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TRANSIENT SIMULATION
OF THE MDAC RECEIVER
TEST PANEL IN ITS STTF
TEST CONFIGURATION

15 June 1978

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June 27, 1978

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Subject: Transmittal of Aerospace Report on STTF Simulations,
Report No. ATR-78(7695-02)-2

Dear Mr. Castellano:

The subject report, a compilation of results obtained to date on the Aerospace STTF/MDAC receiver simulation task, is forwarded for your information. Please notify us if you wish distribution in addition to that listed below.

Very truly yours,

Elliott L. Katz
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FOREWORD

This report is written as a partial account of work performed for the Department of Energy, on the Solar Thermal Test Facility Project, under Contract Number E(04-3)-1101, Project Agreement No. 2.

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1. INTRODUCTION

This report describes the initial transient simulation of the McDonnell-Douglas (MDAC) receiver experiment integrated with the Solar Thermal Test Facility (STTF) configuration. The recently developed STTF computer simulation program (Reference 1) was used for the simulation. The program was amended to include MDAC receiver experiment and the hardware modifications to the STTF facility as required to support the experiment.

The thermal-hydraulic transients of the MDAC once-through steam generator for the 10 MW_t Solar Thermal Pilot Plant are essential in the study of the overall system performance of the receiver as well as for the design of its control system. The computer program was used to simulate the transient and steady-state characteristics and performance of the receiver test panel and to study key technical areas such as receiver panel/controller interaction and response. The program was also used to simulate part of the MDAC receiver test program at the STTF.

The STTF computer simulation program was first modified to incorporate facilities changes for the MDAC test configuration. The original program contained individual modules to simulate the collector field, cooling subsystem, steam depressurization/desuperheat subsystem, feedwater and control subsystems. The feedwater module was modified to add the new regenerative heat exchanger which is required to increase feedwater temperature to the MDAC receiver. A new subroutine was developed to simulate the MDAC receiver panel and the control module was modified to reflect MDAC experiment requirements.

The completed program was then used to study some key technical issues including:

- (1) Partial simulation of the panel test program at STTF
- (2) Receiver panel/controller interaction/response
- (3) Receiver panel steady state and transient characteristics

Unfortunately, lack of time (prior to contract closure) prevented the simulation of the full MDAC test program and prevented a full review of

operating conditions which an operational receiver panel would be subject to. A full analysis of the panel operating range could have led to extended recommendations on receiver development and test.

2. STTF/MDAC RECEIVER SYSTEM DESCRIPTION

The parts of STTF that are important to a dynamic simulation of the MDAC receiver experiment include the collector field, the heat rejection system, the control systems, and the experimental hardware. Figure 1 illustrates these subsystems in the MDAC test configuration. Each of these subsystems is described below.

2.1 INSOLATION

Insolation is not a physical part of STTF but is, nevertheless, an essential part of the overall system. Its characteristics and transients largely determine the capability and dynamic behavior of the system at any given time. Lack of control over behavior of the basic energy source places unusual demands on the designers and operators of the experiments. Insolation data for the simulation were extracted from the Albuquerque data tapes (Reference 2).

2.2 COLLECTOR FIELD

Power to the MDAC test panel is provided by the north field configuration of the STTF collector field. A total of 222 heliostats are available.

2.3 HEAT REJECTION SYSTEM (HRS)

The HRS provides preconditioned feedwater to the experiment and receives and processes high temperature, high pressure steam from the experiment. Excess energy is rejected by the cooling loop. Boiler quality feedwater can be supplied at a maximum rate of 25,000 lb/hr, at a pressure of 2250 psi, and at a maximum temperature of 400°F.

The HRS consists of the feedwater, depressurization/desuperheat, and cooling subsystems. These subsystems are lumped together in the present discussion since they operate essentially as a unit. However, special test requirements may require regrouping them in a different configuration. A more detailed description of this system and the analytical models used to simulate them is included in Reference 1.

The HRS processes high pressure steam returning from the receiver experiment. The steam passes through a pressure reducing valve, and into the deaerator/desuperheater vessel where it is condensed in the feedwater spray water loop. Part of the drain flow from the vessel is split and returned as condensate to the experiment, thus completing the experiment steam cycle. The remaining flow is directed to a heat exchanger where waste heat is rejected to a cooling tower system.

2.4 MDAC RECEIVER TEST ASSEMBLY

The parts of the MDAC test receiver assembly used in the simulation are the panel, flow control subassembly, and electrical control and instrumentation. A complete description of the MDAC experiment is included in Reference 3. The panel subassembly includes the tubes, insulation, thermal expansion provisions, backup structure, and manifolds. The function of the panel subassembly is to efficiently utilize incident thermal energy to convert inlet water into superheated steam.

The flow control subassembly includes orifices, valves, filters, and plumbing. The function of this subassembly is to direct and control the flow of water to the various parts of the receiver as directed by the electrical control and instrumentation subassembly. This subassembly also provides for filtering, flushing, and purging of the receiver panel.

The electrical control and instrumentation subassembly includes the sensors, signal conditioning equipment controller and control valve actuators. This subassembly determines the condition of the receiver and utilizes the data to inform the test operators and to direct the flow control subassembly in conjunction with commands received from the test operators.

2.5 TEST ASSEMBLY OPERATION

The experiment operation begins with feedwater from the receiver/STTF interface. The feedwater passes through the receiver water inlet valve (RWIV) and enters the receiver preheater where, during the early part of startup, it is electrically heated to the desired receiver inlet temperature. When sufficient energy becomes available later in the start sequence, all feedwater heating is accomplished in the facility preheater using receiver generated steam. After leaving the receiver preheater,

the feedwater passes through a flow measuring orifice (RBWFR-1) and a shedding vortex flowmeter (RBWFR-2) before arriving at the receiver boiler panel temperature control valve (RBTCV). The temperature control valve modulates the feedwater flow to the receiver panel to maintain the selected receiver steam outlet temperature despite diurnal and seasonal variations in heat load on the panel. The valve also regulates the start and shutdown sequences.

Under normal operating conditions, the feedwater flows upward through the receiver boiler panel, absorbs heat from the incident solar radiation, and leaves the upper end of the panel as superheated steam. As the steam exits from the receiver panel discharge manifold, it passes through a cyclone type receiver moisture separator (RMS) as a precautionary measure to ensure absolutely dry steam, and is then directed through the steam manifold and receiver downcomer steam inlet valve (RDSIV) to the receiver/STTF interface and the facility heat rejection system.

3. DYNAMIC MODELS OF THE MDAC RECEIVER PANEL AND CONTROLLER

This section describes the analytical model of the MDAC receiver test panel and the receiver steam temperature controller.

3.1 MDAC RECEIVER MODEL

The MDAC Receiver Model supplies the transient and steady-state performance characteristics of the actual receiver test panel. The panel (Figure 2) consists of 70 Incoloy 800 seamless tubes longitudinally seam welded together. Each tube is 0.550 inch O. D. by 269 inch I. D. by 45.5 feet long. The length includes a 3 foot length folded over at the bottom to protect the panel's water manifold from insolation and a 1.4 foot length folded over on top to protect the panel's steam manifold from insolation. Only the vertically oriented 41 foot center section will be exposed to concentrated insolation.

Nominally, a receiver panel will be required to accept water at 1800 psia and 550°F and deliver superheated steam at rated conditions of 1515 psia and 960°F. The panel must also be capable of delivering steam at derated conditions of 1515 psia and 650°F.

The receiver panel model was based on the performance of a typical tube shown schematically in Figure 3. The tube was partitioned into three sections, i. e., subcooled (or compressed) water, saturated two-phase mixture, and superheated steam. The length of each section was allowed to vary with time. Consequently, the other process variables such as pressure, temperature, enthalpy, etc., at these phase boundaries were also time-varying.

The basic model equations were derived from the integral forms of the fundamental equations of conservation of mass, momentum, and energy through the control volume approach. These three equations are presented in Table 1 for each of the three control volumes at the following three conditions:

- 1) The panel containing only subcooled water
- 2) The panel containing subcooled water and saturated two-phase mixture

Figure 2. MDAC Receiver Panel

- Node 1 - inlet properties
 2 - average subcooled properties
 3 - saturated liquid boundary
 4 - average saturated properties
 5 - saturated vapor boundary
 6 - average superheated properties
 7 - outlet properties

- Δ - tube metal nodes
 O - working fluid nodes
 l_{13} - subcooled length
 l_{35} - two-phase length
 l_{57} - superheated length
 l_{17} - insulation exposed length

Figure 3. Receiver Panel Model Schematic

Table 1
Receiver Panel Model Equations

Condition 1 - Receiver Panel Containing Subcooled Water

$$w_{f3} = w_{f2} = w_{f1}$$

$$P_{f3} = P_{f1} - \frac{g}{v_{f2}} \ell_{13} - F_{f2} v_{f2} w_{f2}^2$$

$$Q_{f2} = U_{f2} S \ell_{13} (T_{m2} - T_{f2})$$

$$\frac{du_{f2}}{dt} = \frac{v_{f2}}{\ell_{13} A} \left[w_{f2} (h_{f1} - h_{f3}) + Q_{f2} \right]$$

$$\frac{dh_{f3}}{dt} = \frac{v_{f2}}{\ell_{13} A} \left[2w_{f2} (h_{f2} - h_{f3}) + Q_{f2} \right]$$

$$\frac{dT_{m2}}{dt} = \frac{Q_{m2} - Q_{f2}}{C_m \ell_{13}}$$

Condition 2 - Receiver Panel Containing Subcooled Water and Saturated Two-Phase Mixture

$$w_{f2} = w_{f4} = w_{f3}$$

$$P_{f3} = \text{equation for condition 1}$$

$$P_{f5} = P_{f3} - \frac{g}{v_{f4}} \ell_{35} - F_{f4} v_{f4} w_{f4}$$

$$Q_{f2} = \text{equation for condition 1}$$

$$Q_{f4} = U_{f4} S \ell_{35} (T_{m4} - T_{f4})$$

Table 1 (Continued)

$$h_{f3} = h_{fsat}$$

$$h_{f5} = h_{f3} + \frac{Q_{f4}}{w_{f4}}$$

$$\frac{dT_{m2}}{dt} = \frac{Q_{m2} - Q_{f2}}{C_m \ell_{13}} + \frac{[T_{m3} - T_{m2}]}{\ell_{13}} \frac{d\ell_{13}}{dt}$$

$$\frac{d\ell_{13}}{dt} = - \frac{v_{f3}}{A} \frac{[w_{f2} (h_{f1} - h_{f3}) + Q_{f2}]}{(h_{f3} - u_{f2})}$$

Condition 3 - Receiver Panel Containing Subcooled Water, Saturated Two-Phase Mixture, and Superheated Steam

$$w_{f7} = w_{f6} = w_{f5}$$

$$P_{f3} = \text{equation for condition 1}$$

$$P_{f5} = \text{equation for condition 2}$$

$$P_{f7} = P_{f5} - \frac{g}{v_{f6}} \ell_{57} - F_{f6} v_{f6} w_{f6}^2$$

$$Q_{f2} = \text{equation for condition 1}$$

$$Q_{f4} = \text{equation for condition 2}$$

$$Q_{f6} = U_{f6} S \ell_{57} (T_{m4} - T_{f4})$$

$$h_{f3} = h_{fsat}$$

$$h_{f5} = h_{vsat}$$

Table 1 (Continued)

$$h_{f7} = h_{f5} + Q_{f6}/w_{f6}$$

$$\frac{dT_{m2}}{dt} = \text{equation for condition 2}$$

$$\frac{dT_{m4}}{dt} = \frac{Q_{m4} - Q_{f4}}{C_m l_{35}} - \frac{[T_{m3} - T_{m4}]}{l_{35}} \frac{dl_{13}}{dt} + \frac{[T_{m5} - T_{m4}]}{l_{35}} \frac{dl_{15}}{dt}$$

$$\frac{dT_{m6}}{dt} = \frac{Q_{m6} - Q_{f6}}{C_m l_{57}} - \frac{[T_{m5} - T_{m6}]}{l_{57}} \frac{dl_{15}}{dt}$$

$$\frac{dl_{13}}{dt} = \text{equation for condition 2}$$

$$\frac{dl_{15}}{dt} = - \frac{v_{fs}}{A} \frac{[w_{f4} (h_{f1} - h_{f5}) + Q_{f2} + Q_{f4}]}{(h_{f5} - u_{f4})}$$

Nomenclature

• Parameters

- A = cross-sectional area
- C_m = panel heat capacity per unit length
- F = steady-state flow coefficient
- g = local acceleration due to gravity
- h = specific enthalpy
- l = length
- P = pressure
- Q = rate of heat transfer
- S = surface area per unit length
- T = temperature
- u = specific internal energy

Table 1 (Continued)

U = heat transfer coefficient

v = specific volume

w = mass flow rate

• Subscripts

f = fluid

m = metal

1 = inlet properties

2 = average subcooled properties

3 = saturated liquid boundary

4 = average saturated properties

5 = saturated vapor boundary

6 = average superheated properties

7 = outlet properties

- 3) The panel containing all three fluid states - subcooled water, two-phase mixture, and superheated steam.

Different forms of the conservation equations were required for each of the above conditions to insure continuity at the phase boundaries and to optimize computation speed.

The applicable tube wall to working fluid heat transfer equations are also presented in Table 1. The convective heat transfer coefficient used in the subcooled water and superheated steam control volumes was a slightly modified form of the Dittus Boelter correlation (Reference 4).

Heat transfer in the saturated two-phase region takes place by nucleate boiling in the low quality area and then shifts to film boiling in the higher quality region. The heat transfer correlation proposed by Thom, et al (Reference 5) was used for nucleate boiling and the correlation proposed by Bertoletti, et al (Reference 6) was used for the film boiling coefficient. The average heat transfer coefficient between the tube wall and the saturated two-phase liquid was determined by integrating the local heat transfer coefficient over the entire length of the two-phase central volume surface.

The receiver model also incorporates the pressure losses associated with the flow control valve at the inlet of the receiver panel. The position of this valve determines the flow rate through the panel for given feedwater inlet and steam header outlet conditions.

A receiver panel model solution diagram indicating the inlet and outlet variables is given in Figure 4.

3.2 TEMPERATURE CONTROLLER MODEL

The Temperature Controller Model strives to maintain the receiver panel outlet temperature at a selected set point value by commanding the position of the inlet flow control valve. The control logic proposed by MDAC could not be implemented due to the unavailability of the controller gain constants. Therefore, a simple proportional-and-integral controller (Figure 5) was implemented in the simulation.

Figure 4. Receiver Panel Solution Diagram

Figure 5. Receiver Temperature Control Logic

4. RESULTS AND DISCUSSION

The performance of the nonlinear dynamic model was evaluated at conditions specified by MDAC for 5 of 20 tests planned for the receiver panel at the STTF. The model was also used to predict the steady-state, transient open-loop, and transient closed-loop (controlled outlet temperature) characteristics of the receiver panel.

The normalized insolation profile of Figure 6 was used for all simulation runs and was derived from actual STTF data at noon equinox. All simulation runs also assumed an ambient temperature of 70°F and a wind velocity of 1 ft/sec. Plots of the simulation runs are included in Appendix A.

4.1 STEADY STATE PERFORMANCE

A summary of the steady-state performance of the model is shown in Table 2. The table also lists the proposed MDAC test number at the STTF which corresponds to the given simulation conditions. The MDAC test conditions are noted in Reference 3.

It should be realized that the various flow rates resulted from commanded positions of the flow control valve from a modeled outlet temperature controller. The differences between incident and absorbed power are due to reflected, emitted, and convected heat losses. All pressures, enthalpies and temperatures were rounded to whole numbers.

4.2 TRANSIENT OPEN LOOP PERFORMANCE

The results of the transient open-loop simulation runs are presented in the form of a series of curves representing the transient response of selected process variables at the steady-state conditions of Table 2 for step increases in incident power and flow rate. These results are open-loop in the sense that no effort was made to control the receiver panel's outlet temperature. For the given constant inlet and outlet conditions the process variables respond only to the step variations in incident power or flow rate (valve position) and therefore give an indication of the receiver panel's inherent thermal inertia.

Open loop response to changes in incident power are shown in Figures 7a to 7j and 8a to 8j. (App. A). Increased incident power increases the rate of heat transfer from the tube metal to the working fluid. The subcooled

Figure 6

TYPICAL MDAC RECEIVER PANEL HEAT FLUX PROFILE (FROM STTF DATA)

Table 2. Steady State Model Performance

MDAC Test No.		6	6	7	7	8	8	22	25	30
Process Variables		MODEL RESULTS								
INPUTS	incident power, MW	.53	.53	.78	.78	1.05	1.05	1.29	2.63	3.28
	inlet enthalpy, BTU/lbm	548	548	548	548	548	548	548	548	548
	inlet pressure, psia	1800	1800	1800	1800	1800	1800	1800	1800	1800
	outlet pressure, psia	1515	1515	1515	1515	1515	1515	1515	1515	1515
	flow rate, lbm/sec	.56	.37	.88	.62	1.24	.90	1.13	2.44	3.08
OUTPUTS	absorbed power, MW	.41	.36	.64	.60	.90	.87	1.09	2.36	2.98
	P ₁ psia	1517	1516	1518	1517	1519	1518	1518	1527	1533
	P ₃ psia	1515	1515	1516	1515	1517	1516	1516	1525	1531
	T ₃ °F	598	598	598	598	598	598	598	598	599
	h ₃ BTU/lbm	613	613	613	613	613	613	613	614	615
	l ₁₃ ft	8.0	6.7	7.7	6.5	7.6	6.5	6.5	6.5	6.5
	h ₅ BTU/lbm	1170	1169	1169	1169	1169	1169	1169	1169	1168
	l ₃₅ ft	24.1	17.2	25.8	18.6	26.1	19.1	19.3	19.8	19.8
	T ₇ °F	650	960	650	960	650	960	960	960	960
	h ₇ BTU/lbm	1238	1465	1238	1465	1238	1465	1465	1465	1465
	l ₅₇ ft	8.9	17.1	7.5	15.9	7.3	15.4	15.2	14.7	14.7

and two-phase mixture lengths (Figures 7a and 7b) decrease, whereas the superheated length (Figure 7c) increases. The saturated liquid enthalpy increases slightly due to the pressure increases at the saturated liquid boundary. These increases result from the diminishing gravity head loss in the subcooled control volume. For the initial input powers and the constant flow rates, insufficient energy exists to produce superheated steam and the panel's outlet temperature remains at the saturated value of 598°F. With increases in input power superheated steam is created and the temperature rises.

The transient response of the three control volume lengths is extremely fast, indicating very small hydraulic time lags. Much slower response is seen in the panel's outlet enthalpy and temperature. The time lag associated with these two parameters is primarily due to the thermal inertia of the metal mass in the tube wall.

Open loop response to changes in the valve position are shown in Figures 9a to 9j. In general, step decreases in flow rate produce the same qualitative effect as step increases in incident power.

The results can be generalized as follows. As input power or flow rate increase, the damping in the system decreases. This is most clearly revealed by comparing the step responses from incident power steps of .78 MW to 1.05 MW and 2.63 MW to 3.28 MW. These two step increases are both on the order 30% and therefore provide a valid system response comparison to identical system input perturbations. The settling time for outlet temperature at the smaller power levels is seen to be about twice that for the higher power levels. This increased damping is essentially due to the lower flow rates and tube metal to fluid temperature gradients. These lower flow rates increase both the hydraulic time lags and the thermal resistance between the tube wall and the working fluid (smaller heat transfer coefficients).

The results of the transient closed-loop simulation runs are presented in the same format as the open-loop runs. Three different cases were investigated. Figures 10a-10j are the response curves for incident power step changes of .53 MW, .78 MW, and 1.05 MW, and a controlled outlet temperature of 650°F. Figures 11a-11j are the response curves to the previous incident power levels but a controlled outlet temperature of 960°F. Figures 13a-13j are the response curves for incident power step changes of 1.23 MW, 2.63 MW, and 3.28 MW, and a controlled outlet temperature of 960°F.

The response curves for the incident power step cases all show similar results. As the outlet temperature increases in response to higher incident power levels, the temperature controller commands the flow control valve to open allowing greater flow rates. The outlet temperature does not respond immediately to the increased flow rates commanded by the controller, however, which results in the process variables undergoing a period of oscillations about their eventual steady-state values. The overshoot and settling time of these oscillations can be influenced to some extent by modifying either the flow coefficient of the flow control valve or the gain constants of the temperature controller, but these effects were not investigated for this report. As expected, the settling time of the process variable oscillations decreases at the higher incident power levels. This phenomenon is due to a decrease in system damping (see open loop discussion) and a correspondingly shorter outlet temperature time lag to changes in inlet flow rate.

The greater flow rates corresponding to the increase in power levels also influence the pressure at the receiver panel inlet. Because the pressure drop through the flow control valve and receiver panel remains constant, increases in pressure drop through the receiver panel are compensated by decreases in pressure drop across the flow control valve. Therefore, as the flow rate through the panel increases, resulting in a greater pressure loss through the panel, the inlet pressure also increases. (See Figures 10c, 11c and 12c).

4.4 CLOUD PASSAGE SIMULATION

The response curves for the simulated cloud passage are presented in Figures 13a to 13j. The cloud passage was simulated by stepping the incident power level to zero for 5 sec. and then returning it back to its original value.

At the instant power is cut the outlet temperature begins decreasing rapidly due to the high flow rate through the panel. As the temperature controller accumulates temperature error the flow rate is decreased and the outlet temperature decline is reversed. The flow rate eventually obtains a minimum value established by a minimum valve position (95% full closed). The outlet temperature begins another decline but at a much slower rate than the initial one. After the incident power returns to its original value, the outlet temperature overshoots its set point due to the inability of the temperature controller to command the required flow rate instantaneously. Controller gain constant variations would undoubtedly have a strong effect on cloud passage transients, but these effects could not be investigated for this report.

5.0 FUTURE WORK

The STTF computer simulation of the MDAC receiver experiment has further applications beyond those briefly noted in this report. These applications are in the area of test planning, test support, and data evaluation. A recommended applications program in support of the MDAC receiver experiment is outlined below:

- (1) Complete the simulation of the MDAC recommended test program
- (2) Perform parametric study of receiver panel/controller interaction/response
- (3) Study panel transient behavior including:
  - startup/shutdown; normal and emergency conditions
  - flux level transients; investigated a range of flux rate changes
  - cloud patterns
  - transient response to set point change
  - feedwater temperature pressure and flow transients
- (4) Compare model against actual test data when available
  - STTF equipment first
  - MDAC receiver experiment later
- (5) Make recommendations to the STTF MDAC receiver test program based on the above analysis.

6.0 REFERENCES

1. Best, E.N., J.V. Coggi, R.A. Jamieson, K.L. Zondervan, "Dynamic Simulation Model of the Solar Thermal Test Facility (STTF)," Aerospace Report No. ATR-78(7695-02)-1, March, 1978.
2. Insolation Data Base Available from The Aerospace Corporation, Report No. ATR-76(7523-11)-9, The Aerospace Corporation, December, 1976.
3. Receiver/STTF Test Requirements Document, McDonnell-Douglas Drawing No. 1T50721, December 2, 1977, Preliminary Draft.
4. Steam, Its Generation and Use, 38th ed., The Babcock and Wilcox Company, 1972.
5. Thom, J.R.S., W.M. Walker, T.A. Fallon, and G.F.S. Reising, "Boiling in Subcooled Water During Flow Up Heated Tubes or Annuli," Proc. Institution of Mechanical Engineers, 3C180, (1965-66).
6. Tong, L.S., Boiling Heat Transfer in Two-Phase Flow , pps 111-134, Wiley, 1965.

APPENDIX A

SIMULATION RESULTS

Enclosed are plots of receiver panel open-loop and closed-loop simulation runs. Each figure contains the following subset:

- a. Input Heat Flux or Valve Position
- b. Flow Rate
- c. Inlet Pressure
- d. Subcooled Liquid Length
- e. Saturated Liquid-Vapor Mixture Length
- f. Superheated Vapor Length
- g. Saturated Liquid Enthalpy
- h. Saturated Vapor Enthalpy
- i. Outlet Enthalpy
- j. Outlet Temperature

Figure 7a to 7j

Open Loop Transient response to step changes in panel incident power level from 0.53 MWt to .78 MWt and to 1.05 MWt. Flow rate kept constant at 0.772 lb/sec. Feedwater inlet properties and steam header outlet properties kept constant at the values given in Table 1.

STTF MDAC RECEIVER PANEL

Figure 7a

STTF MDAC RECEIVER PANEL

Figure 7b

STTF MDAC RECEIVER PANEL

Figure 7c

STTF MDAC RECEIVER PANEL

STTF MDAC RECEIVER PANEL

Figure 7e

STTF MDAC RECEIVER PANEL

Figure 7f

STTF MDAC RECEIVER PANEL

Figure 7g

STTF MDAC RECEIVER PANEL

Figure 7h

STTF MDAC RECEIVER PANEL

Figure 7i

STTF MDAC RECEIVER PANEL

Figure 7j

Figures 8a to 8j

Open Loop Transient Response to Step Changes in panel incident Power Level from 1.29 MWt to 2.63 MWt and 3.28 MWt. Flow rate kept constant at 2.61 lbs/sec. Feedwater inlet properties and steam header outlet properties kept constant at the values given in Table 1.

STTF MDAC RECEIVER PANEL

Figure 8a

STTF MDAC RECEIVER PANEL

Figure 8b

STTF MDAC RECEIVER PANEL

Figure 8c

STTF MDAC RECEIVER PANEL

Figure 8d

STTF MDAC RECEIVER PANEL

Figure 8e

Figure 8f

STTF MDAC RECEIVER PANEL

Figure 8g

STTF MDAC RECEIVER PANEL

Figure 8h

Figure 8i

Figure 8j

Figure 9a to 9j

Open Loop transient response to valve position changes from 47.7% to 55.5% and to 66% open position. Incident power was kept at a constant 1.05 MWt. Feedwater inlet properties and steam header outlet properties kept constant at the values given in Table 1.

Figure 9a

STTF MDAC RECEIVER PANEL

Figure 9b

Figure 9c

STTF MDAC RECEIVER PANEL

Figure 9d

STTF MDAC RECEIVER PANEL

Figure 9e

STTF MDAC RECEIVER PANEL

Figure 9f

STTF MDAC RECEIVER PANEL

Figure 9g

STTF MDAC RECEIVER PANEL

Figure 9h

STTF MDAC RECEIVER PANEL

Figure 9i

STTF MDAC RECEIVER PANEL

Figure 9j

Figure 10a to 10j

Closed loop transient response to step changes in panel incident power levels from 0.53 MWt to 0.78 MWt and to 1.05 MWt. Controller set point of 650°F.

STTF MDAC RECEIVER PANEL

Figure 10a

Figure 10b

STTF MDAC RECEIVER PANEL

Figure 10c

STTF MDAC RECEIVER PANEL

Figure 10d

STTF MDAC RECEIVER PANEL

Figure 10e

STTF MDAC RECEIVER PANEL

Figure 10f

STTF MDAC RECEIVER PANEL

Figure 10g

STTF MDAC RECEIVER PANEL

Figure 10h

STTF MDAC RECEIVER PANEL

Figure 10i

STTF MDAC RECEIVER PANEL

Figure 10j

Figure 11a to 11j

Closed Loop transient response to step changes in panel incident power level from 0.53 MWt to 0.78 MWt and to 1.05 MWt. Controller set point of 960°F.

STTF MDAC RECEIVER PANEL

Figure 11a

STTF MDAC RECEIVER PANEL

Figure 11b

Figure 11c

STTF MDAC RECEIVER PANEL

Figure 11d

STTF MDAC RECEIVER PANEL

Figure 11e

STTF MDAC RECEIVER PANEL

Figure 11f

STTF MDAC RECEIVER PANEL

Figure 11g

STTF MDAC RECEIVER PANEL

Figure 11h

STTF MDAC RECEIVER PANEL

Figure 11i

Figure 11j

Figures 12a to 12j

Closed loop transient response to step changes in power level from 1.29 MWt to 2.63 MWt and to 3.28 MWt. Controller set point of 960°F.

STTF MDAC RECEIVER PANEL

Figure 12a

STTF MDAC RECEIVER PANEL

Figure 12b

STTF MDAC RECEIVER PANEL

Figure 12c

STTF MDAC RECEIVER PANEL

Figure 12d

STTF MDAC RECEIVER PANEL

Figure 12e

STTF MDAC RECEIVER PANEL

Figure 12f

STTF MDAC RECEIVER PANEL

Figure 12g

STTF MDAC RECEIVER PANEL

Figure 12h

STTF MDAC RECEIVER PANEL

Figure 12i

STTF MDAC RECEIVER PANEL

Figure 12j

Figure 13a to 13j

Closed loop transient response to typical cloud passage. The incident power level of 2.63 MWt drops to zero and then returns to 2.63 MWt after 5 seconds.

STTF MDAC RECEIVER PANEL

Figure 13a

STTF MDAC RECEIVER PANEL

Figure 13b

STTF MDAO RECEIVER PANEL

Figure 13c

STTF MDAC RECEIVER PANEL

Figure 13d

STTF MDAC RECEIVER PANEL

Figure 13e

STTF MDAC RECEIVER PANEL

Figure 13f

STTF MDAC RECEIVER PANEL

Figure 13g

Figure 13h

STTF MDAC RECEIVER PANEL

Figure 13i

STTF MDAC RECEIVER PANEL

Figure 13j