

$$4553 \text{ MJ/m}^2 \text{ (401,152 Btu/ft}^2\text{)}$$

For Fairfax, Alabama, performance data was calculated using the SUNSIM program developed at Honeywell. The Atlanta, Georgia 1952 weather tape was used and collector orientation of 40° east-of-north as described in the system design was used. Subsection 3.7 describes the performance analysis in detail and compares SUNSIM results for Albuquerque and Omaha with the data taken from Reference 1.

Table 4-1 summarizes the solar contribution data used in the economic analysis. The radiation available, QAVAIL, is the radiation falling on the collector aperture during the 300 working days of the year. The amount of energy delivered to the process, QPROCES, includes the collector losses, system losses, and steam generator efficiency. The percentage of solar contribution to the demand is included in Table 4-1.

**4.1.3 Cost** -- This subsection details the Installed Solar Energy System Cost for the "fiducial" locations of Albuquerque, N.M. and Omaha, Neb. and the site specific location of Fairfax, Ala. These costs are based on estimates made by a general contractor in the Fairfax area using the specifications and drawings.

TABLE 4-1. SOLAR CONTRIBUTION, THREE LOCATIONS

	ALBUQUERQUE, N.M. 1962	OMAHA, NEB. 1962	FAIRFAX, ALA. 1952
QAVAIL/AREA (300 DAYS)	5900 MJ/M <sup>2</sup> (519,000 BTU/FT <sup>2</sup> )	3700 MJ/M <sup>2</sup> (329,700 BTU/FT <sup>2</sup> )	3700 MJ/M <sup>2</sup> (324,600 BTU/FT <sup>2</sup> )
TOTAL QAVAIL (300 DAYS)	4.56 X 10 <sup>6</sup> MJ (4.3 X 10 <sup>9</sup> BTU)	2.86 X 10 <sup>6</sup> MJ (2.7 X 10 <sup>9</sup> BTU)	2.85 X 10 <sup>6</sup> MJ (2.7 X 10 <sup>9</sup> BTU)
QPROCESS	2.1 X 10 <sup>6</sup> MJ (2.0 X 10 <sup>9</sup> BTU)	1.3 X 10 <sup>6</sup> MJ (1.2 X 10 <sup>9</sup> BTU)	1.3 X 10 <sup>6</sup> MJ (1.2 X 10 <sup>9</sup> BTU)
PERCENT OF DEMAND	75%	46%	46%

The installed solar system costs by major subcontractor are listed in Table 4-2. These categories were convenient in costing due to the manner in which Honeywell received its estimates. Tables 4-3, 4-4, and 4-5 detail the General Contractors estimate. Note that the labor estimate is in hours and \$15 per hour is used in the "fiducial" location analysis (although the local labor rate at the site is \$10 per hour). Table 4-6 itemizes the collector materials and Table 4-7 details the systems engineering and the collector assembly labor costs. Based on these costs; the installed solar system cost used in the economic analysis is:

\$53.28/sq. ft. "Fiducial" locations

\$51.13/sq. ft. Fairfax, Alabama

TABLE 4-2. INSTALLED SOLAR SYSTEM COST

	Fairfax	Albuquerque & Omaha
General Contractor Estimate Materials & Installation	\$224,083	\$256,153
Collector Materials	\$110,296	\$110,296
System Engr., Tech., Assembly	\$ 78,675	\$ 64,500
Crating & Shipping	\$ 12,000	\$ 12,000
<b>TOTAL COST</b>	<b>\$425,054</b>	<b>\$442,949</b>
Cost Per Square Foot	\$51.13	\$53.28

TABLE 4-3. GENERAL CONTRACTOR MATERIALS COST

<u>Item</u>	<u>Cost</u>
Steam Generator (Patterson Kelly)	\$ 9,864.00
Field Flow Pump (Buffalo)	2,783.00
Feedwater Pump (Skidmore)	705.00
Masonry (door, etc.)	680.00
Steam Flow Meter & Recorder (Hays)	1,965.00
Air Eliminator	771.00
Air Trap	250.00
Expansion Tank	1,461.00
Nitrogen Equipment	600.00
Temp Wells	140.00
Fence	1,185.00
Prefab Penthouse & Landing	11,463.00
Collector Supports (pipe supports)	14,664.00
Pitch Pans, Pitch, & Plywood	4,654.00
Other Steel	2,002.00
Piping & Fittings & Valves	8,471.00
Pipe Hangers & Wall Sleeves	4,078.00
Stand-by Generator	6,320.00
Transformers, Relays & Annunciator	3,121.00
Misc. & OH	20,561.00
Electrical Materials	27,331.00
Insulation	10,506.00
Paint	<u>1,080.00</u>
<b>TOTAL</b>	<b>\$134,655.00</b>

TABLE 4-4. GENERAL CONTRACTOR'S LABOR COSTS

ITEM	HOURS	COST \$	
		FAIRFAX <sup>a</sup>	ALBQ. & OMAHA <sup>b</sup>
Assemble Collectors	720	7,200	10,800
Assemble Penthouse	120	1,200	1,800
Install Steam Generator	48	480	720
Install Door	48	480	720
Install Standby Generator	32	320	4,800
Welding and Assembly	1440	14,400	21,600
Supervision	17 wks.	6,800	6,800
14% Soc. Sec., Work. Comp., etc		4,323	4,323
Painting	540	5,500	8,100
Electrical	2152	23,020	32,280
Insulation	1250	<u>14,000</u>	<u>18,750</u>
TOTAL		<u>78,623</u>	<u>110,693</u>

a - local labor rates

b - average labor rate of \$15 per hour

TABLE 4-5. GENERAL CONTRACTOR TOTALS (\$)

	FAIRFAX	ALBQ. & OMAHA
Materials	134,655	134,655
Labor	78,623	110,693
Mark-Up	10,805	10,805
TOTAL	\$224,083	\$256,153

TABLE 4-6. COLLECTOR MATERIALS & INSTRUMENTATION

Single Collector Subassembly	
Reflector Assembly	\$ 907
Absorber Assembly	307
Motor/Gearbox Assembly	595
Unit Controller	<u>454</u>
TOTAL	\$2,263

Instrumentation	
Photocell	\$ 12
Anemometer	360
Flow Switch	85
Pressure Sensor	420
Temperature Sensor (3)	81
Steam Flow Meter	<u>729</u>
TOTAL	\$1,687

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Total Cost - Complete Field	
Material cost per Collector	\$ 2,263
48 Collectors	
Total Material Cost	\$110,296
Instrumentation	<u>1,687</u>
TOTAL	\$108,609

TABLE 4-7. SYSTEMS ENGR., TECH., SUBASSEMBLY

	Hours	Dollars	
		Fairfax <sup>a</sup>	Albq. & Omaha <sup>b</sup>
Systems Engr.	500	\$15,973	\$ 7,500
Technician	800	18,897	12,000
Sub-assembly	3000	<u>43,805</u>	<u>45,000</u>
TOTALS		<u>\$78,675</u>	<u>\$64,500</u>

a - includes local labor rates and overhead

b - average labor rate of \$15 per hour

#### 4.2 LAWRENCE LIVERMORE LABS FORMAT RESULTS (AND COST OF ENERGY)

Four sets of results were generated using the LLL format. They are

Albuquerque - no escalation

Albuquerque - escalation

Omaha - no escalation

Omaha - escalation

Tables 4-8, 4-9, 4-10, and 4-11 tabulate these results (two pages per table) in the prescribed format based on the methodology and inputs described above. The OMRI inputs is discussed in detail in subsection 4.4.

The cost of energy and payback times determined in this analysis are:

	COST (\$/MBtu)			
	Albuquerque		Omaha	
	No Escal.	Fuel Escal.	No Escal.	Fuel Escal.
Plan A - Convention Fuel (Fuel Oil)	3.89	5.46	3.89	5.46
Plan B - Combined/Solar/ Conventional	29.74	30.14	30.79	31.63
Plan C - Solar only	38.27	38.27	62.22	62.22

Payback Times (Years)	31.6	28.1	35.5	32.7
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**Table 4e8a. Economics Analysis Results  
Albuquerque, No Escalation**

PLAN A - ANNUAL ENERGY COST CALCULATION

COST OF FUEL OIL ENERGY:		9775.86
BOILERS:		529.20
DEDUCTIBLE EXPENSES:		
FUEL OIL:	9775.86	
BOILERS:	529.20	
TOTAL	10305.06	
EFFECT OF EXPENDITURES:		-5152.53
AFTER TAX ENERGY COST:		5152.53
BEFORE TAX ENERGY COST:		10305.06
COST PER MILLION BTUS: (BEFORE TAX)		3.89

PLAN B ANNUAL ENERGY COST CALCULATION

REPAYMENT TO EQUITY FOR SOLAR FACILITY:		52024.98
10 PERCENT INVESTMENT TAX CREDIT:		-5202.50
COST OF FUEL OIL ENERGY:		2467.98
BOILERS:		529.20
DEDUCTIBLE EXPENSES:		
FUEL OIL-	2467.98	
BOILERS-	529.20	
OMRI-	4205.00	
DEPRECIATION-	22145.83	
TOTAL	29348.01	
EFFECT OF EXPENDITURES:		-14674.01
AFTER TAX ENERGY COST:		39350.66
BEFORE TAX ENERGY COST:		73701.31
COST PER MILLION BTUS: (BEFORE TAX)		29.74

Table 4-8b. Economics Analysis Results  
Albuquerque, No Escalation

ANNUAL COST CALCULATION FOR SOLAR ENERGY ALONE

REPAYMENT TO EQUITY FOR SOLAR FACILITY:		52024.93
10 PERCENT INVESTMENT TAX CREDIT:		-5202.50
SOLAR O&M REPLACEMENT AND INSURANCE:		4205.00
DEDUCTIBLE EXPENSES:		
OMRI-	4205.00	
DEPRECIATION-	22145.83	
TOTAL	26350.83	
EFFECT OF EXPENDITURES: AFTER TAX COST:		-13175.42 37852.07
BEFORE TAX COST:		75704.14
RATE PER MILLION BTU: (BEFORE TAX)		39.27

CALCULATION OF PAYBACK PERIOD FOR PLAN B

ANNUAL PLAN B CASH SAVINGS:	3102.88
ADDED INCOME BEFORE TAX:	-19042.95
ADDED INCOME TAX:	-9521.47
NET ANNUAL INCREMENTAL CASHFLOW:	12621.36
PAYBACK PERIOD:	31.58YEARS

**Table 4-9a. Economics Analysis Results  
Albuquerque, Fuel Escalation**

PLAN A - ANNUAL ENERGY COST CALCULATION

COST OF FUEL OIL ENERGY:	13907.79
BOILERS:	529.20
DEDUCTIBLE EXPENSES:	
FUEL OIL:	13907.79
BOILERS:	529.20
TOTAL	14436.99
EFFECT OF EXPENDITURES:	-7213.50
AFTER TAX ENERGY COST:	7213.50
BEFORE TAX ENERGY COST:	14436.99
COST PER MILLION BTUS: (BEFORE TAX)	5.46

PLAN B ANNUAL ENERGY COST CALCULATION

REPAYMENT TO EQUITY FOR SOLAR FACILITY:	52024.98
10 PERCENT INVESTMENT TAX CREDIT:	-5202.50
COST OF FUEL OIL ENERGY:	3511.11
BOILERS:	529.20
DEDUCTIBLE EXPENSES:	
FUEL OIL-	3511.11
BOILERS-	529.20
OMRI-	4203.00
DEPRECIATION-	22145.83
TOTAL	30391.15
EFFECT OF EXPENDITURES:	-15195.57
AFTER TAX ENERGY COST:	39872.23
BEFORE TAX ENERGY COST:	79744.45
COST PER MILLION BTUS: (BEFORE TAX)	30.14

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Table 4-10a. Economics Analysis Results  
Omaha, No Escalation

PLAN A - ANNUAL ENERGY COST CALCULATION

COST OF FUEL OIL ENERGY:		9775.86
BOILERS:		529.20
DEDUCTIBLE EXPENSES:		
FUEL OIL:	9775.86	
BOILERS:	529.20	
TOTAL	10305.06	
EFFECT OF EXPENDITURES:		-5152.53
AFTER TAX ENERGY COST:		5152.53
BEFORE TAX ENERGY COST:		10305.06
COST PER MILLION BTUS: (BEFORE TAX)		3.89

PLAN B ANNUAL ENERGY COST CALCULATION

REPAYMENT TO EQUITY FOR SOLAR FACILITY:		52024.96
10 PERCENT INVESTMENT TAX CREDIT:		-5202.50
COST OF FUEL OIL ENERGY:		5283.25
BOILERS:		529.20
DEDUCTIBLE EXPENSES:		
FUEL OIL-	5283.25	
BOILERS-	529.20	
OMRI-	4159.00	
DEPRECIATION-	22145.83	
TOTAL	32117.29	
EFFECT OF EXPENDITURES:		-15058.64
AFTER TAX ENERGY COST:		40735.30
BEFORE TAX ENERGY COST:		81470.59
COST PER MILLION BTUS: (BEFORE TAX)		30.79

Table 4-10b. Economics Analysis Results  
Omaha, No Escalation

<u>ANNUAL COST CALCULATION FOR SOLAR ENERGY ALONE</u>		
REPAYMENT TO EQUITY FOR SOLAR FACILITY:		52024.93
10 PERCENT INVESTMENT TAX CREDIT:		-5202.50
SOLAR O&M REPLACEMENT AND INSURANCE:		4159.00
DEDUCTIBLE EXPENSES:		
DMRI-	4159.00	
DEPRECIATION-	22145.83	
TOTAL	26304.83	
EFFECT OF EXPENDITURES:		-13152.42
AFTER TAX COST:		37829.07
BEFORE TAX COST:		75658.14
RATE PER MILLION BTU: (BEFORE TAX)		62.22

CALCULATION OF PAYBACK PERIOD FOR PLAN B

ANNUAL PLAN B CASH SAVINGS:	333.61
ADDED INCOME BEFORE TAX:	-21812.22
ADDED INCOME TAX:	-10906.11
NET ANNUAL INCREMENTAL CASHFLOW:	11239.72
PAYBACK PERIOD:	35.47YEARS

Table 4-11a. Economics Analysis Results  
Omaha, Fuel Escalation

PLAN A - ANNUAL ENERGY COST CALCULATION

COST OF FUEL OIL ENERGY:		13307.79
BOILERS:		529.20
DEDUCTIBLE EXPENSES:		
FUEL OIL:	13307.79	
BOILERS:	529.20	
TOTAL	14436.99	
EFFECT OF EXPENDITURES:		-7218.50
AFTER TAX ENERGY COST:		7218.50
BEFORE TAX ENERGY COST:		14436.99
COST PER MILLION BTUS: (BEFORE TAX)		5.46

PLAN B ANNUAL ENERGY COST CALCULATION

REPAYMENT TO EQUITY FOR SOLAR FACILITY:		52024.98
10 PERCENT INVESTMENT TAX CREDIT:		-5202.50
COST OF FUEL OIL ENERGY:		7516.31
BOILERS:		529.20
DEDUCTIBLE EXPENSES:		
FUEL OIL-	7516.31	
BOILERS-	529.20	
OMRI-	4159.00	
DEPRECIATION-	22145.83	
TOTAL	34350.34	
EFFECT OF EXPENDITURES:		-17175.17
AFTER TAX ENERGY COST:		41851.82
BEFORE TAX ENERGY COST:		93703.64
COST PER MILLION BTUS: (BEFORE TAX)		31.63

**Table 4-11b. Economics Analysis Results  
Omaha, Fuel Escalation**

ANNUAL COST CALCULATION FOR SOLAR ENERGY ALONE

REPAYMENT TO EQUITY FOR SOLAR FACILITY:		52024.98
10 PERCENT INVESTMENT TAX CREDIT:		-5202.50
SOLAR O&M REPLACEMENT AND INSURANCE:		4159.00
DEDUCTIBLE EXPENSES:		
DMRI-	4159.00	
DEPRECIATION-	22145.83	
TOTAL	26304.83	
EFFECT OF EXPENDITURES: AFTER TAX COST:		-13152.42 37829.07
BEFORE TAX COST:		75638.14
RATE PER MILLION BTU: (BEFORE TAX)		62.22

CALCULATION OF PAYBACK PERIOD FOR PLAN B

ANNUAL PLAN B CASH SAVINGS:	2232.49
ADDED INCOME BEFORE TAX:	-19913.34
ADDED INCOME TAX:	-9956.67
NET ANNUAL INCREMENTAL CASHFLOW:	12189.16
PAYBACK PERIOD:	32.70YEARS

### 4.3 INDUSTRY FORMAT RESULTS (AND COST OF ENERGY)

The results based on the industry specific data are given in Table 4-12 and 4-13 (two pages per table). Because of the lower fuel costs and less solar contribution at Fairfax, Alabama, payback time is longer and the cost of the solar energy is higher.

The cost of energy determined in this analysis is:

	COST (\$/MBtu)	
	No Escalation	Fuel Escalation
Plan A - Conventional Fuel gas/coal	2.60	4.19
Plan B - Combined Solar/ Conventional	28.61	29.46
Plan C - Solar only	57.91	57.91

The payback times are,

36.4 years for no escalation,

33.2 years for fuel escalation

### 4.4 OPERATION, MAINTENANCE, REPLACEMENT AND INSURANCE (OMRI)

These costs are broken down in the following subsections and estimated for the "fiducial" locations and for Fairfax, Ala. Table 4-14 summarizes and totals the OMRI costs. The sensitivity of the system payback to the OMRI cost was investigated by running the economics analysis program and parametrically varying the value of OMRI over the expected range. Figure 4-2 shows that the payback period is not sensitive to the OMRI value.

Using \$4000 per year as a nominal OMRI value, reducing the OMRI by 50%

Table 4-12a. Economics Analysis Results Fairfax, No Escalation

PLAN A - ANNUAL ENERGY COST CALCULATION

COST OF FUEL OIL ENERGY:		6350.40	
BOILERS:		529.20	
DEDUCTIBLE EXPENSES:			
FUEL OIL-	6350.40		
BOILERS-	529.20		
TOTAL	6879.60		
EFFECT OF EXPENDITURES:		-3439.80	
AFTER TAX ENERGY COST:		3439.80	
BEFORE TAX ENERGY COST:		6879.60	
COST PER MILLION BTUS:			2.60
(BEFORE TAX)			

PLAN B - ANNUAL ENERGY COST CALCULATION

REPAYMENT TO EQUITY FOR SOLAR FACILITY:		49925.40	
10 PERCENT INVESTMENT TAX CREDIT:		-4992.55	
COST OF FUEL OIL ENERGY:		3374.40	
BOILERS:		529.20	
DEDUCTIBLE EXPENSES:			
FUEL OIL-	3374.40		
BOILERS-	529.20		
SMRI-	3151.00		
DEPRECIATION-	21252.13		
TOTAL	28346.73		
EFFECT OF EXPENDITURES:		-14173.39	
AFTER TAX ENERGY COST:		37954.13	
BEFORE TAX ENERGY COST:		75703.27	
COST PER MILLION BTUS:			29.61
(BEFORE TAX)			

Table 4-12b. Economics Analysis Results Fairfax, No Escalation

PLAN C - ANNUAL COST CALCULATION FOR SOLAR ENERGY ALONE

REPAYMENT TO EQUITY FOR SOLAR FACILITY:		49925.48
10 PERCENT INVESTMENT TAX CREDIT:		-4992.55
SOLAR O&M REPLACEMENT AND INSURANCE:		3191.00
DEDUCTIBLE EXPENSES:		
DMRI-	3191.00	
DEPRECIATION-	21252.18	
TOTAL	24443.18	
EFFECT OF EXPENDITURES: AFTER TAX COST:		-12221.59 35902.34
BEFORE TAX COST:		71804.67
RATE PER MILLION BTU: (BEFORE TAX)		57.91

CALCULATION OF PAYBACK PERIOD FOR PLAN B

ANNUAL PLAN B CASH SAVINGS:	-215.00
ADDED INCOME BEFORE TAX:	-21467.18
ADDED INCOME TAX:	-10733.59
NET ANNUAL INCREMENTAL CASH FLOW:	10518.59
PAYBACK PERIOD:	38.37 YEARS

Table 4-13a. Economics Analysis Results Fairfax, Fuel Escalation  
PLAN A - ANNUAL ENERGY COST CALCULATION

COST OF FUEL OIL ENERGY:		10562.03	
BOILERS:		529.20	
DEDUCTIBLE EXPENSES:			
FUEL OIL-	10562.03		
BOILERS-	529.20		
TOTAL	11091.23		
EFFECT OF EXPENDITURES:		-5545.61	
AFTER TAX ENERGY COST:		5545.61	
BEFORE TAX ENERGY COST:		11091.23	
COST PER MILLION BTUS: (BEFORE TAX)			4.19

PLAN B - ANNUAL ENERGY COST CALCULATION

REPAYMENT TO EQUITY FOR SOLAR FACILITY:		4992.45	
10 PERCENT INVESTMENT TAX CREDIT:		-4992.35	
COST OF FUEL OIL ENERGY:		5612.33	
BOILERS:		529.20	
DEDUCTIBLE EXPENSES:			
FUEL OIL-	5612.33		
BOILERS-	529.20		
OMRI-	3191.00		
DEPRECIATION-	21252.18		
TOTAL	30584.71		
EFFECT OF EXPENDITURES:		-15299.36	
AFTER TAX ENERGY COST:		39973.02	
BEFORE TAX ENERGY COST:		77946.19	
COST PER MILLION BTUS: (BEFORE TAX)			29.46

Table 4-13b. Economics Analysis Results Fairfax, Fuel Escalation  
PLAN C - ANNUAL COST CALCULATION FOR SOLAR ENERGY ALONE

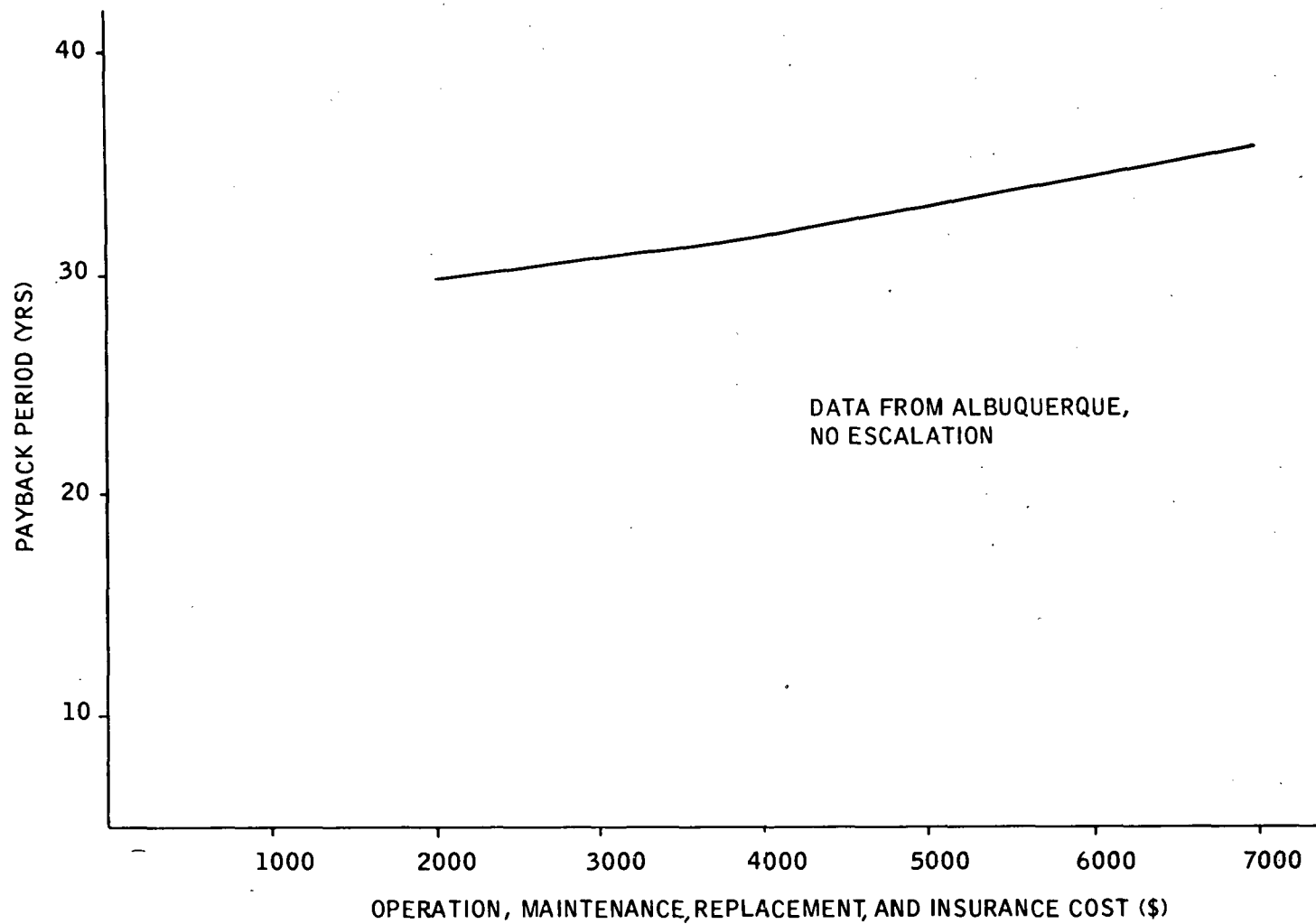
REPAYMENT TO EQUITY FOR SOLAR FACILITY:		49925.48
10 PERCENT INVESTMENT TAX CREDIT:		-4992.56
SOLAR OWN REPLACEMENT AND INSURANCE:		3191.00
DEDUCTIBLE EXPENSES:		
OMRI-	3191.00	
DEPRECIATION-	21252.18	
TOTAL	24443.18	
EFFECT OF EXPENDITURES: AFTER TAX COST:		-12221.59 35902.34
BEFORE TAX COST:		71804.67
RATE PER MILLION BTU: (BEFORE TAX)		57.91

CALCULATION OF PAYBACK PERIOD FOR PLAN B

ANNUAL PLAN B CASH SAVINGS:	1753.70
ADDED INCOME BEFORE TAX:	-19493.48
ADDED INCOME TAX:	-9746.74
NET ANNUAL INCREMENTAL CASH FLOW:	11505.44
PAYBACK PERIOD:	33.25 YEARS

TABLE 4-14. TOTAL OMRI

	Albuquerque	Omaha	Fairfax
Operation Costs	\$ 197	\$ 151	\$ 101
Maintenance Costs	1,350	1,350	540
Replacement Costs	2,215	2,215	2,125
Insurance Costs	443	443	425
TOTALS	\$4,205	\$4,159	\$3,191



4-31

Figure 4-2. PAYBACK PERIOD OF COLLECTOR SYSTEM VS. OMRI COSTS

(to \$2000) reduces the payback period by only 7% (31.7 years to 29.5 years). Furthermore, if the OMRI is 50% higher (\$6000) the payback period increases by only 7% (31.7 years to 34.0 years).

**4.4.1 Operations Costs** -- The operating costs are the costs of the electrical usage. Each of the electrical components was evaluated for power demand and duty cycle. Table 4-15 summarizes the results of this evaluation. As will be apparent below, these costs are small and the economics analysis is relatively insensitive to the assumptions made in the operating costs.

The field flow pump will operate continuously when the collector system is in operation. This is estimated to be 2200 hours/yr. in Albuquerque and 1400 hours/yr. in Omaha and Fairfax. The feedwater pump operates intermittently as demanded by the steam generator. Based on predicted performance, this pump will operate 1100 hrs/yr in Albuquerque and 730 hrs/yr. in Omaha and Fairfax. The collector field motors stow and unstow sequenced, and track on a staggered sequence. Each collector motor is expected to operate approximately 50 hours/yr. in all locations. Although more sunshine days and operation hours occur in Albuquerque, the system will experience additional stowing and unstowing at the other locations due to variable weather. The system controller will be on continuously 24 hours/day, 365 days/yr. Since the system is daylight dependent, very little lighting power is expected to be needed. Safety lighting and outlets are provided. They will be used approximately 300 Kwh per year.

TABLE 4-15. OPERATING COSTS

	Power (kw)	Hours of Operation/yr			Operating Cost		
		Albq.	Omaha	Fairfax	Albq. <sup>a</sup>	Omaha <sup>a</sup>	Fairfax <sup>b</sup>
Field Flow Pump	1.5	2200	1400	1400	\$99	\$63	\$42
Feedwater Pump	0.9	1100	730	730	\$30	\$20	\$13
Field 48 Motors and Unit Control System	12.0 <sup>c</sup>	50 <sup>c</sup>	50	50	\$18	\$18	\$12
System Controller	.1	13760	13766	13766	\$41	\$41	\$28
Lights and Misc.					\$ 9	\$ 9	\$ 6
TOTALS					\$197	\$151	\$101

a - electricity cost at 3¢/kwh

b - electricity cost at 2¢/kwh

c - operation is randomly sequenced  
 resulting in duty cycle of approximately  
 2.5% (average)

4.4.2 Maintenance Costs -- Maintenance costs are estimated for this system by averaging maintenance over the 20 year lifetime of the equipment. Thus, the expected increasing maintenance near the end of the 20 year lifetime is averaged into the total. Furthermore, the Phase II setup and check out task, and any Phase III tests or debugging is not considered as typical maintenance costs for the operational system.

The hours of maintenance per year are summarized in Table 4-16 along with the costs at various locations. The visual inspection of the system is a scheduled 20 minute walk around the field and into the penthouse every-other day - 150 days per year. The maintenance man will perform no maintenance or repair during this inspection but will note items in a log book.

Major component maintenance is scheduled for every quarter. It is expected to take 4 hours to accomplish the following tasks,

- drain and refill steam generator shell
- maintain two pumps/motors
- check gearbox oil level
- inspect hoses/rotary joints

The mirror surfaces will be washed two times per year. This flushing of the surface with process water is estimated to take 15 minutes per collector or 12 hours for the complete field.

4.4.3 Replacement Costs -- Replacement costs are estimated based on replacement of 10% of the system over the 20 year lifetime. For the "fiducial" locations, the installed system cost is \$442,949. Therefore,

TABLE 4-16. MAINTENANCE COSTS

	Hours/yr	Cost (\$)	
		Albuquerque & a Omaha	Fairfax b
Visual Inspection of System	50	750	300
Major Component Maintenance	16	240	96
Wash Mirrors	24	360	144
TOTALS	90	\$1350	\$540

a average labor rate of \$15/hr

b local labor rate of \$6/hr

the replacement cost is \$44,295 total and \$2,215 per year.

For Fairfax, the installed system cost is \$425,054. The replacement cost is \$42,505 total and \$2,125 per year.

4.4.4 Insurance Cost -- Discussions with WestPoint Pepperell's Insurance underwriter, Factory Mutual, have defined the cost of insurance as 10¢ per \$100 of system value. Therefore, insurance at the "fiducial" locations is \$443 per year, at Fairfax the insurance permium is \$425 per year.

#### 4.5 COST EFFECTIVENESS

The potential for cost effectiveness is addressed by reexamining the costs listed above in subsection 4.1.3. System effectiveness can be expected to improve by percentage points as equipment is redesigned and further developed based on experience gained in the ERDA demonstrations. However, any marked improvements in cost effectiveness will have to come through cost reduction.

Table 4-2 shows that the conventional construction cost portion of the installed solar cost represents approximately 55% of the total cost. The remaining 45% is for the solar collector materials and assembly. Thus system cost is not sensitive to one particular item and cost reduction must address not only collector design but also system design to reduce the cost of installation. It should be noted that these costs represent a retrofit project and collector costs would probably be a larger percentage of the system cost if it were not a retrofit of an existing mill.

From the systems viewpoint, the areas where cost reductions could be achieved are the following:

- piping and insulation
- supports for the collector field
- electrical wiring for tracking system

Further attempts to minimize the material and labor costs could result in sizable reductions of solar systems cost, however, for retrofit solar demonstration systems much of the design is constrained by existing facilities.

For the solar collector, the areas of significant cost reductions are the following:

- unit controller with reduced flexibility
- motor/drive system
- reflector assembly
- gang driven collectors

Multiple units driven by the same motor/drive and controller system could reduce the tracking system cost considerably. However, this would result in sacrifice of the tracking accuracy and flexibility of operation. It is felt that as the design matures and the collectors and systems are installed in large fields, the solar system installed costs should come down.

Further economy in solar system design can be realized through size. The system proposed is of demonstration size, and represents a relatively small job to the general contractors. Larger fields of collectors would

realize some economy of size. Furthermore, the general contractors are unfamiliar with this type of installation and may be expected to bid high due to uncertainties and lack of history. When solar systems become more routine, the cost for installation may come down.

SECTION V  
REFERENCES

- (1) Method of Economic Analysis for Comparison of Solar Process Heat Systems, Dickenson, W. C. and Shearer, J. N. (Revised August 1, 1976) Lawrence Livermore Laboratory, Livermore, California.
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- (3) Journal of Heat Transfer 98, no. 199 (1976).
- (4) Analysis of Heat & Mass Transfer, Eckert, E.R.G. and Drake, R. M. Jr., McGraw Hill, New York, 1972, p.628.