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Central Receiver Test Facility (CRTF) Experiment Manual

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David B. Davis, David L. King

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CENTRAL RECEIVER TEST FACILITY (CRTF) EXPERIMENT MANUAL

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ABSTRACT

The Central Receiver Test Facility is operated by Sandia Laboratories for the US Department of Energy. The CRTF is being used for component and subsystem evaluation within the Solar Thermal Large Power Systems Program. This Experiment Manual provides users of the CRTF detailed information about

- Implementation of testing at the CRTF
- Details of the CRTF capabilities and interfaces
- Requirements of experimenters

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Glossary of Abbreviations and Acronyms

A/D	Analog-to-Digital
AISC	American Institute for Steel Construction
ALO	Albuquerque Operations Office
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing Materials
BCS	Beam Characterization System
CRTF	Central Receiver Test Facility
D/A	Digital-to-Analog
DAS	Data Acquisition System
DIO	Digital Input-Output
DOE	US Department of Energy
DOT	Department of Transportation
DST	Division of Solar Technology
EPRI	Electric Power Research Institute
E-W	East-West
FAA	Federal Aviation Administration
FASS	Focus and Alignment Subsystem
FS	Full Scale
HAC	Heliostat Array Controller
HCE	Heliostat Control Electronics
HFMI	Heliostat Field Mobile Instrumentation
HIM	Heliostat Interface Module
H-P	Hewlett-Packard
HRS	Heat-Rejection System
IATA	International Air Traffic Association
ITP	Integrated Test Procedure
KAFB	Kirtland Air Force Base
LBL	Lawrence Berkeley Laboratory
L/C	Laser Collimator
MCS	Master Control System
MRI	Meteorology Research, Inc.
N-S	North-South
O&M	Operation and Maintenance

Glossary of Abbreviations and Acronyms (cont)

OSHA	Occupational Safety and Health Association
PCS	Pointing Characterization System
QA	Quality Assurance
RTAF	Real-Time Aperture Flux
STLPS	Solar Thermal Large Power System
STTF-UA	Solar Thermal Test Facilities - Users Association
TC	Thermocouple
WR	Working Receiver

Preface to the First Revision

The CRTF experiment manual was first issued in October 1977. This revision updates that manual, simplifies administrative processes (Chapter II), and provides details about CRTF capabilities and interfaces (Chapter III).

This document will be revised as CRTF capabilities are modified, expanded, or improved, or as user needs change.

Detailed questions about the facility should be addressed to:

CRTF Liaison Engineer
Division 4713
Sandia Laboratories
Albuquerque, NM 87185
Commercial: (505) 264-6871
FTS: 475-6871

CENTRAL RECEIVER TEST FACILITY (CRTF) EXPERIMENT MANUAL

CHAPTER I. INTRODUCTION

The CRTF is the primary solar test facility for component and sub-system evaluation within the DOE's STLPS program.

The CRTF (Figure 1), with a thermal capability of about 5 MW, is designed to perform a variety of functions including, but not limited to

- Testing scale models of water-cooled receivers (boilers) for a 10-MWe demonstration pilot plant and future commercial plants
- Testing advanced receivers using water, gas, molten salts, liquid metals, and other coolants
- Testing prototype collectors (heliostats) for the 10-MWe pilot plant and future plants
- Testing components and subsystems for advanced solar thermal systems including heat or other energy storage systems
- Testing direct-energy-conversion cycles such as photo-voltaics or thermionics
- Testing instrumentation systems needed for solar energy
- Training personnel to operate solar facilities
- Developing high-temperature chemical and metallurgical processes and determining high-intensity solar spectrum effects on materials.

This document provides information about administrative procedures, CRTF capabilities, and the requirements made upon the experimenter.

Figure 1. Central Receiver Test Facility

Programmatic experiments that have a direct DOE/Solar Technology Program involvement (e.g., the 10-MWe pilot-plant receivers and heliostats, advanced central receivers, the EPRI receivers, advanced heliostats, and DOE photovoltaic experiments) will have direct access to the facility. Correspondence from these experimenters should be addressed to

CRTF Liaison Engineer
Division 4713
Sandia Laboratories
Albuquerque, NM 87185
Commercial: (505) 264-6871
FTS: 475-6871

Nonprogrammatic experiments (i.e., all other) will be coordinated through the STTF-UA:

Solar Thermal Test Facilities Users Association
Suite 1204, First National Bank Building, East
Albuquerque, NM 87108
Commercial: (505) 268-3994

CHAPTER II. ADMINISTRATIVE PROCESSES

Experimenters may follow one of two routes in implementing experiments at the CRTF. Experimenters with major DOE projects (Route 1) will work directly with the CRTF Liaison Engineer. Other experimenters will work first with the STTF-UA (Route 2) and later with the CRTF Liaison Engineer. The STTF-UA will review, coordinate, recommend priorities, and provide financial assistance in some cases for these experiments. Initial contacts with either organization need to include only a brief description of the experiment and of the testing requirements.

Experiment Implementation

Experiments require strong, direct interaction between the experimenters and the CRTF staff to assure that they are carried out systematically and on time. The experimenter must supply detailed information to the CRTF so that the experiment can be installed and operated safely and reliably to obtain desired test conditions and results. Figure 2 illustrates this process.

For each series of tests at the CRTF, the experimenter must provide a prescribed level of documentation. Table 1 summarizes the required elements. The Experiment Application (sample presented in Appendix A) is used primarily to secure program approval to perform the tests; its submittal formally initiates a potential experiment. The Contract Agreement, required only of non-DOE-funded users, is a legal document whose details are determined by the user and DOE/ALO.

Figure 2. CRTF Experiment Implementation

TABLE 1

Required Test Documentation

<u>Item of Documentation</u>	<u>Prepared By</u>	<u>Approved By</u>	<u>Lead Time Prior to Tests</u>
Experiment Application	User	CRTF Supervisor, SLL, DOE/HQ, STTF-UA*	-
Contract Agreement**	User, DOE/ALO	User, DOE/ALO	-
Data Package	User	CRTF Staff	90 Days
Test Plan***	User	CRTF Staff	90 Days
QA Records And As-Built Drawings	User	CRTF Staff	30 Days
Integrated Test Procedure***	User CRTF	User, CRTF, SLA Safety	7 Days
Test Report	CRTF Staff	CRTF Supervisor, SLA Solar Projects Department Manager	2 Months After Test Completion

* For tests requested by STTF-UA

** For non-DOE-funded users only

*** Information copies will be sent to SLL and DOE/HQ consistent with the indicated lead times

Technical input requirements are detailed in Chapter IV. The Data Package must fully describe the experiment design. This document will include scope and objective, design descriptions, a safety analysis, procedures for testing, and other supplementary information necessary for installing and testing the experiment. The Test Plan must describe the planned tests, including data required, training and operating procedures, and maintenance instructions. The user prepares both the Data Package and the Test Plan and submits them to the CRTF for review. If insufficient information is included, revisions are requested. The QA Records, As-Built Drawings, and other QA documents (if required) are the final documentation required for shipment approval of the hardware to the CRTF. Data in these documents and in the Safe Operating Procedures for the facility are used by the experimenter and the CRTF to jointly prepare the Integrated Test Procedure. This document (the final authority for performing the experiment) requires approval by the user, the CRTF Supervisor, and Sandia/Albuquerque Safety Organizations. After the experiments are completed, the Test Engineer prepares a final Test Report. This report will include conditions for all tests, operational details, and the data required by the user not provided elsewhere (i.e., magnetic tape, computer printout, etc). The experimenter then analyzes the data and publishes the results.

CRTF Liaison Engineer

The CRTF will provide the following engineering services to experimenters through the Liaison Engineer:

1. Expedite user access. Indicate test priorities and schedules.
2. Assist with obtaining approvals for the experiment (see Table 1 for details).
3. Provide information on CRTF capabilities, controls, data systems, and safety requirements.

4. Provide design data on CRTF/experiment interfaces.
5. Consult with experimenters on their designs for mounting and interface hardware. Experimenters will normally provide all connections to existing CRTF systems and utilities.
6. Provide detailed test planning to assure that test conditions and data requirements are met.
7. Assist in transforming experimenter's procedural input into actual test operating procedures and sequences.
8. Provide special safety equipment and procedures to assure facility safety.
9. Provide data reports and a limited amount of data processing and analysis.
10. Provide summary reports on the operation and control of the experiment.

STTF Users Association

The STTF-UA is an organization of scientists and engineers with representatives from universities, the national laboratories, research institutes, private utilities, industrial corporations, and others interested in use of the CRTF and other solar thermal test facilities.

The STTF-UA was organized to

- Act as liaison between Users and the STTFs.
- Solicit and review proposals and make recommendations to DOE regarding STTF uses.
- Disseminate STTF information regularly.
- Fund STTF Users subject to DOE program approval.

The STTF-UA coordinates all non-programatic experiments for the CRTF. It is recommended that those experimenters contact the STTF-UA executive director.

STTF Users Association
Suite 1204, First National Bank Building, East
Albuquerque, NM 87108

Phone: (505) 268-3994

Experiment Operation

Many types of experiments are expected to be proposed for the CRTF. Some will be very complex, requiring strong interfaces with the CRTF systems. Such experiments must be closely coordinated between the CRTF staff and the resident experimenter. Other simpler experiments may be operated by the resident experimenter. In all cases, the CRTF staff will operate the major CRTF systems and diagnostic tools, and will be responsible for personnel and facility safety. The exact role of the experimenter in test operations will be defined during reviews of the Data Package and Test Plan.

The facility can change and tailor the flux or other operating conditions in real time. Allowable changes are in part related to facility safety and will be defined during detailed test planning between the experimenter and the CRTF staff. Other deviations from the Test Plan during actual operation require approval by the CRTF Test Engineer and the Operations/Safety Engineer assigned to the test.

Scheduling

Scheduling is the responsibility of the CRTF Supervisor. Input from the experimenter and advice from the CRTF staff, DOE/DST, the Sandia Livermore Solar Department, and the STTF-UA will be considered when scheduling experiments. The experimenter will be notified of the tentative schedule for his experiment when the Experiment Application is approved. The detailed test schedule will be worked out during the review of the experimenter's Data Package and Test Plan. Weather conditions will affect testing schedules. Some tests may require clear days only, others partly cloudy days. Table 2 is a 38-yr summary of US Weather Bureau data for Albuquerque, NM.

TABLE 2

Typical Albuquerque Sunshine
(Compiled From 38-Yr Record)

<u>Month</u>	<u>Clear</u>	<u>Partly Cloudy</u>	<u>Cloudy</u>
January	13	8	10
February	12	7	9
March	12	10	9
April	13	9	8
May	15	10	6
June	18	8	4
July	12	14	5
August	14	12	5
September	17	8	5
October	18	7	6
November	16	7	7
December	<u>14</u>	<u>8</u>	<u>9</u>
	174	108	83

Access to KAFB and the CRTF

The CRTF is located on KAFB. Visitors must inform the CRTF of their expected arrival time so that arrangements can be made for KAFB visitor passes. A security clearance is normally not required.

When the visitor arrives at either the Gibson or Wyoming entrance to KAFB, he identifies himself and gives the Security Police the name and phone number of his CRTF contact. Visitors must observe all posted traffic regulations while on KAFB. Figure 3 shows the location of the CRTF relative to other prominent features at Sandia Laboratories and KAFB.

Private cameras will be permitted at the CRTF site, but cannot be taken into Sandia or KAFB security areas.

All resident experimenters must sign the Resident Experimenter List (Appendix B) before becoming resident at the CRTF.

Figure 3. Location of CRTF

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ADDENDUM TO SAND77-1173 (REVISED)

The following information should be added to the last paragraph of Chapter II, "Access to KAFB and the CRTF":

The following items are not permitted on the CRTF site:

- Firearms, ammunition, or other dangerous weapons
- Alcoholic beverages or other intoxicants
- Illegal drugs, stimulants, or depressants
- Explosives or incendiaries

Special permission of the CRTF Supervisor is required prior to bringing the following material on the CRTF site:

- Radioactive material
- Pyrophoric or strongly oxidizing materials or chemicals

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- Pyrophoric or strongly oxidizing materials or chemicals

CHAPTER III. DESCRIPTION OF CRTF CAPABILITIES AND INTERFACES

This section describes the general capabilities and design interfaces of interest to experimenters. Additional details of CRTF systems are available through the Liaison Engineer.

Heliostat Array Subsystem

The CRTF energy collection field consists of 222 heliostats (Figure 4). The total heliostat field can concentrate more than 5-MWth power under optimal sun, heliostat, and target conditions. For test flexibility, heliostats may be located on either of two general foundation arrays that form a northern or circular distribution with respect to the tower center (Figure 5).

Each heliostat has 25 individual mirror facets totaling 37.2 m^2 (400 ft^2) of reflective surface per heliostat. The 25 facet reflections are adjusted to coincide at desired target locations with a reflected-energy concentration ratio of 25:1. Each facet is also shaped to give a concentration ratio of 1.5 to 2:1 at its focal length. The facets are mounted on a structure with azimuth and elevation gimbals to allow aiming the reflected energy at the chosen target.

Each heliostat gimbal can be driven at angular rates of 5.6 mrad/s for the fast or slew mode and 0.3 mrad/s for the slow or sun-tracking mode. Gimbal position sensors provide 2^{13} (8192) discrete, angular, switch-position increments ($7.7 \times 10^{-4} \text{ rad}$) to which the gimbal can be directed while tracking. During slew, the control system uses only 2^{10} (1024) increments ($6 \times 10^{-3} \text{ rad}$).

Figure 4. CRTF Working Heliostat

Figure 5. Heliostat Layout

The overall heliostat control system is shown as it interfaces with the MCS in Figure 6. This MCS analyzes heliostat-operating commands from the programmed test sequence or from the facility operator and distributes them to the heliostats for execution. HACs communicate with up to 128 heliostats in their jurisdiction. HACs send MCS-generated commands and HAC-generated azimuth and elevation-pointing information to the MCS's four associated HIMs to be transmitted to the appropriate heliostats. Each heliostat receives these pointing-vector updates once every second and responds with its own status. The HACs also process alarm messages such as tracking or communication errors.

Figure 6. Data and Control System.

Commands and data transmitted to the individual heliostats are received and executed by the HCE. The HCE provides the proper drive-motor power until the gimbal axis encoders indicate attainment of the appropriate heliostat attitude. The HCE and heliostat motors then await the next command.

When not in use, the heliostats are stored with the mirror surface facing the ground. As beams of energy are moved above the horizon, they are controlled to concentrate the beams along specific operating paths. These paths terminate at a standby point near the experiment. The heliostats can be moved individually or in groups to the standby point or to specific target points. When the heliostats are returned to slowage, they retrack the operating path.

One of every 10 heliostats is equipped with a detector to determine if the sun is obstructed by a cloud. Tests sensitive to rapid applications of thermal power such as would likely follow passage of a cloud are protected by moving the heliostats off the target when the sun is interrupted. When the sun is again detected, the heliostats are returned slowly to the target.

At the CRTF, a maximum theoretical temperature for a peak flux of 2400 kW/m^2 can be achieved with the 222 heliostats if the emissivity and absorptivity are equal for the target and the ambient temperature is 300 K:

$$T = 2530 \text{ K} = 2260^\circ\text{C} = 4560^\circ\text{R} = 4100^\circ\text{F}$$

A calculated flux map is presented later in this chapter.

To provide flux intensities higher than those possible with the raw beam, a secondary concentrator is proposed for use by experimenters. (It is under construction now.) The concentrator will provide a 23-cm-dia beam at a peak intensity of $10\,000 \text{ kW/m}^2$. The maximum theoretical temperature for that flux is 3630 K (6530°R). Details of the capabilities of the secondary concentrator are available from the CRTF Liaison Engineer.

Focus and Alignment Subsystem

Every heliostat and every facet upon the heliostat must be properly oriented for effective energy collection and distribution. The FASS consists of an L/C, control and monitoring equipment mounted on a boom truck at the heliostat, and a display target. Figure 7 shows the L/C and target. The target near the top of the tower uses a retroreflective surface for ease in monitoring the laser beam. The L/C is mounted at a lower level in a searchlight structure.

The L/C beam is about the size of a single facet. The control system is used to align the laser reflection from the center facet for display on the target. If the facet has not been focused in the assembly process, it can be mechanically focused using the FASS to give minimum image size at the display target. Heliostat positional encoders are recorded when the L/C reflection from the center facet is centered on the target. For the rest of the facets, the heliostat is oriented by the computer to form the proper relative angle between facets. The facets are individually adjusted to reflect the laser beam to the target center. The centering adjustments are confirmed using a stop-action TV image of the laser reflections from the target.

Figure 8 shows the alignment operation at the heliostat. A 6328-A spike filter on the TV monitor makes the system operational in full daylight.

Figure 7. Focus and Alignment Components

Figure 8. Nighttime Alignment of Heliostats

Heliostat Characterization Systems

The CRTF has a system for the complete performance evaluation of prototype heliostats. The two basic systems used during heliostat evaluations are the BCS and the PCS. These systems will first be used to evaluate prototype heliostat designs at the 10-MWe Pilot Plant in Barstow, CA.

Beam Characterization System -- The BCS uses video radiometer techniques to measure the reflected solar power of a heliostat. The system consists of a 9.1x9.1-m (30x30-ft) beam target, video camera, analog-image analyzer, calibration system, video digitizer, and a minicomputer. Figure 9 shows this basic system configuration. Figure 10 (a plan view of the CRTF facility layout) indicates the location of test heliostat foundations, the BCS building, and the BCS target.

Figure 9. Beam Characterization System

Figure 10. Facility Layout for Heliostat Evaluation

The BCS provides the following basic tabular and graphical outputs: a 256x256 matrix of spatially located heat-flux density values (W/cm^2), total power incident on the BCS target, beam power centroid location relative to the desired aimpoint, 2-D beam profiles, isoflux density contours, 3-D flux distributions, and plots of power vs radius from the centroid location. Figures 11 and 12 show typical BCS outputs. Ancillary equipment interfaced to the BCS provides measured insolation levels, sun shape, and meteorological data.

Figure 11. Typical BCS 3-D Output

Figure 12. Typical BCS 2-D Output

The BCS also has a fast-data capture mode that will be used to evaluate wind loading (heliostat vibration effects) and short-term beam-pointing errors.

Pointing Characterization System -- The PCS consists of a helium/neon laser mounted on the test heliostat, a laser target, a video camera, a time-display input, and a video recorder (Figure 13). This system resolves the pointing characteristics of the heliostat control and drive mechanism from the structural and optical response of the entire heliostat.

The PCS measures track and slew rates, heliostat-pointing repeatability, and electronic-control stability; and directly assesses control/drive pointing accuracy during heliostat operation.

Figure 13. Pointing Characterization System

Cal-Bar -- This system measures single heliostat flux-density profiles. The measurement hardware requires a ground aimpoint and thus introduces constraints in heliostat orientations to be tested.

Measurement involves sweeping an instrumented bar horizontally across a beam projected onto a ground target. The sweeping bar is 5 m long and can accommodate 64 gage positions equally spaced at 7.6 cm (3 in.). The bar is water-cooled to keep the gages within a specified operating range during measurements.

Circular-foil heat-flux gages covered with a quartz window are used. The two ranges used are 0 to 0.1 W/cm^2 and 0 to 0.2 W/cm^2 , with linear response over the entire spectral and thermal range and a nominal response time of 250 ms.

Several tests have been conducted on facility heliostats using this hardware. In these tests the heliostat beams were swept across the bar to eliminate tracking influences. Figure 14 shows the cal-bar in position with a heliostat beam just before sweep. Figure 15 shows a typical heliostat beam-contour plot. Figure 16 compares a mathematical model prediction for a vertical and horizontal cross section of the beam shape. HELIOS input included specific geometric and environmental test conditions and an error distribution half-angle of 2 mrad.

Figure 14. Heliostat Beam on Cal-Bar

Figure 15. Cal-Bar Contour Output

Figure 16. Cal-Bar Measured vs Predicted Beam Shape

Working Receiver

A nominal 1-MWth working receiver that is available for diagnostic and experimental work is built as two major assemblies with interconnecting piping. One assembly is an equipment skid with a heat exchanger, pump, and expansion tank permanently mounted at the 45.7-m (150-ft) level in the tower. The second assembly (Figure 17) is an array of heat-absorbing panels mounted on a mobile base. Figure 18 shows the WR in the 42.7-m (140-ft) test bay.

The interconnecting piping between the two assemblies is two pairs of 6-in. water/glycol lines. One pair of these lines provides a loop through the CRTF HRS dry cooling towers and the equipment skid-heat exchanger. The second pair provides a loop through the heat-absorbing panels and the equipment skid-heat exchanger. This second pair of lines has 6-in. hose connectors at the tower top and in all test bays for connecting the heat-absorbing loop.

Figure 17. 1-MWth Working Receiver

Figure 18. Working Receiver in Operation

The heat exchanger is rated nominally at 1 MWth and more specifically as 50 L/s (800 gal/min) and 72 kPa (10.5 psi) pressure drop across the hot side and 25 L/s (400 gal/min) and 21 kPa (3 psi) pressure drop across the cold side with a 40% glycol/water mixture on both sides. The pump in the hot-side loop is rated at 50 L/s (800 gal/min) at 240 kPa (35 psi). The highest nominal temperature is the 67°C (152°F) fluid from heat-absorbing panels.

The heat-absorbing panels are arranged in a 3x3 planar array. Each panel is nominally 1 m². The panel array hydraulically pivots about a horizontal axis near its center point. The panel-array surface normally

ranges from horizontal to 60° below horizontal. The panel array is cantilevered out from a mobile base that rides on an air-blower/air-caster system.

Each heat-absorbing panel is cooled by a 40% ethylene glycol/water solution. The panels operate at a nominal 240 kPa (35 psi) with the solution kept well below the 136°C (277°F) boiling temperature. The panels are an all-copper-welded fabrication designed to absorb 0.5 MWth of energy uniformly distributed across the panel. All panels cannot absorb this quantity of energy simultaneously without overloading the 1-MW heat exchanger.

Each panel is instrumented with a turbine flowmeter in the coolant inlet line, thermocouples in the coolant inlet and outlet lines, and nine circular-foil heat-flux gages with built-in gage body thermocouples. The panel-array coolant circuit is instrumented with a total-flow turbine flowmeter and thermocouples in both the inlet and outlet lines. All flowmeters have local digital displays for balancing convenience.

Each panel is equipped with a flow-control valve and a calibration valve in the coolant-outlet line. The calibration valve diverts panel flow to a weigh tank or similar device for flowmeter calibration.

Real-Time Aperture Flux System

This system allows actual measurement of the flux density in the aperture plane. Circular-foil heat-flux gages and high-intensity photovoltaic cells are mounted in a water-cooled bar that can be swept through the concentrated beam in front of an experiment. The heat flux calorimeter type gages have a range 0 to 3400 W/m² (0 to 300 Btu/ft²-s) that exhibits a linear response over the entire spectral and thermal range. The gages are linear from 0.25 to 30 m, and the response time is within 100 ms.

The photovoltaic cells are used in conjunction with the gages because of their fast response time. The gages can be used for a slower baseline sweep; then the cells can be used for a fast sweep of the aperture. The cells were designed for

- Dynamic range of 40 to 4000 suns,
- Deviation of short-circuit current response from linearity vs concentration (2%) and temperature (5%).
- Angular acceptance, $\pm 60^\circ$ with less than 10% deviation from cosine law.

Both detectors are mounted together in a fixed array on 7.6-to 10.2-cm (3 to 4-in.) spacings. The data that are collected and analyzed by a dedicated computer system can be used to fine-tune the heliostat beam and provide flux data for the experimenter.

In addition to the instrumented, water-cooled bar, the RTAF has a remote mobile data-acquisition system. This system can be used to gather data from up to 128 channels of millivolt output from flux gages that can be integrally mounted in an experiment. The data collected by this system are treated in the same way as described for the sweeping bar system and can be used to determine flux distributions and power levels at the experiment. Examples of the RTAF data are given in Figures 19 and 20. Two separate aimpoints were used for this example.

Figure 19. 3-D RTAF Data Plot

Figure 20. RTAF Data Contour Map

Computerized heliostat Beam Model

HELIOS, Sandia's ray trace program, is a versatile analytical tool. The CRTF heliostat field has been modeled to allow the user to study many different operating situations. HELIOS will calculate the solar-radiation intensity reflected from the heliostats to any desired location (this allows calculations for many operational and safety situations). HELIOS can be used to calculate the flux density on a given surface (receiver or other experiment) or to determine pointing strategies to give a desired flux distribution. HELIOS can assist in tailoring the beam to the needs of the experimenter. The capabilities of the HELIOS model are described in SAND76-0347.¹

Table 3 lists examples of HELIOS calculations. The calculations are for noon on Day 80 (vernal equinox) for 10:00 (-2), 12:00 (0.0), and 16:00 (4.0) time of day. Insolation was 0.1 W/cm^2 . The results are presented as the sum of the power (W/cm^2) from all heliostats intercepted by an 11×11 node rectangular target mesh ($2 \times 2 \text{ m}$). The target, located on top of the tower, was flat and oriented vertically facing north.

Table 3

222 Helistats Aimed at Tower-Top Receiver

W750 CM ON TARGET SURFACE FOR DAY 8C. AND TIME -2.0000 HOURS.

Z METERS	X(Y)=	1.0000	.8000	.6000	.4000	.2000	0.0000	-.2000	-.4000	-.6000	-.8000	-1.0000 M
1.0000	.176E+02	.255E+32	.354E+02	.462E+02	.561E+02	.622E+02	.628E+02	.548E+02	.434E+02	.315E+02	.215E+02	
.8000	.243E+02	.363E+32	.519E+02	.698E+02	.854E+02	.959E+02	.939E+02	.805E+02	.615E+02	.431E+02	.287E+02	
.6000	.312E+02	.472E+02	.707E+02	.968E+02	.122E+03	.135E+03	.130E+03	.109E+03	.809E+02	.552E+02	.360E+02	
.4000	.377E+02	.581E+02	.872E+02	.123E+03	.156E+03	.173E+03	.165E+03	.136E+03	.986E+02	.661E+02	.424E+02	
.2000	.412E+02	.652E+02	.994E+02	.142E+03	.181E+03	.201E+03	.190E+03	.155E+03	.111E+03	.737E+02	.469E+02	
0.0000	.426E+02	.678E+02	.104E+03	.149E+03	.191E+03	.211E+03	.199E+03	.161E+03	.115E+03	.765E+02	.486E+02	
-.2000	.412E+02	.655E+02	.100E+03	.143E+03	.183E+03	.201E+03	.189E+03	.153E+03	.110E+03	.736E+02	.470E+02	
-.4000	.374E+02	.590E+02	.895E+02	.127E+03	.164E+03	.174E+03	.163E+03	.132E+03	.965E+02	.654E+02	.423E+02	
-.6000	.328E+02	.496E+02	.740E+02	.103E+03	.127E+03	.137E+03	.127E+03	.104E+03	.774E+02	.536E+02	.354E+02	
-.8000	.257E+02	.391E+02	.569E+02	.767E+02	.925E+02	.979E+02	.908E+02	.752E+02	.570E+02	.405E+02	.274E+02	
-1.0000	.195E+02	.289E+02	.409E+02	.531E+02	.623E+02	.642E+02	.593E+02	.497E+02	.386E+02	.282E+02	.196E+02	

TOTAL POWER ON TARGET SURFACE IS .36471E+07 WATTS.

FACEY AREA = 8260.6 M**2

REDUCED BY COS GIVES 7605.7 M**2

FURTHER REDUCED BY SHAL GIVES 6739.1 M**2

POWER INTERCEPTED BY MIRRORS = .7606E+07 WATTS.

W750 CM ON TARGET SURFACE FOR DAY 8D. AND TIME 0.0000 HOURS.

Z METERS	X(Y)=	1.0000	.8000	.6000	.4000	.2000	0.0000	-.2000	-.4000	-.6000	-.8000	-1.0000 M
1.0000	.191E+02	.282E+02	.389E+02	.495E+02	.573E+02	.601E+02	.572E+02	.493E+02	.387E+02	.279E+02	.189E+02	
.8000	.265E+02	.408E+02	.586E+02	.773E+02	.921E+02	.977E+02	.920E+02	.773E+02	.585E+02	.407E+02	.266E+02	
.6000	.348E+02	.546E+02	.810E+02	.110E+03	.134E+03	.144E+03	.135E+03	.111E+03	.811E+02	.546E+02	.347E+02	
.4000	.420E+02	.673E+02	.103E+03	.143E+03	.177E+03	.190E+03	.177E+03	.143E+03	.103E+03	.674E+02	.419E+02	
.2000	.476E+02	.765E+02	.113E+03	.167E+03	.209E+03	.226E+03	.209E+03	.167E+03	.118E+03	.765E+02	.470E+02	
0.0000	.468E+02	.790E+02	.124E+03	.177E+03	.221E+03	.239E+03	.221E+03	.177E+03	.124E+03	.799E+02	.488E+02	
-.2000	.472E+02	.769E+02	.119E+03	.168E+03	.210E+03	.226E+03	.210E+03	.168E+03	.119E+03	.768E+02	.472E+02	
-.4000	.423E+02	.680E+02	.104E+03	.144E+03	.178E+03	.191E+03	.178E+03	.144E+03	.103E+03	.679E+02	.423E+02	
-.6000	.352E+02	.553E+02	.821E+02	.112E+03	.136E+03	.145E+03	.136E+03	.112E+03	.821E+02	.553E+02	.353E+02	
-.8000	.271E+02	.414E+02	.595E+02	.785E+02	.936E+02	.993E+02	.936E+02	.786E+02	.596E+02	.415E+02	.272E+02	
-1.0000	.193E+02	.285E+02	.395E+02	.504E+02	.595E+02	.616E+02	.586E+02	.506E+02	.397E+02	.288E+02	.195E+02	

TOTAL POWER ON TARGET SURFACE IS .41921E+07 WATTS.

FACEY AREA = 8260.6 M**2

REDUCED BY COS GIVES 7850.6 M**2

FURTHER REDUCED BY SHAL GIVES 7055.1 M**2

POWER INTERCEPTED BY MIRRORS = .7861E+07 WATTS.

W750 CM ON TARGET SURFACE FOR DAY 8J. AND TIME 4.0000 HOURS.

Z METERS	X(Y)=	1.0000	.8000	.6000	.4000	.2000	0.0000	-.2000	-.4000	-.6000	-.8000	-1.0000 M
1.0000	.217E+02	.292E+02	.380E+02	.472E+02	.547E+02	.577E+02	.544E+02	.468E+02	.355E+02	.237E+02	.179E+02	
.8000	.267E+02	.368E+02	.490E+02	.624E+02	.739E+02	.790E+02	.746E+02	.624E+02	.474E+02	.337E+02	.231E+02	
.6000	.318E+02	.445E+02	.608E+02	.789E+02	.943E+02	.101E+03	.950E+02	.785E+02	.586E+02	.412E+02	.279E+02	
.4000	.363E+02	.517E+02	.713E+02	.936E+02	.113E+03	.121E+03	.112E+03	.914E+02	.675E+02	.470E+02	.317E+02	
.2000	.497E+02	.773E+02	.998E+02	.128E+03	.156E+03	.163E+03	.156E+03	.128E+03	.987E+02	.724E+02	.503E+02	
0.0000	.415E+02	.603E+02	.845E+02	.111E+03	.132E+03	.138E+03	.124E+03	.994E+02	.728E+02	.506E+02	.342E+02	
-.2000	.412E+02	.608E+02	.839E+02	.110E+03	.129E+03	.132E+03	.118E+03	.937E+02	.688E+02	.483E+02	.329E+02	
-.4000	.385E+02	.568E+02	.779E+02	.101E+03	.116E+03	.118E+03	.104E+03	.832E+02	.617E+02	.438E+02	.302E+02	
-.6000	.338E+02	.489E+02	.674E+02	.856E+02	.978E+02	.981E+02	.871E+02	.700E+02	.527E+02	.380E+02	.266E+02	
-.8000	.279E+02	.398E+02	.541E+02	.679E+02	.766E+02	.767E+02	.686E+02	.561E+02	.431E+02	.317E+02	.226E+02	
-1.0000	.215E+02	.303E+02	.404E+02	.500E+02	.566E+02	.564E+02	.514E+02	.430E+02	.339E+02	.255E+02	.186E+02	

TOTAL POWER ON TARGET SURFACE IS .28654E+07 WATTS.

FACEY AREA = 8260.6 M**2

REDUCED BY COS GIVES 6869.1 M**2

FURTHER REDUCED BY SHAL GIVES 5757.8 M**2

POWER INTERCEPTED BY MIRRORS = .6869E+07 WATTS.

In this example, total power is 5 MW because of the rather small size (2x2 m) of the target. Similar results are available for each contributing facet and each total heliostat, and can be generated for any target size, location, or number of heliostats.

The calculated total power and peak intensity as a function of time and day of year are given in Figures 21 and 22. The total power is for a 4x4-m target size and varies from 5.4 MWth at noon on the day for which the heliostats are aligned, to a low of 3.4 MWth near the winter solstice. Between 10:00 and 14:00 the total power within the 4x4-m target exceeds 4.9 MWth throughout the year. The peak flux is a maximum of about 240 W/cm² at noon on the equinox and a minimum of about 100 W/cm² at 8:00 and 4:00 at the winter solstices.

Figure 21. CRTF Total Power on 4x4-m Tower-Top Target (222 Heliostats)

Figure 22. CRTF Peak Flux Density at Tower-Top Target (222 Heliostats)

HELIOS can also calculate the peak intensity and acceptance angle for test targets. Figure 23 gives these results for a flat target in the 42.7-m-level test bay in which the target was tilted so that its normal vector pointed at the apparent center of the closest 78 heliostats. Similar calculations are available for other test locations.

Receiver Tower

The CRTF receiver tower rises 61 m (200 ft) above ground and extends 15.2 m (50 ft) below ground. The tower cross section is circular with rectangular projections on the north and south (Figure 24).

Figure 23. Acceptance Angles and Peak Flux

Figure 24. Tower Cross Section

The tower cross section begins to taper at 56.4 m (185 ft) and is smallest at 61 m (200 ft) (Figure 25). The taper minimizes flux blockage at 61 m (200 ft). At ground level the tower cross section is basically a circle (Figure 26). The extra area, which is one story high, houses mechanical and electrical equipment.

Figure 25. Tower Cross Section at Top

Figure 26. Tower Cross Section at Ground Level

The south projection of the tower houses stairs and elevators. The north projection provides extra area for experiment locations. Platforms are located inside the tower at 6.1-m (20-ft) intervals both above and below ground level.

Test bays for experiments are located on platforms at the 36.6-, 42.7-, and 48.8-m (120-, 140-, and 160-ft) levels as shown in Figure 27. Experiments can also be conducted at the top of the tower. The test bays at the 36.6- and 42.7-m (120- and 140-ft) levels are in rooms 9.8 m (32 ft) wide (E-W) by 4.3 m (14 ft) deep (N-S) with an overhead clearance of 5.2 m (17 ft). The rooms are equipped with rollup steel doors 6.7 m (22 ft) wide x 4.6 m (15 ft) high on the north walls. These rooms have no south wall as they are open to the tower interior. The test bay at the 48.8-m (160-ft) level is on an exposed platform and is 10.7 m (35 ft) wide (E-W) and 3 m (10 ft) deep (N-S). This test bay has no overhead structure; access is through a 6.7x5.2-m (22x17-ft) rollup door in a wall at the south edge of the test bay.

Figure 27. North Tower Elevation Showing Test Bays

The limiting internal tower dimensions at ground level are given in Figures 28 and 29.

Figure 28. West Elevation Inside Tower

Figure 29. North Elevation Inside Tower

Elevators and Hoists -- Hardware can be transported to the test bays or tower top in two ways. Hardware up to 4536 kg (10 000 lb) can be hoisted up the outside of the tower on the north side. Heavier hardware can be hoisted by the elevating module system in the center of the tower.

The 76.2-m (250-ft) tower interior has a 9.1x7.6-m(30x25-ft) rectangular hoistway with an elevating module. The elevating module is ~9.1 m (30-ft) wide by 7.6 m (25-ft) deep by 13.1 m (43-ft) high. The elevating module roof can be positioned anywhere between ground level and the 61-m (200-ft) level. Ground-level access to the elevating module roof is provided by a sliding steel door 9.7 m (32-ft) wide by 16.8 m (55-ft) high on the north side of the tower. A trapdoor 9.1x7.6 m (30x25-ft) at the top of the tower folds into the tower and provides a tower-top opening for any hardware riding the elevating module roof. The same trapdoor provides a work platform at the 61-m (200-ft) level if the elevating module is at another location. The elevating module will lift experiments weighing up to 90 700 kg (200 000 lb).

The elevating module is itself an enclosed three-story building in which each story is laid out as a single room. The top room contains instrumentation patch panels, the middle room contains the data-acquisition system, and the lower room is a light-machine shop.

The elevating module can be locked into position whenever the roof is located at any of the test levels or at ground level. With the elevating module locked in position, the four lift ropes are detached from the elevating module and are used individually or in any combination for auxiliary hoisting. The working-lift load of each wire rope is 54 400 kg (120 000 lb).

The roof of the elevating module structurally interfaces with tower-top experiments; it is structural steel framing covered with 1/2-in.-thick steel plate. Large tower-top experiments must have support features engineered to match with this roof structure.

A 9.1x7.6 m (30x25-ft) platform below the elevating module stores on the floor of the tower hoistway at the -15.2-m (-50-ft) level. The lift ropes are used to position this working platform flush with any tower platform or to lift material in the hoistway below the elevating module.

The tower interior is also serviced by two 4536-kg (10 000-lb) jib cranes mounted at the 24.4-m (80-ft) level. These cranes primarily support light assembly work on the elevating module with its roof at ground level.

The test bays at the 36.6- and 42.7-m (120-and 140-ft) levels are serviced by 4536-kg (10 000-lb) hand-gearred bridge cranes. The bottom of the bridge beam is 4.4-m (14.5-ft) above floor.

Thermal Protection -- All tower thermal protection is passive. The north face of the tower above the 33.5-m (110-ft) level is built with a replaceable sacrificial layer of concrete. Depending on location, this is either a 5.1-cm (2-in.)-thick layer of concrete-like material sprayed on top of the basic slip-formed tower shell, or 7.6-cm (3-in.)-thick preformed concrete panels that stand off from the tower shell.

The CRTF also has a supply of thermal-protection materials to be used as radiation shields. These materials shield the tower interior and experimental hardware from solar flux spillage.

Utilities -- The tower is built with a mechanical chase running up the east side of the tower and an electrical chase running up the west side of the tower. The mechanical chase contains the following lines:*

*These lines are standard US sizes--metric equivalents are not appropriate.

No.	Line
4	6-in. water/glycol
1	1-1/2-in. water/glycol supply
1	1-1/2-in. water/glycol return
1	3/4-in. compressed nitrogen
1	1-1/2-in. compressed air
1	4-in. drain
1	2-in. receiver feedwater supply
1	1-in. receiver blowdown
1	1/2-in. receiver sampling
1	3-in. high-pressure steam return
1	2-in. cold water
1	1/2-in. chemical feed
1	6-in. compressed air supply (air HRS)
1	12-in. hot compressed air exhaust (air HRS)

All these lines are terminated at the tower top and at each of the lower test bays. Sewer and fire protection lines also run in the mechanical chase. Exact locations of piping and interfacing terminations will be supplied by the CRTF staff.

The electrical chase contains 115-Vac single-phase, 208-Vac three-phase, and 480-Vac three-phase power. The 115 and 208 Vac is distributed throughout the tower. The 480 Vac is available only at the tower top and test bays. Power lines for tower equipment and data-acquisition system lines also run in the electrical chase in separate conduits.

Steam/Water Heat-Rejection System -- The primary functions of the steam/water HRS supply chemically controlled feedwater or water/ethylene glycol to receiver experiments. The steam/water HRS, shown schematically in Figure 30, can supply boiler-quality feedwater at a maximum rate 4.7 L/s (75 gpm) and a maximum temperature and pressure of 204°C (400°F) and 15.5 MPa (2250 psi), respectively. The feedwater temperature can be increased to 288°C (550°F) by using the steamheated preheater, but only if the receiver is generating steam. The steam/water HRS can also supply 25.2 L/s (400 gpm) of a 40% ethylene/glycol/water solution to experiment locations. The steam HRS can accommodate 9000 kg/h (20 000 lb/h) of 518°C (965°F), 13.8-MPa (2000-psi) steam.

Figure 30. Steam/Water HRS

The feedwater system starts at the CRTF raw water supply. Water is passed through cation, anion, and mixed demineralizer beds and stored in a 75 700-L (20 000-gal) tank. The water is pumped from the tank into a low-pressure, 1.6-MPa(233-psi), spray-water loop that contains a deaerator-desuperheater and heat exchanger. Hydrazine is added in this spray-water loop for dissolved oxygen control. Feedwater is pumped into high-pressure pipe running up the tower to the receiver experiment. Acidity control chemicals are added in this high-pressure pipe if required. The feedwater or steam produced by the receiver returns down the tower in a high-pressure steam line, passes through a vessel to complete the cycle.

Water chemistry is monitored at five sample points in the feedwater system. On-line analyzers can measure

- Cation Conductivity
- Specific Conductivity
- pH
- Dissolved Oxygen
- Hydrazine
- Silica
- Copper
- Iron
- Sodium

A closed-loop dry cooling-tower system dissipates energy returned in the feedwater/steam. The cooling-tower loop uses a 40% ethylene glycol-water solution for coolant and passes the coolant through the shell side of the heat exchanger in the spray-water loop. Coolant at 94.6 L/s (1500 gpm) is supplied to the heat exchanger. A second 94.6 L/s (400-gpm) pump taps coolant from the cooling-tower loop, pumps it up the tower to the working receiver equipment skid-heat exchanger, and provides coolant at each test level. The cooling-tower system also provides coolant to the air compressors that supply the air HRS.

A receiver blowdown line is routed down the tower and into an underground blowdown-holding chamber. Two chemical feed-mixing tanks and metering pumps are provided for the feedwater pH and O₂ control chemicals. A glycol-water mixing tank is provided for glycol-water makeup in the dry cooling-tower loop. A 15 000-L (4000-gal) industrial wastewater collection tank is provided for system waste.

Air Heat-Rejection System -- A once-through air HRS supplies 2.7 kg/s (6 lb/s) air at 1.03 MPa (150 psi) to the test bays from four compressors located at ground level. The supply line is 6-in. steel pipe and the exhaust is 12-in. stainless steel pipe capable of routing 538°C (1000°F) air back to the atmosphere at the top of the tower. The air HRS is shown schematically on Figure 31. Two hydrocarbon analyzers are used to monitor the air supply. One provides data at the ppm level (normal hydrocarbon concentration is 5 ppm) to the experimenter; the other is used to alarm and shut down the air supply if it becomes grossly contaminated.

Control and Data Recording

An MCS coordinates control of the CRTF operating and data systems. The MCS is an overall command, control, and data system that performs control management and supervision as well as data collection, analysis, and presentation.

Figure 31. Air Heat - Rejection System

The MCS uses five digital minicomputers in a modular, function-oriented network (Figure 32). Figure 33 shows the physical relationship of the equipment.

1. MCS-Control is the interface for the facility operator's console through which the entire CRTF can be controlled.
2. MCS-Data provides the experimenter's console interface and controls, and acquires data from the heat-rejection system, four metro stations, and from the MCS-DAS minicomputer.
3. MCS-DAS minicomputer acquires data from experiments in the tower and generates control signals.
4. RTAF minicomputer acquires and processes solar-flux data to provide real-time analysis of power into the experiment aperture. RTAF also provides much of the off-line data handling.
5. BCS minicomputer is independent and acquires and analyzes heliostat-beam information to evaluate heliostat performance.

Figure 32. Data and Control System

Figure 33. Layout of Data and Control System

Up to 480 channels of analog data can be connected to the MCS measurement-equipment multiplexers at any tower elevation. Control signals are either digital (for on-off control) or analog (such as proportional voltage or current) to adjust setpoints for analog proportional controllers.

The facility operator will be able to display any of three color-coded data or status pictures stored in his console's refresh memory. One display is the heliostat field status with other current information such as time and weather data; another is the HRS schematic. A third picture will be tailored for experimental data, such as a color image depicting temperature or stress regions within the boiler. The facility operator's keyboard is used to enter real-time, on-line commands that are analyzed

and tested for validity. These commands are passed to the HACs for immediate execution, to the MCS-Data minicomputer to change the data-acquisition configuration, or to the HRS controller set points.

The experimenter sits at a console identical to that of the facility operator and may look at the same three data or status pictures, but cannot change the contents of any but the experiment-data picture.

Off-line posttest data programs allow (1) reformatting for subsequent processing, (2) replaying with time-scale changes for analysis, (3) analysis and presentation for more channels or with more time-consuming analysis than possible in real time, and (4) archiving.

The MCS-DAS computer, located in the control room, can be interfaced to the elevating module data systems and/or the two mobile data systems.

Figure 34 shows the general layout of the elevating module computer-equipment room. Space reserved for experimenters instrumentation is indicated. The MCS-DAS computer has no local data-recording capability but instead transmits experimental data to MCS-Data for recording on disk. The DAS system is thus designed to be operated as a satellite of MCS-Data. The MCS-DAS satellite, the main data-acquisition mode, is remotely interfaced to the elevating module data systems. Part of the data system consists of an industrial-quality HP2313B A/D converter subsystem, complete with modular, expandable-analog multiplexers, programmable pacer (sample-rate clock), sample and hold amplifier, and 12-bit converter. The A/D input subsystem may be programmed in random (multiplexer channels in any order), sequential (consecutively numbered channels), or single one-channel address modes. An industrial-quality HP6940 DIO subsystem is also remotely interfaced to the MCS-DAS satellite for digital input, digital output, and analog output. The 12-bit DIO subsystem is used mostly for control of the central receiver experiment.

Figure 34. Elevating Module Computer Room

The two mobile measurement and control A/D and DIO systems are interfaced to either the MCS-Data or the DAS satellite minicomputer over the same type of double twisted-pair cable connecting the computers. One of these mobile systems will be used at the base of the receiver tower for the facility controls and data. Both these systems and the elevating module data systems are hardware-compatible, with each A/D expander holding up to twelve 16-channel multiplexers for a maximum of 480 channels per system.

The RTAF data and control subsystem consists of an HP2240 measurement and control processor with a total of eight function-card slots. These function cards can be selected from analog or digital inputs or outputs as described in Table 4.

TABLE 4
Data-Acquisition Capability

ELEVATING MODULE MEASUREMENT AND CONTROL SUBSYSTEM

- A. ANALOG INPUT FROM EXPERIMENT TO COMPUTER (HP2312B) 496 CHANNELS MAX.
CHOOSE FROM
 - 1. High-Level Voltage: ± 10.24 V Full Scale (FS)
 - 2. Low-Level Voltage: Programmable, ± 10 to ± 800 mV FS
 - 3. Low-Level Current: Programmable, 2.5 to 200 mA FS
- B. ANALOG OUTPUT FROM COMPUTER FOR CONTROL (HP6940B)
CHOOSE FROM
 - 1. Single-Channel Voltage D/A: ± 10.24 V FS
 - 2. Single-Channel Current D/A: 0 to 20.475 mA FS
- C. DIGITAL INPUT TO COMPUTER FROM EXPERIMENT (HP6940B)
CHOOSE FROM
 - 1. 12-Bit TTL-Compatible, Direct, With Handshake
 - 2. 12-Bit Event Sensing, TTL-Compatible
 - 3. 12-Bit Event Sensing, 10 to 55 Vdc Input
- D. DIGITAL OUTPUT FROM COMPUTER FOR CONTROL (HP6940B)
CHOOSE FROM
 - 1. 12-Bit Mercury-Wetted Relays
 - 2. 12-Bit Solid State ac Relays, 20 to 250 Vac

NOTE: Each Item From B, C, or D Requires 1 Slot;
Total of 30 slots currently available

REMOTE MEASUREMENT AND CONTROL SYSTEMS (Two - One Portable and One in Ground-Level Computer Room)

- A. ANALOG INPUT FROM EXPERIMENT OR HRS TO COMPUTER (HP2313B)-496 Channels
MAX. (each system)
CHOOSE FROM
 - 1. High-Level Voltage: ± 10.24 V FS
 - 2. Low-Level Voltage: Programmable, ± 10 to ± 800 mV FS
 - 3. Low-Level Current: Programmable, 2.5 to 200 mA FS
- B. ANALOG OUTPUT FROM COMPUTER TO EXPERIMENT OR HRS FOR CONTROL
(each system) (HP6940B)
CHOOSE FROM
 - 1. Single-Channel Voltage D/A: ± 10.24 V FS
 - 2. Single-Channel Current D/A: 0 to 20.475 mA FS

TABLE 4 (cont)

C. DIGITAL INPUT TO COMPUTER FROM EXPERIMENT OR HRS (each system)
(HP6940B)

- CHOOSE FROM
1. 12-Bit TTL-Compatible, Direct, With Handshake
 2. 12-Bit Event Sensing, TTL-Compatible
 3. 12-Bit Event Sensing, 10 to 55 Vdc Input

D. DIGITAL OUTPUT FROM COMPUTER TO EXPERIMENT OR HRS FOR CONTROL
(each system) (HP6940B)

- CHOOSE FROM
1. 12-Bit Mercury-Wetted Relays
 2. 12-Bit Solid State ac Relays, 20 to 250 Vac

NOTE: Each Item From B, C, or D Requires 1 Slot;
Total of 30 Slots Currently Available.

RTAF DATA-ACQUISITION SUBSYSTEM

A. ANALOG INPUT FROM EXPERIMENT TO COMPUTER (HP2240A)-256 Channels Max

1. High-Level Volts: +10.24 V FS
(Expandable with 22915A Low-Level Amplifier Cards)
2. Low-Level Volts: STRAPPABLE, +20 mV to +10 V FS

B. ANALOG OUTPUT FROM COMPUTER FOR CONTROL (HP2240A)

1. 4 Channels of Selectable Voltage or Current D/A
 - A. 0 to 10.24 V FS
 - B. +10.24 V FS
 - C. 4 to 20.375 mA FS

C. DIGITAL INPUT FROM EXPERIMENT TO COMPUTER (HP2240A)

1. 32-Bits TTL/CMDs Compatible Inputs With Pull Up to +5 Vdc for Switch Sense
2. 16-Bit Event Sense

D. DIGITAL OUTPUT FROM COMPUTER FOR CONTROL (HP2240A)

1. 32-Bits Open Collector Outputs

NOTE: Each Item From A, B, C, or D Requires 1 Slot;
Total of 8 Slots Currently Available.

Table 4 summarizes the data-acquisition capabilities and Table 5 gives the present CRTF inventory.

TABLE 5
A/D Options - Inventory

ANALOG INPUTS TO COMPUTER

1. 47 cards of 16 channels each (752 channels total), HP91111 low-level solid-state multiplexers
2. 10 cards of 16 channels each (160 channels total), HP91110 high-level multiplexers
3. 10 cards of 16 channels each (160 channels total), HP91225 relay current multiplexers
4. 18 chassis of 36 channels each, type K (chromel-alumel) 150°F reference junctions (648 total)
5. 8 chassis of 36 channels each, type T (copper-constantan) 150°F reference junctions (288 total)
6. 35 chassis of 10 channels each, strain-gauge signal conditioners (350 total)
7. 5 chassis of 10 channels each, LVDT signal conditioners (50 total)
8. 10 cards of 16 channels each (160 channels total), HP22915A low-level analog input
9. 5 cards of 32 channels each (160 channels total), HP22900A analog input

ANALOG OUTPUTS FROM COMPUTER

1. 15 cards (15 channels), HP91206 current D/A converter
2. 25 cards (25 channels), HP91207 voltage D/A converter

DIGITAL INPUTS TO COMPUTER (Each Card is 12 Bits)

1. 20 cards, HP91202 direct-TTL input with handshake, ground-true (240 bits)
2. 4 cards, HP91205, TTL, ac or dc event sense interrupts (48 bits)

DIGITAL OUTPUTS FROM COMPUTER (Each Card is 12 Bits)

1. 6 cards, HP91204 Mercury-Wetted Relays, dual contacts, both NO (72 bits (relays))
2. 2 cards, HP91223 solid-state ac relays, NO (24 relays)

Flexible modularity is used for the signal conditioning as well as

for the digitizing system. Each 36-channel TC reference-junction chassis allows plug-in of the transducer, easy patching of the voltage output to a particular A/D channel, and complete shielding of each channel. All shields are isolated from chassis ground and from each other. Both Type K (chromel-alumel) and Type T (copper-constantan) TC will be referenced, including 250 channels of K and 100 channels of T with the mobile "front ends." Strain gages will have 10 channels of 1-, 2-, or 4-arm bridge completion circuits and a separate 0- to 15-V power supply in each chassis. The elevating module accommodates up to 150 channels of strain gages; 150 more channels are available with the mobile systems.

Experimenters are expected to supply cabling to terminal cabinets located in the upper termination room of the elevating module. Cable connectors are supplied by the CRTF but installed by the experimenter. Connectors and cable are also provided by the CRTF for interconnection between the experimenter's control instruments (if any) and the data computer. The experimenter is expected to supply any special connectors to interface with his instrumentation.

Meteorological System

Components -- The meteorological system consists of

- HP9611A computer.
- Towner Systems Sensor Package that includes

<u>Transducer</u>	<u>Location on Weather Tower (height in m)</u>
Spot wind direction	60, 30, 10
Spot windspeed	60, 30, 10
Air temperature	60, 30, 10
Relative humidity	60, 30, 10
Dewpoint	10
Barometric pressure	0
Precipitation	0

- MRI Integrating Nephelometer, an electrooptical instrument that continuously monitors the air and provides a readout of atmospheric particle contamination.
- Eppley normal incident pyrheliometer, an instrument to measure incident solar radiation.

- Eppley black-and-white pyranometer, an instrument to measure global (total sun and sky) radiation.
- Lawrence Berkeley Laboratories Circumsolar Telescope, a scanning instrument designed to measure the effects of atmospheric conditions on the direct and circumsolar components of the solar flux. It incorporates the measurement of total hemispherical insolation in the horizontal plane normal to the direction of the sun.
- Battelle Pacific Northwest Laboratory mobile automatic scanning photometer to measure total sky radiation from 0.35 to 1.1 wavelengths.

Capabilities -- Towner Systems sensors and other meteorological equipment are coupled to the computer system by a serial current loop. At selected times, the computer will command readings to be made of specified sensors or equipment. The sensor or equipment outputs will be scanned and the readings recorded on digital magnetic tape, or disk, or both. The system is capable of scanning and displaying the data at 35-s intervals. Readings can also be transmitted to the MCS computer if required during a particular experiment.

Data stored will be in standard ASCII format readable by any other computer and will include the National Bureau of Standards localized time, the sensor or equipment station number, and the readings in engineering units.

Towner Systems transducers are rated as follows:

Wind Direction: 0 to 359° azimuth $\pm 2^\circ$ above 2 m/s
Threshold 0.3 m/s, increments of 1° .

Windspeed: 0 to 60 m/s ± 0.4 m/s below 32 m/s.
Threshold 0.3 m/s, increments of 0.1 m/s.

Air Temperature: $-45/+60^\circ\text{C}$ $\pm 1\%$, increments of 1°C .

Relative Humidity: 0 to 99% RH $\pm 5\%$ RH, increments of 1% RH.

Dewpoint: $-33/+33^\circ\text{C}$ $\pm 2^\circ$, increments of 1°C .

Barometric Pressure: 100-mbar range for 1707 m (5600 ft)
 ± 0.3 mbar, increments of 0.1 mbar

Precipitation: 0 to 25.37 cm (9.99 in.) $\pm 1\%$ at 7.62 cm
(3 in.)/h maximum, increments of 0.025 cm (0.01 in.).

The MRI Integrating Nephelometer is rated for sensitivity and range as follows:

Scattering Coefficient: .0.1 to 100 E-4/m.

Local Visual Distance: to 0.3 mi (480 m).

Mass Concentration: 0 to 3800 g/m³.

Accuracy: +10% of scale.

The Eppley Normal Incident Pyrheliometer has a range of 0 to 2800 W/m² at a rated accuracy of +0.5%.

The Eppley Black and White pyranometer has a range of 0 to 1400 W/m² at a rated accuracy of +1%.

Cosine response is: +2% from normalization 0-70°

Zenith angle; +5% 70 to 80° zenith angle.

The LBL circumsolar telescope is rated as follows:

Angular Resolution: 1.5 minutes of arc; from sun center to 2 solar radii.

5.0 minutes of arc; from 2 solar radii to +3° from sun center.

Instrument Contribution: Less than 0.5% with clean entrance window.

Accuracy = +0.5% based on Eppley Normal Incident Pyrheliometer.

The LBL circumsolar telescope is normally used to gather sun shape data, but can also be used to monitor reflected and emitted radiation from experiments.

Administration and Control Building

The Administration and Control Building, which provides facilities for operating personnel, experimenters, and visitors, is composed of the following basic functional areas:

1. Administrative and Technical Offices -- Space for administrative functions to support CRTF requirements. Will include offices for facility personnel and experimenters.

2. Program Presentation and Conference Rooms -- Space for public and contractor solar-test-related audiovisual programs. Conference rooms provide for small administrative and technical conferences.
3. Laboratories -- Space for instrumentation maintenance and calibration functions.
4. Master Control/Computer Room -- Contains control console and computer equipment, including control-safety equipment.
5. Observation Areas -- Will be provided at the first-floor roof level and in an elevated room 60 ft aboveground that gives a 360° view of the surrounding area.

Assembly Building

The 30.48 x 45.72-m (100 x 150-ft) assembly building houses tools, test gear, spare parts, and components. Specific areas are available for assembly and checkout of experimental gear.

The western 15.24 m (50 ft) is a high-bay area 9.14 m (30 ft) and the eastern 30.48 m (100 ft) has a ceiling 5.22 m (15 ft) high. The high-bay area is equipped with a 5-ton bridge crane with a 7.315 m (24-ft.) maximum lift. Access to the low-bay area is by a high door 4.88 m (16 ft) wide by 4.27 m (14 ft) high. The high and low bays are connected by a 5.18 m (17-ft) wide opening. Utilities for light welding and machine operation are provided.

CHAPTER IV. REQUIREMENTS OF EXPERIMENTERS

The experimenter will provide detailed information on his experiment as described in this chapter. Table 6 summarizes requirements and their lead times. These lead times must be met by the experimenter to assure meeting installation and operation schedules.

TABLE 6
Requirements of Experimenters

<u>Experimenter Input</u>	<u>Page No.</u>	<u>Required Lead Time (Days)</u>
Data Package and Test Plan		90
Procedures		
Installation and Quality Assurance		60
Checkout and Presolar Operations		60
Operating		60
Training		60
Maintenance		10
Unpacking and Receiving		10
Experiment Removal and Disposition		30 days before removal
QA Records and As-Built Drawings		30

Data Package

All experiments must be documented. The experimenter shall submit information to the CRTF in the form of a Data Package. Five copies are required, including drawings. Exact contents and amount of detail required depend on the type of the experiment as determined by the Liaison

Engineer working with the experimenter. The Data Package shall cover the following:

1. Scope and Objective -- A summary of the nature of the experiment, including a summary schedule and test duration, operating conditions, and expected or desired results.
2. Design Description -- The final design of the experiment. It may include
 - a. Specifications and Design Criteria
 - b. Drawings - Mechanical and Electrical
 - c. Engineering analysis and calculations to demonstrate the integrity of the equipment during normal, faulted, or emergency conditions. Design calculations and a summary of prior test experience may also be included. Appendix C summarizes the design requirements and the national codes and standards that may be applied to the design and construction of an experiment.
3. Safety Analysis -- Identification of all potential safety problems and failure modes for the experiment and possible hazards to personnel and to the CRTF. The analysis shall include normal and faulted operating conditions and natural hazards such as earthquakes, high winds, rain, snow and hail. It shall list all normal and unique safety features and demonstrate that fail-safe concepts have been incorporated into the design, operating procedures, and sequences. The experimenter will supply this safety-related information to the satisfaction of the CRTF. The CRTF staff will be responsible for overall safety during the test.

The CRTF will operate with the following general safety rules that the experimenter should incorporate in the development of his own safety analysis.

- Personnel will be allowed only in restricted parts of the heliostat field during solar operations.
- Personnel will be allowed at the tower level where the experiment is being performed only after special protective equipment and safety policies are established. Access to other parts of the tower will be reviewed for each experiment, but, in general, access near the experiment will be discouraged.
- Whenever possible, experiments should be designed for remote operations.

- Personnel will normally be allowed in the mechanical/ electrical equipment rooms at the base of the tower and in the 100 ton elevator computer room during solar operations.
4. Quality Assurance -- The plan and procedures for providing QA to the design and construction of the experimental hardware. It shall show how quality requirements will be met and how QA records will be kept. The QA requirements for installation of the equipment at the CRTF shall be listed. A completed QA-records document (if required) will be needed at least 30 days before installation of the experiment at the CRTF.
 5. Supplementary Information -- Additional information may be required that includes (but is not limited to)
 - O&M manuals for commercial components and instruments
 - Spare-parts lists (parts to be supplied by experimenter)
 - Functional wire list
 - Interface drawings
 - Special tool and equipment list
 - Description of assembly building needs
 6. Data Package Changes -- Any design or other changes to an experiment after the Data Package is approved must be submitted as soon as possible as an addendum. The addendum will also be thoroughly reviewed by the CRTF and separately approved. Changes of any kind normally lengthen the implementation schedule. Failure to notify the CRTF of changes at an early date may also result in delays.

Test Plan

The experimenter's test plan will be used to allocate resources and establish the test schedule for the experiment. The input will be used to develop operating strategies and procedures for the actual testing on the CRTF. The test plan shall include

1. The test matrix of the desired set of test conditions as a function of time for
 - Temperature
 - Pressures
 - Solar flux distributions and total power
 - Flow rates
 - Coolant purity
 - Environmental and weather conditions
 - Other parameters
2. A test sequence. The sequence should start with the shipment of hardware to the CRTF and continue through removal and final disposition of the experiment. The CRTF engineer will work with the experimenter to develop an actual test schedule after receiving the proposed sequence of activities.
3. Data acquisition, on-line computer analysis, and computer control needs for the experiment. (This must be a detailed list of data channel and control requirements developed with the CRTF engineer.)
4. Special data needs from other CRTF systems:
 - HRS
 - Heliostat array
 - RTAF system
 - Meteorological data

Detailed Procedures and Training Materials

The experimenter must provide detailed O&M procedures. The CRTF will determine how much detail is required based on the nature of the experiment and how the experiment is to be implemented and operated. The scope of the procedural input required may include

<u>Procedure</u>	<u>Leadtime Required (days)</u>
• System installation, and installation QA requirements	60 (before receipt of hardware)
• Checkout and presolar-testing procedures	60
• Startup, operation, shutdown, and emergency procedures. Emergency procedures shall cover normal and faulted conditions and shall take the experiment and the CRTF to a safe configuration	60
• Operator training procedures including dealing with all unique hazards	60
• Routine and preventive maintenance procedures	10
• Unpacking and receiving inspection procedures. Special needs for heavy equipment shall be submitted at least 30 days in advance	10
• Experiment removal and postexperiment handling procedures	60 (before removal of hardware)

The stated lead times are required to assure meeting the installation and operation schedule. An ITP that includes the experiment and CRTF support system procedures will be used for the actual test. The CRTF staff, working closely with the experimenter, will develop the ITP. The experimenter may need to provide operator training sessions for the CRTF operators.

As-Built Drawings and QA Records

The experimenter shall submit his QA Records at least 30 days before the expected installation date. The contents of the QA Records will vary, depending on specific requirements for quality that are related to potential hazards and the required reliability of the experiment. The CRTF will determine contents of the QA Records at the time the Data Package is approved. The QA Records in all cases will include as-built mechanical drawings (including interfaces) and electrical drawings

(including data and control links). The QA Records may also include

- Mechanical design documentation
- Nondestructive examination procedures and data
- Certified test reports
- Welder certification records
- Materials certifications
- List of archive materials (to be held by experimenter)
- Code-stamped certifications (if required)

The CRTF will review and audit the submitted information. Any serious discrepancies, unexpected design or fabrication changes, or omissions will be brought to the attention of the experimenter. Corrective action by the experimenter and additional CRTF reviews may be required before installing the experiment. Normally 2 to 4 wk are required to review the QA Recprds.

Shipping and Receiving

The experimenter must ship his experiment prepaid to the CRTF. He shall follow all appropriate DOT, FAA, OR IATA standards for crating, packing, rigging, and shipping. The shipment should be addressed to

Central Receiver Test Facility
Division 4713
Sandia Laboratories
Albuquerque, NM 87185

Sandia and the resident experimenter, if present, will inspect the shipment. The experimenter shall rectify any shipping damage.

If the experiment is to be returned to the experimenter at the end of the test program, he shall make the arrangements and pay the costs. Otherwise, the experiment shall become DOE property.

Results and Reports

The CRTF staff will publish general reports related to operation of the CRTF and summary reports on the operation of all experiments. Private or proprietary designs and data will be appropriately protected.

The CRTF staff may be considered as contributing coauthors with the experimenter of certain open-literature reports or publications resulting from CRTF tests. Preparation of joint reports and publications will be shared.

REFERENCES

¹F. Biggs and C. N. Vittitoe, The HELIOS Model for the Optical Behavior of Reflecting Solar Concentrators, SAND76-0347 (Albuquerque, NM: Sandia Laboratories, March 1979).

APPENDIX A

Experiment Application Form

Sandia Laboratories
Solar Energy

CRTF Application
Control Number _____
Date Received _____

(For CRTF Use Only)

CENTRAL RECEIVER TEST FACILITY (CRTF)
EXPERIMENT APPLICATION

EXPERIMENT TITLE:

PRINCIPAL EXPERIMENTER:

(First Name Initial Last Name)

Employer _____

Address _____
(Street) (City)

(State) (Country) (Zip Code)

Telephone: _____
(Commercial) (FTS)

U.S. Citizen Yes ☐ No ☐ _____
(Specify Non-US Citizenship)

FUNDING ORGANIZATION

Organization: _____
(Department)

Address _____
(Street) (City)

(State) (Country) (Zip Code)

Program Manager _____
(Name) (Title)

Telephone _____
(Commercial) (FTS)

TECHNICAL INFORMATION

CRTF Technical Support Required - Attach a separate summary of the technical support requirements such as beam power and intensity, utilities, data or control systems, heat rejection, etc., and any special requirements that may not be within current CRTF capabilities.

Purpose of Experiment:

Interest or Potential Benefit to the U.S. Department of Energy, if any.

Will the experiment involve any classified information or hardware? __

SCHEDULING

Proposed Test Period: From _____ To _____

Experimenter Input to the CRTF

Date To Be
Submitted
To CRTF

a. Data Package (Detailed Description of Experiment) _____

b. Test Plan (Details of runs and test procedures) _____

Total number of solar test days or hours anticipated. _____

Beam exposure time (range) for a single test. _____

Time of day or time of year preferred for test. _____

AGREEMENT FOR TESTING

When this application is approved, the CRTF-Liaison Engineer and/or the STTF-Users Association will assist in establishing an agreement-for-testing contract with the DOE-Albuquerque Operations Office for all experimenters that do not have a formal agreement with DOE for testing at the CRTF. That contract will define:

1. Scope of work
2. Costs and charges
3. Visits or temporary residence at CRTF
4. Key personnel
5. Coordination and administration
6. Responsibility for damage
7. Security, health and safety
8. Disputes
9. Reports
10. Patents
11. Data responsibilities
12. Publicity releases

CRTF EXPERIMENT APPLICATION SIGNATURE PAGE

EXPERIMENT TITLE: _____

PRINCIPAL EXPERIMENTER'S SIGNATURE: (This is an application - not
an agreement)

Signature _____ Date _____

Title _____

Company _____

APPROVALS:

U.S. DEPARTMENT OF ENERGY, DIVISION OF SOLAR TECHNOLOGY Date _____

SANDIA LABORATORIES, ALBUQUERQUE - 4713 Date _____

SANDIA LABORATORIES, LIVERMORE - 8450 Date _____

SOLAR THERMAL TEST FACILITIES - USERS ASSOCIATION
(If a non-programmatic experiment) Date _____

CRTF EVALUATION OF APPLICATION NO. _____

EXPERIMENT TITLE: _____

1. FEASIBILITY FOR TESTING AT THE CRTF.

2. POTENTIAL CONFLICT WITH DOE PROGRAMMATIC TESTING PLANNED FOR
THE REQUESTED TEST PERIOD.

3. ANTICIPATED NON-REIMBURSABLE COST OR EFFORT.

CRTF EVALUATOR

Date

APPENDIX B

Resident Experimenter List

CRTF Control Number _____

Date Received _____

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APPENDIX C

Design Criteria
Codes and Standards

APPENDIX C

Design Criteria Codes and Standards

The CRTF will test equipment and systems that are highly experimental and for which existing codes and standards may not be appropriate. After the feasibility of an experiment is initially established, the CRTF will determine which codes or standards, if any, must be followed. If existing codes or standards cannot be strictly met (due to unconventional design or other reasons), the experimenter must demonstrate by calculations or by test data that the design and fabrication process to be used will provide a safe experiment.

The following detailed mechanical-design documentation may be required with the Data Package, depending on the nature of the experiment. Proprietary designs, design methods, and fabrication methods will be protected.

1. Complete calculations with all assumptions, computer codes, and conclusions reached shall be documented.
2. Assumed static or dynamic loads, and load factors for normal and faulted conditions. Wind loads for gusts up to 100 mph and earthquake loads* for Zone 2 risk shall be included.
3. Assumed working stress and the factors of safety used shall be listed. Any unique temperature gradients or temperature cycles caused by the solar flux or experiment design must be considered.
4. Any applicable codes, standards, requirements, criteria, references, and sources of test data or other data shall be listed.

*The CRTF will supply earthquake response data for the appropriate location and test level on the tower.

The following are potentially applicable codes and standards.

Mechanical

1. ASME Code for Fired and Unfired Pressure Vessels and Relief Valves (applicable sections).
2. ASME (or equivalent ASTM) Materials Specifications.
3. ANSI Code for Pressure Piping (ANSI-B31).
4. Compressed Gas Association Standards.
5. Specification for Architecturally Exposed Structural Steel; AISC.
6. Specification for the Design, Fabrication, and Erection of Steel for Buildings; AISC.
7. OSHA 29CFR1910.

Electrical

1. National Fire Protection Association Standards (includes National Electrical Code).
2. OSHA 29CFR1910

DISTRIBUTION:

TID-4500-R67, UC-62 (263)

STTF User's Association (200)
First National Bank Bldg. East
Suite 1204
Albuquerque, NM 87108
Attn: Executive Director

US Department of Energy (3)
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, NM 87115
Attn: D. Nowlin
G. Pappas (2)

US Department of Energy (5)
Division of Solar Technology
Department of Energy
600 E Street
Washington, DC 20545
Attn: G. M. Kaplan (2)
G. W. Braun
M. U. Gutstein
H. Coleman

White Sands Solar Furnace
Army Material Test and Evaluation
White Sands Missile Range, NM 88002
Attn: R. Hayes

Director, Advanced Components Test Facility
Georgia Institute of Technology
SEMTD/EES
Atlanta, GA 30332

SERI (5)
1536 Cole Blvd.
Golden, CO 80401
Attn: P. Russell
P. Key (2)
Library, Bldg No. 4 (2)

2514 P. J. Brannon
3440 L. M. Jercinovic
4533 B. D. Zak
4700 J. H. Scott
4710 G. E. Brandvold (2)
4713 B. W. Marshall (400)

4713 D. B. Davis
4713 J. T. Holmes
4713 D. L. King
4713 L. K. Matthews
4713 L. O. Seamons
4713 J. M. Stomp
4713 D. G. Skogmo
4713 R. D. Aden
4714 R. P. Stromberg
4715 R. H. Braasch
4716 H. M. Dodd
4719 D. G. Schueler
4719 B. D. Shafer
4721 J. V. Otts
5133 E. P. Eernisse
5834 D. M. Mattox
8450 R. C. Wayne
8451 W. G. Wilson
8451 T. D. Brumleve
8451 C. L. Mavis
8452 A. C. Skinrood
8452 E. T. Cull
8452 Jim Gibson
8452 W. C. Peila
8452 L. N. Tallerico
8453 J. D. Gilson
8463 W. C. Peila
8266 E. A. Aas
3141 T. L. Werner (5)
3151 W. L. Garner (3)
For DOE/TIC
(Unlimited Release)