B&V DOCUMENT 7341.005-A-029

ELECTRIC POWER RESEARCH INSTITUTE

BMSR SOLAR TEST PLAN

1 MWt BENCH MODEL SOLAR RECEIVER
GAS COOLED CENTRAL RECEIVER

BLACK & VEATCH/consulting engineers

B&V Document 7341.005-A-029

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SOLAR RECEIVER
GAS COOLED
CENTRAL RECEIVER

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B&V DOCUMENT 7341.005-A-029

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TABLE OF CONTENTS

A-029
031279

TABLE OF CONTENTS (Continued)

LIST OF TABLES

TABLE OF CONTENTS (Continued)

LIST OF TABLES (Continued)

A-029
031279

TABLE OF CONTENTS (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

A-029
031279

TABLE OF CONTENTS (Continued)

LIST OF FIGURES (Continued)

GLOSSARY

Key terms used in this document are defined below. A complete description of the test variables is given in the Data Use Strategy, B&V Document 7341.005-A-008.

Alarm--Indication of a high-level abnormal test condition sensed by the BMSR Control System or Data Acquisition System, with possible automatic shutdown.

Aperature Input Power--Power from the heliostat field entering the cavity through the aperture.

"Cavity Flux"--Component of heat flux in the cavity due to reradiation and reflection within the cavity.

Direct Incident Flux--Component of heat flux in the cavity directly due to rays from the heliostat field.

Heat Absorbed--Power converted from radiant heat to air thermal content, for receiver or for panel.

Heat Transfer Factor--Ratio of panel heat absorbed to power incident on the panel.

Incident Flux--Total flux impinging on the front of the heat exchanger tubes. For surfaces without tubes, wall flux and incident flux are the same.

"k Factor"--Computed ratio of incident flux to wall flux.

Panel--One of six sides of the BMSR designated A, B, C, D, E, or F. Panels B through F have heat exchangers, and are often referenced with a variable name, e.g., Panel Heat Transfer Factor.

Panel Incident Power--Total radiant power falling on an imaginary surface just in front of the heat exchanger tubes for a panel; i.e., the integral of incident flux over the heat exchanger surface area.

Receiver Efficiency--The ratio of receiver heat absorbed to aperture input power.

Reradiated Power--Power loss out the aperture due to reradiation and reflection.

Wall Flux--Heat flux impinging on the inner surface of BMSR cavity insulation.

Warning--Indication of a low-level abnormal test condition sensed by the BMSR Control System or Data Acquisition System.

Zone Air Temperature--Temperature of air in the duct and header region below the cavity floor.

SECTION 1.0

SCOPE AND OBJECTIVES

This Bench Model Solar Receiver (BMSR) Solar Test Plan is intended to prescribe the various test runs, testing activities, and test facility data system support requirements to a level of detail sufficient to permit detailed interaction between Black & Veatch and the STTF; it is submitted in compliance with the requirements of the STTF Experiment Manual (SAND77-1173), Chapter IV. The step-wise actions required to implement the tests and activities descriptively defined in this plan will be detailed in a separate document, BMSR Solar Test Procedures (B&V Document 7341.005-A-036). This plan, which specifies the BMSR tests, the test purposes, the operating conditions, and the test schedule, also includes details of the data sampling, computation and display functions required of the STTF Data Acquisition System (DAS). The BMSR Solar Test Plan should be reviewed in conjunction with the BMSR Data Package, B&V Document 7341.005-A-031, to provide a working knowledge of the BMSR test objectives and requirements.

The testing described in this plan is intended to contribute to the overall objectives of the EPRI program to design and evaluate solar receivers offering promise for comprising part of a solar thermal gas turbine power plant. In support of that program, the BMSR has four objectives.

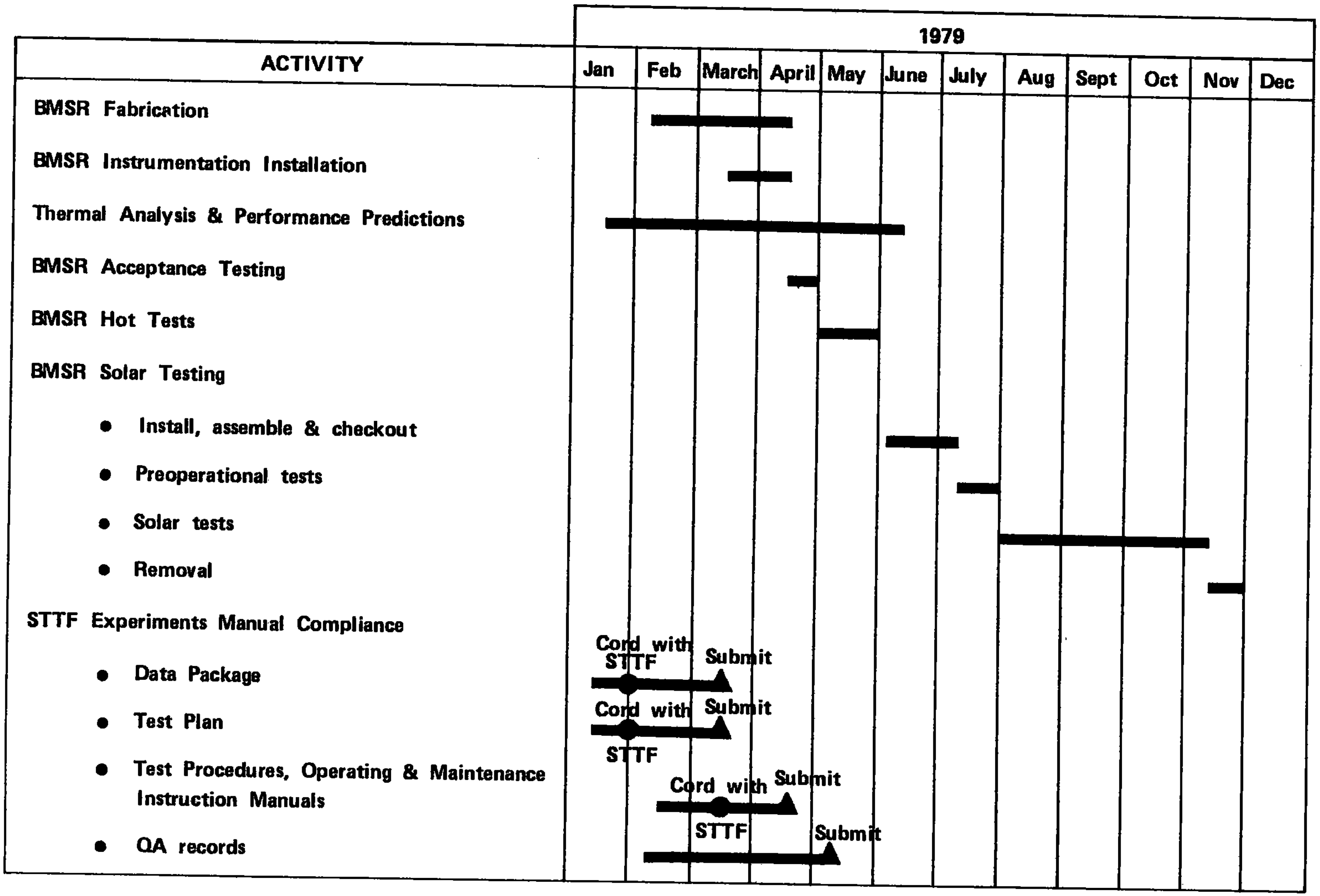
- Heat 130 psia air from 900 F to 1,950 F in an orderly and controlled fashion.
- Demonstrate the high temperature, solar cavity concept.
- Prove that a structural ceramic heat exchanger is technologically feasible.
- Establish the analytic skills utilized in the design of the BMSR as being sufficiently developed to warrant their application to the pilot plant design.

The BMSR Solar Test Plan, consisting of checkout, preoperational, and solar test activities, will define a methodology for demonstrating the fulfillment of those objectives. The test plan has been developed in response to the following test objectives.

- Determine BMSR performance characteristics.
- Verify design predictions of operating conditions.
- Verify material and component performance.
- Provide supplementary information applicable to solar receiver design refinement.

A schedule highlighting the major events occurring during BMSR fabrication, test preparation, and testing is shown on Figure 1-1.

A-029
031279



BLACK & VEATCH BMSR: FABRICATION, TEST PREPARATION AND TESTING SCHEDULE

FIGURE 1-1

SECTION 2.0

REFERENCES

The following documents provide general and/or specific information in support of this BMSR Solar Test Plan.

- BMSR Detail Drawings, B&V Document 7341005-A-003.
- Data Use Strategy, B&V Document 7341.005-A-008.
- B&V Instrument Installation Drawings, B&V Document 7341.005-A-010.
- B&V Instrument Location Drawings, B&V Document 7341.005-A-011.
- B&V Instrumentation and Control Data Base, B&V Document 7341.005-A-014.
- Control System Description, B&V Document 7341.005-A-018.
- B&V Control Logic Diagrams, B&V Document 7341.005-A-019.
- BMSR Control System Operating Instructions, B&V Document 7341.005-A-022.
- BMSR Test Plan, B&V Document 7341.005-A-024.
- B&V Interface Control Drawings, B&V Document 7341.005-A-030.
- BMSR Data Package, B&V Document 7341.005-A-031.
- BMSR Solar Test Procedure, B&V Document 7341.005-A-036.

SECTION 3.0

TEST ARTICLE DESCRIPTION

The BMSR is a gas cooled, ceramic heat exchanger designed to absorb approximately 1,000 kW of thermal power by means of heating 130 psia, 900 F flowing air to 1,950 F. The BMSR, illustrated on Figure 3-1, has a hexagonally shaped shell structure, fabricated of carbon steel, that is approximately 11 feet in diameter and 9 feet high. When fully assembled on support stands and with the air supply manifold piping and U-bend assemblies installed, the BMSR is approximately 13 feet in height. The receiver utilizes a cavity concept, with the cavity being about 5 feet high and about 9 feet in diameter. One side of the BMSR cavity is an inactive, insulating surface (kaowool composite) that includes an aperture 3.3 feet by 3.3 feet. The remaining five sides of the cavity are heat exchanger panels comprised of parallel, vertical SiC tubes (1.125 inches ID, 1.5 inches OD) alternately offset 2 inches and 9 inches from the wall insulation that constitutes the cavity perimeter. The SiC tubes are joined at the top by a stainless steel U-bend to form a U-tube heat exchanger configuration; active panel headers supply air to and accept air from the cold and hot legs respectively of the U-tube. The length of the SiC tubes is about 7.5 feet, thus permitting joints with air headers and U-bends to be made outside the severe, radiant environment of the active cavity. The cavity floor and ceiling surfaces are inactive, with the kaowool insulating material comprising those surfaces. Details of the BMSR design may be found in the drawings that comprise B&V Document 7341.005-A-003.

Redirected solar energy enters the BMSR through the aperture. Multiple reflections within the cavity distribute the energy to all cavity surfaces, heating these materials. Thermal radiation emitted from these materials further distributes the energy, causing a fairly uniform energy flux within the receiver. This energy is extracted from the BMSR by pressurized air that flows through the SiC tubes.

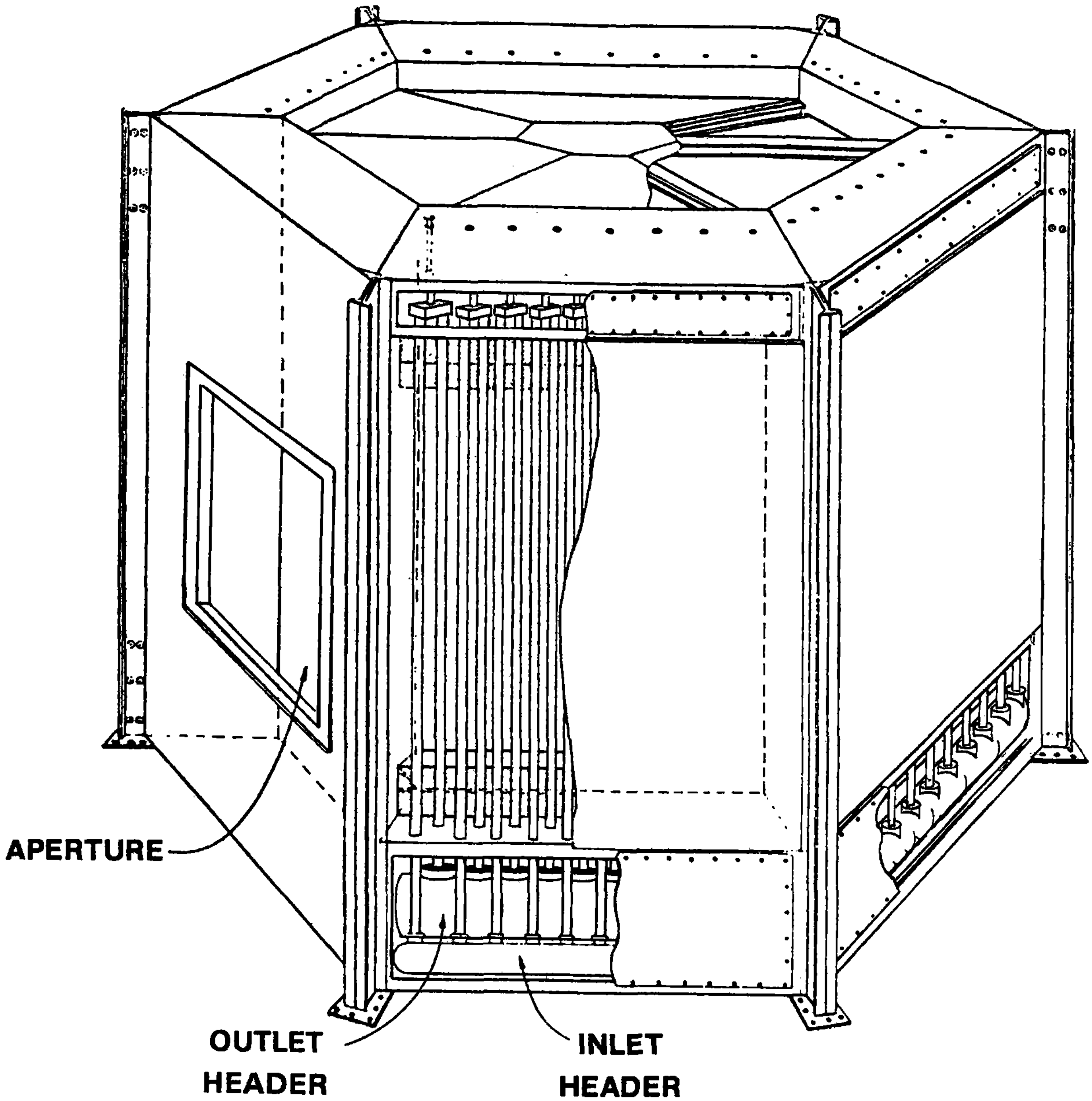


FIGURE 3-1 PERSPECTIVE OF THE 1 MWt BENCH MODEL SOLAR RECEIVER

A-029
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Airflow through the BMSR is regulated by five control valves, one for each active panel of the cavity, such that a desired outlet air temperature from each panel may be independently established and maintained. The valves are controlled by the BMSR Control System; it utilizes analog hardware to modulate control valve position as required to maintain outlet air temperature at a desired set point in response to air temperature as sensed by a thermocouple located in the panel outlet air duct. Detailed descriptions of the BMSR Control System and its logic may be found in B&V Documents 7341.005-A-018 and 7341.005-A-019.

The BMSR is instrumented with a variety of sensors to monitor the operating conditions of the BMSR and its control system during testing. These 188 sensors, which include pressure transmitters, thermocouples, strain gages, flow elements, calorimeters, radiometers, and accelerometers, will provide the data required for real-time operation, control, and post-test evaluation of the BMSR. A listing of these instruments and their functions is provided in the Data Use Strategy (B&V Document 7341.005-A-008); the installation methods and positions of these devices are defined in B&V Documents 7341.005-A-010 and 7341.005-A-011 respectively.

SECTION 4.0

TEST ACTIVITY SUMMARY

Black & Veatch designed the 1 MWt BMSR to be installed in the 140-foot test bay of the DOE STTF located in Albuquerque, New Mexico. Solar tests of the BMSR are intended to demonstrate and to provide a technical basis for the evaluation of the solar receiver design.

Solar testing will require that heliostats be focused on the BMSR aperture target; the number of heliostats required will depend upon the particular test in progress, the time of day and time of year, insolation conditions and heliostat prealignment conditions, but the maximum number will generally be between 78 and 222 heliostats. Incident solar flux entering the receiver aperture will be measured by the STTF RTAF, with automated data conditioning and display by STTF to include all transfer functions and field performance indicators. Material temperatures, energy levels, and other important indicators within the BMSR system will be measured by the BMSR Instrumentation System. The BMSR Control System will monitor BMSR outlet air temperatures and adjust airflows as required to maintain set point conditions. Important BMSR control and instrument information will be displayed in real-time on STTF CRT's via the STTF DAS; all test data will be recorded on computer disks for subsequent retrieval and post-test analysis.

Solar testing of the BMSR will consist of a series of test runs, each of which is intended to provide specific insights to the operation and performance of the receiver. The test runs are grouped into eight sets: checkout tests, preoperational tests, start-up/shutdown sequences, equilibrium flux, nonuniform temperature set, unbalanced flux, transient flux, and sun-following. The test plan defines these test runs in terms of objectives, test methods, operating conditions; testing efforts will be tailored so as to implement these guidelines as closely as possible, recognizing that some divergence will occur due to the lack of fully regulated conditions at STTF.

4.1 CHECKOUT TESTS

Purposes:

- Verify proper BMSR assembly and installation.
- Establish BMSR system interfaces with STTF.

Scope:

- BMSR.
- BMSR Instrumentation System.
- BMSR Control System.
- Air Supply System.
- DAS.

Features:

- Inspections as appropriate.
- Checks of interfaces.

BMSR Checkout Tests will be conducted prior to introducing pressure, airflow, or solar heat to the receiver system at STTF. These tests are intended to verify that no damage has occurred to the BMSR during movement to the test bay, and to verify that the assembly/installation/interfacing of the BMSR and peripheral equipment has been completed satisfactorily. Checkout test activities will consist of general BMSR inspections and an operational readiness review of the BMSR Instrumentation System, BMSR Control System, Air Supply System, and the DAS.

4.1.1 Inspection

Upon positioning in the 140-foot test bay at the STTF, the BMSR will be assembled for testing in accordance with the BMSR Assembly/Installation Instructions, B&V Document 7341.005-A-006, and will be interfaced with the BMSR Control System, BMSR Instrumentation System, Air Supply System, DAS, and the necessary support utilities. Concurrent with and following these assembly/installation/interfacing activities, the BMSR will be inspected in accordance with the following guidelines.

- Prior to assembly, the BMSR and components will be inspected for damage, including a check of air paths for the absence of foreign matter.
- Proper assembly and installation will be verified by appropriate inspections during and/or following the assembly/installation activities.
- Physical interfaces with peripheral equipment will be visually inspected.
- The STTF radiation shield will be examined for adequate protection of the BMSR and other test bay equipment.

4.1.2 BMSR Instrumentation System

Checkouts of the BMSR Instrumentation System will establish proper operation of those instruments installed during BMSR fabrication as well as those requiring installation at STTF, and will verify proper operation of the sensors when interfaced with the DAS. Checkout activities will include the following.

- Visual inspection of previously installed sensors, when practical, to determine that sensors and fittings are intact.
- Continuity checks as appropriate.
- Output signal checks, via the DAS with conversion to engineering units, for readings corresponding to ambient conditions.
- Detection and elimination of ground loops.
- Calorimeter and radiometer coolant flow check. Total coolant will be shown to be as specified. Individual sensors will be checked for the presence of cooling flow. The backup cooling system will be shown to be automatically initiated upon a simulated failure of the primary coolant.

4.1.3 BMSR Control System

Checkouts of the BMSR Control System will verify the functional operation of both the electronics and the control valves after installation at

STTF; tuning of the BMSR Control System will be deferred until during initial solar tests. The checkout methods will be as follows, with additional checks as defined in the BMSR Control System Acceptance Test Procedures, B&V Document 7341.005-A-023, when appropriate.

- Control valves will be individually stroked, first by using manual mode functions of the BMSR Control System, and next by supplying a dummy thermocouple input signal with the controller in the auto mode. Both local and remote (DAS generated) set points will be utilized in the automatic mode checkouts.
- DAS interfaces will be verified as proper.
  - -- DAS command signals to the BMSR Control System.
  - -- DAS monitoring of BMSR Control System signals.
- Alarm conditions will be simulated, using both BMSR Control System and the DAS as the "alarm sensing" unit, and the proper valve opening response verified.

4.1.4 Air Supply System

The Air Supply System as previously utilized at STTF will require modifications for the B&V BMSR tests. These changes include different receiver interface piping, the addition of an attemperator, and the addition of the attemperator control loop. Checkouts of the Air Supply System will include the following.

- Interconnecting piping will be checked for dimensional alignment, piping support devices, freedom/restraint of movement, proper installation, etc.
- Valves will be stroked using manual controls and/or dummied control signals.
- Proper function of the attemperator equipment and its control circuitry will be reviewed.
- DAS interfaces (set points, measurements, contacts, etc.) will be verified.

4.1.5 DAS/Experiment Interfaces

Interfacing of the DAS with the BMSR Control System and Instrumentation Systems will entail both physical connections as described in the B&V Interface Control Drawings, B&V Document 7341.005-A-030, and the development of computer software for the data requirements discussed in Section 6 of this BMSR Solar Test Plan. This interface checkout will address data sampling and storage, data evaluation, display and storage, and control computations/actions assigned to the DAS. These checkouts will include the following.

- Verification that the DAS identifies each signal with its proper source.
- Checkout of proper DAS sampling rates, conversions, computations, etc., as defined in Section 6.1.
- Verification of data displays as per the requirements of Section 6.2.
- Checkout of BMSR Control System and Air Supply System control monitoring and command interfaces with the DAS (e.g., set points, contact closures).

4.2 PREOPERATIONAL TESTS

Purpose:

- Verify BMSR pressure integrity.
- Establish cold flow characteristics.
- Evaluate DAS/BMSR Instrumentation System interaction.
- Verify BMSR thermal integrity.

Scope:

- Pressures to 135 psia.
- Rated airflow.
- Solar power to about 40 kW_t.

Features:

- Static Pressurization Tests.
- Cold Flow Tests.
- Static Solar Tests.

Preoperational tests of the BMSR will be used to establish readiness of the BMSR for solar tests. Preoperational tests will include Static Pressurization Tests to verify BMSR Pressure Integrity, Cold Flow Tests to establish flow characteristics and to demonstrate valve operation, and Static Solar Tests (no airflow, BMSR at ambient pressure) to warm the cavity, thereby providing a functional performance check of some BMSR thermal sensors as well as verifying the BMSR thermal integrity.

4.2.1 Static Pressurization Test

Static Pressurization Tests, to be conducted at ambient temperature, will be used to establish the pressure integrity of the BMSR. These preoperational tests, similar in nature to pressurization tests during the BMSR Acceptance Tests (reference BMSR Acceptance Test Plan, B&V Document 7341.005-A-007), will verify that the SiC tube assemblies have been properly installed, and will demonstrate that the leakage rate from the BMSR flow system is at an acceptable level. It will also be shown qualitatively that no individual silicon carbide tube joint assembly has excessive leakage.

An abbreviated form of this Static Pressurization Test will be repeated occasionally during the solar testing program to identify wear- or temperature-dependent leak developments.

Static Pressurization Test conditions are given in Table 4-1 with key observations and expected results given in Table 4-2. The test methodology will be as follows.

- The BMSR flow network will be pressurized to the designated test pressures at a rate of approximately 5 psi per minute. Upon reaching a desired test pressure, the BMSR may be sealed off by closing Air Supply System valving and/or the hydrocarbon alarm shutoff valve.
- The rate of static pressure decay within the BMSR will be monitored and leakage rates will be inferred from that data. Prior results from the BMSR Acceptance Test will serve as a baseline reference for data comparison. Leakage rate/pressure decay relations are given in the above referenced BMSR Acceptance Test Plan.
- Joint assemblies will be individually inspected for abnormal leaks, utilizing leak detection methods employed during the BMSR Acceptance Test.
- Should the BMSR leakage rates diverge significantly from the BMSR Acceptance Test values, the problem shall be identified and corrected, and the pressure test repeated as appropriate.

An abbreviated version of the pressurization tests will be repeated occasionally as permitted during solar testing of the BMSR.

4.2.2 Cold Flow Tests

Preoperational Cold Flow Tests will be the first exposure of the BMSR to rated airflow. The purposes of the tests are as follow.

- Provide initial flow experience with BMSR/Air Supply System interconnection, demonstrating proper BMSR control valve and Air Supply valve functions.

TABLE 4-1. STATIC PRESSURIZATION TESTS

Test	Pressure (psia)
SP-1	25[a,b]
SP-2	50
SP-3	75[b]
SP-4	100
SP-5	135[b]

[a]Qualitative inspections of joint assemblies for abnormal leakage will be made at the indicated pressure, and at higher pressures as appropriate.

[b]Abbreviated Static Pressurization Tests at the indicated pressures will be conducted occasionally during solar testing.

TABLE 4-2. STATIC PRESSURIZATION TESTS: KEY OBSERVATIONS AND EXPECTED RESULTS

Key Observations	Expected Results
• Total leakage	• Slight leakage both in Air Supply System "seal-off" valving and in BMSR flow network
• BMSR leakage rate	• Less than 55 lbm/h at 135 psia
• Silicon carbide tube joint assemblies	• Insignificant leakage from any individual joint assembly

- Establish baseline cold flow data such as the pressure drop across the BMSR. Similar data from cold flow tests conducted occasionally between solar tests will be compared with this baseline data to verify that no change in flow characteristics has occurred, indicating possible damage.
- Demonstrate airflow sensor function and validate the measurement methodology, including related DAS operations.
- Determine mechanical piping and U-bend strains, and U-bend vibrations. These measurements will serve as bases for comparison between strains and vibrations of mechanical origin and those associated with high temperature operation.

Table 4-3 gives flow rates for the Preoperational Cold Flow Tests. The test methodology is as follows.

- BMSR control valves will be set at their minimum flow, mechanical stop positions via the manual mode of the BMSR Control System. Airflow will be initiated, with the BMSR outlet air pressure maintained at the specified level.
- Valves will be individually adjusted until the receiver airflow rate is at the specified test condition and panel airflow rates are equal. Valve positions will be noted.
- Proceed to the next test flow rate.
- Airflows through the panels will be unbalanced via the BMSR control panel manual mode so as to check the DAS calculated flow imbalance alarm (reference Section 6.1.7). Each panel will be individually checked for both high and low flow conditions.

Key observations and expected results for Cold Flow Tests are given in Table 4-4.

4.2.3 Static Solar Tests

Static Solar Tests will be low power, ambient pressure, no flow tests using power redirected from one and two heliostats as aperture input power. These tests will serve the following purposes.

TABLE 4-3. COLD FLOW TESTS: EXPERIMENTAL CONDITIONS

Test	Airflow Rate (lbm/h)
SCF-1	2,500
SCF-2	5,000
SCF-3	7,500
SCF-4	10,000
SCF-5	Maximum

NOTE: BMSR inlet pressure will be maintained at approximately 130 psia. Maximum airflow is with BMSR valves fully open and the Air Supply System maintaining a pressure drop of approximately 3 psi.

TABLE 4-4. COLD AIRFLOW TESTS: KEY OBSERVATIONS AND EXPECTED RESULTS

Key Observations	Expected Results
Panel airflow rates	Uniform from panel to panel
BMSR pressure differential	<4 psi at design conditions
U-bend strain	<100 $\mu\varepsilon$
U-bend vibration	Small--baseline values for subsequent tests
Piping strain	Small--baseline values for subsequent tests
BMSR flow rate, BMSR differential pressure, BMSR inlet pressure	BMSR Instrumentation System and Air Supply System measurements correspond to another

TABLE 4-3. COLD FLOW TESTS: EXPERIMENTAL CONDITIONS

Test	Airflow Rate (lbm/h)
SCF-1	2,500
SCF-2	5,000
SCF-3	7,500
SCF-4	10,000
SCF-5	Maximum

NOTE: BMSR inlet pressure will be maintained at approximately 130 psia. Maximum airflow is with BMSR valves fully open and the Air Supply System maintaining a pressure drop of approximately 8 psi.

TABLE 4-4. COLD AIRFLOW TESTS: KEY OBSERVATIONS AND EXPECTED RESULTS

Key Observations	Expected Results
Panel airflow rates	Uniform from panel to panel
BMSR pressure differential	<4 psi at design conditions
U-bend strain	<100 με
U-bend vibration	Small--baseline values for subsequent tests
Piping strain	Small--baseline values for subsequent tests
BMSR flow rate, BMSR differential pressure, BMSR inlet pressure	BMSR Instrumentation System and Air Supply System measurements correspond to another

- Checkout of thermal-related instrumentation and associated DAS conversion/computation capabilities.
- Indicate heating characteristics of the BMSR frame and shell.

Test conditions are given in Table 4-5, with key observations and expected results given on Table 4-6. The test methodology is as follows.

- One heliostat will be focused on the BMSR aperture.
- This power will be maintained until insulation temperatures are reasonably stable.
- Power from a second heliostat will be added to the aperture input power.
- Insulation temperatures will again be allowed to stabilize.
- The aperture power will be reduced to zero.

Thermal data will be reviewed for reasonableness and consistency, indicating both sensor function and BMSR thermal integrity. Following the second test (SA-2), calorimeter faces may require touch-up with a high emissivity coating due to residue from insulation binder burnout.

TABLE 4-5. STATIC SOLAR TESTS: EXPERIMENTAL CONDITIONS

Test	Aperture Power	Expected Cavity Temperature (F)
SA-1	One heliostat (approx. 20 kW_t)	930
SA-2	Two heliostats (approx. 40 kW_t)	1,200

TABLE 4-6. STATIC SOLAR TESTS: KEY OBSERVATIONS AND EXPECTED RESULTS

Key Observations	Expected Results
• Wall flux	• Up to 40 kW/m^2
• Cavity surface temperatures	• Up to 1,200 F
• Insulation thermocouple temperatures	• Less than 1,100 F
• BMSR shell temperatures	• Less than 200 F

4.3 START-UP/SHUTDOWN SEQUENCE TESTS AND STANDARD METHODS

Purpose:

- Initial evaluation of BMSR solar operation
- Exercise DAS/BMSR Control System
- Verify start-up/shutdown procedures

Scope:

- Powers to 350 kW_t
- Temperatures to 900 F

Features:

- Sequence tests for airflow-set and temperature-set start-up/shutdown
- Validation of standard start-up/shutdown methods

The Start-up/Shutdown Sequence Tests will be the first, concurrent exposure of the BMSR to solar input power, airflow, and intermediate operating temperatures. These initial, solar-flow tests will provide preliminary indications that no operational abnormalities exist (e.g., high hot duct or header temperatures); the tests will also be used for tuning of the BMSR Control System and Air Supply System, as well as for the evaluation of the performance of the BMSR Control System, Air Supply System, and DAS as an integrated network. Final test runs in this series of tests will be utilized to validate the Standard Start-up/Shutdown Methods defined later in this section.

Test conditions and methods for Start-up/Shutdown Sequence Tests are given in Table 4-7. Two methodologies, "airflow-set" and "temperature-set" are used in these tests.

- Test SS-1 utilizes the "airflow-set" start-up and shutdown methodology; the constant high airflow of this mode provides a conservative heating rate, and permits a validation check of BMSR Control System data before that data is used as a basis for control in the "temperature-set" test mode (i.e., the BMSR Control

TABLE 4-7. START-UP/SHUTDOWN SEQUENCE TESTS: EXPERIMENTAL CONDITIONS AND METHODS

Test	Set Points				Method
	J (kW_t)	T_I (F)	T_O (F)	$\dot{m}$ (lbm/h)	
SS-1	0-275	400	--	≃10,000	Establish full airflow. Increase J from zero at a rate of 0.25 kW_t/sec. Pause and allow system to stabilize when T_O ≃500 F. Continue increasing J to 275 kW_t at 0.25 kW_t/sec. Allow T_O to stabilize and note value of T_O (750 F.) Switch to temperature-set mode with T_O set point at the steady-state value previously noted. Perturb T_O set point to verify controller operation and for control system tuning. Open valves and decrease J to zero at 0.25 kW_t/sec.
SS-2	0-100 100-275	250 400	500 750	-- --	Establish set points for T_I at 250 F and for T_O at 500 F. Increase J to 100 kW_t at 0.25 kW_t/sec. Allow BMSR to stabilize. Reset T_O and T_I to 400 and 750 F respectively. Increase J to 275 kW_t at 0.25 kW_t/sec. Allow BMSR to stabilize. Use Standard Shutdown Method
SS-3	275	400	750	--	Use Standard Start-up and Shutdown Methods

System is in automatic mode). A transition to "temperature-set" control will be made in this test (SS-1) upon stabilization of the BMSR outlet air temperature at the specified test conditions. This use of the temperature-set mode will allow evaluation of controller function and permit initial tuning of the BMSR Control System.

- Tests SS-2 and SS-3 utilize the "temperature-set" start-up and shutdown methodology. Upon establishing minimum airflow and prior to initiating solar heating, airflow characteristics (in particular the BMSR differential pressure) will be compared with baseline, minimum flow characteristics determined in the Pre-operational Cold Flow Tests. This comparison will verify that no significant changes have occurred, indicating possible damage to the BMSR flow path.

Key observations and expected results for Start-up/Shutdown Sequence Tests are given in Table 4-8.

Figures 4-1 and 4-2 define the Standard Start-up Method and the Standard and Emergency Shutdown Methods. Test SS-3 will be used to qualify the Standard Start-up and Shutdown Methods for use in subsequent test runs.

TABLE 4-8. START-UP/SHUTDOWN SEQUENCE TESTS: KEY OBSERVATIONS AND EXPECTED RESULTS

Key Observations	Expected Results
• Outlet air temperatures (receiver and individual panels), Inlet air temperature	• BMSR Control, BMSR Instrumentation, and Air Supply System sensors give equal readings for the same variable. Temperatures maintained at set point when in temperature-set mode at specified power.
• Duct and header temperatures	• Less than 250 F
• Pillbox temperature	• Less than 350 F
• U-bend strain*	• Less than 200 $\mu\varepsilon$
• Duct and header strain*	• Less than 500 $\mu\varepsilon$
• Incident flux	• Fairly uniform
• Airflow rates	• Fairly uniform from panel to panel. Instrumentation System and Air Supply System receiver airflow measurements correspond.

*Initial heating of strain gages will result in weld relaxation, giving temporarily erroneous measurements.

STANDARD START-UP METHOD

STAGE 1

- Commence data recording and display
- Establish minimum BMSR airflow at 130 psia (BMSR valves at minimum stops with Air System maintaining BMSR ΔP)
- BMSR set point air temperatures of 400 F inlet and 500 F outlet
- BMSR inlet and outlet temperatures float
- Solar input commenced at 0.5 kW/second to ~100 kW

STAGE 2

- Increase solar input at 0.5 kW/second to 60 per cent of desired test condition
- Control of BMSR outlet air temperature established with set point(s) 250 F below desired test condition
- Control of BMSR inlet air temperature established with set point 250 F below desired test condition

STAGE 3

- Increase solar input at 0.5 kW/second to 90 per cent of desired test conditions
- Increase BMSR outlet air temperature set point(s) to 50 F below desired test conditions
- Increase BMSR inlet air temperature set point to 50 F below desired test conditions
- Allow system temperatures to stabilize (BMSR efficiency change less than ~2 per cent/hour)
- Proceed to test

FIGURE 4-1 STANDARD START-UP METHOD

STANDARD SHUTDOWN METHOD

- Reduce solar input at 0.5 kW/sec
- When solar power declines to 60 per cent of test conditions, reduce BMSR inlet and outlet set point temperatures by 250 F.
- Maintain airflow until BMSR outlet temperature is below 500 F, and innermost insulation thermocouple temperatures are below 1000 F.
- Stop airflow.
- Discontinue data recording.

EMERGENCY SHUTDOWN METHOD

- Move heliostat field to standby position.
- Reduce BMSR inlet and outlet temperature set points to 250 F below test conditions (valves may, depending on alarm condition, already be in emergency, 100 per cent open position, regardless of set point action).
- Determine and assess problem. Leave field in standby mode with subsequent return to startup Stage 2, or terminate test as follows.
- Maintain airflow until BMSR outlet temperature is below 500 F, and innermost insulation thermocouple temperatures are below 1000 F.
- Stop airflow.
- Discontinue data recording.

FIGURE 4-2 SHUTDOWN METHODS

4.4 SOLAR EQUILIBRIUM FLUX TESTS

Purpose:

- Determine BMSR steady-state performance characteristics
- Establish BMSR energy balance
- Evaluate material temperatures and strains
- Verify BMSR Control System function

Scope:

- Steady-state power and temperatures
  - -- Temperatures from 1,050 to 1,950 F
  - -- Powers from 500 to 1,000 kW_t

Features:

- Checkout of BMSR Control System master/slave and direct panel control mode performance
- BMSR Control System fine tuning
- Verification that materials and components are operating within acceptable limits.

The Equilibrium Flux Tests are a series of experiments with both aperture input power and air temperatures held constant; tests will proceed from intermediate power, intermediate temperature levels to BMSR rated power and temperature. These tests will be used to ascertain steady-state BMSR performance characteristics, including an energy balance and an assessment of the cavity effect, and to determine material and component performance data for a variety of operating conditions. Early equilibrium flux tests will be utilized for fine tuning of the BMSR Control System.

A key function of the equilibrium tests will be to establish, at each successive power and temperature level, the absence of disturbing conditions (e.g., abnormally high duct temperatures). Information such as temperatures, flux levels and strains, as well as the trends of those data, will be evaluated to verify BMSR readiness for tests at more severe temperature and power levels.

Test conditions for Solar Equilibrium Flux Tests are given in Table 4-9. The methodology for conducting these tests is as follows.

- Start-up to test conditions will be as per the Standard Start-up Method given in Section 4.3.
- Test conditions will be maintained until the system stabilizes, as evidenced by receiver efficiency changing less than 1 per cent per hour.
- Temperature set points will be established using both master/slave and individual panel automatic control modes, and the performance of each of these control modes evaluated.
- Proceed to subsequent test or to the Standard Shutdown Method as per the test schedule.

A special test, SE-10, has been included in this test series. The use of Zone B heliostats, in contrast to Zone A heliostats, will demonstrate that the cavity is more efficient with higher direct incident fluxes on the heat transfer surfaces. Whereas Zone A heliostats redirect most of their power to the BMSR ceiling, the Zone B heliostats redirect more power to the BMSR heat transfer walls. Consequently, the higher absorptivity and lower reflectance of the SiC tubes will reduce the reflected losses and promote power absorption in the cavity.

Key observations, along with expected results for the equilibrium tests are recorded in Table 4-10. Typical predictions of BMSR steady-state performance indicators are given in Section 4.10.

TABLE 4-9. SOLAR EQUILIBRIUM FLUX TESTS: EXPERIMENTAL CONDITIONS

T_O/T_I \ J	500 kW_t	750 kW_t	1,000 kW_t
1,050/500 F	SE-1	--	--
1,300/500 F	SE-2, SE-10*	SE-3	--
1,650/600 F	SE-4	SE-5	SE-6
1,950/900 F	SE-7	SE-8	SE-9

*SE-10 shall use only Zone B heliostats. All other tests shall use Zone A heliostats to the greatest extent possible.

TABLE 4-10. SOLAR EQUILIBRIUM FLUX TESTS: KEY OBSERVATIONS AND EXPECTED RESULTS

Key Observations	Expected Results
• Outlet air temperatures	• Maintained at set points. Capability to reach 1,950 F verified.
• Receiver efficiency	• See Figure 4-6 in Section 4.10
• Panel heats absorbed	• Relatively uniform from panel to panel; Panels C and E will be somewhat higher
• U-bend temperatures	• Uniform values at all locations
• Heat transfer factors	• Relatively uniform from panel to panel
• Flux distribution	• Perturbations corresponding to direct incident-flux
• SiC tube temperatures	• Less than 2,400 F
• U-bend temperatures	• Less than 1,550 F
• Duct and header temperatures	• Less than 700 F
• Pillbox temperatures	• Less than 1,300 F
• BMSR floor temperature	• Less than 500 F
• Zone air temperature	• Less than 500 F
• Piping strains	• Less than 500 $\mu\varepsilon$
• BMSR shell temperature	• Less than 300 F
• U-bend region frame temperature	• Less than 800 F

4.5 SOLAR NONUNIFORM TEMPERATURE SET TESTS

Purpose:

- Determine upsets in cavity flux
- Establish impacts on panel performance
- Evaluate capability to increase receiver efficiency

Scope:

- Powers and temperatures to 1,000 kW_t and 1,950 F
- Perturbations in one and two panels simultaneously
- Perturbations to $\pm$ 150 F

Features:

- Highly nonuniform panel heats absorbed and airflow rates
- Adjusting of flux levels to increase efficiency

The Nonuniform Temperature Set Tests are experiments in which the BMSR outlet air temperatures will be controlled individually to allow unique panel outlet temperatures. These tests will be used to determine the impact of air temperature perturbations on cavity flux levels and on the performance of individual panels as indicated by panel heats absorbed and panel heat transfer factors. In addition, the feasibility of increasing overall receiver efficiency via adjustments in individual panel temperatures will be explored.

Test conditions and methods for Nonuniform Temperature Set Tests are given in Table 4-11. The test methodologies are as follow.

- Note: Because these tests evaluate the results of perturbations from balanced cavity conditions, it is essential that they be conducted during midday when aperture input fluxes are approximately symmetrical.
- Specified initial conditions are attained via the Standard Start-up Method given in Section 4-3.
- Adjust individual panel temperatures as per the methods given in Table 4-11. Maintain until panel heats absorbed or efficiency stabilize, as specified.

A-029
031279

TABLE 4-11. SOLAR NONUNIFORM TEMPERATURE TESTS: EXPERIMENTAL CONDITIONS

Test	J	T_{ON}[a]	T'_{ON}[b]	T_I	Test Method
	(kW_t)	(F)	(F)	(F)	
SN-1	1,000	1,800	1,950	750	Establish initial conditions. Raise T_{OD} to 1,950 F. Panel D airflow rate will decrease to maintain energy balance. Maintain until panel heats absorbed stabilize. Return T_{OD} to 1,800 F. Repeat for T_{OB} and T_{OE}.
SN-2	1,000	1,950	1,800	900	Establish initial conditions. Lower T_{OD} to 1,800 F. Panel D airflow rate will increase to maintain energy balance. Maintain until panel heats absorbed stabilize. Return T_{OD} to 1,950 F. Repeat for T_{OB} and T_{OE}.
SN-3	1,000	1,950	1,850[c]	900	Establish initial conditions. Simultaneously lower T_{OB} and T_{OF} to 1,850 F. Maintain until the receiver efficiency stabilizes. Note receiver outlet temperature, T_{OR}. Proceed to SN-4.
SN-4	1,000	T_{OR}[d]	--	900	Set all panel outlet air temperatures to T_{OR} measured in SN-3. Allow to stabilize.

[a]Initial condition for all panel outlet air temperatures (n=B, C, D, E, F).

[b]Perturbation conditions for specified panel (n=B, D, or E).

[c]Panels B and F perturbed simultaneously.

[d]T_{OR} set at value measured in SN-3.

Note: Tests are to be conducted during midday.

- Proceed to subsequent test or initiate Standard Shutdown Method, as per test schedule.

Key observations and expected results are listed in Table 4-12.

TABLE 4-12. SOLAR NONUNIFORM TEMPERATURE TESTS: KEY OBSERVATIONS AND EXPECTED RESULTS

Key Observations	Expected Results
• Incident flux	• Weak variation in same direction (increase or decrease) as temperature perturbation
• Wall flux	• Strong variation in direction of temperature perturbation
• Panel heat transfer factors	• Significantly decreased for perturbed panel in SN-1. Increased for perturbed panel in SN-2.
• Panel D joint, header, and duct temperatures	• Slightly influenced by Panel D outlet air temperature. Insignificant dependence on outlet air temperature of other panels.
• Zone air temperature (under cavity floor)	• Little change with outlet air temperature perturbations
• U-bend temperatures	• Strong outlet air temperature dependence.
• Receiver efficiency	• Slightly higher for SN-3 than for SN-4.

4.6 SOLAR UNBALANCED FLUX TESTS

Purpose:

- Verify cavity effect.
- Establish BMSR capability to operate with simulated cloud coverage or a partially disabled heliostat field.
- Investigate impact on outlet air temperatures.

Scope:

- Power of 500 kW_t
- Temperatures of 1,950 F.
- Power from east field only and west field only.

Features:

- Somewhat asymmetric cavity fluxes.
- Highly asymmetric panel airflows and heats absorbed.

The Solar Unbalanced Flux Tests are steady-state experiments for which the aperture power is redirected from only one side (east or west) of the heliostat field. The objectives of these tests are to demonstrate the cavity effect (the tendency of the cavity to equalize flux levels) as well as to verify the steady-state capability of the BMSR to operate properly with nonsymmetric, direct incident flux pattern. A similar transient test will be conducted as part of the Solar Transient Flux Tests.

Test conditions for the Unbalanced Flux Tests are given in Table 4-13. Tests will be conducted according to the following methodology.

- Start-up to test temperature and power levels as per the Standard Start-up Method given in Table 4-13. Start-up power will be from a symmetric heliostat field
- Shift power, from the balanced field to the east field only, at a rate of 0.5 kW_t/sec.
- Maintain conditions until the system stabilizes, as evidenced by panel heats absorbed changing by less than approximately 1 per cent per hour.
- Shift power to west field only at a rate of 0.5 kW_t/sec.

TABLE 4-13. SOLAR UNBALANCED FLUX TESTS: EXPERIMENTAL CONDITIONS

Test Identification	T_O	T_I	J	Field
	(F)	(F)	(kW_t)	
SU-1	1,950	900	500	East field only
SU-2	1,950	900	500	West field only

TABLE 4-14. SOLAR UNBALANCED FLUX TESTS: KEY OBSERVATIONS AND EXPECTED RESULTS

Key Observations	Expected Results
• Incident flux	• Relatively uniform "cavity" flux component of about 250 to 300 kW/m^2 plus half-field direct incident flux
• Receiver heat absorbed	• Comparable to SE-7 (balanced field at 500 kW_t) results
• Receiver efficiency	• Comparable to SE-7 results
• Panel heats absorbed	• Significantly higher in panels with direct incident flux
• U-bend temperatures	• Relatively uniform from panel to panel
• SiC tube temperatures	• Significantly higher in panels with direct incident flux

- Maintain conditions until the system stabilizes.
- Initiate the Standard Shutdown Method.

Key observations and expected results for the Unbalanced Flux Tests are given in Table 4-14.

4.7 SOLAR TRANSIENT FLUX TESTS

Purpose:

- Establish BMSR thermal response characteristics.
- Evaluate BMSR Control System performance.

Scope:

- Transients in aperture input power to 4 kW_t/sec.
- Powers and temperatures to 1,000 kW_t and 1,950 F.
- Balanced and unbalanced field transients.

Features:

- BMSR thermal lag.
- Recuperator thermal lag will influence test.
- BMSR and Air Supply System control interactions.
- SiC tube temperature overshoot due to control systems lag.

Transient Flux Tests are experiments for which the magnitude and, in one case the geometry, of the aperture input power is rapidly changed. These tests will be used to investigate the BMSR thermal lag, to evaluate the BMSR Control System performance in transient conditions, and to establish total BMSR function under conditions likely to occur during pilot plant operation.

Test conditions and methods are specified on Table 4-15. The general methodology for the tests is as follows.

- Start-up to specified initial test conditions as per the Standard Start-up Method given in Section 4.3.
- Initial conditions will be maintained until the system stabilizes, as evidenced by a rate of change of receiver efficiency of about 1 per cent per hour.
- Proceed with test methods given in Table 4-15.
- Initiate Standard Shutdown Method or proceed to subsequent test as scheduled.

Key observations and expected results are listed in Table 4-16.

TABLE 4-15. SOLAR TRANSIENT TESTS: EXPERIMENTAL CONDITIONS

Test	Phase	J (kW_t)	T_O (F)	T_I (F)	Test Method
ST-1.n[a]	Initial Intermediate Final	1,000 500 1,000	1,650	600	From initial conditions decrease J to intermediate condition at specified rate[a] until the system stabilizes. Increase J as specified rate[a] to final conditions. Maintain until the system stabilizes.
ST-2.n[a]	Initial Intermediate Final	1,000 500 1,000	1,800	750	Same as ST-1
ST-3.n[a]	Initial Intermediate Final	1,000 500 1,000	1,950	900	Same as ST-1. Shutdown from ST-3.2 shall be by decreasing J to zero at 4 kW_t/sec. Maintain temperature set points and airflow until T_O is 500 F.
ST-4	Initial Intermediate Final	750 750 750	1,950 1,650 1,950	900	Temperature set point change should be a step change.
ST-5	Initial Intermediate Final	500[b] 500[c] 500[b]	1,950	900	From initial conditions transfer J from east field only to west field only at a rate of 4 kW_t/sec. Maintain until the system stabilizes and transfer J back to east field only at a rate of 4 kW_t/sec. Maintain until the system stabilizes.

[a]Rates of increase/decrease for J

n = 1, 2 kW_t/sec
n = 2, 4 kW_t/sec

[b]East field only.

[c]West field only.

TABLE 4-16. SOLAR TRANSIENT FLUX TESTS: KEY OBSERVATIONS AND EXPECTED RESULTS

Key Observations	Expected Results
ST-1, ST-2, ST-3	
• Outlet air temperature	• Maintained at set point with some perturbations due to controller lag.
• Receiver heat absorbed	• Transient to new equilibrium value, transition time in 20 to 30 minutes
• Incident flux	• Changes of the order of 100 kW/m^2
• Insulation temperature profiles	• Changes of cavity surface temperatures on the order of 300 F
• SiC tube temperatures	• Changes of the order of 100 F
ST-4	
• Receiver heat absorbed	• Rapid initial increase/decrease with relatively slow transient back to near original value.
• Cavity insulation surface temperature	• Change of the order of 200 F
• SiC tube temperatures	• Change of the order of 300 F
ST-5	
• Outlet air temperature	• Accurately maintained at set point
• Receiver heat absorbed	• Insignificant variations
• Incident flux	• Perturbed by direct incident flux
• Panel heats absorbed	• Significant changes due to direct incident flux

Caution: BMSR Control System and Air Supply System lags may result in SiC tube temperatures overshooting due to momentary airflow deficiency.

4.8 SUN FOLLOWING TESTS

Purpose:

- Establish BMSR performance during "normal" operating day
- Identify start-up/shutdown characteristics pertinent to pilot plant strategy

Scope:

- Aperture power to 1,000 kW_t
- Fixed number of heliostats
- Air set point temperatures fixed or variable

Features:

- Time varying powers and temperatures

Sun Following Tests will utilize a fixed number of heliostats, with the aperture input power varying with sun position; a power range of zero at sunrise to 1,000 kW_t at solar noon and back to zero at sunset will be experienced. These tests will allow the determination of BMSR performance characteristics, particularly the evaluation of average daily receiver efficiency, under normal day-to-day operating conditions. In addition, these tests will provide insights to solar receiver start-up and shutdown characteristics and to receiver power/temperature capabilities during "normal" periods of extended operation; this information will be useful in developing solar power plant operation strategies. As weather conditions and test schedules permit, test runs may be tailored to provide data on the impacts of cloud coverage on receiver operational characteristics.

Test conditions for Sun Following Tests are given in Table 4-17. The methodology for Sun Following Tests is as follows.

- Before Sunrise:
  - -- Heliostats are brought on-line for 1,000 kW_t maximum input at solar noon.
  - -- The outlet air temperature set point is established at the specified value (e.g., 1,950 F); control valves will assume a minimum airflow position.

A-029
031279

TABLE 4-17. SUN FOLLOWING TESTS:: EXPERIMENTAL CONDITIONS AND METHODS

Test	J (kW_t)	T_I(set) (F)	T_O(set) (F)	Method
SF-1	0-1,000	600	1,650	T_I and T_O set points maintained throughout the day.
SF-2	0-1,000	750	1,800	Same as SF-1
SF-3	0-1,000	900	1,950	Same as SF-1
SF-4	0-600 600-900 900-1,000	500 600 900	1,300 1,650 1,950	T_I and T_O set points established in accordance with the corresponding value of J as noted; J varies with time of day.

- Start-up at Sunrise
  - -- Airflow is established from the Air Supply System, and heliostats will begin tracking the sun.
  - -- The BMSR Control System will modulate the airflow as required to reach the receiver outlet air temperature set point (low input powers in the early morning will result in outlet temperatures below the set point value).
- Routine Operation
  - -- BMSR operation is automatically controlled utilizing the temperature set point. In the variable temperature run (SF-4) temperature set points are established in accordance with value of aperture input power as specified.
- Shutdown
  - -- Temperatures will drop towards ambient at a rate determined by aperture input power levels and thermal lags. When the outlet air temperature reaches 500 F and the Standard Shutdown Methods conditions are satisfied, airflow will be terminated.

Key observations and expected results are given in Table 4-18.

TABLE 4-18. SUN FOLLOWING TESTS: KEY OBSERVATIONS AND EXPECTED RESULTS

Key Observations	Expected Results
• Air temperature transients -- Sun position -- Cloud coverage	• Air temperatures maintained at set points except when aperture input power is inadequate. Typical daily fluctuations in outlet temperature determined
• Receiver efficiency	• Varies with redirected power. Psuedo steady-state operation at efficiencies approximately equal to equilibrium values (see Figure 4-6 in Section 4.10)
• Daily energy balance	• Total heat absorbed and thermal losses dependent upon solar conditions. Daily average receiver efficiency to be determined
• Material operating conditions	• Extended operating day should permit BMSR materials to approach condition of thermal equilibrium

4.9 TEST SCHEDULE

A summary chart of the testing activities at STTF is shown on Figure 4-3. The schedule presumes an expected ratio of three working days to one actual solar test day. Additional details on the anticipated duration of individual test runs may be found on Table 4-19.

A-029
031279

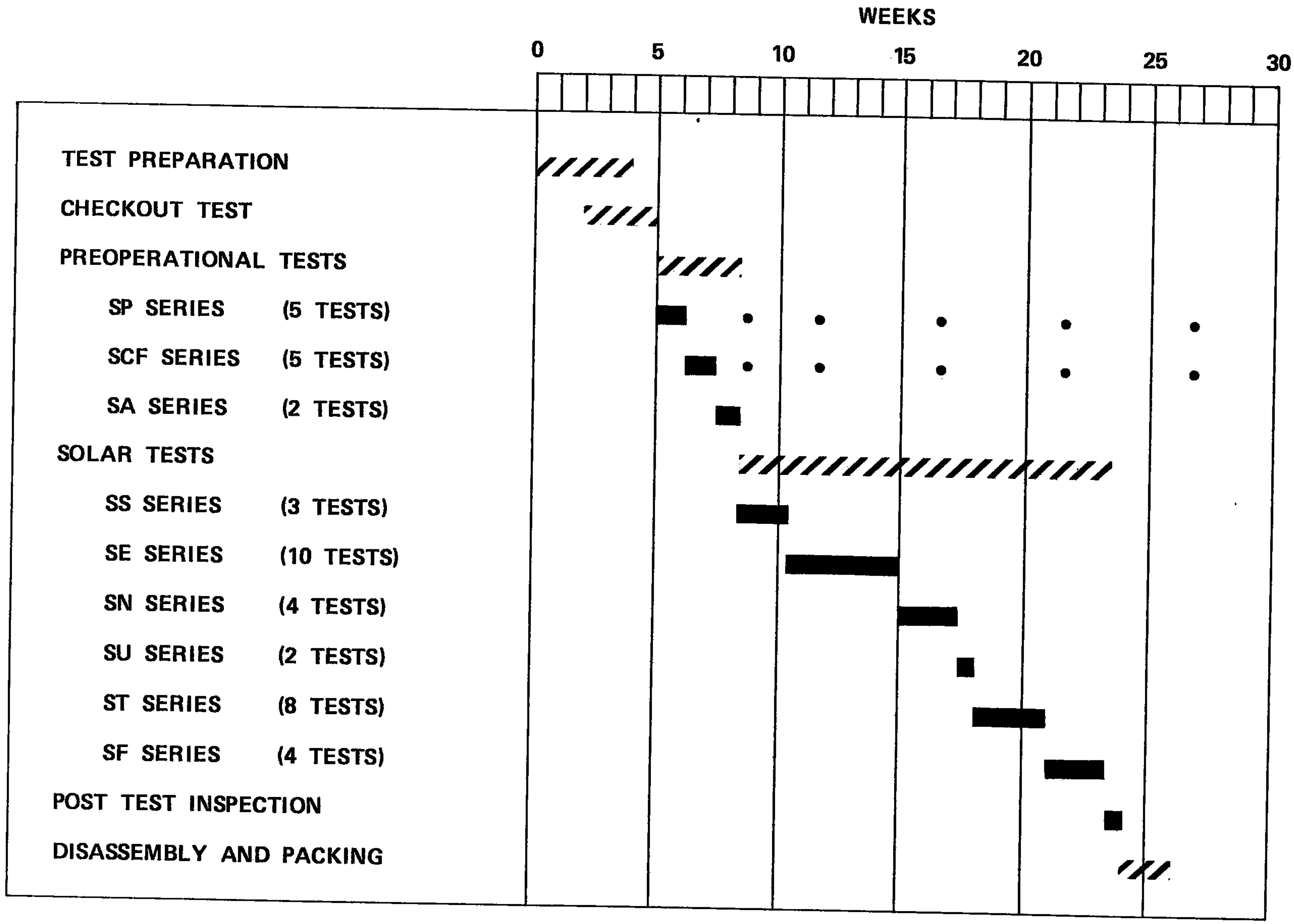

FIGURE 4-3. SOLAR THERMAL TEST ACTIVITY SCHEDULE

A-029
031279

TABLE 4-19. SOLAR THERMAL TESTS SCHEDULE

Activity	Estimated Duration (Days)	
Test Preparation		20*
Checkout Tests		15*
Preoperational Tests		18
SP-1, SP-2, SP-3, SP-4, SP-5	2	
SCF-1, SCF-2, SCF-3, SCF-4, SCF-5	2	
SA-1, SA-2	2	
Preoperational Contingency	12	
Subtotal	18	
Solar Tests		75
SS-1	1	
SS-2	1	
SS-3	1	
SS Series Contingency	6	
Subtotal	9	
SE-1	1	
SE-2	1	
SE-3, SE-10	1	
SE-4	1	
SE-5, SE-6	1	
SE-7	1	
SE-8	1	
SE-9	1	
SE Series Contingency	16	
Subtotal	24	
Solar Tests (Continued)		
SN-1	1	
SN-2	1	
SN-3	1	
SN-4	1	
SN Series Contingency	8	
Subtotal	12	
SU-1, SU-2	1	
SU Series Contingency	2	
Subtotal	3	
ST-1.1, ST-1.2	1	
ST-2.1, ST-2.2	1	
ST-3.1, ST-3.2	1	
ST-4	1	
ST-5	1	
ST Series Contingency	10	
Subtotal	15	
SF-1	1	
SF-2	1	
SF-3	1	
SF-4	1	
SF Series Contingency	8	
Subtotal	12	
Post Test Inspection		3
Disassembly and Shipment		10
Total Estimated Time		131

*Ten day overlap.

4.10 PREDICTIONS OF TYPICAL PERFORMANCE

Anticipated BMSR operational and performance characteristics are useful references in the planning and execution of the solar tests. Typical results of these preliminary computer generated analyses are presented in this section as a general guide to the types of test data expected. Actual test data on items such as cavity flux levels, temperatures and powers will depend upon specific test conditions, including insolation levels, time of day, and heliostats in service among others.

Figure 4-4 gives a family of curves of receiver heat absorbed versus aperture power at three combinations of inlet air temperature and outlet air temperature. Total airflow rates for the receiver are also noted on the figure. Note that the minimum receiver airflow shown here is set at about 2,500 lbm/h via the BMSR control valve stops; this minimum airflow sets the minimum aperture power at which a specified receiver outlet temperature can be attained.

Figure 4-5 is similar to Figure 4-4 except that maximum silicon carbide tube temperatures are designated. Higher powers and higher air temperatures result in higher tube temperatures; the test conditions defined in this test plan should not lead to tube temperatures exceeding the 2,500 F material limit.

Figure 4-6 gives a family of curves for cavity (or receiver) efficiency versus aperture power at the different air temperatures. Airflow rates are also indicated.

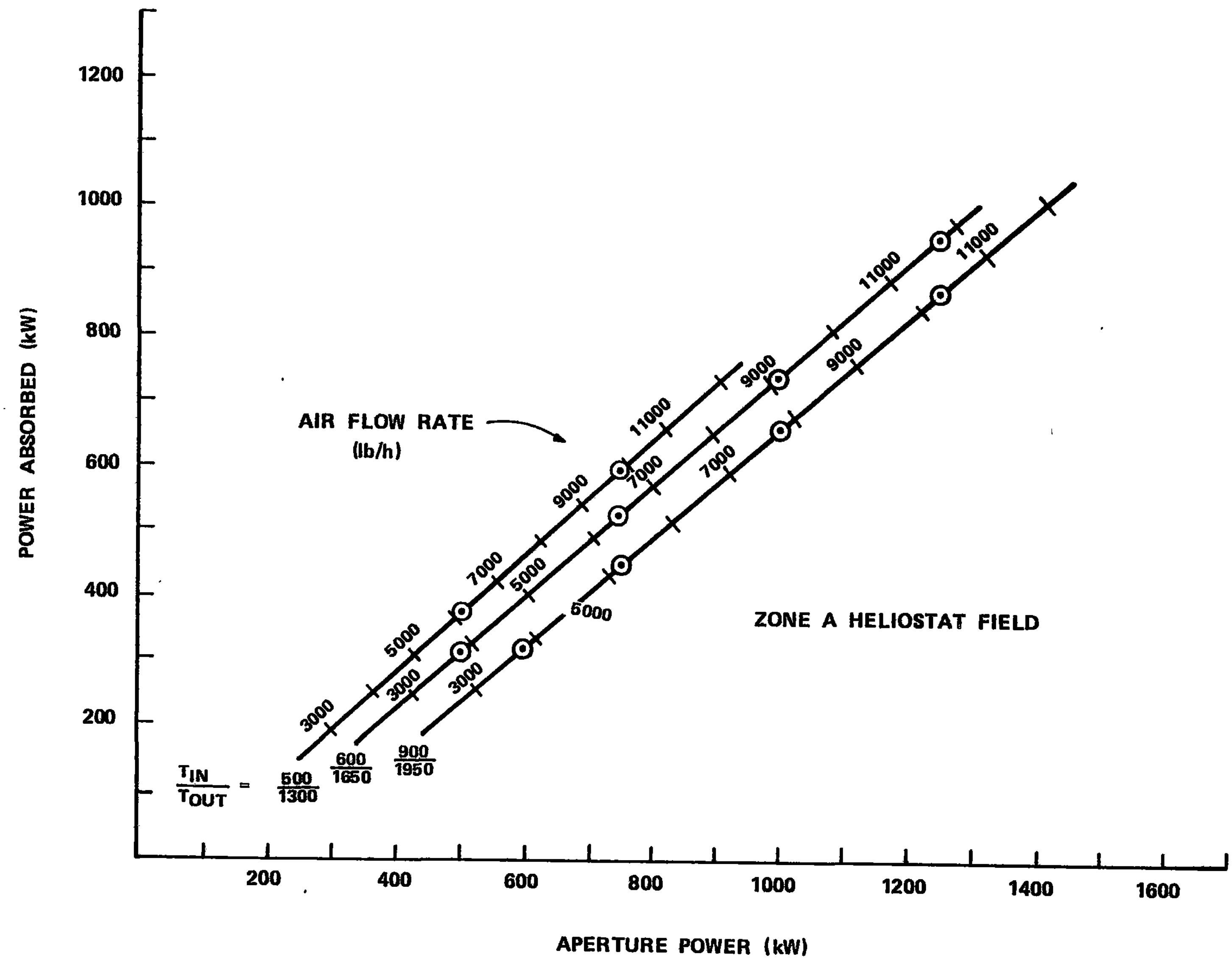

FIGURE 4-4 BMSR STEADY-STATE POWER ANALYSIS WITH AIR FLOW RATES

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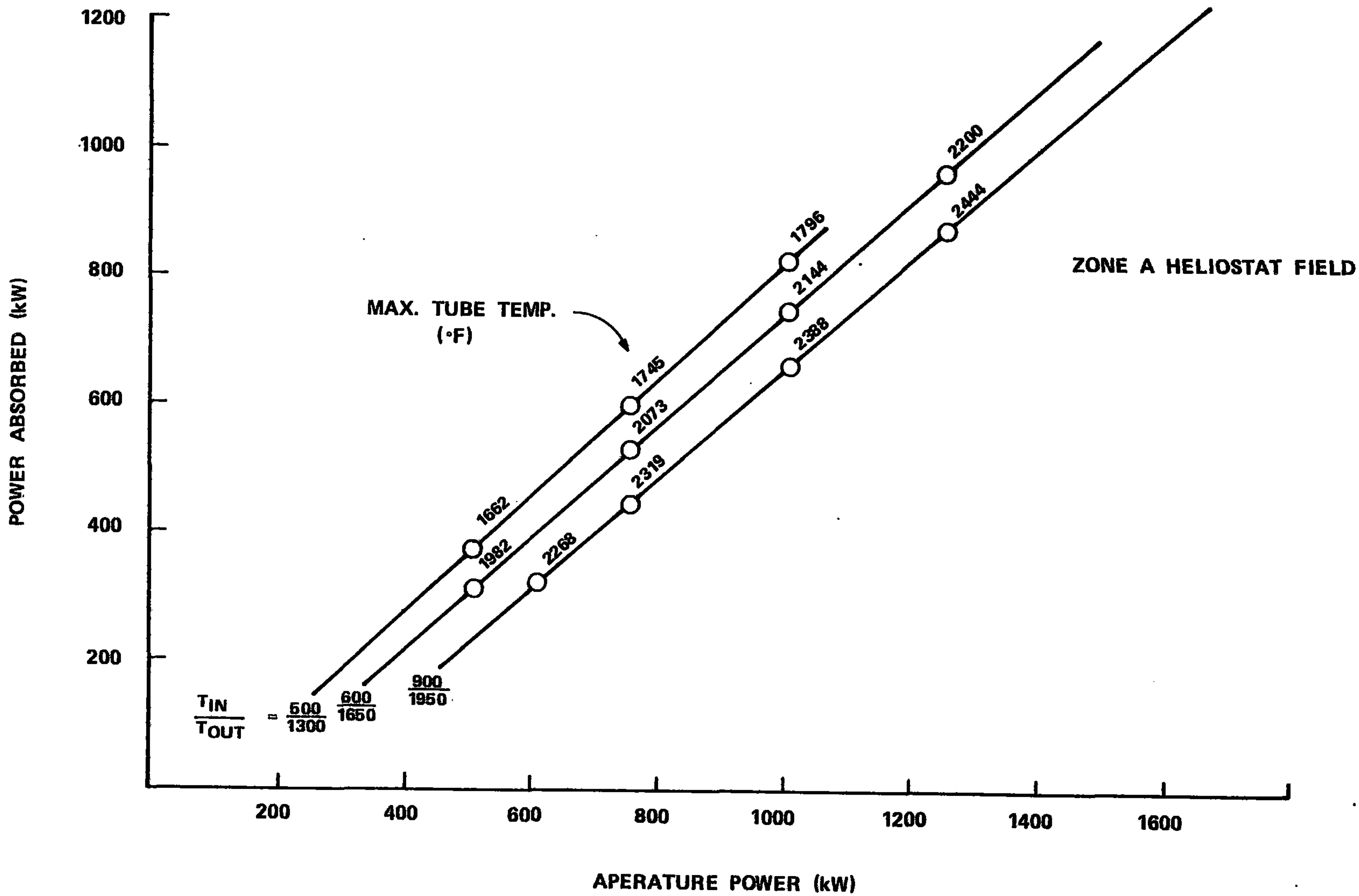


FIGURE 4-5 BMSR STEADY-STATE POWER ANALYSIS WITH TUBE TEMPERATURES

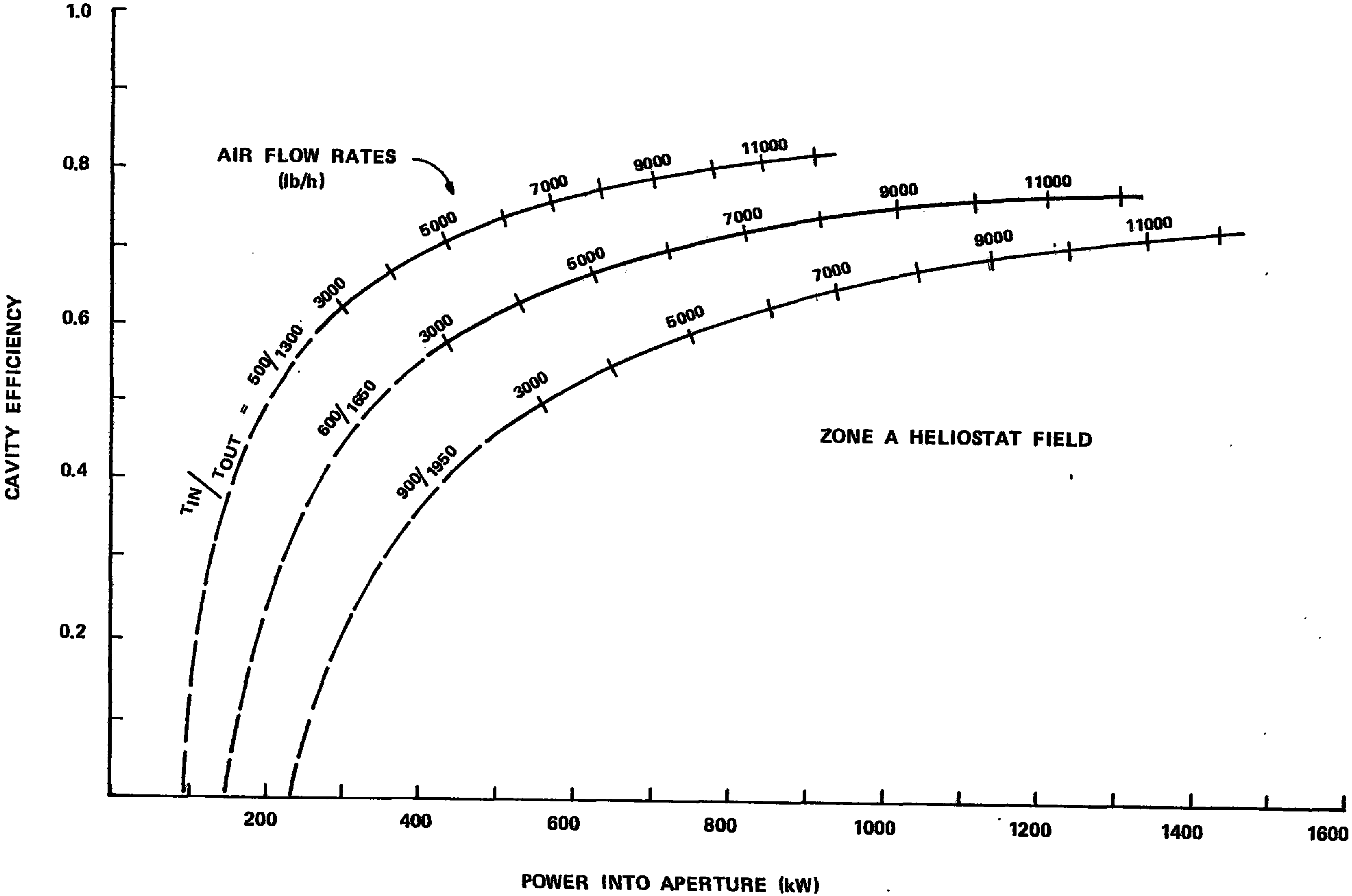


FIGURE 4-6 BMSR STEADY-STATE CAVITY EFFICIENCIES

SECTION 5.0

BMSR INSTRUMENTATION/CONTROLS DESCRIPTION

Overviews of the BMSR Instrumentation and Control Systems are given in this section of the BMSR Solar Test Plan. The BMSR Control System discussion includes a description of capabilities, requirements, and functions. Sensor types, their distribution, and use is described in the BMSR Instrumentation System overview.

5.1 BMSR CONTROL SYSTEM

The Control System is responsible for the orderly operation of the BMSR during start-up, shutdown, and testing procedures. It is also responsible for protecting the BMSR in an emergency situation. A detailed description of the BMSR Control System is given in the Control System Description (B&V Document 7341.005-A-018). Control System functional logic is defined on the B&V Control Logic Drawings (B&V Document 7341.005-A-019).

5.1.1 Capabilities and Major Components

The BMSR Control System is responsive to two basic objectives; it provides 1) orderly operation of the heat exchange process via maintenance of BMSR panel outlet air temperatures at desired values by means of modulating airflow rates with panel control valves, and 2) protection of the BMSR by incorporating fail-safe features, by detecting alarm temperature conditions, and by responding to STTF computer-generated alarm signals.

Individual panel temperature set points may be set locally at the BMSR control panel either by thumbwheel manual settings or by the primary controller, or remotely by the DAS. In addition, set point comparison logic can be bypassed and the control valve positions manually selected by control panel-mounted direct drive switches.

All important control logic parameters can be monitored by the DAS, and commands can be sent to the BMSR control panel from the DAS. These features permit operation of the BMSR either locally at the BMSR control panel or remotely through the DAS.

Air outlet temperatures are compared to "high" and "high-high" limiting values in addition to set point values. If a high-high condition is detected, the control valve for the overheated panel will automatically fully open and as an operator option, a light and buzzer will annunciate the alarm. High temperature conditions may also be annunciated, but will not trip the valves open. Control valve fail-safe features to protect the BMSR include a mechanical stop to prevent total valve closure and a fail open actuator.

In addition to the electronic components required to implement the various capabilities previously described, the BMSR control panel also houses accelerometer amplifiers, power supplies for the BMSR pressure transmitters, and terminal strips for electric signal interfaces.

5.1.2 Requirements

In order to be operational, certain BMSR Control System requirements must be met. For any operational mode, the following conditions are necessary.

- 120 VAC 60 Hz power supply connected.
- Cabling between BMSR and BMSR control panel connected.
- High and high-high temperature alarm levels adjusted.

If control is to be achieved through the DAS, additional requirements, which include the following, must be satisfied.

- Cabling between DAS and BMSR control panel connected.
- Contact closure signals (representing control-enable or alarm conditions) to the BMSR control panel from the DAS present.
- BMSR Control System internal signals monitored by DAS.
- DAS generated temperature set points to the primary or secondary controllers available at the BMSR control panel.

These requirements are detailed in the BMSR Control System Description and the BMSR Control System Operating Instructions, B&V Documents 7341.005-A-018 and 7341.005-A-022.

5.1.3 Self-Contained Functions

Within the BMSR Control System are several self-contained functions. These internal capabilities include the following.

- Conditioning of thermocouple signals.
- Control stroking of valves based upon manually-set positions or automatically-determined positions using temperature set points from remote or local sources.
- Proportional/integral comparison of panel outlet temperatures to set points.
- Comparison of thermocouple signals to high and high-high levels for warning and alarm condition detection.
- Automatic full opening of valve(s) upon detection of high-high temperature(s).
- Automatic full opening of valve(s) upon receipt of alarm condition command signal(s) from DAS.
- Automatic full opening of valves if the BMSR Control System computer watchdog relay indicates the DAS has failed.
- Annunciation (optional) of high or high-high temperatures or DAS alarm condition.
- Release valves to modulate upon receipt of signal from DAS or BMSR control panel-mounted switch.

5.1.4 Functions Supplemented by STTF Computer

The DAS computer will be the means through which control commands will be sent to the BMSR Control System when the BMSR is being operated remotely during testing at STTF. The DAS will also be used to monitor and detect certain faulted conditions; in selected alarm cases, the BMSR Control System will respond to these DAS detected conditions by opening control valve(s).

A general listing of faulted conditions monitored by the DAS includes the following.

- Failure of instrumentation system air outlet thermocouple signals or control system signals--detected by output signal comparisons.
- Airflow imbalance between panels.
- High and high-high air outlet temperatures.
- Discrepancy between total of BMSR panel airflow rates and flow rate indicated by air supply system sensors.
- Low receiver pressure drop.
- SiC tube vibration level above acceptable limit.
- Flux gage temperatures above acceptable limit.
- Low air pressure from Air Supply System.
- Various failures in STTF provided support equipment, e.g., RTAF, DAS, and Air Supply System.

In addition, the DAS will record internal signals of the BMSR Control System such that the performance and operating conditions of the system may be monitored.

5.2 BMSR INSTRUMENTATION SYSTEM

The major responsibility of the BMSR Instrumentation System is to provide necessary data for the fulfillment of test objectives. The number and variety of sensors utilized is large and includes thermocouples, pressure transmitters, flow elements, calorimeters, radiometers, heat flow transducers, strain gages, and accelerometers. Sensor signals will be routed directly to the DAS, with the exception of pressure transmitter and vibration element signals that are first conditioned within the BMSR control panel. A complete sensor listing, with information detailing sensor identification labels, input and output signal ranges, location, function, and other characteristics is given in the B&V Instrumentation and Control Data Base (B&V Document 7341.005-A-014). Other pertinent references are the B&V Instrument Location Drawings (B&V Document 7341.005-A-011), the B&V Instrument Installation Drawings (B&V Document 7341.005-A-010) and the B&V Interface Control Drawings (B&V Document 7341.005-A-030).

5.2.1 Thermocouples

Temperatures will be measured in a number of locations throughout the BMSR by a system of 85 thermocouples, including 70 Type K, seven Type B, and eight Type T. The thermocouples will be mounted on panels, ducts, headers, frames, joint pillboxes, U-bends, and within insulation and various calorimeters. In addition, a number of thermocouples will be installed in ducts and the air supply manifold to measure inlet and outlet air temperatures. Although not included within the present BMSR Instrumentation System, additional Type K thermocouples may be included in the BMSR to provide SiC tube and joint assembly temperature measurement capability.

5.2.2 Pressure Transmitters

Seven pressure transmitters will be used to sense inlet absolute pressure, differential pressure across the BMSR, and flow element output signals for the five active BMSR panels. The transmitters will be mounted on BMSR structural members in positions which allow view of each transmitter's indicating meter. Pressure tubing will connect taps in the air supply mainfold and exhaust duct, as appropriate, to the inlet absolute and differential pressure transmitters. Pressure tubing will also connect airflow primary elements, mounted in ducting leading to each active panel, to the airflow pressure transmitters. Transmitter signals will be conditioned within the BMSR control panel before routing to the DAS.

5.2.3 Calorimeters and Radiometers

Heat flux levels within the BMSR cavity will be monitored by calorimeters and radiometers which are installed on the panels, floor, and ceiling. The sensors extend through the insulation and measure either total heat flux or radiative heat flux in planes flush with the panel insulation or just inboard of the hot leg of the SiC U-tube. A total of 43 heat flux gages will be used, with all but four being calorimeters. Eight of these gages include the Type T thermocouples referenced in Subsection 5.2.1.

5.2.4 Heat Flow Gages

Conductive heat loss through the BMSR panels and ceiling will be sensed by three heat flow gages mounted on the outside shell surfaces. Two gage models, with different sensitivities and output ranges, are used.

5.2.5 Accelerometers

Two vibration elements, installed on top of U-bend spring assemblies, will give an indication of SiC tube and/or U-bend vibration. Capability for mounting the accelerometers will be provided on a number of U-bend spring assemblies so that vibration of various tubes may be monitored throughout the BMSR testing. Accelerometer signals will be conditioned in the BMSR control panel before being routed to the DAS.

5.2.6 Strain Gages

In order to determine stress and strain levels within BMSR components, strain gages will be mounted on U-bend, frame, shell, cold header, hot header, and hot duct surfaces. Twelve of the strain gages will be quarter bridge gages and the remaining 19 will be half-bridge gages. Temperature compensating and balancing resistors will be included as part of the bridge circuit for the half-bridge gages. The bridge completion network will be housed within the DAS.

SECTION 6.0

DATA REQUIREMENTS

This section of the BMSR Solar Test Plan will define, in the context of STTF Data Acquisition System (DAS) operational requirements, the data requirements associated with BMSR testing; this information generally adheres to the conceptual basis for BMSR evaluation as presented in the Data Use Strategy, B&V Document 7341.005-A-008. Sampling rates, data conversions, computations, and data displays for the BMSR Control System, the BMSR Instrumentation System, the Air Supply System, and facility systems such as the Real-Time Aperture Flux (RTAF) are defined in the pages that follow. Requirements for analog recording of test data, for data evaluation, and for data storage and retrieval are also identified.

Black & Veatch understands that all software development, programming and other preparatory work required to enable the DAS to satisfy the requirements defined in this section will be provided by STTF.

6.1 DATA SAMPLING, CONDITIONING, AND COMPUTATIONS

Data from the BMSR Control System, BMSR Instrumentation System sensors, and Air Supply System sensors will be handled by the DAS in two ways. Data will be stored, first on disc and ultimately on tape, for future evaluation. Secondly, real-time data conditioning and computations will be utilized for control purposes and for evaluation of key performance indicators. Functions of the DAS in these tasks are described in Subsections 6.1.1 through 6.1.7.

- 6.1.1--Control System. This section lists BMSR Control System signals, both DAS command and DAS monitoring, along with data sampling intervals, a specification of the conversion to engineering units required, and a reference to warnings/alarms, displays, and computations in which the data is used.

- 6.1.2--Instrumentation System. Similar to Subsection 6.1.1 in approach, but for BMSR Instrumentation System signals.
- 6.1.3--Air Supply System. Similar to Subsection 6.1.1 in approach, but for Air Supply System signals.
- 6.1.4--STTF Support System. Designates measurements and computations to be provided by STTF.
- 6.1.5--Engineering Unit Conversions. The basis for converting sensor signals to engineering units is defined.
- 6.1.6--Computations. A list tabulates BMSR computations, computation intervals, warnings/alarms, and displays. Computations are defined by equations, with input variables identified.
- 6.1.7--Warnings and Alarms. A tabulation of warning and alarm conditions, the computational methods for sensing these conditions, and appropriate actions to be taken is provided.

6.1.1 Control System

The BMSR Control System, described in Section 5.1, will interface with the STTF DAS both through monitoring of the Control System by the DAS and through commands sent to the Control System by the DAS. Control System signals (the CS-_____ series) are defined in the BMSR Instrumentation and Control Data Base, B&V Document 7341.005-A-014. Control System signals, along with sampling intervals and designations of conversions, warnings/alarms, displays, and computations are listed in Table 6-1. Those signals that are DAS-generated command signals to the BMSR Control System are also characterized in Table 6-2, in addition to their initial listing in Table 6-1.

NOTE: BMSR Control System signals with an MP designator, i.e., CS-MP___, are DAS monitors of BMSR Control System signals; those with a KP designator are DAS command signals to the Control System. Command signals are more fully described in Table 6-2, following their initial listing in Table 6-1.

TABLE 6-1. BMSR CONTROL SYSTEM SIGNALS

Data[a] Channel	Sampling[b,c] Interval (sec)	Engineering Units				
		Conversion[d]/ Command	Interval[e] (sec)	Warning[f]/ Alarm	Displays[g]	Computations[h]
CS-MP001	15	C18	15	--	D1	--
CS-KP002	†	C19	--	--	D9	--
CS-MP004	120	C18	120	--	D2	--
CS-MP005	5	C18	5	W12, A12, A13	D1	--
CS-MP006	10	C18	10	--	--	--
CS-KP007	†	††	--	--	--	--
CS-KP008	†	††	--	--	--	--
CS-KP009	†	††	--	--	--	--
CS-KP010	†	††	--	--	--	--
CS-KP011	†	C19	--	--	--	--
CS-MP012	120	C18	120	--	D2	--
CS-MP013	5	C18	5	W12, A12 A13	D1	--
CS-MP014	5	C20	5	--	D1, D2	--
CS-KP015	†	††	--	--	D9	--
CS-KP017	†	C19	--	--	D9	--
CS-MP018	120	C18	120	--	D2	--
CS-MP019	5	C18	5	W12, A12 A13	D1	--

TABLE 6-1 (Continued). BMSR CONTROL SYSTEM SIGNALS

Data[a] Channel	Sampling[b,c] Interval (sec)	Engineering Units Conversion[d]/ Command	Interval[e] (sec)	Warning[f]/ Alarm	Displays[g]	Computations[h]
CS-MP020	5	C20	5	--	D1, D2	--
CS-KP021	†	††	--	--	D9	--
CS-KP023	†	C19	--	--	D9	--
CS-MP024	120	C18	120	--	D2	--
CS-MP025	5	C18	5	W12, A12, A13	D1	--
CS-MP026	5	C20	5	--	D1, D2	--
CS-KP027	†	††	--	--	D9	--
CS-KP029	†	C19	--	--	D9	--
CS-MP030	120	C18	120	--	D2	--
CS-MP031	5	C18	5	W12, A12, A13	D1	--
CS-MP032	5	C20	5	--	D1, D2	--
CS-KP033	†	††	--	--	D9	--
CS-KP035	†	C19	--	--	D9	--
CS-MP036	120	C18	120	--	D2	--
CS-MP037	5	C18	5	W12, A12, A13	D1	--
CS-MP038	5	C20	5	--	D1, D2	--
CS-MP039	5	C21	5	--	--	--

TABLE 6-1 (Continued). BMSR CONTROL SYSTEM SIGNALS

Data Channel[a]	Sampling Interval (sec)[b,c]	Engineering Units: Conversion/ Command[d]	Engineering Units: Interval (sec)[e]	Engineering Units: Warning/ Alarm[f]	Engineering Units: Displays[g]	Engineering Units: Computations[h]
CS-MP040	5	C21	5	--	--	--
CS-KP041	†	††	--	--	--	--
CS-KP042	†	††	--	--	--	--

[a]Labels are defined in the BMSR Instrumentation and Control Data Base, B&V Document 7341-005-A-014. The coding method for data channel labels is presented in Section 10.5 of the BMSR Data Package.

[b]For those BMSR Control System data channels containing information to be sampled and stored by the DAS (indicated under Data Channel as CS-MP___), the sampling interval is recorded.

[c]For those BMSR Control System data channels containing command information from the DAS (indicated Data Channel as CS-KP___), the "sampling interval" title is not strictly applicable; entries of this type are shown as "†". In these cases, the DAS is generating a command signal rather than monitoring a signal that originates in the BMSR system. Command signals should be "sampled" (stored) each time they are transmitted to the BMSR Control System. Command signal characteristics and requirements are defined on Table 6-2.

[d]Algorithms and/or calibration curves for data conversions are designated by indicated reference labels; conversion techniques corresponding to these labels are described in Subsection 6.1.5, Engineering Unit Conversions. The necessary conversion takes place immediately. Command signals involving contact opening or closure are designated by " ". Refer to Table 6-2 for specific requirements for each command signal.

[e]Update time interval for conversion of data to engineering units in real-time.

[f]Warning and Alarm evaluations, for which the data are input variables, are indicated by the reference label. These are described in Subsection 6.1.7.

TABLE 6-1 (Continued). BMSR CONTROL SYSTEM SIGNALS

[g]Data displays, in which the engineering units data are displayed, are indicated by the reference label. The displays are defined in Section 6.2.

[h]Computations described in Subsection 6.1.6, in which the converted data is an input variable, are indicated by computation labels.

†See Footnote c

††See Footnote d

TABLE 6-2. DEFINITION OF BMSR CONTROL SYSTEM COMMAND (CS-KP___) SIGNALS

CS-KP002: Primary Controller Computer Set Point. Operator enters BMSR Control System set point temperature (100-2,100 F) from control terminal/CRT; DAS converts this set point temperature to a constant, uninterruptable 4-20 MA dc signal transmitted to the BMSR Control Panel using conversion relationship C19. Pulses or pauses in this analog set point signal are not acceptable.

CS-KP007: Release Control Valve to Modulate. Operator enters command from control terminal/CRT. DAS supplies a normally open relay contact which, on RELEASE command from the operator, is momentarily closed (2 to 6 seconds).

NOTE: DAS-provided contacts will be subjected to ± 15 vdc (30 v total) differential across the contacts; open contact impedance shall not be less than 100,000 ohms; closed contact impedance shall not exceed 1,000 ohms.

CS-KP008: Computer Set Point Selected by All Secondary Controllers. Operator can send this command, via the control terminal/CRT, which closes this DAS-provided, normally open contact. An open contact results in the secondary controllers, when they are operating in the automatic, remote set point mode, deriving their set points from the primary controller. A closed contact results in all the secondary controllers individually deriving their set points from the computer, e.g., CS-KP011.

NOTE: See CS-KP007 for contact specification.

CS-KP009: Panel B-DAS Calculated Alarm Condition. Transmission of this signal to the BMSR Control System by the DAS causes the Panel B control valve to open fully. The signal is transmitted upon calculation of specified alarm conditions (Subsection 6.1.7). This is a normally open contact in the BMSR Control System which the DAS must maintain closed in order for the BMSR Control System to modulate Panel B airflow (normal operation); activating the alarm sequence results in opening the contact. The contact should close automatically when the alarm condition vanishes (the operator must use the RELEASE, CS-KP007, to resume valve modulation of airflow).

NOTE: See CS-KP007 for contact specification.

CS-KP010: DAS Computer Watchdog. The BMSR Control System monitors the computer operational status by means of this normally open contact. Computer must maintain the contact closed for normal BMSR Control System operation. A time delay contact is suggested to avoid inadvertent shutdown.

NOTE: See CS-KP007 for contact specification.

CS-KP011: Panel B Computer Set Point. Same as CS-KP002, except for Panel B secondary controller only.

CS-KP015: Panel C DAS Calculated Alarm Condition. Same as CS-KP009, except for Panel C.

CS-KP017: Panel C Computer Set Point. Similar to CS-KP011.

CS-KP021: Panel D DAS Calculated Alarm Condition. Similar to CS-KP009.

CS-KP023: Panel D Computer Set Point. Similar to CS-KP011.

CS-KP027: Panel E DAS Calculated Alarm Condition. Similar to CS-KP009.

CS-KP029: Panel E Computer Set Point. Similar to CS-KP011.

CS-KP033: Panel F DAS Calculated Alarm Condition. Similar to CS-KP009.

CS-KP035: Panel F Computer Set Point. Similar to CS-KP011.

CS-KP041: DAS Calculated Alarm Condition--Any Panel. This is a normally closed contact; the DAS must maintain it closed for normal BMSR Control System operation. This contact is to open for specified DAS-calculated alarm conditions, and to remain open for the duration of the alarm condition. Opening this contact activates BMSR Control System Annunciator Panel.

NOTE: See CS-KP007 for contact specification.

CS-KP042: Manual Emergency Override Push Button Contact Opening. These are two normally closed STTF-provided contacts connected in series, one activated via a DAS push button on the control terminal/CRT, the other being a manually operated switch. Contact opening in either case results in opening of BMSR control valves. These contacts should re-close upon release of the DAS push button or closing of the manual switch by the operator. Modulating of airflow by valves will resume after operator use of RELEASE, CS-KP007.

NOTE: See CS-KP007 for contact specification.

References:

- The B&V Instrumentation and Control Data Base, B&V Document 7341.005-A-014, provides a supplemental history of these signals.
- The interaction of these signals with the BMSR Control System may be found on the B&V Control Logic and Interface Drawings K6004, K6005, K6007, and K6011.

6.1.2 Instrumentation System

The BMSR Instrumentation System, described in Section 5.2, is used both in performance evaluation and in evaluation for control purposes. Sensors, along with conversion, warning/alarm, display, and computation references are listed in Table 6-3.

TABLE 6-3. BMSR INSTRUMENTATION SYSTEM SIGNALS

Data Channel[a]	Sampling Interval (sec)	Engineering Units				Computations[f]
		Conversion[b]	Interval[c] (sec)	Warning[d]/ Alarm	Displays[e]	
HF-CA001	15	C14	15	--	D3, D7	QRR, HFMW
HF-CA002	15	C14	15	--	D3, D7	QRR, HFMW
HF-CA003	15	C14	15	--	D3, D7	QRR, KFACN, HFMW
HF-CA004	15	C14	15	--	D3, D7	QRR, KFACN, HFMW
HF-CA005	15	C14	15	--	D3, D7	HFMW, TCAVI

[a]Labels are defined in the BMSR Instrumentation and Control Data Base, B&V Document 7341.005-A-014. The coding method for data channel labels is presented in Section 10.5 of the BMSR Data Package.

[b]Algorithms and/or calibration curves for data conversion to engineering units are designated by indicated reference labels; conversion techniques corresponding to these labels are described in Subsection 6.1.5, Engineering Unit Conversions.

[c]Update time interval for conversion of data to engineering units in real-time.

[d]Warning and Alarm evaluations, described in Subsection 6.1.7 for which the data are input variables, are indicated by the reference label.

[e]Data displays in which the engineering units data are displayed, are indicated by the reference label. The displays are defined in Section 6.2.

[f]Computations, described in Subsection 6.1.6, in which the converted data is an input variable, are indicated by computation labels.

*Provision for thermocouples to measure ceramic material temperatures have been included in the system design. However these thermocouples are not currently included in the BMSR.

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data Channel[a]	Sampling Interval (sec)	Engineering Units Conversion[b]	Engineering Units Interval[c] (sec)	Engineering Units Warning[d]/Alarm	Displays[e]	Computations[f]
HF-CB006	15	C14	15	--	D7	IHFI, HFMW
HF-CB007	15	C14	15	--	D7	KFACN, IHFI, HFMW
HF-CB008	15	C14	15	--	D7	IHFI, HFMW
HF-CB009	15	C14	15	--	D7	IHFI, HFMW
HF-CB010	15	C14	15	--	D7	IHFI, HFMW, TSCI, TCAVI
HF-CC011	15	C14	15	--	D7	IHFI, HFMW
HF-CC012	15	C14	15	--	D7	KFACN, IHFI, HFMW
HF-CC013	15	C14	15	--	D7	IHFI, HFMW, TSCI, TCAVI
HF-CD014	15	C14	15	--	D7	IHFI, HFMW
HF-CD015	15	C14	15	--	D7	KFACN, IHFI, HFMW
HF-CD016	15	C14	15	--	D7	IHFI, HFMW, TSCI, TCAVI
HF-CE017	15	C14	15	--	D7	IHFI, HFMW
HF-CE018	15	C14	15	--	D7	KFACN, IHFI, HFMW
HF-CE019	15	C14	15	--	D7	IHFI, HFMW, TSCI, TCAVI

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data Channel[a]	Sampling Interval (sec)	Engineering Units Conversion[b]	Engineering Units Interval[c] (sec)	Engineering Units Warning[d]/ Alarm	Displays[e]	Computations[f]
HF-CE020	15	C14	15	--	D7	IHFI, HFMW
HF-CE021	15	C14	15	--	D7	IHFI, HFMW
HF-CF022	15	C14	15	--	D7	IHFI, HFMW
HF-CF023	15	C14	15	--	D7	KFACN, IHFI, HFMW
HF-CF024	15	C14	15	--	D7	IHFI, HFMW, TSCI, TCAVI
HF-CH025	15	C14	15	--	D3, D7	HFMC
HF-CH026	15	C14	15	--	D3, D7	HFMC
HF-CH027	15	C14	15	--	D3, D7	HFMC
HF-CH028	15	C14	15	--	D3, D7	HFMC
HF-CH029	15	C14	15	--	D3, D7	HFMC, TCAVI
HF-CG030	15	C14	15	--	D3, D7	HFMW
HF-CG031	15	C14	15	--	D3, D7	HFMW, TCAVI
HF-CG032	15	C14	15	--	D3, D7	HFMW
HF-CG033	15	C14	15	--	D3, D7	HFMW
HF-CC034	15	C14	15	--	D7	KFACN, HFMW
HF-CD035	15	C14	15	--	D7	KFACN, HFMW
HF-CE036	15	C14	15	--	D7	KFACN, HFMW
HF-CG037	15	C14	15	--	D7	HFMW

A-029
031279

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data Channel[a]	Sampling Interval (sec)	Engineering Units: Conversion[b]	Engineering Units: Interval[c] (sec)	Engineering Units: Warning[d]/Alarm	Engineering Units: Displays[e]	Computations[f]
HF-CA038	15	C14	15	--	D7	HFMW
HF-CB039	15	C14	15	--	D7	HFMW
HF-CF040	15	C14	15	--	D7	HFMW
HF-CD041	15	C14	15	--	D7	HFMW
HF-CD042	15	C14	15	--	D7	HFMW
HF-SB043	120	C15	120	--	D7	--
HF-SC044	120	C15	120	--	D7	--
HF-SH045	120	C15	120	--	D7	--
HF-CA046	15	C14	15	--	D7	--
HF-CX047	(Spare)	C14	--	--	--	--
HF-CX048	(Spare)	C14	--	--	--	--
HF-CX049	(Spare)	C14	--	--	--	--
HF-CX050	(Spare)	C14	--	--	--	--
HF-CX051	(Spare)	C14	--	--	--	--
PT-AB001	5	C7	5	W8, A8	D1	MN
PT-AC002	5	C7	5	W8, A8	D1	MN
PT-AD003	5	C7	5	W8, A8	D1	MN
PT-AE004	5	C7	5	W8, A8	D1	MN
PT-AF005	5	C7	5	W8, A8	D1	MN

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data Channel[a]	Sampling Interval (sec)	Engineering Units: Conversion[b]	Engineering Units: Interval[c] (sec)	Engineering Units: Warning[d]/Alarm	Engineering Units: Displays[e]	Computations[f]
PT-AR006	5	C8	5	W3, A3	D1, D2	MN
PT-AR007	5	C9	5	W4, A4	D1, D2	--
SG-UC001	10	C11	10	--	D6	--
SG-UC002	10	C11	10	--	D6	--
SG-UC003	10	C11	10	--	D6	--
SG-FD004	120	C12	120	--	D6	SMAX
SG-FD005	120	C12	120	--	D6	SMAX
SG-FD006	120	C12	120	--	D6	SMAX
SG-FD007	120	C12	120	--	D6	SMAX
SG-FD008	120	C12	120	--	D6	SMAX
SG-FD009	120	C12	120	--	D6	SMAX
SG-FD010	120	C12	120	--	D6	SMAX
SG-FD011	120	C12	120	--	D6	SMAX
SG-FD012	120	C12	120	--	D6	SMAX
SG-AD017	120	C13	120	--	D6	SMAX
SG-AD018	120	C13	120	--	D6	SMAX
SG-AD019	120	C13	120	--	D6	SMAX
SG-AD020	120	C13	120	--	D6	SMAX
SG-AD021	120	C13	120	--	D6	SMAX

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data[a] Channel	Sampling Interval (sec)	Engineering Units Conversion[b]	Interval[c] (sec)	Warning[d]/ Alarm	Displays[e]	Computations[f]
SG-AD022	120	C13	120	--	D6	SMAX
SG-HD023	120	C13	120	--	D6	SMAX
SG-HD024	120	C13	120	--	D6	SMAX
SG-HD025	120	C13	120	--	D6	SMAX
SG-HD026	120	C13	120	--	D6	SMAX
SG-HD027	120	C13	120	--	D6	SMAX
SG-HD028	120	C13	120	--	D6	SMAX
SG-HD029	120	C13	120	--	D6	SMAX
SG-HD030	120	C13	120	--	D6	SMAX
SG-HD031	120	C13	120	--	D6	SMAX
SG-HD032	120	C13	120	--	D6	SMAX
SG-DD033	120	C13	120	--	D6	SMAX
SG-DD034	120	C13	120	--	D6	SMAX
SG-DD035	120	C13	120	--	D6	SMAX
SG-UX036	(Spare)	C11	--	--	--	--
SG-UX037	(Spare)	C11	--	--	--	--
SG-UX038	(Spare)	C11	--	--	--	--
SG-FX039	(Spare)	C12	--	--	--	--
SG-FX040	(Spare)	C12	--	--	--	--

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data Channel[a]	Sampling Interval (sec)	Engineering Units				Computations[f]
		Conversion[b]	Interval[c] (sec)	Warning[d]/ Alarm	Displays[e]	
SG-FX041	(Spare)	C12	--	--	--	--
SG-DX042	(Spare)	C13	--	--	--	--
SG-DX043	(Spare)	C13	--	--	--	--
SG-DX044	(Spare)	C13	--	--	--	--
TE-AE001	Converted to control signal CS-MP001 - See Subsection 6.1.1.					
TE-AC002	5	C3	5	W2, A2	D1, D2, D8	MN, QN, QR
TE-DB003	5	C4	5	W1, A1, W12, A12, A13	D1, D2, D3, D8	QN
TE-DC004	5	C4	5	W1, A1, A12, A13	D1, D2, D3, D8	QN
TE-DD005	5	C4	5	W1, A1, W12, A12, A13	D1, D2, D3, D8	QN
TE-DE006	5	C4	5	W1, A1, W12, A12, A13	D1, D2, D3, D8	QN
TE-DF007	5	C4	5	W1, A1, W12, A12, A13	D1, D2, D3, D8	QN
TE-DR008	5	C4	5	W12, A12, A13	D1, D2, D3	QR

A-029
031279

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data[a] Channel	Sampling Interval (sec)	Engineering Units: Conversion[b]	Engineering Units: Interval[c] (sec)	Engineering Units: Warning[d]/ Alarm	Engineering Units: Displays[e]	Computations[f]
TE-IA009	120	C6	120	--	D5	--
TE-IB010	120	C6	120	--	D5	--
TE-IC011	120	C6	120	--	D5	--
TE-ID012	120	C6	120	--	D5	--
TE-IE013	120	C6	120	--	D5	--
TE-IF014	120	C6	120	--	D5	--
TE-IH015	120	C6	120	--	D5	--
TE-TC017*	--	C5	--	--	--	--
TE-TC018*	--	C5	--	--	--	--
TE-TC019*	--	C5	--	--	--	--
TE-TC020*	--	C5	--	--	--	--
TE-TC021*	--	C5	--	--	--	--
TE-TC022*	--	C5	--	--	--	--
TE-TC023*	--	C5	--	--	--	--
TE-TC024*	--	C5	--	--	--	--
TE-TC025*	--	C5	--	--	--	--
TE-TC026*	--	C5	--	--	--	--
TE-TC027*	--	C5	--	--	--	--
TE-TC028*	--	C5	--	--	--	--

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data[a] Channel	Sampling Interval (sec)	Engineering Units				
		Conversion[b]	Interval[c] (sec)	Warning[d]/ Alarm	Displays[e]	Computations[f]
TE-TC029*	--	C5	--	--	--	--
TE-TC030*	--	C5	--	--	--	--
TE-TC031*	--	C5	--	--	--	--
TE-TC032*	--	C5	--	--	--	--
TE-UB033	15	C4	15	--	D3, D8	TUBMAX
TE-UB034	15	C4	15	--	D3, D8	TUBMAX
TE-UB035	15	C4	15	--	D3, D8	TUBMAX
TE-UB036	15	C4	15	--	D3, D8	TUBMAX
TE-UC037	15	C4	15	--	D3, D8	TUBMAX
TE-UD038	15	C4	15	--	D3, D8	TUBMAX
TE-UE039	15	C4	15	--	D3, D8	TUBMAX
TE-UE040	15	C4	15	--	D3, D8	TUBMAX
TE-UE041	15	C4	15	--	D3, D8	TUBMAX
TE-UE042	15	C4	15	--	D3, D8	TUBMAX
TE-UF043	15	C4	15	--	D3, D8	TUBMAX
TE-JD044*	--	C5	--	--	--	--
TE-JD045*	--	C5	--	--	--	--
TE-JD046*	--	C5	--	--	--	--
TE-JD047*	--	C5	--	--	--	--

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data[a] Channel	Sampling Interval (sec)	Engineering Units				Computations[f]
		Conversion[b]	Interval[c] (sec)	Warning[d]/ Alarm	Displays[e]	
TE-JD048*	--	C5	--	--	--	--
TE-JD049*	--	C5	--	--	--	--
TE-JD050*	--	C5	--	--	--	--
TE-JD051*	--	C5	--	--	--	--
TE-JD052*	--	C5	--	--	--	--
TE-JD053*	--	C5	--	--	--	--
TE-JD054*	--	C5	--	--	--	--
TE-JD055*	--	C5	--	--	--	--
TE-JD056	60	C4	60	--	D4	TPBMAX
TE-JD057	60	C4	60	--	D4	TPBMAX
TE-JD058	60	C4	60	--	D4	TPBMAX
TE-JD059	60	C4	60	--	D4	TPBMAX
TE-JD060	60	C4	60	--	D4	TPBMAX
TE-JD061	60	C4	60	--	D4	TPBMAX
TE-HD062	60	C3	60	--	D4	THDMAX
TE-HD063	60	C3	60	--	D4	THDMAX
TE-HD064	60	C3	60	--	D4	THDMAX
TE-HD065	60	C3	60	--	D4	THDMAX
TE-HD066	60	C3	60	--	D4	THDMAX

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data[a] Channel	Sampling Interval (sec)	Engineering Units				
		Conversion[b]	Interval[c] (sec)	Warning[d]/ Alarm	Displays[e]	Computations[f]
TE-HD067	60	C3	60	--	D4	THDMAX
TE-HD068	60	C3	60	--	D4	THDMAX
TE-HD069	60	C3	60	--	D4	THDMAX
TE-HD070	60	C3	60	--	D4	THDMAX
TE-HD071	60	C3	60	--	D4	THDMAX
TE-DD072	60	C3	60	--	D4	THDMAX
TE-DD073	60	C3	60	--	D4	THDMAX
TE-DD074	60	C3	60	--	D4	THDMAX
TE-DD075	60	C3	60	--	D4	THDMAX
TE-DD076	60	C3	60	--	D4	THDMAX
TE-DD077	60	C3	60	--	D4	THDMAX
TE-ZG078	120	C3	120	--	D4	--
TE-ZG079	120	C3	120	--	D4	--
TE-ZG080	120	C3	120	--	D4	--
TE-SA081	120	C1	120	--	D5	TSFMAX
TE-SB082	120	C1	120	--	D5	TSFMAX
TE-SB083	120	C1	120	--	D5	TSFMAX
TE-SC084	120	C1	120	--	D5	TSFMAX
TE-SC085	120	C1	120	--	D5	TSFMAX

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data[a] Channel	Sampling Interval (sec)	Engineering Units Conversion[b]	Interval[c] (sec)	Warning[d]/ Alarm	Displays[e]	Computations[f]
TE-SD086	120	C1	120	--	D5	TSFMAX
TE-SD087	120	C1	120	--	D5	TSFMAX
TE-SE088	120	C1	120	--	D5	TSFMAX
TE-SE089	120	C1	120	--	D5	TSFMAX
TE-SF090	120	C1	120	--	D5	TSFMAX
TE-SF091	120	C1	120	--	D5	TSFMAX
TE-SH092	120	C1	120	--	D5	TSFMAX
TE-FG093	120	C3	120	--	D4	TSFMAX
TE-FG094	120	C3	120	--	D4	TSFMAX
TE-FG095	120	C3	120	--	D4	TSFMAX
TE-FG096	120	C3	120	--	D4, D5	TSFMAX
TE-FD097	120	C3	120	--	D5	TSFMAX
TE-FD098	120	C3	120	--	D5	TSFMAX
TE-FD099	120	C3	120	--	D5	TSFMAX
TE-FD100	120	C3	120	--	D5	TSFMAX
TE-FD101	120	C3	120	--	D5	TSFMAX
TE-FD102	120	C2	120	--	D5	TSFMAX
TE-IB103	120	C4	120	--	D5	--
TE-IB104	120	C3	120	--	D5	--

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data[a] Channel	Sampling Interval (sec)	Engineering Units: Conversion[b]	Engineering Units: Interval[c] (sec)	Engineering Units: Warning[d]/ Alarm	Engineering Units: Displays[e]	Engineering Units: Computations[f]
TE-IC105	120	C4	120	--	D5	--
TE-IC106	120	C3	120	--	D5	--
TE-DB107	Converted to control signals		CS-MP013	See Subsection 6.1.1		
TE-DC108			CS-MP019			
TE-DD109			CS-MP025			
TE-DE110			CS-MP031			
TE-DF111			CS-MP037			
TE-DR112			CS-MP005			
TE-FD113	120	C2	120	--	D5	TSFMAX
TE-DB114	(Backup)	C4	--	--	--	--
TE-DC115	(Backup)	C4	--	--	--	--
TE-DD116	(Backup)	C4	--	--	--	--
TE-DE117	(Backup)	C4	--	--	--	--
TE-DF118	(Backup)	C4	--	--	--	--
TE-GB119	10	C16	10	W7, A7	D7	TCMAX
TE-GB120	10	C16	10	W7, A7	D7	TCMAX
TE-GD121	10	C16	10	W7, A7	D7	TCMAX
TE-GE122	10	C16	10	W7, A7	D7	TCMAX
TE-GE123	10	C16	10	W7, A7	D7	TCMAX

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

Data[a] Channel	Sampling Interval (sec)	Engineering Units				
		Conversion[b]	Interval[c] (sec)	Warning[d]/ Alarm	Displays[e]	Computations[f]
TE-GD124	10	C16	10	W7, A7	D7	TCMAX
TE-GE125	10	C16	10	W7, A7	D7	TCMAX
TE-GH126	10	C16	10	W7, A7	D7	TCMAX
TE-UX127	(Spare)	C4	--	--	--	--
TE-UX128	(Spare)	C4	--	--	--	--
TE-UX129	(Spare)	C4	--	--	--	--
TE-JX130	(Spare)	C4	--	--	--	--
TE-JX131	(Spare)	C4	--	--	--	--
TE-DX132	(Spare)	C4	--	--	--	--
TE-DX133	(Spare)	C4	--	--	--	--
TE-DX134	(Spare)	C4	--	--	--	--
TE-SX135	(Spare)	C4	--	--	--	--
TE-SC136	(Spare)	C1	--	--	--	--
TE-SX137	(Spare)	C1	--	--	--	--
TE-ZX138	(Spare)	C3	--	--	--	--
TE-DX139	(Spare)	C2	--	--	--	--
TE-DX140	(Spare)	C2	--	--	--	--
TE-DX141	(Spare)	C2	--	--	--	--
TE-DX142	(Spare)	C2	--	--	--	--

TABLE 6-3 (Continued). BMSR INSTRUMENTATION SYSTEM SIGNALS

		Engineering Units				
Data[a] Channel	Sampling Interval (sec)	Conversion[b]	Interval[c] (sec)	Warning[d]/ Alarm	Displays[e]	Computations[f]
TE-DX143	(Spare)	C2	--	--	--	--
TE-DX144	(Spare)	C2	--	--	--	--
TE-DX145	(Spare)	C2	--	--	--	--
TE-DX146	(Spare)	C2	--	--	--	--
TE-DX147	(Spare)	C2	--	--	--	--
TE-QX148	--	--	--	--	--	--
TE-QX149	--	--	--	--	--	--
TE-QX150	--	--	--	--	--	--
TE-QX151	--	--	--	--	--	--
TE-DX152	(Spare)	C2	--	--	--	--
TE-QX153	--	--	--	--	--	--
TE-QX154	--	--	--	--	--	--
TE-GX155	(Spare)	C16	--	--	--	--
TE-GX156	(Spare)	C16	--	--	--	--
TE-GX157	(Spare)	C16	--	--	--	--
VT-UD001	10	C10	10	W9, A9	D8	VIMAX
VT-UD002	10	C10	10	W9, A9	D8	VIMAX

6.1.3 Air Supply System

Evaluation of Air Supply System data is necessary for control of the air supply and is valuable as a means of cross-checking BMSR Instrumentation System and BMSR Control System measurements. Table 6-4 lists Air Supply System sensors, along with associated sampling intervals, conversions, warnings/alarms, displays, and computations. A flow diagram of the Air Supply System including sensors and their data channel labels, may be found on Figure 6-1.

NOTE: Air Supply System command signals include digital to analog conversions of DAS computer set points and contact closures in accordance with the Boeing Company's "Data Package - Air Supply System for 1 MW_{th} Bench Model Solar Receiver," EPRI Contract No. RP 1092-1.

TABLE 6-4. AIR SUPPLY SYSTEM SIGNALS

Data Channel[a]	Sampling Interval (sec)	Engineering Units: Conversion[b]	Engineering Units: Interval[c] (sec)	Engineering Units: Warning[d]/Alarm	Engineering Units: Displays[e]	Computations[f]
AS-001	15	C1	15	--	D2	MAS1, MAS2
AS-002	15	C3	15	--	D1	--
AS-003	15	C4	15	--	D1	--
AS-004	5	C4	5	W10, A10	D1, D2	--
AS-005	15	C2	15	--	D2	--

[a] Labels are defined on Figure 6-1, Air Supply System Schematic.

[b] Algorithms and/or calibration curves for data conversion to engineering units are designated by indicated reference labels; conversion techniques corresponding to these labels are described in Subsection 6.1.5, Engineering Unit Conversions.

[c] Update time interval for conversion of data to engineering units in real-time.

[d] Warning and Alarm evaluations described in Subsection 6.1.7, for which the data are input variables, are indicated by the reference label.

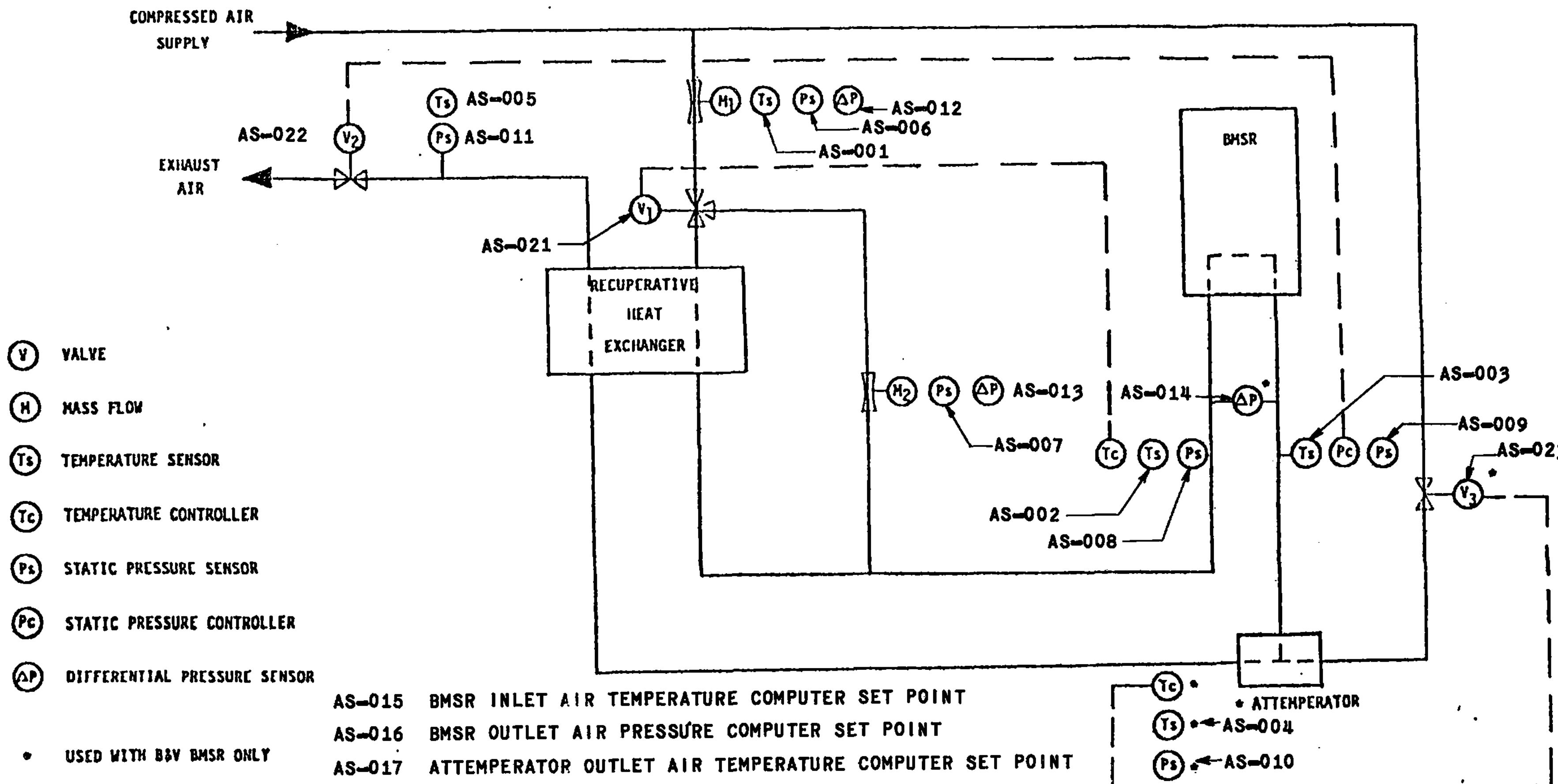
[e] Data displays in which the engineering units data are displayed, are indicated by reference label. The displays are defined in Section 6.2.

[f] Computations, described in Subsection 6.1.6, in which the converted data is an input variable, are indicated by computation labels.

TABLE 6-4 (Continued). AIR SUPPLY SYSTEM SIGNALS

		Engineering Units				
Data[a] Channel	Sampling Interval (sec)	Conversion[b]	Interval[c] (sec)	Warning[d]/ Alarm	Displays[e]	Computations[f]
AS-006	15	C17	15	--	--	MAS1
AS-007	15	C17	15	--	--	MAS2
AS-008	15	C17	5	--	D1	--
AS-009	15	C17	5	--	D2	--
AS-010	15	C17	15	--	D2	--
AS-011	15	C17	15	--	D2	--
AS-012	5	C17	5	W5, A5, W6, A6	D1	MAS1
AS-013	15	C17	15	--	--	MAS2
AS-014	5	C17	5	--	D1	--
AS-015	120	C22	120	--	D9	--
AS-016	120	C22	120	--	D9	--
AS-017	120	C22	120	--	D9	--
AS-018	120	C23*	120	--	--	--
AS-019	120	C23*	120	--	--	--
AS-020	120	C23*	120	--	--	--
AS-021	15	C24*	15	--	D1	--
AS-022	15	C24*	15	--	D1	--
AS-023	15	C24*	15	--	D1	--

*C23 and C24 are not defined at present. Conversion information will be provided by Boeing.



AS-015 BMSR INLET AIR TEMPERATURE COMPUTER SET POINT
AS-016 BMSR OUTLET AIR PRESSURE COMPUTER SET POINT
AS-017 ATTEMPERATOR OUTLET AIR TEMPERATURE COMPUTER SET POINT
AS-018 BMSR INLET AIR TEMP CONTROLLER REMOTE/LOCAL CONTACT
AS-019 BMSR OUTLET AIR PRESSURE CONTROLLER REMOTE/LOCAL CONTACT
AS-020 ATTEMPERATOR OUTLET AIR TEMP CONTROLLER REMOTE/LOCAL CONTACT

FIGURE 6-1 AIR SUPPLY SYSTEM INSTRUMENTATION SCHEMATIC

6.1.4 STTF Support System

Data from STTF support systems will be utilized for both real-time control and evaluation, and for post-test performance analyses. Data requirements include the following.

6.1.4.1 RTAF and Heliostat Data. The RTAF will provide aperture input flux measurements, integrating fluxes so as to automatically provide the DAS with real-time values of "J", the BMSR aperture input power in kW_t. Real-time displays of RTAF data will be available.

- Color coded two-dimensional flux map.
- Three-dimensional flux map.
- Two-dimensional contour map.
- Two-dimensional graphs for each sensor showing flux versus sensor location.

It is anticipated that computers for the RTAF and heliostat field control will be linked so that the real-time calculation of power into the aperture will be fully automated.

RTAF data will be available on tape for post-test evaluation; it may be desirable for this data to be on the same tape as BMSR data. This record will also include a log of on-line heliostats at all times during the test.

6.1.4.2 Weather Data. Weather data, which will be provided for real-time evaluation, include the following.

- Temperature.
- Wind speed.
- Barometric pressure.
- Humidity.
- Insolation.

Other data, such as atmospheric attenuation, will be provided by STTF for post-test evaluation.

6.1.4.3 Calorimeter Coolant Flow. Real-time monitoring of the presence of calorimeter coolant flow will be provided, with capabilities to identify the following conditions with a sampling interval of 5 seconds.

- Primary coolant flow on.
- Secondary coolant flow on.
- No coolant flow.

6.1.4.4 Air Supply Hydrocarbon Count. A real-time monitor of the hydrocarbon level for the BMSR Air Supply will be available, with a sampling interval of at least 60 seconds.

6.1.4.5 Other Data. Measurements not identified at present, may utilize the STTF "net radiometer" and "infra-red thermometer." Methodologies for using these instruments will be developed in conference with STTF personnel.

6.1.5 Engineering Unit Conversions

Subsections 6.1.1 through 6.1.3 listed data signals from the Control System, Instrumentation System, and Air Supply System; these signals will be converted to engineering units according to algorithms and/or calibration curves described or referenced in Table 6-5. When sensor calibration curves are necessary to permit data conversion, those curves are included following Table 6-5. Conversions are to be made on a real-time basis at the rate indicated by the update intervals designated in Tables 6-1, 6-3, and 6-4; the conversion technique label noted in those tables corresponds to labels in Table 6-5. Type K, Type B, and Type T thermocouples will use the STTF DAS built-in routine for conversion to engineering units.

TABLE 6-5. DATA CONVERSION ALGORITHMS/CALIBRATION CURVES

C1. Type K Thermocouple, 0-500 F

Fabricated for special limits of error as per ASTM E 230. Special error limits not guaranteed due to short-range ordering phenomenon.

C2. Type K Thermocouple, 0-1,000 F

Fabricated for special limits of error as per ASTM E 230. Special error limits not guaranteed due to short-range ordering phenomenon.

C3. Type K Thermocouple, 0-1,500 F

Fabricated for special limits of error as per ASTM E 230. Special error limits not guaranteed due to short-range ordering phenomenon.

C4. Type K Thermocouple, 0-2,100 F

Fabricated for special limits of error as per ASTM E 230. Special error limits not guaranteed due to short-range ordering phenomenon.

C5. Type K Thermocouple, 0-2,500 F

Fabricated for special limits of error as per ASTM E 230. Special error limits not guaranteed due to short-range ordering phenomenon.

This category or joint disc has been included to designate the conversion range for SiC tube temperature measurements. Inclusion of these thermocouples in the BMSR Instrumentation System is uncertain at present.

C6. Type B Thermocouple, 0-2,500 F

Limits of error as per ASTM E 230, Table 1.

C7. Flow Element Differential Pressure

Conversion per Rosemount Calibration Certification, B&V Document 7341.005-G-001. Note that the 4-20 mA output of the transmitter is linearly converted to a 2-10 V in the BMSR Control System panel prior to routing to the DAS.

C8. Static Air Pressure

Conversion per Rosemount Calibration Certification, B&V Document 7341-G-005. Note as in C7, the output is 2-10 V.

TABLE 6-5 (Continued). DATA CONVERSION ALGORITHMS/CALIBRATION CURVES

C9. BMSR Differential Pressure

Conversion per Rosemount Calibration Certification, B&V Document 7341.005-G-003. Note as in C7, the output is 2-10 V.

C10. U-bend Vibration

VI = KV x (VIA)

where VI = vibration level in g's

VIA = Indicated data channel signal (0-10 Vdc)

KV = Operator-entered sensitivity in g/volt. The value of KV depends upon charge amplifier sensitivity and range settings manually made prior to tests.

C11. Strain Gage, Low Temperature

Conversion per Ailtech Calibration Data, to be provided at a later date.

C12. Strain Gage, Intermediate Temperature

Conversion per Ailtech Calibration Data, to be provided at a later date.

C13. Strain Gage, High Temperature

Conversion per Ailtech Calibration Data, to be provided at a later date.

C14. Heat Flux Calorimeter

Conversion per Thermogage Calibration Curves, B&V Document 7341.005-E-003.

HFI = (q/10) x VHF

where HFI = Heat Flux in kW/M^2

q = Sensitivity from Thermogage Calibration Curves

VHF = Measured signal in mVdc

C15. Heat Flow, Conductive

As per Hy-Cal Calibrated Sensitivity ("a constant"), B&V document 7341.005-F-010.

Ranges:

- 0-35 mVdc for HF-SB043;
- 0-5 mVdc for HF-SC044 and HF-SH045

TABLE 6-5 (Continued). DATA CONVERSION ALGORITHMS/CALIBRATION CURVES

C16. Type T Thermocouple, 0-1,000 F

C17. Static and Differential Air Pressures (Air Supply System) as per Boeing "Operating and Maintenance Requirements and Procedures--Air Supply System Solar Receiver Bench Model Test Program," Table 5.3-0, (D277-10080-1).

C18. BMSR Control System Temperature Signal; 0-10 Vdc

$$T = 99.81 + 207.4\ V - 3.519\ V^2 + 0.2785\ V^3 \quad F$$

where

V = Signal voltage in volts
$(100 \leq T \leq 2{,}100)$ F

C19. BMSR Control System Temperature Signal; 4-20 mAdc

$$I = 3.236 + 0.007571\ T + 7.733 \times 10^{-7}\ T^2 - 2.751 \times 10^{-10}\ T^3 \quad mA$$

where T = Operator-entered temperature $(100 \leq T \leq 2{,}100)$F

C20. BMSR Control System Signal to Control Valve, 0-10 Vdc,

VPOS = (10-VS) x 10

where VPOS = valve position in per cent

VS = Signal to reverse acting valve (increasing signal to close) in volts.

C21. BMSR Control System Signal, Contact Closure

DAS must sense BMSR Control System contact position, closed or open. Suggested sensing signal: 48 Vdc; 2 amp maximum. Normally closed contact; closed for normal operation; open if in BMSR Control System sensed warning or alarm condition. Assign "0" for closed, "1" for open.

C22. Air Supply System Computer Set Points

Converted from digital to analog signals in accordance with "Data Package--Air Supply System for 1 MW_{th} Bench Model Receiver" prepared by the Boeing Company under EPRI contract RP1092-1.

A-029
031279

6-34

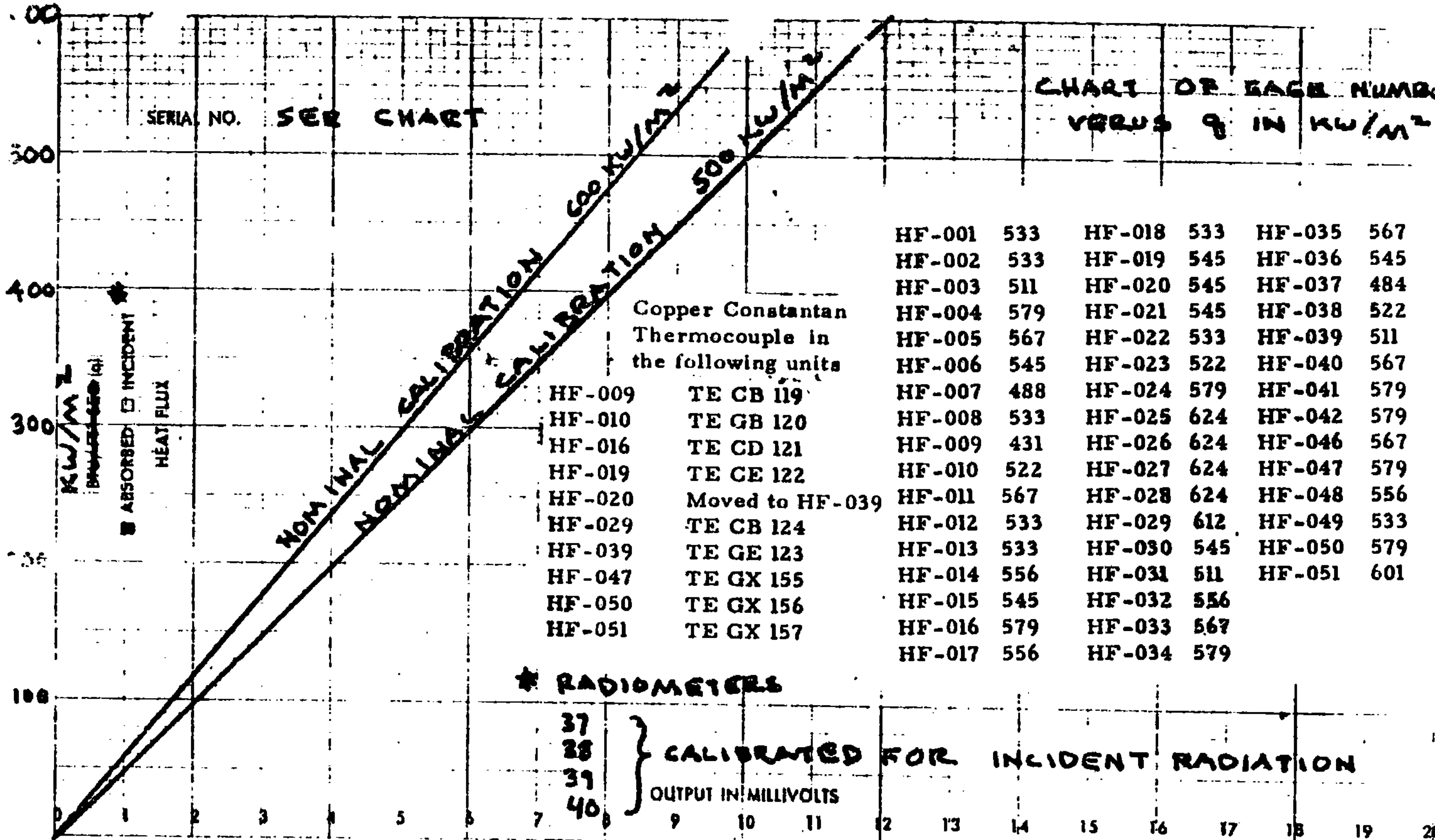


CHART OF GAGE NUMBERS VERUS q IN KW/M²

HF-001	533	HF-018	533	HF-035	567
HF-002	533	HF-019	545	HF-036	545
HF-003	511	HF-020	545	HF-037	484
HF-004	579	HF-021	545	HF-038	522
HF-005	567	HF-022	533	HF-039	511
HF-006	545	HF-023	522	HF-040	567
HF-007	488	HF-024	579	HF-041	579
HF-008	533	HF-025	624	HF-042	579
HF-009	431	HF-026	624	HF-046	567
HF-010	522	HF-027	624	HF-047	579
HF-011	567	HF-028	624	HF-048	556
HF-012	533	HF-029	612	HF-049	533
HF-013	533	HF-030	545	HF-050	579
HF-014	556	HF-031	511	HF-051	601
HF-015	545	HF-032	556		
HF-016	579	HF-033	567		
HF-017	556	HF-034	579		

Copper Constantan Thermocouple in the following units

HF-009	TE CB 119
HF-010	TE GB 120
HF-016	TE CD 121
HF-019	TE CE 122
HF-020	Moved to HF-039
HF-029	TE CB 124
HF-039	TE GE 123
HF-047	TE GX 155
HF-050	TE GX 156
HF-051	TE GX 157

* RADIOMETERS

37
38
39
40 } CALIBRATED FOR INCIDENT RADIATION

OUTPUT IN MILLIVOLTS

DATE 2/15/79

TRANSDUCER, TYPE CIRCULAR FOIL HEAT FLUX GAGES

MODEL 1000-59 MODIFIED AS PER BLACK + VETCH SKETCHES

CUSTOMER BLACK + VETCH

P.O. NO. 318AA

PREPARED BY BILL PARSONS

SENSOR EMISSIVITY 0.98

Q. C. Approval CEB

THERMOGAGE INC.

330 ALLEGANY STREET | FROSTBURG, MARYLAND 21532

B+V 7341.005-E-003.

Calibration Data for Hy-Cal Heat Flow Gages to be provided later.

CALIBRATION CERTIFICATION

ITEM	QUANTITY	CUSTOMER NO.	CALIBRATION
		1151DP3E12LMFB	
01	5	S/N 144900 144894 144897 144895 144901	Each transmitter calibrated to specified range of 0-20" H20 .###

CALIBRATION EQUIPMENT: Calibrated and Approved by Rosemount Standards Lab, Minneapolis, Minnesota.

1. PK-854 Ametek Calibration Tag# S-3-418
2. 8800A Fluke Calibration Tag# S-3-404
3. A-90 Fluke Calibration Tag# S-3-405

CALIBRATION PERFORMED BY Bud Young

DATE 12-15-78

Black & Veatch P.O.# 303CC

AIR FLOW PRESSURE TRANSMITTER CALIBRATION CERTIFICATION

B&V SENSORS PT-AB001, PT-AC002, PT-AD003, PT-AE004, PT-AF005

A-029
031279

ROSEMOUNT INC. 12/15/73

ALPHALINE PRESSURE TRANSMITTER

Model: 1151DP3E12LMFB
Customer: Black & Veatch
RMT H.O.#: 270364

P.O.: 303CC
Item: 01

Span: 0-20" H20
Calibrated Range: 0-20" H20

Output = 4 MA. @ 0" H20
Output = 20 MA. @ 20" H20

Calculated table:

PRESSURE (" H20)	I (MA.)
0	4.0
2	5.6
4	7.2
6	8.8
8	10.4
10	12.0
12	13.6
14	15.2
16	16.8
18	18.4
20	20.0

Transmitter S/N

144900
144894
144895
144897
144901

BLU 7341.005 - G-003

CALIBRATION CERTIFICATION

ITEM	QUANTITY	CUSTOMER NO.	CALIBRATION
02	1	1151DP5E12LMFB S/N 141664	Each transmitter calibrated to specified range of 0-15 PSID .###

CALIBRATION EQUIPMENT: Calibrated and Approved by Rosemount Standards Lab, Minneapolis, Minnesota.

1. PK-854 Ametek Calibration Tag# S-3-418
2. 8800A Fluke Calibration Tag# S-3-404
3. A-90 Fluke Calibration Tag# S-3-405

CALIBRATION PERFORMED BY Bud Young

DATE 12-15-78

Black & Veatch P.O.# 303CC

DIFFERENTIAL PRESSURE TRANSMITTER CALIBRATION CERTIFICATION - PT-AR007

A-029
031279

ROSEMOUNT INC. 12/15/78

ALPHALINE PRESSURE TRANSMITTER

Model: 1151DP5E12LMFB
Customer: Black & Veatch
RMT H.O.#: 270364

P.O.: 303CC
Item: 02

Span: 0-15 PSID
Calibrated Range: 0-15 PSID

Output = 4 MA. @ 0 PSID
Output = 20 MA. @ 15 PSID

Calculated table:

PRESSURE (PSID)	I (MA.)
0	4.0
1.5	5.6
3	7.2
4.5	8.8
6	10.4
7.5	12.0
9	13.6
10.5	15.2
12	16.8
13.5	18.4
15	20.0

Transmitter S/N

141664

CALIBRATION CERTIFICATION

ITEM	QUANTITY	CUSTOMER NO.	CALIBRATION
03	1	1151AP7E12LMPB S/N 149133	Each transmitter calibrated to specified range of 0-150 PSIA .###

CALIBRATION EQUIPMENT: Calibrated and Approved by Rosemount Standards Lab, Minneapolis, Minnesota.

1. HK-1000 Ametek Calibration Tag# S-3-400
2. 8800A Fluke Calibration Tag# S-3-404
3. A-90 Fluke Calibration Tag# S-3-405

CALIBRATION PERFORMED BY Bud Young

DATE 12-15-78

Black & Veatch P.O.# 303CC

ABSOLUTE PRESSURE TRANSMITTER CALIBRATION CERTIFICATION -PT-AR006

A-029
031279

ROSEMOUNT INC. 12/15/78

ALPHALINE PRESSURE TRANSMITTER

Model: 1151AP7E12LMPB
Customer: Black & Veatch
RMT H.O.#: 270364

P.O.: 303CC
Item: 03

Span: 0-150 PSIA
Calibrated Range: 0-150 PSIA

Output = 4 MA. @ 0 PSIA
Output = 20 MA. @ 150 PSIA

Calculated table:

PRESSURE (PSIA)	I (MA.)
0	4.0
15	5.6
30	7.2
45	8.8
60	10.4
75	12.0
90	13.6
105	15.2
120	16.8
135	18.4
150	20.0

Transmitter S/N

149133

Calibration Data for Ailtech Strain Gages to be provided later.

6.1.6 Computations

A limited number of simplified computations using data supplied by the BMSR Instrumentation System, BMSR Control System, or Air Supply System sensors will be made on a real-time basis. This computed data will provide the operator with information necessary to allow determination of the proper function of the Air Supply System and the BMSR, and as computer resources permit, to permit limited, initial evaluation of BMSR key, control-related performance indicators on a real-time basis. A summary listing of the computation labels and names may be found on Table 6-6. Computations are listed in Table 6-7 by label, along with computation intervals, corresponding warnings and alarms, displays, and subsequent computations. Following Table 6-7 are alphabetically arranged descriptions of each computation, including equations and input variables.

TABLE 6-6. DAS COMPUTATIONS

Computation Label	Description
HFMC	Maximum Heat Flux on Ceiling
HFMW	Maximum Heat Flux on Walls and Floor
HTFN	Heat Transfer Factor for BMSR Panel N (N = B, C, D, E, F)
IHFI	Incident Heat Flux Related to Sensor Number I
KFACN	"k factor" for BMSR Panel N
MASI	Airflow Rate for Air Supply System (I = 1, 2)
MN	Airflow Rate for BMSR Panel N
MR	Receiver Airflow Rate
QN	Heat Absorbed for Panel N
QONN	Incident Power on Panel N
QR	Receiver Heat Absorbed
QRR	Reradiated Power
REFF	Receiver Efficiency
SMAX	Maximum Strain
TCAVI	Cavity Surface Temperature
TCMAX	Maximum Calorimeter Temperature
TCVMAX	Maximum Cavity Temperature
THDMAX	Maximum Header/Duct Temperature
TPBMAX	Maximum Pillbox Temperature
TSCI	Silicon Carbide Tube Temperature
TSCMAX	Maximum Silicon Carbide Tube Temperature
TSCTMX	Maximum Measured Silicon Carbide Tube Temperature
TSFMAX	Maximum Shell/Frame Temperature
TUBMAX	Maximum U-bend Temperature
VIMAX	Maximum Vibration

TABLE 6-7. DAS BMSR COMPUTATIONS

Computations[a]	Number[b]	Computation Interval (sec)	Warning/ Alarms[c]	Displays[d]	Subsequent Calculations[e]
HFMC	1	30	--	D1, D2	--
HFMW	1	30	--	D1, D2	--
HTFN, (HTFB, HTFC, HTFD, HTFE HTFF)	5	120 bg*	--	D2, D3	--
IHFI, (IHF06 through IHF24)	19	60	--	D3	QONN

[a]Computations to be performed by DAS, listed in alphabetic order by generic label. Specific labels, if different from the generic label, are listed below the generic label in parentheses (e.g., HTFN is the generic label for specific panel heat transfer factor computations, HTFB, HTFC, HTFD, and HTFE). Computations are described on the pages following this table.

[b]The number of specific calculations of the generic type.

[c]Warning and alarm evaluations, described in Subsection 6.1.7, for which the computation results are input variables, are indicated by the reference label.

[d]Data displays, in which the computation results are displayed, are indicated by the reference label. The displays are defined in Section 6.2.

[e]Subsequent calculations using this computation as an input variable are referenced by the computation generic label.

*Denotes a computation to be executed as a computer "background" activity and, to the extent practical, in general accordance with the indicated computation interval.

TABLE 6-7 (Continued). DAS BMSR COMPUTATIONS

Computations[a]	Number[b]	Computation Interval (sec)	Warning/Alarms[c]	Displays[d]	Subsequent Calculations[e]
KFACN (KFACB, KVACC, KFACD, KFACE, KFACF)	5	60	--	D3	IHFI, TSCI, TSCMAX
MASI (MAS1, MAS2)	2	15 (MAS1) 60 bg (MAS2)	W11, A11	D1 (MAS1) D2 (MAS2)	--
MN (MB, MC, MD ME, MF)	5	15	--	D1, D2, D3	QN
MR	1	15	W11, A11	D1, D2, D3	QR
QN (QB, QC, QD QE, QF)	5	60	--	D2, D3	HTFN TSCI
QONN (QONB, QONC, QOND, QONE, QONF)	5	120 bg	--	D2, D3	HTFN
QR	1	120	--	D2, D3	REFF
QRR	1	120	--	D2	--
REFF	1	120	--	D2	--
SMAX	1	120	--	D1	--

TABLE 6-7 (Continued). DAS BMSR COMPUTATIONS

Computations[a]	Number[b]	Computation Interval (sec)	Warning/Alarms[c]	Displays[d]	Subsequent Calculations[e]
TCAVI (TCAV05, TCAV10, TCAV13, TCAV16, TCAV19, TCAV24, TACV29, TCAV31)	8	60	--	D5	TCVMAX
TCMAX	1	15	--	D1, D2	--
TCVMAX	1	120	--	D1, D2	--
THDMAX	1	60	--	D1	--
TPBMAX	1	120	--	D1	--
TSCI (TSCI0, TSC13, TSC16, TSC19, TSC24)	5	60	--	D3, D8	TSCMAX
TSCMAX	1	60	--	D1, D2	--
TSCTMX	1	60	--	D1	--
TSFMAX	--	120	--	--	--
TUBMAX	1	60	--	D1, D2	--
VIMAX	1	15	--	D1	--

HFMC: Maximum Ceiling Heat Flux

Range: 0-600 kW/m^2

Method: Find the highest measured heat flux from the following list of sensor signals.

Sensors
HF-CH025
HF-CH026
HF-CH027
HF-CH028
HF-CH029

HFMW: Maximum Wall or Floor Heat Flux

Range: 0-500 kW/m^2

Method: Find the highest measured heat flux from the following list of sensor signals.

Sensors			
HF-CA001	HF-CC012	HF-CF023	HF-CB039
HF-CA002	HF-CC013	HF-CF024	HF-CF040
HF-CA003	HF-CD014	HF-CG030	HF-CD041
HF-CA004	HF-CD015	HF-CG031	HG-CD042
HF-CA005	HF-CD016	HF-CG032	
HF-CB006	HF-CE017	HF-CG033	
HF-CB007	HF-CE018	HF-CC034	
HF-CB008	HF-CE019	HF-CD035	
HF-CB009	HF-CE020	HF-CE036	
HF-CB010	HF-CE021	HF-CG037	
HF-CC011	HF-CF022	HF-CA038	

A-029
031279

HTFN: Panel Heat Transfer Factor

Range: 0-40 per cent

Equations:

$$HTFN = \left[(QN \div QONN) \times 100 \right] \quad \text{per cent}$$

where

QN = Heat Absorbed for Nth Panel, in kW_t

QONN = Incident Power on Nth Panel, in kW_t

Appropriate input variables are designated in the following table.

HTFN	QN	QONN
HTFB	QB	QONB
HTFC	QC	QONC
HTFD	QD	QOND
HTFE	QE	QONE
HTFF	QF	QONF

IHFI: Panel Incident Heat Flux

Range: 0-600 kW_t/m^2

Equation:

$$IHFI = KFACN \times HFI \qquad kW_t/m^2$$

where

KFACN = Panel "k Factor", dimensionless

HFI = Measured wall flux in kW_t/m^2 for sensor no. I

Appropriate "k Factors" and wall flux are designated in the following table.

IHFI	KFACN	HFI
IHF06	KFACB	HF-CB006
IHF07	KFACB	HF-CB007
IHF08	KFACB	HF-CB008
IHF09	KFACB	HF-CB009
IHF10	KFACB	HF-CB010
IHF11	KFACC	HF-CC011
IHF12	KFACC	HF-CC012
IHF13	KFACC	HF-CC013
IHF14	KFACD	HF-CD014
IHF15	KFACD	HF-CD015
IHF16	KFACD	HF-CD016
IHF17	KFACE	HF-CE017
IHF18	KFACE	HF-CE018
IHF19	KFACE	HF-CE019
IHF20	KFACE	HF-CE020
IHF21	KFACE	HF-CE021
IHF22	KFACF	HF-CF022
IHF23	KFACF	HF-CF023
IHF24	KFACF	HF-CF024

KFACN: Panel "k Factors"

Range: 0-2.0 (dimensionless)

Equations:

KFACN = (Incident Flux)/(Wall Flux)

where sensors for the appropriate incident and wall fluxes, in kW_t/m^2, are designated in the following table.

KFACN	Incident Flux	Wall Flux
KFACB	HF-CA004	HF-CB007
KFACC	HF-CC034	HF-CC012
KFACD	HF-CD035	HF-CD015
KFACE	HF-CE036	HF-CE018
KFACF	HF-CA003	HF-CF023

MASI: Air Supply System Airflow

Range: 0-13,000 lbm/h

Equation:

$$MASI = 6208.7 \times FA \times Y \times \sqrt{\rho \, dP} \qquad lbm/h$$

where

MASI = Air Supply System Airflows, #1 and #2, lbm/h (refer to Figure 6-1 for identification)

FA = Thermal expansion factor for throat area, dimensionless

$$FA = [1 + (T - 70)(13.5 \times 10^{-6})]^2$$

T = Throat inlet temperature, F, defined in table below

$$Y = \left[\frac{3.356}{(1-r)} \; \frac{(r^{1.428}) \times (1-r^{0.2857})}{(1 - 0.04108r^{1.428})}\right]^{1/2}$$

$$r = \frac{P1 - dP}{P1}$$

P1 = Inlet Absolute Pressure, psia, defined in table below

dP = Measured differential pressure, psi, defined in table below

ρ = Air density at P1 and T

$$\rho \simeq \left(\frac{P1}{14.73}\right) \times \left(\frac{519.6}{T + 459.6}\right) \times 0.0765 \text{ lbm/cu ft}$$

Appropriate sensors for the airflow computations.

MASI	T	P1	dP
MAS1	AS-001	AS-006	AS-012
MAS2	AS-001	AS-007	AS-013

Reference: "Operating and Maintenance Requirements and Procedures--Air Supply System Solar Receiver Bench Model Test Program," The Boeing Company, D277-10080-1, pp. 34-37.

MN: Panel Airflow Rates

Range: 0-4,000 lbm/h

Equation:

$$MN = KA \times FAA \times \left[\frac{P}{(TI + 460)}\right]^{1/2} \times \left[(\Delta PN)\right]^{1/2} \times ADEN \quad \text{lbm/h}$$

where

KA = Lumped constant = 22272

P = Static Air Pressure in psia

TI = Inlet Air Temperature in F

ΔPN = Flow Element Differential Air Pressure for Panel N in inches of H_2O

ADEN = Density of air at standard conditions = 0.0765 lbm/cu ft

FAA = Pipe Expansion Factor (defined below)

KA has been derived from an equation and values provided by Annubar (B&V Document 7341.005-D-002)

$$KA = (TB \times FNA \times K \times D^2 \times FRA \times YA \times FPV \times FM \times FL) \div (PB \times G)$$

where

TB = Base temperature = 520 R

FNA = Grouped Constant = 218.42

K = Annubar Coefficient = 0.6871

D = Pipe Inner Diameter = 2.067 inches

FRA = Reynolds Number Factor = 1.004

YA = Gas Expansion Factor = 1.000

FPV = Supercompressibility = 0.98

FM = Manometer Correction Factor = 1.000

FL = Elevation Correction Factor = 1.000

PB = Base Pressure = 14.73 psia

G = Specific Gravity of gas = 1.000

The pipe expansion factor, FAA, can be characterized as

$$FAA = [1 + 2.0 \times 10^{-5} (TI - 70)]$$

Measurements used in the above equations are designated in the following table.

-Continued-

MN	TI	P	ΔPN
MB	TE-AC002	PT-AR006	PT-AB001
MC	TE-AC002	PT-AR006	PT-AC002
MD	TE-AC002	PT-AR006	PT-AD003
ME	TE-AC002	PT-AR006	PT-AE004
MF	TE-AC002	PT-AR006	PT-AF005

MR: Receiver Airflow

Range: 0-13,000 lbm/h

Equation:

$$MR = MB + MC + MD + ME + MF \quad \text{lbm/h}$$

where

MB = Panel B Airflow Rate in lbm/h

MC = Panel C Airflow Rate in lbm/h

MD = Panel D Airflow Rate in lbm/h

ME = Panel E Airflow Rate in lbm/h

MF = Panel F Airflow Rate in lbm/h

QN: Panel Heat Absorbed

Range: 0-300 kW_t

Equations:

$$QN = MN \times (HTON - HTI) \div 3{,}413 \quad kW_t$$

where

MN = Airflow for Panel N, lbm/h

HTON = Enthalpy of Panel N Outlet Air, Btu/lbm

HTI = Enthalpy of Receiver Inlet Air, Btu/lbm

Refer to Computation QR for enthalpy calculation procedure.

Calculation of HTON and HTI will be with the measurements designated in the following table. H and T are enthalpy and air temperature as used in the enthalpy calculation equation under QR.

H	T
HTOB	TE-DB003
HTOC	TE-DC004
HTOD	TE-DD005
HTOE	TE-DE006
HTOF	TE-DF007
HTI	TE-AC002

A-029
031279

QONN: Panel Incident Power

Range: 0-1,400 kW_t

Equations:

$$QONN = \Sigma\ (IHFI \times AI) \quad kW_t$$

where

IHFI = Panel Incident Heat Flux in kW_t/m^2

AI = Corresponding Heat Exchanger Zone Areas at Front of Tubes, in m^2

Incident heat fluxes and areas are designated in the following table. Note that Panels B and E are summed over five zones; Panels C, D, and F are summed over three zones.

QONN	IHFI	AI
QONB	IHF06	0.603
	IHF07	0.872
	IHF08	0.188
	IHF09	0.226
	IHF10	0.188
QONC	IHF11	0.603
	IHF12	0.872
	IHF13	0.603
QOND	IHF14	0.603
	IHF15	0.872
	IHF16	0.603
QONE	IHF17	0.603
	IHF18	0.872
	IHF19	0.188
	IHF20	0.226
	IHF21	0.188
QONF	IHF22	0.603
	IHF23	0.872
	IHF24	0.603

QR: Receiver Heat Absorbed

Range: 0-1,000 kW_t

Equations:

$$QR = MR \times (HTO - HTI) \div 3413 \qquad kW_t$$

where

MR = Receiver Airflow in lbm/h

HTO = Enthalpy of Receiver Outlet Air in Btu/lbm

HTI = Enthalpy of Receiver Inlet Air in Btu/lbm

Enthalpies are to be calculated as follow.*

$$H = a_o + a_1 T + a_2 T^2 \quad \text{Btu/lbm}$$

where

$a_o = 14.31$

$a_1 = 0.2365$

$a_2 = 1.289 \times 10^{-5}$

T = Air Temperature in F

Calculation of H will use T values as designated in the following table.

H	T
HTO	TE-DR008
HTI	TE-AC002

---

*The enthalpy equation has been curve fit to enthalpy data from Sawyer's Gas Turbine Engineering Handbook, 2nd Edition, Vol. 1, John W. Sawyer, Ed., Gas Turbine Publications, Inc., Stanford Conn., pages 10-16.

QRR: Reradiated Power

Range: 0-450 kW

Equation:

$$QRR = \Sigma\ (HFI \times AI) \qquad kW_t$$

where

HFI = Aperture Perimeter Heat Flux in kW_t/m^2

AI = Corresponding Aperture Zone Areas in m^2

Aperture perimeter heat flux sensors and corresponding zone areas are designated in the following table.

HFI	AI
TE-CA001	0.258
TE-CA002	0.258
TE-CA003	0.258
TE-CA004	0.258

REFF: Receiver Efficiency

Range: 0-100 per cent

Equation:

$$REFF = \left[(QR/J) \times 100 \right] \quad \text{per cent}$$

where

QR = Receiver Heat Absorbed in kW_t

J = Aperture Input Power (RTAF Integration) in kW_t

A-029
031279

SMAX: Maximum Measured BMSR Strain

Range: 0-1000 με

Method: Find highest absolute value of strain for all BMSR strain gages, except U-bend strains. Store and display that value with appropriate sign (+ or -).

Sensors
SG-FD004 through SG-FD011
SG-AD017 through SG-AD022
SG-HD023 through SG-HD032
SG-DD033 through SG-DD035

TCAVI: Cavity Insulation Surface Temperature*

Range: 0-3,000 F

Equation:

$$TCAVI = (HFI/\sigma)^{\frac{1}{4}} - 460 \quad F$$

where

HFI = Measured Heat Flux in kW/m^2

σ = Stefan-Boltzmann Constant = 5.40×10^{-12} kW/m^2R^4

TCAVI	HFI
TCAV05	HF-CA005
TCAV10	HF-CB010
TCAV13	HF-CC013
TCAV16	HF-CD016
TCAV19	HF-CE019
TCAV24	HF-CF024
TCAV29	HF-CH029
TCAV31	HF-CG031

*Calculation assumes emissivity equals absorptivity.

TCMAX: Maximum Calorimeter Temperature

Range: 0-999 F

Method: Find maximum value of calorimeter temperature from among the sensors listed below.

<u>Sensors</u>

TE-GB119

TE-GB120

TE-GD121

TE-GE122

TE-GE123

TE-GD124

TE-GE125

TE-GH126

TCVMAX: Maximum Cavity Surface Temperature

Range: 0-3,000 F

Method: Find the highest value of TCAVI from the values listed below.

TCAVI
TCAV05
TCAV10
TCAV13
TCAV16
TCAV19
TCAV24
TCAV29
TCAV31

THDMAX: Hot Header/Duct Maximum Temperature

Range: 0-1,200 F

Method: Find the highest measured hot header or duct temperature from the following list of sensor signals.

Sensors			
TE-HD062	TE-HD066	TE-HD070	TE-DD074
TE-HD063	TE-HD067	TE-HD071	TE-DD075
TE-HD064	TE-HD068	TE-DD072	TE-DD076
TE-HD065	TE-HD069	TE-DD073	TE-DD077

TPBMAX: Maximum Hot Header Pillbox Temperature

Range: 0-1,600 F

Method: Find the highest measured pillbox temperature from the following list of sensor signals.

Sensors		
TE-JD056	TE-JD058	TE-JD060
TE-JD057	TE-JD059	TE-JD061

TSCI: Silicon Carbide Tube Temperature*

Range: 0-2,500 F

Equations:

$$TSCI = \left[\frac{\alpha\,\phi tube - \phi abs}{\sigma\varepsilon}\right]^{\frac{1}{4}} -460 \quad F$$

where

α = absorptivity = 0.85

ε = emissivity = 0.85

σ = Stefan-Boltzmann Constant = 5.40×10^{-12} kW/m^2R^4

ϕ tube = 0.5 [1 + KFACN] x HFI kW/m^2

ϕ abs $= \frac{1}{8} \times r \times \frac{QN}{A} = 0.348\ QN\ kW/m^2$

r = fraction of heat absorbed in a designated length of tube = 0.105 dimensionless

QN = Heat absorbed for entire panel in kW_t

A = Area of designated length of tube = 0.0377 m^2

TSCI	HFI	KFACN	QN
TSC10	HF-CB010	KFACB	QB
TSC13	HF-CC013	KFACC	QC
TSC16	HF-CD016	KFACD	QD
TSC19	HF-CE019	KFACE	QE
TSC24	HF-CF024	KFACF	QF

---

*Calculation based on B&V Computer Analysis of tube temperatures. Note that real time computation results will be high by 50-100 F due to simplifications.

A-029
062279

TSCMAX: Maximum Computed Silicon Carbide Tube Temperature

Range: 0-2,500 F

Method: Find highest value of TSCI, the computed silicon carbide temperature.

TSCI
TSC010
TSC013
TSC016
TSC019
TSC024

TSCTMX: Maximum Measured Silicon Carbide Tube Temperature

Range: 0-2,500 F

Method: Find the highest value of measured SiC tube temperature from the following list of sensors signals.

Sensors			
TE-TC017	TE-TD021	TE-TC025	TE-TD029
TE-TC018	TE-TD022	TE-TC026	TE-TD030
TE-TC019	TE-TD023	TE-TC027	TE-TD031
TE-TC020	TE-TD024	TE-TC028	TE-TD023

TSFMAX: Maximum Shell/Frame Temperature

Range: 0-1,200 F

Method: Find the highest measured shell or frame temperature from the following list of sensor signals.

Sensors			
TE-SA081	TE-SD087	TE-FG093	TE-FD099
TE-SB082	TE-SE088	TE-FG094	TE-FD100
TE-SB083	TE-SE089	TE-FG095	TE-FD101
TE-SC084	TE-SF090	TE-FG096	TE-FD102
TE-SC085	TE-SF091	TE-FD097	TE-FD113
TE-SD086	TE-SH092	TE-FD098	

TUBMAX: Maximum U-Bend Temperature

Range: 0-1,700 F

Method: Find the maximum measured U-Bend temperature from the following list of sensors signals.

Sensors			
TE-UB033	TE-UB036	TE-UE039	TE-UE042
TE-UB034	TE-UC037	TE-UE040	TE-UF043
TE-UB035	TE-UD038	TE-UE041	

VIMAX: Maximum Vibration

Range: 0-10 g

Method: Find the maximum measured vibration from the following list of sensor signals.

Sensors
VT-UD001
VT-UD002

6.1.7 Warnings and Alarms

The DAS will compute/sense warning and alarm conditions for a number of BMSR and air supply control-related variables. Warnings will detect that a variable, or relation between variables, has reached a level indicating significant, but not critical, variance from the expected value. The result of such a computed warning will be a warning indication on the appropriate display screen. A computed alarm condition indicates that the variance from the expected value has reached a critical amount; alarms result in an alarm display for immediate operator action, and, in some cases, results in automatic, DAS-controlled steps being taken to prevent damage to the BMSR, Air Supply System, or test facility. Alarm actions include some or all of the following as indicated in the alarm sequence descriptions for the individual alarms.

- Display alarm.
- Open some or all BMSR control valves.
- Command the heliostat field to standby.
- Open the Air Supply System back pressure valve.

Operator-set warning and alarm levels will be placed in a test file to be accessed at the beginning of the day's testing. Changes in operating conditions for different tests may require updating of these warning and alarm levels during the day. The occurrence of conditions during start-ups and shutdowns, which might be incorrectly interpreted as abnormal conditions by the warning/alarm algorithms, will require that the warning/alarm functions be permissive, i.e., that the functions will be inactive until the operator enters the warning/alarm enabling signal. Partial groups of these functions may be activated at different stages of test start-up; a DAS-programmed interrogation of the experimenter can be utilized to minimize the possibility of omitting the required "enabling" signals.

Warnings and alarms are summarized on the listing in Table 6-8. Descriptions of the individual warnings/alarms are given on the pages that follow.

TABLE 6-8. WARNINGS AND ALARMS

Label	Warning/Alarm Description
W1/A1	High Outlet Air Temperature
W2/A2	High Inlet Air Temperature
W3/A3	Low BMSR Inlet Air Pressure
W4/A4	Low BMSR Differential Pressure
W5/A5	High Receiver Airflow
W6/A6	Low Receiver Airflow
W7/A7	High Calorimeter Temperature
W8/A8	Airflow Differential Pressure Imbalance
W9/A9	High Vibration Level
W10/A10	High Attemperator Outlet Temperature
W11/A11	Receiver/Air Supply Airflow Comparison
W12/A12, A13	Outlet Air Temperature C/I Comparison
W14/A14	Control System Sensed Warning/Alarm
A15	DAS Calculated Alarm-Signal to Annunciator
W16/A16	Calorimeter Coolant Flow
A17	Loss of Data from Tower DAS

Label: W1/A1

Description: High Outlet Air Temperature Warning/Alarm

Purpose:

- Detect high outlet air temperature in any panel or for the receiver
- Prevent damage to the BMSR or Air Supply System due to high outlet temperature

Action:

- Indicate warning or alarm on designated displays
- As alarm action, open appropriate BMSR control valve

Interval: 5 seconds

Warning Displays: D1, D2

Alarm Displays: D1, D2

Criteria: (activate warning/alarm sequence if following conditions are true)

Warning (checked independently for each individual panel and receiver)

(TON > TOWRNG)

Alarm

(TON > TOALRM) for 2 consecutive data scans

Definition of terms:

TON = Outlet Air Temperature for Panel N in F

TOWRNG = Operator Set Outlet Temperature Warning Level in F

TOALRM = Operator Set Outlet Temperature Alarm in F

Warning Sequence:

- Display Warning

Alarm Sequence:

- In addition to displaying alarm, DAS generates indicated signal to open individual BMSR control valve.

TON	Sensor Signal I.D.	DAS Generated Signal I.D.	DAS Signal Type
TOB	TE-DB003	CS-KP009	Open Contact*
TOC	TE-DC004	CS-KP015	Open Contact*
TOD	TE-DD005	CS-KP021	Open Contact*
TOE	TE-DE006	CS-KP027	Open Contact*
TOF	TE-DF007	CS-KP033	Open Contact*

*Refer to Table 6-2.

Label: W2/A2

Description: High Inlet Air Temperature Warning/Alarm

Purpose:

- Detect abnormally high BMSR inlet air temperature
- Prevent damage to BMSR inlet air piping

Action:

- Indicate warning or alarm on designated displays

Interval: 5 seconds

Warning Displays: D1, D2

Alarm Displays: D1, D2

Criteria: (activate warning/alarm sequence if following conditions are true)

Warning

(TI > TIWRNG)

Alarm

(TI > TIALRM) for 2 consecutive scans

Definition of terms:

TI = TE-AC002 = Inlet Air Temperature in F

TIWRNG = Operator Set Inlet Air Temperature Warning Level in F

TIALRM = Operator Set Inlet Air Temperature Alarm Level in F

Warning Sequence:

- Display Warning

Alarm Sequence:

- Display Alarm

Label: W3/A3

Description: Low BMSR Inlet Air Pressure Alarm/Warning

Purpose:

- Indicate possible failures
  - Compressor
  - Air Supply System back pressure controller
  - Rupture in airflow network
  - Blockage upstream from BMSR

Action:

- Indicate warning or alarm on designated displays
- Alarm action
  - Open all BMSR Control Valves
  - Command heliostat field to standby
  - Open air supply back pressure valve

Interval: 5 seconds

Warning Displays: D1, D2

Alarm Displays: D1, D2

Criteria: (activate warning/alarm sequence if following conditions are true)

Warning

(P < PWRNGL)

Alarm

(P < PALRML) for 2 consecutive data scans

Definition of terms:

P = PT-AR006 = BMSR Inlet Air Pressure in psia

PWRNGL = Operator Set Low Air Pressure Warning Level in psia

PALRML = Operator Set Low Air Pressure Alarm Level in psia

Warning Sequence:

- Display Warning

Alarm Sequence:

- Display Alarm
- Open all BMSR control valves

-Continued-

Valve Signal I.D.	Signal Type
CS-KP009	Open Contact*
CS-KP015	Open Contact*
CS-KP021	Open Contact*
CS-KP027	Open Contact*
CS-KP033	Open Contact*

- Command heliostat field to standby
- Open air supply back pressure valve

---

*Refer to Table 6-2.

Label: W4/A4

Description: Low BMSR Differential Pressure Alarm/Warning

Purpose:

- Indicate possible failures
  - Compressor
  - Air Supply System back pressure controller
  - Leak upstream of BMSR
  - Blockage in air line outside BMSR

Action:

- Indicate warning or alarm on designated displays
  - Open all BMSR control valves
  - Command heliostat field to standby
  - Open air supply back pressure valve

Interval: 5 seconds

Warning Displays: D1, D2

Alarm Displays: D1, D2

Criteria: (activate warning/alarm sequence if following conditions are true)

<u>Warning</u>

(DPR $<$ DPRWGL)

<u>Alarm</u>

(DPR $<$ DPRALL) for 2 consecutive data scans

Definition of terms:

DPR = PT-AR007 = BMSR Differential Pressure in psi

DPRWGL = Operator Set Low BMSR Differential Pressure Warning Level in psi

DPRALL = Operator Set Low BMSR Differential Pressure Alarm Level in psi

Warning Sequence:

- Display Warning

Alarm Sequence:

- Display Alarm

-Continued-

- Open all BMSR control valves

DAS Generated Signal I.D.	DAS Signal Type
CS-KP009	Open Contact*
CS-KP015	Open Contact*
CS-KP021	Open Contact*
CS-KP027	Open Contact*
CS-KP033	Open Contact*

- Command heliostat field to standby
- Open air supply back pressure valve

---

*Refer to Table 6-2.

Label: W5/A5

Description: High Receiver Airflow

Purpose:

- Indicate possible failures
  - Air supply back pressure failure
  - Rupture in air line

Action:

- Indicate warning or alarm on designated displays.

Interval: 5 seconds

Warning Displays: D1

Alarm Displays: D1

Criteria: (activate warning/alarm sequence if following conditions are true)

<u>Warning</u>

(DPAS > DPASWH)

<u>Alarm</u>

(DPAS > DPASAH) for 2 consecutive data scans

Definition of terms:

DPAS = AS-012 = Measured differential pressure for Air Supply System Airflow Measurement in psi

DPASWH = Operator Set Warning Level for High DPAS in psi

DPASAH = Operator Set Alarm Level for High DPAS in psi

Warning Sequence: Display Warning

Alarm Sequence:

- Display alarm
- Open <u>all</u> BMSR control valves

DAS Generated Signal Symbol	DAS Signal Type
CS-KP009	Open Contact*
CS-KP015	Open Contact*
CS-KP021	Open Contact*
CS-KP027	Open Contact*
CS-KP033	Open Contact*

- Command heliostat field to standby

---

*Refer to Table 6-2.

Label: W6/A6

Description: Low Receiver Airflow

Purpose:

- Indicate possible failures
  - Blockage in air line
  - Back pressure controller failure

Action:

- Indicate warning or alarm on designated displays

Interval: 5 seconds

Warning Displays: D1

Alarm Displays: D1

Criteria: (activate warning/alarm sequence if following conditions are true)

<u>Warning</u>

(DPAS < DPASWL)

<u>Alarm</u>

(DPAS < DPASAL) for 2 consecutive data scans

Definition of terms:

DPAS = AS-012 = Measured differential pressure for Air Supply System airflow measurement in psi

DPASWL = Operator Set Warning Level for Low DPAS in psi

DPASAL = Operator Set Alarm Level for Low DPAS in psi

Warning Sequence:

- Display Warning

Alarm Sequence:

- Display alarm
- Open <u>all</u> BMSR control valves

-Continued-

DAS Generated Signal I.D.	DAS Signal Type
CS-KP009	Open Contact*
CS-KP015	Open Contact*
CS-KP021	Open Contact*
CS-KP027	Open Contact*
CS-KP033	Open Contact*

- Command heliostats to standby position
- Open air supply back pressure valve

---

*Refer to Table 6-2.

Label: W7/A7

Description: High Calorimeter Temperature Alarm/Warning

Purpose: Detect abnormallly high calorimeter temperatures which can result in damage of calorimeters

Action:

- Indicate warning or alarm on designated displays

Interval: 10 seconds

Warning Displays: D1

Alarm Displays: D1

Criteria: (activate warning/alarm sequence if following conditions are true)

Warning

(TCI > TCWRNG)

Alarm

(TCI > TCIALRM) for 2 consecutive data scans

Definition of terms:

TCI = Calorimeter temperature in F, see table below

TCWRNG = Operator Set Calorimeter Temperature Warning Level in F

TCALRM = Operator Set Calorimeter Temperature Alarm Level in F

Warning Sequence:

- Display Warning

Alarm Sequence:

- Display Alarm

TCI	Sensor Signal I.D.
TC119	TE-GB119
TC120	TE-GB120
TC121	TE-GD121
TC122	TE-GE122
TC123	TE-GE123
TC124	TE-GD124
TC125	TE-GE125
TC126	TE-GH126

Label: W8/A8

Description: Airflow Differential Pressure Imbalance Alarm/Warning

Purpose: Detect airflow imbalance in BMSR panels indicating possible failure

- Severe leak in panel airflow network
- Blockage in panel airflow network

Action:

- Indicate warning or alarm on designated displays
- As alarm action:
  - Open all BMSR control valves
  - Command heliostat field to standby
  - Open Air Supply System back pressure valve

Interval: 5 seconds

Warning Displays: D1, D2

Alarm Displays: D1, D2

Criteria: (activate warning/alarm sequence if following conditions are true)

<u>Warning</u> (checked independently for each individual panel)

$$(DPN \div DPSUM) < DPNWGL$$

or

$$(DPN \div DPSUM) > DPNWGH$$

<u>Alarm</u>

$$(DPN \div DPSUM) < DPNALL$$

or

$$(DPN \div DPSUM) > DPNALH$$

} for 2 consecutive data scans

Definition of terms:

DPN = Airflow Differential Pressure for Panel N (N = B, C, D, E, F) in inches H_2O. Refer to table later in section

DPSUM = DPB + DPC + DPD + DPE + DPF inches H_2O

DPNWGL = Operator Set Low Differential Pressure Ratio Warning Level (Dimensionless)

DPNWGH = Operator Set High Differential Pressure Ratio Warning Level (Dimensionless)

DPNALL = Operator Set Low Differential Pressure Ratio Alarm Level (Dimensionless)

-Continued-

DPNALH = Operator Set High Differential Pressure Ratio Alarm Level (Dimensionless)

Warning Sequence:

- Display Warning

Alarm Sequence:

- Display alarm
- Open all BMSR control valves as per signals listed in the following table

DPN	Sensor Signal I.D.	DAS Generated Signal I.D	DAS Signal Type
DPB	PT-AB001	CS-KP009	Open Contact
DPC	PT-AC002	CS-KP015	Open Contact
DPD	PT-AD003	CS-KP021	Open Contact
DPE	PT-AE004	CS-KP027	Open Contact
DPF	PT-AF005	CS-KP033	Open Contact

- Command heliostat field to standby
- Open Air Supply System back pressure valve

Label: W9/A9

Description: High Vibration Level Alarm/Warning

Purpose: Indicate abnormal vibration magnitude

Action:

- Indicate warning or alarm on designated displays

Interval: 10 seconds

Warning Displays: D1

Alarm Displays: D1

Criteria: (activate warning/alarm sequence if following conditions are true)

Warning

(VI1 > VWRNG) or (VI2 > VWRNG)

Alarm

(VI1 > VALRM) or (VI2 > VALRM) for 2 consecutive scans

Definition of terms:

VI1 = VT-UD001 }
VI2 = VT-UD002 } Vibration Magnitude, g's

VWRNG = Operator Set Vibration Warning Level in g's

VALRM = Operator Set Vibration Alarm Level in g's

Warning Sequence:

- Display Warning

Alarm Sequence:

- Display Alarm

Label: W10/A10

Description: High Attemperator Outlet Temperature

Purpose:

- Indicate possible attemperator controller or sensor failure
- Prevent damage to Air Supply System piping or recuperator

Action:

- Indicate warning or alarm on designated displays
- Alarm condition
  - Open all BMSR control valves
  - Command heliostat field to standby
  - Open Air Supply System back pressure valve

Interval: 5 seconds

Warning Displays: D1, D2

Alarm Displays: D1, D2

Criteria: (activate warning/alarm sequence if following conditions are true)

<u>Warning</u>

(TA > TAWRNG)

<u>Alarm</u>

(TA > TAALRM) for 2 consecutive data scans

Definition of terms:

TA = Air Supply System Attemperator Outlet Temperature in F

TAWRNG = Operator Set Attemperator Outlet Temperature Warning Level in F

TAALRM = Operator Set Attemperator Outlet Temperature Alarm Level in F

Warning Sequence:

- Display Warning

Alarm Sequence:

- Display Alarm

-Continued-

- Open all BMSR control valves

DAS Generated Signal I.D.	DAS Signal Type
CS-KP009	Open Contact*
CS-KP015	Open Contact*
CS-KP021	Open Contact*
CS-KP027	Open Contact*
CS-KP033	Open Contact*

- Command heliostat field to standby
- Open Air Supply System back pressure valve

---

*Refer to Table 6-2.

Label: W11/A11

Description: Receiver/Air Supply Airflow Comparison

Purpose: Alert operator of large divergence between Air Supply System and Instrumentation System Airflow Computations

- Sensor failure
- Rupture between measurement locations

Action:

- Indicate warning or alarm on designated displays

Interval: 15 seconds

Warning Displays: D1

Alarm Displays: D1

Criteria: (activate warning/alarm sequence if following conditions are true)

Warning

$|MR - MAS1| < MWNG$

Alarm

$|MR - MAS1| < MALM$ for 2 consecutive computations

Definition of terms:

MR = Instrumentation System Computed Receiver Airflow in lbm/h

MAS1 = Air Supply System Computed Receiver Airflow in lbm/h

MWNG = Operator set Receiver Airflow Divergence Warning Level in lbm/h

MALM = Operator set Receiver Airflow Divergence Alarm Level in lbm/h

Warning Sequence:

- Display Warning

Alarm Sequence:

- Display Alarm

Label: W12/A12, A13

Description: Outlet Air Temperature C/I Comparison

Purpose:

- Detect failure in Control System or Instrumentation System outlet air temperature thermocouples
- Prevent damage to BMSR due to possible high outlet air temperatures

Action:

- Indicate warning or alarm on designated displays
- Alarm A12: Open corresponding BMSR Control System Valve

Interval: 10 seconds

Warning Displays: D1

Alarm Displays: D1

Criteria: (activate warning/alarm sequence if following conditions are true)

<u>Warning</u> (Done independently for each individual panel and receiver)

W12: $|TON - TCON| > TDELWG$

$|TOR - TCOR| > TDELWG$

<u>Alarm</u> (Done independently for each individual panel and receiver)

$$\left.\begin{array}{ll} \text{A12:} & (TON - TCON) > TDELAL \\ & (TOR - TCOR) > TDELAL \\ \text{A13:} & (TCON - TON) > TDELAL \\ & (TCOR - TOR) > TDELAL \end{array}\right\} \text{for 2 consecutive computations}$$

Definition of terms:

TON = Instrumentation System Outlet Air Temperatures for Panel N (N = B, C, D, E, F) in F

TCON = Control System Outlet Air Temperature for Panel N in F

TOR = Instrumentation System Receiver Outlet Air Temperature in F

TCOR = Control System Receiver Outlet Air Temperature in F

TDELWG = Operator Set Temperature Difference Warning Level in F

TDELAL = Operator Set Temperature Difference Alarm Level in F

Warning Sequence:

- Display Warning

-Continued-

Alarm Sequence:

A12:

- Display alarm condition
- Open appropriate BMSR control valve. Appropriate signals are given in the following table

Control System Sensor Signals	Instrumentation System Sensor Signals	DAS Generated Signal I.D.	DAS Signal Type	Warning/Alarm
TCON	TON			
CS-MP013	TE-DB003	CS-KP009	Open Contact*	W12.1/A12.1/A13.1
CS-MP019	TE-DC004	CS-KP015	Open Contact*	W12.2/A12.2/A13.2
CS-MP025	TE-DD005	CS-KP021	Open Contact*	W12.3/A12.3/A13.3
CS-MP031	TE-DE006	CS-KP027	Open Contact*	W12.4/A12.4/A13.4
CS-MP037	TE-DF007	CS-KP033	Open Contact*	W12.5/A12.5/A13.5
TCOR	TOR			
CS-MP005	TE-DR008	All the above	Open Contact*	W12.6/A12.6/A13.6

A13:

- Display alarm condition.

---

*Refer to Table 6-2.

Label: W14/A14

Description: Control System Sensed Warning/Alarm

Purpose: Alert operator of BMSR Control System sensed warning or alarm condition

Action:

- Indicate warning or alarm on designated displays
- BMSR Control System has already automatically opened appropriate valve

Interval: 10 seconds

Warning Displays: D1

Alarm Displays: D1

Criteria: (activate warning/alarm sequence if following conditions are true)

<u>Warning</u>

(CS39 = 1)

<u>Alarm</u>

(CS40 = 1)

Definition of terms:

CS39 = CS-MP039 = Control System High Temperature Alarm*

CS40 = CS-MP040 = Control System High-High Temperature Alarm*

Warning Sequence:

- Display Warning

Alarm Sequence:

- Display Alarm

---

*DAS sensed BMSR Control System contact position. Reference C21 on Table 6-5.

Label: A15

Description: DAS Calculated Alarm--Signal to Annunciator

Purpose: Activate BMSR Control System Annunciator Alarm Buzzer, Lights

Action:

- Indicate warning or alarm on designated displays

Interval: 10 seconds

Warning Displays: None

Alarm Displays: None

Criteria: (activate warning/alarm sequence if following conditions are true)

Warning

None

Alarm

If any DAS-calculated alarm condition exists (A1 through A13)

Definition of terms: None

Warning Sequence:

- None

Alarm Sequence:

- Open contact for CS-KP041 (Refer to Table 6-2)

Label: W16/A16

Description: Calorimeter Coolant Flow Warning/Alarm

Purpose: Alert operator of failure of primary or both primary and backup calorimeter coolant flow

Action:

- Indicate warning or alarm on designated displays

Interval: 5 seconds

Warning Displays: D1

Alarm Displays: D1

Criteria: (activate warning/alarm sequence if following conditions are true)

Warning

Primary calorimeter coolant fails, but backup coolant is flowing

Alarm

No calorimeter coolant is flowing

Definition of terms: None

Warning Sequence:

- Display Warning

Alarm Sequence:

- Display Alarm

Label: A17

Description: Loss of Data from Tower DAS Alarm

Purpose: Alert operator of loss of DAS signals from the tower

Action:

- Indicate warning or alarm on designated displays

Interval: 5 seconds

Warning Displays: None

Alarm Displays: D1

Criteria: (activate warning/alarm sequence if following conditions are true)

Warning

None

Alarm

Loss of Data from Tower DAS

Definition of terms: None

Warning Sequence:

- None

Alarm Sequence:

- Display Alarm

6.2 DATA DISPLAYS

Real-time CRT Data Displays will be viewed by B&V test personnel during BMSR testing to monitor control-related variables, to be alerted to warning and alarm conditions, and for real-time evaluation of BMSR performance as computer resources allow. The principal display for operator monitoring for control purposes will be the STFF 2644 alphanumeric CRT, chosen for its fast update potential. All warnings and alarms will be indicated on that display screen. The Ramtek Colorgraphic screen will be used for displaying a flow chart of the BMSR and Air Supply System, as well as key performance indicators. Selected warnings and alarms will also be indicated on that display, although the comparatively long update time for the Colorgraphic display will limit its value for control purposes. The Tektronix display screen will be used for plotting of flux levels within the BMSR. Although the display screen is faint, the capability to hard-copy the display make it the preferred choice; the graphics-related computations involved will be run in the computer background mode. Other displays will be programmed for the Electrohomes alphanumeric screens.

Each of the proposed displays is described in detail on the pages to follow. Each display description includes a page with purpose, update time, screen, and displayed variables listed; this page is followed by a drawing of the display layout. Sensors, computations, and warning/alarms are identified on the drawing (or in the case of displays D1, D2, and D3, on a separate drawing for clarity). Representative variable values have been shown on the drawings. These values are not necessarily typical values, but rather represent the signficant figures (and decimal points) which are to be included. Sensor signals, computations, and warnings/ alarms have been identified in Subsections 6.1.1, 6.1.2, 6.1.3, 6.1.6, and 6.1.7.

Display Label: D1

Description: BMSR Operator Monitor Display

Purpose:

- Operator monitoring of control-related variables
- Display of warning and alarm conditions

Update Time: 4 seconds Screen: 2644

Table of Displayed Data:

BMSR Control System Signals

CS-MP001	CS-MP013	CS-MP026
CS-MP005 (Twice)	CS-MP014	CS-MP031
	CS-MP019	CS-MP032
	CS-MP020	CS-MP037
	CS-MP025	CS-MP038

BMSR Instrumentation System Signals

PT-AB001	PT-AR006	TE-AD005
PT-AC002	PT-AR007	TE-AE006
PT-AD003	TE-AC002	TE-AF007
PT-AE004	TE-AB003	TE-AR008 (Twice)
PT-AF005	TE-AC004	

Air Supply System Signals

AS-001	AS-006	AS-014
AS-002	AS-008	AS-021
AS-003	AS-009	AS-022
AS-004	AS-011	AS-023
AS-005	AS-012	

Computations

HFMW	MR (twice)	MD	MAS1	TCVMAX	TSCMAX
HFMC	MB	ME	SMAX	THDMAX	TSFMAX
	MC	MF	TCMAX	TPBMAX	TUBMAX
				TSCTMX	VIMAX

-Continued-

Warnings/Alarms

W1, A1	W8, A8
W2, A2	W9, A9
W3, A3	W10, A10
W4, A4	W11, A11
W5, A5	W12, A12, A13
W6, A6	W14, A14
W7, A7	W16, A16
A 17	

STTF-Provided Data

Calorimeter Coolant Flow Monitor (ON, OFF)

Aperture Input Power in kW_t (J)

Air Supply Hydrocarbons, HCAR

Data Reference

Date

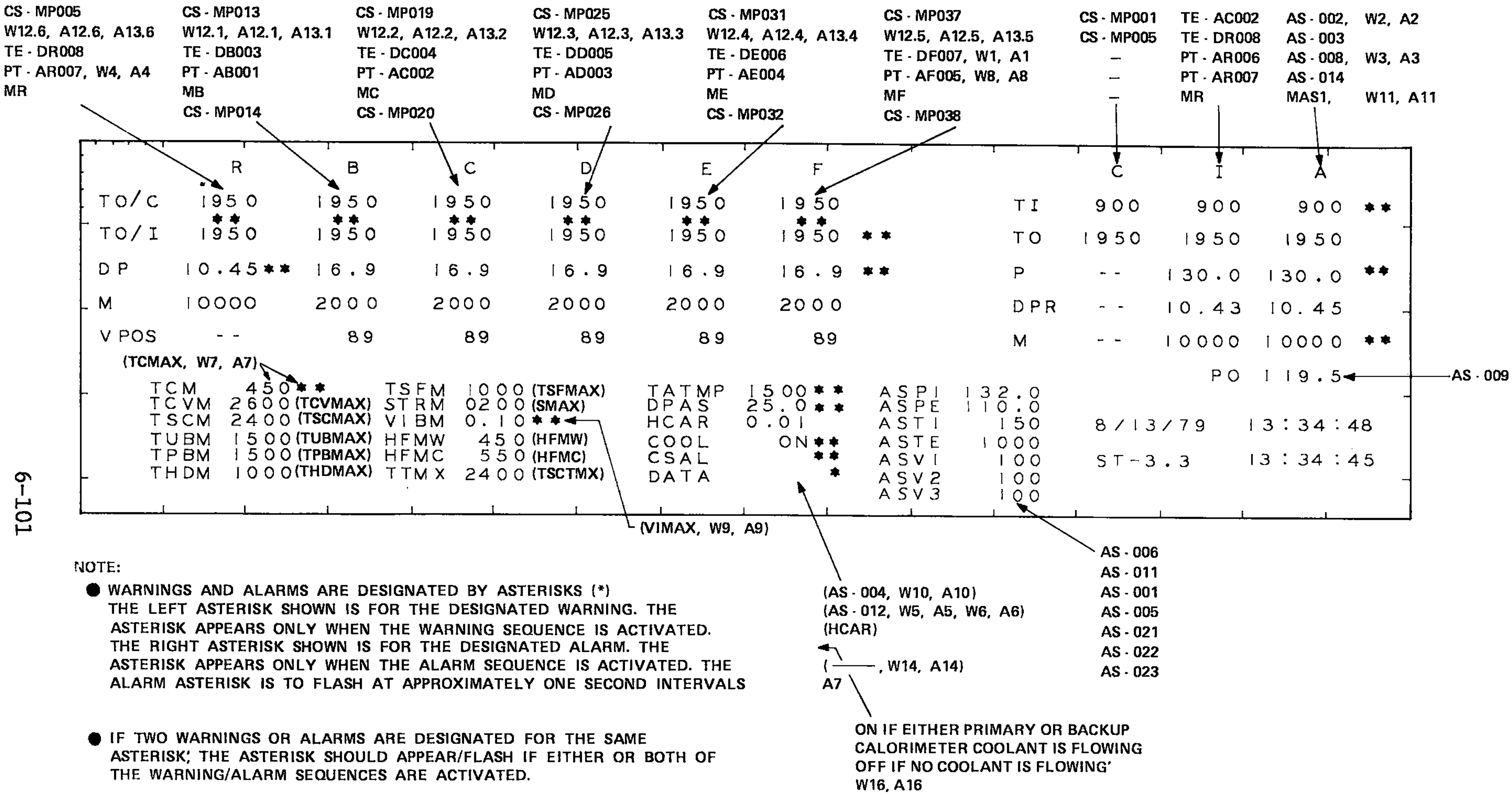
Run I.D. (B&V Test ID)

Real-time

Time of last data update

```
              R        B        C        D        E        F                       C       I       A
TO/C        1950     1950     1950     1950     1950     1950            TI      900     900     900 **
             **       **       **       **       **       **
TO/I        1950     1950     1950     1950     1950     1950 **         TO     1950    1950    1950
DP         10.45**   16.9     16.9     16.9     16.9     16.9 **         P        --   130.0   130.0 **
M          10000     2000     2000     2000     2000     2000            DPR      --   10.43   10.45
VPOS          --       89       89       89       89       89            M        --   10000   10000 **
                                                                                     PO  119.5
    TCM    450**     TSFM  1000        TATMP  1500**   ASPI  132.0
    TCVM  2600       STRM  0200        DPAS   25.0**   ASPE  110.0
    TSCM  2400       VIBM  0.10        HCAR   0.01     ASTI    150     8/13/79     13:34:48
    TUBM  1500       HFMW   450        COOL     ON**   ASTE   1000
    TPBM  1500       HFMC   550        CSAL       **   ASV1    100     ST-3.3      13:34:45
    THDM  1000       TTMX  2400        DATA        *   ASV2    100
                                                       ASV3    100
```

FIGURE 6-2. DISPLAY D1, BMSR OPERATOR MONITOR DISPLAY



NOTE:

- WARNINGS AND ALARMS ARE DESIGNATED BY ASTERISKS (*) THE LEFT ASTERISK SHOWN IS FOR THE DESIGNATED WARNING. THE ASTERISK APPEARS ONLY WHEN THE WARNING SEQUENCE IS ACTIVATED. THE RIGHT ASTERISK SHOWN IS FOR THE DESIGNATED ALARM. THE ASTERISK APPEARS ONLY WHEN THE ALARM SEQUENCE IS ACTIVATED. THE ALARM ASTERISK IS TO FLASH AT APPROXIMATELY ONE SECOND INTERVALS

- IF TWO WARNINGS OR ALARMS ARE DESIGNATED FOR THE SAME ASTERISK; THE ASTERISK SHOULD APPEAR/FLASH IF EITHER OR BOTH OF THE WARNING/ALARM SEQUENCES ARE ACTIVATED.

FIGURE 6-3. DISPLAY D1, BMSR OPERATOR MONITOR DISPLAY: DEFINITION OF DATA IDENTIFYING LABELS

Display Label: D2

Description: BMSR Flow Chart and Performance

Purpose:

- Provide comprehensive display of BMSR variables and performance
- Indicate warnings and alarms

Update Time: 30-40 seconds Screen: Colorgraphic

Table of Displayed Data:

Control System Signals

CS-MP004	CS-MP020	CS-MP030
CS-MP012	CS-MP024	CS-MP036
CS-MP014	CS-MP026	CS-MP038
CS-MP018		

Instrumentation System Signals

PT-AR006	TE-DB003 (twice)	TE-DE006 (twice)
PT-AR007	TE-DC004 (twice)	TE-DF007 (twice)
TE-AC002	TE-DD005 (twice)	TE-DR008 (twice)

Air Supply System Signals

AS-001	AS-005	AS-010
AS-004	AS-009	AS-011

Computations

HTFB	MAS2	MR (twice)	QONB	QRR
HTFC	MB (twice)	QB	QONC	REFF
HTFD	MC (twice)	QC	QOND	
HTFE	MD (twice)	QD	QONE	
HTFF	ME (twice)	QE	QONF	TCVMAX
HFMC	MF (twice)	QF	QR (twice)	TSCMAX
HFMW				TUBMAX

Warnings/Alarms

W1, A1 (twice)	W3, A3	W8, A8
W2, A2	W4, A4	W10, A10

-Continued-

STTF-Provided Data

Aperture Input Power in kW_t (J)

Insolation in kW/m^2

Data Reference

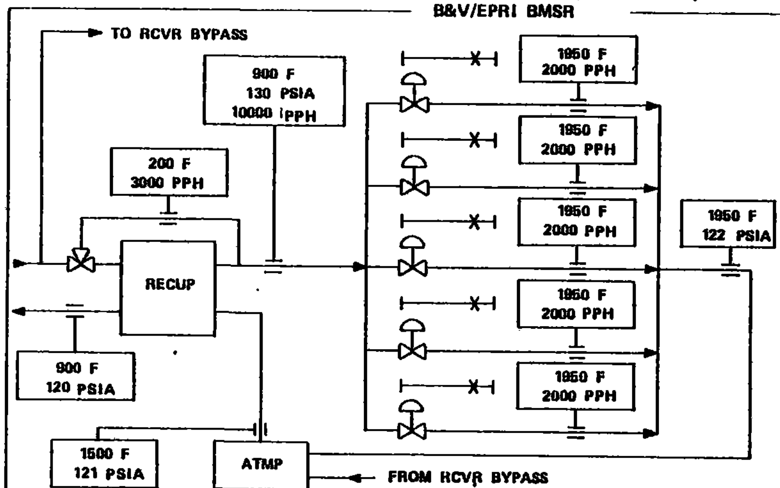
Date

Run ID

Real-time

Data Update Time

B&V/EPRI BMSR



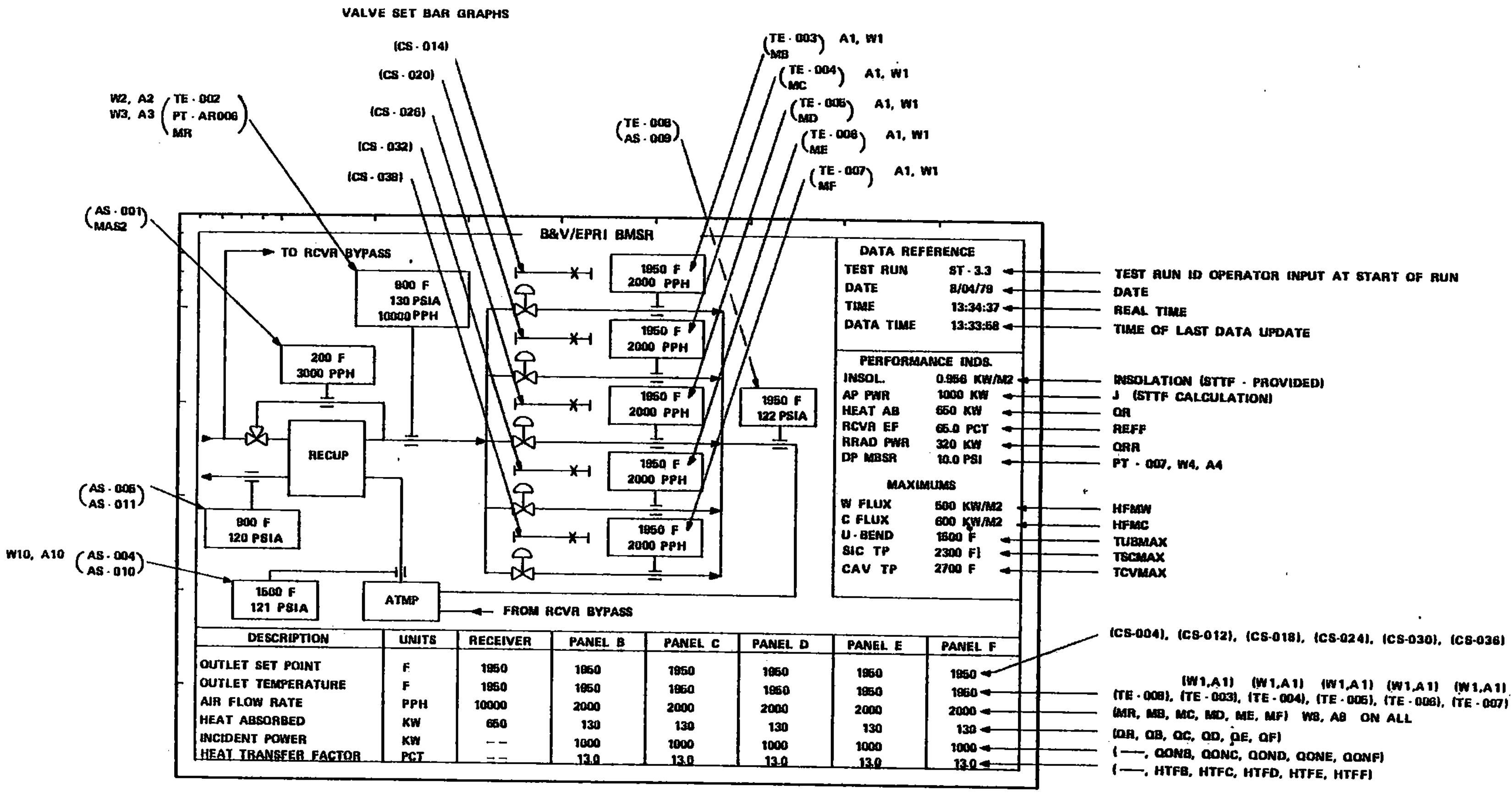
DATA REFERENCE	
TEST RUN	ST - 3.3
DATE	8/04/79
TIME	13:34:37
DATA TIME	13:33:58

PERFORMANCE INDS.	
INSOL.	0.958 KW/M2
AP PWR	1000 KW
HEAT AB	650 KW
RCVR EF	65.0 PCT
RRAD PWR	320 KW
DP BMSR	10.0 PSI
MAXIMUMS	
W FLUX	500 KW/M2
C FLUX	600 KW/M2
U-BEND	1500 F
SIC TP	2300 F
CAV TP	2700 F

DESCRIPTION	UNITS	RECEIVER	PANEL B	PANEL C	PANEL D	PANEL E	PANEL F
OUTLET SET POINT	F	1950	1950	1950	1950	1950	1950
OUTLET TEMPERATURE	F	1950	1950	1950	1950	1950	1950
AIR FLOW RATE	PPH	10000	2000	2000	2000	2000	2000
HEAT ABSORBED	KW	650	130	130	130	130	130
INCIDENT POWER	KW	--	1000	1000	1000	1000	1000
HEAT TRANSFER FACTOR	PCT	--	13.0	13.0	13.0	13.0	13.0

FIGURE 6-4. DISPLAY D2, BMSR FLOW CHART AND PERFORMANCE

A-029
031279



DESCRIPTION	UNITS	RECEIVER	PANEL B	PANEL C	PANEL D	PANEL E	PANEL F
OUTLET SET POINT	F	1950	1950	1950	1950	1950	1950
OUTLET TEMPERATURE	F	1950	1950	1950	1950	1950	1950
AIR FLOW RATE	PPH	10000	2000	2000	2000	2000	2000
HEAT ABSORBED	KW	650	130	130	130	130	130
INCIDENT POWER	KW	--	1000	1000	1000	1000	1000
HEAT TRANSFER FACTOR	PCT	--	13.0	13.0	13.0	13.0	13.0

NOTES:
- WARNINGS ARE INDICATED BY TURNING THE CORRESPONDING BACKGROUND FOR THE VARIABLE YELLOW
- ALARMS ARE INDICATED BY TURNING THE CORRESPONDING BACKGROUND FOR THE VARIABLE RED; ALARMS SUPERSEDE WARNINGS
- FLOW CHART AND TABLE LINES ARE WHITE
- VARIABLE VALUES ARE GREEN
- DESCRIPTIVE LABELS, UNITS, ETC ARE WHITE
- SIGNAL LABELS SHOWN GIVE ONLY SIGNAL TYPE AND NUMBER FOR BREVITY (e.g. TE - 002 RATHER THAN TE - AC002)

FIGURE 6-5. DISPLAY D2, BMSR FLOW CHART AND PERFORMANCE: DEFINITION OF DATA IDENTIFYING LABELS

Display Label: D3

Description: Cavity Flux and Panel Performance

Purpose:

- Provide visual evaluation of cavity flux
- Real-time evaluation of panel performance using key indicators
- Hard-copy graph capabilities in real-time

Update Time: Graphics in computer background mode

Screen: Tektronix

Table of Displayed Data:

Control System Signals

none

Instrumentation System Signals

HF-CA001	HF-CH028	TE-DD005	TE-UC037
HF-CA002	HF-CH029	TE-DE006	TE-UD038
HF-CA003	HF-CG030	TE-DF007	TE-UE039
HF-CA004	HF-CG031	TE-DR008	TE-UE040
HF-CA005	HF-CG032	TE-UB033	TE-UE041
HF-CH025	HF-CG033	TE-UB034	TE-UE042
HF-CH026	TE-DB003	TE-UB035	TE-UF043
HF-CH027	TE-DC004	TE-UB036	TE-AC002

Air Supply System Signals

none

Computations

HTFB	IHF12	IHF23	ME	QOND
HTFC	IHF13	IHF24	MF	QONE
HTFD	IHF14	KFACB	MR	QONF
HTFE	IHF15	KFACC	QB	QR
HTFF	IHF16	KFACD	QC	TSC10
IHF06	IHF17	KFACE	QD	TSC13
IHF07	IHF18	KFACF	QE	TSC16

-Continued-

Computations

IHF08	IHF19	MB	QF	TSC19
IHF09	IHF20	MC	QONB	TSC24
IHF10	IHF21	MD	QONC	
IHF11	IHF22	QRR	REFF	

Warnings/Alarms

none

STFF-Provided Data

Aperture Input Power in kW_t (J)

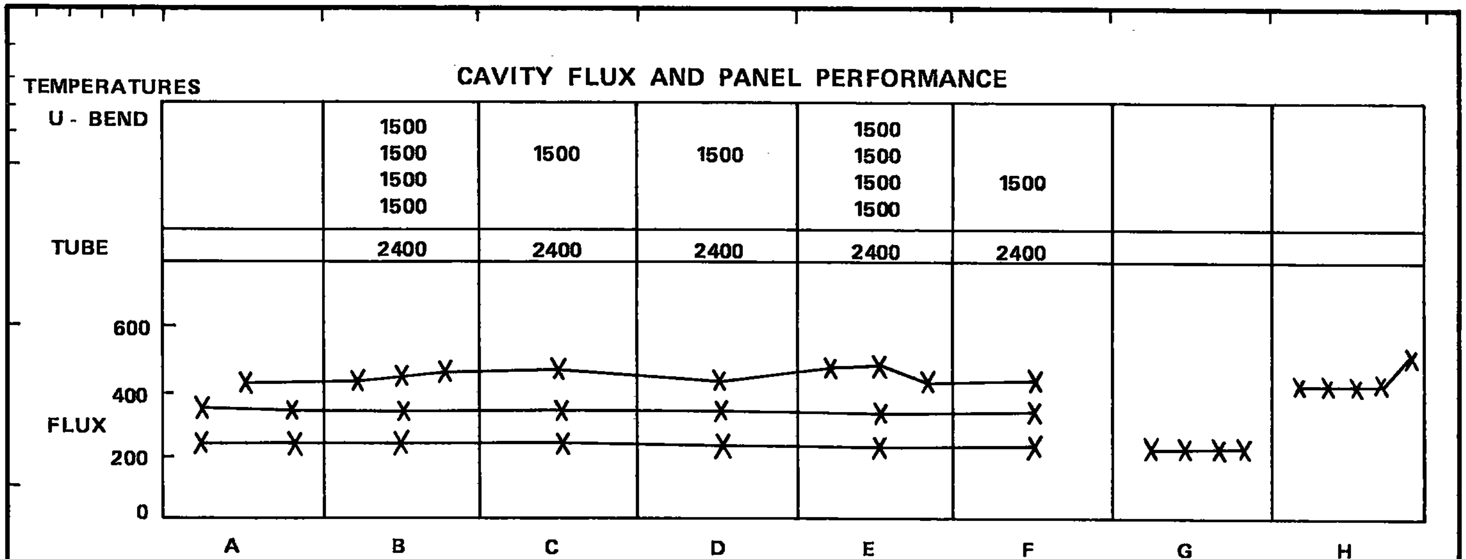
Reference Data

Date

Run ID

Real-Time

Data Update Time



DESCRIPTION	UNITS	RECEIVER	PANEL B	PANEL C	PANEL D	PANEL E	PANEL F
K FACTOR	–	–	1.20	1.20	1.20	1.20	1.20
INCIDENT POWER	KW	–	1000	1000	1000	1000	1000
OUTLET AIR TEMPERATURE	F	1950	1950	1950	1950	1950	1950
AIR FLOW RATE	PPH	10000	2000	2000	2000	2000	2000
HEAT ABSORBED	KW	650	130	130	130	130	130
HEAT TRANSFER FACTOR	PCT	–	13.0	13.0	13.0	13.0	13.0

REAL TIME 13:34:54 TI 0900 F J 1000 kW TEST RUN ST - 3.3

DATA TIME 13:34:14 REFF 65.0 % QRR 350 kW DATE 8/24/79

FIGURE 6-6. DISPLAY D3, CAVITY FLUX AND PANEL PERFORMANCE

A-029
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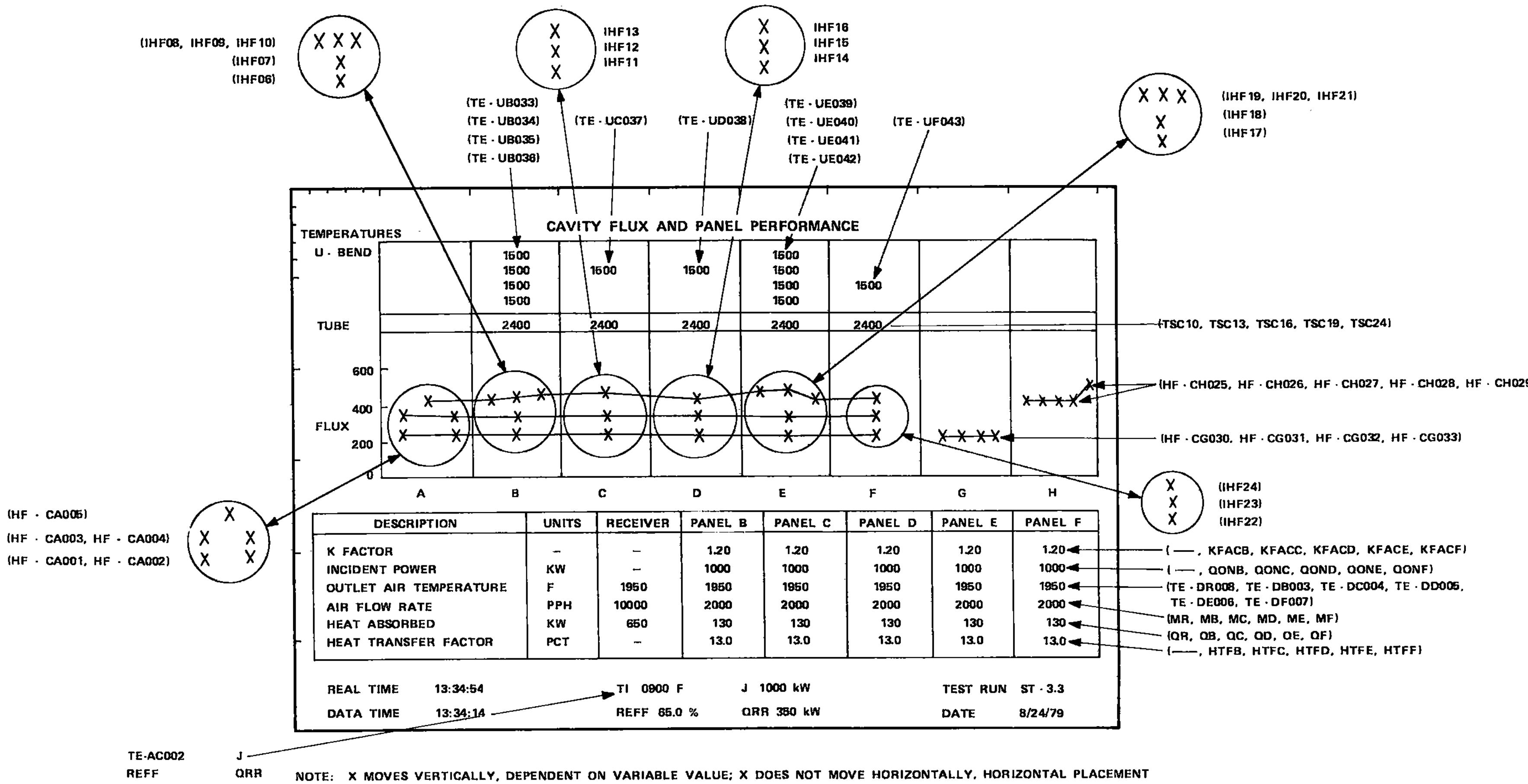

NOTE: X MOVES VERTICALLY, DEPENDENT ON VARIABLE VALUE; X DOES NOT MOVE HORIZONTALLY. HORIZONTAL PLACEMENT OF X's SHOULD DIVIDE THE PANEL SECTION INTO EQUAL PARTS. IN MANY CASES SEVERAL X's ARE ON THE SAME VERTICAL AXIS.

LINES SHOULD CONNECT APPROPRIATE X's AS SHOWN.

FIGURE 6-7. DISPLAY D3, CAVITY FLUX AND PANEL PERFORMANCE: DEFINITION OF DATA IDENTIFYING LABELS

Display Label: D4

Description: BMSR Header/Duct Region Temperatures

Purpose: Real-time evaluation of BMSR duct and header temperatures

Update Time: 60 seconds Screen: Electrohomes alphanumeric

Table of Displayed Data:

Control System Signals

none

Instrumentation System Signals

TE-JD056	TE-HD064	TE-HD071	TE-ZG078
TE-JD057	TE-HD065	TE-DD072	TE-ZG079
TE-JD058	TE-HD066	TE-DD073	TE-ZG080
TE-JD059	TE-HD067	TE-DD074	TE-FG093
TE-JD060	TE-HD068	TE-DD075	TE-FG094
TE-JD061	TE-HD069	TE-DD076	TE-FG095
TE-HD062	TE-HD070	TE-DD077	TE-FG096
TE-HD063			

Air Supply System Signals

none

Computations

none

STTF-Provided Data

none

Reference Data

Date

Run ID

Real-Time

Data Update Time

A-029
031279

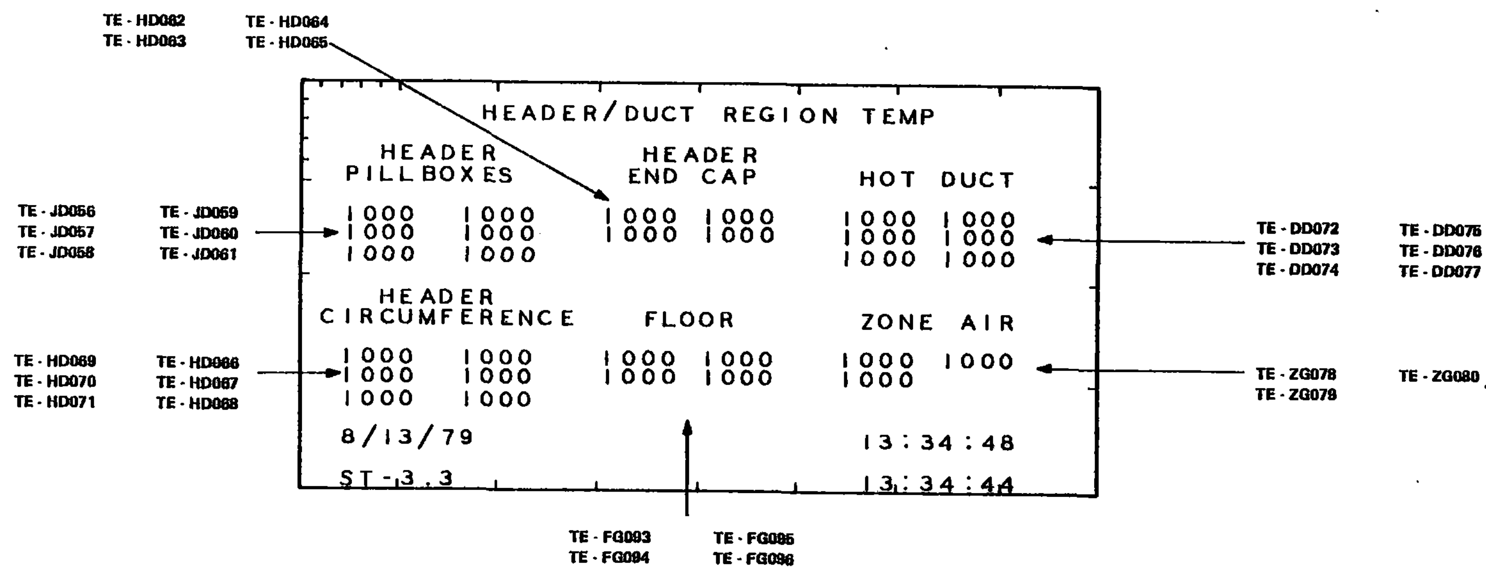

FIGURE 6-8. DISPLAY D4, BMSR HEADER/DUCT REGION TEMPERATURES, WITH DATA IDENTIFYING LABELS

Display Label: D5

Description: BMSR Cavity, Insulation, Shell, and Frame Temperatures

Purpose: Real-time evaluation of cavity and receiver structure temperatures

Update Time: 120 seconds Screen: Electrohomes alphanumeric

Table of Displayed Data:

Control System Signals

none

Instrumentation System Signals

TE-IA009	TE-SB082	TE-SF090	TE-FD101
TE-IB010	TE-SB083	TE-SF091	TE-FD102
TE-IC011	TE-SC084	TE-SH092	TE-IB103
TE-ID012	TE-SC085	TE-FG096	TE-IB104
TE-IE013	TE-SD086	TE-FD097	TE-IC105
TE-IF014	TE-SD087	TE-FD098	TE-IC106
TE-IH015	TE-SE088	TE-FD099	TE-FD113
TE-SA081	TE-SE089	TE-FD100	TE-SX135

Air Supply System Signals

none

Computations

TCAV05	TCAV13	TCAV19	TCAV29
TCAV10	TCAV16	TCAV24	TCAV31

STTF-Provided Data

None

Reference Data

Date

Run ID

Real-Time

Data Update Time

13:34:23 CAVITY, FRAME, SHELL TEMPERATURES ST-3.3 ← Test Run ID
13:34:18 8/08/79 ← Date

	SURF	INNR	MIDL	OUTR	SHL 1	SHL 2	FRME
CL	2600	2200	–	–	200	–	–
FL	2300	–	–	–	700	–	700
A	2300		–	–	200	200	700
B	2300	2000	1400	800	200	200	700
C	2300	2000	1400	800	200	200	200
D	2300	2000	–	–	200	200	700
E	2300	2000	–	–	200	200	700
F	2300	2000	–	–	200	200	700

TCAV29	TE-IH015	–	–	TE-SH092	–	–
TCAV31	–	–	–	TE-FG096	–	TE-FD100
TCAV05	TE-IA009	–	–	TE-SX135	TE-SA081	TE-FD101
TCAV10	TE-IB010	TE-IB103	TE-IB104	TE-SB083	TE-SB082	TE-FD102
TCAV13	TE-IC011	TE-IC105	TE-IC106	TE-SC085	TE-SC084	TE-FD113
TCAV16	TE-ID012	–	–	TE-SD087	TE-SD086	TE-FD097
TCAV19	TE-IE013	–	–	TE-SE089	TE-SE088	TE-FD098
TCAV24	TE-IF014	–	–	TE-SF091	TE-SF090	TE-FD099

FIGURE 6-9. DISPLAY D5, BMSR CAVITY, INSULATION, SHELL AND FRAME TEMPERATURES, WITH DATA IDENTIFYING LABELS

Display Label: D6

Description: BMSR Strains

Purpose: Real-time evaluation of all BMSR strains except U-bend strains

Update Time: 120 seconds Screen: Electrohomes alphanumeric

Table of Displayed Data:

Control System Signals

none

Instrumentation System Signal

SG-FD004	SG-FD011	SG-AD022	SG-HD029
SG-FD005	SG-FD012	SG-HD023	SG-HD030
SG-FD006	SG-AD017	SG-HD024	SG-HD031
SG-FD007	SG-AD018	SG-HD025	SG-HD032
SG-FD008	SG-AD019	SG-HD026	SG-DD033
SG-FD009	SG-AD020	SG-HD027	SG-DD034
SG-FD010	SG-AD021	SG-HD028	SG-DD035
SG-UC001	SG-UC002	SG-UC003	

Air Supply System Signals

none

STFF-Provided Data

none

Reference Data

Date

Run ID

Real-Time

Data Update Time

A-029
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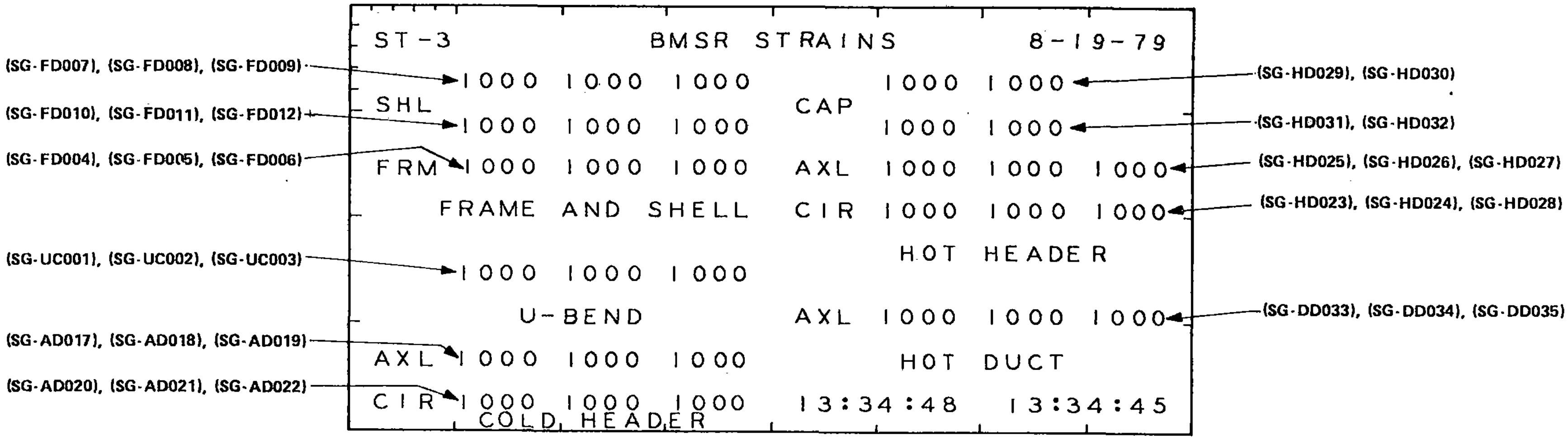

NOTE: Display shall be formatted to allow display of negative strains.

FIGURE 6-10. DISPLAY D6, BMSR STRAINS, WITH DATA IDENTIFYING LABELS

Display Label: D7

Description: Heat Fluxes

Purpose: Real-time monitor of measured heat fluxes and calorimeter temperatures

Update Time: 15 seconds Screen: Electrohomes alphanumeric

Table of Displayed Data:

Control System Signals

none

Instrumentation System Signals

HF-CA001	HF-CC012	HF-CF023	HF-CC034	HF-SH045
HF-CA002	HF-CC013	HF-CF024	HF-CD035	HF-CA046
HF-CA003	HF-CD014	HF-CH025	HF-CE036	TE-GB119
HF-CA004	HF-CD015	HF-CH026	HF-CG037	TE-GB120
HF-CA005	HF-CD016	HF-CH027	HF-CA038	TE-GD121
HF-CB006	HF-CE017	HF-CH028	HF-CB039	TE-GE122
HF-CB007	HF-CE018	HF-CH029	HF-CF040	TE-GE123
HF-CB008	HF-CE019	HF-CG030	HF-CD041	TE-GE124
HF-CB009	HF-CE020	HF-CG031	HF-CD042	TE-GE125
HF-CB010	HF-CE021	HF-CG032	HF-SB043	TE-GH126
HF-CC011	HF-CF022	HF-CG033	HF-SC044	

Air Supply System Sensors

none

Computations

none

STTF-Provided Data

none

Reference Data

Date

Run ID

Real-Time

Data Update Time

A-029
062279

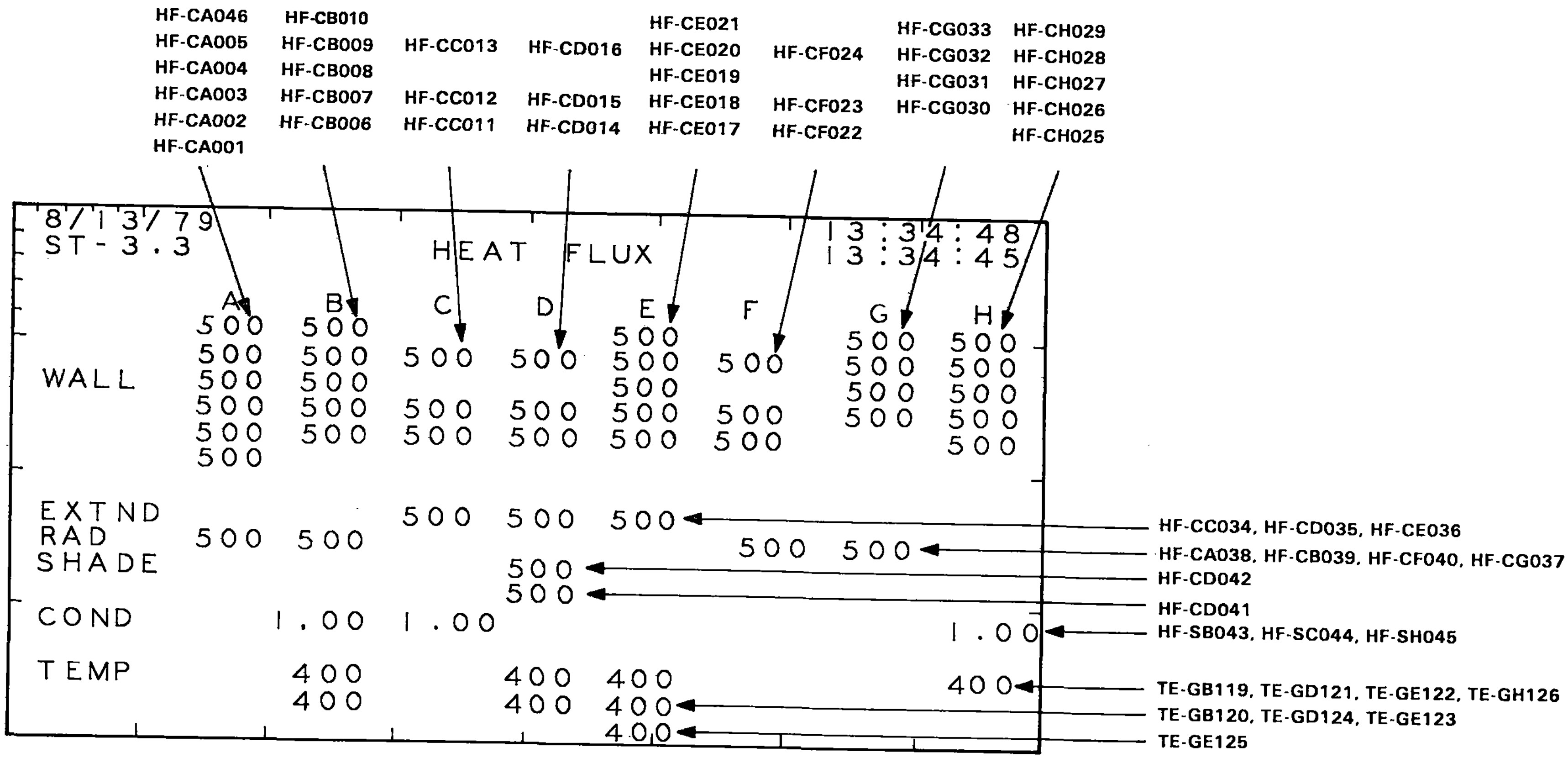

FIGURE 6-11. DISPLAY D7, HEAT FLUXES, WITH DATA IDENTIFYING LABELS

Display Label: D8

Description: U-bend Temperatures

Purpose: Real-time monitoring of U-bend temperature

Update Time: 15 seconds   Screen: Electrohomes alphanumeric

Table of Displayed Data:

BMSR Control System Signals

none

BMSR Instrumentation System Signals

TE-AC002	TE-UB033	TE-UE039
TE-DB003	TE-UB034	TE-UE040
TE-DC004	TE-UB035	TE-UE041
TE-DD005	TE-UB036	TE-UE042
TE-DE006	TE-UC037	TE-UF043
TE-DF007	TE-UD038	VT-UD001
		VT-UD002

Air Supply System Signals

none

Computations

TSC10	TSC13	TSC16	TSC19	TSC24

Warnings/Alarms

none

STTF-Provided Data

none

Reference Data

Date

Run ID

Real-Time

Data Update Time

A-029
031279

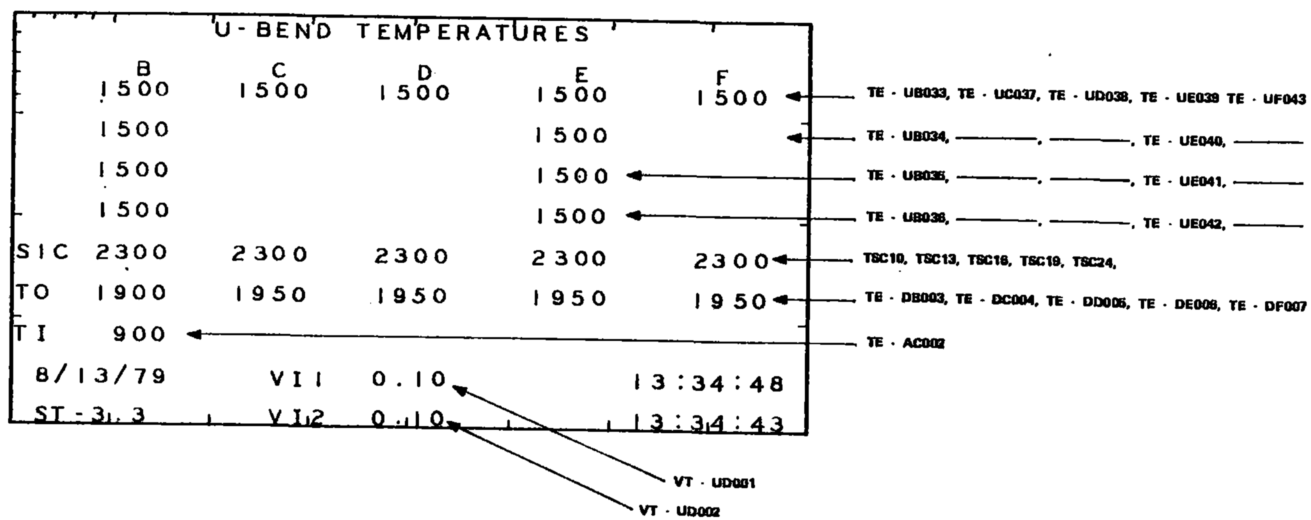

FIGURE 6-12. DISPLAY D8, U-BEND TEMPERATURES WITH DATA IDENTIFYING LABELS

Display Label: D9

Description: Computer Set Points

Purpose: Allows Test Operator to check set points and valve control override signals

Update Time: 10 seconds   Screen: Electrohomes alphanumeric

Table of Displayed Data:

BMSR Control System Signals

CS-KP002	CS-KP011	CS-KP021	CS-KP029
CS-KP008	CS-KP015	CS-KP023	CS-KP033
CS-KP009	CS-KP017	CS-KP027	CS-KP035

BMSR Instrumentation System Signals

none

Air Supply System Signals

AS-015   AS-016   AS-017

Computations

none

Warnings/Alarms

none

STTF-Provided Data

Aperture Input Power, J, in kW_t

Data Reference

Date

Run ID

Real-Time

Data Update Time

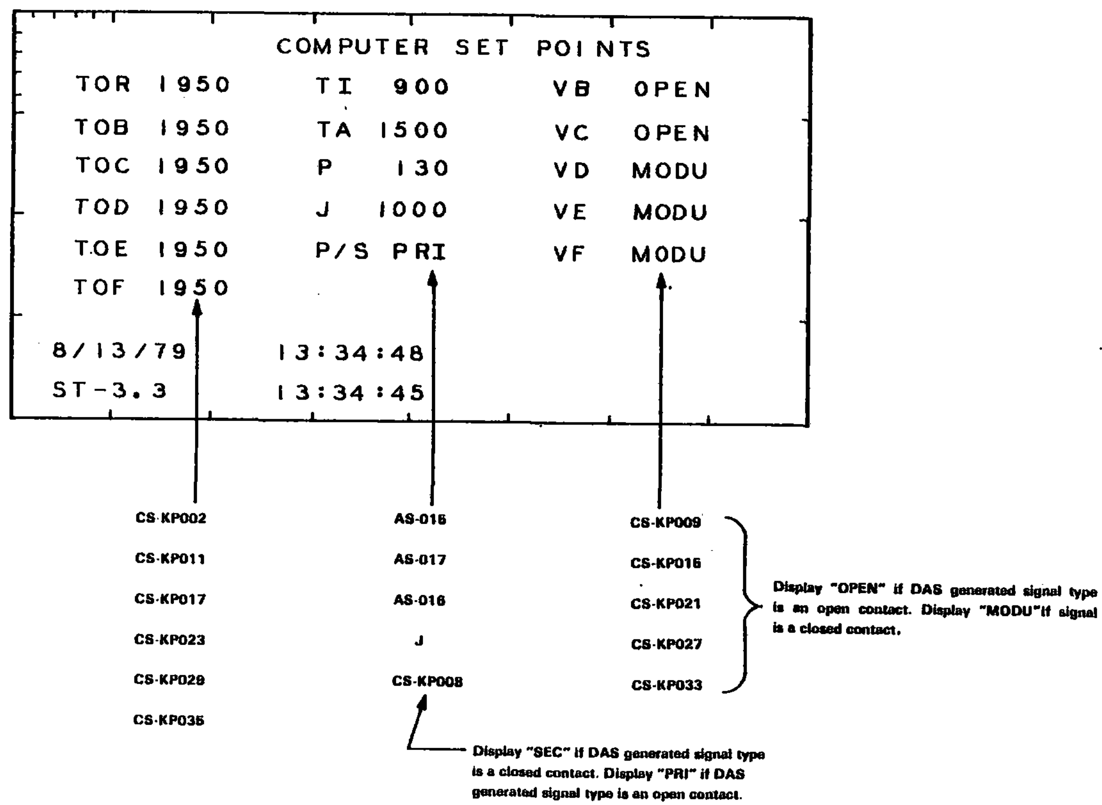

FIGURE 6-13. DISPLAY D9, COMPUTER SET POINTS, WITH DATA IDENTIFYING LABELS

Display Label: D10

Description: SiC Tube and Joint Disc Temperatures

Purpose: Real-time monitor of measured SiC temperatures

Update Time: 15 seconds Screen: Electrohomes alphanumeric

Table of Displayed Data:

Control System Signals

none

Instrumentation System Signals

TE-TC017	TE-TD024	TE-TD031	TE-JD049
TE-TC018	TE-TC025	TE-TD032	TE-JD050
TE-TC019	TE-TC026	TE-JD044	TE-JD051
TE-TC020	TE-TC027	TE-JD045	TE-JD052
TE-TD021	TE-TC028	TE-JD046	TE-JD053
TE-TD022	TE-TD029	TE-JD047	TE-JD054
TE-TD023	TE-TD030	TE-JD048	TE-JD055

Air Supply System Sensors

none

Computations

none

STTF-Provided Data

none

Reference Data

Date

Run ID

Real-Time

Data Update Time

A-029
062279

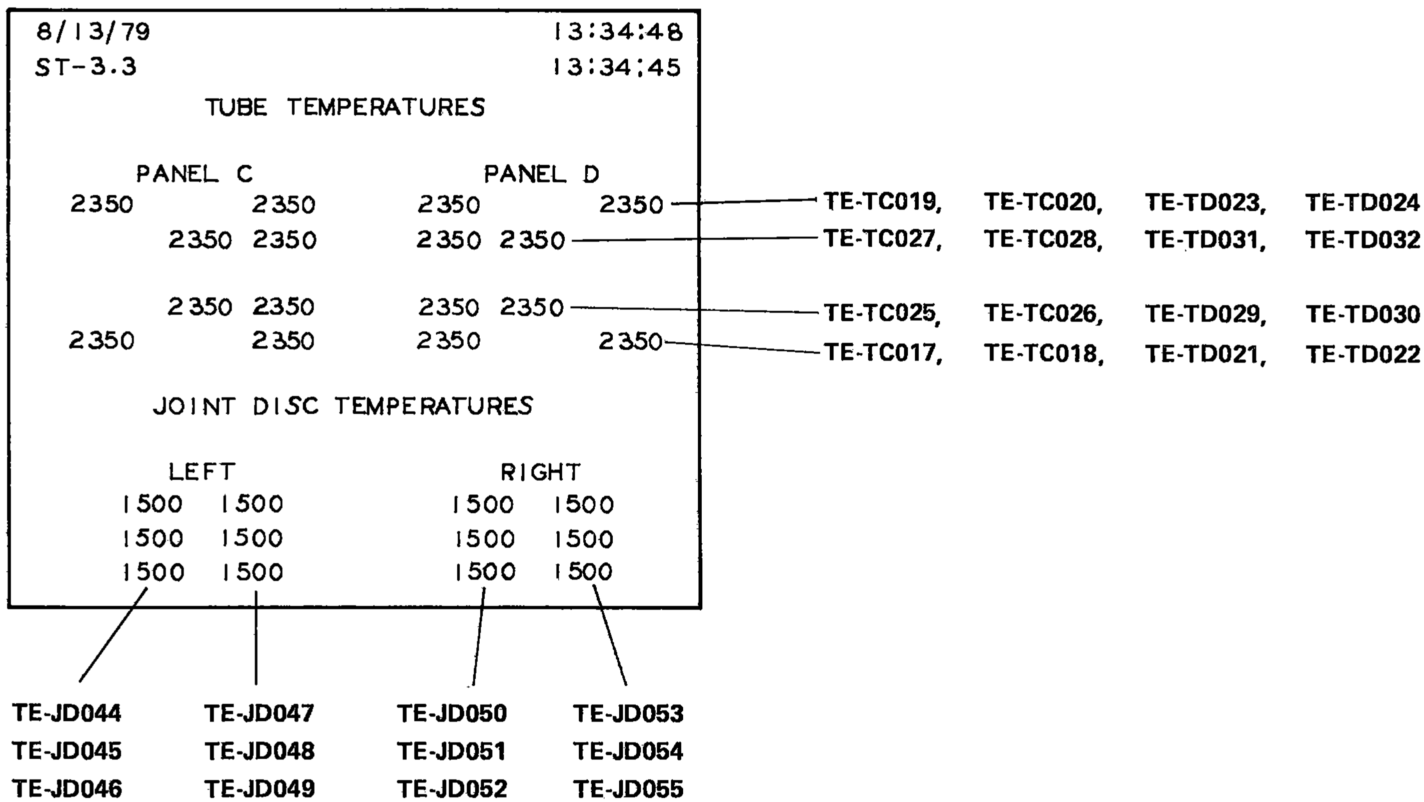

FIGURE 6-14. DISPLAY D10, SIC TUBE AND JOINT DISC TEMPERATURES, WITH DATA IDENTIFYING LABELS

6.3 ANALOG REQUIREMENTS

Analog data acquisition equipment will be required as diagnostic and evaluation tools during initial start-up and early testing of the BMSR. Exact requirements and methodologies will be identified later; the following are expected general requirements.

- High impedence input strip recorder for plotting variables as a function of time. Frequency response requirements are of the order of tens of hertz.
  - 14 channels, 0-10 volt input.
  - 6 channels, 4-20 mA input.
- Two oscilloscopes (or one dual-trace oscilloscope).

6.4 DATA EVALUATION AND STORAGE

Experimental data will be preliminarily evaluated at STTF in accordance with the methods outlined in Section 6.1. Data will be stored on tape for more rigorous post-test evaluation; this stored data will be included in the following.

- All data channels identified in Subsections 6.1.1 through 6.1.3 (BMSR Control System, BMSR Instrumentation System, and Air Supply System) at all sampled times, in engineering units.
- RTAF data (including aperture input power, heliostat status, and weather data), as identified in Subsection 6.1.4, STTF Support System, for all sampled or computed times, in engineering units.
- All computations, identified in Subsection 6.1.6, at 60 second intervals. Values computed less frequently than every 60 seconds need be stored only at update times.