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Volume IV

Solar Power Plant Operation Analysis Computer Program

July 1, 1976 –
December 31, 1976

ADVANCED THERMAL ENERGY STORAGE CONCEPT DEFINITION STUDY FOR SOLAR BRAYTON POWER PLANTS

ERDA Contract No. EY-76-C-03-1300

Solar Power Plant Operation Analysis Computer Program

Final Technical Report
Volume IV

July 1, 1976 - December 31, 1976

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ABSTRACT

This document describes the computer program used to simulate the operation of the high temperature gas-cooled solar power plant. The program was used to assess the interrelations of plant components as opposed to the design of the individual elements. The model estimates the effectiveness of the Brayton cycle solar power plant on an hourly, daily and yearly basis. Herein is a description of the program and how the program is used including inputs, outputs and operating instructions.

This report is an account of work sponsored by ERDA under Contract EY-76-C-03-1300. The work is the first part of a two part cooperative EPRI/ERDA research program. The work was completed in June. A report on that effort was released at the conclusion of the first part of the program.

The report is contained in four separate volumes as follows:

Volume I - Technical Report
Volume II - Thermal Energy Storage Sizing Computer Program
Volume III - Thermochemical TES Sizing Computer Program
Volume IV - Solar Power Plant Operation Analysis Computer Program

The latter three volumes contain technical descriptions and operating instructions for the three computer programs developed as part of this research program.

FOREWORD

In August, 1976, a research project was initiated by the U. S. Energy Research and Development Adminsitration (ERDA) as a continuing study of energy storage concepts for high temperature gas-cooled solar power plants. Obviously, an energy storage facility, no matter how well designed, is not valid unless it can be shown to interface with the power plant it is intended for. The solar power plant and its storage system are interdependent in many ways. The most effective way to evaluate the consequences of this interdependence is a power plant mathematical model.

The solar power plant model described herein has been developed to easily show on an hour-by-hour, seasonal basis the physical effects of any number of storage concepts and their cost impact over an entire year. The results of the computer studies has contributed to the Systems Analysis sections of the Technical Report (Volume I).

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

PAGE

VOLUME IV - SOLAR POWER PLANT OPERATION COMPUTER PROGRAM

Section 1

INTRODUCTION AND SUMMARY

Analytical models and computer programs which mechanize these models have been developed to support the sizing and performance anlaysis of the thermal and chemical energy storage systems. Each of the three major models presented in this volume and volumes II and III have been programmed in Fortran for the IBM 370.

The math model for sizing the thermal storage systems (Volume II) performs the basic function of initial thermal sizing, conceptual configuration sizing, and preliminary cost estimating. The math model for the sizing of the CES system (Volume III) includes the chemical analysis, initial thermal sizing for the reactor and fractionating column, preliminary cost estimating, and overall configuration synthesis. The solar power plant operation math model described in this volume is the result of a major modification to a similar program developed during the EPRI Advanced Thermal Energy Storage Program RP788-1.

The analytical basis and overall program structure for each of these three computer programs is presented in Section 2.0 of each volume. The input, output, operating instructions, and Fortran listings for each of the three Fortran programs are also included.

This volume is a description of the Solar Power Plant Operation computer program. The program emphasizes the interfaces with thermal and thermochemical energy storage devices.

The purpose here is to furnish the prospective user the necessary information to successfully operate the program. While quite complex internally, the inputs have to be kept to a minimum and the program has proven quite reliable in performing the trade studies described in Volume I. The model has been coded in standard IBM FORTRAN IV language using EBCDIC card format. The program encompasses about 4500 cards, and is totally self-contained in batch execution.

Figure 1-1 shows the program logic flow at the executive level. The separate logic blocks represent subroutines that execute the functions described in the figure.

The main program provides the framework for the simulation of the plant as a function of time. At each time step the current thermodynamic state data are combined with the solar heat input to the receiver and heat rates throughout the plant are determined. There rates are integrated to establish new thermodynamic state data. The result of each complete daily cycle are analyzed to determine component efficiency, overall plant efficiencies, component energy consumption, and component energy output.

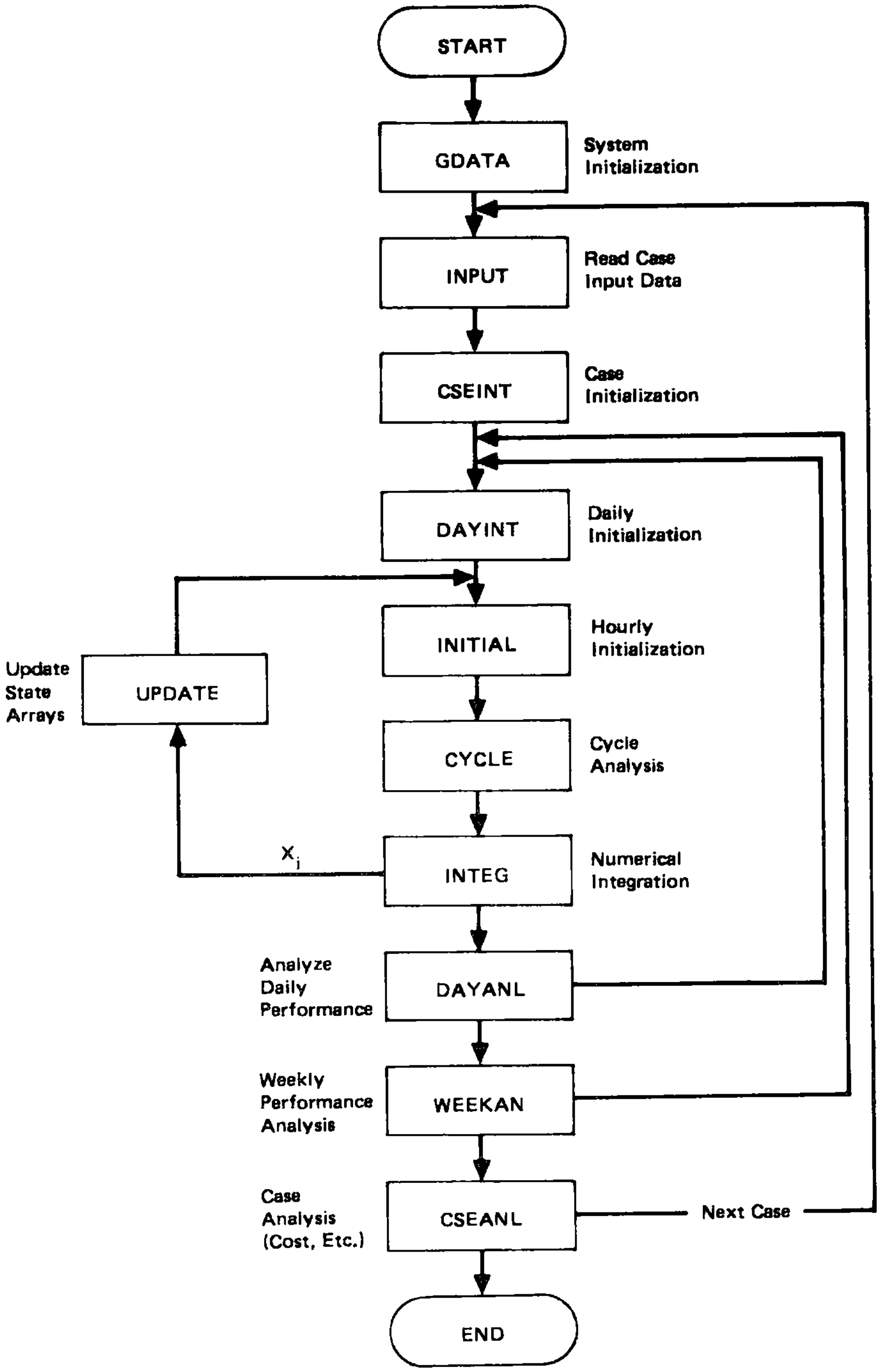


Figure 1-1. Plant Operation Model Program Structure

Section 2
TECHNICAL DESCRIPTION

The operation and control of the STC power plant, with source side thermal energy storage for source leveling, involves an understanding of the source profile, the load profile, and the plant operating policy. The approach used in the plant operating policy affects the energy economics and to some extent, affects the design decisions and operating requirements of the various plant subsystems.

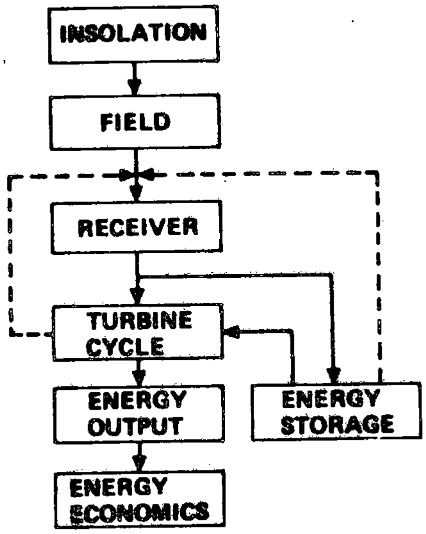
A math model of the high temperature STC power plant operation was developed as a part of the earlier EPRI Advanced Thermal Energy Storage contract to support the plant design and performance analysis. This model predicts the plant performance on an hour-by-hour daily cycle basis, as well as a weekly cycle, including the effects and performance of all of the major plant subsystems. It has been extensively modified and expanded as a part of the study being reported here.

A technical description of the elements of the math model is included in this section. The principal objective of this work was to create a capability to relate storage system design requirements to the seasonal insolation cycle and the basic operating requirements of the power plant. Consequently, it is appropriate to simplify the demand profile and plant operating policy, recognizing that the resultant plant performance estimates are limited by these simplifications. The work reported here is based on a flat demand profile, and the plant operating policy simply provides energy for storage on an as-available basis with first priority to direct generation.

2.1 COMPUTER PROGRAM SUMMARY

A simplified schematic of the plant operation math model is shown in Figure 2-1. Each of the major subsystems in the power plant is characterized in a separate program module. The effects of the major parameters for each subsystem are included in these program modules.

The control logic for the program provides the framework for the simulation of the plant as a function of time. At each time step the current thermodynamic state data at the state points shown in Figure 2-2 are combined with the solar heat input to the receiver and heat rates throughout the plant are determined.



- **Insolation and field modeled as hour by hour solar heat into the receiver aperture**
- **Receiver modeled by efficiency**

$$\eta_R = \frac{\textbf{Heat to helium circuit}}{\textbf{Solar heat into receiver}}$$

- **Turbine generator cycle efficiency, mass flow, and He temperature distribution all modeled**
- **Energy storage–includes parasitic losses, thermal losses and He temperature distribution**
- **Energy economics–levelized fixed charge rate method, input/scaled cost accounts**

Figure 2-1. Plant Operation Computer Program Schematic

These rates are integrated to establish new thermodynamic state data. Input data to the program includes hourly insolation data, reflector field conversion efficiency data, component design parameter data such as storage media thermal properties, component performance data, plant operation data such as storage limits, and energy economic parameters such as itemized cost account numbers. The results of each complete daily cycle are analyzed to determine components efficiency, overall plant efficiencies, component energy consumption, and component energy output. Printed results include thermodynamic state data at each time point, daily analysis results, and the overall results with energy economics of the four seasonal days analyzed as a yearly operation.

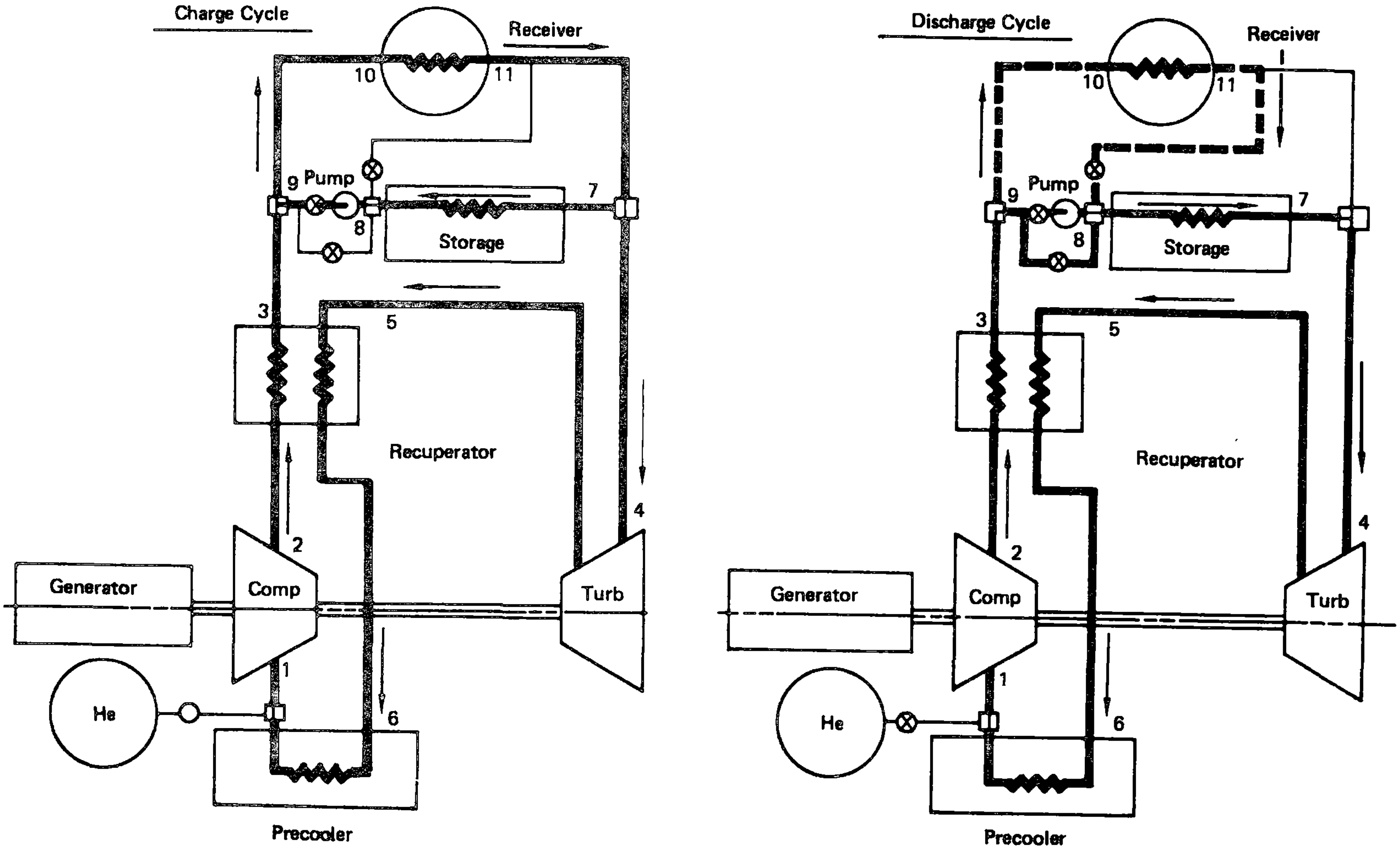


Figure 2-2. Storage/Plant Schematic

At each time point the control logic determines the plant operating mode and calls up the necessary program modules to evaluate each plant function. A brief technical description of each of the subsystem math models and the plant control logic is included in the following sections.

2.2 PLANT CONTROL LOGIC

The following plant operation policy is the framework of the power plant control logic:

- Generator output for demand load is always first priority.
- Insolation energy in excess of generator demand is used to charge storage.
- Demand load profile is flat with a specified start time (normally taken as 8:00 a.m.).
- Early morning insolation prior to generator start-up is used to charge storage.
- Insolation energy in excess of storage limit is rejected in the reflector field.
- Storage is charged in a separate flow circuit (See Figure 2-2).
- Storage is discharged in a series circuit with receiver (See Figure 2-2).
- Power plant operates as a stand-alone system with the turbine providing all power requirements including grid demand and storage parasitic power.

The mathematical logic used in the computer program to implement this operation policy was developed with two key objectives in mind. First, to represent the functional interface among the plant subsystems in terms of the operating variables most likely to enter the real plant control system. Secondly, to provide a simple, flexible system which will allow the investigation of alternate operation policies. Both objectives have been met. The resultant logic algorithm is shown in Figure 2-3.

The first level plant operating condition checks are shown in Figure 2-3 in conjunction with the five major plant operating modes which are shown in the shaded blocks. The operation of the power plant in each of the given modes is controlled by a separate subroutine in accordance with the plant operation schematics shown in Figure 2-2. During periods of high insolation with the utility grid demand active, energy input to the helium stream in excess of that required to drive the turbine is used to charge storage. The high temperature gas flow from the receiver is transported in part to the turbine to meet the plant demand output, and in part to a separate fluid circuit which includes the storage device and a high temperature pump. The pump provides the input energy required to circulate the helium and must be sized to meet the flow requirements encountered as the storage device reaches its fully charged condition. This particular mode is identified in Figure 2-3 as mode 5. Mode 1 is analogous to 5 except there is no demand, and the corresponding control algorithms are simplified.

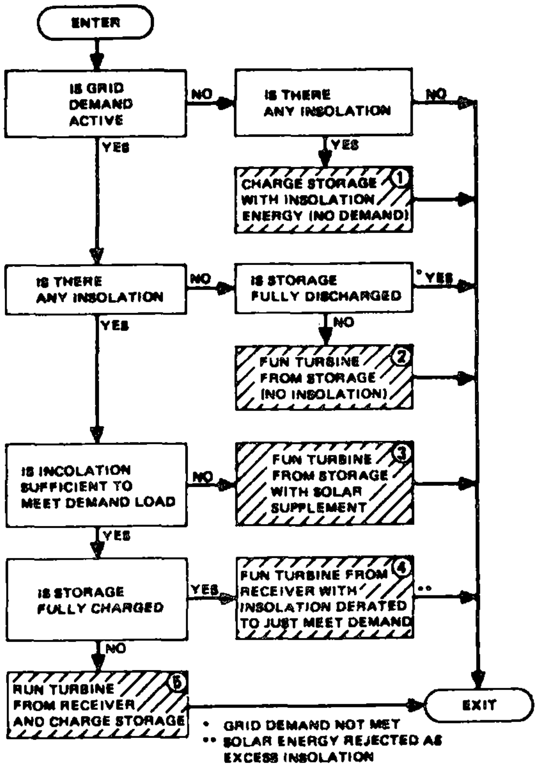


Figure 2-3. Plant Control Algorithm

During periods of reduced or no insolation, thermal energy is withdrawn from storage to supplement the receiver input or to replace the receiver as a heat source in the absence of insolation. During periods of no insolation (control mode 2), the storage device is used directly as the heat source in the helium turbine cycle. In this mode, there is no helium flow into the receiver circuit and the high temperature pump is bypassed on the upstream side of the storage unit.

During periods of partial insolation (control mode 3), helium from the recuperator first passes through the receiver and then through the storage device. In this mode, the receiver and storage device act in series as the heat source for the helium turbine, with the receiver providing the low temperature heat increment and the storage providing the high temperature increment. This approach keeps the high temperature end of the storage unit nearest the turbine inlet and gives the highest conversion efficiency in the receiver.

In mode 4 the storage circuit is inactive since storage is fully charged. In this mode, the insolation input to the receiver is adjusted so that there is just enough heat to meet the turbine demand.

A representative daily plant operating cycle is shown in Figure 2-4. The cycle shown here is typical of the transient nature of the plant operation, when managed in accordance with the operating policy described above. All five modes of operation occur during the daily cycle shown in Figure 2-4 and are identified by their operation mode numbers.

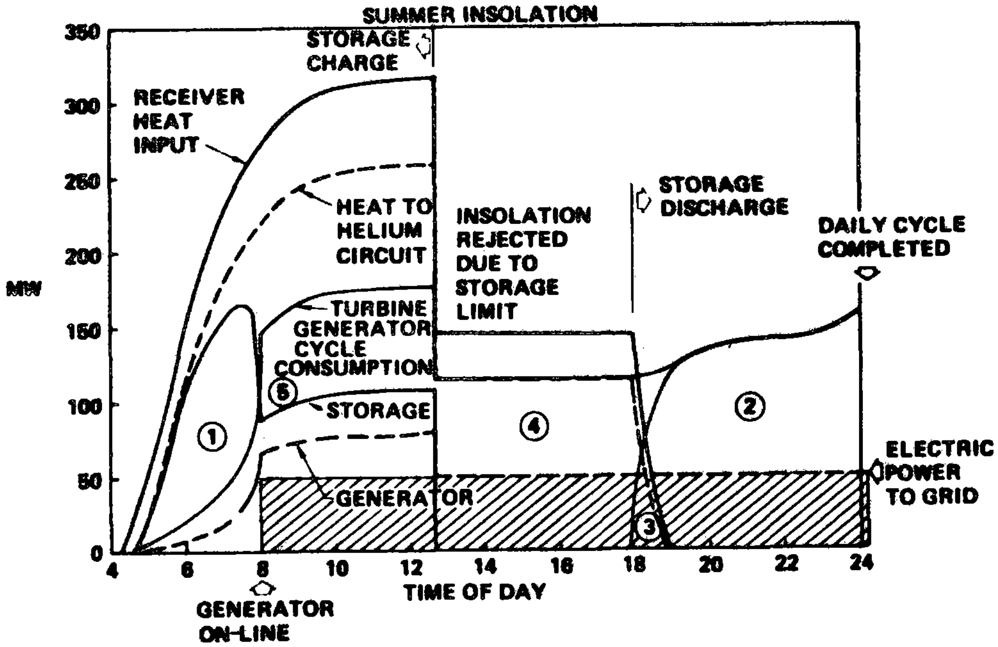


Figure 2-4. Plant Operation—Representative Daily Cycle (Phase Change TES System)

For chemical storage systems (ICHEM = 1) long storage times are attractive because of the low storage cost per unit time. Consequently, a weekly plant operating cycle has been implemented assuming Saturday and Sunday are used to charge the storage device with no on line grid demand.

The control policy is illustrated in Figure 2-5 for two seasonal weeks (winter and summer). The energy stored during the weekend is allocated to each of the five following days as initial stored energy E_I. E_I is selected such that the total time on line for the plant is the same for each weekday.

For the winter week the storage limit is not reached with the insolation available on the weekend. (See Figure 2-5) In this case the energy available at the beginning of each weekday is simply

$$E_I = \frac{1}{5} E_S$$

where E_S = total stored energy at beginning of Monday operation.

For the summer week the storage device has been saturated and the first weekday (Monday) will require a slightly larger allocation of initial stored energy. This is because there can be no contribution to storage during the Monday midday insolation peak. The initial energy allocation is given by

$$E_I = \frac{1}{5} (E_{SL} - E_T) + E_T$$

where E_T = theoretical excess of energy that could be placed in storage if the limit were not in place

E_{SL} = Energy storage limit

For the second (and subsequent) weekdays the initial energy for equalization of plant operation time is

$$E_I = \frac{1}{5} (E_{SL} - E_T)$$

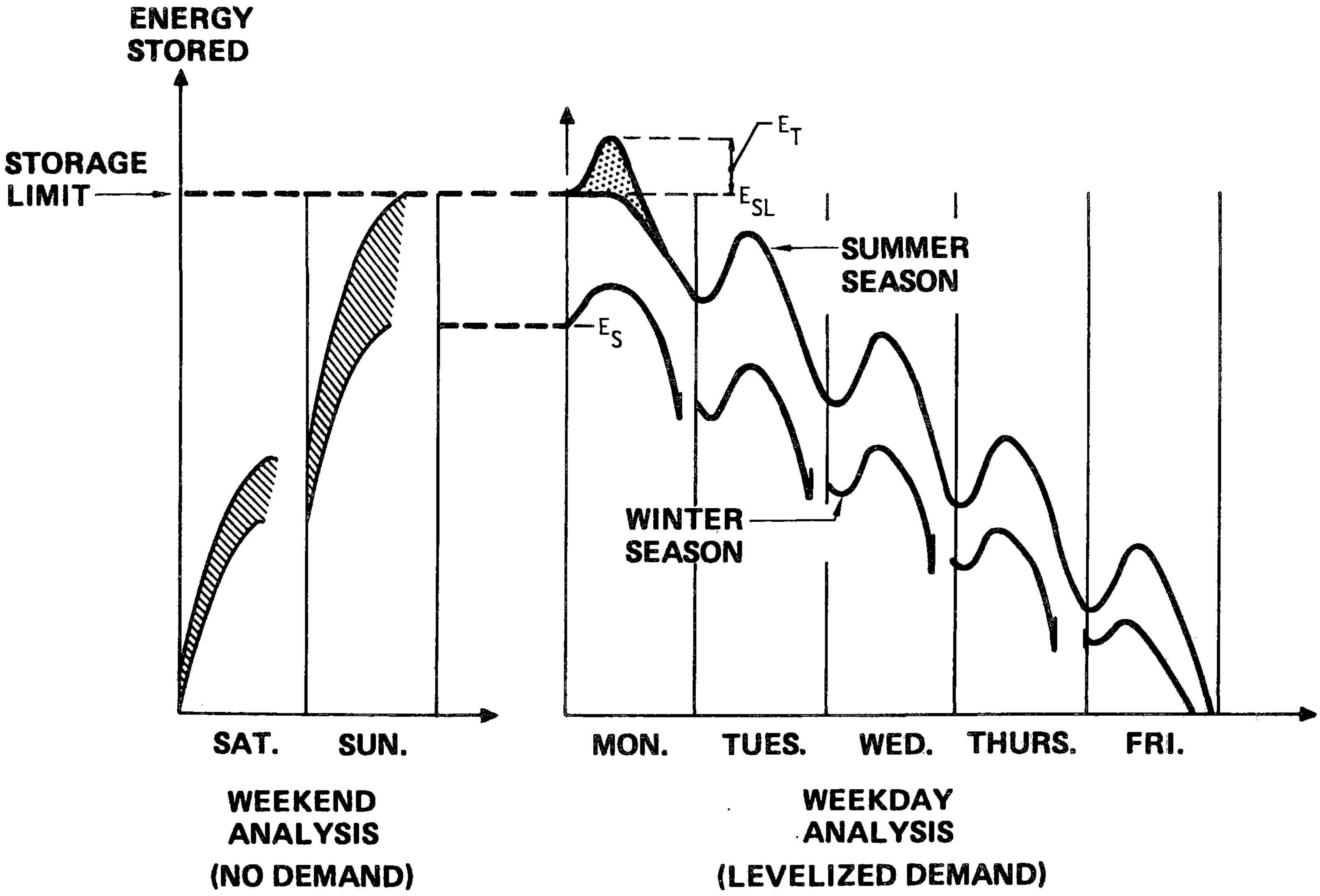


Figure 2-5. Weekly Cycle Analysis

2.3 INSOLATION AND REFLECTOR FIELD MODEL

Hourly insolation data for each day to be analyzed are the primary input variable in the program. Tables of reflector field efficiency are combined with the hourly insolation data and the collector area to compute the receiver heat input. The field efficiency tables are a function of time for each day of the year and include tracking efficiency, mirror reflectivity and receiver intercept efficiency. Default tables are built into the program to simplify the program input. The source of these data is described below.

Insolation Data

The insolation tables are based on clear day specular insolation data taken at Inyokern, California, in 1963. Insolation profiles for four representative days were taken from the data tapes assembled by the Aerospace Corporation. Results are shown in Figure 2-6.

Reflector Field Performance

The reflector field efficiency, η_F, is the product of the tracking efficiency, η_T, the mirror reflectivity, r_M, and the receiver intercept efficiency, η_I. The tracking efficiency includes projected area losses and shadowing and blocking losses. The tracking efficiency data used in the η_F tables are shown in Figure 2-7. The value of mirror reflectivity to be used is $r_M = 0.88$. The receiver intercept efficiency is the fraction of energy reflected from the heliostat field that enters the receiver aperture. The value of η_I to be used is $\eta_I = 0.90$. This value is determined by describing the solar flux pattern from the heliostat field and sizing the receiver aperture such that the captured reflected light is a maximum. This maximum occurs where increasing the aperture size will cause more heat to be lost than would be admitted to this larger opening from the field. The resultant reflector field efficiency is given by $\eta_F = \eta_T \times r_M \times \eta_I$.

2.4 RECEIVER MODEL

The receiver performance analysis is based on a thermal scaling analysis of the preferred gas cooled receiver reported in the final report to RP377-1. An iterative procedure is used to solve for the receiver power output as a function of the average helium temperature, the receiver geometry, and solar heat into the

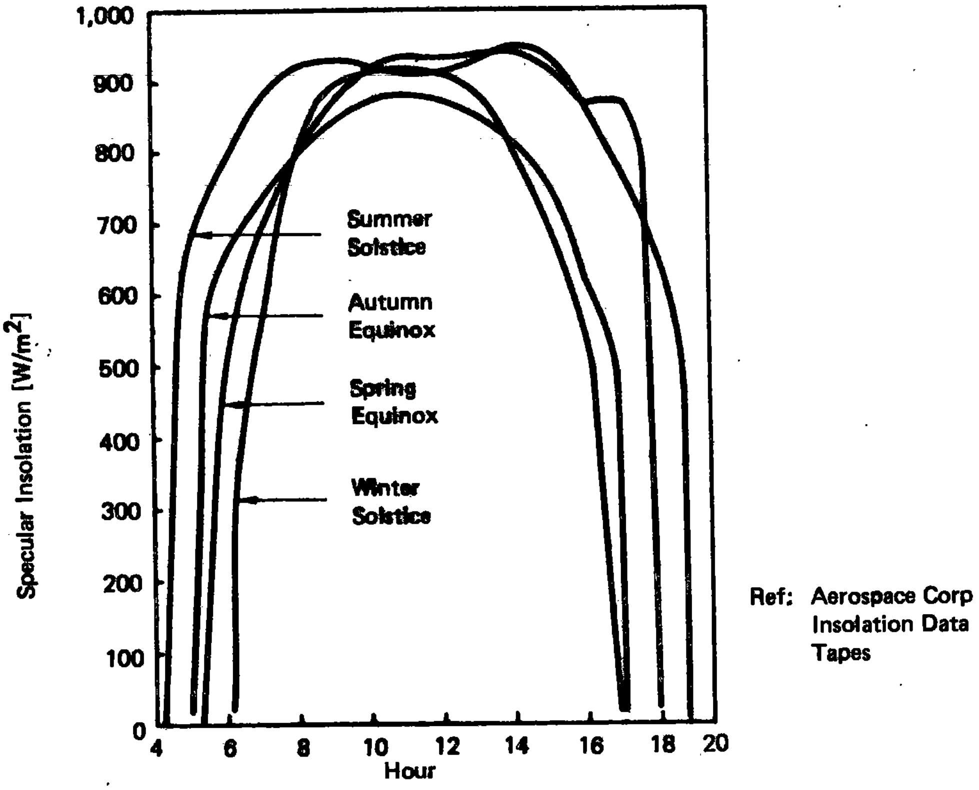


Figure 2-6. Clear Day Specular Insolation (Inyokern, California 1963)

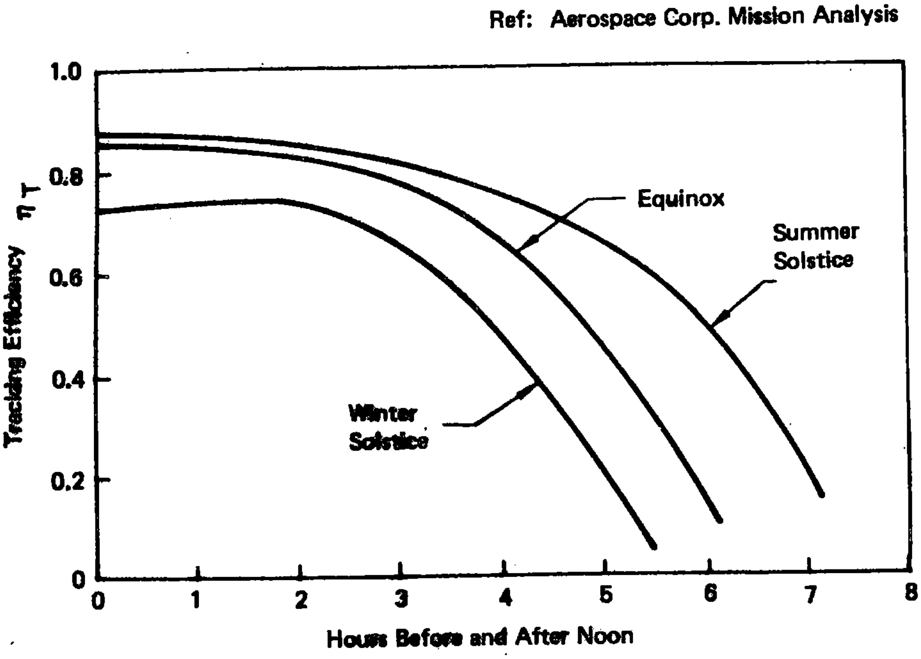


Figure 2-7. Mirror Field Tracking Efficiency

receiver. The thermal analysis includes the radiant heat losses through the aperture, convective heat losses, reflective solar heat losses, and conduction losses through the receiver wall.

The algorithm is shown schematically in Figure 2-8. All the significant heat transfer mechanisms are characterized along with pertinent receiver design variables such as aperture size, wall area, and insulation thickness. The values of constant terms in these formulas were derived for the preferred gas cooled solar receiver configuration referenced above. Computed values are sufficiently accurate for use in system integration and preliminary design studies.

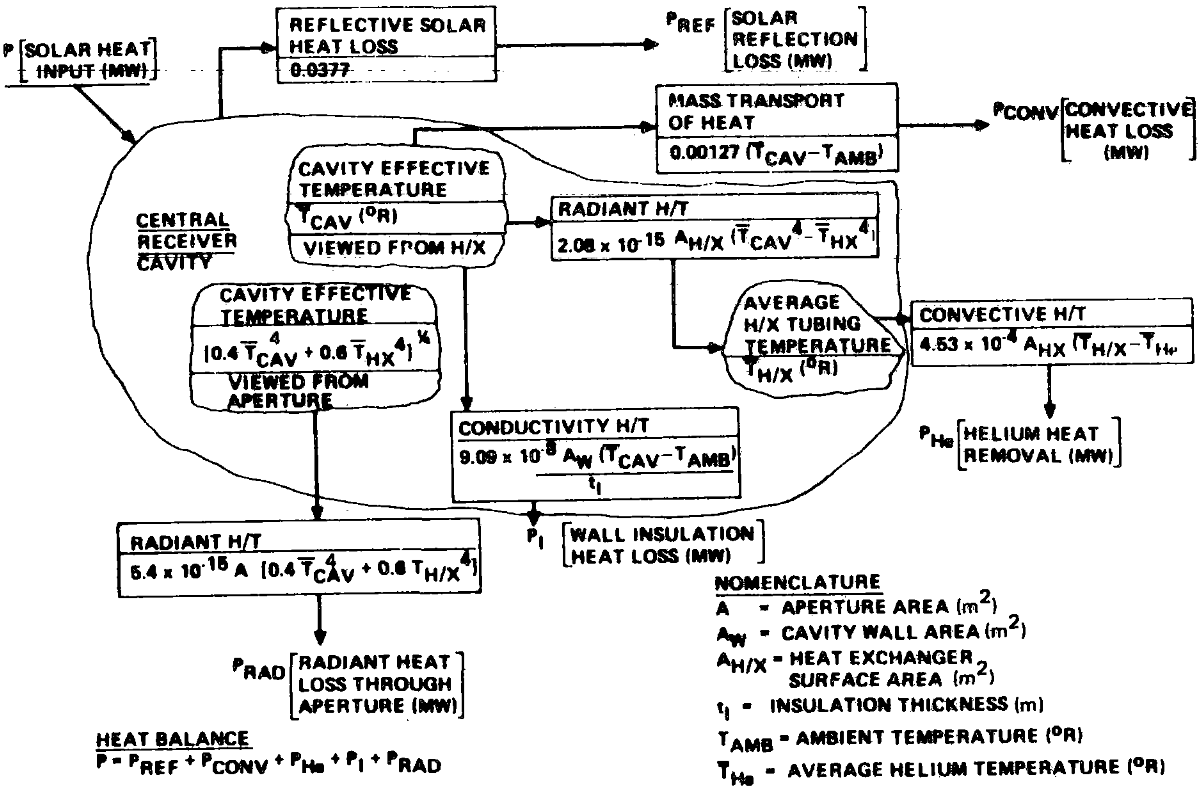
The receiver thermal efficiency at part load solar input is shown in Figure 2-9. These data are derived for demonstration purposes using the performance algorithm described above.

2.5 TURBINE PERFORMANCE MODEL

The turbine cycle performance and operating condition analysis is based on the data shown in Figure 2-10. The thermal cycle conversion efficiency and recuperator outlet temperature are modeled as tabular functions of turbine inlet temperature. These data are used over the operating range of turbine inlet temperature to compute helium mass flow requirements as a function of an electrical output demand. The data shown here are the result of an extensive turbomachinery and cycle analysis effort reported in RP377-1. The analysis methods developed during that effort are compatible with the program structure of the plant operation model. The inclusion of these algorithms in the plant operation program is a major task which would enhance the plant operation program particularly in an area of plant control.

The solar thermal power plant faces a constantly changing solar input. Normal solar variations, a varying electrical demand, and transients caused by the environment, start-up, storage switch-over, or shutdown make plant control a very important item.

Plant output power would normally decrease with decreasing turbine inlet temperature which could be caused by reduced solar input or operation from the storage



HEAT BALANCE

$P = P_{REF} + P_{CONV} + P_{He} + P_I + P_{RAD}$

NOMENCLATURE

A = APERTURE AREA (m^2)

A_W = CAVITY WALL AREA (m^2)

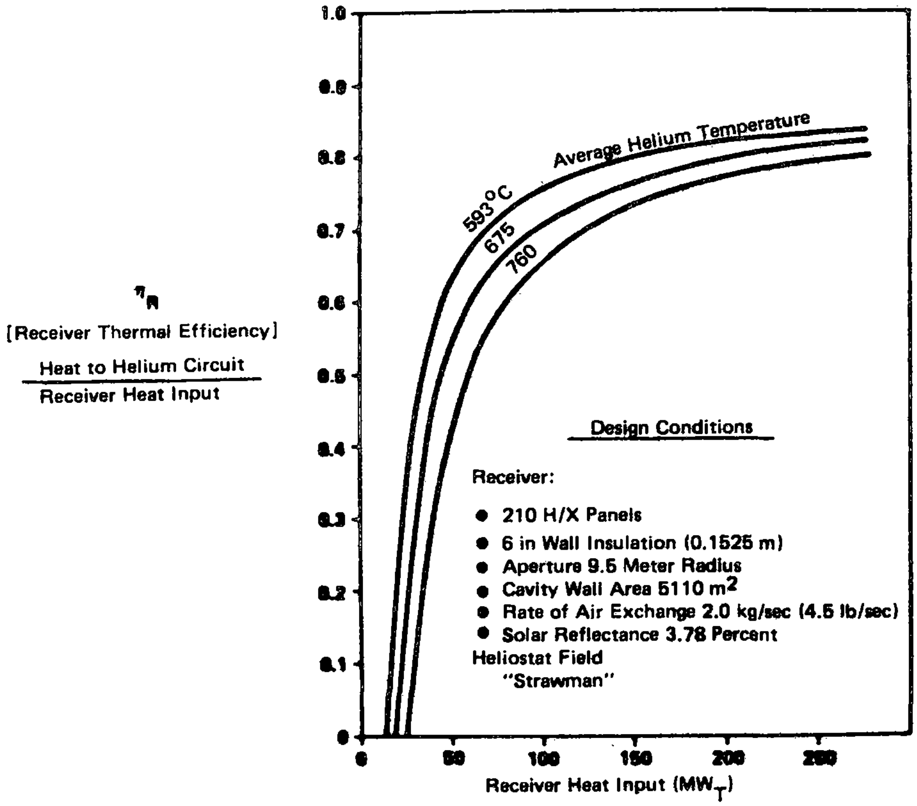
$A_{H/X}$ = HEAT EXCHANGER SURFACE AREA (m^2)

t_I = INSULATION THICKNESS (m)

T_{AMB} = AMBIENT TEMPERATURE (°R)

$\bar{T}_{He}$ = AVERAGE HELIUM TEMPERATURE (°R)

Figure 2-8. Receiver Performance Model for System Integration Studies



Design Conditions

Receiver:

- 210 H/X Panels
- 6 in Wall Insulation (0.1525 m)
- Aperture 9.5 Meter Radius
- Cavity Wall Area 5110 m^2
- Rate of Air Exchange 2.0 kg/sec (4.5 lb/sec)
- Solar Reflectance 3.78 Percent

Heliostat Field
"Strawman"

Figure 2-9. Receiver Thermal Efficiency at Part-Load Conditions

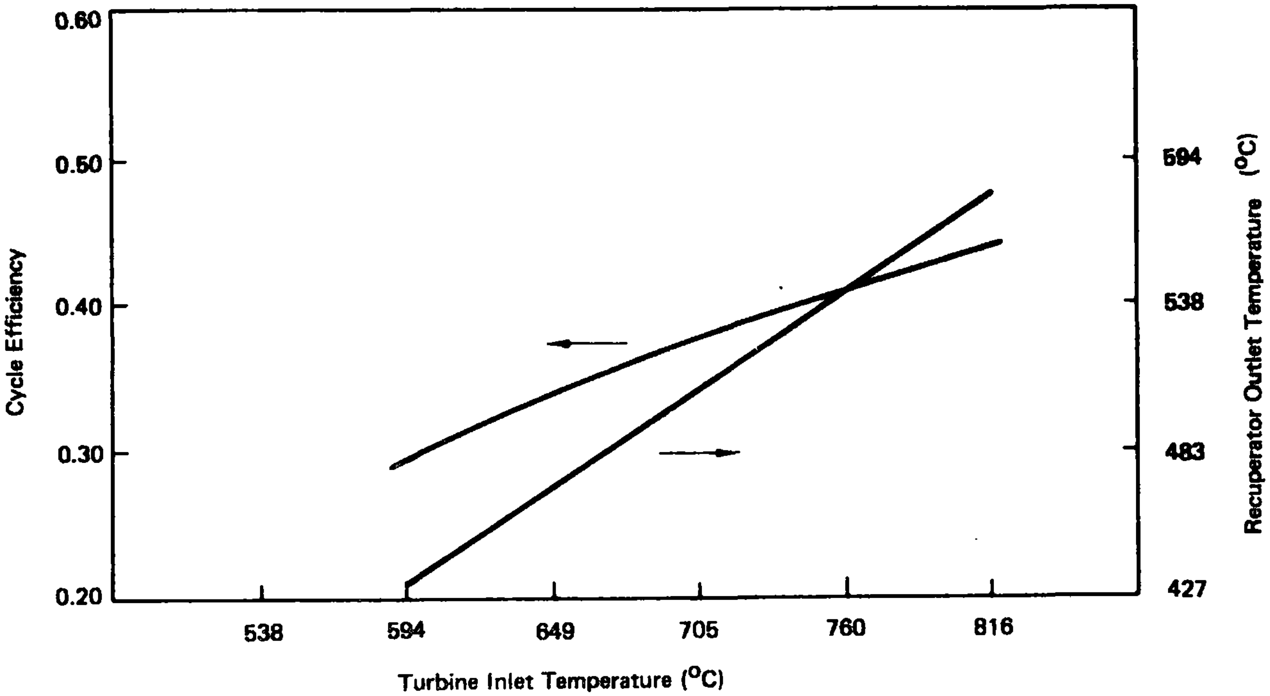


Figure 2-10. Cycle Performance

system. However, by increasing the pressure level (i.e., mass flow) of the system to compensate for the reduced thermal efficiency, the electrical output can be maintained at the desired level. The pressure level variation with turbine inlet temperature is shown in Figure 2-11 for a constant power output.

The turbine will also be operated to produce power to meet the instantaneous demand which includes storage parasitic power requirements. This is accomplished by maintaining a fixed turbine inlet temperature while changing pressure level and mass flow to follow the demand load. The algorithm used assumes that the thermal cycle efficiency is a function only of the turbine inlet temperature, which remains constant with varying electrical output during plant operation in this mode.

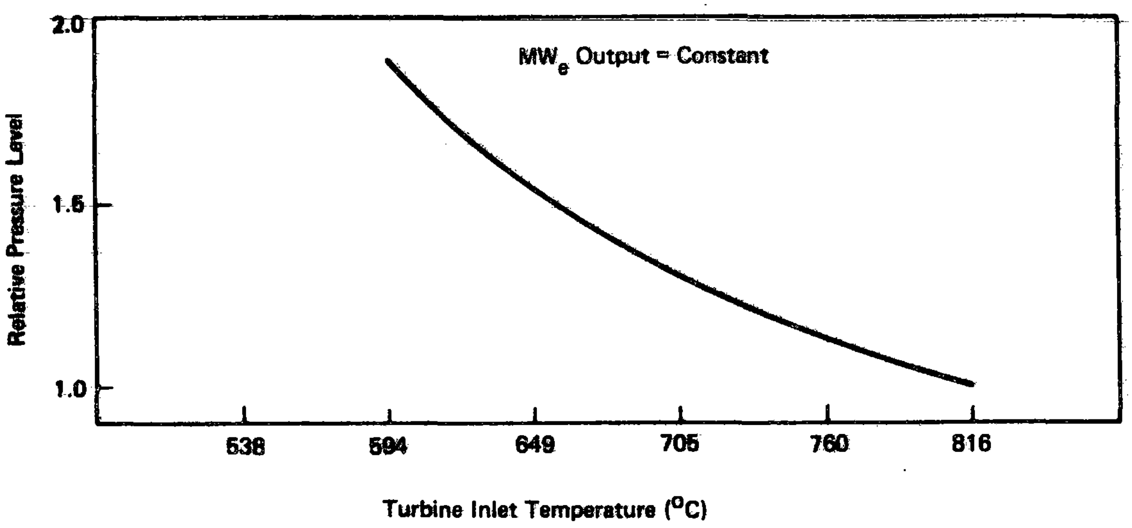


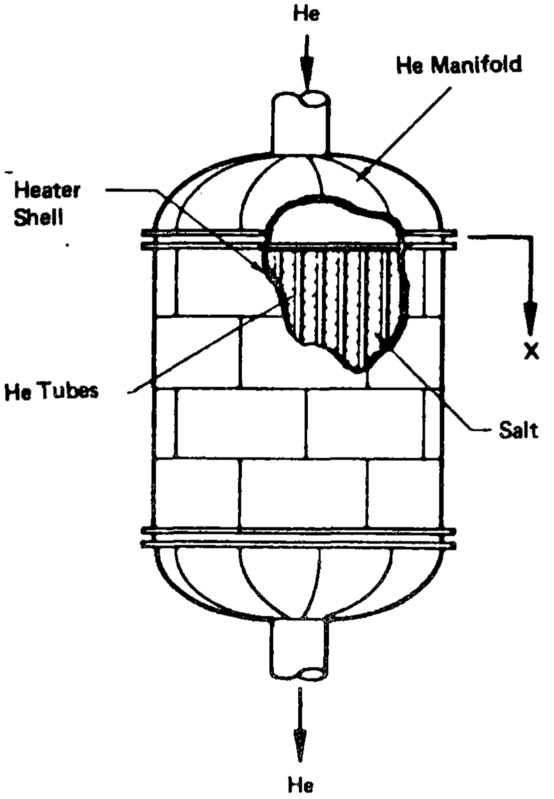
Figure 2-11. Pressure Level

2.6 THERMAL ENERGY STORAGE (TES) MODEL

The purpose of the energy storage model is to compute the parasitic power requirements and the thermal performance of the storage device, and to maintain an accounting of the energy transferred to and from storage. Each of the three basic TES devices has a different thermal behavior and is represented by a separate math model. These models range in complexity from finite difference solutions of the energy balance equations to simple scaling models of parasitic power requirements. A technical description of the math models for each of the three thermal storage devices is presented in the following paragraphs. The approach used to establish the fluid circulation system power requirements is also presented.

Sensible Heat and Phase Change TES Math Model

The transient thermal math model for these two TES devices is based on a finite difference (nodal) solution to the one-dimensional transient partial differential equations shown in Figure 2-12. These equations assume that the heat transfer is dominated by the gas-in-tube convective heat transfer, and that the heat flow into the storage media can be approximated through the overall heat transfer coefficient or the unit thermal conductance on the basis of a single node. The derivation of the energy equations is presented in Appendix I in conjunction with the derivation of the difference equations employed in this program module.



- **Energy Balance**

$$\frac{\partial T_f}{\partial x} = \frac{UA/\Delta x}{\dot{m}\, C_{p_f}} (T_s - T_f)$$

$$\frac{\partial T_s}{\partial \tau} = \frac{UA}{m_s\, C_{p_s}} (T_f - T_s)$$

- **Technical Approach**
  - **No Axial Conduction**
  - **Single Node Lateral Heat Flow**
  - **Reverse Flow Direction for Charge and Discharge**
  - **Lumped Heat Loss Through Heater Shell**

Figure 2-12. TES Performance Model

For both storage devices, the storage media is stationary and the helium flow direction is reversed in order to maintain the natural thermocline developed within the media. For the phase change system, a simple tube-in-bath approach has been taken with the tubes arranged vertically. The hot end of the heater is at the top in order to prevent the formation of voids during the heating and cooling cycle.

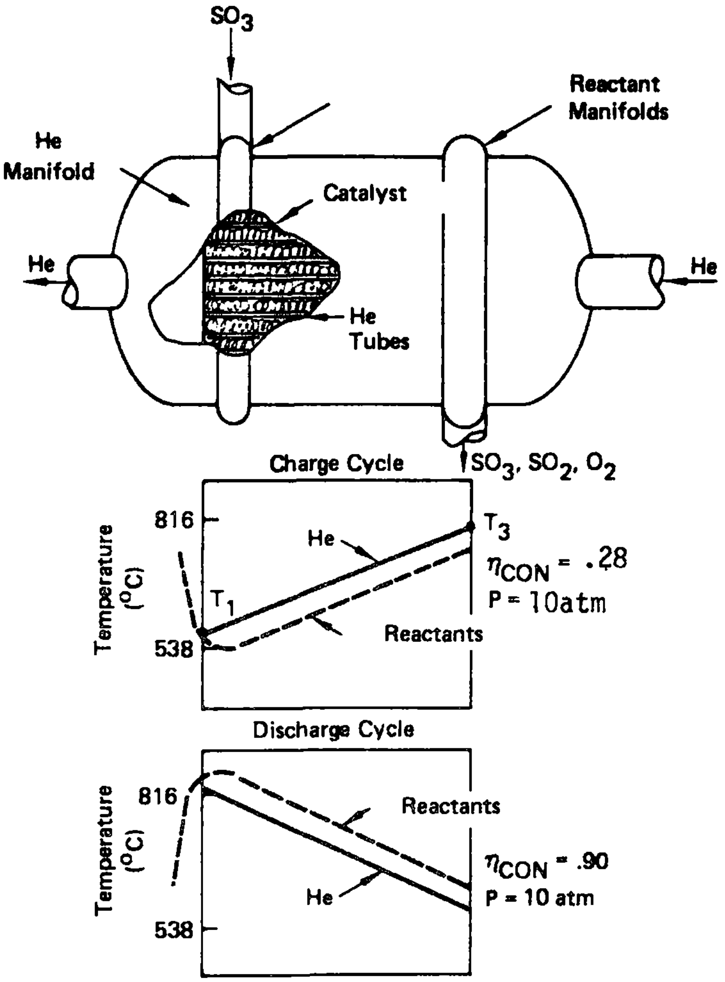
The accuracy of the second simplification has been investigated by comparison with the appropriate exact solution. T_S is taken as the bulk temperature of the media and the unit thermal conductance model is the sum of the three thermal resistances in the heat conduction path; i.e., (1) convective film coefficient, (2) metal tube wall resistance, and (3) storage media thermal resistance. The path length associated with the storage media thermal conduction is taken as the distance to the centroid of the thermal mass enclosed by the adiabatic surface of the symmetry between the tubes. With these assumptions, the comparison of heat rates with the exact solution is very good. Biot and Fourier numbers were varied over two orders of magnitude with representative storage media thermal properties and the maximum heat rate error encountered for the all solid or all liquid media was about 15%. (See Appendix II.)

During periods of phase change of a given node, the storage media thermal conduction path length must be modified to account for the location of the melt face relative to the tube wall. However, the average heat flow rate over the zone of the heater undergoing phase change is adequately represented by the simple nodal approach as discussed in Section 3.4 Volume I of this report.

In the phase change device, energy is transferred to or from a media that can be entirely solid, entirely molten, or a combination. At any one time the rate at which energy can be transferred to or from the media is dependent upon the thermodynamic state of the media. During a phase change, each portion of the media (node) must receive or release a quantity of energy equal to its latent heat of fusion. An energy exchange accounting system is used to simulate the melt face propagation axially through the molten salt heater. Each node is surveyed to see if it is at or undergoing a phase change. If the node is undergoing a phase change, the accounting system corrects the enthalpy of the node and keeps the nodal temperature constant at the melt temperature until the energy exchange matches the nodal latent heat of fusion.

CES Storage System Performance Model

The only thermal interface between the helium flow and the CES System is in the integral reactor heat exchanger. The reactor is designed and controlled to maintain a specific helium temperature distribution from reactor input to reactor output as shown schematically in Figure 2-13. This approach precludes the



- **Reactor Designed for Complete Helium Temperature Swing**
- **Reactant Requirements**

$$\dot{m}_{SO_3} = \frac{m_{He}\, C_{p_{He}}\, (T_3 - T_1)}{H_R\, \eta_{CON}}$$

$$H_R = 295\ cal/g_{SO_3}$$

- **Parasitic Power Requirements — Charge (Proportional to $\dot{m}_{SO_3}$)**
  - **Reactant Compressor**
  - **Oxygen Compressor**
- **Parasitic Power Requirements During Discharge Very Small**

Figure 2-13. Thermochemical Energy Storage Performance

complex thermal performance problem described in the previous paragraph for the other two TES devices. Consequently, the CES performance model reduces to a simple computation of the parasitic power losses as a function of charge and discharge heat rates. Table 2-1 summarizes the parasitic power requirements within the CES system equipment complex for the charge and discharge cycle in the

Table 2-1
CES PARASITIC POWER REQUIREMENTS

	MW_T	MW_E
Endothermic mode		
SO_3 storage heater	TBD	
SO_3 pump		.069
Dissociation product compressor		5.69
Oxygen compressor		7.42
Net cooling load	≈ 15	
Exothermic mode		
SO_2 pump		.068
Oxygen compressor		.275
Net cooling load	≈ 38	

baseline CES system. It is apparent from the data that the dissociation product compressor and the oxygen compressor are the major power consumers.

Each of the parasitic power requirements listed in Table 2-1 apply to the design charge and discharge rate conditions. In each category the parasitic power requirement is proportional to the mass flow rate of the associated reaction constituent. The simplified math model developed for the CES performance analysis determines constituent mass flow rate on the basis of charge and discharge heat rates ($\dot{m}_{HE}Cp_{HE}$ $(T_3 - T_1)$), heat of reaction, and reaction conversion fraction. The design parasitic power requirements are then scaled by these flow rates to determine the instantaneous parasitic power requirements.

Storage System Fluid Circulation System Power Requirements

A separate fluid circuit provides charging energy for the thermal energy storage system as discussed in Section 2.2. This circulation system includes a pump or compressor that must recoup the pressure losses throughout the storage charging fluid circuit. The power required to make up this pressure is determined by the overall pressure losses in the circuit, the instantaneous helium mass flow rate in the charging flow circuit, the discharge temperature from the storage device, and efficiency of the circulating pump.

$$\Delta T_{pump} = T_D \left(\frac{r_P^{\frac{\gamma-1}{\gamma}} - 1}{\eta_C} \right)$$

where:

$r_P = 1 + \frac{\Delta P_{LOSSES}}{P}$

γ = Ratio of specific heats for helium

p = Helium pressure

η_C = Circulation pump (enthalpy) efficiency

T_D = Storage device discharge temperature

The temperature and pressure changes in the helium stream across the pump are determined as a part of each of the storage system performance models. The corresponding pumping power which is provided directly by the primary gas turbine is then simply determined by the temperature rise across the pump and the corresponding gas flow rate.

$$MW_{pump} = \dot{m}_{He} Cp_{He} (\Delta T_{pump})$$

where:

$\dot{m}_{He}$ = Helium mass flow rate

Cp_{He} = Helium specific heat

2.7 ENERGY ANALYSIS

Daily cycle data of the type shown earlier in Figure 2-4 are generated for each of four representative days covering the four seasonal extremes. These data are analyzed to determine the energy losses on a daily basis. These results are then used to establish the yearly energy output of the power plant. The use of this resultant capacity data to establish the energy cost for the plant is described in the following section.

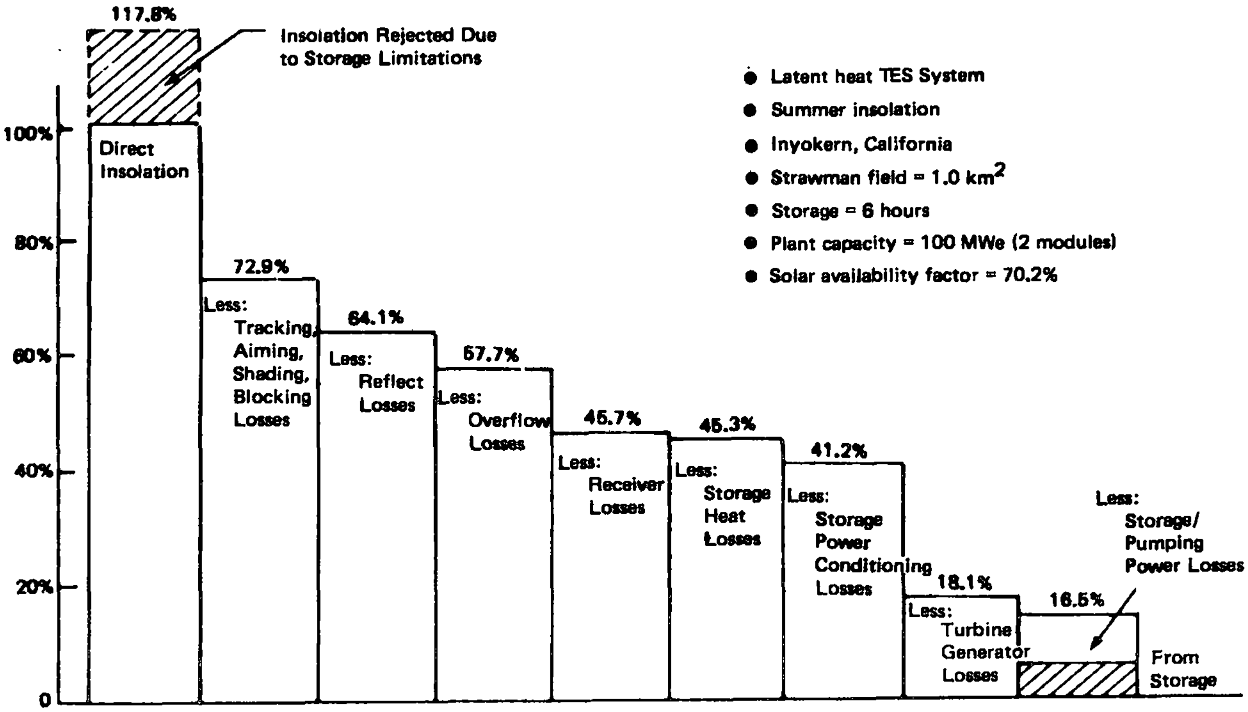
The weekly cycle option for chemical systems is handled assuming each day of the specified seasonal week has the same insolation profile. The computation of the plant capacity factor is based on an average weekday.

Representative plant operation data are shown in Figure 2-14. These data, as indicated in the figures, are based on a 0.5 km^2 module field, a module capacity of 50 MW_e with a storage time of 6 hours. The bar chart at the top of each figure is an analysis of the daily cycle energy losses for the summer insolation condition. The tables at the bottom of the figure summarize the key performance parameters for each of the four insolation conditions. All of the data presented in these figures are provided directly in the program output described in Section 5.0 of this volume.

2.8 ENERGY ECONOMICS ANALYSIS

The purpose of the energy economics analysis is to relate the power plant energy cost to the basic plant design variables. The approach used is based on a levelized fixed charge rate. This approach provides a simple method to relate plant capital investment and energy output to a common variable - busbar energy cost expressed in mills per kilowatt hour.

Busbar energy cost is computed as follows:



- Latent heat TES System
- Summer insolation
- Inyokern, California
- Strawman field = 1.0 km^2
- Storage = 6 hours
- Plant capacity = 100 MWe (2 modules)
- Solar availability factor = 70.2%

Daily Plant Performance Closed Cycle Helium

Season	Plant operatior (hours)	*Plant efficiency η_P	Max-min generator capacity (MW$_e$)	Max receiver mass flow (kg/sec)	Max turbine mass flow (kg/sec)	Max syorage mass flow (kg/sec)	Charge to discharge ratio	Round trip storage efficiency	Daily storage (hours)
Winter	11.7	29.6, 14.9	63–50	196	195	195	0.49	0.60	3.1
Spring	16.3	29.1, 16.3	70–50	256	195	195	0.72	0.64	6.0
Summer	16.8	28.6, 16.5	71–50	259	195	195	0.72	0.62	6.0
Fall	14.3	29.1, 16.5	67–50	233	195	195	0.63	0.64	5.3

*Plant efficiency definition

$$\eta_P = \frac{\text{Net generator energy}}{\text{Heat energy input to receiver}}, \quad \frac{\text{Net generator energy}}{\text{Specular insolation energy}}$$

Figure 2-14. Four-Day Performance Summary (Phase Change TES System)

$$\text{BBEC} = \frac{\text{CC} \times \text{FCR}}{\text{CF} \times 8760} \times \frac{1000 \text{ mills}}{\text{dollar}} + \text{O\&M}$$

where CC = capital cost - $ per kWh
FCR = fixed charge rate - %/yr
CF = capacity factor - %
O&M = levelized operation and maintenance cost - mills/kWh

The busbar energy cost computed by this approach is the cost of energy at the busbar levelized over the operating life of the plant. This cost is composed of two parts:

1) cost of the capital investment, and 2) the cost of operating and maintaining the power plant.

The cost of the capital investment is determined on the basis of a levelized annual discount rate which includes depreciation, cost of money, insurance, and taxes. This is a fixed annual charge, it is based on total capital investment at the time of initial commercial operation, and it is proportioned to the total yearly energy output of the plant. Levelized operation and miantenance costs is expressed as an increment in mills per kilowatt hour of output.

Plant capital cost in dollars per kilowatt is computed in the following manner. Total direct plant cost is computed by summing the costs associated with each of the plant subsystems. Contingency allowance and spare parts allowance, indirect costs, and interest during construction are added to this cost. The final summing of costs yields the total capital cost in dollars per kilowatt. Figure 2-15 summarizes the costing procedure and gives the actual subsystem costs which are used as default values in the plant operation program. These particular cost account numbers are based on the phase change storage device design costs presented in Volume I.

The yearly energy output of the plant (i.e., capacity factor) is determined by the plant operation analysis discussed in the preceeding section. The capacity factor is theaverage of the four seasonal capacity factors and is expressed as a percent of continuous operation at the plant rated capacity. It typically includes a 10% reduction for planned maintenance.

Power rating (MWe) – ED	50
Collector area (km^2)– CA	0.5
Storage time (hour) – SL	6
Account	
Land	2
Structures and facilities	44
Heliostats*	600
Central receiver/heat exchanger***	169
Tower****	40
Storage/tanks**	141
Boiler plant	—
Turbine plant equipment	119
Electric plant equipment	20
Miscellaneous plant equipment	4
Allowance for cooling towers	15
Total direct cost	1,154
Contingency and spare parts allowance (5%)	58
Indirect costs (10%)	115
Total capital investment (1975)	1,327
Interest during construction (15%)	199
Total cost at year of commercial operation	1,526

* Collector cost = $K_1 \times 1000 \times CA/ED$; $K_1 = \$\ 60/m^2$

** Storage cost = $K_1 \times SL + K_2$; $K_1 = \$\ 15.2/kW\text{-}hR$, $K_2 = \$\ 50/kW$

*** Receiver cost = $K_1 \times 1000 \times CA/ED$; $K_1 = \$\ 16.9/m^2$

**** Tower cost = $K_1 \times 50/\sqrt{0.5} \times \sqrt{CA}/ED$; K1 = \$ 40/m

Figure 2-15. Baseline Cost Accounts

Section 3
INPUT DESCRIPTION

The following is a list of the inputs required to operate the Plant Operation Model. For the convenience of the user, all inputs are defined and listed at the beginning of each case. The variables given are FORTRAN names identical to those in the program code.

3.1 NAMELIST

The inputs to the Power Plant Operation Math model are completely on cards. All variables have default values built in which may be overridden by standard IBM/NAMELIST statements. The inputs are free field separated by commas (,). Card column one (1) may not be used, however.

Input for a given case is initiated by the symbol &IN and computation is started when the symbol &END is encountered. For example, inputs changes are started with a card as follows:

```
✓&IN✓CA=0.5,IØHR=1, ...
```

Input is terminated and case execution begins with the following:

```
... ,TSTART=6.0,RAP=8.4✓&END
```

where ✓ represents a blank space. Any variable defined in Sections 3.2, 3.3, and 3.4 may be changed for a given case. Once an input has been modified it will remain the same for all following cases or until changed again. The NAMELIST example shown in Figure 3-1 are the inputs for the example cases described in Section 5.0 and are typical.

```
&IN
CA=0.5,SL=6.0
AC2(5)=5.0,AC3(5)=442.0
RAP=9.0,
ICHEM=1,
STURL=692.4,
&END
&IN
AC2(5)=16.3,AC3(5)=66.0
      ICHEM=0
DTPP=211.0
RAP=9.6,
UAIN=.07,
HFUS=18.42,
STURL=930.0,
XMCPL=.015,
XMCPS=.015,
&END
&IN
AC2(5)=48.7,AC3(5)=44.0
DTPP=211.0
RAP=9.6,
UAIN=.075
TFUS=2000.,
STURL=828.0,
XMCPL=.04662,
XMCPS=.04662,
&END
&IN
IOHR=1
 CA=0.5,NDAY=3
DTPP=211.0,RAP=9.5
TSTART=5.0,IPS=1
      NODS=2*20,3*0
      UAINN=2*0.06,3*0.0
      TFUSN=1835.0,1635.0,3*0.0
      HFUSN=2*17.84,3*0.0
      XMCPLN=2*0.017,3*0.0
      XMCPSN=2*0.017,3*0.0
      STURL=806.0 &END
```

Figure 3-1 NAMELIST Example

3.2 GENERAL INPUTS

VARIABLE	DEFAULT VALUE	DEFINITION
AHXAP	16.44	Ratio of the receiver heat exchanger area to the receiver aperture area (π x RAP^2)
AHXI	0.0	Receiver heat exchanger area - m^2
AWAP	17.65	Ratio of the receiver wall area to the receiver aperture area (π x RAP^2)
AWI	0.0	Receiver wall area - m^2
CA	0.5	Cavity collector area - sq. kilometers
DTAUI	1.0	Computer interval - hrs.
DMRPMW	2.79	The reactant product flow rate per MW of energy stored (chemical systems) - lb/sec/mw
DTPP	200.0	Pinch point temperature limit for thermal energy storage systems - deg. R. DTPP is the limiting value of temperature difference between the helium temperature at the storage device inelt and the helium temperature at the storage circulation pump outlet.
ED	50.0	Electrical grid demand - MW
EFCOM	0.8	Enthalpy efficiency of the storage circulation system compressor
EPCOM	0.64	Endothermic conversion fraction for the thermochemical storage system. For the SO_3/SO_2 system EPCON is the total SO_3 dissociation fraction in the endothermic reactor. The 36% SO_3 not dissociated must be recirculated, adding to the effective parasitic energy consumption of the CES system.
FACTOR	1.0	Plant operation yearly fraction
FCR	15.0	Fixed charge rate for economic analysis - %
HFUS*	20.0	Nodal heat of fusion of thermal energy storage media - MW-hr. The approximate sizing relationship for HFUS is as follows: $(HFUS)*(NODES) = \frac{MW_e}{\bar{\eta}_{TG}} \tau_{ESD} - M_M C_P \Delta T_M$

VARIABLE	DEFAULT	DEFINITION
		where MW_e = ED - MW $\bar{\eta}_{TG}$ = Expected conversion efficiency of turbine during storage discharge τ_{ESD} = Desired storage time - hrs. M_M C_P = Nodal sensible heat capacity of storage media (XMCPS)*(NODES and (XMCPL)*(NODES) - MW-hr/DEG-R ΔT_M = Expected temperature swing of storage media - DEG R
HFUSN(I)*	0.0	Same as HFUS and used when a multiple number of storage media (up to 5) are used. See NODS (I)
ICHEM	0	Indicator for storage concept desired = 0 thermal energy storage device = 1 thermochemical storage device
IOHR	0	Set equal to 1 to get thermodynamic state point output at each computer interval (see Section 5.0 Output Description)
IPS	0	For thermal energy storage (ICHEM=0) set equal to 1 to obtain nodal temperature data at each computer interval (valid only if IOHR=1)
IWEEK	0	Indicator for weekly cycle analysis (chemical system ICHEM=1) = 0 Daily cycle = 1 Weekly cycle
NDAY	0	NDAY defines which of the four insolations and reflector field efficiency tables are to be used = 0 All four seasonal days are analyzed in sequence and yearly plant capacity and energy costs are estimated = 1 Winter day P11(I) = 2 Spring day P12(I) = 3 Summer day P13(I) = 4 Fall day P14(I)

VARIABLE	DEFAULT VALUE	DEFINITION
NODES	40	Number of equal axial nodal divisions of the thermal energy storage device (ICHEM=0) for analysis in the finite difference equations (MAX = 99)
NODS(I) (I = 1 to 5)	0	Same as NODES except for use when a multi-phase thermal energy system is defined. The 5 separate NODS correspond to up to 5 separate storage salts. (NODS(1) = 0 indicates a multi-phase system. See UAINN(I), TFUSN(I), HFUSN(I), XMCPSN(I), XMCPLN(I) . The sum of NODS(1) through NODS(N) must not exceed 99.)
OM	6.0	Plant operation and maintenance cost - mills/kW
PP0C	0.165	Oxygen compressor parasitic power per unit mass flow rate (chemical systems) - MW/lb/sec
PPPC	0.069	Product compressor parasitic power per unit mass flow rate (chemical system) - MW/lb/sec
RAP	9.6	Aperture radius used in receiver performance model - meter
RSL	0.02	Energy reserve in storage device expressed as a fraction of STORL. This reserve accounts for thermal losses in storage system lines and due to conduction through container walls.
RT	1.07	Storage Circulation fluid circuit loop total pressure ratio $RT = 1 + \frac{\Sigma\Delta P_{LOSSES}}{P}$ where: ΔP_{LOSSES} = component pressure losses P = system pressure level (storage circulation pump or compressor operates at this pressure ratio)
SL	6.0	Storage limit hours. SL is used as a parameter in the cost model as described in the cost account input.
STORL	900.0	Energy storage limit for thermochemical (CES) system - MW hr. STORL is also used in the thermal (TES) system to compute the stored energy reserve (see RSL). The thermal storage system is limited by the pinch point temperature limit (DTPP) rather than the energy stored.

VARIABLE	DEFAULT VALUE	DEFINITION
TDS	8.0	Start time for level grid demand load (ED) - hours.
TED	1960.0	Turbine inlet design point operating temperature - DEG R
TFUS	1630.0	Melt temperature of thermal energy storage media - DEG R (set greater than TED for sensible heat device.)
TFUSN(I) (I = 1 to 5)	0.0	Same as TFUS and used when a multiple number of storage salts are used (see NODS(I))
TSTART	4.0	Hour of day to start power plant cycle analysis. Plant will not begin operation until some insolation is available. The model will not generate power until time equals TDS.
TWZER0	1410.0	Initial nodal temperature in thermal storage device - DEG R. Starting temperature profile in device is flat (neutral).
UAIN	0.075	Nodal value of the product of overall conductance and heat transfer surface area for thermal storage system - MW/DEG-R. The approximate sizing relationship for UAIN is as follows

$$(\text{UAIN})*(\text{NODES}) = \frac{MW_e}{\eta_{TG}\ \Delta T_{TG}}\ \text{NTU}$$

for the discharge condition, and

$$(\text{UAIN})*(\text{NODES}) = \frac{C_r\ MW_e}{\eta_{TG}\ \Delta T_{PP}}\ \text{NTU}$$

for the critical charge condition.

where MW_e = ED - MW

η_{TG} = Turbine conversion efficiency at minimum expected operating temperature

ΔT_{TG} = Turbine to recuperator outlet temperature and minimum expected operating temperature - DEG-R.

VARIABLE	DEFAULT VALUE	DEFINITION
		C_r = Charge to discharge power ratio ΔT_{PP} = Pinch point temperature limit - DEG-R (see DTPP) NTU = Number of thermal transfer units
UAINN(I)	0.0	Same as UAIN and used when a multiple number of storage salts (up to 5) are used (see NODS(I))
XMCPL*	0.2	Nodal value of sensible heat capacity of storage media above fusion temperature - MW-hr/DEG-R. Approximate sizing relationship used for HFUS can be used to estimate XMCPL.
XMCPLN(I) (I = 1 to 5)	0.0	Same as XMCPL and used when a multiple number of storage salts (up to 5) are used (see NODS(I))
XMCPS*	0.2	Nodal value of sensible heat capacity of storage media at temperature below the melt point. - MW-hr/DEG-R. Approximate sizing relationship for HFUS can be used to estimate XMCPS.
XMCPSN(I) (I = 1 to 5)	0.0	Same as XMCPS and used when a multiple of storage salts (up to 5) are used (see NODES(I))

*The actual mass of the storage media, the heat of fusion, and the solid and liquid specific heats can be used to set these values. The approximate sizing relationships shown here are roughly how these parameters relate to the overall performance of the storage system.

3.3 INSOLATION AND REFLECTOR FIELD TABLES

The solar insolation tables and the refelctor field efficiency tables are given in two arrays, PIA (24,4) and FEA (24,4). The first dimension (24) corresponds to the 24 hour day. The second dimension (4) represents

for 1 - winter day
for 2 - spring day
for 3 - summer day
for 4 - fall day.

The two arrays correspond point for point.

PIA (N,M) = direct insolation
FEA (N,M) = field efficiency - product of tracking efficiency, mirror reflectivity and receiver intercept efficiency.

The default values are given here in Figure 3-2.

In order to change the tables the standard NAMELIST statements are used. For example, to modify the 12th hour of insolation in the spring day to 890.0 from 930.0

```
PI1(12) = 890.0
```

Reducing the entire fall day by 10.0 one could do the following:

```
PI4 = 5*0.0, 640.0, 720.0, 790.0, 830.0, 860.0
      8/0.0, 860.0, 840.0, 810.0, 740.0, 620.0
      8*0.0
```

The values of reflector field efficiency are analogous

```
FE2(12) = 0.119
```

or

```
FE4 = 6*.0, 0.119, 0.347, 0.513, 0.60, 0.643,
      0.663, 0.667, 0.663, 0.643, 0.60, 0.513,
      0.347, 0.119, 6*0.0
```

```
PI - 4 DAYS - 24 HRS

   0.0       0.0       0.0       0.0       0.0       0.0
 550.000   600.000   850.000   910.000   920.000   910.000
 850.000   610.000   670.000   550.000     0.0       0.0
   0.0       0.0       0.0       0.0       0.0       0.0

   0.0       0.0       0.0       0.0       0.0     480.000
 690.000   800.000   870.000   910.000   930.000   930.000
 940.000   940.000   920.000   870.000   870.000     0.0
   0.0       0.0       0.0       0.0       0.0       0.0

   0.0       0.0       0.0       0.0     650.000   780.000
 870.000   920.000   930.000   920.000   910.000   910.000
 930.000   950.000   940.000   870.000   780.000   660.000
   0.0       0.0       0.0       0.0       0.0       0.0

   0.0       0.0       0.0       0.0       0.0     650.000
 730.000   800.000   640.000   870.000   880.000   870.000
 850.000   820.000   750.000   630.000     0.0       0.0
   0.0       0.0       0.0       0.0       0.0       0.0

FIELD EFF. - 4 DAYS - 24 HRS

  0.0       0.0       0.0       0.0       0.0       0.0
  0.167     0.381     0.508     0.578     0.587     0.569
  0.587     0.578     0.508     0.381     0.167     0.0
  0.0       0.0       0.0       0.0       0.0       0.0

  0.0       0.0       0.0       0.0       0.0       0.129
  0.357     0.523     0.610     0.653     0.673     0.677
  0.673     0.653     0.610     0.523     0.357     0.129
  0.0       0.0       0.0       0.0       0.0       0.0

  0.0       0.0       0.0       0.0       0.157     0.389
  0.517     0.593     0.645     0.674     0.689     0.692
  0.689     0.674     0.645     0.593     0.517     0.389
  0.157     0.0       0.0       0.0       0.0       0.0

  0.0       0.0       0.0       0.0       0.0       0.129
  0.357     0.523     0.610     0.653     0.673     0.677
  0.673     0.653     0.610     0.523     0.357     0.129
  0.0       0.0       0.0       0.0       0.0       0.0

POWER PLANT COST ACCOUNTS

  2.000    44.000     0.0       0.0       0.0       0.0       0.0     119.000    20.000     4.000
 15.000     0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

  0.0       0.0      60.000   169.000    40.000     5.000     0.0       0.0       0.0       0.0
  0.0       0.0       0.050     0.100     0.0       0.150     0.0       0.0       0.0       0.0

  0.0       0.0       0.0       0.0       0.0     442.000     0.0       0.0       0.0       0.0
  0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
```

Figure 3-2 Insolation Values and Cost Accounts

3.4 POWER PLANT COST ACCOUNTS

The power plant cost model is based on the standard EPRI and ERDA account structure. The accounts are contained in an array ACC (20,3) to allow for future expansion of the model. This expansion is based on the total cost of each item being based on a direct charge and a proportional charge or slope term.

$$\mathrm{ACC}(N,1) = \underbrace{\mathrm{ACC}\ (N,2) * A}_{\text{Proportional Term}} + \underbrace{\mathrm{ACC}\ (N,3)}_{\text{Direct Charge}}$$

If no proportional term is required the item cost is stored directly in the first array element ACC(N,1).

The array elements currently being used are defined below with their default values. Also see Figure 3-2.

The defaults may be overridden with NAMELIST inputs as described in Section 3.3 for PIA.

AC1(N) = ACC(N,1)
AC2(N) = ACC(N,2)
AC3(N) = ACC(N,3)

VARIABLE	DEFAULT VALUE	DEFINITION
ACC(1,1)	2.0	Land Cost - $/kW
ACC(2,1)	44.0	Structures and facilities cost - $/kW
ACC(3,2)	60.0	Heliostat cost per unit of heliostat area (CA) - $/kW/meters **2
ACC(4,2)	16.9	Central receiver - heat exchanger cost - $/kW/meters^2 (proportioned to heliostat collector area - CA)
ACC(5,2)	40.0	Central receiver tower cost - $/kW/meter (proportioned to heliostat field width)
ACC(6,2)	48.7	Storage system cost - $/kWh (proportioned to storage limit - SL)
ACC(6,3)	44.0	Storage system cost - $/kW

VARIABLE	DEFAULT VALUE	DEFINITION
ACC(7,1)	0.0	Boiler plant cost - \$/kW
ACC(8,1)	119.0	Turbine plant cost - \$/kW
ACC(9,1)	20.0	Electric plant cost - \$/kW
ACC(10,1)	4.0	Misc. plant and equipment - \$/kW
ACC(11,1)	15.0	Cooling Tower Cost - \$/kW
ACC(13,2)	0.05	Contingency and spare parts allowance - fraction of total direct cost.
ACC(14,2)	0.1	Indirect cost - fraction of total direct cost
ACC(16,2)	0.15	Interest during construction - fraction of total capital investment

Capital Cost Accounts (\$/kW)

Land	ACC(1,1)
Structures and Facilities	ACC(2,1)
Heliostats	ACC(3,2) x 1000 x CA/ED
Central Receiver/Heat Exchanger	ACC(4,1) x 1000 x CA/ED
Tower	ACC(5,2) x 50/ $\sqrt{.5}$ x $\sqrt{CA}$/ED
Storage Tanks (chemical)	ACC(6,2)xSL+ACC(6,3)
Boiler Plant	ACC(7,1)
Turbine Plant and Equipment	ACC(8,1)
Electric Plant and Equipment	ACC(9,1)
Misc. Plant and Equipment	ACC(10,1)
Allowance for cooling towers	ACC(,1)
Total Direct Cost	(TDC)
Contingency and Spare Parts Allowance	ACC(12,2) x TDC
Indirect Costs	ACC(14,2) x TDC
Total Capital Investment	(TCI)
Interest During Construction	ACC(16,2) x TCI
Total Cost at Commercial Operation	(TC)

Section 4

OPERATING INSTRUCTIONS

The computer program exists in the form of card decks and is executed in the batch mode. The source cards are coded in FORTRAN IV language and are compatible with IBM 360/370 computer systems.

Conversion to other computer systems should not be difficult, if required. The program uses only standard FORTRAN instructions and there is no machine-dependent software used and no known numerical significance concerns. The program should readily adapt to Remote Job Entry (RJE) or time-sharing terminals.

4.1 CONTROL CARDS

The program is executed by standard FORTRAN compile, LINKEDIT, and G0 steps run in sequence with IBM Job Control Language (JCL). In order to resolve installation dependent system differences, JCL procedures (PROCS) exist at all IBM facilities for accomplishing the execution sequence. The example shown below illustrates one of the PROCS used at Boeing System 370 computers and will be similar, if not identical, elsewhere.

```
              ┌───Column 1
              ↓
Card 1        //✓EXEC✓F0RTHCLG
Card 2        //FORT.SYSIN✓DD✓*
               { FORTRAN   }
               {   SOURCE  }
Card n        /*
Card n+1      //G0.SYSIN✓DD✓*
               { NAMELIST   }
               { STATEMENTS }
Card Last     /*
```

4.2 TIME AND OUTPUT ESTIMATES

Run time for FORTRAN compilation and LINKEDIT steps are constant for any case and will average about 4.5 seconds and 1 second, respectively. The values given here are based on Boeing IBM 370 computer CPU time (CPU = central processing unit).

The run time and printed output for a given case is dependent on several things including plant configuration (CES versus TES), output options, and the number of days considered. The following graph will best illustrate the variations.

Case Type	CPU time Seconds	Page of Output
TES-single day (NDAY 0)	2.5	4
TES-single day with hourly output (IOHR = 1, DTAUI = 1.0)	23.5	42 60 (IPS = 1)
TES-4 day with cost estimates (NDAY = 0)	7.0	8

CES cases will be fractionally lower in CPU time with page counts the same. (IPS = 1 does not apply)

Section 5

OUTPUT DESCRIPTION

Program output is determined by the type of case being run and the output options as described in Section 3.0. At the beginning of each case a list of all the inputs and their definitions is given as well as insolation and cost accounts. The examples shown here are the outputs generated from inputs shown in Figure 3-1.

In the first 3 cases a full yearly analysis with cost data is requested (NDAY = 0) with no output options. The first case represents a thermochemical system (ICHEM = 1). In the second case a phase change thermal energy storage device is modeled (ICHEM = 0), and in the third case a sensible heat thermal energy case is executed (TFUS TED).

In the last example, a multiple salt phase change thermal energy case is shown [NØDS (1)>0] for a single summer day (NDAY = 3). In this case the thermodynamic state point is given for each computer step (IØHR = 1) and nodal temperature data from the storage device are printed (IPS = 1).

```
     **** INPUTS ****

AHXAP   =         16.440      RECIEVER HEAT EXCHANGER/APERTURE AREA RATIO
AHXI    =          0.0        RECIEVER HEAT EXCHANGER AREA - M**2
AWAP    =         17.650      RECIEVER WALL/APERTURE AREA RATIO
AWI     =          0.0        RECIEVER WALL AREA - M**2
CA      =          0.500      COLLECTOR AREA - KM**2
DMRPMW  =          2.790      REACTANT PRODUCT FLOW PER MW STORED - LB/SEC/MW
DTAUI   =          1.000      COMPUTE INTERVAL - HRS
DTPP    =        200.000      PINCH POINT TEMPERATURE LIMIT (THERMAL SYSTEM) - R
ED      =         50.000      ELECTRICAL GRID DEMAND - MW
EFCOM   =          0.800      ENTHALPY EFFICENCY OF STORAGE SYSTEM COMPRESSOR
EPCON   =          0.640      ENDOTHERMIC CONVERSION FRACTION (CHEMICAL SYSTEM)
FACTOR  =          1.000      PLANT OPERATING YEARLY FRACTION
FCR     =         15.000      FIXED CHARGE RATE
HFUS    =         20.000      HEAT OF FUSION OF THERMAL STORAGE MEDIA - MWH
ICHEM   =          1          = 0 THERMAL ENERGY STORAGE DEVICE
                              = 1 THERMOCHEMICAL (CES) STORAGE DEVICE
IOHR    =          0          = 0 NO THERMODYNAMIC STATE POINT OUTPUT GENERATED
                              = 1 THERMODYNAMIC STATE POINT OUTPUT GENERATED
IPS     =          0          = 1 NODAL TEMPERATURES PRINTED FOR EACH STEP
                              = 0 NO NODAL TEMPERATURES PRINTED
IWEEK   =          0          = 1 FOR ANALYSIS OF WEEKLY CYCLE
NDAY    =          0          =  0 ANALYSE ALL FOUR DAYS FOR YEARLY RESULTS
                              =  1 WINTER DAY
                              =  2 SPRING DAY
                              =  3 SUMMER DAY
                              =  4 FALL DAY
NODES   =         40          NUMBER OF EQUAL AXIAL THERMAL ENERGY DIVISIONS
OM      =          6.000      OPERATING AND MAINTENANCE COST - MILLS/KW
PPOC    =          0.165      O2 COMP PARA POWER / UNIT MASS FLOW - MW/LB/SEC
PPPC    =          0.069      PROD COMP PARA POWER / UNIT MASS FLOW - MW/LB/SEC
RAP     =          9.600      APETURE RADIUS - METERS
RSL     =          0.02000    FRACTION OF STORAGE ENERGY HELD IN RESERVE
RT      =          1.070      PRESSURE RATIO OF TOTAL FLUID CIRCUIT LOOP
SL      =          6.000      STORACE LIMIT FOR COST MODEL - HRS
STORL   =        692.400      ENERGY LIMIT FOR CES SYSTEM - MWH
TDS     =          8.000      START TIME FOR LEVEL GRID DEMAND LOAD - HRS
TED     =       1960.000      DESIGN POINT OPERATING TEMPERATURE - R
TFUS    =       1630.000      MELT TEMPERATURE OF THERMAL STORAGE MEDIA - R
TSTART  =          4.000      STARTING TIME FOR POWER PLANT CYCLE ANALYSIS - HRS
TWZERO  =       1410.000      INITIAL NODAL TEMPERATURE OF STORAGE DEVICE - R
UAIN    =          0.07500    PRODUCT OF CONDUCTANCE AND SURFACE AREA - MW/R
XMCPL   =          0.02000    SENSIBLE HEAT CAPACITY OF STORAGE MEDIA - MWH/R
XMCPS   =          0.02000    SENSIBLE HEAT CAPACITY BELOW MELT POINT - MWH/R
```

```
PI = 4 DAYS = 24 HRS

      0.0        0.0        0.0        0.0        0.0        0.0
    550.000    800.000    890.000    910.000    920.000    910.000
    890.000    810.000    670.000    550.000      0.0        0.0
      0.0        0.0        0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0        0.0      480.000
    690.000    800.000    870.000    910.000    930.000    930.000
    940.000    940.000    920.000    870.000    870.000      0.0
      0.0        0.0        0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0      650.000    780.000
    870.000    920.000    930.000    920.000    910.000    910.000
    930.000    950.000    940.000    870.000    780.000    660.000
      0.0        0.0        0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0        0.0      650.000
    730.000    800.000    840.000    870.000    880.000    870.000
    850.000    820.000    750.000    630.000      0.0        0.0
      0.0        0.0        0.0        0.0        0.0        0.0

FIELD EFF. = 4 DAYS = 24 HRS

      0.0        0.0        0.0        0.0        0.0        0.0
      0.167      0.381      0.508      0.578      0.587      0.569
      0.587      0.578      0.508      0.381      0.167      0.0
      0.0        0.0        0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0        0.0        0.129
      0.357      0.523      0.610      0.653      0.673      0.677
      0.673      0.653      0.610      0.523      0.357      0.129
      0.0        0.0        0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0        0.157      0.389
      0.517      0.593      0.645      0.674      0.689      0.692
      0.689      0.674      0.645      0.593      0.517      0.389
      0.157      0.0        0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0        0.0        0.129
      0.357      0.523      0.610      0.653      0.673      0.677
      0.673      0.653      0.610      0.523      0.357      0.129
      0.0        0.0        0.0        0.0        0.0        0.0

POWER PLANT COST ACCOUNTS

      2.000     44.000      0.0        0.0        0.0        0.0        0.0      119.000     20.000      4.000
     15.000      0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0

      0.0        0.0       60.000    169.000      5.000      5.000      0.0        0.0        0.0        0.0
      0.0        0.0        0.050      0.100      0.0        0.150      0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0      442.000    442.000      0.0        0.0        0.0        0.0
      0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
```

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          DAILY PLANT PERFORMANCE  (WINTER)
          ***** ***** ***********

                                         % ENERGY          MWH

  DIRECT INSOLATION                        100.0         3950.00

      LESS: INSOLATION REJECTED DUE TO     100.0         3950.00
            STORAGE LIMITATIONS
      LESS: REFLECTOR FIELD LOSSES          50.3         1986.55

      LESS: RECIEVER LOSSES                 39.7         1566.90

      LESS: STORAGE HEAT LOSSES             39.3         1553.05

      PLUS: STORAGE CIRCULATION PUMP HEAT   40.4         1597.04
            & INITIAL STORED ENERGY
      LESS: NET STORAGE POWER               40.4         1597.04
            CONDITIONING LOSSES
      LESS: TURBINE GENERATOR LOSSES        17.9          705.89

      LESS: STORAGE PARASITIC ENERGY        14.1          558.77
            LOSSES
      LESS: DIRECT GENERATION                4.4          175.18

   COLECTOR AREA (KM**2)                    0.50
   PLANT CAPACITY (MW)                     50.00
   DAILY PLANT CAPACITY FACTOR (%)         46.56

   MAXIMUM MASS FLOWS (LBS/SEC)
      TURBINE                                        294.42
      STORAGE (CHARGE) *                             108.93
      STORAGE (CHARGE)                               100.10
      STORAGE (DISCHARGE)                            203.43
      RECIEVER                                       394.52

   MAXIMUM POWER CONDITIONS (MW)
      GENERATOR *                                     24.33
      GENERATOR                                       72.36
      STORAGE (CHARGE) *                              67.85
      STORAGE (CHARGE)                                62.35
      STORAGE (DISCHARGE)                            113.12
      RECIEVER                                       219.38

   TEMPERATURE EXTREMES (DEG-R)
      MINIMUM TURBINE INLET                         1960.00
      MAXIMUM STORAGE SYSTEM DISCHARGE              1538.00
      MAXIMUM RECIEVER INLET                        1538.00

   STORAGE SYSTEM DESIGN CONDITIONS
      ROUND TRIP EFFICIENCY (%)                       56.70
      MAXIMUM ENERGY IN STORAGE (MW)                 410.19
      EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)   42.71
      STORAGE TIME (HRS)                               3.50

   * CONDITION WITH GENERATOR OFF-LINE
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          DAILY PLANT PERFORMANCE  (SPRING)
          ***** ***** ***********

                                                   % ENERGY          MWH

   DIRECT INSOLATION                                  103.7          5075.77

        LESS: INSOLATION REJECTED DUE TO              100.0          4692.49
              STORAGE LIMITATIONS
        LESS: REFLECTOR FIELD LOSSES                   56.2          2747.40

        LESS: RECIEVER LOSSES                          44.9          2198.39

        LESS: STORAGE HEAT LOSSES                      44.7          2184.56

        PLUS: STORAGE CIRCULATION PUMP HEAT            46.2          2258.82
              & INITIAL STORED ENERGY
        LESS: NET STORAGE POWER                        46.2          2258.82
              CONDITIONING LOSSES
        LESS: TURBINE GENERATOR LOSSES                 20.4           998.40

        LESS: STORAGE PARASITIC ENERGY                 15.3           750.00
              LOSSES
        LESS: DIRECT GENERATION                         6.1           300.00

   COLECTOR AREA (KM**2)                                0.50
   PLANT CAPACITY (MW)                                 50.00
   DAILY PLANT CAPACITY FACTOR (%)                     62.50

   MAXIMUM MASS FLOWS (LBS/SEC)
       TURBINE                                               329.41
       STORAGE (CHARGE) *                                    156.11
       STORAGE (CHARGE)                                      138.60
       STORAGE (DISCHARGE)                                   203.43
       RECIEVER                                              468.01

   MAXIMUM POWER CONDITIONS (MW)
       GENERATOR *                                            34.88
       GENERATOR                                              80.96
       STORAGE (CHARGE) *                                     97.24
       STORAGE (CHARGE)                                       86.33
       STORAGE (DISCHARGE)                                   113.12
       RECIEVER                                              260.25

   TEMPERATURE EXTREMES (DEG-R)
       MINIMUM TURBINE INLET                                1960.00
       MAXIMUM STORAGE SYSTEM DISCHARGE                     1538.00
       MAXIMUM RECIEVER INLET                               1538.00

   STORAGE SYSTEM DESIGN CONDITIONS
       ROUND TRIP EFFICIENCY (%)                              57.51
       MAXIMUM ENERGY IN STORAGE (MW)                        692.56
       EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)          43.32
       STORAGE TIME (HRS)                                      6.00

   * CONDITION WITH GENERATOR OFF-LINE
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          DAILY PLANT PERFORMANCE  (SUMMER)
          ***** ***** ***********

                                                % ENERGY          MWH

   DIRECT INSOLATION                             117.7          6007.50

       LESS: INSOLATION REJECTED DUE TO          100.0          5105.97
             STORAGE LIMITATIONS
       LESS: REFLECTOR FIELD LOSSES               56.7          2896.99

       LESS: RECIEVER LOSSES                      44.9          2293.72

       LESS: STORAGE HEAT LOSSES                  44.7          2279.87

       PLUS: STORAGE CIRCULATION PUMP HEAT        46.1          2354.12
             & INITIAL STORED ENERGY
       LESS: NET STORAGE POWER                    46.1          2354.12
             CONDITIONING LOSSES
       LESS: TURBINE GENERATOR LOSSES             20.4          1040.52

       LESS: STORAGE PARASITIC ENERGY             15.5           792.17
             LOSSES
       LESS: DIRECT GENERATION                     5.9           299.92

   COLECTOR AREA (KM**2)                          0.50
   PLANT CAPACITY (MW)                           50.00
   DAILY PLANT CAPACITY FACTOR (%)               66.01

   MAXIMUM MASS FLOWS (LBS/SEC)
      TURBINE                                          330.36
      STORAGE (CHARGE) *                               208.97
      STORAGE (CHARGE)                                 139.64
      STORAGE (DISCHARGE)                              203.43
      RECIEVER                                         470.00

   MAXIMUM POWER CONDITIONS (MW)
      GENERATOR *                                       46.68
      GENERATOR                                         81.20
      STORAGE (CHARGE) *                               130.16
      STORAGE (CHARGE)                                  86.98
      STORAGE (DISCHARGE)                              113.12
      RECIEVER                                         261.36

   TEMPERATURE EXTREMES (DEG=R)
      MINIMUM TURBINE INLET                           1960.00
      MAXIMUM STORAGE SYSTEM DISCHARGE                1538.00
      MAXIMUM RECIEVER INLET                          1538.00

   STORAGE SYSTEM DESIGN CONDITIONS
      ROUND TRIP EFFICIENCY (%)                         57.50
      MAXIMUM ENERGY IN STORAGE (MW)                   692.41
      EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)     43.32
      STORAGE TIME (HRS)                                 6.00

   * CONDITION WITH GENERATOR OFF=LINE
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          DAILY PLANT PERFORMANCE  (FALL)
          ***** ***** ***********

                                                  % ENERGY         MWH

   DIRECT INSOLATION                                 100.0         4345.00

      LESS: INSOLATION REJECTED DUE TO              100.0         4345.00
            STORAGE LIMITATIONS
      LESS: REFLECTOR FIELD LOSSES                   56.6         2459.55

      LESS: RECIEVER LOSSES                          45.2         1963.07

      LESS: STORAGE HEAT LOSSES                      44.9         1949.22

      PLUS: STORAGE CIRCULATION PUMP HEAT            46.4         2015.80
            & INITIAL STORED ENERGY
      LESS: NET STORAGE POWER                        46.4         2015.80
            CONDITIONING LOSSES
      LESS: TURBINE GENERATOR LOSSES                 20.5          890.98

      LESS: STORAGE PARASITIC ENERGY                 15.4          668.30
            LOSSES
      LESS: DIRECT GENERATION                         6.2          268.30

   COLECTOR AREA (KM**2)                             0.50
   PLANT CAPACITY (MW)                              50.00
   DAILY PLANT CAPACITY FACTOR (%)                  55.69

   MAXIMUM MASS FLOWS (LBS/SEC)
        TURBINE                                             314.15
        STORAGE (CHARGE) *                                  156.11
        STORAGE (CHARGE)                                    121.81
        STORAGE (DISCHARGE)                                 203.43
        RECIEVER                                            435.95

   MAXIMUM POWER CONDITIONS (MW)
        GENERATOR *                                          34.88
        GENERATOR                                            77.21
        STORAGE (CHARGE) *                                   97.24
        STORAGE (CHARGE)                                     75.87
        STORAGE (DISCHARGE)                                 113.12
        RECIEVER                                            242.42

   TEMPERATURE EXTREMES (DEG-R)
        MINIMUM TURBINE INLET                              1960.00
        MAXIMUM STORAGE SYSTEM DISCHARGE                   1538.00
        MAXIMUM RECIEVER INLET                             1538.00

   STORAGE SYSTEM DESIGN CONDITIONS
        ROUND TRIP EFFICIENCY (%)                            57.37
        MAXIMUM ENERGY IN STORAGE (MW)                      620.86
        EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)        43.21
        STORAGE TIME (HRS)                                    5.37

   * CONDITION WITH GENERATOR OFF-LINE
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SOLAR POWER PLANT ECONOMICS
***** ***** ***** *********

POWER RATING                      (MWE)             50.00
COLLECTOR AREA                    (KM**2)            0.50
STORAGE TIME                      (HR)               6.00


CAPITAL COST ACCOUNTS ($/KW)
******* **** ********* ******

LAND                                                 2.00
STRUCTURES AND FACILITIES                           44.00
HELIOSTATS                                         600.00
CENTRAL RECIEVER/HEAT EXCHANGER                    169.00
TOWER                                              447.00
STORAGE TRANKS (CHEMICAL)                          472.00
BOILER PLANT                                         0.0
TURBINE PLANT AND EQUIPMENT                        119.00
ELECTRIC PLANT AND EQUIPMENT                        20.00
MISC PLANT AND EQUIPMENT                             4.00
ALLOWANCE FOR COOLING TOWERS                        15.00

     TOTAL DIRECT COST                            1892.00

CONTINGENCY AND SPARE PARTS             ( 5%)       94.60
INDIRECT COSTS                          (10%)      189.20

     TOTAL CAPITAL INVESTMENT                     2175.80

INTEREST DURING CONSTRUCTION            (15%)      326.37

     TOTAL COST AT COMMERCIAL OPERATION           2502.17


ENERGY COSTS
****** *****

CAPITAL COST                      ($/KW)          2502.17
FIXED CHARGE RATE                 (%)               15.00
CAPACITY FACTOR (CORRECTED)       (%)               57.69
LEVALIZED O & M COST              (MILLS/KWH)        6.00

BUSBAR ENERGY COST                (MILLS/KWH)       80.27
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         **** INPUTS ****

   AHXAP   =        16.440    RECIEVER HEAT EXCHANGER/APERTURE AREA RATIO
   AHXI    =         0.0      RECIEVER HEAT EXCHANGER AREA = M**2
   AWAP    =        17.450    RECIEVER WALL/APERTURE AREA RATIO
   AWI     =         0.0      RECIEVER WALL AREA = M**2
   CA      =         0.500    COLLECTOR AREA = KM**2
   DMRPMW  =         2.790    REACTANT PRODUCT FLOW PER MW STORED = LB/SEC/MW
   DTAUI   =         1.000    COMPUTE INTERVAL = HRS
   DTPP    =       211.000    PINCH POINT TEMPERATURE LIMIT (THERMAL SYSTEM) = R
   ED      =        50.000    ELECTRICAL GRID DEMAND = MW
   EFCOM   =         0.800    ENTHALPY EFFICENCY OF STORAGE SYSTEM COMPRESSOR
   EPCON   =         0.440    ENDOTHERMIC CONVERSION FRACTION (CHEMICAL SYSTEM)
   FACTOR  =         1.000    PLANT OPERATING YEARLY FRACTION
   FCR     =        15.000    FIXED CHARGE RATE
   HFUS    =        18.420    HEAT OF FUSION OF THERMAL STORAGE MEDIA = MWH
   ICHEM   =         0        = 0 THERMAL ENERGY STORAGE DEVICE
                              = 1 THERMOCHEMICAL (CES) STORAGE DEVICE
   IOHR    =         0        = 0 NO THERMODYNAMIC STATE POINT OUTPUT GEWERATED
                              = 1 THERMODYNAMIC STATE POINT OUTPUT GENERATED
   IPS     =         0        = 1 NODAL TEMPERATURES PRINTED FOR EACH STEP
                              = 0 NO NODAL TEMPERATURES PRINTED
   IWEEK   =         0        = 1 FOR ANALYSIS OF WEEKLY CYCLE
   NDAY    =         0        =  0 ANALYSE ALL FOUR DAYS FOR YEARLY RESULTS
                              =  1 WINTER DAY
                              =  2 SPRING DAY
                              =  3 SUMMER DAY
                              =  4 FALL DAY
   NODES   =        40        NUMBER OF EQUAL AXIAL THERMAL ENERGY DIVISIONS
   OM      =         6.000    OPERATING AND MAINTENANCE COST = MILLS/KW
   PPOC    =         0.165    O2 COMP PARA POWER / UNIT MASS FLOW = MW/LB/SEC
   PPRC    =         0.069    PROD COMP PARA POWER / UNIT MASS FLOW = MW/LB/SEC
   RAP     =         9.600    APETURE RADIUS = METERS
   RSL     =         0.02000  FRACTION OF STORAGE ENERGY HELD IN RESERVE
   RT      =         1.070    PRESSURE RATIO OF TOTAL FLUID CIRCUIT LOOP
   SL      =         6.000    STORAGE LIMIT FOR COST MODEL = HRS
   STORL   =       930.000    ENERGY LIMIT FOR CES SYSTEM = MWH
   TDS     =         8.000    START TIME FOR LEVEL GRID DEMAND LOAD = HRS
   TED     =      1960.000    DESIGN POINT OPERATING TEMPERATURE = R
   TFUS    =      1630.000    MELT TEMPERATURE OF THERMAL STORAGE MEDIA = R
   TSTART  =         4.000    STARTING TIME FOR POWER PLANT CYCLE ANALYSIS = HRS
   T-ZERO  =      1410.000    INITIAL NODAL TEMPERATURE OF STORAGE DEVICE = R
   UAIN    =         0.07000  PRODUCT OF CONDUCTANCE AND SURFACE AREA = MW/R
   XMCPL   =         0.01500  SENSIBLE HEAT CAPACITY OF STORAGE MEDIA = MWH/R
   XMCPS   =         0.01500  SENSIBLE HEAT CAPACITY BELOW MELT POINT = MWH/R
```

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PI - 4 DAYS - 24 HRS

      0.0        0.0        0.0        0.0        0.0        0.0
    550.000    800.000    890.000    910.000    920.000    910.000
    890.000    810.000    670.000    550.000      0.0        0.0
      0.0        0.0        0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0        0.0      480.000
    690.000    800.000    870.000    910.000    930.000    930.000
    940.000    940.000    920.000    870.000    870.000      0.0
      0.0        0.0        0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0      650.000    780.000
    870.000    920.000    930.000    920.000    910.000    910.000
    930.000    950.000    940.000    870.000    780.000    660.000
      0.0        0.0        0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0        0.0      650.000
    730.000    800.000    840.000    870.000    880.000    870.000
    850.000    820.000    750.000    630.000      0.0        0.0
      0.0        0.0        0.0        0.0        0.0        0.0

FIELD EFF. - 4 DAYS - 24 HRS

      0.0        0.0        0.0        0.0        0.0        0.0
      0.167      0.381      0.508      0.578      0.587      0.569
      0.587      0.578      0.508      0.381      0.167      0.0
      0.0        0.0        0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0        0.0        0.129
      0.357      0.523      0.610      0.653      0.673      0.677
      0.673      0.653      0.610      0.523      0.357      0.129
      0.0        0.0        0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0        0.157      0.389
      0.517      0.593      0.645      0.674      0.689      0.692
      0.689      0.674      0.645      0.593      0.517      0.389
      0.157      0.0        0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0        0.0        0.129
      0.357      0.523      0.610      0.653      0.673      0.677
      0.673      0.653      0.610      0.523      0.357      0.129
      0.0        0.0        0.0        0.0        0.0        0.0

PO-ER PLANT COST ACCOUNTS

      2.000     44.000      0.0        0.0        0.0        0.0        0.0      119.000     20.000      4.000
     15.000      0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0

      0.0        0.0       60.000    169.000     16.300      5.000      0.0        0.0        0.0        0.0
      0.0        0.0        0.050      0.100      0.0        0.150      0.0        0.0        0.0        0.0

      0.0        0.0        0.0        0.0       66.000    442.000      0.0        0.0        0.0        0.0
      0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
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```
          DAILY PLANT PERFORMANCE  (WINTER)
          ***** ***** ***********

                                          % ENERGY        MWH

   DIRECT INSOLATION                        100.0       3950.00

      LESS: INSOLATION REJECTED DUE TO      100.0       3950.00
            STORAGE LIMITATIONS
      LESS: REFLECTOR FIELD LOSSES           50.3       1986.55

      LESS: RECIEVER LOSSES                  39.7       1567.77

      LESS: STORAGE HEAT LOSSES              39.2       1549.13

      PLUS: STORAGE CIRCULATION PUMP HEAT    41.2       1626.57
            & INITIAL STORED ENERGY
      LESS: NET STORAGE POWER                37.0       1461.20
            CONDITIONING LOSSES
      LESS: TURBINE GENERATOR LOSSES         16.4        645.85

      LESS: STORAGE PARASITIC ENERGY         14.4        568.58
            LOSSES
      LESS: DIRECT GENERATION                 4.7        186.54

   COLECTOR AREA (KM**2)                      0.50
   PLANT CAPACITY (MW)                       50.00
   DAILY PLANT CAPACITY FACTOR (%)           47.38

   MAXIMUM MASS FLOWS (LBS/SEC)
        TURBINE                                         483.78
        STORAGE (CHARGE) *                              145.46
        STORAGE (CHARGE)                                184.24
        STORAGE (DISCHARGE)                             483.78
        RECIEVER                                        442.45

   MAXIMUM POWER CONDITIONS (MW)
        GENERATOR *                                       9.22
        GENERATOR                                        63.46
        STORAGE (CHARGE) *                              105.07
        STORAGE (CHARGE)                                 89.83
        STORAGE (DISCHARGE)                             178.07
        RECIEVER                                        218.68

   TEMPERATURE EXTREMES (DEG-R)
        MINIMUM TURBINE INLET                          1525.23
        MAXIMUM STORAGE SYSTEM DISCHARGE               1685.69
        MAXIMUM RECIEVER INLET                         1599.14

   STORAGE SYSTEM DESIGN CONDITIONS
        ROUND TRIP EFFICIENCY (%)                        60.53
        MAXIMUM ENERGY IN STORAGE (MW)                  599.57
        EFFECTIVE TEMPERATURE SWING (THERMAL) (DEG-R)   365.71
        EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)    31.11
        CRITICAL THERMAL SIZE  (M-DOT=   483.78)          4.39
        STORAGE TIME (HRS)                                3.73

    * CONDITION WITH GENERATOR OFF-LINE
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          DAILY PLANT PERFORMANCE  (SPRING)
          ***** ***** ***********

                                          % ENERGY          MWH

  DIRECT INSOLATION                          104.7        5077.06

      LESS: INSOLATION REJECTED DUE TO       100.0        4849.84
                STORAGE LIMITATIONS
      LESS: REFLECTOR FIELD LOSSES            56.2        2723.94

      LESS: RECIEVER LOSSES                   44.8        2171.24

      LESS: STORAGE HEAT LOSSES               44.4        2152.64

      PLUS: STORAGE CIRCULATION PUMP HEAT     47.4        2297.99
                & INITIAL STORED ENERGY
      LESS: NET STORAGE POWER                 42.8        2076.44
                CONDITIONING LOSSES
      LESS: TURBINE GENERATOR LOSSES          18.9         917.79

      LESS: STORAGE PARASITIC ENERGY          15.9         772.45
                LOSSES
      LESS: DIRECT GENERATION                  6.6         322.40

  COLECTOR AREA (KM**2)                        0.50
  PLANT CAPACITY (MW)                         50.00
  DAILY PLANT CAPACITY FACTOR (%)             64.36

  MAXIMUM MASS FLOWS (LBS/SEC)
     TURBINE                                          476.22
     STORAGE (CHARGE) *                               220.96
     STORAGE (CHARGE)                                 282.40
     STORAGE (DISCHARGE)                              476.22
     RECIEVER                                         570.31

  MAXIMUM POWER CONDITIONS (MW)
     GENERATOR *                                       14.40
     GENERATOR                                         70.76
     STORAGE (CHARGE) *                               148.07
     STORAGE (CHARGE)                                 119.35
     STORAGE (DISCHARGE)                              176.59
     RECIEVER                                         258.68

  TEMPERATURE EXTREMES (DEG-R)
     MINIMUM TURBINE INLET                           1531.25
     MAXIMUM STORAGE SYSTEM DISCHARGE                1749.00
     MAXIMUM RECIEVER INLET                          1630.43

  STORAGE SYSTEM DESIGN CONDITIONS
     ROUND TRIP EFFICIENCY (%)                         63.25
     MAXIMUM ENERGY IN STORAGE (MW)                   969.52
     EFFECTIVE TEMPERATURE SWING (THERMAL) (DEG-R)    483.16
     EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)     33.25
     CRITICAL THERMAL SIZE  (M-DOT=   476.22)           4.46
     STORAGE TIME (HRS)                                 6.45

  * CONDITION WITH GENERATOR OFF-LINE
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          DAILY PLANT PERFORMANCE  (SUMMER)
          ***** ***** ***********

                                              % ENERGY          MWH

  DIRECT INSOLATION                             120.0          6009.17

       LESS: INSOLATION REJECTED DUE TO         100.0          5009.22
             STORAGE LIMITATIONS
       LESS: REFLECTOR FIELD LOSSES              56.5          2830.10

       LESS: RECIEVER LOSSES                     44.5          2229.04

       LESS: STORAGE HEAT LOSSES                 44.1          2210.66

       PLUS: STORAGE CIRCULATION PUMP HEAT       46.9          2351.00
             & INITIAL STORED ENERGY
       LESS: NET STORAGE POWER                   42.2          2113.12
             CONDITIONING LOSSES
       LESS: TURBINE GENERATOR LOSSES            18.6           934.00

       LESS: STORAGE PARASITIC ENERGY            15.8           793.56
             LOSSES
       LESS: DIRECT GENERATION                    6.0           301.67

  COLECTOR AREA (KM**2)                           0.50
  PLANT CAPACITY (MW)                            50.00
  DAILY PLANT CAPACITY FACTOR (%)                66.13

  MAXIMUM MASS FLOWS (LBS/SEC)
      TURBINE                                               449.90
      STORAGE (CHARGE) *                                    404.23
      STORAGE (CHARGE)                                      319.51
      STORAGE (DISCHARGE)                                   449.90
      RECIEVER                                              621.83

  MAXIMUM POWER CONDITIONS (MW)
      GENERATOR *                                            29.36
      GENERATOR                                              74.31
      STORAGE (CHARGE) *                                    182.61
      STORAGE (CHARGE)                                      117.20
      STORAGE (DISCHARGE)                                   171.16
      RECIEVER                                              257.21

  TEMPERATURE EXTREMES (DEG-R)
      MINIMUM TURBINE INLET                                1553.10
      MAXIMUM STORAGE SYSTEM DISCHARGE                     1749.04
      MAXIMUM RECIEVER INLET                               1646.44

  STORAGE SYSTEM DESIGN CONDITIONS
      ROUND TRIP EFFICIENCY (%)                              61.23
      MAXIMUM ENERGY IN STORAGE (MW)                        936.89
      EFFECTIVE TEMPERATURE SWING (THERMAL) (DEG-R)         466.97
      EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)          32.20
      CRITICAL THERMAL SIZE  (M-DOT=   449.90)                4.72
      STORAGE TIME (HRS)                                      6.03

  * CONDITION WITH GENERATOR OFF-LINE
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          DAILY PLANT PERFORMANCE  (FALL)
          ***** ***** ***********

                                          % ENERGY         MWH

 DIRECT INSOLATION                          100.0         4345.00

      LESS: INSOLATION REJECTED DUE TO      100.0         4345.00
            STORAGE LIMITATIONS
      LESS: REFLECTOR FIELD LOSSES           56.6         2459.55

      LESS: RECIEVER LOSSES                  45.0         1957.39

      LESS: STORAGE HEAT LOSSES              44.6         1938.97

      PLUS: STORAGE CIRCULATION PUMP HEAT    47.6         2066.77
            & INITIAL STORED ENERGY
      LESS: NET STORAGE POWER                42.9         1863.14
            CONDITIONING LOSSES
      LESS: TURBINE GENERATOR LOSSES         19.0          823.51

      LESS: STORAGE PARASITIC ENERGY         16.0          695.85
            LOSSES
      LESS: DIRECT GENERATION                 6.8          295.72

 COLECTOR AREA (KM**2)                        0.50
 PLANT CAPACITY (MW)                         50.00
 DAILY PLANT CAPACITY FACTOR (%)             57.99

 MAXIMUM MASS FLOWS (LBS/SEC)
      TURBINE                                          448.81
      STORAGE (CHARGE) *                               223.55
      STORAGE (CHARGE)                                 242.58
      STORAGE (DISCHARGE)                              448.81
      RECIEVER                                         518.12

 MAXIMUM POWER CONDITIONS (MW)
      GENERATOR *                                       14.65
      GENERATOR                                         67.73
      STORAGE (CHARGE) *                               147.66
      STORAGE (CHARGE)                                 105.53
      STORAGE (DISCHARGE)                              170.89
      RECIEVER                                         241.05

 TEMPERATURE EXTREMES (DEG-R)
      MINIMUM TURBINE INLET                           1553.98
      MAXIMUM STORAGE SYSTEM DISCHARGE                1692.86
      MAXIMUM RECIEVER INLET                          1607.59

 STORAGE SYSTEM DESIGN CONDITIONS
      ROUND TRIP EFFICIENCY (%)                         63.57
      MAXIMUM ENERGY IN STORAGE (MW)                   891.02
      EFFECTIVE TEMPERATURE SWING (THERMAL) (DEG-R)    468.93
      EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)     33.19
      CRITICAL THERMAL SIZE  (M-DOT=   448.81)           4.73
      STORAGE TIME (HRS)                                 5.91

 * CONDITION WITH GENERATOR OFF-LINE
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SOLAR POWER PLANT ECONOMICS
***** ***** ***** *********

POWER RATING                    (MWE)              50.00
COLLECTOR AREA                  (KM**2)             0.50
STORAGE TIME                    (HR)                6.00


CAPITAL COST ACCOUNTS ($/KW)
******* **** ******** ******

LAND                                                2.00
STRUCTURES AND FACILITIES                          44.00
HELIOSTATS                                        600.00
CENTRAL RECIEVER/HEAT EXCHANGER                   169.00
TOWER                                              82.30
STORAGE TRANKS (THERMAL )                         472.00
BOILER PLANT                                       0.0
TURBINE PLANT AND EQUIPMENT                       119.00
ELECTRIC PLANT AND EQUIPMENT                       20.00
MISC PLANT AND EQUIPMENT                            4.00
ALLOWANCE FOR COOLING TOWERS                       15.00

     TOTAL DIRECT COST                           1527.30

CONTINGENCY AND SPARE PARTS           ( 5%)        76.36
INDIRECT COSTS                        (10%)       152.73

     TOTAL CAPITAL INVESTMENT                    1756.39

INTEREST DURING CONSTRUCTION          (15%)       263.46

     TOTAL COST AT COMMERCIAL OPERATION          2019.85


ENERGY COSTS
****** *****

CAPITAL COST                    ($/KW)           2019.85
FIXED CHARGE RATE               (%)                15.00
CAPACITY FACTOR (CORRECTED)     (%)                58.96
LEVALIZED O & M COST            (MILLS/KWH)         6.00

BUSBAR ENERGY COST              (MILLS/KWH)        64.66
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**** INPUTS ****

 AHXAP  =        16.440     RECIEVER HEAT EXCHANGER/APERTURE AREA RATIO
 AHXI   =         0.0       RECIEVER HEAT EXCHANGER AREA = M**2
 AWAP   =        17.650     RECIEVER WALL/APERTURE AREA RATIO
 AWI    =         0.0       RECIEVER WALL AREA = M**2
 CA     =         0.500     COLLECTOR AREA = KM**2
 DMRPMW =         2.790     REACTANT PRODUCT FLOW PER MW STORED = LB/SEC/MW
 DTAUI  =         1.000     COMPUTE INTERVAL = HRS
 DTPP   =       211.000     PINCH POINT TEMPERATURE LIMIT (THERMAL SYSTEM) = R
 ED     =        50.000     ELECTRICAL GRID DEMAND = MW
 EFCOM  =         0.800     ENTHALPY EFFICENCY OF STORAGE SYSTEM COMPRESSOR
 EPCON  =         0.640     ENDOTHERMIC CONVERSION FRACTION (CHEMICAL SYSTEM)
 FACTOR =         1.000     PLANT OPERATING YEARLY FRACTION
 FCR    =        15.000     FIXED CHARGE RATE
 HFUS   =        18.420     HEAT OF FUSION OF THERMAL STORAGE MEDIA = MWH
 ICHEM  =         0         = 0 THERMAL ENERGY STORAGE DEVICE
                            = 1 THERMOCHEMICAL (CES) STORAGE DEVICE
 IOHR   =         0         = 0 NO THERMODYNAMIC STATE POINT OUTPUT GEWERATED
                            = 1 THERMODYNAMIC STATE POINT OUTPUT GENERATED
 IPS    =         0         = 1 NODAL TEMPERATURES PRINTED FOR EACH STEP
                            = 0 NO NODAL TEMPERATURES PRINTED
 IWEEK  =         0         = 1 FOR ANALYSIS OF WEEKLY CYCLE
 NDAY   =         0         =  0 ANALYSE ALL FOUR DAYS FOR YEARLY RESULTS
                            =  1 WINTER DAY
                            =  2 SPRING DAY
                            =  3 SUMMER DAY
                            =  4 FALL DAY
 NODES  =        40         NUMBER OF EQUAL AXIAL THERMAL ENERGY DIVISIONS
 OM     =         6.000     OPERATING AND MAINTENANCE COST = MILLS/KW
 PPOC   =         0.165     O2 COMP PARA POWER / UNIT MASS FLOW = MW/LB/SEC
 PPPC   =         0.069     PROD COMP PARA POWER / UNIT MASS FLOW = MW/LB/SEC
 RAP    =         9.600     APETURE RADIUS = METERS
 RSL    =         0.02000   FRACTION OF STORAGE ENERGY HELD IN RESERVE
 RT     =         1.070     PRESSURE RATIO OF TOTAL FLUID CIRCUIT LOOP
 SL     =         6.000     STORAGE LIMIT FOR COST MODEL = HRS
 STORL  =       828.000     ENERGY LIMIT FOR CES SYSTEM = MWH
 TDS    =         8.000     START TIME FOR LEVEL GRID DEMAND LOAD = HRS
 TED    =      1960.000     DESIGN POINT OPERATING TEMPERATURE = R
 TFUS   =      2000.000     MELT TEMPERATURE OF THERMAL STORAGE MEDIA = R
 TSTART =         4.000     STARTING TIME FOR POWER PLANT CYCLE ANALYSIS = HRS
 TWZERO =      1410.000     INITIAL NODAL TEMPERATURE OF STORAGE DEVICE = R
 UAIN   =         0.07500   PRODUCT OF CONDUCTANCE AND SURFACE AREA = MW/R
 XMCPL  =         0.04662   SENSIBLE HEAT CAPACITY OF STORAGE MEDIA = MWH/R
 XMCPS  =         0.04662   SENSIBLE HEAT CAPACITY BELOW MELT POINT = MWH/R
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 PI - 4 DAYS - 24 HRS

      0.0       0.0       0.0       0.0       0.0       0.0
    550.000   800.000   890.000   910.000   920.000   910.000
    890.000   810.000   670.000   550.000     0.0       0.0
      0.0       0.0       0.0       0.0       0.0       0.0

      0.0       0.0       0.0       0.0       0.0     480.000
    690.000   800.000   870.000   910.000   930.000   930.000
    940.000   940.000   920.000   870.000   870.000     0.0
      0.0       0.0       0.0       0.0       0.0       0.0

      0.0       0.0       0.0       0.0     650.000   780.000
    870.000   920.000   930.000   920.000   910.000   910.000
    930.000   950.000   940.000   870.000   780.000   660.000
      0.0       0.0       0.0       0.0       0.0       0.0

      0.0       0.0       0.0       0.0       0.0     650.000
    730.000   800.000   840.000   870.000   880.000   870.000
    850.000   820.000   750.000   630.000     0.0       0.0
      0.0       0.0       0.0       0.0       0.0       0.0

 FIELD EFF. - 4 DAYS - 24 HRS

      0.0       0.0       0.0       0.0       0.0       0.0
      0.167     0.381     0.508     0.578     0.587     0.569
      0.587     0.578     0.508     0.381     0.167     0.0
      0.0       0.0       0.0       0.0       0.0       0.0

      0.0       0.0       0.0       0.0       0.0       0.129
      0.357     0.523     0.610     0.653     0.673     0.677
      0.673     0.653     0.610     0.523     0.357     0.129
      0.0       0.0       0.0       0.0       0.0       0.0

      0.0       0.0       0.0       0.0       0.157     0.389
      0.517     0.593     0.645     0.674     0.689     0.692
      0.689     0.674     0.645     0.593     0.517     0.389
      0.157     0.0       0.0       0.0       0.0       0.0

      0.0       0.0       0.0       0.0       0.0       0.129
      0.357     0.523     0.610     0.653     0.673     0.677
      0.673     0.653     0.610     0.523     0.357     0.129
      0.0       0.0       0.0       0.0       0.0       0.0

 POWER PLANT COST ACCOUNTS

      2.000    44.000     0.0       0.0       0.0       0.0       0.0     119.000    20.000     4.000
     15.000     0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

      0.0       0.0      60.000   169.000    48.700     5.000     0.0       0.0       0.0       0.0
      0.0       0.0       0.050     0.100     0.0      -0.150     0.0       0.0       0.0       0.0

      0.0       0.0       0.0       0.0      44.000   442.000     0.0       0.0       0.0       0.0
      0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
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          DAILY PLANT PERFORMANCE  (WINTER)
          ***** ***** ***********

                                                 % ENERGY          MWH

  DIRECT INSOLATION                                100.0          3950.00

       LESS: INSOLATION REJECTED DUE TO            100.0          3950.00
             STORAGE LIMITATIONS
       LESS: REFLECTOR FIELD LOSSES                 50.3          1986.55

       LESS: RECIEVER LOSSES                        39.8          1572.34

       LESS: STORAGE HEAT LOSSES                    39.4          1555.78

       PLUS: STORAGE CIRCULATION PUMP HEAT          40.8          1613.03
             & INITIAL STORED ENERGY
       LESS: NET STORAGE POWER                      37.7          1490.28
             CONDITIONING LOSSES
       LESS: TURBINE GENERATOR LOSSES               16.7           658.70

       LESS: STORAGE PARASITIC ENERGY               15.2           601.80
             LOSSES
       LESS: DIRECT GENERATION                       5.5           218.49

  COLECTOR AREA (KM**2)                             0.50
  PLANT CAPACITY (MW)                              50.00
  DAILY PLANT CAPACITY FACTOR (%)                  50.15

  MAXIMUM MASS FLOWS (LBS/SEC)
      TURBINE                                              513.94
      STORAGE (CHARGE) *                                   145.08
      STORAGE (CHARGE)                                     133.38
      STORAGE (DISCHARGE)                                  513.94
      RECIEVER                                             371.29

  MAXIMUM POWER CONDITIONS (MW)
      GENERATOR *                                            9.19
      GENERATOR                                             58.48
      STORAGE (CHARGE) *                                   105.14
      STORAGE (CHARGE)                                      96.05
      STORAGE (DISCHARGE)                                  183.66
      RECIEVER                                             219.90

  TEMPERATURE EXTREMES (DEG-R)
      MINIMUM TURBINE INLET                               1502.20
      MAXIMUM STORAGE SYSTEM DISCHARGE                    1510.95
      MAXIMUM RECIEVER INLET                              1534.76

  STORAGE SYSTEM DESIGN CONDITIONS
      ROUND TRIP EFFICIENCY (%)                             70.24
      MAXIMUM ENERGY IN STORAGE (MW)                       631.86
      EFFECTIVE TEMPERATURE SWING (THERMAL) (DEG-R)        336.08
      EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)         34.58
      CRITICAL THERMAL SIZE  (M-DOT=   513.94)               4.43
      STORAGE TIME (HRS)                                     4.37

  * CONDITION WITH GENERATOR OFF-LINE
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             DAILY PLANT PERFORMANCE  (SPRING)
             ***** ***** ***********

                                                  % ENERGY          MWH

    DIRECT INSOLATION                               113.8          5075.00

         LESS: INSOLATION REJECTED DUE TO           100.0          4458.97
               STORAGE LIMITATIONS
         LESS: REFLECTOR FIELD LOSSES                55.4          2471.45

         LESS: RECIEVER LOSSES                       43.9          1957.53

         LESS: STORAGE HEAT LOSSES                   43.5          1940.99

         PLUS: STORAGE CIRCULATION PUMP HEAT         45.5          2030.04
               & INITIAL STORED ENERGY
         LESS: NET STORAGE POWER                     42.8          1908.85
               CONDITIONING LOSSES
         LESS: TURBINE GENERATOR LOSSES              18.9           843.71

         LESS: STORAGE PARASITIC ENERGY              16.9           754.91
               LOSSES
         LESS: DIRECT GENERATION                      6.8           304.74

    COLECTOR AREA (KM**2)                             0.50
    PLANT CAPACITY (MW)                              50.00
    DAILY PLANT CAPACITY FACTOR (%)                  62.91

    MAXIMUM MASS FLOWS (LBS/SEC)
        TURBINE                                                 506.49
        STORAGE (CHARGE) *                                      207.84
        STORAGE (CHARGE)                                        327.25
        STORAGE (DISCHARGE)                                     506.49
        RECIEVER                                                632.04

    MAXIMUM POWER CONDITIONS (MW)
        GENERATOR *                                              13.18
        GENERATOR                                                74.91
        STORAGE (CHARGE) *                                      150.20
        STORAGE (CHARGE)                                        128.27
        STORAGE (DISCHARGE)                                     182.64
        RECIEVER                                                258.76

    TEMPERATURE EXTREMES (DEG-R)
        MINIMUM TURBINE INLET                                  1508.21
        MAXIMUM STORAGE SYSTEM DISCHARGE                       1755.27
        MAXIMUM RECIEVER INLET                                 1650.50

    STORAGE SYSTEM DESIGN CONDITIONS
        ROUND TRIP EFFICIENCY (%)                                73.39
        MAXIMUM ENERGY IN STORAGE (MW)                          827.13
        EFFECTIVE TEMPERATURE SWING (THERMAL) (DEG-R)           439.23
        EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)            36.64
        CRITICAL THERMAL SIZE  (M-DOT=   506.49)                  4.50
        STORAGE TIME (HRS)                                        6.09

    * CONDITION WITH GENERATOR OFF-LINE
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           DAILY PLANT PERFORMANCE  (SUMMER)
           ***** ***** ***********

                                              % ENERGY           MWH

   DIRECT INSOLATION                            127.2          6010.45

       LESS: INSOLATION REJECTED DUE TO         100.0          4724.98
             STORAGE LIMITATIONS
       LESS: REFLECTOR FIELD LOSSES              55.7          2632.80

       LESS: RECIEVER LOSSES                     43.7          2062.58

       LESS: STORAGE HEAT LOSSES                 43.3          2046.17

       PLUS: STORAGE CIRCULATION PUMP HEAT       45.3          2139.18
             & INITIAL STORED ENERGY
       LESS: NET STORAGE POWER                   42.5          2007.75
             CONDITIONING LOSSES
       LESS: TURBINE GENERATOR LOSSES            18.8           887.43

       LESS: STORAGE PARASITIC ENERGY            16.8           794.69
             LOSSES
       LESS: DIRECT GENERATION                    6.4           302.53

   COLECTOR AREA (KM**2)                          0.50
   PLANT CAPACITY (MW)                           50.00
   DAILY PLANT CAPACITY FACTOR (%)               66.22

   MAXIMUM MASS FLOWS (LBS/SEC)
         TURBINE                                         445.31
         STORAGE (CHARGE) *                              295.17
         STORAGE (CHARGE)                                289.15
         STORAGE (DISCHARGE)                             445.31
         RECIEVER                                        580.08

   MAXIMUM POWER CONDITIONS (MW)
         GENERATOR *                                      19.23
         GENERATOR                                        71.51
         STORAGE (CHARGE) *                              198.12
         STORAGE (CHARGE)                                120.77
         STORAGE (DISCHARGE)                             170.18
         RECIEVER                                        255.69

   TEMPERATURE EXTREMES (DEG-R)
         MINIMUM TURBINE INLET                          1557.07
         MAXIMUM STORAGE SYSTEM DISCHARGE               1749.04
         MAXIMUM RECIEVER INLET                         1625.72

   STORAGE SYSTEM DESIGN CONDITIONS
         ROUND TRIP EFFICIENCY (%)                        72.16
         MAXIMUM ENERGY IN STORAGE (MW)                  831.30
         EFFECTIVE TEMPERATURE SWING (THERMAL) (DEG-R)   441.35
         EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)    36.39
         CRITICAL THERMAL SIZE  (M-DOT=   445.31)          5.11
         STORAGE TIME (HRS)                                6.05

   * CONDITION WITH GENERATOR OFF-LINE
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```
         DAILY PLANT PERFORMANCE  (FALL)
         ***** ***** ***********

                                                  % ENERGY          MWH

   DIRECT INSOLATION                                103.8          4345.00

        LESS: INSOLATION REJECTED DUE TO            100.0          4186.14
              STORAGE LIMITATIONS
        LESS: REFLECTOR FIELD LOSSES                 56.5          2365.18

        LESS: RECIEVER LOSSES                        45.0          1882.01

        LESS: STORAGE HEAT LOSSES                    44.6          1865.63

        PLUS: STORAGE CIRCULATION PUMP HEAT          46.8          1958.65
              & INITIAL STORED ENERGY
        LESS: NET STORAGE POWER                      43.9          1837.41
              CONDITIONING LOSSES
        LESS: TURBINE GENERATOR LOSSES               19.4           812.13

        LESS: STORAGE PARASITIC ENERGY               17.2           719.27
              LOSSES
        LESS: DIRECT GENERATION                       7.6           319.16

   COLECTOR AREA (KM**2)                              0.50
   PLANT CAPACITY (MW)                               50.00
   DAILY PLANT CAPACITY FACTOR (%)                   59.94

   MAXIMUM MASS FLOWS (LBS/SEC)
       TURBINE                                               481.86
       STORAGE (CHARGE) *                                    207.94
       STORAGE (CHARGE)                                      235.80
       STORAGE (DISCHARGE)                                   481.86
       RECIEVER                                              512.51

   MAXIMUM POWER CONDITIONS (MW)
       GENERATOR *                                            13.18
       GENERATOR                                              68.01
       STORAGE (CHARGE) *                                    150.19
       STORAGE (CHARGE)                                      115.43
       STORAGE (DISCHARGE)                                   177.70
       RECIEVER                                              242.72

   TEMPERATURE EXTREMES (DEG-R)
       MINIMUM TURBINE INLET                                1526.76
       MAXIMUM STORAGE SYSTEM DISCHARGE                     1762.58
       MAXIMUM RECIEVER INLET                               1641.33

   STORAGE SYSTEM DESIGN CONDITIONS
       ROUND TRIP EFFICIENCY (%)                              73.91
       MAXIMUM ENERGY IN STORAGE (MW)                        859.67
       EFFECTIVE TEMPERATURE SWING (THERMAL) (DEG-R)         456.64
       EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)          37.13
       CRITICAL THERMAL SIZE  (M-DOT=   481.86)                4.72
       STORAGE TIME (HRS)                                      6.38

   * CONDITION WITH GENERATOR OFF-LINE
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SOLAR POWER PLANT ECONOMICS
***** ***** ***** *********

POWER RATING                       (MWE)               50.00
COLLECTOR AREA                     (KM**2)              0.50
STORAGE TIME                       (HR)                 6.00


CAPITAL COST ACCOUNTS ($/KW)
******* **** ******** ******

LAND                                                    2.00
STRUCTURES AND FACILITIES                              44.00
HELIOSTATS                                            600.00
CENTRAL RECIEVER/HEAT EXCHANGER                       169.00
TOWER                                                  92.70
STORAGE TRANKS (THERMAL )                             472.00
BOILER PLANT                                            0.0
TURBINE PLANT AND EQUIPMENT                           119.00
ELECTRIC PLANT AND EQUIPMENT                           20.00
MISC PLANT AND EQUIPMENT                                4.00
ALLOWANCE FOR COOLING TOWERS                           15.00

     TOTAL DIRECT COST                               1537.70

CONTINGENCY AND SPARE PARTS               ( 5%)        76.88
INDIRECT COSTS                            (10%)       153.77

     TOTAL CAPITAL INVESTMENT                        1768.35

INTEREST DURING CONSTRUCTION              (15%)       265.25

     TOTAL COST AT COMMERCIAL OPERATION              2033.61


ENERGY COSTS
****** *****

CAPITAL COST                       ($/KW)            2033.61
FIXED CHARGE RATE                  (%)                 15.00
CAPACITY FACTOR (CORRECTED)        (%)                 59.81
LEVALIZED O & M COST               (MILLS/KWH)          6.00

BUSBAR ENERGY COST                 (MILLS/KWH)         64.23
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```
      **** INPUTS ****

 AHXAP   =        16.440     RECIEVER HEAT EXCHANGER/APERTURE AREA RATIO
 AHXI    =         0.0       RECIEVER HEAT EXCHANGER AREA - M**2
 AWAP    =        17.650     RECIEVER WALL/APERTURE AREA RATIO
 AWI     =         0.0       RECIEVER WALL AREA - M**2
 CA      =         0.500     COLLECTOR AREA - KM**2
 DMRPMW  =         2.790     REACTANT PRODUCT FLOW PER MW STORED - LB/SEC/MW
 DTAUI   =         1.000     COMPUTE INTERVAL - HRS
 DTPP    =       211.000     PINCH POINT TEMPERATURE LIMIT (THERMAL SYSTEM) - R
 ED      =        50.000     ELECTRICAL GRID DEMAND - MW
 EFCOM   =         0.800     ENTHALPY EFFICENCY OF STORAGE SYSTEM COMPRESSOR
 EPCON   =         0.640     ENDOTHERMIC CONVERSION FRACTION (CHEMICAL SYSTEM)
 FACTOR  =         1.000     PLANT OPERATING YEARLY FRACTION
 FCR     =        15.000     FIXED CHARGE RATE
 HFUS    =        18.420     HEAT OF FUSION OF THERMAL STORAGE MEDIA - MWH
 ICHEM   =         0         = 0 THERMAL ENERGY STORAGE DEVICE
                             = 1 THERMOCHEMICAL (CES) STORAGE DEVICE
 IOHR    =         1         = 0 NO THERMODYNAMIC STATE POINT OUTPUT GEWERATED
                             = 1 THERMODYNAMIC STATE POINT OUTPUT GENERATED
 IPS     =         1         = 1 NODAL TEMPFRATURES PRINTED FOR EACH STEP
                             = 0 NO NODAL TEMPERATURES PRINTED
 IWEEK   =         0         = 1 FOR ANALYSIS OF WEEKLY CYCLE
 NDAY    =         3         =  0 ANALYSE ALL FOUR DAYS FOR YEARLY RESULTS
                             =  1 WINTER DAY
                             =  2 SPRING DAY
                             =  3 SUMMER DAY
                             =  4 FALL DAY
 NODES   =        40         NUMBER OF EQUAL AXIAL THERMAL ENERGY DIVISIONS
 OM      =         6.000     OPERATING AND MAINTENANCE COST - MILLS/KW
 PPOC    =         0.165     O2 COMP PARA POWER / UNIT MASS FLOW - MW/LB/SEC
 PPPC    =         0.069     PROD COMP PARA POWER / UNIT MASS FLOW - MW/LB/SEC
 RAP     =         9.500     APETURE RADIUS - METERS
 RSL     =         0.02000   FRACTION OF STORAGE ENERGY HELD IN RESERVE
 RT      =         1.070     PRESSURE RATIO OF TOTAL FLUID CIRCUIT LOOP
 SL      =         6.000     STORACE LIMIT FOR COST MODEL - HRS
 STORL   =       806.000     ENERGY LIMIT FOR CES SYSTEM - MWH
 TDS     =         8.000     START TIME FOR LEVEL GRID DEMAND LOAD - HRS
 TED     =      1960.000     DESIGN POINT OPERATING TEMPERATURE - R
 TFUS    =      2000.000     MELT TEMPERATURE OF THERMAL STORAGE MEDIA - R
 TSTART  =         5.000     STARTING TIME FOR POWER PLANT CYCLE ANALYSIS - HRS
 TWZERO  =      1410.000     INITIAL NODAL TEMPERATURE OF STORAGE DEVICE - R
 UAIN    =         0.07500   PRODUCT OF CONDUCTANCE AND SURFACE AREA - MW/R
 XMCPL   =         0.04662   SENSIBLE HEAT CAPACITY OF STORAGE MEDIA - MWH/R
 XMCPS   =         0.04662   SENSIBLE HEAT CAPACITY BELOW MELT POINT - MWH/R

 MULTIPLE PHASE STORAGE

      NODS      UAINN       HFUSN      TFUSN      XMCPLN     XMCPSN

       20      0.06000     17.840   1833.000    0.01700    0.01700
       20      0.06000     17.840   1635.000    0.01700    0.01700
```

```
PI - 4 DAYS - 24 HRS

       0.0        0.0        0.0        0.0        0.0        0.0
   550.000    800.000    890.000    910.000    920.000    910.000
   890.000    810.000    670.000    550.000      0.0        0.0
       0.0        0.0        0.0        0.0        0.0        0.0

       0.0        0.0        0.0        0.0        0.0      480.000
   690.000    800.000    870.000    910.000    930.000    930.000
   940.000    940.000    920.000    870.000    870.000      0.0
       0.0        0.0        0.0        0.0        0.0        0.0

       0.0        0.0        0.0        0.0      650.000    780.000
   870.000    920.000    930.000    920.000    910.000    910.000
   930.000    950.000    940.000    870.000    780.000    660.000
       0.0        0.0        0.0        0.0        0.0        0.0

       0.0        0.0        0.0        0.0        0.0      650.000
   730.000    890.000    840.000    870.000    880.000    870.000
   850.000    820.000    750.000    630.000      0.0        0.0
       0.0        0.0        0.0        0.0        0.0        0.0

FIELD EFF. - 4 DAYS - 24 HRS

       0.0        0.0        0.0        0.0        0.0        0.0
     0.167      0.381      0.508      0.578      0.587      0.569
     0.587      0.578      0.508      0.381      0.167        0.0
       0.0        0.0        0.0        0.0        0.0        0.0

       0.0        0.0        0.0        0.0        0.0      0.129
     0.357      0.523      0.610      0.653      0.673      0.677
     0.673      0.653      0.610      0.523      0.357      0.129
       0.0        0.0        0.0        0.0        0.0        0.0

       0.0        0.0        0.0        0.0      0.157      0.389
     0.517      0.593      0.645      0.674      0.689      0.692
     0.689      0.674      0.645      0.593      0.517      0.389
     0.157        0.0        0.0        0.0        0.0        0.0

       0.0        0.0        0.0        0.0        0.0      0.129
     0.357      0.523      0.610      0.653      0.673      0.677
     0.673      0.653      0.610      0.523      0.357      0.129
       0.0        0.0        0.0        0.0        0.0        0.0

POWER PLANT COST ACCOUNTS

     2.000     44.000        0.0        0.0        0.0        0.0        0.0    119.000     20.000      4.000
    15.000        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0

       0.0        0.0     60.000    169.000     48.700      5.000        0.0        0.0        0.0        0.0
       0.0        0.0      0.050      0.100        0.0     -0.150        0.0        0.0        0.0        0.0

       0.0        0.0        0.0        0.0     44.000    442.000        0.0        0.0        0.0        0.0
       0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
```

```
THERMODYNAMIC STATE POINT DATA ( TIME =   5.00 )
************** ***** ***** ****

                     (                  T U R B I N E   G E N E R A T O R              )(      S T O R A G E           )( R E C I E V E R )
                     *    1     *    2     *    3     *    4     *    5     *    6     *    7     *    8     *    9     *   10     *   11     *

TEMPERATURE               0.0        0.0     1538.000  1960.000       0.0        0.0     1960.000  1410.001  1458.056  1474.433  1960.000

POWER TRANSFER            0.0        0.0        0.0       4.959       0.0        0.0        0.0      25.085     2.192       0.0      27.852

ENERGY CONSUMPTION        0.0        0.0        0.0       4.959       0.0        0.0        0.0      25.085     2.192       0.0      27.852


SYSTEM PERFORMANCE DATA
****** *********** ****

TURBINE MASS FLOW                          (LBS/SEC)           8.92
STORAGE MASS FLOW                          (LBS/SEC)          34.61
RECIEVER MASS FLOW                         (LBS/SEC)          43.53

SPECULAR INSOLATION                        (MW)              325.00
SOLAR HEAT INTO RECIEVER                   (MW)               51.02
TOTAL GENERATOR OUTPUT                     (MW)                2.19

CONVERSION EFFICIENCY                                          0.44

POWER INPUT TO STORAGE   =ELEC EQUIV       (MWE)              12.31
POWER OUTPUT FROM STORAGE =ELEC EQUIV      (MWE)               0.0


SPECULAR INSOLATION ENERGY                 (MWH)             325.00
RECIEVER INPUT ENERGY                      (MWH)              51.02
NET GENERATOR OUTPUT ENERGY                (MWH)               0.0
ENERGY INPUT TO STORAGE   =ELEC EQUIV      (MWH)              12.31
ENERGY OUTPUT FROM STORAGE =ELEC EQUIV     (MWH)               0.0
```

```
 NODE      WALL         FLUID       FRACTION
        TEMPERATURE  TEMPERATURE     MELTED

   1     1833.00      1960.00       0.0602
   2     1760.07      1867.08       0.0
   3     1652.26      1763.98       0.0
   4     1565.39      1656.34       0.0
   5     1504.14      1568.71       0.0
   6     1464.56      1506.50       0.0
   7     1440.52      1464.09       0.0
   8     1426.59      1441.46       0.0
   9     1418.80      1427.13       0.0
  10     1414.58      1419.11       0.0
  11     1412.34      1414.74       0.0
  12     1411.18      1412.43       0.0
  13     1410.58      1411.22       0.0
  14     1410.29      1410.61       0.0
  15     1410.14      1410.30       0.0
  16     1410.07      1410.14       0.0
  17     1410.03      1410.07       0.0
  18     1410.01      1410.03       0.0
  19     1410.01      1410.02       0.0
  20     1410.00      1410.01       0.0
  21     1410.00      1410.00       0.0
  22     1410.00      1410.00       0.0
  23     1410.00      1410.00       0.0
  24     1410.00      1410.00       0.0
  25     1410.00      1410.00       0.0
  26     1410.00      1410.00       0.0
  27     1410.00      1410.00       0.0
  28     1410.00      1410.00       0.0
  29     1410.00      1410.00       0.0
  30     1410.00      1410.00       0.0
  31     1410.00      1410.00       0.0
  32     1410.00      1410.00       0.0
  33     1410.00      1410.00       0.0
  34     1410.00      1410.00       0.0
  35     1410.00      1410.00       0.0
  36     1410.00      1410.00       0.0
  37     1410.00      1410.00       0.0
  38     1410.00      1410.00       0.0
  39     1410.00      1410.00       0.0
  40     1410.00      1410.00       0.0
```

```
THERMODYNAMIC STATE POINT DATA ( TIME =  11.13 )
************* ***** ***** ****

                      (              T U R B I N E   G E N E R A T O R           )(       S T O R A G E           )( R E C I E V E R  )
                      *    1    *    2    *    3     *     4     *     5    *      6     *    7     *    8     *    9     *   10    *    11     *

TEMPERATURE               0.0       0.0    1538.000  1960.000       0.0        0.0    1960.000  1691.525  1749.174  1646.388  1960.000

POWER TRANSFER            0.0       0.0        0.0    167.719       0.0        0.0        0.0    112.518    24.161       0.0    256.092

ENERGY CONSUMPTION        0.0       0.0        0.0    644.281       0.0        0.0        0.0    814.793   128.330       0.0   1331.014


SYSTEM PERFORMANCE DATA
****** *********** ****

TURBINE MASS FLOW                           (LBS/SEC)       301.61
STORAGE MASS FLOW                           (LBS/SEC)       318.05
RECIEVER MASS FLOW                          (LBS/SEC)       619.66

SPECULAR INSOLATION                         (MW)            455.00
SOLAR HEAT INTO RECIEVER                    (MW)            313.67
TOTAL GENERATOR OUTPUT                      (MW)             74.13

CONVERSION EFFICIENCY                                         0.44

POWER INPUT TO STORAGE  =ELEC EQUIV         (MWE)            63.19
POWER OUTPUT FROM STORAGE =ELEC EQUIV       (MWE)             0.0


SPECULAR INSOLATION ENERGY                  (MWH)          3049.58
RECIEVER INPUT ENERGY                       (MWH)          1664.94
NET GENERATOR OUTPUT ENERGY                 (MWH)           156.55
ENERGY INPUT TO STORAGE  =ELEC EQUIV        (MWH)           431.76
ENERGY OUTPUT FROM STORAGE =ELEC EQUIV      (MWH)             0.0
```

```
NODE       WALL          FLUID      FRACTION
       TEMPERATURE TEMPERATURE     MELTED

  1      1960.00       1960.00      1.0000
  2      1959.99       1960.00      1.0000
  3      1959.96       1960.00      1.0000
  4      1959.79       1959.99      1.0000
  5      1958.52       1959.96      1.0000
  6      1953.43       1959.71      1.0000
  7      1937.79       1958.65      1.0000
  8      1865.36       1955.12      1.0000
  9      1833.00       1940.99      0.8518
 10      1833.00       1926.58      0.7467
 11      1833.00       1910.10      0.6393
 12      1833.00       1903.28      0.5427
 13      1833.00       1893.91      0.4654
 14      1833.00       1885.78      0.3909
 15      1833.00       1878.74      0.3355
 16      1833.00       1872.64      0.2867
 17      1833.00       1867.35      0.2437
 18      1833.00       1862.77      0.2025
 19      1833.00       1858.80      0.1723
 20      1833.00       1855.36      0.1456
 21      1849.87       1852.38      1.0000
 22      1849.53       1851.95      1.0000
 23      1849.17       1851.54      1.0000
 24      1848.74       1851.14      1.0000
 25      1848.16       1850.73      1.0000
 26      1847.25       1850.30      1.0000
 27      1845.46       1849.78      1.0000
 28      1842.07       1849.05      1.0000
 29      1835.16       1847.87      1.0000
 30      1820.74       1845.72      1.0000
 31      1785.70       1841.49      1.0000
 32      1717.66       1832.04      1.0000
 33      1635.00       1812.68      0.9503
 34      1635.00       1788.98      0.8159
 35      1635.00       1768.44      0.6993
 36      1635.00       1750.64      0.5863
 37      1635.00       1735.22      0.5034
 38      1635.00       1721.85      0.4314
 39      1635.00       1710.26      0.3688
 40      1635.00       1700.22      0.3142
```

```
THERMODYNAMIC STATE POINT DATA ( TIME =  23.66 )
************** ***** ***** ****

                     (               T U R B I N E   G E N E R A T O R             )(      S T O R A G E        )( R E C I E V E R )
                     *   1   *   2   *    3    *    4    *    5   *        6   *    7    *    8    *    9    *   10   *   11   *

TEMPERATURE             0.0      0.0   1248.648  1529.321    0.0          0.0   1529.321  1248.648  1248.648    0.0      0.0

POWER TRANSFER          0.0      0.0      0.0     177.021    0.0          0.0      0.0    =176.973     0.0      0.0      0.0

ENERGY CONSUMPTION      0.0      0.0      0.0    2204.611    0.0          0.0      0.0      16.544   128.330    0.0   2093.185


SYSTEM PERFORMANCE DATA
****** *********** ****

TURBINE MASS FLOW                           (LBS/SEC)        478.50
STORAGE MASS FLOW                           (LBS/SEC)        478.50
RECIEVER MASS FLOW                          (LBS/SEC)          0.0

SPECULAR INSOLATION                         (MW)               0.0
SOLAR HEAT INTO RECTEVER                    (MW)               0.0
TOTAL GENERATOR OUTPUT                      (MW)              50.00

CONVERSION EFFICIENCY                                          0.28

POWER INPUT TO STORAGE  =ELEC EQUIV         (MWE)              0.0
POWER OUTPUT FROM STORAGE =ELEC EQUIV       (MWE)             49.99


SPECULAR INSOLATION ENERGY                  (MWH)           6010.00
RECIEVER INPUT ENERGY                       (MWH)           2668.76
NET GENERATOR OUTPUT ENERGY                 (MWH)            783.20
ENERGY INPUT TO STORAGE  =ELEC EQUIV        (MWH)            431.76
ENERGY OUTPUT FROM STORAGE =ELEC EQUIV      (MWH)            292.52
```

```
 NODE        WALL        FLUID      FRACTION
         TEMPERATURE TEMPERATURE     MELTED

   1       1533.21     1479.90       0.0
   2       1515.38     1474.08       0.0
   3       1502.75     1469.38       0.0
   4       1496.94     1464.85       0.0
   5       1491.93     1460.41       0.0
   6       1487.45     1455.97       0.0
   7       1483.27     1451.49       0.0
   8       1479.08     1446.96       0.0
   9       1474.91     1442.37       0.0
  10       1470.72     1437.72       0.0
  11       1466.46     1433.00       0.0
  12       1462.13     1428.22       0.0
  13       1457.72     1423.37       0.0
  14       1453.23     1418.47       0.0
  15       1448.66     1413.52       0.0
  16       1444.03     1408.51       0.0
  17       1439.31     1403.45       0.0
  18       1434.53     1398.35       0.0
  19       1429.67     1393.21       0.0
  20       1424.75     1388.04       0.0
  21       1635.00     1363.38       0.0829
  22       1597.38     1338.14       0.0
  23       1461.26     1317.18       0.0
  24       1422.73     1299.85       0.0
  25       1346.93     1292.13       0.0
  26       1335.54     1285.00       0.0
  27       1318.20     1279.55       0.0
  28       1304.71     1275.42       0.0
  29       1295.56     1272.12       0.0
  30       1288.58     1269.42       0.0
  31       1285.01     1266.86       0.0
  32       1281.77     1264.41       0.0
  33       1278.62     1262.07       0.0
  34       1275.69     1259.84       0.0
  35       1272.90     1257.70       0.0
  36       1270.16     1255.65       0.0
  37       1267.46     1253.71       0.0
  38       1264.81     1251.89       0.0
  39       1262.20     1250.20       0.0
  40       1259.65     1248.65       0.0
```

```
              DAILY PLANT PERFORMANCE  (SUMMER)
              ***** ***** ***********

                                             % ENERGY         MWH

    DIRECT INSOLATION                             125.8        6010.00

         LESS: INSOLATION REJECTED DUE TO         100.0        4776.03
               STORAGE LIMITATIONS
         LESS: REFLECTOR FIELD LOSSES              55.9        2668.76

         LESS: RECIEVER LOSSES                     43.8        2093.18

         LESS: STORAGE HEAT LOSSES                 43.5        2076.64

         PLUS: STORAGE CIRCULATION PUMP HEAT       46.2        2204.61
               & INITIAL STORED ENERGY
         LESS: NET STORAGE POWER                   43.2        2062.05
               CONDITIONING LOSSES
         LESS: TURBINE GENERATOR LOSSES            19.1         911.42

         LESS: STORAGE PARASITIC ENERGY            16.4         783.20
               LOSSES
         LESS: DIRECT GENERATION                    6.1         292.52

    COLECTOR AREA (KM**2)                          0.50
    PLANT CAPACITY (MW)                           50.00
    DAILY PLANT CAPACITY FACTOR (%)               65.26

    MAXIMUM MASS FLOWS (LBS/SEC)
        TURBINE                                           478.50
        STORAGE (CHARGE) *                                444.30
        STORAGE (CHARGE)                                  318.05
        STORAGE (DISCHARGE)                               478.50
        RECIEVER                                          619.66

    MAXIMUM POWER CONDITIONS (MW)
        GENERATOR *                                        33.05
        GENERATOR                                          74.13
        STORAGE (CHARGE) *                                177.74
        STORAGE (CHARGE)                                  114.33
        STORAGE (DISCHARGE)                               176.97
        RECIEVER                                          256.17

    TEMPERATURE EXTREMES (DEG-R)
        MINIMUM TURBINE INLET                            1529.32
        MAXIMUM STORAGE SYSTEM DISCHARGE                 1749.17
        MAXIMUM RECIEVER INLET                           1672.24

    STORAGE SYSTEM DESIGN CONDITIONS
        ROUND TRIP EFFICIENCY (%)                          67.75
        MAXIMUM ENERGY IN STORAGE (MW)                    814.79
        EFFECTIVE TEMPERATURE SWING (THERMAL) (DEG-R)     404.26
        EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)      35.90
        CRITICAL THERMAL SIZE  (M-DOT=   478.50)            1.90      1.90
        STORAGE TIME (HRS)                                  5.85

    * CONDITION WITH GENERATOR OFF-LINE
```

```
      BLOCK DATA
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (AT    (1)   ,C(1325))
C
      DIMENSION AT    (24)
C
      DATA C     /2000*0.0/
C
      DATA AT    /1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,9.0,10.0,11.0,12.0
     X           ,13.0,14.0,15.0,16.0,17.0,18.0,19.0,20.0,21.0,22.0
     X           ,23.0,24.0/
C
      EQUIVALENCE (PIA   (1,1),C(1350)),(FEA   (1,1),C(1446))
C
      EQUIVALENCE (PI1   (1)   ,PIA(1,1)),(FE1   (1)    ,FEA(1,1))
      EQUIVALENCE (PI2   (1)   ,PIA(1,2)),(FE2   (1)    ,FEA(1,2))
      EQUIVALENCE (PI3   (1)   ,PIA(1,3)),(FE3   (1)    ,FEA(1,3))
      EQUIVALENCE (PI4   (1)   ,PIA(1,4)),(FE4   (1)    ,FEA(1,4))
C
      DIMENSION PIA   (24,4),PI1   (24),PI2   (24),PI3   (24),PI4   (24)
      DIMENSION FEA   (24,4),FE1   (24),FE2   (24),FE3   (24),FE4   (24)
C
      DATA PI1 /0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,550.0,800.0
     X         ,890.0,910.0,920.0,910.0,890.0,810.0,670.0,550.0
     X         ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  /
      DATA PI2 /0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,480.0,690.0,800.0
     X         ,870.0,910.0,930.0,930.0,940.0,940.0,920.0,870.0
     X         ,870.0,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  /
      DATA PI3 /0.0  ,0.0  ,0.0  ,0.0  ,650.0,780.0,870.0,920.0
     X         ,930.0,920.0,910.0,910.0,930.0,950.0,940.0,870.0
     X         ,780.0,660.0,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  /
      DATA PI4 /0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,650.0,730.0,800.0
     X         ,840.0,870.0,880.0,870.0,850.0,820.0,750.0,630.0
     X         ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  /
C
      DATA FE1 /0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.167,0.381
     X         ,0.508,0.578,0.587,0.569,0.587,0.578,0.508,0.381
     X         ,0.167,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  /
```

```
      DATA FE2 /0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.129,0.357,0.523
     X         ,0.610,0.653,0.673,0.677,0.673,0.653,0.610,0.523
     X         ,0.357,0.129,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  /
      DATA FE3 /0.0  ,0.0  ,0.0  ,0.0  ,0.157,0.389,0.517,0.593
     X         ,0.645,0.674,0.689,0.692,0.689,0.674,0.645,0.593
     X         ,0.517,0.389,0.157,0.0  ,0.0  ,0.0  ,0.0  ,0.0  /
      DATA FE4 /0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.129,0.357,0.523
     X         ,0.61 ,0.653,0.673,0.677,0.673,0.653,0.61 ,0.523
     X         ,0.357,0.129,0.0  ,0.0  ,0.0  ,0.0  ,0.0  ,0.0  /
C
      EQUIVALENCE (ACC   (1,1),C(1542))
C
      EQUIVALENCE (AC1   (1)   ,ACC(1,1)),(AC2   (1)   ,ACC(1,2))
      EQUIVALENCE (AC3   (1)   ,ACC(1,3))
C
      DIMENSION ACC   (20,3),AC1   (20),AC2   (20),AC3   (20)
C
      DATA AC1 /2.  ,44. ,0.  ,0.  ,0.  ,0.  ,0.  ,119.,20. ,4.
     X         ,15. ,0.  ,0.  ,0.  ,0.  ,0.  ,0.  ,0.  ,0.  ,0.  /
C
      DATA AC2 /0.  ,0.  ,60. ,16.9,40. ,5.  ,0.  ,0.  ,0.  ,0.
     X         ,0.  ,0.  ,.05 ,.1  ,0.  ,.15 ,0.  ,0.  ,0.  ,0.  /
C
      DATA AC3 /0.  ,0.  ,0.  ,0.  ,0.  ,442.,0.  ,0.  ,0.  ,0.
     X         ,0.  ,0.  ,0.  ,0.  ,0.  ,0.  ,0.  ,0.  ,0.  ,0.  /
C
C
      END
```

```
C
C**** SCLAR POWER PLANT OPERATING MODEL
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (XMELT (1)  ,C( 452)),(XMELTP(1)  ,C( 752))
      EQUIVALENCE (TF    (1)  ,C( 854)),(TFP   (1)  ,C(1101))
      EQUIVALENCE (TWT   (1)  ,C( 145)),(TWP   (1)  ,C(  45))
      EQUIVALENCE (NODES      ,C( 446)),(NDAY       ,C(1202))
      EQUIVALENCE (TWZERO     ,C( 956))
      EQUIVALENCE (ND         ,C(1201))
      EQUIVALENCE (ED         ,C(  16)),(EDI        ,C( 992))
      EQUIVALENCE (IPWEEK     ,C(1611))
      EQUIVALENCE (ISTL       ,C( 996))
      EQUIVALENCE (PSO        ,C(1620))
C
      DIMENSION XMELTP(100)
      DIMENSION TFP   (100)
      DIMENSION TWP   (100)
      DIMENSION XMELT (100)
      DIMENSION TF    (100)
      DIMENSION TWT   (100)
C
      CALL GDATA
C
   25 CALL INPUT(&500)
C
      CALL CSEINT
C
   50 IF(NDAY.EQ.0)ND=ND+1
C
      DO 100 I=1,NODES
C
      XMELTP(I)=0.0
      TFP   (I)=TWZERO
  100 TWP   (I)=TFP(I)
C
      EDI=ED
C
      IPWEEK=0
```

```
      ISTL=-1
C
      PSC=0.0
C
  200 CALL DAYINT
C
  3C0 CALL INITAL
C
      CALL CYCLE
C
      CALL INTEG
C
      CALL UDATE(&300)
C
      CALL WEEKAN(&200)
C
      CALL DAYANL(&400)
C
      GC TC 25
C
  400 CALL CSEANL(&50)
C
      GC TO 25
C
  500 STCP
C
      END
```

```
      SUBROUTINE CAVITY
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (TI          ,C(   9)),(PI          ,C(   1))
      EQUIVALENCE (TED         ,C(   6)),(DMCM        ,C(   4))
      EQUIVALENCE (PH          ,C(  15)),(DMC         ,C(  14))
      EQUIVALENCE (TE          ,C(   7))
      EQUIVALENCE (CPF         ,C(  44)),(RAP         ,C( 445))
C
      EQUIVALENCE (DMWT  (1)   ,C(1001)),(P     (1)   ,C(1041))
      EQUIVALENCE (T     (1)   ,C(1061)),(DP    (1)   ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T10   ,T     (10)),(T11   ,T     (11))
      EQUIVALENCE (DMWT11,CMWT  (11))
C
      COMMON/FPHC/POE
C
C**** COMPUTE CAVITY PERFORMANCE
C
      EXTERNAL FPH
C
      DIMENSION XI(3)
C
      TOL=0.0001
      IS=0
C
C**** CHECK OPERATION AT MINIMUM TEMPERATURE
C
      XI(1)=T10
      XI(2)=RAP
      XI(3)=PI
C
      PDUMY=FPH(0.0,XI)
C
```

```
      POEP=POE
C
      IF(POE.GT.PI)GO TO 30
C
C**** CHECK OPERATION AT DESIGN TEMPERATURE
C
      T11=TED
C
      XI(1)=(T10+T11)/2.0
C
      PDUMY=FPH(0.0,XI)
C
      IF(POE.LE.PI)GO TO 20
C
      DMWT11=0.5*(PI-POEP)
C
      GO TO 50
C
C**** RECIEVER OPERATIONAL AT DESIGN TEMPERATURE
C
   20 TBAR=AMAX1((T10+T11)/2.0,1200.0)
C
      EFREC=.883+(37.5-0.0325*TBAR)/PI
C
      DMWT11=AMAX1(EFREC*PI,0.05)
C
      GO TO 40
C
   30 DMWT11=0.0
      DMC   =0.0
      T11   =T10
C
      RETURN
C
   40 IX=0
C
      THE=(T10+T11)/2.0
C
      XI(1)=THE
      XI(2)=RAP
```

```
      XI(3)=PI
C
      CALL ITER8(DMWT11,XI,FPH,TOL,IX)
C
      DMC=DMWT11*3.415E+06/CPF /3600.0/(T11-T10)
C
      IF(DMC.GT.DMCM)RETURN
C
   50 DMC=DMCM
C
C**** SOLUTION IS ITERATIVE (MASS FLOW LESS THAN REGUIRED VALUE)
C
      CC=3.415E+06/CPF/3600.0/DMC
      DC=T10
C
      DMWT1P=DMWT11
C
  100 TEP=T11
C
      T11=T10+DMWT11*CC
C
      TBAR=AMAX1((T10+T11)/2.0,1200.0)
C
      EFREC=0.883+(37.5-0.0325*TBAR)/PI
C
      DMWT11=AMAX1(EFREC*PI,0.05)
C
      IX=0
C
      THE=(T10+T11)/2.0
C
      XI(1)=THE
      XI(2)=RAP
      XI(3)=PI
C
      CALL ITER8(DMWT11,XI,FPH,TOL,IX)
C
      CALL ITER (T11,TEP ,TOL,IS,&200)
C
      AC=(DMWT1P-DMWT11)/(TEP-T11)
```

```
      BC=DMWT11-T11/(TEP-T11)*(DMWT1P-DMWT11)
C
      DMWT1P=DMWT11
C
      IF(IS.EQ.1)GO TO 100
C
      DMWT11=(AC*DC+BC)/(1.0-AC*CC)
C
      GO TO 100
C
  200 RETURN
C
      END
```

```
      SUBROUTINE CHARGE(*,*)
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (DMCP       ,C(   5)),(EDT        ,C(  17))
      EQUIVALENCE (ED         ,C(  16)),(DMC        ,C(  14))
      EQUIVALENCE (DMS        ,C(  20)),(DMTG       ,C(  18))
      EQUIVALENCE (ISTL       ,C( 996)),(PI         ,C(   1))
      EQUIVALENCE (PII        ,C( 994)),(PIS        ,C(  11))
      EQUIVALENCE (POS        ,C(  12)),(TEP        ,C(   8))
      EQUIVALENCE (DTAU       ,C(   2)),(EFTG       ,C(  35))
      EQUIVALENCE (NODES      ,C( 446)),(STORL      ,C( 960))
C
      EQUIVALENCE (XMELT (1)  ,C( 452)),(XMELTP(1)  ,C( 752))
      EQUIVALENCE (TF    (1)  ,C( 854)),(TFP   (1)  ,C(1101))
      EQUIVALENCE (TWT   (1)  ,C( 145)),(TWP   (1)  ,C(  45))
C
      DIMENSION XMELT (100)
      DIMENSION XMELTP(100)
      DIMENSION TF    (100)
      DIMENSION TFP   (100)
      DIMENSION TWT   (100)
      DIMENSION TWP   (100)
C
      EQUIVALENCE (DMWT  (1)  ,C(1001)),(P     (1)  ,C(1041))
      EQUIVALENCE (T     (1)  ,C(1061)),(DP    (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T9    ,T      ( 9))
      EQUIVALENCE (T7    ,T      ( 7))
      EQUIVALENCE (T4    ,T      ( 4))
      EQUIVALENCE (T11   ,T      (11))
      EQUIVALENCE (DMWT8 ,DMWT   ( 8))
      EQUIVALENCE (DMWT9 ,DMWT   ( 9))
      EQUIVALENCE (DMWT11,DMWT   (11))
C
```

```
      EQUIVALENCE (XN     (1)   ,C(1225)),(XO     (1)   ,C(1250))
      EQUIVALENCE (XDN    (1)   ,C(1275)),(XDO    (1)   ,C(1300))
C
      DIMENSION XN    (25)
      DIMENSION XO    (25)
      DIMENSION XDN   (25)
      DIMENSION XDO   (25)
C
      EP1 =0.0
C
      TOL=0.002
      TOL1=0.0001
C
      IS=0
      IS1=0
C
      DMCP=0.0
      DMSP=0.0
C
      ISTOP=0
C
C**** COMPUTE RECIEVER PERFORMANCE
C
  200 CALL CAVITY
C
C**** IS SOLAR INPUT SUFFICIENT TO START RECIEVER ?
C
      IF(CMWT11.EQ.0.0)RETURN 1
C
      ISTOP=ISTOP+1
C
      IF(ISTOP.GT.100)WRITE(6,1100)
      IF(ISTOP.GT.100)CALL UABEND(100)
C
      EOT=EO+DMWT9
      EPP=DMWT9
C
C**** COMPUTE TURBINE PERFORMANCE
C
      T4 =T11
```

```
C
      CALL TRBINE
C
C**** IS INSOLATION SUFFICIENT TO DRIVE TURBINE GENERATOR ?
C
      IF(DMC .LE.DMTG)RETURN 2
C
      DMS=DMC-DMTG
C
      IF(DMS.GT.0.0)GO TO 222
C
      DO 224 I=1,NODES
      XMELT(I)=XMELTP(I)
      TF(I)=TFP(I)
  224 TWT(I)=TWP(I)
C
      PGS=0.0
      PIS=0.0
      DMWT8 =0.0
      DMWT9 =0.0
      DMS=0.0
      T9 =T11
C
      GO TO 226
C
C**** COMPUTE PERFORMANCE OF ENERGY STORAGE DURING CHARGING
C
  222 T7=T11
C
      IF(ISTL.EQ.-1)ISTL=0
C
C**** COMPUTE STORAGE PERFORMANCE
C
      CALL STORGE
C
C**** COMPUTE CAVITY INLET TEMP
C
C**** MIXING OF TURBINE CYCLE GAS WITH STORAGE EXIT GAS
C
  226 CALL INLET
```

```
C
C**** RECIEVER MASS FLOW CONVERGENCE TEST
C
      CALL ITER (DMC,DMCP,TOL,IS1,&230)
C
      GO TO 250
C
C**** STORAGE MASS FLOW CONVERGENCE TEST
C
  230 CALL ITER (DMS ,DMSP,TOL,IS,&1000)
C
  250 TEP=T4
C
C**** PROJECT TO PARASITIC POWER SOLUTION
C
      EP1=DMWT9
      XK1=DMWT9/DMS
C
      IF(IS1.EQ.1)XK2=DMTG
C
      XK3=(DMTG-XK2)/EPP
      DMWT9=XK1*(DMC-XK2)/(1.0+XK3*XK1)
C
      DMCP=DMC
      DMSP=DMS
C
      GO TO 200
C
 1000 RETURN
C
 1100 FORMAT('0MAXIMUM ITERATIONS IN PI CONSTRAINT LOGIC')
C
      END
```

```
      SUBROUTINE CHSS(*)
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (DMCP        ,C(   5)),(DMS         ,C(  20))
      EQUIVALENCE (DMC         ,C(  14)),(DMTG        ,C(  18))
      EQUIVALENCE (DTAU        ,C(   2)),(ISTL        ,C( 996))
      EQUIVALENCE (PI          ,C(   1)),(ED          ,C(  16))
      EQUIVALENCE (EDT         ,C(  17)),(EFTG        ,C(  35))
      EQUIVALENCE (STORL       ,C( 960))
      EQUIVALENCE (PII         ,C( 994))
C
      EQUIVALENCE (DMWT  (1)   ,C(1001)),(P     (1)   ,C(1041))
      EQUIVALENCE (T     (1)   ,C(1061)),(DP    (1)   ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T4    ,T     ( 4))
      EQUIVALENCE (T7    ,T     ( 7))
      EQUIVALENCE (T11   ,T     (11))
      EQUIVALENCE (DMWT8 ,DMWT  ( 8))
      EQUIVALENCE (DMWT9 ,DMWT  ( 9))
      EQUIVALENCE (DMWT11,DMWT  (11))
      EQUIVALENCE (P7    ,P     ( 7))
      EQUIVALENCE (P11   ,P     (11))
C
      EQUIVALENCE (XN    (1)   ,C(1225)),(XO    (1)   ,C(1250))
      EQUIVALENCE (XDN   (1)   ,C(1275)),(XDO   (1)   ,C(1300))
C
      DIMENSION XN    (25)
      DIMENSION XO    (25)
      DIMENSION XDN   (25)
      DIMENSION XDO   (25)
C
      TOL =0.002
      DMTG=0.0
      DMCP=0.0
```

```
      DMSP=0.0
      IS  =0
      IS1 =0
C
C**** COMPUTE RECIEVER PERFORMANCE
C
  200 CALL CAVITY
C
C**** IS SOLAR INPUT SUFFICIENT TO RUN RECIEVER ?
C
      IF(DMWT11.EQ.0.0)RETURN 1
C
      DMS=DMC-DMTG
      P7 =P11
      T7 =T11
C
C**** COMPUTE STORAGE PERFORMANCE
C
      CALL STORGE
C
      T4=T11
      EDT=DMWT9
C
C**** COMPUTE TURBINE PERFORMANCE (PARASITIC POWER ONLY)
C
      CALL TRBINE
C
C**** MIX STORAGE EXIT GAS WITH TURBINE EXHAUST GAS
C
      CALL INLET
C
C**** RECIEVER MASS FLOW CONVERGENCE TEST
C
      CALL ITER (DMC,DMCP,TOL,IS1,&300)
C
      GO TO 400
C
  300 CALL ITER (DMS,DMSP,TOL,IS,&1000)
C
C**** CORRECT TURBINE MASS FLOW AND ITERATE
```

```
C
  400 DMTG=DMC*DMTG/(DMS+DMTG)
C
      DMCP=DMC
      DMSP=DMS
C
      GO TO 200
C
 1000 RETURN
C
      END
```

```
      SUBROUTINE CSEANL(*)
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (ND          ,C(1201)),(RAP          ,C( 445))
      EQUIVALENCE (CA          ,C(1203)),(EDI          ,C( 992))
      EQUIVALENCE (STORL       ,C( 960)),(ACC     (1,1),C(1542))
      EQUIVALENCE (FCR         ,C(1206)),(OM           ,C(1207))
      EQUIVALENCE (XO     (1)  ,C(1250)),(SL           ,C(1208))
      EQUIVALENCE (ICHEM       ,C( 955))
      EQUIVALENCE (FACTOR      ,C(1609))
C
      DIMENSION XO    (25)
      DIMENSION ACC   (20,3)
C
      DIMENSION CC    (20,1)
C
      DIMENSION IST   (4)
C
      DATA IST    /'THER','MAL ','CHEM','ICAL'/
C
      IF(ND.GT.1)GO TO 100
C
      PCFS=0.0
C
  100 PEFF=(XO(19)-XO(9))/XO(23)
      RTF =XO(17)/XO(16)
      STP =XO(17)/EDI
      PCF =(XO(19)-XO(9))/EDI/24.0
C
      PCFS=PCFS+PCF
C
      IF(ND.LT.4)RETURN 1
C
      DO 200 I=1,20
  200 CC(I,1)=ACC(I,1)
C
      CF=PCFS/4.0*100.0*FACTOR
C
      CC(3,1)=ACC(3,2)*1000.0*CA/EDI+ACC(3,3)
```

```
      CC(4,1)=ACC(4,2)*1000.0*CA/EDI+ACC(4,3)
      CC(5,1)=ACC(5,2)*50.0/SQRT(.5)*SQRT(CA)/EDI+ACC(5,3)
      CC(6,1)=ACC(6,2)*SL+ACC(6,3)
C
      DO 300 I=1,11
  300 CC(12,1)=CC(12,1)+CC(I,1)
C
      CC(13,1)=CC(12,1)*ACC(13,2)
      CC(14,1)=CC(12,1)*ACC(14,2)
C
      DO 400 I=12,14
  400 CC(15,1)=CC(15,1)+CC(I,1)
C
      CC(16,1)=CC(15,1)*ACC(16,2)
      CC(17,1)=CC(15,1)+ CC(16,1)
C
      BBEC=(FCR*CC(17,1))/(CF*8.76)+OM
C
      WRITE(6,1010)
C
      WRITE(6,1020)EDI
      WRITE(6,1030)CA
      WRITE(6,1040)SL
C
      WRITE(6,1300)
C
      WRITE(6,1050)
C
      IF(ICHEM.EQ.0)IS=1
      IF(ICHEM.EQ.1)IS=3
C
      IPC13=ACC(13,2)*100.0+0.001
      IPC14=ACC(14,2)*100.0+0.001
      IPC16=ACC(16,2)*100.0+0.001
C
      WRITE(6,1060)CC(1,1)
      WRITE(6,1070)CC(2,1)
      WRITE(6,1080)CC(3,1)
      WRITE(6,1090)CC(4,1)
      WRITE(6,1095)CC(5,1)
```

```
      WRITE(6,1100)IST(IS),IST(IS+1),CC(6,1)
      WRITE(6,1110)CC(7,1)
      WRITE(6,1120)CC(8,1)
      WRITE(6,1130)CC(9,1)
      WRITE(6,1140)CC(10,1)
      WRITE(6,1150)CC(11,1)
      WRITE(6,1160)CC(12,1)
      WRITE(6,1170)IPC13,CC(13,1)
      WRITE(6,1190)IPC14,CC(14,1)
      WRITE(6,1200)CC(15,1)
      WRITE(6,1210)IPC16,CC(16,1)
      WRITE(6,1220)CC(17,1)
C
      WRITE(6,1300)
C
      WRITE(6,1230)
C
      WRITE(6,1240)CC(17,1)
      WRITE(6,1250)FCR
      WRITE(6,1260)CF
      WRITE(6,1270)OM
      WRITE(6,1280)BBEC
C
      RETLRN
C
 1010 FCRMAT('1SOLAR POWER PLANT ECONOMICS',
     X      /' ***** ***** ***** *********')
 1020 FORMAT('OPOWER RATING                 (MWE)          ',F10.2)
 1030 FCRMAT(' COLLECTOR AREA               (KM**2)        ',F10.2)
 1040 FORMAT(' STORAGE TIME                 (HR)           ',F10.2)
C
 1050 FORMAT('OCAPITAL COST ACCOUNTS ($/KW)',
     X      /' ******* **** ******** ******')
C
 1060 FORMAT('OLAND                                        ',F10.2)
 1070 FCRMAT(' STRUCTURES AND FACILITIES                   ',F10.2)
 1080 FCRMAT(' HELIOSTATS                                  ',F10.2)
 1090 FORMAT(' CENTRAL RECIEVER/HEAT EXCHANGER             ',F10.2)
 1095 FORMAT(' TOWER                                       ',F10.2)
 1100 FORMAT(' STORAGE TRANKS (',2A4 ,')                   ',F10.2)
```

```
 1110 FORMAT(' BOILER PLANT                               ',F10.2)
 1120 FORMAT(' TURBINE PLANT AND EQUIPMENT                ',F10.2)
 1130 FORMAT(' ELECTRIC PLANT AND EQUIPMENT               ',F10.2)
 1140 FORMAT(' MISC PLANT AND EQUIPMENT                   ',F10.2)
 1150 FORMAT(' ALLOWANCE FOR COOLING TOWERS               ',F10.2)
 1160 FORMAT('0     TOTAL DIRECT COST                     ',F10.2)
 1170 FORMAT('0CONTINGENCY AND SPARE PARTS        ('I2,'%)   ',F10.2)
 1190 FORMAT(' INDIRECT COSTS                     ('I2,'%)   ',F10.2)
 1200 FORMAT('0     TOTAL CAPITAL INVESTMENT              ',F10.2)
 1210 FORMAT('0INTEREST DURING CONSTRUCTION       ('I2,'%)   ',F10.2)
 1220 FORMAT('0     TOTAL COST AT COMMERCIAL OPERATION    ',F10.2)
C
 1230 FORMAT('0ENERGY COSTS',
     X      /' ****** *****')
 1240 FORMAT('0CAPITAL COST                 ($/KW)        ',F10.2)
 1250 FORMAT(' FIXED CHARGE RATE            (%)           ',F10.2)
 1260 FORMAT(' CAPACITY FACTOR (CORRECTED)  (%)           ',F10.2)
 1270 FORMAT(' LEVALIZED O & M COST         (MILLS/KWH)   ',F10.2)
 1280 FORMAT('0BUSBAR ENERGY COST           (MILLS/KWH)   ',F10.2)
C
 1300 FORMAT('0')
C
      END
```

```
      SUBROUTINE CSEINT
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (ND       ,C(1201)),(NDAY      ,C(1202))
      EQUIVALENCE (STORL    ,C( 960)),(RSL       ,C(  38))
      EQUIVALENCE (STLRSL   ,C(1613))
C
      IF(NDAY.EQ.0)ND=0
      IF(NDAY.NE.0)ND=NDAY
C
      STLRSL=STORL*RSL
C
      RETURN
      END
```

```
      SUBRCUTINE CYCLE
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (ED         ,C(  16)),(PI         ,C(   1))
      EQUIVALENCE (ISTL       ,C( 996))
C
      EQUIVALENCE (DMWT  (1)  ,C(1001)),(P     (1)  ,C(1041))
      EQUIVALENCE (T     (1)  ,C(1061)),(DP    (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
C**** IS CURRENT TIME IN THE DEMAND WINDOW ?
C
      IF(ED.GT.0.0)GO TO 500
C
C**** IS SUN SHINING ?
C
      IF(PI.LE.0.0)GO TO 200
C
C**** IS STORAGE FULL ?
C
      IF(ISTL.EQ.1)GO TO 200
C
C**** CHARGE STORAGE WITH SUN
C
      CALL CHSS(&200)
C
      RETURN
C
C**** NO POWER AVAILABLE
C
  200 CALL ZRATE
C
      RETURN
C
C**** IS SUN SHINING ?
```

```
C
  500 IF(PI.GT.0.0)GO TO 1000
C
C**** IS STORAGE FULLY DISCHARGED ?
C
  300 IF(ISTL.EQ.-1)GO TO 200
C
C**** RUN TURBINE FROM STORAGE
C
      CALL DCHG
C
      RETURN
C
C**** IS STORAGE FULL ?
C
 1000 IF(ISTL.NE.1)GO TO 1500
C
C**** RUN TURBINE AT DEMAND
C
      CALL FRATE(&300,&1600)
C
      RETURN
C
C**** RUN NORMAL CHARGE CYCLE
C
 1500 CALL CHARGE(&300,&1600)
C
      RETURN
C
C**** PI INSUFFICIENT TO MEET DEMAND
C
C**** IS STORAGE FULLY DISCHARGED ?
C
 1600 IF(ISTL.EQ.-1)GO TO 2000
C
C**** DISCHARGE STORAGE WITH SOLAR SUPPLEMENTS
C
      CALL DCHGS
C
      RETURN
```

```
C
C**** RUN TURBINE AT MAXIMUM RATE
C
 2000 CALL DRATE
C
      RETURN
C
      END
```

```
      SUBROUTINE DAYANL(*)
C
      COMMON/SCLAR/C(2000)
C
      EQUIVALENCE (EOS         ,C(  33)),(EIS         ,C(  32))
      EQUIVALENCE (ED          ,C(  16)),(EDEF        ,C(  26))
      EQUIVALENCE (EI          ,C(  27)),(EDI         ,C( 992))
      EQUIVALENCE (ND          ,C(1201)),(NDAY        ,C(1202))
      EQUIVALENCE (XO     (1)  ,C(1250)),(EFTGD       ,C( 997))
      EQUIVALENCE (CA          ,C(1203)),(ED          ,C(  16))
      EQUIVALENCE (NODES       ,C( 446))
      EQUIVALENCE (DMTGMX      ,C(1210))
      EQUIVALENCE (DMSMXO      ,C(1211)),(DMSMXG      ,C(1212))
      EQUIVALENCE (DMSMXL      ,C(1213)),(DMCMX       ,C(1214))
      EQUIVALENCE (EDTMXO      ,C(1215)),(EDTMX       ,C(1216))
      EQUIVALENCE (PSMXO       ,C(1217)),(PSMX        ,C(1218))
      EQUIVALENCE (PSMN        ,C(1219)),(D11MX       ,C(1220))
      EQUIVALENCE (T4MN        ,C(1221)),(T9MX        ,C(1222))
      EQUIVALENCE (T10MX       ,C(1223)),(DS8MX       ,C(1224))
      EQUIVALENCE (TMED        ,C(1602))
      EQUIVALENCE (POS         ,C(  12)),(EFDC        ,C(1603))
      EQUIVALENCE (CTS    (1)  ,C(1604)),(NODS   (1)  ,C( 986))
      EQUIVALENCE (NODES       ,C( 446)),(UAIN        ,C( 449))
      EQUIVALENCE (CPF         ,C(  44)),(UAINN  (1)  ,C( 971))
      EQUIVALENCE (ICHEM       ,C( 955))
      EQUIVALENCE (IPWEEK      ,C(1611))
      EQUIVALENCE (ESS         ,C( 993))
      EQUIVALENCE (IWEEK       ,C(1610))
C
      DIMENSION XO    (25)
      DIMENSION CTS   (5)
      DIMENSION NODS  (5)
      DIMENSION UAINN (5)
C
      DIMENSION ISEA(4,4,3)
C
      DIMENSION ISEA1(4),ISEA2(4),ISEA3(4),ISEA4(4)
      DIMENSION ISEA5(4),ISEA6(4),ISEA7(4),ISEA8(4)
      DIMENSION ISEA9(4),ISEAA(4),ISEAB(4),ISEAC(4)
C
```

```
      EQUIVALENCE (ISEA1(1) ,ISEA(1,1,1)),(ISEA2(1) ,ISEA(1,2,1))
      EQUIVALENCE (ISEA3(1) ,ISEA(1,3,1)),(ISEA4(1) ,ISEA(1,4,1))
      EQUIVALENCE (ISEA5(1) ,ISEA(1,1,2)),(ISEA6(1) ,ISEA(1,2,2))
      EQUIVALENCE (ISEA7(1) ,ISEA(1,3,2)),(ISEA8(1) ,ISEA(1,4,2))
      EQUIVALENCE (ISEA9(1) ,ISEA(1,1,3)),(ISEAA(1) ,ISEA(1,2,3))
      EQUIVALENCE (ISEAB(1) ,ISEA(1,3,3)),(ISEAC(1) ,ISEA(1,4,3))
C
      DATA ISEA1  /'(WINTER WEEKEND)'/
      DATA ISEA2  /'(SPRING WEEKEND)'/
      DATA ISEA3  /'(SUMMER WEEKEND)'/
      DATA ISEA4  /'(FALL   WEEKEND)'/
      DATA ISEA5  /'(WINTER WEEKDAY)'/
      DATA ISEA6  /'(SPRING WEEKDAY)'/
      DATA ISEA7  /'(SUMMER WEEKDAY)'/
      DATA ISEA8  /'(FALL   WEEKDAY)'/
      DATA ISEA9  /'(WINTER)        '/
      DATA ISEAA  /'(SPRING)        '/
      DATA ISEAB  /'(SUMMER)        '/
      DATA ISEAC  /'(FALL)          '/
C
      RTF =XO(17)/XO(16)*100.0
      STP =XO(17)/EDI
      PEFF=(XO(19)-XO(9))/XO(23)*100.0
      PEFC=(XO(19)-XO(9))/EDI/24.0*100.0
C
      OUT1=XO(22)/XO(23)*100.0
      OUT2=100.0
      OUT3=XO(18)/XO(23)*100.0
      OUT4=XO(11)/XO(23)*100.0
      OUT5=(XO(11)-XO(8))/XO(23)*100.0
      OUT6=XO(19)/EFTGD/XO(23)*100.0
      OUT7=XO(19)/XO(23)*100.0
      OUT8=XO(20)/XO(23)*100.0
C
      OUT9 =XO(11)-XO(8)
      OUT10=XO(19)/EFTGD
      OUT11=XO(4)/XO(23)*100.0
      OUT12=XO(17)/XO(23)*100.0
C
      IF(IPWEEK.EQ.1)IP=1
```

```
      IF(IPWEEK.NE.1)IP=2
      IF(IWEEK .EQ.0)IP=3
C
      WRITE(6,1000)(ISEA(I,ND,IP),I=1,4)
      WRITE(6,1005)
C
      WRITE(6,1010)OUT1,XO(22)
      WRITE(6,1020)OUT2,XO(23)
      WRITE(6,1030)OUT3,XO(18)
      WRITE(6,1040)OUT4,XO(11)
      WRITE(6,1050)OUT5,OUT9
      WRITE(6,1055)OUT11,XO(4)
      WRITE(6,1060)OUT6,OUT10
      WRITE(6,1070)OUT7,XO(19)
      WRITE(6,1080)OUT8,XO(20)
      WRITE(6,1090)OUT12,XO(17)
C
      IF(IPWEEK.EQ.1)GO TO 50
C
      WRITE(6,2010)CA
      WRITE(6,2030)EDI
      WRITE(6,2040)PEFC
C
   50 WRITE(6,3010)
      WRITE(6,3020)DMTGMX
      WRITE(6,3030)DMSMXO
      WRITE(6,3040)DMSMXG
      WRITE(6,3050)DMSMXL
      WRITE(6,3060)DMCMX
C
      PSMN =-PSMN
C
      WRITE(6,3070)
      WRITE(6,3080)EDTMXO
      WRITE(6,3090)EDTMX
      WRITE(6,3100)PSMXO
      WRITE(6,3110)PSMX
      WRITE(6,3120)PSMN
      WRITE(6,3130)D11MX
C
```

```
      WRITE(6,3140)
      WRITE(6,3150)T4MN
      WRITE(6,3160)T9MX
      WRITE(6,3170)T10MX
C
      IF(IPWEEK.EQ.1)GO TO 300
C
      WRITE(6,3180)
      WRITE(6,3190)RTF
      WRITE(6,3200)DS8MX
C
      DMSMX =AMAX1(DMSMXG,CMSMXL)
C
      CTS(1)=UAIN*FLOAT(NODES)*3.415E+6/DMSMX /CPF/3600.0
C
      NODS2=NODES
C
      IF(NODS(1).EQ.0)NODS1=1
      IF(NODS(1).EQ.0)GO TO 200
C
      NODS2=0
C
      DO 100 I=1,5
C
      NCDS2=NODS2+NODS(I)
C
      IF(NODS(I).EQ.0)GO TO 200
C
      CTS(I)=UAINN(I)*FLOAT(NODS(I))*3.415E+6/DMSMX /CPF/3600.0
C
  100 NCDS1=I
C
  200 TMED=TMED/FLOAT(NODS2)
C
      IF(ICHEM .EQ.0)WRITE(6,3210)TMED
C
      EFDC=XO(17)*100.0/ESS
C
      WRITE(6,3220)EFDC
C
```

```
      IF(ICHEM .EQ.0)WRITE(6,3230)DMSMX,(CTS(I),I=1,NODS1)
      WRITE(6,3235)STP
C
  300 WRITE(6,3240)
C
      IF(NDAY.EQ.0)RETURN 1
C
      RETURN
C
 1000 FORMAT('1',10X,'DAILY PLANT PERFORMANCE',2X,4A4,
     X      /' ',10X,'***** ***** ***********')
 1005 FORMAT('0',40X,' % ENERGY ',5X,'   MWH    ')
 1010 FORMAT('ODIRECT INSOLATION                        ',F10.1,5X,F10.2)
 1020 FORMAT('0     LESS: INSOLATION REJECTED DUE TO    ',F10.1,5X,F10.2,
     X      /'            STORAGE LIMITATIONS           ')
 1030 FORMAT('      LESS: REFLECTOR FIELD LOSSES        ',F10.1,5X,F10.2)
 1040 FORMAT('0     LESS: RECIEVER LOSSES               ',F10.1,5X,F10.2)
 1050 FORMAT('0     LESS: STORAGE HEAT LOSSES           ',F10.1,5X,F10.2)
 1055 FORMAT('0     PLUS: STORAGE CIRCULATION PUMP HEAT',F10.1,5X,F10.2,
     X      /'            & INITIAL STORED ENERGY       ')
 1060 FORMAT('      LESS: NET STORAGE POWER             ',F10.1,5X,F10.2,
     X      /'            CONDITIONING LOSSES           ')
 1070 FORMAT('      LESS: TURBINE GENERATOR LOSSES      ',F10.1,5X,F10.2)
 1080 FORMAT('0     LESS: STORAGE PARASITIC ENERGY      ',F10.1,5X,F10.2,
     X      /'            LOSSES                        ')
 1090 FORMAT('      LESS: DIRECT GENERATION             ',F10.1,5X,F10.2)
C
 2010 FORMAT('OCOLECTOR AREA (KM**2)                    ',F10.2)
 2030 FORMAT(' PLANT CAPACITY (MW)                      ',F10.2)
 2040 FORMAT(' DAILY PLANT CAPACITY FACTOR (%)          ',F10.2)
 3010 FORMAT('OMAXIMUM MASS FLOWS (LBS/SEC)                  ')
 3020 FORMAT('     TURBINE                                       ',F10.2)
 3030 FORMAT('     STORAGE (CHARGE) *                            ',F10.2)
 3040 FORMAT('     STORAGE (CHARGE)                              ',F10.2)
 3050 FORMAT('     STORAGE (DISCHARGE)                           ',F10.2)
 3060 FORMAT('     RECIEVER                                      ',F10.2)
 3070 FORMAT('OMAXIMUM POWER CONDITIONS (MW)                 ')
 3080 FORMAT('     GENERATOR *                                   ',F10.2)
 3090 FORMAT('     GENERATOR                                     ',F10.2)
 3100 FORMAT('     STORAGE (CHARGE) *                            ',F10.2)
```

```
 3110 FORMAT('     STORAGE (CHARGE)                             ',F10.2)
 3120 FORMAT('     STORAGE (DISCHARGE)                          ',F10.2)
 3130 FORMAT('     RECIEVER                                     ',F10.2)
 3140 FORMAT('OTEMPERATURE EXTREMES (DEG-R)                 ')
 3150 FORMAT('     MINIMUM TURBINE INLET                        ',F10.2)
 3160 FORMAT('     MAXIMUM STORAGE SYSTEM DISCHARGE             ',F10.2)
 3170 FORMAT('     MAXIMUM RECIEVER INLET                       ',F10.2)
 3180 FORMAT('OSTORAGE SYSTEM DESIGN CONDITIONS             ')
 3190 FORMAT('     ROUND TRIP EFFICIENCY (%)                    ',F10.2)
 3200 FORMAT('     MAXIMUM ENERGY IN STORAGE (MW)               ',F10.2)
 3210 FORMAT('     EFFECTIVE TEMPERATURE SWING (THERMAL) (DEG-R)',F10.2)
 3220 FORMAT('     EFFECTIVE DISCHARGE CONVERSION EFFICIENCY (%)',F10.2)
 3230 FORMAT('     CRITICAL THERMAL SIZE  (M-DOT=',F9.2,')     ',5F10.2)
 3235 FORMAT('     STORAGE TIME (HRS)                           ',F10.2)
 3240 FORMAT('0* CONDITION WITH GENERATOR OFF-LINE')
C
      END
```

```
      SUBROUTINE DAYINT
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (DTAU            ,C(   2)),(ES            ,C(  31))
      EQUIVALENCE (ESO             ,C(  34)),(EDEF          ,C(  26))
      EQUIVALENCE (EI              ,C(  27)),(EH            ,C(  28))
      EQUIVALENCE (ETG             ,C(  29)),(EETG          ,C(  30))
      EQUIVALENCE (EIS             ,C(  32)),(EOS           ,C(  33))
      EQUIVALENCE (ED              ,C(  16))
      EQUIVALENCE (DTAUI           ,C( 958)),(TAU           ,C( 991))
      EQUIVALENCE (EDI             ,C( 992)),(ESS           ,C( 993))
      EQUIVALENCE (ICHK            ,C( 995))
      EQUIVALENCE (TSTART          ,C( 957))
      EQUIVALENCE (ND              ,C(1201)),(NDAY          ,C(1202))
      EQUIVALENCE (XMELT (1)       ,C( 452)),(XMELTP(1)     ,C( 752))
      EQUIVALENCE (TF    (1)       ,C( 854)),(TFP   (1)     ,C(1101))
      EQUIVALENCE (TWT   (1)       ,C( 145)),(TWP   (1)     ,C(  45))
      EQUIVALENCE (NODES           ,C( 446))
      EQUIVALENCE (TWZERO          ,C( 956))
      EQUIVALENCE (DMTGMX          ,C(1210))
      EQUIVALENCE (DMSMXO          ,C(1211)),(DMSMXG        ,C(1212))
      EQUIVALENCE (DMSMXL          ,C(1213)),(DMCMX         ,C(1214))
      EQUIVALENCE (EDTMXO          ,C(1215)),(EDTMX         ,C(1216))
      EQUIVALENCE (PSMXO           ,C(1217)),(PSMX          ,C(1218))
      EQUIVALENCE (PSMN            ,C(1219)),(D11MX         ,C(1220))
      EQUIVALENCE (T4MN            ,C(1221)),(T9MX          ,C(1222))
      EQUIVALENCE (T10MX           ,C(1223)),(DS8MX         ,C(1224))
      EQUIVALENCE (TMED            ,C(1602))
      EQUIVALENCE (T9C             ,C(1349))
      EQUIVALENCE (DS8MN           ,C(1612))
      EQUIVALENCE (PSO             ,C(1620))
C
      DIMENSION XMELTP(100)
      DIMENSION TFP   (100)
      DIMENSION TWP   (100)
      DIMENSION XMELT (100)
      DIMENSION TF    (100)
      DIMENSION TWT   (100)
C
```

```
      EQUIVALENCE (DMWT   (1)   ,C(1001)),(P      (1)   ,C(1041))
      EQUIVALENCE (T      (1)   ,C(1061)),(DP     (1)   ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (XN     (1)   ,C(1225)),(XO     (1)   ,C(1250))
      EQUIVALENCE (XDN    (1)   ,C(1275)),(XDO    (1)   ,C(1300))
C
      DIMENSION XN    (25)
      DIMENSION XO    (25)
      DIMENSION XDN   (25)
      DIMENSION XDO   (25)
C
      TAU=TSTART-DTAUI
      DTAU=DTAUI
C
      ES  =ESO
      ESS=0.0
      EDEF=0.0
      EI  =0.0
      EH  =0.0
      ETG =0.0
      EETG=0.0
      EIS =0.0
      EOS =0.0
C
      DO 100 I=1,25
      XO  (I)=0.0
      XN  (I)=0.0
  100 XDN (I)=0.0
C
      XO(16)=PSO
C
      ICHK=0
      XO(8)=ESO
      XO(21)=ESC
C
```

```
      DMTGMX=0.0
      DMSMXO=0.0
      DMSMXG=0.0
      DMSMXL=0.0
      DMCMX =0.0
      EDTMXO=0.0
      EDTMX =0.0
      PSMXC =0.0
      PSMX  =0.0
      PSMN  =100000.0
      D11MX =0.0
      T4MN  =100000.0
      T9MX  =0.0
      T10MX =0.0
      DS8MX =0.0
      DS8MN =100000.0
      TMED  =0.0
      T9C   =0.0
C
      RETURN
      END
```

```
      SUBROUTINE DCHEM
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (TED        ,C(   6)),(T2         ,C(  19))
      EQUIVALENCE (TM         ,C(  22)),(DMS        ,C(  20))
      EQUIVALENCE (PS         ,C(  13)),(DTFS       ,C(  25))
      EQUIVALENCE (EFTG       ,C(  35)),(TE         ,C(   7))
      EQUIVALENCE (CPF        ,C(  44)),(PIS        ,C(  11))
      EQUIVALENCE (POS        ,C(  12)),(TSE        ,C(  21))
C
      EQUIVALENCE (DMWT  (1)  ,C(1001)),(P     (1)  ,C(1041))
      EQUIVALENCE (T     (1)  ,C(1061)),(DP    (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T4    ,T      ( 4))
      EQUIVALENCE (T7    ,T      ( 7))
      EQUIVALENCE (T8    ,T      ( 8))
      EQUIVALENCE (DMWT8 ,DMWT   ( 8))
      DTFS=TED-T8
C
      DMWT8=-DMS*CPF *DTFS*3600.0/3.415E+06
C
      PIS=0.0
      POS=-DMWT8*EFTG
C
      T7= T8+DTFS
      T4 =T7
C
      TSE=T7
C
      RETURN
      END
```

```
      SUBROUTINE DCHG
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (TED         ,C(   6)),(TEP         ,C(   8))
      EQUIVALENCE (EDT         ,C(  17)),(ED          ,C(  16))
      EQUIVALENCE (DMS         ,C(  20)),(DMTG        ,C(  18))
      EQUIVALENCE (DMC         ,C(  14))
      EQUIVALENCE (ISTL        ,C( 996))
      EQUIVALENCE (TITMIN      ,C( 959))
C
      EQUIVALENCE (DMWT   (1)  ,C(1001)),(P      (1)  ,C(1041))
      EQUIVALENCE (T      (1)  ,C(1061)),(DP     (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T3    ,T     ( 3))
      EQUIVALENCE (T4    ,T     ( 4))
      EQUIVALENCE (T7    ,T     ( 7))
      EQUIVALENCE (T8    ,T     ( 8))
      EQUIVALENCE (T9    ,T     ( 9))
      EQUIVALENCE (T10   ,T     (10))
      EQUIVALENCE (T11   ,T     (11))
      EQUIVALENCE (DMWT11,DMWT  (11))
C
      EXTERNAL FDCHG
C
      DIMENSION XI(1)
C
C**** THIS SUBROUTINE DETERMINES PLANT PERFORMANCE DURING
C**** DISCHARGE WITH WITH NO SOLAR FLUX
C
      IF(ISTL.EQ.1)ISTL=0
C
      TOL1=0.0005
C
      IS =0
```

```
      T4 =TED
      TEP=T4
      EDT=ED
      DMC=0.0
C
      T10=0.0
      T11=0.0
C
C**** NO CAVITY POWER
C
      CALL ITER8(TEP,XI,FDCHG,TOL1,IS)
C
      RETURN
C
      END
```

```
      SUBROUTINE DCHGS
C
      CCMMCN/SOLAR/C(2000)
C
      EQUIVALENCE (TED         ,C(   6)),(TEP         ,C(   8))
      EQUIVALENCE (EDT         ,C(  17)),(ED          ,C(  16))
      EQUIVALENCE (DMTG        ,C(  18)),(DMCM        ,C(   4))
      EQUIVALENCE (DMC         ,C(  14)),(DMS         ,C(  20))
      EQUIVALENCE (ISTL        ,C( 996))
C
      EQUIVALENCE (DMWT  (1)   ,C(1001)),(P     (1)   ,C(1041))
      EQUIVALENCE (T     (1)   ,C(1061)),(DP    (1)   ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T3    ,T      ( 3))
      EQUIVALENCE (T4    ,T      ( 4))
      EQUIVALENCE (T7    ,T      ( 7))
      EQUIVALENCE (T8    ,T      ( 8))
      EQUIVALENCE (T9    ,T      ( 9))
      EQUIVALENCE (T10   ,T      (10))
      EQUIVALENCE (T11   ,T      (11))
      EQUIVALENCE (DMWT9 ,DMWT   ( 9))
C
C**** THIS PROGRAM COMPUTES PLANT PERFORMANCE DURING STORAGE
C**** DISCHARGE WITH PARTIAL SOLAR FLUX
C
      IF(ISTL.EQ.1)ISTL=0
C
C**** INITIALIZE TO MINIMUM TURBINE OPERATING CONDITIONS
C
      T9   =0.0
      T4   =TED
      TEP  =T4
      EDT  =ED
      DMWT9 =0.0
      DMC  =0.0
```

```
      IS=0
      TOL =0.002
      TOL1=0.0001
      DMSP=0.0
C
  700 DMC=0.0
C
C**** COMPUTE TURBINE PERFORMANCE
C
      CALL TRBINE
C
      T10 =T3
      DMS =DMTG
      DMCM=DMTG
C
C**** COMPUTE CAVITY PERFORMANCE
C
      CALL CAVITY
C
      T8 =T11
C
C**** COMPUTE STORAGE DISCHARGE PERFORMANCE
C
      CALL DCHRGE
C
      T4 =T7
C
      CALL ITER (T7 ,TEP ,TOL1,IS,&900)
C
      GO TO 910
C
  900 CALL ITER (DMS,DMSP,TOL,IS,&1000)
C
  910 TEP=T7
      DMSP=DMS
      GO TO 700
C
C**** INTEGRATE EACH BASIC POWER VARIABLE
C
 1000 RETURN
```

```
      SUBROUTINE DCHRGE
C
      COMMON/SOLAR/C(2000)
      EQUIVALENCE (ICHEM      ,C( 955))
C
      IF(ICHEM.EQ.0)CALL DTHERM
      IF(ICHEM.EQ.1)CALL DCHEM
C
      RETLRN
      END
```

```
      SUBROUTINE DRATE
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (TED         ,C(   6)),(DMC         ,C(  14))
      EQUIVALENCE (DMCP        ,C(   5)),(EDT         ,C(  17))
      EQUIVALENCE (TEP         ,C(   8)),(DMCM        ,C(   4))
      EQUIVALENCE (ED          ,C(  16))
      EQUIVALENCE (DMTG        ,C(  18))
      EQUIVALENCE (EFTG        ,C(  35)),(CPF         ,C(  44))
C
      EQUIVALENCE (DMWT   (1)  ,C(1001)),(P     (1)  ,C(1041))
      EQUIVALENCE (T      (1)  ,C(1061)),(DP    (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T3    ,T     ( 3))
      EQUIVALENCE (T4    ,T     ( 4))
      EQUIVALENCE (T7    ,T     ( 7))
      EQUIVALENCE (T8    ,T     ( 8))
      EQUIVALENCE (T9    ,T     ( 9))
      EQUIVALENCE (T10   ,T     (10))
      EQUIVALENCE (T11   ,T     (11))
      EQUIVALENCE (P3    ,P     ( 3))
      EQUIVALENCE (P4    ,P     ( 4))
      EQUIVALENCE (P10   ,P     (10))
      EQUIVALENCE (P11   ,P     (11))
C
C**** RUN TURBINE AT MAXIMUM RATE CONSISTENT WITH AVAILABLE HEAT RATE
C****      ( EDT REDUCED - NOT MEETING DEMAND
C
      TCL1=0.0001
      TCL =0.002
      IS  =0
C
      T7  =0.0
      T8  =0.0
```

```
      T9   =0.0
      T4   =TED
      DMC  =0.0
      DMCP=0.0
      EDT  =ED
      TEP  =T4
C
C**** COMPUTE TURBINE PERFORMANCE
C
  100 CALL TRBINE
C
      T10=T3
      P10=P3
      DMCM=DMTG
C
C**** COMPUTE CAVITY PERFORMANCE
C
      CALL CAVITY
C
      T4=T11
      P4=P11
C
      CALL ITER (T4,TEP,TOL1,IS,&200)
C
      GO TO 300
C
  200 CALL ITER (DMC,DMCP,TOL,IS,&500)
C
  300 DMCP=DMC
      TEP =T4
C
      EDT=DMC*EFTG*CPF *(T4 -T3)*3600.0/3.415E+06
C
      GO TO 100
C
  500 RETURN
C
      END
```

```
      SUBROUTINE DTHERM
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (RSL        ,C(  38)),(EFCOM       ,C(  39))
      EQUIVALENCE (RT         ,C(  40)),(TE          ,C(   7))
      EQUIVALENCE (DMS        ,C(  20)),(DTAU        ,C(   2))
      EQUIVALENCE (CPF        ,C(  44)),(EFTG        ,C(  35))
      EQUIVALENCE (PS         ,C(  13)),(TSE         ,C(  21))
      EQUIVALENCE (POS        ,C(  12)),(PIS         ,C(  11))
      EQUIVALENCE (PH         ,C(  15)),(DTFS        ,C(  25))
      EQUIVALENCE (ED         ,C(  16)),(EP          ,C(  10))
      EQUIVALENCE (TWP   (1)  ,C(  45)),(TWT   (1)  ,C( 145))
      EQUIVALENCE (UA    (1)  ,C( 245)),(XMCP  (1)  ,C( 345))
      EQUIVALENCE (NODES      ,C( 446))
      EQUIVALENCE (T2         ,C(  19))
      EQUIVALENCE (UAIN       ,C( 449)),(XMCPL       ,C( 447))
      EQUIVALENCE (XMCPS      ,C( 448))
      EQUIVALENCE (XMELT (1)  ,C( 452)),(HFM   (1)  ,C( 552))
      EQUIVALENCE (XTM   (1)  ,C( 652)),(XMELTP(1)  ,C( 752))
      EQUIVALENCE (TF    (1)  ,C( 854))
      EQUIVALENCE (DTAUI      ,C( 958))
C
      DIMENSION TWP    (100)
      DIMENSION UA     (100)
      DIMENSION XMCP   (100)
      DIMENSION TWT   (100)
      DIMENSION XMELT  (100)
      DIMENSION HFM    (100)
      DIMENSION XTM    (100)
       DIMENSION XMELTP (100)
      DIMENSION TF    (100)
C
      EQUIVALENCE (DMWT  (1)  ,C(1001)),(P     (1)  ,C(1041))
      EQUIVALENCE (T     (1)  ,C(1061)),(DP    (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
```

```
C
C
      EQUIVALENCE (T8    ,T     ( 8)),(T7    ,T     ( 7))
      EQUIVALENCE (T4    ,T     ( 4))
      EQUIVALENCE (T7    ,T     ( 7))
      EQUIVALENCE (DMWT8 ,DMWT  ( 8))
C
      EQUIVALENCE (XN    (1)  ,C(1225)),(XO    (1)  ,C(1250))
      EQUIVALENCE (XDN   (1)  ,C(1275)),(XDO   (1)  ,C(1300))
C
      DIMENSION XN    (25)
      DIMENSION XO    (25)
      DIMENSION XDN   (25)
      DIMENSION XDO   (25)
C
C     UA(I)    CONVECTIVE CONDUCTANCE (NODAL) - MW/DEG
C     XMCP(I)  THERMAL MASS (NODAL) - MW-HRS-DEG
C     TWT(I)   WALL TEMPERATURE (NODAL) - DEG
C     TF(I)    FLUID TEMPERATURE (NODAL) - DEG
C
C**** ENERGY DISCHARGE (SENSIBLE HEAT OPTION WITH MELTING)
C
      ES=0.0
C
      DO 100 I=1,NODES
      XMELT(I)=XMELTP(I)
  100 TWT(I)=TWP(I)
C
      TF(NODES)=T8
C
      DTAUP=AMIN1(DTAU,DTAUI/4.0,0.4*XMCPL/UAIN,0.4*XMCPS/UAIN)
C
      NDTAU=DTAU/DTAUP+0.9
      DTAUP=DTAU/FLOAT(NDTAU)
C
      DO 500 J=1,NDTAU
      DO 300 I=1,NODES
C
      K=NODES+1-I
C
```

```
      CALL NODPRP(K)
C
      FACT=UA(K)/DMS/CPF/3600.0*3.415E+06
C
      DELT=(TWT(K)-TF(K))
C
      TWTP=TWT(K)
C
      UAEFF=UA(K)*(1.0-EXP(-FACT))/FACT
C
      IF(XMELT(K).NE.0.0.AND.
     X   XMELT(K).NE.1.0)GO TO 250
C
      TWT(K)=TF(K)+DELT*EXP(-UAEFF/XMCP(K)*DTAUP)
C
C**** ALL FROZEN OR ALL MELTED
C
      IF(TWT(K).GE.XTM(K).AND.
     X  TWTP   .LE.XTM(K))GO TO 220
C
      IF(TWT(K).GT.XTM(K).OR.
     X   TWTP  .LT.XTM(K))GO TO 280
C
  220 XMELT(K)=XMELT(K)+(TWT(K)-XTM(K))*XMCP(K)/HFM(K)
      TWT  (K)=XTM(K)
C
      GO TO 280
C
C**** PARTIALLY MELTED
C
  250 XMELT(K)=XMELT(K)-UAEFF*DELT*DTAUP/HFM(K)
C
      IF(XMELT(K).LT.1.0.AND.
     X   XMELT(K).GT.0.0)GO TO 280
C
      IF(XMELT(K).GT.1.0)GO TO 270
C
      TWT(K)=XTM(K)+XMELT(K)*HFM(K)/XMCP(K)
      XMELT(K)=0.0
C
```

```
      GO TO 280
C
  270 TWT(K)=XTM(K)+(XMELT(K)-1.0)*HFM(K)/XMCP(K)
      XMELT(K)=1.0
C
  280 IF(K.NE.1)GO TO 300
C
      TE      =(TWT(K)+TWTP)/2.0-((TWT(K)+TWTP)/2.0-TF(K))*EXP(-FACT)
      GO TO 310
C
  300 TF(K-1)=(TWT(K)+TWTP)/2.0-((TWT(K)+TWTP)/2.0-TF(K))*EXP(-FACT)
C
  310 EPSP=DMS*CPF*3600.0/3.415E+06*(TE-T8)
C
  500 ES=ES+EPSP*DTAUP
C
      DMWT8=-ES/DTAU
C
      DTFS=3.415E+06*(-DMWT8) /DMS/CPF/3600.0
C
      PIS=0.0
      POS=-DMWT8*EFTG
C
      T7=T8+DTFS
      T4 =T7
C
      TSE=T7
C
      RETURN
      END
```

```
      SUBROUTINE EXTRM
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (ED          ,C(  16)),(DMTG        ,C(  18))
      EQUIVALENCE (DMS         ,C(  20)),(DMC         ,C(  14))
      EQUIVALENCE (PIS         ,C(  11)),(EDT         ,C(  17))
      EQUIVALENCE (T9C         ,C(1349)),(DMTGMX      ,C(1210))
      EQUIVALENCE (DMSMXO      ,C(1211)),(DMSMXG      ,C(1212))
      EQUIVALENCE (DMSMXL      ,C(1213)),(DMCMX       ,C(1214))
      EQUIVALENCE (EDTMXO      ,C(1215)),(EDTMX       ,C(1216))
      EQUIVALENCE (PSMXO       ,C(1217)),(PSMX        ,C(1218))
      EQUIVALENCE (PSMN        ,C(1219)),(D11MX       ,C(1220))
      EQUIVALENCE (T4MN        ,C(1221)),(T9MX        ,C(1222))
      EQUIVALENCE (T10MX       ,C(1223)),(DS8MX       ,C(1224))
      EQUIVALENCE (TMED        ,C(1602))
      EQUIVALENCE (TWZERO      ,C( 956)),(NODES       ,C( 446))
      EQUIVALENCE (TWP    (1)  ,C(  45))
      EQUIVALENCE (NODS   (1)  ,C( 986))
      EQUIVALENCE (DS8MN       ,C(1612))
C
      DIMENSION TWP   (100)
      DIMENSION NODS  (5)
C
      EQUIVALENCE (DMWT   (1)  ,C(1001))
      EQUIVALENCE (T      (1)  ,C(1061))
C
      DIMENSION DMWT  (20)
      DIMENSION T     (20)
C
      EQUIVALENCE (DMWT8 ,DMWT  ( 8))
      EQUIVALENCE (DMWT11,DMWT  (11))
      EQUIVALENCE (T4    ,T     ( 4))
      EQUIVALENCE (T10   ,T     (10))
C
      EQUIVALENCE (XN     (1)  ,C(1225))
C
      DIMENSION XN    (25)
C
      TME    =0.0
```

```
C
      DMTGMX=AMAX1(DMTGMX,DMTG)
C
      IF(ED    .EQ.0.0.AND.
     X   DMWT8 .GT.0.0)DMSMXO=AMAX1(DMSMXO,DMS)
C
      IF(ED    .GT.0.0.AND.
     X   DMWT8 .GT.0.0)DMSMXG=AMAX1(DMSMXG,DMS)
C
      IF(DMWT8 .LT.0.0)DMSMXL=AMAX1(DMSMXL,DMS)
C
      DMCMX =AMAX1(DMCMX ,DMC)
C
      IF(ED    .EQ.0.0)EDTMXO=AMAX1(EDTMXO,EDT)
C
      EDTMX =AMAX1(EDTMX ,EDT)
C
      IF(ED    .EQ.0.0)PSMXO =AMAX1(PSMXO ,DMWT8)
      IF(ED    .GT.0.0)PSMX  =AMAX1(PSMX  ,DMWT8)
C
      PSMN  =AMIN1(PSMN  ,DMWT8)
      D11MX =AMAX1(D11MX,DMWT11)
      T4MN  =AMIN1(T4MN  ,T4)
      T9MX  =AMAX1(T9MX  ,T9C)
      T10MX =AMAX1(T10MX ,T10)
      DS8MX =AMAX1(DS8MX ,XN(8))
      DS8MN =AMIN1(DS8MN ,XN(8))
C
      NODS2=0
C
      IF(NODS(1).EQ.0)NODS2=NODES
      IF(NODS(1).EQ.0)GO TO 75
C
      DO 50 I=1,5
C
   50 NODS2=NODS2+NODS(I)
C
   75 DO 100 I=1,NODS2
  100 TME =TME +TWP(I)-TWZERO
C
```

```
      FUNCTION FDCHG(TEP,XI)
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (DMS        ,C(  20)),(DMTG      ,C(  18))
      EQUIVALENCE (EDT        ,C(  17)),(ED        ,C(  16))
      EQUIVALENCE (DMC        ,C(  14))
C
      EQUIVALENCE (DMWT  (1)  ,C(1001)),(P     (1)  ,C(1041))
      EQUIVALENCE (T     (1)  ,C(1061)),(DP    (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T3    ,T     ( 3))
      EQUIVALENCE (T4    ,T     ( 4))
      EQUIVALENCE (T7    ,T     ( 7))
      EQUIVALENCE (T8    ,T     ( 8))
      EQUIVALENCE (T9    ,T     ( 9))
C
      DIMENSION XI(1)
C
      T4=TEP
C
C**** COMPUTE TURBINE PERFORMANCE
C
      CALL TRBINE
C
      DMS=DMTG
      T8 =T3
      T9 =T3
C
C**** COMPUTE STORAGE DISCHARGE PERFORMANCE
C
      CALL DCHRGE
C
      FDCHG=T7
C
```

```
      FUNCTION FIELD(TT,ND)
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (CA         ,C(1203)),(PIA   (1,1),C(1350))
      EQUIVALENCE (AT    (1)  ,C(1325)),(FEA   (1,1),C(1446))
      EQUIVALENCE (SIE        ,C(1204)),(FE         ,C(1205))
C
      DIMENSION PIA   (24,4)
      DIMENSION FEA   (24,4)
      DIMENSION AT    (24)
C
      PINS=TABLE1(AT,PIA(1,ND),24,TT)
C
      SIE=PINS*CA
C
C**** LOOK UP FIELD EFFICIENCY
C
      FE=TABLE1(AT,FEA(1,ND),24,TT)
C
      FIELD=FE*SIE
C
      RETURN
      END
```

```
      FUNCTION FPH(PHE,XI)
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (AHXI       ,C(1614)),(AWI        ,C(1615))
      EQUIVALENCE (AHXAP      ,C(1616)),(AWAP       ,C(1617))
C
      COMMON/FPHC/POE
C
      DIMENSION XI(3)
C
C**** FUNCTION FOR SOLVING POWER AT CAVITY EXIT GIVEN POWER INPUT,
C**** CAVITY RADIUS AND HELIUM TEMPERATURE
C
      DATA PIE  /3.14159/
C
      THE=XI(1)
      RAP=XI(2)
      P  =XI(3)
C
      A=PIE*RAP**2
      AHX =AHXAP*A
C
      IF(AHX.EQ.0.0)AHX=AHXI
C
      AW  =AWAP*A
C
      IF(AW .EQ.0.0)AW =AWI
C
      THX=PHE/4.53E-04/AHX+THE
C
      TCAV4=PHE/2.08E-15/AHX+THX**4
      TCAV=TCAV4**0.25
C
      PRAD=5.4E-15*A*(0.4*TCAV4+0.6*THX**4)
      PI=9.09E-08*AW/0.1525*(TCAV-500.0)
      PCONV=0.00127*(TCAV-500.0)
C
      POE=(PHE+PRAD+PI+PCONV)/0.9623
C
```

```
      SUBROUTINE FRATE(*,*)
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (DMCP        ,C(   5)),(ED          ,C(  16))
      EQUIVALENCE (EDT         ,C(  17)),(DMC         ,C(  14))
      EQUIVALENCE (DMTG        ,C(  18)),(PI          ,C(   1))
      EQUIVALENCE (EFTG        ,C(  35)),(DMS         ,C(  20))
C
      EQUIVALENCE (DMWT  (1)   ,C(1001)),(P     (1)   ,C(1041))
      EQUIVALENCE (T     (1)   ,C(1061)),(DP    (1)   ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T3    ,T      ( 3))
      EQUIVALENCE (T4    ,T      ( 4))
      EQUIVALENCE (T10   ,T      (10))
      EQUIVALENCE (T11   ,T      (11))
      EQUIVALENCE (DMWT11,DMWT   (11))
      EQUIVALENCE (P3    ,P      ( 3))
      EQUIVALENCE (P10   ,P      (10))
C
      DMCP=0.0
      IS1 =0
      TCL =0.002
C
C**** COMPUTE RECIEVER PERFORMANCE
C
  100 CALL CAVITY
C
C**** IS SOLAR INPUT SUFFICIENT TO RUN RECIEVER ?
C
      IF(DMWT11.EQ.0.0)RETURN 1
C
      T4=T11
      EDT=ED
C
```

```
C**** COMPUTE TURBINE PERFORMANCE
C
      CALL TRBINE
C
      IF(IS1.GT.0)GO TO 400
C
C**** IS SOLAR INPUT SUFFICIENT TO MEET ELECTRICAL DEMAND ?
C
      IF(DMC.LE.DMTG)RETURN 2
C
      DO 300 I=7,9
      P   (I)=0.0
      T   (I)=0.0
      DP  (I)=0.0
  300 DMWT(I)=0.0
C
  400 T10=T3
      P10=P3
C
      CALL ITER (DMC,DMCP,TOL,IS1,&1000)
C
      DMCP=DMC
      XK4=DMWT11/PI
C
      TBAR=AMAX1((T10+T11)/2.0,1200.0)
C
      A=0.883
      B=37.5-0.0325*TBAR
C
      PI=ED*(A+B/PI)/A/EFTG/XK4-B/A
C
      GO TO 100
C
 1000 RETURN
C
      END
```

```
      SUBROUTINE GDATA
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (ESO        ,C(  34)),(ES         ,C(  31))
      EQUIVALENCE (RAP        ,C( 445)),(NODES      ,C( 446))
      EQUIVALENCE (ICHEM      ,C( 955)),(IPS        ,C( 954))
      EQUIVALENCE (CPF        ,C(  44)),(DMCD       ,C(   3))
      EQUIVALENCE (RSL        ,C(  38)),(EFCOM      ,C(  39))
      EQUIVALENCE (RT         ,C(  40)),(EPLC       ,C(  41))
      EQUIVALENCE (EPLD       ,C(  43)),(ED         ,C(  16))
      EQUIVALENCE (TM         ,C(  22)),(TED        ,C(   6))
      EQUIVALENCE (TFUS       ,C( 451)),(HFUS       ,C( 450))
      EQUIVALENCE (UAIN       ,C( 449)),(XMCPL      ,C( 447))
      EQUIVALENCE (XMCPS      ,C( 448)),(EPCON      ,C( 853))
      EQUIVALENCE (DMRPMW     ,C( 852))
      EQUIVALENCE (TWZERO     ,C( 956)),(TSTART     ,C( 957))
      EQUIVALENCE (DTAUI      ,C( 958)),(TITMIN     ,C( 959))
      EQUIVALENCE (STORL      ,C( 960))
      EQUIVALENCE (TDS        ,C( 998)),(TDE        ,C( 999))
      EQUIVALENCE (CA         ,C(1203))
      EQUIVALENCE (FCR        ,C(1206)),(OM         ,C(1207))
      EQUIVALENCE (SL         ,C(1208)),(FACTOR     ,C(1609))
      EQUIVALENCE (DTPP       ,C(1000))
      EQUIVALENCE (AHXI       ,C(1614)),(AWI        ,C(1615))
      EQUIVALENCE (AHXAP      ,C(1616)),(AWAP       ,C(1617))
      EQUIVALENCE (PPPC       ,C(1618)),(PPOC       ,C(1619))
C
      EQUIVALENCE (DMWT  (1)  ,C(1001)),(P     (1)  ,C(1041))
      EQUIVALENCE (T     (1)  ,C(1061)),(DP    (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      CALL ERRSET(208,1000,-1,1)
      CALL ERRSET(209,1000,-1,1)
      CALL ERRSET(217,1   ,-1,1)
C
```

```
      WRITE(6,1150)
C
      DIMENSION AC    (20)
C
   55 REAC(5,1170,END=60)AC
      WRITE(6,1175)AC
C
      GO TO 55
C
   60 REWIND 5
C
C**** DATA PER DAY
C
      DTAUI=1.0
      RAP =9.6
      TWZERO=1410.0
      TITMIN=1560.0
      TSTART=4.0
      TDS =8.0
      TDE =24.0
C
      NODES=40
      ICHEM =0
      IPS   =0
C
C**** DATA PER HOUR
C     INITIALIZE FOR EACH POWER INCREMENT
C
      CPF=1.25
      DMCD=10.0
      RSL=0.02
      EFCOM=0.8
      RT=1.07
      ED=50.0
      TED=1960.0
      TFUS  =1630.0
      HFUS =20.0
      UAIN  =0.075
      XMCPL =0.02
      XMCPS =0.02
```

```
      DMRPMW=2.79
      EPCON=0.64
      STORL=900.0
      CA  =0.5
      FCR   =15.0
      OM    =6.0
      SL    =6.0
      FACTOR=1.0
      DTPP  =200.0
      AHXAP =16.44
      AWAP  =17.65
      PPPC  =0.069
      PPOC  =0.165
C
      RETURN
C
 1150 FORMAT('1')
 1170 FORMAT(20A4)
 1175 FORMAT(1X,20A4)
C
      END
```

```
      SUBROUTINE INITAL
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (DMCM       ,C(   4)),(DMCD       ,C(   3))
      EQUIVALENCE (DMCP       ,C(   5)),(TEP        ,C(   8))
      EQUIVALENCE (TE         ,C(   7)),(PIS        ,C(  11))
      EQUIVALENCE (TI         ,C(   9)),(EDT        ,C(  17))
      EQUIVALENCE (POS        ,C(  12)),(DTAU       ,C(   2))
      EQUIVALENCE (T2         ,C(  19)),(PI         ,C(   1))
      EQUIVALENCE (PS         ,C(  13)),(DMC        ,C(  14))
      EQUIVALENCE (TED        ,C(   6)),(EP         ,C(  10))
      EQUIVALENCE (TAU        ,C( 991))
      EQUIVALENCE (PII        ,C( 994)),(ICHK       ,C( 995))
      EQUIVALENCE (TSTART     ,C( 957)),(EDI        ,C( 992))
      EQUIVALENCE (ISTL       ,C( 996)),(DMS        ,C(  20))
      EQUIVALENCE (ED         ,C(  16))
      EQUIVALENCE (TDS        ,C( 998)),(TDE        ,C( 999))
      EQUIVALENCE (EFTG       ,C(  35)),(EFTGD      ,C( 997))
      EQUIVALENCE (AT    (1)  ,C(1325))
      EQUIVALENCE (DMTG       ,C(  18))
      EQUIVALENCE (ND         ,C(1201))
      EQUIVALENCE (IWEEK      ,C(1610)),(IPWEEK     ,C(1611))
C
      DIMENSION AT    (24)
C
      EQUIVALENCE (DMWT  (1)  ,C(1001)),(P     (1)  ,C(1041))
      EQUIVALENCE (T     (1)  ,C(1061)),(DP    (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T3    ,T     ( 3))
      EQUIVALENCE (T4    ,T     ( 4))
      EQUIVALENCE (T10   ,T     (10))
      EQUIVALENCE (T11   ,T     (11))
      EQUIVALENCE (DMWT8 ,DMWT  ( 8))
      EQUIVALENCE (DMWT9 ,DMWT  ( 9))
```

```
C
      IF(ICHK.GT.0)GO TO 150
C
  100 TAU =TAU +DTAU
C
      TT=AMOD(TAU,24.0)
C
      PI=FIELD(TT,ND)
C
      IF(TAU.GE.TDS    )GO TO 150
C
      IF(PI.LE.0.0)GO TO 100
C
  150 DMCM=DMCD
      PII =PI
      T4  =TED
      TEP =T4
      PIS =0.0
      POS =0.0
      DMWT8 =0.0
C
      EC  =EDI
C
      DMC =0.0
      EDT =ED
C
      CALL TRBINE
C
      IF(TAU.LE.TDS.OR.TAU.GT.(TDS+TDE))ED=0.0
      IF(IWEEK.GT.0.AND.IPWEEK.EQ.0)ED=0.0
C
      T10 =T3
      EFTGD=EFTG
C
      T11 =T4
      DMTG=0.0
      DMS =0.0
C
      DO 200 I=1,20
      DMWT(I)=0.0
```

```
      SUBROUTINE INLET
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (DMS         ,C(   20)),(DMC         ,C(   14))
      EQUIVALENCE (DMTG        ,C(   18)),(T2          ,C(   19))
      EQUIVALENCE (TI          ,C(    9))
C
      EQUIVALENCE (DMWT  (1)   ,C(1001)),(P     (1)   ,C(1041))
      EQUIVALENCE (T     (1)   ,C(1061)),(DP    (1)   ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T10    ,T     (10)),(T9    ,T     ( 9))
      EQUIVALENCE (T3     ,T     ( 3))
C
C**** COMPUTE CAVITY INLET TEMPERATURE
C
      T10=(DMS*T9+DMTG*T3)/(DMS+DMTG)
C
      RETURN
      END
```

```
      SUBROUTINE INPUT
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (PI           ,C(   1)),(DTAU         ,C(   2))
      EQUIVALENCE (DMCD         ,C(   3)),(DMCM         ,C(   4))
      EQUIVALENCE (DMCP         ,C(   5)),(TED          ,C(   6))
      EQUIVALENCE (TE           ,C(   7)),(TEP          ,C(   8))
      EQUIVALENCE (TI           ,C(   9)),(EP           ,C(  10))
      EQUIVALENCE (PIS          ,C(  11)),(POS          ,C(  12))
      EQUIVALENCE (PS           ,C(  13)),(DMC          ,C(  14))
      EQUIVALENCE (PH           ,C(  15)),(ED           ,C(  16))
      EQUIVALENCE (EDT          ,C(  17)),(DMTG         ,C(  18))
      EQUIVALENCE (T2           ,C(  19)),(DMS          ,C(  20))
      EQUIVALENCE (TSE          ,C(  21)),(TM           ,C(  22))
      EQUIVALENCE (IBP          ,C(  23)),(CBPAS        ,C(  24))
      EQUIVALENCE (DTFS         ,C(  25)),(EDEF         ,C(  26))
      EQUIVALENCE (EI           ,C(  27)),(EH           ,C(  28))
      EQUIVALENCE (ETG          ,C(  29)),(EETG         ,C(  30))
      EQUIVALENCE (ES           ,C(  31)),(EIS          ,C(  32))
      EQUIVALENCE (EOS          ,C(  33)),(ESO          ,C(  34))
      EQUIVALENCE (EFTG         ,C(  35)),(PTG          ,C(  36))
      EQUIVALENCE (TIT          ,C(  37)),(RSL          ,C(  38))
      EQUIVALENCE (EFCOM        ,C(  39)),(RT           ,C(  40))
      EQUIVALENCE (EPLC         ,C(  41)),(WC           ,C(  42))
      EQUIVALENCE (EPLD         ,C(  43))
      EQUIVALENCE (CPF          ,C(  44))
      EQUIVALENCE (TWP   (1)    ,C(  45)),(TWT   (1)    ,C( 145))
      EQUIVALENCE (UA    (1)    ,C( 245)),(XMCP  (1)    ,C( 345))
      EQUIVALENCE (RAP          ,C( 445)),(NODES        ,C( 446))
      EQUIVALENCE (XMCPL        ,C( 447)),(XMCPS        ,C( 448))
      EQUIVALENCE (UAIN         ,C( 449)),(HFUS         ,C( 450))
      EQUIVALENCE (TFUS         ,C( 451))
      EQUIVALENCE (XMELT (1)    ,C( 452)),(XFM   (1)    ,C( 552))
      EQUIVALENCE (XTM   (1)    ,C( 652)),(XMELTP(1)    ,C( 752))
      EQUIVALENCE (DMRPMW       ,C( 852)),(EPCON        ,C( 853))
      EQUIVALENCE (TF    (1)    ,C(854))
      EQUIVALENCE (IPS          ,C( 954))
      EQUIVALENCE (ICHEM        ,C( 955))
      EQUIVALENCE (XMCPLN(1)    ,C( 961)),(XMCPSN(1)    ,C( 966))
```

```
      EQUIVALENCE (UAINN (1)   ,C( 971)),(HFUSN (1)   ,C( 976))
      EQUIVALENCE (TFUSN (1)   ,C( 981)),(NODS  (1)   ,C( 986))
      EQUIVALENCE (TFP   (1)   ,C(1101))
      EQUIVALENCE (TWZERO      ,C( 956))
      EQUIVALENCE (TSTART      ,C( 957)),(DTAUI       ,C( 958))
      EQUIVALENCE (TITMIN      ,C( 959)),(STORL       ,C( 960))
      EQUIVALENCE (TDS         ,C( 998)),(TDE         ,C( 999))
      EQUIVALENCE (DTPP        ,C(1000))
      EQUIVALENCE (NDAY        ,C(1202)),(CA          ,C(1203))
      EQUIVALENCE (PIA   (1,1),C(1350)),(FEA   (1,1),C(1446))
      EQUIVALENCE (FCR         ,C(1206)),(OM          ,C(1207))
      EQUIVALENCE (SL          ,C(1208))
      EQUIVALENCE (IOHR        ,C(1209))
      EQUIVALENCE (ACC   (1,1),C(1542))
      EQUIVALENCE (FACTOR      ,C(1609))
      EQUIVALENCE (IWEEK       ,C(1610))
      EQUIVALENCE (AHXI        ,C(1614)),(AWI         ,C(1615))
      EQUIVALENCE (AHXAP       ,C(1616)),(AWAP        ,C(1617))
      EQUIVALENCE (PPPC        ,C(1618)),(PPOC        ,C(1619))
C
      EQUIVALENCE (PI1   (1)   ,PIA(1,1)),(FE1   (1)     ,FEA(1,1))
      EQUIVALENCE (PI2   (1)   ,PIA(1,2)),(FE2   (1)     ,FEA(1,2))
      EQUIVALENCE (PI3   (1)   ,PIA(1,3)),(FE3   (1)     ,FEA(1,3))
      EQUIVALENCE (PI4   (1)   ,PIA(1,4)),(FE4   (1)     ,FEA(1,4))
C
      DIMENSION PIA   (24,4),PI1    (24),PI2    (24),PI3    (24),PI4    (24)
      DIMENSION FEA   (24,4),FE1    (24),FE2    (24),FE3    (24),FE4    (24)
C
      EQUIVALENCE (AC1   (1)   ,ACC(1,1)),(AC2   (1)   ,ACC(1,2))
      EQUIVALENCE (AC3   (1)   ,ACC(1,3))
C
      DIMENSION ACC   (20,3),AC1    (20),AC2    (20),AC3    (20)
C
      DIMENSION TWP   (100)
      DIMENSION TWT   (100)
      DIMENSION UA    (100)
      DIMENSION XMCP  (100)
      DIMENSION XMELT (100)
      DIMENSION XFM   (100)
      DIMENSION XTM   (100)
```

```
      DIMENSION XMELTP(100)
      DIMENSION TF    (100)
      DIMENSION XMCPLN(5)
      DIMENSION XMCPSN(5)
      DIMENSION UAINN (5)
      DIMENSION HFUSN (5)
      DIMENSION TFUSN (5)
      DIMENSION NODS  (5)
      DIMENSION TFP   (100)
C
      EQUIVALENCE (DMWT  (1)  ,C(1001)),(P     (1)  ,C(1041))
      EQUIVALENCE (T     (1)  ,C(1061)),(DP    (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
C     VARIABLE DEFINITIONS
C
C     CA             COLLECTOR AREA - KM**2
C     DTAUI          COMPUTE INTERVAL - HRS
C     DTPP           PINCH POINT TEMPERATURE LIMIT (THERMAL SYSTEM) - R
C     ED             ELECTRICAL GRID DEMAND - MW
C     EFCOM          ENTHALPY EFFICENCY OF STORAGE SYSTEM COMPRESSOR
C     EPCON          ENDOTHERMIC CONVERSION FRACTION (CHEMICAL SYSTEM)
C     HFUS           HEAT OF FUSION OF THERMAL STORAGE MEDIA - MWH
C     HR             HEAT OF REACTION (THERMOCHEMICAL SYSTEM) - BTU/LBM
C     ICHEM          = 0 THERMAL ENERGY STORAGE DEVICE
C                    = 1 THERMOCHEMICAL (CES) STORAGE DEVICE
C     IOHR           = 0 NO THERMODYNAMIC STATE POINT OUTPUT GEWERATED
C                    = 1 THERMODYNAMIC STATE POINT OUTPUT GENERATED
C     IPS            = 1 NODAL TEMPERATURES PRINTED FOR EACH STEP
C                    = 0 NO NODAL TEMPERATURES PRINTED
C     NDAY           =  0 ANALYSE ALL FOUR DAYS FOR YEARLY RESULTS
C                    =  1 WINTER DAY
C                    =  2 SPRING DAY
C                    =  3 SUMMER DAY
C                    =  4 FALL DAY
C     NODES          NUMBER OF EQUAL AXIAL THERMAL ENERGY DIVISIONS
```

```
C       RAP              APETURE RADIUS - METERS
C       RSL              FRACTION OF STORAGE ENERGY HELD IN RESERVE
C       RT               PRESSURE RATIO OF TOTAL FLUID CIRCUIT LOOP
C       SL               STORACE LIMIT FOR COST MODEL - HRS
C       STORL            ENERGY LIMIT FOR CES SYSTEM - MWH
C       TDS              START TIME FOR LEVEL GRID DEMAND LOAD - HRS
C       TED              DESIGN POINT OPERATING TEMPERATURE - R
C       TFUS             MELT TEMPERATURE OF THERMAL STORAGE MEDIA - R
C       TSTART           STARTING TIME FOR POWER PLANT CYCLE ANALYSIS - HRS
C       TWZERO           INITIAL NODAL TEMPERATURE OF STORAGE DEVICE - R
C       UAIN             PRODUCT OF CONDUCTANCE AND SURFACE AREA - MW-R
C       XMCPL            SENSIBLE HEAT CAPACITY OF STORAGE MEDIA - MWH/R
C       XMCPS            SENSIBLE HEAT CAPACITY BELOW MELT POINT - MWH/R
C
        DIMENSION ID1  (13),ID2  (13),ID3  (13),ID4  (13),ID5  (13)
        DIMENSION ID6  (13),ID7  (13),ID8  (13),ID9  (13),ID10 (13)
        DIMENSION ID11 (13),ID12 (13),ID13 (13),ID14 (13),ID15 (13)
        DIMENSION ID16 (13),ID17 (13),ID18 (13),ID19 (13),ID20 (13)
        DIMENSION ID21 (13),ID22 (13),ID23 (13),ID24 (13),ID25 (13)
        DIMENSION ID26 (13),ID27 (13),ID28 (13),ID29 (13),ID30 (13)
        DIMENSION ID31 (13),ID32 (13),ID33 (13),ID34 (13),ID35 (13)
        DIMENSION ID36 (13)
        DIMENSION ID201(13),ID301(13),ID231(13),ID232(13),ID233(13)
        DIMENSION ID234(13),ID281(13)
C
        DATA ID1  /' NUMBER OF EQUAL AXIAL THERMAL ENERGY DIVISIONS    '/
        DATA ID2  /' = 0 THERMAL ENERGY STORAGE DEVICE                 '/
        DATA ID201/' = 1 THERMOCHEMICAL (CES) STORAGE DEVICE           '/
        DATA ID3  /' = 1 NODAL TEMPERATURES PRINTED FOR EACH STEP      '/
        DATA ID301/' = 0 NO NODAL TEMPERATURES PRINTED                 '/
        DATA ID4  /' STARTING TIME FOR POWER PLANT CYCLE ANALYSIS - HRS'/
        DATA ID5  /' COMPUTE INTERVAL - HRS                            '/
        DATA ID6  /' APETURE RADIUS - METERS                           '/
        DATA ID7  /' INITIAL NODAL TEMPERATURE OF STORAGE DEVICE - R   '/
        DATA ID8  /' FRACTION OF STORAGE ENERGY HELD IN RESERVE        '/
        DATA ID9  /' ENTHALPY EFFICENCY OF STORAGE SYSTEM COMPRESSOR   '/
        DATA ID10 /' PRESSURE RATIO OF TOTAL FLUID CIRCUIT LOOP        '/
        DATA ID11 /' ELECTRICAL GRID DEMAND - MW                       '/
        DATA ID12 /' DESIGN POINT OPERATING TEMPERATURE - R            '/
        DATA ID13 /' MELT TEMPERATURE OF THERMAL STORAGE MEDIA - R     '/
```

```
      DATA ID14 /'  HEAT OF FUSION OF THERMAL STORAGE MEDIA - MWH       '/
      DATA ID15 /'  PRODUCT OF CONDUCTANCE AND SURFACE AREA - MW/R      '/
      DATA ID16 /'  SENSIBLE HEAT CAPACITY OF STORAGE MEDIA - MWH/R     '/
      DATA ID17 /'  SENSIBLE HEAT CAPACITY BELOW MELT POINT - MWH/R     '/
      DATA ID18 /'  REACTANT PRODUCT FLOW PER MW STORED - LB/SEC/MW     '/
      DATA ID19 /'  ENDOTHERMIC CONVERSION FRACTION (CHEMICAL SYSTEM)   '/
      DATA ID20 /'  ENERGY LIMIT FOR CES SYSTEM - MWH                   '/
      DATA ID21 /'  START TIME FOR LEVEL GRID DEMAND LOAD - HRS         '/
      DATA ID22 /'  PINCH POINT TEMPERATURE LIMIT (THERMAL SYSTEM) - R'/
      DATA ID23 /'  =  0 ANALYSE ALL FOUR DAYS FOR YEARLY RESULTS       '/
      DATA ID231/'  =  1 WINTER DAY                                     '/
      DATA ID232/'  =  2 SPRING DAY                                     '/
      DATA ID233/'  =  3 SUMMER DAY                                     '/
      DATA ID234/'  =  4 FALL DAY                                       '/
      DATA ID24 /'  COLLECTOR AREA - KM**2                              '/
      DATA ID25 /'  = 1 FOR ANALYSIS OF WEEKLY CYCLE                    '/
      DATA ID26 /'  RECIEVER HEAT EXCHANGER AREA - M**2                 '/
      DATA ID27 /'  STORACE LIMIT FOR COST MODEL - HRS                  '/
      DATA ID28 /'  = 0 NO THERMODYNAMIC STATE POINT OUTPUT GEWERATED   '/
      DATA ID281/'  = 1 THERMODYNAMIC STATE POINT OUTPUT GENERATED      '/
      DATA ID29 /'  RECIEVER WALL AREA - M**2                           '/
      DATA ID30 /'  RECIEVER HEAT EXCHANGER/APERTURE AREA RATIO         '/
      DATA ID31 /'  RECIEVER WALL/APERTURE AREA RATIO                   '/
      DATA ID32 /'  FIXED CHARGE RATE                                   '/
      DATA ID33 /'  PLANT OPERATING YEARLY FRACTION                     '/
      DATA ID34 /'  OPERATING AND MAINTENANCE COST - MILLS/KW           '/
      DATA ID35 /'  PROD COMP PARA POWER / UNIT MASS FLOW - MW/LB/SEC   '/
      DATA ID36 /'  O2 COMP PARA POWER / UNIT MASS FLOW - MW/LB/SEC     '/
C
      WRITE(6,3000)
C
      NAMELIST/IN   /TSTART        ,DTAUI,RAP,TWZERO,NODES
     X                       ,RSL,EFCOM,RT           ,ED
     X              ,TED      ,TFUS,HFUS,UAIN,XMCPL,XMCPS
     X              ,DMRPMW,EPCON,IPS,ICHEM,STORL
     X              ,NODS,UAINN,TFUSN,HFUSN,XMCPLN,XMCPSN
     X              ,TDS    ,DTPP
     X              ,PI1,PI2,PI3,PI4,FE1,FE2,FE3,FE4,NDAY,CA
     X              ,FCR,OM,SL,AC1,AC2,AC3,IOHR,FACTOR
     X              ,IWEEK,AHXI,AWI,AHXAP,AWAP,PPPC,PPOC
```

```
C
      READ(5,IN    ,END=500)
C
      WRITE(6,1000)
C
      WRITE(6,1300)AHXAP ,ID30
      WRITE(6,1260)AHXI  ,ID26
      WRITE(6,1310)AWAP  ,ID31
      WRITE(6,1290)AWI   ,ID29
      WRITE(6,1240)CA    ,ID24
      WRITE(6,1180)DMRPMW,ID18
      WRITE(6,1050)DTAUI ,ID5
      WRITE(6,1220)DTPP  ,ID22
      WRITE(6,1110)ED    ,ID11
      WRITE(6,1090)EFCOM ,ID9
      WRITE(6,1190)EPCON ,ID19
      WRITE(6,1330)FACTOR,ID33
      WRITE(6,1320)FCR   ,ID32
      WRITE(6,1140)HFUS  ,ID14
      WRITE(6,1020)ICHEM ,ID2 ,ID201
      WRITE(6,1280)IOHR  ,ID28 ,ID281
      WRITE(6,1030)IPS   ,ID3 ,ID301
      WRITE(6,1250)IWEEK ,ID25
      WRITE(6,1230)NDAY  ,ID23 ,ID231,ID232,ID233,ID234
      WRITE(6,1010)NODES ,ID1
      WRITE(6,1340)OM    ,ID34
      WRITE(6,1360)PPOC  ,ID36
      WRITE(6,1350)PPPC  ,ID35
      WRITE(6,1060)RAP   ,ID6
      WRITE(6,1080)RSL   ,ID8
      WRITE(6,1100)RT    ,ID10
      WRITE(6,1270)SL    ,ID27
      WRITE(6,1200)STORL ,ID20
      WRITE(6,1210)TDS   ,ID21
      WRITE(6,1120)TED   ,ID12
      WRITE(6,1130)TFUS  ,ID13
      WRITE(6,1040)TSTART,ID4
      WRITE(6,1070)TWZERO,ID7
      WRITE(6,1150)UAIN  ,ID15
      WRITE(6,1160)XMCPL ,ID16
```

6-69

```
      WRITE(6,1170)XMCPS ,ID17
C
      IF(NODS(1).EQ.0)GO TO 200
C
      WRITE(6,3010)
C
      DO 100 I=1,5
C
      IF(NODS(I).EQ.0)GO TO 200
C
      WRITE(6,3020)NODS(I),UAINN(I),HFUSN(I),TFUSN(I),XMCPLN(I)
     X            ,XMCPSN(I)
C
  100 CONTINUE
C
  200 WRITE(6,3000)
C
      WRITE(6,3040)PIA
      WRITE(6,3050)FEA
      WRITE(6,3030)ACC
C
      RETURN
C
  500 RETURN 1
C
 1000 FORMAT('       **** INPUTS ****',/)
 1010 FORMAT(' NODES  = ',I9,4X,3X,13A4)
 1020 FORMAT(' ICHEM  = ',I9,4X,3X,13A4,/26X,13A4)
 1030 FORMAT(' IPS    = ',I9,4X,3X,13A4,/26X,13A4)
 1040 FORMAT(' TSTART = ',F13.3,3X,13A4)
 1050 FORMAT(' DTAUI  = ',F13.3,3X,13A4)
 1060 FORMAT(' RAP    = ',F13.3,3X,13A4)
 1070 FORMAT(' TWZERO = ',F13.3,3X,13A4)
 1080 FORMAT(' RSL    = ',F13.5,3X,13A4)
 1090 FORMAT(' EFCOM  = ',F13.3,3X,13A4)
 1100 FORMAT(' RT     = ',F13.3,3X,13A4)
 1110 FORMAT(' ED     = ',F13.3,3X,13A4)
 1120 FORMAT(' TED    = ',F13.3,3X,13A4)
 1130 FORMAT(' TFUS   = ',F13.3,3X,13A4)
 1140 FORMAT(' HFUS   = ',F13.3,3X,13A4)
```

```
 1150 FORMAT(' UAIN   = ',F13.5,3X,13A4)
 1160 FORMAT(' XMCPL  = ',F13.5,3X,13A4)
 1170 FORMAT(' XMCPS  = ',F13.5,3X,13A4)
 1180 FORMAT(' DMRPMW = ',F13.3,3X,13A4)
 1190 FORMAT(' EPCON  = ',F13.3,3X,13A4)
 1200 FORMAT(' STORL  = ',F13.3,3X,13A4)
 1210 FORMAT(' TDS    = ',F13.3,3X,13A4)
 1220 FORMAT(' DTPP   = ',F13.3,3X,13A4)
 1230 FORMAT(' NDAY   = ',I9,4X,3X,13A4,4(/26X,13A4))
 1240 FORMAT(' CA     = ',F13.3,3X,13A4)
 1250 FORMAT(' IWEEK  = ',I9,4X,3X,13A4)
 1260 FORMAT(' AHXI   = ',F13.3,3X,13A4)
 1270 FORMAT(' SL     = ',F13.3,3X,13A4)
 1280 FORMAT(' IOHR   = ',I9,4X,3X,13A4,/26X,13A4)
 1290 FORMAT(' AWI    = ',F13.3,3X,13A4)
 1300 FORMAT(' AHXAP  = ',F13.3,3X,13A4)
 1310 FORMAT(' AWAP   = ',F13.3,3X,13A4)
 1320 FORMAT(' FCR    = ',F13.3,3X,13A4)
 1330 FORMAT(' FACTOR = ',F13.3,3X,13A4)
 1340 FORMAT(' CM     = ',F13.3,3X,13A4)
 1350 FORMAT(' PPPC   = ',F13.3,3X,13A4)
 1360 FORMAT(' PPOC   = ',F13.3,3X,13A4)
C
 3000 FORMAT('1')
 3010 FORMAT('OMULTIPLE PHASE STORAGE',
     X      /'0   NODS      UAINN       HFUSN      TFUSN     XMCPLN   '
     X        ,'  XMCPSN  ',/)
 3020 FORMAT(1X,I6,4X,F10.5,2F10.3,2F10.5)
 3030 FORMAT('OPOWER PLANT COST ACCOUNTS',/
     X        (1X,2(/1X,10F10.3)))
 3040 FORMAT('OPI - 4 DAYS - 24 HRS',/
     X        (1X,4(/1X,6F10.3)))
 3050 FORMAT('OFIELD EFF. - 4 DAYS - 24 HRS',/
     X        (1X,4(/1X,6F10.3)))
C
      END
```

```
      SUBROUTINE INTEG
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (EDEF        ,C(  26)),(EDT         ,C(  17))
      EQUIVALENCE (EP          ,C(  10)),(DTAU        ,C(   2))
      EQUIVALENCE (EI          ,C(  27)),(PI          ,C(   1))
      EQUIVALENCE (EH          ,C(  28)),(PH          ,C(  15))
      EQUIVALENCE (ETG         ,C(  29)),(EFTG        ,C(  35))
      EQUIVALENCE (EETG        ,C(  30)),(ES          ,C(  31))
      EQUIVALENCE (EIS         ,C(  32)),(EOS         ,C(  33))
      EQUIVALENCE (PIS         ,C(  11)),(POS         ,C(  12))
      EQUIVALENCE (PS          ,C(  13))
      EQUIVALENCE (ESS         ,C( 993))
      EQUIVALENCE (ED          ,C(  16))
      EQUIVALENCE (SIE         ,C(1204)),(FE          ,C(1205))
C
      EQUIVALENCE (DMWT  (1)   ,C(1001)),(P     (1)   ,C(1041))
      EQUIVALENCE (T     (1)   ,C(1061)),(DP    (1)   ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (DMWT4 ,DMWT  ( 4))
      EQUIVALENCE (DMWT8 ,DMWT  ( 8))
      EQUIVALENCE (DMWT9 ,DMWT  ( 9))
      EQUIVALENCE (DMWT11,DMWT  (11))
C
      EQUIVALENCE (XN    (1)   ,C(1225)),(XO    (1)   ,C(1250))
      EQUIVALENCE (XDN   (1)   ,C(1275)),(XDO   (1)   ,C(1300))
C
      DIMENSION XN    (25)
      DIMENSION XO    (25)
      DIMENSION XDN   (25)
      DIMENSION XDO   (25)
C
      XDN ( 4)=DMWT4
      XDN ( 8)=DMWT8
```

```
      XDN ( 9)=DMWT9
      XDN (11)=DMWT11
      XDN (16)=PIS
      XDN (17)=POS
      XDN (18)=PI
      XDN (19)=EDT
      XDN (20)=ED
      XDN (21)=AMAX1(0.0,DMWT8)
      XDN (22)=SIE
      XDN (23)=PI/FE
C
      DO 100 I=1,25
  100 XN(I)=XO(I)+XDN(I)*DTAU
C
      EDEF=XN (19)-XN (9)
      EI   =XN (18)
      EH   =XN (11)
      ETG  =XN ( 4)
      EETG=XN (19)
      ESS  =XN (21)
      ES   =XN ( 8)
      EIS  =XN (16)
      EOS  =XN (17)
C
      RETURN
      END
```

```
      SUBROUTINE  ITER(X,XP,TOL,IS,*)
C
      IF(IS.GE.20)GO TO 100
C
      IS=IS+1
C
      IF(ABS((X-XP)/X).LE.TOL)RETURN 1
C
      RETURN
C
  100 WRITE(6,150)IS,X,XP,TOL
C
      RETURN 1
C
  150 FORMAT(' ',I4,' ITERATIONS EXCEEDED IN ITER  X=',F12.3,'  XP='
     X      ,F12.3,'  TOL=',F12.6)
      END
```

```
      SUBROUTINE ITER8 (T,XI,FCT,TOL,I)
      DIMENSION XI(1)
      T1=T
      DO 4 N=1,100
      I=I+2
      T2=FCT (T1,XI)
      T3=FCT (T2,XI)
      IF(T3)10,1,10
10    IF(ABS((T3-T2)/T3)-TOL)5,5,1
1     IF(T2-T1)11,2,11
11    A=(T3-T2)/(T2-T1)
      IF(A-1.)3,2,3
2     T1=T3
      GO TO 4
3     Q=A/(A-1.)
      T1=Q*T2+(1.-Q)*T3
      IF(T1)4,2,4
4     CONTINUE
      I=1
      WRITE (6,1000)
1000  FORMAT(1H040X33HCONVERGENCE NOT ACHIEVED IN ITER8)
      WRITE(6,2000)T1
2000  FORMAT(1H030X4HT = G10.4)
5     T=T3
      RETURN
      END
```

```
      SUBROUTINE NODPRP(I)
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (XMCPL      ,C( 447)),(XMCPS      ,C( 448))
      EQUIVALENCE (UAIN       ,C( 449)),(HFUS       ,C( 450))
      EQUIVALENCE (TFUS       ,C( 451)),(UA    (1)  ,C( 245))
      EQUIVALENCE (XMCP  (1)  ,C( 345)),(XMELT (1)  ,C( 452))
      EQUIVALENCE (HFM   (1)  ,C( 552)),(XTM   (1)  ,C( 652))
      EQUIVALENCE (XMCPLN(1)  ,C( 961)),(XMCPSN(1)  ,C( 966))
      EQUIVALENCE (UAINN (1)  ,C( 971)),(HFUSN (1)  ,C( 976))
      EQUIVALENCE (TFUSN (1)  ,C( 981)),(NODS  (1)  ,C( 986))
C
      DIMENSION UA    (100)
      DIMENSION XMCP  (100)
      DIMENSION XMELT (100)
      DIMENSION HFM   (100)
      DIMENSION XTM   (100)
      DIMENSION XMCPLN(5)
      DIMENSION XMCPSN(5)
      DIMENSION UAINN (5)
      DIMENSION HFUSN (5)
      DIMENSION TFUSN (5)
      DIMENSION NODS  (5)
C
      XMCP(I)=XMELT (I)*XMCPL+(1.0-XMELT (I))*XMCPS
      UA  (I)=UAIN
      HFM (I)=HFUS
      XTM  (I)=TFUS
C
      NODT=0
      K   =0
C
  100 K=K+1
C
      IF(K      .GT.5.OR.
     X   NODS(K).EQ.0)RETURN
C
      NODT=NODT+NODS(K)
C
```

```
      IF(I.GT.NODT)GO TO 100
C
      XMCP(I)=XMELT (I)*XMCPLN(K)+(1.0-XMELT (I))*XMCPSN(K)
      UA   (I)=UAINN (K)
      HFM (I)=HFUSN (K)
      XTM (I)=TFUSN (K)
C
      RETURN
C
      END
```

```
      SUBROUTINE OUTPUT
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (DTAU        ,C(   2)),(PI          ,C(   1))
      EQUIVALENCE (DMC         ,C(  14)),(DMTG        ,C(  18))
      EQUIVALENCE (TSE         ,C(  21)),(EDT         ,C(  17))
      EQUIVALENCE (DMS         ,C(  20))
      EQUIVALENCE (PIS         ,C(  11)),(POS         ,C(  12))
      EQUIVALENCE (NODES       ,C( 446)),(TF     (1)  ,C( 854))
      EQUIVALENCE (XMELT (1)   ,C( 452)),(XMELTP(1)   ,C( 752))
      EQUIVALENCE (TFP   (1)   ,C(1101)),(TWP    (1)  ,C(  45))
      EQUIVALENCE (TWT   (1)   ,C( 145))
      EQUIVALENCE (IBP         ,C(  23)),(IPS         ,C( 954))
      EQUIVALENCE (EFTG        ,C(  35))
      EQUIVALENCE (TAU         ,C( 991))
      EQUIVALENCE (SIE         ,C(1204))
      EQUIVALENCE (IOHR        ,C(1209))
      EQUIVALENCE (WC          ,C(  42)),(ICHEM       ,C( 955))
C
      DIMENSION XMELTP(100)
      DIMENSION XMELT (100)
      DIMENSION TF    (100)
      DIMENSION TFP   (100)
      DIMENSION TWT   (100)
      DIMENSION TWP   (100)
C
      EQUIVALENCE (DMWT  (1)   ,C(1001)),(P      (1)  ,C(1041))
      EQUIVALENCE (T     (1)   ,C(1061)),(DP     (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (XN    (1)   ,C(1225)),(XDN    (1)  ,C(1275))
C
      DIMENSION XN    (25)
      DIMENSION XDN   (25)
C
```

```
      CALL EXTRM
C
      IF(IOHR.EQ.0)RETURN
C
      WRITE(6,1010)TAU
C
      WRITE(6,1020)
      WRITE(6,1030)(T(I),I=1,11)
      WRITE(6,1060)(XON(I),I=1,11)
      WRITE(6,1070)(XN(I),I=1,11)
C
      DMW9WC=DMWT(9)-WC
C
      IF(ICHEM.EQ.1.AND.
     X   PIS  .GT.0.0)WRITE(6,1330)DMW9WC
C
      WRITE(6,1300)
C
      WRITE(6,1040)
C
      WRITE(6,1090)DMTG
      WRITE(6,1100)DMS
      WRITE(6,1080)DMC
      WRITE(6,1110)SIE
      WRITE(6,1120)PI
      WRITE(6,1130)EDT
      WRITE(6,1140)EFTG
      WRITE(6,1150)PIS
      WRITE(6,1160)POS
C
      WRITE(6,1300)
C
      WRITE(6,1170)XN(22)
      WRITE(6,1180)XN(18)
      WRITE(6,1190)XN(20)
      WRITE(6,1200)XN(16)
      WRITE(6,1210)XN(17)
C
      IF(IPS.EQ.0)GO TO 200
C
```

```
      WRITE(6,1310)
C
      DO  100 I=1,NODES
C
      IF(MOD(I,50).EQ.0)WRITE(6,1310)
C
  100 WRITE(6,1320)I,TWT(I),TF(I),XMELT(I)
C
  200 RETURN
C
 1010 FORMAT('1THERMODYNAMIC STATE POINT DATA ( TIME = ',F6.2,' )'
     X      /' ************* ***** ***** ****')
 1020 FORMAT('0',19X,'(                  T U R B I N E  G E N E R '
     X              ,'A T O R          )(      S T O R A G E         )'
     X              ,'(  R E C I E V E R  )'
     X      /' ',19X,'*    1    *    2    *    3    *    4    *    5   '
     X             ,'*     6    *    7    *    8    *    9    *   10   '
     X             ,'*    11    *')
 1030 FORMAT('OTEMPERATURE        ' ,11F10.3)
 1040 FORMAT('OSYSTEM PERFORMANCE DATA',
     X      /' ****** *********** ****')
 1060 FORMAT('OPOWER TRANSFER      ' ,11F10.3)
 1070 FORMAT('OENERGY CONSUMPTION  ' ,11F10.3)
 1080 FORMAT(' RECIEVER MASS FLOW                    (LBS/SEC) ',F12.2)
 1090 FORMAT('OTURBINE MASS FLOW                     (LBS/SEC) ',F12.2)
 1100 FORMAT(' STORAGE MASS FLOW                     (LBS/SEC) ',F12.2)
 1110 FORMAT('OSPECULAR INSOLATION                   (MW)      ',F12.2)
 1120 FORMAT(' SOLAR HEAT INTO RECIEVER              (MW)      ',F12.2)
 1130 FORMAT(' TOTAL GENERATOR OUTPUT                (MW)      ',F12.2)
 1140 FORMAT('OCONVERSION EFFICIENCY                           ',F12.2)
 1150 FORMAT('OPOWER INPUT TO STORAGE  -ELEC EQUIV   (MWE)     ',F12.2)
 1160 FORMAT(' POWER OUTPUT FROM STORAGE -ELEC EQUIV (MWE)     ',F12.2)
 1170 FORMAT('OSPECULAR INSOLATION ENERGY            (MWH)     ',F12.2)
 1180 FORMAT(' RECIEVER INPUT ENERGY                 (MWH)     ',F12.2)
 1190 FORMAT(' NET GENERATOR OUTPUT ENERGY           (MWH)     ',F12.2)
 1200 FORMAT(' ENERGY INPUT TO STORAGE  -ELEC EQUIV  (MWH)     ',F12.2)
 1210 FORMAT(' ENERGY OUTPUT FROM STORAGE -ELEC EQUIV (MWH)    ',F12.2)
C
 1300 FORMAT('0')
C
```

```
 1310 FORMAT('1  NODE       WALL         FLUID     FRACTION  ',
     X      /'            TEMPERATURE TEMPERATURE    MELTED   '/)
C
 1320 FORMAT(I6,3X,2F12.2,F12.4)
 1330 FORMAT('0',20X,'* POWER TRANSFER (9) INCLUDES',F10.2,'  MWT FOR ',
     X               'CES PUMPING')
C
      END
```

```
      SUBROUTINE SCHEM
C
      COMMCN/SOLAR/C(2000)
C
      EQUIVALENCE (RT         ,C(   40)),(EFCOM     ,C(   39))
      EQUIVALENCE (T9C        ,C(1349)),(DMS       ,C(   20))
      EQUIVALENCE (TE         ,C(    7)),(CPF       ,C(   44))
      EQUIVALENCE (PS         ,C(   13)),(POS       ,C(   12))
      EQUIVALENCE (PIS        ,C(   11)),(PH        ,C(   15))
      EQUIVALENCE (EFTG       ,C(   35)),(ED        ,C(   16))
      EQUIVALENCE (EP         ,C(   10)),(WC        ,C(   42))
      EQUIVALENCE (DMRPMW     ,C(  852)),(EPCON     ,C(  853))
      EQUIVALENCE (T2         ,C(   19))
      EQUIVALENCE (PPPC       ,C(1618)),(PPOC      ,C(1619))
C
      EQUIVALENCE (DMWT  (1)  ,C(1001)),(P     (1)  ,C(1041))
      EQUIVALENCE (T     (1)  ,C(1061)),(DP    (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T3    ,T      ( 3))
      EQUIVALENCE (T7    ,T      ( 7))
      EQUIVALENCE (T8    ,T      ( 8))
      EQUIVALENCE (T9    ,T      ( 9))
      EQUIVALENCE (DMWT8 ,DMWT   ( 8))
      EQUIVALENCE (DMWT9 ,DMWT   ( 9))
      EQUIVALENCE (DMWT11,DMWT   (11))
C
C     HR       HEAT OF REACTION - BTU/LB
C     EPCCN    REACTION DISSOCIATION FRACTION.
C
      DATA GAMMA /1.66/
C
      T9 =T3
C
      T9C=T9
C
```

```
      TSDO=T9 /(1.0+((RT**((GAMMA-1.0)/GAMMA)-1.0)/EFCOM))
C
      T8=TSDO
C
      WC=CPF*(T9 -TSDO)*DMS*3600.0/3.415E+06
C
      DTS=T7-TSDO
C
      DMWT8=DMS*CPF*DTS*3600.0/3.415E+06
C
      PCS=0.0
      PIS=DMWT11*EFTG-ED
C
      DMPROD=DMRPMW*DMWT8
      DMO2 =DMPROD*EPCON*0.2
C
      DMWT9=PPPC*DMPROD+PPOC*DMO2+WC
C
      RETURN
      END
```

```
      SUBROUTINE STHERM
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (RSL        ,C(  38)),(EFCOM     ,C(  39))
      EQUIVALENCE (RT         ,C(  40)),(TE        ,C(   7))
      EQUIVALENCE (DMS        ,C(  20)),(DTAU      ,C(   2))
      EQUIVALENCE (CPF        ,C(  44)),(EFTG      ,C(  35))
      EQUIVALENCE (PS         ,C(  13)),(TSE       ,C(  21))
      EQUIVALENCE (POS        ,C(  12)),(PIS       ,C(  11))
      EQUIVALENCE (PH         ,C(  15))
      EQUIVALENCE (ED         ,C(  16)),(EP        ,C(  10))
      EQUIVALENCE (TWP     (1) ,C(  45)),(TWT  (1)  ,C( 145))
      EQUIVALENCE (UA      (1) ,C( 245)),(XMCP (1)  ,C( 345))
      EQUIVALENCE (NODES      ,C( 446))
      EQUIVALENCE (UAIN       ,C( 449)),(XMCPL     ,C( 447))
      EQUIVALENCE (XMCPS      ,C( 448))
      EQUIVALENCE (XMELT (1)  ,C( 452)),(HFM  (1)  ,C( 552))
      EQUIVALENCE (XTM     (1) ,C( 652)),(XMELTP(1) ,C( 752))
      EQUIVALENCE (TF    (1)  ,C( 854))
      EQUIVALENCE (DTAUI      ,C( 958))
C
      EQUIVALENCE (T9C        ,C(1349))
      DIMENSION TWP   (100)
      DIMENSION UA    (100)
      DIMENSION XMCP  (100)
      DIMENSION TWT   (100)
      DIMENSION XMELT (100)
      DIMENSION HFM   (100)
      DIMENSION XTM   (100)
      DIMENSION XMELTP(100)
      DIMENSION TF    (100)
C
      EQUIVALENCE (DMWT  (1)  ,C(1001)),(P    (1)  ,C(1041))
      EQUIVALENCE (T     (1)  ,C(1061)),(DP   (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
```

```
C
      EQUIVALENCE (T8    ,T     ( 8)),(T9    ,T     ( 9))
      EQUIVALENCE (DMWT9 ,DMWT  ( 9)),(DMWT11,DMWT  (11))
      EQUIVALENCE (DMWT8 ,DMWT  ( 8))
      EQUIVALENCE (T7    ,T     ( 7))
      EQUIVALENCE (P8    ,P     ( 8)),(P9    ,P     ( 9))
      EQUIVALENCE (DP8   ,DP    ( 8)),(DP9   ,DP    ( 9))
      EQUIVALENCE (P7    ,P     ( 7))
C
      EQUIVALENCE (XN    (1)  ,C(1225)),(XO    (1)  ,C(1250))
      EQUIVALENCE (XDN   (1)  ,C(1275)),(XDO   (1)  ,C(1300))
C
      DIMENSION XN    (25)
      DIMENSION XO    (25)
      DIMENSION XDN   (25)
      DIMENSION XDO   (25)
C
C     UA(I)    CONVECTIVE CONDUCTANCE (NODAL) - MW/DEG
C     XMCP(I)  THERMAL MASS (NODAL) - MW-HRS/DEG
C     TWT(I)   WALL TEMPERATURE (NODAL) - DEG
C     TF(I)    FLUID TEMPERATURE (NODAL) - DEG
C
      DATA GAMMA /1.66/
C
C**** ENERGY STORAGE (SENSIBLE HEAT OPTION WITH MELTING)
C
      ES=C.0
C
C**** INITIALIZE NODAL TEMPERATURES TO PREVIOUS VALUES
C
      DO 100 I=1,NODES
      XMELT (I)=XMELTP(I)
  100 TWT(I)=TWP(I)
C
C**** SET UP INLET FLUID TEMPERATURE
C
      TF(1)=T7
C
C**** SET COMPUTE STEP FOR DIFFERENCE SOLUTION
C
```

```
      DTAUP=AMIN1(DTAU,DTAUI/4.0,0.4*XMCPL/UAIN,0.4*XMCPS/UAIN)
C
      NDTAU=DTAU/DTAUP+0.9
      DTAUP=DTAU/FLOAT(NDTAU)
C
C**** FINITE DIFFERENCE SOLUTION
C
      DO 500 J=1,NDTAU
      DO 300 I=1,NODES
C
C**** SET UP PROPERTIES OF EACH NODE
C
      CALL NODPRP(I)
C
      FACT=UA(I)/DMS/CPF/3600.0*3.415E+06
C
      DELT=(TWT(I)-TF(I))
C
      TWTP=TWT(I)
C
      UAEFF=UA(I)*(1.0-EXP(-FACT))/FACT
C
      IF(XMELT(I).NE.0.0.AND.
     X   XMELT(I).NE.1.0)GO TO 250
C
      TWT(I)=TF(I)+DELT*EXP(-UAEFF/XMCP(I)*DTAUP)
C
C**** ALL FROZEN OR ALL MELTED
C
      IF(TWT(I).GE.XTM(I).AND.
     X  TWTP   .LE.XTM(I))GO TO 220
C
      IF(TWT(I).GT.XTM(I).OR.
     X   TWTP  .LT.XTM(I))GO TO 300
C
  220 XMELT(I)=XMELT(I)+(TWT(I)-XTM(I))*XMCP(I)/HFM(I)
      TWT  (I)=XTM(I)
C
      GO TO 300
C
```

```
C**** PARTIALLY MELTED
C
  250 XMELT(I)=XMELT(I)-UAEFF*DELT*DTAUP/HFM(I)
C
      IF(XMELT(I).LT.1.0.AND.
     X   XMELT(I).GT.0.0)GO TO 300
C
      IF(XMELT(I).GT.1.0)GO TO 270
C
      TWT(I)=XTM(I)+XMELT(I)*HFM(I)/XMCP(I)
      XMELT(I)=0.0
C
      GO TO 300
C
  270 TWT(I)=XTM(I)+(XMELT(I)-1.0)*HFM(I)/XMCP(I)
      XMELT(I)=1.0
C
  300 TF(I+1)=(TWT(I)+TWTP)/2.0-((TWT(I)+TWTP)/2.0-TF(I))*EXP(-FACT)
C
      EPSP=DMS*CPF*3600.0/3.415E+06*(T7-TF(NODES+1))
C
  500 ES=ES+EPSP*DTAUP
C
C**** COMPUTE AVERAGE TEMPERATURES AND STORAGE ENERGY TRANSFER
C
      DMWT8= ES/DTAU
C
      DTS=3.415E+06* DMWT8 /DMS/CPF/3600.0
C
      T8=T7-DTS
C
      T9 =    T8    *(1.0+(RT**((GAMMA-1.0)/GAMMA)-1.0)/EFCOM)
C
      T9C=TF(NODES+1)*(1.0+(RT**((GAMMA-1.0)/GAMMA)-1.0)/EFCOM)
C
      TSE=T9
C
      DMWT9=CPF*(T9 -    T8    )*DMS*3600.0/3.415E+06
C
      PCS=0.0
```

```
      PIS=DMWT11*EFTG-ED
C
      DP8=1.0-RT
      DP9=(RT-1.0)/(1.0+DP8)
C
      P8=P7*(1.0+DP8)
      P9=P8*(1.0+DP9)
C
      RETURN
      END
```

```
      SUBROUTINE STORGE
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (ICHEM      ,C( 955))
C
      IF(ICHEM.EQ.0)CALL STHERM
      IF(ICHEM.EQ.1)CALL SCHEM
C
      RETURN
      END
```

```
      FUNCTION TABLE1(X,Y,N,AX)
      DIMENSION X(1),Y(1)
C
      I=1
      IF(AX-X(I))40,40,80
   40 I=2
      GO TO 110
   80 IF(I-N)100,90,90
   90 SL=(Y(N)-Y(N-1))/(X(N)-X(N-1))
      TABLE1=SL*(AX-X(N))+Y(N)
      RETURN
  100 I=I+1
      IF(AX-X(I))110,110,80
  110 SL=(Y(I)-Y(I-1))/(X(I)-X(I-1))
      TABLE1=SL*(AX-X(I-1))+Y(I-1)
      RETURN
      END
```

```
      SUBROUTINE TRBINE
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (ED          ,C(  16)),(TE          ,C(   7))
      EQUIVALENCE (DMC         ,C(  14)),(DMTG        ,C(  18))
      EQUIVALENCE (EFTG        ,C(  35)),(T2          ,C(  19))
      EQUIVALENCE (PTG         ,C(  37)),(EDT         ,C(  17))
      EQUIVALENCE (CPF         ,C(  44))
C
      EQUIVALENCE (DMWT  (1)   ,C(1001)),(P     (1)   ,C(1041))
      EQUIVALENCE (T     (1)   ,C(1061)),(DP    (1)   ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
      EQUIVALENCE (T3    ,T      ( 3)),(T4    ,T      ( 4))
      EQUIVALENCE (DMWT4 ,DMWT   ( 4))
C
      DIMENSION ATEMP (6)
      DIMENSION AEFF  (6)
      DIMENSION AT2   (6)
C
      DATA ATEMP   /0.0,960.,1360.,1560.0,1760.0,1960.0/
      DATA AEFF    /0.180,.18,.213,0.295,0.377,0.442/
      DATA AT2     /0.,870.0,1136.0,1269.0,1402.0,1538.0/
      DATA NPTS    /6/
C
      EFTG=TABLE1(ATEMP,AEFF,NPTS,T4)
      T3  =TABLE1(ATEMP,AT2 ,NPTS,T4)
C
      DMTG=3.415E+06*EDT/EFTG/CPF /(T4 -T3)/3600.0
C
      DMWT4=EDT/EFTG
C
      RETURN
      END
```

```
      SUBROUTINE UDATE(*)
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (ES         ,C(  31)),(ESO        ,C(  34))
      EQUIVALENCE (STORL      ,C( 960)),(RSL        ,C(  38))
      EQUIVALENCE (NODES      ,C( 446)),(XMELT (1)  ,C( 452))
      EQUIVALENCE (XMELTP(1)  ,C( 752)),(TF    (1)  ,C( 854))
      EQUIVALENCE (TFP   (1)  ,C(1101)),(TWT   (1)  ,C( 145))
      EQUIVALENCE (TWP   (1)  ,C(  45)),(TAU        ,C( 991))
      EQUIVALENCE (DTAU       ,C(   2)),(PI         ,C(   1))
      EQUIVALENCE (ICHK       ,C( 995)),(ISTL       ,C( 996))
      EQUIVALENCE (IBP        ,C(  23))
      EQUIVALENCE (AT    (1)  ,C(1325))
      EQUIVALENCE (DTPP       ,C(1000)),(DTAUI      ,C( 958))
      EQUIVALENCE (PIS        ,C(  11))
      EQUIVALENCE (T9C        ,C(1349))
      EQUIVALENCE (ICHEM      ,C( 955))
      EQUIVALENCE (ND         ,C(1201))
      EQUIVALENCE (IWEEK      ,C(1610)),(IPWEEK     ,C(1611))
      EQUIVALENCE (STLRSL     ,C(1613))
      EQUIVALENCE (TDS        ,C( 998))
      EQUIVALENCE (TED        ,C(   6))
C
      DIMENSION XMELT (100)
      DIMENSION XMELTP(100)
      DIMENSION TF    (100)
      DIMENSION TFP   (100)
      DIMENSION TWT   (100)
      DIMENSION TWP   (100)
C
      DIMENSION PIA   (24)
      DIMENSION AT    (24)
C
      EQUIVALENCE (DMWT  (1)  ,C(1001)),(P     (1)  ,C(1041))
      EQUIVALENCE (T     (1)  ,C(1061)),(DP    (1)  ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
```

```
      DIMENSION DP     (20)
C
      EQUIVALENCE (T7    ,T      ( 7))
      EQUIVALENCE (T9    ,T      ( 9))
C
      EQUIVALENCE (XN    (1)  ,C(1225)),(XO    (1)  ,C(1250))
      EQUIVALENCE (XDN   (1)  ,C(1275)),(XDO   (1)  ,C(1300))
C
      DIMENSION XN     (25)
      DIMENSION XO     (25)
      DIMENSION XDN    (25)
      DIMENSION XDO    (25)
C
      DATA ICHKS  /   0/
C
      IBP =0
C
      IF(ICHKS.NE.-2)GO TO 10
C
      ICHKS=0
      DTAU =DTAUI
C
   10 IF(ICHKS.GT.0)GO TO 1000
C
      IF(PIS     .GT.0.0.AND.
     X   ICHEM   .EQ.0  .AND.
     X   (TED-T9C).LT.DTPP )GO TO 1000
C
      IF(PIS     .GT.0.0.AND.
     X   ICHEM   .EQ.1  .AND.
     X   XN(8)   .GT.STORL)GO TO 1000
C
      IF(ICHK.GT.0)GO TO 400
C
      IF(XN(8).LE. STLRSL .AND.
     X   TAU  .GT.12.0        )GO TO 400
C
      IF(IWEEK .EQ.1.AND.
     X   IPWEEK.EQ.0.AND.
     X   TAU   .GT.12.0.AND.
```

```
     X    PI     .LT.10.0)GO TO 500
C
   50 TAUS=TAU
      DTPPS=T7-T9C
C
      DO 100 I=1,NODES
      XMELTP(I)=XMELT (I)
      TFP   (I)=TF    (I)
  100 TWP   (I)=TWT   (I)
C
      DO 200 I=1,25
  200 XO (I)=XN (I)
C
      IF(TAU   .GT.12.0.AND.
     X  (IPWEEK.EQ.1   .OR.
     X    IPWEEK.EQ.2)  .AND.
     X     XDN(8).LT.0.0 )RETURN
C
      CALL OUTPUT
C
      IF(ICHKS.EQ.-1)GO TO 1610
C
      IF(TAU.GE.(24.0+TDS-DTAU/10.0))GO TO 500
C
      RETURN 1
C
  400 IF(ICHK.GT.10)GO TO 500
C
      XX    =       (XO(8)-  STLRSL )/(XO(8)-XN(8))
C
      IF(XX.GT.0.995.AND.
     X   XX.LT.1.005)GO TO 500
C
      DTAU=DTAU * XX
C
      TAU=TAUS+DTAU
C
      ICHK=ICHK+1
C
  350 TT=AMOD(TAU,24.0)
```

```
C
      PI=FIELD(TT,ND)
C
      RETURN 1
C
  500 DO 600 I=1,NODES
      XMELTP(I)=XMELT (I)
      TFP   (I)=TF    (I)
  600 TWP   (I)=TWT   (I)
C
      DO 700 I=1,25
  700 XO (I)=XN (I)
C
      CALL OUTPUT
C
      TAU =TAUS
C
      RETURN
C
 1000 IF(ICHKS.GT.5 )GO TO 1600
C
      XX=(DTPPS-DTPP)/(DTPPS-(T7-T9C))
C
      IF(ICHEM.GT.0)XX=(STORL-XO(8))/(XN(8)-XO(8))
C
      IF(XX.GT.0.995.AND.
     X   XX.LT.1.005)GO TO 1600
C
      DTAU=DTAU*XX
C
      TAU=TAUS+DTAU
C
      ICHK =1
      ICHKS=ICHKS+1
C
      GO TO 350
C
 1600 ICHKS=-2
C
      IF(IWEEK .EQ.1.AND.
```

```
     X  (IPWEEK.EQ.0.OR.
     X   IPWEEK.EQ.2))GO TO 500
C
      ICHKS=-1
C
      GO TO 50
C
 1610 DTAU=DTAUI-DTAU
C
      ISTL =1
      ICHK =0
      ICHKS=-2
C
      RETURN 1
C
      END
```

```
      SUBROUTINE WEEKAN(*)
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (IWEEK      ,C(1610)),(IPWEEK     ,C(1611))
      EQUIVALENCE (ESO        ,C(  34))
      EQUIVALENCE (NDAY       ,C(1202))
      EQUIVALENCE (EDI        ,C( 992)),(STORL      ,C( 960))
      EQUIVALENCE (DS8MX      ,C(1224)),(ED         ,C(  16))
      EQUIVALENCE (DS8MN      ,C(1612))
      EQUIVALENCE (ISTL       ,C( 996))
      EQUIVALENCE (ESS        ,C( 993))
      EQUIVALENCE (STLRSL     ,C(1613))
      EQUIVALENCE (PSO        ,C(1620))
C
      EQUIVALENCE (XN    (1)  ,C(1225)),(XO    (1)  ,C(1250))
C
      DIMENSION XN    (25)
      DIMENSION XO    (25)
C
      IF(IWEEK.EQ.0)RETURN
C
      GO TO (100,200,300,400),IPWEEK
C
      EST=AMIN1(2.0*XO(8),STORL)
C
      STORLS=STORL
      STORL =1000000.0
C
      ED   =EDI
C
      IPWEEK=1
C
      ESOS=ESO
C
      ESO=EST
C
      ISTL=0
C
      PISFAC=XO(16)/DS8MX
```

```
C
C
      ESWE=2.0*XO(8)
C
      CALL DAYANL(&50)
C
   50 RETURN 1
C
  100 ET=ESS
C
      STORL=STORLS
C
      IF(EST.EQ.STORL)ISTL=1
C
      IPWEEK=2
C
      EMAXNL=DS8MX
C
      RETURN 1
C
  200 EM=ESS
C
      ESO   =0.2*(EST-(ET-EM))+(ET-EM)
C
      ESOM=ESO
C
      IPWEEK=3
C
      STORLS=STORL
      STORL  =ESO+(STORLS-EST)
C
      STLRSS=STLRSL
      STLRSL=0.2*STLRSL
C
      RETURN 1
C
  300 STORL=1000000.0
C
      ESO=0.2*(EST-(ET-EM))
C
```

```
      ESOT=ESO
C
      IPWEEK=4
C
      PSO=ESO*PISFAC
C
C
      RETURN 1
C
  400 ESO=ESOS
      STORL=STORLS
      PSO=0.0
      STLRSL=STLRSS
C
      WRITE(6,1000)
      WRITE(6,1010)ESWE
      WRITE(6,1020)EMAXNL
      WRITE(6,1030)ESOM
      WRITE(6,1040)ESOT
C
      RETURN
C
 1000 FORMAT('0         WEEKLY CYCLE ENERGY ACCUMULATION')
 1010 FORMAT('OMAXIMUM WEEKEND STORED ENERGY (NO DEMAND)        ',F10.2)
 1020 FORMAT(' MAXIMUM WEEKDAY STORED ENERGY (NO STORAGE LIMIT) ',F10.2)
 1030 FORMAT(' MONDAY INITIAL ENERGY BANK                       ',F10.2)
 1040 FORMAT(' TUESDAY INITIAL ENERGY BANK                      ',F10.2)
C
      END
```

```
      SUBROUTINE ZRATE
C
      COMMON/SOLAR/C(2000)
C
      EQUIVALENCE (EDT        ,C(  17)),(PIS       ,C(  11))
      EQUIVALENCE (POS        ,C(  12))
      EQUIVALENCE (NODES      ,C( 446))
C
      EQUIVALENCE (TWP   (1)  ,C(  45)),(TWT   (1) ,C( 145))
      EQUIVALENCE (XMELT (1)  ,C( 452)),(TF    (1) ,C( 854))
      EQUIVALENCE (TFP   (1)  ,C(1101))
C
      DIMENSION TWP   (100)
      DIMENSION TWT   (100)
      DIMENSION XMELT (100)
      DIMENSION TF    (100)
      DIMENSION TFP   (100)
C
      EQUIVALENCE (DMWT  (1)  ,C(1001)),(P     (1) ,C(1041))
      EQUIVALENCE (T     (1)  ,C(1061)),(DP    (1) ,C(1081))
C
      DIMENSION DMWT  (20)
      DIMENSION P     (20)
      DIMENSION T     (20)
      DIMENSION DP    (20)
C
C**** THIS ROUTINE SETS DERIVATIVES FOR ZERO RECIEVER OUTPUT
C**** AND STORAGE FULLY DISCHARGED
C
      DO 100 I=1,15
  100 DMWT(I)=0.0
C
      DO 200 I=1,NODES
      XMELT (I)=0.0
      TF    (I)=TFP(I)
  200 TWT   (I)=TWP(I)
C
      T(7)=0.0
      T(8)=0.0
      T(9)=0.0
```

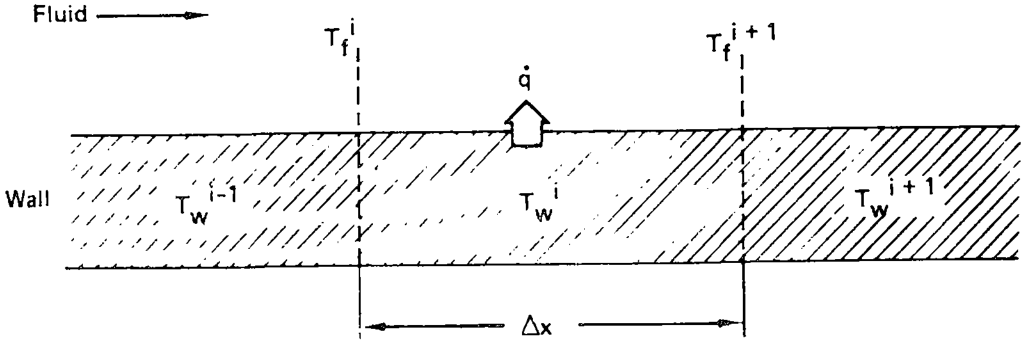
APPENDIX I

TRANSIENT THERMAL ANALYSIS

The transient thermal model for the sensible heat and phase change storage devices is based on a finite difference solution to the one-dimensional energy equations. The derivation of these equations in conjunction with the simplifying assumptions is presented in this appendix.

For the purpose of this math model, the thermal problem is separated into two one-dimensional problems - axial or along the direction of the fluid flow and lateral or perpendicular to the flow of the fluid. The tube in bath construction chosen for the phase change device adapts particularly well to this approach. Specifically, the lateral heat flow from the helium to the media can be modeled by a single node reducing the total problem to a one-dimensional axial analysis. The length of the bath is subdivided into many small increments (nodes) and the analysis proceeds as follows:

Consider the fluid flow past wall node i as shown below.



Extending the nodal boundaries into the fluid, the energy balance within those boundaries in time increment $\Delta\tau$ is:

$$(\dot{m}_f \, Cp_f \, T_f^{i+1} - \dot{m}_f \, Cp_f \, T^i) \, \Delta\tau = -\Delta m_f \, Cp_f \, \Delta\overline{T}_f + \dot{q} \, \Delta\tau$$

where: $\Delta\bar{T}_f$ = change in average fluid temperature nodal boundary over time interval $\Delta\tau$

$\dot{m}_f$ = fluid flow rate

Cp_f = fluid specific heat

Δm_f = fluid mass within nodal boundaries

$\dot{q}$ = heat flow rate into fluid

Dividing by $\Delta X \Delta\tau$ gives

$$\dot{m}_f \, Cp_f \left(\frac{T_f^{i+1} - T_f^{i}}{\Delta X} \right) = - Cp_f \frac{\Delta m_f}{\Delta X} \frac{\Delta T_f^{i}}{\Delta\tau} + \frac{\dot{q}}{\Delta X}$$

but

$$\frac{\Delta\bar{T}_f}{\Delta\tau} = \frac{\partial T_f}{\partial\tau}$$

$$\frac{\Delta m_f}{\Delta X} = \frac{\dot{m}_f}{\nu_f}$$

and

$$\frac{T_f^{i+1} - T_f^{i}}{\Delta X} = \frac{\partial T_f}{\partial X}$$

where: ν_f = fluid velocity

The lumped lateral heat flow is

$$\dot{q} = UA\,(T_W - T_f)$$

where: U = unit thermal conductance

A = heat transfer area

The final energy equation for the fluid is then

$$\frac{1}{\nu_f} \frac{\partial T_f}{\partial\tau} + \frac{\partial T_f}{\partial X} = \frac{UA}{\dot{m}_f Cp_f} \frac{(T_W - T_f)}{\Delta X} \tag{I-1}$$

The one-dimensional energy equation for the wall is written from the basic heat transfer equations with the lumped lateral heat flow out of the wall.

$$-\alpha \frac{\partial^2 T_W}{\partial X^2} + \frac{\partial T_W}{\partial \tau} = -\frac{UA}{M_S\ Cp_S} (T_W - T_f) \tag{I-2}$$

where:

α = thermal diffusivity of the wall material
M_S = wall mass
Cp_S = wall specific heat

By expanding (I-1) and (I-2) in difference form, the order of magnitude of each term and stability criteria for the difference solution can be established. In this way it can be shown that

$$\frac{1}{\nu_f} \frac{\partial T_f}{\partial \tau} << \frac{\partial T_f}{\partial X} \qquad \alpha \frac{\partial^2 T_W}{\partial X^2} << \frac{\partial T_W}{\partial \tau}$$

and the integration must be carried out such that

$$\frac{UA}{\dot{m}_f\ Cp_f} << 1 \qquad \frac{UA}{M_S\ Cp_S} \Delta\tau << 1$$

With these observations, equations (I-1) and (I-2) become:

$$\frac{\partial T_f}{\partial X} = \frac{UA}{\dot{m}_f Cp_f\ \Delta X} (T_W - T_f) \tag{I-3}$$

$$\frac{\partial T_W}{\partial \tau} = -\frac{UA}{M_S\ Cp_S} (T_W - T_f) \tag{I-3a}$$

The difference solution of these two equations is developed as follows.

The fluid temperature along node i is given by integrating equation (I-3)

$$T_f - T_f^i = (T_W^i - T_f^i) \left(1 - e^{-\frac{UA}{\dot{m}_f Cp_f}\left(\frac{X}{\Delta X}\right)} \right) \tag{I-4}$$

and

$$T_f^{i+1} = T_f^i + (T_W^i - T_f^i)\frac{\mathcal{U}}{\dot{m}_f\, Cp_f} \tag{I-5}$$

where $\mathcal{U}$ is an effective UA product given by

$$\mathcal{U} = \dot{m}_f\, Cp_f\,(1 - e^{-\frac{UA}{\dot{m}_f\, Cp_f}}) \tag{I-6}$$

The wall temperature can be found by integrating equation (I-2) for node i

$$\frac{d\,T_W^i}{d\,\tau} = -\frac{UA}{M_S\, Cp_S}\,(T_W^i - \bar{T}_f) \tag{I-7}$$

The fluid temperature in this equation is the average value over node i

$$\bar{T}_f = \frac{1}{\Delta X}\int_0^{\Delta X} T_f\, dx \tag{I-8}$$

using T_f from equation (I-4) and integrating, yields

$$\bar{T}_f = T_W^i - (T_W^i - T_f^i)\left(\frac{\dot{m}_f\, Cp_f}{UA}\right)(1 - e^{-\frac{UA}{\dot{m}_f\, Cp_f}})$$

with the definition of $\mathcal{U}$ given by equation (I-6),

$$\bar{T}_f = T_W^i - \frac{\mathcal{U}}{UA}\,(T_W^i - T_f^i) \tag{I-9}$$

Combining equations (I-9) and (I-7) gives

$$\frac{d\,T_W^i}{d\,\tau} = \frac{\mathcal{U}}{M_S\, Cp_S}\,(T_W^i - T_f^i) \tag{I-10}$$

Assuming T_f^i = constant over time increment $\Delta\tau$, equation **(I-10)** can be integrated to give

$$T_W^i - T_{W_o}^i = -(T_{W_o}^i - T_f^i)(1 - e^{-\frac{\mathcal{U}\Delta\tau}{M_S\, Cp_S}}) \tag{I-11}$$

where T_W^i = wall temperature at new time

$T_{W_o}^i$ = wall temperature at old time

The heat transfer from the wall over time period $\Delta\tau$ for a fixed fluid temperature T_f^i is:

$$-q_W^i = M_S \, Cp_S \, (T_{W_o}^i - T_f^i) \, (1 - e^{-\frac{U\Delta\tau \; U}{M_S \, Cp_S}}) \qquad \text{(I-12)}$$

The heat transfer to the fluid over $\Delta\tau$ is given by

$$q_f^i = \dot{m}_f \, Cp_f \int_o^{\Delta\tau} (T_f^{i+1} - T_f^i) \, dt$$

or using equation (I-5)

$$q_f^i = U \int_o^{\Delta\tau} (T_W^i - T_f^i) \, dt \qquad \text{(I-13)}$$

For a fixed fluid temperature T_f^i, equation (I-13) can be integrated by substituting for T_W^i from equation (I-11),

$$q_f^i = U \int_o^{\Delta\tau} (T_{W_o}^i - T_f^i) \, e^{-\frac{U\tau}{M_S \, Cp_S}} \, dt$$

$$q_f^i = M_S \, Cp_S \, (T_{W_o}^i - T_f^i) \, (1 - e^{-\frac{U\Delta\tau}{M_S \, Cp_S}}) \qquad \text{(I-14)}$$

Thus, for a given node, the heat transfer to the fluid matches that from the wall as it should. However, in a finite difference solution a discrepancy between these heat transfer terms may arise.

If the outlet fluid temperature T_f^{i+1} is based on the old wall temperature $T_{W_o}{}^i$ the heat transfer to the fluid is given in finite difference form as follows:

$$q_f = \dot{m}_f \, Cp_f \, (T_f^{i+1} - T_f^i) \, \Delta\tau = U \, (T_W^i - T_f^i) \, \Delta\tau = U \, (T_{W_o}^i - T_f^i) \, \Delta\tau \qquad \text{(I-15)}$$

This results in an error between q_f and q_W

$$-\frac{q_W^i}{q_f} = \frac{M_S \, Cp_S}{U\Delta\tau}(1 - e^{-\frac{U\Delta\tau}{M_S \, Cp_S}}) = 1 - \frac{1}{2} \, \frac{U\Delta\tau}{M_S \, Cp_S} + \frac{1}{6} \, (\frac{U\Delta\tau}{M_S \, Cp_S})^2 - \ldots \qquad \text{(I-16)}$$

This error has been substantially reduced by basing the outlet fluid temperature T_f^{i+1} on the time average wall temperature $\bar{T}_W^i$

$$\bar{T}_W^i = \frac{1}{2}\left(T_W^i + T_{W_o}^i\right)$$

∴ using equation (I-12)

$$\bar{T}_W^i = \frac{1}{2}\left[2\,T_{W_o}^i - \left(T_{W_o}^i - T_f^i\right)\left(1 - e^{-\frac{U\Delta\tau}{M_S\,Cp_S}}\right)\right] \qquad \text{(I-17)}$$

The average outlet fluid temperature is thus (using equation I-5)

$$\bar{T}_f^{i+1} = T_f^i + \frac{U}{2\,\dot{m}_f\,Cp_f}\left(T_{W_o}^i - T_f^i\right)\left(1 + e^{-\frac{U\Delta\tau}{M_S\,Cp_S}}\right) \qquad \text{(I-18)}$$

The heat transfer to the fluid is then

$$q_f^i = \frac{U\Delta\tau}{2}\left(1 + e^{-\frac{U\Delta\tau}{M_S\,Cp_S}}\right)\left(T_{W_o}^i - T_f^i\right) \qquad \text{(I-19)}$$

The error between wall and fluid heating is now given by

$$-\frac{q_W^i}{q_f} = \frac{2\,M_S\,Cp_S}{U\Delta\tau}\;\frac{\left(1 - e^{-\frac{U\Delta\tau}{M_S\,Cp_S}}\right)}{\left(1 - e^{-\frac{U\Delta\tau}{M_S\,Cp_S}}\right)} = \frac{\tanh\left(\frac{U\Delta\tau}{2\,M_S\,Cp_S}\right)}{\frac{(U\,\Delta\tau)}{2\,M_S\,Cp_S}} \qquad \text{(I-20)}$$

$$-\frac{q_W^i}{q_f^i} = 1 - \frac{1}{12}\left(\frac{U\Delta\tau}{M_S\,Cp_S}\right)^2 + 0\left(\frac{U\Delta\tau}{M_S\,Cp_S}\right)^4 \qquad \text{(I-21)}$$

For $\frac{U\,\Delta\tau}{M_S Cp_S} = 0.1$, the error between q_W^i and q_f^i is $\frac{1}{12}\left(\frac{U\Delta\tau}{M_S\,Cp_S}\right) \approx 10^{-3}$ which is very adequate

In summary then, the final difference equations used in the TES performance model are as follows. Given T_f^i and $T_{W_o}^i$ as initial conditions for all i and T_f^i as a boundary condition:

$$T_W^i = T_{W_o}^i - (T_{W_o}^i - T_f^i)\,(1 - e^{-\frac{U\Delta\tau}{M_S\, Cp_S}}) \qquad \text{(I-22)}$$

and

$$T_f^{i+1} = T_f^i + (\frac{T_W^i}{2} + \frac{T_{W_o}^i}{2} - T_f^i)\,\frac{U}{\dot{m}_f Cp_f} \qquad \text{(I-23)}$$

When a node is undergoing a phase change, equation (I-22) does not apply, the wall temperature is held constant, and an amount of heat equal to the heat of fusion of the node must be absorbed before equation (I-22) once again applies.

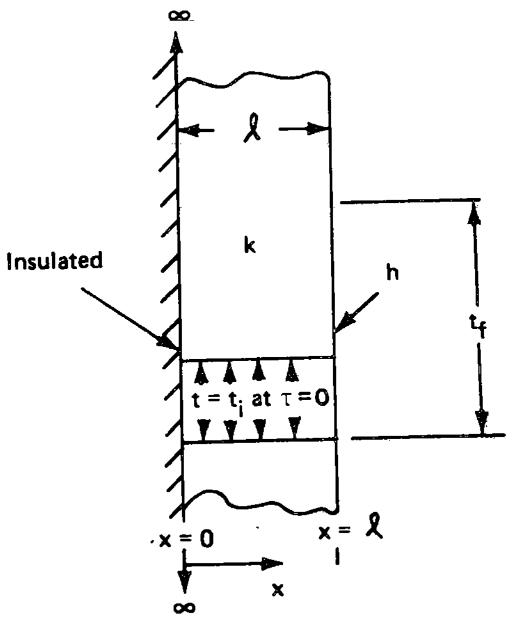
APPENDIX II

UNIT THERMAL CONDUCTANCE ANALYSIS

The thermal analysis for the sensible heat and phase change TES systems has been set up as two one-dimensional problems. The thermal performance analysis along the direction of the fluid flow has been treated in depth in Appendix I. The treatment of the lateral heat flow problem is presented in this appendix. For the purpose of the initial presentation, a planar heat flow model has been adopted. This approach greatly simplifies the presentation and leads to a conclusion that applies equally well to the radial heat flow problem.

At a given axial position in the storage device, the heat flow from the working fluid into the storage media is substantially a one-dimensional problem. The working fluid temperature varies with time at a given axial location and the media simply responds to that temperature change. Symmetrical adiabatic surfaces develop between the uniformly heated tubes which further reduces the problem to the classical case of the semi-infinite plate uniformly heated on one side and insulated on the other. Any basic heat transfer text treats this transient problem. There is an exact solution to this problem, but it is complex in the general case. Over a wide range of parameters of practical interest in our problem, these solutions can be avoided by the adoption of a single node approximation. The accuracy of this approach is demonstrated in the following paragraphs by comparison to the step change response characteristic of the partial differential equation.

Under the above conditions, the one-dimensional temperature distribution within the media shown below must satisfy the following partial differential equations.



$$\frac{\partial^2 t}{\partial x^2} = 1/\alpha \frac{\partial t}{\partial \tau}$$

where:

α = storage media thermal diffusivity

In addition, the following initial and boundary conditions apply:

$$t - t_f = t_i - t_f \text{ at } \tau = 0 \qquad \text{(II-1)}$$

$$\frac{\partial\,(t-t_f)}{\partial x} = 0 \text{ at } x = 0 \text{ for all } \tau \qquad \text{(II-2)}$$

$$\frac{-k\,\partial^2(t-t_f)}{\partial x^2} = h\,(t-t_f) \text{ at } x = \ell \qquad \text{(II-3)}$$

The solution to the partial differential equation with these boundary and initial conditions is obtained by the separation of variables technique and is as follows:

$$\frac{t-t_f}{t_i-t_f} = 2\sum_{n=1}^{\infty} \left(\frac{\sin \lambda n\,\ell}{\lambda n\,\ell + \sin \lambda n\,\ell \cos \lambda n\,\ell} \right) e^{-\lambda_n^2 \alpha\tau} \cos \lambda_n x \qquad \text{(II-4)}$$

The λ_n satisfy the transcendental equation

$$\cot \lambda n\,\ell = \frac{k}{n}\lambda_n \qquad \text{(II-5)}$$

and are referred to as the eigenvalues.

The condition of concern in our problem is the heat flux rate at the surface which is given by

$$q = -k\left(\frac{\partial(t-t_f)}{\partial x}\right)_{x=\ell} \tag{II-6}$$

Then by defining the unit thermal conductance as,

$$U = \frac{q}{(t_o - t_f)} \tag{II-7}$$

U can be written in terms similar to equation (I-4) as follows:

$$U = \frac{k}{\ell}\,\frac{\sum\limits_{n=1}^{\infty}\left(\dfrac{N_n \sin^2 N_n}{N_n + \sin N_n \cos N_n}\right) e^{-N_n^2 N_{Fo}}}{\sum\limits_{n=1}^{\infty}\left(\dfrac{\sin N_n}{N_n + \sin N_n \cos N_n}\right) e^{-N_n^2 N_{Fo}}} \tag{II-8}$$

and the eigenvalues (N_n) now satisfy the expression,

$$N_n \tan N_n - N_{Bi} = 0 \tag{II-9}$$

The non-dimensional quantities that have been introduced in equations (II-8) and (II-9) are the Fourier number (N_{Fo}) and the Biot number (N_{Bi}) which are defined as follows:

$$N_{Fo} = \frac{\alpha\tau}{\ell^2}$$

$$N_{Bi} = \frac{h\ell}{k}$$

The Fourier number is a measure of the degree heating or cooling effects have penetrated the plate and the Biot number is indicative of the resistance to heat transfer at the surface of the plate compared to its internal resistance.

For our particular problem, $\frac{N_{Fo}}{\tau}$ runs about 3.0 hr^{-1} and N_{Bi} runs about 4-5. The data presented below include variations in N_{Bi} from 1.0 to 10.0 and variations in N_{Fo} from 0.3 to 5.0. Since the time response in our axial heat transfer problem is about 0.5 hour, considerations of longer times here are of little significance.

The solution of the unit thermal conductance in equation (II-8) is a complex series solution. Fortunately, the series converges rather rapdily and satisfactory accuracy is obtained by considering only five terms. A chart of the eigenvalues for the first five terms is shown as a function of the Biot number in Figure AII-1. The single node approximation to the unit thermal conductance is shown for comparison with the exact data. The accuracy of the single node approximation is obviously very good, particularly for low Biot numbers.

The final conclusion applies equally well to the lateral heat flow problem in cylindrical coordinates. Specifically, the lateral heat flow problem can be adequately represented by a single thermal node approximation if that node is taken as the centroid of the thermal mass of the storage media enclosed by the adiabatic surface of symmetry between the heat exchanger tubes. The derivation and presentation of the resultant unit thermal conductance in cylindrical coordinates are given in Volume I, section 6.1 of this report.

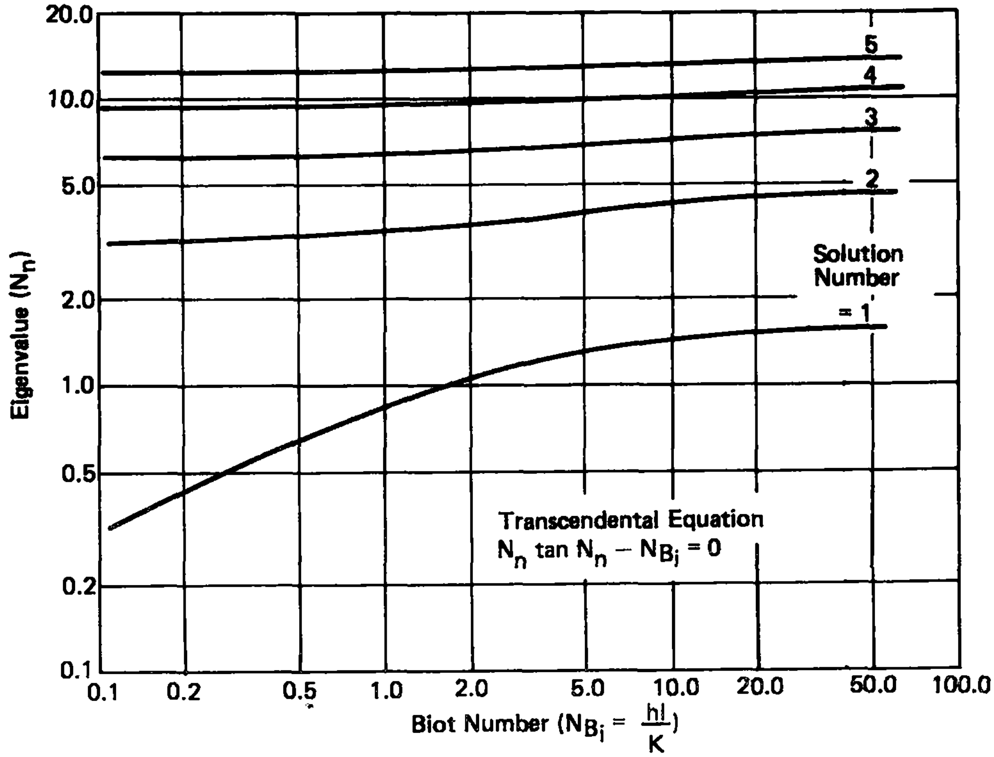


Figure II-1. Exact Unit Thermal Conductance Eigenvalues

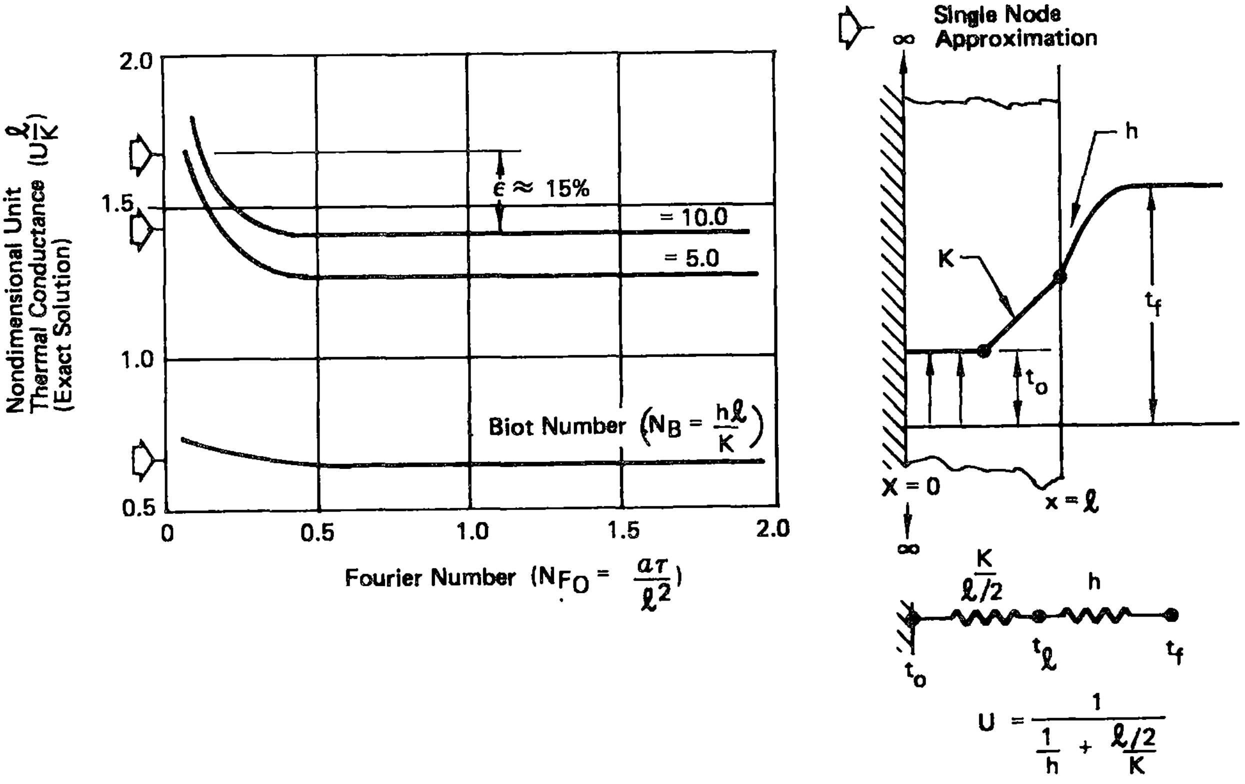


Figure II-2. Single Node Unit Thermal Conductance Accuracy