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User Manual for GEOCOST: A Computer Model for Geothermal Cost Analysis

Volume 2. Binary Cycle Version

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by
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ABSTRACT

A computer model called GEOCOST has been developed at Battelle, Pacific Northwest Laboratories, to simulate the production of electricity from geothermal resources and calculate the potential costs of geothermal power. GEOCOST combines resource characteristics, power recovery technology, tax rates, and financial factors into one systematic model and provides the flexibility to individually or collectively evaluate their impacts on the cost of geothermal power. Both the geothermal reservoir and power plant are simulated to model the complete energy production system.

In the version of GEOCOST in this report, geothermal fluid is supplied from wells distributed throughout a hydrothermal reservoir through insulated pipelines to a binary power plant. The power plant is simulated using a binary fluid cycle in which the geothermal fluid is passed through a series of heat exchangers. Thermal energy is transferred from the hot geothermal fluid to a working fluid. The working fluid is brought to a superheated state and then expanded through a turbine which is coupled to a generator. After passing through the heat exchangers, the geothermal fluid is reinjected.

The thermodynamic state points in basic subcritical and supercritical Rankine cycles are calculated for a variety of working fluids. Working fluids which are now in the model include isobutane, n-butane, R-11, R-12, R-22, R-113, R-114, and ammonia. Thermodynamic properties of the working fluids at the state points are calculated using empirical equations of state. The Starling equation of state is used for hydrocarbons and the Martin-Hou equation of state is used for fluorocarbons and ammonia. Physical properties of working fluids at the state points are calculated using polynomial functions of phase and temperature, which were correlated to data in the literature by least-squares curve fits.

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1. INTRODUCTION

In a research program sponsored by the United Stated Energy Research and Development Administration, Battelle, Pacific Northwest Laboratories (BNW), developed a computer model for geothermal energy cost analysis called GEOCOST.[1] GEOCOST is composed of two principal parts: a reservoir model which simulates the costs associated with the exploration, development, and operation of a geothermal reservoir; and a power plant model which simulates the costs associated with the design, construction, and operation of the power plant. GEOCOST simulates the production of electricity from most types of geothermal resources: dry steam, hydrothermal, geopressured and hot dry rock formations. Several different power conversion technologies are simulated, including the steam cycle, binary fluid cycle, geopressured concept and total flow concept.

A user manual for the steam cycle version of GEOCOST was published in November, 1975.[2] This version simulates the production of electricity using steam derived from dry steam or low salinity hydrothermal resources. The source code has been made available on one reel of magnetic tape through the Argonne Code Center.

This report is a user manual for the binary cycle version of GEOCOST. Its theoretical concepts have been discussed in an earlier publication.[3] The binary cycle version simulates the production of electricity using a binary fluid cycle in which the geothermal fluid is passed through a series of heat exchangers. Thermal energy is transferred from the hot geothermal fluid to a working fluid. After passing through the heat exchangers, the geothermal fluid is reinjected. The working fluid is brought to a superheated state and expanded through a turbine which is coupled to a generator. The superheated exhaust vapor from the turbine is cooled by a desuperheater

to a saturated vapor state before entering a surface condenser supplied with cooling water from an induced draft evaporative cooling tower. The working fluid is recondensed and pumped to the heat exchangers as a compressed liquid for repetition of the cycle. Both subcritical and supercritical Rankine cycles can be simulated for the following working fluids: isobutane, n-butane, R-11, R-12, R-21, R-22, R-113, R-114, and ammonia.

The reservoir model in the binary version is identical to that of the steam cycle version. This includes the fluid transmission submodel which simulates the transmission of geothermal water, steam, and two-phase mixture from the reservoir to the power plant. Since the binary cycle version utilizes thermal energy from hydrothermal resources, only water transmission capabilities are discussed in this report. The transmission of steam or two-phase mixture has previously been discussed in the user manual for the steam cycle version. In the binary cycle version, only single-phase flow is allowed in the transmission of water from the reservoir to the power plant. In order to avoid two-phase flow, the water is pressurized through booster pumps in the fluid transmission submodel and continuously maintained as a liquid in the transmission lines.

The discussion of the reservoir model in the user manual for the steam cycle version is included in this manual, subject to the limitation already noted for the fluid transmission submodel. This approach was adopted so that each user manual and computer code would be complete by itself. Since the binary cycle conversion technology is different from that of the steam cycle, the binary power plant model and its input parameters are discussed in detail in this manual.

GEOCOST is programmed in FORTRAN IV and is operational on the Control Data Cyber 74-18 computer with Scope 3.4.2 operating system. The source code for GEOCOST and the 1967 ASME Steam Tables[4,5] used to calculate thermodynamic and physical properties of water and steam are available from the Argonne Code Center on one reel of magnetic tape. The tape recording mode is optional: 7-track, 556 BPI, even parity, and BCD code; or 9-track, 800 BPI, odd parity, and EBCDIC code.

The standard FORTRAN system library functions, such as the square root, exponential, logarithm, sine, cosine, minimum, and maximum functions, are

assumed to be available at the user's computer installation and are not included on the tape. In addition, users without access to the Control Data Corporation Math Science Library[6] will have to supply a subroutine for solving systems of nonlinear equations. A subroutine called RQNWT was used from this library in executing the code on the Cyber 74 computer. Seven other subroutines from the Math Science Library are called by subroutine RQNWT in solving the nonlinear equations: DECOM, EVAL, FBSUBS, GLESOS, QNWT, RAND, and VIP. These eight subroutines could not be released due to proprietary restrictions.

Subroutine RQNWT is called from two locations in subroutine BUTANE and two locations in subroutine FREON. These four locations are flagged in the code. Four different systems of nonlinear equations, each two nonlinear equations in two unknowns, from the equations of state are solved in calculating the thermodynamic state points of the working fluid cycle. A dummy subroutine called RQNWT was included in the code on tape to satisfy external references of subroutines BUTANE and FREON.

In the GEOCOST code, subroutines BFT2D2, BFT2V2, EFT2V2, and FFT2V2 are used by subroutine RQNWT to calculate residuals between known and predicted values in solving the nonlinear equations. These subroutines may have to be slightly modified if a subroutine other than RQNWT is adopted by the user to solve the nonlinear equations.

The authors have duplicated the results of the code using subroutines ZSYSTM and UERTST from the International Mathematical and Statistical Library (IMSL) to solve the systems of nonlinear equations. The example problem input and output (based on RQNWT) in this report describe a bench mark case for use in verifying the conversion of the code to the user's computer installation.

The algorithms coded in subroutines RQNWT and ZSYSTM require initial estimates for solving systems of nonlinear equations. These algorithms have generally solved the nonlinear equations in subroutines BUTANE and FREON without difficulty. If problems should occur in solving the nonlinear equations for a particular working fluid or thermodynamic cycle, the initial estimates of the unknown variables in subroutines BUTANE and FREON may have to be modified by the program user.

2. DESCRIPTION OF PROGRAM

2.1 GENERAL PROGRAM DESIGN

GEOCOST is designed in modular fashion, with 100 technical and economic subroutines. In addition to the standard FORTRAN library functions, 63 subroutines comprising the 1967 ASME Steam Tables are used to calculate thermodynamic and physical properties of water and steam, including pressure, temperature, enthalpy, entropy, specific volume, density, viscosity, and steam quality. GEOCOST and the steam tables contain approximately 10,000 and 4000 FORTRAN statements respectively. The entire program requires approximately 55,000 decimal words of computer memory without overlay or segmented loading and 40,000 decimal words with segmented loading. One disk file is required for storage of summary printout when using the consecutive case generation input option described later in this manual.

The block diagram in Figure 1 shows an overview of the technoeconomic model used in GEOCOST to represent a geothermal power system. Figure 2 shows the computational flow through the major submodels of GEOCOST. Figure 3 shows the detailed, logical layout of the subroutines in each major submodel and serves as the basis for the operational description of the major sequence of calculations in GEOCOST. The user may find referring to Figure 3 helpful in reading the following description of the major submodels and their associated subroutines. The steam table functions are called from many subroutines in GEOCOST, but are not shown in Figure 3 for the sake of brevity. These functions are summarized following the description of the subroutines in GEOCOST.

2.2 EXECUTIVE PROGRAM AND DATA INPUT SUBMODEL

The executive program GEOCOST controls the sequence of processing by the major submodels to simulate the technical and economic components of the geothermal model. This includes the data input; binary power plant; fluid transmission and disposal; cash flow for the reservoir exploration, development, and operation; and cash flow for the power plant design,

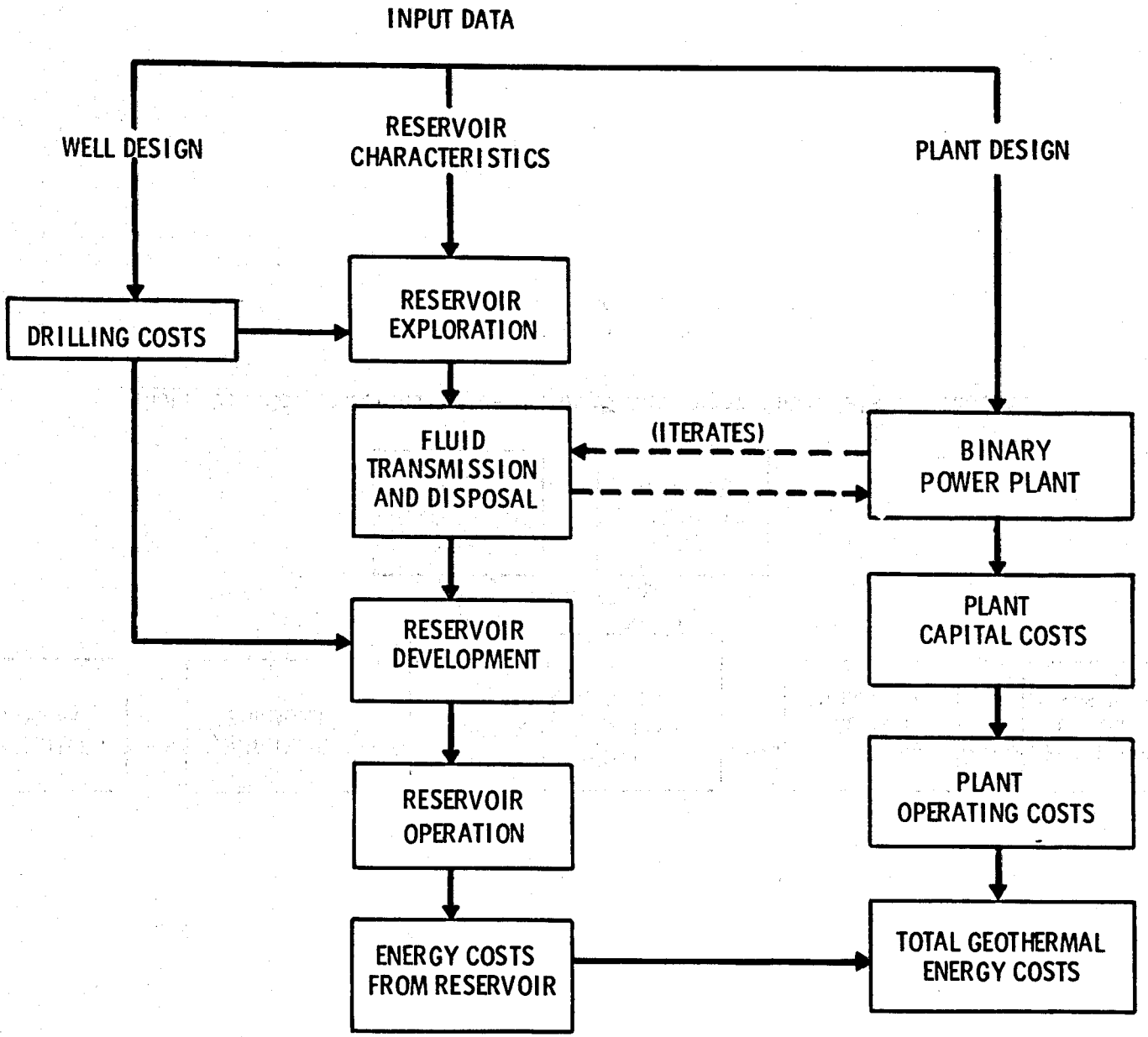

FIGURE 1. Technoeconomic Model for a Geothermal Power System

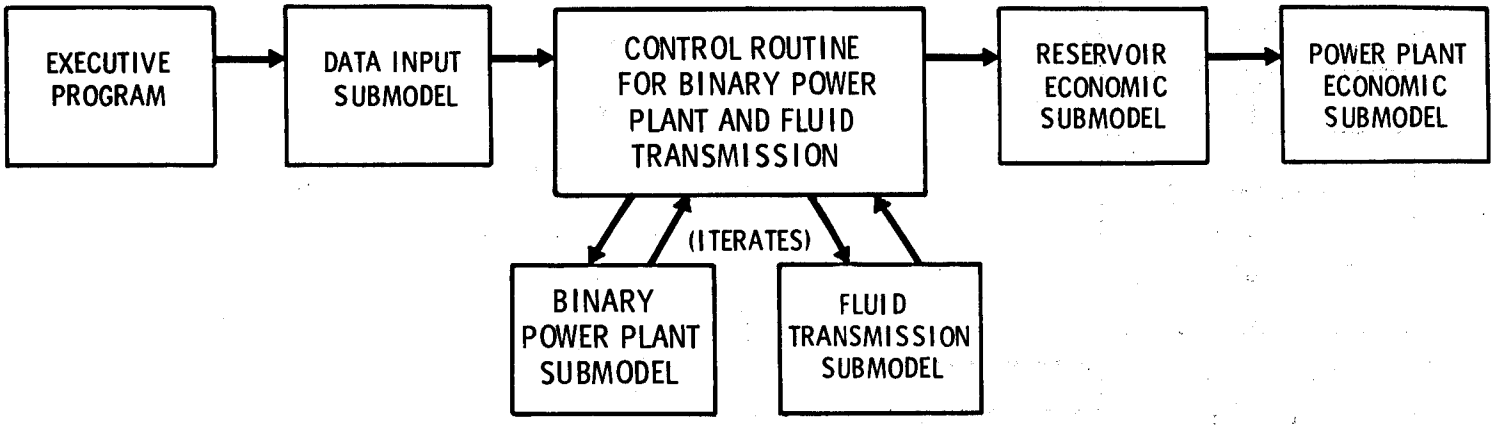

FIGURE 2. Computational Flow Through the Major Submodels of GEOCOST

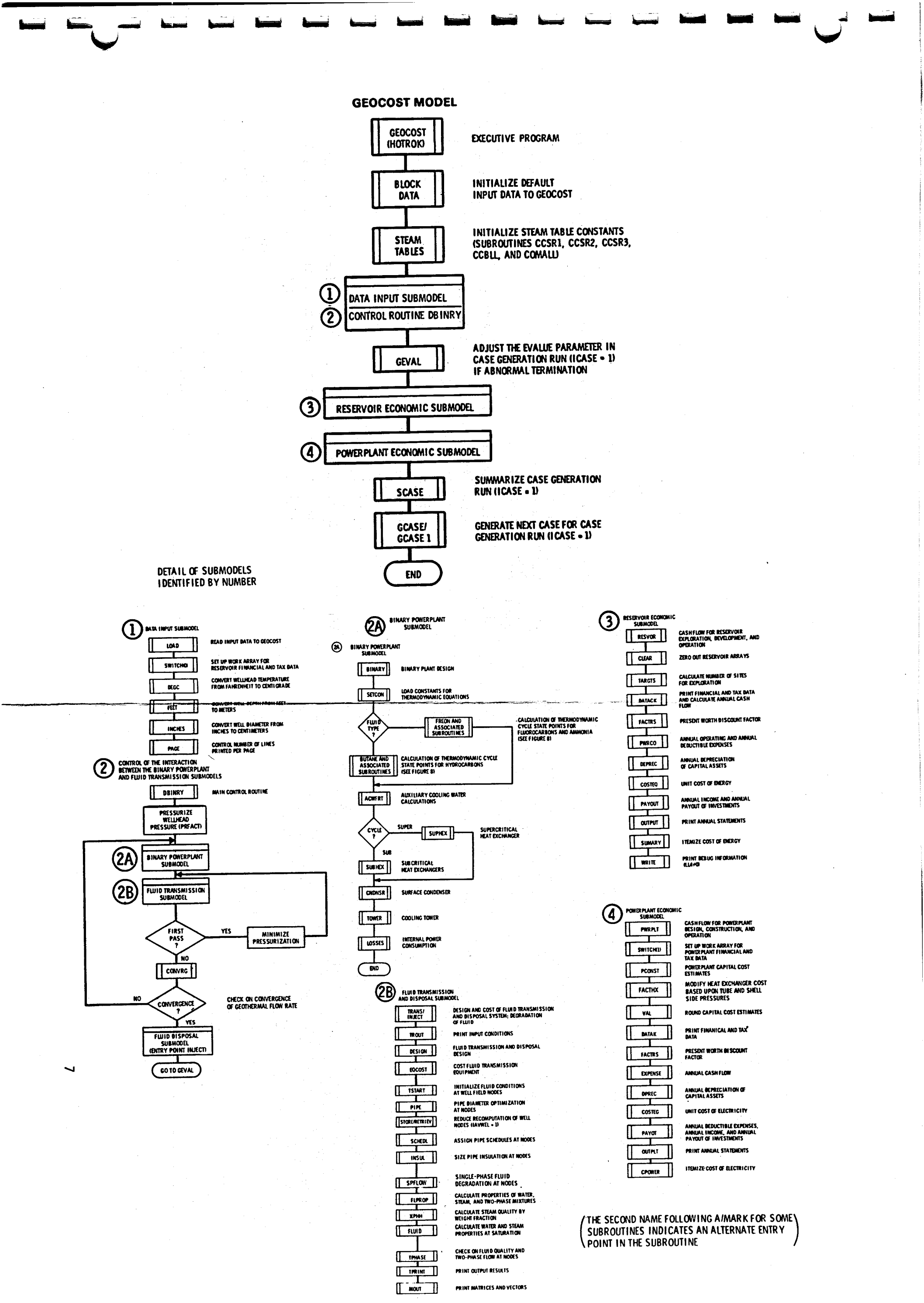

FIGURE 3. Detailed Flow Diagram for GEOCOST (Binary Cycle Version)

construction, and operation. GEOCOST calls the data input submodel simulated by subroutine LOAD and its associated subroutines to set up the initialization and read the technical and economic input data. This includes the reservoir characteristics, wellhead conditions of the geothermal fluid, well field layout, fluid transmission and disposal parameters, drilling costs, binary power plant design and capacity, and financial and tax data for the reservoir and power plant. Each subroutine associated with the executive program and with the data input submodel is described in the order of its execution in the program (Figure 3).

GEOCOST	Controls the sequence of calculations by the major submodels.
BLOCK DATA	Initializes representative values for the input data when the program is loaded into computer memory.
CCSR1, CCSR2, CCSR3, CCBLL, and COMALL	Initialize steam constants required in calculations by the steam table functions.
LOAD	Reads the input data using NAMELIST to override the default values initialized in BLOCK DATA; sets up initial values for the GEOCOST variables; and prints the input data defining reservoir characteristics, well properties, and fluid composition. Subroutine LOAD also calls subroutine DBINRY to execute the binary power plant and fluid transmission and disposal submodels.
SWITCH(0)	Stores the first 35 values of the DINPUT array defining input reservoir financial and tax data into an internal work array, D(N), N = 1,...,35. SWITCH(1) stores the second set of 35 values of the DINPUT array, DINPUT(N), N = 36,...,70, defining input power plant financial and tax data into the same work array, D(N), N = 1,...,35. The common work array has similar definitions for the reservoir and power plant, although the individual elements transferred from the first and second set of 35 values in the DINPUT array can have different numerical values.

DEGC	Returns Centigrade temperature expressed as a positive number when Fahrenheit temperature is input as a negative number. Centigrade temperature input as a positive number is returned unchanged. The input parameter which can use this option is the wellhead temperature PWTEMP.
FEET	Returns meters expressed as a positive number when feet are input as a negative number. Meters input as a positive number are returned unchanged. The input parameter which can use this option is the well depth STRATA (2,1)
INCHES	Returns centimeters expressed as a positive number when inches are input as a negative number. Centimeters input as a positive number are returned unchanged. The input parameter which can use this option is the well diameter DIA.
PAGE	Controls the number of lines printed per page, prints an input title at the top of the page, and numbers pages when called from various subroutines.
GEVAL	Adjusts the input design parameter EVALUE(1) during case generation runs if an abnormal termination occurs during the iteration between the binary power plant and fluid transmission submodels. The parameter EVALUE(1) is adjusted to change the internal diameters of the fluid transmission pipes to alter the pressure degradation. The adjusted EVALUE(1) parameter is used to restart a case that aborted due to unacceptable fluid quality in the transmission pipes. This may be due to excessive pressure degradation or two-phase flow, which is not allowed in the conduction of water to the power plant.
SCASE	Summarizes case generation runs by printing the parametric combinations defining the case; final values of the EVALUE(1) parameter when subroutine GEVAL adjusts this parameter; and reservoir cost, power plant cost, and total cost of geothermal power.

GCASE — Generates consecutive cases when the case generation option is employed to facilitate parametric studies as combinations of the parameters: wellhead temperature (°C), wellhead flow rate (lb/hr), power plant size (MWe), well spacing (acres), and well life (years).

2.3 CONTROL ROUTINE FOR BINARY POWER PLANT AND FLUID TRANSMISSION SUBMODELS

Subroutine LOAD calls subroutine DBINRY to set the wellhead fluid pressure and control the interaction between the binary power plant submodel and the fluid transmission submodel. Subroutine DBINRY pressurizes the wellhead fluid above saturation by multiplying the saturation pressure by the pressurization factor PRFACT ($\geq 1.$) specified in the input data. The fluid pressure is continuously maintained above saturation (compressed liquid state) to prevent flashing and two-phase flow in the fluid transmission lines. The pressurization prevents the loss of latent heat through vaporization and reduces the pressure drop of the fluid as it is transmitted from the wellhead to the plant. The precipitation of dissolved solids in the piping and pumps is also reduced if flashing to steam is prevented. The pressurization is simulated through the use of booster pumps in the fluid transmission submodel (subroutine TRANS).

A sufficiently large pressurization factor PRFACT should be initially chosen by the program user to ensure that the fluid pressure remains above saturation throughout the degradation process in the transmission to the plant. A value of 2 for PRFACT is usually a judicious choice. Subroutine DBINRY minimizes the pressurization factor chosen by the user by making two passes through the fluid transmission submodel during the first iteration between the binary power plant and fluid transmission submodels. The adjusted pressurization is calculated so that the fluid arrives at the plant at approximately saturation pressure + DELPHX + 10 psia. The variable DELPHX, specified in the input data, allows for geothermal fluid pressure drops across the heat exchangers inside the power plant. The value 10 was added arbitrarily as a conservative measure to be certain that the geothermal fluid pressure remains above saturation throughout the transmission pipelines and power plant.

Subroutine DBINRY initiates and controls the iteration between the binary power plant and fluid transmission submodels. Subroutine DBINRY calls subroutine BINARY to initially calculate the power plant's geothermal fluid flow requirements from the reservoir using wellhead conditions. Based upon the total flow requirements, the fluid transmission submodel simulated by subroutine TRANS and its associated subroutines is called to calculate the number of required wells, pipe lengths and diameters, pumping requirements, and temperature and pressure drop (fluid degradation) between the reservoir and power plant. Subroutine DBINRY controls the iteration between the binary power plant submodel, which calculates the increased geothermal fluid flow rate required for the power plant under the degraded fluid conditions, and the fluid transmission submodel, which provides the increased flow requirements by adding wells and determining the new temperature and pressure drop.

Subroutine DBINRY calls subroutine CONVRG to test the iteration between the binary power plant and fluid transmission submodels for convergence of geothermal flow rate. Subroutine CONVRG compares the total geothermal flow requirements computed by the binary power plant submodel, based upon the degraded temperature and pressure delivered by the fluid transmission submodel in the current iteration, with the total flow requirement calculated in the previous iteration. The convergence criterion requires that the new flow requirement computed for the power plant differ by less than 2% from the flow requirement computed in the previous iteration. After satisfying the convergence criterion, the binary power plant and fluid transmission submodels are executed one more time at the control of subroutine DBINRY. This provides flexibility to satisfy the input options of printing the final iteration only or printing the entire iteration history. Failure to converge within a maximum limit of 10 iterations results in an abnormal termination and printout of an appropriate error message.

After convergence, subroutine DBINRY calls the fluid disposal submodel, beginning with the entry point INJECT in subroutine TRANS to calculate the number of injection wells, injection pipe diameters, and lengths.

2.4 BINARY POWER PLANT SUBMODEL

Subroutine DBINRY calls subroutine BINARY to simulate the binary power plant submodel. This submodel calculates: 1) the thermodynamic cycle state points in a simple Rankine cycle and 2) the operating characteristics of the major components of the binary power plant. Both subcritical and supercritical Rankine cycles are modeled. The binary power plant configuration for a subcritical Rankine cycle is shown in Figure 4.

2.4.1 Operational Description of Calculations in Binary Power Plant Submodel

The flow diagram for the binary power plant submodel is displayed in 2A of Figure 3. Subroutine BINARY calls subroutine SETCON to load values for empirical coefficients in complex equations of state used to predict the thermodynamic properties of various working fluids. Only those coefficients required for the working fluid selected in the input data are loaded in subroutine SETCON. Ten working fluids can be selected through the input parameter NFLUID. Additional working fluids can be programmed into subroutine SETCON as the demand for their use arises, subject to the availability of data on fluid properties. The working fluids corresponding to the values of NFLUID are:

1 = water	
2 = isobutane	hydrocarbons
3 = n-butane	hydrocarbons
4 = R-11	fluorocarbons
5 = R-12	fluorocarbons
6 = R-21	fluorocarbons
7 = R-22	fluorocarbons
8 = R-113	fluorocarbons
9 = R-114	fluorocarbons
10 = ammonia	

If the selected working fluid is a hydrocarbon (isobutane, n-butane), subroutine SETCON calls subroutine BUTANE to calculate the thermodynamic cycle state points. The Starling equation of state is used for calculating the thermodynamic properties of the hydrocarbons.[7] If the working fluid

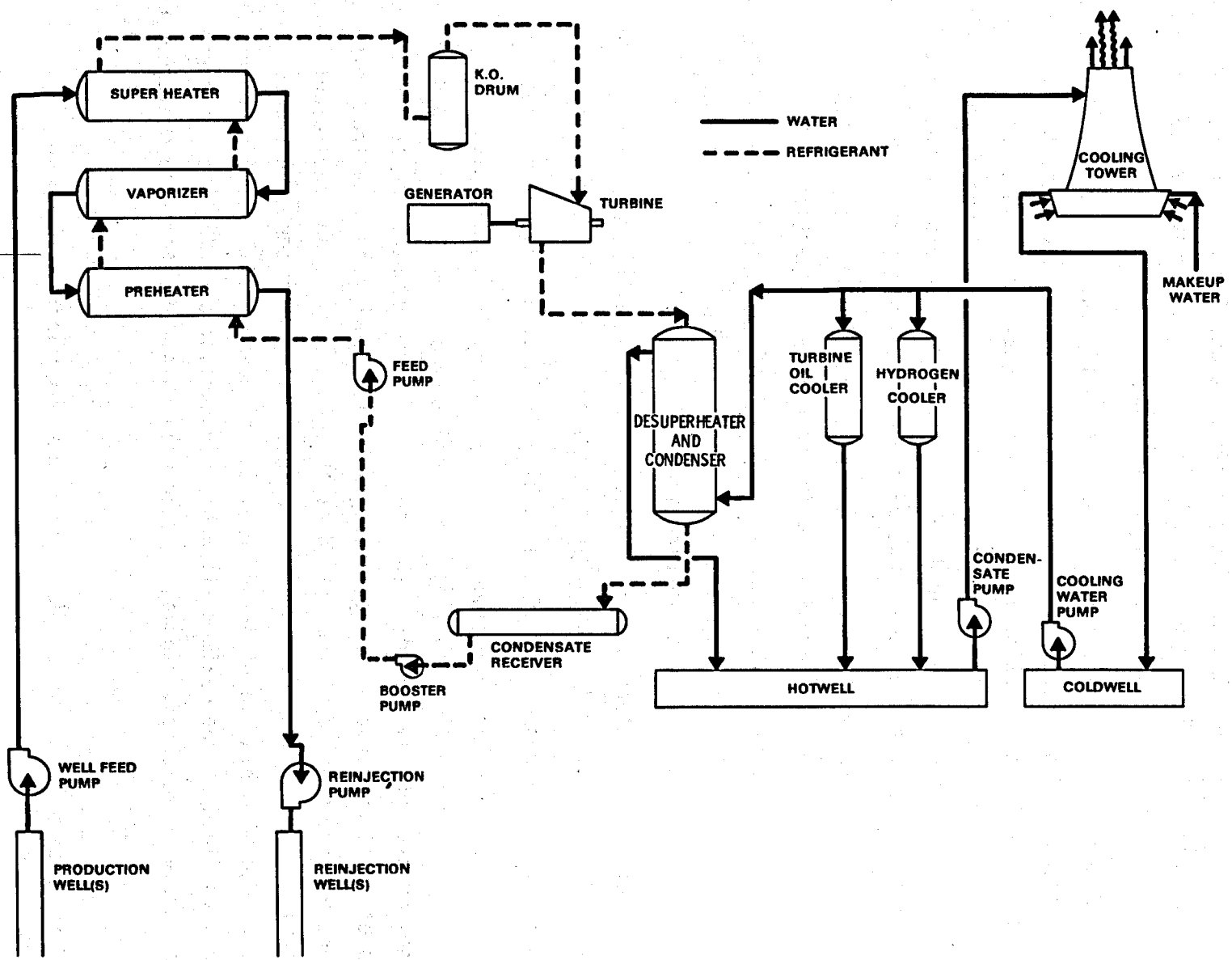

FIGURE 4. Sub-Critical Binary Fluid Cycle Power Plant

is a fluorocarbon (freon) or ammonia, subroutine SETCON calls subroutine FREON to calculate the thermodynamic state points, The Martin-Hou equation of state is used in the thermodynamic calculations for the fluorocarbons and ammonia.[8,9,10] These equations of state and other equations used in the thermodynamic calculations are listed in Appendix B.

Figures 5 and 6 illustrate the thermodynamic state points in the basic subcritical and supercritical Rankine cycles respectively. In the supercritical cycle, the working fluid receives thermal energy while at a pressure exceeding its critical pressure. In the subcritical cycle, the working fluid passes through the vapor dome, i.e., at a pressure below the critical pressure. The processes that make up these cycles are as follows:

3-1: constant pressure addition of heat to the working fluid from the geothermal fluid in the heat exchanger(s);

1-2: reversible adiabatic (isentropic) expansion of the working fluid in the turbine (the dotted line depicts the actual path, due to turbine inefficiencies);

2-2SATL: constant pressure rejection of heat from the working fluid to cooling water in the desuperheater and condenser;

2SATL-3: compression of the working fluid with booster and feed pumps.

The options for selecting a thermodynamic cycle are discussed in Section 3.2. In the first option, the thermodynamic cycle is determined through an iterative process based on the geothermal fluid temperature at the plant inlet, heat exchanger approach, heat exchanger pinch point, desired temperature of the spent geothermal fluid at the plant outlet, and the calculated working fluid pressure at the turbine inlet.* If the iterative process tends to exceed a turbine inlet pressure of 0.9 times the critical pressure of the working fluid at the maximum allowable pinch point of 30°F, the supercritical cycle is selected. In cases other than this, the iteration converges on a subcritical cycle.

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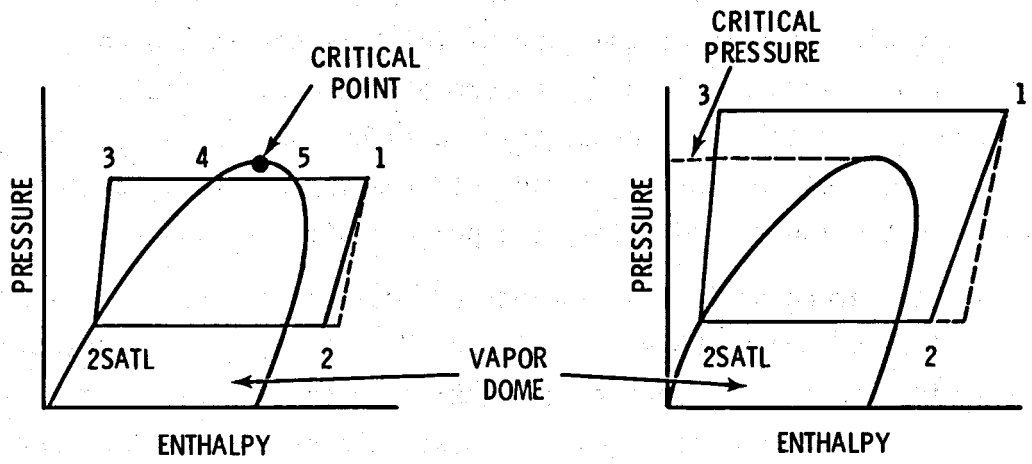
* See Section 3.3.5 for the definition and nomenclature of these variables.



THERMODYNAMIC CYCLE STATE POINTS

1 - Turbine Inlet
2 - Turbine Exhaust
2SATL - Condenser Outlet
3 - Heat Exchanger Inlet
4 - Vaporizer Inlet
5 - Superheater Inlet

FIGURE 5. Subcritical Cycle

FIGURE 6. Supercritical Cycle

This technique is discussed in detail in Sections 2.4.2 and 2.4.3. It results in a realistic cycle that can be rapidly calculated from the equations of state. The selected cycle does not necessarily operate at maximum thermal efficiency or optimize the geothermal system based on cost. Nevertheless, the cycle does provide a sound basis for investigating the technical and economic feasibility of applying the binary cycle power generation system to hydrothermal geothermal resources. Currently an optimization technique is being developed for inclusion into the code as an option at a future date.

In the second option, the working fluid pressure at the turbine inlet is set in the input data by the user below the critical pressure of the working fluid. The subcritical cycle is selected by the user and the iterative process for calculating the working fluid pressure at the turbine inlet is overridden.

In the third option, the supercritical cycle is selected by the user. The working fluid pressure at the turbine inlet is set in the code as the minimum of 1.5 times the critical pressure of the working fluid and 1000 psia or alternately set in the input data by the user above the critical pressure of the working fluid. If the supercritical cycle is not feasible with the input conditions, the program will terminate.

Once the thermodynamic state points are determined, subroutine BUTANE or FREON calls subroutine WFFRT (see Figure 7) to calculate the required working fluid flow rate. Subroutine BINARY then calculates the geothermal fluid flow rate requirements based on a heat balance between the geothermal fluid and working fluid. The product of the enthalpy drop and mass flow rate of the geothermal fluid in the tube side of the heat exchangers is equated to the product of the enthalpy rise and mass flow rate of the working fluid in the shell side of the heat exchangers. This equation is then solved for the required mass flow rate of geothermal fluid.

Subroutine BINARY next calls a series of subroutines to simulate the major components of the binary power plant shown in Figure 4. First, the auxiliary cooling water flow rates required by the turbine oil cooler and hydrogen cooler are calculated in subroutine ACWFRT. Next, the heat exchangers are simulated in subroutines SUBHEX or SUPHEX, depending upon whether a subcritical or supercritical cycle is used to transfer heat from the geothermal fluid to the working fluid. In the subcritical cycle, there are three heat exchangers: preheater, vaporizer, and superheater. In the supercritical cycle, there is one heat exchanger. However, this heat exchanger is simulated as a series of 25 different heat exchangers in subroutine SUPHEX. The individual heat transfer areas and lengths are then summed over all 25 incremental heat exchangers to obtain a single size and length heat exchanger. This approach was adopted because the thermodynamic and physical properties of the working fluid are quite variable and nonlinear in the supercritical region.

The working fluid is brought to a superheated state in the heat exchangers and then expanded through a turbine which is coupled to a

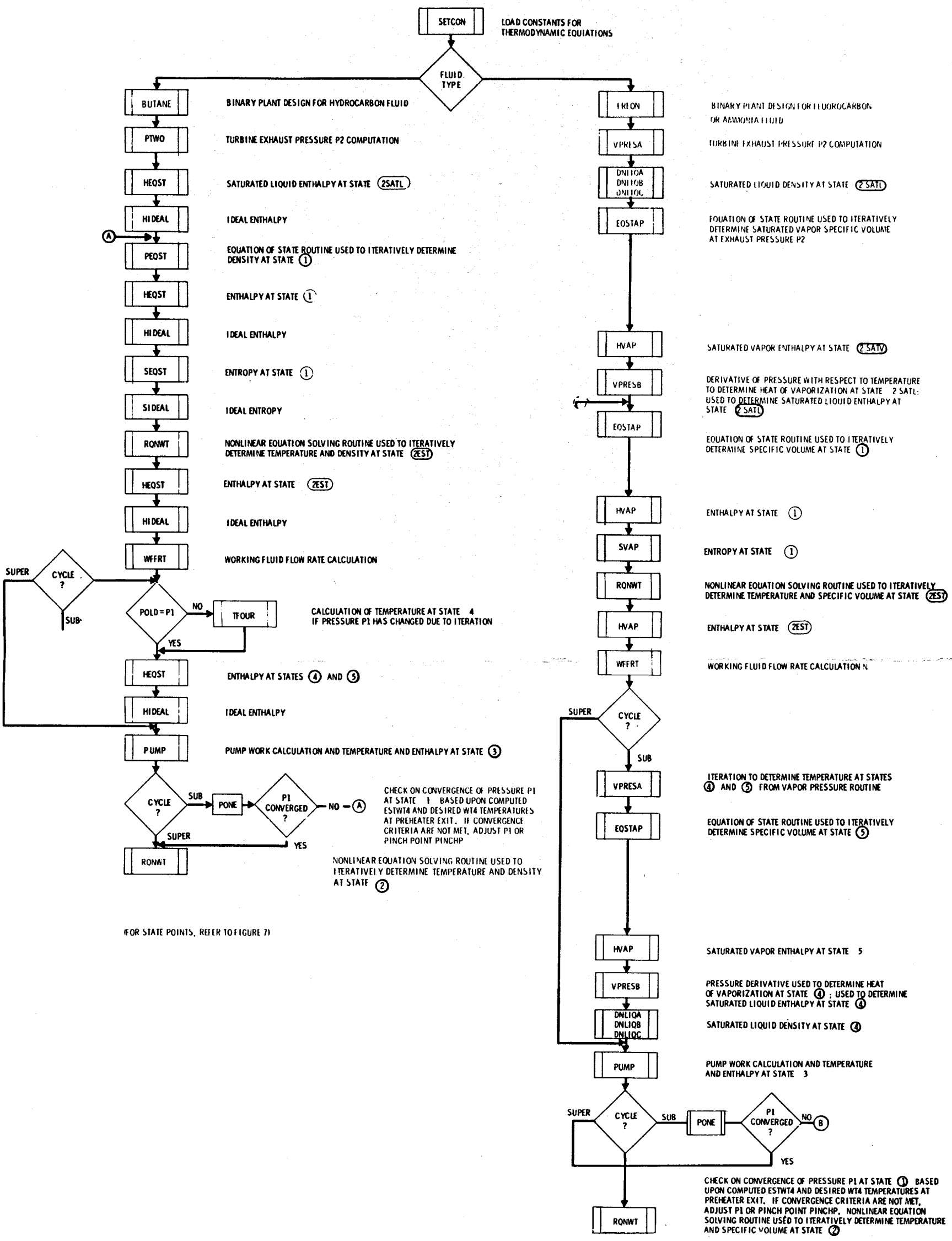


FIGURE 7. Detailed Flow Diagram for Determination of Thermodynamic State Points

generator. A knock-out drum is situated upstream of the turbine to remove any condensate in the working fluid. The turbo-generator set is simulated in subroutine WFFRT.

The working fluid is exhausted from the turbine in a superheated state to prevent the formation of liquid droplets in the turbine. The superheated vapor is cooled to a saturated vapor state in a desuperheater supplied with cooling water from the condenser outlet. The saturated vapor is then condensed in a surface condenser supplied with cooling water from the cooling tower. The desuperheater and condenser are simulated in subroutine CNDNSR.

In the Rankine cycle modeled, no provision is made for reheat or regeneration to use heat from turbine exhaust gases prior to condensation for utilization elsewhere in the cycle. These design features can be added to the model at a later date if there is sufficient interest.

The condensed working fluid is transferred to a condensate receiving tank which holds the reserve working fluid. The fluid is extracted from this tank, repressurized with booster and feed pumps driven by electric motors and returned to the heat exchangers for repetition of the cycle. This process is simulated in subroutine PUMP.

Cooling water is supplied to the condenser, turbine oil cooler, and hydrogen cooler from an induced-draft evaporative cooling tower. Makeup water to replace water lost due to blow-down, evaporation, and drift is required for the cooling tower. The cooling tower is simulated in subroutine TOWER.

Internal power requirements for cooling tower fans, condensate pumps, cooling water pumps, and reinjection pumps for reinjecting the spent geothermal fluid from the power plant are calculated in subroutine LOSSES. Power consumption by the booster and feed pumps for the working fluid are calculated in subroutine BINARY. Standard centrifugal pumps driven by electric motors are simulated for the cooling water and working fluid loops. Power consumption by booster pumps for pressurizing geothermal fluid in the fluid transmission lines is determined in subroutine TRANS. Turbine pumps driven by electric motors are simulated for pressurizing the geothermal fluid

in the fluid transmission and reinjection lines. The total internal power consumption is subtracted from the gross kilowatt output in subroutine BINARY to obtain the net kilowatt output.

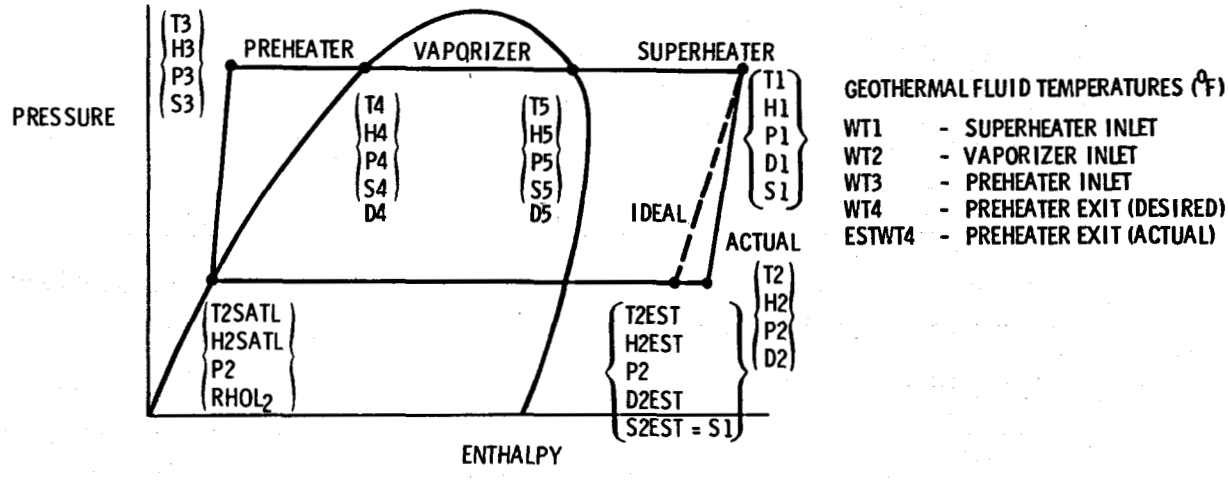
2.4.2 Calculation of Thermodynamic Cycle State Points for Hydrocarbons

The calculation of the thermodynamic cycle state points for hydrocarbons is described in detail in this section. The reader may find referring to Figure 7 helpful in recognizing specific points and variables in the cycle during the discussion. Subroutine SETCON calls subroutine BUTANE if the working fluid specified in the input data is a hydrocarbon. The flow diagram in Figure 8 shows the sequence of subroutines called by subroutine BUTANE to calculate the thermodynamic state points for either a subcritical or supercritical Rankine cycle. Only the subcritical cycle is discussed since the supercritical cycle is computed in a similar but less complex manner.

The state point values are calculated using an iterative procedure in the steps described below. The geothermal fluid temperature ESTWT4 calculated for the preheater exit is compared in step 10 with the desired temperature WT4 input by the program user. Steps 3 through 9 are repeated until the absolute value of the difference between the computed temperature ESTWT4 and the desired temperature WT4 is less than the convergence criterion (set to 10°F in subroutine PONE).

1) The minimum working fluid temperature T2SATL at the condenser outlet is set in subroutine LOAD on the basis of the cooling water temperature CWT1 at the condenser inlet and the approach APPCON to the condenser: T2SATL = CWT1 + APPCON. These variables are discussed in Section 3.3.5. The saturation pressure P2 at temperature T2SATL is calculated iteratively in subroutine PTWO. In the process of this calculation, the largest density root RHOL, which is the density of the saturated liquid at P2, is calculated. The enthalpy H2SATL is calculated using subroutines HEQST and HIDEAL.

2) For the iteration to follow through step 9, an initial value for the turbine inlet pressure P1 is selected in subroutine BUTANE based on the



THERMODYNAMIC STATE POINTS LISTED IN ORDER OF CALCULATION

2SATL - Saturated Liquid at Condenser Outlet
1 - Superheated Vapor at Turbine Inlet
2EST - Superheated Vapor at Turbine Exhaust (Ideal)
4 - Saturated Liquid at Vaporizer Inlet
5 - Saturated Vapor at Superheater Inlet
3 - Compressed Liquid at Preheater Inlet
2 - Superheated Vapor at Turbine Exhaust (Actual)

FIGURE 8. Subcritical Cycle State Points

working fluid and temperature T1 of the working fluid at the turbine inlet. The temperature T1 is computed based on the geothermal fluid temperature WT1 at the plant inlet and the approach APPHX to the heat exchanger. The approach APPHX is defined in the input data (Section 3.3.5). The initial value for the preheater pinch point PINCHP is defined in the input data as PINSUB (Section 3.3.5).

3) The density D1 at state 1 is calculated iteratively using subroutine PEQST and the assumed value of P1. The enthalpy and entropy, H1 and S1, are determined using subroutines HEQST, HIDEAL, SEQST, and SIDEAL.

4) The thermodynamic properties at state 2EST are calculated on the basis of an isentropic expansion (S2EST = S1) through the turbine. The

temperature and density, T2EST and D2EST, are calculated by simultaneously solving the equation of state and the entropy equation. A subroutine called RQNWT was used for this purpose. This subroutine solves systems of nonlinear, algebraic or transcendental equations with initial estimates using a quasi-Newton algorithm. Once temperature and density are known, the enthalpy H2EST can be calculated using subroutines HEQST and HIDEAL.

5) The working fluid flow rate QISO is calculated using subroutine WFFRT based on plant size; enthalpies H1, H2EST, and H2SATL; and overall turbine efficiency. The actual exhaust enthalpy H2 is also determined in subroutine WFFRT.

6) The saturation temperature, T4 = T5, is calculated in the first iteration for P1 and in subsequent iterations if P1 has changed. The calculation is performed in subroutine TFOUR using a modification of the iteration referred to in step 1. In the process of this calculation, the largest density root D_4 and smallest density root D_5, which are the density of saturated liquid and saturated vapor respectively, are calculated.

7) The saturation pressures, P4 and P5, are set equal to P1. The enthalpy H4 is calculated based on temperature T4 and density D4, using subroutines HEQST and HIDEAL. The enthalpy H5 is calculated in an analogous manner based on temperature T5 and density D5. Entropies S4 and S5 are calculated using subroutines SEQST and SIDEAL.

8) Pressure P3 is set equal to P1. The temperature and enthalpy, T3 and H3, are determined in subroutine PUMP and are based on the pump work done between state 2SATL and state 3.

9) Water temperatures WT3 and ESTWT4 are determined through a heat balance formulation based on the working fluid states and preheater pinch point PINCHP in subroutine BUTANE.

10) The original pressure P1 or the pinch point PINCHP are adjusted in subroutine PONE and steps 3 through 9 are reiterated until the computed temperature ESTWT4 differs from the desired temperature WT4 by less

than ± 10°F. As long as the difference between ESTWT4 and WT4 is continuously decreasing (and the sign of the difference does not change), P1 is adjusted up or down with constant pinch point PINCHP. If the difference does not continually decrease or if the sign changes between the differences, the pinch point PINCHP is increased by 10°F with constant P1. The iteration is continued until P1 is greater than 0.9 times the critical pressure and PINCHP is equal to the maximum allowable pinch point of 30°F. At this point, two possible outcomes exist. The pinch point PINCHP based on the desired temperature WT4 is computed in subroutine BUTANE. If this pinch point does not exceed 30°F, the subcritical cycle is selected and computed with the new PINCHP, P1 set to 0.9 times the critical pressure and ESTWT4 = WT4. If the pinch point exceeds 30°F, the supercritical cycle is selected and computed with P1 set to the minimum of 1.5 times the critical pressure and 1000 psia and PINCHP set to the supercritical pinch point, defined in the input data as PINSUP (Section 3.3.5).

11) After the final value of P1 is found, the actual exhaust temperature and density, T2 and D2, are determined through a procedure similar to step 4. In this case, however, the enthalpy equation is used in place of the entropy equation.

The subroutines called by subroutine BUTANE to calculate the thermodynamic cycle state points for hydrocarbons are described below. Function FLUID is described first because it is called from many of the subroutines in Figure 8 to calculate physical properties of the working fluids.

FLUID — Correlates physical properties of 10 different fluids to temperature at saturation. Each physical property for a particular fluid is expressed as a polynomial function of temperature in the elementary form:

$$\text{Property Value} = K_0 + K_1T + K_2T^2 + K_3T^3 \text{ for } T_x < T < T_y$$

These expressions were correlated to available data in the temperature range T_x to T_y. The data were acquired through a search of numerous reference texts and publications.[5,11-17]

FLUID (Contd)

Within the specified temperature range, there is good agreement between the actual and predicted values. A warning message is printed if the input temperature requires extrapolating the polynomials beyond the temperature range specified in function FLUID for a given equation.

The polynomial functions are used to predict the following physical properties as a function of temperature at saturation: specific heat, thermal conductivity, density, viscosity, heat of vaporization, and surface tension. Critical pressure, critical temperature, and molecular weight are included as constants. When a physical property is desired, the following statement is made:

Property Value = FLUID (I,J,T)

where T = temperature at which the property is required, °F

I = 1,13 - Property Index

1 - specific heat (liquid)(Btu/lb/°F)
2 - thermal conductivity (liquid)(Btu/hr/ft/°F)
3 - density (liquid)(lb/ft^3)
4 - viscosity (liquid)($lb_m/ft/hr$)
5 - specific heat (gas)(Btu/lb/°F)
6 - thermal conductivity (gas)(Btu/hr/ft/°F)
7 - density (gas)(lb/ft^3)
8 - viscosity (gas)($lb_m/ft/hr$)
9 - heat of vaporization (Btu/lb)
10 - critical pressure (psia)
11 - critical temperature (°F)
12 - surface tension (lb_f/ft)
13 - molecular weight (lb/lb_{mole})

J = 1,10 - Fluid Index

1 - water
2 - isobutane
3 - n-butane
4 - R-11
5 - R-12
6 - R-21
7 - R-22
8 - R-113
9 - R-114
10 - ammonia

PTWO

Calculates the saturation pressure P_{sat} of hydrocarbons as a function of temperature using the Starling equation of state B1 in Appendix B. An iteration is required, whereby an initial guess is made for P_{sat}, and then the density roots are found from the equation of state using subroutine RHOITR. There can be three or more roots to equation B1. The largest root is the saturated liquid density, and the smallest root is the saturated vapor density. These two density roots are then used to calculate the liquid and vapor fugacities based upon equation B6 using subroutine FUG. At saturation, the liquid fugacity is equal to the vapor fugacity. The ratio of liquid to vapor fugacities can be used to generate a better guess for P_{sat} as follows:

$$P_{new} = P_{old} * [0.9 + 0.1*(FL/FV)]$$

where:

P_{new} and P_{old} are the new and old estimates of P_{sat} respectively, and

FL/FV is the ratio of liquid to vapor fugacities.

This process is repeated by again solving for the density roots using equation B1 based on the new estimate of P_{sat}. The iteration continues until the ratio of liquid to vapor

PTWO (Contd)	fugacities converges to 1 within a specified tolerance of 0.001. The final estimate of P_{sat} at convergence is used as the saturation pressure.
RHOITR	Determines the saturated vapor and saturated liquid densities of hydrocarbons from the Starling equation of state B1 for a given estimate of P_{sat} when called by subroutine PTWO. This routine uses a one-dimensional direct search algorithm to converge to the largest root (saturated liquid density) from above and to the smallest root (saturated vapor density) from below. The convergence criterion requires that the predicted saturation pressure based on equation B1 using the computed densities differ from the saturation pressure input to subroutine RHOITR by less than $\pm$ 0.1 psia. If the algorithm does not converge within 2000 iterations, an error message is printed by subroutine PTWO.
FUG	Calculates liquid and vapor fugacities of hydrocarbons as a function of temperature and density using equation B6.
HEQST	Calculates the enthalpy of hydrocarbons using equation B2, except for the ideal gas enthalpy term H_0, based upon temperature and density.
HIDEAL	Calculates the ideal gas enthalpy H_0 of hydrocarbons based upon temperature using equation B3.
PEQST	Calculates pressure as a function of temperature and density using the Starling equation of state B1 for hydrocarbons. This subroutine is called by subroutine BUTANE in iteratively calculating the density at state 1 based upon the pressure P1 and temperature T1 of the working fluid at the turbine inlet. The initial estimate of density is calculated using the ideal gas law. The new estimate is calculated from the previous estimate using an increment based on the difference between the predicted and known (see step 2, page 20) values of pressure P1:

$$D1_{new} = D1_{old} * [1. + (P1 - PESTV)/P1]$$

where:

$D1_{new}$ and $D1_{old}$ are the new and old estimates of density respectively, P1 is the turbine inlet pressure at state 1, and PESTV is the predicted turbine inlet pressure at state 1 using equation B1 with temperature T1 and density estimate $D1_{old}$. The iteration converges when the absolute value of the difference between predicted and known values of pressure is less than 0.5 psia.

SEQST — Calculates the entropy of hydrocarbons using equation B4, except for the ideal gas entropy term S_0, based upon temperature and density.

SIDEAL — Calculates the ideal gas entropy S_0 of hydrocarbons based upon temperature using equation B5.

WFFRT — Calculates the working fluid flow rate (lb/hr) required by the binary power plant based on the gross kilowatt output specified for the plant, working fluid enthalpy H1 at turbine inlet, ideal working fluid enthalpy H2EST at turbine exhaust, and overall turbine efficiency. The latter is based on the internal efficiency of the turbine (set to 0.80), mechanical losses, and brake efficiency. Subroutine WFFRT also calculates the actual working fluid enthalpy H2 at the turbine exhaust.

TFOUR — Calculates the saturation temperature T_{sat} of isobutane or n-butane based upon pressure using the Starling equation of state B1. Subroutine TFOUR is called by subroutine BUTANE in the subcritical cycle to calculate the saturation temperature, T4 = T5, at states 4 and 5 if the turbine inlet pressure P1 has changed due to iteration. In a modification of the iterative procedure used by subroutine PTWO, an initial guess is made for T_{sat}, and then the density roots are found from the equation of state B1 using subroutine RHOITR.

The saturated liquid density and saturated vapor density are then used to calculate the liquid and vapor fugacities in subroutine FUG based upon equation B6. At saturation, the liquid and vapor fugacities are equal. The ratio of vapor to liquid fugacities can be used to generate a better guess for T_{sat} as follows:

$$T_{new} = T_{old} * [0.9 + 0.1* (FV/FL)]$$

where:

T_{new} and T_{old} are the new and old estimates of T_{sat},

FV/FL is the ratio of vapor to liquid fucacities.

This process is repeated by again solving for the density roots using equation B1 based on the new estimate of T_{sat}. The iteration continues until the ratio of vapor to liquid fugacities converges to 1 within a specified tolerance of 0.001. The final estimate of T_{sat} at convergence is used as the saturation temperature.

PUMP — Calculates the working fluid temperature T3 and enthalpy H3 obtained at the preheater inlet by compressing the working fluid with booster and feed pumps between state 2SATL and state 3. The calculation is based on the saturated liquid temperature T2SATL, pressure P2, enthalpy H2SATL, and specific volume SVSATL at the pump inlet; preheater inlet pressure P3; and pump efficiency (set to 0.90).

PONE — Tests the iteration for the turbine inlet pressure P1 in the subcritical cycle for convergence. Subroutine PONE compares the geothermal fluid temperature ESTWT4 at the preheater exit resulting from the current value of P1 with the desired exit temperature WT4 specified in the input data. The convergence criterion requires that the absolute value of the difference between the calculated and desired temperatures be less than 10°F. The pressure P1 or the pinch point PINCHP is adjusted in subroutine PONE and the iteration for P1 continued until the convergence criterion is satisfied (see step 10, page 21).

2.4.3 Calculation of Thermodynamic Cycle State Points for Fluorocarbons and Ammonia

Subroutine SETCON calls subroutine FREON if the working fluid specified in the input data is a fluorocarbon or ammonia. Subroutine FREON calls the subroutines shown in Figure 7 to calculate the thermodynamic state points for either a subcritical or supercritical Rankine cycle. The state point values are calculed using an iterative procedure similar to that for the hydrocarbons in the steps described below.

1) The minimum working fluid temperature T2SATL at the condenser outlet is set in subroutine LOAD, as previously described for the hydrocarbons. The saturation pressure P2 at temperature T2SATL is calculated in subroutine VPRESA. The density of the saturated liquid at state 2SATL is calculated in one of the following subroutines depending on the working fluid: DNLIQA for R-11, R-22, or ammonia; DNLIQB for R-12 or R-114; and DNLIQC for R-21 or R-113. The specific volume SVSATV of the saturated vapor is calculated iteratively based upon temperature T2SATL and pressure P2 using the equation of state subroutine EQSTAP. The enthalpy of the saturated vapor H2SATV is calculated based on the temperature T2SATL, specific volume SVSATV, and pressure P2 using subroutine HVAP. The derivative of pressure with respect to temperature at saturation is calculated in subroutine VPRESB based on the temperature T2SATL and pressure P2. The heat of vaporization at state 2SATL is determined based on the temperature T2SATL; specific volumes at saturated liquid and saturated vapor states, SVSATL and SVSATV; and the derivative of pressure with respect to temperature at saturation. The enthalpy of the saturated liquid at state 2SATL is calculated by subtracting the heat of vaporization from the enthalpy of the saturated vapor H2SATV.

2) For the iteration to follow through step 9, an initial value for the turbine inlet pressure P1 is selected in subroutine FREON. Other known values are the geothermal fluid temperature WT1 at the plant inlet; working fluid temperature T1 at the turbine inlet; and preheater pinch point PINCHP, defined in the input data as PINSUB (Section 3.3.5).

3) The specific volume V1 at state 1 is calculated iteratively using subroutine EQSTAP and the assumed value of P1. The enthalpy and entropy, H1 and S1, are determined using subroutines HVAP and SVAP respectively.

4) The thermodynamic properties at state 2EST are calculated on the basis of an isentropic expansion (S2EST = S1) through the turbine. The temperature and specific volume, T2EST and V2EST, are calculated by simultaneously solving the equation of state and the entropy equation. Subroutine RQNWT was used for this purpose. Once the temperature T2EST, specific volume V2EST, and pressure P2 are known, the enthalpy H2EST can be calculated using subroutine HVAP.

5) The working fluid flow rate QISO is calculated using subroutine WFFRT based on plant size; enthalpies H1, H2EST and H2SATL; and overall turbine efficiency. The actual exhaust enthalpy H2 is also determined in WFFRT.

6) The saturation temperature, T4 = T5, is calculated iteratively using subroutine VPRESA. The specific volume V5 of the saturated vapor at state 5 is determined iteratively using the equation of state subroutine EQSTAP.

7) The saturation pressures, P4 and P5, are set equal to P1. The enthalpy of the saturated vapor H5 is calculated based on the temperature T5, specific volume V5, and pressure P5 using subroutine HVAP. The density of the saturated liquid at temperature T4 is calculated using of the following subroutines depending on the working fluid: DNLIQA for R-11, R-22, or ammonia; DNLIQB for R-12 or R-114; and DNLIQC for R-21 or R-113. The derivative of pressure with respect to temperature at saturation is calculated in subroutine VPRESB based on the temperature T4 and pressure P4. The heat of vaporization at state 4 is determined based upon the temperature T4; specific volumes at saturated liquid and saturated vapor states, V4 and V5; and the derivative of pressure with respect to temperature at saturation. The enthalpy of the saturated liquid at state 4 is calculated by subtracting the heat of vaporization from the enthalpy of the saturated vapor at state 5.

8) Pressure P3 is set equal to P1. The temperature and enthalpy, T3 and H3, are determined in subroutine PUMP and are based on the pump work done between state 2SATL and state 3.

9) Water temperatures WT3 and ESTWT4 are determined through a heat balance formulation based on the working fluid states and preheater pinch point PINCHP in subroutine FREON.

10) The original pressure P1 or the pinch point PINCHP are adjusted in subroutine PONE and steps 3 through 9 are reiterated until the computed temperature ESTWT4 differs from the desired temperature WT4 by less than $\pm$10°F. The procedure is discussed in step 10 on page 21 for the hydrocarbons.

11) After the final value of P1 is found, the actual exhaust temperature and specific volume, T2 and V2, are determined through a procedure similar to step 4. In this case, however, the enthalpy equation is used in place of the entropy equation.

The subroutines in Figure 7 called by subroutine FREON to calculate the thermodynamic cycle state points for fluorocarbons are described below. The descriptions of subroutines FLUID, WFFRT, PUMP, PONE, and RQNWT have already been given in conjunction with the hydrocarbons and are not repeated here.

VPRESA — Calculates the common logarithm of the saturation pressure of fluorocarbons and ammonia based upon temperature using equation B11.

DNLIQA, DNLIQB, DNLIQC — Determine the saturated liquid densities of fluorocarbons and ammonia using equations B8, B9, and B10 respectively. Equation B8 is used for R-11, R-22, and ammonia; equation B9 for R-12 and R-114; and equation B10 for R-21 and R-113.

EQSTAP — Calculates pressure as a function of temperature and specific volume for fluorocarbons and ammonia using the Martin-Hou equation of state B7. This subroutine is called by subroutine FREON in iteratively calculating the specific volumes at states 2SATV, 1, and 5 based upon the temperatures and pressures at these states. The iterative procedure is similar to that described for subroutine PEQST, in that each new

EQSTAP (Contd)	estimate of specific volume is calculated from the previous estimate using an increment based on the difference between the predicted and known values of pressure.
HVAP	Calculates the enthalpy of fluorocarbons and ammonia as a function of temperature, pressure, and specific volume using equation B13.
VPRESB	Calculates the derivative of pressure with respect to temperature for fluorocarbons and ammonia as a function of temperature and pressure using equation B12. This quantity is used in subroutine FREON to calculate the heat of vaporization of saturated liquids at state 2SATL and state 4 using equation B15.
SVAP	Calculates the entropy of fluorocarbons and ammonia as a function of temperature and specific volume using equation B14.

2.4.4 Fluid Property Adjustments for Salt Concentration

High concentrations of sodium chloride in the geothermal fluid can cause significant changes in the fluid's properties. Modifications to the GEOCOST code have been made to allow for such property changes. These modifications adjust the fluid mass flow rate, density, specific volume, and viscosity to appropriate values for the prescribed salt concentration. Other fluid properties which are also functions of the salt content include thermal conductivity, specific heat, and boiling point elevation. These properties do not have a significant impact on the results of GEOCOST and were left independent of the salt content, pending the availability of accurate experimental data.

The enthalpy of the geothermal fluid is assumed to be equal to the enthalpy of pure water, which is within reasonable accuracy as long as the salt concentration by weight is less than 30%. However, the mass flow rate of the geothermal fluid is adjusted to compensate for the presence of salt, as in the following equation.

$$QNA = \frac{Q}{(1.-WPDS/100.)}$$

where

QNA = geothermal fluid flow rate (includes water, salts, and noncondensible gases)

Q = pure water flow rate, with noncondensible gases.

If salt concentrations of less than 30% by weight are used, the pure-water approximation yields an error of 5% or less for the fluid enthalpy. The error decreases to zero as the salt concentration decreases to zero.

The presence of salt in the geothermal fluid increases the fluid density. This increase is approximated by a linear function of salt concentration using the following equation taken from Reference 18.

$$\rho_f = \rho_w * (0.007566 * WPDS + 1.)$$

where

ρ_f = density of the geothermal fluid

ρ_w = pure-water density

WPDS = weight percentage of salt in the geothermal fluid

The pure-water densities are calculated using subroutine FLUID and the Steam Library. The adjustment to the fluid density (and specific volume) for the presence of salt is implemented in subroutines BINARY, FLPROP, SUBHEX, SUPHEX, TPFLOW, and TRANS.

The increase in the viscosity of the geothermal fluid with increased salt concentration is approximated by the following equation taken from Reference 18.

$$\mu_f = (-0.30361 + 218.277/T - 2532.8/T^2) * (1. + 0.0276 * WPDS)$$

where:

μ_f = viscosity of the geothermal fluid

T = temperature (°F) of the geothermal fluid

WPDS = weight percentage of salt in the geothermal fluid

The pure-water viscosities are calculated using subroutine FLUID and the Steam Library. The adjustment to the fluid viscosity for the presence of salt is implemented in subroutines FLPROP, SUBHEX, SUPHEX, TPFLOW, and TRANS.

The equations for both fluid density and viscosity are given as approximations in Reference 18 for temperatures in the range 60°F to 300°F and 0 to 11% salt concentration. GEOCOST extrapolates these equations for temperatures greater than 300°F or salt concentrations greater than 11%.

2.4.5 Simulation of Major Components of the Binary Power Plant

After calculation of the thermodynamic cycle state points, subroutine BINARY calls the sequence of subroutines beginning with ACWFRT and ending with LOSSES in 2A of Figure 3 to simulate the operating characteristics of the major components of the binary power plant. This includes the auxiliary cooling water system, subcritical or supercritical heat exchangers, desuperheater and condenser, cooling tower, and internal power consumption of these components. The turbo-generator set and booster and feed pumps for the working fluid are simulated in subroutines WFFRT and PUMP respectively during calculation of the state points. This section describes the subroutines in 2A of Figure 3 together with supporting subroutines used to simulate the components of the binary power plant.

ACWFRT — Calls function QCC to calculate the auxiliary cooling water flow rates for the turbine oil cooler and hydrogen cooler. The calculation is based on the cooling water inlet temperature TCI; cooling water exit temperatures from the turbine oil cooler and hydrogen cooler, TCOOC and TCOHC; and the kilowatt equivalent of heat removed from the turbine oil cooler and hydrogen cooler (set to 0.5% and 1.9% respectively of the power plant gross kilowatts).

QCC — Calculates the cooling water flow rate for either a turbine oil cooler or hydrogen cooler as a function of the kilowatt equivalent of heat removed, cooling water inlet temperature and exit temperature.

$$QCC = \frac{CKW}{c_p * (TCEXIT - TCI)}$$

where:

QCC = cooling water flow rate, lb/hr
CKW = kilowatt equivalent of heat removed

c_p = specific heat of water at the average of the inlet and exit temperatures, Btu/lb-°F

TCI = cooling water inlet temperature, °F

TCEXIT = cooling water exit temperature, °F

SUBHEX

Simulates the basic characteristics of the three subcritical heat exchangers: preheater, vaporizer, and superheater. The basic type of heat exchanger modeled is a counterflow, single-pass, shell-and-tube unit with a fixed tube sheet on an equilateral triangular pitch. In the subcritical cycle, heat exchangers are required for three applications. In the superheater, the hottest geothermal fluid exchanges heat with the working fluid to heat the working fluid from a saturated vapor to a superheated state. The vaporizer receives the geothermal fluid from the outlet of the superheater to bring the working fluid from a saturated liquid to a saturated vapor state. The preheater receives the geothermal fluid from the outlet of the vaporizer to heat the working fluid up to a saturated liquid state. This process is depicted in Figure 9, together with the FORTRAN nomenclature for the geothermal and working fluid temperatures in subroutine SUBHEX. Typical temperature profiles in the three counterflow heat exchangers for the subcritical cycle are shown in Figure 10.

The input conditions to subroutine SUBHEX are:

a) Geothermal fluid flow rate, lb/hr
b) Working fluid flow rate, lb/hr
c) Geothermal fluid temperatures at the superheater inlet and preheater inlet and outlet, °F
d) Geothermal fluid pressures at the inlet and outlet of the three heat exchangers, psia
e) Working fluid temperatures (°F) and enthalpies (Btu/lb) at the inlet and outlet of the three heat exchangers
f) Inside and outside fouling factors, hr-ft^2-°F/Btu
g) Inside and outside tube diameters, ft

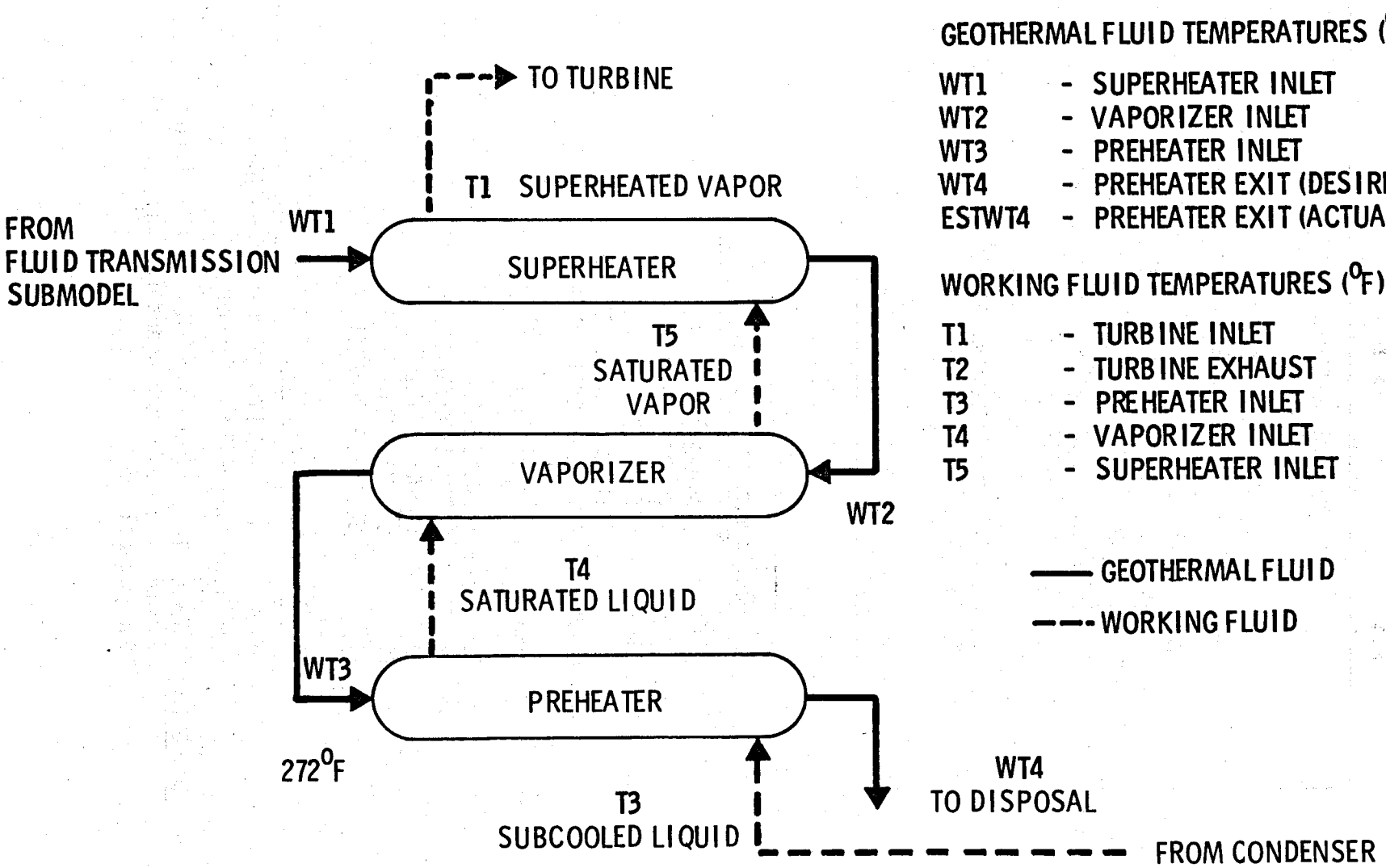
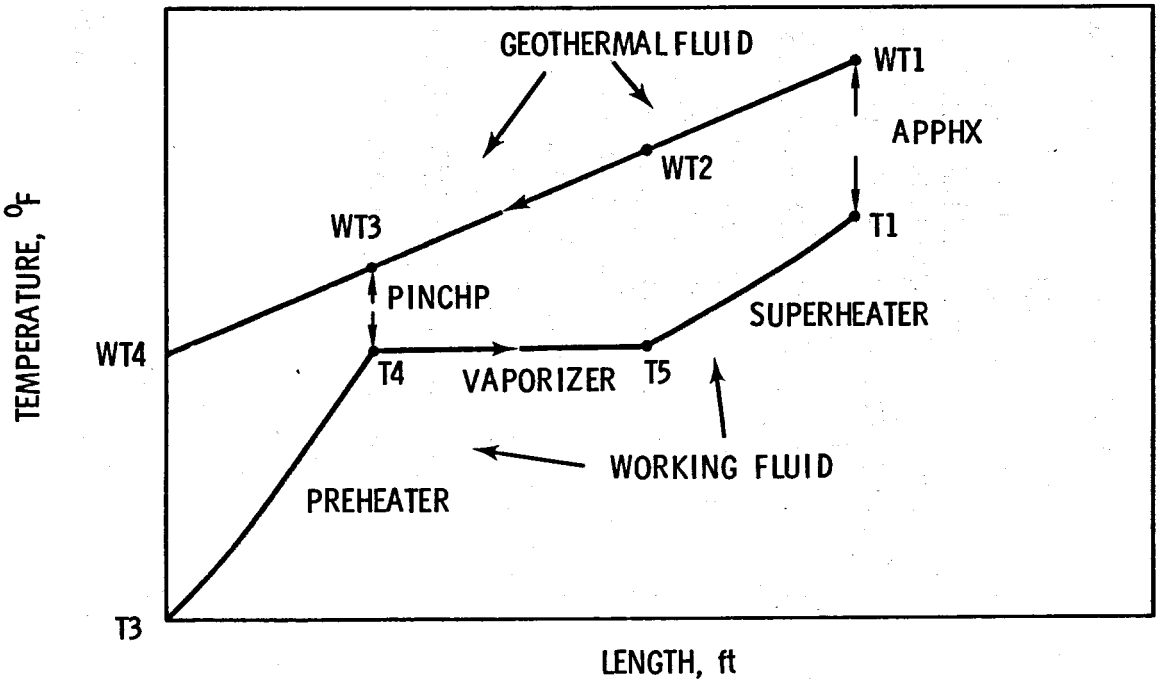


FIGURE 9. Typical Heat Exchanger Configuration for Binary Cycle Plant



GEOTHERMAL FLUID TEMPERATURES (°F)

WT1	- SUPERHEATER INLET
WT2	- VAPORIZER INLET
WT3	- PREHEATER INLET
WT4	- PREHEATER EXIT (DESIRED)
ESTWT4	- PREHEATER EXIT (ACTUAL)

WORKING FLUID TEMPERATURES (°F)

T1	- TURBINE INLET
T2	- TURBINE EXHAUST
T3	- PREHEATER INLET
T4	- VAPORIZER INLET
T5	- SUPERHEATER INLET

TEMPERATURE DIFFERENCES

APPHX	- APPROACH TO THE HEAT EXCHANGERS
PINCHP	- PREHEATER PINCH POINT

FIGURE 10. Typical Temperature Profiles in the Three Counterflow Heat Exchangers for the Subcritical Cycle

h) Geothermal fluid velocities in the tubes of the three heat exchangers, ft/hr

i) Type of working fluid.

The basic characteristics calculated for the heat exchangers are:

a) Inside and outside heat transfer coefficients, Btu/hr-ft^2-°F

b) Overall heat transfer coefficient, Btu/hr-ft^2-°F

c) Number of heat exchanger tubes

d) Total flow area (ft^2) and equivalent flow diameter (ft) for the shell side

e) Heat exchanger area, ft^2

f) Heat exchanger length, ft.

The characteristics of the three heat exchangers are calculated in the steps described below, first for the tube-side or geothermal fluid and then for the shell-side or working fluid. All 12 computational steps are repeated for each of the heat exchangers in the order: preheater, vaporizer, and superheater.

1) The average of the inlet and exit temperatures is calculated for the geothermal fluid and working fluid respectively for use in computation of physical properties.

2) The thermal conductivity, density, and viscosity of the geothermal fluid are calculated at the geothermal temperature in step 1 using function FLUID.

3) The Reynolds number of the geothermal fluid is calculated in function REYNO. The Prandtl number is calculated in subroutine SUBHEX based on the specific heat c_p, viscosity μ, and thermal conductivity k of the geothermal fluid:

$$Pr = \frac{c_p * \mu}{k}$$

4) The inside or tube-side heat transfer coefficient is determined in function HTCOEF.

5) The number of tubes required for the geothermal fluid is calculated in function TUBES.

6) The total flow area and equivalent flow diameter for the shell side are determined in subroutine QAREA.

7) The specific heat, thermal conductivity, density, and viscosity of the liquid working fluid in the preheater are calculated at the working fluid temperature in step 1 using function FLUID. In the vaporizer, the working fluid passes through the vapor dome so these properties are calculated both for saturated liquid and saturated vapor states using function FLUID. In the calculations for the vaporizer, the temperature WT2 of the geothermal fluid at the inlet to the vaporizer is determined through a heat balance formulation. In the superheater, the density and viscosity of the superheated working fluid are estimated using an iterative procedure based upon the equation of state. The equation of state is calculated in function PEQST for hydrocarbons and function EQSTAP for fluorocarbons and ammonia.

8) The velocity of the geothermal fluid in the tubes is set in the input data. The velocity of the working fluid in the heat exchanger shell is calculated in function VELOCY.

9) The Reynolds number of the working fluid is calculated in function REYNO. The Prandtl number is calculated in subroutine SUBHEX based on the specific heat, viscosity, and thermal conductivity of the working fluid.

10) The outside or shell-side heat transfer coefficient is determined in subroutine HTCOEF for the preheater and superheater. In the vaporizer, the working fluid passes through the vapor dome. The outside heat transfer coefficient is calculated in subroutine SUBHEX based upon

macroconvective heat transfer in two-phase flow using Chen's correlation and the Martinelli parameter.[19] The calculations are based on equation B16 in Appendix B.

11) The inside and outside heat transfer coefficients are combined with the thermal conductivity of the tube wall and the fouling factors to determine the overall heat transfer coefficient in function OHTCOE.

12) Knowing the amount of overall heat transfer desired, the heat transfer area and heat transfer length are calculated in functions HTAREA and HTLNGH respectively.

REYNO — Calculates the Reynolds number based upon the fluid density ρ, viscosity μ, velocity V, and flow diameter D:

$$Re = \frac{\rho DV}{\mu}$$

HTCOEF — Calculates inside and outside heat transfer coefficients based on the Dittus-Boelter equation[20] for fully developed turbulent flow in smooth tubes. The Dittus-Boelter equation is summarized by equation B17 in Appendix B. Subroutine HTCOEF is called by subroutine SUBHEX to calculate the inside heat transfer coefficients for the geothermal fluid in the preheater, vaporizer, and superheater. Subroutine HTCOEF is also used to calculate the outside heat transfer coefficients for the working fluid in the preheater and superheater.

TUBES — Determines the number N of tubes required for each heat exchanger based on the geothermal fluid mass flow rate Q, velocity V, density ρ, and flow diameter D. Fractional values of N are increased to the next largest integer. The basic relationship is:

$$N = \frac{(Q/\rho)}{V * \frac{\pi D^2}{4}}$$

where:

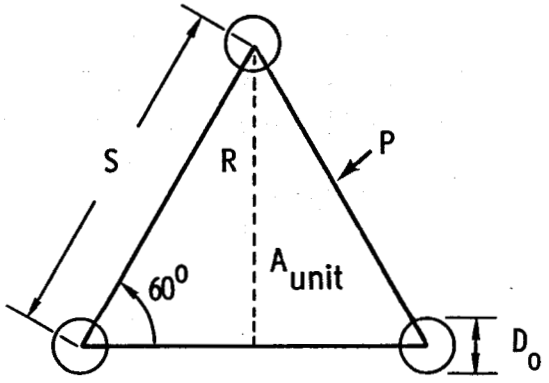
(Q/ρ) is the total required volumetric flow rate of geothermal fluid,

$\frac{\pi D^2}{4}$ is the cross-sectional flow area per tube,

$V * \frac{\pi D^2}{4}$ is the volumetric flow rate per tube.

QAREA

Calculates the total cross-sectional flow area A and equivalent flow diameter D_e for the shell-side or working fluid side in each heat exchanger. An equilateral triangular pitch is assumed for the tube configuration, as shown below.



S - TUBE SPACING, ft

D_o - TUBE OUTER DIAMETER, ft

P - WETTED PERIMETER, ft

A_{unit} - UNIT FLOW AREA, ft

The tube spacing S is assumed to be 1.75 times the tube outer diameter D_o. Based on the area for an equilateral triangle, the unit flow area for the working fluid is calculated by the following equation.

$$A_{unit} = \frac{SR}{2} - \frac{3}{6} * \frac{\pi D^2}{4}$$

where:

$R = S * \sin 60°$

$\frac{SR}{2}$ = area of the equilateral triangle

$\frac{3}{6} * \frac{\pi D^2}{4}$ = area of the 3 pie shapes in the 3 tubes which are not included in the flow area for the working fluid.

The total cross-sectional flow area A is calculated as the number of tubes times the unit flow area A_{unit}. The equivalent flow diameter D_e for the shell-side is calculated as:

$$D_e = \frac{4 * A_{unit}}{\text{wetted perimeter}}$$

The wetted perimeter P is calculated as:

$$P = 3(S-D_o) + \frac{3\pi D_o}{6}$$

VELOCY

Calculates the fluid velocity V as a function of the mass flow rate Q, fluid density ρ, and total cross-sectional flow area A as follows:

$$V = \frac{(Q/\rho)}{A}$$

where:

(Q/ρ) is the volumetric flow rate.

OHTCOE

Combines the inside and outside heat transfer coefficients with the thermal resistance of the heat exchanger tube walls and the fouling factors. This yields an overall heat transfer coefficient on the basis of the following equation.

$$U = \frac{1}{\frac{A_o}{A_i} * \frac{1}{h_i} + \frac{A_o \ln (r_o/r_i)}{2\pi KL} + \frac{1}{h_o} + f_i + f_o}$$

where:

U = overall heat transfer coefficient, Btu/hr-ft^2-°F
A_o = outside tube surface area, ft^2
A_i = inside tube surface area, ft^2
h_i = inside heat transfer coefficient, Btu/hr-ft^2-°F
h_o = outside heat transfer coefficient, Btu/hr-ft^2-°F
r_i = inside tube radius, ft

r_o = outside tube radius, ft

K = thermal conductivity for the tube wall, Btu/hr-ft-°F

L = tube length, ft

f_i = inside fouling factor, hr-ft^2-°F/Btu

f_o = outside fouling factor, hr-ft^2-°F/Btu

The fouling factors reduce the overall heat transfer coefficient to allow for the accumulation of corrosion deposits on the heat transfer surfaces.

HTAREA

Calculates the heat transfer area A for each heat exchanger. The calculation is based on the working fluid flow rate Q; enthalpies of the working fluid at the inlet and outlet, H_1 and H_2; overall heat transfer coefficient U; and the logarithmic mean temperature difference LMTD in the following equation.

$$A = \frac{Q * (H_1 - H_2)}{U * (LMTD)}$$

The logarithmic mean temperature difference between the geothermal fluid and working fluid is based on the temperature difference at the two ends of the heat exchanger.

$$LMTD = \frac{\Delta T_{in} - \Delta T_{out}}{\ln (\Delta T_{in}/\Delta T_{out})}$$

where:

ΔT_{in} = temperature difference (°F) between the geothermal fluid and working fluid at the working fluid inlet to the heat exchanger

ΔT_{out} = temperature difference (°F) between the geothermal fluid and working fluid at the working fluid outlet from the heat exchanger

HTLNGH

Calculates the tube length L in each heat exchanger. The calculation is based on the heat transfer area A, tube outer diameter D_o, and number N of tubes in the heat exchanger.

$$L = \frac{A}{\pi D_o N}$$

SUPHEX

Simulates the basic characteristics of the supercritical heat exchanger. This heat exchanger is modeled as a counter-flow, single-pass, shell-and-tube unit with a fixed tube sheet on an equilateral triangular pitch. The input conditions to subroutine SUPHEX are as follows:

a) Geothermal fluid flow rate, lb/hr
b) Working fluid flow rate, lb/hr
c) Geothermal fluid temperatures at the inlet and outlet of the heat exchanger, °F
d) Working fluid temperatures (°F) and enthalpies (Btu/lb) at the inlet and outlet of the heat exchanger
e) Working fluid pressure at the turbine inlet, psia
f) Inside and outside fouling factors, hr-ft^2-°F/Btu
g) Inside and outside tube diameters, ft
h) Geothermal fluid velocity in the tubes, ft/hr
i) Type of working fluid

The basic characteristics calculated for the supercritical heat exchanger are:

a) Inside and outside heat transfer coefficients, Btu/hr-ft^2-°F
b) Overall heat transfer coefficient, Btu/hr-ft^2-°F
c) Number of heat exchanger tubes
d) Heat exchanger area, ft^2
e) Heat exchanger length, ft

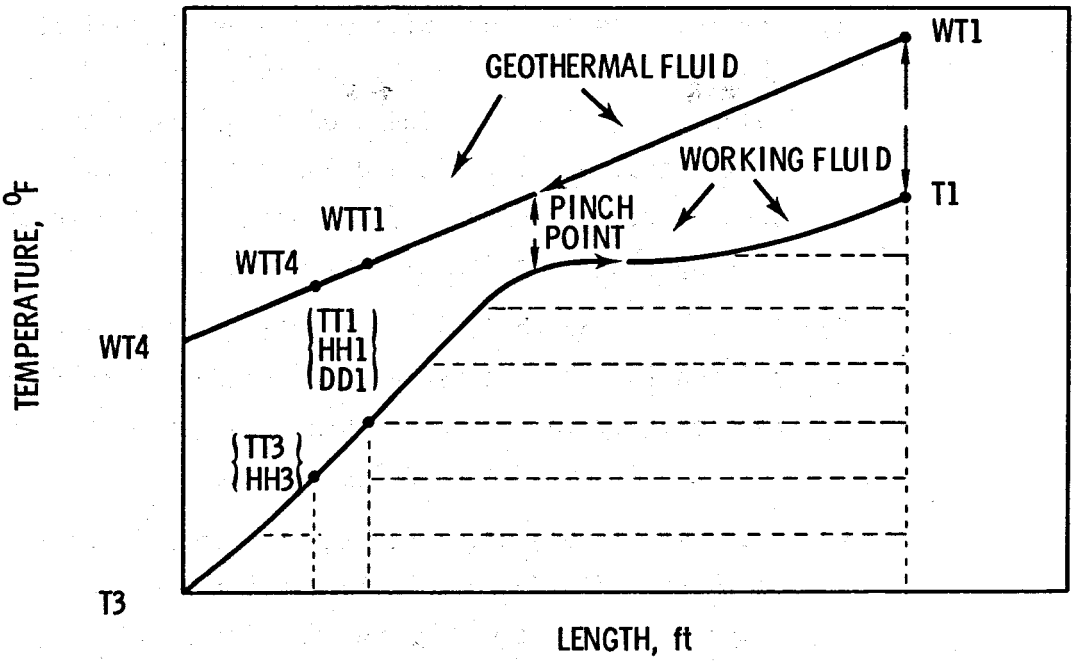
The major difference in the operation of this heat exchanger from the subcritical heat exchangers is that the working

SUPHEX (Contd)

fluid does not pass through the vapor dome. This allows the calculation of the entire heat exchange from the working fluid pump outlet to the turbine inlet to be made as if there were one heat exchanger. However, this assumption is inadequate since the change in thermodynamic and physical properties of the working fluid is quite variable and nonlinear in the supercritical region. For this reason, the supercritical heat exchanger is assumed to be a series of 25 incremental heat exchangers.

The typical temperature profile in a counterflow heat exchanger for the supercritical cycle is nonlinear, as shown in Figure 11. In subroutine SUPHEX, the working fluid temperature difference between the inlet and outlet of the supercritical heat exchanger is divided into 25 equal increments. The nonlinear working fluid temperature profile is then divided into piece-wise profiles in 25 successive heat exchangers of different lengths, as illustrated in Figure 11. The characteristics of each of the 25 heat exchangers are calculated in the steps described below.

1) The enthalpy HH1 of the working fluid is calculated at the incremental heat exchanger outlet. If the working fluid is a hydrocarbon, the enthalpy is calculated based on the temperature TT1 and density DD1 using functions HEQST and HIDEAL. The density DD1 is calculated iteratively based on the working fluid temperature TT1 and pressure P1 at the turbine inlet using the equation of state function PEQST. If the working fluid is a fluorocarbon or ammonia, the enthalpy is calculated based on the working fluid temperature TT1, specific volume VV1, and pressure P1 at the turbine inlet using function HVAP. The specific volume VV1 at the incremental heat exchanger outlet is calculated iteratively based on the working fluid temperature TT1 and pressure P1 at the turbine inlet using the equation of state function EQSTAP.



GEOTHERMAL FLUID TEMPERATURES (°F)

WT1 - HEAT EXCHANGER INLET
WTT1 - INCREMENTAL HEAT EXCHANGER INLET
WTT4 - INCREMENTAL HEAT EXCHANGER OUTLET
WT4 - HEAT EXCHANGER OUTLET

WORKING FLUID TEMPERATURES (°F)

T1 - HEAT EXCHANGER OUTLET
TT1 - INCREMENTAL HEAT EXCHANGER OUTLET
TT3 - INCREMENTAL HEAT EXCHANGER INLET
T3 - HEAT EXCHANGER INLET

OTHER WORKING FLUID CONDITIONS

HH1 - ENTHALPY AT INCREMENTAL HEAT EXCHANGER OUTLET
DD1 - DENSITY AT INCREMENTAL HEAT EXCHANGER OUTLET
HH3 - ENTHALPY AT INCREMENTAL HEAT EXCHANGER INLET

FIGURE 11. Typical Temperature Profile in Counterflow Heat Exchanger for the Supercritical Cycle

SUPHEX (Contd)

2) The inlet temperature WTTl of the geothermal fluid to the incremental heat exchanger is calculated from a heat balance formulation. The product of the enthalpy drop in the geothermal fluid and its mass flow rate is equated to the product of the enthalpy rise in the working fluid and its mass flow rate.

3) The average of the inlet and outlet temperatures is calculated for the geothermal fluid and working fluid respectively in the incremental heat exchanger for use in computation of physical properties.

4) The thermal conductivity, density, and viscosity of the geothermal fluid are calculated at the geothermal temperature in step 3 using function FLUID.

5) The Reynolds number of the geothermal fluid is calculated in function REYNO. The Prandtl number is calculated in subroutine SUPHEX based on the specific heat c_p, viscosity μ, and thermal conductivity k of the geothermal fluid:

$$Pr = \frac{c_p * \mu}{k}$$

6) The inside or tube-side heat transfer coefficient is calculated in function HTCOEF.

7) The number of tubes required for the geothermal fluid is calculated in function TUBES.

8) The total flow area and equivalent flow diameter for the shell side are determined in subroutine QAREA.

9) The specific heat, thermal conductivity, density, and viscosity of the working fluid are calculated based on the working-fluid temperature in step 3 using function FLUID.

SUPHEX (Contd)

10) The velocity of the geothermal fluid in the supercritical heat exchanger tubes is set in the input data. The velocity of the working fluid in the heat exchanger shell is calculated in function VELOCY.

11) The Reynolds number of the working fluid is calculated in function REYNO. The Prandtl number is calculated in subroutine SUPHEX based on the specific heat, viscosity, and thermal conductivity of the working fluid.

12) The outside or shell-side heat transfer coefficient is determined in subroutine HTCOEF.

13) The inside and outside heat transfer coefficients are combined with the thermal conductivity of the tube wall and the fouling factors to determine the overall heat transfer coefficient in function OHTCOE.

14) If the pinch point at the outlet of any incremental heat exchanger is less than the minimum allowable pinch point PINSUP defined in the input data, the geothermal fluid temperature WT4 set for the outlet of the supercritical heat exchanger is increased by 5°F. The calculations in steps 1-13 are then repeated. If at the last (25th) incremental heat exchanger, the minimum calculated pinch point FTMIN for the supercritical heat exchanger is greater than the maximum allowable pinch point of PINSUP + 10°F, the geothermal fluid temperature WT4 is decreased by 5°F. The calculations in steps 1-13 are then again repeated. If temperature WT4 is reset in subroutine SUPHEX, the mass flow rate of geothermal fluid required is recalculated based on the new value of WT4 and a heat balance formulation:

$$Q_w = \frac{Q * (H1 - H3)}{c_p * (WT1 - WT4)}$$

SUPHEX (Contd)

where:

Q_W = mass flow rate of geothermal fluid, lb/hr

Q = mass flow rate of working fluid, lb/hr

WT1 and WT4 = geothermal fluid temperatures at the geothermal inlet and outlet respectively of the supercritical heat exchanger, °F

H1 and H3 = working fluid enthalpies at the working fluid outlet and inlet respectively of the supercritical heat exchanger, Btu/lb

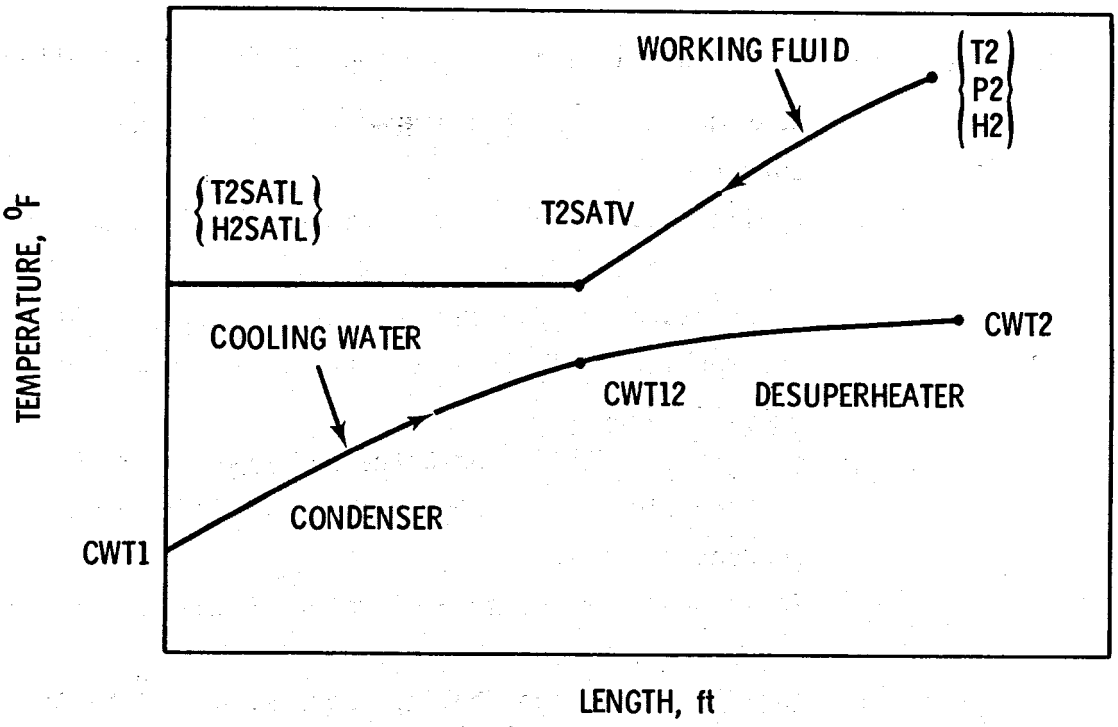
c_p = specific heat of the geothermal fluid at the average of the temperatures WT1 and WT4, Btu/lb-°F

15) Knowing the amount of overall heat transfer desired, the heat transfer area and heat transfer length are calculated in functions HTAREA and HTLNGH respectively.

After the calculations in steps 1-15 are completed for all 25 incremental heat exchangers, the heat transfer areas and lengths are summed over all incremental heat exchangers to obtain a single size and length heat exchanger. Average values are calculated for the inside, outside, and overall heat transfer coefficients.

CNDNSR

Simulates the basic characteristics of: 1) a desuperheater and 2) a surface condenser. The desuperheater cools the working fluid from a superheated vapor at the turbine exhaust to a saturated vapor. The saturated vapor is then condensed in a surface condenser. Both the desuperheater and surface condenser are modeled as counterflow, single-pass, shell-and-tube heat exchangers supplied with cooling water. The geometric design configuration is based on an equilateral triangular pitch and fixed tube sheet. Typical temperature profiles in the desuperheater and condenser are shown in Figure 12.



COOLING WATER TEMPERATURES (°F)

CWT1 - CONDENSER INLET
CWT12 - DESUPERHEATER INLET
CWT2 - DESUPERHEATER OUTLET

WORKING FLUID TEMPERATURES (°F)

T2 - SUPERHEATED VAPOR AT TURBINE EXHAUST
T2SATV - SATURATED VAPOR AT DESUPERHEATER OUTLET
T2SATL - SATURATED LIQUID AT CONDENSER OUTLET

OTHER WORKING FLUID CONDITIONS

P2 - PRESSURE AT TURBINE EXHAUST
H2 - ENTHALPY AT TURBINE EXHAUST
H2SATL - ENTHALPY AT CONDENSER OUTLET

FIGURE 12. Typical Temperature Profiles in Desuperheater and Condenser

CNDNSR (Contd) The input conditions to subroutine CNDNSR are as follows:

a) Cooling water inlet temperature CWT1 to the condenser, °F
b) Cooling water outlet temperature CWT2 from the desuperheater, °F
c) Temperature T2, pressure P2, and enthalpy H2 of the working fluid in a superheated state at the turbine exhaust
d) Temperature T2SATL and enthalpy H2SATL of the working fluid in a saturated liquid state at the condenser outlet
e) Inside and outside tube diameters (same for the desuperheater and condenser), ft
f) Inside and outside fouling factors, hr-ft^2-°F/Btu
g) Working fluid flow rate, lb/hr
h) Water velocity in the tubes (same for the desuperheater and condenser), ft/hr
i) Type of working fluid.

The basic characteristics calculated for the desuperheater and condenser are:

a) Inside and outside heat transfer coefficients, Btu/hr-ft^2-°F
b) Overall heat transfer coefficient, Btu/hr-ft^2-°F/Btu
c) Number of heat exchanger tubes
d) Heat transfer area, ft^2
e) Heat transfer length, ft
f) Cooling water flow rate (same for the desuperheater and condenser), lb/hr

Subroutine CNDNSR first calculates the characteristics of the desuperheater in the steps described below.

1) The mass flow rate of water required to cool the working fluid from a superheated state to a saturated liquid

CNDNSR (Contd)

state is calculated based on a heat balance formulation. The product of the enthalpy drop and mass flow rate of the working fluid is equated to the product of the enthalpy rise and mass flow rate of the cooling water. This equation is then solved for the mass flow rate of cooling water.

2) The cooling water temperature CWT12 at the desuperheater inlet is calculated iteratively based on a heat balance formulation. The product of the mass flow rate and enthalpy drop of the working fluid from a superheated state to a saturated vapor state is equated to the product of the mass flow rate and enthalpy rise of the cooling water from temperature CWT12 to CWT2.

3) The next sequence of calculations for the cooling water in the desuperheater are similar to those described for the geothermal fluid in the superheater of the subcritical cycle (subroutine SUBHEX). However, in this case the working fluid is cooled from a superheated state to a saturated vapor state. The following quantities are calculated for the cooling water in the desuperheater:

   a) Average of the inlet and exit temperatures, CWT12 and CWT2, for use in computation of physical properties
   b) Thermal conductivity, density, and viscosity at the average temperature in (a)
   c) Reynolds and Prandtl numbers
   d) Number of tubes required for the cooling water
   e) Inside or cooling water heat transfer coefficient.

4) In another sequence of calculations similar to those described for the working fluid in the superheater of the subcritical cycle, the following quantities are calculated for the working fluid:

CNDNSR (Contd)

a) Average of the inlet and exit temperatures, T2 and T2SATL. Temperature T2SATV is equal to T2SATL.
b) Specific heat and thermal conductivity at the average temperature in (a)
c) If the working fluid is a hydrocarbon, the density is calculated iteratively at the average temperature in (a) and pressure P2 at the turbine exhaust using the equation of state function PEQST. Since the working fluid is cooled at constant pressure, P2SATL and P2SATV are equal to P2. If the working fluid is a fluorocarbon or ammonia, the specific volume is calculated iteratively at the average temperature in (a) and pressure P2 using the equation of state function EQSTAP.
d) Total flow area and equivalent flow diameter for the working fluid
e) Viscosity of the working fluid at the average temperature in (a)
f) Velocity of the working fluid in the desuperheater tubes. The velocity of the cooling water in the desuperheater tubes (same as for the condenser tubes) is set in the input data
g) Reynolds and Prandtl numbers of the working fluid
h) Outside or working fluid heat transfer coefficient
i) Overall heat transfer coefficient.

Knowing the amount of overall heat transfer desired, the heat transfer area and heat transfer length are calculated in functions HTAREA and HTLNGH respectively.

Subroutine CNDNSR calculates the basic characteristics of the condenser in steps similar to those described in subroutine SUBHEX for the vaporizer in the subcritical cycle. However, in this case the working fluid is cooled from a saturated vapor state to a saturated liquid state.

TOWER

Simulates the performance of an induced-draft evaporative cooling tower in which air is drawn through the tower with large propeller-type fans. The input conditions to subroutine TOWER are:

a) Cooling water mass flow rate, (lb/hr)
b) Cooling water inlet temperature, °F
c) Inlet air dry bulb temperature, °F
d) Inlet air wet bulb temperature, °F
e) Barometric pressure, in. Hg
f) Humidity ratio
g) Cooling water outlet temperature, °F.

The basic characteristics calculated for the cooling tower are:

a) Cooling tower air flow rate, cfm
b) Evaporation rate, lb/hr
c) Makeup water flow rate, lb/hr
d) Heat load of tower, Btu/hr

The cooling water flow rate at the cooling tower inlet is the sum of the cooling water flow rates computed for the condenser and desuperheater, turbine oil cooler, and hydrogen cooler. The cooling water temperature at the cooling tower inlet is a mass-weighted average of the cooling water exit temperatures from the condenser and desuperheater, turbine oil cooler, and hydrogen cooler. The cooling tower is modeled with the requirement that the approach temperature, i.e., difference between the water exit temperature and inlet air wet bulb temperature, be at least 8°F. The characteristics of the cooling tower are calculated in the steps described below.

1) The saturated vapor pressure of the air is computed at the inlet air dry bulb temperature.

TOWER (Contd)

2) The actual vapor pressure is determined from the relative humidity and the saturated vapor pressure.

3) Based upon the actual vapor pressure, the inlet air enthalpy is determined.

4) Assuming saturated air at the tower exit, the outlet air enthalpy is determined.

5) Based upon water-weight balance and enthalpy balance equations, the air flow rate and water evaporation rate are computed.

6) Makeup water flow rate is computed based on evaporation and blowdown.

7) The heat load is determined from the air flow rate and its enthalpy change.

LOSSES

Calculates the internal power (kilowatts) consumed by the cooling tower fans, condensate pumps, cooling water pumps, and reinjection pump for reinjecting spent geothermal fluid from the power plant. Power consumption by the booster and feed pumps for the working fluid is calculated in subroutine BINARY. Power consumption by booster pumps for pressurizing geothermal fluid in the fluid transmission lines is calculated in subroutine TRANS. Efficiency factors used in calculating power consumption are defined in subroutine LOSSES, BINARY, and TRANS for the various pumps, cooling tower fans, and fan motors. Pumping pressures are defined in subroutine LOSSES and BINARY. The booster pump pressure for pressurizing the geothermal fluid is calculated in subroutine DBINRY. The total power losses are subtracted in subroutine BINARY from the gross kilowatt output specified for the power plant to yield the net kilowatt output.

2.5 FLUID TRANSMISSION AND DISPOSAL SUBMODEL

Based upon the total flow requirements calculated by the binary power plant submodel, subroutine TRANS calls the subroutines described below to simulate the fluid transmission submodel. The fluid transmission submodel calculates the following quantities: number of producing wells required, the well field layout, pipeline lengths, optimum pipeline diameters, pipe schedules, pipe insulation, pumping requirements, fluid degradation during conduction from the wellhead to the power plant, and cost of the pipes, insulation, pumps, valves, and associated equipment. The degradation of the geothermal fluid (temperature, pressure, enthalpy, steam quality, viscosity, and density) is modeled on a nodal basis during conduction in a compressed liquid state.

Subroutine INJECT, coded as an entry point in subroutine TRANS, performs analogous functions for fluid disposal by simulating the conduction of the spent geothermal fluid from the heat exchangers to the injection well field. It calculates the number of injection wells required, injection well field layout, effluent pipeline lengths and diameters, and cost of the disposal piping system and associated equipment. In contrast to the fluid transmission submodel, which calculates fluid degradation on a nodal basis, the more simplified fluid disposal submodel in this version of GEOCOST does not calculate effluent fluid degradation. Instead, the effluent pipeline diameters are sized on a nodal basis as a function of the mass flow rate exiting each node, holding constant the temperature, pressure, viscosity, and density of the effluent in effect at the outlet from the binary power plant heat exchangers.

TROUT	Prints the input conditions for the fluid transmission and disposal submodel.
DESIGN	Calculates the number of producing, nonproducing, and injection wells based on the total geothermal fluid flow rate demanded by the binary power plant submodel and several input conditions. The latter include: mass flow rate of individual producing wells, ratio of nonproducing to

DESIGN (Contd) producing wells drilled, and ratio of injection well to producing well flow rate. The wells are located at the vertices of equilateral triangles (nodes in a triangular lattice) as shown in Figure 13, with pipe runs parallel to the horizontal X-axis. The fluid transmission system has a manifold pipeline for transmitting the geothermal fluid from all rows of wells to the power plant. Subroutine DESIGN calculates an effective average acreage (WACRE) per producing well based upon the input well spacing (WELSPC) in acres and the fraction (FRCNPW) of nonproducing (dry) wells according to the following equation:

WACRE = WELSPC * (1.+FRCNPW)

The area (WACRE) encompassed by each producing well (Figure 12) is equal to the area of two equilateral triangles.

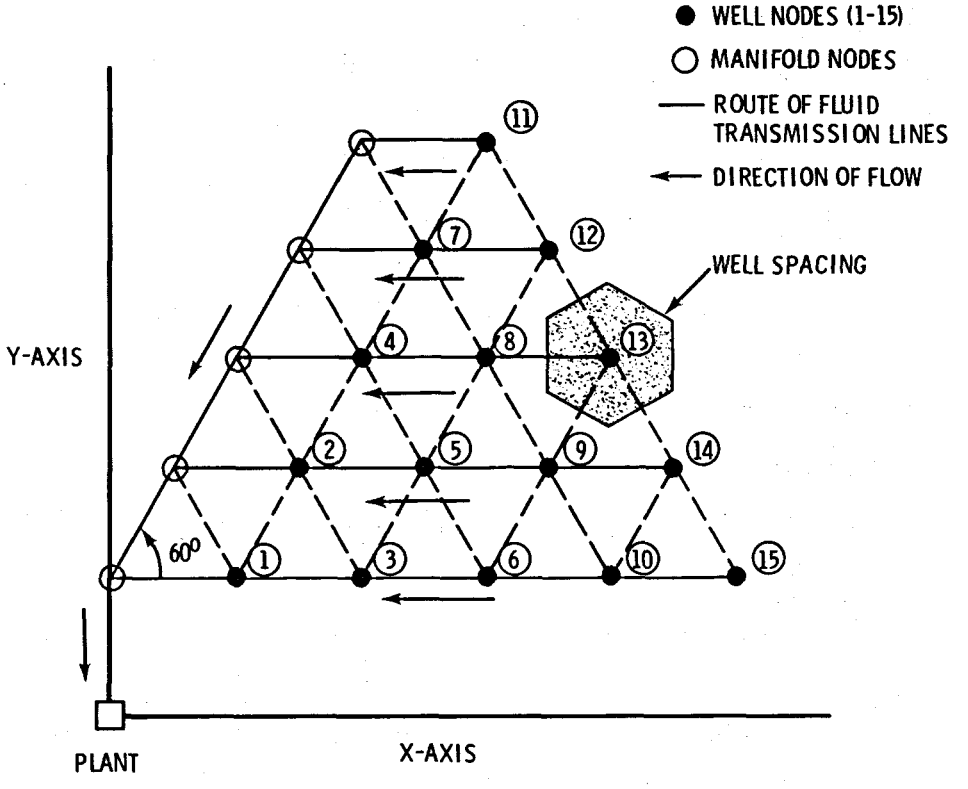


FIGURE 13. Well Layout Design and Routing of Fluid Transmission Lines

DESIGN (Contd) Subroutine DESIGN calculates the pipe length between producing wells based on the equation for the area of an equilateral triangle as follows:

$$\text{Pipe length (m)} = (0.3048006)\ (5280)\sqrt{\frac{\text{WACRE (acres)}}{(0.86603)\ (640)}}$$

EQCOST Calculates the cost of valves, instrumentation, rock separators, and cyclone separator for the fluid transmission submodel.

TSTART Initializes the thermodynamic and physical conditions of the geothermal fluid at the two types of nodes in the triangular lattice defining the well field layout. These types are 1) well nodes and 2) pipe junctions or manifold nodes collecting the fluid from the parallel rows of pipes into one large pipe leading to the power plant. The following fluid conditions are initialized on a nodal basis for a compressed liquid state: temperature, pressure and flow rate (input variables); enthalpy (computed as a function of the input temperature and pressure); and density and viscosity (computed from the preceding conditions). All well nodes in the field are initialized with the same average conditions. Variable well conditions can be simulated with minor code modifications. The initial conditions at the nodes are used as the starting point for computing the fluid degradation on a nodal basis during conduction from the well field nodes to the power plant.

PIPE Calculates the optimum pipe diameter exiting each node. The calculation is based on the fluid mass flow rate, fluid density and viscosity, and economic trade-offs between the components comprising the cost function for the fluid transmission system: capital cost of the pipe, annual value of energy lost due to friction in the pipeline, and capital cost of pumps and drive motors for pumping the fluid to the plant.

PIPE (Contd) The cost function for the fluid transmission system is minimized on a nodal basis with respect to internal pipe diameter D by setting its derivative with respect to D to zero. An iterative solution based upon the Newton-Raphson algorithm is obtained for optimum pipe diameter on a nodal basis from the resultant equation.

The pipe equations include a parameter EVALUE(1) which can be adjusted by the program user in the input data to change all pipe diameters in the pipeline network. This option permits the user to avoid unacceptable fluid quality resulting from excessive pressure degradation or two-phase flow.

STORE/RETRIEV Saves and retrieves information associated with the pipeline and thermodynamic condition of the fluid computed in simulating fluid conduction and degradation from well nodes (non-manifold nodes) to adjacent nodes. Calculations are required only once for each set of well nodes in the well layout with the same number of active wells upstream of the nodes, providing all wells have the same average conditions.* The subsequent retrieval of this information in lieu of recomputation can reduce the execution time for simulating the fluid transmission submodel almost 50% for large well fields. This option is selected by setting the input parameter IAVWEL = 1.

SCHEDL Assigns pipe schedules on a nodal basis by selecting the smallest pipe schedule from a range of 10 to 160 that can withstand the maximum fluid pressure exiting each node. The maximum pressure each schedule can accommodate is a function of the fluid temperature and ranges from about 350 psia for schedule 10 up to 3000 psia for schedule 160, with

* See description of sample case output.

SCHEDL (Contd)	temperature ranges from 100 to 900°F. The pipe schedule and diameter are used in subroutine TRANS to calculate the cost of piping and installation.
INSUL	Sizes pipe insulation on a nodal basis as a function of the fluid temperature, nominal outer pipe diameter, insulation thickness availability, and cost, using one or more types of insulation. The cost of insulation is calculated based on the thickness of each type of insulation used.
SPFLOW	Calculates the pressure, enthalpy, and temperature drop of the geothermal fluid during single-phase flow in the pipeline between nodes. Fluid degradation is calculated in one step-size equal to the distance between nodes. Calculation with smaller stepsize increments, such as 50 ft, in the conduction of water showed no significant difference in the degradation. The enthalpy drop is calculated as a function of nominal outer pipe diameter, fluid temperature, and insulation thickness. The pressure drop is calculated as a function of the mass flow rate, viscosity, density, and internal pipe diameter. The temperature drop is obtained from the pressure and enthalpy drop by using the steam table function TPHL for a compressed liquid.
FLPROP	Identifies the fluid state in the transmission pipeline as compressed liquid, saturated liquid, two-phase mixture, saturated vapor or superheated steam. Subroutine TRANS calls FLPROP on a node-by-node basis. The fluid state is identified based upon the pressure and enthalpy by interrogating subroutine XPHH and the ASME Steam Table functions. After identification of the fluid state at a particular node, subroutine FLPROP calls the appropriate steam table function to compute the specific volume, density, viscosity, temperature, or entropy as requested by subroutine TRANS.

XPHH — Calculates the steam quality by weight fraction as a function of pressure and enthalpy. It returns 0 for saturated and compressed liquid, 1 for saturated vapor and superheated steam, and values in between for two-phase mixtures of steam and water at saturation.

TPHASE — Tests whether the fluid quality in the pipeline has become unacceptable due to two-phase flow, which is not allowed in the conduction of water to the power plant.

TPRINT — Prints the results calculated by the fluid transmission submodel for the transmission line from the well field to the power plant. Results can be printed for the entire binary power plant and fluid transmission iteration history, or only for the final iteration satisfying the convergence criterion. In the final iteration, results calculated by the fluid disposal submodel are also printed. The input parameter LL6 controls the printout for the binary power plant and fluid transmission iteration: LL6 = 0 suppresses all printout, LL6 = 1 prints the last iteration only, and LL6 = 2 prints the full iteration history.

MOUT — Prints the arrays calculated in the fluid transmission and disposal submodel as matrices or vectors with accompanying titles.

2.6 RESERVOIR ECONOMIC SUBMODEL

After the required total fluid flow is established, GEOCOST calls the reservoir economic submodel simulated by subroutine RESVOR and its associated subroutines. This submodel determines the cash flow associated with the exploration, development, and operation of the reservoir from the beginning of exploration through the economic life of the power plant. The exploration process identifies and evaluates potential reservoir sites by a series of discrete steps, which can occur either sequentially in time or with some specified time overlap. Each step has a task description, time period,

associated cost, and success ratio (finding rate). The major steps are: 1) identification of target sites, 2) preliminary reconnaissance, 3) detailed reconnaissance, 4) identification of drillable sites, 5) exploratory drilling, 6) development of the reservoir and fluid transmission and disposal system, and 7) operation of that system. Both capitalized and expensed costs are determined for each of the steps in the reservoir exploration. Only that fraction of the total exploration cost calculated for the specified reservoir producing capacity required to provide the energy supply for the specified power plant size is included in the cost of energy to the power plant.

Reservoir development and operation expenses are based upon the number of producing, nonproducing, and injection wells and the fluid transmission and disposal system established in the steam power plant and fluid transmission iteration. Reservoir development costs include: drilling costs based upon the required number of wells and the drilling costs input for individual producing, nonproducing, and injection wells; capital cost of the fluid transmission system calculated in subroutine TRANS; and capital cost of the fluid disposal system calculated in subroutine INJECT. The cost of drilling producing wells is subdivided into both tangible and intangible drilling costs because tax regulations may treat these costs differently. Costed reservoir operation tasks include: replacement well drilling, subdivided into tangible and intangible costs; nonproducing well drilling associated with replacement wells; well abandonment and maintenance; overhead and management; well redrilling due to scale buildup; and fluid transmission and disposal maintenance. Both reservoir development and operation costs are computed on the basis of the specified power plant size.

Using discounted cash flow analysis, the unit cost of energy from the reservoir is calculated by equating the present worth of the revenues and expenses from the beginning of reservoir exploration through the economic life of the power plant. Descriptions follow of the subroutines associated with subroutine RESVOR and the reservoir economic submodel.

CLEAR — Clears consecutive locations in memory for initializing arrays in various subroutines to zero.

TARGTS — Calculates the number of prospective geothermal sites to explore in each of the successive discrete steps comprising the reservoir

TARGTS (Contd) exploration process, based upon the success ratios (finding rates) input for each step. The successive reduction in the number of sites to explore at each step culminates in a single producible site at the last step, completing the exploration process.

DATACK Prints the financial and tax input data for the reservoir and both calculates and prints the reservoir's annual cash flow statement from exploration through the economic life of the power plant. This statement includes each year of exploration, development, and operation of the reservoir, the power plant load factor or fraction of annual time the power plant is operating at full capacity, and the cash flows computed on an annual basis for the following items: identifying geothermal target sites, remaining reservoir exploration beginning with preliminary reconnaissance, reservoir development, reservoir operation, property taxes and insurance, interim capital replacements for the fluid transmission and disposal system, and the sum of these costs.

FACTRS Calculates the present worth discount factor based on the cost of capital from both debt (bond) and equity (stock) financing, using the effective bond interest rate after taxes. All expenses and revenues are assumed to be incurred at midyear. If year-end discounting is desired, the variable TIMD appearing in subroutine FACTRS should be reset from 0.5 to 1.0 in the BLOCK DATA subroutine. Subroutine FACTRS is called by both the reservoir and power plant subroutines as shown in Figure 3.

PWRCO Calculates the annual reservoir operating expenses from exploration through the economic life of the power plant. Subroutine PWRCO also calls subroutine DEPREC to calculate well depreciation and reservoir depletion and depreciation. These are printed by subroutine OUTPUT in the statement of annual deductible expenses.

DEPREC Calculates the annual depreciation of the reservoir capital assets, including interim capital replacements. The input parameter LL2

DEPREC (Contd) selects one of two available options: the straight line method (LL2 = 1) or the sum-of-years-digits method (LL2 = 2).

COSTEQ Calculates the unit cost of energy from the reservoir by setting the present worth of the revenues equal to the present worth of the expenses from the beginning of reservoir exploration through the economic life of the power plant.

> Unit cost of energy (mills/kW-hr) =(present worth of the expenses - present worth of tax credits) / [(present worth of energy supplied) * (1 - state gross revenue tax rate) * (1 - combined federal and state income tax rate)].

PAYOUT Calculates the annual income statement and annual payout of investments for the reservoir. This includes the total energy sales (gross revenues), state and federal income taxes, revenue taxes, royalty payments, and the changes in capitalization: outstanding bonds, bonds repaid, unrecovered equity, equity recovered, bond interest, and earnings on unrecovered equity.

OUTPUT Prints the statements of annual deductible expenses, income, and payout of investments for the reservoir from the beginning of reservoir exploration through the economic life of the power plant. The statement of annual deductible expenses lists the items: year, present worth factor for that year, reservoir operating expenses, bond interest, well depreciation, reservoir depletion and depreciation, total deductible operating expenses, and state income taxes. The statement of annual income lists the items: year, million megawatt-hours of energy supplied, energy sales, byproduct sales (zero for this version of GEOCOST), revenue taxes, royalty payments, total tax deductible expenses, taxable income (federal), and federal income tax. The statement of payout of investments lists the items: year, net cash flow, outstanding bonds, equity capital not recovered, bond interest, earnings on unrecovered equity, bonds repaid, and recovery of equity.

SUMARY Calculates and prints the breakdown of the unit cost of energy from the reservoir in mills/kW-hr and equivalent annual costs in millions of dollars. These are itemized as follows: identification and exploration, development, operating costs, revenue taxes, state income taxes, royalty payments, federal income taxes, bond interest, and byproduct revenue (zero for this version of GEOCOST). In another set of calculations, the taxes, royalty payments, and bond interest are reallocated to the direct cost components for the reservoir: identification and exploration, development, and operating costs. The rate of return on investment is included in the distributed energy cost for each component. The deductible nature of the bond interest causes this expense to be partially included in the rate of return (the part which is included in the present worth factor) and the remainder to be accounted for separately.

WRITE Prints debugging information from the reservoir economic submodel when the variable LL4 is nonzero. The variable LL4 is currently set to 0 in the BLOCK DATA subroutine.

2.7 POWER PLANT ECONOMIC SUBMODEL

The reservoir revenue is a cost to the power plant. GEOCOST calls the power plant economic submodel, simulated by subroutine PWRPLT and its associated subroutines. This submodel combines the reservoir cost with the other power plant capital and operating costs and generates the cash flow associated with the design, construction, and operation of the power plant throughout its useful life. The required revenue and unit cost of electricity are determined by using discounted cash flow analysis, and equating the present worth of the revenues and expenses over the economic life of the power plant. Descriptions of the subroutines associated with subroutine PWRPLT and the power plant economic submodel follow.

PCONST Generates capital cost estimates for the design and construction of the power plant, heat rejection system, and electrical switchyard as a function of power level or process flow rates. Equipment cost data were obtained from industry vendors and utility

PCONST (Contd)

operators for geothermal power plants. The cost data were correlated by least squares to the following equation, which is used to predict costs for various power levels and geothermal conditions.

$$\text{Installed cost (thousands of dollars)} = a + b(x)^s$$

where:

- a reflects fixed costs.
- b reflects materials, equipment, and installation dependent costs.
- s is a size scale factor.
- x is the independent variable such as plant power or some process flow rate.

The cost categories use a decimal indexing account system. Table 1 presents the coefficients of the equations for costing the various components of the power plant. All costs are in December 1974 dollars.

Heat exchanger cost data were obtained from manufacturer sources for carbon-steel, shell-and-tube heat exchangers. These data were correlated by a nonlinear curve fit to heat exchanger area to obtain the following equation for estimating costs of the geothermal fluid/working fluid heat exchangers.

$$\text{Installed cost (\$)} = \sum_{i=1}^{N} \left[M_i (79.1398)(5000)^{0.77896} + 79.1398(A_i)^{0.77896} \right]$$

where:

- N = number of heat exchangers (3 for subcritical cycle, 1 for supercritical cycle).
- M_i = number of incremental heat exchanger areas of 5000 ft^2 in the i^{th} heat exchanger.
- A_i = remaining heat exchanger area of less than 5000 ft^2 in the i^{th} heat exchanger not accounted for by M_i.

The heat exchanger area requirements are calculated in subroutines SUBHEX and SUPHEX for subcritical and supercritical cycles respectively.

TABLE 1. Binary Power Plant Capital Cost Coefficients

Account Number	Component	a	b	s	Comments
1.0	Power Plant				
1.1	Piping, Insulation, Pumps and Tanks	160	6.5E-3	1	(2)
1.2	Crane	160	0.53	1	(1)
1.3	Turbo Generator	340	0.32	1	(2)
1.5	Vapor Generator Heat Exchangers				
1.7	Aux. Heat Exchanger	84	0.055	1	(2)
1.9	Misc. Support Equipment	0	4.4	0.85	(1)
1.10	Instrumentation and Controllers	120	3.8E-3	1	(2)
1.12	Electrical Support Equipment	4	18	0.92	(1)
1.16	Condenser and Desuperheater				
1.17	Installation Testing	5	3	1	(1)
1.18	Buildings, Structures, and Foundations	250	24	1	(1)
1.21	Reinjection Pump (Plant-Located)				
1.99	Total 1.0				
2.0	Heat Rejection System				
2.1	Wet Cooling Tower System	610	11	1	(1)
2.99	Total 2.0				
3.0	Switch Yard	6	96	0.52	(1)
3.99	Total 3.0				
5.0	Other Costs				
5.1	Engineering and Design	$C_{ED} = 0.1 \sum_{A=1.99}^{3.99} \text{cost}$			
5.2	Administration and Indirect Costs	$0.8\ C_{ED}$			
5.99	Total 5.0				

1. Use x = plant power (MWe)
2. Use x = working fluid flow rate (10^3 lb/hr)

PCONST (Contd) The same equation (with N=1) is used to estimate the installed cost ($) of the condenser and desuperheater. The heat exchanger area requirements of the condenser and desuperheater were summed to yield one overall heat exchanger area for use in the above equation. The heat exchanger areas are calculated in subroutine CNDNSR.

Pumping costs for reinjecting the spent geothermal fluid from the heat exchangers were correlated to the following equation.

$$\text{Installed cost (\$)} = 2.43\,[(\text{reinjection flow rate, lb/hr}) * (\text{nominal pumping pressure increase of } 50 \text{ psi})]^{0.568}$$

FACTHX Calculates a cost factor used to multiply heat exchanger, condenser, and desuperheater costs estimated from the heat exchanger area. The cost factor is applied when the shell-side pressure exceeds 100 psia or the tube-side pressure exceeds 200 psia.

VAL Called from subroutine PCONST to round the estimated capital costs of the power plant to the nearest thousands of dollars.

DATAK Prints the financial and tax input data for the power plant.

EXPENSE Calculates the power plant capital investment expenditure as a function of time over the number of years input for plant construction. The calculation is based on the following function.

$$C(t) = \frac{100}{\left[1 + e^{k(a-t)}\right]}$$

where:

C(t) is the cumulative percent expenditure at time t.
k is a constant, 0.0847.
a is the 50% expenditure point in time, currently set to the 60% point in the construction schedule.
t is the time in years.

Subroutine EXPENSE calculates the following costs appearing in the annual cash flow statement for the power plant: capital investment expenditure, plant operating costs, interim capital replacement, property taxes and insurance, and the sum of these costs with the energy cost from the reservoir. Annual plant operating cost is calculated as a function of plant size based on utility statistics.

$$\text{Operating cost (\$)} = 1455 * (\text{plant size in MWe})^{0.9}$$

Added to this cost is an annual maintenance cost, calculated as a function of plant capital cost.

$$\text{Maintenance cost (\$)} = 0.004 * (\text{plant capital cost})$$

Interim capital replacements are also calculated as a function of plant capital costs.

$$\text{Interim capital replacement (\$)} = [\text{input constant DINPUT(53), with default value } 0.0035] * (\text{plant capital cost})$$

Property taxes and insurance are calculated as a function of plant capital cost as well.

$$\text{Property tax (\$)} = [\text{input constant DINPUT(52), with default value } 0.0250] * (\text{plant capital cost})$$

$$\text{Property insurance (\$)} = [\text{input constant DINPUT(54), with default value } 0.0012] * (\text{plant capital cost})$$

Subroutine EXPENSE also calculates the power plant's annual net production of electricity in units of kilowatt-hours and millions of megawatt-hours, taking into account the power plant load factor or fraction of the annual time the power plant is operating at full capacity and the in-house consumption of electricity.

DPREC Calculates the annual depreciation of the power plant capital assets, including interim capital replacements. The input parameter LL2 selects one of two available options: the straight line method (LL2 = 1) or the sum-of-years-digits method (LL2 = 2).

COSTEG Calculates the unit cost of electricity from the power plant by setting the present worth of the revenues equal to the present worth of the expenses throughout the economic life of the power plant.

> Unit cost of electricity (mills/kW-hr) = (present worth of expenses - present worth of tax credits) / [(present worth of power production) * (1 - state gross revenue tax rate) * (1 - combined federal and state income tax rate)].

The present worth of power production takes into account the power plant load factor and the in-house consumption of electricity.

PAYOT Calculates the power plant's annual income statement and annual payout of investments. This includes the total power sales (gross revenues), total tax deductible expenses, taxable income (federal), state and federal income taxes, revenue taxes, and the changes in capitalization: outstanding bonds, bonds repaid, unrecovered equity, equity recovered, bond interest, and earnings on unrecovered equity.

OUTPLT Prints the statements of annual cash flow, tax deductible expenses, income and payout of investments from the beginning of power plant construction through its economic life. The statement of annual cash flow lists the items: year, power plant load factor, capital costs, energy costs from the reservoir, plant operating costs, interim capital replacements, property taxes and insurance, and the sum of these costs. The statement of annual tax deductible expenses lists the items: year, present worth factor for that year, operating expenses, bond interest, depreciation, total deductible operating expenses, and state income taxes. The statement of annual income lists the items: year, million megawatt-hours of electricity produced, power sales, revenue taxes, total tax deductible expenses, taxable income (federal), and federal income tax. The statement of payout of investments lists the items: year, net cash flow,

OUTPLT (Contd) outstanding bonds, equity capital not recovered, bond interest, earnings on unrecovered equity, bonds repaid, and recovery of equity.

CPOWER Calculates and prints the breakdown of the unit cost of electricity from the power plant in mills/kW-hr and equivalent annual costs in millions of dollars. These are itemized as follows: power plant capital costs, interim capital replacements, energy supply from the reservoir, operating expenses, property taxes and insurance, revenue taxes, state income taxes, federal income taxes, and bond interest. The difference between the unit cost for energy supply at the plant and the unit cost of energy from the reservoir calculated in subroutine COSTEQ is caused by the in-house consumption of electricity. In another set of calculations, the taxes and bond interest are reallocated to the direct cost components for the power plant: capital costs, interim capital replacements, energy supply, operating expenses, and property taxes and insurance.

2.8 STEAM TABLE FUNCTIONS

Tables 2 and 3 give the 1967 ASME Steam Table functions used to calculate thermodynamic and physical properties of water and steam, their arguments, and the temperature-pressure subregions in which they are applicable. The subregions are illustrated relative to the saturation line on the temperature-pressure diagram in Figure 14. Subregion 6 is the area just above and below the saturation line. When calculations of properties are needed near the critical point in subregion 5, the accuracy of the functions used should be checked against the individual requirements since the properties vary rapidly in this area. Definitions for the symbols used in Tables 2 and 3 follow.

p - Pressure, psia
t - Temperature, °F
h - Specific Enthalpy, Btu/lb
s - Specific Entropy, Btu/lb-F
v - Specific Volume, ft^3/lb

TABLE 2. ASME Steam Table Single Valued Functions

State Unknown
(either wet (two-phase) or superheated)

FORTRAN Code Name	Function	Subregion
HPS	h = f(p,s)	2, 3, 4
SPH	s = f(p,h)	2, 3
VPH	v = f(p,h)	2, 3
VPS	v = f(p,s)	2, 3, 4
TPH	t = f(p,h)	2, 3, 4
TPS	t = f(p,s)	2, 3, 4
THS	t = f(h,s)	2, 3, 4, 6
PHS	p = f(h,s)	2, 3, 4, 6
XPH	x = f(p,h)	
XPS	x = f(p,s)	

Saturation Line and Wet Steam

FORTRAN Code Name	Function	Subregion
HPSW	h = f(p,s)	6
SPHW	s = f(p,h)	6
VPHW	v = f(p,h)	6
VPSW	v = f(p,s)	6
TSL/TSATP	t = f(p)	Sat. Line
PHSW	p = f(h,s)	6
PSL/PSATT	p = f(t)	Sat. Line

Superheated Steam

HPSD	h = f(p,s)	2, 3, 4
HPTD	h = f(p,t)	2, 3, 4
SPHD	s = f(p,h)	2, 3, 4
SPTD	s = f(p,t)	2, 3, 4
VPHD	v = f(p,h)	2, 3, 4
VPSD	v = f(p,s)	2, 3, 4
VPTD	v = f(p,t)	2, 3, 4
TSUPH/TPHD	t = f(p,h)	2
TSUPS/TPSD	t = f(p,s)	2, 3, 4
THSD	t = f(h,s)	2, 3, 4
PHSD	p = f(h,s)	2, 3, 4
VISV	μ = f(p,t)	2, 3, 4
CONDV	k = f(p,t)	2, 3, 4
PRSTM	Pr = f(p,t)	2, 3, 4

Compressed Liquid

HPTL	h = f(p,t)	1, 3, 4
SPTL	s = f(p,t)	1, 3, 4
VPTL/VCL	v = f(p,t)	1, 3, 4
TPHL	t = f(p,h)	1, 4
TPSL	t = f(p,s)	1, 4
VISL	μ = f(p,t)	1, 2, 3, 4
CONDL	k = f(p,t)	1
PRLIQ	Pr = f(p,t)	1

Saturated Vapor

HGP	h = f(p)	Sat. Line
HGT	h = f(t)	Sat. Line
SGP	s = f(p)	Sat. Line
SGT	s = f(t)	Sat. Line
VGP	v = f(p)	Sat. Line
VGT	v = f(t)	Sat. Line
PSV	p = f(s)	Sat. Line

Saturated Liquid

TSLH	t = f(h)	Sat. Line
HFP	h = f(p)	Sat. Line
HFT/HSL	h = f(t)	Sat. Line
SFP	s = f(p)	Sat. Line
SFT/SSL	s = f(t)	Sat. Line
VFP	v = f(p)	Sat. Line
VFT/VSL	v = f(t)	Sat. Line

Some subroutines have been given two names separated by a / mark. When calling these subroutines, the names can be used interchangeably.

TABLE 3. ASME Steam Table Multiple Valued Functions

FORTRAN Code Name	Function	State
HSSISS	$h,t,v,x = f(p,s)$	Wet or Superheated Steam
HPSISS	$h,t,v,x = f(p,s)$	Superheated Steam
HSS	$h,s,v = f(p,t)$	Superheated Steam
HSV	$h,t,s,v = f(p)$	Saturated Vapor
HCL	$h,s = f(p,t)$	Compressed Liquid
HSSICL	$h,t = f(p,s)$	Compressed Liquid
SSSISS	$s,t,v,x = f(p,h)$	Wet or Superheated Steam
SPSISS	$s,t,v,x = f(p,h)$	Superheated Steam
SSICL	$s,t = f(p,h)$	Compressed Liquid
CRFLO	$fc, °S = f(p,h)$	Wet or Superheated Steam
CRVEL	$Vc, \gamma = f(p,h)$	Wet or Superheated Steam
Isentropic Drop Subroutines		
ZSDT	$h_1,s_1,x_1,v_1,t_2,x_2,v_2,h_2 = f(p_1,p_2,t_1)$	Wet or Superheated Steam
ZSDH	$t_1,s_1,x_1,v_1,t_2,x_2,v_2,h_2 = f(p_1,p_2,h_1)$	Wet or Superheated Steam
ZSRT	$h_1,s_1,t_2,h_2 = f(p_1,p_2,t_1)$	Compressed Liquid
ZSRH	$t_1,s_1,t_2,h_2 = f(p_1,p_2,h_1)$	Compressed Liquid

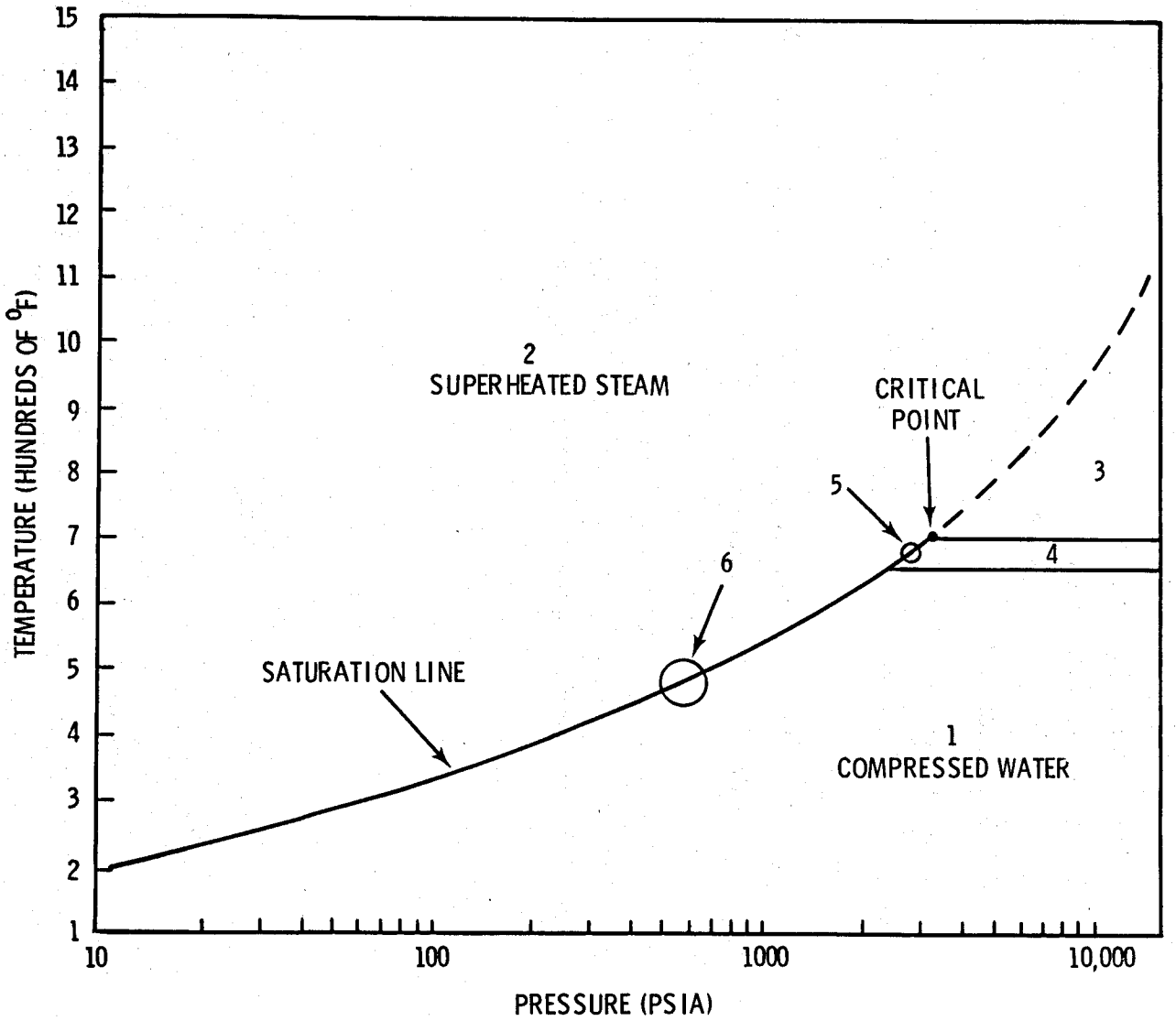


FIGURE 14. Steam Table Subregions as a Function of Temperature and Pressure

x - Quality by weight fraction, %/100

μ - Viscosity, lb/ft-sec

k - Thermal conductivity, Btu/hr-ft-F

Pr - Prandtl number

Vc - Critical velocity, ft/sec

Fc - Critical flow, lb/hr-in.^{2}

γ - Isentropic exponent (pv^{γ} = Constant)

°s - Degrees superheat

Many of the functions are interdependent. Consequently, if the use of a function is desired the majority of the steam table functions must be loaded into computer memory.

GEOCOST initially calls the following subroutines in the steam tables to initialize steam table constants appearing in labeled common using a series of data statements: CCSR1, CCSR2, CCSR3, CCBLL, and COMALL. These subroutines were converted from original BLOCK DATA subroutines in setting up the steam tables as a user library on the Cyber computer at Battelle-Northwest. The call statements cause the subroutines to be loaded into memory.

3. PREPARATION OF INPUT DATA

3.1 NAMELIST INPUT RULES

The first card required in the input data specifies a Hollerith title of 80 characters or less for identifying the simulation printout. The remainder of the data cards permit the user to override default values initialized for the input variables in the BLOCK DATA subroutine. These cards are input using the NAMELIST statement, which permits input of numerical values for variables and arrays preceded by the identifying variable or array names. No format specification is used. This section gives a brief description of the NAMELIST rules for the Cyber computer, which are applicable to most other machines with minor variations. The reader may wish to consult the FORTRAN manual available at his/her installation for a more detailed discussion. A sample case illustrating the NAMELIST input is given in the next section. The reader may find it helpful to refer to the sample input during the following discussion. The definitions of the NAMELIST input variables and their default values in GEOCOST are given following the sample input.

The NAMELIST input in GEOCOST begins in column 2 of the second data card with $GEOTHM, a NAMELIST group name separated by one or more spaces from the succeeding list of variables, array names, and their numerical values. Input variables and arrays may be defined in three ways.

- variable=constant,
- array name=constant,...,constant,
- array name(integer constant subscript)=constant,...,constant,

Commas separate each definition from succeeding definitions. Constants can be preceded by a repetition number and an asterisk, as for example, array name=3*1.0. This sets the first three locations in the array to the values 1.0. In defining arrays, the number of constants, including repetitions, given for an array name should not exceed the number of elements in the array. The number of elements in the GEOCOST arrays are given accompanying the definition of the input variables and their default values following the

sample input case. When data are input using the definition, array name (integer constant subscript)=constant,...,constant, the array elements are defined consecutively beginning with the location given by the integer constant subscript. The number of constants need not equal, but may not exceed, the remaining number of elements in the array.

Integer or real constants are converted to the type of the variable or array. All input variables in GEOCOST beginning with the letters I through N are integer. All other input variables, except STSEPR which is declared an integer variable in the program, are real.

The variables, array names, and their numerical values succeeding the $GEOTHM group name are read until another $ is encountered to complete the definition of the input data for the simulation case. Variables may be in any order. Blanks may be used freely to improve readability except between $ and GEOTHM, within array names and variable names, and within numerical values. More than one data card is usually needed to define the input data for a simulation case. The first column of each card is ignored and should not contain any data. All cards except the last must end with a constant followed by a comma. The last card must end with a $ sign.

Consecutive simulation cases can be set up in the input data. Each new simulation case requires the following cards: 1) a title card and 2) a $GEOTHM card and, when necessary, continuation cards defining the NAMELIST input variables to be changed from the preceding simulation case. The last card for each case must end with a $ sign. The input data for a simulation case may consist of any subset of the NAMELIST input variables. In setting up consecutive simulation cases in the input data, only the input variables with values differing from the preceding simulation case require redefinition. The values of variables and arrays not included in the input data for a particular simulation case remain unchanged from:

- The default values in BLOCK DATA for the first simulation case.
- The values from the preceding simulation case for cases after the first case.

If no values are to be changed from the default values in BLOCK DATA in the first simulation case, the input data consist of a title card followed by a card with $GEOTHM $ beginning in column two.

3.2 INPUT INSTRUCTIONS AND SAMPLE CASE INPUT

The data input to GEOCOST consists of the following two types of cards:

- A title card of 80 characters or less to identify the simulation printout.
- Data cards defining values for the input variables beginning in column two according to NAMELIST input rules.

The following steps are suggested for preparing the data input:

Step 1. Review the NAMELIST input rules summarized in the preceding section.

Step 2. Prepare a title card of 80 characters or less.

Step 3. Select values for the technical and economic input variables beginning in column two following the NAMELIST input rules. All input variables and their default values are defined in the next section. Those input variables not included in the list of variables in the data cards for a given case are left set to the default values. To aid the user, an overview of the key technical and economic input variables and default values is summarized in Table 4.

Three options are available in Step 3 for defining the thermodynamic cycle for the working fluid, through the input variables SUPER, PONEP, and WTFOUR. The working fluid is selected by setting the input variable NFLUID to an integer between 2 and 10 (see description of NFLUID on page 88).

Option 1. SUPER = .F., PONEP = 0., WTFOUR $\geq$ 0.

In this definition, the subcritical cycle is initially chosen to start the iterative process for selecting the final thermodynamic cycle. The variable PONEP for externally setting the turbine inlet pressure P1 is left set to its default value of 0. With the default value of PONEP, the turbine inlet pressure P1 is calculated iteratively in GEOCOST. The iteration for P1 converges when the absolute value of the difference between the calculated temperature

TABLE 4. Key Technical and Economic Input Variables and Default Values

Input Variable	FORTRAN Name	Default Value
Reservoir Characteristics and Well Properties		
Well Flow Rate	FLORAT	400,000 lb/hr
Wellhead Temperature	PWTEMP	200°C
Well Life	AVGWL	10 yr
Well Spacing	WELSPC	20 acres
Reservoir Financial and Tax Data		
Fraction of Initial Investment in Bonds	DINPUT(4)	0.42
Bond Interest Rate	DINPUT(5)	0.08
Equity Earning Rate After Taxes	DINPUT(6)	0.15
Federal Income Tax Rate	DINPUT(7)	0.48
State Income Tax Rate	DINPUT(15)	0.07
Property Tax Rate	DINPUT(17)	0.025
Power Plant Operating Life	DINPUT(26)	30 yr
Royalty Payment	DINPUT(27)	10%
Binary Power Plant		
Working Fluid	NFLUID	2 (Isobutane)
Thermodynamic Cycle	SUPER	.F. (Subcritical)
Variable to Externally Set Turbine Inlet Pressure P1	PONEP	0. (Internal Iteration for P1)
Variable to Externally Set Desired Temperature WT4 of Spent Geothermal Fluid from Heat Exchangers	WTFOUR	0. (Internal Step Function for WT4)
Minimum Allowable Subcritical Pinch Point	PINSUB	10°F
Minimum Allowable Supercritical Pinch Point	PINSUP	20°F
Heat Exchanger Approach	APPHX	30°F

Input Variable	FORTRAN Name	Default Value
Individual Well Drilling Costs		
Producing Well	DCPW	$400,000.
Nonproducing Well	DCNPW	$300,000.
Injection Well or Exploratory Well	DCINJW	$350,000.
Power Plant Financial and Tax Data		
Fraction of Initial Investment in Bonds	DINPUT(39)	0.59
Bond Interest Rate	DINPUT(40)	0.08
Equity Earning Rate After Taxes	DINPUT(41)	0.12
Federal Income Tax Rate	DINPUT(42)	0.48
Power Plant Capacity	DINPUT(43)	55 MWe
State Income Tax Rate	DINPUT(50)	0.07
Property Tax Rate	DINPUT(52)	0.025
Power Plant Operating Life	DINPUT(61)	30 yr
Power Plant Load Factor	PF	0.80

ESTWT4 and desired temperature WT4 of the spent geothermal fluid from the heat exchangers is less than 10°F. The iteration converges upon either a subcritical or supercritical cycle, depending upon the geothermal fluid inlet temperature, heat exchanger approach, heat exchanger pinch point, desired temperature of the spent geothermal fluid from the heat exchangers, and the calculated turbine inlet pressure (see Step 10, page 21).

There are two methods via the variable WTFOUR for obtaining a desired temperature WT4 for the spent geothermal fluid leaving the heat exchangers. If WTFOUR is left at its default value of 0, WT4 is set in subroutine BINARY using a step function based on the inlet geothermal fluid temperature WT1 (see description of WTFOUR on page 90). If WTFOUR is set greater than 0, WT4 is set equal to WTFOUR (°F). The minimum allowable pinch points (PINSUB and PINSUP) and the approach to the heat exchanger (APPHX) can be left either set to their default values or chosen by the user (Section 3.3.5).

Option 2. SUPER = .F., 0.< PONEP < critical pressure of the working fluid, WTFOUR = 0.

The subcritical cycle is selected for the working fluid. The turbine inlet pressure P1 is set through the variable PONEP. By setting PONEP greater than 0 and less than the critical pressure of the working fluid, the iteration for P1 is overridden and P1 is set to PONEP (psia). The variable WTFOUR is left at its default value of 0. The desired temperature WT4 for the spent geothermal fluid leaving the heat exchangers is not used in the calculation of the thermodynamic cycle state points. The actual temperature ESTWT4 of the spent geothermal fluid is calculated in subroutines BUTANE or FREON.

Option 3. SUPER = .T., PONEP = 0. or PONEP >critical pressure of the working fluid, WTFOUR = 0.

The supercritical cycle is selected for the working fluid. The turbine inlet pressure P1 is set through the variable PONEP. If PONEP is left at its default value of 0., P1 is set in subroutines BUTANE or FREON as the minimum of 1.5 times the critical pressure of the working fluid and 1000 psia. If PONEP is set greater than the critical pressure of the working fluid, P1 is set equal to PONEP (psia). The variable WTFOUR is left at its default value of 0. In the supercritical cycle, WT4 is the actual temperature of the spent geothermal

fluid leaving the heat exchanger. This temperature is initially set in subroutine BINARY using a step function based on the inlet geothermal fluid temperature WT1 (see description of WTFOUR on page 90). This value of WT4 is then increased or decreased in subroutine SUPHEX so that the calculated pinch point for the supercritical heat exchanger lies between the minimum and maximum allowable pinch points (see Step 14 for the supercritical heat exchanger, page 47).

To illustrate the input instructions, a sample case input is shown below for simulating the production of electricity using a 180°C, low salinity hydrothermal resource and 55 MWe power plant with a subcritical thermodynamic cycle based on isobutane as the working fluid.

Sample Case Input

```
Col.          ISOBUTANE SUBCRITICAL CYCLE FOR 55 MWE PLANT
2
$GEOTHM FLORAT=500000., PWTEMP=180., PRFACT=2., IAVWEL=1, FRCNPW=0., AVGWL=15.,
LL6=2, DINPUT(43)=55., NFLUID=2, SUPER=.F., PONEP=0., WTFOUR=180. $
```

The key technical and economic input conditions selected for defining the reservoir and power plant characteristics are as follows:

Average flow rate per well (FLORAT)	500,000 lb/hr
Temperature (PWTEMP)	180°C
Average well life (AVGWL)	15 yr
Average well spacing (WELSPC, default)	20 acres
Power plant capacity [DINPUT(43)]	55 MWe
Reservoir capacity [DINPUT(8), default]	275 MWe
Working fluid (NFLUID)	Isobutane
Thermodynamic cycle (SUPER)	Subcritical
Desired temperature of spent geothermal fluid leaving heat exchangers (WTFOUR)	180°F
Turbine inlet pressure (PONEP) (calculated iteratively in code)	0.
Minimum allowable subcritical pinch point (PINSUB, default)	10°F
Heat exchanger approach (APPHX, default)	30°F

The initial fluid (water) pressure from the wellhead is pressurized by a factor of 2 above saturation (PRFACT = 2). The pressurization is used to avoid two-phase flow due to fluid degradation during conduction to the plant. No two-phase

flow is allowed in the transmission pipelines. The pressurized fluid is pumped to the plant in a compressed liquid state. The pressurization factor PRFACT should be selected sufficiently large to ensure that the fluid pressure remains above saturation throughout the degradation process in the transmission to the plant. A value of 2 for PRFACT is generally a judicious choice. This value is then reduced by the code, as discussed in Section 2.3.

If the fluid pressure entering the transmission pipeline at the wellhead is low, the pressure degradation during conduction to the power plant can result in two-phase flow. This will cause an abnormal termination during the iterations between the binary power plant and fluid transmission submodels. In this event, the user should proceed as follows:

1) Obtain a full iteration history (LL6 = 2) of the binary power plant and fluid transmission submodels to analyze the problem.

2) Increase the wellhead pressurization factor PRFACT above its default value of 2 or increase EVALUE(1) above its default value of 0.02. Doubling PRFACT or EVALUE(1) is usually a judicious choice, although an additional increase may be necessary. Increasing PRFACT will increase the pressurization of the water above saturation at the wellhead. Increasing EVALUE(1) will result in larger internal pipe diameters and less pressure degradation in the pipeline.

The spent geothermal fluid is pressurized a nominal 50 psi above the exit pressure from the plant heat exchangers and pumped to the reinjection field (IJPUMP = 1, default).

The option to reduce the amount of recomputation in the fluid transmission submodel was selected in computing the geothermal fluid degradation on a nodal basis (IAVWEL = 1). This option takes advantage of the assumption that all reservoir wells have the same average conditions to speed up the execution time of the fluid transmission submodel.

The option to print only the final iteration between the binary power plant and fluid transmission submodels was selected (LL6 = 1). The default option to print the full economic output for the reservoir and power plant was used (LL11 = 1, LL12 = 1). All reservoir and power plant financial data and tax rates were left set at the default values defined in the next section.

3.3 DEFINITION OF NAMELIST INPUT VARIABLES AND DEFAULT VALUES

This section defines all NAMELIST input variables and default values for GEOCOST. The input variables are grouped into the following categories:

- Reservoir Characteristics and Well Properties
- Well Drilling Costs
- Fluid Composition
- Fluid Transmission and Disposal
- Binary Power Plant
- Reservoir Financial and Tax Data
- Power Plant Financial and Tax Data
- Reservoir Exploration, Development, and Operation
- Input and Output Options
- Miscellaneous Variables Used Only for Printout Information
  - Well Design and Stratigraphy
  - Noncondensible Gases

The variables in the categories Well Design and Stratigraphy, and Noncondensible Gases are used only for informative purposes in the printout. Well drilling costs are input directly rather than calculated internally as a function of well design and stratigraphy. Noncondensible gases are assumed to have no impact on the binary cycle in this version of GEOCOST.

3.3.1 Reservoir Characteristics and Well Properties

AVGWL Average production life (years) of reservoir wells. The default is 10 years.

FLORAT Flow rate (lb/hr) of the geothermal fluid from the reservoir wellhead. The default is 400,000 lb/hr/well.

FRCEPW Fraction of excess producing wells to provide spare wells. The default is 0.2.

FRCNPW Fraction of nonproducing (dry) wells. The default is 0.2.

PRDRAT Ratio of injection well to producing well flow rate. The default is 2.

PWTEMP Temperature of the geothermal fluid at the reservoir wellhead. Positive input values are treated as Centigrade and negative input values as Fahrenheit. The default is 200°C.

WELSPC Reservoir well spacing in acres. The default is 20 acres.

3.3.2 Well Drilling Costs

DCPW Total cost ($) of all tasks involved in drilling one producing well. The default is $400,000.

DCNPW Total cost ($) of all tasks involved in drilling one nonproducing well. The default is $300,000.

DCINJW Total cost ($) of all tasks involved in drilling either one exploratory well or one injection well. The default is $350,000.

PERCNT(N) N = 1,2 Fraction (not percentage) tangible and intangible parts respectively of the drilling costs for producing wells. The optional breakdown into tangible and intangible parts is provided because of possible differential tax treatment. The tangible part is capitalized and expensed through a depreciation account. The intangible part is expensed immediately. Nonproducing wells are expensed and injection wells are capitalized, with costs recovered through the depreciation account. The default values for the PERCNT array are as follows:

PERCNT(1) = 1/3 fraction tangible,

PERCNT(2) = 2/3 fraction intangible.

3.3.3 Fluid Composition

CACO3 Weight percentage of calcium carbonate in the geothermal fluid at the reservoir wellhead. The default is 0.

WPDS Weight percentage of salt in the geothermal fluid at the reservoir wellhead. The default is 3%.

ODS Weight percentage of dissolved solids, other than calcium carbonate, salt, and silicon dioxide, in the geothermal fluid at the reservoir wellhead. The default is 0.

PH The pH factor of the geothermal fluid at the reservoir wellhead. The default is 7, indicating a neutral solution.

3.3.4 Fluid Transmission and Disposal

CINLAB Cost of labor ($/ft) for installing pipe insulation in the fluid transmission system. The default is $4.50/ft.

EVALUE(1) Design parameter to change the internal diameters of all pipes in the fluid transmission system in order to alter the pressure degradation. The equations optimizing the internal pipe diameters are programmed in subroutine PIPE. Since EVALUE(1) occurs with an exponent of 0.163 in these equations, an increase (decrease) in EVALUE(1) by a factor of 2, for example, will increase (decrease) the internal pipe diameter by about 12%. EVALUE(1) is an estimate of the value of electrical energy ($/kW-hr). The default value of EVALUE (1) is 0.02.

IAVWEL Option to speed up the execution time required to calculate the fluid degradation on a nodal basis in the transmission system. This option eliminates redundant calculations in a uniform matrix of well nodes. The execution time for the transmission system can be reduced almost in half for large well fields. This option activates subroutine STORE, which saves and retrieves variables previously calculated to describe the characteristics of the pipe and fluid exiting well (nonmanifold) nodes. Assuming that all reservoir wells have the same average conditions (temperature, pressure, etc.), the characteristics of the pipe and fluid exiting each node in a set of well (nonmanifold) nodes that have the same number of active wells upstream are identical. Therefore, these characteristics need only be computed once for this set of nodes. This property is illustrated in Section 4.1 describing the sample case output. This option should not be used when inactive well sites are present in the well field matrix or when the wells have variable conditions.

0, calculate the fuild degradation individually for each well node.

1, calculate the fluid degradation individually only for those well nodes that have a different number of active wells upstream.

The default option requires more execution time by calculating the fluid degradation individually for each well node.

IJPUMP Option to pump the spent geothermal fluid from the plant heat exchangers to the injection field.
0 = gravity flow
1 = pump

The default uses pumping for reinjection. With gravity flow, the geothermal fluid from the plant heat exchangers is reinjected at pressure WP4 calculated as follows:

WP4 = WP1 - DELPHX

where:

WP1 = pressure of the geothermal fluid at the plant inlet from the fluid transmission submodel

DELPHX = pressure drop of the geothermal fluid across the heat exchangers, defined in the input data.

Pumping increases the pressure at the plant outlet by a nominal 50 psi. Both the capital cost and internal consumption of electricity of the pumps are calculated.

PLINJP Distance (m) from the power plant to the injection field. A pipe of this length is used to conduct the spent geothermal fluid from the heat exchangers to the origin of the injection field. The default distance is 1000 m.

PRFACT Wellhead pressurization factor ($\geq$ 1.) provided to set the wellhead pressure of the geothermal fluid at saturation or above. Subroutine DBINRY sets the wellhead pressure as follows:

Wellhead Pressure (psia) = PRFACT * (Pressure at saturation corresponding to the input wellhead temperature PWTEMP).

The default value of PRFACT is 2.

PSALVG Fraction of transmission or disposal pipe that can be salvaged from a depleted or plugged well and used with a replacement well. This quantity is used in calculating the transmission and disposal interim capital replacement rates, as discussed later in the definition of DINPUT(18) and DINPUT(20). The default value for PSALVG is 0.1.

3.3.5 Binary Power Plant

APPCON Approach (°F) to the condenser. The minimum working fluid temperature T2SATL at the condenser outlet is set in subroutine LOAD based on the cooling water temperature CWT1 at the condenser inlet and the approach to the condenser:

T2SATL = CWT1 + APPCON

The default values are as follows:

APPCON = 30°F

CWT1 = 62°F

This yields a default value of 92°F for T2SATL.

APPCT — Approach (°F) to the cooling tower. The exit temperature CWT1 from the cooling tower is set in subroutine LOAD based on the approach to the cooling tower and the inlet air wet bulb temperature WBAT:

CWT1 = WBAT + APPCT

The default values are as follows:

APPCT = 12°F

WBAT = 50°F

This yields a default value of 62°F for CWT1. The variable CWT1 also represents the cooling water temperature entering the hydrogen cooler, turbine oil cooler, and condenser. The cooling tower is simulated in subroutine TOWER with the requirement that the approach be at least 8°F.

APPHX — Approach (°F) to the heat exchanger. The working fluid temperature T1 at the turbine inlet is set in subroutine BINARY based on the inlet geothermal fluid temperature WT1 transmitted by the fluid transmission submodel to the heat exchanger and the approach to the heat exchanger:

T1 = WT1 - APPHX

The default value of APPHX is 30°F.

B — Barometric pressure (in. of Hg), used in calculating the performance of the cooling tower. The default is 29.92 in. of Hg.

DBAT — Dry bulb air temperature (°F), used in calculating the performance of the cooling tower. The default is 70°F.

DELPHX — Tube-side or geothermal fluid pressure drop (psia) across the heat exchangers. The default value of DELPHX is 75 psia. In the three heat exchangers for the subcritical cycle, the pressure drop is set equally across each heat exchanger to DELPHX/3. The geothermal fluid pressure at each heat exchanger outlet is set in subroutine BINARY for the subcritical cycle as follows:

DELPHX (Contd)

WP2 = WP1 - DELPHX/3

WP3 = WP1 - 2*DELPHX/3

WP4 = WP1 - DELPHX

where:

WP1 = geothermal fluid pressure at the superheater inlet, transmitted by the fluid transmission submodel

WP2 = geothermal fluid pressure at the superheater outlet

WP3 = geothermal fluid pressure at the vaporizer outlet

WP4 = geothermal fluid pressure at the preheater outlet

The geothermal fluid pressure WP4 at the heat exchanger outlet for the supercritical cycle is:

WP4 = WP1 - DELPHX

DIAC, DIAOC — Inner and outer tube diameters (ft) of the condenser and desuperheater. The default values are:

DIAC = 0.075 ft

DIAOC = 0.0833 ft

DIAL, DIAOL — Inner and outer tube diameters (ft) of the preheater. The default values are:

DIAL = 0.1 ft

DIAOL = 0.1104 ft

DIAV, DIAOV — Inner and outer tube diameters (ft) of the vaporizer. The default values are:

DIAV = 0.1 ft

DIAOV = 0.1104 ft

DIAS, DIAOS — Inner and outer tube diameters (ft) of the superheater. The default values are:

DIAS = 0.1 ft

DIAOS = 0.1104 ft

DIASC, DIAOSC — Inner and outer tube diameters (ft) of the supercritical heat exchanger. The default values are:

DIASC = 0.1 ft

DIAOSC = 0.1104 ft

FOULFI, FOULFO — Inside and outside fouling factors for the heat exchangers, desuperheater, and condenser. These factors reduce the overall heat transfer coefficient in subroutine OHTCOE to allow for the accumulation of corrosion deposits on the inside or tube-side and outside or shell-side heat transfer surfaces. The default values are:

FOULFI = 0.001 hr-ft^2-°F/Btu

FOULFO = 0.001 hr-ft^2-°F/Btu

IPLANT — Power plant type. This variable should be left preset to its default value of 1, which specifies a binary power plant.

NFLUID — Index for selecting the working fluid in the binary fluid cycle. The working fluids selected by the values of NFLUID are:

1 = water
2 = isobutane
3 = n-butane
4 = R-11
5 = R-12
6 = R-21
7 = R-22
8 = R-113
9 = R-114
10 = ammonia

PINSUB — Minimum allowable temperature difference (pinch point, °F) between the geothermal fluid and working fluid in the subcritical heat exchangers. The pinch point occurs at the preheater outlet for the subcritical cycle. The default is 10°F for all working fluids.

PINSUP — Minimum allowable temperature difference (pinch point, °F) between the geothermal fluid and working fluid in the supercritical heat exchanger. The default is 20°F for all working fluids.

PONEP — Option to set the pressure P1 (psia) of the working fluid at the turbine inlet. The default value of PONEP is 0. With the default value, the turbine inlet pressure P1 is calculated iteratively in subroutines BUTANE or FREON. The iteration for P1 converges when the absolute value of the difference between

PONEP (Contd) the calculated temperature ESTWT4 and desired temperature WT4 of the geothermal fluid at the preheater outlet is less than 10°F in subroutine PONE. The final thermodynamic cycle selected by subroutines BUTANE or FREON may be either subcritical or supercritical (see Step 10, page 22). If PONEP is greater than 0 in the input data, the iteration for P1 is overridden and P1 is set to -PONEP in subroutines BUTANE or FREON. If PONEP is less than the critical pressure of the selected working fluid, the subcritical cycle should be selected by setting SUPER = .F. in the input data. If PONEP is greater than the critical pressure, the supercritical cycle should be selected by setting SUPER = .T. in the input data.

PVELC Velocity of the cooling water in the condenser and desuperheater tubes. The default is 28,800 ft/hr.

RANGE Cooling water range (°F) between the condenser inlet and desuperheater outlet temperatures. The cooling water outlet temperature CWT2 from the desuperheater is set in subroutine LOAD based on the inlet temperature CWT1 to the condenser and the range between the condenser inlet and desuperheater outlet temperatures:

CWT2 = CWT1 + RANGE

The default values are:

RANGE = 25°F

CWT1 = 62°F

This yields a default value of 87°F for CWT2.

RI Humidity ratio from the psychrometric chart, used in calculating the performance of the cooling tower. The default is 0.2.

SUPER Logical variable for selecting the thermodynamic cycle.

.T. = supercritical cycle

.F. = subcritical cycle

If SUPER is set to .F. and PONEP to 0, the final thermodynamic cycle selected in the iterative calculation for the turbine inlet pressure P1 may be subcritical or supercritical (see option 1 in Section 3.2). The default is the subcritical cycle.

WBAT — Wet bulb air temperature (°F), used in calculating the performance of the cooling tower. The default is 50°F.

WTFOUR — Option (°F) to override the temperature WT4 specified in subroutine BINARY for the spent geothermal fluid from the heat exchangers. The default value of WTFOUR is 0. With the default value, temperature WT4 is defined using a step function in subroutine BINARY based on the inlet geothermal fluid temperature WT1 delivered to the heat exchangers by the fluid transmission submodel:

$$WT4 = \begin{cases} 210°F & \text{if } WT1 \geq 350°F \\ 190°F & \text{if } 350°F > WT1 > 250°F \\ 170°F & \text{if } WT1 \leq 250°F \end{cases}$$

If WTFOUR is greater than 0 in the input data, the step function is overridden and WT4 is set equal to WTFOUR in subroutine BINARY. In the supercritical cycle, WT4 may be adjusted up or down in subroutine SUPHEX, simulating the supercritical heat exchanger (see Step 14, page 47).

WVELL — Velocity of the geothermal fluid (ft/hr) in the preheater tubes. The default is 28,800 ft/hr.

WVELV — Velocity of the geothermal fluid (ft/hr) in the vaporizer tubes. The default is 28,800 ft/hr.

WVELS — Velocity of the geothermal fluid (ft/hr) in the superheater tubes. The default is 28,800 ft/hr.

WVELSC — Velocity of the geothermal fluid (ft/hr) in the supercritical heat exchanger tubes. The default is 28,800 ft/hr.

3.3.6 Reservoir Financial and Tax Data

DINPUT(N), N = 1, ... , 35 is the array of financial and tax data for the reservoir defined below.

N	Description of Reservoir Parameters
1	Reservoir capital investment (millions of dollars), which is not input directly but calculated in subroutine RESVOR as the following sum: capitalized reservoir exploration costs + tangible part of drilling costs for producing wells + drilling cost of injection wells + capital cost of fluid transmission system + capital cost of fluid disposal system.
2	Project life (years) of reservoir and power plant together, which is not input directly but calculated in subroutine RESVOR as the following sum: number of years from the beginning of reservoir exploration to the startup of power plant operation + number of operating years of the power plant, defined in DINPUT(26).
3	Not used; default is 0.
4	Fraction of initial investment in bonds; default is 0.42.
5	Bond interest rate; default is 0.08.
6	Earning rate on equity after taxes; default is 0.15.
7	Federal income tax rate; default is 0.48.
8	Reservoir power level (MWe); default is 275 MWe.
9	Depreciable life of reservoir wells (years); default is 10 yr. This is automatically set equal to the average reservoir well life (AVGWL) in subroutine LOAD.
10-13	Not used; default is 0.
14	Startup year for operation of the power plant; default is 1980.
15	State income tax rate; default is 0.07.
16	State gross revenue tax rate; default is 0.

17 Property tax rate; default is 0.025.

18 Transmission system interim capital replacement rate, fraction of transmission capital cost. This rate is not input directly, but calculated in subroutine TRANS as (1. - PSALVG)/AVGWL, where PSALVG, input through NAMELIST, is the fraction of transmission pipe that can be salvaged, and AVGWL, input through NAMELIST, is the average reservoir well life (years).

19 Property insurance rate; default is 0.0012.

20 Disposal system interim capital replacement rate, fraction of disposal capital cost and cost of drilling injection wells. This rate is not input directly, but set equal to the transmission system interim capital replacement rate calculated in subroutine TRANS.

21-25 Not used; default values are 0.

26 Power plant operating life (years); default is 30 years.

27 Royalty payments, percentage of reservoir annual power sales; default is 10%.

28 Transmission system maintenance rate, fraction of transmission capital cost; default is 0.05.

29 Disposal system maintenance rate, fraction of disposal capital cost; default is 0.05.

30-35 Not used; default values are 0.

3.3.7 Power Plant Financial and Tax Data

DINPUT(N), N = 36, ... , 70 is the array of financial and tax data for the power plant defined below.

N	Description of Power Plant Parameters
36	Power plant capital investment (millions of dollars), which is not input directly, but calculated in subroutine PCONST.

37 Project life (years) of power plant, which is not input directly but calculated in subroutine PWRPLT as follows: number of years of power plant construction, input through NAMELIST as NYC, + number of operating years of the power plant, defined in DINPUT(61).

38 Not used; default is 0.

39 Fraction of initial investment in bonds; default is 0.59.

40 Bond interest rate; default is 0.08.

41 Earning rate on equity after taxes; default is 0.12.

42 Federal income tax rate; default is 0.48.

43 Power plant power level (MWe); default is 55 MWe.

44 Depreciable life of power plant (years); default is 30 yr.

45-48 Not used; default is 0.

49 Start-up year for operation of the power plant; default is 1980.

50 State income tax rate; default is 0.07.

51 State gross revenue tax rate; default is 0.04.

52 Property tax rate, fraction of power plant capital investment; default is 0.025.

53 Interim capital replacement rate, fraction of power plant capital investment; default is 0.0035.

54 Property insurance rate, fraction of power plant capital investment; default is 0.0012.

55-60 Not used; default is 0.

61 Power plant operating life (years); default is 30 yr.

62-70 Not used; default is 0.

NYC Number of years to construct the power plant. The default is 3 yr.

LL2 Depreciation option for recovering the reservoir and power plant capital costs, including interim capital replacements.

1 = straight line

2 = sum-of-years-digits

Default is sum-of-years-digits.

PF Power plant load factor or fraction of the annual time the power plant is operating at full capacity. The default is 0.80.

3.3.8 Reservoir Exploration, Development, and Operation

ACRES Size (acres) of each prospective geothermal site leased for reservoir exploration. This quantity is multiplied by the input unit costs per acre associated with lease procurement (UNITO(N), N = 6, 7, 8 in Tables 5A and 5B) to calculate the lease cost per site. Appendix A contains the cost equations for lease procurement. The default value is 15000 acres.

LAGS (ITEX(N), K), ITEX(N) = 1, ..., 22; K = 1, 2 - Time array to schedule the tasks defining reservoir exploration, development, and operation in Tables 5A and 5B according to costs and the time the tasks are to take place. An internal array in subroutine RESVOR, ITEX(N), N = 1, ..., 39, currently subdivides the 39 tasks in Tables 5A and 5B into 22 subgroups of tasks as shown in Table 6. All tasks within a given subgroup are presumed to occur parallel in time. However, the user has the flexibility to schedule the different subgroups of tasks either sequentially or parallel in time.

The starting month and duration in months ($\geq$1) for each set of tasks grouped together are defined by means of the input time array LAGS(ITEX(N), 1) and LAGS(ITEX(N), 2) respectively, indexed by the array ITEX. The starting month for each subgroup of tasks is defined relative to the first task, which is given the base value 0. The starting date for the first task, defining the beginning of reservoir exploration, is back calculated by subroutine RESVOR from the starting date input for the operation of the power plant. GEOCOST schedules the starting date for the operation of the power plant in January of the year defined in NAMELIST by DINPUT(14). The default value is January, 1980. The back calculation ensures the

TABLE 5A. Tasks and Input Costs for Reservoir Exploration, Development, and Operation

Index for Itemizing Individual Tasks	Index for Grouping Tasks	Description of Grouped Tasks	Unit Costs (Dollars) for[a] Individual Tasks
N	IGP = GROUP(N)	RESERVOIR EXPLORATION TASKS	UNITO(N)
		Identification of Targets	
1	1	Literature Search	100./site
2	2	Preliminary Land Check	250./site
		Preliminary Reconnaissance	
3	3	Literature Search	700./site
4	4	Geological Reconnaissance	1000./site
5	5	Detailed Land Check	1200./site
		Detailed Reconnaissance	
6, 7, 8[b]	6	Lease Procurement	1./acre, 1./acre/year, 2./acre
9	7	Field Geology	5000./site
10	8	Geochemical Examination	5000./site
11, 12[b]	9	Geophysical Examination	4500., 5500./site
		Identification of Drillable Sites	
13	10	Heat Flow Wells (4 per site)	3000./well
14	11	Temperature Gradient Wells (10 per site)	1250./well
15	12	Electrical Resistivity	3500./well
16	13	Microseismic	5000./site
17	14	Detailed Geochemistry	7500./site
		Exploration Drilling	
18, 19, 20, 21[c]	15	Well Drilling	DCINJW/well
22	16	Well Testing	10000./site
		FIELD DEVELOPMENT TASKS	UNITO(N)
23, 24[c]	17	Production Well Drilling	DCPW/well
25[c]	18	Nonproduction Well Drilling	DCNPW/well
26, 27[c]	19	Injection Well Drilling	DCINJW/well
28	20	Transmission System	1.

TABLE 5A. (contd)

Index for Itemizing Individual Tasks	Index for Grouping Tasks	Description of Grouped Tasks	Unit Costs (Dollars) for(a) Individual Tasks
N	IGP = GROUP(N)		
29	21	Disposal System	1.
		FIELD OPERATION TASKS	
30	22	Replacement Well Drilling	1.
31	23	Nonproduction Well Drilling	0.2
32	24	Abandonment	10000./abandoned well
33	25	Well Maintenance	1000./production or injection well
34	26	Overhead and Management	Computed -- Ref. Appendix
35	27	Well Redrilling	5000./production well
36	28	Injection	0.
37	29	Injection Well Maintenance	0.
38	30	Transmission System Maintenance	Computed -- Ref. Appendix
39	31	Disposal System Maintenance	Computed -- Ref. Appendix

(a) NAMELIST input array -- default values.
(b) Tasks done at the same time that were consolidated into one aggregate task as follows:

Lease Procurement
6) Bonus payment to leaseholder
7) Annual payment to leaseholder
8) Administrative procurement cost

Geophysical Examination
11) Gravity survey
12) Seismic noise

(c) Drilling tasks were also consolidated into aggregate tasks, costed in this version of GEOCOST by means of the following input variables in NAMELIST defining drilling costs for each type of well:

Exploratory Well Drilling
18), 19), 20), 21) DCINJW with default value $350,000./well

Production Well Drilling
23), 24) DCPW with default value $400,000./well

Nonproduction Well Drilling
25) DCNPW with default value $300,000./well

Injection Well Drilling
26), 27) DCINJW with default value $350,000./well

TABLE 5B. Tasks, Input Times and Success Ratios for Reservoir Exploration, Development, and Operation

Index for Itemizing Individual Tasks	Index for Grouping Tasks	Index for Time Grouping	Start Month Relative to N=1[a]	Duration in Months[a]	Index for Decision Grouping	Success Ratio[a]	Number of Favorable Sites
N	IGP=GROUP(N)	ITEX(N)	LAGS[ITEX(N),1]	LAGS[ITEX(N),2]	NTARG(N)	FTF[NTARG(N)-1]	FAVSIT(IGP)
1	1	1	0	6	1		128
2	2						
3	3	2	1	7	2	0.5	64
4	4						
5	5						
6,7,8	6	3,3,3	2	11	3	0.5	32
9	7	4	4	10	4	0.67	21
10	8						
11,12	9						
13	10	5	11	24	5	0.75	16
14	11						
15	12						
16	13						
17	14						
18,19,20,21	15	6,6,6,6	23	24	6	0.25	4
22	16	7	47	1			
23,24	17	8,8	47	42	7	0.25	1
25	18	9	47	42			
26,27	19	10,10	89	27			
28	20	11	89	27			
29	21	12	89	27			
30	22	13	116	348			
31	23	14	116	348			
32	24	15	116	360	7	0.25	1
33	25	16	116	360			
34	26	17	116	360			
35	27	18	116	360			
36	28	19	116	360			
37	29	20	116	360			
38	30	21	116	360			
39	31	22	116	360			

(a) NAMELIST input arrays -- default values.

last task in the reservoir exploration and development ends in the month prior to the starting date input for the operation of the power plant. With the default values, this date is December, 1979.

The default values shown for the starting months for all tasks included in reservoir operation are defined relative to the first task in reservoir exploration so as to coincide with the startup date input for the operation of the power plant. However, regardless of the starting months specified for the tasks in the reservoir operation, subroutine RESVOR schedules the starting months to coincide with the startup date input for the operation of the power plant. Similarly, regardless of the duration in months specified for the tasks in the reservoir operation, subroutine RESVOR schedules the duration based upon the operating life of the power plant. Table 6 lists the subgrouping of the tasks presumed to occur parallel in time by the array ITEX and the default values of the array LAGS.

TABLE 6. Subgrouping of Reservoir Tasks Occurring Parallel in Time

	Reservoir Exploration																					
Task N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
ITEX(N)	1	1	2	→		3	→		4	→			5	→				6	→			7
LAGS[ITEX(N), 1]	0		1			2			4				11					23				47
LAGS[ITEX(N), 2]	6		7			11			10				24					24				1

	Reservoir Development						
Task N	23	24	25	26	27	28	29
ITEX(N)	8	8	9	10	10	11	12
LAGS[ITEX(N), 1]	47	47	89		89	89	
LAGS[ITEX(N), 2]	42	42	27		27	27	

	Reservoir Operation									
Task N	30	31	32	33	34	35	36	37	38	39
ITEX(N)	13	14	15	16	17	18	19	20	21	22
LAGS[ITEX(N), 1]	116	116	116	116	116	116	116	116	116	116
LAGS[ITEX(N), 2]	348	348	360	360	360	360	360	360	360	360

The time sequences of the tasks corresponding to the default values of the LAGS array and default power plant startup date of January, 1980 are delineated in the bar graph of Figure 15. A discussion of the use of these arrays in subroutine RESVOR is in the appendix.

UNITO(N), N = 1, ..., 39 - Cost array defining costs (dollars) for the tasks in the exploration, development, and operation of the reservoir on a unit basis, primarily per target site, acre, or well, based upon industry estimates. The total cost associated with each task is calculated in subroutine RESVOR by multiplying the appropriate unit cost in the UNITO array by the number of favorable target sites, acres, or wells calculated by GEOCOST for that task. The cost equations based on the UNITO array are given in Appendix A. The default values for the UNITO array are shown for each of the reservoir tasks in Table 5A.

FTF[NTARG(N) - 1], NTARG(N) = 1, ..., 7 - Success ratios, indexed by the array NTARG(N), associated with the major decision points in the step-by-step process of reducing the number of prospective reservoir sites. The process converges on one site for development and operation. An internal variable NUMFTF in subroutine RESVOR currently sets the number of major decision points in the reservoir exploration process to six. An internal array, NTARG(N), N=1,...,39, subdivides the 39 tasks in Table 5B into 7 series of tasks (one more than the number of decision points) according to the major decision points. Appendix A has a description of the calculation by GEOCOST of the initial number of target sites to identify for exploration and number of sites to retain at each decision point for further exploration based upon the success ratios FTF[NTARG(N) -1). Table 7A shows the subgrouping of the tasks by the array NTARG, the corresponding decision points and the default values of the array FTF. Table 7B describes the decision points.

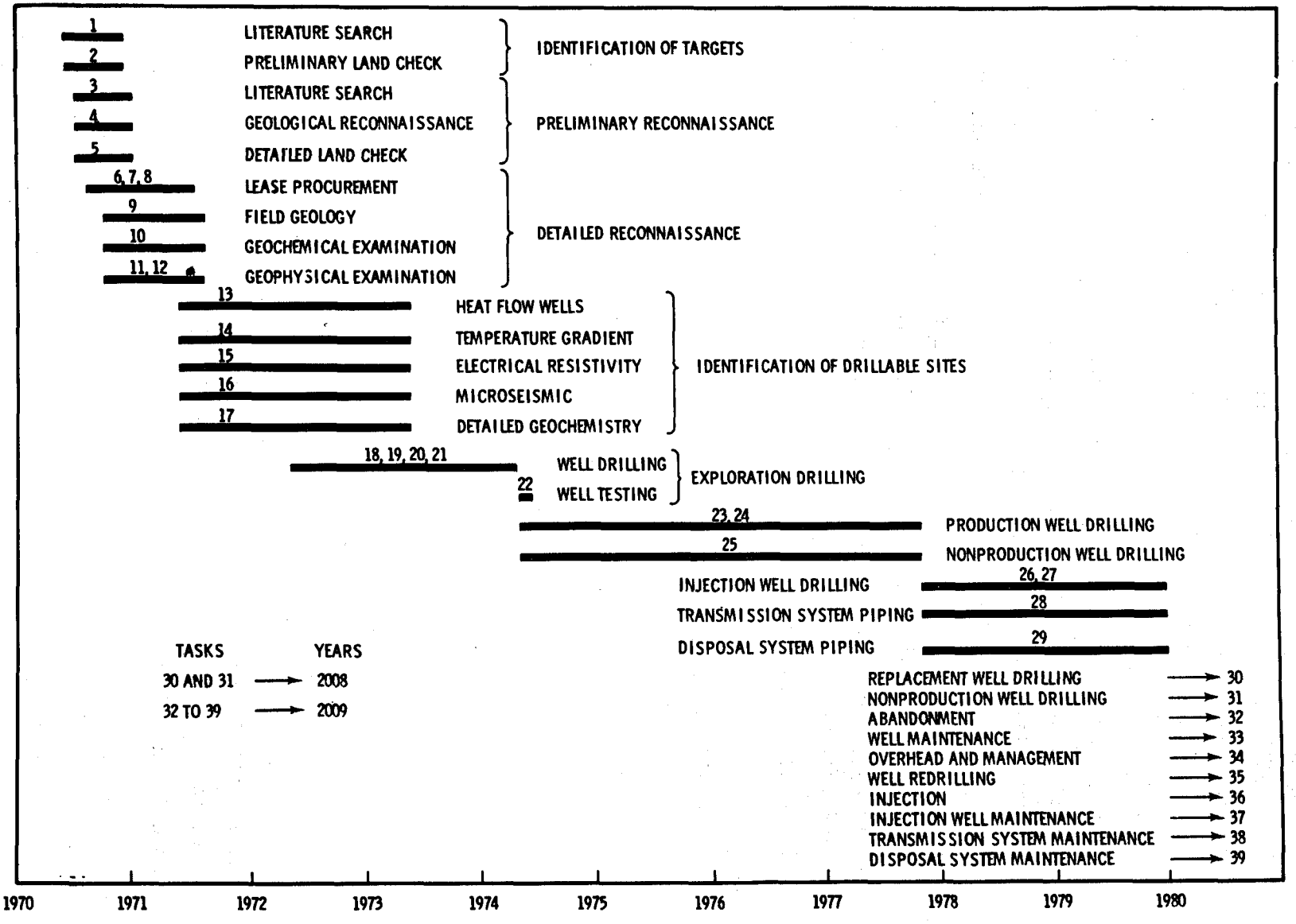


FIGURE 15. Default Time Sequence of Reservoir Exploration, Development, and Operation Tasks

TABLE 7A. Subgrouping of Reservoir Tasks by Decision Points

Task N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
NTARG(N)	1	1	2→			3→			4→				5→				
NTARG(N)-1= Decision Point					1			2				3					4
FTF[NTARG(N)-1]					0.5			0.5				0.67					0.75

Task N	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
NTARG(N)	6→					7→																
NTARG(N)-1= Decision Point					5																	6
FTF[NTARG(N)-1]					0.25																	0.25

TABLE 7B. Description of Decision Points

Decision Point	Description
1	Fraction of sites to retain for preliminary reconnaissance after identification of target sites
2	Fraction of sites to lease after preliminary reconnaissance
3	Fraction of leased sites to retain for detailed reconnaissance
4	Fraction of sites to evaluate for subsequent exploratory drilling
5	Fraction of sites to retain for exploratory drilling
6	Fraction of sites to develop and operate

3.3.9 Input and Output Options

ICASE Input option to generate consecutive cases automatically in subroutine GCASE as combinations of multiple input values for each of the parameters: wellhead temperature (°C), wellhead flow rate (lb/hr), power plant size (MWe), well spacing (acres), and well life (years). This option is provided to reduce the number of title and NAMELIST input cards to prepare when the different cases

represent a large number of combinations of values for the above parameters. Use of this input option requires additional data cards following the NAMELIST input cards. These cards are defined following the description of the NAMELIST input variables.

0 = no case generation
1 = case generation

The default is no case generation.

LL6 Print switch for selecting the power plant and fluid transmission iteration history, essentially comprising the technical, as opposed to economic, output from GEOCOST.

0, suppresses printout of the iterations
1, prints only the last iteration upon convergence
2, prints all iterations

Default suppresses all iteration printout.

LL11, LL12 Print switches for selecting the reservoir and power plant economic printout.

LL11 = 1, LL12 = 1, prints all economic output
LL11 = 1, LL12 = 0, prints an economic summary of the reservoir and power plant, including the breakdown of power costs from the reservoir and power plant, but excluding the statements of annual cash flow, tax deductible expenses, income, and payout of investments.
LL11 = 0, LL12 = 0, suppresses all economic output.

Default is full economic printout.

3.3.10 Miscellaneous Variables Used Only for Printout Information

3.3.10.1 Well Design and Stratigraphy

CASFRC Fraction of each producing well cased. The default cases the entire well depth.

DIA — Average diameter (centimeters if positive, inches if negative) of the reservoir wells to be drilled. The default is 22.225 centimeters.

NUMTYP — Number of different generic types of rock hardness comprising the strata encountered in drilling the entire depth of each reservoir well. The variable NUMTYP should be left preset to its default value of 1, indicating one hardness for the entire depth of the well.

STRATA(M,N) — M = 1,2; N = 1,.... 10. Stratigraphic data array defining the type of rock hardness to be drilled (M = 1) and the depth (M = 2, positive if meters, negative if feet) of each type of strata (N) encountered in drilling the reservoir wells. The possible values of STRATA(1,N) are:

1 = soil, 2 = soft, 3 = medium, 4 = hard, and 5 = very hard.

The default values are as follows:

STRATA(1,1) = 4, indicating that the rock type to drill is hard for the entire depth of the well.

STRATA(2,1) = 2000., total well depth in meters.

3.3.10.2 Noncondensible Gases

WPH2S — Weight percentage of hydrogen sulphide in the geothermal fluid at the reservoir wellhead. The default is 0.003%.

WPCO2 — Weight percentage of carbon dioxide in the geothermal fluid at the reservoir wellhead. The default is 0.097%.

WPCH4 — Weight percentage of methane in the geothermal fluid at the reservoir wellhead. The default is 0.

WPONCG — Weight percentage of noncondensible gases other than hydrogen sulphide, carbon dioxide, and methane in the geothermal fluid at the reservoir wellhead. The default is 0.

TOTNCG — The total weight percentage of noncondensible gases is calculated in subroutine LOAD as the following sum of noncondensible gases:

TOTNCG = WPH2S + WPCO2 + WPCH4 + WPONCG.

The default value of TOTNCG is 0.1%.

3.4 CONSECUTIVE CASE GENERATION INPUT OPTION

As discussed in the NAMELIST input rules, consecutive simulation cases can be set up using NAMELIST input. Each new case requires the following cards: 1) a title card and 2) a $GEOTHM card and, when necessary, continuation cards defining the NAMELIST input variables to be changed from the preceding simulation case. The last card for each case ends with a $ sign. As an alternative option defined by setting ICASE = 1 in the NAMELIST input, consecutive cases can be generated automatically in GEOCOST as combinations of key case generation variables. An array of numerical values is input for each of the case generation variables. GEOCOST then generates consecutive simulation cases as combinations of these values from the input arrays for the case generation variables. This reduces the number of title and NAMELIST cards that the user must prepare. Use of the case generation option requires the following set of cards.

- Title card
- NAMELIST input cards beginning in column 2 with $GEOTHM on the first NAMELIST input card
- Case generation cards, prepared according to the appropriate format specifications, which provide the following information:
  - Index of the starting element in an array of numerical values for each case generation variable to use in generating combinations (one card with format 5I1)
  - Size of the array for each case generation variable (one card with format 5I1)
  - Hollerith titles identifying the array of numerical values for each case generation variable (one card for each variable with format 8A10)
  - Array of numerical values for each case generation variable (one card for each variable with format 8F10.0)

All case generation variables are omitted from the NAMELIST input cards since they are defined using the case generation cards. Five items frequently varied in parametric studies comprise the case generation variables. The variables in order of definition on the case generation cards are:

1) Wellhead Temperature (°C)
2) Average Flow Rate per Well (lb/hr)
3) Power Plant Capacity (MWe)
4) Average Well Spacing (acres)
5) Average Well Life (years)

This order of definition must be retained throughout the case generation cards. Other items could be selected as case generation variables with minor modifications of the code in subroutine GCASE.

To illustrate the case generation input, the sample case previously illustrated using NAMELIST input is shown below using the case generation input option.

Sample Case Input Using Case Generation Input Option

```
                    Cols.
                    12345678910
Title Card          SAMPLE
NAMELIST            $GEOTHM  PRFACT=2., IAVWEL=1, FRCNPW=0., AVGWL=15.,
Cards               LL6=2, NFLUID=2, SUPER=.F., PONEP=0.,  WTFOUR=180.,
                    ICASE=1 $
Starters            11211
Array Sizes         31311
Titles              TEMP=180C TEMP=190C TEMP=200C
                    FLOW=500K
                    MWE = 55 MWE = 75 MWE = 110
                    WACRES=20
                    WLIFE = 15
Numerical           180.      190.     200.
Arrays              500000.
                    55.       75.      110.
                    20.
                    15.
```

With the case generation option, the title card preceding the NAMELIST input should be limited to descriptive Hollerith information in the first 10 columns. The remainder of the title appearing in the simulation printout is set up in GEOCOST as appropriate combinations of the titles in the case generation cards.

The first card following the NAMELIST data specifies the first position in each array of values to be used in setting up the parametric combinations of case generation variables. In most situations, the user will want to specify that the parametric combinations be set up starting with the first element in each array (11111). However, to show the flexibility of the case generation option, the sample case specifies that the combinations be set up starting with the first elements of the 1st, 2nd, 4th and 5th arrays and the second element of the third array (11211). With these starting values, the first parametric combination will be as follows:

Wellhead Temperature	180°C
Average Flow Rate per Well	500,000 lb/hr
Power Plant Capacity	75 MWe
Average Well Spacing	20 acres
Average Well Life	15 year

The first element in the power plant capacity array will not appear in any case combination since the starting element is the 2nd value in the array.

The second card defines the size of the array of numerical values for each case generation variable (31311).

The next set of five cards, one card per variable, lists titles to associate with the different values for each case generation variable. The titles on these cards are used in GEOCOST to set up the remaining title after the first 10 columns in the main title card to identify the simulation cases generated from the combination of values for the case generation variables.

The final set of five cards, one card per variable, defines the array of multiple input values for each case generation variable used in generating parametric combinations. In generating case combinations, the last case

generation variable (average well life) is varied most rapidly over its range of values. The first case generation variable (wellhead temperature) is varied least rapidly.

The consecutive simulation cases generated by the sample input data are listed in order below. For the sake of brevity, the generated cases are described by listing the titles generated in GEOCOST for each case:

1) SAMPLE TEMP=180C FLOW=500K MWE= 75 WACRES=20 WLIFE=15
2) SAMPLE TEMP=180C FLOW=500K MWE=110 WACRES=20 WLIFE=15
3) SAMPLE TEMP=190C FLOW=500K MWE= 75 WACRES=20 WLIFE=15
4) SAMPLE TEMP=190C FLOW=500K MWE=110 WACRES=20 WLIFE=15
5) SAMPLE TEMP=200C FLOW=500K MWE= 75 WACRES=20 WLIFE=15
6) SAMPLE TEMP=200C FLOW=500K MWE=110 WACRES=20 WLIFE=15

4. DESCRIPTION OF OUTPUT

4.1 SAMPLE CASE OUTPUT

Appendix D lists the computer output generated by the sample case described previously, illustrating the input data using NAMELIST. The 26 pages of printout show the output for the final iteration between the binary power plant and fluid transmission submodels (LL6=1) and the full output from the reservoir and power plant economic submodels (LL11=1,LL12=1). The output results are printed in an easy-to-read format with an accompanying description. Table 8 presents an overview of the output, identifying the pages of output generated by the major submodels in GEOCOST. For the sake of brevity, a more detailed description is provided below only for output results that require further elucidation.

The output from the final iteration of the binary power plant submodel is shown on pages D.1 through D.3 including information on:

- Binary power plant input conditions
- Thermodynamic cycle state points for the working fluid and geothermal fluid
- Heat exchanger characteristics
- Condenser and cooling tower characteristics
- Cooling water requirements
- Internal power requirements
- Overall results for the binary power plant.

The input conditions to the fluid transmission submodel are on page D.4. The output from the final iteration of the fluid transmission submodel is on pages D.5 to D.8. The geothermal fluid at the wellhead is pressurized by a factor of 2 above saturation for the first iteration of the fluid transmission submodel. As discussed on page 10, the pressurization factor is minimized by making two passes through the fluid transmission submodel during the first iteration between the binary power plant and fluid transmission submodels. The minimized pressurization factor of 1.66 used in subsequent iterations is still sufficient to prevent the fluid from entering into two-phase flow in

TABLE 8. Summary of Computer Output from GEOCOST

Description of Output	Appendix Pages D-
Binary Power Plant and Fluid Transmission Iteration History (Final Iteration)	1 - 11
• Binary Power Plant Submodel Input and Output	1 - 3
• Fluid Transmission Submodel Input	4
• Fluid Transmission Submodel Output	5 - 8
• Convergence Test for Binary Power Plant and Fluid Transmission Iteration	9
• Injection Submodel Output	10 - 11
Reservoir Technical and Economic Input and Output	12 - 19
• Reservoir Characteristics, Well Properties, and Noncondensible Gases	12
• Reservoir Exploration, Development, and Operation Costs	13
• Financial and Tax Data Input	14
• Annual Cash Flow Statement	15
• Annual Tax Deductible Expense Statement	16
• Annual Income Statement	17
• Annual Payout of Investments (Capitalization)	18
• Summary Breakdown of Cost of Energy from Reservoir	19
Plant Economic Input and Output	20 - 26
• Capital Cost Output	20
• Financial and Tax Data Input	21
• Annual Cash Flow Statement	22
• Annual Tax Deductible Expense Statement	23
• Annual Income Statement	24
• Annual Payout of Investments (Capitalization)	25
• Summary Breakdown of Cost of Power from Plant	26

the pipeline during conduction to the plant. The pressurization is simulated through the use of booster pumps in the fluid transmission submodel.

The binary power plant submodel initially calculates the total geothermal fluid flow requirements for the power plant based on wellhead conditions. After the initial iteration between the binary power plant and fluid transmission submodels, the total geothermal fluid flow requirement for the power plant is calculated based on the degraded fluid conditions transmitted by the fluid transmission submodel. Table 9 summarizes the degradation of the fluid during conduction from the wellhead to the plant for the final iteration of the fluid transmission submodel.

TABLE 9. Fluid Transmission Line from the Reservoir to the Power Plant

Location	Flow Rate (lb/hr)	Temperature (°F)	Pressure (psia)	Enthalpy (Btu/lb)
Wellhead	8,057,497	356	241.9	328.3
Plant Inlet	8,057,497	355.7	229.8	327.9

Degradation of the fluid during conduction is shown on a nodal basis on pages D.5 to D.8. Figure 16 shows the fluid pressure degradation on a nodal basis, corresponding to the output on pages D.5 to D.8.

The layout of the nodes in the well field design is shown on page D.6 and illustrated in Figure 16. The well field is based on a triangular grid in the 4th quadrant of a Cartesian coordinate system with plant at the origin. The previous representation in Figure 13, page 56, showed the well field in the 1st quadrant. However, the concepts and results are independent of the quadrant used in representing the well field layout.

The routing of the fluid transmission lines is shown in Figure 16. The pipe runs are parallel to the horizontal X-axis, joining with one manifold line leading to the plant. The fluid degradation is calculated in the order shown on page D.5, beginning with the perimeter well node (I=6,J=2) and proceeding downstream to the plant.

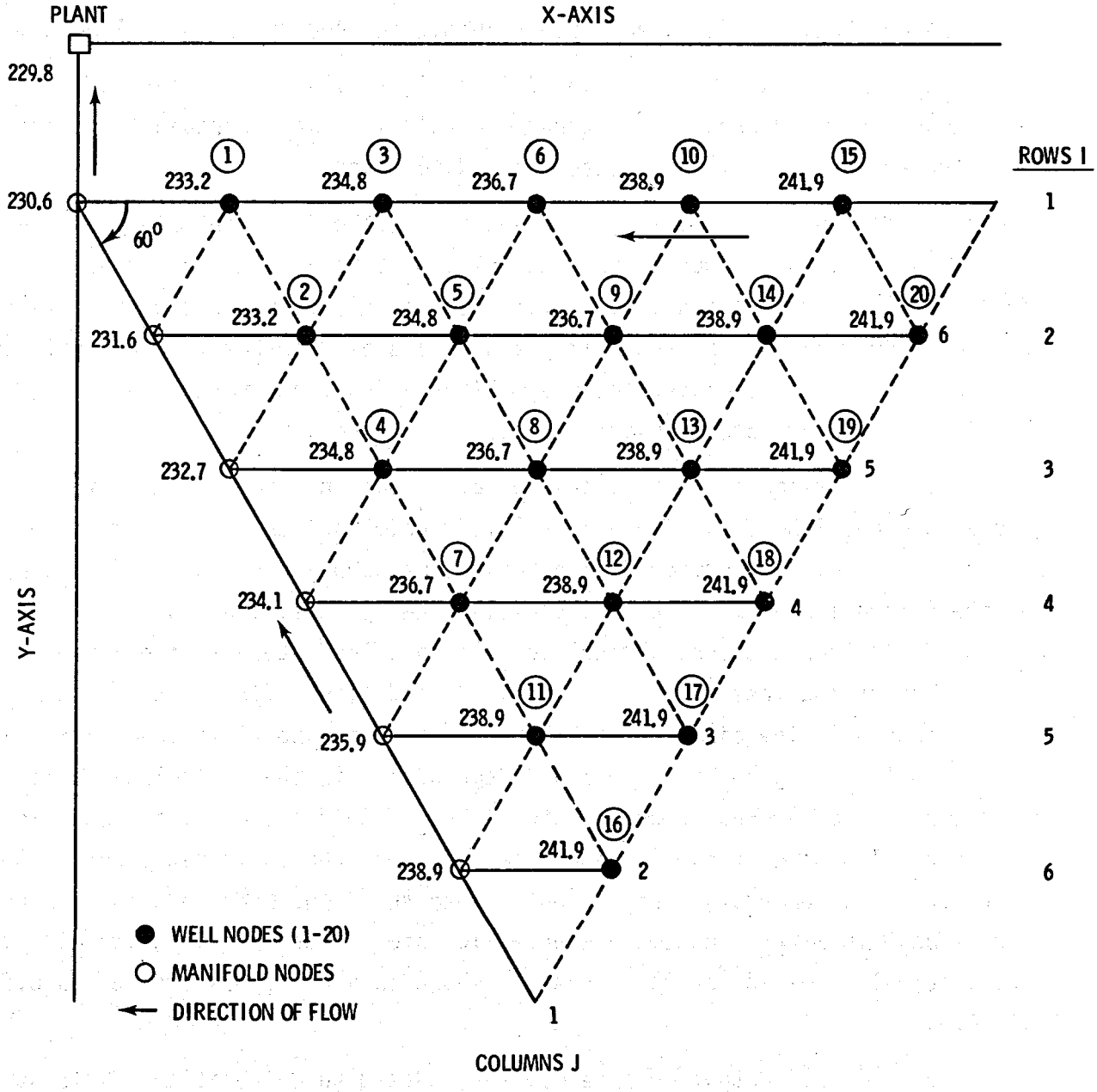


FIGURE 16. Well Field Nodes and Fluid Pressure Degradation on a Nodal Basis

The output from the first iteration at a node (iteration 1 on page D.5) shows the condition of the fluid exiting the node. The letter M is used to indicate the mixture of two inlet flows of fluid at a node:

- Fluid exiting a well node (J>1 in Figure 16) is a mixture of fluid from the wellhead and degraded fluid transmitted from upstream well nodes.
- Fluid exiting a manifold node (J=1 in Figure 16) is a mixture of degraded fluid from the upstream manifold line and degraded fluid from the row of wells leading into the manifold node.

The exit enthalpy is a mass-weighted average of the inlet enthalpies. The exit pressure is the lower of the two inlet pressures. The exit steam fraction (0 for compressed liquid state) is calculated using the steam library function XPHH, based upon the exit pressure and exit enthalpy. The exit temperature is calculated using the steam library functions based upon the exit pressure, enthalpy, steam fraction, and fluid state.

The output from the last iteration at a node on page D.5 shows the degraded condition of the fluid immediately prior to its entry into the next downstream node. Fluid degradation between neighboring nodes is a function of the internal pipe diameter. Inversely, the optimization algorithm used in the fluid transmission submodel to calculate the internal pipe diameter is a function of the mass flow rate and fluid conditions. The initial estimate of the internal pipe diameter is calculated assuming no fluid degradation between neighboring nodes. The fluid degradation is then calculated as a function of the internal pipe diameter. Using the degraded fluid conditions, the internal pipe diameter is recalculated. The process iterates until the degraded fluid temperature at the entry into the downstream node changes by less than 0.10°F from the temperature calculated in the previous iteration. The internal diameters of the pipes are shown on a nodal basis on pages D.5 and D.8.

The condensed output on page D.5 for nodes with 0 iterations lists only the degraded fluid conditions immediately prior to entry into the next downstream node. Well nodes with 0 iterations reflect the savings in nodal computations obtained by setting the input option IAVWEL=1. This option takes advantage of the property that well nodes with the same number of upstream wells have identical inlet and outlet fluid conditions, provided that all wells in the well field have identical flow rates and fluid conditions. The well nodes can be grouped according to the number of upstream wells shown for each node on page D.6 as follows:

Number of Upstream Wells	Well Node Identification Number
1	15,16,17,18,19,20
2	10,11,12,13,14
3	6,7,8,9
4	3,4,5
5	1,2

The number of well nodes that require recomputation can thus be reduced from 20 to 5 nodes. This reduction in recomputation cannot be extended to manifold nodes which are all individually computed. In addition, the reduction in computation cannot be used if the wells have variable flow rates or variable fluid conditions.

The output from the fluid disposal submodel is shown on pages D.10 to D.11. The condition and flow rate of the fluid from the heat exchangers used in rejection are summarized in Table 10. In this version of GEOCOST, fluid degradation is not simulated in the reinjection lines. The capital costs for the fluid transmission and disposal systems are shown on pages D.8 and D.11.

TABLE 10. Fluid Reinjection Line from the Power Plant to the Injection Field

Flow Rate (lb/hr)	Temperature (°F)	Pressure (psia)
8,057,497	183.7	204.8

The output from the reservoir economic submodel is on pages D.12 to D.19. Page D.12 lists the characteristics of the reservoir, properties of the wells, dissolved salts, and noncondensible gases in the geothermal fluid. The output listed under well properties includes the following information; descriptions of the calculation of these quantities are in succeeding paragraphs.

1) Number of producing wells
2) Number of nonproducing (dry) wells
3) Number of injection wells
4) Thermal energy per well
5) Gross electrical power per well

6) Net electrical power per well

7) Actual flow rate per well

1) Number of producing wells =
{[total flow rate (lb/hr) demanded by the power plant]/maximum flow rate (lb/hr) per well} * (1. + fraction of excess producing wells)

where:

Fractional results are rounded up to the next largest integer.

The maximum flow rate per well is input as the variable FLORAT.

The fraction of excess producing wells is input as the variable FRCEPW.

2) Number of nonproducing (dry) wells =
(number of producing wells) * (fraction of nonproducing wells)

where:

Fractional results are rounded to the nearest integer.

The fraction of nonproducing wells is input as the variable FRCNPW.

3) Number of injection wells =
geothermal fluid flow rate (lb/hr) from the heat exchangers/maximum injection well flow rate (lb/hr)

where:

Fractional results are rounded to the next largest integer.

The maximum injection well flow rate = (ratio of injection well to producing well flow rate, input as PRDRAT) * (maximum producing well flow rate, input as FLORAT).

4) Thermal energy (MWt) per well =
[maximum flow rate (lb/hr) per well] * (enthalpy at the wellhead enthalpy at the exit from the cooling tower)/($3.41443 * 10^6$)

5) Gross electrical power (MWe) per well =
power plant capacity (MWe)/number of producing wells

6) Net electrical power (MWe) per well -
net power plant output (MWe)/number of producing wells

7) Actual flow rate (lb/hr) per well =
total flow rate (lb/hr) required by the power plant/number of producing wells.

The direct expenses associated with reservoir exploration, development and operation are on page D.13. Page D.14 contains the financial and tax input data for the reservoir and case identification information. Annual cash flow data for the major reservoir expenses are on page D.15; summary accounts of deductible expenses are on page D.16. A simplified income statement is on page D.17 and the net cash flow and investment position are on page D.18.

The cost of energy for the reservoir is summarized on page D.19. The unit cost of energy for this sample case is 14.7 mills/kW-hr. The equivalent annual cost during the operating life of the power plant is $5,681,000. In the right-hand column labeled distribution of energy costs, the taxes, royalty payments, and bond interest are reallocated to the direct cost components for the reservoir. The rate of return on investment is included in the distributed energy cost for each component. The deductible nature of bond interest causes this expense to be partially included in the rate of return (the part which is included in the present worth factor) and the remainder is accounted for separately under the caption "Bond Interest."

The output from the power plant economic submodel is on pages D.20 to D.26. Page D.20 lists the power plant capital costs in 1974 dollars. Pages D.21 to D.25 contain the same economic and accounting information for the power plant as pages D.14 to D.18 for the reservoir. The cost of power for the power plant is summarized on page D.26. The unit cost of power for this sample case is 26.9 mills/kW-hr. The equivalent annual cost during the operating life of the power plant is $8,665,000. All costs from the reservoir are included in the energy supply cost item. The energy supply costs are derived from the energy cost account on page D.22. The energy cost account is identical to the total power sales from the reservoir on page D.17. The difference between the unit cost for energy supply at the plant and the unit cost of energy from the reservoir is caused by the in-house consumption of electricity.

Unit cost of energy supply at power plant = Unit cost of energy supply at reservoir * $\frac{\text{gross output (MWe) of power plant}}{\text{net output (MWe) of power plant}}$

The potential savings in the cost of power from the power plant if the in-house consumption of electricity were reduced to 0 for this sample case is 4.5 mills/kW-hr or $1,436,000/yr during the operating life of the power plant. As with the reservoir cost distribution, the taxes and bond interest are reallocated to the direct cost components in the right-hand columns of the cost distribution.

4.2 CYBER COMPUTER COMPILATION AND EXECUTION TIMES

The GEOCOST and Steam Library FORTRAN code required 3-1/2 minutes to compile with the FTN version 4.2 compiler at optimization level 1 on the Cyber 74-18 computer with Scope 3.4.2 operating system. The sample case described in the previous section required 8 seconds of CPU time for execution. The execution time is principally dependent upon the number of wells required to supply the mass flow rate of geothermal fluid needed by the binary power plant submodel. This follows from the fact that the fluid transmission submodel calculates the conduction and degradation of the geothermal fluid on a nodal basis from the reservoir to the power plant. The number of wells depends upon many factors, including:

- Wellhead temperature
- Well flow rate
- Fluid degradation during conduction to the power plant
- Power plant size

5. CONTROL CARDS

5.1 MINIMAL CONTROL CARD REQUIREMENTS

The GEOCOST program can be converted to the user's computing facilities with a minimal set of basic control cards necessary to compile, load and execute a FORTRAN source program available on tape. One disk file (TAPE11 below) is used internally in GEOCOST to store summary printout obtained with the case generation input option. In order to execute GEOCOST, it is necessary to compile and load all GEOCOST subroutines and the following steam table subroutines:

STEAM TABLE SUBROUTINES REQUIRED BY GEOCOST

CCSR1	COMT3	P23T	STER	VISL
CCSR2	GRS	PSL	SVT3	VPH
CCSR3	HCL	PVT3	TPS	VPT1
CCBLL	HPT1	SPH	TPSL	VPT2
COMALL	HPT2	SPT1	TSL	VPT3
COMT1	HPTL	SPT2	TSLH	VPTD
COMT2	HVT3	SPTL	VFT	VPTL

The object code generated by compiling the GEOCOST and steam table subroutines can be stored on disk as a sequential file or as a random library file. The file containing the object code can be subsequently attached and loaded for executing input data sets.

5.2 CYBER COMPUTER CONTROL CARDS ILLUSTRATING THE USE OF PROGRAM AND USER LIBRARIES WITH GEOCOST

This section illustrates a more elaborate set of control cards used with the Cyber computer at Battelle-Northwest for updating and executing GEOCOST with program and user libraries. The source code for GEOCOST was maintained on a disk file called GEOTHERMALSRC, organized as a random program library using UPDATE software. The object code for GEOCOST and the 1967 ASME Steam Library was maintained on a disk file called GEOTHERMALIB, organized as a random user library using EDITLIB software.

Four small, compiled drivers were maintained on separate disk files to load the subset of GEOCOST subroutines required to simulate four different types of power plants: steam, binary fluid, total flow, and geopressured reservoirs. The choice of a user library for the object code provided a convenient means for loading into computer memory only the subset of GEOCOST and steam library subroutines required to simulate the particular type of power plant selected. In this version of GEOCOST, which simulates the binary power plant, the corresponding driver simplifies to the following code on the Cyber, which was maintained on a disk file called GEOCOSTBINARY:

```
PROGRAM GEOCOST (INPUT, OUTPUT, TAPE5 = INPUT, TAPE6 = OUTPUT,
  TAPE11)
CALL HOTROK
STOP
END
```

With this background of the file structure at Battelle-Northwest in perspective, the set of control cards in Table 11 specifies the following sequence of job steps used to update and execute GEOCOST:

- Attach the disk file GEOCOSTBINARY, containing the compiled driver for selecting the binary power plant.
- Attach the disk file GEOTHERMALSRC of GEOCOST source subroutines, organized into a random program library using UPDATE.
- Attach the disk file GEOTHERMALIB of compiled GEOCOST and steam library subroutines, organized into a random user library using EDITLIB.
- Modify the program library using UPDATE, putting only the modified source subroutines on the compile file.
- Catalog the newly updated program library.
- Purge the old program library.
- Compile the modified source subroutines.
- Extend the user library using EDITLIB to incorporate the compiled subroutines that were modified.

TABLE 11. Control Cards to Update, Compile, Load and Execute GEOCOST on the Cyber Computer

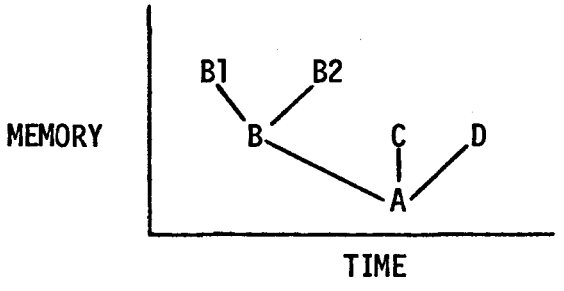
```
Installation Job Card
Installation Account Card
ATTACH(GEOCOST,GEOCOSTBINARY,ID=X,PW=X)
ATTACH(OLDPL,GEOTHERMALSRC,ID=X,PW=X)
ATTACH(LIB,GEOTHERMALIB,ID=X,PW=X)
LIBRARY(LIB)
REQUEST(NEWPL,*PF)
RFL(40000)
UPDATE(E,N)
RETURN(OLDPL)
CATALOG(NEWPL,GEOTHERMALSRC,RP=999,ID=X,PW=X)
RETURN(NEWPL)
PURGE(NEWPL,GEOTHERMALSRC,LC=1,ID=X,PW=X)
RETURN(NEWPL)
REQUEST(LGO,*PF)
RFL(100000)
FTN(I,R=2,B=LGO,OPT=1)
REWIND(LGO)
EDITLIB(USER)
EXTEND(LIB)
RFL(155000)
LDSET(USEP=DATA) -- Used only when BLOCK DATA in GEOCOST is not modified to
                    force it to be loaded from the user library GEOTHERMALIB.
LOAD(GEOCOST)
REDUCE.
EXECUTE.
7/8/9
*IDENT MODIFY
UPDATE Correction Directives and Modified FORTRAN Statements
7/8/9
LIBRARY(LIB,OLD)
REPLACE(*,LGO,AL=1)
FINISH.
ENDRUN.
7/8/9
Input Data Sets
6/7/8/9
```

- Load the entire set of subroutines required for execution into 155,000 octal words of computer memory.
- Execute the input data sets using the modified program.

The user may wish to prepare a corresponding set of control cards to accomplish the same job processing steps with his/her computer software or else design an alternative sequence of job steps.

5.3 CYBER COMPUTER CONTROL CARDS ILLUSTRATING SEGMENTED LOADING OF GEOCOST

The set of control cards in Table 12 illustrates the segmented loading and execution of GEOCOST, in which the program is partitioned into six main parts called segments. The segmented loading enables different segments of the program to reside in the same area of memory at different times to reduce the memory requirements from 155,000 to 120,000 octal words. The segmentation is based upon the following tree structure, patterned after the hierarchical layout of the subroutines shown in Figures 2 and 3, pages 5 and 6.



where A = Root segment (executive program GEOCOST/HOTROK and associated subroutines), always residing in memory during execution.

B = Subroutines LOAD and DBINRY, together with associated subroutines, to read the input data and control the iterations between the binary power plant and fluid transmission submodels.

B1 = Binary power plant submodel, simulated by subroutine BINARY and its associated subroutines.

B2 = Fluid transmission and disposal submodel, simulated by subroutine TRANS and its associated subroutines.

C = Reservoir economic submodel, simulated by subroutine RESVOR and its associated subroutines.

D = Power plant economic submodel, simulated by subroutine PWRPLT and its associated subroutines.

TABLE 12. Control Cards for Segmented Loading and Execution of GEOCOST on the Cyber Computer

```
Installation Job Card
Installation Account Card
ATTACH(GEOCOST,GEOCOSTBINARY,ID=X,PW=X)
ATTACH(LIB,GEOTHERMALIB,ID=X,PW=X)
LIBRARY(LIB)
MAP(ON)
RFL(120000)
SEGLOAD.
LOAD(GEOCOST)
REDUCE.
EXECUTE.
RFL(20000)
REWIND(TAPE11)
COPYBF(TAPE11,OUTPUT)
EXIT.
RFL(20000)
REWIND(TAPE11)
COPYBF(TAPE11,OUTPUT)
```

Used only when case generation mode (ICASE=1) is specified in the input data set.

```
7/8/9
A   INCLUDE  GEOCOST,HOTROK,DATA,GCASE,GEVAL,SCASE
A   INCLUDE  CCSR1,CCSR2,CCSR3,CCBLL,COMALL
A   INCLUDE  SWITCH,CLEAR,PAGE,FACTRS,CFLASH
A   GLOBAL      NAMLST,WORK,DATUM,PSEUDO,FLASH,STEAM
A   GLOBAL      INTRAN,OUTRAN,POINT,FLAGS,STORE,TPRNT
A   GLOBAL      BINARY,CONST1,CONST2,CONST3,CONSTL,COMCON,HXOUT,WFFRT
A   GLOBAL      STM1,STM2,STM3,CURENT,BUTANE,RQNCOM,FRECON
B   INCLUDE     LOAD,DRIVER,DBINRY,CONVRG
B1  INCLUDE     ACWFRT,AVGTMP,BFT2D2,BFT2V2,BINARY,BUTANE
B1  INCLUDE     CNDNSR,DNLIQA,DNLIQB,DNLIQC,EFT2V2,EQSTAP
B1  INCLUDE     FFT2V2,FLUID,FREON,FUG,HEQST,HIDEAL
B1  INCLUDE     HTAREA,HTCOEF,HTLNGH,HVAP,LOSSES,OHTCOE,PEQST
B1  INCLUDE     PONE,PTWO,PUMP,QAREA,QCC,REYNO
B1  INCLUDE     RHOITR,SEQST,SETCON,SIDEAL,SUBHEX,SUPHEX
B1  INCLUDE     SVAP,TOWER,TFOUR,TUBES,VELOCY,VPRESA,VPRESB,WFFRT
B2  INCLUDE     TRANS,TROUT,FLPROP,XPHH,DESIGN,EQCOST,TSTART,PIPE
B2  INCLUDE     STORE,SCHEDL,INSUL,SPFLOW,TPFLOW,TPHASE,TPRINT,MOUT
C   INCLUDE     RESVOR,TARGTS,DATACK,PWRCO,DEPREC,COSTEQ
C   INCLUDE     PAYOUT,OUTPUT,SUMARY,WRITE
D   INCLUDE     PWRPLT,PCONST,VAL,FACTHX,DATAK,EXPENSE,DPREC
D   INCLUDE     COSTEG,PAYOT,OUTPLT,CPOWER
BINARY   TREE  B-(B1,B2)
GEOCOST  TREE  A-(BINARY,C,D)
END
7/8/9
Input Data Sets
6/7/8/9
```

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APPENDIX A

RESERVOIR EXPLORATION, DEVELOPMENT, AND OPERATION COST EQUATIONS

APPENDIX A

RESERVOIR EXPLORATION, DEVELOPMENT, AND OPERATION COST EQUATIONS

The basic equations used in subroutine RESVOR to calculate the costs associated with the exploration, development, and operation of the reservoir are given in this section to aid program users who may wish to change the default input values in Table 5A, page 95. The original list of 39 tasks indexed by N in Table 5B are grouped in three different ways during the calculations in subroutine RESVOR by means of the internal arrays: GROUP(N), ITEX(N), and NTARG(N), N = 1, ..., 39. The array GROUP is used to consolidate the 39 tasks into 31 tasks according to the description of the task. The array ITEX is used to group the tasks according to the time the tasks are scheduled to take place. The array NTARG is used to group the tasks by the major decision points in the reservoir exploration process. Any changes contemplated for these arrays, such as adding tasks or decision points, will require some slight reprogramming in subroutine RESVOR. For this reason, these three arrays are not listed as input arrays.

The cost equations given in this section calculate the total, capitalized, and expensed costs for the tasks in Tables 5A and B without breaking the costs down according to the time in which the tasks occurred. Since the reservoir exploration and development tasks may start in any month during 1 year and end in any month during another year, subroutine RESVOR uses the input time arrays LAGS(ITEX(N), 1) and LAGS(ITEX(N), 2), ITEX(N) = 1, ..., 22, to calculate total, capitalized, and expensed costs for the tasks according to the months in which the tasks are scheduled to occur. This enables the total, capitalized, and expensed costs of the tasks to be accurately totaled on an annual basis in order to calculate annual statements of cash flow, deductible expenses, income, and payout of investments for the reservoir from the beginning of exploration through the economic life of the power plant.

The input array FTF(NTARG(N)-1), NTARG(N) = 2, ..., 7, is used by subroutine RESVOR to calculate the total number of target sites to be

initially identified in order to converge on one site for development and operation after the final decision point.

(Expected number of target sites to identify) * (Fraction of sites retained after decision point I, I = 1, ..., number of decision points) = 1. Substituting FORTRAN variables from subroutine RESVOR and solving this equation,

Expected number of target sites to identify,

FAVSIT(1) = 1/[FTF(1) * FTF(2) ... * FTF(NUMFTF)].

For the default values,

FAVSIT(1) = 1/[1/2 * 1/2 * 2/3 * 3/4 * 1/4 * 1/4] = 128.

The number of sites to retain after each decision point is calculated as follows:

Number of sites to retain after decision point J = (Expected number of target sites to identify) * (Fraction of sites retained after decision point I, I = 1, ..., J).

Substituting FORTRAN variables from subroutine RESVOR,
Number of sites to retain after decision point J =

FAVSIT(1) * FTF(1) * FTF(2) * ... FTF(J).

The array UNIT representing unit costs used in the calculations below is defined at the beginning of subroutine RESVOR as the following function of the input array UNITO (defined in Table 5):

UNIT(N) = RATPR * UNITO(N), N = 1, . . ., 22

UNITO(n) , N = 23, . . ., 39

where:

RATPR is defined in subroutine LOAD as the ratio of the input power-plant size (MWe) to the input reservoir size (MWe):

RATPR = DINPUT(43) / DINPUT(8), DINPUT(8) ≧ DINPUT(43).

The ratio RATPR is used to scale the input array UNITO in order to allocate only the fraction of the costs for the reservoir exploration tasks (N = 1, ..., 22) required to provide enough energy supply for the specified power plant size.

The FORTRAN variables appearing in the following equations taken from subroutine RESVOR are defined as follows:

CSTNEW(IGP) = total dollars required by task IGP

FAVSIT(IGP) = number of favorable sites for task IGP

CAP(IGP) = capitalized dollars for task IGP

EXPENZ(IGP) = expensed dollars for task IGP

where:

IGP = GROUP(N) as defined in Table 5.

Reservoir Exploration Tasks Indexed by N = 1 to 5, N = 9 to 12, N = 15 to 17, and N = 22

$$\text{CSTNEW(IGP)} = \sum_{\text{N in Group IGP}} \text{UNIT(N)} * \text{FAVSIT(N)}$$

$$\text{CAP(IGP)} = \sum_{\text{N in Group IGP}} \text{UNIT(N)}$$

$$\text{EXPENZ(IGP)} = \text{CSTNEW(IGP)} - \text{CAP(IGP)}$$

where:

IGP is defined as GROUP(N) in Table 5.

Lease Procurement, N = 6, 7, 8; IGP = 6

$$\text{CSTNEW(6)} = \sum_{\text{N in Group IGP}} \text{UNIT(N)} * \text{ACRES} * \text{FAVSIT(N)}$$

$$\text{CAP(6)} = \sum_{\text{N in Group IGP}} \text{UNIT(N)} * \text{ACRES}$$

EXPENZ (6) = CSTNEW(6) - CAP(6)

where:

ACRES, input through NAMELIST, is the size of each geothermal site leased.

Heat Flow Wells, N = 13, IGP = 10

CSTNEW(10) = UNIT(13) * 4. * FAVSIT(10)

CAP(10) = UNIT(13)* 4.

EXPENZ(10) = CSTNEW(10) - CAP(10)

based upon the assumption that 4 wells are drilled per site to measure heat flow.

Temperature Gradient Wells, N = 14, IGP = 11

CSTNEW(11) = UNIT(14) * 10. * FAVSIT(11)

CAP(11) = UNIT(14) * 10.

EXPENZ(11) = CSTNEW(11) - CAP(11)

based upon the assumption that 10 wells are drilled per site to measure temperature gradient.

Exploratory Well Drilling, N = 18, 19, 20, 21; IGP = 15

RATPR = DINPUT(43) / DINPUT(8)

CSTNEW(15) = RATPR * DCINJW * FAVSIT(15)

CAP(15) = PERCNT(1) * CSTNEW(15) / FAVSIT(15)

EXPENZ (15) = CSTNEW(15) - CAP(15)

where:

RATPR is the ratio of the input power plant to input reservoir size (MWe). DCINJW, input through NAMELIST, is the cost (dollars) of drilling one exploratory or injection well.

PERCNT(1), input through NAMELIST, is the tangible fraction of the drilling cost.

Production Well Drilling, N = 23, 24; IGP = 17

CSTNEW(17) = DCPW * WELLS * FAVSIT(17)

CAP(17) = PERCNT(1) * CSTNEW(17)

EXPENZ(17) = CSTNEW(17) - CAP(17)

where:

DCPW, input through NAMELIST, is the cost (dollars) of drilling one production well.

WELLS, calculated in subroutine TRANS, is the number of required production wells.

PERCNT(1), input through NAMELIST, is the tangible fraction of the drilling cost.

Nonproduction Well Drilling, N = 25, IGP = 18

CSTNEW(18) = DCNPW * BADWEL * FAVSIT(18)

CAP(18) = 0.

EXPENZ(18) = CSTNEW(18)

where:

DCNPW, input through NAMELIST, is the cost (dollars) of drilling one nonproduction well.

BADWEL, calculated in subroutine TRANS, is the number of nonproduction wells.

Injection Well Drilling, N = 26, 27; IGP = 19

CSTNEW(19) = DCINJW * WELINJ * FAVSIT(19)

CAP(19) = CSTNEW(19)

EXPENZ(19) = 0.

where:

DCINJW, input through NAMELIST, is the cost of drilling one injection well.

WELINJ, calculated in subroutine INJECT, is the total number of injection wells.

Transmission System, N = 28, IGP = 20

CSTNEW(20) = UNIT(28) * TCCOST * FAVSIT(20)

CAP(20) = CSTNEW(20)

EXPENZ(20) = 0.

where:

TCCOST, calculated in subroutine TRANS, is the capital cost of the fluid transmission system.

Disposal System, N = 29, IGP = 21

CSTNEW(21) = UNIT(29) * DCCOST * FAVSIT(21)

CAP(21) = CSTNEW(21)

EXPENZ(21) = 0.

where:

DCCOST, calculated in subroutine INJECT, is the capital cost of the fluid disposal system

Replacement Wells Based on Production Well Life, N = 30, IGP = 22

CSTNEW(22) = CSTNEW(17) * UNIT(30) / AVGWL

CAP(22) = PERCNT(1) * CSTNEW(22)

EXPENZ(22) = CSTNEW(22) - CAP(22)

where:

CSTNEW(17) is the production well drilling cost.

AVGWL, input through NAMELIST, is the production well life (years).

PERCNT(1), input through NAMELIST, is the tangible fraction of the drilling cost.

Nonproduction Well Drilling Associated with Replacement Wells, N = 31, IGP = 23

CSTNEW(23) = FRCNPW * CSTNEW(22)

CAP(23) = 0.

EXPENZ(23) = 0.

where:

FRCNPW, input through NAMELIST, is the ratio of nonproduction to production wells drilled.

CSTNEW(22) is the cost of replacement wells drilled.

Well Abandonment, N = 32, IGP = 24

CSTNEW(24) = UNIT(32) * (WELLS/AVGWL) * FAVSIT(24)

CAP(24) = 0.

EXPENZ(24) = 0.

where:

WELLS, calculated in subroutine TRANS, is the number of required production wells.

AVGWL, input through NAMELIST, is the production well life (years).

Well Maintenance, N = 33, IGP = 25

CSTNEW(25) = UNIT(33) * (WELLS + WELINJ) * FAVSIT(25)

CAP(25) = 0.

EXPENZ(25) = 0.

where:

WELLS, calculated in subroutine TRANS, is the number of required production wells.

WELINJ, calculated in subroutine INJECT, is the number of injection wells.

Overhead and Management, N = 34, IGP = 26

CSTNEW(26) = 0.01 * (Total reservoir development cost) + 0.10 * (Total reservoir operation cost excluding overhead and management)

CAP(26) = 0.

EXPENZ(26) = 0.

Well Redrilling Due to Scale Build-Up in the Production Wells, N = 35, IGP = 27

CSTNEW(27) = UNIT(35) * WELLS * FAVSIT(27)

CAP(27) = 0.

EXPENZ(27) = 0.

where:

WELLS is the number of required production wells.

Annual Injection Well Costs, N = 36, IGP = 28

CSTNEW(28) = UNIT(36) * WELINJ * FAVSIT(28)

CAP(28) = 0.

EXPENZ(28) = 0.

where:

WELINJ, calculated in subroutine INJECT, is the number of injection wells.

Injection Well Maintenance, N = 37, IGP = 29

CSTNEW(29) = UNIT(37) * FAVSIT(29)

CAP(29) = 0.

EXPENZ(29) = 0.

Transmission System Maintenance, N = 38, IGP = 30

CSTNEW(30) = UNIT(38) * TMCOST * FAVSIT(30)

CAP(30) = 0.

EXPENZ(30) = 0.

where:

TMCOST is calculated in subroutine TRANS as TMAINT * TCCOST, TMAINT, input through NAMELIST, is the transmission maintenance factor (fractional).

TCCOST, calculated in subroutine TRANS, is the capital cost of the fluid transmission system.

Disposal System Maintenance, N = 39, IGP = 31

CSTNEW(31) = UNIT(39) * DMCOST * FAVSIT(31)

CAP(31) = 0.

EXPENZ(31) = 0.

where:

DMCOST is calculated in subroutine INJECT as DMAINT * DCCOST, DMAINT, input through NAMELIST, is the disposal maintenance factor (fractional).

DCCOST, calculated in subroutine INJECT, is the capital cost of the fluid disposal system.

APPENDIX B

THERMODYNAMIC EQUATIONS

APPENDIX B

Starling Equations for Describing the Thermodynamic Properties of the Light Hydrocarbons - Isobutane and N-Butane

(B1) Equation of State

$$P = \rho RT + (B_o RT - A_o - \frac{C_o}{T^2} + \frac{D_o}{T^3} - \frac{E_o}{T^4})\,\rho^2 + (bRT - a - \frac{d}{T})\,\rho^3$$

$$+ \alpha(a + \frac{d}{T})\,\rho^6 + \frac{c\rho^3}{T^2}(1 + \gamma\rho^2)\exp(-\gamma\rho^2)$$

(B2) Enthalpy, H

$$H = (B_o RT - 2A_o - \frac{4C_o}{T^2} + \frac{5D_o}{T^3} - \frac{6E_o}{T^4})\,\frac{\rho}{\phi} + \frac{1}{2}(2bRT - 3a - \frac{4d}{T})\,\frac{\rho^2}{\phi}$$

$$+ \frac{1}{5}\alpha(6a + \frac{7d}{T})\,\frac{\rho^5}{\phi} + \frac{c}{\gamma\phi T^2}[3-(3 + \frac{1}{2}\gamma\rho^2 - \gamma^2\rho^4)\exp(-\gamma\rho^2)] + H_o$$

(B3) Ideal Gas Enthalpy, H_o

$$H_o = A_o' + A_1 T + A_2 T^2 + A_3 T^3 + A_4 T^4 + A_5 T^5$$

(B4) Entropy, S

$$S = -\frac{R}{\phi}\ln(\rho RT) - (B_o R + \frac{2C_o}{T^3} - \frac{3D_o}{T^4} + \frac{4E_o}{T^5})\,\frac{\rho}{\phi} - \frac{1}{2}(bR + \frac{d}{T^2})\,\frac{\rho^2}{\phi}$$

$$+ \frac{\alpha d\rho^5}{5T^2\phi} + \frac{2C}{\gamma T^3\phi}[1 - (1 + \frac{1}{2}\gamma\rho^2)\exp(-\gamma\rho^2)] + S_o$$

(B5) Ideal Gas Entropy, S_o

$$S_o = B_o + B_1 T + B_2 T^2 + B_3 T^3 + B_4 T^4 + B_5 T^5$$

(B6) Fugacity, f

$$\ln f = \ln(\rho RT) + 2\left(B_o RT - A_o - \frac{C_o}{T^2} + \frac{D_o}{T^3} + \frac{E_o}{T^4}\right)\frac{\rho}{RT} + \frac{3}{2}\left(bRT - a - \frac{d}{T}\right)\frac{\rho^2}{RT}$$

$$+ \frac{6\alpha}{5}\left(a + \frac{d}{T}\right)\frac{\rho^5}{RT} + \frac{c}{\gamma RT^3}\left[1 - \left(1 - \frac{1}{2}\gamma\rho^2 - \gamma^2\rho^4\right)\exp\left(-\gamma\rho^2\right)\right]$$

Nomenclature for the Starling Equations in GEOCOST

Symbol	FORTRAN Name of Variable	Definition
f	F	Fugacity
H	H	Enthalpy, Btu/lb
H_o	HIDEAL	Ideal enthalpy, Btu/lb
P	P	Pressure, psia
S	S	Entropy, Btu/lb-°R
S_o	SIDEAL	Ideal entropy, Btu/lb-°R
T	T	Temperature, °R
ρ	RHO or D	Density, lb mole/ft^3

Symbol	FORTRAN Name of Constants (Defined in Subroutine SETCON)	Symbol	FORTRAN Name of Constants (Defined in Subroutine SETCON)
A_o	AZERO	A_o'	AB
B_o	BZERO	A_1	AB1
C_o	CZERO	A_2	AB2
D_o	DZERO	A_3	AB3
E_o	EZERO	A_4	AB4
a	SMA	A_5	0 (not used)
b	SMBB	B_o	BB
c	SMC	B_1	BB1
d	SMD	B_2	BB2
α	ALPHAB	B_3	BB3
γ	GAMMA	B_4	BB4
ϕ	PHI	B_5	0 (not used)
		R	RB

Martin-Hou Equations for Describing the Thermodynamic Properties of the Fluorocarbons and Ammonia

(B7) Equation of State

$$P = \frac{RT}{V - b} + \frac{A_2 + B_2T + C_2 \exp(-KT/T_c)}{(V - b)^2} + \frac{A_3 + B_3T + C_3 \exp(-KT/T_c)}{(V - b)^3}$$

$$+ \frac{A_4 + B_4T + C_4 \exp(-KT/T_c)}{(V - b)^4} + \frac{A_5 + B_5T + C_5 \exp(-KT/T_c)}{(V - b)^5}$$

$$+ \frac{A_6 + B_6T + C_6 \exp(-KT/T_c)}{\exp(\alpha V)(1 + C' \exp(\alpha V))}$$

(B8) Liquid Density of R-11, R-22, and Ammonia

$$d_{L_1} = A_L + B_L (1 - T/T_c)^{1/3} + C_L(1 - T/T_c)^{2/3} + D_L(1 - T/T_c) + E_L(1 - T/T_c)^{4/3}$$

(B9) Liquid Density of R-12 and R-114

$$d_{L_2} = A_L + B_L(T_c - T) + C_L(T_c - T)^{1/2} + D_L(T_c - T)^{1/3} + E_L(T_c - T)^2$$

(B10) Liquid Density of R-21 and R-113

$$d_{L_3} = A_L + B_LT + C_LT^2$$

(B11) Saturated Pressure

$$\log_{10}P = A + \frac{B}{T} + C \log_{10}T + DT + E\left(\frac{F - T}{T}\right)\log_{10}(F - T)$$

(B12) Pressure Derivative

$$\frac{dP}{dT} = P[-\frac{(\ln 10)(B + EF\log_{10}(F - T))}{T^2} + \frac{(C - E)}{T} + D\ln 10]$$

(B13) Enthalpy

$$H = aT + \frac{bT^2}{2} + \frac{cT^3}{3} + \frac{dT^4}{4} - \frac{f}{T} + JPV + J[\frac{A_2}{(V-b)} + \frac{A_3}{2(V-b)^2} + \frac{A_4}{3(V-b)^3} + \frac{A_5}{4(V-b)^4}$$

$$+ \frac{A_6}{\alpha}(\frac{1}{\exp(\alpha V)} - C1'(\ln 10)\log_{10}(1 + \frac{1}{C'\exp(\alpha V)}))]$$

$$+ J\exp(-KT/T_c)(1 + KT/T_c)[\frac{C_2}{(V-b)} + \frac{C_3}{2(V-b)^2} + \frac{C_4}{3(V-b)^3} + \frac{C_5}{4(V-b)^4}$$

$$+ \frac{C_6}{\alpha\exp(\alpha V)} - \frac{C_6C'}{\alpha}(\ln 10)^* \log_{10}(1 + \frac{1}{C'\exp(\alpha V)})] + X$$

(B14) Entropy

$$S = a(\ln 10)\log_{10} T + bT + \frac{cT^2}{2} + \frac{dT^3}{3} - \frac{f}{2T^2} + JR(\ln 10)\log_{10}(V - b)$$

$$- J[\frac{B_2}{(V-b)} + \frac{B_3}{2(V-b)^2} + \frac{B_4}{3(V-b)^3} + \frac{B_5}{4(V-b)^4} + \frac{B_6}{\alpha}(\frac{1}{\exp(\alpha V)} - C'(\ln 10)^*$$

$$\log_{10}(1 + \frac{1}{C'\exp(\alpha V)}))] + \frac{JK\exp(-KT/T_c)}{T_c} * [\frac{C_2}{(V-b)} + \frac{C_3}{2(V-b)^2} + \frac{C_4}{3(V-b)^3}$$

$$+ \frac{C_5}{4(V-b)^4} + \frac{C_6}{\alpha\exp(\alpha V)} - \frac{C_6C'(\ln 10)}{\alpha}\log_{10}(1 + \frac{1}{C'\exp(\alpha V)})] + \gamma$$

(B15) Heat of Vaporization

$$\Delta H_{lat} = \left(\frac{dP}{dT}\right)T(V_{vap} - V_{liq})(0.185053)$$

Nomenclature for the Martin-Hou Equations in GEOCOST

Symbol	FORTRAN Name of Variable	Definition
dL_1	DNLIQA	Density, lb/ft^3
dL_2	DNLIQB	Density, lb/ft^3
dL_3	DNLIQC	Density, lb/ft^3
$\frac{dP}{dT}$	VPRESB	Pressure derivative
ΔH_{lat}	DHVAP	Heat of vaporization, Btu/lb
H	H	Enthalpy, Btu/lb
$P_{saturation}$	VPRESA	Saturation pressure, psia
P	P	Pressure, psia
S	S	Entropy, Btu/lb-°R
T	T	Temperature, °R
V	V1 or V2	Specific volume, ft^3lb

Symbol	FORTRAN Name of Constants (Defined in Subroutine SETCON)	Symbol	FORTRAN Name of Constants (Defined in Subroutine SETCON)
A	A	B_6	B6
B	B	C_6	C6
C	C	A_L	AL
D	D	B_L	BL
E	E	C_L	CL
F	F	D_L	DL
A_2	A2	E_L	EL
B_2	B2	a	HCA
C_2	C2	b	HCB[$\frac{bT^2}{2}$ and bT terms]
		b	SB[(V-b) terms]
A_3	A3	c	HCC
B_3	B3	d	HCD
C_3	C3	f	HCF
A_4	A4	α	ALPHA
B_4	B4	J	JAY
C_4	C4	K	KAY
A_5	A5	P_c	PC (critical pressure, psia)
B_5	B5	R	R (gas constant)
C_5	C5	T_c	TC (critical temperature, °R)
		V_c	VC (critical specific volume, ft^3/lb)
A_6	A6	X	XFR
		Y	YFR

(B16) Macroconvective Heat Transfer Coefficient for Two-Phase Flow Based on the Martinelli Parameter and Chen's Correlation

$$h_{mac} = 0.023\ Re_L^{0.8}\ Pr_L^{0.4}\ \frac{KL}{D}\ F$$

where:

F is the ratio of the two-phase Reynolds number to the liquid Reynolds number, based on the liquid fraction of the flow. This ratio can be expressed as a function of the Martinelli parameter (M) as follows:

$$F = 1.76998 + 1.179312\ M - 0.0074865\ M^2 + (2.85855E\text{-}05)M^3$$

Nomenclature for Equation B16 in GEOCOST

Symbol	FORTRAN Name of Variable	Definition
D	EQDIA	Diameter, ft
F	F	Ratio of two-phase Reynolds number to liquid Reynolds number
h_{mac}	FTHTCO	Macroconvective heat transfer coefficient, Btu/hr-ft^2-°F
K_L	PCONDL	Liquid thermal conductivity Btu/hr-ft-°F
Pr_L	PRANOL	Liquid Prandtl number
Re_L	REYNOL	Liquid Reynolds number

(B17) Dittus - Boelter Equation for Predicting the Convective Heat Transfer Coefficient for Fully Developed Turbulent Flow in Smooth Tubes

$$h_{conv} = 0.023\ Re_d^{0.8}\ Pr^x\ \frac{K}{d}$$

Nomenclature for Equation B17 in GEOCOST

Symbol	FORTRAN Name of Variable	Definition
d	DIA	Tube diameter, ft
h_{conv}	HTCOEF	Convective heat transfer coefficient, Btu/hr-ft^2-°F
K	COND	Thermal conductivity, Btu/hr-ft-°F
Pr	PRANO	Prandtl number
Re_d	REYNO	Reynolds number based on tube diameter
x	EXPN	0.4 when fluid is being heated, 0.3 when fluid is being cooled

APPENDIX C

DIMENSIONAL RESTRICTIONS ON INPUT DATA

APPENDIX C

DIMENSIONAL RESTRICTIONS ON INPUT DATA

The nodal arrays beginning with NODE and ending with EWH in the FORTRAN code for subroutine TRANS, which are used in modeling the fluid conduction and degradation in the fluid transmission submodel, are dimensioned 25 x 25 to accommodate a maximum well field size of 625 wells. Selection of low wellhead temperatures and low flow rates in the input data could result in more than 625 wells. This will cause the program to abnormally terminate and print an error message indicating that the dimensions have been exceeded. Since no dynamic storage is used and no economically viable geothermal plant is likely to require 625 wells, these dimensions could be reduced to 20 x 20 or 15 x 15 if memory size is a problem at the user's computing facilities.

The nodal arrays are currently equivalenced to 9425 decimal locations in the blank common array CCC. A set of economic arrays beginning with CAP and ending with BPSALE, which are used in the reservoir and power plant economic submodels, are equivalenced to the first 6950 decimal locations in the array CCC. The nodal and economic arrays are permitted to share the same locations in blank common to conserve memory, since they are required at different times in the program execution and need not be saved. A reduction in the dimension of the well field to 15 x 15 (225 wells) would permit equivalencing the nodal arrays to the first 3390 decimal locations in the array CCC. The dimension of the CCC array could then be reduced to 6950, the maximum size based upon the economic arrays. The result would be a reduction in memory requirements of 2475 decimal (4653 octal) words. The following changes would also be necessary in the code:

1) Reset MD and KD to 15 in subroutine DBINRY
2) Reset NDUP used in subroutine TRANS to 15 in BLOCK DATA
3) Change the FORTRAN statement, CALL CLEAR [CCC(1276),MK],to read CALL CLEAR [CCC(466),MK] in subroutine TSTART.

If the user wishes to modify the code in this manner, any questions should be directed to the authors of this manual.

The majority of the reservoir and power plant economic arrays are dimensioned to reflect a maximum operating period of 50 yr. The cumulative effect of a reduction in the maximum time period to 40 yr and the maximum well field size to 15 x 15 would permit reducing the dimension of the blank common array CCC from 9425 to 5560 decimal. This is a reduction of 3865 decimal (7431 octal) words. A change in the dimensions of the economic arrays from the current size of 50 will require careful examination of the reservoir and power plant economic subroutines since some slight changes in the code will be required at various places.

APPENDIX D

LISTING OF SAMPLE CASE OUTPUT

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

B I N A R Y P O W E R P L A N T S Y S T E M A N D T R A N S M I S S I O N M O D E L

THE WORKING FLUID IS ISOBUTANE
THE CYCLE IS SUB-CRITICAL

COOLING WATER	
TURBINE OIL COOLER	
INLET TEMPERATURE (DEG. F)	6.200000E+01
OUTLET TEMPERATURE (DEG. F)	1.200000E+02
FLOW RATE (LB/HR)	1.616547E+04
HYDROGEN COOLER	
INLET TEMPERATURE (DEG. F)	6.200000E+01
OUTLET TEMPERATURE (DEG. F)	1.200000E+02
FLOW RATE (LB/HR)	6.142880E+04

FINAL CYCLE CONDITIONS

WORKING FLUID CONDITIONS

TEMPERATURES (DEG. F)	
APPHX-HEAT EXCHANGER APPROACH	3.000000E+01
T1-TURBINE INLET	3.257216E+02
T2EST-TURBINE OUTLET (IDEAL)	2.068035E+02
T2-TURBINE OUTLET (ACTUAL)	2.241968E+02
T2SATL-CONDENSER OUTLET	9.200000E+01
T3-PREHEATER INLET	9.590598E+01
T4-VAPORIZER INLET	2.549341E+02
T5-SUPERHEATER INLET	2.549341E+02
PRESSURES (PSIA)	
P1-TURBINE INLET	4.421796E+02
P2-TURBINE EXHAUST	6.493394E+01
P3-PREHEATER INLET	4.421796E+02
P4-VAPORIZER INLET	4.421796E+02
P5-SUPERHEATER INLET	4.421796E+02
SPECIFIC VOLUMES (CU.FT./LB)	
V1-TURBINE INLET	2.392818E-01
V2EST-TURBINE OUTLET (IDEAL)	1.764268E+00
ENTHALPY (BTU/LB)	
H1-TURBINE INLET	-5.576894E+02
H2-TURBINE EXHAUST	-5.895365E+02
H2EST-TURBINE OUTLET (IDEAL)	-5.982543E+02
H3-PREHEATER INLET	-7.886563E+02
H4-VAPORIZER INLET	-6.661859E+02
H5-SUPER HEATER INLET	-6.109138E+02
ENTROPY (BTU/LB/DEG. F)	
S1-TURBINE INLET	1.251203E+00
S2EST-TURBINE OUTLET (IDEAL)	1.251203E+00

GEOTHERMAL FLUID CONDITIONS

WATER TEMPERATURES (DEG F)	
WT1-SUPER HEATER INLET	3.557216E+02
WT2-VAPORIZER INLET	3.164122E+02
WT3-PREHEATER INLET	2.749341E+02
WT4-PREHEATER EXIT (PRESET)	1.800000E+02
ESTWT4-PREHEATER EXIT (ACTUAL)	1.837415E+02
DELPHX-TOTAL PRESSURE DROP	7.500000E+01
TURBINE EFFICIENCY	
IDEAL RANKINE EFFICIENCY	1.739092E-01
ACTUAL RANKINE EFFICIENCY	1.367469E-01
OVERALL TURBINE EFFICIENCY	7.863236E-01

HEAT EXCHANGERS SUB-CRITICAL CYCLE
TEMPERATURE (DEG. F) - PRESSURE (PSIA) - ENTHALPY (BTU/LB)

	SUPER HEATER	VAPORIZER	PREHEATER
WORKING FLUID			
INLET TEMPERATURE	2.549341E+02	2.549341E+02	9.598698E+01
INLET PRESSURE	4.421796E+02	4.421796E+02	4.421796E+02
INLET ENTHALPY	-6.109136E+02	-5.661859E+02	-7.886563E+02
OUTLET TEMPERATURE	3.257216E+02	2.549341E+02	2.549341E+02
OUTLET PRESSURE	4.421796E+02	4.421796E+02	4.421796E+02
OUTLET ENTHALPY	-5.576894E+02	-6.109136E+02	-5.661859E+02
GEOTHERMAL FLUID			
INLET TEMPERATURE	3.557216E+02	3.164122E+02	2.749341E+02
INLET PRESSURE	2.297970E+02	2.047970E+02	1.797970E+02
OUTLET TEMPERATURE	3.164122E+02	2.749341E+02	1.837415E+02
OUTLET PRESSURE	2.047970E+02	1.797970E+02	1.547970E+02
INSIDE TUBE DIAMETER (FT)	1.000000E-01	1.000000E-01	1.000000E-01
OUTSIDE TUBE DIAMETER(FT)	1.104000E-01	1.104000E-01	1.104000E-01
NUMBER OF TUBES	6.190000E+02	5.040000E+02	5.850000E+02
EQUIVALENT OUTSIDE DIAMETER (FT)	1.078814E-01	1.078814E-01	1.078814E-01
INSIDE HEAT TRANSFER COEFFICIENT (BTU/HR/SQ.FT./DEG. F)	3.075677E+03	2.800756E+03	2.341804E+03
OUTSIDE HEAT TRANSFER COEFFICIENT (BTU/HR/SQ.FT./DEG. F)	5.674672E+02	2.451740E+03	7.199818E+02
OVERALL HEAT TRANSFER COEFFICIENT (BTU/HR/SQ.FT./DEG. F)	2.356702E+02	3.351092E+02	2.473775E+02
HEAT TRANSFER AREA (SQ.FT.)	3.030672E+04	2.628990E+04	6.358126E+04
HEAT TRANSFER LENGTH (FT.)	1.411654E+02	1.254956E+02	3.133670E+02

MAIN CONDENSER
TEMPERATURE (DEG. F) - PRESSURE (PSIA) - ENTHALPY (BTU/LB)

	DESUPERHEATER	CONDENSER
WORKING FLUID		
INLET TEMPERATURE	2.241968E+02	9.200000E+01
INLET PRESSURE	6.493994E+01	6.493994E+01
INLET ENTHALPY	-5.895865E+02	-6.531033E+02
OUTLET TEMPERATURE	9.200000E+01	9.200000E+01
OUTLET PRESSURE	6.493994E+01	6.493994E+01
OUTLET ENTHALPY	-6.531033E+02	-7.886563E+02
COOLING WATER		
INLET TEMPERATURE	7.908658E+01	6.200000E+01
INLET PRESSURE	5.145814E+01	5.500000E+01
OUTLET TEMPERATURE	8.700000E+01	7.908658E+01
OUTLET PRESSURE	4.500000E+01	5.145814E+01
INSIDE TUBE DIAMETER (FT)	7.500000E-02	7.500000E-02
OUTSIDE TUBE DIAMETER(FT)	8.330000E-02	8.330000E-02
NUMBER OF TUBES	5.957000E+03	5.944000E+03
EQUIVALENT OUTSIDE DIAMETER (FT)	8.139963E-02	8.139963E-02
INSIDE HEAT TRANSFER COEFFICIENT (BTU/HR/SQ.FT./DEG. F)	2.814879E+03	1.997333E+03
OUTSIDE HEAT TRANSFER COEFFICIENT (BTU/HR/SQ.FT./DEG. F)	1.316453E+02	1.583436E+03
OVERALL HEAT TRANSFER COEFFICIENT (BTU/HR/SQ.FT./DEG. F)	9.715224E+01	3.000001E+02
HEAT TRANSFER AREA (SQ.FT.)	7.316839E+04	1.334499E+05
HEAT TRANSFER LENGTH (FT.)	4.694818E+01	8.579133E+01

SUBROUTINE TOWER -- COOLING TOWER

APPCT-APPROACH TO COOLING TOWER (F)	1.200000E+01
COOLING TOWER AIR FLOW RATE (CFM)	6.322239E+06
COOLING TOWER EVAPORATION RATE (LB/HR)	9.445719E+05
WET BULB AIR TEMPERATURE (F)	5.000000E+01
DRY BULB AIR TEMPERATURE (F)	7.000000E+01
BAROMETRIC PRESSURE (IN. HG)	2.992000E+01
HUMIDITY RATIO	2.000000E-01
HEAT LOAD (BTU/HR)	1.154436E+09

COOLING WATER REQUIREMENTS (LB/HR)

TURBINE OIL COOLER	1.516547E+04
HYDROGEN COOLER	6.142880E+04
APPCON-APPROACH TO CONDENSER (F)	3.000000E+01
RANGE-COOLING WATER RANGE (F)	2.500000E+01
FLOW RATE IN CONDENSER	4.720735E+07
MAKEUP FLOW RATE TO COOLING TOWER	9.445719E+05

KILOWATT LOSSES

FANS	1.220970E+03
CONDENSATE PUMPS TO COOLING TOWER	1.146766E+03
COOLING WATER PUMPS	2.146313E+03
REINJECTION PUMPS	4.357460E+02
BOOSTER PUMPS TO OVERPRESSURIZE WATER	7.993104E+01
DOWNHOLE PUMPS TO PREVENT TWO PHASE FLOW	0.
BOOSTER PUMPS	2.191199E+02
FEED PUMPS	3.913915E+03

OVERALL RESULTS

GROSS KILOWATT OUTPUT OF THE PLANT	5.500000E+04
GEOTHERMAL FLUID FLOW RATE (LB/HR) (INCLUDING SALT)	8.157497E+06
FLOW RATE (LB/HR) OF ISOBUTANE	5.887471E+06
COOLING WATER FLOW RATE (LB/HR)	4.728494E+07
TOTAL KILOWATT LOSSES	9.112761E+03
NET KILOWATT OUTPUT	4.588724E+04
NET HEAT RATE (BTU/KW HR)	5.259607E+04

INPUT CONDITIONS -- TRANSMISSION MODEL

GEOTHERMAL PLANT TYPE	BINARY
GEOPRESSURE OPTION	0
WELLHEAD TEMPERATURE (F)	3.560000E+02
WELLHEAD PRESSURE AT SATURATION (PSIA)	1.454240E+02
WELLHEAD FLUID STATE	COMPRESSED
WATER OVERPRESSURIZATION FACTOR	2.000000E+00
ADJUSTED OVERPRESSURIZATION FACTOR	1.663389E+00
MAXIMUM FLOW RATE/WELL (LB/SEC)	1.388889E+02
WELL SPACING (ACRES)	2.000000E+01
FRACTION EXCESS PRODUCING WELLS	2.000000E-01
FRACTION NONPRODUCING WELLS	0.
WELL LIFE (YRS)	1.500000E+01
MAXIMUM ROWS IN WELL DESIGN MATRIX	25
MAXIMUM COLUMNS IN WELL DESIGN MATRIX	25
TRANSMISSION MAINTENANCE FACTOR	5.000000E-02
DISPOSAL MAINTENANCE FACTOR	5.000000E-02
FRACTION OF PIPE THAT CAN BE SALVAGED	1.000000E-01
PLANT AVAILABILITY (HRS/YR)	7.013760E+03
TOTAL FLOW RATE REQUIRED BY PLANT (LB/HR)	8.057497E+06
OPTIONAL INJECTION WELLS USING PLANT EFFLUENT	1
DISTANCE FROM PLANT TO INJECTION WELLS (M)	1.000000E+03
RATIO OF INJECTION/PRODUCTION WELL FLOW RATE	2.000000E+00
REINJECTION PUMPING OPTION	1
LABOR COST FOR PIPE INSULATION ($/FT)	4.500000E+00
OPTION TO REDUCE NODAL RECOMPUTATION	1
VALUE OF OUTPUT ELECTRIC ENERGY (EVALUE)	2.000000E-02
ANNUALIZED COST FACTOR	1.220183E-01
NET HEAT RATE FOR TRANSMISSION LINE(S) (KWT/KWE)	1.540155E+01

NODAL FLUID TRANSMISSION THERMODYNAMIC DEGRADATION FOR LINE 1

NODE I	J	ITR	MIX	FLUID STATE	STEAM FRACT	FLOW RATE (LB/SEC)	HEAT LOSS (BTU/SEC-FT)	TEMP (F)	PRES(PSIA)	SATURATION PRES(PSIA)	ENTHALPY (BTU/LB)	PIPE SCHD	INTER DIAM(IN)	EXTER DIAM(IN)	INSUL THK(IN)
6	2	1		COMPRESSED	0.0000	112.	0.000	356.000	241.897	145.424	328.300	10.	8.704	10	5.000
6	2	2		COMPRESSED	0.0000	112.	.023	355.878	238.919	145.198	328.194	10.	8.704	10	5.000
6	2	3		COMPRESSED	0.0000	112.	.023	355.878	238.919	145.198	328.194	10.	8.704	10	5.000
6	1	1		COMPRESSED	0.0000	112.	0.000	355.878	238.919	145.198	328.194	10.	8.704	10	5.000
6	1	2		COMPRESSED	0.0000	112.	.023	355.687	235.941	144.843	327.888	10.	8.704	10	5.000
6	1	3		COMPRESSED	0.0000	112.	.023	355.687	235.941	144.843	327.886	10.	8.704	10	5.000
5	3	0		COMPRESSED	0.0000	112.	.023	355.878	238.919	145.198	328.194	10.	8.704	10	5.000
5	2	1	M	COMPRESSED	0.0000	224.	0.000	355.976	238.919	145.379	328.197	10.	12.037	14	5.000
5	2	2		COMPRESSED	0.0000	224.	.030	355.651	236.699	145.148	328.062	10.	12.037	14	5.000
5	2	3		COMPRESSED	0.0000	224.	.030	355.651	236.699	145.148	328.062	10.	12.037	14	5.000
5	1	1	M	COMPRESSED	0.0000	336.	0.000	355.797	235.941	145.047	328.004	10.	14.552	16	5.000
5	1	2		COMPRESSED	0.0000	336.	.033	355.705	234.072	144.877	327.905	10.	14.552	16	5.000
4	4	0		COMPRESSED	0.0000	112.	.023	355.878	238.919	145.198	328.194	10.	8.704	10	5.000
4	3	0	M	COMPRESSED	0.0000	224.	.030	355.651	236.699	145.148	328.062	10.	12.037	14	5.000
4	2	1	M	COMPRESSED	0.0000	336.	0.000	355.927	236.699	145.288	328.142	10.	14.552	16	5.000
4	2	2		COMPRESSED	0.0000	336.	.033	355.834	234.838	145.117	328.042	10.	14.552	16	5.000
4	1	1	M	COMPRESSED	0.0000	671.	0.000	355.770	234.072	144.998	327.973	10.	20.132	22	5.000
4	1	2		COMPRESSED	0.0000	671.	.043	355.711	232.682	144.888	327.909	10.	20.132	22	5.000
3	5	0		COMPRESSED	0.0000	112.	.023	355.878	238.919	145.198	328.194	10.	8.704	10	5.000
3	4	0	M	COMPRESSED	0.0000	224.	.030	355.651	236.699	145.148	328.062	10.	12.037	14	5.000
3	3	0	M	COMPRESSED	0.0000	336.	.033	355.834	234.838	145.117	328.042	10.	14.552	16	5.000
3	2	1	M	COMPRESSED	0.0000	448.	0.000	355.896	234.838	145.230	328.186	10.	16.651	18	5.000
3	2	2		COMPRESSED	0.0000	448.	.037	355.820	233.178	145.090	328.024	10.	16.651	18	5.000
3	1	1	M	COMPRESSED	0.0000	1119.	0.000	355.755	232.682	144.969	327.955	10.	25.578	26	6.000
3	1	2		COMPRESSED	0.0000	1119.	.042	355.721	231.565	144.905	327.917	10.	25.578	26	6.000
2	6	0		COMPRESSED	0.0000	112.	.023	355.878	238.919	145.198	328.194	10.	8.704	10	5.000
2	5	0	M	COMPRESSED	0.0000	224.	.030	355.651	236.699	145.148	328.062	10.	12.037	14	5.000

2	4	0	M	COMPRESSED	0.0000	336.	.033	355.834	234.830	145.117	328.042	10.	14.552	16	5.000
2	3	0	M	COMPRESSED	0.0000	448.	.037	355.620	233.178	145.090	328.024	10.	16.651	18	5.000
2	2	1	M	COMPRESSED	0.0000	560.	0.000	355.873	233.178	145.187	328.079	10.	18.484	20	5.000
2	2	2		COMPRESSED	0.0000	560.	.040	355.807	231.675	145.065	328.038	10.	18.484	20	5.000
2	1	1	M	COMPRESSED	0.0000	1679.	0.000	355.749	231.565	144.959	327.947	10.	30.934	32	6.000
2	1	2		COMPRESSED	0.0000	1679.	.050	355.722	230.626	144.909	327.918	10.	30.934	32	6.000
1	5	0		COMPRESSED	0.0000	112.	.023	355.670	238.919	145.198	328.134	10.	8.704	10	5.000
1	5	0	M	COMPRESSED	0.0000	224.	.030	355.651	236.699	145.146	328.062	10.	12.037	14	5.000
1	4	0	M	COMPRESSED	0.0000	336.	.033	355.834	234.830	145.117	328.042	10.	14.552	16	5.000
1	3	0	M	COMPRESSED	0.0000	448.	.037	355.620	233.178	145.090	328.024	10.	16.651	18	5.000
1	2	0	M	COMPRESSED	0.0000	560.	.040	355.807	231.675	145.065	328.038	10.	18.484	20	5.000
1	1	1	M	COMPRESSED	0.0000	2238.	0.000	355.744	230.626	144.948	327.940	10.	35.401	36	6.000
1	1	2		COMPRESSED	0.0000	2238.	.055	355.722	229.797	144.907	327.916	10.	35.401	36	6.000

TRANSMISSION DESIGN, THERMODYNAMICS, AND COST

LINE NUMBER 1 (WATER)

INLET TEMPERATURE INTO LINE	3.560000E+02	(F)
INLET PRESSURE INTO LINE	2.418967E+02	(PSIA)
INLET ENTHALPY INTO LINE	3.282998E+02	(BTU/LB)
NUMBER OF TRANSMISSION LINES INTO PLANT	1	(LINES)
NUMBER OF PRODUCING WELLS	20	(WELLS)
NUMBER OF DRY WELLS	0	(WELLS)
ACTUAL WELL FLOW RATE	1.119097E+02	(LBM/SEC)
EFFECTIVE WELL SPACING	2.000000E+01	(ACRES)
PIPE LENGTH BETWEEN NODES	3.057090E+02	(METERS)

WELLFIELD DESIGN LATTICE WITH ACTIVE WELLS NUMBERED

PLANT COL 1 = MANIFOLD NODES, OTHER COLS = WELL NODES

0	1	3	6	10	15
0	2	5	9	14	20
0	4	8	13	19	0
0	7	12	18	0	0
0	11	17	0	0	0
0	16	0	0	0	0

NUMBER OF UPSTREAM WELLS FLOWING INTO EACH NODE

PLANT COL 1 = MANIFOLD NODES, OTHER COLS = WELL NODES

20	5	4	3	2	1
15	5	4	3	2	1
10	4	3	2	1	0
6	3	2	1	0	0
3	2	1	0	0	0
1	1	0	0	0	0

INITIAL WELLHEAD CONDITIONS

TEMPERATURE (F) COL 1 = MANIFOLD NODES, OTHER COLS = WELL NODES

	COL 1	COL 2	COL 3	COL 4	COL 5	COL 6
ROW 1	0.	3.560000E+02	3.560000E+02	3.560000E+02	3.560000E+02	3.560000E+02
ROW 2	0.	3.560000E+02	3.560000E+02	3.560000E+02	3.560000E+02	3.560000E+02
ROW 3	0.	3.560000E+02	3.560000E+02	3.560000E+02	3.560000E+02	0.
ROW 4	0.	3.560000E+02	3.560000E+02	3.560000E+02	0.	0.
ROW 5	0.	3.560000E+02	3.560000E+02	0.	0.	0.
ROW 6	0.	3.560000E+02	0.	0.	0.	0.

PRESSURE (PSIA)

	COL 1	COL 2	COL 3	COL 4	COL 5	COL 6
ROW 1	0.	2.418967E+02	2.418967E+02	2.418967E+02	2.418967E+02	2.418967E+02
ROW 2	0.	2.418967E+02	2.418967E+02	2.418967E+02	2.418967E+02	2.418967E+02
ROW 3	0.	2.418967E+02	2.418967E+02	2.418967E+02	2.418967E+02	0.

ROW	4	0.	2.418967E+02	2.418967E+02	2.418967E+02	0.	0.
ROW	5	0.	2.418967E+02	2.418967E+02	0.	0.	0.
ROW	6	0.	2.418967E+02	0.	0.	0.	0.

VISCOSITY (LB/FT-SEC)

		COL 1	COL 2	COL 3	COL 4	COL 5	COL 6
ROW	1	0.	8.708804E-05	8.708804E-05	8.708804E-05	8.708804E-05	8.708804E-05
ROW	2	0.	8.708804E-05	8.708804E-05	8.708804E-05	8.708804E-05	8.708804E-05
ROW	3	0.	8.708804E-05	8.708804E-05	8.708804E-05	8.708804E-05	0.
ROW	4	0.	8.708804E-05	8.708804E-05	8.708804E-05	0.	0.
ROW	5	0.	8.708804E-05	8.708804E-05	0.	0.	0.
ROW	6	0.	8.708804E-05	0.	0.	0.	0.

DENSITY (LB/CU FT)

		COL 1	COL 2	COL 3	COL 4	COL 5	COL 6
ROW	1	0.	5.665323E+01	5.665323E+01	5.665323E+01	5.665323E+01	5.665323E+01
ROW	2	0.	5.665323E+01	5.665323E+01	5.665323E+01	5.665323E+01	5.665323E+01
ROW	3	0.	5.665323E+01	5.665323E+01	5.665323E+01	5.665323E+01	0.
ROW	4	0.	5.665323E+01	5.665323E+01	5.665323E+01	0.	0.
ROW	5	0.	5.665323E+01	5.665323E+01	0.	0.	0.
ROW	6	0.	5.665323E+01	0.	0.	0.	0.

NODAL EXIT CONDITIONS AFTER DEGRADATION AND MIXING

TEMPERATURE (F) COL 1 = MANIFOLD NODES, OTHER COLS = WELL NODES

		COL 1	COL 2	COL 3	COL 4	COL 5	COL 6
ROW	1	3.557438E+02	3.558725E+02	3.558958E+02	3.559266E+02	3.559760E+02	3.560000E+02
ROW	2	3.557494E+02	3.558725E+02	3.558956E+02	3.559266E+02	3.559760E+02	3.560000E+02
ROW	3	3.557552E+02	3.558958E+02	3.559266E+02	3.559760E+02	3.560000E+02	0.
ROW	4	3.557704E+02	3.559266E+02	3.559760E+02	3.560000E+02	0.	0.
ROW	5	3.557972E+02	3.559760E+02	3.560000E+02	0.	0.	0.
ROW	6	3.558782E+02	3.560000E+02	0.	0.	0.	0.

PRESSURE (PSIA)

		COL 1	COL 2	COL 3	COL 4	COL 5	COL 6
ROW	1	2.306264E+02	2.331778E+02	2.348304E+02	2.366988E+02	2.389188E+02	2.418967E+02
ROW	2	2.315649E+02	2.331778E+02	2.348304E+02	2.366988E+02	2.389188E+02	2.418967E+02
ROW	3	2.326828E+02	2.348304E+02	2.366988E+02	2.389188E+02	2.418967E+02	0.
ROW	4	2.340721E+02	2.366988E+02	2.389188E+02	2.418967E+02	0.	0.
ROW	5	2.359486E+02	2.389188E+02	2.418967E+02	0.	0.	0.
ROW	6	2.389188E+02	2.418967E+02	0.	0.	0.	0.

VISCOSITY (LB/FT-SEC)

		COL 1	COL 2	COL 3	COL 4	COL 5	COL 6
ROW	1	8.721217E-05	8.714979E-05	8.713851E-05	8.712359E-05	8.709964E-05	8.708804E-05
ROW	2	8.720947E-05	8.714979E-05	8.713851E-05	8.712359E-05	8.709964E-05	8.708804E-05
ROW	3	8.720668E-05	8.713851E-05	8.712359E-05	8.709964E-05	8.708804E-05	0.
ROW	4	8.719938E-05	8.712359E-05	8.709964E-05	8.708804E-05	0.	0.
ROW	5	8.718628E-05	8.709964E-05	8.708804E-05	0.	0.	0.
ROW	6	8.714705E-05	8.708804E-05	0.	0.	0.	0.

DENSITY (LB/CU FT)

		COL 1	COL 2	COL 3	COL 4	COL 5	COL 6
ROW	1	5.665961E+01	5.665547E+01	5.665508E+01	5.665447E+01	5.665325E+01	5.665323E+01
ROW	2	5.665968E+01	5.665547E+01	5.665508E+01	5.665447E+01	5.665325E+01	5.665323E+01
ROW	3	5.665980E+01	5.665508E+01	5.665447E+01	5.665325E+01	5.665323E+01	0.
ROW	4	5.665963E+01	5.665447E+01	5.665325E+01	5.665323E+01	0.	0.
ROW	5	5.665917E+01	5.665325E+01	5.665323E+01	0.	0.	0.
ROW	6	5.665698E+01	5.665323E+01	0.	0.	0.	0.

INTERNAL PIPE DIAMETER (IN)

	COL 1	COL 2	COL 3	COL 4	COL 5	COL 6
ROW 1	3.540137E+01	1.848445E+01	1.665060E+01	1.455200E+01	1.203656E+01	8.703734E+00
ROW 2	3.093362E+01	1.848445E+01	1.665060E+01	1.455200E+01	1.203656E+01	8.703734E+00
ROW 3	2.557778E+01	1.665060E+01	1.455200E+01	1.203656E+01	8.703734E+00	0.
ROW 4	2.013239E+01	1.455200E+01	1.203656E+01	8.703734E+00	0.	0.
ROW 5	1.495188E+01	1.203656E+01	8.703734E+00	0.	0.	0.
ROW 6	8.703654E+00	8.703734E+00	0.	0.	0.	0.

PIPE INSULATION THICKNESS (IN)

	COL 1	COL 2	COL 3	COL 4	COL 5	COL 6
ROW 1	6.000000E+00	5.000000E+00	5.000000E+00	5.000000E+00	5.000000E+00	5.000000E+00
ROW 2	6.000000E+00	5.000000E+00	5.000000E+00	5.000000E+00	5.000000E+00	5.000000E+00
ROW 3	6.000000E+00	5.000000E+00	5.000000E+00	5.000000E+00	5.000000E+00	0.
ROW 4	5.000000E+00	5.000000E+00	5.000000E+00	5.000000E+00	0.	0.
ROW 5	5.000000E+00	5.000000E+00	5.000000E+00	0.	0.	0.
ROW 6	5.000000E+00	5.000000E+00	0.	0.	0.	0.

P L A N T I N L E T C O N D I T I O N S
(INCLUDES DEGRADATION FROM LAST NODE TO PLANT)

FLOW RATE	8.057497E+06	(LBM/HR)
TEMPERATURE	3.557216E+02	(F)
PRESSURE	2.297370E+02	(PSIA)
ENTHALPY	3.279155E+02	(BTU/LB)

T R A N S M I S S I O N S Y S T E M C O S T S (*)

TOTAL TRANSMISSION COST	2.693756E+06
PIPE COST	1.925369E+06
INSULATION COST	4.547513E+05
WELLHEAD VALVES	1.000000E+05
PRESSURE INSTRUMENTS	2.000000E+04
ROCK SEPARATORS	1.000000E+05
CYCLONE SEPARATOR	3.500000E+04
MUFFLING DRAG VALVES	0.
TRANSMISSION BOOSTER PUMPS	5.863599E+04
TRANSMISSION MAINTENANCE COST	1.346878E+05
TRANSMISSION CAPITAL REPLACEMENT	6.000000E-02 (RATE)

POWERPLANT-FLUID TRANSMISSION CONVERGENCE TEST

PREVIOUS GEOTHERMAL FLOW RATE DEMANDED BY PLANT (LBM/HR)	8.057594E+06
CURRENT GEOTHERMAL FLOW RATE DEMANDED BY PLANT (LBM/HR)	8.057497E+06
DIFFERENCE (LBM/HR)	-9.706017E+01
DIFFERENCE (PER CENT)	1.204595E-03
CONVERGENCE CRITERION (PER CENT)	2.000000E+00

POWERPLANT AND FLUID TRANSMISSION MODELS SATISFY CONVERGENCE CRITERION

NUMBER OF POWERPLANT - FLUID TRANSMISSION ITERATIONS	3
DISPOSAL/INJECTION PIPING ANNUALIZED COST FACTOR	1.220183E-01

PIPE FROM PLANT TO INJECTION FIELD

FLUID TEMPERATURE (F)	1.837415E+02	FLUID PRESSURE (PSIA)	2.047970E+02	PIPE LENGTH (M)	1.000000E+03
INTERNAL DIAMETER (IN)	2.649920E+01	PIPE SCHEDULE	1.000000E+01	PIPE COST ($)	4.553308E+05

INJECTION (PLANT) DESIGN, THERMODYNAMICS, AND COST (NO FLUID DEGRADATION)

NUMBER OF INJECTION WELLS 9 (WELLS)

ACTUAL WELL FLOW RATE 2.486882E+02 (LBM/SEC)

WELLFIELD DESIGN LATTICE WITH ACTIVE WELLS NUMBERED

PLANT COL 1 = MANIFOLD NODES, OTHER COLS = WELL NODES

0	1	3	6
0	2	5	9
0	4	8	0
0	7	0	0

NUMBER OF UPSTREAM WELLS FLOWING INTO EACH NODE

PLANT COL 1 = MANIFOLD NODES, OTHER COLS = WELL NODES

9	3	2	1
6	3	2	1
3	2	1	0
1	1	0	0

INITIAL WELLHEAD CONDITIONS

TEMPERATURE (F) COL 1 = MANIFOLD NODES, OTHER COLS = WELL NODES

	COL 1	COL 2	COL 3	COL 4
ROW 1	0.	1.837415E+02	1.837415E+02	1.837415E+02
ROW 2	0.	1.837415E+02	1.837415E+02	1.837415E+02
ROW 3	0.	1.837415E+02	1.837415E+02	0.
ROW 4	0.	1.837415E+02	0.	0.

PRESSURE (PSIA)

	COL 1	COL 2	COL 3	COL 4
ROW 1	0.	2.047970E+02	2.047970E+02	2.047970E+02
ROW 2	0.	2.047970E+02	2.047970E+02	2.047970E+02
ROW 3	0.	2.047970E+02	2.047970E+02	0.
ROW 4	0.	2.047970E+02	0.	0.

VISCOSITY (LB/FT-SEC)

	COL 1	COL 2	COL 3	COL 4
ROW 1	0.	2.434271E-04	2.434271E-04	2.434271E-04
ROW 2	0.	2.434271E-04	2.434271E-04	2.434271E-04
ROW 3	0.	2.434271E-04	2.434271E-04	0.
ROW 4	0.	2.434271E-04	0.	0.

DENSITY (LB/CU FT)

	COL 1	COL 2	COL 3	COL 4
ROW 1	0.	6.189863E+01	6.189863E+01	6.189863E+01
ROW 2	0.	6.189863E+01	6.189863E+01	6.189863E+01
ROW 3	0.	6.189863E+01	6.189863E+01	0.
ROW 4	0.	6.189863E+01	0.	0.

NODAL EXIT CONDITIONS AFTER DEGRADATION AND MIXING

TEMPERATURE (F) COL 1 = MANIFOLD NODES, OTHER COLS = WELL NODES

	COL 1	COL 2	COL 3	COL 4
ROW 1	1.837415E+02	1.837415E+02	1.837415E+02	1.837415E+02
ROW 2	1.837415E+02	1.837415E+02	1.837415E+02	1.837415E+02
ROW 3	1.837415E+02	1.837415E+02	1.837415E+02	0.
ROW 4	1.837415E+02	1.837415E+02	0.	0.

PRESSURE (PSIA)

	COL 1	COL 2	COL 3	COL 4
ROW 1	2.047970E+02	2.047970E+02	2.047970E+02	2.047970E+02
ROW 2	2.047970E+02	2.047970E+02	2.047970E+02	2.047970E+02
ROW 3	2.047970E+02	2.047970E+02	2.047970E+02	0.
ROW 4	2.047970E+02	2.047970E+02	0.	0.

VISCOSITY (LB/FT-SEC)

	COL 1	COL 2	COL 3	COL 4
ROW 1	2.434271E-04	2.434271E-04	2.434271E-04	2.434271E-04
ROW 2	2.434271E-04	2.434271E-04	2.434271E-04	2.434271E-04
ROW 3	2.434271E-04	2.434271E-04	2.434271E-04	0.
ROW 4	2.434271E-04	2.434271E-04	0.	0.

DENSITY (LB/CU FT)

	COL 1	COL 2	COL 3	COL 4
ROW 1	6.189863E+01	6.189863E+01	6.189863E+01	6.189863E+01
ROW 2	6.189863E+01	6.189863E+01	6.189863E+01	6.189863E+01
ROW 3	6.189863E+01	6.189863E+01	6.189863E+01	0.
ROW 4	6.189863E+01	6.189863E+01	0.	0.

INTERNAL PIPE DIAMETER (IN)

	COL 1	COL 2	COL 3	COL 4
ROW 1	2.649920E+01	1.593403E+01	1.320673E+01	9.581167E+00
ROW 2	2.136355E+01	1.593403E+01	1.320673E+01	9.581167E+00
ROW 3	1.593403E+01	1.320673E+01	9.581167E+00	0.
ROW 4	9.581167E+00	9.581167E+00	0.	0.

DISPOSAL/INJECTION FLUID CONDITIONS

FLOW RATE 8.057497E+05 (LBM/HR)

TEMPERATURE 1.837415E+02 (F)

PRESSURE 2.047970E+02 (PSIA)

DISPOSAL/INJECTION SYSTEM COSTS ($)

TOTAL COST 1.342867E+06

MAINTENANCE COST 6.714333E+04

CAPITAL REPLACEMENT 6.000000E-02 (RATE)

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

ECONOMIC ANALYSIS FOR GEOTHERMAL POWER

HIGH TEMPERATURE-LOW SALINITY RESERVOIR

RESERVOIR CHARACTERISTICS

AVERAGE DEPTH	2000.0	M
AVERAGE TEMPERATURE	180.0	C
PRODUCING CAPACITY	275.0	MW(E)

FLUID COMPOSITION

CACO3	0.00	%	
NACL	3.00	%	
SIO2	.03	%	272. PPM
OTHER	0.00	%	
TOTAL DISSOLVED SOLIDS	3.03	%	

PH= 7.00

WELL DESIGN (AVERAGE)

DEPTH	2000.0	M
BOTTOM DIAMETER	22.225	CM
FRACTION CASED	1.00	

NONCONDENSIBLE GASES

H2S	.003	%	30. PPM
CO2	.097	%	
CH4	0.000	%	
OTHER	0.000	%	
TOTAL NONCONDENSIBLE GASES	.100	%	

WELL PROPERTIES (AVERAGE)

MW(TH)/WELL	43.6	
MW(E) /WELL (GROSS)	2.8	
MW(E) /WELL (NET)	2.3	
MAXIMUM FLOW RATE/WELL	500000.0	LB/HR
WELL LIFE	15.0	YEARS
PRODUCING WELLS ON LINE	20.0	
DRY WELLS	0.0	
INJECTION WELLS	9.0	
INPUT WELL SPACING	20.0	ACRES
ACTUAL FLOW RATE/WELL	402874.9	#/HR
TOTAL FLOW RATE	8057497.2	#/HR
WELL PRESSURE AT SATURATION	145.4	PSIA
WATER OVERPRESSURIZATION	2.000	
ADJUSTED OVERPRESSURIZATION	1.663	
WELL WATER PRESSURE	241.9	

STRATIGRAPHY

ROCK TYPE	DEPTH(M)
HARD	2000.0

RESERVOIR ECONOMIC DEVELOPMENT FACTORS

FAVORABLE TARGET FRACTION	.500
FAVORABLE SITE FRACTION	.500
FRACTION OF SITES TO EVALUATE	.667
FRACTION OF SITES TO DRILL	.750
FRACTION OF WELLS TO CASE	.250
FRACTION OF SITES TO DEVELOP	.250
PERCENT NONPRODUCING WELLS	0.0
INJECTION/PRODUCTION WELL FLOW RATE	2.000
FRACTION EXCESS PRODUCING WELLS	.20

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

RESERVOIR EXPLORATION COSTS

	TOTAL (DOLLARS)	CAPITALIZED (DOLLARS)	EXPENSED (DOLLARS)	FAVORABLE SITES	BEGINNING MONTH/YEAR	ENDING MONTH/YEAR
IDENTIFICATION OF TARGETS						
LITERATURE SEARCH	2560.	20.0	2540.0	128.	MAY/1970	OCT/1970
PRELIMINARY LAND CHECK	6400.	50.0	6350.0	128.	MAY/1970	OCT/1970
PRELIMINARY RECONNAISSANCE						
LITERATURE SEARCH	8960.	140.0	8820.0	64.	JUN/1970	DEC/1970
GEOLOGICAL RECONNAISSANCE	12800.	200.0	12600.0	64.	JUN/1970	DEC/1970
DETAILED LAND CHECK	15360.	240.0	15120.0	64.	JUN/1970	DEC/1970
DETAILED RECONNAISSANCE						
LEASE COST	384000.	12000.0	372000.0	32.	JUL/1970	MAY/1971
FIELD GEOLOGY	21000.	1000.0	20000.0	21.	SEP/1970	JUN/1971
GEOCHEMICAL EXAMINATION	25200.	1200.0	24000.0	21.	SEP/1970	JUN/1971
GEOPHYSICAL EXAMINATION	105000.	5000.0	100000.0	21.	SEP/1970	JUN/1971
IDENTIFICATION OF DRILLABLE SITES						
HEAT FLOW	38400.	2400.0	36000.0	16.	APR/1971	MAR/1973
TEMPERATURE GRADIENT	40000.	2500.0	37500.0	16.	APR/1971	MAR/1973
ELECTRICAL RESISTIVITY	11200.	700.0	10500.0	16.	APR/1971	MAR/1973
MICROSEISMIC	16000.	1000.0	15000.0	16.	APR/1971	MAR/1973
DETAILED GEOCHEMISTRY	24000.	1500.0	22500.0	16.	APR/1971	MAR/1973
EXPLORATION DRILLING						
COST OF DRILLING	280000.	23333.3	256666.7	4.	APR/1972	MAR/1974
WELL TESTING	8000.	2000.0	6000.0	4.	APR/1974	APR/1974
TOTAL EXPLORATION COST *	998880.	53283.3	945596.7	1.00		
FIELD DEVELOPMENT						
PRODUCING WELLS	8000000.	2666666.7	5333333.3		APR/1974	SEP/1977
NONPRODUCING WELLS	0.	0.0	0.0		APR/1974	SEP/1977
INJECTION WELLS	3150000.	3150000.0	0.0		OCT/1977	DEC/1979
TRANSMISSION SYSTEM	2693756.	2693756.3	0.0		OCT/1977	DEC/1979
DISPOSAL SYSTEM	1342867.	1342866.6	0.0		OCT/1977	DEC/1979
TOTAL FIELD DEVELOPMENT COST	15186623.					
FIELD OPERATION						
REPLACEMENT WELL COST	444444.	148148.1	296296.3		JAN/1980	DEC/2008
NONPRODUCING WELL DRILLING COST	0.	0.0	0.0		JAN/1980	DEC/2008
ABANDONMENT	13333.	0.0	0.0		JAN/1980	DEC/2009
WELL MAINTENANCE	29000.	0.0	0.0		JAN/1980	DEC/2009
OVERHEAD AND MANAGEMENT	231727.	0.0	0.0		JAN/1980	DEC/2009
WELL REDRILLING COST	100000.	0.0	0.0		JAN/1980	DEC/2009
INJECTION COST	0.	0.0	0.0		JAN/1980	DEC/2009
INJECTION WELL MTE.	0.	0.0	0.0		JAN/1980	DEC/2009
TRANSMISSION SYSTEM MTE.	134688.	0.0	0.0		JAN/1980	DEC/2009
DISPOSAL SYSTEM MTE.	67143.	0.0	0.0		JAN/1980	DEC/2009
TOTAL FIELD OPERATION COST	1019336.					

* TOTAL EXPLORATION COST ALLOCATED TO THIS 55. MWE POWER PLANT IS .2000 OF TOTAL EXPLORATION COST FOR THIS 275. MWE RESERVOIR PRODUCING CAPACITY

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

R E S E R V O I R I N P U T D A T A

BOND REPAYMENT PROPORTIONAL		
SUM OF YEARS DIGITS DEPRECIATION		
CAPITAL INVESTMENT, $M	9.9066	(INITIAL FINANCING)
PROJECT LIFE, YEARS	40.0000	
FRACTION OF INITIAL INVESTMENT IN BONDS	.4200	
BOND INTEREST RATE	.0800	
EQUITY EARNING RATE (AFTER TAXES)	.1500	
FEDERAL INCOME TAX RATE	.4800	
POWER PLANT SIZE (MWE)	55.0000	
DEPRECIABLE LIFE OF WELLS, YRS.	15.0000	
FIRST YEAR OF OPERATION	1980.	
STATE INCOME TAX RATE	.0700	
STATE GROSS REVENUE TAX RATE	0.0000	
PROPERTY TAX RATE	.0250	
DISPOSAL SYSTEM REPLACEMENT RATE	.0500	
TRANSMISSION SYSTEM REPLACEMENT RATE	.0600	
PROPERTY INSURANCE RATE	.0012	
ROYALTY PAYMENT,%	10.00	
PLANT OPERATING LIFE	30.0000	
TRANSMISSION SYSTEM MTE. RATE	.0500	
DISPOSAL SYSTEM MTE. RATE	.0500	
EVALUE	.020000	
GEOTHERMAL PLANT TYPE	1	
PLANT REINJECTION OPTION	1	
DISTANCE(M) PLANT TO INJECTION FIELD	1000.0000	
CASE GENERATION OPTION	0	
REINJECTION PUMP OPTION	1	
DRILLING COST PER PRODUCING WELL($)	400000.	
DRILLING COST PER NONPRODUCING WELL($)	380000.	
DRILLING COST PER INJECTION WELL($)	350000.	

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

ANNUAL CASH FLOW DATA, EXPENSES IN $M/YR

	YEAR	LOAD FACTOR	FIELD IDENT.	FIELD EXPLOR.	FIELD DEVELOPMENT	RESERVOIR OPERATION	PROPERTY TAXES AND INSURANCE	INTERIM CAPITAL REPLACEMENT	TOTAL
1	1978	0.00000	.00896	.30705	0.00000	0.00000	.00026	0.00000	.31628
2	1979	0.00000	0.00000	.31387	0.00000	0.00000	.00060	0.00000	.31447
3	1980	0.00000	0.00000	.16980	0.00000	0.00000	.00094	0.00000	.17074
4	1981	0.00000	0.00000	.15620	0.00000	0.00000	.00127	0.00000	.15747
5	1982	0.00000	0.00000	.04300	1.71429	0.00000	.01637	0.00000	1.77365
6	1983	0.00000	0.00000	0.00000	2.28571	0.00000	.03633	0.00000	2.32204
7	1984	0.00000	0.00000	0.00000	2.28571	0.00000	.05629	0.00000	2.34201
8	1985	0.00000	0.00000	0.00000	2.51280	0.00000	.09218	0.00000	2.60498
9	1986	0.00000	0.00000	0.00000	3.19405	0.00000	.17587	0.00000	3.36992
10	1987	0.00000	0.00000	0.00000	3.19405	0.00000	.25955	0.00000	3.45361
11	1988	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
12	1989	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
13	1990	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
14	1991	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
15	1992	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
16	1993	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
17	1994	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
18	1995	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
19	1996	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
20	1997	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
21	1998	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
22	1999	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
23	2000	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
24	2001	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
25	2002	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
26	2003	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
27	2004	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
28	2005	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
29	2006	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
30	2007	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
31	2008	.80000	0.00000	0.00000	0.00000	1.01934	.25955	.43120	1.71009
32	2009	.80000	0.00000	0.00000	0.00000	.57489	.25955	0.00000	.83444

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

ANNUAL DEDUCTIBLE EXPENSES, $M

	YEAR	10.325 PCT PRESENT WORTH FACTOR	FIELD OPERATING EXPENSES	BOND INTEREST	WELL DEPRECIATION	RESERVOIR DEPLETION AND DEPRECIATION	TOTAL DEDUCTIBLE OPER. EXP.	STATE INCOME TAXES
1	1978	.95266	.00474	0.00000	0.00000	0.00000	.00474	-.00033
2	1979	.86296	.16055	.01054	0.00000	0.00000	.17109	-.01196
3	1980	.78220	.09719	.01941	0.00000	0.00000	.11660	-.00816
4	1981	.70899	.22885	.02547	0.00000	0.00000	.25432	-.01780
5	1982	.64264	1.61656	.02942	0.00000	0.00000	1.64598	-.11522
6	1983	.58250	1.56014	.06400	0.00000	0.00000	1.62414	-.11369
7	1984	.52799	1.58010	.12156	0.00000	0.00000	1.70166	-.11912
8	1985	.47857	1.23504	.18539	0.00000	0.00000	1.42043	-.09943
9	1986	.43373	.17587	.27063	0.00000	0.00000	.44649	-.03125
10	1987	.39319	.25955	.40874	0.00000	0.00000	.66830	-.04678
11	1988	.35639	1.13074	.56249	.33333	.46543	2.49199	.18345
12	1989	.32304	1.13074	.56146	.44138	.85428	2.98846	.14976
13	1990	.29281	1.13074	.55171	.40494	.81379	2.90117	.15481
14	1991	.26540	1.13074	.54228	.37037	.77515	2.81854	.16060
15	1992	.24057	1.13074	.53316	.33627	.73637	2.74054	.16606
16	1993	.21805	1.13074	.52429	.30864	.70344	2.66711	.17120
17	1994	.19765	1.13074	.51562	.28148	.67036	2.59821	.17602
18	1995	.17915	1.13074	.50711	.25679	.63914	2.53378	.18053
19	1996	.16238	1.13074	.49868	.23457	.60978	2.47377	.18473
20	1997	.14719	1.13074	.49028	.21481	.58227	2.41811	.18863
21	1998	.13341	1.13074	.48184	.19753	.55661	2.36672	.19222
22	1999	.12093	1.13074	.47326	.18272	.53281	2.31953	.19553
23	2000	.10961	1.13074	.46448	.17037	.51087	2.27645	.19854
24	2001	.09935	1.13074	.45537	.16049	.49078	2.23738	.20126
25	2002	.09005	1.13074	.44565	.15309	.47254	2.20222	.20374
26	2003	.08163	1.13074	.43579	.14815	.45616	2.17084	.20594
27	2004	.07399	1.13074	.42507	.14815	.44163	2.14558	.20770
28	2005	.06706	1.13074	.41348	.14815	.42896	2.12133	.20940
29	2006	.06079	1.13074	.40192	.14815	.41814	2.09795	.21104
30	2007	.05510	1.13074	.38725	.14815	.40917	2.07531	.21262
31	2008	.04994	1.13074	.37233	.14815	.40206	2.05328	.21416
32	2009	.04527	1.13074	.35599	.14815	.39681	2.03168	.21568
33	2010	.04103	1.13074	.33805	.14815	.39341	2.01035	.21717
34	2011	.03719	1.13074	.31832	.14815	.39186	1.98907	.21866
35	2012	.03371	1.13074	.29658	.14815	.39217	1.96764	.22016
36	2013	.03056	1.13074	.27259	.14815	.39434	1.94581	.22169
37	2014	.02770	1.13074	.24606	.14815	.39835	1.92332	.22326
38	2015	.02510	1.13074	.21677	.14815	.40423	1.89988	.22490
39	2016	.02275	1.13074	.18432	.14815	.41195	1.87517	.22663
40	2017	.02063	.83444	.14840	.83951	4.58973	6.41213	-.09396
TOTALS=					6.96296	19.74463		

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

ANNUAL INCOME STATEMENT, $M

	YEAR	POWER UNITS (M MWH)	TOTAL POWER SALES	BY PRODUCT SALES	REVENUE TAXES	ROYALTY PAYMENTS EXPENSES	TOTAL TAX DEDUCTIBLE EXPENSES	TAXABLE INCOME (FEDERAL)	FEDERAL INCOME TAX
1	1970	0.00000	0.00000	0.00000	0.00000	0.00000	.00441	-.00441	-.00212
2	1971	0.00000	0.00000	0.00000	0.00000	0.00000	.15912	-.15912	-.07638
3	1972	0.00000	0.00000	0.00000	0.00000	0.00000	.10844	-.10844	-.05205
4	1973	0.00000	0.00000	0.00000	0.00000	0.00000	.23652	-.23652	-.11353
5	1974	0.00000	0.00000	0.00000	0.00000	0.00000	1.53076	-1.53076	-.73476
6	1975	0.00000	0.00000	0.00000	0.00000	0.00000	1.51045	-1.51045	-.72502
7	1976	0.00000	0.00000	0.00000	0.00000	0.00000	1.58254	-1.58254	-.75962
8	1977	0.00000	0.00000	0.00000	0.00000	0.00000	1.32100	-1.32100	-.63408
9	1978	0.00000	0.00000	0.00000	0.00000	0.00000	.41524	-.41524	-.19931
10	1979	0.00000	0.00000	0.00000	0.00000	0.00000	.62152	-.62152	-.29833
11	1980	.38576	5.68085	0.00000	0.00000	.56809	2.67544	2.43733	1.16992
12	1981	.38576	5.68085	0.00000	0.00000	.56809	3.13716	1.97561	.94829
13	1982	.38576	5.68085	0.00000	0.00000	.56809	3.05598	2.05679	.98726
14	1983	.38576	5.68085	0.00000	0.00000	.56809	2.97914	2.13363	1.02414
15	1984	.38576	5.68085	0.00000	0.00000	.56809	2.90660	2.20617	1.05896
16	1985	.38576	5.68085	0.00000	0.00000	.56809	2.83831	2.27446	1.09174
17	1986	.38576	5.68085	0.00000	0.00000	.56809	2.77423	2.33854	1.12250
18	1987	.38576	5.68085	0.00000	0.00000	.56809	2.71431	2.39846	1.15126
19	1988	.38576	5.68085	0.00000	0.00000	.56809	2.65850	2.45427	1.17805
20	1989	.38576	5.68085	0.00000	0.00000	.56809	2.60674	2.50603	1.20290
21	1990	.38576	5.68085	0.00000	0.00000	.56809	2.55895	2.55382	1.22583
22	1991	.38576	5.68085	0.00000	0.00000	.56809	2.51506	2.59771	1.24690
23	1992	.38576	5.68085	0.00000	0.00000	.56809	2.47500	2.63777	1.26613
24	1993	.38576	5.68085	0.00000	0.00000	.56809	2.43866	2.67411	1.28357
25	1994	.38576	5.68085	0.00000	0.00000	.56809	2.40596	2.70681	1.29927
26	1995	.38576	5.68085	0.00000	0.00000	.56809	2.37677	2.73600	1.31328
27	1996	.38576	5.68085	0.00000	0.00000	.56809	2.35329	2.75948	1.32455
28	1997	.38576	5.68085	0.00000	0.00000	.56809	2.33073	2.78204	1.33538
29	1998	.38576	5.68085	0.00000	0.00000	.56809	2.30698	2.80578	1.34582
30	1999	.38576	5.68085	0.00000	0.00000	.56809	2.28794	2.82483	1.35592
31	2000	.38576	5.68085	0.00000	0.00000	.56809	2.26745	2.84532	1.36576
32	2001	.38576	5.68085	0.00000	0.00000	.56809	2.24736	2.86541	1.37540
33	2002	.38576	5.68085	0.00000	0.00000	.56809	2.22752	2.88525	1.38492
34	2003	.38576	5.68085	0.00000	0.00000	.56809	2.20773	2.90504	1.39442
35	2004	.38576	5.68085	0.00000	0.00000	.56809	2.18788	2.92497	1.40399
36	2005	.38576	5.68085	0.00000	0.00000	.56809	2.16750	2.94527	1.41373
37	2006	.38576	5.68085	0.00000	0.00000	.56809	2.14656	2.96619	1.42377
38	2007	.38576	5.68085	0.00000	0.00000	.56809	2.12478	2.98799	1.43423
39	2008	.38576	5.68085	0.00000	0.00000	.56809	2.10180	3.01097	1.44527
40	2009	.38576	5.68085	0.00000	0.00000	.56809	6.32117	-1.21540	-.58003

CASH FLOW AND POWER COSTS

@SOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

PAYOUT OF INVESTMENTS, $M

	YEAR	NET CASH FLOW	OUTSTANDING BONDS	EQUITY CAPITAL NOT RECOVERED	BOND INTEREST	EARNINGS ON UNRECOVERED EQUITY	BONDS REPAID	RECOVERY OF EQUITY
1	1970	-.31383	0.00000	0.60000	0.00000	0.00000	-.13181	-.18202
2	1971	-.26396	.13181	.18202	.01054	.02730	-.11086	-.15310
3	1972	-.18020	.24267	.33512	.01941	.05027	-.07569	-.10452
4	1973	-.11755	.31836	.43964	.02547	.06595	-.04937	-.05818
5	1974	-1.02926	.36773	.50782	.02942	.07617	-.43229	-.59697
6	1975	-1.71306	.80002	1.10479	.06400	.16572	-.71948	-.99357
7	1976	-1.89958	1.51950	2.09836	.12156	.31475	-.79782	-1.10176
8	1977	-2.53688	2.31733	3.20012	.18539	.48002	-1.06549	-1.47139
9	1978	-4.11070	3.38282	4.67151	.27063	.70073	-1.72650	-2.38421
10	1979	-4.57560	5.10931	7.05572	.40874	1.05836	-1.92175	-2.65385
11	1980	.03039	7.03106	9.70956	.56249	1.45643	.01276	.01763
12	1981	.29044	7.01830	9.69194	.56146	1.45379	.12198	.16845
13	1982	.28039	6.89632	9.52348	.55171	1.42852	.11776	.16262
14	1983	.27153	6.77855	9.36086	.54228	1.40413	.11404	.15749
15	1984	.26400	6.66451	9.20337	.53316	1.38051	.11088	.15312
16	1985	.25792	6.55363	9.05025	.52429	1.35754	.10833	.14959
17	1986	.25344	6.44531	8.90066	.51562	1.33513	.10645	.14700
18	1987	.25074	6.33886	8.75367	.50711	1.31305	.10531	.14543
19	1988	.24999	6.23355	8.60824	.49868	1.29124	.10499	.14499
20	1989	.25139	6.12856	8.46325	.49028	1.26949	.10558	.14581
21	1990	.25517	6.02297	8.31744	.48184	1.24762	.10717	.14800
22	1991	.26158	5.91580	8.16944	.47326	1.22542	.10986	.15171
23	1992	.27088	5.80594	8.01773	.46448	1.20266	.11377	.15711
24	1993	.28337	5.69217	7.86062	.45537	1.17903	.11901	.16435
25	1994	.29938	5.57316	7.69627	.44585	1.15444	.12574	.17364
26	1995	.31928	5.44742	7.52262	.43579	1.12839	.13410	.18518
27	1996	.34475	5.31332	7.33744	.42507	1.10062	.14479	.19995
28	1997	.37380	5.16853	7.13749	.41348	1.07062	.15699	.21680
29	1998	.40680	5.01153	6.92069	.40092	1.03810	.17086	.23595
30	1999	.44418	4.84067	6.68474	.38725	1.00271	.18655	.25762
31	2000	.48637	4.65412	6.42712	.37233	.96407	.20427	.28209
32	2001	.53387	4.44984	6.14502	.35599	.92175	.22423	.30964
33	2002	.58724	4.22562	5.83538	.33805	.87531	.24664	.34060
34	2003	.64707	3.97898	5.49478	.31832	.82422	.27177	.37530
35	2004	.71404	3.70721	5.11948	.29658	.76792	.29990	.41414
36	2005	.78888	3.40731	4.70534	.27259	.70580	.33133	.45755
37	2006	.87241	3.07599	4.24779	.24608	.63717	.36641	.50600
38	2007	.96551	2.70958	3.74179	.21677	.56127	.40552	.56000
39	2008	1.06919	2.30406	3.18180	.18432	.47727	.44906	.62013
40	2009	4.41666	1.85500	2.56167	.14840	.38425	1.85500	2.56167

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

	DETAILED CASH FLOW		DISTRIBUTION OF ENERGY COSTS	
	MILLS PER KWHE	ANNUAL ($ MILLIONS)	MILLS PER KWHE	ANNUAL ($ MILLIONS)
COST OF POWER	14.72652	5.68085		
FIELD IDENTIFICATION AND EXPLORATION	.60555	.23360	.81234	.31337
FIELD DEVELOPMENT (TOTAL)	5.37648	2.07401	8.23036	3.17432
PRODUCING WELLS	3.20434	1.23618	4.28430	1.65270
TRANSMISSION SYSTEM	.81418	.31408	1.47910	.57057
DISPOSAL SYSTEM	1.35736	.52384	2.46697	.95165
NONPRODUCING WELLS	0.00000	0.00000	0.00000	0.00000
FIELD OPERATING COSTS (TOTAL)	4.62574	1.78441	5.68381	2.19257
DISPOSAL COSTS	.88888	.33517	1.22041	.47078
PRODUCING WELLS	1.51432	.58424	1.81902	.70170
TRANSMISSION COSTS	.76574	.29539	1.00371	.38719
OTHER OPERATING COSTS	1.47650	.56961	1.64067	.63290
REVENUE TAXES	0.00038	0.00008		
STATE INCOME TAXES	.24293	.09371		
ROYALTY PAYMENTS	1.47255	.56809		
FEDERAL INCOME TAXES	1.54920	.59761		
BOND INTEREST	.85396	.32942		
BY PRODUCT REVENUE	0.00000	0.00000	0.00000	0.00000
TOTALS	14.72652	5.68085	14.72652	5.68085

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

POWERPLANT CAPITAL COSTS

ACCOUNT			
1.0	POWER PLANT		
1.1	PIPING, INSULATION, & PUMPS	193.	$K
1.2	CRANE	169.	$K
1.3	TURBO GENERATOR	2224.	$K
1.5	VAPOR GENERATOR (BOILER)	2561.	$K
1.7	AUXILIARY HEAT EXCHANGERS	403.	$K
1.9	MISC. PROCESS SUPPORT EQUIPMENT	133.	$K
1.10	INSTRUMENTATION AND CONTROLLERS	142.	$K
1.12	ELECTRICAL SUPPORT EQUIPMENT	722.	$K
1.16	CONDENSER	2494.	$K
1.17	INSTALLATION TESTING	178.	$K
1.18	BUILDINGS, FOUNDATIONS, AND SUPPORT EQUIPMENT	1570.	$K
1.21	REINJECTION PUMP (PLANT-LOCATED)	185.	$K
1.99	SUBTOTAL 1.0	10969.	$K
ACCOUNT			
2.0	HEAT REJECTION SYSTEM (COOLING TOWERS)		
2.1	COOLING TOWER SYSTEM (FORCED DRAFT WET)	1215.	$K
2.99	SUBTOTAL 2.0	1215.	$K
ACCOUNT			
3.0	SWITCH YARD		
3.99	SUBTOTAL 3.0	777.	$K
ACCOUNT			
5.0	OTHER COSTS		
5.1	ENGINEERING AND DESIGN	1299.	$K
5.2	ADMINISTRATION AND INDIRECT COSTS	1033.	$K
5.99	SUBTOTAL 5.0	2333.	$K
	TOTAL POWER PLANT COST	15323.	$K

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

POWERPLANT INPUT DATA

BOND REPAYMENT PROPORTIONAL		
SUM OF YEARS DIGITS DEPRECIATION		
PLANT INVESTMENT, $M	15.3290	(INITIAL FINANCING)
PROJECT LIFE, YEARS	33.0000	
FRACTION OF INITIAL INVESTMENT IN BONDS	.5900	
BOND INTEREST RATE	.0800	
EQUITY EARNING RATE (AFTER TAXES)	.1200	
FEDERAL INCOME TAX RATE	.4800	
POWER PLANT SIZE (MWE)	55.0000	
DEPRECIABLE LIFE OF PLANT,YRS.	30.0000	
PLANT CONSTRUCTION AND LICENSING, YRS.	3.0000	
FIRST YEAR OF OPERATION	1980	
STATE INCOME TAX RATE	.0700	
STATE GROSS REVENUE TAX RATE	.0400	
PROPERTY TAX RATE	.0250	
INTERIM CAPITAL REPLACEMENTS, RATE/YR	.0035	
PROPERTY INSURANCE RATE	.0012	
ROYALTY PAYMENT, %	0.0000	
PLANT OPERATING LIFE	30.0000	

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

CASH FLOW TABLE POWER PLANT, $ MILLIONS

	YEAR	LOAD FACTOR	CAPITAL COSTS	ENERGY COSTS	PLANT OPERATING COSTS	INTERIM CAPITAL REPLACEMENT	PROPERTY TAXES INSURANCE	TOTAL COSTS
1	1977	0.00000	1.45019	0.00000	0.00000	0.00000	0.00000	1.45019
2	1978	0.00000	8.32253	0.00000	0.00000	0.00000	.03800	8.36052
3	1979	0.00000	5.55628	0.00000	0.00000	0.00000	.25605	5.81232
4	1980	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
5	1981	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
6	1982	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
7	1983	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
8	1984	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
9	1985	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
10	1986	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
11	1987	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
12	1988	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
13	1989	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
14	1990	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
15	1991	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
16	1992	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
17	1993	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
18	1994	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
19	1995	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
20	1996	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
21	1997	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
22	1998	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
23	1999	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
24	2000	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
25	2001	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
26	2002	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
27	2003	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
28	2004	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
29	2005	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
30	2006	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
31	2007	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
32	2008	.80000	0.00000	5.68085	.11492	.05365	.40162	6.25105
33	2009	.80000	0.00000	5.68085	.11492	0.00000	.40162	6.19739

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

ANNUAL TAX DEDUCTIBLE EXPENSES, $ MILLIONS

	YEAR	7.203 PCT PRESENT WORTH FACTOR	OPERATING EXPENSES	BOND INTEREST	DEPRECIATION	TOTAL DEDUCTIBLE OPERATING EXPENSES	STATE INCOME TAX
1	1977	.96582	0.00000	0.00000	0.00000	0.00000	0.00000
2	1978	.90093	.03800	.06845	0.00000	.10644	-.00745
3	1979	.84040	.25605	.46707	0.00000	.72312	-.05062
4	1980	.78394	6.19739	.76881	.98897	7.95517	.02540
5	1981	.73127	6.19739	.75421	1.00631	7.95791	.02521
6	1982	.68214	6.19739	.73813	.97023	7.90575	.02886
7	1983	.63631	6.19739	.72177	.93438	7.85354	.03252
8	1984	.59355	6.19739	.70511	.89876	7.80126	.03618
9	1985	.55368	6.19739	.68811	.86337	7.74888	.03984
10	1986	.51648	6.19739	.67076	.82821	7.69636	.04352
11	1987	.48176	6.19739	.65301	.79328	7.64369	.04721
12	1988	.44941	6.19739	.63483	.75859	7.59081	.05091
13	1989	.41921	6.19739	.61619	.72412	7.53771	.05462
14	1990	.39105	6.19739	.59705	.68989	7.48433	.05836
15	1991	.36477	6.19739	.57736	.65588	7.43064	.06212
16	1992	.34027	6.19739	.55713	.62211	7.37659	.06590
17	1993	.31740	6.19739	.53618	.58857	7.32214	.06971
18	1994	.29608	6.19739	.51458	.55526	7.26723	.07356
19	1995	.27619	6.19739	.49223	.52217	7.21180	.07744
20	1996	.25763	6.19739	.46908	.48932	7.15580	.08136
21	1997	.24032	6.19739	.44507	.45671	7.09917	.08532
22	1998	.22417	6.19739	.42012	.42432	7.04183	.08934
23	1999	.20911	6.19739	.39416	.39216	6.98371	.09348
24	2000	.19506	6.19739	.36712	.36023	6.92475	.09753
25	2001	.18196	6.19739	.33891	.32854	6.86484	.10173
26	2002	.16973	6.19739	.30944	.29707	6.80390	.10599
27	2003	.15833	6.19739	.27851	.26583	6.74184	.11034
28	2004	.14769	6.19739	.24632	.23483	6.67855	.11477
29	2005	.13777	6.19739	.21247	.20406	6.61392	.11929
30	2006	.12851	6.19739	.17692	.17351	6.54783	.12392
31	2007	.11988	6.19739	.13956	.14320	6.48016	.12865
32	2008	.11182	6.19739	.10025	.11312	6.41076	.13351
33	2009	.10431	6.19739	.05894	.08320	6.33953	.13852

DEPRECIATION SUM = 16.6849

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

ANNUAL INCOME STATEMENT, $ MILLIONS

	YEAR	POWER UNITS (M MWH)	TOTAL POWER SALES	REVENUE TAXES	TOTAL TAX DEDUCTIBLE EXPENSES	TAXABLE INCOME (FEDERAL)	FEDERAL INCOME TAX
1	1977	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	1978	0.00000	0.00000	0.00000	.09899	-.09899	-.04752
3	1979	0.00000	0.00000	0.00000	.67250	-.67250	-.32280
4	1980	.32184	8.66465	.34659	7.98058	.33749	.16200
5	1981	.32184	8.66465	.34659	7.98312	.33495	.16077
6	1982	.32184	8.66465	.34659	7.93461	.38346	.18406
7	1983	.32184	8.66465	.34659	7.88606	.43201	.20736
8	1984	.32184	8.66465	.34659	7.83743	.48063	.23070
9	1985	.32184	8.66465	.34659	7.78872	.52935	.25409
10	1986	.32184	8.66465	.34659	7.73988	.57818	.27753
11	1987	.32184	8.66465	.34659	7.69089	.62717	.30104
12	1988	.32184	8.66465	.34659	7.64172	.67634	.32465
13	1989	.32184	8.66465	.34659	7.59233	.72573	.34835
14	1990	.32184	8.66465	.34659	7.54269	.77537	.37218
15	1991	.32184	8.66465	.34659	7.49276	.82530	.39615
16	1992	.32184	8.66465	.34659	7.44250	.87557	.42027
17	1993	.32184	8.66465	.34659	7.39185	.92621	.44458
18	1994	.32184	8.66465	.34659	7.34078	.97728	.46909
19	1995	.32184	8.66465	.34659	7.28924	1.02883	.49384
20	1996	.32184	8.66465	.34659	7.23716	1.08091	.51883
21	1997	.32184	8.66465	.34659	7.18449	1.13358	.54412
22	1998	.32184	8.66465	.34659	7.13117	1.18690	.56971
23	1999	.32184	8.66465	.34659	7.07712	1.24095	.59565
24	2000	.32184	8.66465	.34659	7.02228	1.29579	.62198
25	2001	.32184	8.66465	.34659	6.96656	1.35150	.64872
26	2002	.32184	8.66465	.34659	6.90989	1.40817	.67592
27	2003	.32184	8.66465	.34659	6.85217	1.46589	.70363
28	2004	.32184	8.66465	.34659	6.79331	1.52475	.73188
29	2005	.32184	8.66465	.34659	6.73321	1.58486	.76073
30	2006	.32184	8.66465	.34659	6.67175	1.64632	.79023
31	2007	.32184	8.66465	.34659	6.60881	1.70925	.82044
32	2008	.32184	8.66465	.34659	6.54426	1.77379	.85142
33	2009	.32184	8.66465	.34659	6.96033	1.35774	.65171

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

PAYOUT OF INVESTMENTS, $ MILLIONS

	YEAR	NET CASH FLOW	OUTSTANDING BONDS	EQUITY CAPITAL NOT RECOVERED	BOND INTEREST	EARNINGS ON UNRECOVERED EQUITY	BONDS REPAID	RECOVERY OF EQUITY
1	1977	-1.45019	0.00000	0.00000	0.00000	0.00000	-.05501	-.59450
2	1978	-8.44536	.85561	.59459	.06845	.07135	-4.98276	-3.46260
3	1979	-6.39284	5.83837	4.05717	.46707	.48686	-3.77177	-2.62106
4	1980	.30942	9.61015	6.67824	.76861	.80139	.18256	.12686
5	1981	.34066	9.42759	6.55137	.75421	.78615	.20099	.13967
6	1982	.34657	9.22660	6.41170	.73813	.76940	.20447	.14209
7	1983	.35302	9.02212	6.26951	.72177	.75235	.20826	.14474
8	1984	.36005	8.81384	6.12487	.70511	.73498	.21243	.14762
9	1985	.36771	8.60141	5.97725	.68811	.71727	.21695	.15076
10	1986	.37604	8.38447	5.82649	.67076	.69916	.22186	.15417
11	1987	.38508	8.16260	5.67232	.65301	.68068	.22720	.15786
12	1988	.39490	7.93541	5.51443	.63483	.66173	.23299	.16191
13	1989	.40555	7.70241	5.35252	.61619	.64238	.23927	.16627
14	1990	.41706	7.46314	5.18625	.59705	.62235	.24606	.17100
15	1991	.42956	7.21706	5.01525	.57736	.60183	.25344	.17612
16	1992	.44306	6.96362	4.83913	.55709	.58070	.26141	.18165
17	1993	.45765	6.70222	4.65747	.53618	.55890	.27001	.18764
18	1994	.47341	6.43220	4.46984	.51458	.53638	.27931	.19410
19	1995	.49042	6.15289	4.27574	.49223	.51309	.28935	.20107
20	1996	.50876	5.86354	4.07456	.46908	.48896	.30018	.20860
21	1997	.52859	5.56336	3.86616	.44507	.46393	.31187	.21672
22	1998	.54993	5.25149	3.64934	.42012	.43792	.32446	.22547
23	1999	.57293	4.92703	3.42387	.39416	.41086	.33803	.23496
24	2000	.59771	4.58900	3.18897	.36712	.38268	.35265	.24506
25	2001	.62440	4.23635	2.94330	.33891	.35327	.36839	.25600
26	2002	.65312	3.86796	2.68730	.30944	.32255	.38534	.26778
27	2003	.68403	3.48261	2.42012	.27861	.29041	.40356	.28045
28	2004	.71729	3.07904	2.13957	.24632	.25676	.42320	.29409
29	2005	.75306	2.65583	1.84558	.21247	.22147	.44431	.30876
30	2006	.79153	2.21153	1.53682	.17692	.18442	.46700	.32453
31	2007	.83289	1.74453	1.21230	.13956	.14548	.49140	.34146
32	2008	.87734	1.25312	.87081	.10025	.10450	.51763	.35971
33	2009	1.24659	.73549	.51110	.05884	.06133	.73549	.51110

CASH FLOW AND POWER COSTS

ISOBUTANE SUBCRITICAL BINARY CYCLE FOR 55 MWE PLANT

INSTALLED COST — 278.71 $ PER KWE (GROSS); 334.36 $ PER KWE (NET)

	DETAILED CASH FLOW MILLS PER KWHR	DETAILED CASH FLOW ANNUAL ($ MILLIONS)	EQUIVALENT CASH FLOW MILLS PER KWHR	EQUIVALENT CASH FLOW ANNUAL ($ MILLIONS)
COST OF POWER	26.92206	8.66465	26.92206	8.66465
COST DISTRIBUTION				
INITIAL PLANT	4.12511	1.32763	6.56492	2.11287
INTERIM CAPITAL REPLACEMENTS	.16510	.05310	.21981	.07074
ENERGY SUPPLY	17.65116	5.68085	18.38652	5.91756
OPERATING EXPENSES	.35717	.11492	.37194	.11971
PROPERTY TAXES AND INSURANCE	1.32371	.42602	1.37886	.44378
STATE REVENUE TAX	1.07638	.34659		
STATE INCOME TAX	.16455	.05299		
FEDERAL INCOME TAX	1.04997	.33792		
BOND INTEREST	1.00851	.32461		
TOTAL	26.92206	8.66465	26.92206	8.66465
INTERNAL POWER CONSUMPTION 9.1 MWE	4.46962	1.43862		
NET POWER OUTPUT 45.9 MWE				
GROSS POWER OUTPUT 55.0 MWE				

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