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**CENTRAL RECEIVER SOLAR THERMAL
POWER SYSTEM, PHASE 1**

**Quarterly Progress Report for
Period Ending June 30, 1976**

July 1976

Work Performed Under Contract E(04-3)-1110

**Martin Marietta Corporation
Denver, Colorado**

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SECTION I

I. INTRODUCTION

During this report period (April 1976 through June 1976), the major program activities were aimed toward the fabrication of the three major research experiments and continued evaluation of the Pilot Plant performance and operating modes. The detail designs were completed early in this period.

Effort was continued in the evaluation of Pilot Plant start transients. Both warm and hot starts from Thermal Storage were evaluated as was a cold start from the Receiver. In addition, we continued to collect and evaluate insolation data for use in these start transient studies.

In the Collector Subsystem Experiment the heliostat structures and drive mechanisms were completed and delivered. The sensor and associated electronics for the first heliostat were completed as were installation and checkout of the PDP-11 computer and control console for the entire Collector Experiment. By the end of May the first twenty-five mirror heliostat had been erected and was operational. By the end of this period this heliostat was being operated in conjunction with the calorimeter in order to conduct calorimeter checkout and calibration.

The detail design of the 5 MW Receiver Experiment was completed at Foster Wheeler. Fabrication of the receiver was initiated and a detailed receiver erection schedule was prepared and coordinated with Sandia. Erection of the receiver is scheduled to begin July 6, 1976, at the Radiant Heat Test Facility at Sandia Albuquerque.

In the Thermal Storage Subsystem the detail design of the experiment was completed early in the period. A final selection of the heat transport media was made with Hitec selected as the molten salt and Caloria HT-43 selected as the hydrocarbon oil. During this period the procurement of the last of the major hardware items was completed. In addition the bids for the experiment construction were received and it is expected that a contractor will be selected and erection initiated in July 1976.

During this period Bechtel continued its efforts in the optimization of the Electrical Power Generation Subsystem. Work was also continued on the completion of data that will be used in the Electrical Power Generation Subsystem analytical model being prepared by Martin as a part of the overall Pilot Plant Simulation Model.

SECTION II

II. 10 MW_e PILOT PLANT

A. INTRODUCTION

The daily morning startup of the pilot plant has been previously analyzed and reported. Those analysis assumed startup operations from the receiver.

Presented herein are two additional types of pilot plant startup. First is a plant startup using thermal storage and second is a start-up using the receiver after the plant has been shutdown for an extended period (cold start). In addition, measured insolation data and related calculations that support the thermal input power to the receiver for the daily morning startup calculations are discussed.

B. PILOT PLANT START FROM THERMAL STORAGE

An analysis has been performed to determine and evaluate pilot plant performance for a plant startup using steam from the Thermal Storage Subsystem (TSS). The analysis was performed to evaluate plant performance when a peak electrical demand must be met several hours after normal plant shutdown. The analysis determines the time required to bring the plant to design point operating conditions after 2, 4 and 24 hours of plant shutdown as well as the energy penalty associated with each.

For the purposes of this analysis startup time was defined as beginning when the turbine rolls off turning gear and ending when design point output (from TSS) is achieved (7.7 MW_e gross). The shutdown period is defined as the time elapsed since thermal storage was last charged and the turbine was last operated. In addition, thermal storage has just completed charging, and is fully charged, at the start of the shutdown period. The gross energy available from the turbine is defined as the energy generated during startup plus the energy generated at the design point.

1. Analysis Objectives

As previously described, the purpose of the analysis is to determine the startup times and energy penalties associated with various periods of plant shutdown. The analysis objectives required to accomplish this end can be stated as follows:

- a. Determine the turbine startup time to 7.7 MW_e for both hot (0-12 hours) and warm (12-72 hours) starts from admission steam only.
- b. Calculate the thermal storage subsystem losses and the energy available from Thermal Storage as a function of stand time.
- c. Calculate the energy loss due to the cooldown of the piping between the Electrical Power Generation Subsystem (EPGS) and the TSS.
- d. Calculate the gross energy available from the turbine after 2, 4 and 24 hours of system stand time and the energy loss relative to design point TSS operation.

2. Turbine Startup from Admission Steam

The turbine startup profiles using admission steam only were generated from existing turbine startup curves and input from General Electric. Figure II-1 shows the turbine startup profiles from admission steam to design point output for both hot and warm starts. The hot start requires 37.5 minutes to reach design point output, and the warm start 64 minutes. The inset of the curve also shows the total thermal energy required for startup as well as the electrical energy generated during startup for both the hot and warm case.

3. Thermal Storage Energy Loss Analysis

The energy stored within the Thermal Storage Subsystem is contained in either the oil system (used for preheating and boiling the working fluid) or the salt system (used for adding superheat to the working fluid). Each of these systems loses energy as a function of stand time due to the cooling of the oil (or salt), the heat exchangers and the piping. These losses were calculated and used to determine the energy available from each system as a function of stand time, as shown in Figure II-2. During TSS discharge energy is extracted from the oil and salt systems in a fixed ratio of 81.5% from oil and 18.5% from the salt. Using this ratio the total energy available from the TSS was calculated and is shown in Figure II-3. It should be noted that the apparent excess energy in the oil system is normally used to supply sealing steam to the turbine and trace steam to the TSS.

Figure II-1 Turbine Start-up From Admission Steam to Design Point

Figure II-2 Thermal Energy Available from Oil and Salt Systems vs Stand Time

4. Piping Loss Analysis

In addition to the energy loss in the TSS the energy loss due to the cool down of EPGS-TSS piping must be considered. The EPGS-TSS piping consists of an admission steam supply pipe and a TSS feedwater pipe.

NOTE:

1. Assumes TSS is fully charged at time = 0 from a charging mode.
2. Assumes available energy from salt and oil systems will contribute to the total by a ratio of 18.5% salt and 81.5% oil.

Figure II-3 TSS Thermal Energy Available vs Stand Time

- a. Admission Steam Supply Pipe - The admission steam supply pipe is assumed to be 8 in. schedule 100 pipe with 15.2 cm (6 in.) of calcium silicate insulation (same as the downcomer). It is also assumed that the pipe is vented to the condenser when the admission valve closes. The ambient temperature is assumed to be 225 K (0°F). Based on these assumptions the pipe temperature and energy loss was calculated as a function of stand time and is shown in Figure II-4. In addition, the heat loss rate was calculated to be 0.011 MW_{th} and the maximum energy loss was calculated to be 0.213 MW-HR_{th}.
- b. TSS Feedwater Pipe - The TSS feedwater pipe is assumed to be 4 in. schedule 80 pipe with 7.6 cm (3 in.) of calcium silicate insulation. It is also assumed that the pipe is filled with 477 K (400°F) water when the stand begins and the ambient temperature is 255 K (0°F). Based on these assumptions the pipe temperature and energy loss was calculated as a function of stand time and is shown in Figure II-4. In addition the heat loss rate was calculated to be 0.006 MW_{th} and the maximum energy loss was calculated to be 0.122 MW-HR_{th}.

5. Summary

Table II-1 gives a summary of this analysis for 0, 2, 4 and 24 hours of system stand time. The 0 stand time case is used as a baseline for comparison and represents pilot plant design point operation from thermal storage. There is no electrical energy loss or TSS energy loss due to stand time and no startup time since the turbine is already running. The piping loss shown is just the energy lost during the discharge and is a part of the piping loss shown for all cases. As the stand time increases from 0 to 24 hours the gross available electrical energy decreases from 46.5 MW-HR_e to 42.9 MW-HR_e, a loss of 7.7%. The startup times, discussed previously, are also shown in Table II-1.

The results of this analysis indicate that an evening plant startup from thermal storage to support peak loads is feasible and has an energy cost of about 2% for short term shutdown (2-4 hours) and about 8% for a full day shutdown (24 hours).

C. PILOT PLANT COLD START

The performance requirement for pilot plant cold startup is to bring the plant from ambient conditions to design point power output in six hours. An analysis has been performed to describe a plant cold

Figure II-4 Steam Supply and Feedwater Pipe Energy Loss and Temperature vs Stand Time

start profile and compare it with the six hour requirement. It should be noted that the startup rate given for the receiver in this analysis does not necessarily represent the maximum rate, only an acceptable rate.

Table II-1 Summary - Startup and Operation from TSS

	Stand Time, Hours			
	0	2	4	24
TSS Energy Loss, MW-HR _{th}	0	0.9	1.8	10.5
Energy Available from TSS, MW-HR _{th}	184.9	184.0	183.1	174.4
EPGS to TSS Piping Loss, MW-HR _{th}	0.10	0.33	0.33	0.40
Total Turbine Gross Electrical Output, MW-HR _e	46.5	45.6	45.4	42.9
Total Electrical Energy Loss Due to Stand, MW-HR _e	0	0.9	1.1	3.6
Turbine Start-Up Time, Min	0	37.5	37.5	64.0

1. Analysis Approach

The approach used for this analysis was to supply power to the receiver on demand; thus allowing the receiver to start at a pre-determined, acceptable rate. In the pilot plant this would be accomplished by the sequencing of heliostats to provide the desired power input profile. The power input profile required for the startup rate used in this analysis is shown in Figure II-5. Once the receiver output steam reached a level acceptable to the turbine, 3448 kPa (500 psig) and 56 K (100°F) of superheat, the turbine then began its ramp to rated output. This approach is different from that of a hot start (as discussed in the summary progress report) in that the receiver startup rate will be fixed and the input power will be controlled to maintain that rate. In a morning hot start the receiver accepts all the solar power as it becomes available.

Although the constraints for a cold turbine startup are of the same type as those for a hot or warm start (the temperature rate of change must be controlled) the time required to reach full load is much greater. Hot and warm starts require 53 and 90 minutes, respectively, to reach full load. The cold start requires 230 minutes. Figure II-6 shows the predicted starting and loading curves for a cold start.

2. Performance Characteristics

The predicted receiver startup rates together with the turbine cold start curves are shown in Figure II-7. The receiver startup begins at 0 minutes. The turbine is placed on turning gear at 100 minutes and begins actual startup when the minimum steam conditions are met at 240 minutes. The receiver outlet steam reaches rated output conditions at 280 minutes and achieves maximum flow at 360 minutes. The turbine reaches design point output (11 MW_e gross) at 446 minutes and maximum output (12.5 MW_e gross) at 470 minutes. Once rated steam conditions are achieved (280 minutes) steam not useable by the turbine could be used to charge thermal storage. During this cold start sequence the receiver generates 31,979 Kg (20,500 lb) of steam (approximately 20 MW-HR_{th}) that is unuseable for turbine or TSS operation. Approximately 2 MW-HR_{th} of this steam is required to heat the riser and downcomer, the rest is waste heat.

For the receiver startup rate used in this analysis, plant startup from ambient conditions to design point required 446 minutes (7.4 hours). Again, this does not necessarily represent the maximum achievable rate but does represent an acceptable startup rate.

Figure II-5 Solar Power-to-Receiver Pilot Plant Cold Start

Figure II-6 Predicted Turbine Starting and Loading Curves

Figure II-7 Pilot Plant Cold Startup

D. SOLAR INSOLATION MEASUREMENTS AND RECEIVER SOLAR POWER INPUT PROFILES

In order to establish a requirement for the receiver morning startup rate, it is necessary to know the morning rate of increase of solar power to the receiver. Insolation data, as a function of time from sunrise, is necessary as input data to determine this rate of increase of solar power to the receiver. Reliable, accurate data of this type is not readily available. Therefore insolation measurements were made at Waterton, Colorado, for January, February, and March of 1976. These insolation curves are shown in Figures II-8, II-9, and II-10. In addition, the first two hours of each of these curves is shown in Figure II-11.

These data were coupled with the performance characteristics of a collector field located at Inyokern, California to establish solar power as a function of time. Table II-2 shows the calculations and system characteristics used to establish the amount of solar power put into the receiver cavity as a function of time. In addition to insolation, the effects of tower shadow and the effective cosine of the collector field varies as a function of time of day and time of year, as shown in Figure II-12. The resultant solar power to the receiver cavity as function of time after sunrise is shown in Figure II-13 for January, February and March.

Table II-2 Solar Power Through Receiver Aperture

Solar Power Through Aperture = (Mirror Area) (Effective Cosine)
(Solar Insolation) (System
Efficiency Factors)

Mirrors Area = (1718 Heliostats) (400 ft²/Helio.) = 63,843 m²
(687,200 ft²)

Effective Cosine = Average Field Cosine; Shading; Blocking for
Inyokern, December 21

Solar Insolation = Data from Waterton, January 20, 1976

System Efficiency Factors = Utilization	0.994
Tower Shadow	0.969 - 1.00
Mirror Reflectivity	0.8565
Tracking	0.982
Optical	0.988
Tower Sway	1.0

Figure II-8 Direct Insolation - Waterton, Colorado 01-20-76

Figure II-9 Direct Insolation - Waterton, Colorado 02-19-76

Figure II-10 Direct Insolation - Waterton, Colorado 03-24-76

Figure II-11 Direct Insolation, Morning Startup - Waterton, Colorado

Figure II-12 Effective Mirror Fraction and Tower Shadowing - Inyokern, California

NOTE:

1. Insolation Data from Waterton, Colorado
2. Effective Mirror Fraction and Tower Shadowing from Inyokern, California
3. Assumes:
 - Field Use: 0.994
 - Mirror Area: 63,842.97
 - Reflectivity: 0.8565
 - Optical: 0.988
 - Tower Sway: 1.000
 - Tracking: 0.982

Figure II-13 Receiver Morning Startup Solar Power Input Profile

This data clearly indicates that the maximum rate of increase of solar power to the receiver occurs at winter solstice and the minimum at summer solstice.

SECTION III

III. COLLECTOR SUBSYSTEM

The contents of this section highlight the detail design, fabrication, field assembly, and testing phases of the collector SRE (Subsystem Research Experiment) from April through June 1976.

A. HELIOSTAT DESIGN AND FABRICATION

As detailed below, the detailed design phase of the collector SRE is 100% complete. With the exception of the nine honeycomb-substrate mirrors, all fabrication is complete.

1. 25-Mirror Heliostat Fabrication

Three 25-mirror heliostat structures have been fabricated and delivered to Martin Marietta by Rio Grande Fabricators. One of these structures has been erected and is undergoing engineering testing. The remaining two 25-mirror units will be erected at a later date (see Key Milestones, paragraph D).

The variable focus mirror assemblies for the first heliostat have been fabricated and installed. With the exception of spares, the mirror assemblies for each of the remaining two heliostat structures will be fabricated to meet the individual installation dates.

2. 9-Mirror Heliostat Fabrication

The structure for the 9-mirror heliostat is complete and is awaiting installation at the upper solar test facility for the passive wind test. Before delivery of this unit from Rio Grande, a fit check was performed to insure compliance to the drawings and specification.

Testing of the fixed focus, honeycomb-substrate mirrors to verify the fabrication of the nine mirrors for the experiment has been completed. The verification testing consisted of projecting the sun's image on the calorimeter at the slant range for which the mirror was designed (494m or 1290 feet) and comparing the actual image size and shape against the theoretical image size of 3.65m (12.2 feet).

Both aluminum and paper honeycomb substrate mirrors were tested. For the SRE, seven additional paper honeycomb substrate mirrors will be fabricated to make a full complement of nine mirrors.

3. Drive Mechanism Procurement

Four sets of elevation and azimuth drive mechanisms have been fabricated and delivered by the Morse Chain Division of Borg Warner. The procurement of this component is complete.

B. INSTALLATION, ASSEMBLY AND CHECKOUT OF FIRST 25-MIRROR HELIOSTAT

1. Field Installation and Assembly

The installation and assembly of the first 25-mirror heliostat was completed at Site 4 in the MMC Solar Thermal Test Facility (STTF) on May 19, 1976. Site 4 is located immediately adjacent to the control trailer and was selected for the first heliostat because of its ease of access by support vehicles. Site 4 has a slant range to the calorimeter of approximately 335m (1100 ft) and simulates a position near the center of the 10 MWe collector field. At this range, the optimum image diameter for all twenty five mirrors is approximately 3.1m (10.2 ft) and the average concentration is approximately 4.8 suns.

The first step was to assemble the limit switches and potentiometer inside each drive mechanism. Using a fork lift and chain hoist, the azimuth drive mechanism, which weighted approximately 386 kg (850 lbs), was lowered onto the heliostat foundation and bolted in place. The elevation drive mechanism was assembled into the vertical beam assembly while this structure was lying on the ground.

Erection of the yoke assembly and vertical beam assembly was accomplished with the use of an overhead crane. Figure III-1(a) shows the yoke assembly being lowered onto the main shaft of the azimuth drive mechanism. To avoid distortion of the yoke assembly, a spreader bar was placed between the upright arms to resist compressive loads. A spreader bar was also used on the crane to further minimize distortion.

After the yoke assembly was bolted to the azimuth drive mechanism, the vertical beam assembly was lifted into place and secured using the overhead crane and variable length spreader bar (Figure III-1(b)).

Mirror assemblies were installed while the heliostat was in a "mirrors up" stow position with the use of a mobile elevated platform. The heliostat control electronics box and cabling were mounted and connected to the cabling from the control trailer. The complete

(a) Installation of the Yoke Assembly to the Azimuth Drive Mechanism

(b) Attachment of the Vertical Beam Assembly to the Yoke Assembly

Figure III-1 Installation and Assembly of the First 25-Mirror Heliostat

heliostat with all twenty five mirrors installed is shown in Figure III-2(a). The photograph shows the position of the sensor tower with respect to the heliostat. Approximately sixteen feet from the base of the heliostat, the tower positions the fine tracking sensor on a direct line between the center of the central mirror and the center of the target or calorimeter.

Figure III-2(b) shows the details of the dual beam mirror support and the variable focus mirror assemblies. The mirror assemblies are attached to the dual beams at three points, allowing maximum ease of alignment. The photograph also shows the location of the Heliostat Control Electronics (HCE) box on the rear of the yoke assembly. The small ground-mounted installation in the foreground is the power and instrumentation junction box, one of which is adjacent to each of the four SRE heliostat sites.

2. Checkout and Mirror Alignment

After assembly, the heliostat was commanded through its various control modes to insure its operation under emergency conditions and to check the performance of the limit switches. Figure III-3 shows the heliostat in the "mirrors-down" stow position in which it can survive winds up to 193 km/hr (120 mph).

After initial checkout, the heliostat mirrors were aligned and focused. First, the center mirror was positioned to be parallel to the vertical beam assembly. All mirrors including the center mirror were then covered with 1.2 x 1.2m (4.0 x 4.0 ft) sheets of plywood. The sheet covering the center mirror had a 25.4 cm (10 inch) square hole cut in the center. At noon, local sun time, the image from the small square was centered upon the calorimeter. The in-line sensor was adjusted visually so that its centerline coincided with the center of the small reflected beam.

The plywood cover was removed from the center mirror and it was focused to the smallest image. As each of the remaining mirrors was uncovered, it was aligned and focused to produce the smallest composite image upon the calorimeter surface. Figure III-4 shows the heliostat during this final stage of alignment. In the photograph, seven mirrors have been focused and aligned in addition to the center mirror.

(a) Front View of Heliostat Showing Mirror Surfaces and Sensor Tower

(b) Back View Showing Details of Variable Focus Mirrors

Figure III-2 Details of Installed 25-Mirror Heliostat

Figure III-3 Heliostat in Stowed Position

Figure III-4 Alignment and Focusing of Heliostat

3. Detailed Description of Components

- a. Control Subsystem - The control subsystem, which includes both the executive and fine-tracking functions, was bench tested prior to its installation at the Solar Thermal Test Facility. Using motors and a load box, which simulated motor operation, each control mode was checked. Figure III-5(a) shows the bench test setup with the following test and experimental equipment, (A) stimulator (simulates heliostat position response) (B) Heliostat Control Electronics (HCE), (C) control and display panel, (D) PDP 11/03 computer, (E) input typewriter and (F) load box.

Figure III-5(b) shows the executive control equipment after installation in the control trailer. The additional components shown in Figure III-5(b) are power supplies, recorders and calibration equipment necessary to operate and monitor the experiment. The PDP 11/03 computer used to control the four SRE heliostats has sufficient capacity to operate the 10 MWe pilot plant.

A closeup view of the installed Heliostat Control Electronics is shown in Figure III-6. One box is mounted on the yoke of each heliostat with cabling extending to the motors and drive mechanisms and to the site junction box. The Heliostat Control Electronics are designed for easy access and maintenance, both on or off the heliostat. The low cost, commercial power supplies (D) and motor control electronics (A) are mounted inside a watertight metal housing. The cards containing the analog (B) and digital (C) circuitry are mounted on the lid of the housing. All wiring enters through four hermetically-sealed connectors mounted on the side and bottom of the housing.

Detailed views of the digital and analog cards are provided in Figure III-7. The digital board provides the interface between the heliostat and the centrally-located executive control computer. Connected to the motor drive circuits, the digital board receives commands and applies appropriate signals to the slew or tracking motors during stowing, slewing and synthetic tracking operations.

The analog board receives error signals from the fine-tracking sensor and commands the tracking motors to drive the heliostat so as to reduce the pointing error.

Details of the motor control electronics are shown in Figure III-8.

(a) Bench Testing of Heliostat Control System before Installation

(b) Installed Executive Control System and Instrumentation during Post Installation Checkout

Figure III-5 Development and Installation of the Heliostat Control System

Figure III-6 Internal View of Installed HelioStat Control Electronics Showing Location of Major Subassemblies

(a) Front View of Digital Control Subassembly

(b) Front View of Analog Control Subassembly

Figure III-7 Details of Digital and Analog Control Subassemblies

(a) Assembled Motor Control and Power Section

(b) Lower Section of Motor Control and Power Subassembly Showing Solid-State Switch Networks

Figure III-8 Details of Motor Control and Power Subassembly

- b. Drive Mechanisms - The azimuth drive mechanism is shown in Figure III-9(a). The motor assembly, consisting of tandem-mounted tracking and slew motors, is keyed to the shaft of the worm gear and bolts to the side of the housing. The opposite end of the worm gear shaft protrudes through the housing and provides a means for manually cranking the heliostat. Electrical wiring enters the housing through two parts on the top of the housing.

A view of the elevation drive mechanism with the tandem motor assembly installed is shown in Figure III-9(b). The elevation drive is mounted between two flanges on the main shaft with studs and self-centering lug nuts.

Except for the drive shaft and external housing, both the elevation and azimuth drive mechanisms are alike. Figure III-10(a) shows a disassembled azimuth drive. Some of the more important elements are (A) housing, (B) main shaft which mounts through the yoke, (C) main bull gear, and (D) worm gear.

The tandem motor assembly, shown in detail in Figure III-10(b) contains both the tracking (A) and slew (B) motors for a given axis. The case of the Bodine slew motor bolts directly to the drive housing. During slew, the tracking motor, the shaft of which is connected to the shaft of the slew motor, spins freely. When tracking the sun, however, the Sigma synchronous motor utilizes the gearbox of the slew motor to achieve the proper speed reduction.

- c. Fine-Tracking Inline Sensor and Support Tower - The heliostat is controlled during fine tracking operations by a tower-mounted sensor. The sensor, which is aligned on the centerline between the center mirror of the heliostat and the center of the target (calorimeter), detects movement of the reflected beam and generates error signals which are applied to the appropriate tracking motors to bring the heliostat into proper orientation.

Figure III-11 shows views of both the sensor and its support tower. The square central tube in the sensor is used both visual and laser alignment. As with the heliostat, the sensor tower is grounded to protect against direct lightning strikes.

(a) View of Azimuth Drive Mechanism Showing Tandem-Mounted Motor, Cabling, and Electronics Control Box

(b) View of Elevation Drive Mechanism with Tandem-Mounted Tracking and Slew Motors.

Figure III-9 Installed Azimuth and Elevation Drive Mechanisms on Heliostat No. 1

(a) Exploded View of Azimuth Drive Mechanism

(b) Tandem-Mounted Motor Assembly

Figure III-10 Details of Azimuth Drive Mechanism

(a) Closeup View of Fine Tracking Sensor Showing Details of Mounting. Photo Taken between Sensor Tower and Heliostat

(b) Fine Tracking Sensor Mounted on Tower

Figure III-11 Details of the Fine Tracking Sensor and Support Tower

C. INSTALLATION AND ASSEMBLY OF CALORIMETER

One of the most important pieces of test equipment developed for use in the SRE is the company-funded experimental calorimeter. This calorimeter, with a receiving surface of nearly 54 M^2 (576 ft^2), provides a means to measure the collection efficiency of the SRE heliostats as a function of time of year and day. The receiving surface is large enough to capture the image of the most distant SRE heliostat (503 m or 1650 ft) and is representative of the size of the aperture of the 10 MWe receiver. By varying the rate of flow of water through the receiving surface, the calorimeter can measure the four heliostats individually or collectively.

Erection of the calorimeter was started in March. Various steps are shown in Figure III-12. One of the crucial steps in the assembly process, the mounting of the receiver surface, is shown in the Figure III-12(b) and (c).

The receiver surface which collects the reflected solar energy from the heliostats, consists of fifty-three 7.3 m (24 ft) long, finned tubes coated with a black anodized finish. This coating, a proprietary finish developed by Martin Marietta, has an absorptance in excess of 99.9%. The plating tanks are limited in size and in order to plate the aluminum fin tubes, the tubes were rolled up on a fixture to a diameter of 1.2 m (4.0 ft). After plating, the surface of each tube is very sensitive to contamination by fingerprint, dirt or oil. Therefore, the plates tubes were unrolled, straightened and lifted into position in one operation as shown in Figure III-12(b).

After installation, the black surface may be cleaned by spraying it lightly with clean water (no detergents) to remove dust.

Figure III-13 shows front and rear views of the completed calorimeter. The control trailer houses the valving to control the flow and the weight tank. The large external tank is used for storage and holds approximately 8000 liters (2100 gallons) of water.

Although the installation of both back-surface insulation and instrumentation was not completed, engineering tests with both the calorimeter and heliostat were conducted near summer solstice. In addition to obtaining preliminary performance data, the purpose of these tests was to develop testing procedures and checkout the basic operation of the calorimeter. The performance data is currently undergoing evaluation.

(a) Erection of the Calorimeter Support Structure

(b) Unrolling of the Martin Black Receiver Element

(c) Installation of Straightened Receiver Element

Figure III-12 Installation and Assembly of Experimental Calorimeter

(a) Front View of Completed Calorimeter Showing Receiver Surface of 53 Elements

(b) Rear View of Calorimeter Showing Support Trailer (A) and Main Water Storage Tank (B)

Figure III-13 Views of the Experimental Calorimeter with Receiver Surface Fully Installed

D. KEY MILESTONES OF TIME PERIOD JULY THROUGH DECEMBER 1976

During the next three month time period, several key milestones are planned, as shown in Figure 14.

Task	Month		
	July	August	September
1. Complete Field Installation of 9-Mirror Heliostat for Passive Wind Test
2. Complete Field Installation of Remaining Two 25-Mirror Heliostats
3. Demount and Move 9-Mirror Heliostat to Site 9 for Individual and Subsystem Tests
4. Begin Subsystem Testing with Four Heliostats

Figure III-14 Key Milestones of the Period July-August 1976

SECTION IV

IV. RESEARCH EXPERIMENT RECEIVER TEST SUPPORT EQUIPMENT

A. SUPPORT EQUIPMENT MODULE STATUS

During the past quarter, approximately 95% of the purchase requisitions were placed for those items needed for the fabrication of the support equipment module.

All procurement items are on schedule and we do not foresee any problems.

B. FABRICATION STATUS

The structure for the support equipment module is completed and ready for the installation of the components. The high pressure heat exchanger sub-assemblies are presently being detailed in preparation for welding. The heat exchanger will be completed by the end of July.

All instrumentation cutouts for the electrical console are completed and the panels are now in for painting. We will then install all indicators and controllers and wire up the system.

All design and fabrication efforts are presently on schedule and we have no concerns with meeting our end ship date.

C. WELDING PROCESSES

All manufacturing is being done in conformance with applicable ASME codes. The following process documentation has been completed to support the build and will be supplied on request:

1. H65003, Fabrication Process Plan for the 5 MW High Pressure Feed-water Heat Exchanger.
2. Welding Process Specification EPL-2, Welding P-1 to P-1 Materials, Thickness Range 1/16 to 3/4 inch.

3. Welding Process Specification EPL-5, Welding P-4 to P-5 Materials, Thickness Range 1/16 to 1/2 inch.
4. Welding Process Specification EPL-6, Welding P-1 to P-5 Materials, Thickness Range 1/16 to 1/2 inch.
5. Welding Process Specification EPL-7, Welding P-4 to P-1 Materials, Thickness Range 1/16 to 1/2 inch.
6. Welding Process Specification EPL-9, Welding P-4 to P-4 Materials, Thickness Range 1/16 to 1/2 inch.
7. Welding Process Specification EPL-13, Welding P-4 to P-8 Materials, Thickness Range 1/16 to 1/2 inch.

D. FABRICATION DRAWINGS

All of the detail fabrication drawings are complete and have been released to our fabrication shop. The following is a list of the released top assembly drawings, which are included as Figures through

Figure IV-1 - SKSCSG500100, Equipment Skid Assembly

Figure IV-2 - SKSCSG500200, High Pressure Heat Exchanger Assembly, 4 sheets

Figure IV-3 - SKSCSG500300, Equipment Module Assembly, 6 sheets

Figure IV-4 - SKSCSG500400, Electrical Console Front Panel

These drawings show the installation of all equipment shown in the schematic Figure IV-5 within the Phantom lines identified by MMC supplied.

E. INTERFACES

During this quarter, we have been in continuous contact with Sandia and Foster Wheeler Corporation. Coordination effort has been worked in the following areas:

1. Condenser interfaces.

2. Design input on Feedwater makeup.
3. Design input on plot plan design.
4. MMC and FWEC have defined electrical console instrumentation interfaces.

F. MAJOR MILESTONES

The Master Schedule identifying the program framework within which detail actions must fit is shown below for the Support Equipment Module. As previously stated, no major problems are evident and it is anticipated that delivery will be made as planned.

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Figure IV-1
Page IV-5

REVISIONS			
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1		INITIAL RELEASE	1984-2
2		8/F DELETED -044 12.00 DIMENSION	1984-3

-030 ASSY
STEAM-BYPASS ASSY
WELD PER WPS EPL-9 EXCEPT WHERE NOTED OTHERWISE

0022	0004 IDENT NO.	SKSCSG500200
2	04236	
0000		
0000	1/10 J.G. HALFORD	4

1. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES.
2. M/F MEANS "MAKE FROM
AR MEANS "AS REQUIRED"

B. PREPARE BUTT WELDED JOINTS WITH $37\frac{1}{2}^{\circ}$ & $2\frac{1}{2}^{\circ}$ BEVEL TO $\frac{1}{16}''$ LAND AT ID. ALL PIPE WELDS SHALL BE MADE WITH AN ARGON GAS BACKING. ALL PIPE WELDS SHALL BE DYE PENETRANT INSPECTED PER STN-TC-1A.

4. SHOP FABRICATE ALL U-BOLTS APPROPRIATE TO ACCOMMODATE A 1/8" THICK ASBESTOS OVERWRAP OF THE PIPE. SINGLE NUTTED U-BOLTS SHALL FIRMLY CLAMP THE PIPE. DOUBLED NUTTED U-BOLTS SHALL BE MADE UP TO PROVIDE FREE MOVEMENT OF THE PIPE. SHOP SHALL LOCATE AND DRILL HOLES FOR U-BOLTS, AS REQUIRED FOR INSTALLATION.

5. APPLY THREAD COMPOUND, TO MALE PIPE THREAD ONLY, PRIOR TO TIGHTENING. COMPOUND SHALL BE APPLIED TO ALL BUT THE FIRST TWO THREADS TO PREVENT COMPOUND FROM CONTAMINATING ID OF PIPE. ALL THREADED PIPE JOINTS SHALL BE PER PARAGRAPH PG. 39.6 OF ASME CODE SECTION 1. 6. THREAD ENGAGEMENT MIN.

6. REFER TO MANUFACTURERS INSTRUCTION MANUAL FOR HOLE SIZE AND WELD REQUIREMENTS PRIOR TO INSTALLATION.

7. FILLET WELD WITH A MINIMUM THROAT DIAMETER OF .77 TIMES THE MATING PIPE WALL THICKNESS. INSERTION OF PIPE INTO SOCKET SHALL BE $\frac{3}{8}$ " MINIMUM. PULL-BACK FROM MAX INSERTION $\frac{1}{16}$ ".

VS. ACTUAL POSITIONING OF RV-4 AND RV-6 RELIEF VALVES AND ROUTING AND LENGTHS OF OUTLET PIPING TO BE DETERMINED AT FINAL ASSEMBLY TO INSURE PERSONNEL SAFETY..

2. HYDROSTATIC PROOF AND LEAK TESTING OF THE -009 ASSY WILL BE ACCOMPLISHED DURING THE "SMW SUPPORT EQUIPMENT MODULE TEST AND CHECKOUT PROCEDURE." SEE DRAWING SK5C50800500 FOR INTERCONNECTING TEST AND CHECKOUT PIPING.

[illegible]

SECURITY/PAGE NO.		PAGE NO.		DESCRIPTION		PRIORITY		NATIONAL OR FOREIGN		INTERNAL OR EXTERNAL		FILE NO.	
LIST OF MATERIAL													
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				3. NUMBER OF IN INVENTORY				DATE		3. NAME			
				4. AND THE OTHER IDENTIFIER				DATE		3. NAME			
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				282. NAME				DATE		3. NAME			

REVISIONS			
NO.	DATE	DESCRIPTION	BY
1	6/2/66	INITIAL RELEASE	40000

NOTES: (FOR -010 ASSY ONLY)

1. HYDROSTATIC PROOF TEST THIS ASSEMBLY, AT 70°F MIN. FOR 3 MINUTES MIN. AS FOLLOWS:

FROM	TO	PRESSURE
PUMP DISCHARGE THRU PBPV-1 FFP	2000 ± 50 PSIG	
PUMP BYPASS INLET PBPV-1	110 ± 50 PSIG	
SUMP OUTLET FFP	110 ± 50 PSIG	

THERE SHALL BE NO EVIDENCE OF DEFORMATION OR LEAKAGE.

2. AFTER PROOF TEST, LEAK TEST THIS ASSEMBLY, USING WATER AT 70°F ± 5°F, AS FOLLOWS:

FROM	TO	PRESSURE
PUMP DISCHARGE THRU PBPV-1 FFP	1720 ± 50 PSIG	
PUMP BYPASS INLET PBPV-1	85 ± 50 PSIG	
SUMP OUTLET FFP	85 ± 50 PSIG	

AFTER HOLDING PRESSURE FOR 30 MINUTES MIN. THERE SHALL BE NO LEAKAGE ALLOWED.

3. WELDS PER WPS EPL-2 EXCEPT WHERE NOTED.

Figure IV-3 - Sheet 3

Page IV-12

-010 ASSEMBLY
PUMP DISCHARGE

SKSCSG500300
1/10 J.G. HALFORD

NOTES: (FOR -019 ASSY ONLY)

1. HYDROSTATIC PROOF TEST THIS ASSEMBLY TO 188 $\pm$ 25 PSIG, AT 70°F MIN, FOR 3 MINUTES MIN. THERE SHALL BE NO EVIDENCE OF DEFORMATION OR LEAKAGE.
2. AFTER PROOF TEST, LEAK TEST THIS ASSY USING WATER, AT 70°F $\pm$ 5°F, TO 85 $\pm$ 25 PSIG. AFTER HOLDING PRESSURE FOR A MINIMUM OF 30 MINUTES, THERE SHALL BE NO LEAKAGE ALLOWED.

Figure IV-3 - Sheet 4
Page IV-13

-019 ASSEMBLY
PUMP SECTION
COOLING WATER
OUTLET

- NOTES: (FOR -030 ASSEMBLY ONLY)**
1. ALL TUBING AND WIRING SHALL BE FIELD ROUTED FROM PORTS INDICATED TO INSTRUMENT MOUNTING AREA. (SEE SHEET 2)
 2. ALL TRANSMITTERS MUST BE MOUNTED LOWER THAN THEIR PRESSURE PORTS. REFER TO MANUFACTURER'S INSTRUCTIONS BEFORE SYSTEM PRESSURE IS APPLIED.
 3. CLAMPS SHALL BE INSTALLED EVERY 3 FT MIN. FIELD LOCATE AND INSTALL CLAMPING BRACKETS WHERE REQUIRED TO SUPPORT TUBING. USE EXISTING STRUCTURE WHERE POSSIBLE.
 4. PLACE ONE WRAP OF -041 AROUND PIPE BEFORE INSTALLING TRANSMITTER MOUNTING BRACKET.

Figure IV-3 - Sheet 6
Page IV-15

-030 ASSEMBLY
INSTRUMENTATION FAIR

Symbols

- Manually Operated Valve
- Remotely Operated Manual Valve
- Temperature Measurement
- Pressure Measurement
- Flow Measurement
- Relief Valve
- Check Valve
- Filter

(1)
P = 11722 kPa (1700 psig)
T = 494 K (429°F)
H = 949 J/g (408 Btu/lb)
W = 7348 kg/h (16200 lb/hr)

(2)
P = 11722 kPa (1700 psig)
T = 466 K (380°F)
H = 823 J/g (354 Btu/lb)
W = 7348 kg/h (16200 lb/hr)

P = 11894 kPa (1725 psig)
T = 380 K (225°F)
H = 454 J/g (195 Btu/lb)

(1)
P = 8171 kPa (1185 psig)
T = 594 K (610°F)
H = 2912 J/g (1252 Btu/lb)

(2)
P = 8171 kPa (1185 psig)
T = 640 K (692°F)
H = 3038 J/g (1306 Btu/lb)

Supplied by Foster Wheeler

P = 10860 kPa (1575 psig)
T = 590 K (603°F)
H = 2705 J/g (1163 Btu/lb)

P = 9136 kPa (1325 psig)
T = 789 K (960°F)
H = 3422 J/g (1471 Btu/lb)

P = 517 kPa (75 psig)
T = 380 K (225°F)
NPSH = 51.2 m (168 ft)
Pump Inlet Conditions

Supplied by Sandia

*Visual Readout Required on Control Console.
**Continuous Stripchart Recording Required

Electrical Control & Instrumentation Console

Supplied by Martin Marietta Corporation

REVISIONS

SYM	ZONE	DESCRIPTION	DATE	APPROVED
		INITIAL RELEASE	6-21-76	F. B. Sch
A		ADDED SV-3 & LPD-6, REROUTED BOILER & SUPERHEATER DRAIN TO CONDENSER	76 JUL 11	J. G. Halford

Valve Identification

- CB-1
- CV-1, 2
- FPP
- LLS-1, 1R
- LLS-2, 2R
- LPD-1, 2, 3, 3R, 4, 5, 6
- PBPV-1
- PCV-1
- PV-1
- RV-1, 2
- RV-3
- RV-4
- RV-5
- RV-6
- SP-1, 1R, 2, 2R
- TCV-1, 2, 3, 4

Function

- Condenser Bleed Valve
- Cooling Water Control Valve
- Feedwater Pump Pressure Control Valve
- Boiler Liquid Level Control
- Condenser Liquid Level Control
- Low Point Drain Valve
- Pump Bypass Valve
- Pressure Control Valve (Steam)
- Pump Isolation Valve
- Boiler Relief Valve
- Superheater Relief Valve
- Pump Relief Valve
- Condenser Relief Valve
- Cooling Water Relief Valve
- Sampling Port Test Valve
- Feedwater Temperature Control Valve

(1)
P = 586 kPa (85 psig)
T = 505 K (450°F)
H = 2912 J/g (1252 Btu/lb)

(2)
P = 586 kPa (85 psig)
T = 566 K (560°F)
H = 3038 J/g (1306 Btu/lb)

Figure IV-5
Page IV-17

MARTIN MARIETTA CORPORATION
POST OFFICE BOX 179, DENVER, COLORADO

SMW RESEARCH RECEIVER TEST
SYSTEM SCHEMATIC

SIZE C CODE IDENT NO. 04236 SKSCSG5000

SCALE NONE J.G. HALFORD SHEET 1 OF 1

SKSCSG5000

SECTION V
RECEIVER SUBSYSTEM

BY:

J. F. COX
W. T. KLAMM
S. F. WU
R. J. ZOSCHAK

FOSTER WHEELER ENERGY
CORPORATION

JOHN BLIZARD RESEARCH CENTER
12 PEACH TREE HILL ROAD
LIVINGSTON, NEW JERSEY 07039

V. RECEIVER SUBSYSTEM DESIGN

A. PILOT PLANT RECEIVER

No activity was scheduled during this reporting period on the pilot plant receiver. However, to assist in visualizing the assembled pilot plant receiver, the perspective drawing shown in Figure V-1 was prepared. Since the supporting structure for the pilot plant receiver has not been designed, the structure shown in Figure 1 was based on the arrangement of the supporting structure of the experimental receiver.

B. RESEARCH EXPERIMENT RECEIVER

1. Test Plan

The Test Plan for Radiant Heat Testing of the Research Experiment Receiver has been issued. This document will be updated as the project proceeds. Descriptions of the instrumentation and locations of measurement sensors on the receiver were included in Quarterly Report No. 2 of this project. Outlined in this section are the types and scheduling of tests, the updated receiver schematic, the test facility and the data logging system. The tests proposed in this plan are classified and defined as follows:

- (1) Low Temperature and Pressure Trial Runs - To check out overall system operating characteristics by running the receiver at reduced pressure, temperature and incident heat energy.
- (2) High Temperature and Pressure Trial Runs - To obtain a full load operating condition by starting the receiver from the ambient condition and stepping up the heat input in small increments.
- (3) Cold Start-up - To demonstrate the receiver cold start-up performance by a sequence of progressively shorter periods of start-up.
- (4) Hot Start-up - To demonstrate the receiver hot start-up performance by a sequence of progressively faster rates of increase of drum pressure.
- (5) Restart after Cloud Passage - To simulate a cloud obscuring the incident radiation and then a restart reaching the peak heat flux within a minimum time span.
- (6) Steady State and Reduced Flow Runs - To demonstrate the receiver operating characteristics at 100%, 75%, 50%, and 25% of the rated flow rates at the full pressure and temperature.

Figure V-1 Perspective Drawing of the Pilot Plant Receiver

(7) Biased Heat Flux Superheater Test - To simulate the peak heat flux condition locally on the superheater to obtain the temperature, stress, and deflection data at this condition.

(8) Biased Heat Flux Boiler Test - To simulate the extreme boiler circulation characteristics of the pilot plant receiver by exposing one particular boiler panel to the desired higher heat input.

Early in June Sandia Labs concluded that graphite heaters could not be used for radiant heat input to the receiver because tests had shown that the heating elements would deteriorate too rapidly under the anticipated operating conditions. It was therefore decided to use tungsten and tungsten-halogen quartz lamps as the heat source. Since these lamps are less efficient than the graphite heaters, the maximum net heat input to the receiver may be in the 4 to 4.5 MWt range rather than the planned 5 MWt unless Sandia can add to the power supply. Accordingly, new biased heat flux distributions were calculated which will provide for peak heat flux conditions on selected areas of the waterwalls and superheater equivalent to those originally planned for the graphite heaters. Thus, although the maximum net heat input may be lower than originally planned, the receiver will be thoroughly tested under peak heat flux conditions at critical locations.

The test plan is designed to obtain, in a two-month test period, the data necessary to evaluate transient and steady state operating characteristics of the proposed Pilot Plant Receiver preliminary design concept. The scheduling of these tests is shown in Figure V-2.

An updated schematic of the research experiment receiver is shown in Figure V-3. This revised schematic reflects the elimination of the second-stage attemperator and its associated controls and the replacement of some of the remote actuated valves with manually operated ones. These modifications were implemented as economy measures, and do not compromise the test objectives.

The test facility is shown schematically in Figure V-4. The receiver, the support equipment and the transformer will be mounted outdoors on their respective pads as indicated in the figure. The control panel and the necessary data read-out and recording equipment for the receiver and the support equipment will be located inside a trailer. The radiant heater control and data acquisition system will be situated inside an existing building.

Figure V-5 shows schematically the data acquisition system for the receiver tests. Signals from all the sensing locations will be scanned by multiplexers and transmitted to a central data processing system where a computer will be used to process, store and print out the test data. The signals required for control

	1st Week	2nd Week	3rd Week	4th Week	5th Week	6th Week	7th Week	8th Week
LOW TEMPERATURE & PRESSURE TRIAL RUNS								
HIGH TEMPERATURE & PRESSURE TRIAL RUNS								
COLD START-UP								
HOT RESTART								
RESTART AFTER CLOUD PASSAGE								
STEADY STATE REDUCED FLOW RUNS								
BIASED FLUX SUPERHEATER TEST								
BIASED FLUX BOILER TEST								

Figure V-2 Test Schedule for the Research Experiment Receiver

SYMBOLS

T- TEMPERATURE MEASUREMENT
P- PRESSURE MEASUREMENT
F- FLOW MEASUREMENT

Figure V-3 Schematic of the Research Experiment Receiver.

Figure V-4 Test Facility Schematic

Figure V-5 Data Acquisition Schematic

functions and real-time visual display purpose will be directly wired from the receiver to the control panel. Provision is also being made to extract certain important test data from the computer on a close-to-real time basis. These data can be displayed on a TV screen and printed out, if desired, with a hard-copy unit.

2. Instrumentation

The design of the venturi flow meters to be installed in the selected downcomers and feeders has been completed. Three venturi meters have been fabricated and installed for the three designated feeder sections. After flow calibration, these sections have been shipped to our shop for inclusion as part of the feeders. Fabrication and installation of three more venturi meters for the selected downcomers have been started and are expected to be completed early in July, 1976.

Heat flux meters and thermocouple wire and extension cable required for the receiver instrumentation have been ordered.

3. Plastic Scale Model

During this reporting period a 1/16-scale, plastic model of the research experiment receiver was built to Foster Wheeler specifications by United Scale Models, Inc., of Concordville, Pa. The cost of the model was borne by Martin Marietta and not charged to the project. Late in June the model was delivered to Foster Wheeler where it was observed and photographed prior to final shipment to Martin Marietta one week later. Three views of the model are shown in Figures V-6, V-7 and V-8.

4. Detailed Design

The detailed design of the research experiment receiver was completed during this reporting period. Shop details of the waterwalls, feeders, risers and downcomers have been completed and released to the shops for fabrication. Shop detailing of the superheater will be completed early in July, with fabrication starting immediately thereafter. The cavity door and enclosures were released for shop detailing in June.

The arrangement of the cavity door is shown in Figure V-9. The door is made up of two pieces mounted on tracks which can be rolled aside in a horizontal direction to the open position and which meet at the center of the aperture when closed. Opening and closing will be done manually. The door will also be manually dogged down to a tight seal when closed. This door is an inexpensive assembly to be used only for the radiant heating tests. A new

Figure V-6 Scale Model of the Research Experiment Receiver,
Front View

Figure V-7 Scale Model of the Research Experiment Receiver,
Front-Side View

Figure V-8 Scale Model of the Research Experiment Receiver,
Side View Looking Downward

Figure V-9 Cavity Door Arrangement

remote-operated door, as well as aperture frame cooling, will have to be furnished for future testing in the solar facility.

During this reporting period it was decided that freeze protection of the receiver should be added to the scope of work because of the possibility that ambient temperature will fall considerably below freezing for extended periods at the Albuquerque test site. Accordingly, the insulation specifications for the feedwater, steam, drain and miscellaneous piping have been prepared so that electrical trace heating can be accommodated. Lines that cannot be conveniently drained will be provided with trace heaters. No specific freeze protection will be provided for the receiver itself because the radiant heaters can supply heat, if needed. In the unlikely event of a power failure, the entire system, receiver included, will be completely drained.

5. Procurement

All pressure part material has been ordered. The following sub-contracted items and auxiliary equipment have also been ordered during this reporting period.

- (1) Structural steel
- (2) Grating
- (3) Railing
- (4) Miscellaneous valves

In addition, the design and specification of the insulation and lagging have been completed, and these materials are scheduled to be purchased in July.

6. Fabrication

Fabrication of the steam drum, which began in April, is nearing completion at the Mountaintop plant. Figure V-10 is a shop photograph of the steam drum taken at the end of June. The drum internals have been fabricated at the Dansville plant and shipped to Mountaintop for installation in the drum after the drum is stress-relieved. The drum will be shipped on or before the scheduled ship date of July 16, 1976.

The waterwall headers have been fabricated in the Mountaintop plant and shipped to the Dansville plant for assembly into the waterwall panels. Fabrication of the waterwall panels, feeders, risers and downcomer bottles has begun at the Dansville plant. The photograph in Figure V-11, taken on June 28th, shows a portion of one of the waterwall panels being welded on the panel welder

Figure V-10 Shop Photograph of Nearly-Completed Steam Drum (The cylindrical pieces on the ends are temporary attachments used in handling during shop operations)

in the Dansville Welding Laboratory. These panels are being fabricated in the Welding Laboratory because of their relatively small size in comparison to the panels normally fabricated on the shop panel welding machine.

Since the waterwall tubes of the receiver are much thinner than the tubes normally joined into panels in the shop, and therefore much more susceptible to burn-through and distortion, some development work was required before production welding could begin. Figure V-12 shows two views of a sample panel weld made at the end of the development program. As can be seen, the fin joining the tubes is made up of a 1/4 inch wide bar which is welded to the tube, rather than being made up solely of weld metal, as are the fins between the heavier wall tubing normally handled by the shop. The cost of the development work was absorbed by Foster Wheeler.

7. Field Erection

A detailed construction schedule was prepared early in June. Foundations for the experimental receiver were poured in mid-June. The structural steel, grating and railing were delivered to the site during the latter half of June. The Foster Wheeler erection superintendent arrived on site on June 21st to prepare for start of construction on July 6th. A condensed erection schedule is given in Figure V-13.

Figure V-11 Welding Operation of Waterwall Panel

Figure V-12 Sample Section of Waterwall Panel

Figure V-13 Field Assembly and Erection Schedule for Research Experiment Receiver

CENTRAL RECEIVER SOLAR THERMAL POWER SYSTEM
(PHASE I)

Quarterly Report

SECTION VI

THERMAL STORAGE SUBSYSTEM

Authors:

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Charles A. Murphy
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VI. THERMAL STORAGE SUBSYSTEM

A. INTRODUCTION

During the period covered by this Quarterly Report, April 1976 through June 1976, several of the major activities that were in progress during the previous quarter were concluded. The completed activities are: (1) the detailed design of the Thermal Storage Subsystem Research Experiment, (2) specification preparation and order placement for all major components for the Research Experiment, and (3) selection of the construction contractor and award of the contract. In addition, the Research Experiment Final Test Plan was written, a study that lead to the storage media selection was completed and preparation of the Research Experiment Test Procedures was begun.

1. Thermal Storage Subsystem Research Experiment

The detail design of the Research Experiment was completed during this quarter. The design effort included:

- o Layout and analysis of all of the steam, feedwater, molten salt and oil piping.
- o Specification and selection of pumps and valves.
- o Review and approval of heat exchanger designs.
- o Review and approval of storage media tank designs.
- o Review and approval of control console and control system components.

Orders for all system components have been placed and the oil circulation pump, the oil bypass cooler, all the flow reversing valves, four flow control valves and one pressure relief valve have been received. The construction of the heat exchangers and storage media tanks is proceeding on schedule.

Thermxchanger, Inc., the subcontractor that is supplying the heat exchangers, has ordered and received all components and materials required for fabrication except gaskets, sealing rings and the mesh separator for the evaporator. All of the sub-assemblies of the two molten salt heat exchangers are complete and final assembly of these units will begin early in July. Sub-assembly fabrication for the two oil heat exchangers is scheduled to begin in early July. J. J. Finnigan Industries, Inc., will supply the tanks for the Research Experiment. All

tank components have been delivered to J. J. Finnigan and fabrication is 30 percent complete.

A request for quotation for the construction of the Research Experiment was issued on May 6, 1976. The quotation request included general specifications, piping drawings, code requirements, electrical requirements, desuperheater detail drawings and construction date requirements. Responses to the request were opened on June 7. After reviewing the respondents quotes and qualifications, Broyles and Broyles, Inc., Atlanta Division, was selected as the contractor. Construction of the Research Experiment at Plant Yates, a Georgia Power Company facility, is scheduled to begin on or about July 12, 1976.

Selection of the storage media was also made during this quarter. The hydrocarbon oil will be EXXON heat transfer oil, HT-43. The molten salt will be heat transfer salt, HTS. The by weight chemical composition of the salt is 53 percent potassium nitrate, 40 percent sodium nitride and 7 percent sodium nitrate. Orders for both storage media will be placed early in July.

2. Other Program Activities

Two program reviews were conducted during this quarter: (1) the Quarterly Program Review and Detailed Design Review on May 20 and 21, (2) the Semi-Annual Program Review on June 2. The Research Experiment Final Test Plan was written during this quarter, the detailed test procedures were defined, and writing of the procedures was begun.

B. THERMAL STORAGE SUBSYSTEM RESEARCH EXPERIMENT DETAILED DESIGN

The major program efforts this quarter were the completion of the detailed design of the Research Experiment and the preparation of the Final Test Plan and Detailed Procedures. The test plan will be discussed in the next section of this report. The design effort, which was concentrated in the first half of the report period, is covered in this section.

1. Research Experiment Detailed Schematic

Some modifications to the Research Experiment design have been made since the last Quarterly Report was published. These changes have all been incorporated into the detailed schematic shown in Figure VI-1. Generally, the changes simplify system operation or improve system safety. A nitrogen cover gas system

has been added to the main steam line. When the Research Experiment is not being operated, the steam and water side of the heat exchangers and piping will be drained. The pressure will then be reduced to near atmospheric and a 10 psig nitrogen line into the main steam line will be opened. The nitrogen line will have a check valve in it to prevent backflow into the nitrogen cover gas system. The cover gas will minimize the formation of condensate in the piping and heat exchangers overnight and eliminate oxygen contamination of feedwater and steam during system start-up.

Two piping changes have been made to make it easier to drain condensate from the steam lines. The low point in the steam line into the Research Experiment has been moved so that this line can now be drained through FCV6. The separate drain line that contained the blowdown valve, BDV1 was eliminated. The drain valve, DV10, on the head of HE1 has been changed to a blowdown valve and the corresponding drain line is now connected to the silencer. Steam and feedwater sampling lines have been added. Samples of feedwater into the system and condensate out of the system will be drained off through SV2. The samples will be cooled and a conductivity measurement will be made. Additional tests will measure sample pH, oxygen content and nitrate content. Steam samples will be collected through SV1 during charging and discharging. The steam will be condensed and then analysed in the same manner as the condensate and feedwater.

Approximately 20 surface contact thermocouples have been added to the schematic. These sensors will monitor temperatures that are important for safety reasons or necessary for system analysis. It was recognized at the beginning of the program that these thermocouples would be needed, but their location was dependent on the details of the design, and so the locations were not specified until the design was largely complete. These thermocouples are designated as SCTC's on the schematic.

2. Heat Exchangers

The heat transfer parameters, surface areas, number of tubes, etc., for the Research Experiment heat exchangers were reported in the last Quarterly Report. Thermxchanger, Inc., completed the detailed design of the exchangers during this quarter and some of the design features will influence the heat exchangers performance and the operation of the Research Experiment. These features are shown in Figures VI-2 to VI-4, the outline drawings of the heat exchangers.

Figure VI-2. Drawing of Superheating-Desuperheating Heat Exchanger HE2.

NOTE:
 1. CONSTRUCTED IN ACCORDANCE WITH THE
 ASME CODE SECT. 8, DIV. 1
 2. POSTWELD HEAT TREAT ENTR-ENT BONNET
 3. 100% X-RAY ENTR-ENT JOINT
 4. ROLL & STRENGTH WELD TUBES TO TUBE SHEET
 5. (USING 7/8\"/>

THIS DRAWING IS THE PROPERTY OF
 THERMEXCHANGER, INC.
 OAKLAND, CALIFORNIA
 and is not to be used for reproduction or other
 purposes without the written consent of
 THERMEXCHANGER, INC. If it is used for
 reproduction or other purposes without the
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 the user assumes all liability for any
 damages or losses resulting therefrom.

16	FLANGING RING	1	STEEL SA-182-C	3/4" THK	6-1129	
15	BOLTING - E-E BONNET	16	SP. SA-193-B7	1 1/4" DIA		NUT: SA-193-2H
14	SHELL PASS RING	1	STEEL SA-182-C	3/4" THK	6-1662	
13	SHELL SUPPORTS	8	FORGED STEEL		6-1130	
12	O-RING	1	3.5" STEEL "C" RING	3/4" DIA		
11	GASKETS	10	STEEL SA-182	3/4" THK	6-1662	
10	TIE RODS	8	STEEL	3/4" DIA	6-1662	
9	SPLICERS	60	STEEL	3/4" O.D. x 11.000	6-1662	
8	TUBING	304	FORGED STEEL 20-179	3/4" O.D. x 16.000	6-1187	14" RING PER TUBE
7	TUBE SHEET	1	STEEL SA-182-C	5" THK x 23" O.D.	6-1187	
6	REINFORCING RING	2	STEEL SA-182-C	3/4" THK x 3" O.D.	6-1187	
5	SHELL FLANGE	1	STEEL SA-182-C	10" I.D. x 10" O.D. x 1 1/2" THK	6-1130	
4	SHELL	1	STEEL SA-182-C	10" I.D. x 23" O.D.	6-1130	
3	ENTR-EXIT COVER	1	STEEL SA-182-C	1 1/2" THK x 10" O.D.	6-1129	
2	ENTR-EXIT BONNET FLG.	1	STEEL SA-182-C	1 1/2" THK x 23" O.D.	6-1129	
1	ENTR-EXIT BONNET	1	FORGED STEEL SA-182-C	1 1/2" WALL x 10" O.D.	6-1129	
ITEM	DESCRIPTION	QTY	MATERIAL	SIZE	DRG	REMARKS

NET WEIGHT: 2476 LB.
 GROSS WEIGHT: 2894 LB.

FINISH	DESIGN	TEST	TEMP
SHELL	300	550	600
TUBE	1400	2150	650

DESIGN	DATE	BY
CHECKED	DATE	BY
APPROVED	DATE	BY
THERMEXCHANGER, INC.		
OAKLAND, CALIFORNIA		
PROJECT	DATE	BY
REVISION	DATE	BY
NOTE	12-10-76	E-1109

Figure VI-4. Drawing of Subcooling-Preheating Heat Exchanger HE3.

It is anticipated that the biggest thermal stresses during temperature transients will occur in the tube sheets of the two HE1 exchangers, Figure VI-2. When heat is being stored in the Research Experiment in the charging mode, steam will enter the top desuperheating exchanger at 755 K (900° F). When steam is generated by the Research Experiment discharging operation, steam will exit this exchanger at 673 K (752° F). The reversing operation requires that the steam side of the head of the heat exchanger undergo a temperature change of 83 K (150° F). Thermxchanger is collaborating with Nuclear Services of Oakland, California to determine the effect of rate of temperature change on the thermal stresses and fatigue life of the tube sheet which is 0.144 m (5-11/16 inch) thick. The study is not complete, but preliminary calculations indicate that Research Experiment operation can be reversed in 30 minutes. Details of the study will be presented in a later report.

The head of HE2, Figure VI-3, will act as the steam separator when the Thermal Storage Subsystem Research Experiment is generating steam. The water level will be maintained 0.622 m (24½ inch) above the top tube sheet during discharge. HE2 will function as a natural circulation boiler in this mode of operation, and a 0.102 m (4 inch) diameter recirculation line enters the top head 0.318 m (12½ inch) above the tube sheet. The baffle around the recirculation line entrance will minimize the amount of entrained steam vapor that is drawn down this line. The liquid level in the top head will be measured with two differential pressure sensors. The output of one sensor will be used to control and the output from the second sensor will be used to monitor the liquid level. This approach is conventional power plant practice. The bottom taps for both sensors will be located in a quiescent area inside the recirculation line baffle. A 0.152 m (6 inch) thick wire mesh drying screen is located 0.724 m (28½ inch) above the nominal liquid level. Steam will exit the top of HE2 through a 0.102 m (4 inch) diameter T-shaped dry pipe in the head. When the Research Experiment is being charged, the water level in HE2 will be maintained 0.312 m (12¼ inch) above the bottom tube sheet. The liquid level will again be measured with a differential pressure sensor. The bottom tap of the sensor is located in the bottom head of HE2 and the top tap is located in the recirculation line.

HE3 is similar in construction to the HE1 units. It is the smallest of the heat exchangers and undergoes a relatively small temperature change during a reversal of operation from charging to discharging. HE3 always functions as a liquid to liquid heat exchanger and its design is the most conventional of the three units.

3. Research Experiment Tanks

Some of the design features of the salt tanks reported in the last Quarterly Report have been changed. Only one tank, the hot tank, will have three thermocouple wells. The low temperature salt tank will have two wells. The liquid level sensor for the salt tanks has been changed from a flowing nitrogen manometer to a differential pressure sensor. This level sensor will incorporate thermal isolation lines between the pressure sensing ports on the tank and the pressure cells. The isolation lines will be filled with a high temperature silicon-based oil. The liquid level will be measured in only one salt tank. The function and design of the oil tanks have not been changed.

4. Research Experiment Pumps

The pumps for the Research Experiment have been ordered. The pump specifications are given in Table VI-1. The two salt pumps which were described in the last Quarterly Report will be located in the salt tanks. Each of these pumps will pump the salt from the tank in which it is located into the other tank. The pump in T1, the hot tank, will operate only during the discharging operation, and the pump in T2, the cold tank, will operate only during the charging operation. Since these pumps will always be submerged in molten salt, there is no need to provide cooling to them when they are running, but control valve FCV1 is closed and there is no flow through the pumps. The heat generated during this operation will be carried away by the salt in the tank. The single oil pump operates during both charging and discharging. Valves are used to reverse oil flow through the heat exchangers and to the tanks. A bypass loop around this pump contains a small heat exchanger which will protect the pump from overheating during periods of low or no oil flow.

5. Desuperheater Design Considerations

The two desuperheaters, DS1 and DS2, as shown in Figure VI-5, are designed to provide full range operation from 20 to 100 percent of system flow in the charging mode under condition of operation and no-operation of heat exchanger No. 1 (HE1). The spray nozzle assemblies are commercially available Forney Engineering Co. MA-330 units. Due to the requirements for 5-to-1 turndown, venturi sections have been incorporated into the devices to provide enhanced atomization of the injected feed-water at the "low" steam flow rates. The uniqueness of these

TABLE VI-1
PUMP SPECIFICATIONS AND SUPPLIERS

Parameter	CP-1 & 2	CP-3
Storage Fluid Circulated	Heat transfer salt (molten)	Heat transfer oil (hydrocarbon oil)
Pump Type	Centrifugal, single stage	Centrifugal, single stage
Mounting	Vertical, tank mounted	Horizontal, base mounted
Casing Material	Stainless steel	Cast steel
Impeller Material	Stainless steel	Cast iron
Rated Drive Power, kW (hp)	3.73 (5)	22.37 (30)
Speed, rad/s (rpm)	183 (1750)	366 (3500)
Rated Capacity, liter/s (gpm)	1.14 (18)	25.23 (400)
Total Developed Head, m (ft)	21.34 (70)	76.20 (250)
Pump Size, Discharge x Suction mm (inch)	38.1 x 50.8 (1.5 x 2)	76.2 x 101.6 (3 x 4)
Supplier	Lawrence Pump and Engine Co. Lawrence, Massachusetts	Dean Brothers Pumps, Inc. Indianapolis, Indiana

Figure VI-5. Desuperheater Drawing, Thermal Storage Subsystem Research Experiment.

venturi units is that they must function in both flow directions (i.e., charging and discharging flow) and consequently, the venturi sections are "double exit cone" designs to eliminate large pressure losses. Another feature of the desuperheaters is the incorporation of stainless steel liners which provide for resistance to thermal erosion and protect the pressure piping.

6. Piping Design Considerations

Figures VI-6 and VI-7 show two of the piping drawings for the Research Experiment. Figure VI-6 is a plan view of the salt system and VI-7 is an elevation view of the salt system. These drawings are typical of the system drawings that were included in the request for quote package that was sent to potential construction contractors. Only the molten salt and steam trace lines are shown in these figures. Both salt lines that connect the tanks to HE1 have expansion loops in them. The loop in the line connecting tank T1 to HE1 is vertical and the loop in the T2 to HE1 line is horizontal. These salt lines are traced with two 0.013 m ($\frac{1}{2}$ inch) diameter steam lines to preheat the lines before molten salt is pumped through them.

The salt heat exchangers are located above the storage tanks (see Figure VI-7). When the Research Experiment is not in operation, the salt lines and heat exchangers will drain back into the tanks. Most of the salt will drain into Tank T2, the low temperature tank. The salt lines slope back towards the tanks to facilitate the draining operation.

Figures VI-6 and VI-7 are two of the twelve piping installation drawings that were made during the detailed design phase of the Research Experiment. These drawings were published at the Fourth Project Review Meeting held on May 20, at the Martin Marietta Corporation in Denver, Colorado. The drawings and the design calculations including the piping code calculations constitute a major portion of the detailed design effort.

7. Research Experiment Control Console

Figure VI-8 is a drawing of the control console for the Research Experiment. The console is "laid-out" to resemble the operational schematic as much as possible. The major components are in the same relative locations and the steam and feedwater circulation lines have the same orientation. The output from all of the flow rate sensors, liquid level sensors and most of the temperature sensors can be read from meters located in the panel in their proper schematic locations.

Figure VI-6. Plan View of Heat Storage Salt Piping System.

Figure VI-7. Elevation View of Heat Storage Salt Piping System.

Figure VI-8. Drawing of the Research Experiment Control Panel.

Operation of the Research Experiment requires nine electronic controllers. The controllers, which are Electronic Control Systems, Inc., Model 6812 units, are located in a row across the center portion of the control panel. The nominal value of the process variable to be controlled is manually set on a digital dial on the face of the controller. Output and deviation from set point meters are located on the face of each controller. Two of these units are dual function controllers in the sense that they are used to control one process variable during charging and a different variable during discharge. The input to the FCV1 controller will come from DTS1 during discharging and from CTS1 during charging. The input for the FCV2 controller will come from DPS1 during discharging and from CPS1 during charging. When the Research Experiment is turned around from the charging mode to the discharging mode of operation, the set points of these controllers will have to be changed. The control action of both controllers will also have to be changed, for the following reason. During charging, a drop in the temperature read by CTS1 requires that FCV1 be closed as a corrective action. This action will slow the flow of salt through HE1 and raise the exit steam temperature. During discharging, a drop in the temperature read by DTS1 requires that FCV1 be opened as a corrective action. An increased flow of salt is required to raise the steam temperature. The action of the controllers is reversed by a switch located on the side of the unit. The rest of the controllers in the panel are single function units and they will not have to be adjusted during a mode reversal of the Research Experiment.

The mode selection switches for charge, discharge and standby, are located on the panel between the two salt tank lines. The standby override switch for each controller is positioned directly below the unit. This switch removes the ground from the controller output and allows actuation of the flow control valves in the standby mode. Manual switches are located next to each flow reversing valve on the control console. These switches open the corresponding valves in the standby mode.

C. TEST PLAN

The Preliminary Test Plan was outlined in the last quarterly report. During this quarter, the Final Test Plan was prepared. There are only a few significant differences between the final and preliminary test plans. An appendix was added to the Final Test Plan. The appendix included the drawings and documents referenced in the test plan. A section on operations control was added which included the control trailer arrangement, the crew organization and safety requirements. The instrumentation

section was updated and the surface contact thermocouples were added to the instrumentation list. A system cleaning procedure was also added.

Detailed Test Procedures are now being written for the Research Experiment. The procedures have been grouped into nine major categories as follows:

1. System Description - The first procedure section will contain verbal and schematic descriptions of the salt, oil and steam circuits. An instrumentation list and controls description will be included in this section.
2. Initial System Preparation - This second section will include those procedures that will only be performed once at the beginning of the test program. Some examples are the initial loading of the salt and oil and the initial component function evaluation.
3. Startup Tests - Section three will consist of the procedures that will be used to conduct the first operational tests of the Research Experiment such as the initial charging of the oil and salt systems.
4. Component Handling - Section four contains the procedures that describe the sampling and testing of water, steam, salt, etc.
5. Normal Operations - This section contains the procedures that will be used in the daily operation of the Research Experiment. Procedures for steady state and transient charging and discharging operations as well as mode reversing operations will be included.
6. Emergency Conditions - These procedures describe the steps to be taken if a major system failure such as a steam or oil line rupture occurs.
7. Disaster Plans - This section will describe the actions that should be taken to coordinate with Georgia Power Company personnel in the event of a major natural disaster.
8. Maintenance - Procedures for both preventive maintenance and component repair will be put in this section.
9. Instrumentation Calibration - The procedures here will cover the calibration of temperature, flow and level sensors as well as the readout meters, strip chart recorders and controllers.

Procedure writing began on June 4, and is scheduled to be completed before the end of August. It is intended that each procedure include every action that is required to accomplish

the specified task and any cautions or unusual circumstances that operators should be aware of during execution of the procedure.

D. HYDROCARBON STORAGE FLUIDS

During this report period a study into the thermal stability of commercially available hydro-carbon heat transfer oils was undertaken. The intent of this study was to determine the best oil for the research experiment. The results of this study are summarized herein.

All hydrocarbon oils decompose. The rate of decomposition is an exponentially increasing function of increasing temperature. The products of decomposition are classified into two groups: (1) high boilers (H.B.) those compounds that boil at temperatures higher than the fresh fluid and (2) low boiler (L.B.) those compounds that boil at temperatures lower than the fresh fluid. The H.B. concentration in a heat transfer fluid tends to increase the viscosity of the fluid. The low boilers tend to vent off and must be replaced with make up fluid.

The hydrocarbon heat transfer fluids commercially available are relatively stable, that is, they have a low decomposition rate in the temperature range of ordinary use. However, when these oils are used in a thermal storage application, large quantities of the fluid are kept at elevated temperatures for extended periods of time; under these conditions even a small decomposition rate can be important.

Three sources of decomposition data were found: Dow Chemical, Monsanto and the Atomic Energy of Canada Limited (AECL). This decomposition data is presented in Figure VI-9. This data (low cost oil line on Figure VI-9) was used to predict long term oil performance. This oil performance prediction indicates that an oil maintenance unit could be necessary to continuously reprocess the oil.

There are several cautions as to how applicable the degradation data presented in the figure is to the thermal storage problem. These cautions are:

- (1) The data was generated by oil and chemical companies for comparison purposes.
- (2) The bulk of the data is taken at temperatures higher than the temperature range of interest of this program.

Figure VI-9. Oil Decomposition Rate as a Function of Temperature.

(3) Test data was generated in small sealed containers which is not like our intended use.

(4) The test samples were small which gives a large surface to volume ratio that will magnify any catalytic effect of the container as compared to our intended use.

In view of the above, Sandia Labs is in the process of undertaking a test program to gather test data on oil decomposition that will be directly applicable to a thermal storage application.

Decomposition data for EXXON Caloria HT-43, Mobiltherm 500 and Therminol 55 are shown in Figure VI-9. The experiment duration is short, 8 to 10 weeks, and, it is clear from the decomposition data presented in Figure VI-9 that we will not experience any decomposition problems from any of the oils in this period of time. The Mobiltherm is currently not on the market. The Therminol 55 cost approximately \$1.50 per gallon. The Caloria HT-43 cost approximately \$0.85 per gallon. As such, we have selected Caloria HT-43 as the Research Experiment oil.

E. SCHEDULE

The master schedule for the Research Experiment is found in Table VI-2. All major efforts listed there are proceeding on schedule. As indicated, the activities completed during this quarter include:

- (1) The detailed design of the Research Experiment.
- (2) Research Experiment equipment order placement.
- (3) Letting of all subcontracts, including the construction contract.
- (4) Writing of the Final Test Plan.

The fabrication of major system components, heat exchangers, tanks, etc., is also proceeding on schedule. The construction of items that are critical to the program schedule is being closely monitored. An example is HE2, which must be delivered to the test site by September 3, if the construction schedule is not to be delayed. Thermxchanger, Inc., has agreed to a detailed component procurement and fabrication schedule and a report on schedule progress is being made on a regular basis.

Major activities for the coming quarter will include:

- (1) Monitoring of component fabrication and delivery.

TABLE VI-2
MASTER SCHEDULE FOR THE RESEARCH EXPERIMENT

VI-21

- (2) Generation of Research Experiment detailed procedures.
- (3) The construction of the Research Experiment.
- (4) Completion of the First Annual Report.
- (5) The beginning of the final pilot plant conceptual design studies.

No significant schedule changes are anticipated.

SECTION VII

VII. BALANCE OF PLANT--INCLUDING ELECTRIC POWER GENERATION SUBSYSTEM

A. INTRODUCTION

Technical effort during the past quarter has included "EPGS Optimization," the completion of "Input to Martin Marietta Corporation (MMC) Computer Simulation Model," and "Consulting on Other Program Tasks."

EPGS Optimization has been paced by the preparation and checkout of a Solar Heat Balance Computer Program. This effort has been funded with Bechtel Company funds. It is a modification of a Bechtel Power Plant Heat Balance Program to cover turbine admission-steam as well as extractions and including the General Electric 12.5 MWe turbine performance parameters. The standard program was also modified to permit performance calculations without feedwater heaters in the EPGS. Checkout was completed and use of the program will be extensive in the next quarter.

Input to the MMC Computer Simulation Model has been completed. Refinements to data provided will be developed as EPGS optimization work continues.

Consulting work has included meetings on: Design criteria, the Thermal Storage Subsystem, the receiver interface, control design, and conceptual cost analysis. Further effort is planned in the technical interface areas.

B. EPGS OPTIMIZATION

A Bechtel-funded EPGS Solar Heat Balance Computer Program was developed and is now operational. Data obtained has been utilized in several trade study areas and to evaluate EPGS performance over a range of ambient conditions. A parametric study is in progress to evaluate EPGS performance versus Thermal Storage Subsystem (TSS) admission steam temperature and pressure conditions. In addition, an evaluation of the feasibility of performing feedwater heating in the TSS has been initiated and is discussed here.

1. Pump Optimization

Vendor contacts have been made to determine the flow ranges and efficiencies of commercially available positive displacement and centrifugal flow feedwater pumps. For a system with full rated flow rate available in either of two low pressure or high pressure pumps, both centrifugal and positive displacement pumps can be obtained. The positive displacement pumps must be driven through reduction gears. Efficiencies are comparable for the two systems when the gear box effects are considered. Further information is now being sought from vendors to permit an evaluation of system reliability. Larger power plants often utilize three high or low pressure pumps in parallel with less than full capacity in each pump. Such a system could improve the EPGS performance by permitting operation higher on the pump efficiency curve when less than maximum system flow is required. Maximum high pressure pump flow will only be required at maximum insolation condition and may be over 30% greater than feedwater flow rate required for rated insolation conditions. Centrifugal flow pumps may not be available in flow rates low enough to permit the three pump option. Studies are continuing to evaluate the available pumps relative to efficiency, reliability, and cost. These studies will also be extended to include similar evaluation of the two parallel mounted booster pumps since a significant part of total auxiliary power, (7%), is also consumed here.

2. Condenser

Technical input from GEA was used for the conceptual design of the EPGS. A second source (Hudson) has now been included in the consideration of a dry condenser system. The design, control, maintenance, and reliability of the GEA and Hudson systems are being evaluated relative to system cost. A design feature of the Hudson system is the use of variable pitch condenser fan blades permitting a continuously variable fan power demand versus load curve. This feature will permit some reduction in auxiliary power consumption at conditions other than maximum condenser cooling load. Figure VII-1 is a set of curves prepared from GEA data to illustrate the dry condenser performance with a two speed fan system and a system capable of operating at 16.9 k Pa (5" Hga) turbine back pressure at 315°K (108°F) ambient temperature.

A study has been performed using the Solar Heat Balance Program to determine the effect of turbine discharge pressure on EPGS efficiency for a turbine with .254 m (10") last stage blading. The turbine specified in previous reports used .2 m (8") last stage blades which are suitable for higher turbine exhaust pressures. Figure VII-2 is

Figure VII-1 Dry Condenser Performance

Figure VII-2 EPGS Performance

a plot of the turbine cycle heat rate versus turbine discharge pressure for the .254 m (10") last stage blades. The heat rate has been shown as an index rather than dimensionally as other optimization changes are expected to result in further heat rate reductions. The figure shows that a 3.4 K Pa (1" Hg) reduction from the conceptual design 20.2 K Pa (6" Hg) design point will decrease the EPGS heat rate by 1.8% with the resulting opportunity to decrease collector field size (cost) a similar amount. Dry condensers capable of meeting the CRSTPP needs at 16.9 K Pa (5" Hga) back pressure have recently been proposed by both GEA and Hudson. Reductions in turbine back pressure to values lower than 16.9 K Pa (5" Hga) would be feasible with a wet-dry or a totally wet type of cooling tower using a turbine suitable for the 16.9 K Pa (5" Hga) back pressure level. Figure VII-2 indicates an 8% decrease in EPGS heat rate at 6.8 K Pa (2" Hga) back pressure. Evaluation of wet-dry or wet systems is not included in these trade studies but the data has been included here to permit subsequent evaluation if desired. A totally wet recirculating cooling tower system could be expected to require at least 0.25 m³/sec (400 gal/min) of makeup water.

3. Line Sizing and Valving

Points are being run on the Solar Heat Balance Program to obtain pressure change effects on EPGS performance. Small increases in turbine inlet pressure can be realized from reduced line and valve losses. The conceptual design maximum pressure loss for main steam from receiver to turbine inlet was calculated to be 345 K Pa (50 psi). The Solar Heat Balance Program will be used to estimate the performance improvement. The results will be used in cost trade analysis of pipe and valving changes to evaluate pressure losses. Preliminary Solar Heat Balance Program results indicate that the actual performance gain from turbine inlet pressure increases may be small. Other factors, however, such as TSS performance could provide an added driver to reduce pressure losses. Changes which are being considered in the study are line size increases, use of low loss fittings and valves, and use of bellows instead of pipe loops for piping thermal expansion.

4. EPGS System

Contacts with GEA and Hudson have confirmed that dry condenser systems are available from both sources in either the chevron design for minimizing space requirements or in a flat design. The conceptual design configuration specified in chevron design mounted over the turbine generator. Current information from the condenser suppliers indicates that the flat surface configuration will be less

costly than the chevron design and in addition will permit use of forced draft cooling fans rather than induced draft. Since the forced draft fan system is more efficient, this change would be expected to drive costs down. Maintenance access to the condenser equipment would be improved with a flat field separate from the Turbine-Generator (T-G) building making a slight improvement in availability probable. If the T-G building design is kept separate from the condenser the modular concept of the plant will be enhanced by making conversion to wet or wet-dry condensing possible, independent of the T-G building design or arrangement.

Layout of the T-G building relative to the Receiver Tower and TSS is being coordinated with MMC and GIT. Final decisions on condenser configuration and location will be influenced by these layout decisions. Further information is due from a third condenser source being evaluated. The final decisions on T-G and condenser building locations will include cost and efficiency considerations as well as aesthetic appearance, maintenance, and operating convenience considerations.

5. EPGS Operation

During this period turbine performance characteristics for startup from admission steam only were generated. In addition, Figure VII-3 shows turbine performance during the transition from admission to main steam resulting from a subsequent receiver startup.

The curve assumes that main steam temperature will approach 783°K (950°F) before main steam pressure exceeds admission steam pressure, as shown in Figures V-28 and V-29 of Summary Progress Report issued in April, 1976. Some simplifying assumptions were necessary in constructing the curve, but the results provide an approximation of turbine output for the conditions under consideration. Further startup data will be generated in the next quarter using the Solar Heat Balance Program.

6. Optimization Related to Thermal Storage

Performance benefits in the TSS could be obtained if the turbine main steam inlet pressure is increased above 8720 K Pa (1250 psig) when the TSS and turbine are both receiving main steam. This is due to the increase in the steam saturation temperature which would permit achievement of higher temperature in the TSS storage oil and resulting decrease in TSS equipment size and fluid quantities. Data on EPGS performance for a range of pressure increases up to 10101 K Pa (1450 psig) are being obtained with the Solar Heat Balance

12.5 MWe TURBINE - GENERATOR 600 psig/750°F.
ADMISSION STEAM 6" HgA CONDENSER PRESSURE

Figure VII-3 Steam Turbine Performance Transition from Admission Steam Operation to Main Steam Operation

Program. Preliminary results show a straight line relationship up to 10101 K Pa (1450 psig) or greater. These improvements are minimal in the current design due to increased shaft leakages and less efficient blade path design at the higher pressures. The practical limit for operation of the 12.5 MWe turbine will be about 9756 K Pa (1400 psig) due to internal blade path limitations. Computer points will also be run to determine the effects of changes in admission steam temperature and pressure on EPGS performance.

Suggestions have been made that feedwater heating by the TSS would benefit TSS performance while operating from storage by increasing the storage medium temperature range and also permitting reduced heat exchanger sizes. The Bechtel Solar Heat Balance Program is being modified to permit EPGS performance evaluation with some or all of the feedwater heaters out of the system. Preliminary results from the computer are verifying hand calculations previously reported. EPGS performance is degraded when the feedwater heating is removed from the EPGS system.

Although some cost savings are realized in the TSS, the degradation in EPGS heat rate at 7 MWe (net) output under these conditions requires an increase in the total energy storage to accomplish the required 6 hour storage objective. The additional energy storage required adversely affects costs in the collector field, i.e., more energy must be diverted from the EPGS to the TSS to charge the system. Consequently, a large collector field must be constructed to meet overall energy input requirements. Preliminary indications are that the collector field penalties preclude use of the TSS for feedwater heating.

C. INPUT TO MMC COMPUTER SIMULATION MODEL

EPGS operating details relative to startup, control, ambient conditions, condenser performance and other parameters were provided for the pilot plant computer simulation. Available conceptual design values were confirmed where possible and new data was developed from hand heat balance calculations and from vendors. Significant items from this effort are discussed in the applicable optimization paragraphs of this report. The Bechtel Solar Heat Balance Program is now operating and refinements to prior results are expected. New input relative to the computer simulation model will be supplied to MMC as it becomes available during the EPGS optimizations.

D. CONSULTING ON OTHER PROGRAM TASKS

1. Receiver Interface

The receiver tower structure and cost have been re-examined for a 5.4×10^5 kg (600 ton) rather than a 2.7×10^5 kg (300 ton) receiver weight. The conceptual design tower weight and strength was high enough to provide the stiffness required to meet sway limits, so for conceptual design and cost estimating purposes, the concrete tower previously reported can accommodate a 5.4×10^5 kg (600 ton) receiver. Seismic induced accelerations were calculated for the top of a 132 m (432 foot) tower during the conceptual design. These driving forces will induce significant loads into a receiver structure of either concrete or steel mounted on the tower top. Discussions have been held between MMC, Foster Wheeler, and Bechtel to describe the response spectrum method of dynamic analysis and how it should be applied for tower top structure.

Piping and equipment located above the Receiver-Tower interface can be designed for seismic loadings using the response spectrum method of analysis and the response spectra of the interface motions previously reported. The response spectrum method assumes that the supported piping and equipment is dynamically uncoupled from the supporting structure (tower), which will be true if (1) the mass of the piping and equipment is much less than the mass of the tower; or (2) the natural frequencies of the piping and equipment are greater than 30 cps. If the systems are not uncoupled the response spectrum method will over-estimate the response of the piping and equipment.

a. Detailed Analysis - The natural frequencies of the supported piping and equipment can be determined from the principles of dynamics. The spectral accelerations corresponding to each natural frequency should be independently applied to each mode of vibration and the design quantities determined as the square root of the sum of the squares of the individual modal responses.

b. Simplified Analysis--Case I - If the supported equipment can be idealized as a single mass supported by a flexible support, the following equation can be used to determine its natural frequency:

$$f = 2\pi \sqrt{\frac{K}{M}}$$

where f = natural frequency
 k = support stiffness
 M = system mass

The spectral acceleration corresponding to the natural frequency should be used as a coefficient applied to the system mass in determining the seismic loads.

c. Simplified Analysis--Case II - For simple piping spans, the fundamental frequency can be calculated as:

$$f_1 = \frac{\pi}{2} \sqrt{\frac{EI}{mL^4}} \quad \text{where } f_1 = \text{fundamental frequency}$$

E = modulus of elasticity
 I = moment of inertia
 m = mass per unit length
 L = span length

The design values can then be determined as:

$$\begin{aligned}
 u &= 0.0194wL^4 Sa'/EI \\
 M &= 0.88wL^2 Sa' \\
 R &= 0.5wL Sa'
 \end{aligned}
 \quad \text{where }
 \begin{aligned}
 u &= \text{maximum displacement} \\
 M &= \text{internal moment} \\
 R &= \text{end reaction} \\
 w &= \text{weight per unit length} \\
 Sa' &= \text{maximum of } Sa(f), f \geq f_1 \\
 L &= \text{span length} \\
 I &= \text{moment of inertia}
 \end{aligned}$$

d. Response Spectra - During the conceptual design, vertical and horizontal response spectra for a 0.3 g acceleration were developed for the 132 m (432 foot) tower. These curves were previously reported and are repeated with minor modifications as Figures VII-4 and VII-5 for ease of reference. Similar response spectra have been developed for .2 g vertical and horizontal ground acceleration for both 101 m (332 ft) and 132 m (432 ft) towers and for .3 g ground accelerations for a 101 m (332 ft) tower. Figures VII-6 and VII-7 are the .3 g curves for the 101 m (332 ft) tower and Figures VII-8, VII-9, VII-10, and VII-11 are the .2 g curves for 101 m (332 ft) and 132 m (432 ft) towers. These curves illustrate the significant reduction of spectral acceleration for a 0.2 g ground acceleration compared to 0.3 g.

The above curves illustrate that for both 0.2 g and 0.3 g ground acceleration a reduction in tower height of 30.5 m (100 ft) results in a frequency increase for all modes. The significance of these shifts is reflected in reduction of the spectra acceleration values for frequencies above 10 Hz horizontal and 15 Hz vertical. This

Figure VII-4 Horizontal Response Spectra at Receiver-Tower Interface for 0.3g Ground Acceleration, 2% and 7% Damping, 131.7 m (432 ft) Tower

Figure VII-5 Vertical Response Spectra at Receiver-Tower Interface for 0.3g Ground Acceleration, 2% and 7% Damping, 131.7 m (432 ft) Tower

Figure VII-6 Horizontal Response Spectra at Receiver-Tower Interface for 0.3g Ground Acceleration, 2% and 7% Damping, 101.2 m (332 ft) Tower

Figure VII-7 Vertical Response Spectra at Receiver-Tower Interface for 0.3g Ground Acceleration, 2% and 7% Damping, 101.2 m (332 ft) Tower

Figure VII-8 Horizontal Response Spectra at Receiver-Tower Interface for 0.2g Ground Acceleration, 2% and 7% Damping, 101.2 m (332 ft) Tower

Figure VII-9 Vertical Response Spectra at Receiver-Tower Interface for 0.2g Ground Acceleration, 2% and 7% Damping, 101.2 m (332 ft) Tower

Figure VII-10 Horizontal Response Spectra at Receiver-Tower Interface for 0.2g Ground Acceleration, 2% and 7% Damping, 131.7 m (432 ft) Tower

Figure VII-11 Vertical Response Spectra at Receiver-Tower Interface for 0.2g Ground Acceleration, 2% and 7% Damping, 131.7 m (432 ft) Tower

reduction is important because natural frequencies of the receiver and supporting structure would be expected to fall approximately within these values.

The maximum ground acceleration for an actual site will be influenced by several factors. First, the proximity to a fault of known or suspected activity will directly impact maximum ground acceleration. Figure VII-12 was taken from University of California Earthquake Engineering Center notes by H. Bolton Seed, et al (Report #EERC 68-5, dated September, 1968), and illustrates the attenuation which may be expected at specific distances from a fault. The values shown in Figure VII-12 are approximate since other factors such as fault slip focal depth, soil stiffness, and foundation depth could cause $\pm 50\%$ variability in the maximum accelerations. Maps have been obtained for the Southwest United States which show the locations of known faults and may be helpful in site evaluation.

2. Conceptual Cost Analysis

Meetings were held with MMC, ERDA, and Sandia cognizant personnel to provide backup details on the Bechtel methods used for the Conceptual Cost Estimate. The reasons why the 10 MWe Pilot Plant costs per kW exceeded those for a conventional power plant were discussed.

In the solar power plant, solar unique components are the major costs, and the EPGS contributes a smaller portion of total plant cost. This relation is unique in the solar plant and permits efficiency improvements in the EPGS to yield great cost benefit through reductions in the size requirements for the collector field and other major cost components. As a result, the EPGS has more stages of feedwater heating, a lower back pressure dry condenser and larger pumps and pipes than would otherwise be cost effective for a fossil or nuclear plant of such capacity. Also the admission-extraction turbine is a "state-of-the-art" machine, but it is not a standard power plant unit. That difference combines with the turbine's small MWe capability to result in a much higher turbine-generator cost per kW than would be the case in a large conventional plant. The Conceptual Pilot Plant has been considered independent of any other power facility, and therefore there are no facilities that can be shared with an existing plant. If some facilities were shared, BPO costs would be less. Selection of dry condensing was a special feature permitting use of similar pilot plant modules in water scarce areas. This feature increases EPGS condenser cost over what would be expected in a conventional plant and reduces EPGS maximum efficiency due to higher design point turbine discharge pressures.

Figure VII-12 Variation of Maximum Acceleration with Earthquake Magnitude and Distance from Causative Fault