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User's Manual for Computer Code SOLTES-1 (Simulator of Large Thermal Energy Systems)

Merton E. Fewell, Norman R. Grandjean, James C. Dunn, Michael W. Edenburn

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department
of Energy under Contract AT(29—1)-789

Printed September 1978

Sandia Laboratories

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Printed in the United States of America

Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Printed Copy $10.75; Microfiche $3.00

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Distribution
Category UC-32

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(Simulator of Large Thermal Energy Systems)

Volume I
Edition 1

Merton E. Fewell
Fluid Mechanics and Heat Transfer Division II, 5512

Norman R. Grandjean
Dispersed Power Applications Division 4722

James C. Dunn
Fluid Mechanics and Heat Transfer Division II, 5512

Michael W. Edenburn
Systems Analysis Division 4716

Sandia Laboratories
Albuquerque, NM 87185

ABSTRACT

SOLTES simulates the steady-state response of thermal energy systems to time-varying data such as weather and loads. Thermal energy system models of both simple and complex systems can easily be modularly constructed from a library of routines. These routines mathematically model solar collectors, pumps, switches, thermal energy storage, thermal boilers, auxiliary boilers, heat exchangers, extraction turbines, extraction turbine/generators, condensers, regenerative heaters, air conditioners, heating and cooling of buildings, process vapor, etc; SOLTES also allows user-supplied routines. The analyst need only specify fluid names to obtain readout of property data for heat-transfer fluids and constants that characterize power-cycle working fluids from a fluid property data bank. A load management capability allows SOLTES to simulate total energy systems that simultaneously follow heat and power loads and demands. Generalized energy accounting is available and values for system performance parameters may be automatically determined by SOLTES. Because of its modularity and flexibility, SOLTES can be used to simulate a wide variety of thermal energy systems such as solar power/total energy, fossil-fired power plants/total energy, nuclear-fired power plants/total energy, solar energy heating and cooling, geothermal energy, and solar hot-water.

ACKNOWLEDGMENTS

The authors wish to acknowledge J.F. Banas of Div. 4722 for his continuing support of this project. We would also like to acknowledge R.H. Nilson of Div. 5512 for his contributions through technical discussions and comments.

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CUT OR TEAR ALONG DASHED LINE

MAILBACK SHEET

I would like to receive any new information regarding SOLTES, and all change pages for this document (SAND78-1315).

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USER'S MANUAL FOR COMPUTER CODE SOLTES-1
(Simulator of Large Thermal Energy Systems)

1. Introduction

1.1 Background

The 1973 energy crisis reminded us that fossil-fuel reserves are finite, and that we must therefore use our energy resources more prudently. Identifying potential alternate energy sources such as solar, wind, nuclear fusion and fission, and geothermal is easy. Developing energy-efficient systems to use these alternate sources and to conserve fossil fuel, however, is difficult.

Since we can no longer waste the energy rejected from conventional power plants, the cogeneration of power and process heat from these plants should be matched with both power and process heat loads. We must determine the design and feasibility of small solar systems that provide hot water, heating, and cooling for residences and small businesses. Also, we need to investigate larger solar total-energy systems that can provide power and process heat for industrial and agricultural applications. Design options for these solar systems (such as collector type, thermal storage, load-following techniques, heat-transfer fluids, power-cycle working fluids, power cycles, etc) are seemingly endless. Moreover, point design studies cannot adequately predict the effects of time-varying weather and loads. Therefore, the task of choosing proper combinations of these options for each application and location would be overwhelming without computer simulation.

Computer codes for simulating solar energy systems have been written. TRNSYS,[1] a computer program that simulates solar hot water and heating-and-cooling systems, and SOLSYS,[2] a computer code for simulating solar energy systems that may include simple Rankine-power cycles, have been widely used. Since many studies require simulation of complex power cycles as well as process heat, heating, and cooling, a more general modular computer simulation code is needed. Such a code, SOLTES (Simulator of Large Thermal Energy Systems), has been developed at Sandia Laboratories, Albuquerque, NM and is currently available on a CDC6600 system. Some of the SOLSYS logic and mathematical models are used in SOLTES. The greater capabilities of SOLTES, including the addition of load management, energy accounting, and a preprocessor, make SOLTES much more flexible and usable.

Because of its modularity and flexibility, SOLTES can be used to simulate a wide variety of thermal-energy systems such as

Solar Power/Total Energy
Fossil-Fired Power Plants/Total Energy
Nuclear-Fired Power Plants/Total Energy
Solar Energy Heating and Cooling
Geothermal Energy
Solar Hot Water

1.2 Philosophy

This section acquaints users with SOLTES philosophy. This material is not essential in learning to execute the code; however, it provides information that will be useful in model construction and in interpreting SOLTES results. Subsequent sections and appendices of this manual include instructions and examples.

1.2.1 Quasi-Transient Method -- SOLTES simulates the time-varying performance of thermal-energy systems by a quasi-transient method, which assumes that the transient performance of the system can be predicted by steady-state calculations at successive time intervals. Simulation or problem time is specified by user input. The steady-state response of the system to the values of time-varying weather and load data at the start of the simulation period is calculated. Time is then advanced by a user-supplied, constant time interval; new values for the weather and load data are obtained; and a new steady-state response is calculated.

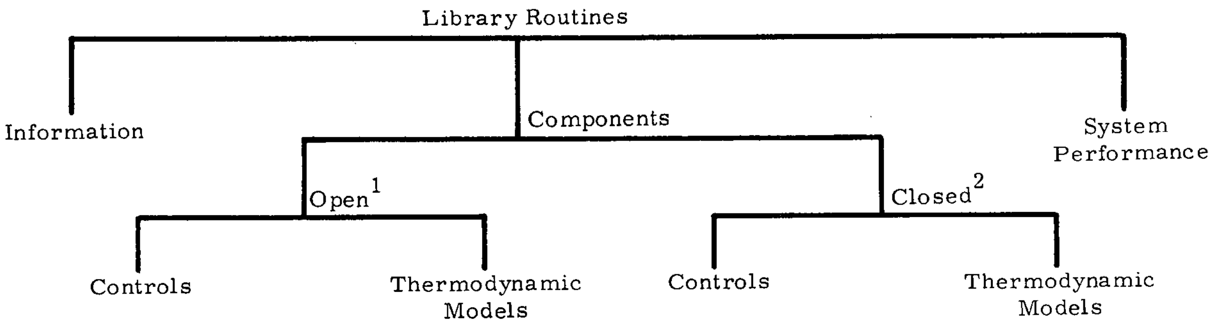
This procedure is repeated until time exceeds the end of the simulation period, whereupon a steady-state solution is not sought and the time-marching algorithm is ended. The accuracy of the quasi-transient method is improved by choosing a time interval small enough so that large variations in loads and weather data do not occur during the interval. Since many calculations are omitted at times during simulation when the energy system is operating at steady-state, the increase in computer time associated with small time steps is minimized.

1.2.2 Modularity and Routines Library -- Because of its flexibility, SOLTES can be used to model small thermal-energy systems such as residential hot-water systems or large thermal-energy systems that include complex power-generation cycles.* This flexibility is achieved by the selection of appropriate routines from a routine library. This library contains routines that mathematically model solar collectors, pumps, switches, thermal-energy storage, thermal boilers, auxiliary boilers, heat exchangers, extraction turbines, extraction turbine/generators, condensers, regenerative heaters, air-conditioners, heating and cooling of buildings, process vapor, etc. Thus the analyst can construct a system model that simulates his thermal-energy system. SOLTES also allows user-supplied routines.

---

*Simulation of generalized Rankine-type power cycles with load management is discussed in Appendix B.

Figure 1 shows the general categories of the routines used in system model construction.



[1] Working fluids flow across the boundaries of devices modeled by open components.

[2] Working fluids do not flow across the boundaries of devices modeled by closed components.

Figure 1. Routine Categories

Information routines supply time-varying load and weather data to the system model. System performance routines calculate system performance parameters such as system efficiency and also assist in energy accounting and summing.

Open thermodynamic models are mathematical models of components in thermal-energy systems across the boundaries of which system working fluids flow. Each component routine is a "black box" or control volume in which changes in the thermodynamic states and flow rates of fluids flowing through it are calculated. These models satisfy the first and second laws of thermodynamics, conserve mass, and may include fluid mechanics and heat-transfer effects. In addition to energy convected across its boundaries by fluids flowing across them, energy can cross the boundaries by radiation or conduction, or may be convected to or from the boundaries by the flow of an external fluid or by shaft work and/or electricity.

Open control routines allow the analyst to switch fluid flows from one branch to another and to control such variables as flow rates and temperatures. Unlike open thermodynamic models, these routines do not allow energy to cross their boundaries other than that convected across by fluids flowing through them and do not consider heat-transfer effects. Hence, the laws of thermodynamics are automatically satisfied; the control routines may only consider steady-state conservation of mass and fluid mechanics effects.

Closed thermodynamic models are mathematical models of components in thermal-energy systems across the boundaries of which system working fluids do not flow. These models satisfy the first and second laws of thermodynamics, conserve mass, and may include fluid mechanics and heat-transfer effects. Energy can cross the boundaries by radiation or conduction or may be convected to or from the boundaries by the flow of an external fluid or by shaft work and/or electricity.

Closed control routines send signals to other components in the thermal-energy system model.

A set of unique numbers is specified by the user to identify all the state points and components in a system model. Values for the pressure, temperature, quality and fluid-flow rate at each of these state points, and energy flow rates between components, are calculated and stored.

1.2.3 Steady-State Algorithm -- The steady-state algorithm is initiated by calling the information routines (which the analyst has included in his system model) to obtain values for the time-varying data at the time corresponding to the beginning of the time step. Then the component and system performance routines are called in the order in which they occur in the system model. New values of pressure, temperature, quality, and flow rate are calculated for each state point and stored. The call sequence to the routines is repeated; current and old values of temperature, pressure, fluid flow rate, and quality are compared.

This procedure is repeated until convergence. The user defines convergence by specifying values for steady-state convergence error criteria for fluid flow rate, temperature, pressure, and quality. The iteration is considered to have converged to steady state when the convergence criteria for fluid flow rate, temperature, pressure, and quality are satisfied. The convergence criterion for fluid flow rate, temperature, and pressure is the weaker of the user-supplied absolute and relative convergence criteria for the respective variables, while the convergence criterion for quality is the user-supplied value for the absolute error.

If convergence is not achieved in a user-specified number of iterations, a diagnostic "UNABLE TO CONVERGE EXIT WILL BE CALLED" is printed and a user-supplied number of additional iterations are made before the run is terminated. After each additional iteration, the thermodynamic state and the values for pressure, temperature, fluid flow rate, and quality at each state point in the model are printed. (The printout for the thermodynamic state and the values of pressure, temperature, fluid flow rate, and quality is henceforth referred to as TABLE 1 output.) During the last of these iterations, diagnostics denoting unreasonable conditions in each routine are printed.

Upon reaching steady state, the values of pressure, temperature, fluid flow rate, and quality at each state point are checked for negative values. If a negative value is discovered, the diagnostic "ERROR ERROR ERROR CONVERGENCE WAS REACHED BUT THERE ARE NEGATIVE VALUES. CHECK THE FOLLOWING TABLE 1 DUMP PROGRAM STOP" is printed, followed by TABLE 1 output. Another call sequence to the routines is then made to calculate values for other output variables, check for unreasonable steady-state conditions in each routine, and allow the system performance routines to do energy accounting and summing. If an unreasonable steady state is reached, the program is stopped. Otherwise, the steady-state algorithm for the next time is initiated.

1.2.4 Output -- SOLTES has generalized output capability. The user-controlled output consists of several sets of information. One of these, TABLE 1, has already been discussed. The remaining user-controlled output data sets are component/information-routine input and initial conditions, component/information-routine output, system performance, and postprocessor output.

1.2.5 Executive Routine -- The main SOLTES program is referred to as the "executive routine." The executive routine manages quasi-transient solutions; controls output; and executes the steady-state algorithm by making calls to information, component, and system performance routines. Component routines may be used several times in a system model; however, information and system performance routines may be used only once. The executive routine's ability to direct calls enables the user to simulate several systems consecutively during a single computer run.

The flexibility to simulate many different thermal-energy systems can be achieved by including calls to every routine in the library, but this results in excessive computer core storage. To minimize core requirements, the user can either modify the executive routine to include calls only to those routines required by his system model, or he can use the preprocessor PRESOL (see Appendix A).

1.2.6 Energy Accounting -- Proper energy accounting is essential to evaluate and compare energy systems performance. Energy accounting includes the ability to make calculations of system efficiency, segregate energy from its primary and auxiliary sources, and sum energy by category (see Subroutine ENGAC1 in Appendix C). Energy accounting in SOLTES distinguishes among the following definitions of energy transfer rates:

> An energy supply rate is the rate at which energy is transferred to the thermal-energy system model from an external energy source. SOLTES considers both primary and auxiliary sources.
>
> A load is the rate at which useful energy (excluding sources) crosses the boundaries of the thermal-energy system model. Useful energy is energy that benefits the system's environment; i.e. energy for cooling, heating, electrical power, etc. Energy exchanges between components in a system model are not loads. Loads or load information as a function of time may be read from a data file, or loads can be calculated by component routines in the thermal-energy model. SOLTES considers heating, cooling, hot-water, electrical power, mechanical power, and thermal loads. A characteristic temperature is associated with each thermal load. Cooling loads are the rate at which energy is added to the system, whereas all the other loads are energy rates leaving the system.

A demand is the rate at which energy (excluding that convected across component boundaries by fluids flowing through the components) is required for steady-state operation of a component that provides a benefit in the system or the system's environment. A demand can cross system boundaries. SOLTES considers heating, cooling, electrical power, and mechanical power demands. Cooling demands are positive in components calculating the demand and negative in those satisfying the demand. The other demands are positive in components demanding the energy and negative in those meeting those demands.

A parasitic is the rate at which energy must be transferred by electrical or mechanical work to a component. The component provides no benefit but is necessary for system operation. SOLTES distinguishes between electrical and mechanical parasitics. Parasitics are positive for components requiring energy and negative in those supplying the energy to satisfy the parasitic.

A heat loss is the rate at which energy is lost from a system component that is space-heated.

An advective loss is the rate at which energy is lost from the system by working fluids leaving the system. Energy added to the system by working fluids entering the system (an advective gain) is a negative advective loss.

A thermal loss is the rate (excluding heat and advective losses) at which energy is lost from the thermal-energy system.

A heat gain is the rate at which energy is gained (excluding energy gained from equipment, people, etc) by a component that is air-conditioned.

Heat is the rate (excluding those rates defined above) at which energy is transferred as heat into components in the system. This energy may be calculated by components in the system or read from a data file, and transferred across system boundaries or between components in the system.

Storage rate is the rate at which energy is stored within a component in the system. The rate is positive when energy is added to the component.

A particular component may have no energy transferred across its boundaries, or it may have energy transferred across its boundaries by various combinations of the above categories.

The following examples may clarify the relationships among these various energy-transfer rates.

Example 1

An analyst needs to simulate a solar total-energy system that is to provide electricity for lighting and cooling via a vapor-compression chiller for a new apartment complex. The electrical power required for lighting is known as a function of time, but cooling requirements are unknown. The system model includes the necessary routines for collectors, pumps, boilers, turbines, air conditioners, etc, for the system, including a routine for heating and cooling buildings. Since the electricity required for lighting is known, an information routine reads this information as an electrical load from data files. The routine for heating and cooling buildings calculates the energy-transfer rate required to cool the building, a heat gain, plus heat transferred from equipment in the building. This rate is passed to an air-conditioner component routine as a cooling demand on the air-conditioner. A vapor-compression air-conditioner component calculates the electrical or mechanical power required to meet the cooling demand. These electrical or mechanical requirements for cooling are electrical or mechanical demands that may be met by another component--a turbine, for instance--in the system model, or by electrical or mechanical energy transferred across the system boundaries. If the energy that must leave the condenser of the vapor-compression chiller is transferred to the ambient air outside the building, this energy transfer rate is heat transferred from the system model. Energy lost from the solar collectors is a thermal loss, and the power required to run each pump in the system is either an electrical or mechanical parasitic. On the other hand, if the vapor-compression condenser is cooled by a heat-transfer fluid flowing through it and this energy is ultimately stored in thermal storage, there is no heat transferred from the air-conditioner model. There is, however, a storage rate in the thermal-energy storage model.

Example 2

A system similar to that of Example 1 is to be designed for an existing building. Both the electricity required for lighting and the rate at which energy must be extracted from the building for cooling are known functions of time. In this case, the system model need not include the heating and cooling routine, and the energy extraction rate from the building is a cooling load on the air-conditioners. This cooling load is supplied to the air-conditioner component model by an information routine that reads from a data file.

Example 3

The existing vapor-compression chiller in the system in Example 2 had been monitored so that the electrical requirements for air-conditioning are known as a function of time. The system model need not include an air-conditioner model. Electrical requirements are supplied to the system model as electrical loads that are read by an information routine from a data file.

Example 4

The power required to run each collector pump and each boiler-feed pump in a solar irrigation system is either an electrical or mechanical parasitic; but since the power required to run the irrigation pump provides a useful function other than continuous system operation, this power is either an electrical or mechanical load, or an electrical or mechanical demand.

1.2.7 Fluid Property Data -- Component routines, which model components in Rankine-type power cycles, require only constants to characterize the working fluid. These constants and the properties of heat-transfer fluids, as functions of temperature, are stored and retrieved from a fluid property data file by fluid name. Thus only the fluid name is required as SOLTES input.

1.2.8 Unit System and Time -- Although almost half of SOLTES is written to allow the user to define the unit system, SOLTES currently uses only the International (SI) system of units.

Since SOLTES time is the local standard time at the energy system site, load and weather data must therefore be supplied to SOLTES in local standard time. Also, the first day of the year is assumed to be Sunday. The SOLTES clock is a 24-hour clock with hour zero denoting midnight.

2. SOLTES Input

Four categories of input are essential to make a SOLTES run. Depending on the system model and the options chosen, there may be two additional categories of input. The following list contains the categories and their associated file names.

Component/Information Routine Data (TAPE 1)
Executive Routine Control Data (TAPE 6)
Loop Definition Data (TAPE 8)
Fluid Property Data (TAPE 9)
Weather Data (TAPE 12) - optional
Load Data (TAPE 11) - optional

This section describes the general format associated with each category. A preprocessor PRESOL has been written to aid the user in constructing the first four categories of input (see Appendix A). To aid the user in the relationship between a system model and the required input to SOLTES, examples are furnished in Appendix D.

2.1 Component/Information Routine Data (TAPE 1)

This file contains the input required by individual information, component, and system performance routines. Actual data requirements and formats for each routine are contained in Appendix C. The general format of this file is a series of card-image records[*] followed by an end-of-file (EOF)[**], [***] record for each routine in the system model. If more than one system model is to be run, a double EOF separates the system models.

2.2 Executive Routine Control Data (TAPE 6)

2.2.1 Discussion -- This file contains the executive routine input data that define the simulation period, time increment, desired output, steady-state convergence, and problem identification.

SOLTES uses the following names as identifiers for executive routine control data:

ID, TIME, PRINT, PRNTCON, WRITE, CONVER, and RUN

ID (Optional) -- The ID card is used to supply the simulation with a descriptive name that appears on the printed output. If this card is not used, no descriptive name will be printed. After the ID card, up to four additional cards are permitted.

TIME -- The TIME card specifies the simulation period and the constant time increment.

---

[*] "Cards" and "records" are words used interchangeably in this report. Also, the words "characters" and "columns" are interchangeable.

[**] An EOF record for batch is a card with a 7/8/9 punch in Column 1.

[***] An EOF record for NOS is a record containing only a keyboard RETURN character.

PRINT -- PRINT cards specify the tables that are to be printed, the time interval for printing, and the frequency within the interval in which the tables are to be printed. If the interval is omitted, printing occurs during the entire simulation period. If the frequency is omitted, printing occurs at each time step within the interval. Four tables may be printed: TABLES 1, 2, 3, and DUMP. TABLE 1 contains the values for temperature, pressure, fluid flow rate, quality (if applicable), and thermodynamic state at each state point. TABLE 2 contains values for selected parameters defined by each component and information subroutine. TABLE 3 contains system performance data. DUMP is TABLE 1 output that is printed after every iteration within a user-selected time interval.

PRINTCON (Optional) -- A summary of input data will be printed unless it is suppressed using the PRINTCON card.

WRITE -- The WRITE card enables the user to write values for selected parameters which are defined by each routine and written to TAPE 40 for post-plotting or printing.

CONVER (Optional) -- The CONVER card contains convergence criteria data, the number of maximum iterations permitted per time step, and the number of iterations with TABLE 1 output if convergence fails. The use of this card allows changes to one or more of the program default value parameters.

RUN -- The RUN card marks the end of the executive routine control data and directs the executive program to execute the system simulation.

NOTE: If two or more system models are to be run, the user does not need to repeat all of the executive routine control information. SOLTES uses previously defined data unless changed by new information. The RUN card is the only exception--there must be one RUN card for every system model.

2.2.2 Format -- The following formats define each of the executive routine control cards.

ID -- The ID card gives the simulation a name and may contain up to five data cards. The word "LAST" must appear in Columns 71 to 74 of the last data card.

Parameter	Format	Columns	Description
"ID"	A2	1-2	Card identifier
Name	A380	11 of first card to 70 of last card	Any desired name or description
"LAST"	A4	71-74 of last card	

TIME -- The TIME card specifies start time, end time, and time step (in local standard time).

Parameter	Format	Columns	Description
"TIME"	A4	1-4	Card identifier
NYEARI	I5	11-15	Initial year
NDAYI	I5	16-20	Initial day
NHRI	I5	21-25	Initial hour
NSECI	I5	26-30	Initial second
NYEARF	I5	31-35	Final year
NDAYF	I5	36-40	Final day
NHRF	I5	41-45	Final hour
NSECF	I5	46-50	Final second
ITIME	I10	51-60	Time step size (s)
"LAST"	A4	71-74	

PRINT -- If printouts of DUMP, TABLE 1, TABLE 2, or TABLE 3 are desired, print cards for these tables must be included in the data deck.

Parameter	Format	Columns	Description
"PRINT"	A5	1-5	Card identification
NAME	A10	11-20	Table name, DUMP, TABLE1, TABLE2, or TABLE3 (left-justified)
NYI	I5	21-25	Starting year
NDI	I5	26-30	Starting day
NHI	I5	31-35	Starting hour
NSI	I5	36-40	Starting second
NYF	I5	41-45	Final year
NDF	I5	46-50	Final day
NHF	I5	51-55	Final hour
NSF	I5	56-60	Final second
NT	I5	61-65	Print every NT time steps (not used for DUMP)
IT	I5	66-70	0⇒ print 1⇒ don't print
"LAST"	A4	71-74	

PRNTCON -- The PRNTCON card is used to suppress printing tables containing input parameter summaries.

Parameter	Format	Columns	Description
"PRNTCON"	A7	1-7	Card identification
IFLAG	I10	11-20	-1 to suppress input printout
"LAST"	A4	71-74	

WRITE -- The WRITE card instructs the program to store values for parameters for future printing and/or plotting by user-written postprocessors. The file or tape written on is TAPE 40.

Parameter	Format	Columns	Description
"WRITE"	A4	1-4	Card identifier
NAME	A10	11-20	Descriptive name attached to plot variables (left-justified)
NYI	I5	21-25	Initial year
NDI	I5	26-30	Initial day
NHI	I5	31-35	Initial hour
NSI	I5	36-40	Initial second
NYF	I5	41-45	Final year
NDF	I5	46-50	Final day
NHF	I5	51-55	Final hour
NSF	I5	56-60	Final second
NT	I5	61-65	Plot variables recorded every NT time steps
IP	I5	66-70	1⇒ suppresses plotting 0⇒ allows plotting -1⇒ special option for storing data on a tape contains information from previous runs
"LAST"	A4	71-74	

TAPE 40 Format as Generated by SOLTES

Card 1

ID , NV

Format (A10 , I10)

Card 2

$IDVAR_i$ $i = 1, NV$

Format (8A10)

Card 3

$Data_{ij}$ $i = 1, NV$ $j = 1$

Format (8E10.4)

Card 4

$Data_{ij}$ $i = 1, NV$ $j = 2$

.
.
.
.

These data records are repeated throughout the time interval as specified by the WRITE card.

Following the last data record, SOLTES writes an EOF.

When the SOLTES run is completed, an additional EOF is written.

NOTES:

1. The ID on Card 1 is the user-supplied ID found on the WRITE card. (It is suggested that unique ID's are given for each system model in a SOLTES run.)
2. NV is automatically calculated for each system model.
3. $IDVAR_i$ are the variable names.
4. $j = 1$ corresponds to the initial time as specified on the WRITE card. Each data record thereafter corresponds to the increment as specified by the parameter NT on the WRITE card.

CONVER -- This card can be omitted entirely, resulting in all parameters taking default values as specified.

Parameter	Format	Columns	Descriptions
"CONVER"	A6	1-6	Card identifier
EAT	F5.0	11-15	Absolute error - temperature Blank => default value of 0.1 K
ERT	F5.0	16-20	Relative error - temperature Blank => default value of 0.01%
EAF	F5.0	21-25	Absolute error - fluid flow rate Blank => default value of 0.05 kg/s
ERF	F5.0	26-30	Relative error - fluid flow rate Blank => default value of 0.01%
EAP	F5.0	31-35	Absolute error - pressure Blank => default value of 0.1 Pa
ERP	F5.0	36-40	Relative error - pressure Blank => default value of 0.01%
EAQ	F5.0	41-45	Absolute error - quality Blank => default value of 0.005
MAXIT	I5	46-50	Maximum number of iterations allowed in seeking steady-state convergence Blank => default value of 50
EXTIT	I5	51-55	Number of iterations after failure of steady-state convergence. With TABLE 1 printout after each iteration Blank => default value of 10 .
"LAST"	A4	71-74	

RUN -- The RUN card tells the executive program that system definition is complete and that the call sequence can be started.

Parameter	Format	Columns	Description
"RUN"	A3	1-3	Card identifier
"LAST"	A4	71-74	

An EOF must follow the last RUN card in the executive routine data file.

2.3 Loop Definition Data (TAPE 8)

2.3.1 Discussion -- This file contains the data required to define the fluid loops in each system model. Each loop must be defined by specifying the fluid name; a unique loop integer between 1 and 10; initial values for temperature, pressure, and fluid flow rate; and a set of unique integers that contain all the component and state numbers within the loop.

The initial values for temperature, pressure, and fluid flow rate for each loop should be good estimates for the values at the inlet state point for the first component called in the loop. This is not a stringent requirement but will expedite steady-state convergence.

Each loop may contain several records of data. There must be an EOF card following the last record for the loop. After the last loop has been defined (including its EOF), there must be an additional EOF card. These data must be repeated if additional system models are to be run.

2.3.2 Format

Parameter	Format	Columns	Description
Card 1			
Name	A10	1-10	Fluid name (must correspond to a name on TAPE 9 input)
Number	I5	11-15	Unique loop integer between 1 and 10
T_0	F10.4	16-25	Initial temperature (K)
P_0	E12.5	26-37	Initial pressure (Pa)
F_0	E12.5	38-49	Initial mass flow rate (kg/s)
N_1	I5	50-54	Component and state numbers in loop.
N_2	I5	55-59	
N_3	I5	60-64	
N_4	I5	65-69	
Card 2			
N_5	I5	1-5	Additional component and state numbers in loop.
N_6	I5	6-10	
⋮	⋮	⋮	
N20	I5	76-80	

Card 2 may be omitted or repeated as many times as needed in specifying the component and state numbers in the loop.

Card 3 (EOF)

Cards 1, 2, and 3 must be repeated for each fluid loop in the system model. After the last loop has been defined, an additional EOF card must be specified.

2.4 Fluid Property Data (TAPE 9)

2.4.1 Discussion

-- This file contains the constants used to calculate heat-transfer fluid properties as a function of temperature, and the constants that characterize power-cycle working fluids.

Calculations of the heat-transfer fluid properties--density (ρ), specific heat (c), kinematic viscosity (ν), and thermal conductivity (k)--are based on polynomial fits of measured data.

Density, specific heat, and thermal conductivity are expressed by a power series in absolute temperature as

$$(\rho, c, k) = C_0 + C_1 T + C_2 T^2 + C_3 T^3 + C_4 T^4 + C_5 T^5 ,$$

while kinematic viscosity is expressed by a power series in reciprocal temperature as

$$\nu = C_0 + C_1/T + C_2/T^2 + C_3/T^3 + C_4/T^4 + C_5/T^5 .$$

In all cases the series coefficients are obtained from available data by a least-squares procedure.

The temperature range for which each property correlation is valid is defined by a low- and high-temperature limit. Property data calculated outside this range are unreliable.

The temperature range for each property is divided into two subranges by an intermediate temperature. Power series coefficients must be supplied for each of these subranges. Therefore, 12 coefficients (C_{01} - C_{52}), and 3 temperatures (T_L, T_I, T_H) must be provided for each property in the following order: ρ, c, ν, k.

The constants in Table I characterize each power-cycle working fluid. The first 13 constants may be found for some 200 fluids in Appendix A, of Reid and Sherwood.[3] Values for the other constant, Goldhammer's constant, may be obtained from Table II.

TABLE I

Power-Cycle Fluid Constants

Parameters	Description
MOLWT	Molecular weight
TB	Normal boiling point (K)
TC	Critical temperature (K)
PC	Critical pressure (atm)
VC	Critical volume (cm^3/g-mol)
OMEGA	Pitzer's acentric factor
LIQDEN	Liquid density at TDEN (g/cm^3)
TDEN	Reference temperature for LIQDEN (K)
CPVAPA, CPVAPB, CPVAPC, CPVAPD	Constants in ideal-gas heat-capacity equation, with CP in calories per gram-mole kelvin and T in kelvins. CP = CPVAPA + (CPVAPB) * T + (CPVAPC) * T ** 2 + (CPVAPD) * T ** 3
HV	Heat of vaporization at normal boiling point (cal/g-mol)
N	Goldhammer's constant

TABLE II

Goldhammer's Constant

Fluid Classification	Goldhammer's Constant
Alcohols and water	0.25
Hydrocarbons and ethers	0.29
All other organic compounds	0.31
All other inorganic compounds except water	0.33

The preprocessor PRESOL will automatically generate TAPE 9 from a fluid property data bank that contains property data for some of the more common heat-transfer fluids and power-cycle working fluids (see Appendix A, p A-4).

2.4.2 Format

Parameter	Format	Columns	Description
Card 1			
Fluid	A10	1-10	Fluid name must correspond with the name on TAPE 8
Type	A5	11-15	"POWER" or "THERM"

Parameter	Format	Columns	Description

Card 2 (Omit if TYPE = "POWER")

Parameter	Format	Columns	Description
$T_{L\rho}$	E12.6	1-10	Lower temperature limit for density (K)
$T_{I\rho}$*	E12.6	11-20	Intermediate temperature for density (K)
$T_{H\rho}$	E12.6	21-30	Upper temperature limit for density (K)

---

*If $C\rho_{02}$ --- $C\rho_{52}$ are all zeroes $T_{I\rho} = T_{H\rho}$

Card 3 (Omit if TYPE = "POWER")

Parameter	Format	Columns	Description
$C\rho_{01}$	E12.6	1-12	Coefficients for $\rho(T) = C_{01} + C_{11}T + C_{21}T^2 \ldots$ $T_{L\rho} \leq T \leq T_{I\rho}$
$C\rho_{11}$	E12.6	13-24	
.	.	.	
.	.	.	
.	.	.	
$C\rho_{51}$	E12.6	61-72	

Card 4 (Omit if TYPE = "POWER")

This record must be included even if coefficients are all zeroes.

Parameter	Format	Columns	Description
$C\rho_{02}$	E12.6	1-12	Coefficients for $\rho(T) = C_{02} + C_{12}T \ldots$ $T_{I\rho} < T \leq T_{H\rho}$
.	.	.	
.	.	.	
.	.	.	
$C\rho_{52}$	E12.6	61-72	

NOTE: Cards 2, 3, and 4 must be repeated if TYPE = "THERM" for defining C, ν, and k in this order.

Card 5 (Omit if TYPE = "THERM")

Parameter	Format	Columns	Description
MOLWT	E12.6	1-12	Molecular weight
TB	E12.6	13-24	Normal boiling point (K)
TC	.	.	Critical temperature (K)
PC	.	.	Critical pressure (atm)
VC	.	.	Critical volume (cm^3/g-mol)
OMEGA	E12.6	61-72	Pitzer's acentric factor

Parameter	Format	Columns	Description
Card 6 (Omit if TYPE = "THERM")			
LIQDEN	E12.6	1-12	Liquid density at TDEN (g/cm^3)
TDEN	E12.6	13-24	Reference temperature for LIQDEN (K)
CPVAP A	.	.	Constants in ideal-gas heat-capacity equation, with CP in calories per gram-mole kelvin and T in kelvins
CPVAP B	.	.	Same as above
CPVAP C	.	.	Same as above
CPVAP D	E12.6	61-72	Same as above
Card 7 (Omit if TYPE = "THERM")			
HV	E12.6	1-12	Heat of vaporization at normal boiling point (cal/g-mol)
N	E12.6	13-24	Goldhammer's constant

NOTE: Cards 1-7 are to be repeated for additional fluids in the system model. The maximum number of fluids is 10.

Card 8 (EOF)

NOTE: If additional system models are to be run, the above sequence must be repeated for each.

2.5 Weather Data (TAPE 12)

2.5.1 Discussion -- The weather records are specified hourly with an EOF after the last record, and each station is on a separate magnetic tape. These data are compatible with the typical year data[4] for 26 locations compiled by SLA using the SOLMET weather data tapes.

2.5.2 Format -- The sequence of variables for each record is

Station No.
Year
Month
Day
Hour
Direct Normal Radiation (kJ/m^2/hr)
Standard Year Corrected Total Horizontal (kJ/m^2/hr)
Station Pressure (kPa)
Dry Bulb Temperature (° C)
Wind Direction (degrees)
Windspeed (m/s)

The time-varying weather data format for SOLTES is
(I5, 3I2, I4, 9X, F4.0, 26X, F4.0, 40X, F5.2, F4.1, 4X, F3.0, F4.1).

2.6 Time-Varying Load Data (TAPE 11)

2.6.1 Discussion -- The time-varying load input (TAPE 11) to SOLTES may contain multiple files. Each file may contain load data for cooling, heating, hot-water, electrical, mechanical power, and thermal loads. Subroutine DAREXL reads this file.

2.6.2 Format

Record 1

ID_1, ID_2, IDIM, NV, IYEAR IDAY IHOUR

Format (2A10, 5I10)

ID_1	first word identifier of file
ID_2	second word identifier of file
IDTM	constant time interval in seconds between data
NV	number of load variables to be read
IYEAR	starting year of file
IDAY	starting day of file
IHOUR	starting hour of file

Record 2

$IVAR_i$ (i = 1, NV)

Format (8A10)

This record contains the unique identifiers for each load variable.

Record 3

$XDATA_i$ (i = 1, NV)

Format (5E16.8)

This record contains load or load information data. The units for each category depend on the component that will use the load.

Record 4 (EOF)

An EOF record must follow each file on TAPE 11. After the last file there must be at least two EOFs.

NOTE: Days 1, 8, 15 --- are Sundays.

3. Model Construction

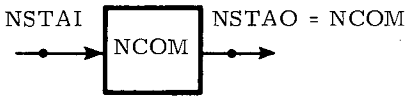
3.1 Discussion

Component routines in the SOLTES library are individual models for thermal-energy system components and controls.

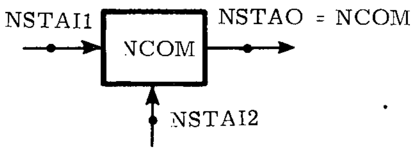
SOLTES thermal-energy system models contain a unique set of integers ranging from 1 to 150. This unique set is created by assigning component numbers to each component model and outlet state numbers for each open component.

Open components in the SOLTES library are of the types depicted in Figure 2. These types are distinguished by the number of sides, inlets, and outlets.

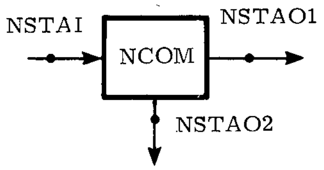
Nomenclature:
NSTAI - Inlet state number
NSTAI1 - Inlet 1 state number
NSTAI2 - Inlet 2 state number
NCOM - Component number
NCOM1 - Side 1 component number
NCOM2 - Side 2 component number
NSTAO - Outlet state number
NSTAO1 - Outlet 1 state number
NSTAO2 - Outlet 2 state number



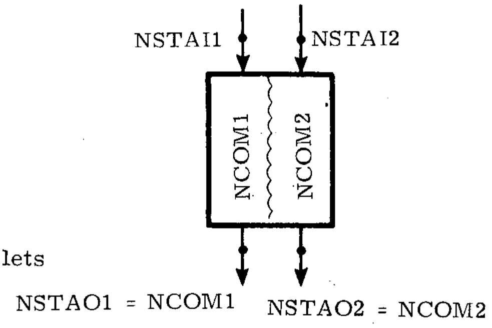
Type 1. Simple Component



Type 2. Two inlets; one outlet



Type 3. One inlet; two outlets



Type 4. Two-sided. Each side is a simple component.

Figure 2. Open Component Types

A single component number is assigned for models of Types 1, 2, or 3, and a component number is assigned for each side of two-sided models (Type 4). Unique numbers must be given to outlet states of models with two outlets (Type 3). For the other types (Types 1, 2, and 4), the outlet state number is the same as the component number.

Fluid loops in the system model must be defined and each loop uniquely numbered with integers ranging from 1 to 10. A fluid loop may contain a single component or many components through which the same fluid flows. Each of these components must be connected to at least one of the other components in the loop by a fluid path.

SOLTES models are included in the examples of Appendix D.

3.2 Procedure

The following is a step-by-step procedure for creating system models. The intent is to provide a useful procedure for new SOLTES users and a reference for the experienced.

a. Draw a system model schematic with boxes or appropriate system symbols for each component in the thermal-energy system. Each symbol denoting open components must be one of the four types shown in Figure 2. Denote fluid paths between open components as straight lines with arrowheads that indicate the direction of fluid flow.

b. Choose the names of the routines that simulate components in the thermal-energy system from the SOLTES routine library. These routines may be used more than once in a system model.

c. Place routine names next to the appropriate boxes or symbols.

d. Choose an open component in the schematic and assign component and outlet state numbers. These numbers must be integers ranging from 1 to 150.

e. Repeat d., choosing unique numbers, until all the open components in the schematic are assigned unique component and outlet state numbers.

f. Assign a unique component number to each closed component in the system model.

g. Draw arrows denoting the directions of energy transferred across the system boundaries and the components receiving or rejecting the energy. Place the word describing the category of energy transfer next to each arrow. Table III lists these words and conventions for directions of energy transfer. (See 1.2.6 for an explanation of each category.)

NOTES: 1. Demands or parasitics cross the boundaries of the system model only if the demand or parasitic is not satisfied by another component in the system.

2. A characteristic temperature is denoted with each thermal load as shown in Table III.

TABLE III

Thermal Energy System - Environment Energy Transfer Categories

Nomenclature:
A = □←
B = □→

Word	Convention	Category
ELCLD*	B	Electrical load
POWLD*	B	Mechanical load
HWATLD	B	Hot-water load
THMLD, T	B	Thermal load, characteristic temperature
HEATLD	B	Heating load
COOLLD	A	Cooling load
ELCPS	A	Electrical parasitic
POWPS	A	Mechanical parasitic
PRISUP	A	Supply rate from primary source
AUXSUP	A	Supply rate from auxiliary source
HTGAIN	A	Heat gain
ELCDM	A	Electrical demand
POWDM	A	Power demand
COOLDM	B	Cooling demand
HEATDM	A	Heating demand
HTLOSS	B	Heat loss
THMLOS	B	Thermal losses
HEAT	A or B	Heat
ADLOS	B	Advective loss
ADGAIN	A	Negative advective loss

*Electrical and mechanical loads are associated only with load management components.

h. Draw arrows denoting the energy exchanges between components. Place the word describing the category of energy exchange next to each arrow. Table IV lists these words and conventions for energy transfer directions. Place the number of the component receiving the energy next to the arrow into that component and next to the arrow out of the component supplying the energy.

TABLE IV

System Internal Energy Transfer*

Nomenclature:

A - □←

B - □→

LM = Load management routine

R = Component requiring the demand or parasitic

S = Component, other than load management, satisfying the demand or parasitic

Word	Energy Exchange Relationship	Convention	Category
ELCDM	R	A	Electrical demand
ELCDM	LM	B	Electrical demand
POWDM	R	A	Mechanical demand
POWDM	LM	B	Mechanical demand
COOLDM	R	B	Cooling demand
COOLDM	S	A	Cooling demand
HEATDM	R	A	Heating demand
HEATDM	S	B	Heating demand
ELCPS	R	A	Electrical demand
ELCPS	LM	B	Electrical parasitic
POWPS	R	A	Mechanical parasitic
POWPS	LM	B	Mechanical parasitic
HEAT	To	A	Heat
HEAT	From	B	Heat

*Energy transferred between turbines and load management is automatically accounted and should not be denoted on the system schematic.

i. Denote fluid and power loops by enclosing all open components and outlet states in a loop with dashed lines. Power loops are more restrictive than fluid loops. See Appendix B for power-loop restrictions.

j. Assign a unique integer between 1 and 10 to each loop.

k. Choose from the SOLTES routine library the names of information routines that provide load and energy source information for components and denote on the schematic.

l. Choose from the SOLTES routine library the appropriate system performance routines.

m. Construct component/information input data from the schematic by referring to Appendix C for individual routine input information.

NOTES: 1. Calls are made to the routines in the order that individual routine data is input.

(a) The component/information input data must be sequenced as follows:

(1) Input for all information routines.

(2) Input for all component routines.

(3) Input for all system performance routines.

(b) Unless otherwise specified in the individual routine writeup, there are no rigid restrictions on the order of calls to component routines. However, the steady-state convergence can take much longer for system models that have awkward sequencing. The suggested sequence of open component models is as follows:

(1) The component that receives the energy from the primary source; i.e., a solar collector.

(2) The remaining components in this loop in the same sequence that the fluid enters the models as it flows through the loop.

(3) The components in an adjacent loop into which the fluid flows or in which energy is transferred between the two loops.

(4) The routines in this loop in the same sequence that the fluid flowing through the loop enters the models.

(5) Repeat (3) and (4) for the remaining adjacent loops.

(6) Repeat (3) through (5) until all the open component data are constructed.

2. The outlet state for model Types 1, 2, and 4 are automatically equated to the component number. Thus, the outlet state numbers are required input only for model Type 3.

3. Inlet state numbers are the outlet state numbers of upstream components.

4. Systems models with only closed components do not have state numbers .

n. Construct the fluid loop information data from the schematic and from the instructions in Section 3.

NOTES:

1. The state-point and component numbers that must be placed on TAPE 8 are the unique set of all component and state-point numbers found in each loop shown on the schematic.

2. Closed components are not included in fluid loops. System models with only closed components do not have fluid loops but may require fluid property data.

o. Other required SOLTES input such as executive routine control data is straightforward and can be constructed from the instructions in Section 2.

4. Conclusion

In addition to completing or writing those routines in the routine library index (Appendix C, p. C-1) that are denoted as being partially written or as extensions of present methods, the following extension to SOLTES would further expand its applications and usefulness:

- Add generalized thermal energy storage management
- Add generalized second law of thermodynamics accounting; i.e., generalized availability accounting
- Add photovoltaics with load management
- Extend the generalized Rankine-cycle capabilities to include supercritical cycles
- Add generalized Brayton cycles with load management
- Add more detailed heat exchanger, condenser, and thermal boiler models to include heat-transfer effects and off-design performance
- Include more detailed collector and storage models
- Include storage models with rate effects
- Add generalized Stirling cycles with load management

4

5. References

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2. M. W. Edenburn and N. R. Grandjean, SOLSYS, Energy System Simulation Computer Program, SAND75-0048, Sandia Laboratories, Albuquerque, NM, June 1975.
3. R. C. Reid, J. M. Prausnitz, and T. K. Sherwood, The Properties of Gases and Liquids, 3rd ed., McGraw-Hill Book Co., NY, 1977.
4. I. J. Hall, R.R. Prairie, H.E. Anderson, and E.C. Boes, "Generation of Typical Meteorological Year for 26 SOLMET Stations," National Climatic Center in Ashville, NC, to be published.
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APPENDIX A

The Preprocessor (PRESOL)

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Examples

APPENDIX A

The Preprocessor (PRESOL)

Introduction

The preprocessor PRESOL is a computer code that aids users in creating SOLTES input. The code also generates the SOLTES executive routine with calls only to those subroutines required by a particular system model. Although PRESOL has been written for execution under SLA's Network Operations System (NOS) time-sharing system, minimum changes should enable it to run under other time-sharing systems or under batch. Extensive knowledge of NOS is not required to make full use of PRESOL.

In general, PRESOL accepts user input and determines if it is data or command. The following SOLTES data may be prepared by PRESOL:

Component/Information Data (TAPE 1)

Executive Routine Control Data (TAPE 6)

Property Data for Heat-Transfer Fluids and Constants
Characterizing Power-Cycle Working Fluids (TAPE 9)

Loop Definition Data (TAPE 8)

All this data need not be generated in a single execution of PRESOL, because component/information data may be built in modules saved in the component/information routine data bank and in future execution of PRESOL retrieved, edited, and again saved. This process can continue until the complete system model has been constructed. This feature of PRESOL also enables the user to construct partial system models that at a later date may be merged and edited to form an entirely new system. A complete list of PRESOL commands can be found on page A13.

The following terms and definitions may help in using and understanding PRESOL:

RECORD - a record or card image consisting of 80 characters. By definition, eight CDC 6600 words.

FILE - one or more records followed by an EOF mark. (RETURN key on NOS.) Input data to each SOLTES routine is a FILE.

SYSTEM - one or more files.

CN1 - always refers to Columns 11 through 20 of the first RECORD for every FILE.

WORD - 10 consecutive characters, the first character of which must be in Columns 1, 11, 21, ..., or 71.

Disk or Tape Input for PRESOL

This section briefly describes the necessary disk or tape input to PRESOL. PRESOL does not require all this input to be present for every execution.

Component/Information Routine Data Bank (TAPE 2) -- This file may contain component/information routine data for complete or partial system models. PRESOL is directed to access this data bank by the "SYSTEM..." command or when the user specifies "DATA" in Columns 51-54 of the first RECORD of a FILE. TAPE 2 must be an NOS local file before executing PRESOL only if the data bank is to be accessed. This data bank is generated for future executions of PRESOL by the "SAVE..." command.

Fluid Property Data Bank (TAPE 7) -- This file contains fluid property data for heat-transfer fluids and for constants characterizing power-cycle working fluids. Before PRESOL runs containing "LOOP..." commands, TAPE 7 must be attached with the NOS command "GET, TAPE 7/UN=NRGRAND". Heat-transfer properties and power-cycle constants are now available for the following fluids:

Heat-Transfer Fluids

		Temperature Range in K			
		(ρ, C_p, k)		ν	
Data Bank Name	Fluid	Lower	Upper	Lower	Upper
"THERM 44"	Therminol 44	219	533	255	533
"THERM 44"	Therminol 55	255	616	283	616
"THERM 60"	Therminol 60	219	616	255	616
"THERM 66"	Therminol 66	255	644	283	644
"THERM 88"	Therminol 88	422	755	422	755
"WATER"	Water	273	573	273	573
"SILON B"	Silicone B	228	644	228	644

Power-Cycle Fluids

"WATER"	Water
"TOLUENE"	Toluene
"FREON 11"	Freon 11
"FREON 12"	Freon 12

Partial Executive Routine (TAPE 10)--This is a three-file source deck containing most of the coding for the executive routine. This file is necessary only when the user desires to generate an executive routine by answering "YES" to the question, "DO YOU WISH TO GENERATE THE EXECUTIVE ROUTINE YES OR NO". Before execution of PRESOL in which the executive routine is to be generated, TAPE 10 must be attached to the user's local file with the NOS command "GET, TAPE 10/UN=NRGRAND".

Disk or Tape Output From PRESOL

TAPE 1 - SOLTES component/information routine data.

TAPE 5 - PRESOL component/information routine data bank. (This file may be an input for future executions of PRESOL under the name TAPE 2.)

TAPE 6 - SOLTES executive routine

TAPE 8 - SOLTES loop definition data.

TAPE 9 - SOLTES fluid property data and power-cycle constants.

Constructing TAPE 1 From Terminal Input

Entering RECORDS Into a FILE--Component/information data file TAPE 1 is easily constructed using PRESOL. Once the preprocessor has been initiated

```
.
.  NOS commands for logging into the system, etc
.

/  GET, BINPRE/UN=NRGRAND
/  BINPRE
?   PRESOL response
```

the user starts inputting data RECORDS as prescribed for each FILE in creating his SYSTEM.

For example, if the user wishes to create a FILE of information for component XXXXX, the sequence would be

```
.
.
?  XXXXX      1    14     RETURN
?  30.4   RETURN
?   1    RETURN
?   RETURN
?   (at this point PRESOL is waiting for a new FILE to begin or for a command)
```

The keyboard "RETURN" is given after the last entry for each RECORD has been made in the proper character positions.

Closing a FILE--To close a FILE, the user must send a record containing only a RETURN keyboard code (EOF). The keyboard RETURN as in the above example will be henceforth referred to as RETURN. The sequence shown in the example may continue until all the FILES have been constructed and the user wishes to close the SYSTEM and either start another SYSTEM or exit PRESOL.

Closing a SYSTEM--To close a SYSTEM, the user inputs "CLOSE" after the "?", and answers the PRESOL question "DO YOU..." with a "RETURN"

Starting Another SYSTEM -- After the user has closed his SYSTEM he may build a completely new system by entering "NEWSYS" (see A10) or by modifying the FILES currently available on TAPE1.

Exiting PRESOL -- To exit PRESOL the user must close the SYSTEM as above and then send an EOF to PRESOL. PRESOL will then respond with two self-explanatory questions. The user will exit PRESOL by answering "NO" to the first question and "YES" or "NO" to the second.

Saving FILES and SYSTEMS From TAPE 1 for Future Use by PRESOL as TAPE 2 Input

PRESOL allows the user to SAVE a single FILE of information or a set of FILES. This feature of PRESOL enables the user to build modularly and edit SOLTES system models by saving discrete FILES of information from TAPE 1. The "SAVE..." command initiates a write to TAPE 5, which then may be input to PRESOL in future executions as TAPE 2. The "SAVE..." command may be exercised at any time while building a SYSTEM and as many times as necessary, but must be exercised

After a FILE has been closed;

Before the SYSTEM is closed.

NOTE: The user must permanently retain TAPE 5 using the NOS command "SAVE" or "REPLACE" after exiting PRESOL.

Saving a Single FILE ("SAVE" Edit Command)--The PRESOL command by characters is

(Column) 1-4	11-20	21-30	31-40
"SAVE"	Name	CN1	File Name

where Name is the routine name. CN1 is the component number. File Name is a unique name under which the FILE is to be saved on TAPE 5 for future recall.

Saving a SYSTEM ("SAVE" Command) -- The user may SAVE a SYSTEM from TAPE1 before advancing to another SYSTEM by issuing the command

(Column) 1-4	11-20	21-30	31-40
"SAVE"	"SYSTEM"	Blank	File Name

Individual FILES from the SYSTEM or the entire SYSTEM, may be retrieved in future runs of PRESOL.

Retrieving a SYSTEM or FILE From the Component/Information Data Bank (TAPE 2)

Individual FILES or SYSTEMS may be entered to TAPE 1 from the data bank (TAPE 2). This data bank may contain whole SYSTEMS and/or individual FILES. PRESOL is directed to access this data bank when the user enters the word "DATA" in Columns 51-54 of the first RECORD for a given FILE, or when the "SYSTEM..." command is issued. TAPE 2 must be a local file before the execution of PRESOL whenever access is intended.

First RECORD ACCESS--This procedure is used when the FILE was saved using the "SAVE (name)..." command (saving a single FILE). PRESOL will search TAPE 2 whenever the user enters "DATA" in Columns 51-54 of the first RECORD of a FILE. PRESOL matches the first 10 characters of the given RECORD and Columns 61-70 of that RECORD with identifications found in the data bank. Upon finding a match, the preprocessor loads to TAPE 1 the first 50 characters found on RECORD 1 given through the terminal and then the last 30 characters of RECORD 1 from the data bank, along with any remaining RECORDS in the data bank for that FILE.

PRESOL "SYSTEM" Command--This command allows the user to retrieve a single FILE from a SYSTEM or the entire SYSTEM. The data retrieved is then written to TAPE 1.

If the user wishes to retrieve a particular FILE from a SYSTEM, he gives the command:

(Column)	1-6	11-20	21-30	31-40
	"SYSTEM"	File Name	Name	CN1

If the user wishes to retrieve the entire SYSTEM, Columns 21-40 of the above command must be blank.

Editing Commands for FILES and SYSTEMS (TAPE 1)

Various editing commands have been established to aid the user in generating, modifying, and correcting FILES and SYSTEMS on TAPE 1. Thus far the commands that have been introduced allow the user to SAVE and retrieve ("SYSTEM" command) data in constructing TAPE 1. As mentioned previously, PRESOL distinguishes between commands and data. For this reason commands and data may be given to the preprocessor in almost any order, following only a few basic rules:

A FILE must be closed before starting another
A FILE must be closed before issuing a command.
Once a SYSTEM is closed, the user may not return to it.
Issuing any command, excluding the MARK and SYSTEM command, when TAPE 1 is empty is fatal.

This section deals with each command individually. A summary may be found on page A-13.

Edit Command "MARK"--This command provides the user with reference numbers indicating column positions on the terminal.

Edit Command "LIST"--This command will list the first RECORD of each FILE of your current SYSTEM as found on TAPE 1. If you choose to see all the RECORDS of every FILE, this may be done by including "ALL" in Columns 11-13.

Edit Command "EDIT"--This command enables the user to change any number of words in one or all RECORDS within a FILE. To issue, the user inputs

(Column)	1-4	11-20	21-30
	"EDIT"	Name	Number (CN1)

PRESOL will respond by

1. Automatically printing the "MARK" card
2. Printing the first RECORD of the FILE
3. Accept changes to the RECORD (if no changes are desired, do a RETURN).

   NOTES: a. Some components require two data entries in a WORD. If the user desires to change either one, he must also enter the other.

   b. To convert a WORD to all blanks, enter "XXXXXXXXXX".

4. Print the new RECORD.

The above sequence will continue for the remaining RECORDS until either the preprocessor encounters an EOF for that file or until the user types "NEXT" (this will return the user to the control).

Edit Command "REPLACE"--This command allows the user to remove a file from his SYSTEM and replace it with another. To use this command the user input is:

(Column)	1-7	11-20	21-30
	"REPLACE"	Name	CN1

The processor then removes the FILE given and replaces it with the next FILE, which is either retrieved from the data bank or input from the terminal. Only one FILE may be inputted. If more than one file is needed, the "DELETE" and "INSERT" commands should be used.

Edit Command "INSERT"--The "INSERT" command has two forms.

(Column)	1-6	11-20	21-30
	"INSERT"	Name	CN1

The first allows the user to insert before that specified FILE any number of FILES, either from the terminal or the data bank or both. This feature is helpful when introducing a subsystem into TAPE 1. With this command, PRESOL continues accepting FILES until you type "NEXT" in Columns 1-4.

The second form of the "INSERT" command enables the user to insert RECORDS within a specified FILE. Columns 1-30 designate which file, as before, and Columns 31-40 (right-adjust) specify the record in the file where the insert is to take place. A positive number in this field causes the insert to take place after the record specified; a negative, before. After the last RECORD has been inserted, do a RETURN from the keyboard and then type "NEXT" in Columns 1-4.

Edit Command "DELETE"--The "DELETE" command is of the same form as the INSERT. To delete an entire file, the user inputs

(Column)	1-6	11-20	21-30
	"DELETE"	Name	CN1

To delete a RECORD within a FILE, add the record number to be deleted in Columns 31-40 (right-adjust).

Edit Command "RECONNECT"--The "RECONNECT" command allows the user to change from one to four of six numbers (CN1, US1, OS1, CN2, US2, OS2) found on the first RECORD of each component FILE. (These numbers correspond to the component and state numbers.) This command is useful when inserting or deleting files in the SYSTEM. The full command for RECONNECT is:

Column	Instruction
1-9	"RECONNECT"
11-20	Name
21-30	CN1 (right-adjust)
31-35	Old number
36-40	New number
41-45	Second old number
46-50	Second new number
51-55	Third old number
56-60	Third new number
61-65	Fourth old number
66-70	Fourth new number

The sequence of the changes is not important; i.e., if the user wanted to change CN1 and US1 to CN1' and US1', he could specify on his RECONNECT card US1 in Columns 31-35, US1' in 36-40, and then CN1 and CN1' in 41-50. *The user is reminded that only four of the six numbers may be changed since there is no component type in SOLTES that requires more than four of the six to be set at any one time.*

Edit Command "CLOSE"--When the user is finished building and editing a SYSTEM and has saved his current SYSTEM, if so desired (see "Saving FILES and SYSTEMS," page A-6), he may start building another SYSTEM, closing his current SYSTEM with a "CLOSE" command.

Edit Command "NEWSYS"--Immediately after the "CLOSE" command is given, PRESOL regenerates the previous SYSTEM for modification. If the new SYSTEM is an entirely new SYSTEM to be built, the user must inform PRESOL with a "NEWSYS" command. This command will cause PRESOL to forget what it knew about the previous SYSTEM and start a new one for you.

Other commands that are recognized by the preprocessor are:

"LOOP", "PROP", "CONVER", "PRINT", "PLOT", "TIME", "PRINTCON", "ID", "WRITE".

It is important that these keys are never used as names of FILES. These commands, used in building the other SOLTES input files, are discussed next.

Constructing Executive Routine Data (TAPE 6)

EXECUTIVE CONTROL data (PRINT, TIME, etc) is written to TAPE 6. Unlike the component/information routine data, PRESOL returns to the monitor control when it processes the "LAST" flag in Columns 71-74 of the Executive Control Data.

Constructing Loop Definition Data (TAPE 8)

TAPE 8 is generated for the user when the "LOOP" control/command is executed in PRESOL.

"LOOP" Command--The "LOOP" command furnishes PRESOL with the following information:

Fluid name (FNAME)

Loop number (LN)

Initial temperature (T_0)

Initial pressure (P_0)

Initial flow rate (F_0)

The component and state numbers in the loop (N_i)

To execute the "LOOP" command, type:

Variable	Column
"LOOP"	1-4
FNAME	11-20 (left-adjust)
LN	21-30 (right-adjust)
T_0	31-40
P_0	41-50
F_0	51-60
N_1	61-65
N_2	66-70 (right-adjust)
N_3	71-75 (right-adjust)
N_4	76-80 (right-adjust)

If there are more than four component or state numbers to be entered, they must appear on the next record, which has the following format:

Variable	Column
N_5	1-5
N_6	6-10
.	.
.	.
.	.
.	.
N_{18}	76-80

Records with the above format may be repeated if necessary. After all the loop data for a specific loop has been entered it is necessary to give PRESOL an EOF. This will return PRESOL to the monitor level.

Constructing Fluid Property Data and Constants (TAPE 9)

The PRESOL command "LOOP" aids the user in building TAPE 9 (Fluid Property Data and Constants). To execute the "LOOP" command, TAPE 7 (Fluid Property Data and Constants Data Bank) must be present. PRESOL searches TAPE 7 for the various coefficients required to build TAPE 8 (see LOOP definition data, TAPE 8). If the user wishes to specify his own coefficients and/or constants, as described in Section 2.3, he may enter them with the "PROP" control command. The "PROP" command not only permits new coefficients to be written to TAPE 9, but also allows the user to override coefficients that already exist on TAPE 7 (as long as he used the same fluid name).

"PROP" Command--To execute the "PROP" command, the user types "PROP" in Columns 1-4, the fluid name in 11-20, and either "POWER" or "THERM" in 21-30. If

Columns 21-30 contain "THERM", then Columns 31-40 must contain either "DENS", "SPHT", "VISC", or "COND". This is all that is contained on the first record. PRESOL will respond by asking for the data in free format (separate the data by commas). Once the user supplies all the data, PRESOL returns to the monitor or control level.

Generating the Executive Routine (TAPE 4)

Once the user has generated the component/information routine data (TAPE 1) and is satisfied with his system model(s), he can generate the executive routine for SOLTES by

1. Executing the "CLOSE"
2. Entering an EOF
3. Entering a second EOF
4. Answering "NO" to the second question "DO YOU WANT TO RETURN..."
5. Answering "YES" to the question "DO YOU WANT TO GENERATE THE EXECUTIVE ROUTINE?"

TAPE 10 (the partial executive routine) and TAPE 1 must be local files before executing the above commands. PRESOL will search the entire set of data on TAPE 1 and select all the unique component and information routines it finds for as many SYSTEMS as it finds on TAPE 1. The proper data statement and the necessary call statements are then written into the executive routine.

Incorporating User-Written Subroutines

PRESOL, when generating the executive routine, automatically includes call statements to any component/information routines that it finds on TAPE 1. The user may input his source deck by using the "ADD" command.

"ADD" Command--This command automatically adds source decks to the proper file for compilation. After the last record of the source decks, the user must supply PRESOL with a record containing "LAST" in Columns 71-74, whereupon the preprocessor returns to the control point.

Summary of Commands

Variable	Column	Format	Description
ADD			
"ADD"	1-3	A3	Control identifier
CLOSE			
"CLOSE"	1-5	A-5	Control identifier
DELETE			
"DELETE"	1-6	A6	Control identifier
Name	11-20	A10	Routine name
Number	21-30	I10	CN1 (component number)
Record	31-40	I10	Record to be deleted (if blank, delete entire file)
EDIT			
"EDIT"	1-4	A4	Control identifier
Name	11-20	A10	Routine name
Number	21-30	I10	CN1 (component number)
INSERT			
"INSERT"	1-6	A6	Control identifier
Name	11-20	A10	Routine name
Number	21-30	I10	CN1 (component number)
Record	31-40	I10	If blank, insert 1-n new files before file specified

NOTE: If Columns 31-40 are blank, end each new FILE with an EOF; then end the INSERT with "NEXT". If Columns 31-40 are not blank, end the INSERT of records with an EOF and then "NEXT".

Variable	Column	Format	Description
LIST			
"LIST"	1-4	A4	Control identifier
"ALL"	11-13	A3	Optional: if omitted, list only the first record of each FILE. If included, list all records of each FILE.
LOOP			
"LOOP"	1-4	A4	Control identifier
Name	11-20	A10	Fluid name
LN	21-30	I10	Loop number
T_0	31-40	F10.0	Initial temperature
P_0	41-50	F10.0	Initial pressure
F_0	51-60	F10.0	Initial flowrate

Variable	Column	Format	Description
N_1	61-65	I5	Component and state numbers in loop LN
N_2	66-70	I5	
N_3	71-75	I5	
N_4	76-80	I5	
Next Record (if needed)			
N_5	1-5	I5	Additional component and state numbers in loop LN
N_6	6-10	I5	
↓	↓	↓	
N_{18}	76-80	I5	
Repeat above for additional numbers			
Return to control level when finished with an EOF			
MARK "MARK"	1-4	A4	Control identifier
NEWSYS "NEWSYS"	1-6	A6	Control identifier
NEXT "NEXT"	1-4	A4	Control identifier
PROP "PROP"	1-4	A4	Control identifier
Name	11-20	A10	Fluid name
	21-30	A10	"POWER" or "THERM"
Type	31-40	A4	Blank if TYPE is "POWER"; "DENS", "SPHT", "VISC", or "COND" if TYPE is "THERM"
Next record if TYPE = "THERM"			
T_L	Free		Lower temperature limit (K)
T_I			Intermediate limit (K) ($T_I = T_H$ if $C_{02} \cdots C_{52}$ are all zeros)
T_H			Upper temperature limit (K)

Variable	Column	Format	Description
Next record if TYPE = "THERM"			
C_{01}	Free		Heat-transfer-fluid property constants (refer to Section 2.4)
C_{11}			
C_{51}			
C_{02}			
C_{12}			
C_{52}			
Next record if TYPE = "POWER"			
MOLWT	Free		Power-cycle working-fluid constants (refer to Section 2.4)
TB			
TC			
PC			
VC			
OMEGA			
LIQDEN			
TDEN			
CPVAP			
CPVAP B			
CPVAP C			
CPVAP D			
HV			
N			
Control to monitor level is automatic after completing data input			
RECONNECT			
"RECONNECT"	1-9	A9	Control identifier
Name	11-20	A10	Routine name
Number	21-30	I10	CN1 (component number)
O_1	31-35	I5	Old number
N_1	36-40	I5	New number

Variable	Column	Format	Description	
O_2	41-45	I5	Old number	optional
N_2	46-50	I5	New number	
O_3	51-55	I5	Old number	optional
N_3	56-60	I5	New number	
O_4	61-65	I5	Old number	optional
N_4	66-70	I5	New number	
REPLACE				
"REPLACE"	1-7	A7	Control identification	
Name	11-20	A10	Routine name	
Number	21-30	I10	CN1 (component number)	
SAVE				
"SAVE"	1-4	A4	Control identifier	
"SYSTEM" or Name	11-20	A10		
Number	21-30	I10	Leave blank if 11-20 is "SYSTEM"	
ID	31-40	A10		
SYSTEM				
"SYSTEM"	1-6	A6	Control identifier	
ID	11-20	A10	Identification of system	
Name*	21-30	A10	Routine name	
Number*	31-40	I10	CN1 (component number)	

*If Columns 21-40 are blank, retrieve entire SYSTEM; otherwise, retrieve the FILE as indicated by name and number.

Diagnostic Messages and Cautions

Nonfatal diagnostic messages are provided to the user when mistakes detectable by PRESOL are encountered.

All the diagnostics in PRESOL are self-explanatory, therefore, details will be omitted in this manual. However, the following cautions should be kept in mind.

1. PRESOL does not permanently retain or save any of the files produced. The user must use the NOS commands "SAVE" or "REPLACE" after exiting PRESOL.
2. TAPE 1 and TAPE 10 must be local files before generating the executive routine for SOLTES.
3. TAPE 7 must be a local file before executing a "LOOP" command.
4. Do not execute a LIST, EDIT, etc, command if TAPE 1 is empty.
5. Correct spelling of PRESOL commands is important. Also, be sure they are all left-justified.
6. Execute the PRESOL "SAVE" command before advancing to the next SYSTEM or exiting PRESOL.

NOTE: If during the execution of PRESOL the user encounters problems, he can always regain control by sending a series of EOFs until the question "DO YOU WANT TO RETURN TO YOUR CURRENT SYSTEM?" appears. By answering "YES" the user may then return to the SYSTEM and edit it.

Examples

Example 1: Generating a SOLTES Model on NOS and Sending It to the BATCH Processor for Execution -- This example demonstrates the generation of a SOLTES model from start to end using PRESOL. The example corresponds directly with Example 1 in Appendix D. Following the example are the two procedure files used in sending the model to execute under SLA's 6600 Batch system. The construction of procedure files may be seen in the NOS News Notes.

```
 |
 6000 SYSTEM UP

 78/08/28. 18.44.23.
SANDIA NOS SN53 ECS                      NOS 1.2-460
USER NUMBER, PASSWORD

TERMINAL:     12, TTY
RECOVER /SYSTEM: BAT
$RFL,0.
/GET,BINPRE/UN=NRGRAND
/GET,TAPE7/UN=NRGRAND
/GET,TAPE10/UN=NRGRAND
/BINPRE
? MARK
      5   10   15   20   25   30   35   40   45   50   55   60   65   70   75
? WEATHR                                                 23050
?
? DAREXL
? HWATLD             88.76E   -6
? LAST
?
? MKPFLD             1                              290.      3.E       5
?          3NO
?
? PUMP               2    1                         4.E      5.9        FIXED
? 2.2E    -5
?
? FLTPLT             3    2                                  3         16.31E
3
? 3.16E   -62.        1.7       .15       2.        35.       .03       .05
? .077      .91       .1        .9        .06       .08
?
? PIPE               4    3                         10.       .011      6.
?          1.25
?
? STORE5             5    4                          .5       340.
?                     30.6      VARIABLE           8
?
? PIPE               6    5                         10.       .011      6.
?          1.25
?
? AUXFUR             7    6                         340.      .9
?
? WATHTR             8    7                                  1
?
? ENGAC1
?
? LIST      ALL
  WEATHR                                                 23050

          END OF FILE
  DAREXL

  HWATLD             88.76E   -6

  LAST

          END OF FILE
```

```
  MKPFLD             1                              290.      3.E      5

           3NO

          END OF FILE
  PUMP               2    1                         4.E      5.9       FIXED

  2.2E    -5

          END OF FILE
  FLTPLT             3    2                                  3         16.31E

  3.16E   -62.        1.7       .15       2.        35.       .03       .05

  .077      .91       .1        .9        .06       .08

          END OF FILE
  PIPE               4    3                         10.       .011      6.

           1.25

          END OF FILE
  STORES             5    4                         .5        340.

                      30.6      VARIABLE           8

          END OF FILE
  PIPE               6    5                         10.       .011      6.

           1.25

          END OF FILE
  AUXFUR             7    6                         340.      .9

          END OF FILE
  WATHTR             8    7                                  1

          END OF FILE
  ENGAC1

          END OF FILE
? MARK
      5    10   15   20   25   30   35   40   45   50   55   60   65   70   75
? TIME       1975   84   12    0 1975   85   12    0      3600          LAST
? PRINT     TABLE1     1975   84   12    0 1975   85   12    0    1    0LAST
? PRINT     TABLE3     1975   84   12    0 1975   85   12    0    1    0LAST
? PRINT     TABLE2     1975   84   12    0 1975   85   12    0   .1    0LAST
? ID          EXAMPLE 1 FOR REPORT
?                                HOT WATER SYSTEM                       LAST
? RUN                                                                   LAST
? MARK
      5    10   15   20   25   30   35   40   45   50   55   60   65   70   75
? LOOP      WATER              1290.      .3E      6.01           1    2    3
4
?     5    6    7    8
?
? CLOSE
 WOULD YOU LIKE TO ENTER ANY "SAVE" COMMANDS ? IF "YES"
 PLEASE TYPE "YES" AND THEN ENTER THEM AND THEN THE "CLOSE" CONTROL
 IF NOT DO A RETURN.
?
?
 DO YOU WANT TO RETURN TO YOUR CURRENT SYSTEM YES OR NO
? NO
 DO YOU WANT TO GENERATE THE EXECUTIVE ROUTINE YES OR NO
? YES
     1.196 CP SECONDS EXECUTION TIME
/-SYS
 ROUTE COMPLETE. JOB NAME IS  MEFR1RF
/BYE


 19.09.56  78/08/28.
OFF MEFEWEL
TTY 012      3.754 SRU
```

Procedure Files

CSYS --

JOB CARD
ACCOUNT CARD

```
REQUEST,DUMF12,HY,S.     VRN=14606
COPYCF,DUMF12,TAPE12.
UNLOAD,DUMF12.
COPYBF,INPUT,MAIN.
REWIND,MAIN.
FTN,I=MAIN.
ATTACH,LGO1,A9SOLLIB.
REWIND,OUTPUT.
PREP,LGO1,X.
COLLECT,LGO,X,FTNLIB,FXMATH.
COPYBF,INPUT,TAPE1,12.
COPYBF,INPUT,TAPE6.
COPYBF,INPUT,TAPE8,2.
COPYBF,INPUT,TAPE9.
ATTACH,TAPE13,SOL-UNITS-DATABNK,CY=1,CN=MEF.
LGO,LC=77777.
```

SYS

```
NOEXIT.
REWIND,TAPE1.
REWIND,TAPE4.
REWIND,TAPE6.
REWIND,TAPE8.
REWIND,TAPE9.
COPYBF,TAPE4,FILE1.
COPYBF,TAPE1,FILE1,12.
COPYBF,TAPE6,FILE1.
COPYBF,TAPE8,FILE1,2.
COPYBF,TAPE9,FILE1.
CALL,SENDJOB(CC=CSYS,D=FILE1,CS=R1)
```

7

Example 2: Retrieving a SYSTEM from an NOS Permanent File, Modifying It, and Replacing the Modified Version for Future Executions of PRESOL. The Component/Information Data Generated, TAPE 1, Is Also Replaced on an NOS Routine Permanent File -- The purpose of this example is to show the following:

1. The retrieval of a previously generated component/information routine data bank from an NOS permanent file (GET, TAPE2=TAPE5).
2. The modification of the SYSTEM using most of the PRESOL edit commands.
3. The saving of the modified SYSTEM by PRESOL for future use.
4. The replacement of the newly generated component/information routine data tape (TAPE1) in an NOS permanent file and the replacement of the newly generated component/information routine data bank, TAPE5. (REPLACE, TAPE1, TAPE5)

Note: The input on TAPE1 is similar to Example 2 in Appendix D but does not correspond exactly.

```
/GET,BINPRE,TAPE2=TAPE5
/BINPRE
? SYSTEM    TAPE
? DELETE    SOLEN1
? MARK
      5   10   15   20   25   30   35   40   45   50   55   60   65   70   75
? INSERT    DAREXL
? WEATHR                                                 23050
?
? NEXT
? DELETE    STORE2                 5
? RECONNECT THMBLR                 6    5    3
? LIST      ALL
  WEATHR                                                 23050

          END OF FILE
  DAREXL                                            TEST      CASE

  THMLD               18.1        437.5

  ELCLD               14TAPE

  GRID                  AIRCOND

  .9        100000.   1.

  LAST

          END OF FILE
  FOCOL                1    9

           120.       40.       .9

          END OF FILE
  PIPE                 2    1                         3.         .100     20.

           10.25

          END OF FILE
  PUMP                30    2                         4.E       5.7       VARIABLE

          END OF FILE
  MIXJNT               3   12             30

          END OF FILE
```

```
THMBLR             6    3        13   23          10.       1.

        END OF FILE
PUMP              10    6                         4.E       5.9       VARIABLE

        END OF FILE
SWITCH             7   10     8              9              1TEMP     400.

1000.              9

        END OF FILE
PIPE              11    8                         3.         .100     20.

         10.25

        END OF FILE
AUXFUR            12   11                         600.       .7       4.4E

        END OF FILE
LODMG             14   13                         POWER      YES

ELCDM     NONE

ELCPS

    1        30

    2        10

    3        21

POWDM     NONE

POWPS

    3ALL

        END OF FILE
XTURBG            15   14   16              17    95.                 85.

65.       75.       437.5     437.5

        END OF FILE
PRSVAP            18   16                         350.       1.013  E5

437.5     30.                1         11.                 19

        END OF FILE
MKPFLD            19                              288.       1.E      5

        16NO        POWER

        END OF FILE
MIXJNT            31   18              19

        END OF FILE
DCONHT            20   31              25         380.       5.516E   5

        END OF FILE
XTURBG            24   17   25              26    90.        UNSPEC   80.

60.       70.       437.5     310.

        END OF FILE
BFDPMP            21   20                         1.379E    685.      95.


        END OF FILE
CNDHTR            27   26        28   29

10.       5.        LAST

        END OF FILE
```

```
  MIXJNT            22   27             21

          END OF FILE
  BFDPMP            23   22                         1.379E   680.       90.

  POWER

          END OF FILE
  COOLTOW           29   28                         295.

          END OF FILE
  ENGAC1

          END OF FILE
? REPLACE   SWITCH             7
? FLODIV             7   10    9              8              1
?
? EDIT      FOCOL              1
      5   10   15   20   25   30   35   40   45   50   55   60   65   70   75
  FOCOL              1    9

?                                                   600.
  FOCOL              1    9                         600.

      5   10   15   20   25   30   35   40   45   50   55   60   65   70   75
           120.       40.       .9

? NEXT
? SAVE      SYSTEM              REPORT
? CLOSE
 WOULD YOU LIKE TO ENTER ANY "SAVE" COMMANDS ? IF "YES"
 PLEASE TYPE "YES" AND THEN ENTER THEM AND THEN THE "CLOSE" CONTROL
 IF NOT DO A RETURN.
?
?
 DO YOU WANT TO RETURN TO YOUR CURRENT SYSTEM YES OR NO
? NO
 DO YOU WANT TO GENERATE THE EXECUTIVE ROUTINE YES OR NO
? NO
     2.009 CP SECONDS EXECUTION TIME
/REPLACE,TAPE5,TAPE1
/
```

APPENDIX B

Generalized Rankine-Type Power-Conversion Cycles

Simple-to-complex Rankine-type power-conversion cycles can be constructed modularly from component routines. A generalized equation-of-state for real gases--the HMBS equation--is used along with thermodynamic state relationships, the Watson correlations for latent heat of vaporization, Riedel-Plank-Miller and Miller semireduced correlations for vapor pressure, and correlations for real fluid heat capacities at zero pressure to calculate the change in thermodynamic state between any two subcritical states. The 14 constants required by this method are input to SOLTES for each power-cycle working fluid in the system model (see Section 2.4.1, p 2-8).

A typical power cycle is shown in Figure B1. The cascaded turbines may be separate pieces of hardware, or the cascading can be used to simulate a single turbine with multiple extraction ports. Turbines and/or extraction turbines are separately and automatically numbered in the sequence in which their data occur in the information/control data file.

The number of flow branches from the turbine cascade is equal to the number of extraction turbines in the cascade plus one. The turbine cascade may consist of any combination of extraction and nonextraction turbines, and each turbine may or may not be coupled with an electrical generator.

The cascade may include one or more turbines or extraction turbines, but the total number may not exceed five (to minimize computer storage, the number of turbines is limited to five). Each flow branch may include a regenerative heater, condensers, and/or components that supply process heat. However, the second law of thermodynamics restricts the total number of regenerative heaters in a power cycle to the number of extraction turbines in the cascade, and fixes the number of flow branches from which energy can be independently transferred from the power cycle.

SOLTES power-cycle operating modes are distinguished by the independent energy transfer rates from the power cycle. These modes are as follows:

Mode	Description
Power	The electrical and/or mechanical power outputs of the power cycle are independent and must be specified; i.e., electrical and/or mechanical power loads are followed; electrical demands, electrical parasitics, mechanical demands, and/or

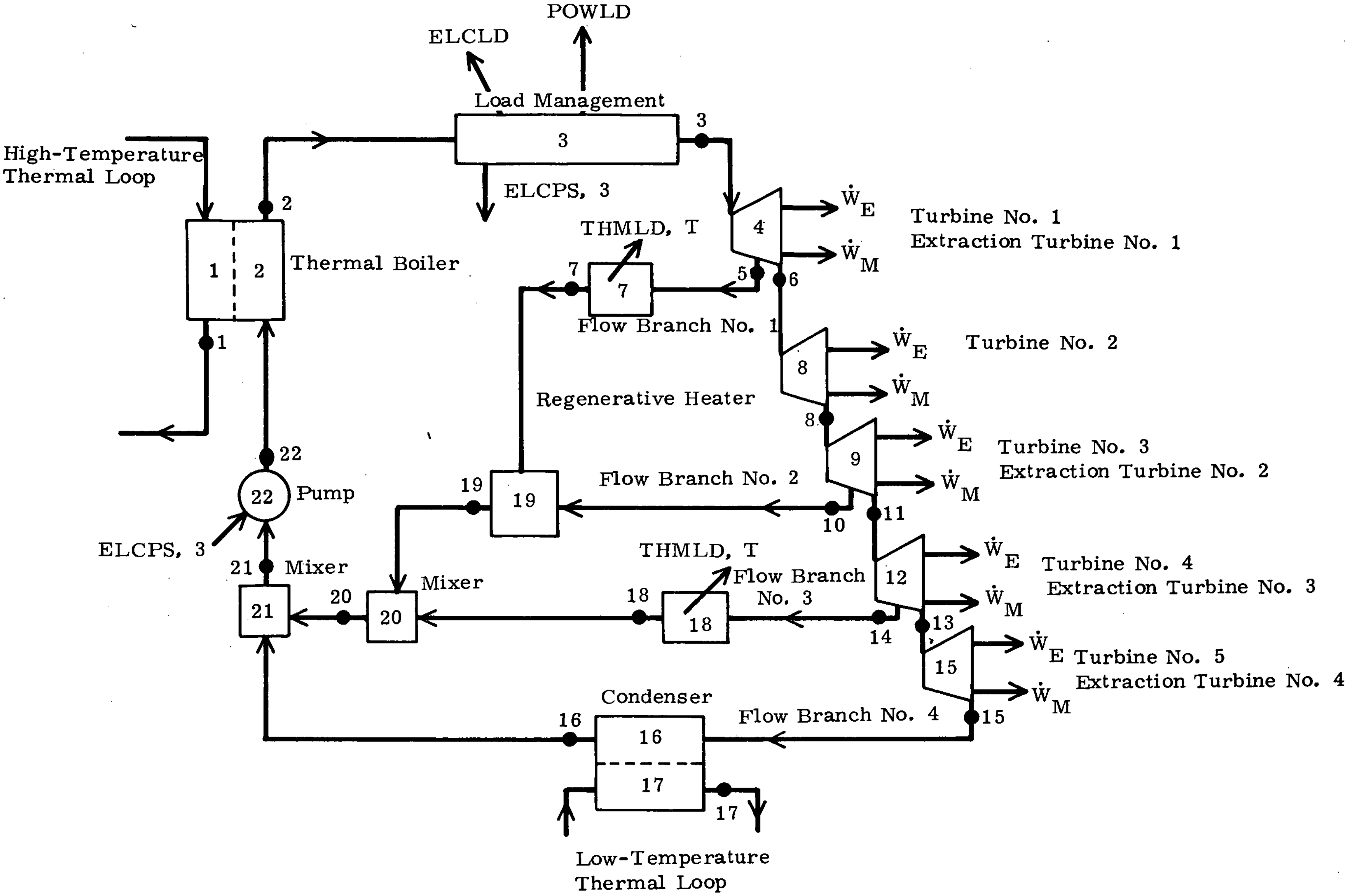

Figure B1. A Typical Complex Rankine-Type Power Cycle

Mode	Description
	mechanical parasitics are satisfied. Energy can be independently transferred from all but one of those flow branches that do not contain regenerative heaters. Thus, the number of independent energy-transfer rates from the flow branches is equal to the number of extraction turbines in the cascade less the number of regenerative heaters. There must be at least one flow branch that does not contain a regenerative heater. The independent transfer rates from the flow branches are specified by thermal load information that may be read from a data file and/or by flow rates demanded by condensers. Neither the fluid-flow rate through nor the energy-transfer rate from the remaining flow branch is independent. For continuous operation of the power cycle, the energy required by specifying all of these energy-transfer rates must be supplied by thermal boilers and/or auxiliary boilers.
Heat	The *energy transfer from* each flow branch that does not contain a regenerative heater is independent and the rate must be specified. The energy-transfer rate in each of these flow branches is specified by flow demands from the thermal side of condensers or by thermal load information that may be read from a data file. The mechanical and electrical outputs from the cascade are not independent. For continuous operation of the power cycle, the energy required by specifying all of these energy-transfer rates must be supplied by thermal boilers and/or auxiliary boilers.
Simulation	No energy-transfer rates are independent, but the *extraction rates from each turbine must be specified.* The mechanical and electrical outputs of the turbine cascade and the energy-transfer rates from each flow branch vary as the energy that can be transferred from the thermal to the power sides of the thermal boilers varies.

A load management routine manages the energy transfer from generalized Rankine-type power cycles and performs energy accounting for each power loop. Load management also allows the user to (1) select one of the three operational modes discussed above, (2) select the electrical demands/parasitics and/or mechanical demands/parasitics that are satisfied by the power loop, and (3) direct the power loop to follow electrical and mechanical loads. In addition, the load management routine determines the unspecified fluid-flow rates and energy-transfer rates for each of the three operational modes and automatically informs the user if the independent energy-transfer rates defined by his input to the components in the power loop are under or overspecified.

SOLTES will simulate systems with parallel power loops, but load information must be provided separately for each power loop. Each power loop must operate in the POWER or HEAT mode.

Load management places the following restrictions on power loops:

1. Each power loop is a fluid loop that may include other components but must include a load management component, each turbine in the turbine cascade, all process-heat components from which the energy-transfer rate is independent, all regenerative heaters, and the power sides of all condensers.*

2. The load management component must be downstream of all boilers and upstream to all turbines, components following thermal loads, and condensers.

---

*For generalized power cycles that do not contain turbines and the energy-transfer rate from each process-heat component is unspecified, a load management component is not required.

APPENDIX C

Routine Library Index

This appendix contains the routine library of information, component, and system performance routines.

Routine Library Index

	Subcategory	Section	Article	Description	Page
I. Information Routines					
1. Weather	-	1			C-I-1
WEATHR		1	1	TMY data and sun angle	C-I-3
2. Loads		2			C-I-5
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1. Thermodynamic Models					C-II-1
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Routine Library Index (cont)

	Subcategory	Section	Article	Description	Page
s. Space Heaters	a	19			C-II-85
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ELRES[†]		19	2	Electrical resistance	-----
HTPMP1[†]		19	3	Heat pump -COP model	-----
HTPMP2[†]		19	4	Heat pump - COP model liquid source	-----
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a. Fluid Flow Control		1			C-II-119
FLODIV		1	1	Flow divider	C-II-119
FLOVLV		1	2	Flow valve	C-II-121
DIVJNT		1	3	Divide joint	C-II-123
SWITCH		1	4	Switch	C-II-125
TIMSWH		1	5	Time switch	C-II-127
b. Miscellaneous		2			-----
TIMER[†]		2	1	Timer	-----
c. Temperature		3			C-II-135
TEMCON		3	1	Heat-transfer fluid temperature control	C-II-135

Routine Library Index (cont)

[†] These routines are not currently available; however, they are either near completion or are simple extensions of methods now employed in SOLTES.

[‡] Complex Rankine-type power-generation cycles with load management can be modularly constructed from routines in this library (see Appendix B).

CI. INFORMATION ROUTINES

1. Weather

1. Weather

Subroutine WEATHR

Program Description -- WEATHR is an information routine that supplies the system model with time-varying weather information and sun angles. WEATHR reads typical meteorological year (TMY)* weather data from TAPE 12. Data for 26 stations are currently available. The routine also calculates the sun's azimuth angle from the south and elevation angle, using results of a geometric analysis.

The information read from TAPE 12 is:

Station No.
Year
Month
Day
Hour
Direct Normal Radiation (kJ/m^{2}hr)
Standard Year Corrected Total Horizontal (kJ/m^{2}hr)
Station Pressure (kPa)
Dry Bulb Temperature (°C)
Wind Direction (degrees)
Windspeed (m/s)

(See p for TAPE 12 format)

Input --

Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"WEATHR"
SN	110	51-60	Station number
LAD	F10.0	61-70	Latitude** of station site (degrees) Blank ⇒ table lookup
LON	F10.0	71-80	Longitude** of station site (degrees) Blank ⇒ table lookup
Card 2			
EOF			

---

* I. J. Hall, R. R. Prairie, H. E. Anderson, and E. C. Boes, "Generation of Typical Meteorological Year for 26 SOLMET Stations," Nat'l Climatic Center in Ashville, NC, to be published.

**Latitude and longitude may be table lookup if station is one of 26 TMY data.

CI. INFORMATION ROUTINES

2. Loads

Subroutine DAREXL

Program Description -- DAREXL is an information routine that provides load or load-related information to one or more components in the system model. The load or load-related information is for the following types:

Electrical Power	"ELCLD"	(W)
Mechanical Power	"POWLD"	(W)
Thermal	"THMLD"	(kg/s or W)
Hot Water[1]	"HWATLD"	(m^3/s or W)
Cooling	"COOLLD"	(W)
Heating	"HEATLD"	(W)
Heat[2]	"HEAT"	(W)

Upon user direction, DAREXL will supply constant or time-varying information for any of the above types. DAREXL reads time-varying information from the user-supplied TAPE 11 (see p 2-12 for TAPE 11 format). The data contained on TAPE 11 may be combined by DAREXL in forming each load type. This feature of DAREXL allows the user to conduct parametric studies for evaluating the effects of individual loads or combinations of separate loads. It also allows simulation of peak-shaving and load-scaling. Up to four loads may be used in defining a load type.

Input --

Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"DAREXL"
ID_1	A10	51-60	First word identifier of file on TAPE 11 (blank if all loads are constant)
ID_2	A10	61-70	Second word identifier of file on TAPE 11 (blank if all loads are constant)

---

[1] Although the name implies hot water, this load can be used to provide load or load-related information for providing other hot liquids.

[2] HEAT is not a load or load information. However, the manner in which data for HEAT are defined in DAREXL is identical to the subsequent description for defining load or load-related information. See Section 1 for the definition of heat and loads.

Parameter	Format	Columns	Description
Card 2			
TYPE	A10	1-10	Load type to be satisfied: "ELCLD", "POWLD", "THMLD", "HWATLD", "COOLLD", "HEATLD", "HEAT".
NUMBER	I10	11-20	Component number where load is to be used
FLAG	A10	21-24	"TAPE" ⇒ loads to be read from tape
or	or	or	or
CONSTANT	F10.0	21-30	Constant value of load to be used
TEMP	F10.0	31-40	Character's temperature (K) needed only if TYPE = "THMLD)
Card 3			
This card is required only if Col. 21-24 of Card 2 is "TAPE")			
$IVAR_1$*	A10	1-10	Identifier for load variable
$IVAR_2$	A10	21-30	Identifier if needed
$IVAR_3$	A10	41-50	↓
$IVAR_4$	A10	61-70	↓
Card 4			
This card required only if 21-24 of Card 2 is "TAPE"			
C_1	F10.0	1-10	Coefficients for equation: $TYPE\ (t) = C_1\ (IVAR_1(t) - B_1) + C_2\ (IVAR_2(t) - B_2) + C_3\ (IVAR_3(t) - B_3) + C_4\ (IVAR_4(t) - B_4)$
B_1	F10.0	11-20	
C_2	F10.0	21-30	
B_2	F10.0	31-40	
C_3	F10.0	41-50	
B_3	F10.0	51-60	
C_4	F10.0	61-70	
B_4	F10.0	71-80	

---

* These names need not be sequential on the file

NOTE: Cards 2, 3, and 4 may be repeated in defining up to 48 other load or load-related information data for the system model. After the last load has been defined, the user must include

Parameter	Format	Columns	Description
Card 5			
ENDFLG	A4	1-4	"LAST"
Card 6			
EOF			

This completes the input to DAREXL.

Example Input --

```
DAREXL                                              S14       TEST
THMLD              18.1           437.5
ELCLD              14TAPE
GRID                 AIRCOND
.9      50000.       1.           0.
LAST
END OF FILE RECORD HERE
```

In this example, Component 18 is supplied for load type THMLD, with a characteristic temperature of 437.5 K, a constant value of 0.1 kg/s for its load-related data.

Component 14 is supplied a time-varying electrical load by combining loads "GRID" and "AIRCOND" from file "S14 TEST" on TAPE II. The equation used is

$$ELCLD(t) = 0.9(GRID(t) - 50000.) + AIRCOND(t)$$

Diagnostics -- Diagnostics are provided when

1. The user defines time-varying load without specifying the file from TAPE 11 (fatal).
2. DAREXL cannot find the file as specified on TAPE 11 (fatal).
3. DAREXL cannot find a specified load-variable identifier (fatal).

CII. COMPONENT ROUTINES

1. Thermodynamic Models

a. Air Conditioners

Subroutine AIRCOND*

Program Description--Subroutine AIRCOND models an absorption air-conditioning unit. The air conditioner removes energy from its inlet fluid and returns the fluid at a specified lower temperature. The rate of energy removal depends on the cooling loads and demands and the COP of the unit. Fluid-flow rate is calculated to satisfy all loads and demands.

Mathematical Algorithm--

$$\dot{m} = \frac{\sum (C_D + C_L)}{-COP \int_{T_i}^{T_o} C \, dT}$$

where

$\dot{m}$ = fluid-flow rate through air conditioner (kg/s)

C_D = cooling demand (COOLLD) (W)

C_L = cooling load (COOLDM) (W)

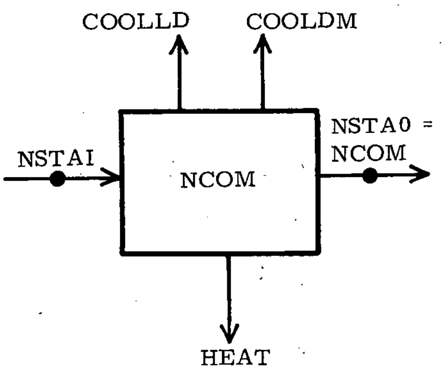
C = fluid specific heat (J/kg/K)

T_i = fluid inlet temperature (K)

T_o = fluid outlet temperature (K)

COP = coefficient of performance

Input--



---

*Open Type 1 thermodynamic model

Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (AIRCOND)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
TOFIX	F10.0	51-60	Fixed outlet temperature (K)
COP	F10.0	61-70	Coefficient of performance
Card 2			
LOAD	A10	1-10	LOAD = "COOLLD" if external cooling load is supplied by subroutine DAREXL. This field is blank when external loads are not supplied.
DEMAND	A10	11-20	DEMAND = "COOLDM" if component supplied cooling demands are to be met. This field is blank if no demands are to be met.
NCD	I5 or A5	21-80	List of component numbers supplying demands, in fields of five. If all cooling demands in the system are met by this air-conditioning component, the word "ALL" can be used in Columns 21-25.
Card 3			
EOF			

Table 2 Output--

Parameter	Description
EER	Rate at which energy is extracted from fluid (W)

Tape 40 Output --

Parameter	Description
EER	Rate at which energy is extracted from fluid (W)
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

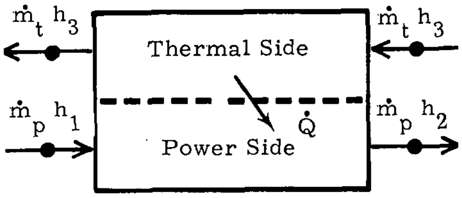
Note -- This component uses heat-transfer-fluid property data

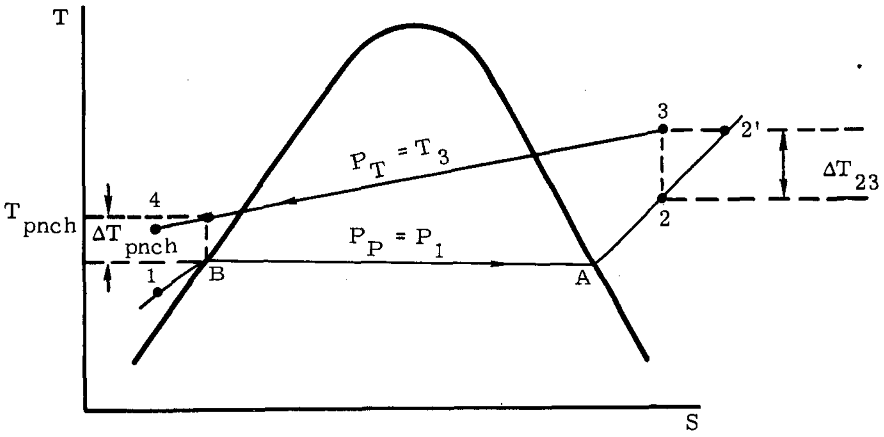
c. Boilers

Subroutine THMBLR*

Program Description--THMBLR is a model for an adiabatic boiler wherein energy is transferred to the power-cycle working fluid (power side) by cooling a counterflowing heat-transfer fluid (thermal side). The power-side inlet and outlet states may be superheated vapor, liquid-vapor mixture, or compressed liquid states. Temperature differences between the power and thermal fluids at the thermal-side inlet and at the pinch-point or the power-side inlet are user input. Pressure is assumed constant in each side of THMBLR.

Mathematical Algorithm--





---

*Open Type 4 thermodynamic model

$$T_2 = T_3 - \Delta T_{23} \tag{1}$$

$$T_{pnch} = T_A + \Delta T_{pnch} \tag{2}$$

Case I. $T_2 > T_A$, $T_1 < T_A$, and $T_3 < T_{pnch}$

$$\dot{m}_p(h_2 - h_B) = \dot{m}_t \int_{T_{pnch}}^{T_3} C\, dT \qquad (3)^1$$

$$\dot{m}_p(h_B - h_1) = \dot{m}_t \int_{T_4}^{T_{pnch}} C\, dT \tag{4}$$

$$\dot{Q}_{PH} = \dot{m}_p(h_B - h_1) \tag{5}$$

$$\dot{Q}_{VP} = \dot{m}_p(h_A - h_B) \tag{6}$$

$$\dot{Q}_{SH} = \dot{m}_p(h_2 - h_A) \tag{7}$$

$$T_{SH} = T_2 - T_A \tag{8}$$

Case II. $T_2 < T_1$ or $T_2 = T_1 \neq T_A$

The thermal- and power-side outlet states are set to ambient conditions, and

$$\dot{m}_p = \dot{m}_t = \dot{Q}_{PH} = \dot{Q}_{VP} = \dot{Q}_{SH} = T_{SH} = 0 \tag{9}$$

Case III. $T_2 > T_A$ and $T_1 = T_A$

$$T_4 = T_{pnch} \tag{10}$$

If $T_4 \geq T_3$, algorithm is the same as for Case II.

$$\dot{m}_p(h_2 - h_1) = \dot{m}_t \int_{T_{pnch}}^{T_3} C\, dT \qquad (11)^1$$

$$\dot{Q}_{PH} = 0 \tag{12}$$

$$\dot{Q}_{VP} = \dot{m}_p(h_A - h_1) \tag{13}$$

$$\dot{Q}_{SH} = \dot{m}_p(h_2 - h_A) \tag{14}$$

$$T_{SH} = T_2 - T_A \tag{15}$$

<u>Case IV</u>. $T_2 > T_A$, $T_1 > T_2$, and $T_1 < T_2$

$$T_4 = T_1 + \Delta T_{pnch} \tag{16}$$

If $T_4 \geq T_3$, algorithm is the same as for Case II; otherwise,

$$\dot{m}_p(h_2 - h_1) = \dot{m}_t \int_{T_3}^{T_4} C\, dT \qquad (17)^1$$

$$\dot{Q}_{PH} = \dot{Q}_{VP} = 0 \tag{18}$$

$$\dot{Q}_{SH} = \dot{m}_p(h_2 - h_1) \tag{19}$$

$$T_{SH} = T_2 - T_A$$

<u>Case V</u>. $T_2 = T_A$ and $T_1 < T_A$

If $T_3 \leq T_{pnch}$, algorithm is the same as for Case II; otherwise,

$$\dot{m}_p(h_B - h_A) = \dot{m}_t \int_{T_{pnch}}^{T_3} C\, dT \qquad (20)^1$$

$$\dot{Q}_{PH} = \dot{m}_p(h_B - h_1) \tag{21}$$

$$\dot{Q}_{VP} = \dot{m}_p(h_A - h_B) \tag{22}$$

$$\dot{Q}_{SH} = T_{SH} = 0 \tag{23}$$

Case VI. $T_2 > T_A$, $T_1 \leq T_A$, and $T_3 \leq T_{pnch}$

Fatal diagnostic

Case VII. $T_2 = T_1 = T_A$

If $T_3 \leq T_{pnch}$, algorithm is the same as for Case II; otherwise,

$T_4 = T_{pnch}$

$$\dot{m}_p(h_A - h_1) = \dot{m}_t \int_{T_{pnch}}^{T_3} C\ dT \qquad (24)^1$$

$$\dot{Q}_{PH} = \dot{Q}_{SH} = T_{SH} = 0 \qquad (25)$$

$$\dot{Q}_{VP} = \dot{m}_p(h_A - h_1) \qquad (26)$$

Case VIII. $T_2 < T_A$, $T_1 < T_A$, and $T_2 > T_1$

$T_4 = T_1 + \Delta T_{pnch}$

If $T_4 \geq T_3$, algorithm is the same as for Case II; otherwise,

$$\dot{m}_p(h_2 - h_1) = \dot{m}_t \int_{T_4}^{T_3} C\ dT \qquad (27)^1$$

$$\dot{Q}_{PH} = \dot{m}_p(h_2 - h_1) \qquad (28)$$

$$\dot{Q}_{VP} = \dot{Q}_{SH} = T_{SH} = 0 \qquad (29)$$

Case IX. $T_1 > T_A$, $T_2 > T_A$, and $T_2 > T_1$

$$T_4 = T_1 + \Delta T_{pnch} \qquad (30)$$

If $T_4 \leq T_3$, algorithm is the same as for Case II; otherwise,

$$\dot{m}_p(h_2 - h_1) = \dot{m}_t \int_{T_4}^{T_3} C \, dT \qquad (31)^1$$

$$\dot{Q}_{PH} = \dot{Q}_{VP} = 0 \qquad (32)$$

$$\dot{Q}_{SH} = \dot{m}_p(h_2 - h_1) \qquad (33)$$

$$T_{SH} = T_2 - T_A \qquad (34)$$

For each of these cases,

$$\dot{Q} = \dot{Q}_{PH} + \dot{Q}_{VP} + \dot{Q}_{SH} \qquad (35)$$

when

$$\dot{Q} = 0, \ \text{EFF} = 0$$

and when

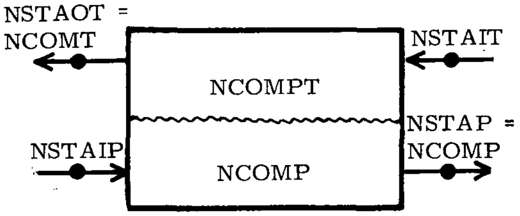
$$\dot{Q} \neq 0, \ \text{EFF} = \frac{\dot{Q}}{\dot{Q} + \dot{m}_p(h_{2'} - h_2)} \qquad (36)$$

where

$\dot{m}_p$	is the fluid-flow rate through the power side,
$\dot{m}_t$	is the fluid-flow rate through the thermal side,
h_1	is the specific enthalpy of the power fluid entering THMBLR,
h_2	is the specific enthalpy of the power fluid leaving THMBLR,
h_3	is the specific enthalpy of the thermal fluid entering THMBLR,
h_4	is the specific enthalpy of the thermal fluid leaving THMBLR,
A	denotes the saturated vapor state of the power fluid at the pressure $P_p = P_1$,
B	denotes the saturated liquid state of the power fluid at the pressure $P_p = P_1$,

T_A	is the power fluid saturation temperature,
P_p	is the power-side pressure,
P_t	is the thermal-side pressure,
ΔT_{23}	is the temperature difference between the thermal fluid and power fluid at the thermal-fluid inlet,
ΔT_{pnch}	is the temperature difference between the thermal fluid and power fluid at the pinch point or at the power-fluid inlet,
T_1	is the temperature of the power fluid entering THMBLR,
T_2	is the temperature of the power fluid leaving THMBLR,
T_3	is the temperature of the thermal fluid entering THMBLR,
T_4	is the temperature of the thermal fluid leaving THMBLR,
T_{pnch}	is the temperature of the thermal fluid at the pinch point,
h_A	is the specific enthalpy of the power fluid at the saturated vapor state,
h_B	is the specific enthalpy of the power fluid at the saturated liquid state,
C	is the specific heat of the thermal fluid,
$\dot{Q}_{PH}$	is the preheater heat rate,
$\dot{Q}_{VP}$	is the vaporizer heat rate,
$\dot{Q}_{SH}$	is the superheater heat rate,
$\dot{Q}$	is the boiler heat rate,
T_{SH}	is degrees superheat of the power fluid leaving THMBLR,
EFF	is the boiler effectiveness,
$h_{2'}$	is the specific enthalpy of the power fluid at state 2'.

Input--



Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"THMBLR"
NCOMT	I10	11-20	Thermal-side component number
NSTAIT	I5	21-25	Thermal-side inlet state number
NCOMP	I5	31-35	Power-side component number
NSTAIP	I5	36-40	Power-side inlet state number
DT23	F10.0	51-60	Temperature difference between thermal-side inlet and power-side outlet states (K)
DTpnch	F10.0	61-70	Temperature difference between thermal fluid and power fluid at the pinch point or between the thermal-side outlet and power-side inlet states (K)
Card 2			
EOF			

Notes--

1. The thermal-side flow rate is calculated from this equation when the power side demands energy from the thermal side. The load management routine LODMG directs the boiler to demand energy from the thermal side in the POWER or HEAT operational modes. The power-side flow rate is calculated from this equation when the power side does not demand energy from the thermal side. The power side does not demand energy from the thermal side in systems with no load management or in system with LODMG in the simulation operational mode.
2. This component requires both heat-transfer-fluid properties and power-cycle working-fluid constants.

Table 2 Output--

Parameter	Description
T_{SH}	Power-side inlet superheat (K)
T_4	Vaporization temperature (K)
$\dot{Q}_{PH}$	Preheater heat rate (W)
$\dot{Q}_{VP}$	Vaporizer heat rate (W)

Parameter	Description
$\dot{Q}_{SH}$	Superheater heat rate (W)
$\dot{Q}$	Boiler heat rate (W)
EFF	Boiler effectiveness (%)

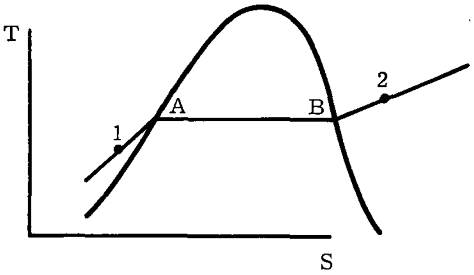
Tape 40 Output--

Parameter	Description
$\dot{Q}$	Boiler heat rate (W)
T_2	Power-side outlet temperature (K)
P_p	Power-side pressure (Pa)
$\dot{m}_p$	Power-side fluid-flow rate (kg/s)
$\dot{m}_t$	Thermal-side fluid-flow rate (kg/s)
EFF	Boiler effectiveness (%)

Subroutine AUXBLR[*]

Program Description--AUXBLR is a model for an adiabatic auxiliary boiler. The heat rates required for preheating, vaporizing, and superheating the fluid entering AUXBLR and leaving at the user-supplied thermodynamic state are calculated. The entering fluid may be a compressed liquid, liquid-vapor mixture, or superheated vapor. AUXBLR may be placed in series or parallel to other boilers in the system model.

Mathematical Algorithm--



Case I. $T_1 > T_2$, or $T_1 = T_2 \neq T_A$

Fatal diagnostic

Case II. $T_2 < T_A$

Fatal diagnostic

Case III. $T_1 < T_A$, $T_2 = T_A$

$$\dot{Q}_{PH} = \dot{m}(h_A - h_1) \qquad (1)$$

$$\dot{Q}_{VP} = \dot{m}(h_2 - h_A) \qquad (2)$$

$$\dot{Q}_{SH} = 0 \qquad (3)$$

$$T_{SH} = 0 \qquad (4)$$

---

[*] Open Type 1 thermodynamic model

$T_1 < T_A, T_2 > T_A$

$$\dot{Q}_{PH} = \dot{m}(h_A - h_1) \tag{5}$$

$$\dot{Q}_{VP} = \dot{m}(h_B - h_A) \tag{6}$$

$$\dot{Q}_{SH} = \dot{m}(h_2 - h_B) \tag{7}$$

$$T_{SH} = T_2 - T_B \tag{8}$$

Case IV. $T_1 = T_2 = T_A$

$$\dot{Q}_{PH} = \dot{Q}_{SH} = T_{SH} = 0 \tag{9}$$

$$\dot{Q}_{VP} = \dot{m}(h_2 - h_1) \tag{10}$$

Case V. $T_1 = T_A; T_2 > T_A$

$$\dot{Q}_{PH} = 0 \tag{11}$$

$$\dot{Q}_{VP} = \dot{m}(h_B - h_1) \tag{12}$$

$$\dot{Q}_{SH} = \dot{m}(h_2 - h_B) \tag{13}$$

$$T_{SH} = T_2 - T_B \tag{14}$$

Case VI. $T_1 > T_A, T_2 > T_1$

$$\dot{Q}_{PH} = \dot{Q}_{VP} = 0 \tag{15}$$

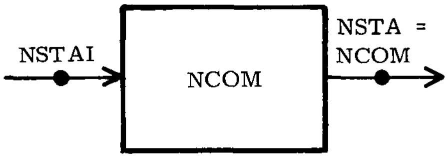
$$\dot{Q}_{SH} = \dot{m}(h_2 - h_1) \tag{16}$$

$$T_{SH} = T_2 - T_1 \tag{17}$$

Case VII. $\dot{m} = 0$

The outlet state is set to ambient conditions.

Input--



Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"AUXBLR"
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Inlet state number
T_2	F10.0	51-60	Outlet temperature (K)
X_2	F10.0	61-70	Outlet quality (%) if outlet state is a liquid-vapor mixture

Table 2 Output--

Parameter	Description
T_S	Vaporization temperature (K)
$\dot{Q}_{PH}$	Preheater heat rate (W)
$\dot{Q}_{VP}$	Vaporizer heat rate (W)
$\dot{Q}_{SH}$	Superheater heat rate (W)
$\dot{Q}$	Boiler heat rate (W)
T_{SH}	Outlet superheat (K)

Tape 40 Output--

Parameter	Description
P	Boiler pressure (Pa)
T_s	Vaporization temperature (K)
$\dot{Q}_{PH}$	Preheater heat rate (W)
$\dot{Q}_{VP}$	Vaporizer heat rate (W)

Parameter	Description
$\dot{Q}_{SH}$	Superheater heat rate (W)
$\dot{Q}$	Boiler heat rate (W)
T_{SH}	Outlet superheat (K)

Note--Power-cycle working-fluid constants are required by this component.

d. Collectors

Subroutine FOCOL*

Program Description -- Subroutine FOCOL is a simple model of a focusing collector based on known-collector efficiency. A specified fraction of the incident solar energy is transmitted to the fluid flowing through the collector. Two options are available. In the first, outlet temperature is specified. Fluid-flow rate through the collector needed to achieve this temperature is then calculated. In the second, outlet temperature is not specified. The inlet-flow rate is not changed and outlet temperature is calculated. When the sun's elevation angle is less than zero, the fluid-flow rate is set to zero, and outlet temperature and pressure are set to ambient conditions. Pressure drop through the collector is not calculated.

Mathematical Algorithm--

$$Q_f = W \cdot L \cdot \eta \cdot q_s \cdot N = \dot{m} \int_{T_i}^{T_o} C \, dT$$

$$\text{PRISUP} = [\text{ENT} + \text{ENS}\,(1 - \sin\alpha)] \cdot W \cdot L \cdot N$$

$$\text{THMLOS} = \text{PRISUP} - Q_f$$

where

Q_f = rate of energy transfer to fluid (W)

W = reflector width (m)

L = reflector length (m)

η = collector efficiency (-)

q_s = direct solar insolation (W/m^2)

N = number of collectors in parallel (-)

$\dot{m}$ = fluid-flow rate (kg/s)

C = fluid specific heat (J/kg/K)

T = fluid temperature (K)

T_i = fluid temperature at inlet conditions (K)

T_o = fluid temperature at outlet conditions (K)

PRISUP = $[\text{ENT} + \text{ENS}\,(1 - \sin\alpha)] \cdot W \cdot L \cdot N$

ENT = total horizontal solar insolation (W/m^2)

ENS = the specular insolation $\left(W/m^2\right)$

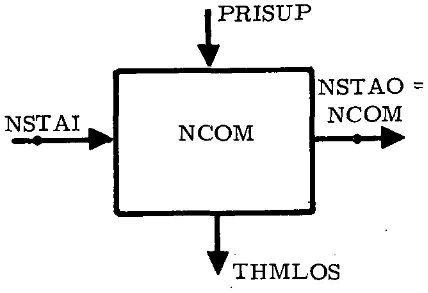
α = elevation angle

THMLOS = thermal loss (W)

---

[*] Open Type 1 thermodynamic model

Input--



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (FOCOL)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
TOFIX	F10.0	51-60	Fixed outlet temperature (K) (when left blank, outlet temperature will be calculated)
Card 2			
NCOL	I10	11-10	Number of collectors in parallel
W	F10.0	11-20	Reflector width (m)
XL	F10.0	21-30	Reflector length (m)
FRACT	F10.0	31-40	Collector efficiency (-)
Card 3			
EOF			

Table 2 Output --

Parameter	Description
Q	Rate of energy transfer to fluid (W)

Tape 40 Output --

Parameter	Description
Q	Rate of energy transfer to fluid (W)
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

Note--This component uses heat-transfer-fluid property data.

Subroutine DISH*

Program Description--Subroutine DISH models a focusing dish reflector with its own receiver. A complete field of collectors is specified in a regular diamond or rectangle pattern. Dish-shadowing calculations are made at each time step. Receiver efficiency is calculated based on an energy balance at the receiver. Dish efficiency combines reflectance, receiver efficiency, and shadowing effects. Rate of energy transfer to fluid flowing through the receiver is computed as a function of dish efficiency, area, and solar insolation. Two options are available for computation of the outlet fluid state. In the first, outlet temperature is specified. Fluid-flow rate through the receiver needed to achieve this temperature is then calculated. In the second, outlet temperature is not specified. The inlet-flow rate is not changed and outlet temperature is calculated. When the sun's elevation angle is less than zero, the fluid-flow rate is set to zero, and outlet temperature and pressure are set to ambient conditions. Pressure drop through the receiver is not calculated.

Mathematical Algorithm--

$$Q_{i,r} = q_s A_d \rho_d \eta_{shad} \qquad ; \; A_d = \frac{\pi}{4} D_d^2 \tag{1}$$

$$Q_{\ell,r} = A_r \left[\epsilon_r \sigma T_w^4 + h_c (T_w - T_a) \right] \tag{2}$$

$$\eta_r = \alpha_r - \frac{Q_{\ell,r}}{Q_{i,r}} \tag{3}$$

$$\eta_d = \rho_d \eta_{shad} \, \eta_r \tag{4}$$

$$Q_f = Q_{i,r} \eta_r \, N = \dot{m} \int_{T_i}^{T_o} C \; dT \tag{5}$$

$$\text{PRISUP} = [\text{ENT} + \text{ENS}\,(1 - \sin\alpha] \cdot A_d \cdot N$$

$$\text{THMLOS} = \text{PRISUP} - Q_f$$

where

$Q_{i,r}$ = energy rate incident on receiver (W)

q_s = direct solar insolation (W/m^2)

ρ_d = dish reflectance (-)

---

*Open Type 1 thermodynamic model

[*]η_{shad} = fraction of dish reflector surface not shadowed (-)

D_d = dish diameter (m)

$Q_{\ell,r}$ = radiation and convection losses from receiver (W)

A_r = receiver aperture area (m^2)

ϵ_r = receiver emittance (IR) (-)

σ = Stephan-Boltzmann constant ($W/m^2/K^4$)

T_w = receiver wall temperature (K)

T_a = ambient air temperature (K)

h_c = convection heat-transfer coefficient ($W/m^2/K$)
(Note: $h_c = 22.713\ W/m^2/K$ is used)

η_r = receiver efficiency (-)

α_r = receiver absorptance (solar) (-)

η_d = dish efficiency (-)

Q_f = rate of energy transfer to fluid (W)

N = number of collectors in parallel (-)

$\dot{m}$ = fluid-flow rate (kg/s)

C = fluid specific heat (J/kg/K)

T = fluid temperature (K)

T_i = fluid temperature at inlet conditions (K)

T_o = fluid temperature at outlet conditions (K)

PRISUP = primary supply rate (W)

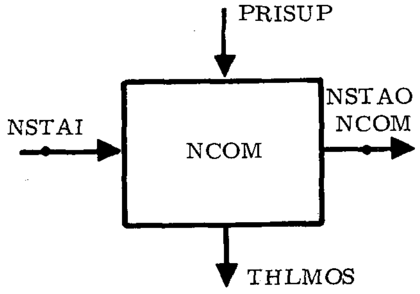
ENT = total horizontal solar insolation (W/m^2)

ENS = the specular insolation $\left(W/m^2\right)$

α = elevation angle

THMLOS = thermal loss (W)

Input --



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[*] Subroutine furnished by J. C. Zimmerman, Sandia Laboratories, Dispersed Power Applications Division, Albuquerque, NM.

Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (DISH)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
TOFIX	F10.0	51-60	Fixed outlet temperature (K) (when left blank, outlet temperature will be calculated)
Card 2			
NCOL	I10	1-10	Number of collectors in parallel
DISHDIA	F10.0	11-20	Dish diameter (m)
REFL	F10.0	21-30	Dish spectral reflectance
NSHAPE	A10	31-40	Field layout (rectangle or diamond)
SNS	F10.0	41-50	North-south dish spacing (m)
SEW	F10.0	51-60	East-west dish spacing (m)
DWEST	F10.0	61-70	Slope of land to the west (m/100 m)
DNORTH	F10.0	71-80	Slope of land to the north (m/100 m)
Card 3			
AREC	F10.0	1-10	Receiver aperture area (m^2)
ABSOR	F10.0	11-20	Receiver absorptance (solar)
EMITT	F10.0	21-30	Receiver emittance (infrared)
Card 4			
EOF			

Table 2 Output --

Parameter	Description
HTFLD	Rate of energy transfer to fluid (W)
COLEFF	Dish efficiency

Tape 40 Output --

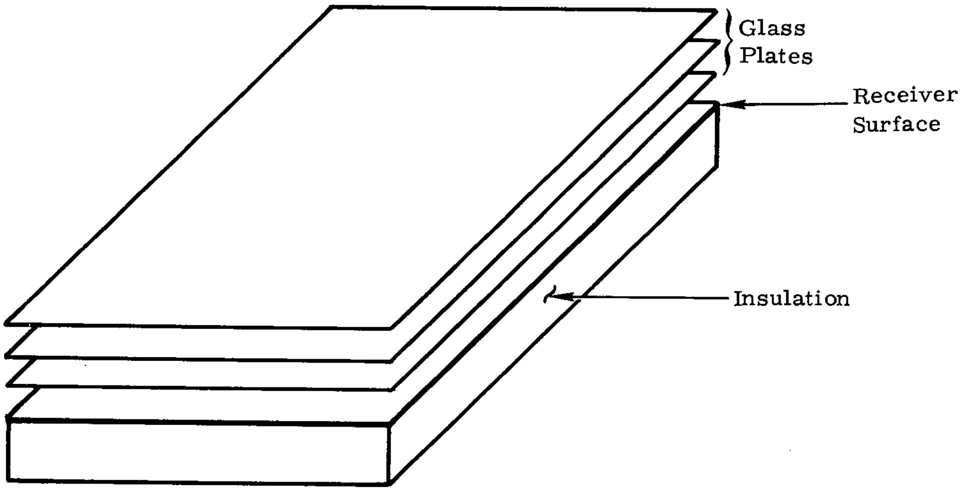
Parameter	Description
HTFLD	Rate of energy transfer to fluid (W)
COLEFF	Dish efficiency (-)

TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

Note--This component uses heat-transfer-fluid property data.

Subroutine FLTPLT*

Program Description -- Subroutine FLTPLT models a flat-plate collector with up to nine equally spaced glass plates above the receiver plate, which is insulated below (see figure).



Flat-Plate Collector With Equally Spaced Glass
Plates Above the Insulated Receiver Plate

The model considers visible spectrum and infrared radiative transfer between the glass and receiver plates, convective and radiative losses from the top plate, conductive transfer across the gaps between the plate surfaces, conductive losses through the insulation, and convective energy transfer into the fluid (assuming a uniform temperature-receiver plate). Energy balance equations for the glass plates and receiver plate are solved simultaneously to determine temperatures. The rate of energy transfer to the fluid is calculated.

Mathematical Algorithm --**

$$\text{PRISUP} = [\text{ENT} + \text{ENS}\,(1 - \sin\alpha)] \cdot A_r \cdot N$$

$$\text{THMLOS} = \text{PRISUP} - Q_f$$

---

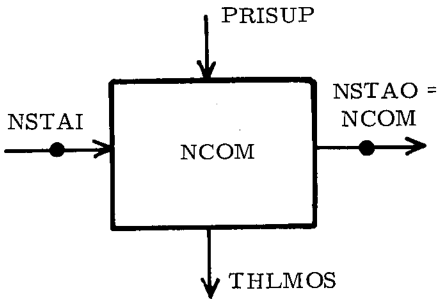
*Open Type 1 thermodynamic model

**M. W. Edenburn and N. R. Grandjean, Energy System Simulation Computer Program - SOLSYS, SAND75-0048, Sandia Laboratories, Albuquerque, NM, June 1975.

where

PRISUP = primary supply rate (W)
ENT = total horizontal solar insolation (W/m^2)
ENS = the specular insolation $\left(W/m^2\right)$
A_r = receiver area (m^2)
N = number of collectors in parallel
α = elevation angle
THMLOS = thermal loss (W)
Q_f = rate of energy transfer to fluid (W)

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (FLTPLTC)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
NCOL	I10	51-60	Number of collectors in parallel
NG	I10	61-70	Number of glass plates
PERIFL	F10.0	71-80	Wetted perimeter of fluid channel (m)
Card 2			
ARFL	F10.0	1-10	Cross-sectional area of fluid channel (m^2)
XLFL	F10.0	11-20	Length of fluid channel (m)
ARPL	F10.0	21-30	Receiver area (m^2)
SPACPL	F10.0	31-40	Spacing between plates (m)
XLPL	F10.0	41-50	Receiver length (m)
BET	F10.0	51-60	Collector tilt from horizontal (degrees)
CGAP	F10.0	61-70	Thermal conductivity of gap between plates (W/m/K)
REFCV	F10.0	71-80	Receiver reflectance (visible)

Card 3

REFGV	F10.0	1-10	Glass reflectance (visible)
TRNGV	F10.0	11-20	Glass transmittance (visible)
EMTCI	F10.0	21-30	Receiver emittance (IR)
EMTGI	F10.0	31-40	Glass emittance (IR)
CONDINS	F10.0	41-50	Thermal conductivity of back insulation (W/m/K)
THCKINS	F10.0	51-60	Insulation thickness (m)

Table 2 Output --

Parameter	Description
EFF	Collector efficiency (-)
HTFLD	Rate of energy transfer to fluid (W)

Tape 40 Output --

Parameter	Description
EFF	Collector efficiency (-)
HTFLD	Rate of energy transfer to fluid (W)
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

Note -- This component uses heat-transfer-fluid property data.

Subroutine FOCMWE*

Program Description--Subroutine FOCMWE determines the performance of a focusing cylindrical parabolic collector using the following assumptions.

1. The system is in equilibrium.
2. The incident sun's rays are parallel.
3. The reflector has a perfect parabolic surface.
4. Envelope- and receiver-tube temperatures are uniform circumferentially.
5. The envelope- and receiver-tube walls are thin and have no temperature gradient through them in the radial direction.

Energy balance equations for the envelope and receiver tube consider the following (see figure).

1. Solar-energy reflection and transmission.
2. Infrared radiation transfer between the receiver-tube surface and separate silvered envelope and envelope-window surfaces.
3. Radiation energy losses from the envelope's outside surface.
4. Convective heat transfer from the receiver tube to a fluid flowing in the receiver tube.
5. Convective heat transfer between the receiver tube and envelope.
6. Convective losses from the envelope to the ambient.
7. Wind velocity over the envelope.

Receiver-tube and envelope temperatures that solve the energy balance equations are determined using a nonlinear equation solver. The temperature rise of the fluid flowing through the receiver tube is computed.

End effects due to the sun's rays not being perpendicular to the collector's axis are considered.

Orientation for east-west, north-south, and tracking collectors are determined as functions of the sun's azimuth and elevation angles.

Fluid pressure drop through the receiver is calculated.

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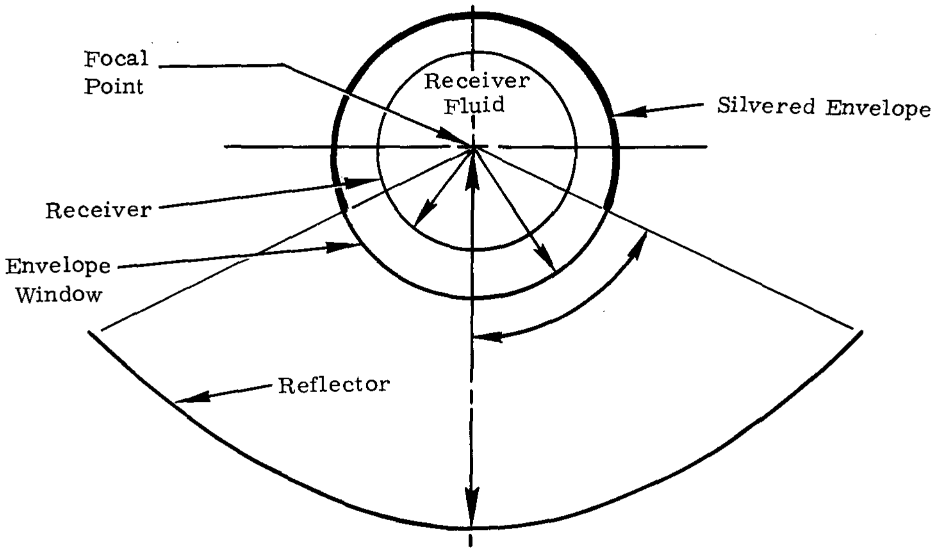
*Open Type thermodynamic model



Receiver Tube, Envelope Geometry

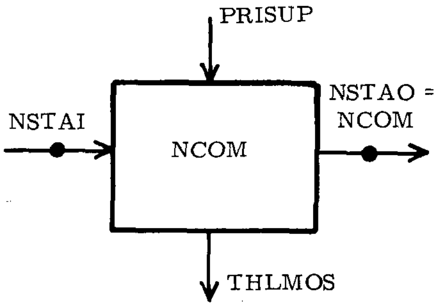
Mathematical Algorithm --*

$$PRISUP = [ENT + ENS(1 - \sin \alpha)] \cdot W \cdot L \cdot N$$
$$THMLOS = PRISUP - Q_f$$

where

PRISUP = primary supply rate (W)
ENT = total horizontal solar insolation (W/m^2)
ENS = the specular insolation $\left(W/m^2\right)$
W = reflector width (m)
L = reflector length (m)
N = number of collectors in parallel
α = elevation angle
THMLOS = thermal loss (W)
Q_f = rate of energy transfer to fluid (W)

Input --



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*M. W. Edenburn, "Performance Analysis of a Cylindrical Focusing Collector and Comparison with Experimental Results," Solar Energy, 18, pp 437-444, 1976.

Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (FOCMWE)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
NCOL	I10	51-60	Number of collectors in parallel
RW	F10.0	61-70	Reflector width (m)
XLR	F10.0	71-80	Reflector length (m)
Card 2			
XLC	F10.0	1-10	Receiver length (m)
XF	F10.0	11-20	Focal length (m)
DE	F10.0	21-30	Receiver envelope diameter (m)
DC	F10.0	31-40	Receiver diameter (m)
DI	F10.0	41-50	Plug diameter (m)
BETAD	F10.0	51-60	Tilt angle for NS collector (degrees)
TYPE	A10	61-70	Collector type (NS, EW, or TR)
INL	I10	71-80	Inlet side (+1 if south or east)
Card 3			
REFRV	F10.0	1-10	Reflector reflectance (visible)
REFWV	F10.0	11-20	Window reflectance (visible)
TRNWV	F10.0	21-30	Window transmittance (visible)
REFCV	F10.0	31-40	Receiver reflectance (visible)
REFWI	F10.0	41-50	Window reflectance (IR)
EMTWI	F10.0	51-60	Window emittance (IR)
REFEI	F10.0	61-70	Silvered envelope reflectance (IR)
EMTEI	F10.0	71-80	Silvered envelope emittance (IR)

Parameter	Format	Columns	Description
Card 4			
REFCI	F10.0	1-10	Receiver reflectance (IR)
EMTCI	F10.0	11-20	Receiver emittance (IR)
NAIR	F10.0	21-30	Annulus condition (-1 for conduction, 0 for low pressure convection, 1 for atmospheric-pressure convection)
CONDA	F10.0	31-40	Annulus heat-transfer parameter (thermal conductivity (W/m/K) for NAIR = -1; convective heat-transfer coefficient (W/m^2/K) for NAIR = 0; not required for NAIR = 1).
Card 5			
EOF			

Table 2 Output --

Parameter	Description
EFF	Collector efficiency (-)
HTFLD	Rate of energy transfer to fluid (W)

TAPE 40 Output --

Parameter	Description
EFF	Collector efficiency (-)
HTFLD	Rate of energy transfer to fluid (W)
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

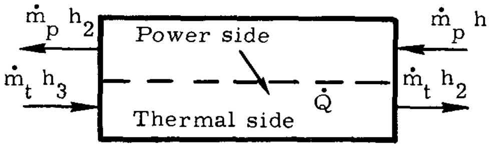
Note -- This component uses heat-transfer-fluid property data.

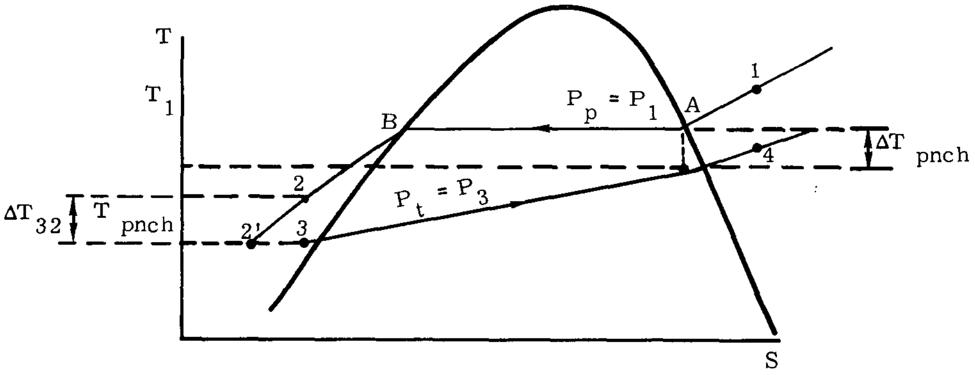
e. Condensers

Subroutine CNDHTR*

Program Description--CNDHTR is a model for an adiabatic condenser heater wherein energy is removed from the power-cycle working fluid (power side) by heating a counterflowing heat-transfer fluid (thermal side). The power-side inlet and outlet states may be superheated vapor, liquid-vapor mixture, or compressed liquid states. Temperature differences between the power and thermal fluids at the thermal-side inlet and at the pinch-point or at the power-side inlet are user input. Pressure is assumed constant in each side of CNDHTR.

Mathematical Algorithm--*





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*Open Type 4 thermodynamic model

$$T_2 = T_3 + \Delta T_{32} \tag{1}$$

$$T_{pnch} = T_A - \Delta T_{pnch} \tag{2}$$

Case I. $T_2 < T_A$, $T_1 > T_A$, and $T_3 < T_{pnch}$

$$\dot{m}_p(h_A - h_2) = \dot{m}_t \int_{T_3}^{T_{pnch}} C\, dT \qquad (3)^1$$

$$\dot{m}_p(h_1 - h_A) = \dot{m}_t \int_{T_{pnch}}^{T_4} C\, dT \tag{4}$$

$$\dot{Q}_{LQ} = \dot{m}_p(h_B - h_2) \tag{5}$$

$$\dot{Q}_{LH} = \dot{m}_p(h_A - h_B) \tag{6}$$

$$\dot{Q}_{VP} = \dot{m}_p(h_1 - h_A) \tag{7}$$

$$TSH = T_1 - T_A \tag{8}$$

Case II. $T_2 > T_1$, or $T_2 = T_1 \neq T_A$

The thermal- and power-side outlet states are set to ambient conditions, and

$$\dot{m}_p = \dot{m}_t = \dot{Q}_{LQ} = \dot{Q}_{LH} = \dot{Q}_{VP} = EFF = T_{SH} = 0 \tag{9}$$

Case III. $T_2 < T_A$ and $T_1 = T_A$

$$T_4 = T_{pnch} \tag{10}$$

If $T_4 \leq T_3$, algorithm is the same as for Case II;

otherwise,

$$\dot{m}_p(h_1 - h_2) = \dot{m}_t \int_{T_3}^{T_{pnch}} C\, dT \qquad (11)^1$$

$$\dot{Q}_{LQ} = \dot{m}_p(h_B - h_2) \tag{12}$$

$$\dot{Q}_{LH} = \dot{m}_p(h_A - h_B) \tag{13}$$

$$\dot{Q}_{VP} = T_{SH} = 0 \tag{14}$$

Case IV. $T_2 < T_A$, $T_1 < T_A$, and $T_1 > T_2$

$$T_4 = T_1 - \Delta T_{pnch} \tag{15}$$

If $T_4 \leq T_3$, algorithm is the same as for Case II;

otherwise

$$\dot{m}_p(h_1 - h_2) = \dot{m}_t \int_{T_3}^{T_4} C\, dT \tag{16}$$ [1]

$$\dot{Q}_{LQ} = \dot{m}_p(h_1 - h_2) \tag{17}$$

$$\dot{Q}_{LH} = \dot{Q}_{VP} = T_{SH} = 0 \tag{18}$$

Case V. $T_2 = T_A$ and $T_1 > T_A$

If $T_3 \geq T_{pnch}$, algorithm is the same as for Case II;

otherwise

$$\dot{m}_p(h_A - h_B) = \dot{m}_t \int_{T_3}^{T_{pnch}} C\, dT \tag{19}$$

$$\dot{m}_p(h_1 - h_A) = \dot{m}_t \int_{T_{pnch}}^{T_4} C\, dT \tag{20}$$

$$\dot{Q}_{LQ} = 0 \tag{21}$$

$$\dot{Q}_{LH} = \dot{m}_p(h_A - h_B) \tag{22}$$

$$\dot{Q}_{VP} = \dot{m}_p(h_1 - h_A) \tag{23}$$

$$T_{SH} = T_1 - T_A \tag{24}$$

Case VI. $T_2 < T_A$, $T_1 \geq T_A$, and $T_3 \geq T_{pnch}$

Fatal diagnostic

Case VII. $T_2 = T_1 = T_A$

If $T_3 \geq T_{pnch}$, algorithm is the same as for Case II;

otherwise

$T_4 = T_{pnch}$

$$\dot{m}_p(h_1 - h_B) = \dot{m}_t \int_{T_3}^{T_{pnch}} C\,dT \qquad (25)^1$$

$$\dot{Q}_{LQ} = \dot{Q}_{VP} = T_{SH} = 0 \qquad (26)$$

$$\dot{Q}_{LH} = \dot{m}_p(h_1 - h_B) \qquad (27)$$

Case VIII. $T_2 > T_A$, $T_1 > T_A$, and $T_1 > T_2$

$$T_4 = T_1 - \Delta T_{pnch} \qquad (28)$$

If $T_4 \leq T_3$, algorithm is the same as for Case II;

otherwise

$$\dot{m}_p(h_1 - h_2) = \dot{m}_t \int_{T_3}^{T_4} = C\,dT \qquad (29)^1$$

$$\dot{Q}_{LQ} = \dot{Q}_{LH} = 0 \qquad (30)$$

$$\dot{Q}_{VP} = \dot{m}_p(h_1 - h_2) \qquad (31)$$

$$T_{SH} = T_1 - T_A \qquad (32)$$

Case IX. $T_1 < T_A$, $T_2 < T_A$, and $T_1 > T_2$ (32)

$$T_4 = T_1 - \Delta T_{pnch} \qquad (33)$$

If $T_4 \leq T_3$, algorithm is the same as for Case II;

otherwise

$$\dot{m}_p(h_1 - h_2) = \dot{m}_t \int_{T_3}^{T_4} C\,dT \qquad (34)^1$$

$$\dot{Q}_{LQ} = \dot{m}_p(h_1 - h_2) \qquad (35)$$

$$\dot{Q}_{VP} = \dot{Q}_{LH} = T_{SH} = 0 \qquad (36)$$

For each of these cases

$$\dot{Q} = \dot{Q}_{LQ} + \dot{Q}_{LH} + \dot{Q}_{VP} \qquad (37)$$

when

$$\dot{Q} = 0\,,\quad EFF = 0$$

and when

$$\dot{Q} \neq 0\,,\quad EFF = \frac{\dot{Q}}{\dot{Q} + \dot{m}_p(h_2 - h_{2'})} \qquad (38)$$

where

$\dot{m}_p$ is the fluid-flow rate through the power side,

$\dot{m}_t$ is the fluid-flow rate through the thermal side,

h_1 is the specific enthalpy of the power fluid entering CNDHTR,

h_2 is the specific enthalpy of the power fluid leaving CNDHTR,

h_3 is the specific enthalpy of the thermal fluid entering CNDHTR,

h_4 is the specific enthalpy of the thermal fluid leaving CNDHTR,

A denotes the saturated vapor state of the power fluid at the pressure $P_p = P_1$,

B denotes the saturated liquid state of the power fluid at the pressure $P_p = P_1$,

T_A is the power-fluid saturation temperature,

P_p is the power-side pressure,

P_t is the thermal-side pressure,

ΔT_{32} is the temperature difference between the power fluid and the thermal fluid at the thermal-fluid inlet,

ΔT_{pnch} is the temperature difference between the power fluid and the thermal fluid at the pinch-point or at the power-fluid inlet,

T_1 is the temperature of the power fluid entering CNDHTR,

T_2 is the temperature of the power fluid leaving CNDHTR,

T_3 is the temperature of the thermal fluid entering CNDHTR,

T_4 is the temperature of the thermal fluid leaving CNDHTR,

T_{pnch} is the temperature of the thermal fluid at the pinch point,

h_A is the specific enthalpy of the power fluid at the saturated vapor state,

h_B is the specific enthalpy of the power fluid at the saturated liquid state,

C_p is the specific heat at constant pressure of the thermal fluid,

$\dot{Q}_{LQ}$ is the rate at which energy is removed from the power fluid while it is a liquid,

$\dot{Q}_{LH}$ is the rate at which energy is removed from the power fluid while it is condensing,

$\dot{Q}_{SH}$ is the rate at which energy is removed from the power fluid while it is a superheated vapor,

$\dot{Q}$ is the condenser heat rate,

T_{SH} is degrees superheat of the power fluid entering CNDHTR,

EFF is the condenser effectiveness and $h_{2'}$ is the specific enthalpy of the power fluid at state 2'

Input--

Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"CNDHTR"
NCOM1	I10	11-20	Power-side component number
NSTAT1	I5	21-25	Power-side inlet state number
NCOM2	I5	31-35	Thermal-side component number
NSTAI2	I5	36-40	Thermal-side inlet state number
Card 2			
DT32	F10.2	1-10	Temperature difference between power-side outlet and thermal-side inlet states (K)
DT_{pnch}	F10.2	11-20	Temperature difference between power fluid and thermal fluid at the pinch-point or between the power-side inlet and thermal-side outlet states (K)
NBR			Cascade flow branch number
Option 1	A10		Blank ⟹ this component does not determine the flow rate in a flow branch
Option 2	A4	21-24	"LAST"--this component determines the flow rate in the condensate return from the last turbine in the cascade
Option 3	I10	21-30	This component determines the flow rate in the flow branch number NBR in the turbine cascade
IQMTCH	I10	31-40	"1", "0", or blank IQMTCH = 1 ⟹ the thermal-side demands energy from the power side; IQMTCH = 0 or blank ⟹ the thermal side does not demand energy from the power side
Card 3			
EOF			

Notes--1. The power-side flow rate is calculated from this equation when the thermal side demands energy from the power side. The thermal-side flow rate is calculated from this equation when the thermal side does not demand energy from the power side. If the thermal- and power-side flow rates are zero, the outlet states are set to the ambient state.

2. This component requires both heat-transfer-fluid properties and power-cycle working-fluid constants.

Table 2 Output--

Parameter	Description
T_{SH}	Power-side inlet superheat (K)
T_A	Power-side saturation temperature (K)
$\dot{Q}_{VP}$	Vapor-heat rate (W)
$\dot{Q}_{LH}$	Latent-heat rate (W)
$\dot{Q}_{LQ}$	Liquid-heat rate (W)
$\dot{Q}$	Condenser-heat rate (W)
EFF	Condenser effectiveness (%)

Tape 40 Output--

Parameter	Description
$\dot{Q}$	Condenser-heat rate (W)
T_2	Power-side outlet temperature (K)
P_p	Power-side pressure (Pa)
$\dot{m}_p$	Power-side fluid-flow rate (kg/s)
$\dot{m}_t$	Thermal-side fluid-flow rate (kg/s)
EFF	Effectiveness (%)

f. Cooling Towers

Subroutine COOLTOW*

Program Description -- Subroutine COOLTOW models a dry cooling tower with an outlet temperature specified for the tower. If the fluid's inlet temperature exceeds this specified temperature, the outlet temperature is set to the specified value. The rate at which energy must be removed from the fluid to reach the outlet temperature is calculated. If the fluid's inlet temperature is less than the specified temperature, the outlet temperature is set equal to the inlet temperature, and the energy extraction rate is zero.

Mathematical Algorithm --

$$\text{for } T_i > T_o,\ q = \dot{m} \int_{T_o}^{T_i} C\, dT \qquad (1)$$

$$\text{for } T_i \le T_o,\ q = 0 \qquad (2)$$

$$\text{HEAT} = q$$

where

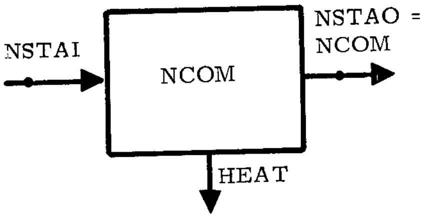
T_i = fluid inlet temperature (K)
T_o = fluid outlet temperature (K)
q = rate at which heat is lost by fluid (W)
$\dot{m}$ = fluid-flow rate (kg/s)
C = fluid specific heat (J/kg/K)

---

[*] Open Type 1 thermodynamic model

Subroutine COOLTOW

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (COOLTOW)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
TOFIX	F10.0	51-60	Specified outlet temperature (K)
Card 2			
EOF			

Table 2 Output --

Parameter	Description
ENEXT	Rate of energy extraction from fluid (W)

Tape 40 Output --

Parameter	Description
ENEXT	Rate of energy extraction from fluid (W)
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

Note -- This component uses heat-transfer-fluid property data.

g. Furnaces

Subroutine AUXFUR*

Program Description -- Subroutine AUXFUR models a furnace that heats a fluid flowing through the furnace. Fluid temperature at the furnace outlet is specified. Inlet fluid temperature is monitored, and if it is below the outlet temperature heat is added to the fluid at the furnace efficiency. Furnace heat rate necessary to maintain the desired outlet temperature is calculated. The rate at which energy must be supplied by the auxiliary source is also computed.

Mathematical Algorithm --

If $T_i \geq T_{o,fix}$, the furnace is not operated, $T_o = T_i$

If $T_i < T_{o,fix}$ (1)

$$Q = \dot{m} \int_{T_i}^{T_o} C \, dT \tag{2}$$

$$AUXSUP = Q/\eta \tag{3}$$

$$T_o = T_{o,fix} \tag{4}$$

$$THMLOS = AUXSUP - Q$$

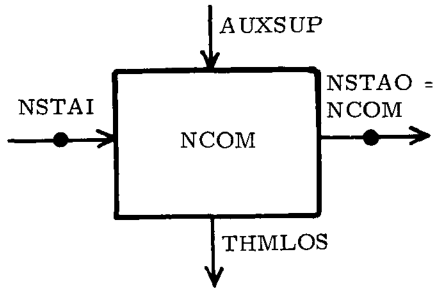
where

T_i = fluid inlet temperature (K)
T_o = fluid outlet temperature (K)
$T_{o,\ fix}$ = specified fluid-outlet temperature (K)
Q = furnace-heat rate (W)
$\dot{m}$ = fluid-flow rate (kg/s)
C = fluid specific heat (J/kg/K)
AUXSUP = rate of energy supplied by auxiliary source (W)
η = thermal loss (W)
THMLOS = thermal loss (W)

---

[*] Open Type 1 thermodynamic model

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (AUXFUR)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
TOFIX	F10.0	51-60	Specified outlet temperature (K)
EFF	F10.0	61-70	Furnace efficiency
Card 2			
EOF			

Table 2 Output --

Parameter	Description
Q	Furnace heat rate (W)
AUXSUP	Rate of energy supplied by auxiliary source (W)

Tape 40 Output --

Parameter	Description
Q	Furnace heat rate (W)
AUXSUP	Rate of energy applied by auxiliary source (W)
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

Note -- This component uses heat-transfer-fluid property data.

h. Heat Exchanger

Subroutine HTEXC *

Program Description -- Subroutine HTEXC models a counterflow heat exchanger. The heat exchanger is assumed to have a uniform heat-transfer coefficient between the two fluids. The local heat transfer depends on the heat-transfer area and coefficient and on the temperature difference between the two fluids. Temperature gradients due to local heat transfer are integrated to determine outlet temperatures.

Mathematical Algorithm -- for $\dot{m}_2 C_2 \neq \dot{m}_1 C_1$:

$$T_{o,1} = T_{i,1} + \frac{\dot{m}_2 C_2}{\dot{m}_1 C_1} \left(T_{i,2} - T_{o,2}\right) \tag{1}$$

$$T_{o,2} = \frac{T_{i,2}\left(1 - \frac{\dot{m}_2 C_2}{\dot{m}_1 C_1}\right) + T_{i,1}\left\{\exp\left[\frac{UA}{\dot{m}_2 C_2}\left(1 - \frac{\dot{m}_2 C_2}{\dot{m}_1 C_1}\right)\right] - 1\right\}}{\exp\left[\frac{UA}{\dot{m}_2 C_2}\left(1 - \frac{\dot{m}_2 C_2}{\dot{m}_1 C_1}\right)\right] - \frac{\dot{m}_2 C_2}{\dot{m}_1 C_1}} \tag{2}$$

for $\dot{m}_2 C_2 = \dot{m}_1 C_1$:

$$T_{o,1} = T_{i,1} + \left(T_{i,2} - T_{o,2}\right) \tag{3}$$

$$T_{o,2} = \frac{T_{i,2} + \frac{UA}{\dot{m}_2 C_2} T_{i,1}}{1 + \frac{UA}{\dot{m}_2 C_2}} \tag{4}$$

Rate of heat transfer is

$$Q = \dot{m} \int_{T_{o,1}}^{T_{i,1}} C_1 \, dT \tag{5}$$

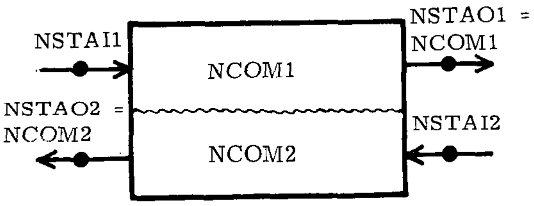
---

*Open Type 4 thermodynamic model

where

$\dot{m}_1$ = fluid-flow rate - Side 1
$\dot{m}_2$ = fluid-flow rate - Side 2
C_1 = fluid specific heat - Side 1
C_2 = fluid specific heat - Side 2
$T_{o,1}$ = outlet-fluid temperature - Side 1
$T_{o,2}$ = outlet-fluid temperature - Side 2
$T_{i,1}$ = inlet-fluid temperature - Side 1
$T_{i,2}$ = inlet-fluid temperature - Side 2
U = overall heat-transfer coefficient ($W/m^2/K$)
A = heat-transfer surface area (m^2)
Q = rate of heat transfer from Side 1 fluid to Side 2 fluid

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (HTEXC)
NCOM1	I10	11-20	Component number - Side 1
NSTAI1	I5	21-25	Upstream state number - Side 1
NCOM2	I5	31-35	Component number - Side 2
NSTAI2	I5	36-40	Upstream state number - Side 2
U	F10.0	51-60	Heat-transfer coefficient ($W/m^2/K$)
S	F10.0	61-70	Heat-transfer surface area (m^2)
Card 2			
EOF			

Table 2 Output --

Parameter	Description
Q	Rate of heat transfer from Side 1 fluid to Side 2 fluid (W)

Tape 40 Output --

Parameter	Description
Q	Rate of heat transfer from Side 1 fluid to Side 2 fluid (W)
TO1	Outlet temperature - Side 1 (K)
PO1	Outlet pressure - Side 2 (Pa)
FM1	Outlet flow rate - Side 1 (kg/s)
TO2	Outlet temperature - Side 2 (K)
PO2	Outlet pressure - Side 2 (Pa)
FM2	Outlet flow rate - Side 2 (kg/s)

Note -- This component uses heat-transfer-fluid property data.

j. Hot Water Heaters

Subroutine HOTWAT*

Program Description--Subroutine HOTWAT determines the rate (a hot-water load HWATLD) at which energy must be supplied to heat water from the water supply temperature to the hot-water temperature. The water-supply temperature is user input; the hot-water temperature is the water temperature entering HOTWAT. The hot-water requirements (volumetric flow rate) may be read as a function of time from a data file.

Mathematical Algorithm --

If $m_i = 0$, HWATLD = 0, and the outlet pressure and temperature are set to ambient conditions; otherwise

$$T_o = T_S \tag{1}$$

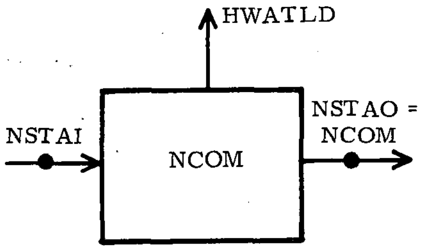
$$P_o = P_S \tag{2}$$

$$\dot{m} = \rho_i G \tag{3}$$

where

$\dot{m}_i$	is the water-flow rate entering HOTWAT (kg/s)
$\dot{m}$	is the water-flow rate through HOTWAT (kg/s)
HWATLD	is the hot-water load (W)
T_o	is the temperature of the hot water leaving HOTWAT (K)
P_o	is the pressure of the hot water leaving HOTWAT (Pa)
ρ_i	is water density entering HOTWAT (kg/m^3)
G	is the volumetric flow rate of the hot water (m^3/s)
T_i	is the water-entering temperature (K)
T_S	is the water-supply temperature (K)
P_S	is the water-supply pressure (Pa)
C	is the water specific heat (J/kg/K).

Input --



---

[*] Open Type 1 thermodynamic model

Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (HOTWAT)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Inlet state number
TOFIX	F10.0	51-60	Fixed water supply temperature (K)
POFIX	F10.0	61-70	Fixed water-supply temperature (K)

Card 2

EOF

Table 2 and Tape 40 Output --

Parameter	Description
VFR	Hot-water volumetric flow rate (m^3/s)
HWATLD	Rate at which energy must be supplied to heat the water (W)

Notes--1. This component uses heat-transfer-fluid property data.

2. HWATLD load-related information must be defined for this routine in the information routine DAREXL. This information must be supplied to DAREXL as a volumetric flow rate (m^3/s).

3. Although the name and description imply that this routine simulates hot-water heaters, it is equally applicable for simulating devices that provide hot liquids other than water.

Subroutine WATHTR[*]

Program Description -- Subroutine WATHTR determines the rate (a hot-water load HWATLD) at which energy must be supplied to heat water from the makeup water temperature to the hot-water temperature. The state point number of the makeup water is user input. The hot-water supply temperature and pressure are the water temperature and pressure entering WATHTR. The hot-water requirements (volumetric flow rate) may be read as a function of time from a data file.

Mathematical Algorithm -- If $\frac{|Gi - G|}{G} > \epsilon_{RF}$ and $G \neq 0$, fatal diagnostic

otherwise

$$T_o = T_i \tag{1}$$

$$P_o = P_o \tag{2}$$

$$\dot{m} = \rho_i G \tag{3}$$

$$HWATLD = \dot{m} \int_{T_i}^{T_{MKP}} C \, dT \tag{4}$$

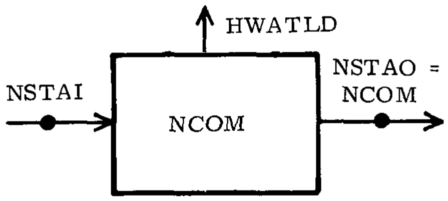
where

Gi	is the water volumetric flow rate entering WATHTR (m^3/s),
G	is the volumetric flow rate of the hot water (m^3/s),
ϵ_{RF}	is the steady-state relative convergence criteria for fluid flow rate (-),
$\dot{m}$	is the water flow rate through WATHTR (kg/s),
HWATLD	is the hot-water load (W),
T_o	is the hot-water supply temperature (K)
T_i	is the temperature of the water entering WATHTR (K),
ρ_i	is the density of the hot water (kg/m^3),
G	is the volumetric flow rate of the hot water (m^3/s),
T_{MKP}	is the temperature of the makeup water (K)
C	is the water specific heat (J/kg/K).

---

[*] Open Type 1 thermodynamic model.

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	Subroutine name (WATHTR)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Inlet state number
NMKP	I10	51-60	Outlet state number of component MKPFLD
Card 2			
EOF			

Table 2 and Tape 40 Output --

Parameter	Description
VFR	Hot-water volumetric flow rate (m^3/s)
HWATLD	Rate that energy must be supplied to heat the water (W)

Notes -- 1. This component uses heat-transfer-fluid property data.

2. HWATLD load-related information must be defined for this routine in the information routine DAREXL. This information must be supplied to DAREXL as a volumetric flow rate (m^3/s).

3. Although the name and description imply that this routine simulates hot-water heaters, it is equally applicable for simulating devices that provide hot liquids other than water.

k. Load Management

Subroutine LODMG*

Program Description--LODMG is a model that provides load management for generalized Rankine-type power cycles and performs energy accounting for each power loop. LODMG also allows the user to (1) select one of the three power-loop operational modes discussed in Appendix B, (2) select the electrical demands and parasitics, mechanical power demands and/or parasitics that are satisfied by the power loop, and (3) direct the power loop to follow external electrical and/or mechanical power loads. In addition, LODMG determines the unspecified fluid-flow rates and energy-transfer rates for each of the three operational modes and automatically informs the user if the independent energy-transfer rates defined by this input to the components in the power loop are under- or overspecified.

Mathematical Algorithm--For each operational mode, the values of pressure, temperature, and quality at the inlet and outlet states are identical.

Power Mode

$$(A - B_I)\dot{m} = \sum_{i=1}^{I-1} (B_i - B_I)\dot{m}_i + \sum_{i=I+1}^{NT} (B_i - B_I)\dot{m}_i - B_I\,\dot{m}_{NT+1} + \frac{\dot{W}_M}{\eta_{M_{jun}}} + \frac{\dot{W}_E}{\eta_{G_{jun}}} \qquad (1)$$

$$\dot{m}_I = \dot{m} - \sum_{i=1}^{I-1} \dot{m}_i - \sum_{i=I+1}^{NT+1} \dot{m}_i \qquad (2)$$

$$\dot{W} = \dot{W}_E + \dot{W}_M \qquad (3)$$

$$\dot{W}_E = ELCLD + ELCDM + ELCPS \qquad (4)$$

$$\dot{W}_M = POWLD + POWDM + POWPS \qquad (5)$$

where

A and B_i are functions of the enthalpy change, and mechanical efficiency of each turbine in the cascade; and the mechanical efficiency, electrical generating efficiency, and the ratio of mechanical and electrical power outputs of each turbine/generator in the cascade,

$\dot{m}$	is the fluid-flow rate through LODMG that is necessary to meet the electrical and mechanical power, and thermal loads; and the electrical demands and parasitics, mechanical power demands and parasitics satisfied by the power loop,
$\dot{m}_i$	is the fluid-flow rate through the i^{th} flow branch in the cascade,
$\dot{m}_I$	is the fluid-flow rate through the flow branch number I from which thermal loads are not specified or a flow rate is not demanded by a condenser,
NT	is the number of turbines in cascade,
$\eta_{M_{jun}}$	is the mechanical efficiency of the turbine/generator for which the ratio of the mechanical and electrical outputs is unspecified (if there are no turbine/generators in the cascade, jun = NT)
$\eta_{G_{jun}}$	is the electrical-generator efficiency of the turbine/generator for which the ratio of the mechanical and electrical outputs is unspecified (if there are no turbine/generators in the cascade, jun = NT),
$\dot{W}$	is the total power output of the loop,
ELCLD	are the electrical loads followed by this power loop and defined by Subroutine DAREXL,
ELCDM	is the electrical power required to meet all the electrical demands satisfied by the power loop,
ELCPS	is the electrical power required to meet all the electrical parasitics satisfied by the power loop,
POWLD	are the mechanical power loads followed by this power loop and defined by Subroutine DAREXL,
POWDM	is the mechanical power required to meet all the mechanical power demands satisfied by the power loop,
POWPS	is the mechanical power required to meet all the mechanical power parasitics satisfied by the power loop.

Heat Mode

$$\dot{m} = \sum_{i=1}^{NBR} \dot{m}_i \qquad (6)$$

$$\dot{W}_E = \sum_{i=1}^{NT} \dot{W}_{E_i} \qquad (7)$$

$$\dot{W}_M = \sum_{i=1}^{NT} \dot{W}_{M_i} \qquad (8)$$

$$\dot{W} = \dot{W}_E + \dot{W}_M \qquad (9)$$

$$ELCLD = \dot{W}_E - ELCDM - ELCPS \qquad (10)$$

$$POWLD = W_M - POWDM - POWPS \qquad (11)$$

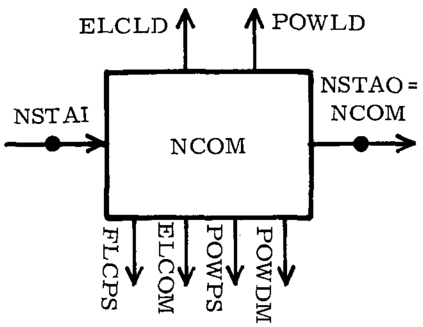
where

NBR	is the number of flow branches in the turbine cascade,
$\dot{m}_i$	is the flow rate in the i^{th} flow branch that is required for a component in the flow branch to follow a thermal load or meet the flow-rate demand of a condenser,
$\dot{W}_{E_i}$	is the electrical power output of the i^{th} turbine in the cascade,
$\dot{W}_{M_i}$	is the mechanical power output of the i^{th} turbine in the cascade,
ELCLD	is the electrical power crossing the system boundaries from LODMG. If ELCLD is negative, electrical power is required from the system's environment so that the electrical demands and parasitics are satisfied,
POWLD	is the mechanical power crossing the system boundaries from LODMG. If POWLD is negative, mechanical power is required from the system's environment so that the mechanical demands and parasitics are satisfied,

W_E, W_M, ELCDM, ELCPS, POWDM, and POWPS are defined as for the POWER mode.

Simulation Mode -- The mathematical algorithm for the simulation mode is the same as that for the HEAT mode except the fluid-flow rate from LODMG is not calculated but is set equal to that entering.

Input--



Parameter	Format	Columns	Description
Card 1			
NAME	A5	1-5	"LODMG"
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Inlet state number
LOPMOD[1]	A5	51-55	Power loop operational mode "POWER", "HEAT", or blank; Blank ⇒ simulation mode
NLPB[2]	I5	56-60	Fluid-loop number that contains the thermal boiler (THMBLR) that supplies the energy for this power loop; Blank ⇒; thermal-boiler loop number and this LODMG are in the same fluid loop
ELCLD	A10	61-70	Required only if LOPMOD = "POWER" Blank ⇒; no external electrical load is followed by this power loop. Otherwise an external electrical power load is read from component DAREXL and followed
POWLD	A10	71-80	Required only if LOPMOD = "POWER" Blank ⇒; no external mechanical load is followed by this power loop; otherwise an external mechanical power load is read from component DAREXL and followed

LODMG reads and processes demand definition cards in the following order:

Electrical demands - ELCDM

Electrical parasitics - ELCPS

Mechanical power parasitics - POWPS

Each demand card must be input in sequence until all the demands and parasitics for the power loop have been specified. For example, in power loops that satisfy electrical parasitics, both the ELCDM and ELCPS definition cards must be input to LODMG. However, the POWDM and POWPS cards may be omitted if the power loop is not directed to satisfy these demands and parasitics.

Demand and Parasitic Input Data Format

Parameter	Format	Columns	Description
Card 1			
DEM	A5	1-5	Demand or parasitic type "ELCDM", "ELCPS", "POWDM", and "POWPS" denote electrical demands, electrical parasitics, mechanical power demands, and mechanical power parasitics, respectively.
DEMMOD	A4	11-14	"ALL" ⇒; all type DEM parasitics or demands in the system model are satisfied by this power loop "NONE" ⇒; no type DEM demands or parasitics are satisfied for this power loop Blank ⇒; only those type DEM demands or parasitics required by the components, which are specified by the next series of cards, are satisfied by this power loop
Card 2			
LPNO		1-5	Required only if Columns 11-14 of the previous card are blank
Option 1	A5	1-5	Blank ⇒; this power loop satisfies those type DEM demands or parasitics required by the components whose component numbers appear in Columns 11-80 of this card.
Option 2	I5	1-5	Fluid-loop number that contains components with type DEM demands or parasitics that are satisfied by this power loop
LPMD	A5	6-10	Read only when Option 2 is used Blank ⇒; this power loop satisfies those type DEM demands or parasitics required by the components in the fluid loop designated by the number in Columns 1-5 of this card and whose component numbers appear in Columns 11-80 of this card "ALL" ⇒; this power loop satisfies all of the type DEM demands or parasitics required by components in the fluid loop designated by the number in Columns 1-5 of this card

Parameter	Format	Columns	Description
$NCOM_1$	I5	11-15	Component numbers for Option 1 or Option 2 with LPMD = Blank
$NCOM_2$	I5	16-20	
⋮	↓	⋮	
$NCOM_{14}$	I5	76-80	

Notes--1. See Appendix B for a discussion of power-loop operational modes.

2. Must be used to simulate parallel power loops.

3. After the last data card, there must be an EOF card.

4. Power-cycle working-fluid constants are required for this routine.

Examples--

Example 1
- Inlet state number = 3
- Component number = 5
- LOPMOD = POWER
- The power loop and thermal boiler are in the same fluid loop
- External electrical loads are followed
- No external mechanical power loads are followed
- No electrical demands or parasitics or mechanical demands or parasitics are satisfied

LODMG Input--

```
LODMG     5  3            Power   Yes
          EOF Card
```

Example 2
- Inlet state number = 3
- Component number = 5
- LOPMOD = POWER
- The power loop and thermal boiler are in the same fluid loop
- No external electrical loads are followed
- External mechanical-power loads are followed

- Electrical demands are required by components with component numbers 4, 6, and 8 and are satisfied by this power loop. No other components in the system model require electrical demands. Components 4 and 6 are in fluid-loop No. 1 while Component 8 is a closed component.
- No electrical parasitics or mechanical power or parasitics are to be satisfied by this power loop.

Example 2 Input:

```
    LODMG      5   3            Power   Yes

          ELCDM      All

                       EOF Card
```

Example 3
- Inlet state number = 3
- Component number = 5
- LOPMOD = HEAT
- The power loop is fluid loop No. 2
- Thermal boiler is in fluid loop No. 3
- Mechanical power parasitics are required by Components 7 and 8 in Fluid Loop 6 and by 11, 12, 13 in Fluid Loop 7. Other components in the system model may require mechanical power but are not satisfied by this power loop.
- No electrical demands or parasitics or mechanical demands are satisfied by this power loop.

Example 3 Input:

```
    LOGMG      5   3            Heat     3
    ELCDM   None
    ELCPS   None
    POWDM   None
    POWPS
        7  8   11  12  13
                   EOF Card
```

Note --The demand cards for POWPS could have been input as

```
    POWPS  6    7   8
           7   11  12   13
```

1. Mixers

Subroutine MIXJNT*

Program Description--Subroutine MIXJNT combines fluid flow from two inlets into one outlet flow.

Mathematical Algorithm--

$$\dot{m}_o = \dot{m}_{i,1} + \dot{m}_{i,2} \tag{1}$$

$$T_o = \frac{\dot{m}_{i,1} T_{i,1} + \dot{m}_{i,2} T_{i,2}}{\dot{m}_o} \tag{2}$$

$$P_o = \frac{m_{i,1} P_{i,1} + m_{i,2} P_{i,2}}{\dot{m}_o} \tag{3}$$

where

$\dot{m}_o$ = fluid-flow rate at outlet

$\dot{m}_{i,1}$ = fluid-flow rate at Inlet 1

$\dot{m}_{i,2}$ = fluid-flow rate at Inlet 2

T_o = fluid temperature at outlet

$T_{i,1}$ = fluid temperature at Inlet 1

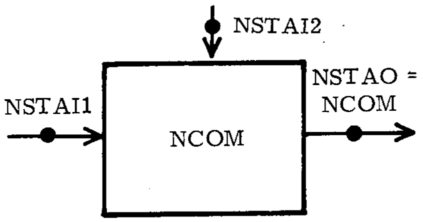
$T_{i,2}$ = fluid temperature at Inlet 2

P_o = fluid pressure at outlet

$P_{i,1}$ = fluid pressure at Inlet 1

$P_{i,2}$ = fluid pressure at Inlet 2

Input--



---

[*] Open Type 2 thermodynamic

Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (MIXJNT)
NCOM	I10	11-20	Component number
NSTAI1	I5	21-25	Upstream state number - Inlet 1
NSTAI2	I5	36-40	Upstream state number - Inlet 2
Card 2			
EOF			

Table 2 Output -- None

Tape 40 Output --

Parameter	Description
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

m. Miscellaneous

Subroutine DUMCOM*

Program Description--Subroutine DUMCOM supplies fluid at a constant outlet temperature and pressure. This component is often used when entire system simulation is not desired or when the operation of only one or two components is evaluated. Energy accounting does not include energy transfer required by DUMCOM.

Mathematical Algorithm--

$$T_o = T_{o,fix} \tag{1}$$

$$P_o = P_{o,fix}$$

where

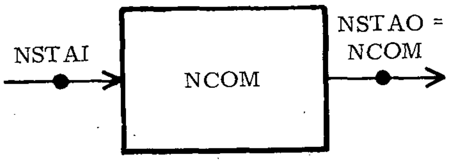
T_o = fluid-outlet temperature (K)

$T_{o,fix}$ = specified fluid-outlet temperature (K)

P_o = fluid-outlet pressure (Pa)

$P_{o,fix}$ = specified fluid-outlet pressure (Pa)

Input--



---

*Open Type 1 thermodynamic model

Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (DUMCOM)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Inlet state number
TOFIX	F10.0	51-60	Fixed outlet temperature (K)
POFIX	F10.0	61-70	Fixed outlet pressure (Pa)
Card 2			
EOF			

Table 2 Output--None

Tape 40 Output--

Parameter	Description
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Fluid-flow rate (kg/s)

Subroutine MKPFLD*

Program Description--MKPFLD is a model that calculates the fluid-flow rate for steady-state operation of the system. MKPFLD does not require an inlet state number since the makeup fluid crosses the system boundary and, therefore, the inlet is not connected to any other component on the system. The fluid-flow rate required for makeup is determined by calculating the difference in fluid-flow rate at two user-supplied state points. The user also specifies if the makeup fluid is a heat-transfer fluid or a power-cycle working fluid. The rate at which energy is gained by the system (a negative advective loss) is calculated unless the user directs MKPFLD not to make this calculation. The reference state for this calculation is the ambient state for heat-transfer fluid makeup and the normal boiling point state for power-cycle makeup.

Mathematical Algorithm--

$$\dot{m} = \dot{m}_2 - \dot{m}_1 \tag{1}$$

If $\dot{m} \leq 0$, reset to $\dot{m} = 0$

$$T = T_{fix} \tag{2}$$

$$P = P_{fix} \tag{3}$$

$$\text{If IADV} = 0,\ \text{ADLOSS} = 0 \tag{4}$$

If IADV = 1

$$\text{Heat-transfer fluids,}\quad \text{ADLOS} = -\dot{m}\int_{T_{amb}}^{T} C_p\, dT \tag{5}$$

$$\text{Power-cycle working fluids,}\quad \text{ADLOS} = -\dot{m}(h - h_{ref}) \tag{6}$$

where

$\dot{m}$ = the makeup fluid-flow rate,

$\dot{m}_2$ = the fluid-flow rate at state point NS2,

$\dot{m}_1$ = the fluid-flow rate at state point NS1, or =0,

T = the temperature of the makeup fluid,

T_{fix} = the fixed user-specified makeup fluid temperature,

---

*Open Type 1 thermodynamic model

P_{fix} = fixed user-specified makeup fluid pressure,

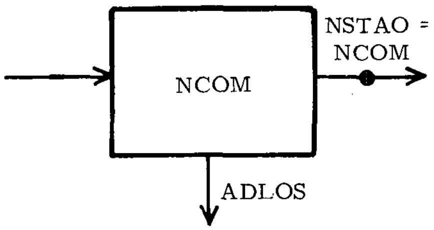
ADLOS = advective loss,

C_p = heat-transfer fluid specific heat at constant pressure,

T_{amb} = ambient pressure

$(h-h_{ref})$ = enthalpy of the makeup fluid relative to the normal boiling point state.

Input--



Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"MKPFLD"
NCOM	I10	11-20	Component number
T_{fix}	F10.0	51-60	Fixed makeup fluid temperature (K)
P_{fix}	F10.0	61-70	Fixed makeup fluid pressure (Pa)
NS1	I5	71-75	Reference 1 state number Blank ⇒ $\dot{m}_1 = 0$
NS2	I5	76-80	Reference 2 state number
Card 2			
TYPE	A5	1-5	"THERM" ⇒ heat-transfer fluid "POWER" ⇒ power-cycle working fluid
IADV	I5	6-10	Blank ⇒ IADV = 1; advective gains are calculated No ⇒ IADV = 0; advective gains are not calculated
Card 3			
EOF			

Table 2 Output--None

Tape 40 Output--

Parameter	Description
T	Makeup fluid temperature (K)
P	Makeup fluid pressure (Pa)
FM	Makeup fluid-flow rate (kg/s)

Note--Type = "THERM"; heat-transfer fluid properties are required.
Type = "POWER"; power-cycle working constants are required.

n. Pipes

Subroutine PIPE*

Program Description -- Subroutine PIPE models thermal and viscous losses in a pipe. Thermal losses are computed based on an energy balance written for a differential pipe length. Pipe pressure drop is determined using a friction factor that is calculated as a function of Reynolds number. If pressure drop exceeds a specified acceptable drop, the pipe system is redesigned to meet the acceptable pressure drop.

Mathematical Algorithm --

Outlet Temperature

$$T_o = T_a + (T_i - T_a)/\exp\left(\frac{\pi DLU}{\dot{m}C}\right) \tag{1}$$

where

T_o = outlet fluid temperature (K)

T_i = inlet fluid temperature (K)

T_a = ambient temperature (K)

D = pipe diameter (m)

L = pipe length (m)

$\dot{m}$ = fluid-flow rate (kg/s)

C = fluid specific heat (J/kg/K)

U = overall heat transfer coefficient (W/m^2/K)

For a pipe insulated with N layers of insulation

$$U = \frac{1}{r_1 \sum_{i=1}^{N} \frac{1}{k_i} \ell n\left(\frac{r_{i+1}}{r_i}\right) + \frac{r_1}{r_N} \frac{1}{h_o}} \tag{2}$$

---

[*] Open Type 1 thermodynamic model

where

r_1 = pipe outside radius (m)

r_i = inside radius of i^{th} insulation layer (m)

k_i = thermal conductivity of i^{th} insulation layer (W/m/K)

h_o = outside convection heat transfer coefficient (W/m^2/K)

Pressure Drop

$$p_o = p_i - \frac{1}{2}\rho f \frac{L}{D} V^2 \qquad (3)$$

where

$$V = \frac{4\dot{m}}{\pi D^2 \rho}$$

and f is computed as a function of Reynolds number, Re.

$$Re = \frac{VD}{\nu}$$

for

$$0 < Re < 2100: \quad f = 64/Re \qquad (4)$$

$$2100 \le Re < 10,000: \quad f = 0.0305 + 0.0037(Re - 2100)/7900 \qquad (5)$$

$$Re \ge 10,000: \quad f = 0.008 + 0.5/Re^{0.32} \qquad (6)$$

where

p_o = outlet fluid pressure (Pa)

p_i = inlet fluid pressure (Pa)

ρ = fluid density (kg/m^3)

f = pipe friction factor (-)

V = fluid velocity (m/s)

ν = fluid kinematic viscosity (m^2/s)

Energy Loss Rate

$$\dot{E}_\ell = - \dot{m}\int_{T_i}^{T_o} C\, dT \tag{7}$$

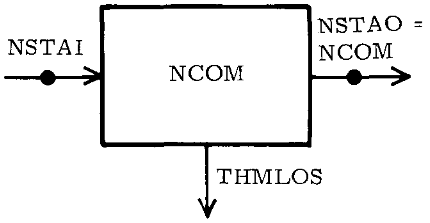
THMLOS = $\dot{E}_\ell$

where

$\dot{E}_\ell$ = pipe energy loss rate (W)

THMLOS = thermal loss (W)

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (PIPE)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
XL	F10.0	51-60	Pipe length (m)
DI	F10.0	61-70	Pipe diameter (m)
H	F10.0	71-80	Overall heat-transfer coefficient $(W/m^2/K)$
Card 2			
NPIPE	I10	1-10	Number of pipes in parallel
PLOSS	F10.0	11-20	Maximum acceptable pressure drop (fraction of inlet pressure)
Card 3			
EOF			

Table 2 Output --

Parameter	Description
ELR	Rate of energy loss (W)

Tape 40 Output --

Parameter	Description
ELR	Rate of energy loss (W)
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

Note -- This component uses heat-transfer-fluid property data.

p. Process Heat and Vapor

Subroutine PRSVAP*

Program Description -- PRSVAP is a model for a device that supplies process vapor at a specified saturation temperature. The process-vapor flow-rate requirements are defined in Subroutine DAREXL as load information for a thermal load at the specified saturation temperature, or process vapor is supplied at an unspecified rate. The inlet temperature may be greater than the specified saturation temperature. Fluid losses in the device are considered part of the energy requirement for supplying the process vapor (a thermal load) and are assumed to be lost at the outlet thermodynamic state. Energy is transferred from PRSVAP as heat; the heat-transfer rate is either the thermal load or the rate at which this energy must be removed from a region to maintain it at ambient pressure and at the user-supplied reference temperature.

Mathematical Algorithm --

$$\mathrm{THMLD} = \dot{m}_1(h_1-h_2) + \dot{m}_3(h_2-h_4) \qquad (1)$$

$$\dot{m}_3 = X\dot{m}_1 \qquad (2)$$

$$|T_S - \mathrm{Temp}| \le \mathrm{TOL} \text{ or fatal diagnostic} \qquad (3)$$

and

$$\mathrm{HEAT} = \mathrm{THMLD} \qquad (4)$$

or

$$\mathrm{HEAT} = \dot{m}_1(h_1-h_2) + \dot{m}_3(h_2-h_{ref}) \qquad (5)$$

where

THMLD = thermal load (W),
$\dot{m}_1$ = fluid-flow rate into PRSVAP (the process-vapor flow rate) (kg/s),
$\dot{m}_3$ = fluid flow losses in PRSVAP (kg/s),

---

*Open Type 1 thermodynamic model

X = fraction of the inlet flow that is lost from PRSVAP,

T_S = saturation temperature at the inlet pressure (K),

Temp = process-vapor temperature (K),

TOL = temperature tolerance (K),

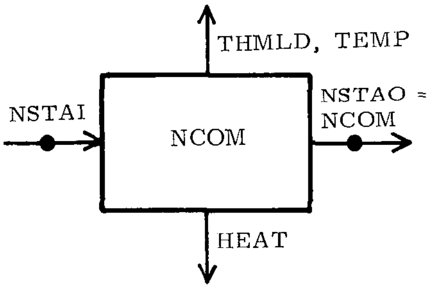
$(h_1 - h_2)$ = drop in specific enthalpy as the fluid flows through PRSVAP (J/kg)

$(h_2 - h_4)$ = difference in enthalpy between the outlet state and the thermodynamic state of the makeup fluid (J/kg),

HEAT = rate at which energy is transferred as heat from PRSVAP (W),

$(h_2 - h_{ref})$ = difference in enthalpy between the outlet state and the state defined by the user-supplied reference temperature and ambient pressure (J/kg).

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"PRSVAP'"
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Inlet state number
T_2	F10.0	51-60	Outlet state temperature
P_2		61-70	Outlet state pressure
Option 1	F10.0	61-70	Value for pressure (Pa)
Option 2	A10	61-70	Blank ⇒exit state will be defined by X_2 and T_2; i.e., liquid-vapor mixture
X_2	F10.0	71-80	Required only for Option 2 exit state quality - value 0 to 100%

Parameter	Format	Columns	Description
Card 2			
TEMP	F10.0	1-10	Process-vapor temperature (K) If IQMTCH = 1, this value must be equal to the temperature associated with the thermal load in DAREXL
X	F10.0	11-20	Fluid-flow loss-percent of inlet flow
NBR		21-30	Flow branch number in turbine cascade
Option 1	A10	21-30	Blank - This component does not determine the fluid-flow rate in a flow branch in the turbine cascade. IQMTCH must be 0.
Option 2	A4	21-23	"LAST" - This component determines the fluid-flow rate in the condensate return from the last turbine in the cascade. IQMTCH must be 1.
Option 3	I10	21-30	This component determines the fluid-flow rate in flow branch number NBR in the turbine cascade. IQMTCH must be 1.
IQMTCH	I10	31-40	IQMTCH = 0 ⇒ A thermal load is not followed. IQMTCH = 1 ⇒ A thermal load is followed and must be defined in DAREXL.
TOL	A10	41-50	The allowable tolerance between the process-vapor temperature TEMP and the saturation temperature of the inlet state.
Option 1	A10	41-50	Blank - defaults to steady-state absolute temperature convergence error.
Option 2	F10.0	41-50	Value (K)
N_{MKP}	I10	51-60	Outlet state number of component MKPFLD
T_{ref}	F10.0	61-70	Reference temperature
Option 1	A10	61-70	Blank ⇒ The heat-transfer rate from PRSVAP is the thermal load
Option 2	F10.0	61-70	T_{ref} (K) ⇒ The heat-transfer rate from PRSVAP is the rate at which the energy from PRSVAP must be removed from a region to maintain it at ambient pressure and at T_{ref}.

Card 3

EOF

Table 2 Output --

Parameter	Description
THMLD	Energy required to supply to process vapor
$\dot{m}_3$	Fluid-flow rate loss (kg/s)
HEAT	Heat-transfer rate (W)

Tape 40 Output --

Parameter	Description
THMLD	Energy required to supply the process vapor (W)
$\dot{m}_3$	Fluid-flow rate loss (kg/s)
HEAT	Heat-transfer rate (W)

Note -- The component requires power-cycle working-fluid constants.

q. Pumps

Subroutine PUMP*

Program Description -- Subroutine PUMP models a pump. The pump restores fluid pressure to a specified value and computes the necessary power. Two options are available for outlet flow rate. In the first, the pump maintains a fixed volume flow rate. In the second, the outlet mass flow rate is set equal to the inlet mass flow rate. Outlet temperature is set equal to the inlet temperature.

Mathematical Algorithm --

$$\mathrm{ELCPS} = \frac{\dot{v}(p_o - p_i)}{\eta} \tag{1}$$

$$\dot{v} = \dot{v}_{\mathrm{fixed}} \text{ for "FIXED" operation} \tag{2}$$

$$\dot{v} = \frac{\dot{m}}{\rho_f} \quad \text{for "VARIABLE" operation} \tag{3}$$

where

ELCPS = pump power (electrical parasitic) (W)

$\dot{v}$ = volume-flow rate (m^3/s)

p_o = pump-outlet pressure (Pa)

p_i = pump-inlet pressure (Pa)

η = pump efficiency (-)

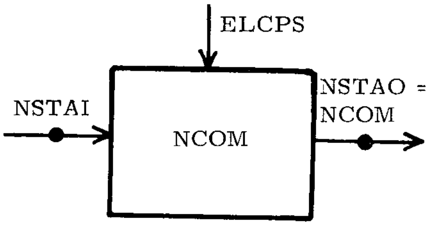
$\dot{m}$ = mass-flow rate (kg/s)

ρ_f = fluid density (kg/m^3)

---

*Open Type 1 thermodynamic model

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (PUMP)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
PFIX	F10.0	51-60	Fixed outlet pressure (Pa)
EFF	F10.0	61-70	Pump efficiency
NPUOP	A10	71-80	Pump operation ("FIXED" or "VARIABLE")
Card 2			
FMV	F10.0	1-10	Fixed volume-flow rate (m^3/s) (only required when NPUOP = FIXED)
Card 3			
EOF			

Table 2 Output --

Parameter	Description
ELCPS	Pump power used (W)

Tape 40 Output --

Parameter	Description
ELCPS	Pump power used (W)
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

Note -- This component uses heat-transfer-fluid property data.

Subroutine BFDPMP*

Program Description -- BFDPMP is a model for a boiler-feed pump. The power required to operate the pump is either an electrical- or mechanical-power parasitic.

Mathematical Algorithm -- The power required to run the pump is given by

$$\dot{W}_p = \frac{v_1(P_2 - P_i)\dot{m}}{\eta_I \eta_M} , \tag{1}$$

and the liquid temperature at the pump outlet is obtained by inverting the following equation

$$[h_2(T_2, P_2) - h_1] = \eta_M \dot{W}_p \tag{2}$$

and

$$G = \dot{m}V_1 \tag{3}$$

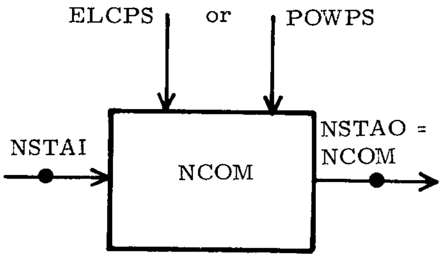
where

$\dot{W}_p$ = power required to run the pump (W)
v_1 = specific volume of liquid entering the pump (m^3/kg),
P_2 = pressure of the liquid leaving the pump point (Pa),
P_1 = pressure of the liquid entering the pump (Pa),
$\dot{m}$ = liquid flow rate through the pump (kg/s),
η_I = isentropic efficiency of the pump (-),
η_M = mechanical efficiency of the pump (-),
$[h_2(T_2, P_2) - h_1]$ = liquid enthalpy rise through the pump (J/kg),
G = volumetric flow rate through the pump (m^3/s).

---

[*] Open Type 1 thermodynamic model

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"BEDPMP"
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Inlet state number
P2	E10.4	51-60	Outlet pressure (Pa)
ETAI	F10.2	61-70	Pump isentropic efficiency (%)
ETAM	F10.2	71-80	Pump mechanical efficiency (%)
Card 2			
PARMOD	A10	1-10	Blank ⇒ pump power is supplied by electrical power[1] Power ⇒ pump power is supplied by mechanical power.[2]
Card 3			
EOF			

Table 2 Output --

Parameter	Description
G	Liquid volumetric flow rate (m^3/s)
$\dot{W}_P$	Pump power requirements (W)

Tape 40 Output --

Parameter	Description
G	Liquid volumetric flow rate (m^3/s)
$\dot{W}_P$	Pump power requirements (W)
T_2	Outlet temperature (K)
$\dot{m}$	Liquid flow rate (kg/s)

Notes --

1. The electrical power supplied is an electrical parasitic; i.e., ELCPS = $\dot{W}_P$, POWPS = 0.
2. The mechanical power supplied is a mechanical power parasitic; i.e., POWPS = $\dot{W}_P$, ELCPS = 0.
3. This routine requires power-cycle working-fluid constants.

r. Regenerative Heaters

Subroutine DCONHT*

Program Description -- DCONHT is a model for a direct contact, regenerative heater. Fluid in the liquid state flows into one inlet and is mixed and heated by fluid entering through the other inlet. The same fluid type must flow through both inlets. The heating fluid may enter DCONHT as a liquid-vapor mixture or as a superheated vapor but not as a compressed liquid. The fluid mixture leaves DCONHT as a compressed liquid at user-supplied values for pressure and temperature. The hotter fluid-flow rate and the outlet fluid-flow rate are calculated; the heating fluid-flow rate is the fluid-flow rate through the flow branch in the turbine cascade designated by user-input.

Mathematical Algorithm --

$$\dot{m}_2 = \dot{m}_1 \frac{(h_3 - h_1)}{(h_2 - h_3)} \tag{1}$$

$$\dot{m}_3 = \dot{m}_1 + \dot{m}_3 \tag{2}$$

$$\dot{Q} = \dot{m}_1 (h_3 - h_1) \tag{3}$$

where

$\dot{m}_2$ = fluid-flow rate of the hotter fluid (kg/s),

$\dot{m}_1$ = liquid flow rate (kg/s),

$(h_3 - h_1)$ = enthalpy rise of the liquid (J/kg),

$(h_2 - h_3)$ = enthalpy drop of the hotter fluid (J/kg),

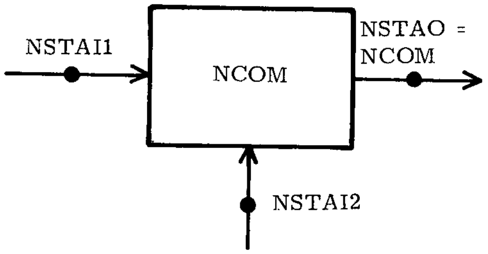
$\dot{m}_3$ = fluid-flow rate leaving DCONHT (kg/s),

$\dot{Q}$ = regeneration heat rate (W).

---

[*] Open Type 2 thermodynamic model

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"DCONHT"
NCOM	I10	11-20	Component number
NSTAI1	I5	21-25	Inlet 1 state number - the liquid inlet
NSTAI2	I5	36-40	Inlet 2 state number - the heating-fluid inlet
T3	F10.4	51-60	Outlet temperature (K)
P3	E10.4	61-70	Outlet pressure (Pa)
NBR		71-80	Flow branch number in turbine cascade
Option 1	A10	71-80	Blank ⇒ this component does not determine the fluid-flow rate in a flow branch in the turbine cascade
Option 2	A4	71-80	"LAST" - this component determines the fluid-flow rate in the condensate return from the last turbine in the cascade
Option 3	I10	71-80	This component determines the fluid-flow in flow branch number NBR in the turbine cascade
Card 2			
EOF			

Table 2 Output --

Parameter	Description
$\dot{Q}$	Regeneration heat rate (W)

Tape 40 Output --

Parameter	Description
$\dot{Q}$	Regeneration heat rate (W)

Note -- This component requires power-cycle working-fluid constants.

s. Space Heaters

Subroutine SPHEAT*

Program Description--Subroutine SPHEAT models a space-heating unit which removes energy from its inlet fluid and returns it at a specified lower temperature. The rate of energy removal depends on the heating demands and heating loads specified on input. Fluid-flow rate is calculated to satisfy all loads and demands.

Mathematical Algorithm--

$$\dot{m} = \frac{\sum (H_D + H_L)}{-\int_{T_i}^{T_o} C\, dT}$$

where

$\dot{m}$ = fluid-flow rate through space heater (kg/s)

H_D = heating demand (HEATDM) (W)

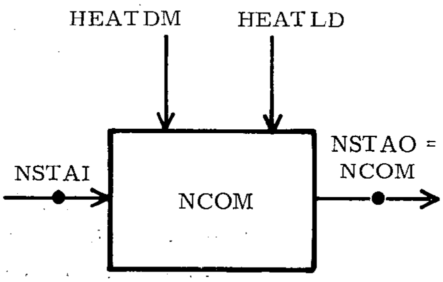
H_L = heating load (HEATLD) (W)

C = fluid specific heat (J/kg/K)

T_i = fluid inlet temperature (K)

T_o = fluid outlet temperature (K)

Input--



---

*Open Type 1 thermodynamic model

Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (SPHEAT)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
TOFIX	F10.0	51-60	Fixed outlet temperature (K)
Card 2			
LOAD	A10	1-10	If external heating load is supplied by subroutine DAREXL, LOAD = HEATLD. If external heating load is not supplied, this field is blank.
DEMAND	A10	11-20	DEMAND = HEATDM if component-supplied heating demands are to be met. This field is blank if no demands are to be met.
NCD	I5 or A5	21-80	List of component numbers supplying demands in fields of five. If all demands are to be met by this space-heating component, the word "ALL" can be used in Columns 21-25.
Card 3			
EOF			

Table 2 Output --

Parameter	Description
EER	Rate at which energy is extracted from fluid (W)

Tape 40 Output --

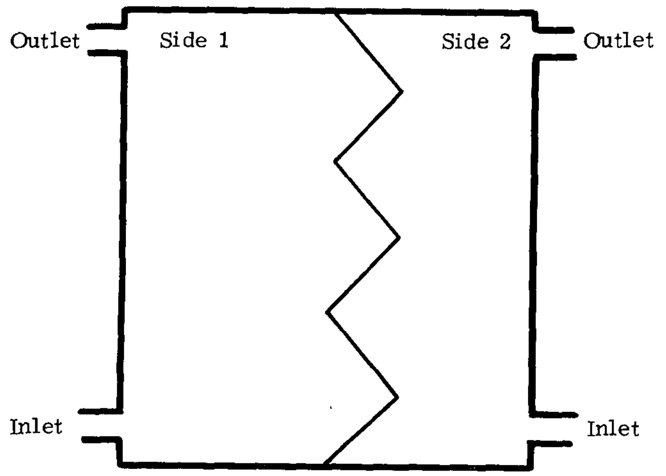
Parameter	Description
EER	Rate at which energy is extracted from fluid (W)
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

Note -- This component uses heat-transfer-fluid property data.

t. Thermal Storage

Subroutine STORE1*

Program Description--Subroutine STORE1 models a two-fluid, mixed, sensible-heat-storage unit (see figure). The storage unit consists of two reservoirs that may contain two different fluids. Heat is transferred from the warmer to the cooler fluid through the separating wall. Temperatures in each reservoir are assumed to be uniform (perfect mixing), and the outlet fluid temperature of each reservoir is equal to the reservoir temperature. Reservoir temperatures change with time due to heat transfer between reservoirs and due to the reservoir's inlet fluid temperature being either warmer or cooler than the reservoir's temperature.



Storage Unit for STORE1

Mathematical Algorithm--

Storage Temperature

$$T_{s,1} = T_{s,1\ \mathrm{old}} + \frac{\dot{m}_1 (T_{i,1} - T_{s,1\ \mathrm{old}}) \Delta t}{M_1} - \frac{\bar{h}_c A (T_{s,1\ \mathrm{old}} - T_{s,2\ \mathrm{old}}) \Delta t}{M_1 C_1} \qquad (1)$$

$$T_{s,2} = T_{s,2\ \mathrm{old}} + \frac{\dot{m}_2 (T_{i,2} - T_{s,2\ \mathrm{old}}) \Delta t}{M_2} + \frac{\bar{h}_c A (T_{s,1\ \mathrm{old}} - T_{s,2\ \mathrm{old}}) \Delta t}{M_2 C_2} \qquad (2)$$

---

*Open Type 4 thermodynamic model

where

$$\bar{h}_c = \frac{h_{c,1} h_{c,2}}{h_{c,1} + h_{c,2}}$$

$T_{s,1}$ = stored fluid temperature - Side 1 (K)

$T_{s,1\ old}$ = stored fluid temperature - Side 1 at previous time (K)

$T_{s,2}$ = stored fluid temperature - Side 2 (K)

$T_{s,2\ old}$ = stored fluid temperature - Side 2 at previous time (K)

$T_{i,1}$ = fluid inlet temperature - Side 1 (K)

$T_{i,2}$ = fluid inlet temperature - Side 2 (K)

$\dot{m}_1$ = fluid-flow rate - Side 1 (kg/s)

$\dot{m}_2$ = fluid-flow rate - Side 2 (kg/s)

M_1 = fluid mass stored in Side 1 (kg)

M_2 = fluid mass stored in Side 2 (kg)

C_1 = fluid specific heat - Side 1 (J/kg/K)

C_2 = fluid specific heat - Side 2 (J/kg/K)

Δt = time increment(s)

$h_{c,1}$ = convection-heat-transfer coefficient, wall to fluid - Side 1 ($W/m^2/K$)

$h_{c,2}$ = convection-heat-transfer coefficient wall to fluid - Side 2 ($W/m^2/K$)

A = heat-transfer area between Sides 1 and 2 (m^2)

Energy Storage Rate

$$\dot{E}_{s,1} = \dot{m}_1(C_{1i}T_{i,1} - C_{1s}T_{s,1}) \qquad (3)$$

$$\dot{E}_{s,2} = \dot{m}_2(C_{2i}T_{i,2} - C_{2s}T_{s,2}) \qquad (4)$$

where

$E_{s,1}$ = rate of energy storage - Side 1 (W)

$E_{s,2}$ = rate of energy storage - Side 2 (W)

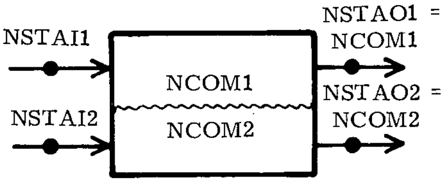
C_{1i} = fluid specific heat at Inlet 1 conditions (J/kg/K)

C_{2i} = fluid specific heat at Inlet 2 conditions (J/kg/K)

C_{1s} = fluid specific heat at Side 1 storage conditions (J/kg/K)

C_{2s} = fluid specific heat at Side 2 storage conditions (J/kg/K)

Input--



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (STORE1)
NCOM1	I10	11-20	Component number - Side 1
NSTAI1	I5	21-25	Upstream state number - Side 1
NCOM2	I10	31-35	Component number - Side 2
NSTAI2	I5	36-40	Upstream state number - Side 2
H1	F10.0	51-60	Wall convection heat-transfer coefficient - Side 1 ($W/m^2/K$)
H2	F10.0	61-70	Wall convection heat-transfer coefficient - Side 2 ($W/m^2/K$)
A	F10.0	71-80	Heat-transfer area between Sides 1 and 2 (m^2)
Card 2			
M1	F10.0	1-10	Fluid mass - Side 1 (kg)
M2	F10.0	11-20	Fluid mass - Side 2 (kg)
TI1	F10.0	21-30	Initial stored fluid temperature - Side 1 (K)
TI2	F10.0	31-40	Initial stored fluid temperature - Side 2 (K)
Card 3			
EOF			

Table 2 Output --

Parameter	Description
ESR1	Energy storage rate - Side 1 (W)
ESR2	Energy storage rate - Side 2 (W)

Tape 40 Output --

Parameter	Description
ESR1	Energy storage rate - Side 1 (W)
ESR2	Energy storage rate - Side 2 (W)
TO1	Outlet temperature - Side 1 (K)
PO1	Outlet pressure - Side 1 (Pa)
FM1	Outlet flow rate - Side 1 (kg/s)
TO2	Outlet temperature - Side 2 (K)
PO2	Outlet pressure - Side 2 (Pa)
FM2	Outlet flow rate - Side 2 (kg/s)

Note -- This component uses heat-transfer-fluid property data.

Subroutine STORE2*

Program Description--Subroutine STORE2 models a mixed sensible-heat storage unit with one inlet and one outlet. Outlet flow rate is equal to the inlet flow rate; therefore, storage accumulation or depletion cannot occur. The fluid is assumed to be completely mixed at a uniform temperature. Fluid enters storage at a temperature of the upstream component and leaves at the mixed-mean-storage temperature.

Mathematical Algorithm--

$$T_s = T_{old} + \frac{\dot{m}\Delta t}{M} (T_i - T_{old})$$

where

T_s = computed storage temperature at present time (K)

T_{old} = storage temperature at previous time (K)

$\dot{m}$ = fluid-flow rate (kg/s)

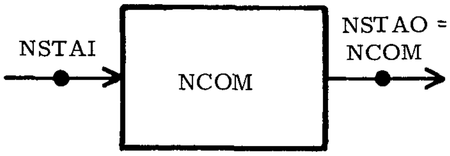
Δt = time step (s)

ρ = fluid density (kg/m^3)

M = stored-fluid mass (kg)

T_i = inlet temperature (K)

Input--



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (STORE2)
NCOM	I10	11-20	Component number

---

[*] Open Type 1 thermodynamic model

Parameter	Format	Columns	Description
NSTAI	I5	21-25	Upstream state number
M	F10.0	51-60	Stored fluid mass (kg)
STEMP	F10.0	61-70	Initial storage temperature (K)

Card 2

EOF

Table 2 Output --

Parameter	Description
ENERS	Energy storage rate (W)

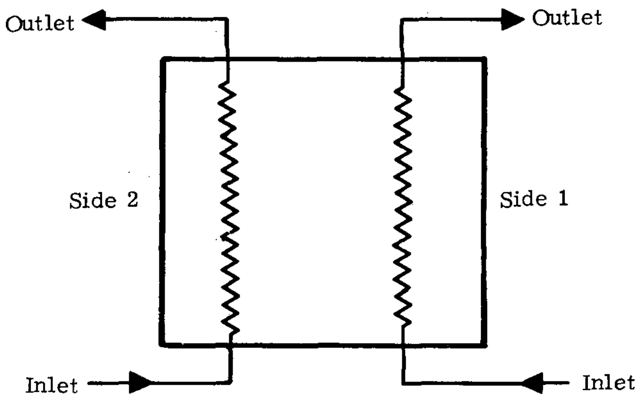
Tape 40 Output --

Parameter	Description
ENERS	Energy storage rate (W)
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

Note -- This component uses heat-transfer-fluid property data.

Subroutine STORE3*

Program Description--Subroutine STORE3 models a one-material, sensible-heat storage unit with heat exchangers between the two energy-carrying fluids and the storage medium (see figure). One fluid enters the storage unit at Side 1, passes through a heat exchanger and leaves the unit. The same process occurs at Side 2. Energy is exchanged between the two fluids and the storage medium. The local heat-transfer coefficient and the temperature of the storage medium are assumed to be uniform. The amount of heat transferred between the storage medium and the flowing fluid depends on the local fluid temperature, heat-transfer coefficient, and the surface area of the heat-exchanger. Total heat-transfer rate is found by integrating local heat-transfer rates; the storage temperature is determined by integrating the total heat-transfer rate over time.



Storage Unit for STORE3

Mathematical Algorithm--

Storage and Outlet Fluid Temperatures

$$T_{o,1} = T_s + (T_{i,1} - T_s)/\exp\left(\frac{U_1A_1}{\dot{m}_1C_1}\right) \tag{1}$$

$$T_{o,2} = T_s + (T_{i,2} - T_s)/\exp\left(\frac{U_2A_2}{\dot{m}_2C_2}\right) \tag{2}$$

$$T_s = T_{s,old} + \frac{(T_{i,1} - T_{o,1})\dot{m}_1C_1\Delta t}{M_sC_s} + \frac{(T_{i,2} - T_{o,2})\dot{m}_2C_2\Delta t}{M_sC_s} \tag{3}$$

---

[*] Open Type 4 thermodynamic model

where

$T_{o,1}$ = fluid outlet temperature - Side 1 (K)

$T_{o,2}$ = fluid outlet temperature - Side 2 (K)

$T_{i,1}$ = fluid inlet temperature - Side 1 (K)

$T_{i,2}$ = fluid inlet temperature - Side 2 (K)

T_s = stored-fluid temperature (K)

T_s, old = stored-fluid temperature at previous time (K)

$\dot{m}_1$ = fluid-flow rate - Side 1 (kg/s)

$\dot{m}_2$ = fluid-flow rate - Side 2 (kg/s)

U_1 = heat-transfer coefficient - Side 1 ($W/m^2/K$)

U_2 = heat-transfer coefficient - Side 2 ($W/m^2/K$)

A_1 = heat-transfer area - Side 1 (m^2)

A_2 = heat-transfer area - Side 2 (m^2)

C_1 = fluid specific heat - Side 1 (J/kg/K)

C_2 = fluid specific heat - Side 2 (J/kg/K)

C_s = stored material specific heat (J/kg/K)

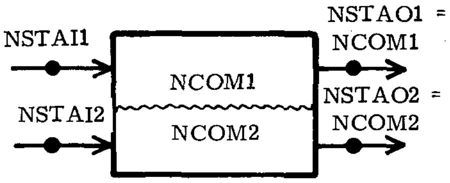
M_s = mass of stored material (kg)

Δt = time increment (s)

Energy Storage Rate

$$\dot{E}_s = \dot{m}_1 \int_{T_{i,1}}^{T_{o,1}} C_1 \, dT + \dot{m}_2 \int_{T_{i,2}}^{T_{o,2}} C_2 \, dT \qquad (4)$$

Input--



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (STORE3)
NCOM1	I10	11-20	Component number - Side 1
NSTAI1	I5	21-25	Upstream state number - Side 1
NCOM2	I10	31-35	Component number - Side 2
NSTAI2	I5	36-40	Upstream state number - Side 2
U1	F10.0	51-60	Heat-transfer coefficient - Side 1 ($W/m^2/K$)
U2	F10.0	61-70	Heat-transfer coefficient - Side 2 ($W/m^2/K$)
A1	F10.0	71-80	Heat-transfer area - Side 1 (m^2)
Card 2			
A2	F10.0	1-10	Heat-transfer area - Side 2 (m^2)
TMS	F10.0	11-20	Total storage mass (kg)
SPHTS	F10.0	21-30	Specific heat of stored material (J/kg/K)
TS	F10.0	31-40	Initial temperature of stored material (K)
Card 3			
EOF			

Table 2 Output --

Parameter	Description
ESR	Energy storage rate (W)

Tape 40 Output --

Parameter	Description
ESR	Energy storage rate (W)
TO1	Outlet temperature - Side 1 (K)
PO1	Outlet pressure - Side 1 (Pa)
FM1	Outlet flow rate Side 1 (kg/s)
TO2	Outlet temperature - Side 2 (K)
PO2	Outlet pressure - Side 2 (Pa)
FM2	Outlet flow rate - Side 2 (kg/s)

Note -- This component uses heat-transfer-fluid property data.

Subroutine STORE5*

Program Description--Subroutine STORE5 models a mixed sensible-heat storage unit with one inlet and one outlet. Storage mass accumulates (or is depleted) according to the difference between inflow and outflow. Three options exist for control of the outlet flow rate: (1) fixed outlet flow rate, (2) variable flow rate equal to the flow rate of a specified component, (3) outlet flow rate equal to inlet flow rate. The fluid is assumed to be completely mixed. Heat capacity of the tank and surrounding insulation is included, as is heat loss (a thermal loss) to the environment. The tank temperature is assumed equal to the mixed mean-fluid temperature. Temperature in the insulation is assumed to vary linearly between the mean-storage temperature and ambient temperature. Fluid enters storage at a temperature of the upstream component and leaves at the mean-storage temperature.

Mathematical Algorithm--

Storage Temperature -- For exit flow rate not equal to the inlet flow rate.

$$T_s = \frac{\dfrac{\dot{m}_i C_i T_i + UAT_a}{\dot{m}_i C_s + UA} + \left(T_{s,old} - \dfrac{\dot{m}_i C_i T_i + UAT_a}{\dot{m}_i C_s + UA}\right)}{\left[1 + \dfrac{C_s(\dot{m}_i - \dot{m}_o)\Delta t}{C_s M_{s,old} + C_w M_w + 1/2\, C_I M_I}\right]^{\frac{\dot{m}_i C_s + UA}{C_s(\dot{m}_i - \dot{m}_o)}}} . \qquad (1)$$

When exit flow rate is equal to the inlet flow rate,

$$T_s = \frac{\dot{m}_i C_i T_i + UAT_a}{\dot{m}_i C_s + UA} + \frac{T_{s,old} - \dfrac{\dot{m}_i C_i T_i + UAT_a}{\dot{m}_i C_s + UA}}{\exp\left[\dfrac{(\dot{m}_i C_s + UA)\Delta t}{C_s M_{s,old} + C_w M_w + 1/2\, C_I M_I}\right]} , \qquad (2)$$

---

*Open Type 1 thermodynamic model

where

T_s = new mixed mean-storage temperature (K)

$T_{s,old}$ = old mixed mean-storage temperature - at previous time (K)

T_i = inlet fluid temperature (K)

T_a = ambient temperature (K)

$\dot{m}_i$ = inlet fluid-flow rate (kg/s)

$\dot{m}_o$ = outlet fluid-flow rate (kg/s)

U = overall heat-transfer coefficient for heat loss from storage tank (W/m^2/K)

A = outermost surface area of insulated tank (m^2)

C_i = fluid specific heat at inlet temperature (J/kg/K)

C_s = fluid specific heat at storage temperature (J/kg/K)

C_W = specific heat of storage tank wall (J/kg/K)

C_I = specific heat of insulation (J/kg/K)

$M_{s,old}$ = mass of stored fluid at previous time (kg)

M_W = mass of tank wall (kg)

M_I = mass of insulation (kg)

Δt = time increment (s)

Stored Mass

$$M_s = M_{s,old} + (\dot{m}_i - \dot{m}_o)\Delta t \qquad (3)$$

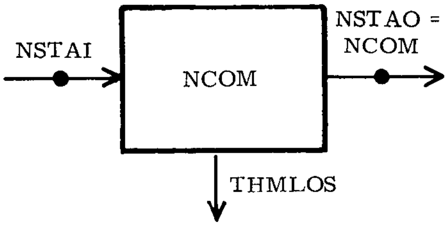
Energy Storage Rate

$$\dot{E}_s = \dot{m}_i C_i T_i - \dot{m}_o C_s T_s - UA(T_s - T_a) \qquad (4)$$

Thermal Loss

$$THMLOS = UA(T_s - T_a)$$

Input--



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (STORE5)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
SVOLI	F10.0	51-60	Initial stored-fluid volume (m^3)
STEMPI	F10.0	61-70	Initial stored-fluid temperature (K)
VOLMIN	F10.0	71-80	Minimum allowed fluid volume (m^3)
Card 2			
SPHMW	F10.0	1-10	Mass/specific-heat product for tank wall (J/K)
SPHMI	F10.0	11-20	Mass/specific-heat product for insulation (J/K)
UA	F10.0	21-30	Overall heat-transfer coefficient - area product (W/K)
NFMOP	A10	31-40	Outlet flow option ("EQUAL", "FIXED", or "VARIABLE")
FMFIX	F10.0	41-50	Fixed outlet-flow rate (kg/s) (used when NFMOP = FIXED)
NCC	I10	41-50	Component number controlling outlet-flow rate (used when NFMOP = VARIABLE)

Table 2 Output --

Parameter	Description
VOLS	Stored fluid volume (m^3)
ENERS	Energy storage rate (W)

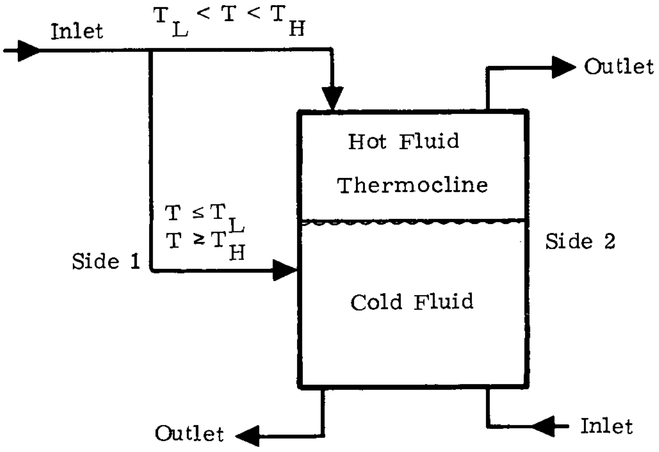
Tape 40 Output --

Parameter	Description
VOLS	Stored fluid volume (m^3)
ENERS	Energy storage rate (W)
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

Notes -- This component uses heat-transfer-fluid property data.

Subroutine TCSTORE*

Program Description--Subroutine TCSTORE models a stratified or thermocline storage unit (see figure). The storage unit is assumed to contain a thermally stratified fluid with two uniform temperature regions. Warm fluid is pumped into the top of the unit on Side 1 and out on Side 2. Cool fluid is pumped out of the bottom on Side 1 and in on Side 2. Inlet fluid is mixed with the fluid already in the temperature region into which it is pumped. If the inlet temperature on Side 1 is not between T_L and T_H, the fluid is diverted to the bottom of the tank and is mixed with the low-temperature fluid. There are no heat losses from the sides of the unit and no heat transferred across the thermocline. It is assumed that a discontinuous change in temperature is maintained across the thermocline.



Storage Unit for TCSTORE

Mathematical Algorithm--

Stored Mass

If $T_L < T_{i,1} < T_H$,

then

$$M_{hot} = M_{hot,old} + (\dot{m}_1 - \dot{m}_2)\,\Delta t \tag{1}$$

and

$$M_{cold} = M_s - M_{hot}$$

---

*Open Type 4 thermodynamic model

If $T_L < T_{i,1} < T_H$ *is not satisfied,*

then

$$M_{cold} = M_{cold,\ old} + \dot{m}_2 \Delta t \qquad (3)$$

and

$$M_{hot} = M_s - M_{cold} \ , \qquad (4)$$

where

T_L = low limit-control temperature (K)

T_H = high limit-control temperature (K)

$T_{i,1}$ = fluid-inlet temperature - Side 1 (K)

M_s = total fluid-mass stored (kg)

M_{hot} = fluid mass - hot side (kg)

$M_{hot,\ old}$ = fluid mass - hot side at previous time (kg)

M_{cold} = fluid mass - cold side (kg)

$M_{cold,\ old}$ = fluid mass - cold side at previous time (kg)

$\dot{m}_1$ = fluid-flow rate - Side 1 (kg/s)

$\dot{m}_2$ = fluid-flow rate - Side 2 (kg/s)

Δt = time increment (s)

Storage Temperatures

If $T_L < T_{i,1} < T_H$,

then

$$T_{hot} = \frac{M_{hot,\ old}}{M_{hot}} T_{hot,\ old} + \frac{\left(\dot{m}_1 T_{i,1} - \dot{m}_2 T_{hot,\ old}\right) \Delta t}{M_{hot}} \qquad (5)$$

and

$$T_{cold} = \frac{M_{cold,\ old}}{M_{cold}} T_{cold,\ old} + \frac{\left(\dot{m}_2 T_{i,2} - \dot{m}_1 T_{cold,\ old}\right) \Delta t}{M_{cold}} \qquad (6)$$

If $T_L < T_{i,1} < T_H$ is not satisfied,

then

$$T_{hot} = T_{hot,\,old}$$

and

$$T_{cold} = \frac{M_{cold,\,old}}{M_{cold}} \cdot T_{cold,\,old} + \frac{\left[\dot{m}_2 T_{i,2} + \dot{m}_1 (T_{i,1} - T_{cold,\,old})\right] \Delta t}{M_{cold}}$$

where

T_{hot} = fluid temperature - hot side (K)

$T_{hot,\,old}$ = fluid temperature - hot side at previous time (K)

T_{cold} = fluid temperature - cold side (K)

$T_{cold,\,old}$ = fluid temperature - cold side at previous time (K)

$T_{i,2}$ = fluid inlet temperature - Side 2 (K)

Energy Storage Rate

$$\dot{E}_s = \dot{m}_1 (C_1 T_{i,1} - C_{cold} T_{cold}) + \dot{m}_2 (C_2 T_{i,2} - C_{hot} T_{hot}) \qquad (9)$$

where

C_1 = inlet fluid specific heat - Side 1 (J/kg/K)

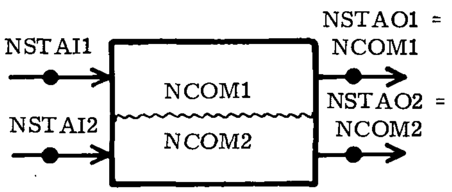
C_2 = inlet fluid specific heat - Side 2 (J/kg/K)

C_{cold} = stored fluid specific heat - cold side (J/kg/K)

C_{hot} = stored fluid specific heat - hot side (J/kg/K)

$\dot{E}_s$ = energy storage rate (W)

Input--



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (TCSTORE)
NCOM1	I10	11-20	Component number - Side 1
NSTAI1	I5	21-25	Upstream state number - Side 1
NCOM2	I10	31-35	Component number - Side 2
NSTAI2	I5	36-40	Upstream state number - Side 2
MS	F10.0	51-60	Total stored fluid mass (kg)
MHI	F10.0	61-70	Initial high-temperature-fluid mass (kg)
THI	F10.0	71-80	Initial high-temperature-fluid temperature (K)
Card 2			
TCI	F10.0	1-10	Initial cold-temperature-fluid temperature (K)
TH	F10.0	11-20	High-limit control temperature (K)
TL	F10.0	21-30	Low-limit control temperature (K)
Card 3			
EOF			

Table 2 Output --

Parameter	Description
ESR	Energy Storage Rate (W)

Tape 40 Output --

Parameter	Description
ESR	Energy storage rate (W)
TO1	Outlet temperature - Side 1 (K)
PO1	Outlet pressure - Side 1 (Pa)
FM1	Outlet flow rate - Side 1 (kg/s)
TO2	Outlet temperature - Side 2 (K)
PO2	Outlet pressure - Side 2 (Pa)
FM2	Outlet flow rate - Side 2 (kg/s)

v. Turbines

Subroutine XTURBG*

Program Description--This routine is a model for a turbine generator with a single extraction port. The turbine/generator output is electrical and/or mechanical power.

Mathematical Algorithm--

$$\dot{W}_M = X \dot{W}_E \tag{1}$$

$$\dot{W}_E = \frac{\eta_g \eta_m}{(1 + X\eta_g)} \left[\dot{m}_1(h_1 - h_3) - \dot{m}_2(h_2 - h_3)\right] , \tag{2}$$

$$\dot{m}_2 = Y\dot{m}_1 \tag{3}$$

$$(h_2 - h_3) = \eta_L(h_2 - h_{3s}) \tag{4}$$

$$(h_1 - h_3) = \eta_H(h_1 - h_{2s}) + (h_2 - h_3) \tag{5}$$

where

$\dot{W}_M$	is the mechanical-power output of the turbine/generator (W),
$\dot{W}_E$	is the electrical-power output of the generator (W),
X	is the ratio of mechanical- and electrical-power outputs of the turbine generator (-),
η_g	is the generator efficiency (-),
η_m	is the turbine-mechanical efficiency (-),
$\dot{m}_1$	is the fluid-flow rate entering the turbine (kg/s),
$\dot{m}_2$	is the fluid-flow rate through the turbine extraction port (kg/s),
$(h_2 - h_3)$	is the change in enthalpy between the extraction port and exit thermodynamic states (J/kg),
η_L	is the isentropic efficiency for the expansion from the turbine extraction port state to the turbine exit state (-),
$(h_2 - h_{3s})$	is the enthalpy drop during an isentropic expansion from the extraction port state to the exit state pressure (J/kg),
$(h_1 - h_3)$	is the change in enthalpy between the inlet state and exit state (J/kg),

---

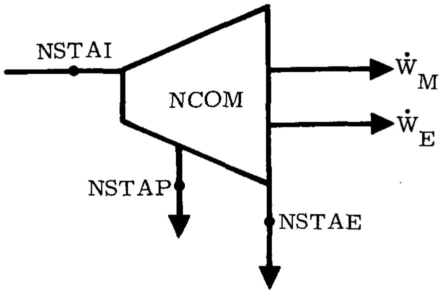
*Open Type 3 thermodynamic model

η_H is the isentropic efficiency for the expansion from the turbine inlet state to the extraction port state (-),

$(h_1 - h_{2s})$ is the enthalpy drop during an isentropic expansion from the inlet state to the extraction port state,

and Y is the extraction rate.

Input--



Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"XTURBG"
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Inlet state number
NSTAP	I5	26-30	Extraction port state number
NSTAE	I5	41-45	Exit state number
ETAG	F10.2	51-60	Electrical generator efficiency (%)
X		61-70[1]	Ratio of mechanical- and electrical-power output (%)
Option 1	Blank	61-70	X = 0
Option 2	F10.2	61-70	Value input in percent
Option 3	A6	61-70	"UNSPEC"
ETAM	F10.2	71-80	Turbine mechanical efficiency (%)
Card 2			
ETAH	F10.2	1-10	Isentropic efficiency for expansion from inlet to extraction port (%)
ETAL	F10.2	21-30	Isentropic efficiency for expansion from extraction port to exit (%)

Parameter	Format	Columns	Description
Card 2 (cont)			
T_B	F10.2	21-30	Saturation temperature of extraction port state (K)
T_D	F10.2	31-40	Saturation temperature of exit state (K)
Y	F10.2	41-50[2]	Turbine extraction rate - ratio of fluid flow through extraction port and the fluid-flow rate entering the turbine (%)
Card 3			
EOF			

Table 2 Output--

Parameter	Description
$\dot{W}_E$	Electrical-power output of generator (W)
$\dot{W}_M$	Mechanical-power output from turbine/generator (W)

Tape 40 Output--

Parameter	Description
$\dot{W}_E$	Electrical-power output of generator (W)
$\dot{W}_M$	Mechanical-power output of turbine/generator (W)
T_P	Extraction port temperature (K)
T_E	Exit temperature (K)

Notes--

1. Options 1 and 2 for X are used for each turbine/generator when the LODMG power loop operational mode is not "POWER". Option 1 is used for each turbine/generator when the LODMG operational mode is "POWER" and no mechanical-power output is specified by LODMG for the power loop. Options 1 and 2 are used for all but one of the turbine/generators in the cascade when the LODMG operational mode is "POWER". Option 3 is used for the remaining turbine/generator in the cascade.
2. Values for Y are only required when the LODMG routine for this power loop is the simulation mode.
3. This routine requires power-cycle working-fluid constants.

Subroutine TURBG*

Program Description--This routine is a model for a turbine/generator with output of electrical and/or mechanical power.

Mathematical Algorithm--

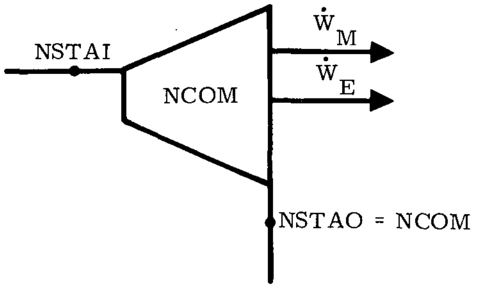
$$\dot{W}_M = X\,\dot{W}_E \tag{1}$$

$$\dot{W}_E = \left[\frac{\eta_g \eta_m}{(1 + X\eta_g)}\right] \dot{m}(h_1 - h_2) \tag{2}$$

$$(h_1 - h_2) = \eta_I\,(h_1 - h_{2s}) \tag{3}$$

$\dot{W}_M$	is the mechanical-power output of the turbine/generator (W),
$\dot{W}_E$	is the electrical-power output of the turbine/generator (W),
X	is the ratio of mechanical- and electrical-power outputs of the turbine/generator (-),
η_g	is the electrical-generator efficiency (-),
η_m	is the turbine-mechanical efficiency (-),
$\dot{m}$	is the fluid-flow rate through the turbine (kg/s),
$(h_1 - h_2)$	is the change in enthalpy between the inlet and exit states (J/kg),
η_I	is the turbine isentropic efficiency (-),
$(h_1 - h_{2s})$	is the enthalpy drop during an isentropic expansion from the inlet state to the exit state pressure (J/kg).

Input--



---

[*] Open Type 1 thermodynamic model

Parameter	Format	Columns	Description
Card 1			
NAME	A5	1-10	"TURBG"
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Inlet state number
ETAG	F10.2	51-60	Electrical generator efficiency (%)
X		61-70[1]	Ratio of mechanical- and electrical-power outputs
Option 1	Blank	61-70	X = 0
Option 2	F10.2	61-70	Value input in percent
Option 3	A6	61-70	UNSPEC
ETAM	F10.2	71-80	Turbine mechanical efficiency (%)
Card 2			
ETA	F10.2	1-10	Turbine isentropic efficiency (%)
T_B	F10.2	11-20	Saturation temperature of exit state (K)
Card 3			
EOF			

Table 2 Output--

Parameter	Description
$\dot{W}_E$	Electrical-power output of generator (W)
$\dot{W}_M$	Mechanical-power output of turbine/generator (W)

Tape 40 Output--

Parameter	Description
$\dot{W}_E$	Electrical-power output of generator (W)
$\dot{W}_M$	Mechanical-power output of turbine/generator (W)
T_E	Exit temperature (K)

Notes--

1. Options 1 and 2 for X are used for each turbine/generator when the LODMG power loop operational mode is not "POWER". Option 1 is used for each turbine/generator when the LODMG operational mode is "POWER" and no mechanical-power output is specified by LODMG for the power loop. Options 1 and 2 are used for all but one of the turbine/generators in the cascade when the LODMG operational mode is "POWER". Option 3 is used for the remaining turbine/generator in the cascade.

2. This routine requires power-cycle working-fluid constants.

Subroutine XTURB[*]

Program Description--This routine is a model for a turbine with a single extraction port; the output is mechanical power.

Mathematical Algorithm--

$$\dot{W}_M = \eta_M \left[\dot{m}_1(h_1 - h_3) - \dot{m}_2(h_2 - h_3)\right] \tag{1}$$

$$\dot{m}_2 = Y\dot{m}_1 \tag{2}$$

$$(h_2 - h_3) = \eta_L(h_2 - h_{3s}) \tag{3}$$

$$(h_1 - h_3) = \eta_H(h_1 - h_{2s}) + (h_2 - h_3) \tag{4}$$

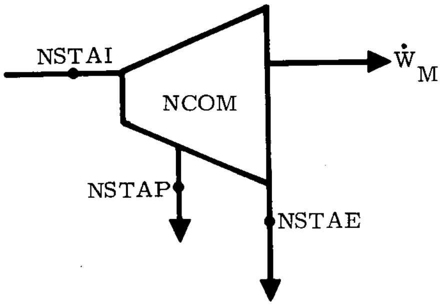
where

$\dot{W}_M$	is the mechanical-power output of the turbine/generator (W),
η_M	is the turbine mechanical efficiency (-),
$\dot{m}_1$	is the fluid-flow rate entering the turbine (kg),
$\dot{m}_2$	is the fluid-flow rate through the turbine extraction port (kg/s),
$(h_2 - h_3)$	is the change in enthalpy between the extraction port and exit thermodynamic states (J/kg),
η_L	is the isentropic efficiency for the expansion from the turbine extraction port state to the turbine exit state (-),
$(h_2 - h_{3s})$	is the enthalpy drop during an isentropic expansion from the extraction port state to the exit state pressure (J/kg),
$(h_1 - h_3)$	is the change in enthalpy between the inlet state and exit states (J/kg),
η_H	is the isentropic efficiency for the expansion from the turbine inlet state to the extraction port state (-),
$(h_1 - h_{2s})$	is the enthalpy drop during an isentropic expansion from the inlet state to the extraction port state (J/kg),
Y	is the extraction rate (-).

---

[*] Open Type 3 thermodynamic model

Input--



Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"XTURB"
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Inlet state number
NSTAP	I5	26-30	Extraction port state number
NSTAE	I5	41-45	Exit state number
ETAM	F10. 2	51-60	Turbine mechanical efficiency (%)
Card 2			
ETAH	F10. 2	1-10	Isentropic efficiency for expansion from inlet to extraction port (%)
ETAL	F10. 2	11-20	Isentropic efficiency for expansion from extraction port to exit (%)
T_B	F10. 2	21-30	Saturation temperature of extraction port state (K)
T_D	F10. 2	31-40	Saturation temperature of exit state (K)
Y	F10. 2	41-50	Turbine extraction rate-ratio of fluid flow through extraction port and the fluid-flow rate entering the turbine (%)
Card 3			
EOF			

Table 2 Output--

Parameter	Description
$\dot{W}_M$	Mechanical-power output from turbine/ generator (W)

Tape 40 Output--

Parameter	Description
$\dot{W}_M$	Mechanical-power output of turbine generator (W)
T_P	Extraction port temperature (K)
T_E	Exit temperature (K)

Notes--

1. Values for Y are only required when the LODMG routine for this power loop is in the simulation mode.
2. This routine requires power-cycle working-fluid constants.

Subroutine TURB*

Program Description--This routine is a model for a turbine with mechanical-power output.

Mathematical Algorithm--

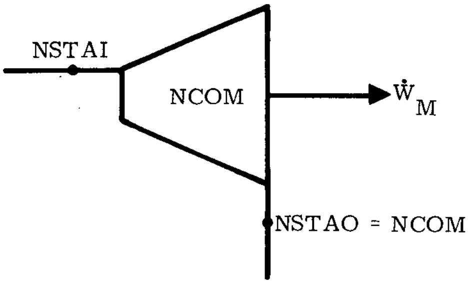
$$\dot{W}_M = \eta_m \dot{m}(h_1 - h_2) \quad (1)$$

$$(h_1 - h_2) = \eta_I(h_1 - h_{2s}) \quad (2)$$

where

$\dot{W}_M$	is the mechanical-power output of the turbine/generator (W),
η_m	is the turbine mechanical efficiency (-),
$\dot{m}$	is the fluid-flow rate through the turbine (kg/s),
$(h_1 - h_2)$	is the change in enthalpy between the inlet and exit states (J/kg),
η_I	is the turbine isentropic efficiency (-),
$(h_1 - h_{2s})$	is the enthalpy drop during an isentropic expansion from the inlet state to the exit state pressure (J/kg).

Input--



---

[*] Open Type 1 thermodynamic model

Parameter	Format	Columns	Description
Card 1			
NAME	A5	1-6	"TURB"
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Inlet state number
ETAM	F10. 2	51-60	Turbine mechanical efficiency (%)
Card 2			
ETA	F10. 2	1-10	Turbine isentropic efficiency (%)
T_B	F10. 2	11-20	Saturation temperature of exit state (K)
Card 3			
EOF			

Table 2 Output--

Parameter	Description
$\dot{W}_M$	Mechanical-power output of turbine/ generator (W)

Tape 40 Output--

Parameter	Description
$\dot{W}_M$	Mechanical-power output of turbine/ generator (W)
T_E	Exit temperature (K)

Note--This routine requires power-cycle working-fluid constants.

CII. COMPONENT ROUTINES

2. Controls

a. Fluid-Flow Controls

Subroutine FLODIV*

Program Description -- FLODIV is a model that allows the flow to be divided.

Mathematical Algorithm --

$$\dot{m}_1 = \text{Minimum of } \dot{m}_{inlet} \text{ and } \dot{m}_{ref} \quad (1)$$

$$\dot{m}_2 = \dot{m}_{inlet} - \dot{m}_1 \quad (2)$$

where

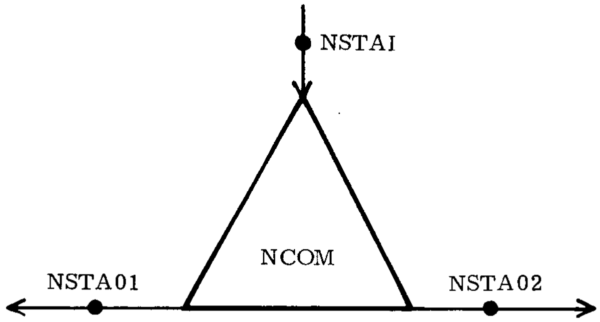
$\dot{m}_1$ is the flow-through outlet state NSTA01,

$\dot{m}_2$ is the flow-through outlet state NSTA02,

$\dot{m}_{inlet}$ is the inlet flow to FLODIV from the upstream state point NSTAI,

$\dot{m}_{ref}$ is the flow-through a user-supplied state point NSREF.

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"FLODIV"
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	System state point
NSTA01	I5	26-30	Outlet State 1
NSTA02	I5	41-45	Outlet State 2
NSREF	I10	51-60	Reference state point

---

*Open Type 3 control model

Card 2

EOF

Output -- Table 1 output only.

Note -- No property data required.

Subroutine FLOVLV*

Program Description -- FLOVLV is a model that sets the output flow to either the inlet flow or to zero, depending on the inlet temperature and user-supplied temperatures.

Mathematical Algorithm --

$$\text{If } T_{in} \geq T_L \text{ or } \leq T_H \text{ ,} \tag{1}$$

$$\text{then } \dot{m}_{out} = \dot{m}_{in} \text{ ;} \tag{2}$$

otherwise, $\dot{m}_{out} = 0$, pressure and temperature set to ambient conditions.

where

$\dot{m}_{out}$ is the flow rate out of FLOVLV,

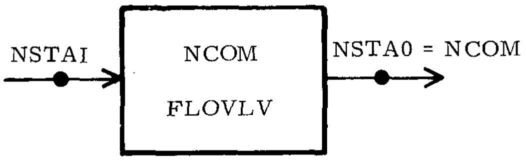
$\dot{m}_{in}$ is the fluid-flow rate into FLOVLV,

T_{in} is the temperature entering FLOVLV,

T_L is the user-specified value for the low temperature,

T_H is the user-specified value for the high temperature,

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A6	1-6	"FLOVLV"
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Inlet state number
T_L	F10.0	51-60	Low temperature (K)
T_H	F10.0	61-70	High temperature (K)

---

*Open Type 1 control model

Card 2

EOF

Note -- No fluid properties are required.

Subroutine DIVJNT[*]

Program Description -- Subroutine DIVJNT divides a fluid stream into two fluid streams. Fluid enters the component through a single inlet and leaves through two outlets, each having a specified fraction of the inlet flow rate. Temperatures and pressures are not altered.

Mathematical Algorithm --

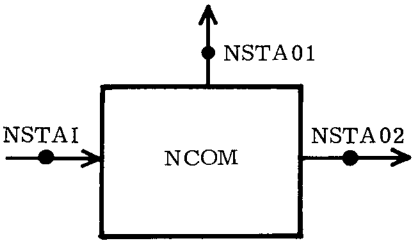
$$\dot{m}_{o,1} = f_1 \dot{m}_i \tag{1}$$

$$\dot{m}_{o,2} = (1 - f_1)\dot{m}_i \tag{2}$$

where

$\dot{m}_{o,1}$ = fluid-flow rate at Outlet 1
$\dot{m}_{o,2}$ = fluid-flow rate at Outlet 2
$\dot{m}_1$ = fluid-flow rate at inlet
f_1 = fraction of flow leaving Outlet 1

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (DIVJNT)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
NSTA01	I5	26-30	Outlet state number - Outlet 1
NSTA02	I5	41-45	Outlet state number - Outlet 2
FRACT1	F10.0	51-60	Fraction of flow leaving Outlet 1

---

[*] Open Type 3 control model

Card 2

EOF

Table 2 and Tape 40 Output -- None

Subroutine SWITCH[*]

Program Description -- Subroutine SWITCH models a two-branch switch. If the parameter ACON is "TEMP". the subroutine uses the outlet temperature of component NCC as a control parameter. If ACON is "CORD", the value of SAVEVAR (1, NCC) is used as a control parameter. At this time, the following subroutines store values in SAVEVAR (1, NCC):

Subroutine	Parameter
TCSTORE	High-temperature storage volume
STORE5	Volume of stored fluid

If the control parameter is less than X_L, the flow is sent through Outlet 1 (flow through Outlet 2 is zero). If the control parameter is greater than X_H, the flow is sent through Outlet 2. If the control parameter is between X_L and X_H, the flow goes through the same outlet through which it previously went.

If the flow in a fluid branch connected to the switch has been zero and then becomes positive due to a start-up situation, the switch component will switch to direct flow into this branch. (The solar collectors have start-up logic to start operation at the beginning of each day when the sun's elevation angle becomes greater than zero.)

Mathematical Algorithm --

$$\text{if } X < X_L \ , \qquad \dot{m}_{o,1} = \dot{m}_i \text{ and } \dot{m}_{o,2} = 0 \qquad (1)$$

$$\text{if } X > X_H \ , \qquad \dot{m}_{o,1} = 0, \text{ and } \dot{m}_{o,2} = \dot{m}_i \qquad (2)$$

$$\text{if } X \leq X \leq X_H \ , \qquad \text{flow path remains the same} \qquad (3)$$

where

X = control parameter

X_L = low-control value

X_H = high-control value

$\dot{m}_i$ = inlet fluid-flow rate

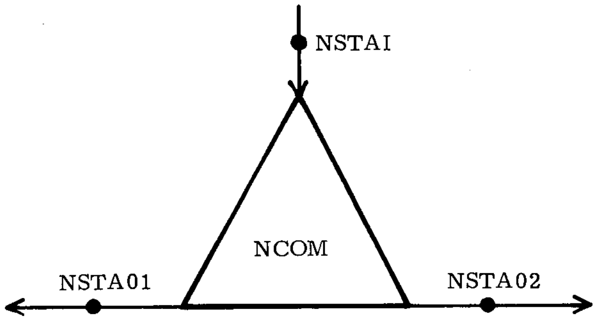
$\dot{m}_{o,\ 1}$ = Outlet 1 fluid-flow rate

$\dot{m}_{o,\ 2}$ = Outlet 2 fluid-flow rate

---

[*] Open Type 3 control model.

Input --



Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (SWITCH)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
NSTA01	I5	26-30	State number - Outlet 1
NSTA02	I5	41-45	State number - Outlet 2
NCC	I10	51-60	Component number supplying control parameter
ACON	A10	61-70	Type of control ("TEMP" for temperature control; "CORD" for other variable control
XL	F10.0	71-80	Low-control value
Card 2			
XH	F10.0	1-10	High-control value
NOUT	I10	11-20	Outlet number for initial flow ("1" or "2")
Card 3			
EOF			

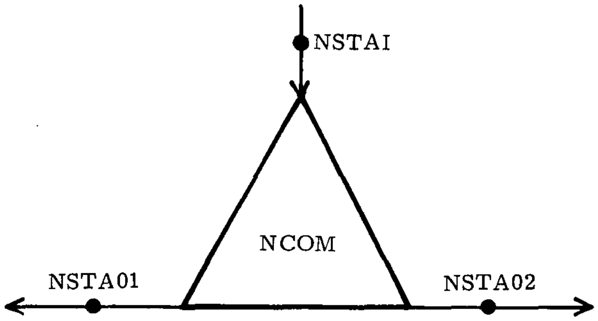
Table 2 Output -- None

Tape 40 Output --

Parameter	Description
FM1	Flow rate - Outlet 1 (kg/s)
FM2	Flow rate - Outlet 2 (kg/s)

Subroutine TIMSWH*

Program Description -- TIMSWH is a model that allows the user to select the fluid path as a function of time and/or sun angle. User-input directs fluid flow through either the outlet state point NSTA01 or through NSTA02.



Normally fluid flows through NSTA01 but is directed through NSTA02 via the cards

PERIOD, WEEK, DAY, HOUR, WEEKEND, NIGHT, END.

In general, the user selects groups of days, then hours and/or sun elevation angles during those days for which flow is diverted through NSTA02. Various modes of operation may be constructed for an entire year by supplying TIMSWH with sets of the above control cards.

The sequence in which the control cards are specified within a set is very important. For example, if TIMSWH encounters a DAY card it will not honor a PERIOD or WEEK card until it encounters an END card.

The sequence in which each set is provided to TIMSWH is also critical. For example, the user supplies set (1) date, which directs the flow through NSTA02 for every weekend of the year, and then supplies TIMSWH with an additional set such that the flow through NSTA02 should occur only in weekends during the winter months. This sequence will not work. Once flow has been directed through NSTA02 for a particular time, it cannot be directed through NSTA01 for that time.

The following section describes TIMSWH control cards and is in the same order in which each control card is processed by TIMSWH. Individual control cards may be omitted from a set, and no more than one card of each type is allowed per set.

---

*Open Type 3 control model

PERIOD Card -- Eight separate groups of days have been preestablished for use with this card. The user is allowed to specify up to three of the groups on the PERIOD card or define his own days for which flow is to be diverted. By definition, Day 1 is the first day of the year and is a Sunday. Thus, the day sequence is:

Sundays	1, 8, 15, . . .
Mondays	2, 9, 16, . . .
Etc.	

The eight groups of days and associated names are:

Name	Days (inclusive)
"WINTER"	1 - 78 and 354 - 365
"SPRING"	79 - 170
"SUMMER"	171 - 262
"FALL"	263 - 353
"QUARTER 1"	1 - 90
"QUARTER 2"	91 - 181
"QUARTER 3"	182 - 273
"QUARTER 4"	274 - 365

WEEK Card -- The WEEK card allows the user to specify which weeks of the year he will switch on. Up to seven separate weeks may be defined on the card. Using the day definition above. Week 1 is Days 1 - 7 inclusive; Week 2 is 8 - 14; etc.

DAY Card -- This card defines on which day(s) of the week switching is to take place for the time frame given by the PERIOD and WEEK cards. The numbers on this card may range from 1 to 7 only. If omitted, switching will take place every day of the week in the time frame for the hours as specified on the HOUR card.

HOUR Card -- This card allows the user to specify within which groups of hours of each day switching is to take place for the defined time frame. If the HOUR, WEEKEND, and NIGHT cards are omitted in a set, switching occurs for every hour of each day in the time frame. Up to three groups of hours may be included on this card.

WEEKEND Card -- The use of this card allows switching to take place from a specified time on Friday through and including a specified time on Monday for every hour of each Friday, Saturday, Sunday, and Monday in the time frame.

T_1, the first time on this card, is for Friday; the second time, T_2, is for Monday. The default time for T_1 is 6 p.m. Friday. The default time for T_2 is 7 a.m. Monday.

NIGHT Card -- The input on this card is:

α_m	morning elevation angle - default sunrise
Δt_m	time increment in hours. Morning - default 0
α_e	evening elevation angle - default sunset
Δt_e	time increment in hours. Evening - default 0

Given the above input TIMSWH calculates times T_M and T_E as follows:

$$\left.\begin{array}{l} T_M = T(\alpha_m) + \Delta t_m \\ \\ T_E = T(\alpha_e) + \Delta t_e \end{array}\right\} \text{TM and TE are rounded to the nearest hour.}$$

Switching for each day as specified in the time frame will occur through NSTA02 for the hours 00 - T_M and T_E - 23.

END Card -- This card ends each set and initiates the search for new PERIOD, WEEK, . . . cards.

NOTES --

1. Once flow is directed through NSTA02 for a particular time, the flow for that time cannot be changed. Therefore, it is very important that users carefully construct their input to TIMSWH.
2. If both the PERIOD and WEEK cards are omitted from a set, TIMSWH assumes that switching will take place for every day of the year.
3. If the DAY card is omitted from a set, TIMSWH assumes switching is to take place for every day of the week in the time frame as specified by the PERIOD and WEEK card(s).
4. If the HOUR, WEEKEND, and NIGHT cards are omitted from a set, switching will occur for every hour of the time frame as specified by the PERIOD, WEEK, and DAY cards in the set.
5. When Week 52 is included on the WEEK card, Days 358 - 365 inclusive are added to the time frame.
6. Day 1 is assumed to be Sunday and the first day of the year. Therefore, if TIMSWH is being used with time-varying loads data, the day must be adjusted accordingly.
7. TIMSWH cannot switch on an interval less than a whole hour.
8. An output table may be printed that indicates the outlet state through which the fluid will flow (see input for Card 1).

Formats --

Parameter	Format	Columns	Description
Card 1			
"TIMSWH"	A6	1-6	Component name
NCOM	I10	11-20	Component number
NCOMI	I5	21-25	Upstream component number
NSTA01	I5	26-30	Outlet State 1
NSTA02	I5	41-45	Outlet State 2
FLAG	A10	51-60	Blank ⇒ Do not print switch setting table Nonblank ⇒ Print switch setting table
Card 2 (Optional)			
"PERIOD"	A6	1-6	Card name
$NAME_1$	A10		Group name "WINTER", "FALL", etc (left-adjust)
or	or	11-20	or
S_{D1}	I10		Starting day of time frame (right-adjust)
E_{D1}	I10	21-30	Ending day of time, frame (right-adjust)
$NAME_2$	A10		Group name if any
or	or	31-40	or
S_{D2}	I10		Starting day of next time frame (if any)
E_{D2}	I10	41-50	Ending day of next time frame (if any)
$NAME_3$	A10		Group name if any
or	or	51-60	or
S_{D3}	I10		Starting day of next time frame (if any)
E_{D3}	I10	61-70	Ending day of next time frame (if any)
Card 3 (Optional)			
"WEEK"	A4	1-4	Card name
N_1	I10	11-20	
N_2	I10	21-30	Weeks of year
.	.	.	$1 \leq N_i \leq 52$
.	.	.	
.	.	.	
N_7	I10	71-80	

Parameter	Format	Columns	Description
Card 4 (Optional)			
"DAY"	A3	1-3	Card name
DOW_1	I10	11-20	Weeks of year $1 \le DOW_i \le 7$
DOW_2	I10	21-30	
.	.	.	
.	.	.	
.	.	.	
DOW_7	I10	71-80	
Card 5 (Optional)			
"HOUR"	A4	1-4	Card name
S_{H1}	I10	11-20	Starting and ending hours for switching $S_{Hi} \le E_{Hi}$ $0 \le S_{Hi}$ and $E_{Hi} \le 23$
E_{H1}	.	21-30	
S_{H2}	.	31-40	
E_{H2}	.	41-50	
S_{H3}	.	51-60	
E_{H3}	I10	61-70	
Card 6 (Optional)			
"WEEKEND"	A7	1-7	Card name
T_1	I10	11-20	Friday time
T_2	I10	21-30	Monday time
Card 7 (Optional)			
"NIGHT"	A5	1-5	Card name
α_m	F10.0	11-20	Morning sun elevation angle (degrees) Blank ⇒ sunrise; $0. \le \alpha_m \le 90$
Δt_m	I10	21-30	Time constant in hours, which is added to $T(\alpha_m)$; Blank ⇒ 0
α_e	F10.0	31-40	Evening sun elevation angle (degrees) Blank ⇒ sunset; $0. \le \alpha_e \le 90$
Δt_e	I10	41-50	Time constant in hours, which is added to $T(\alpha_e)$; Blank ⇒ 0

Parameter	Format	Columns	Description
Card 8			
"END"	A3	1-3	Card name

Cards 2 - 8 may be repeated in creating the switching effect desired. After the last "END" card there must be a Card 9.

Card 9

EOF

This concludes the input description for TIMSWH.

Examples --

1. The following input will switch the flow through state point 15 for every weekend of the year from Friday at 6 p.m. to and including 5 a.m. Monday.

```
TIMSWH             12    11    13          15
WEEKEND                         5
END
```

2. In this example, flow will be switched as in Example 1 and also when the sun is down.

```
TIMSWH             12    11    13          15
WEEKEND                         5
NIGHT
END
```

3. This example is similar to 2 above but also switches the flow for the entire last week of the year.

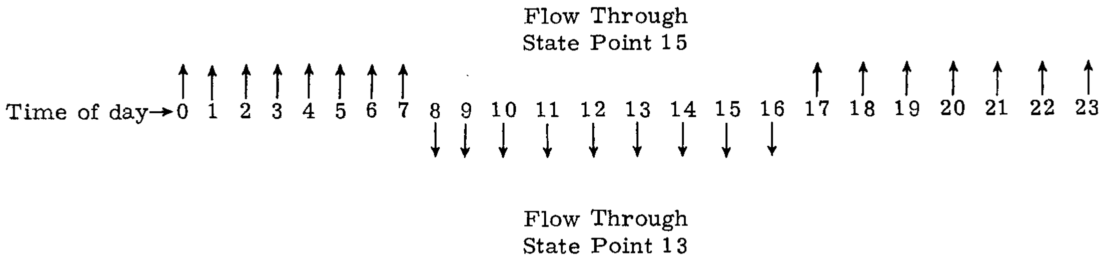
```
TIMSWH             12    11    13          15
WEEKEND                         5
NIGHT
END
WEEK               52
END
```

4. In this final example, switching through state point 15 will occur for the days 1-120 and 305-365 for hours 0-7 and 17-23. The following figure illustrates the mode of operation for a single day in the time frame. The input data would look like:

```
TIMSWH             12    11    13          15
PERIOD   QUARTER  1                  91          120        305         365
HOUR                0           7    17           23
END
```

In this example, the period card could have been

```
PERIOD              1          120   305          365
```



Mode of Operation for a Single Day in the Selected Time Frame

TABLE 1 output only from TIMSWH.

No diagnostics.

No fluid property data needed for TIMSWH.

c. Temperature

Subroutine TEMCON[*]

Program Description -- Subroutine TEMCON is used to control the outlet temperature of an individual component or a string of components by adjusting flow rate. Rate of energy addition to the component string is computed based on temperature rise and flow rate at the previous iteration. Flow rate for the present iteration is calculated using this energy rate, the present inlet temperature to the string, and the desired outlet temperature. In system model construction, component TEMCON must be placed immediately in front of the component string to be controlled.

Mathematical Algorithm --

$$\dot{m}_{new} = \dot{m}_{old} \frac{\int_{T_{i,\,old}}^{T_o} C\,dT}{\int_{T_{i,\,new}}^{T_d} C\,dT}$$

where

$\dot{m}_{new}$ = component string flow rate for present iteration (kg/s)

$\dot{m}_{old}$ = component string flow rate at previous iteration (kg/s)

C = fluid specific heat (J/kg/K)

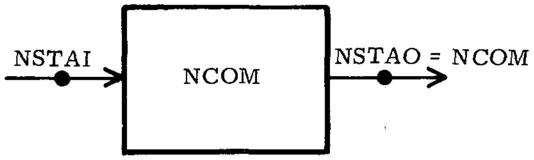
$T_{i,\,old}$ = temperature of upstream state at previous iteration (K)

$T_{i,\,new}$ = temperature of upstream state for present iteration (K)

T_o = controlled string outlet temperature at previous iteration (K)

T_d = desired controlled string outlet temperature (K)

Input --



---

[*] Open Type 1 thermodynamic model

Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (TEMCON)
NCOM	I10	11-20	Component number
NSTAI	I5	21-25	Upstream state number
NO	I10	51-60	Outlet state number of controlled string
TOD	F10.0	61-70	Desired outlet temperature (K)
ERR	F10.0	71-80	Allowed error (K)
Card 2			
FMAX	F10.0	1-10	Maximum allowed flow rate (kg/s)
FMIN	F10.0	11-20	Minimum allowed flow rate (kg/s)
Card 3			
EOF			

Table 2 Output -- None

Tape 40 Output --

Parameter	Description
TO	Outlet temperature (K)
PO	Outlet pressure (Pa)
FM	Outlet flow rate (kg/s)

Notes --

1. This component uses heat-transfer-fluid property data.
2. Component TEMCON must immediately precede the component string to be controlled.

CIII. SYSTEM PERFORMANCE ROUTINES

1. Energy Accounting

Subroutine ENGAC1*

Program Description -- ENGAC1 is a system performance routine that performs energy accounting for the system model. Current values and integrated values from the beginning of the simulation period to the current time for the energy transfer rates are defined in 1.2.6, and the system energy conversion efficiency is calculated. These system performance data are printed as TABLE 3 output for times defined by the PRINT card (see Section 2.2). Only values for those rates that are associated with the system model are printed; all others are automatically deleted from TABLE 3 output. All rates are written to Tape 40 for post-SOLTES calculations, plotting, and printing.

Mathematical Algorithm --

$$Q(t_s) = 0 \qquad (1)$$

$$Q(t + \Delta t) = \int_{t_s}^{t+\Delta t} \dot{Q}(\sigma)\, d\sigma = \int_{t_s}^{t} \dot{Q}(\sigma)\, d\sigma + \int_{t}^{t+\Delta t} \dot{Q}(\sigma)\, d\sigma \qquad (2)$$

$$\simeq Q(t) + \dot{Q}(t)\,\Delta t \qquad (3)$$

$$\begin{aligned} \dot{B}(t) = {} & L_{EL}(t) + L_{PW}(t) + L_{TH}(t) + L_{CL}(t) + L_{HT}(t) \\ & + L_{HW}(t) + D^{s}_{CL}(t) + D^{s}_{HT}(t) - \left[D_{EL}(t) - D^{s}_{EL}(t)\right] \\ & - \left[D_{PW}(t) - D^{s}_{PW}(t)\right] - \left[P_{EL}(t) - P^{s}_{EL}(t)\right] - \left[P_{PW}(t) - P^{s}_{PW}(t)\right] \end{aligned} \qquad (4)$$

$$\dot{S}(t) = S_P(t) + S_A(t) \qquad (5)$$

If $\dot{S}(t) = 0$, $\eta(t)$ is undefined;

otherwise

$$\text{If } \dot{S}_T(t) \geq 0,\ \eta(t) = \frac{\dot{B}(t)}{\dot{S}(t)} \qquad (6)$$

$$\text{If } \dot{S}_T(t) < 0,\ \eta(t) = \frac{\dot{B}(t)}{\dot{S}(t) - \dot{S}_T(t)} \qquad (7)$$

If $S(t) = 0$, $\eta_c(t)$ is undefined,

$$\eta_c(t) = \frac{B(t)}{S(t) + S_{Ti}} \qquad (8)$$

---

*System performance routine

where

t_s	is the starting time of the simulation period,
$Q(t)$	is the integrated value of an energy transfer rate $\dot{Q}$ over the time interval from t_s to t,
Δt	is the SOLTES time increment,
$\dot{Q}(t)$	is an energy transfer rate at time t,
$\dot{B}(t)$	is the rate that the system provides beneficial energy at time t,
${}^1L_{EL}(t)$	is the total electrical load produced by the system at time t (ELCLD),
${}^2L_{PW}(t)$	is the total mechanical-power load produced by the system at time t (POWLD),
$L_{TH}(t)$	is the total thermal load met by the system at time t (THMLD),
$L_{CL}(t)$	is the total cooling load met by the system at time t (COOLLD),
$L_{HT}(t)$	is the total heating load met by the system at time t (HEATLD),
$L_{HW}(t)$	is the total hot-water load met by the system at time t (HWATLD),
$D^s_{CL}(t)$	is the total of the cooling demands satisfied by the system at time t (COOLDM),
$D^s_{HT}(t)$	is the total heating demands satisfied by the system at time t (HEATDM),
$\left[D_{EL}(t) - D^s_{EL}(t)\right]$	is the total electrical demands satisfied externally to the system at time t,
$D_{EL}(t)$	is the total electrical demands of the system at time t (ELCDM),
$D^s_{EL}(t)$	is the total electrical demands satisfied by the system at time t (ELCDM),
$\left[P_{EL}(t) - P^s_{EL}(t)\right]$	is the total electrical parasitics satisfied externally to the system at time t,
$P_{EL}(t)$	is the total electrical parasitics of the system at time t (ELCPS),
$P^s_{EL}(t)$	is the total electrical parasitics satisfied by the system at time t (ELCPS),
$\left[D_{PW}(t) - D^s_{PW}(t)\right]$	is the total mechanical-power demands satisfied externally to the system at time t,
$D_{PW}(t)$	is the total mechanical-power demands of the system at time t (POWDM),
$D^s_{PW}(t)$	is the total mechanical-power demands satisfied by the system at time t (POWDM),
$\left[P_{PW}(t) - P^s_{PW}(t)\right]$	is the total mechanical-power parasitics satisfied externally to the system at time t,

P_{PW}	is the total mechanical-power parasitics of the system at time t POWPS),
P^s_{PW}	is the total mechanical-power parasitics satisfied by the system at time t (POWPS),
$\dot{S}(t)$	is the total rate at which energy is supplied to the system at time t,
$\dot{S}_P(t)$	is the rate that energy is supplied from the primary source at time t (PRISUP),
$\dot{S}_A(t)$	is the rate that energy is supplied from the auxiliary source at time t (AUXSUP),
$\eta(t)$	is the system energy conversion efficiency at time t,
$\eta_c(t)$	is the cumulative system energy conversion efficiency over the time interval from t_s to t,
$B(t)$	is the integrated value of $\dot{B}(t)$ over the time interval from t_s to t,
$S(t)$	is the integrated value of $\dot{S}(t)$ over the time interval from t_s to t,
S_{Ti}	is the thermal energy that is stored in the system at the beginning of the simulation period; i. e., at time t_s,
$S_T(t)$	is the rate that thermal energy is stored in the system at time t (THMSTO),

Input --

Parameter	Format	Column	Description
Card 1			
NAME	A6	1-6	ENGAC1
Card 2			
EOF			

Table 2 Output -- None

Table 3 Output -- Integrated values and values for those energy transfer rates defined in Section 1.2.6 that are associated with the system and system energy conversion efficiencies are printed. The output format is self-explanatory.

Tape 40 Output -- The energy transfer rates associated with the system, $\dot{B}(t)$, and $\dot{S}(t)$ are available at each time step.

Notes --

1. A negative value indicates that electricity must be transferred into the system from the system's environment at the rate corresponding to the absolute value of $L_{EL}(t)$.
2. A negative value indicates that mechanical power must be transferred into the system from the system's environment at the rate corresponding to the absolute value of $L_{PW}(t)$.

CIII. SYSTEM PERFORMANCE ROUTINES

2. Energy Summing

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Subroutine QMETER*

Program Description -- Subroutine QMETER measures the rate of energy addition to a fluid in a single component or in a string of components. Up to nine combinations of strings and components can be monitored. The total energy added is approximated by multiplying the rate of energy addition at a given time by the time step.

Mathematical Algorithm --

$$Q_k = \dot{m}_k \int_{T_{i,k}}^{T_{o,k}} C_k \, dT \qquad (1)$$

and

$$E_k = Q_k \Delta t \qquad (2)$$

where

Q_k = rate of energy addition to fluid in k^{th} component string,

E_k = total energy added to fluid during time step,

$\dot{m}_k$ = fluid-flow rate in k^{th} component string,

C_k = fluid specific heat in k^{th} component string,

$T_{i,k}$ = inlet-fluid temperature to k^{th} component string,

$T_{o,k}$ = outlet-fluid temperature of k^{th} component string,

Δt = time interval.

Table 2 and Tape 40 Output --

Parameter	Description
Q_k	Rate of energy addition to k^{th} component string
E_k	Total energy added to k^{th} component string during calculation time period

Note -- This component uses heat-transfer-fluid property data.

---

*System performance routine

Input --

Parameter	Format	Columns	Description
Card 1			
NAME	A10	1-10	Subroutine name (QMETER)
NCAL	I10	51-60	Number of energy measurements (maximum is nine)
NI	I10	61-70	State number upstream of component string to be monitored
NO	I10	71-80	Component number of last component in string
Cards 2 and 3			
NI	I10	1-10	State number upstream of component string to be measured
NO	I10	11-20	Component number of last component in string
NI	I10	21-30	State number upstream of component string to be measured
NO	I10	31-40	Component number of last component in string
NI	I10	41-50	State number upstream of component string to be measured
NO	I10	51-60	Component number of last component in string
NI	I10	61-70	State number upstream of component string to be measured
NO	I10	71-80	Component number of last component in string

APPENDIX D

SOLTES Examples*

The following examples are included to complement the discussion and instructions for SOLTES and to show the flexibility of SOLTES. These examples do not necessarily represent good system designs but are illustrations.

Example 1

A solar, open hot-water system for a residence is simulated. The system model schematic is shown in Figure D1. Three parallel flat-plate solar collectors heat water to charge an uninsulated, thin-walled tank that is used for thermal storage. An auxiliary heater is placed in series with the storage to assure that the hot-water supply temperature is at least 340 K. The hot-water volumetric flow requirement is 8.76×10^{-6} m^3/s (200 gal/day) and is constant throughout the day and night. The volumetric flow rate through the collectors is controlled by the pump at 2.2×10^{-5} m^3/s. The performance of this system is simulated with an hourly time step from noon of the 84th day through noon of the 85th day of a typical meteorological year in Albuquerque, NM.

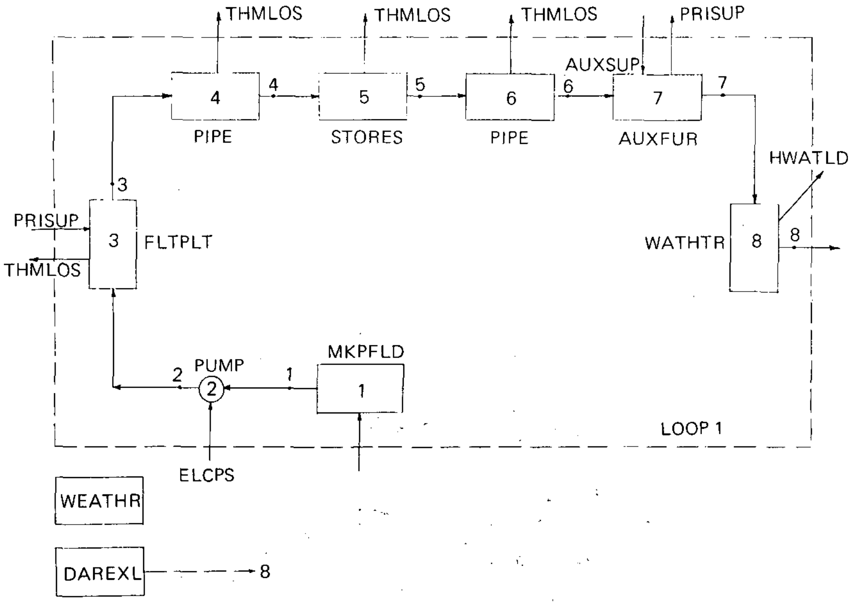

Figure D1. System Model Schematic for a Solar, Open Hot-Water System for a Residence

---

*The necessary EOF records are not shown in these listings.

Input

omponent/Information Routine Data (TAPE 1) --

```
WEATHR                                                                  23050
DAREXL
HWATLD                   80.F0C
LAST
MKPFLD                   1                                    290.      3.E       5
          3NO
PUMP                     2    1                               4.E       5.9       FIXED
2.2E      -5
FLTPLT                   3    2                                         3         16.31E   -3
3.16E     -62.            1.7         .15         2.          35.       .03       .05
.077       .91            .1          .9          .06         .08
PIPE                     4    3                               10.       .011      6.
          1.25
STORE5                   5    4                               .5        340.      0.
0.         0.             30.6        VARIABLE               8
PIPE                     6    5                               10.       .011      6.
          1.25
AUXFUR                   7    6                               340.      .9
WATHTR                   8    7                                         1
ENGAC1
```

Executive Routine Control Data (TAPE 6) --

```
TIME        1975   84    12     0 1975    85    12     0        3600          LAST
PRINT       TABLE1       1975   84    12     0 1975    85    12     0     1   0LAST
PRINT       TABLE3       1975   84    12     0 1975    85    12     0     1   0LAST
PRINT       TABLE2       1975   84    12     0 1975    85    12     0     1   0LAST
ID            EXAMPLE 1 FOR REPORT
                                      HOT WATER SYSTEM                          LAST
RUN                                                                             LAST
```

Loop Definition Data (TAPE 8) --

```
WATER          1  290.0000  .30000E+06  .10000E-01   1    2    3    4
    5    6    7    8    0    0    0    0    0    0    0    0    0    0    0    0
```

Fluid Property Data (TAPE 9) --

Notes: 1. The constants characterizing the power-cycle working fluid for WATER are not necessary.

2. TAPE9 is automatically generated by PRESOL.

```
WATER     THERM
 .273000E+03 .573000E+03 .573000E+03
 .921342E+03 .740090E+00-.130148E-02-.106738E-050.          0.
0.          0.          0.          0.          0.          0.
 .273000E+03 .573000E+03 .573000E+03
-.365498E+05 .554955E+03-.296600E+01 .778268E-02-.100529E-04 .514200E-08
0.          0.          0.          0.          0.          0.
 .273000E+03 .353000E+03 .573000E+03
 .806824E-04-.113673E+00 .601153E+02-.141529E+05 .125809E+070.
 .995082E-05-.208012E-01 .174487E+02-.725029E+04 .148851E+07-.119064E+09
 .273000E+03 .573000E+03 .573000E+03
-.117614E+01 .791539E-02 .148630E-04-.131695E-06 .247601E-09-.155647E-12
0.          0.          0.          0.          0.          0.
WATER     POWER
 .180150E+02 .373200E+03 .647300E+03 .217600E+03 .560000E+02 .344000E+00
   98000E+00 .293000E+03 .770100E+01 .459500E-03 .252100E-05-.859000E-09
     700E+04 .250000E+00
```

Weather Data (TAPE 12) -- intentionally omitted

Executive Routine -- intentionally omitted

Output

```
                    EXAMPLE 1 FOR REPORT
                                       HOT WATER SYSTEM




NYEARI = 1975 INITIAL YEAR
NDAYI  =   84 INITIAL DAY
NHRI   =   12 INITIAL HOUR
NSECI  =    0 INITIAL SECOND
NYEARF = 1975 FINAL YEAR
NDAYF  =   85 FINAL DAY
NHRF   =   12 FINAL HOUR
NSECF  =    0FINAL SECOND

ITIME = 3600 TIME INCREMENT (SECONDS)



CONVERGENCE PARAMETERS
**********************
ABSOLUTE CONVERGENCE CRITERIA FOR TEMPERATURE           =  .1000
RELATIVE CONVERGENCE CRITERIA FOR TEMPERATURE (PERCENT) =  .0100
ABSOLUTE CONVERGENCE CRITERIA FOR FLOW RATE             =  .0500
RELATIVE CONVERGENCE CRITERIA FOR FLOW RATE (PERCENT)   =  .0100
ABSOLUTE CONVERGENCE CRITERIA FOR PRESSURE              =  .0500
RELATIVE CONVERGENCE CRITERIA FOR PRESSURE (PERCENT)    =  .0100
ABSOLUTE CONVERGENCE CRITERIA FOR QUALITY               =  .0050
MAXIMUM NUMBER OF ITERATIONS PER TIME STEP              =     50
NUMBER OF EXTENDED ITERATIONS WITH TABLE 1 PRINTOUT     =     10
```

```
 DATA FOR SUBROUTINE WEATHR
          ISTATNO=      23050 STATION NUMBER
          DLAT   =      35.05 LATITUDE ANGLE (DEG)
          DLAT   =     106.62 LONGITUDE ANGLE (DEG)



 DATA FOR COMPONENT DAREXL
                              NO LOAD TAPE REQUESTED


          LOOTYP  =HWATLO      LOAD TYPE
          NCOM    =          8 NUMBER OF THE COMPONENT RECEIVING THIS LOAD
          EXLOAD  = .8760E-05 CONSTANT VALUE OF LOAD



 DATA FOR COMPONENT MKPFLD
          NCOM    =          1 COMPONENT NUMBER
          NSTAO   =          1 OUTLET STATE NUMBER
          NLP     =          1 LOOP NUMBER
          TO      = .2900E+03 MAKEUP FLUID TEMPERATURE (DEG K)
          PO      = .3000E+06 MAKEUP FLUID PRESSURE (PA)
          FLUID   = WATER      WORKING FLUID
          NS1     =            REFERENCE STATE 1
          NS2     =          3 REFERENCE STATE 2
          TYPE    = THERM      HEAT TRANSFER FLUID PROPERTIES ARE REQUIRED
          IADV    =          0 ADVECTIVE GAINS ARE NOT CALCULATED



 DATA FOR COMPONENT PUMP
          NCOM     =          2 COMPONENT NUMBER
          NSTAI    =          1 INLET STATE NUMBER
          TOI      = .2980E+03 INITIAL INLET TEMPERATURE (DEG K)
          POI      = .3000E+06 INITIAL INLET PRESSURE (N/M2)
          FMI      = .1000E-01 INITIAL INLET FLUID FLOW RATE (KG/S)
          PFIX     = .4000E+06 FIXED OUTLET PRESSURE (N/M2)
          EFF      = .9000E+00 PUMP EFFICIENCY
          FLUID    =WATER      FLUID PUMPED
          NPUOP    =FIXED      PUMP OPERATION (≠FIXED≠ OR ≠VARIABLE≠)
          FMV      = .2200E-04 FIXED  VOLUME FLOW RATE (M3/S)
```

```
DATA FOR COMP
          NCOM               3 COMPONENT NUMBER
          NSTAI   =          2 INLET STATE NUMBER
          TOI     =   .290E+03 INITIAL OUTLET TEMPERATURE (K)
          POI     =   .400E+06 INITIAL OUTLET PRESSURE (PA)
          FMI     =   .220E-01 INITIAL VOLUME FLOW RATE (M3/S)
          NCOL    =          3 NUMBER OF COLLECTORS IN PARALLEL
          NG      =          1 NUMBER OF GLASS PLATES
          PERIFL  =   .631E-02 WETTED PERIMETER (M)
          ARFL    =   .316E-05 FLOW CROSS SECTIONAL AREA (M2)
          XLFL    =   .200E+01 LENGTH OF FLUID CHANNEL (M)
          ARPL    =   .170E+01 PLATE AREA (M2)
          SPACPL  =   .150E+00 SPACING BETWEEN PLATES (M)
          XLPL    =   .200E+01 PLATE LENGTH (M)
          BET     =   .350E+02 COLLECTOR TILT FROM HORIZONTAL (DEG)
          CGAP    =   .300E-01 CONDUCTIVITY OF GAP BETWEEN PLATES (W/M/K)
          REFCV   =   .500E-01 COLLECTOR REFLECTANCE VISIBLE
          REFGV   =   .770E-01 GLASS REFLECTANCE VISIBLE
          TRNGV   =   .910E+00 GLASS TRANSMITTENCE VISIBLE
          EMTCI   =   .100E+00 COLLECTOR EMITTANCE INFRARED
          EMTGI   =   .900E+00 GLASS EMITTANCE INFRARED
          CONDINS=    .600E-01 INSULATION CONDUCTIVITY (W/M/K)
          THKINS =    .800E-01 INSULATION THICKNESS (M)
          FLUID   =WATER       FLUID
```

```
DATA FOR COMPONENT PIPE
          NCOM      =           4 COMPONENT NUMBER
          NSTAI     =           3 INLET STATE NUMBER
          TOI       = .3064E+03 INITIAL INLET TEMPERATURE (K)
          POI       = .3145E+06 INITIAL INLET PRESSURE (N/M2)
          FMI       = .2201E-01 INITIAL FLUID FLOW RATE (KG/S)
          FLUID     =WATER      FLUID
          XL        = .1000E+02 PIPE LENGTH (M)
          DI        = .1100E-01 PIPE DIAMETER (M)
          H         = .6000E+01 HEAT TRANSFER COEFFICIENT (W/M2/K)
          NPIPE     =           1 NUMBER OF PIPES IN PARALLEL
          PLOSS     = .2500E+00 MAX ACCEPTABLE PRESS DROP(FRACTION OF  INLET PRESSURE)
```

```
DATA FOR COMPONENT STORE5
          NCOM    =           5 COMPONENT NUMBER
          NSTAI   =           4 UPSTREAM COMP COMP NUMBER
          TOI     = .3058E+03 INITIAL INLET TEMPERATURE (K)
          POI     = .3137E+06 INITIAL INLET PRESSURE (N/M2)
          FMI     = .2201E-01 INITIAL FLUID FLOW RATE (KG/S)
          SVOLI   = .5000E+00 INITIAL STORED FLUID VOL (M3)
          STEMPI  = .3400E+03 INITIAL STORED FLUID TEMP (K)
          VOLMIN  =0.         MIN. FLUID VOL ALLOWED (M3)
          SPHMW   =0.         MASS-SPHT PRODUCT FOR TANK WALL (J/K)
          SPHMI   =0.         MASS-SPHT PRODUCT FOR INSULAT. (J/K)
          UA      = .3060E+02 OVERALL H.T. COEF.-AREA PRODUCT (W/K)
          NFMOP   =VARIABLE   OUTLET FLOW OPTION (≠EQUAL≠,≠FIXED≠, OR ≠VARIABLE≠)
          NCC     =           8 COMP. NO. CONTROLLING OUTLET FLOW
          FLUID   =WATER      STORED FLUID
```

Output: Example 1 (cont'd)

```
DATA FOR COMPONENT PIPE
         NCOM     =          6 COMPONENT NUMBER
         NSTAI    =          5 INLET STATE NUMBER
         TOI      = .3400E+03 INITIAL INLET TEMPERATURE (K)
         POI      = .3137E+06 INITIAL INLET PRESSURE (N/M2)
         FMI      = .2201E-01 INITIAL FLUID FLOW RATE (KG/S)
         FLUID    =WATER      FLUID
         XL       = .1000E+02 PIPE LENGTH (M)
         DI       = .1100E-01 PIPE DIAMETER (M)
         H        = .6000E+01 HEAT TRANSFER COEFFICIENT (W/M2/K)
         NPIPE    =          1 NUMBER OF PIPES IN PARALLEL
         PLOSS    = .2500E+00 MAX ACCEPTABLE PRESS DROP(FRACTION OF  INLET PRESSURE)



DATA FOR COMPONENT AUXFUR
         NCOM     =          7 COMPONENT NUMBER
         NSTAI    =          6 UPSTREAM COMPONENT NUMBER
         TOI      = .3387E+03 INITIAL INLET TEMPERATURE (K)
         POI      = .3130E+06 INITIAL INLET PRESSURE (N/M2)
         FMI      = .2201E-01 INITIAL FLUID FLOW RATE (M3/S)
         FLUID    =WATER      FLUID
         TOFIX    = .3400E+03 FIXED OUTLET TEMPERATURE (K)
         EFF      = .9000E+00 EFFICIENCY OF FURNACE



DATA FOR COMPONENT WATHTR
         NCOM     =          8 COMPONENT NUMBER
         NSTAO    =          8 OUTLET STATE NUMBER
         NSTAI    =          7 INLET STATE NUMBER
         NSMKP    =          1 OUTLET STATE NUMBER OF MKPFLD
         NLP      =          1 LOOP NUMBER
         FLUID    = WATER     FLUID
         TOI      = .3400E+03 INITIAL INLET TEMPERATURE (DEG K)
         POI      = .3130E+06 INITIAL INLET PRESSURE (PA)
         FMI      = .2201E-01 INITIAL FLUID FLOW RATE (KG/S)



ELECTRICAL PARASITICS IN SYSTEM

COMPONENT NUMBER                   LOOP NUMBER WHERE
GENERATING                          PARASITIC IS MET
PARASITIC                           (*99 IF NOT MET)
        2                                *99
```

Output: Example 1 (cont'd)

```
                         ************ TABLE 3 OU.              ******
YEAR =               DAY =    85      HOUR =    12                 =     0

TABLE OF PRIMARY SUPPLY (PRISUP)
COMPONENT                            INTEGRATED
NAME    NO.          VALUE             VALUE
                      (W)               (J)
FLTPLT   3        5.1163E+03        1.2946E+08
    TOTALS        5.1163E+03        1.2946E+08


TABLE OF AUXILIARY SUPPLY (AUXSUP)
COMPONENT                            INTEGRATED
NAME    NO.          VALUE             VALUE
                      (W)               (J)
AUXFUR   7        1.4932E+03        1.1759E+08
    TOTALS        1.4932E+03        1.1759E+08


TABLE OF THERMAL STORAGE (THMSTO)
COMPONENT                            INTEGRATED
NAME    NO.          VALUE             VALUE
                      (W)               (J)
STORE5   5        1.9035E+04        2.8819E+08
    TOTALS        1.9035E+04        2.8819E+08


TABLE OF THERMAL LOSSES (THMLOS)
COMPONENT                            INTEGRATED
NAME    NO.          VALUE             VALUE
                      (W)               (J)
FLTPLT   3        1.1909E+03        5.7291E+07
PIPE     4        9.4482E+01        3.5650E+06
STORE5   5        5.2167E+02        7.7007E+07
PIPE     6        3.4350E+01        5.0705E+06
    TOTALS        1.8414E+03        1.4293E+08
```

Output: Example 1 (cont'd)

```
TABLE OF ELECTRICAL [illegible] [illegible]
REQUIRING                                            SATISFYING
COMPONENT                         INTEGRATED         COMPONENT
NAME    NO.         VALUE           VALUE            NAME    NO.
                     (W)             (J)
PUMP      2      2.4444E+00      1.1440E+05
    TOTALS       2.4444E+00      1.1440E+05

    TOTAL SATISFIED BY THE SYSTEM (W)                                                0.
    TOTAL SATISFIED EXTERNAL TO THE SYSTEM (W)                                       2.4444E+00
    CUMULATIVE TOTAL SATISFIED BY THE SYSTEM (J)                                     0.
    CUMULATIVE TOTAL SATISFIED EXTERNAL TO THE SYSTEM (J)                            1.1440E+05


TABLE OF HOT WATER OR LIQUID LOADS (HWATLD)
COMPONENT                         INTEGRATED
NAME    NO.         VALUE           VALUE
                     (W)             (J)
WATHTR    8      1.7981E+03      1.5536E+08
    TOTALS       1.7981E+03      1.5536E+08
```

Output: Example 1 (cont'd)

```
                   SUMMARY

TOTAL ENERGY SUPPLY RATE TO THE SYSTEM (W)                                    6.6096E+03
RATIO OF PRIMARY AND TOTAL SUPPLY RATES (PERCENT)                            77.41
RATE THAT THE SYSTEM PROVIDES BENFICIAL ENERGY (W)                            1.7957E+03
SYSTEM ENERGY CONVERSION EFFICIENCY (PERCENT)                                27.17
CUMULATIVE TOTAL ENERGY SUPPLIED TO THE SYSTEM (J)                            2.4705E+08
RATIO OF CUMULATIVE PRIMARY AND TOTAL ENERGY SUPPLIES (PERCENT)              52.40
CUMULATIVE BENFICIAL ENERGY PROVIDED BY THE SYSTEM (J)                        1.5524E+08
CUMULATIVE SYSTEM ENERGY CONVERSION EFFICIENCY (PERCENT)                     42.06
ELECTRICITY REQUIRED TO RUN THE SYSTEM (W)                                    2.4444E+00
ELECTRICITY SUPPLIED TO THE SYSTEM (W)                                        2.4444E+00
CUMULATIVE ELECTRICITY REQUIRED TO RUN THE SYSTEM (J)                         1.1440E+05
CUMULATIVE ELECTRICITY SUPPLIED TO THE SYSTEM (J)                             1.1440E+05
```

Output: Example 1 (cont'd)

```
                    ********** TABLE 1 OUTPUT **********
YEAR = 1975      DAY =    85      HOUR =    12      SEC =     0

 COMPONENT OUTLET STATE   FLOW RATE     TEMPERATURE     PRESSURE          STATE              QUALITY
    NAME        NUMBER     (KG/S)         (DEG K)         (PA)                              (PERCENT)
MKPFLD            1       .2201E-01      .2900E+03      .3000E+06  COMPRESSED LIQUID
PUMP              2       .2201E-01      .2900E+03      .4000E+06  COMPRESSED LIQUID
FLTPLT            3       .2201E-01      .3326E+03      .3098E+06  COMPRESSED LIQUID
PIPE              4       .2201E-01      .3316E+03      .3090E+06  COMPRESSED LIQUID
STORE5            5       .8590E-02      .3035E+03      .3090E+06  COMPRESSED LIQUID
PIPE              6       .8590E-02      .3026E+03      .3089E+06  COMPRESSED LIQUID
AUXFUR            7       .8590E-02      .3400E+03      .3089E+06  COMPRESSED LIQUID
WATHTR            8       .8590E-02      .3400E+03      .3089E+06  COMPRESSED LIQUID
```

```
                    ********** TABLE 2 OUTPUT **********
YEAR = 1975      DAY =    85      HOUR =    12      SEC =     0

WEATHR                      AMBIENT TEMPERATURE (K)                                     .2865E+03
WEATHR                      PRESSURE (PASCALS)                                          .8350E+05
WEATHR                      WIND SPEED (M/S)                                            .3600E+01
WEATHR                      TOTAL HORIZONTAL SOLAR INTENSITY (W/M2)                     .8640E+03
WEATHR                      DIRECT NORMAL SOLAR INTENSITY  (W/M2)                       .8456E+03
WEATHR                      SOLAR ELEVATION ANGLE (DEG)                                 .5665E+02
WEATHR                      SOLAR AZIMUTH ANGLE (DEG)                                   .4071E-12
MKPFLD                  1   MAKE UP FLUID MASS FLOW RATE (KG/S)                         .2201E-01
PUMP                    2   POWER-PUMP POWER (WATTS)                                    .2444E+01
FLTPLT                  3   COLLECTOR EFFICIENCY                                        .7672E+00
FLTPLT                  3   RATE OF ENERGY TRANSFER TO FLUID                            .3925E+04
PIPE                    4   PIPE HEAT LOSS                                              .9448E+02
STORE5                  5   FLUID VOLUME STORED (M3)                                    .8297E+00
STORE5                  5   ENERGY STORAGE RATE (W)                                     .1903E+05
PIPE                    6   PIPE HEAT LOSS                                              .3435E+02
AUXFUR                  7   AUXILIARY FURNACE HEAT RATE (W)                             .1344E+04
AUXFUR                  7   AUXILIARY FURNACE-ENERGY SUPPLIED BY FUEL (W)               .1493E+04
WATHTR                  8   VOLUMETRIC FLOW RATE (M3/S)                                 .8760E-05
WATHTR                  8   ENERGY REQUIRED -HWATLD (W)                                 .1798E+04
EXECUTIVE                   NUMBER OF ITERATIONS REQUIRED FOR CONVERGENCE                       3
```

Example 2

A solar total-energy system that supplies 437.5 K process steam at a constant flow rate 0.1 kg/s and follows external electrical loads is simulated. The system model schematic is shown in Fig. D2. Solar energy is collected by a 800 m^2 field of focusing collectors with an overall thermal efficiency of 60%. The heat-transfer fluids in the collector loop and in the cooling tower loop are Therminol 66 and water, respectively. The collectors and the auxiliary furnace supply the thermal boiler with Therminol 66 at 600 K. No thermal storage is included; however, an auxiliary furnace is included in the system to assure that sufficient energy is supplied to meet the loads and satisfy parasitics. The electrical loads are defined as a function of time by the sum of the electricity required for air conditioning (AIRCOND) and 95% of the electrical grid load (GRID) above 100,000 W (see Fig. D3). The power required to run the pumps (Components 30, 10, and

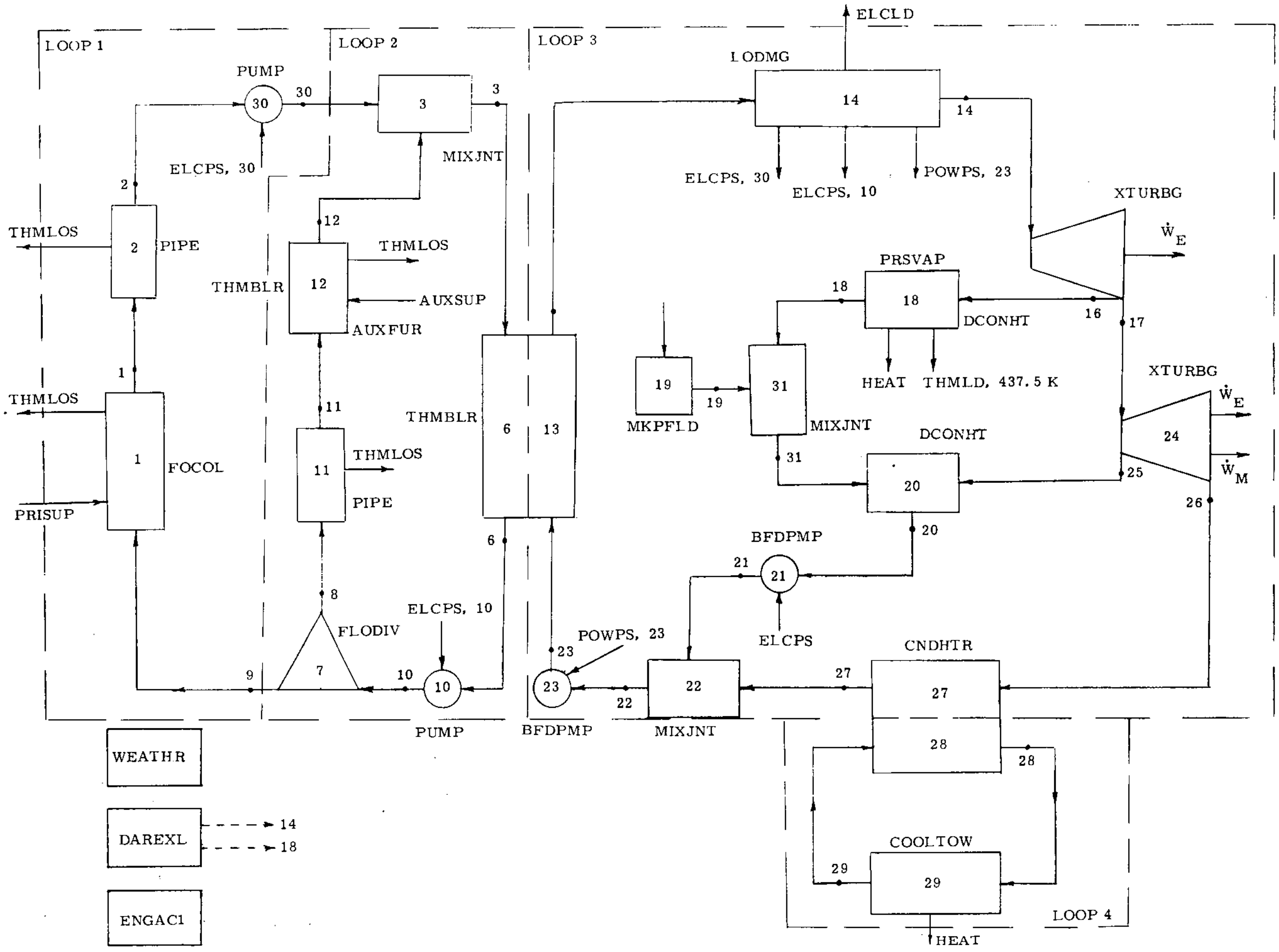

Figure D2. System Model Schematic for a Solar Total-Energy System

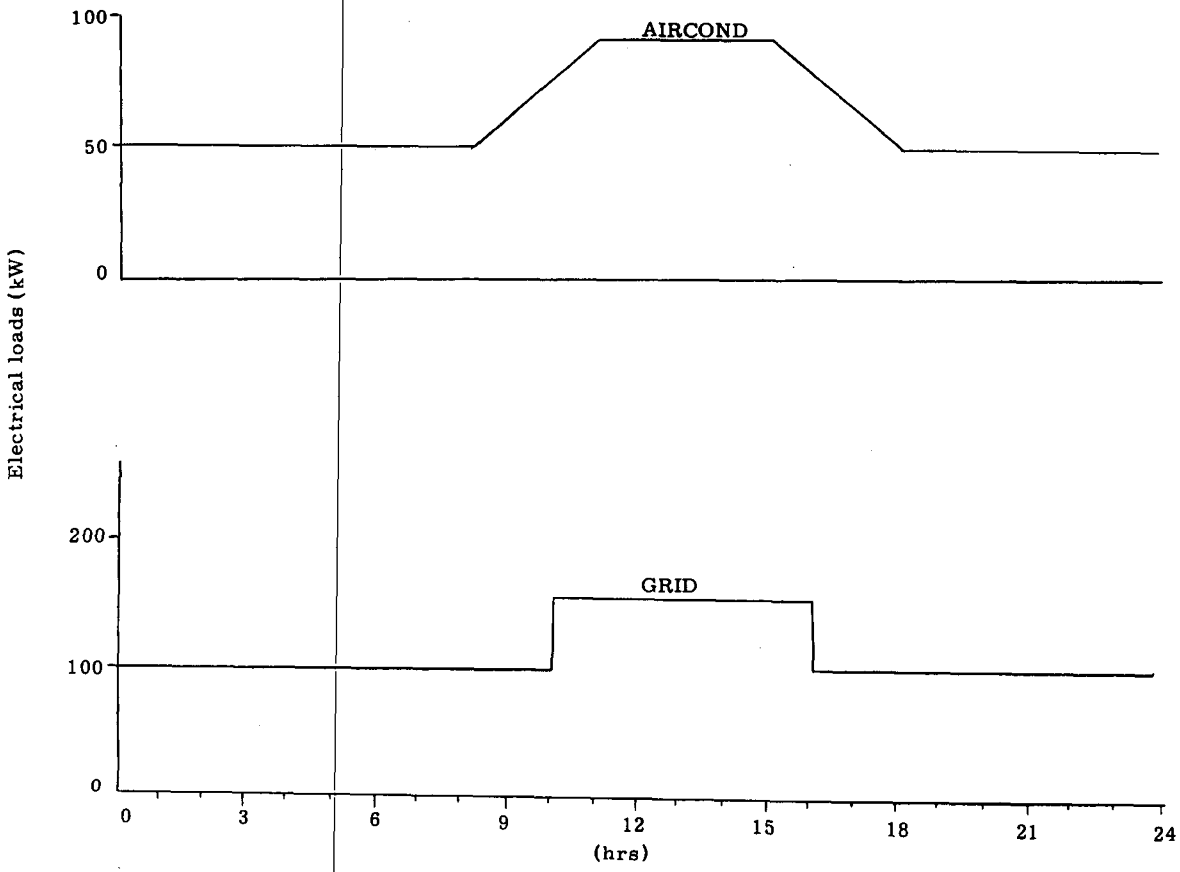

Figure D3. Electrical Loads for a Typical Day During the Simulation Period

21) is supplied by electricity and are parasitics. The electrical parasitics associated with Components 30 and 10 are satisfied by the system, while the electricity required to run Component 21 is supplied externally. The power required to run the other pump, Component 23, is supplied by mechanical power and is a mechanical power parasitic that is satisfied by the system. The power loop, Fluid Loop 3, contains two extraction turbine/generators and a direct-contact regenerative heater. Since the electrical power and mechanical power output of the loop is specified, and the energy transferred from the first flow branch is specified by meeting the process steam requirement, and one flow branch contains a regenerative heater, the energy transferred from the other flow branch through the condenser cannot be specified. This unspecified energy is transferred into water in the condenser and is ultimately rejected from the system by a cooling tower. The water lost in supplying the process steam is supplied by makeup fluid at 288 K and 1 x 10^5 Pa. The first turbine/generator produces only electricity and the second turbine generator produces both electrical and mechanical power. The performance of this system is simulated by an hourly step from noon of the 84th day through noon of the 97th day of a typical meteorological year in Albuquerque, NM.

The extrapolated computer time required to simulate this system for a year is 16 minutes; the simulation requires 137.3_8 K of central memory.

Input

Component/Information Routine Data (TAPE 1)--

```
WEATHR                                                    50
DAREXL                                                      CASE
THMLD             18.1        437.5
ELCLD             14TAPE
GRID                AIRCOND
.9        100000.   1.        0.
LAST
FOCOL              1    9                         600.
         120.       40.       .6
PIPE               2    1                         3.         .100     20.
         10.25
PUMP              30    2                         4.E      5.7        VARIABLE
MIXJNT             3   12             30
THMBLR             6    3        13   23          10.       1.
PUMP              10    6                         4.E      5.9        VARIABLE
FLODIV             7   10    9              8              1
PIPE              11    8                         3.        .100      20.
         10.25
AUXFUR            12   11                         600.      .7        4.4E     7
LODMG             14   13                         POWER     YES
ELCDM     NONE
ELCPS
    1        30
    2        10
POWDM     NONE
POWPS
    3ALL
XTURBG            15   14   16             17     95.                 85.
65.       75.       437.5     437.5
PRSVAP            18   16                         350.      1.013   E5
437.5     30.                1         11.                19
MKPFLD            19                              288.      1.E      5        18
        16NO        POWER
MIXJNT            31   18             19
DCONHT            20   31             25          380.      5.516E   5         2
XTURBG            24   17   25             26     90.       UNSPEC    80.
60.       70.       437.5     310.
BFDPMP            21   20                         1.379E   685.       95.

CNDHTR            27   26        28   29
10.       5.        LAST
MIXJNT            22   27             21
BFDPMP            23   22                         1.379E   680.       90.
POWER
COOLTOW           29   28                         295.
ENGAC1
```

Executive Routine Control Data (TAPE 6)--

```
TIME       1975   84   12     0 1975   97   12     0      3600          LAST
PRINT     TABLE1     1975   84   12     0 1975   97   12     0   24    0LAST
PRINT     TABLE3     1975   97   11     0 1975   97   12     0    1    0LAST
PRINT     TABLE2     1975   84   12     0 1975   97   12     0   24    0LAST
ID          EXAMPLE 2 FOR REPORT
                               TOTAL ENERGY SYSTEM                    LAST
RUN                                                                   LAST
```

Loop Definition Data (TAPE 8)--

```
THERM 6           1                       +06  .10000E+02    1    2
THERM 66          2  550.0000  .40000E+06  .10000E+02    3    5    6   10
    7    8   11   12    0    0    0    0    0    0    0    0    0    0    0    0
WATER             3  550.0000  .13790E+07  .20000E+00   14   13   15   16
   17   18   19   31   20   21   22   23   24   25   26   27    0    0    0    0
WATER             4  304.9000  .10000E+06  .12000E+02   28   29    0    0
```

Fluid Property Data (TAPE 9)--

NOTES: 1. The constants characterizing the power-cycle working fluid for THERMINOL 66 are not necessary.

2. TAPE9 is automatically generated by PRESOL.

```
THERM 66  THERM
 .255000E+03 .644000E+03 .644000E+03
 .124975E+04-.812334E+000.           0.           0.           0.
0.          0.          0.           0.           0.           0.
 .255000E+03 .644000E+03 .644000E+03
 .390480E+03 .382071E+010.           0.           0.           0.
0.          0.          0.           0.           0.           0.
 .283000E+03 .394000E+03 .644000E+03
 .701064E-01-.996187E+02 .529938E+05-.125100E+08 .110599E+100.
-.317083E-04 .862897E-01-.932986E+02 .505262E+05-.137203E+08 .151416E+10
 .255000E+03 .644000E+03 .644000E+03
 .137560E+00-.512883E-040.           0.           0.           0.
0.          0.          0.           0.           0.           0.
THERM 66  POWER
0.          0.          0.           0.           0.           0.
0.          0.          0.           0.           0.           0.
0.          0.
WATER     THERM
 .273000E+03 .573000E+03 .573000E+03
 .921342E+03 .740090E+00-.130148E-02-.106738E-050.           0.
0.          0.          0.           0.           0.           0.
 .273000E+03 .573000E+03 .573000E+03
-.365498E+05 .554955E+03-.296600E+01 .778268E-02-.100529E-04 .514200E-08
0.          0.          0.           0.           0.           0.
 .273000E+03 .353000E+03 .573000E+03
 .806824E-04-.113673E+00 .601153E+02-.141529E+05 .125809E+070.
 .995082E-05-.208012E-01 .174487E+02-.725029E+04 .148851E+07-.119064E+09
 .273000E+03 .573000E+03 .573000E+03
-.117614E+01 .791539E-02 .148630E-04-.131695E-06 .247601E-09-.155647E-12
0.          0.          0.           0.           0.           0.
WATER     POWER
 .180150E+02 .373200E+03 .647300E+03 .217600E+03 .560000E+02 .344000E+00
 .998000E+00 .293000E+03 .770100E+01 .459500E-03 .252100E-05-.859000E-09
 .971700E+04 .250000E+00
```

Time-Sharing Load Data (TAPE 11)--

NOTE: This listing has been shortened.

```
TEST      CASE          3600        2     1975     84       0
AIRCOND   GRID
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
60.E         3100.E        3
70.E         3150.E        3
80.E         3150.E        3
80.E         3150.E        3
80.E         3150.E        3
80.E         3150.E        3
80.E         3150.E        3
70.E         3150.E        3
60.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
60.E         3100.E        3
70.E         3150.E        3
80.E         3150.E        3
80.E         3150.E        3
80.E         3150.E        3
80.E         3150.E        3
80.E         3150.E        3
70.E         3150.E        3
60.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
50.E         3100.E        3
60.E         3100.E        3
70.E         3150.E        3
80.E         3150.E        3
```

(each succeeding day is the same)

Executive Routine--intentionally omitted

Weather Data--intentionally omitted

Output

NOTE: For TABLE1, TABLE2, and TABLE 3 only the output for the simulation end time is shown.

```
                    EXAMPLE 2 FOR REPORT
                                       TOTAL ENERGY SYSTEM




 NYEARI = 1975 INITIAL YEAR
 NDAYI  =   84 INITIAL DAY
 NHRI   =   12 INITIAL HOUR
 NSECI  =    0 INITIAL SECOND
 NYEARF = 1975 FINAL YEAR
 NDAYF  =   97 FINAL DAY
 NHRF   =   12 FINAL HOUR
 NSECF  =    0FINAL SECOND

 ITIME = 3600 TIME INCREMENT (SECONDS)



 CONVERGENCE PARAMETERS
 **********************
 ABSOLUTE CONVERGENCE CRITERIA FOR TEMPERATURE           =  .1000
 RELATIVE CONVERGENCE CRITERIA FOR TEMPERATURE (PERCENT) =  .0100
 ABSOLUTE CONVERGENCE CRITERIA FOR FLOW RATE             =  .0500
 RELATIVE CONVERGENCE CRITERIA FOR FLOW RATE (PERCENT)   =  .0100
 ABSOLUTE CONVERGENCE CRITERIA FOR PRESSURE              =  .0500
 RELATIVE CONVERGENCE CRITERIA FOR PRESSURE (PERCENT)    =  .0100
 ABSOLUTE CONVERGENCE CRITERIA FOR QUALITY               =  .0050
 MAXIMUM NUMBER OF ITERATIONS PER TIME STEP              =     50
 NUMBER OF EXTENDED ITERATIONS WITH TABLE 1 PRINTOUT     =     10
```

Output: Example 2 (cont)

```
DATA FOR SUBROUTINE WEATHR
         ISTATNO=     23050 STATION NUMBER
         DLAT   =     35.05 LATITUDE ANGLE (DEG)
         DLAT   =    106.62 LONGITUDE ANGLE (DEG)




DATA FOR COMPONENT DAREXL
         ID1      =TEST       FIRST WORD IDENTIFER OF LOAD DATA TAPE
         ID2      =CASE       SECOND WORD IDENTIFER OF LOAD DATA TAPE
         IYEAR    =      1975 INITIAL YEAR OF DATA ON LOAD TAPE
         IDAY     =        84 INITIAL DAY OF DATA ON LOAD TAPE
         IHOUR    =         0 INITIAL HOUR OF DATA ON LOAD TAPE
         IDTM     =      3600 CONSTANT TIME INTEVERAL BETWEEN DATA ON LOAD TAPE (SEC)


         LODTYP   =THMLD      LOAD TYPE
         NCOM     =        18 NUMBER OF THE COMPONENT RECEIVING THIS LOAD
         TEMP     = .4375E+03 THERMAL LOAD SUPPLY TEMPERATURE
         EXLOAD   = .1000E+00 CONSTANT VALUE OF LOAD



         LODTYP   =ELCLD      LOAD TYPE
         NCOM     =        14 NUMBER OF THE COMPONENT RECEIVING THIS LOAD
         NAME     =GRID       LOAD NAME
         C        = .9000E+00 C OF EQUATION C(NAME-B)
         B        = .1000E+06 B OF EQUATION C(NAME-B)
         NAME     =AIRCOND    LOAD NAME
         C        = .1000E+01 C OF EQUATION C(NAME-B)
         B        =0.         B OF EQUATION C(NAME-B)



DATA FOR COMPONENT FOCOL
         NCOM    =          1 COMPONENT NUMBER
         NSTAO   =          1 OUTLET STATE NUMBER
         NSTAI   =          9 INLET STATE NUMBER
         NLP     =          1 LOOP NUMBER
         FLUID   = THERM 66   RECEIVER HEAT TRANSFER FLUID
         TOUT    = .6000E+03 COLLECTOR OUTLET TEMPERATURE (DEG K)
         NCOL    =          1 NUMBER OF COLLECTORS IN PARALLEL
         W       = .2000E+02 REFLECTOR WIDTH (M)
         XL      = .4000E+02 REFLECTOR LENGTH (M)
         EFF     = .6000E+00 COLLECTOR EFFICIENCY (-)
         TOI     = .5500E+03 INITIAL INLET TEMPERATURE (DEG <)
         POI     = .4000E+06 INITIAL INLET PRESSURE (PA)
         FMI     = .1000E+02 INITIAL INLET FLOW RATE (KG/S)
```

Output: Example 2 (cont)

```
DATA FOR COMPONENT PIPE
         NCOM     =         2 COMPONENT NUMBER
         NSTAI    =         1 INLET STATE NUMBER
         TOI      = .6000E+03 INITIAL INLET TEMPERATURE (K)
         POI      = .4000E+06 INITIAL INLET PRESSURE (N/M2)
         FMI      = .2721E+00 INITIAL FLUID FLOW RATE (KG/S)
         FLUID    =THERM 66   FLUID
         XL       = .3000E+01 PIPE LENGTH (M)
         DI       = .1000E+00 PIPE DIAMETER (M)
         H        = .2000E+02 HEAT TRANSFER COEFFICIENT (W/M2/K)
         NPIPE    =         1 NUMBER OF PIPES IN PARALLEL
         PLOSS    = .2500E+00 MAX ACCEPTABLE PRESS DROP(FRACTION OF  INLET PRESSURE)
```

```
DATA FOR COMPONENT PUMP
         NCOM     =        30 COMPONENT NUMBER
         NSTAI    =         2 INLET STATE NUMBER
         TOI      = .5916E+03 INITIAL INLET TEMPERATURE (DEG K)
         POI      = .4000E+06 INITIAL INLET PRESSURE (N/M2)
         FMI      = .2721E+00 INITIAL INLET FLUID FLOW RATE (KG/S)
         PFIX     = .4000E+06 FIXED OUTLET PRESSURE (N/M2)
         EFF      = .7000E+00 PUMP EFFICIENCY
         FLUID    =THERM 66   FLUID PUMPED
         NPUOP    =VARIABLE   PUMP OPERATION (≠FIXED≠ OR ≠VARIABLE≠)
```

```
DATA FOR COMPONENT MIXJNT
         NCOM    =         3 COMPONENT NUMBER
         NSTAI1  =        12 FIRST UPSTREAM COMPONENT NUMBER
         NSTAI2  =        30 SECOND UPSTREAM COMPONENT NUMBER
         TOI1    = .5500E+03 INITIAL TEMPERATURE-INLET 1 (K)
         POI1    = .4000E+06 INITIAL PRESSURE-INLET 1 (N/M2)
         FMI1    = .1000E+02 INITIAL FLOW RATE-INLET 1 (KG/S)
         TOI2    = .5916E+03 INITIAL TEMPERATURE-INLET 2 (K)
         POI2    = .4000E+06 INITIAL PRESSURE-INLET 2 (N/M2)
         FMI2    = .2721E+00 INITIAL FLOW RATE-INLET 2 (KG/S)
         FLUID   =THERM 66   FLUID
```

Output: Example 2 (cont)

```
DATA FOR COMPONENT THMBLR
          NCOMT    =          6 THERMAL SIDE COMPONENT NUMBER
          NSTAOT   =          6 THERMAL SIDE OUTLET STATE NUMBER
          NSTAIT   =          3 THERMAL SIDE INLET STATE NUMBER
          NLPT     =          2 THERMAL LOOP NUMBER
          FLUIDT   = THERM 66   THERMAL LOOP WORKING FLUID
          NCOMP    =         13 POWER SIDE COMPONENT NUMBER
          NSTAOP   =         13 POWER SIDE OUTLET STATE NUMBER
          NSTAIP   =         23 POWER SIDE INLET STATE NUMBER
          NLPP     =          3 POWER LOOP NUMBER
          FLUIDP   = WATER      POWER LOOP WORKING FLUID
          DT23     = .1000E+02 DIFFERENCE BETWEEN POWER SIDE OUTLET TEMPERATURE AND THERMAL SIDE INLET TEMPERATURE (DEG K)
          DTPNCH   = .1000E+01 DIFFERENCE BETWEEN POWER SIDE TEMPERATURE AND THERMAL SIDE TEMPERATURE AT THE PINCH POINT (DEG K)
          TOIP     = .5500E+03 INITIAL POWER SIDE INLET TEMPERATURE (DEG K)
          POIP     = .1379E+07 INITIAL POWER SIDE INLET PRESSURE (PA)
          FMIP     = .2000E+00 INITIAL POWER SIDE INLET FLOW RATE (KG/S)
          TOIT     = .5511E+03 INITIAL THERMAL SIDE INLET TEMPERATURE (DEG K)
          POIT     = .4000E+06 INITIAL THERMAL SIDE INLET PRESSURE (PA)
          FMIT     = .1027E+02 INITIAL THERMAL SIDE INLET FLOW RATE (KG/S)



DATA FOR COMPONENT PUMP
          NCOM     =         10 COMPONENT NUMBER
          NSTAI    =          6 INLET STATE NUMBER
          TOI      = .5500E+03 INITIAL INLET TEMPERATURE (DEG K)
          POI      = .4000E+06 INITIAL INLET PRESSURE (N/M2)
          FMI      = .1000E+02 INITIAL INLET FLUID FLOW RATE (KG/S)
          PFIX     = .4000E+06 FIXED OUTLET PRESSURE (N/M2)
          EFF      = .9000E+00 PUMP EFFICIENCY
          FLUID    =THERM 66    FLUID PUMPED
          NPUOP    =VARIABLE    PUMP OPERATION (≠FIXED≠ OR ≠VARIABLE≠)



DATA FOR COMPONENT FLODIV
          NCOM     =          7 COMPONENT NUMBER
          NSTAI    =         10 INLET STATE NUMBER
          NLP      =          2 LOOP NUMBER
          NSTAO1   =          9 OUTLET 1 STATE NUMBER
          NSTAO2   =          8 OUTLET 2 STATE NUMBER
          NSREF    =          1 OUTLET 1 FLOW RATE IS SET EQUAL TO THE FLOW RATE AT REFERENCE STATE
          NUMBER NSREF
          FLUID    =THERM 66    WORKING FLUID
          TOI      = .5500E+03 INITAL INLET TEMPERATURE (DEG K)
          POI      = .4000E+06 INITAL INLET PRESSURE (PA)
          FMI      = .1000E+02 INITAL INLET FLOW RATE (KG/S)
```

Output: Example 2 (cont)

```
DATA FOR COMPONENT PIPE
          NCOM     =          11 COMPONENT NUMBER
          NSTAI    =           8 INLET STATE NUMBER
          TOI      = .5500E+03 INITIAL INLET TEMPERATURE (K)
          POI      = .4000E+06 INITIAL INLET PRESSURE (N/M2)
          FMI      = .9728E+01 INITIAL FLUID FLOW RATE (KG/S)
          FLUID    =THERM 66   FLUID
          XL       = .3000E+01 PIPE LENGTH (M)
          DI       = .1000E+00 PIPE DIAMETER (M)
          H        = .2000E+02 HEAT TRANSFER COEFFICIENT (W/M2/K)
          NPIPE    =           1 NUMBER OF PIPES IN PARALLEL
          PLOSS    = .2500E+00 MAX ACCEPTABLE PRESS DROP(FRACTION OF  INLET PRESSURE)
```

```
DATA FOR COMPONENT AUXFUR
          NCOM     =          12 COMPONENT NUMBER
          NSTAI    =          11 UPSTREAM COMPONENT NUMBER
          TOI      = .5498E+03 INITIAL INLET TEMPERATURE (K)
          POI      = .3995E+06 INITIAL INLET PRESSURE (N/M2)
          FMI      = .9728E+01 INITIAL FLUID FLOW RATE (M3/S)
          FLUID    =THERM 66   FLUID
          TOFIX    = .6000E+03 FIXED OUTLET TEMPERATURE (K)
          EFF      = .7000E+00 EFFICIENCY OF FURNACE


DATA FOR COMPONENT LOOMG
          NCOM     =          14 COMPONENT NUMBER
          NSTAO    =          14 OUTLET STATE NUMBER
          NSTAI    =          13 INLET STATE NUMBER
          NLP      =           3 LOOP NUMBER
          FLUID    = WATER       WORKING FLUID

          LPMOD    = POWER       THIS POWER LOOP PRODUCES ELECTRICAL POWER AND MECHANICAL POWER TO MEET ALL POWER LOADS,
                                   POWER DEMANDS, AND POWER PARASITICS AS DEFINED BY INPUT TO THIS ROUTINE AND
                                   SATISFIES THERMAL LOADS AND THERMAL DEMANDS WHOSE SUM TOTAL IS EQUAL TO THE
                                   NUMBER OF EXTRACTION TURBINES LESS THE NUMBER OF REGENERATIVE HEATERS IN THIS POWER LOOP.
                                   ENERGY IS TRANSFERRED FROM THE OTHER FLOW BRANCH AT AN UNSPECIFIED RATE.
          IELCLD   = YES         EXTERNAL ELECTRICAL POWER LOADS ARE SATISFIED BY THIS POWER LOOP
          IPOWLD   =             NO EXTERNAL MECHANICAL POWER LOADS ARE SATISFIED BY THIS POWER LOOP
          EDMMOD   = NONE        NO ELECTRICAL DEMANDS ARE SATISFIED BY THIS POWER LOOP
          EPSMOD   =             ELECTRICAL PARASITICS GENERATED BY COMPONENTS WHOSE NUMBERS ARE IN THE
                                 FOLLOWING LIST ARE SATISFIED BY THIS POWER LOOP
                                           30   10
          PDMMOD   = NONE        NO MECHANICAL POWER DEMANDS ARE SATISFIED BY THIS POWER LOOP
          PPSMOD   =             MECHANICAL POWER PARASITICS GENERATED BY COMPONENTS WHOSE NUMBERS ARE IN THE
                                 FOLLOWING LIST ARE SATISFIED BY THIS POWER LOOP
                                          14    13    15    16    17    18    19    31    20    21
                                          22    23    24    25    26    27
          TOI      = .5500E+03 INITIAL INLET TEMPERATURE (DEG K)
          POI      = .1379E+07 INITIAL INLET PRESSURE (PA)
          FMI      = .2000E+00 INITIAL INLET FLOW RATE (KG/S)
```

Output: Example 2 (cont)

```
DATA FOR COMPONENT XTURBG
         NCOM     =          15 COMPONENT NUMBER
         NSTAP    =          16 EXTRACTION PORT STATE NUMBER
         NSTAE    =          17 EXIT STATE NUMBER
         NSTAI    =          14 INLET STATE NUMBER
         NLP      =           3 LOOP NUMBER
         FLUID    = WATER       WORKING FLUID
         NT       =           1 TURBINE NUMBER
         NXT      =           1 EXTRACTION TURBINE NUMBER
         ETAH     =       65.00 TURBINE ISENTROPIC EFFICIENCY FROM INLET TO EXTRACTION PORT (PERCENT)
         ETAL     =       75.00 TURBINE ISENTROPIC EFFICIENCY FROM EXTRACTION PORT TO EXIT (PERCENT)
         ETAG     =       95.00 GENERATOR EFFICIENCY (PERCENT)
         ETAM     =       85.00 TURBINE MECHANICAL EFFICIENCY (PERCENT)
         TB       = .4375E+03 SATURATION TEMPERATURE AT THE TURBINE EXTRACTION PORT (DEG K)
         TD       = .4375E+03 SATURATION TEMPERATURE AT TURBINE EXIT (DEG K)
         X        =       -0.00 RATIO OF TURBINE MECHANICAL POWER AND ELECTRICAL POWER (PERCENT)
         TOI      = .5500E+03 INITIAL INLET TEMPERATURE (DEG K)
         POI      = .1379E+07 INITIAL INLET PRESSURE (PA)
         FMI      = .2000E+00 INITIAL INLET FLOW RATE (KG/S)



DATA FOR COMPONENT PRSVAP
         NCOM     =          18 COMPONENT NUMBER
         NSTAO    =          18 OUTLET STATE NUMBER
         NSTAI    =          16 INLET STATE NUMBER
         NLP      =           3 LOOP NUMBER
         NBR      =           1 THIS COMPONENT DETERMINES THE THE FLOW RATE IN THE FLOW BRANCH NUMBER NBR
         FLUID    = WATER       WORKING FLUID
         TEMP     = .4375E+03 PROCESS VAPOR SUPPLY TEMPERATURE (DEG K)
         TOL      = .1000E+01 PROCESS VAPOR TEMPERATURE TOLERANCE (DEG K)
         FMLOSS   =       30.00 FLUID LOSS IN PRSVAP (PERCENT)
         T2       = .3500E+03 FIXED OUTLET STATE TEMPERATURE (DEG K)
         P2       = .1013E+06 FIXED OUTLET STATE PRESSURE (PA)
         IQMTCH   =           1 EXTERNAL LOADS ARE FOLLOWED
         NMKP     =          19 MKPFLD OUTLET STATE NUMBER
         TREF     =             HEAT IS EQUAL TO THMLD
         TOI      = .4946E+03 INITIAL INLET TEMPERATURE (DEG K)
         POI      = .7042E+06 INITIAL INLET PRESSURE (PA)
         FMI      =0.           INITIAL INLET FLOW RATE (KG/S)
```

Output: Example 2 (cont)

```
DATA FOR COMPONENT MKPFLD
         NCOM    =         19 COMPONENT NUMBER
         NSTAO   =         19 OUTLET STATE NUMBER
         NLP     =          3 LOOP NUMBER
         TO      = .2880E+03 MAKEUP FLUID TEMPERATURE (DEG K)
         PO      = .1000E+06 MAKEUP FLUID PRESSURE (PA)
         FLUID   = WATER      WORKING FLUID
         NS1     =         18 REFERENCE STATE 1
         NS2     =         16 REFERENCE STATE 2
         TYPE    = POWER      POWER CYCLE WORKING FLUID CONSTANTS ARE REQUIRED
         IADV    =          0 ADVECTIVE GAINS ARE NOT CALCULATED
```

```
DATA FOR COMPONENT MIXJNT
         NCOM    =         31 COMPONENT NUMBER
         NSTAI1  =         18 FIRST UPSTREAM COMPONENT NUMBER
         NSTAI2  =         19 SECOND UPSTREAM COMPONENT NUMBER
         TOI1    = .3500E+03 INITIAL TEMPERATURE-INLET 1 (K)
         POI1    = .1013E+06 INITIAL PRESSURE-INLET 1 (N/M2)
         FMI1    = .7000E-01 INITIAL FLOW RATE-INLET 1 (KG/S)
         TOI2    = .2880E+03 INITIAL TEMPERATURE-INLET 2 (K)
         POI2    = .1000E+06 INITIAL PRESSURE-INLET 2 (N/M2)
         FMI2    =0.          INITIAL FLOW RATE-INLET 2 (KG/S)
         FLUID   =WATER       FLUID
```

```
DATA FOR COMPONENT DCONHT
         NCOM     =         20 COMPONENT NUMBER
         NSTAO    =         20 OUTLET STATE NUMBER
         NSTAI1   =         31 STATE NUMBER OF LIQUID INLET
         NSTAI2   =         25 STATE NUMBER OF SUPERHEATED VAPOR OR LIQUID-VAPOR MIXTURE INLET
         NLP      =          3 LOOP NUMBER
         FLUID    = WATER      WORKING FLUID
         NBR      =          2 THIS COMPONENT DETERMINES THE FLOW RATE IN THE FLOW BRANCH NUMBER NBR
         T3       = .3800E+03 OUTLET TEMPERATURE (DEG K)
         P3       = .5516E+06 OUTLET PRESSURE (PA)
         TOI1     = .3500E+03 INITIAL LIQUID INLET TEMPERATURE (DEG K)
         POI1     = .1013E+06 INITIAL LIQUID INLET PRESSURE (PA)
         FMI1     = .7000E-01 INITIAL LIQUID INLET FLOW RATE (KG/S)
         TOI2     = .5500E+03 INITIAL SUPERHEATED VAPOR OR LIQUID-VAPOR INLET TEMPERATURE (DEG K)
         POI2     = .1379E+07 INITIAL SUPERHEATED VAPOR OR LIQUID-VAPOR INLET PRESSURE (PA)
         FMI2     = .2000E+00 INITIAL SUPERHEATED VAPOR OR LIQUID-VAPOR INLET FLOW RATE (KG/S)
```

Output: Example 2 (cont)

```
DATA FOR COMPONENT XTURBG
         NCOM     =          24 COMPONENT NUMBER
         NSTAP    =          25 EXTRACTION PORT STATE NUMBER
         NSTAE    =          26 EXIT STATE NUMBER
         NSTAI    =          17 INLET STATE NUMBER
         NLP      =           3 LOOP NUMBER
         FLUID    = WATER       WORKING FLUID
         NT       =           2 TURBINE NUMBER
         NXT      =           2 EXTRACTION TURBINE NUMBER
         ETAH     =       60.00 TURBINE ISENTROPIC EFFICIENCY FROM INLET TO EXTRACTION PORT (PERCENT)
         ETAL     =       70.00 TURBINE ISENTROPIC EFFICIENCY FROM EXTRACTION PORT TO EXIT (PERCENT)
         ETAG     =       90.00 GENERATOR EFFICIENCY (PERCENT)
         ETAM     =       80.00 TURBINE MECHANICAL EFFICIENCY (PERCENT)
         TB       = .4375E+03 SATURATION TEMPERATURE AT THE TURBINE EXTRACTION PORT (DEG K)
         TD       = .3100E+03 SATURATION TEMPERATURE AT TURBINE EXIT (DEG K)
         X        = UNSPEC      THE RATIO OF TURBINE MECHANICAL POWER AND ELECTRICAL POWER IS UNSPECIFIED
         TOI      = .4946E+03 INITIAL INLET TEMPERATURE (DEG K)
         POI      = .7042E+06 INITIAL INLET PRESSURE (PA)
         FMI      = .2000E+00 INITIAL INLET FLOW RATE (KG/S)



DATA FOR COMPONENT BFDPMP
         NCOM     =          21 COMPONENT NUMBER
         NSTAO    =          21 OUTLET STATE NUMBER
         NSTAI    =          20 INLET STATE NUMBER
         NLP      =           3 LOOP NUMBER
         FLUID    = WATER       WORKING FLUID
         P2       = .1379E+07 OUTLET PRESSURE (PA)
         ETAI     =       85.00 PUMP ISENTROPIC EFFICIENCY (PERCENT)
         ETAM     =       95.00 PUMP MECHANICAL EFFICIENCY (PERCENT)
         MODE     =             PUMP POWER IS SUPPLIED BY ELECTRICITY
         TOI      = .3800E+03 INITIAL INLET TEMPERATURE (DEG K)
         POI      = .5516E+06 INITIAL INLET PRESSURE (PA)
         FMI      = .7403E-01 INITIAL INLET FLOW RATE (KG/S)
```

Output: Example 2 (cont)

```
DATA FOR COMPONENT CNDHTR
         NCOM1    =           27 POWER SIDE COMPONENT NUMBER
         NSTAO1   =           27 POWER SIDE OUTLET STATE NUMBER
         NSTAI1   =           26 POWER SIDE INLET STATE NUMBER
         NLP1     =            3 POWER LOOP NUMBER
         FLUID1   = WATER        POWER LOOP WORKING FLUID
         NCOM2    =           28 THERMAL SIDE COMPONENT NUMBER
         NSTAO2   =           28 THERMAL SIDE OUTLET STATE NUMBER
         NSTAI2   =           29 THERMAL SIDE INLET STATE NUMBER
         NLP2     =            4 THERMAL LOOP NUMBER
         FLUID2   = WATER        THERMAL LOOP WORKING FLUID
         NBR      = LAST         THIS COMPONENT DETERMINES THE FLOW RATE IN THE CONDENSATE RETURN FROM THE LAST TURBINE
         DT32     = .1000E+02 TEMPERATURE DIFFERENCE BETWEEN THERMAL SIDE INLET AND POWER SIDE OUTLET (DEG K)
         DTPNCH   = .5000E+01 TEMPERATURE DIFFERENCE BETWEEN THERMAL SIDE AND POWER SIDE AT THE PINCH POINT (DEG K)
         IQMTCH   =        -0 THERMAL DEMAND IS NOT MET
         TOI1     = .3100E+03 INITIAL POWER SIDE INLET TEMPERATURE (DEG K)
         POI1     = .6150E+04 INITIAL POWER SIDE INLET PRESSURE (PA)
         FMI1     = .1960E+00 INITIAL POWER SIDE INLET FLOW RATE (KG/S)
         TOI2     = .3049E+03 INITIAL THERMAL SIDE INLET TEMPERATURE (DEG K)
         POI2     = .1000E+06 INITIAL THERMAL SIDE INLET PRESSURE (PA)
         FMI2     = .1200E+02 INITIAL THERMAL SIDE INLET FLOW RATE (KG/S)



DATA FOR COMPONENT MIXJNT
         NCOM    =          22 COMPONENT NUMBER
         NSTAI1 =           27 FIRST UPSTREAM COMPONENT NUMBER
         NSTAI2 =           21 SECOND UPSTREAM COMPONENT NUMBER
         TOI1    = .5500E+03 INITIAL TEMPERATURE-INLET 1 (K)
         POI1    = .6150E+04 INITIAL PRESSURE-INLET 1 (N/M2)
         FMI1    = .2000E+00 INITIAL FLOW RATE-INLET 1 (KG/S)
         TOI2    = .3800E+03 INITIAL TEMPERATURE-INLET 2 (K)
         POI2    = .1379E+07 INITIAL PRESSURE-INLET 2 (N/M2)
         FMI2    = .7403E-01 INITIAL FLOW RATE-INLET 2 (KG/S)
         FLUID   =WATER      FLUID
```

Output: Example 2 (cont)

```
DATA FOR COMPONENT BFOPMP
         NCOM     =          23 COMPONENT NUMBER
         NSTAO    =          23 OUTLET STATE NUMBER
         NSTAI    =          22 INLET STATE NUMBER
         NLP      =           3 LOOP NUMBER
         FLUID    = WATER       WORKING FLUID
         P2       = .1379E+07 OUTLET PRESSURE (PA)
         ETAI     =       80.00 PUMP ISENTROPIC EFFICIENCY (PERCENT)
         ETAM     =       90.00 PUMP MECHANICAL EFFICIENCY (PERCENT)
         MODE     = POWER       PUMP POWER IS SUPPLIED BY MECHANICAL POWER
         TOI      = .5041E+03 INITIAL INLET TEMPERATURE (DEG K)
         POI      = .3770E+06 INITIAL INLET PRESSURE (PA)
         FMI      = .2740E+00 INITIAL INLET FLOW RATE (KG/S)


DATA FOR COMPONENT COOLTOW
         NCOM    =         29 COMPONENT NUMBER
         NSTAI   =         28 UPSTREAM COMPONENT COMP NUMBER
         TOI     = .3049E+03 INITIAL INLET TEMPERATURE (K)
         POI     = .1000E+06 INITIAL INLET PRESSURE (N/M2)
         FMI     = .1200E+02 INITIAL FLOW RATE (KG/S)
         TOFIX   = .2950E+03 FIXED OUTLET TEMPERATURE (K)
         FLUID   =WATER      FLUID
```

Output: Example 2 (cont)

```
ELECTRICAL PARASITICS IN SYSTEM


COMPONENT NUMBER              LOOP NUMBER WHERE
GENERATING                     PARASITIC IS MET
PARASITIC                      (*99 IF NOT MET)
       30                             3
       10                             3
       21                           *99
```

```
MECH POWER PARASITICS IN SYSTEM


COMPONENT NUMBER              LOOP NUMBER WHERE
GENERATING                     PARASITIC IS MET
PARASITIC                      (*99 IF NOT MET)
       23                             3
```

Output: Example 2 (cont)

```
                         ********** TABLE 3 OUTPUT **********
YEAR = 1975       DAY =    97      HOUR =    12      SEC =     0

TABLE OF PRIMARY SUPPLY (PRISUP)
COMPONENT                        INTEGRATED
NAME    NO.         VALUE          VALUE
                     (W)            (J)
FOCOL     1      8.9865E+05     3.7294E+11
    TOTALS       8.9865E+05     3.7294E+11


TABLE OF AUXILIARY SUPPLY (AUXSUP)
COMPONENT                        INTEGRATED
NAME    NO.         VALUE          VALUE
                     (W)            (J)
AUXFUR  12       5.3772E+06     3.5399E+12
    TOTALS       5.3772E+06     3.5399E+12


TABLE OF THERMAL LOSSES (THMLOS)
COMPONENT                        INTEGRATED
NAME    NO.         VALUE          VALUE
                     (W)            (J)
FOCOL     1      4.9981E+05     1.8267E+11
PIPE      2      5.7571E+03     6.3125E+09
PIPE     11      2.2497E+03     2.7561E+09
    TOTALS       5.0782E+05     1.9174E+11
```

Output: Example 2 (cont)

```
TABLE OF HEAT TRANSFER (HEAT)
  FROM                                                  TO
COMPONENT                             INTEGRATED     COMPONENT
NAME    NO.          VALUE              VALUE        NAME    NO.
                      (W)                (J)
PRSVAP  18       2.7581E+05         3.0981E+11
COOLTOW 29       3.1851E+06         1.9258E+12
    TOTALS       3.4609E+06         2.2356E+12

    TOTAL TRANSFERRED BETWEEN COMPONENTS IN THE SYSTEM (W)                  0.
    TOTAL TRANSFERRED FROM THE SYSTEM (W)                                   3.4609E+06
    CUMULATIVE TOTAL TRANSFERRED BETWEEN COMPONENTS (J)                     0.
    CUMULATIVE TOTAL TRANSFERRED FROM THE SYSTEM (J)                        2.2356E+12
```

```
TABLE OF ELECTRICAL PARASITICS (ELCPS)
REQUIRING                                            SATISFYING
COMPONENT                             INTEGRATED      COMPONENT
NAME    NO.          VALUE              VALUE         NAME    NO.
                      (W)                (J)
PUMP    30       1.1912E-02         6.0107E+03        LODMG   14
PUMP    13       4.7094E+00         1.7949E+06        LODMG   14
BFDPMP  21       1.2033E+02         1.3516E+08
    TOTALS       1.2505E+02         1.3696E+08

    TOTAL SATISFIED BY THE SYSTEM (W)                                       4.7214E+00
    TOTAL SATISFIED EXTERNAL TO THE SYSTEM (W)                              1.2033E+02
    CUMULATIVE TOTAL SATISFIED BY THE SYSTEM (J)                            1.8009E+06
    CUMULATIVE TOTAL SATISFIED EXTERNAL TO THE SYSTEM (J)                   1.3516E+08
```

Output: Example 2 (cont)

```
TABLE OF MECHANICAL POWER PARASITICS (POWPS)
REQUIRING                                    SATISFYING
COMPONENT                    INTEGRATED       COMPONENT
NAME   NO.       VALUE          VALUE         NAME   NO.
                  (W)            (J)
BFDPMP   23    2.5008E+03      1.5167E+09     LODMG   14
    TOTALS     2.5008E+03      1.5167E+09

    TOTAL SATISFIED BY THE SYSTEM (W)                                       2.5008E+03
    TOTAL SATISFIED EXTERNAL TO THE SYSTEM (W)                              0.
    CUMULATIVE TOTAL SATISFIED BY THE SYSTEM (J)                            1.5167E+09
    CUMULATIVE TOTAL SATISFIED EXTERNAL TO THE SYSTEM (J)                   0.


TABLE OF ELECTRICAL LOADS (ELCLD)
COMPONENT                    INTEGRATED
NAME   NO.       VALUE          VALUE
                  (W)            (J)
LODMG   14     1.2500E+05      8.0730E+10
    TOTALS     1.2500E+05      8.0730E+10


TABLE OF MECHANICAL POWER LOADS (POWLO)
COMPONENT                    INTEGRATED
NAME   NO.       VALUE          VALUE
                  (W)            (J)
LODMG   14     0.              0.
    TOTALS     0.              0.


TABLE OF THERMAL LOADS (THMLO)
COMPONENT                    INTEGRATED
NAME   NO.       VALUE          VALUE
                  (W)            (J)
PRSVAP  18     2.7581E+05      3.0981E+11
    TOTALS     2.7581E+05      3.0981E+11
```

Output: Example 2 (cont)

```
                SUMMARY

TOTAL ENERGY SUPPLY RATE TO THE SYSTEM (W)                              6.2758E+06
RATIO OF PRIMARY AND TOTAL SUPPLY RATES (PERCENT)                      14.32
RATE THAT THE SYSTEM PROVIDES BENFICIAL ENERGY (W)                      4.0069E+05
SYSTEM ENERGY CONVERSION EFFICIENCY (PERCENT)                           6.38
CUMULATIVE TOTAL ENERGY SUPPLIED TO THE SYSTEM (J)                      3.9128E+12
RATIO OF CUMULATIVE PRIMARY AND TOTAL ENERGY SUPPLIES (PERCENT)         9.53
CUMULATIVE BENFICIAL ENERGY PROVIDED BY THE SYSTEM (J)                  3.9040E+11
CUMULATIVE SYSTEM ENERGY CONVERSION EFFICIENCY (PERCENT)                9.98
ELECTRICITY REQUIRED TO RUN THE SYSTEM (W)                              1.2505E+02
ELECTRICITY SUPPLIED TO THE SYSTEM (W)                                  1.2033E+02
ELECTRICITY PRODUCED AND USED BY THE SYSTEM (W)                         4.7214E+00
ELECTRICITY PRODUCED AND AVAILABLE FOR EXTERNAL USE (W)                 1.2500E+05
TOTAL ELECTRICITY PRODUCED BY THE SYSTEM (W)                            1.2500E+05
CUMULATIVE ELECTRICITY REQUIRED TO RUN THE SYSTEM (J)                   1.3696E+08
CUMULATIVE ELECTRICITY SUPPLIED TO THE SYSTEM (J)                       1.3516E+08
CUMULATIVE ELECTRICITY PRODUCED AND USED BY THE SYSTEM (J)              1.8009E+06
CUMULATIVE ELEC PRODUCED AND AVAILABLE FOR EXTERNAL USE (J)             8.0730E+10
CUMULATIVE TOTAL ELECTRICITY PRODUCED BY THE SYSTEM (J)                 8.0732E+10
MECHANICAL POWER REQUIRED TO RUN THE SYSTEM (W)                         2.5008E+03
MECHANICAL POWER SUPPLIED TO THE SYSTEM (W)                             0.
MECHANICAL POWER PRODUCED AND USED BY THE SYSTEM (W)                    2.5008E+03
MECHANICAL POWER PRODUCED AND AVAILABLE FOR EXTERNAL USE (W)            0.
TOTAL MECHANICAL POWER PRODUCED BY THE SYSTEM (W)                       2.5008E+03
CUMULATIVE MECHANICAL POWER REQUIRED TO RUN THE SYSTEM (J)              1.5167E+09
CUMULATIVE MECHANICAL POWER SUPPLIED TO THE SYSTEM (J)                  0.
CUMULATIVE MECH POWER PRODUCED AND USED BY THE SYSTEM (J)               1.5167E+09
CUMULATIVE MECH PWR PRODUCED AND AVAILABLE FOR EXTERNAL USE (J)         0.
CUMULATIVE TOTAL MECHANICAL POWER PRODUCED BY THE SYSTEM (J)            1.5167E+09
```

Output: Example 2 (cont)

```
                             ********** TABLE 1 OUTPUT **********
YEAR = 1975      DAY =    97      HOUR =    12      SEC =     0

 COMPONENT  OUTLET STATE   FLOW RATE      TEMPERATURE      PRESSURE          STATE               QUALITY
   NAME        NUMBER       (KG/S)         (DEG K)          (PA)                                 (PERCENT)
FOCOL            1        .9163E+00      .6000E+03      .4000E+06   COMPRESSED LIQUID
PIPE             2        .9163E+00      .5977E+03      .4000E+06   COMPRESSED LIQUID
PUMP            30        .9163E+00      .5977E+03      .4000E+06   COMPRESSED LIQUID
MIXJNT           3        .9559E+01      .5998E+03      .3996E+06   COMPRESSED LIQUID
THMBLR           6        .9559E+01      .4128E+03      .3996E+06   COMPRESSED LIQUID
THMBLR          13        .1402E+01      .5898E+03      .1379E+07   SUPERHEATED VAPOR
PUMP            10        .9559E+01      .4128E+03      .4000E+06   COMPRESSED LIQUID
FLODIV           9        .9163E+00      .4128E+03      .4000E+06   COMPRESSED LIQUID
FLODIV           8        .8643E+01      .4128E+03      .4000E+06   COMPRESSED LIQUID
PIPE            11        .8643E+01      .4127E+03      .3996E+06   COMPRESSED LIQUID
AUXFUR          12        .8643E+01      .6000E+03      .3996E+06   COMPRESSED LIQUID
LODMG           14        .1402E+01      .5898E+03      .1379E+07   COMPRESSED LIQUID
XTURBG          16        .1000E+00      .5317E+03      .7042E+06   SUPERHEATED VAPOR
XTURBG          17        .1302E+01      .5317E+03      .7042E+06   SUPERHEATED VAPOR
PRSVAP          18        .7000E-01      .3500E+03      .1013E+06   COMPRESSED LIQUID
MKPFLD          19        .3000E-01      .2880E+03      .1000E+06   COMPRESSED LIQUID
MIXJNT          31        .1000E+00      .3314E+03      .1009E+06   COMPRESSED LIQUID
DCONHT          20        .1093E+00      .3800E+03      .5516E+06   COMPRESSED LIQUID
XTURBG          25        .9317E-02      .5317E+03      .7042E+06   SUPERHEATED VAPOR
XTURBG          26        .1292E+01      .3100E+03      .6150E+04   LIQUID VAPOR MIXTURE    94.68
BFDPMP          21        .1093E+00      .3800E+03      .1379E+07   COMPRESSED LIQUID
CNDHTR          27        .1292E+01      .3050E+03      .6150E+04   COMPRESSED LIQUID
CNDHTR          28        .7683E+02      .3049E+03      .1000E+06   COMPRESSED LIQUID
MIXJNT          22        .1402E+01      .3109E+03      .1132E+06   COMPRESSED LIQUID
BFDPMP          23        .1402E+01      .3109E+03      .1379E+07   COMPRESSED LIQUID
COOLTOW         29        .7683E+02      .2950E+03      .1000E+06   COMPRESSED LIQUID
```

Output: Example 2 (cont)

```
                   ********** TABLE 2 OUTPUT **********
YEAR = 1975     DAY =    97     HOUR =    12     SEC =     0

WEATHR                 AMBIENT TEMPERATURE (K)                                 .2934E+03
WEATHR                 PRESSURE (PASCALS)                                      .8377E+05
WEATHR                 WIND SPEED (M/S)                                        .3600E+01
WEATHR                 TOTAL HORIZONTAL SOLAR INTENSITY (W/M2)                 .1021E+04
WEATHR                 DIRECT NORMAL SOLAR INTENSITY  (W/M2)                   .8309E+03
WEATHR                 SOLAR ELEVATION ANGLE (DEG)                             .6130E+02
WEATHR                 SOLAR AZIMUTH ANGLE (DEG)                               .8366E-05
FOCOL              1   ENERGY RATE AVAILABLE FROM SUN -PRISUP (W)              .8986E+06
FOCOL              1   THERMAL LOSS -THMLOS (W)                                .4998E+06
FOCOL              1   ENERGY TRANSFER RATE TO FLUID (W)                       .3988E+06
PIPE               2   PIPE HEAT LOSS                                          .5757E+04
PUMP              30   POWER-PUMP POWER (WATTS)                                .1191E-01
THMBLR            13   THERMAL BOILER OUTLET STATE SUPERHEAT (DEG K)           .1231E+03
THMBLR            13   THERMAL BOILER VAPORIZATION TEMPERATURE (DEG K)         .4667E+03
THMBLR            13   THERMAL SUPERHEATER HEAT RATE (W)                       .3689E+06
THMBLR            13   THERMAL VAPORIZOR HEAT RATE (W)                         .2699E+07
THMBLR            13   THERMAL PREHEATER HEAT RATE (W)                         .1087E+07
THMBLR            13   THERMAL BOILER HEAT RATE (W)                            .4155E+07
THMBLR            13   THERMAL BOILER EFFECTIVENESS (PERCENT)                  .9929E+02
PUMP              10   POWER-PUMP POWER (WATTS)                                .4709E+01
PIPE              11   PIPE HEAT LOSS                                          .2250E+04
AUXFUR            12   AUXILIARY FURNACE HEAT RATE (W)                         .3764E+07
AUXFUR            12   AUXILIARY FURNACE-ENERGY SUPPLIED BY FUEL (W)           .5377E+07
LODMG             14   ELECTRICAL LOAD MET BY LOOP (W)                         .1250E+06
LODMG             14   TOTAL ELECT POWER DEMANDS MET BY LOOP (W)              0.
LODMG             14   TOTAL ELECT PARISITICS MET BY LOOP (W)                  .4721E+01
LODMG             14   TOTAL ELECT POWER PRODUCED BY LOOP (W)                  .1250E+06
LODMG             14   MECHANICAL LOAD MET BY LOOP (W)                        0.
LODMG             14   TOTAL MECH. POWER DEMANDS MET BY LOOP (W)              0.
LODMG             14   TOTAL MECH. PARISITICS MET BY LOOP (W)                  .2501E+04
LODMG             14   TOTAL MECHANICAL POWER PRODUCED BY LOOP (W)             .2501E+04
LODMG             14   TOTAL POWER PRODUCED BY LOOP (W)                        .1275E+06
XTURBG            15   EXTRACTION TURBINE ELECTRICAL POWER (W)                 .1241E+06
XTURBG            15   EXTRACTION TURBINE MECHANICAL POWER (W)                0.
PRSVAP            18   PROCESS VAPOR RATE (W)                                  .2758E+06
PRSVAP            18   WORKING FLUID LOSSES (KG/S)                             .3000E-01
MKPFLD            19   MAKE UP FLUID MASS FLOW RATE (KG/S)                     .3000E-01
DCONHT            20   HEAT RATE (W)                                           .2353E+05
XTURBG            24   EXTRACTION TURBINE ELECTRICAL POWER (W)                 .9537E+03
XTURBG            24   EXTRACTION TURBINE MECHANICAL POWER (W)                 .2501E+04
BFDPMP            21   VOLUMETRIC FLOW RATE (M3/S)                             .1174E-03
BFDPMP            21   PUMP ELECTRICAL POWER (W)                               .1203E+03
CNDHTR            27   CONDENSER INLET STATE SUPERHEAT (DEG K)                 .1200E+00
CNDHTR            27   CONDENSER SATURATION TEMPERATURE (DEG K)                .3099E+03
CNDHTR            27   CONDENSER VAPOR HEAT RATE (W)                           .2909E+03
CNDHTR            27   CONDENSER LATENT HEAT RATE (W)                          .3156E+07
CNDHTR            27   CONDENSER LIQUID HEAT RATE (W)                          .2899E+05
CNDHTR            27   CONDENSER HEAT RATE (W)                                 .3185E+07
```

Output: Example 2 (cont)

```
                    ********** TABLE 2 OUTPUT **********
YEAR = 1975      DAY =    97      HOUR =    12      SEC =     0

CNDHTR             27   CONDENSER EFFECTIVENESS (PERCENT)                         .9818E+02
BFDPMP             23   VOLUMETRIC FLOW RATE (M3/S)                               .1423E-02
BFDPMP             23   PUMP MECHANICAL POWER (W)                                 .2501E+04
COOLTOW            29   ENERGY EXTRACTED BY COOLING TOWER (W)                     .3185E+07
COOLTOW            29   INTEGRATED ENERGY EXTRACTED BY COOLING TOWER (J)          .1937E+13
EXECUTIVE               NUMBER OF ITERATIONS REQUIRED FOR CONVERGENCE                     2
```

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