CONCEPTUAL DESIGN AND ANALYSIS OF A 100 MWe DISTRIBUTED LINE FOCUS SOLAR CENTRAL POWER PLANT

TEST PLAN

DO NOT MICROFILM
COVER

PREPARED BY

THE BDM CORPORATION
TECHNOLOGY APPLICATIONS CENTER
2600 YALE BLVD., S.E.
ALBUQUERQUE, NEW MEXICO 87106

DOE CONTRACT ET-78-C-03-2073

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONCEPTUAL DESIGN AND ANALYSIS OF A 100 MWe LINE FOCUS SOLAR CENTRAL POWER PLANT

"LFPP"

(BDM/TAC-79-189-TR)

**RESEARCH SPONSORED UNDER
DOE CONTRACT NO. ET-78-C-03-2073**

TEST PLAN

(UNCLASSIFIED)

PREPARED BY: THE BDM CORPORATION

**M.G. SEMMENS, A. FONG, G.J. COLLAROS, R.E. DASCHER
R.E. GRASSBERGER, D.B. GRIEGO, T.F. STUEBER**

SUBCONTRACTORS:

STEARNS-ROGER

SOLAR KINETICS

PUBLIC SERVICE CO. OF NEW MEXICO

—NOTICE—

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use or the results of such use of any information, apparatus, product or process disclosed in this report or represents that its use by such third party would not infringe privately owned rights.

TABLE OF CONTENTS

MASTER

	Page
A. INTRODUCTION	1
B. COLLECTOR CONFIGURATION	3
C. TEST AND MEASUREMENTS	5
1. Test Objective	5
2. Operating Range	7
3. Measurements and Instrumentation	9
4. Data Processing and Management	12
D. PERFORMANCE AND STATISTICAL ANALYSIS	14
1. Efficiency Calculations and Thermal Loss Determination	14
2. Sample Population and Confidence	18
E. MODEL VALIDATION	18
1. Receiver Tube Subsystem Model and Acceptance Criteria	18
F. TEST SCHEDULE AND PERT DIAGRAM	22

APPENDIX

A	BDM HIGH TEMPERATURE SOLAR TEST FACILITY	A-1
---	--	-----

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DOE/ET/20524--T6

DE82 007174

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	LFPP Experiment Flow Diagram	2
2	LFPP Test Dendritic Structure	4
3	Test Objectives	6
4	Operating Range	8
5	Measurements and Instrumentation	10
6	Data Acquisition and Data Analysis Flow	13
7(a)	Energy Flow	15
7(b)	Energy Balances	16
8	Sample Population and Confidence	19
9	Analytical Model Validation	21
10	Test Schedule	23

THE BDM CORPORATION

A. INTRODUCTION

The CS (Collector Subsystem)/RTS (Receiver Tube Subsystem) hardware tests are designed to verify the efficiency of the SKI (Solar Kinetics, Inc.) Model T-700 LPT (Linear Parabolic Trough) solar collector with varied RTS configurations and to validate the analytical efficiency models of the CS/RTS.

BDM/TAC has designed and constructed a solar test facility to be located in Albuquerque, New Mexico (see appendix A). This facility will be operated in conjunction with DOE Contract ET-78-R-03-2073 for the Conceptual Design of a LFPP (Line Focus Power Plant). Tests will be performed on a SKI T-700 collector which is representative of the type of collector being used in the design of the LFPP.

The purpose of these tests is to ascertain collector efficiencies in temperatures ranging from 32-750°F (0-400°C) for the different possible combinations of RTS materials and configurations and to validate analytical models designed to represent collector operation.

A flow diagram of the LFPP experiment is depicted in figure 1. The origin of this flow is dependent upon the construction of the test facility and the proper configuration of equipment to be tested. Tests will be conducted (and data collected) for several conditions selected to represent extremes and average conditions based on the operating temperatures expected to be experienced by the heat transport fluid. These initial test conditions will be replicated to provide a statistical data base which will be analyzed in the block labeled Performance and Statistical Analyses. In this step, two operations will be performed concurrently. The first will be the statistical analysis and the second the data reduction of the test results. The results of the statistical analyses will provide the initial answers to questions such as how many intermediate temperature conditions must be simulated and how many sets of replications are required for each temperature. This analysis will also provide the mean, deviation, and levels of confidence to be expected for the collected data.

Figure 1. LFP Experiment Flow Diagram

THE BDM CORPORATION

Upon exiting the Performance and Statistical Analysis block, the test information will be interrogated serially by the three questions shown in the diamond-shaped blocks.

The first question checks the validity of the model by comparing collected data to like data derived analytically from the model under comparable conditions. Invalid comparison leads to an alteration of the model and subsequent re-entry to the next question.

The second question asks if there is sufficient data to give meaningful results. If more data is needed (either for more test points, more replications, or to validate altered models), the test cycle is re-entered at the test and measurement block.

If all test configurations have been examined, the final decision block permits exit from the test loop, identification of additional test requirements or new developments, and finally documentation of the test results.

B. COLLECTOR CONFIGURATION

The test facility will be used to examine the efficiency of a low temperature and high temperature operation with two different receiver tube coatings, three thermal transport fluids, and two annulus configurations. These 24 possible combinations of parameters have been reduced to four test configurations that will provide a synoptic view of the four variables, as shown in figure 2.

The structure on the left represents the low temperature tests, the structure on the right, the high temperature. The low temperature tests incorporate both the ordinary black chrome and the stabilized black chrome surface. Only Therminol 55 will be tested as the low temperature fluid; the other fluids were eliminated because of their higher costs. The first test will then consist of a low temperature test of standard black chrome, Therminol 55, and the Pyrex glass annulus. This test will formulate the baseline for the remaining comparative tests.

Figure 2. LFPP Test Dendritic Structure

For the second configuration to the test bed, the only variable to be changed will be the receiver tube coating. The collector will be reconfigured with another receiver tube which has been plated under highly controlled conditions. This "stabilized" black chrome process was developed by Sandia Laboratories and is applied by the Highland Plating Company of Hollywood, California.

The high temperature tests, shown on the right, include neither ordinary black chrome surface coating nor T-55 as a thermal fluid. These parameters are of necessity eliminated because they have characteristics that cannot withstand temperatures above 600°F.

The remaining tests (#3 and #4) each introduce a new RTS parameter and continue to add to the original baseline. In test 3, Syltherm 800 replaces the Therminol 55 as a heat transport fluid. Syltherm is a silicon based fluid which permits testing to the higher temperature range. Test 4 requires a new configuration of the receiver tube assembly consisting of a "D" cross section receiver tube and an insulated annulus.

C. TEST AND MEASUREMENTS

1. Test Objectives

The objectives of the test program, shown in figure 3, are to verify the overall efficiency of the SKI Model T-700 LPT solar collector with varied RTS configurations and to validate the analytical efficiency models of the CS/RTS. The overall efficiency will be determined as a function of the solar insolation and average collector thermal transfer fluid temperature using a minimum of three different receiver tube/annulus configurations and two thermal transfer fluids for each configuration.

This test program will utilize the T-700 concentrator whose axis is oriented in the north/south direction to allow tracking of the sun from east to west (i.e., the concentrator normal is always aligned in the east-west vertical plane).

- 1) DETERMINE THE OVERALL EFFICIENCY (η_{cs}) OF EACH CS CONFIGURATION AS A FUNCTION OF OPERATING TEMPERATURE

$$\eta_{cs} = \frac{\dot{m} c_p \Delta T}{A_{cs} I_{net}}$$

MEASURE: T_{in} , T_{out} , VOLUMETRIC FLOW, SOLAR INSOLATION AND WEATHER CONDITIONS

- 2) COMPARE SURFACE TEMPERATURES, EFFICIENCY VALUES TO DERIVED VALUES FROM ANALYTIC MODEL, CALCULATE HEAT LOSSES OF THE RECEIVER TUBE, AND PLOT OPTICAL EFFICIENCY (η_{opt}) VERSUS TEMPERATURE

$$\eta_{cs} = \frac{\eta_{opt} (I_{net} A_c) - (\text{LOSSES})_{RT}}{I_{net} A_c}$$

- 3) IDENTIFY THE OPTIMAL RECEIVER TUBE AND ANNULUS COMBINATION AS DETERMINED BY ECONOMICAL, OPTICAL, AND THERMAL EFFICIENCY

Figure 3. Test Objectives

The specific objective of each individual test is to establish the axial and radial temperature profiles of the receiver tube subsystem under constant conditions of mass flow rate and insolation. The axial temperature profile of the fluid is used to calculate the overall collector efficiency. The radial temperature profile of the receiver tube surfaces quantifies the thermal losses of the subsystem for calculation of the optical efficiency and collector/receiver tube model validation.

The measured data from the test program will be used to verify the empirical data used in the development of analytical models and to refine the models to accurately reflect the measured data. These models will then be capable of accurately projecting the performance of the full-scale system which will utilize the SKI Model T-2100 LPT.

Analysis of the test data in conjunction with the output of the analytical models will be used to determine the optimal concentrator, receiver tube, and annulus configuration on a basis of optical, thermal, and economical efficiencies.

2. Operating Range

The test program measurements will cover the range of temperatures and flow rates expected for actual operation in different portions of the two-stage array field. Each collector row of the array is 1000 feet (304.8 meters) in length, consisting of 50 collectors, each 20-ft. (6.1m) long and connected in series. As shown in figure 4, the low-temperature stage operates between 492°F (255.5°C) and 592°F (311.1°C) ($\Delta T = 2^\circ\text{F}$ (1.1°C) per collector), while the high-temperature stage operates between 554°F (290°C) and 740°F (393.3°C) ($\Delta T = 3.72^\circ\text{F}$ (2.1°C) per collector). Testing will simulate conditions expected for the first, middle (25th), and last (50th) collectors of the 1000-ft. (304.8m) row of each of the two stages.

In full-scale operation, each collector in the row will have a unique average operating temperature ranging between the lower and upper limits of the stage. Each collector receives the thermal transfer fluid at one end (T_{IN}) and heats the fluid a small amount prior to discharge at the other end (T_{OUT}). The output of one collector becomes the input to

• LOW-TEMPERATURE STAGE •

• HIGH TEMPERATURE STAGE •

Figure 4. Operating Range

the next collector in the row. This situation is repeated until the output of the final (50th) collector, where the fluid temperature must equal the design output temperature of the stage. A sampling of the collectors in each row will provide a temperature profile and overall collector efficiency for each collector and the total row.

In order to maintain a constant temperature at the outlet of each stage, the mass flow rate of the thermal transfer fluid will be adjusted to compensate for diurnal insolation changes. Using manufacturer's specifications for the fluid and concentrator, the range in volumetric flow rates expected to be tested is calculated to be between 18 and 55 GPM 1.14-3.47 l/sec. The range in volumetric flow rates is dependent upon the desired temperature differential across the collector, the average temperature of the collector, and the insolation level. Initial testing will be performed at 40 GPM (2.52 l/sec) volumetric flow rate and adjusted as necessary to compensate for the above variables.

3. Measurements and Instrumentation

The test facility for the T-700 collector is fully instrumented to obtain the necessary thermal, flow, and meteorological data, as shown in figure 5 and appendix A.

Heat transfer fluid temperatures are measured at the inlet and outlet of the receiver tube. The sensors are RTD (Resistance Temperature Detectors) inserted directly into the fluid stream. These devices utilize the positive resistive temperature coefficient of platinum wire to sense temperatures in the range -364°F (-220°C) to +1562°F (+850°C) with an accuracy of $\pm 1\%$ of the resistance value.

Surface temperatures are measured at two positions along the axis of the receiver tube, 18 inches from the ends. At each of the two positions, four radial temperatures will be measured to provide a radial profile of the temperatures on the front and back sides of the receiver tube and annulus. The sensors are also of the RTD type, with platinum deposited on a ceramic substrate and etched to provide a serpentine resistance element. These sensors are useful in the temperature range -364°F (-220°C) to +1562°F (+850°C) with an accuracy within $\pm 5\%$ of the resistance value.

Figure 5. Measurements and Instrumentation

THE BDM CORPORATION

Ambient air temperature is sensed using an RTD of the nickel-iron variety, useful over the range -328°F (-200°C) $+500^{\circ}\text{F}$ ($+260^{\circ}\text{C}$) and with an accuracy of within $\pm 1\%$ of the resistance value.

Flow rate in GPM (gallons per minute) is sensed using an inline, turbine-type meter with magnetic pickoff, analog-to-digital signal conditioning, and remote digital readout in GPM. The readout is accurate to within $\pm 1\%$ over the range 0 to 50 GPM (0 to 3.15 l/sec) with kinematic fluid viscosities less than 3 centistokes. The flowmeter is capable of withstanding temperatures to 750°F (398.9°C).

The DP (differential pressure) across the receiver tube is measured using a differential pressure meter calibrated in inches of water. The temperature limitation is 150°F (65.6°C), so measurements will be made at low temperature and the results extrapolated to high temperature conditions.

Direct normal insolation is measured with a clock-driven tracking pyrheliometer. The accuracy of this instrument is within $\pm .5\%$ over the range zero to $445 \text{ BTU/hr} \cdot \text{ft}^2$ (0 to 1400 W/m^2).

Wind speed and direction are monitored for nominal values with an anemometer and wind vane, respectively. Accuracies are typically within $\pm 5\%$ over the ranges zero to 100 MPH (0 to 44.7 m/sec) and zero to 360 degrees.

The frequency of measurement recording is dependent upon the type of test being run. For diurnal efficiencies, each test point is measured every five minutes. Measurements of efficiency as a function of operating temperature are made every fifteen seconds for a continuous five minute period after all conditions have stabilized. A measurement consists of a computer scan of fifteen data channels: eight surface temperatures, two fluid temperatures, one flow rate, and four meteorological sensors (wind speed and direction, pyrheliometer, ambient air temperature). Each computer scan is executed in less than one second of time to ensure the simultaneity of the measurements.

THE BDM CORPORATION

4. Data Processing and Management

Data acquisition and processing is accomplished by a fully-complemented automated data system comprised of signal conditioning, computer mainframe, and input/output peripherals, shown schematically in figure 6.

All signals from the RTD's, TFD's and environmental sensors are routed into a signal conditioning unit. The analog signals are conditioned to read from zero to ten volts DC, and fed to a 10-bit ($1 \text{ in } 2^{10}$ resolution) AD (analog-to-digital) converter. The output of the A/D converter is hardwired to the computer.

The computer is a 12-bit minicomputer which executes the data acquisition and reduction programs. The software used is high-level BASIC, with 12K words of core memory.

Computer programs and test data are stored on a dual floppy disk drive. Floppy disks lower the execution time for large programs and enhance the storage capacity of the computer.

The real-time output of the test data is available on the CRT (cathode ray tube) terminal. Hard copy data can be produced real-time on the line printer. Program execution can be controlled from either the CRT or the line printer.

The line printer also has capability, through an acoustic coupler, to access larger mainframe computers employing such options, for the purpose of greater computing power. The line printer also has a dual cassette tape drive for program and data storage.

A digital plotter is also connected to the computer system for use in data display.

A real-time clock capability of the minicomputer allows data to be recorded at any desired time interval. The measured parameters are combined with look-up tables of component specifications (e.g., fluid specific gravity as a function of temperature) to produce a real-time computation of instantaneous collector efficiency, which can be plotted real-time for graphical representation. The data can also be stored on floppy disks for posttest retrieval, reduction, and analysis.

Figure 6. Data Acquisition and Data Analysis Flow

The automated processes will produce both tabular and graphical output of the means and standard deviations for the test points being measured during each test.

D. PERFORMANCE AND STATISTICAL ANALYSIS

1. Efficiency Calculations and Thermal Loss Determination

Calculation of the collector efficiency requires a detailed analysis of the energy balance equations for the annulus, receiver tube, and fluid, as shown in figure 7.

The overall collector efficiency (η_{CS}) is the ratio of the energy output from the receiver tube to the energy input to the concentrator.

The energy input to the collector is given by

$$E_i = I_o \cdot A_{CS} \cdot C_I \text{ Watts}$$

where I_o = solar beam radiation in Watts/sq meter

A_{CS} = concentrator aperture area in sq meters

C_I = correction factor for incident angle of beam radiation (no units)

The energy output from the receiver tube is the energy removed from the receiver tube by the thermal transfer fluid:

$$E_o = \dot{m} \cdot C_p \cdot \Delta T \cdot C_c \text{ Watts}$$

where $\dot{m}$ = mass flow rate in pounds/min

C_p = fluid specific heat in BTU/pound/°F

ΔT = fluid temperature rise in °F

C_c = conversion factor for BTU/min to Watts

$$(E_i) \cdot (\text{OPTICAL EFFICIENCY}) = (E_o) + (\text{THERMAL LOSSES})$$

Figure 7(a). Energy Flow

- ENERGY BALANCE ON RECEIVER

- ENERGY BALANCE ON ANNULUS

- ENERGY BALANCE ON FLUID
 $\dot{m} C_p (T_{out} - T_{in}) = \text{ENERGY INTO FLUID}$

Figure 1(b). Energy Balances

The energy available for removal by the thermal transfer fluid is dependent upon the optical efficiency (η_{OPT}) of the collector and the thermal losses (L_T) of the receiver tube:

$$E_i \cdot \eta_{OPT} = E_o + L_T$$

The optical efficiency is calculated from

$$\eta_{OPT} = \rho_C \cdot \tau_G \cdot p_A \cdot \alpha_A$$

where

ρ_C = reflectance of the concentrator surface

τ_G = transmittance of the glass annulus (.91)

p_A = fraction of light intercepted by absorber
(~.98)

α_A = absorptance of the absorber (manufacturer's specifications)

The thermal losses are a complicated combination of radiative and convective losses to the ambient environment but can be quantified using the energy balance equation for the entire system:

$$L_T = E_i \cdot \eta_{OPT} - E_o$$

This result can then be used to validate and refine the heat transfer model.

Alternatively, the energy balance equation can be solved for the optical efficiency using the model output for the thermal losses:

$$\eta_{OPT} = \frac{E_o + L_T}{E_i}$$

The accurate solution to the energy balance equation must be an interactive process which combines the actual test measurements with the model output.

2. Sample Population and Confidence

Each test configuration shall contain a large enough number of test point measurements to adequately characterize the variability of the data and instrumentation. Figure 8 shows sample population and confidence. Some test points may be somewhat invariant while others may exhibit a large dependence upon external variables which cannot be controlled. The tests will be conducted in a manner which minimizes or normalizes variables to the greatest extent possible within the scope of the tests. This methodology assures maximum repeatability of the data and minimizes variability.

The data is acquired by a computerized digital data acquisition and processing system. All of the data channels are scanned by the computer in less than one second, constituting a measurement, and the data stored on magnetic disks for subsequent reduction. The data is also available for real-time examination on a CRT, line printer, or plotter.

The data for each test point will be accumulated, and the distribution of the data will be updated until all test points have been adequately characterized. The mean ($\bar{x}$) and standard deviation (σ) will be calculated for each test point with the constraint that three standard deviations (3σ) from the mean value ($\bar{x}$) of the measured data will be no more than $\pm 5\%$ away from the mean. A minimum of twenty measurements is expected for each test point for each test.

A test point measurement matrix will be prepared for each test summarizing the data and results of the statistical calculations.

E. MODEL VALIDATION

1. Receiver Tube Subsystem Model and Acceptance Criteria

The RTS (Receiver Tube Subsystem) model is designed to calculate the overall collector efficiency as a function of insolation and average temperature of the thermal transfer fluid within the receiver tube.

The primary output of the model is the overall collector efficiency as a function of the average fluid temperature, producing a family of curves for various values of constant insolation.

Figure 8. Sample Population and Confidence

The alternate output of the model is in the form of overall collector efficiency as a function of insolation for a family of constant collector temperatures.

The former output is useful in examining the efficiencies of several design points while the latter output is more appropriate for a single given design point. Typical examples of the model output are shown in figure 9.

The RTS (Receiver Tube Subsystem) model determines the temperatures at fifteen nodes through a radial cross section of the receiver tube and annulus.

Given the fluid and ambient temperatures along with the physical characteristics of the annulus, receiver tube, and fluid, the model performs an energy balance on three portions of the RTS simultaneously to calculate the temperature at each node.

The RTS model has been verified to 400°F (204.4°C) using the collector manufacturer's data. No test data currently exists beyond 400°F (204.4°C). The test program will provide the necessary additional data to validate the model through 800°F (426.7°C). Using actual measurements of selected nodes, six nodes will be measured at two positions along the RTS. The remaining nine nodes are inaccessible for sensor placement, being either on interior walls of the receiver tube and annulus or within the walls themselves. The nodes chosen for sensor installation will provide adequate resolution of the radial cross section. The remaining nodes are characterized by well-known parameters of the air, glass, and steel.

The overall collector efficiency is the ratio of the energy removed from the collector by the thermal transfer fluid to the energy input to the collector in the form of solar radiation. The energy removed by the thermal transfer fluid is identical to the increase in energy of the fluid, which occurs as a rise in temperature of the fluid. The test program will measure this temperature rise.

The model will be refined as necessary, on the basis of the hardware test program measurements to agree within $\pm 2\%$ of the mean of the measured data.

Figure 9. Analytical Model Validation

F. TEST SCHEDULE AND PERT DIAGRAM

The test schedule shown in figure 10 has been developed to provide three weeks of testing for each of the four planned test configurations. Additional test time has been included after completion of configuration four for re-evaluation of any of the test configurations if necessary or further testing of additional configurations as required. Also, one week has been included prior to the start of actual testing for system checkout at low temperature.

The low temperature testing will allow verification of the fluid loop integrity (e.g., fittings and seals) prior to installation of the pipe insulation. It will also allow familiarization of the mechanical characteristics of the pump, throttling, and heat exchanger aspects as well as familiarization with the interrelationship and interdependence of the variables involved (e.g., change in volumetric flow rate with change in fluid temperature).

Each configuration requires complete disassembly of the receiver tube. One week of the anticipated three weeks of test time is required for opening the fluid loop, deinstrumenting the RTS, removal and reinstallation of the RTS and/or fluid, reinstrumenting the RTS, and securing the fluid loop.

Data analysis will be performed concurrently with the testing in order to maximize the coverage of the test variables.

APPENDIX A

BDM HIGH TEMPERATURE SOLAR TEST FACILITY

The BDM HTSTF (High Temperature Solar Test Facility) was designed to be capable of component and subsystem hardware testing up to fluid temperatures of 750°F (398.9°C). All major components have been selected to meet or exceed this temperature requirement while remaining as flexible as possible in range of operation.

The HTSTF is a dedicated portion of total STF located atop a BDM office building in the Newport Industrial Park in Albuquerque, New Mexico. The STF supports solar testing of flat plate and concentrating photovoltaic and photothermal solar collectors for component development or subsystem experimentation. The schematic layout of the HTSTF is presented in figure A-1. Figures A-2 through A-10 show details of the HTSTF.

The concentrator for the HTSTF is a Solar Kinetics Incorporated (SKI) model T-700 LPT (Linear Parabolic Trough) 20 feet in length and 7 feet in clear aperture. The concentrator is aligned in a north-south orientation with single-axis solar tracking from east to west. Solar position is detected by a shadowbar differential light sensor aligned parallel to the concentrator normal. Alignment of the concentrator is accomplished by a hydraulic drive unit located in the drive pylon and coupled to the shadowbar sensor. Alignment accuracy can be adjusted to be within five milliradians (less than one-third of a degree). The reflective surface of the concentrator is an aluminized acrylic film with a specular reflectivity of .84. The focal length is 22 inches. Its 90° rim angle is optimum for LPT concentrators as discussed in the Sandia Report SAND74-0124. It should be noted that the SKI T-700 was chosen by Sandia for the Willard Solar Irrigation Project in Willard, New Mexico. Figure A-11 presents a descriptive summary of the T-700 concentrator and standard receiver tube for photothermal applications.

THERMAL SYSTEM

Figure A-1. HTSTF Schematic Layout

Figure A-2. Overall HTSTF

Figure A-3a. Overall Mechanical Area

Figure A-3b. Heat Exchanger
A-4

Figure A-4. Fluid Temperature Probe Installation

Figure A-5. Surface Temperature Sensor Installation

Figure A-6. Turbine Flowmeter Installation

Figure A-7. Wind Speed and Direction Sensors
A-6

Figure A-8. Pyrhelimeter

Figure A-9. Low Temperature Heat Exchanger Pump & Thermal Exp. Tank
A-7

CRT TERMINAL AND LINE PRINTER

PCM-12 MINICOMPUTER AND
DUAL FLOPPY DISC DRIVES

INSTRUMENTATION
RACK

Figure A-10. STF Control Room Instrumentation

① STEEL RECEIVER TUBE SURROUNDED BY A DRY AIR/ANNULUS AND PROTECTED BY GLASS TUBING. FOCUS IS ADJUSTABLE DURING INSTALLATION.	SPECIFICATIONS	T-700
② A PRECISELY CONSTRUCTED MIRROR SURFACE IS COVERED WITH METALLIZED ACRYLIC FILM, COMBINING WEATHER RESISTANCE AND HIGH REFLECTIVITY.	MODULE WIDTH	95.0 IN (2.41 M)
③ THE PARABOLIC CONTOUR OF THE CAST ALUMINUM RIBS IS N/C MACHINE GENERATED FOR AN ACCURATE FOCUS.	MODULE LENGTH	10/20 FT (3.05/6.1M)
④ THE THERMAL EXPANSION BELLOWES ALLOWS FOR EXPANSION OF THE RECEIVER ASSEMBLY AND MAINTAINS A SEALED, DRY ENVIRONMENT IN THE ANNULUS.	MIRROR WIDTH	84.5 IN (2.15 M)
⑤ AN INSULATED STAINLESS STEEL FLEX HOSE ALLOWS ROTATION OF THE COLLECTOR WITH UNRESTRICTED FLOW.	SOLAR AREA (SQ FT)	70/140 (6.5/13.0 M)
⑥ SELF ALIGNING SEALED BALL BEARINGS ABSORB STRUCTURAL LOADS MAINTAINING COLLECTOR MOTION WITHOUT BINDING.	REFLECTANCE	0.84
⑦ A FORGED STEEL FLANGE CARRIES TORSIONAL LOADS INTO THE COLLECTOR STRUCTURE. ALLOWS MIRROR INSTALLATION WITH EIGHT BOLTS.	MAX VERT HEIGHT	105 IN (2.67 M)
⑧ THE STEEL SUPPORT PYLON IS GALVANIZED FOR CORROSION PROTECTION.	ROTATION AXIS HT	57 IN (1.45 M)
⑨ MOUNTING STUDS ARE A STANDARD PATTERN FOR EACH COLLECTOR.	TRACKING ANGLE	270 °
⑩ THIS LOAD BEARING JOINT PROTECTS THE COLLECTOR STRUCTURE FROM STRAINS INDUCED BY MISALIGNMENT FOUNDATION SHIFTS.	STOW ANGLE	45 °
	SYSTEM WEIGHT	4.0 LB/FT ² (19.53 Kg/M ²) (ALUMINUM)

Figure A-11. Description of Solar Kinetics T-700 Concentrating Collector

THE BDM CORPORATION

Any receiver tube design can be placed at the focal point of the concentrator with appropriate mounting modifications as required. Fluid inlet to and outlet from the receiver tube is accomplished by flexible metal hose, insulated by flexible stainless steel bellows. The receiver tube is mounted on adjustable standoffs which maintain positioning of the receiver tube at the focal point.

Mild carbon-steel pipe and tubing is used throughout the installation for carrying the thermal transfer fluid.

Any fluid can be used as the thermal transfer fluid provided it does not solidify or become excessively viscous at temperatures near 0°F (-17.8°C). Standard fluids available for use at elevated temperatures are Monsanto's THERMINOL 55 and Dow's SYLTHERM 800.

Heat transfer fluids are circulated through the closed-loop fluid system by a Kontro sealless centrifugal pump with a magnetically-coupled impeller, capable of withstanding temperatures to 750°F (398.9°C). A 7-1/2 horsepower electric motor provides power for the pump, which has a rated capacity of forty GPM (gallons per minute) (2.52 l/sec) at 60 feet (18.3m) of head. The pump is protected from particulates by a 20-mesh screen on the suction side.

A throttle valve controls the flow rate of the thermal transfer fluid through the system. The flow rate in GPM is sensed using a Flow Technology in-line turbine-type flow meter. A magnetic pick-off converts the mechanical motion to an electrical signal which is digitized and remotely displayed in GPM.

Heat is extracted from the thermal transfer fluid by an Omega liquid-to-liquid heat exchanger of the shell and tube design. The cold side of the heat exchanger uses ethylene glycol/water which transfers the heat to a Baltimore Aircoil vertical evaporative cooling tower.

Thermal expansion of the thermal transfer fluid is absorbed by a Wendland expansion tank, which also serves as a filling point for the system. The tank has a nitrogen overpressure to isolate the thermal transfer fluid from the atmosphere, if necessary to control oxidation of the fluid. The tank has climb/dive valves to maintain constant inerting gas pressure.

THE BDM CORPORATION

A Bernadette air trap removes any bubbles which might form in the fluid, either through leakage or low-boiler by-products of the fluid. Bubbles are removed from the system through the expansion tank and are saved for future analysis if desired.

Thermal transfer fluid temperatures are sensed using Minco RTD (Resistance Temperature Detectors). These sensors utilize the positive resistive temperature coefficient of platinum wire to indirectly measure temperature. The resistive temperature coefficient is very accurately known and the resistance easily measured. Each fluid RTD is tailored to be accurate within $\pm 1\%$ of its resistance at any temperature over the range -364°F (-220°C) to $+1562^{\circ}\text{F}$ ($+850^{\circ}\text{C}$).

Receiver tube surface temperatures are sensed using Omega TFD (Thin-Film Detectors). These sensors utilize the same principle as the RTD with the exception that the platinum is vacuum-deposited on a ceramic substrate and etched to give the desired nominal resistance. The characteristics of the platinum are identical. Each TFD is accurate within $\pm 1\%$ of its resistance over the same temperature range as the RTD.

The above-mentioned flow meter is accurate to within $\pm 0.5\%$ over the range zero to fifty GPM (0 to 3.15 l/sec) with fluid viscosities less than three centistokes.

Wind speed and direction are monitored for nominal values with a Weathermeasure cup anemometer and vane, respectively. Accuracies are within $\pm 5\%$ over the ranges 0-100 MPH (44.7 m/sec) and 0-360 degrees.

Solar beam radiation is measured with an Eppley clock-driven tracking pyrhelimeter whose accuracy is within $\pm 0.5\%$ over the range 0-445 BTU/hr $\cdot$ ft² (0-1400 W/m²).

All signals from the measurement instrumentation are wired into a ninety-six channel signal conditioning unit. The analog signals are converted to 10-bit digital format for interfacing with the computer.

Data acquisition is controlled by a Pacific Cyber/Metrix PCM-12 minicomputer, with 12k words of core memory and 12-bit resolution. Data acquisition and reduction programs are written in high-level BASIC software.

THE BDM CORPORATION

Software and test data are stored on a Data Systems dual floppy-disk drive. The floppy disks lower the execution time for large programs and greatly enhance the storage capacity of the computer.

Real-time output of the test data is available on a Lear-Siegler CRT terminal or a Texas Instruments line printer. Program execution can be controlled from either the CRT or the line printer. The line printer has the additional capability, through an acoustic coupler, to access larger mainframe computers employing such options, for greater computing power or peripheral options. The line printer has a dual cassette tape drive for program and data storage.

Graphical data can be produced on a Houston Instruments digital plotter, connected to the PCM-12 minicomputer.