CLEAN WATER
WATER POLLUTION CONTROL RESEARCH SERIES • 16130 DHS 01/71

A SURVEY OF ALTERNATE METHODS FOR COOLING CONDENSER DISCHARGE WATER

SYSTEM, SELECTION, DESIGN, AND OPTIMIZATION

ENVIRONMENTAL PROTECTION AGENCY • WATER QUALITY OFFICE

WATER POLLUTION CONTROL RESEARCH SERIES

A SURVEY OF ALTERNATE METHODS

FOR COOLING CONDENSER DISCHARGE WATER

SYSTEM, SELECTION, DESIGN, AND OPTIMIZATION

by

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for the

WATER QUALITY OFFICE
ENVIRONMENTAL PROTECTION AGENCY

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Section 1

INTRODUCTION

1.1 Overall Program Goals

In December 1968, Dynatech R/D Company undertook a program for the Federal Water Quality Administration (then the FWPCA) with the ultimate aim of performing a survey and economic analysis of alternate methods for cooling condenser discharge water from thermal power plants. The first phase of this program was to consist of a systematic gathering of present state-of-the-art information in the areas of large scale heat rejection equipment, power plant operating characteristics, and total community considerations. The second phase of this program was to consist of work in the areas of:

1. Selection of input parameters and optimization criteria.
2. Limitations and advances in heat rejection units.
3. Extensive modifications of present power cycles.
4. Advanced total community concepts.

This report will document the results of Phase II, Task I of this program.

1.2 Scope of Task I

The first task of the second phase of this program has as an overall goal the quantitfication of cooling system costs as a function of various parameters, the definition of the interface requirements between the power plant and the cooling system, and the optimization of the total power cost.

A previous task, as reported in July 1969, (Ref. 1) presented, in detail, considerations of alternate methods of transferring large quantities of rejected heat to the atmosphere. The results of this analysis led to the expected conclusion that, for a given heat level and ambient conditions, the size and cost of the heat rejection equipment decreases with an increase in process side temperature. This cost relationship is shown as curve A in Figure 1.1.

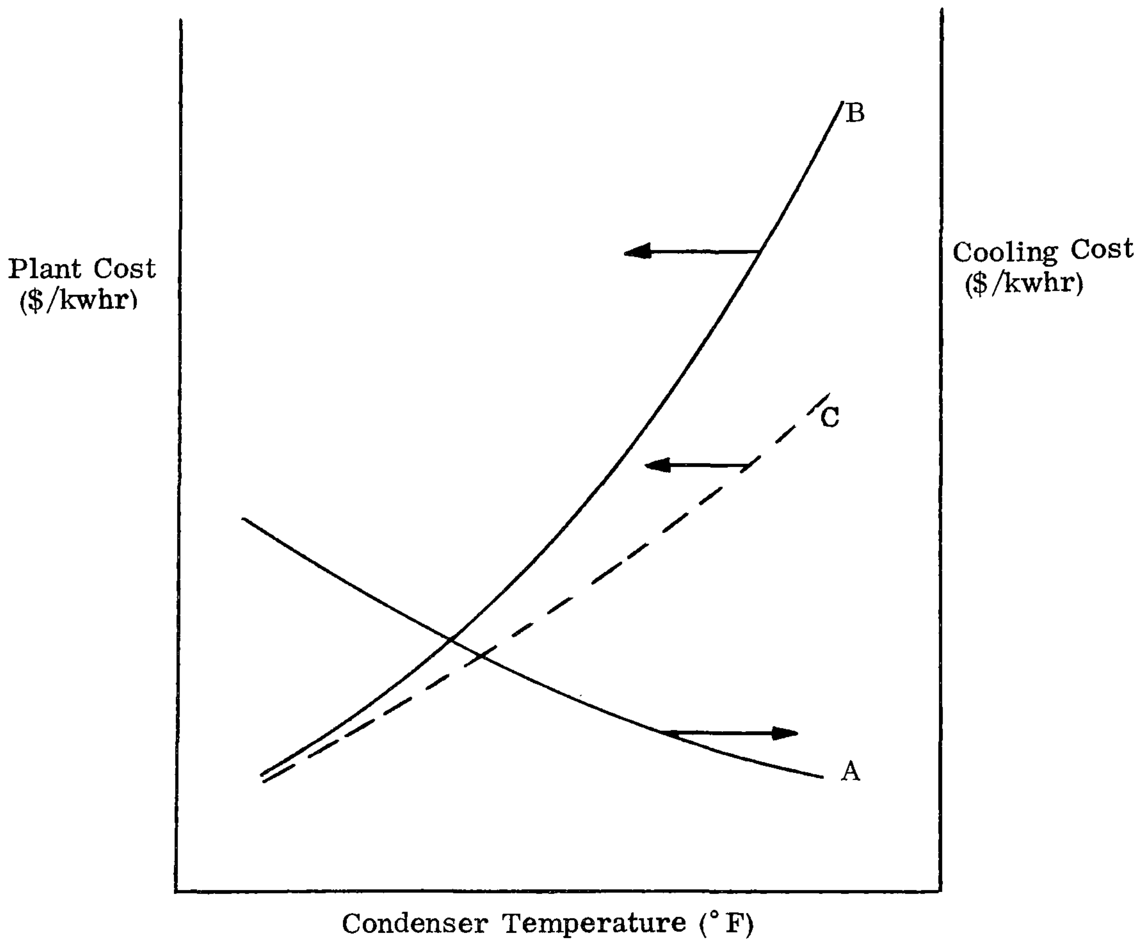


Figure 1.1. System Cost Versus Condenser Temperature

A later task, as reported in May 1970 (Ref. 2), described, in detail, the increase in power plant cost as a result of an increase in condenser temperature. This type of relationship is shown as curves B and C in Figure 1.1. Curve B may be thought of as representing an existing power plant forced to operate at a higher than design condenser temperature while curve C represents a possible locus of costs for plants designed for various condenser temperatures.

The goal of this task then is to quantify these curves, and to find a means of obtaining the minimum of the sum of the two costs for a wide range of ambient conditions and power plant parameters.

1.3 General Method

The general method of approach to this task has been the development of a computer program for the calculation of both cooling system and power plant costs and the determination of the minimum total cost for a given set of parameters. To this end, the effect of various design parameters have been studied to determine which have significant effects on the performance of the various cooling schemes and which parameters are important to the calculation of power plant costs. Design equations based on these parameters have been developed for the cooling systems and power plant, and incorporated into a computer program through which the minimum total cost is calculated.

A number of options are open to the user of the program such as full time or part time use of the cooling system, an open or closed cooling system, a specified or "designed" condenser, and variable ambient conditions. Also available is the ability to match projected power plant operation at different capacities over varying time periods.

Part time use of the cooling system is represented in Figure 1.2 and is applicable only to cooling systems that use a water cooled condenser such as cooling towers and cooling ponds.

An open cooling system, or "topping" operation is shown in Figure 1.3 and is again applicable only to cooling systems that use a water cooled condenser.

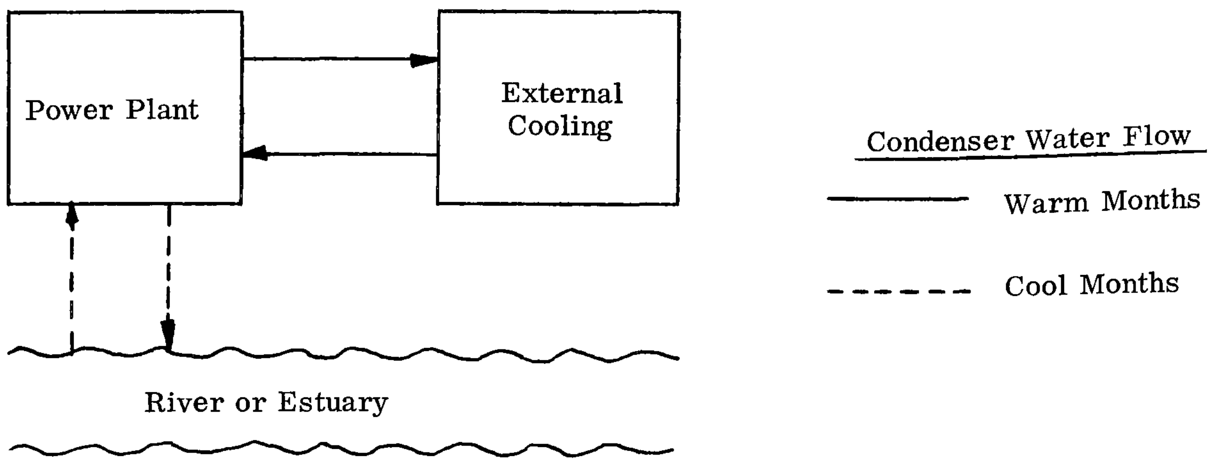


Figure 1.2. Part Time Use of External Cooling

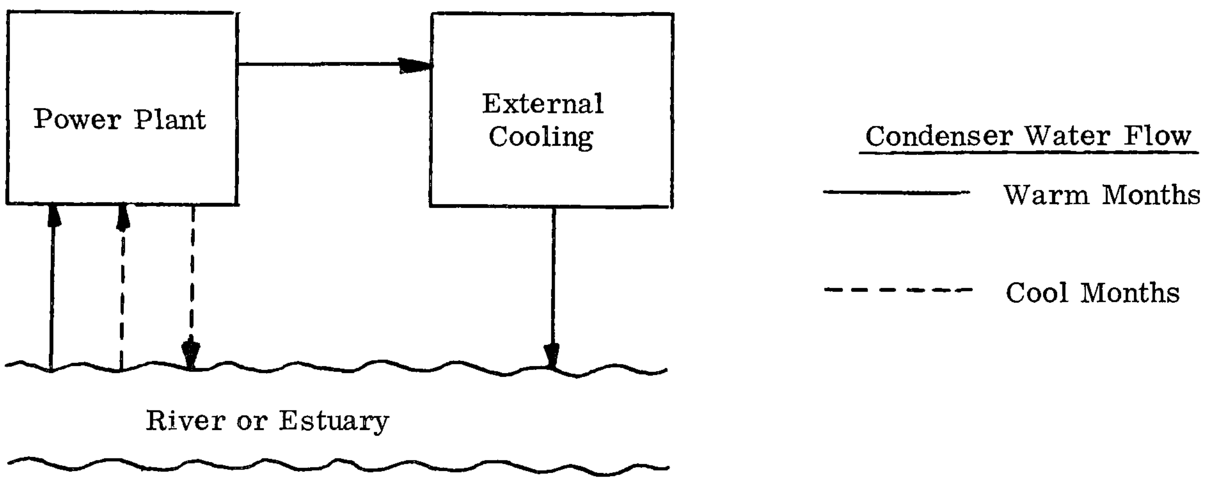


Figure 1.3. Open or Topping Cooling System (Shown as seasonal operation--can be used as full time open system also)

The water cooled condenser, as part of the external cooling system, may be specified or it will be "designed" by the program. This provides the option, for existing power plants that must have external cooling systems added, of either building an oversized external system to match the existing condenser or rebuilding the condenser such that the external cooling system and the condenser are matched and of minimum cost. Depending on the particular power plant, either method may result in the least overall cost.

Operation of the power plant and the cooling system at various ambient conditions for different periods of time has been provided for in the program. This is because cooling systems are usually designed for adverse and seldom occurring ambient conditions and do not operate under these extreme conditions most of the time. The program accounts for this in that it "designs" a cooling system for a given set of ambient conditions (usually specified as the most severe) but calculates operating costs of both the cooling system and power plant for up to five other sets of ambient conditions with a specified operating time per year for each.

Operation of the power plant at up to five off-design capacities for a specified number of hours per year has been provided in the program and is necessary to simulate actual power plant practice. The disadvantage to this is that plant operating characteristics (heat rate and auxiliary power) often are quite different for off design operation, and therefore must be specified for each capacity used. This is simplified somewhat, however, by available data such as contained in GE 2050B, included in Reference 2.

The remainder of this report, which describes the computer program, is divided into five sections. The first section describes the model of the power plant and the input data that is required. The following sections provide brief descriptions of the input (interface) requirements for each cooling system, review the general computational procedures, and describe the output. The details are obtainable from the program listings themselves (included in the appendix) which contain "comment" cards for ease of interpretation. A glossary of variable names for the whole program is also provided in the Appendix.

Section 2

POWER PLANT MODEL

2.1 General Description

As indicated in Section 1, the total design and optimization program consists of providing a mathematical description of the operating characteristics and system costs of the power plant itself, a similar model for alternative cooling schemes, and a means of interfacing these two subsystems and computing the total cost. Various combinations are then searched to find a minimum cost solution.

The first part of this program contains not only the mathematical description of power plant operation but it is also the control program which provides the interface information between the plant and the cooling system. This is indicated in a generalized flow chart of the program in Figure 2.1.

Basically, the "Power Plant Model" carries out two functions. First, it receives and manipulates all of the required input information to the optimization program. These inputs include such items as plant design capacity, projected load demands, plant efficiency ratings, projected cooling requirements, expected ambient conditions, and relevant economic data. A complete listing is given in Section 2.2. These input data are then manipulated to put the data into a form directly useful in the forthcoming computations. This portion of the model is contained in the first part of the main program.

The second function of the Power Plant Model is accomplished in subroutine PAFCST, an operational subroutine, which simulates power plant operation and provides heat rejection requirements and plant cost information to the cooling system subroutines.

2.2 Input Data

The data describing the power plant and the operation of it are read in the first portion of the program and, in order of input, are as follows:

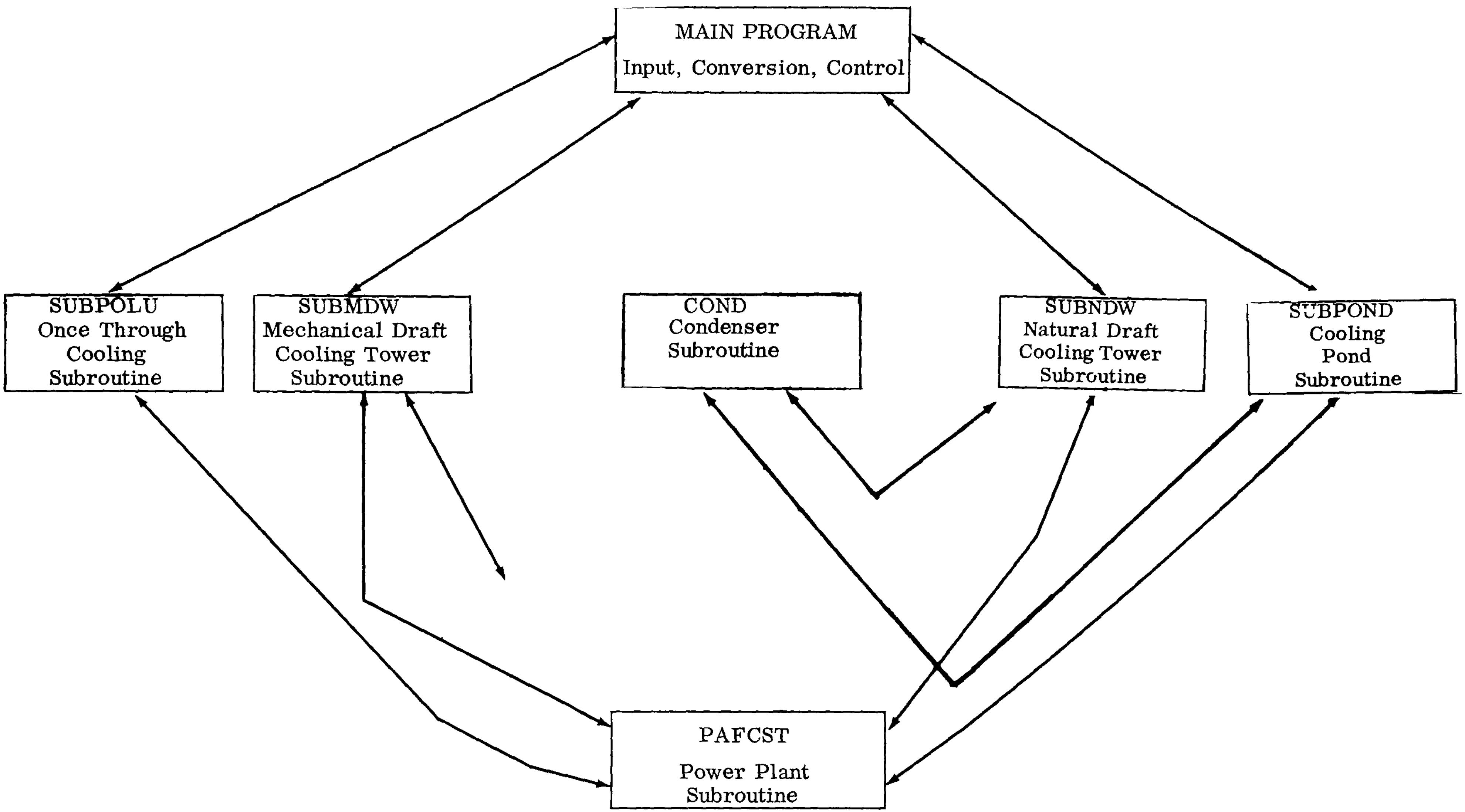

MAIN PROGRAM
Input, Conversion, Control
SUBPOLU
Once Through
Cooling
Subroutine
SUBMDW
Mechanical Draft
Cooling Tower
Subroutine
COND
Condenser
Subroutine
SUBNDW
Natural Draft
Cooling Tower
Subroutine
SUBPOND
Cooling
Pond
Subroutine
PAFCST
Power Plant
Subroutine

Figure 2.1

Variable		Description
PSIZE	-	Power plant size--the maximum electrical output of the plant and the size for which the cooling systems are to be designed (Mwe).
CCPKW	-	Power plant capital cost including a standard once through condenser ($/kw).
ANFCR	-	Annual fixed charge rate (%/yr).
FUCST	-	Fuel cost (¢/million Btu).
PRPAGR	-	Land cost ($/acre).
NCAPS	-	Number of different plant capacities for which heat rate data is supplied (maximum of 5 excluding design capacity).
CAP(I)	-	Various plant capacities (%/100).
TOTLD(I)	-	Total loading--number of hours per year that the plant operates at each capacity (hrs/yr).
COLPCT(I)	-	Cooling percent--percent of the total operating time at each capacity (TOTLD(I)) that the cooling system is used. (%/100).
NHRPTS(I)	-	Number of heat rate points--the number of condenser pressures and corresponding heat rates to be input for each capacity.
PCMIN(I)	-	Minimum condenser pressure at each capacity (in. Hg.).
PCMAX(I)	-	Maximum condenser pressure at each capacity (in. Hg.).

Variable		Description
HRP(I, J)*	-	Condenser pressure for each heat rate at each capacity (in. Hg.) (do not have to include PCMAX(I) and PCMIN(I))
TURBHR(I, J)*	-	Turbine heat rate corresponding to each condenser pressure, HRP(I, J), for each capacity (Btu/kwhr).

The following input data pertain more to the cooling systems than to the power plant but are included here since they are read in the same part of the program as the power plant data.

TDB	-	Design ambient dry bulb temperature (°F)
TWB	-	Design ambient wet bulb temperature (°F)
TAVH2O	-	Design available water temperature (°F)
PCBASE	-	Base condenser pressure--a base average condenser pressure at which the plant would operate if external cooling were not required (in. Hg.).
WIND		Design wind velocity (MPH)
RAD		Design radiation intensity (Btu/ ft^2 /day)
NH2O	-	Type of cooling water to be used in the cooling system -1 = Seawater Ø = Untreated fresh water +1 = Treated fresh water
NTAMB	-	Number of different ambient temperatures.
TAMDB(I)	-	Various ambient dry bulb temperatures (°F)
TAMWB(I)	-	Various ambient wet bulb temperatures (°F)

*These values are obtained from General Electric Heat Rate Tables (Ref. 2) or other similar data.

Variable		Description
TAMRV(I)	-	Various river temperature(° F)
AMWIND (I)	-	Various wind velocities (MPH)
AMRAD (I)	-	Various radiation fluxes (Btu/ft^2/day)
PCTAMB(I, J)	-	Percent of the cooling system use time, COLPCT(I) x TOTLD(I), at each capacity. that the cooling system operates at the specified ambient temperatures, TAMDB(I) and TAMWB(J) (%/100).
WIDTH	-	Width of river or estuary (ft).
NSYSOP	-	Type of cooling system operation 0 = closed cycle operation 2 = topping
NSPCON	-	Whether or not the condenser is specified 0 = no 1 = yes
TDISMX	-	Maximum water discharge temperature (only if topping used) (° F)
UOVALL	-	Overall heat transfer coefficient for the condenser (only if condenser is specified) (Btu/hr-ft^2-° F).
AREAC	-	Total heat transfer area (only if condenser is specified) (ft^2)
SPFLOW	-	Condenser water flow (only if condenser is specified) (lbm/hr)
NSUBS(I)	-	Controls which of the cooling subroutines is called. If NSUBS (I) is zero, the Ith subroutine is not called.

I	Subroutine
1	Listing of input data (part of main program)
2	Once through cooling (SUBPOLU)
3	Cooling Pond (SUBPOND)
4	Mechanical Draft Wet Tower (SUBMDW)
5	Natural Draft Wet Tower (SUBNOW)

2.3 Preparation of input data cards

All cards are required for each set of input conditions, although all cooling options may be run with one set of plant and ambient data. FORTRAN format specifications are shown for each input card required.

Card 1:	PSIZE, CCPKW, ANFCR, FUCST, PRPAGR, NCAPS	(5F10.0,I10)
Card 2:	CAP (I) , I = 1,5	(5F10.2)
Card 3:	TOTLD (I), I = 1,5	(5F10.0)
Card 4:	COLPCT (I), I = 1,5	(5F10.2)
Card 5:	NHRPTS (I), I = 1,6	(6I10)
Card 6:	PCMIN (I), I = 1,6	(6F10.2)
Card 7:	PCMAX (I), I = 1,6	(6F10.2)
Cards 8-X:	NNCAP sets (a set for each capacity, plus one if design data are input. See Section 2.4) of two cards each:	
	card A: HRP (SET NUMBER, J), J = 1,6	(6F10.2)
	card B: TURBHR (SET NUMBER, J), J = 1,6	(6F10.0)
Card X + 1:	TDB, TWB, TAVH20, PCBASE, WIND, RAD, NH20, NTAMB	(6F10.0,2I10)
Card X + 2:	TAMDB (I), I = 1, NTAMB	(5F10.0)
Card X + 3:	TAMWB(I), I = 1, NTAMB	(5F10.0)
Card X + 4:	TAMRV (I), I = 1, NTAMB	(5F10.0)
Card X + 5:	AMWIND (I), I = 1, NTAMB	(5F10.0)
Card X + 6:	AMRAD (I), I = 1, NTAMB	(5F10.0)
Cards X + 7-Y:	NCAPS cards each with PCTAMB (SET NUMBER, J), J = 1, NTAMB	(5F10.2)
Card Y + 1:	WIDTH, NSYSOP, NSPCON, TDISMX, UOVALL, AREAC, SPFLOW	(F10.0,2I10,4F10.0)
Card Y + 2:	NSUBS (I), I = 1,5	(5I10)

2.4 Test Data

Four sets of input data have been used to obtain cooling system costs. These four data sets have been designated SUBD1, SUBD2, SUBD3, and SUBD4. All four sets contain the same power plant data and ambient temperature but each describes a different type of cooling system operation as described below.

SUBD1 - Condenser is specified and the cooling system is used for topping.

SUBD2 - Condenser is specified and the cooling system is a closed system.

SUBD3 - Condenser is "designed" and the cooling system is used for topping.

SUBD4 - Condenser is "designed" and the cooling system is a closed system.

Listings of these four sets of data are included in the Appendix, and the input data printout, when SUBD1 is used, is shown in Table 2.1.

*Number of cards depends on number of capacities specified.

Table 2.1

-----PRINTOUT OF INPUT DATA-----

PSIZE	CAP $	ANFCR	FUEL $	PRPAGR
200	150	.12	10	1000

CAPACITIES AND CORRESPONDING DATA
(EXTRA VALUES ARE DESIGN DATA)

CAPACITY -	1.00	.80	.60	.25	0	
HRS/YEAR -	5150	1750	800	700	360	
PCT COOLING -	.80	.70	.50	.30	.15	
MIN P COND -	1.50	1.00	1.00	1.00	1.00	1.50
MIN T COND -	91.72	79.04	79.04	79.04	79.04	91.72
MAX P COND -	3.50	4.00	4.00	4.50	4.50	3.50
MAX T COND -	120.55	125.41	125.41	129.77	129.77	120.55

CAPACITY FACTOR = .82
COOLING USE FACTOR = .75

COND PRESS AND CORRESPONDING DATA AT EACH CAPACITY

CAPACITY =1.00				
PRESSURE -	1.50	2.50	3.50	
T HEAT RATE -	7987	8037	8153	
CAPACITY = .80				
PRESSURE -	1.00	2.00	3.00	
T HEAT RATE -	7974	8025	8174	
CAPACITY = .60				
PRESSURE -	1.00	2.00	3.00	3.50
T HEAT RATE -	8055	8195	8430	8543
CAPACITY = .25				
PRESSURE -	1.00	2.00	3.00	
T HEAT RATE -	8828	9381	9815	
CAPACITY = 0				
PRESSURE -	1.00	2.00	3.00	
T HEAT RATE -	0	0	0	

DESIGN VALUES (CAPACITY = PLANT SIZE)

PRESSURE -	1.50	2.00	2.50	3.00	3.50
T HEAT RATE -	8000	8009	8042	8089	8151

DRY BULB T	WET BULB T	WIND SPEED	RADIATION
85	75	10.0	4000

AVAIL H2O T	TYPE AVAILABLE H2O
75	-1

BASE P COND	BASE T COND
1.50	91.7

Table 2.1 (Concluded)

VARIABLE AMBIENT TEMPERATURES

DRY BULB -	70	80	85
WET BULB -	60	70	70
RIVER -	60	65	70
WIND	10.0	10.0	10.0
RADIATION	4000	4000	4000

PERCENT OF COOLING SYSTEM TIME AT ABOVE
AMBIENT CONDITIONS

CAP = 1.00 -	.25	.25	.50
CAP = .80 -	.30	.30	.40
CAP = .60 -	.40	.30	.30
CAP = .25 -	.50	.25	.25
CAP = 0 -	0	0	1.00

RIVER WIDTH	TYPE COOLING(2=TOPPING)	COND SPECIFIED(1=YES)
2000	2	1

MAX DISCHARGE TEMP = 85

CONDENSER SPECIFICATIONS

OVERALL U = 350

TUBE AREA = 2.760E 05

H2O FLOW = 4.200E 07

2.5 Power Plant Calculations in the Main Program

The first calculation that is performed in the main program, after the data are read, is to check that the total load duration hours per year equals 8760 hours (including 0 capacity operation), and that, for each capacity, the total percent of operating time at the various ambient conditions equals 100.

The design relative humidity, RH, and the variable ambient relative humidity, AMBRH(I), are then calculated from the wet bulb and dry bulb temperatures with the use of the Carrier equation (cf Ref. 3).

Following the calculation of the relative humidities is the quadratic curve fit of the heat rate points. The curve fit is necessary to provide continuous heat rate values, at the various plant capacities, for condenser pressures between the specified points. The actual curve fit is in terms of condenser temperature rather than pressure, so that the specified condenser pressure input data is first converted to saturation temperature. Also, immediately following this conversion, the maximum and minimum allowable condenser pressures and the base condenser pressure are converted to corresponding saturation temperatures.

If "design" heat rate data is not included in the input, then the program assumes that the 100 percent plant capacity data is to be used for design. This conversion is performed next in the program. Either 100 percent plant capacity data or "design" data must be specified for the program to run. Both may be specified since it may be desirable to "design" the cooling system to match plant operation under special conditions such as above rated capacity ("valves wide open", overpressure, and/or feedwater heaters shut down - see Ref. 2).

Plant capacity factor and cooling system use factor are calculated from the load data. The capacity factor is a measure of the use of the plant relative to its hypothetical maximum design use,

$$CAPFAC = \frac{\text{total kwhrs output in year}}{\text{maximum design output}}$$

(plant at full design capacity for 8760 hours)

The cooling system use factor is the average percent of plant output that is created while the cooling system is in use,

$$USEFAC = \frac{\text{kwhrs output with cooling system in use}}{\text{total kwhrs output in year}}$$

The capacity factor is used to adjust capital cost to be in terms of actual output (kwhrs) in a year, and the use factor is used to adjust cooling system operating cost to be in terms of total plant output in a year.

If the computer system on which the program is to be run cannot handle all the code necessary for the main program and each of the subroutines, the subroutines for cooling methods which will not be used can be omitted, and the references to them in the main program deleted.

2.6 Program Optimization

Following preliminary calculations in the main program, control is transferred to one of the operational subroutines, SUBPOLU, SUBPOND, SUBMDW, or SUBNDW, where the optimum cooling system design is determined. The method of optimization used in these subroutines is a complete search of all allowable combinations of the design variables. Obviously, however, when part of the cooling system is specified, such as the condenser, the design variables describing them are not varied.

In the general case, there are two temperatures that are varied to determine the optimum tower, the condenser temperature and the water discharge temperature from the tower or pond. The condenser temperature is set to the lowest possible value and tower costs are calculated for the full range of possible discharge temperatures. The condenser temperature is then increased by 1° F and the calculations made again for the range of discharge temperatures. The process is repeated until the condenser temperature has been increased to its maximum prescribed value. During the whole process, each time a combination of variables resulted in a tower cost less than the preceeding lowest one, the variables were "saved" for future comparison. Therefore, after all combinations have been tried the "saved" combinations will be the least cost and therefore the optimum.

This optimization procedure is shown in more detail in Figures 3.2, 4.1, and 5.3.

2.7 Subroutine PAFCST (Power and Fuel Cost)

This subroutine, which is "called" by the cooling system subroutines, calculates auxiliary power cost, differential fuel cost, and heat rejected from the power plant for operation at a given capacity and condenser temperature.

At each capacity a base heat rate, HRBASE, is first calculated with the quadratic coefficients, HRCOF2(I), HRCOF1(I), and HRCOFØ(I), and the base condenser temperature. The actual heat rate is then calculated at the desired condenser temperature and the heat rejected, QREJ calculated by

$$QREJ = (HEATR-3413) \times PSIZE \times CAP(I) \quad (2.1)$$

where HEATR = net heat rate - (Btu/kwhr)

PSIZE = total rated plant output (Mw)

CAP(I) = plant capacity of interest (%/100)

Boiler efficiency (stack heat loss) is not included in the above equation since the net heat rate used is defined as the heat added to the steam divided by the net power output.

The differential fuel cost is calculated by

$$\text{DELFC} = \text{FUCST} \times (\text{HEATR} - \text{HRBASE}) \quad \text{(mills/kwhr)} \tag{2.2}$$

where FUCST = fuel cost (¢/million Btu)

HRBASE = base heat rate (Btu/kwhr)

The auxiliary power cost is calculated by

$$\text{PWCST} = \text{FUCST} \times \text{HEATR} + \frac{\text{CCPKW} \times \text{ANFCR}}{\text{CAPFAC} \times 8.76} \quad \text{(mills/kwhr)} \tag{2.3}$$

where CCPKW = plant capital cost ($/kw)

ANFCR = annual fixed charge rate (%/100)

CAPFAC = capacity factor (%/100)

Section 3

ONCE-THROUGH COOLING

3.1 General Description

The calculations and logic for the design of a once-through cooling are contained in two subroutines, SUBPOLU and COND. Subroutine SUBPOLU contains most of the logic and about half of the cost calculations for this type of cooling. It is divided into two parts, a design section in which the cooling system costs are calculated for the design ambient conditions and power output, and an off-design section in which the operating costs are recalculated using the specified variable capacities and ambient conditions. The condenser may be specified as already existing, in which case the capital cost is not included in the total system cost.

Also included in subroutine SUBPOLU is a calculation and printout of river temperatures downstream of the plant. This includes both mixed river temperatures and plume temperatures, and plume width for a specified river. The equilibrium temperature and plume temperature are determined from data and equations taken from Reference 5.

Subroutine COND, which is also used by other cooling systems requiring a water cooled condenser, contains the basic design and cost calculations for the condenser itself.

3.2 Assumptions

Variables and equations for which numerical assumptions have been made in the subroutine are listed below, so that the cards may be changed if different numerical values are desired.

Variable (sequence or line #)	Comments and/or Recommended Values
	Subroutine SUBPOLU
WIND (255)	
QFLRIV (256)	
DEPTH (257)	
RAD (258	4000 - 6000
PMPEF (259)	0.8 - 0.85
WCOFA (264)	Should be of the form used in Reference 5
WCOFB (265)	
DT2 (293)	Need not correspond to (not used for) specified condenser
PLAC (306-310)	1.5, 1.25, 1.0 for seawater, untreated fresh, and treated fresh water, respectively.
PHEAD (315)	
COSMAI (319)	Form of equation and percentages both assumed
	Subroutine COND
PMPEF (1252)	0.8 - 0.85
UALL (1257-1261)	420., 340., and 250 correspond to treated fresh water, untreated fresh water, and sea water, respectively.
CONCST (1270)	Form and coefficients of equation assumed.
CHEAD (1276)	35.

3.3 Basic Equations

For the condenser the basic size equation for the total heat transfer area is

$$ACOND = \frac{QREJ}{UALL \times DTLGM} \tag{3.1}$$

where QREJ = total heat rejected (Btu/hr)

UALL = overall heat transfer coefficient (Btu/hr-ft^2-°F)

DTLGM = log mean temperature difference (°F)

The capital cost equation for the condenser, derived from data in References 7, 12, and 13 is

$$CONCST = 20. x (1.05 x ACOND)^{0.9} \qquad (\$) \qquad (3.2)$$

Added to this is $1/GPM for the cost of the water pumps.

The condenser system cost is the sum of the capital cost (capital charge per year) and the pumping costs, which are

$$PMPCST = \frac{GPM x PHEAD x .7457 x PWCST}{3960 x PMPEF x PSIZE x 1000} \qquad (mills/kwhr) \qquad (3.3)$$

where PHEAD = assumed frictional pumping head (ft)

PWCST = power cost (mills/kwhr)

PMPEF = pump efficiency (%/100)

PSIZE = plant size (Mw)

The above three equations are contained in the subroutine COND.

In the subroutine SUBPOLU, other costs are added to the condenser system cost. These consist of the inlet and outlet water ducting costs, an additional pumping cost for this ducting, and a differential fuel cost obtained from the subroutine PAFCST, due to power plant operation at a condenser pressure higher than PCBASE.

If the condenser is specified, then, since the inlet water temperature is known, the condenser temperature and outlet water temperature may be determined by simultaneous solution of the following three equations. From the power plant subroutine PAFCST, we get

$$QREJ = f \, (TC) \qquad (3.4)$$

In addition,

$$QREJ = SPFLOW x (T1 - T2) x C_p \qquad (3.5)$$

where SPFLOW = specified water flow (lbm/hr)

T1 = outlet water temperature (°F)

T2 = inlet water temperature (°F)

Cp = specific heat of water = 1 (Btu/lbm-°F)

and

$$QREJ = UOVALL \times AREAC \times \frac{(T2 - TC) - (T1 - TC)}{\ln\left(\frac{T2 - TC}{T1 - TC}\right)} \tag{3.6}$$

where UOVALL = specified overall heat transfer coefficient (Btu/hr-ft^2-°F)

AREAC = specified heat transfer area (ft^2)

T1, TC, and QREJ are the only three unknowns, but since the function f of Equation (3.4) is a quadratic curve fit, the simultaneous solution to the three equations is performed by trial and error, in subroutine SUBPOLU.

3.4 Plume Analysis

The final computations performed in subroutine SUBPOLU describe the spread and dissipation of the stream of condenser discharge water, or plume, after it is returned to the flowing river. As was indicated by Edinger and Geyer (Reference 5), even simple limiting models of the spread of warm light water into cold water defy a first-principles analysis at this time. Therefore, the approach taken was to define an arbitrary spreading function which described the increase in plume width with distance downstream of the outfall. This spreading function was prescribed to meet certain physical constraints. These were:

1. the plume width at the outfall was related to the overall width of the river by the ratio of the condenser discharge flow to the undisturbed river flow. That is

$$\frac{PLUMEW}{WIDTH} \text{ (at the outfall)} = \frac{QCON}{QFLRIV} \tag{3.7}$$

where

PLUME	=	width of plume (ft.)
WIDTH	=	totalwidth of river (ft.)
QFLRIV	=	total river flow (ft^3/sec)
QCON	=	condenser discharge flow (ft^3/sec)

2. the spreading rate is of an exponential form.

3. the plume width approaches the total river width smoothly.

A spreading function which satisfies these criteria is

$$PLUMEW = WIDTH \times \left[1 - e^{-(A \times XI + C1)} \right] \tag{3.8}$$

where

A = a constant which can be interpreted as an inverse mixing length (1/miles)

XI = distance downstream of the outfall (miles)

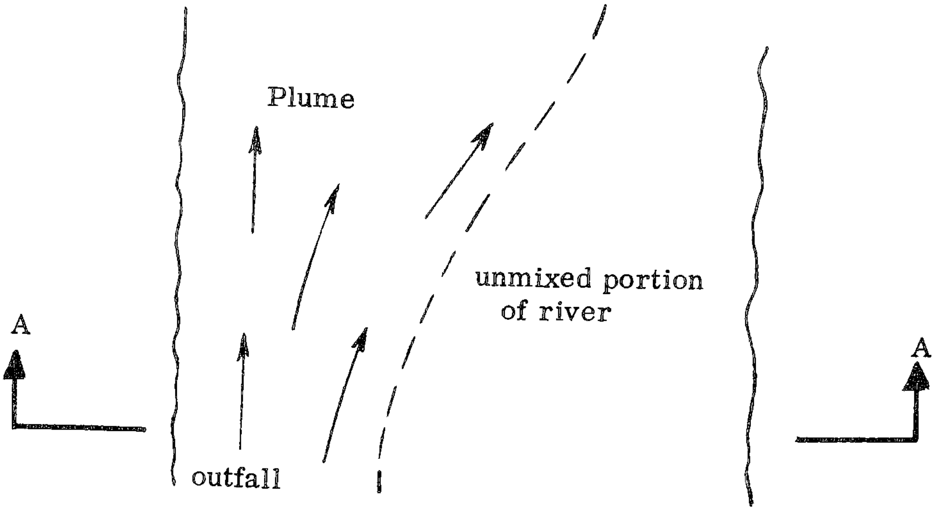
C1 = a constant evaluated so as to satisfy Equation 3.7 at XI = 0.

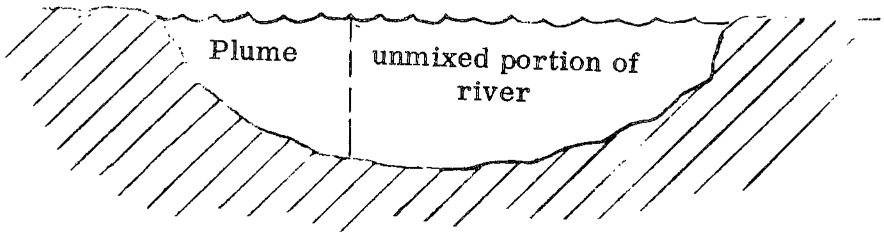
In order to obtain a reasonable approximation to some plume width data in Reference 5, the mixing length was chosen as $\frac{1}{A} = 2$.

Which yielded the final result

$$PLUMEW = WIDTH \times \left[1 - e^{-\left(\frac{XI}{2} + C1 \right)} \right] \tag{3.9}$$

This results in a description which can be interpreted physically according to Figure 3.1, as a two-dimensional unstratified model.





View A-A

Figure 3.1 Schematic of Plume-River Flow

Both streams are subject to heat transfer with the environment and both approach the environmental equilibrium temperature exponentially as derived in Reference 5.

The temperature of the unmixed cold stream, TWREAL, is the easiest to specify since it is by definition unaffected by the plume and simply approaches the equilibrium temperature, TCALC, according to

$$\text{TWREAL} = \text{TCALC} + (\text{TAVH20} - \text{TCALC})\, e^{\text{ALPHA1}} \qquad (3.10)$$

where

TWREAL = unmixed stream temperature (°F)

TCALC = equilibrium temperature (° F)

TAVH20 = temperature just upstream of plant (° F)

ALPHA1 = decay constant

$$= - \frac{\text{XK x XI}}{\text{DENSITY x DEPTH x VELREV}}$$ from Reference 5

The temperature of the plume is most easily defined in terms of a mixed river temperature, TXDIST. The hypothetical temperature is the temperature which the river would be at any point if the plume and the unmixed portion were thoroughly mixed. This temperature, which also approaches the environmental equilibrium temperature, can be shown to be

$$\text{TXDIST} = \text{TCALC} + (\text{TZERO} - \text{TCALC})\, e^{\text{ALPHA1}} \qquad (3.11)$$

where

TXDIST = mixed river temperature at any downstream (°F)

TZERO = mixed river temperature at the outfall (° F)

Therefore,

$$\text{TZERO} = \frac{\text{QCON x T1} + (\text{QFLRIV} - \text{QCON}) \text{ x TREAL}}{\text{QFLRIV}} \qquad (3.12)$$

The plume temperature, PLUMT, is then computed on the basis of a simple energy balance from the mixed river temperature (Equation 3.11) and the plume flow rate (assumed proportional to plume width from Equation 3.9). Hence,

$$\text{QFLRIV} \times \text{TXDIST} = \text{Q PLUM} \times \text{PLUMT} + (\text{QFLRIV} - \text{QPLUM})\ \text{TWREAL} \tag{3.13}$$

$$\frac{\text{PLUMT} - \text{TWREAL}}{\text{TXDIST} - \text{TWREAL}} = \frac{\text{QFLRIV}}{\text{QPLUM}} = \frac{\text{WIDTH}}{\text{PLUMEW}} \tag{3.14}$$

Then from Equation 3.9

$$\frac{\text{PLUMT} - \text{TWREAL}}{\text{TXDIST} - \text{TWREAL}} = \frac{1}{1 - e^{-\sqrt{\text{XI}/2 + \text{C1}}}} \tag{3.15}$$

where

PLUMT = plume temperature (° F)

3.5 Flow Diagram

Figures 3.2 and 3.3 contain the flow diagram for the subroutine SUBPOLU. Some minor calculations and program checks have been omitted for clarity.

3.6 Results

The results using the data of SUBD2 and SUBD4, described in Section 2, are shown in Tables 3.1 and 3.2.

The design values are printed first and consist of the following:

Q REJECT	-	The heat rejected from the plant by the condenser
T CONDENSER	-	The temperature of the condensing steam
CONDENSER FLOW	-	The condenser cooling water flow
PUMP POWER	-	The power required to pump the cooling water
EQUILIBRIUM TEMP	-	The equilibrium temperature corresponding to the design ambient conditions
RANGE	-	The cooling water temperature rise from inlet to exit.

The design costs are printed next. It should be pointed out here that since the various cooling subroutines use common printing subroutines, PRTDS1, PRTDS2, and PRTOD, there are a few quantities in each print out that are not applicable to the cooling system being described. Zeros (with no decimal point)are usually printed as the value of such quantities and the term "not applicable" will be used when describing the results. An example of such a quantity is the first design cost printed, the CAPITAL COST. The capital cost of the condenser is not printed out but it is included in the condenser system cost, described below.

The OPERATING COST result printed for this subroutine consists only of the extra pumping costs associated with the inlet and outlet water ducting for the condenser. Other pumping costs are included in the condenser system cost.

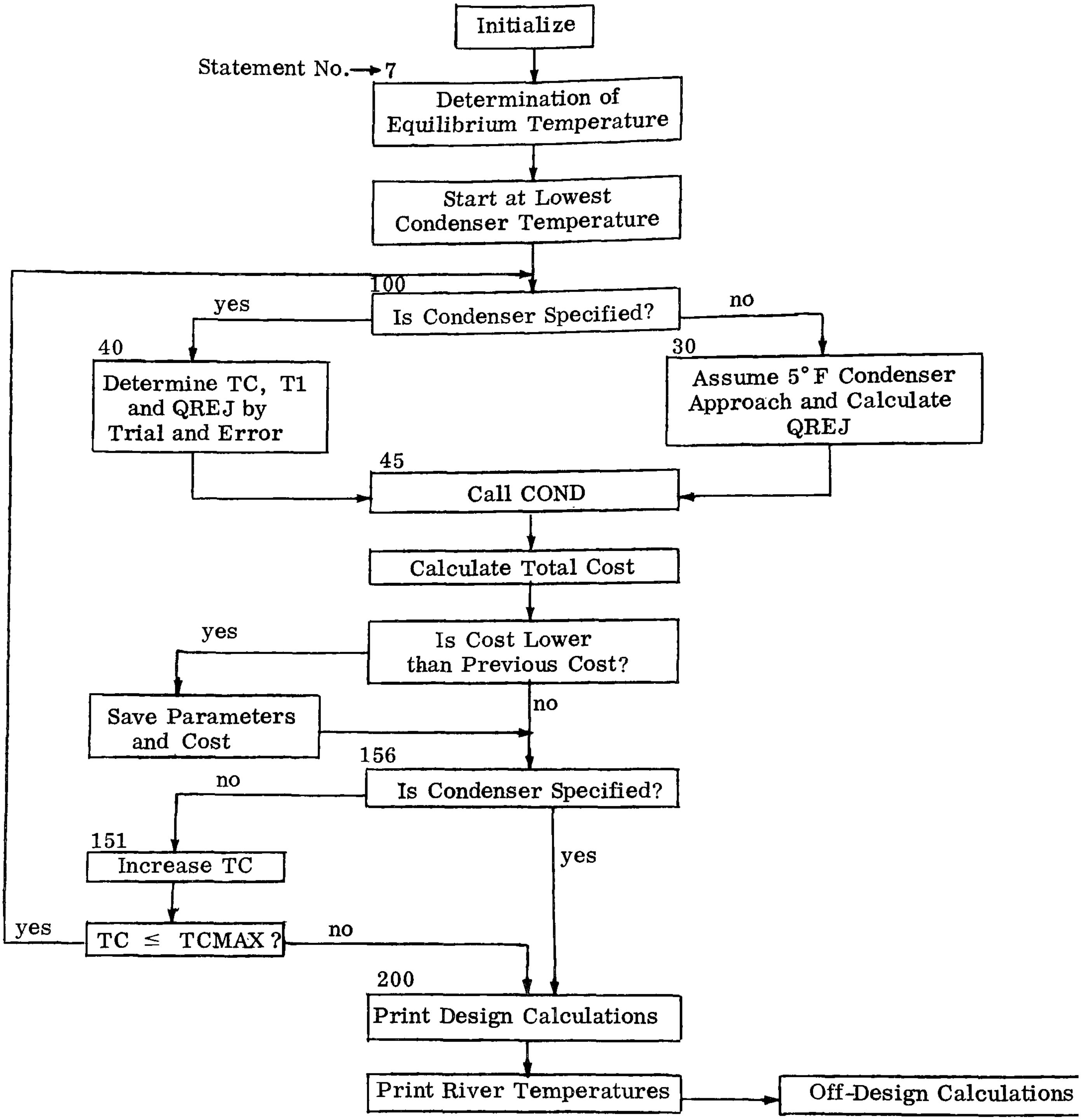


Figure 3.2 Flow Diagram for Design Portion of SUBPOLU

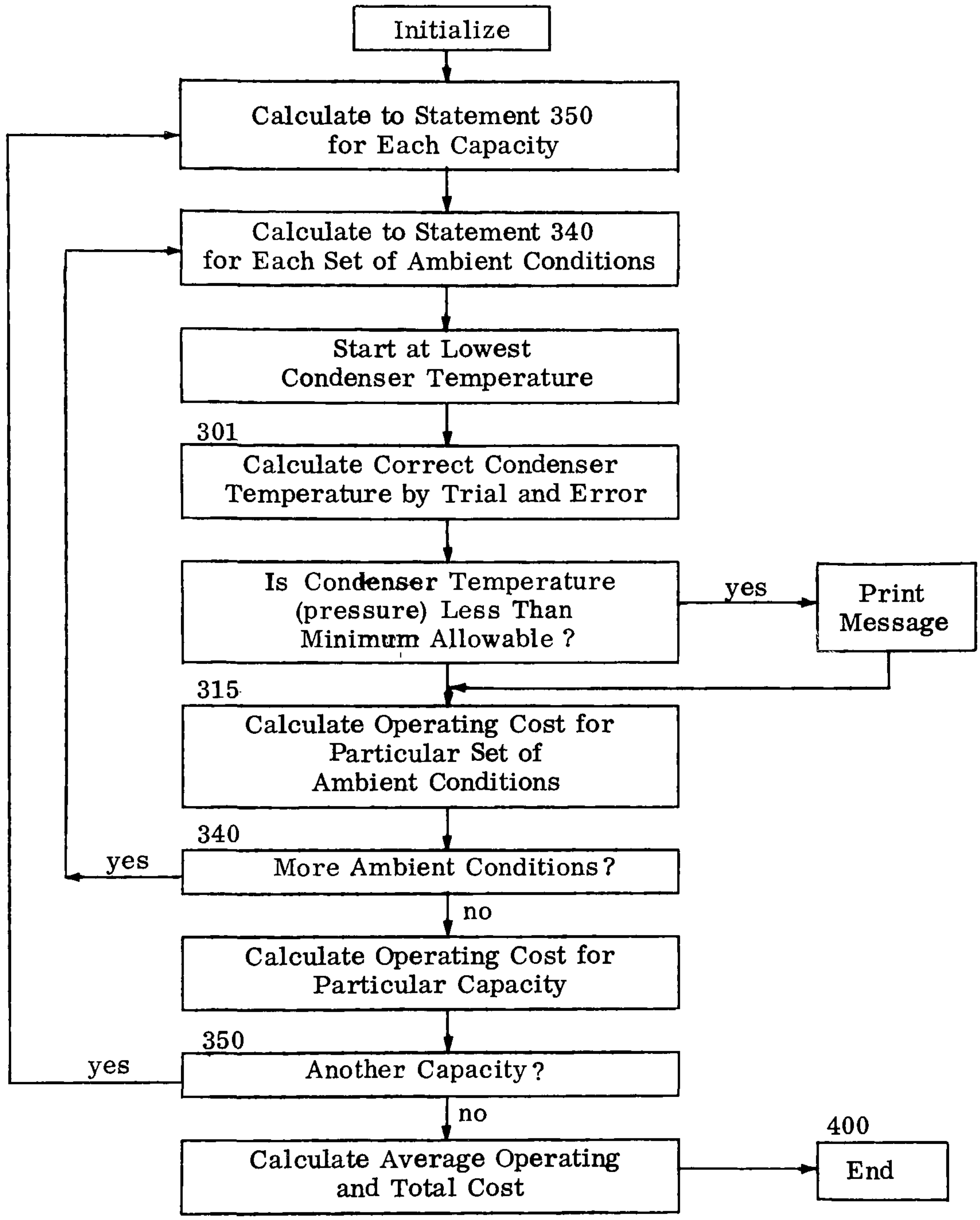


Figure 3.3 Flow Diagram for Off-Design Portion of SUBPOLU

Table 3.1

ONCE-THROUGH COOLING RESULTS USING SUBD2
(CONDENSER SPECIFIED)

-----STRAIGHT CONDENSER COOLING-----

(WITH UNTREATED FRESH WATER)

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.181E 08 BTU/HR AT T CONDENSER = 100
CONDENSER FLOW =1.869E 02 CFS (4.200E 07 LB/HR) PUMP POWER =1.325E 02 HP
EQUILIBRIUM TEMP = 86 RANGE = 22

CAPITAL COST = 0E 00 DOLLARS
CONDENSER AND PUMP COST = 0E 00 DOLLARS/KW
OPERATING COST = .002 MILLS/KW-HR
MAINTENANCE COST = .000 MILLS/KW-HR
CONDENSER SYSTEM COST = 0 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .000 MILLS/KW-HR

TOTAL SYSTEM COST = .002 MILLS/KW-HR

--RIVER TEMPERATURES--

DISTANCE-MILES	STREAM TEMP DEG.F NO PLANT	STREAM TEMP DEG.F MIXED	PLUME TEMP.-DEG.F	PLUME WIDTH-MI
0	75.00	75.58	96.86	.0101
1.0	75.66	76.21	77.01	.1552
2.0	76.29	76.81	77.11	.2432
3.0	76.88	77.38	77.52	.2965
4.0	77.45	77.92	77.99	.3289
5.0	77.98	78.43	78.47	.3485
6.0	78.49	78.91	78.93	.3604
7.0	78.97	79.37	79.38	.3677
8.0	79.42	79.80	79.81	.3720
9.0	79.86	80.22	80.22	.3747
10.0	80.26	80.61	80.61	.3763
20.0	83.35	83.56	83.56	.3788

Table 3.1 (Concluded)

```
                    VARIABLE AMBIENT CONDITIONS

     FOR CAP =1.00,     T WB =   60,  AND  TC =  92
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP =1.00,     T WB =   70,  AND  TC =  92
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .60,     T WB =   60,  AND  TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .25,     T WB =   60,/ AND  TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .25,     T WB =   70,  AND  TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .25,     T WB =   70,  AND  TC =  79


PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

  WITH THE VARIOUS AMBIENT TEMPERATURES
  THE COSTS ARE -

OPERATING COST =  .001 MILLS/KW-HR
DIFFERENTIAL FUEL COST =-0.000 MILLS/KW-HR

TOTAL SYSTEM COST =  .001 MILLS/KW-HR
```

Table 3.2

ONCE-THROUGH COOLING RESULTS USING SUBD4
("DESIGN" CONDENSER)

-----STRAIGHT CONDENSER COOLING-----

(WITH UNTREATED FRESH WATER)

THE DESIGN VALUES AND COSTS ARE -

Q REJECT = 9.454E 08 BTU/HR AT T CONDENSER = 120
CONDENSER FLOW =1.059E 02 CFS (2.380E 07 LB/HR) PUMP POWER =7.507E 01 HP
EQULIBRIUM TEMP = 88 RANGE = 40

CAPITAL COST = 0E 00 DOLLARS
CONDENSER AND PUMP COST =5.093E 00 DOLLARS/KW
OPERATING COST = .001 MILLS/KW-HR
MAINTENANCE COST = .001 MILLS/KW-HR
CONDENSER SYSTEM COST = .112 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .014 MILLS/KW-HR

TOTAL SYSTEM COST = .128 MILLS/KW-HR

--RIVER TEMPERATURES--

DISTANCE-MILES	STREAM TEMP DEG.F NO PLANT	MIXED	PLUME TEMP.-DEG.F	PLUME WIDTH-MI
0	75.00	75.60	114.72	.0057
1.0	75.66	76.23	77.08	.1525
2.0	76.29	76.83	77.14	.2415
3.0	76.88	77.40	77.54	.2955
4.0	77.45	77.93	78.01	.3283
5.0	77.98	78.44	78.48	.3482
6.0	78.49	78.92	78.95	.3602
7.0	78.97	79.38	79.39	.3675
8.0	79.42	79.82	79.82	.3720
9.0	79.86	80.23	80.23	.3746
10.0	80.26	80.62	80.62	.3763
20.0	83.35	83.56	83.56	.3788

VARIABLE AMBIENT CONDITIONS

FOR CAP = .25, T WB = 60, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

FOR CAP = .25, T WB = 70, AND TC = 79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

WITH THE VARIOUS AMBIENT TEMPERATURES
THE COSTS ARE -

OPERATING COST = .001 MILLS/KW-HR
DIFFERENTIAL FUEL COST = .004 MILLS/KW-HR

TOTAL SYSTEM COST = .118 MILLS/KW-HR

The MAINTENANCE COST result is a sum of fixed percentages of the specific capital costs, the operating cost, and the condenser system cost. The three percentages are 0.1%, 10% and 1% respectively.

The CONDENSER SYSTEM COST consists of a capital cost (converted to a cost per output basis) and an operating cost, both described in Section 3.2. The condenser system cost is set equal to zero if the condenser is specified. This is true in all the cooling system subroutines. The reason for this is that if an existing condenser is going to be used, its cost should not be part of the optimization process, and also the costs should already be known. When this cost is given (for the "design" condenser case) it represents a total condenser system cost and is <u>not</u> the cost over and above what a specified condenser might cost.

The DIFFERENTIAL FUEL COST is the added cost, due to increased fuel consumption, of operating the plant at a condenser pressure higher than the specified base pressure (input).

The TOTAL SYSTEM COST is the sum of the capital, operating, maintenance, condenser system, and differential fuel costs. This is the cost with which the optimization is performed; the set of variables resulting in the lowest total system cost is considered to be the best.

The river temperatures and plume width were described in Section 3.2 and the printout is self explanatory.

The initial printout for the variable ambient conditions occurs during calculation of the costs for each set of ambient conditions, and are non-fatal error indications. The two messages that occur are that the condenser pressure, PC, is less than the specified (in the input) minimum, PC MIN, or that the discharge temperature, T DIS, exceeds the maximum allowable, T DIS MAX.* The reason for the first type of message is that the trial calculations for the off design (variable ambient conditions) condenser pressure start at the specified minimum condenser pressure for

*This type of message does not occur for the once-through cooling system, but is discussed here for continuity.

each capacity. If the cooling system is able to handle the heat rejected at this first trial point, it means that the actual operating point should be at a lower condenser pressure. However, this point has been specified as the minimum possible pressure, so it is assumed that the plant operates at this pressure and the operating cost is calculated. A large number of such messages may therefore mean that the "design" ambient conditions are too severe compared to the actual variable conditions, or that the minimum allowable condenser pressures have been set too high.

The second type of message, concerning the discharge temperature from an external cooling system, may occur only when the system is used in a topping operation. The message is self explanatory, and may indicate that the "design" ambient conditions are not severe enough relative to the variable conditions. When the situation indicated by the message occurs (T DIS > T DIS MAX) the program assumes the actual discharge temperature and calculates the operating cost.

The average operating cost and average differential fuel cost for all the variable ambient conditions are calculated and printed out along with a new total system cost. The new modified total system cost is a sum of the original capital, maintenance, and condenser system costs, and the new averaged operating and differential fuel costs.

Section 4

COOLING POND

4.1 General Description

The equations and logic describing the design of a cooling pond are contained in the subroutine SUBPOND. This subroutine "calls" PAFCST for power plant information and COND for condenser specifications. It is possible to have the condenser specified, in which case the cooling pond is sized to match the condenser. If the condenser is not specified, the subroutine "designs" a matched pond and condenser. In both cases, options are available to have the pond used for a topping operation and/or part time use. Pond sizing, in all cases, closely follows the method described in Reference 4.

The subroutine is divided into two sections, a design and an off-design section, similar to the once-through cooling system subroutine.

4.2 Assumptions

Variables and equations for which numerical assumptions have been made in the subroutine are listed below, so that the cards may be changed if different numerical values are desired.

Variable (sequence or line #)	Comment and/or Recommended Values
PMPEF (449)	0.8 - 0.85
WCOFA (452) WCOFB (453)	Should be of the form used in Reference 5.
DT2 (490)	Need not correspond to (not used for) specified condenser
PHEAD (521)	
COSMAI (526)	Form of equation and percentages both assumed.

4.3 Basic Equations

The equation for determining the size of the cooling pond necessary for given inlet and outlet water temperatures and ambient temperatures is taken from Reference 4.

$$AREAP = \frac{24 \times ALPHA \times FLOW}{XK \times 43560} \quad \text{(acres)} \tag{4.1}$$

where FLOW = water flow (lbm/hr)

XK = exchange coefficient (Btu/day-ft^2-°F)

ALPHA is defined by the equation

$$ALPHA = - LOG \frac{(T2 - TCALC)}{(T1 - TCALC)} \tag{4.2}$$

where TCALC = equilibrium temperature (°F)

T1 = inlet water temperature (°F)

T2 = outlet water temperature (°F)

The capital cost of the pond is simply

$$CAPCOS = AREAP \times PRPAGR \tag{4.3}$$

where PRPAGR = land and construction cost ($/acre)

4.4 Flow Diagram

The flow diagram for the subroutine SUBPOND is shown in Figures 4.1 and 4.2.

4.5 Results

The results using the data of all four data sets are shown in Tables 4.1 through 4.4 and are described as follows:

Q REJECT and T CONDENSER	-	described in Section 3.4
PUMP POWER	-	total pumping power required exclusive of condenser
H2O EVAP	-	water evaporation rate
COND FLOW	-	condenser water flow (lbm/hr)
T IN	-	temperature at inlet to pond (exit of condenser) (°F)
RANGE	-	ΔT from inlet to exit of pond (°F)
EQUILIBRIUM TEMP	-	described in Section 3.4 (°F)
POND AREA	-	the designed surface area of the pond
Q REJ POND	-	the amount of heat that is transferred from the pond to the atmosphere. (different from total heat rejected only when topping operation)
CAPITAL COST	-	the capital cost of the cooling pond, exclusive of the condenser

The remaining data and costs are the same as those described in Section 3.4.

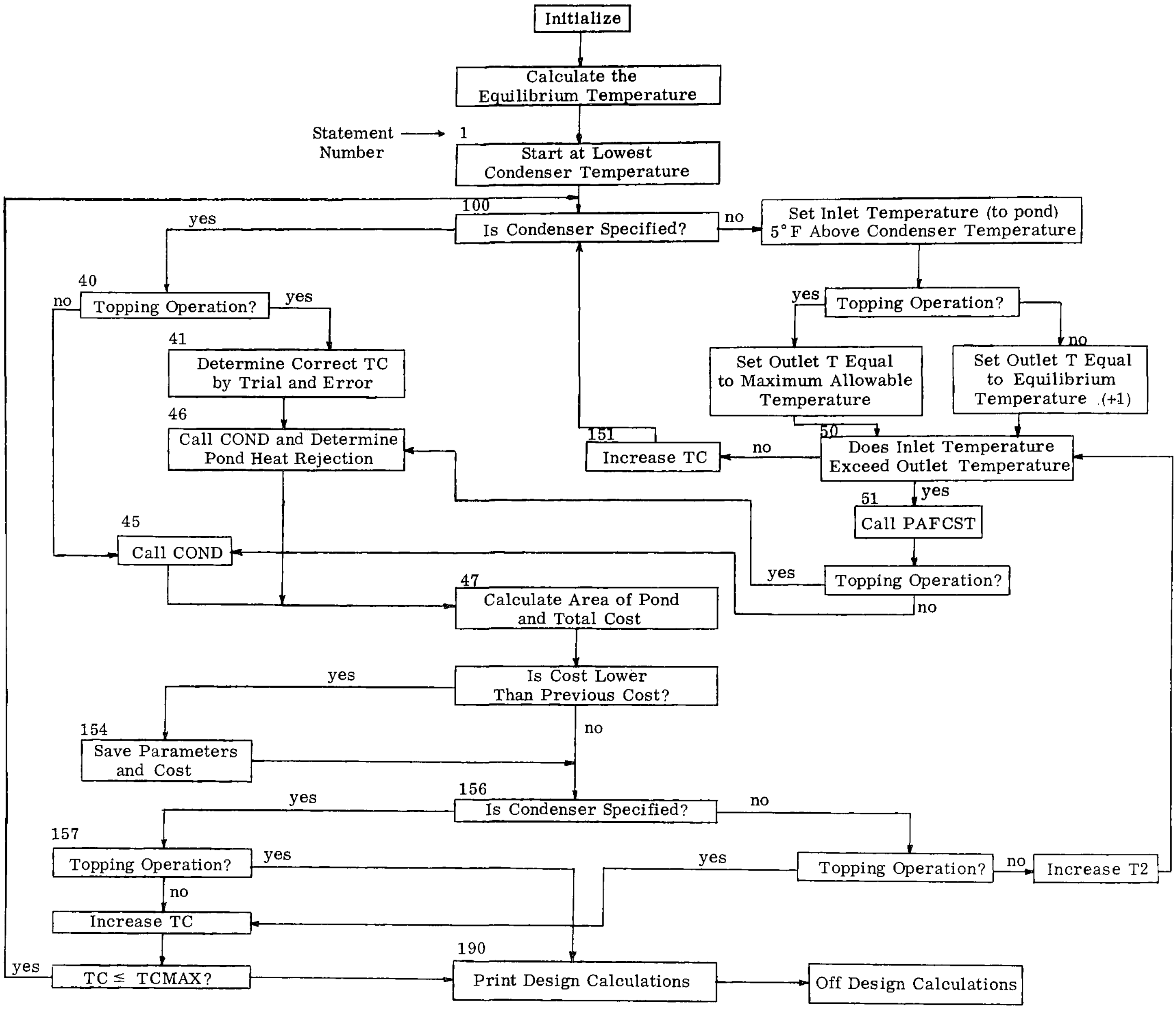


Figure 4.1. Flow Diagram for Design Portion of SUBPOND

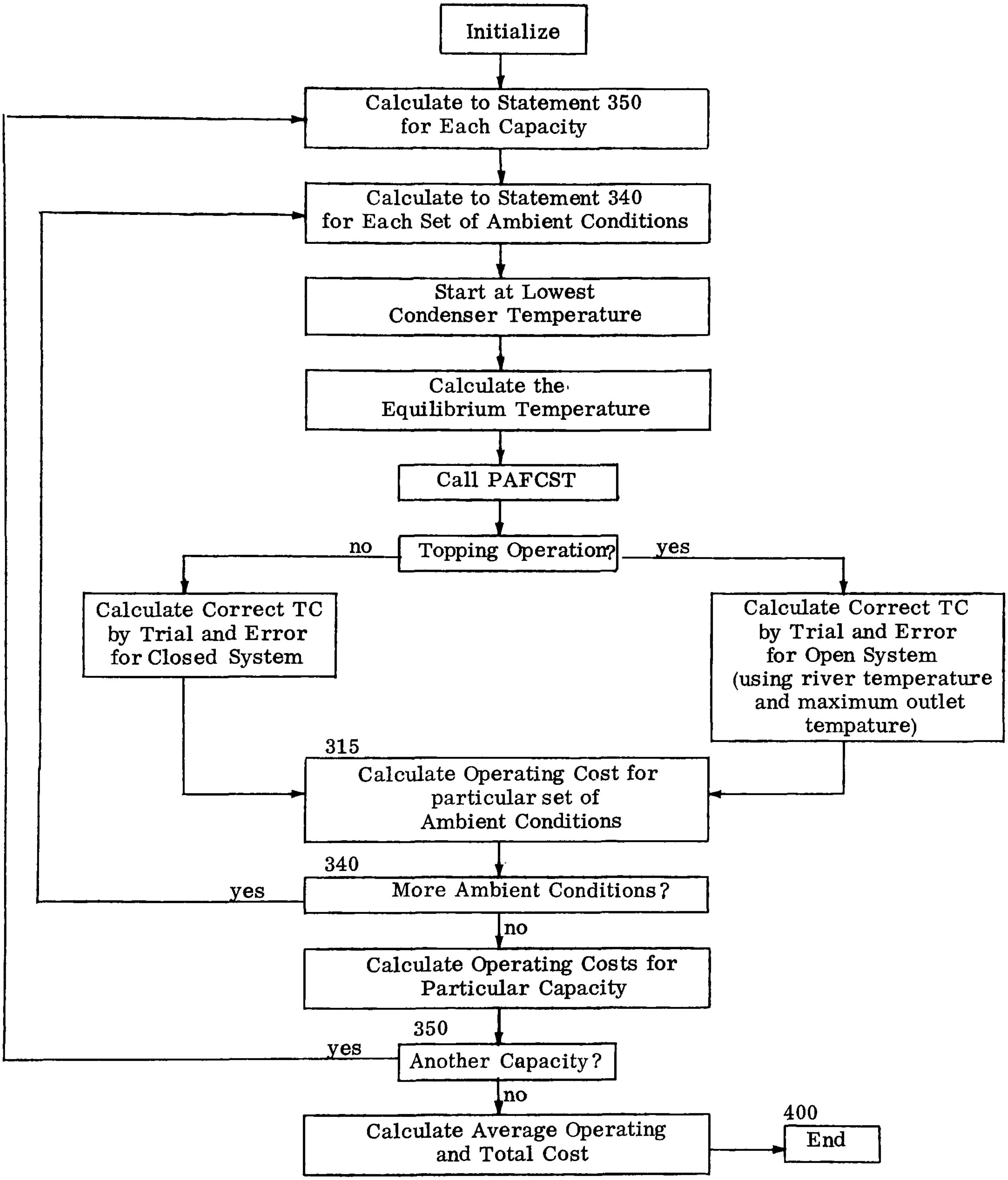


Figure 4.2. Flow Diagram for Off-Design Portion of SUBPOND

Table 4.1

COOLING POND RESULTS USING SUBD1
(SPECIFIED CONDENSER, TOPPING)

```
          ----- COOLING POND -----

     THE DESIGN VALUES AND COSTS ARE -



  Q REJECT =9.181E 08 BTU/HR  AT T CONDENSER =  100
  FAN POWER =     0E 00 HP      PUMP POWER =8.047E 02 HP
  H20 EVAP =2.125E 00 CFS (5.199E 05 LB/HR)
  H20 BLOWDOWN =    0E 00 CFS (     0E 00 LB/HR)
  AIR FLOW RATE =    0E 00 LB/HR
  COND FLOW =4.200E 07    T IN =  97      RANGE =  12
  EQULIBRIUM TEMP =  79     POND AREA =      141 ACRES

  Q REJ POND =5.061E 08 BTU/HR

  CAPITAL COST =1.411E 05 DOLLARS
  CONDENSER AND PUMP COST =     0E 00 DOLLARS/KW
  OPERATING COST =  .007 MILLS/KW-HR
  MAINTENANCE COST =  .001 MILLS/KW-HR
  CONDENSER SYSTEM COST =      0 MILLS/KW-HR
  DIFFERENTIAL FUEL COST =  .000 MILLS/KW-HR

    TOTAL SYSTEM COST =  .021 MILLS/KW-HR



              VARIABLE AMBIENT CONDITIONS


THE POND IS LARGER THAN NECESSARY FOR1.00 CAPACITY AND AMBIENT NO. 1
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

THE POND IS LARGER THAN NECESSARY FOR1.00 CAPACITY AND AMBIENT NO. 2
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

THE POND IS LARGER THAN NECESSARY FOR .60 CAPACITY AND AMBIENT NO. 1
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

THE POND IS LARGER THAN NECESSARY FOR .25 CAPACITY AND AMBIENT NO. 1
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

THE POND IS LARGER THAN NECESSARY FOR .25 CAPACITY AND AMBIENT NO. 2
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

THE POND IS LARGER THAN NECESSARY FOR .25 CAPACITY AND AMBIENT NO. 3
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

    WITH THE VARIOUS AMBIENT TEMPERATURES
    THE COSTS ARE -

  OPERATING COST =  .007 MILLS/KW-HR
  DIFFERENTIAL FUEL COST =-0.000 MILLS/KW-HR

  TOTAL SYSTEM COST =  .020 MILLS/KW-HR
```

Table 4.2

COOLING POND RESULTS USING SUBD2
(SPECIFIED CONDENSER, CLOSED SYSTEM)

```
                    ----- COOLING POND -----

        THE DESIGN VALUES AND COSTS ARE -


Q REJECT =9.351E 08 BTU/HR  AT T CONDENSER =  115
FAN POWER =     0E 00 HP      PUMP POWER =8.107E 02 HP
H2O EVAP =3.438E 00 CFS (8.414E 05 LB/HR)
H2O BLOWDOWN =     0E 00 CFS (     0E 00 LB/HR)
AIR FLOW RATE =    0E 00 LB/HR
COND FLOW =4.200E 07     T IN = 112      RANGE =  22
EQULIBRIUM TEMP =  79      POND AREA =      142 ACRES

CAPITAL COST =1.417E 05 DOLLARS
CONDENSER AND PUMP COST =     0E 00 DOLLARS/KW
OPERATING COST =  .007 MILLS/KW-HR
MAINTENANCE COST =  .001 MILLS/KW-HR
CONDENSER SYSTEM COST =     0 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .007 MILLS/KW-HR

  TOTAL SYSTEM COST =  .027 MILLS/KW-HR


              VARIABLE AMBIENT CONDITIONS


  WITH THE VARIOUS AMBIENT TEMPERATURES
  THE COSTS ARE -

OPERATING COST =  .007 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .005 MILLS/KW-HR

TOTAL SYSTEM COST =  .025 MILLS/KW-HR
```

Table 4.3

COOLING POND RESULTS USING SUBD3
("DESIGN" CONDENSER, TOPPING)

```
----- COOLING POND -----

THE DESIGN VALUES AND COSTS ARE -


Q REJECT =9.454E 08 BTU/HR   AT T CONDENSER =  120
FAN POWER =     0E 00 HP      PUMP POWER =4.623E 02 HP
H20 EVAP =2.564E 00 CFS (6.274E 05 LB/HR)
H20 BLOWDOWN =     0E 00 CFS (     0E 00 LB/HR)
AIR FLOW RATE =     0E 00 LB/HR
COND FLOW =2.380E 07     T IN = 115      RANGE =  30
EQULIBRIUM TEMP =  79      POND AREA =      129 ACRES

Q REJ POND =7.074E 08 BTU/HR

CAPITAL COST =6.432E 05 DOLLARS
CONDENSER AND PUMP COST =5.093E 00 DOLLARS/KW
OPERATING COST =  .004 MILLS/KW-HR
MAINTENANCE COST =  .005 MILLS/KW-HR
CONDENSER SYSTEM COST =  .091 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .010 MILLS/KW-HR

  TOTAL SYSTEM COST =  .164 MILLS/KW-HR


           VARIABLE AMBIENT CONDITIONS

THE POND IS LARGER THAN NECESSARY FOR .25 CAPACITY AND AMBIENT NO. 1
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

THE POND IS LARGER THAN NECESSARY FOR .25 CAPACITY AND AMBIENT NO. 2
COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)

   WITH THE VARIOUS AMBIENT TEMPERATURES
   THE COSTS ARE -

 OPERATING COST =  .004 MILLS/KW-HR
 DIFFERENTIAL FUEL COST =  .004 MILLS/KW-HR

 TOTAL SYSTEM COST =  .158 MILLS/KW-HR
```

Table 4.4

COOLING POND RESULTS USING SUBD4
("DESIGN" CONDENSER, CLOSED SYSTEM)

```
----- COOLING POND -----

THE DESIGN VALUES AND COSTS ARE -


Q REJECT =9.454E 08 BTU/HR  AT T CONDENSER =  120
FAN POWER =    0E 00 HP      PUMP POWER =6.803E 02 HP
H2O EVAP =3.514E 00 CFS (8.599E 05 LB/HR)
H2O BLOWDOWN =    0E 00 CFS (    0E 00 LB/HR)
AIR FLOW RATE =    0E 00 LB/HR
COND FLOW =3.509E 07    T IN = 115     RANGE =  27
EQULIBRIUM TEMP =  79     POND AREA =     150 ACRES

CAPITAL COST =7.487E 05 DOLLARS
CONDENSER AND PUMP COST =6.277E 00 DOLLARS/KW
OPERATING COST =  .006 MILLS/KW-HR
MAINTENANCE COST =  .006 MILLS/KW-HR
CONDENSER SYSTEM COST =  .114 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .010 MILLS/KW-HR

  TOTAL SYSTEM COST =  .199 MILLS/KW-HR


            VARIABLE AMBIENT CONDITIONS


  WITH THE VARIOUS AMBIENT TEMPERATURES
  THE COSTS ARE -

OPERATING COST =  .006 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .008 MILLS/KW-HR

TOTAL SYSTEM COST =  .196 MILLS/KW-HR
```

Section 5

MECHANICAL DRAFT WET COOLING TOWER

5.1 General Description

The calculations and logic for the design of a mechanical draft cooling system are contained in the subroutine SUBMDW. This subroutine "calls" PAFCST for power plant information and COND for condenser specifications. The condenser may be specified or "designed," the cooling system may be open or closed, and part time or full time use of the cooling system may be specified.

The design method that is used is basically a trial and error procedure in which temperatures are varied over permissible ranges, and the total system cost is calculated for each set of conditions. The set of parameters that represents the lowest total system cost is then chosen.

The subroutine is divided into two sections, a design and an off-design section similar to the once through-cooling system subroutine.

5.2 Assumptions

Variables and equations for which numerical assumptions have been made in the subroutine are listed below, so that the cards may be changed if different numerical values are desired.

Variable (sequence or line #)	Comments and/or Recommended Values
FANEF (668)	0.5 - 0.8
PMPEF (669)	0.8 - 0.85
DT2 (703)	Need not correspond to (for not used) specified condenser
DECKHT (735) PHT(736)	Constants must correspond to form of equation - Reference 7
WLOAD (738)	2500.
CONCR (805)	cf Reference 1
CAPCOS (813)	

5.3 Basic Equations

The equations for the size of the cooling tower are based on a calculation of a tower "characteristic," CHAR. Calculation of this characteristic is done with the use of the Tchebycheff (cf Ref. 6) numerical integral approximation, such that

$$CHAR = \frac{RA}{4} \times [RDH1 + RDH2 + RHD3 + RHD4] \qquad (5.1)$$

where RA = range = (T1 - T2) (°F), and the RDH's are defined as follows;

RDH1 - inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at T2 + 0.1 x (T1 - T2) (lbm/Btu)

RDH2 - inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at T2 + 0.4 x (T1 - T2) (lbm/Btu)

RDH3 - inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at T1 - 0.4 x (T1 - T2) (lbm/Btu)

RDH4 - inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at T1 - 0.1 x (T1 - T2) (lbm/Btu)

where T1 = inlet water temperature (°F)
T2 = outlet water temperature (°F)

The packing height in the tower required to give this characteristic is calculated by (Ref. 7)

$$PHT = \frac{DECKHT \times (CHAR - 0.7)}{0.103 \times (WART)^{-0.54}} \tag{5.2}$$

where WART = water to air flow ratio

DECKHT = deck spacing (ft)

The capital cost of the tower is calculated by

$$CAPCOS = 3. \times GPMT \times XK(IK) \times CWB \tag{5.3}$$

where GPMT = total water flow rate (gal/min)

XK(IK) = cooling factor obtained from a curve fit of data of Reference 8, reproduced in Figure 5.1

CWB = wet bulb factor-obtained from Reference 8, reproduced in Figure 5.2

The coefficient, 3, of Equation (5.3) is an average of data from References 8 and 9.

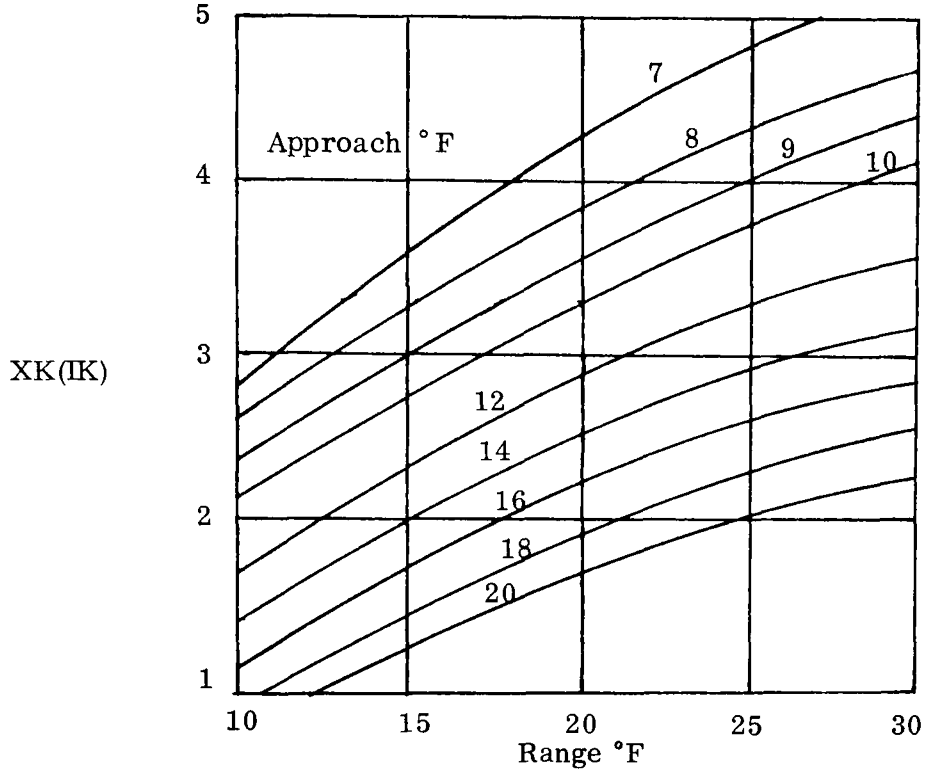


Figure 5.1. Cooling Factor as a Function of Range and Approach (Ref. 8)

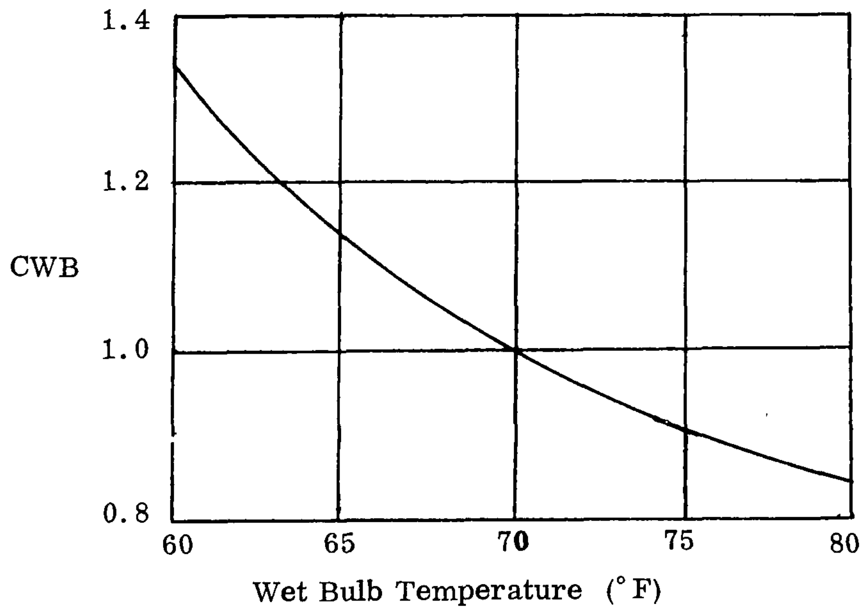


Figure 5.2. Wet Bulb Factor (Ref. 8)

5.4 Flow Diagram

The flow diagram for the design portion of the subroutine SUBMDW is shown in Figure 5.3. A flow diagram for the off-design portion of the program has not been provided since it would be essentially the same as the off design flow diagram for the cooling pond, Figure 4.2.

5.5 Results

The results using the data of all four data sets are shown in Tables 5.1 through 5.4. The description of the results is the same as contained in Sections 3.4 and 4.4 with the exceptions and additions noted below.

FAN POWER	-	the total fan power required for the tower
H2O BLOWDOWN	-	the required water addition to maintain the specified concentration (cf Ref. 4, pg. 65)
AIR FLOW RATE	-	the total air flow rate through the tower
PRESSURE DROP	-	the air pressure drop across the tower packing (inches of water)
APPROACH	-	the difference between the water outlet temperature from the tower and the wet bulb temperature

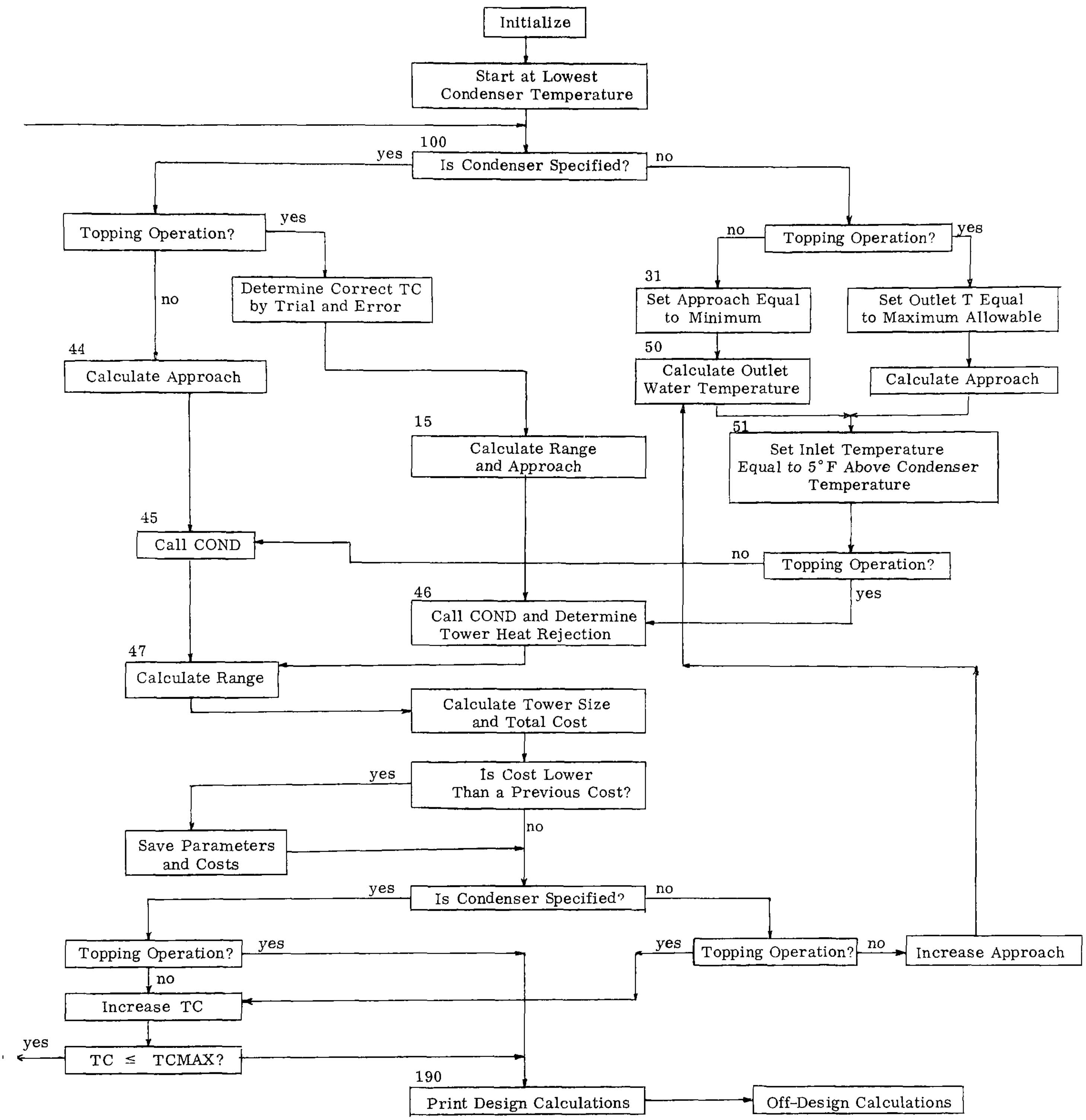


Figure 5.3. Flow Diagram for Design Portion of SUBMDW

Table 5.1

MECHANICAL DRAFT TOWER RESULTS USING SUBD1
(SPECIFIED CONDENSER, TOPPING)

```
                 ----- MECHANICAL DRAFT WET TOWER -----

        THE DESIGN VALUES AND COSTS ARE -


Q REJECT =9.181E 08 BTU/HR  AT T CONDENSER =  100
FAN POWER =4.770E 02 HP     PUMP POWER =1.068E 03 HP
H20 EVAP =1.955E 00 CFS (4.784E 05 LB/HR)
H20 BLOWDOWN =5.176E-01 CFS (1.267E 05 LB/HR)
AIR FLOW RATE =2.679E 07 LB/HR
PRESSURE DROP =  .38    COND FLOW =4.200E 07
RANGE =  12     APPROACH =  10

Q REJ TOWER =5.061E 08 BTU/HR

CAPITAL COST =5.612E 05 DOLLARS
CONDENSER AND PUMP COST =     0E 00 DOLLARS/KW
OPERATING COST =  .014 MILLS/KW-HR
MAINTENANCE COST =  .004 MILLS/KW-HR
CONDENSER SYSTEM COST =     0 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .000 MILLS/KW-HR

  TOTAL SYSTEM COST =  .065 MILLS/KW-HR



           VARIABLE AMBIENT CONDITIONS


     FOR CAP =1.00,     T WB =   60,   AND               TC =  92
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP =1.00,     T WB =   70,   AND               TC =  92
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .60,     T WB =   60,   AND               TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .25,     T WB =   60,   AND               TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .25,     T WB =   70,   AND               TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .25,     T WB =   70,   AND               TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

  WITH THE VARIOUS AMBIENT TEMPERATURES
  THE COSTS ARE -

OPERATING COST =  .014 MILLS/KW-HR
DIFFERENTIAL FUEL COST =-0.000 MILLS/KW-HR

TOTAL SYSTEM COST =  .064 MILLS/KW-HR
```

Table 5.2

MECHANICAL DRAFT TOWER RESULTS USING SUBD2
(SPECIFIED CONDENSER, CLOSED SYSTEM)

```
          ----- MECHANICAL DRAFT WET TOWER -----
       DESIGN VALUES AND COSTS ARE -


Q REJECT =9.431E 08 BTU/HR  AT T CONDENSER =  119
FAN POWER =2.749E 02 HP      PUMP POWER =9.667E 02 HP
H2O EVAP =3.527E 00 CFS (8.631E 05 LB/HR)
H2O BLOWDOWN =9.646E-01 CFS (2.360E 05 LB/HR)
AIR FLOW RATE =2.208E 07 LB/HR
PRESSURE DROP =  .27    COND FLOW =4.200E 07
RANGE =  22      APPROACH =  19

CAPITAL COST =2.631E 05 DOLLARS
CONDENSER AND PUMP COST =    0E 00 DOLLARS/KW
OPERATING COST =  .011 MILLS/KW-HR
MAINTENANCE COST =  .002 MILLS/KW-HR
CONDENSER SYSTEM COST =     0 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .010 MILLS/KW-HR

  TOTAL SYSTEM COST =  .045 MILLS/KW-HR


          VARIABLE AMBIENT CONDITIONS

     FOR CAP =1.00,    T WB =   60,  AND             TC =  92
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .25,    T WB =   70,  AND             TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .25,    T WB =   70,  AND             TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

  WITH THE VARIOUS AMBIENT TEMPERATURES
  THE COSTS ARE -

OPERATING COST =  .011 MILLS/KW-HR
DIFFERENTIAL FUEL COST =-0.000 MILLS/KW-HR

TOTAL SYSTEM COST =  .035 MILLS/KW-HR
```

Table 5.3

MECHANICAL DRAFT TOWER RESULTS USING SUBD3
("DESIGN" CONDENSER, TOPPING)

```
          ----- MECHANICAL DRAFT WET TOWER -----

     THE DESIGN VALUES AND COSTS ARE -


Q REJECT =9.454E 08 BTU/HR  AT T CONDENSER =  120
FAN POWER =7.221E 02 HP     PUMP POWER =7.148E 02 HP
H20 EVAP =2.650E 00 CFS (6.485E 05 LB/HR)
H20 BLOWDOWN =7.235E-01 CFS (1.770E 05 LB/HR)
AIR FLOW RATE =2.154E 07 LB/HR
PRESSURE DROP =  .72    COND FLOW =2.380E 07
RANGE =  30     APPROACH =  10

Q REJ TOWER =7.074E 08 BTU/HR

CAPITAL COST =5.543E 05 DOLLARS
CONDENSER AND PUMP COST =5.093E 00 DOLLARS/KW
OPERATING COST =  .013 MILLS/KW-HR
MAINTENANCE COST =  .005 MILLS/KW-HR
CONDENSER SYSTEM COST =  .091 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .010 MILLS/KW-HR

  TOTAL SYSTEM COST =  .166 MILLS/KW-HR


           VARIABLE AMBIENT CONDITIONS


    FOR CAP = .25,    T WB =   60,  AND            TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

    FOR CAP = .25,    T WB =   70,  AND            TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

  WITH THE VARIOUS AMBIENT TEMPERATURES
  THE COSTS ARE -

OPERATING COST =  .013 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .004 MILLS/KW-HR

TOTAL SYSTEM COST =  .159 MILLS/KW-HR
```

Table 5.4

MECHANICAL DRAFT TOWER RESULTS USING SUBD4
("DESIGN" CONDENSER, CLOSED SYSTEM)

```
----- MECHANICAL DRAFT WET TOWER -----

THE DESIGN VALUES AND COSTS ARE -


Q REJECT =9.454E 08 BTU/HR  AT T CONDENSER =  120
FAN POWER =3.953E 02 HP      PUMP POWER =9.780E 02 HP
H2O EVAP =3.536E 00 CFS (8.652E 05 LB/HR)
H2O BLOWDOWN =9.669E-01 CFS (2.366E 05 LB/HR)
AIR FLOW RATE =2.459E 07 LB/HR
PRESSURE DROP =  .35    COND FLOW =3.985E 07
RANGE =  24      APPROACH =  16

CAPITAL COST =5.523E 05 DOLLARS
CONDENSER AND PUMP COST =6.700E 00 DOLLARS/KW
OPERATING COST =  .013 MILLS/KW-HR
MAINTENANCE COST =  .005 MILLS/KW-HR
CONDENSER SYSTEM COST =  .122 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .010 MILLS/KW-HR

  TOTAL SYSTEM COST =  .197 MILLS/KW-HR


            VARIABLE AMBIENT CONDITIONS


  WITH THE VARIOUS AMBIENT TEMPERATURES
  THE COSTS ARE -

OPERATING COST =  .012 MILLS/KW-HR
DIFFERENTIAL FUEL COST =-0.000 MILLS/KW-HR

TOTAL SYSTEM COST =  .186 MILLS/KW-HR
```

Section 6

NATURAL DRAFT WET COOLING TOWER

6.1 General Description

The logic and calculations for the design of a natural draft cooling tower system are contained in the subroutine SUBNDW. This subroutine obtains power plant information by "calling" PAFCST, and condenser specifications by "calling" COND. The condenser may be specified or designed, the cooling system may be open or closed, and part time or full time use of the coding system may be specified.

The design method is the same as for the mechanical draft system, in that temperatures are varied over permissible ranges and the total system cost is calculated for each set of conditions. The set of conditions resulting in the lowest total cost is then chosen as the design conditions.

The subroutine is divided into a design and an off-design section similar to other cooling system subroutines.

6.2 Assumptions

Variables and equations for which numerical assumptions have been made in the subroutine are listed below, so that the cards may be changed if different numerical values are desired.

Variable (sequence or line#)	Comment and/or Recommended Values
PMPEF (966)	0.8 - 0.85
HDRMAX (968)	1. - 1.75
DT2 (1002)	Need not correspond to (not used for) specified condenser
WLOAD (1014)	Initial value needed
VIN (1046)	2. - 10.
PPK (1055)	Form of equation and constant - Reference 10
PSP (1057)	Form of equation and constants - Reference 16
TPIX (1059)	
CAPCOS (1069)	
CONCR (1070)	cf Reference 1

6.3 Basic Equations

The equations for the size of the cooling tower are based on a calculation of a tower "characteristic," CHAR, and a tower height, THT, necessary to develop the required pressure differential.

The tower characteristic, CHAR, is calculated in the same manner as for the mechanical draft system, Equation (5.1).

The packing height required in the tower to give this characteristic is calculated by (Ref. 10)

$$PHT = \frac{CHAR}{UNC} \tag{6.1}$$

where UNC is the characteristic per foot of packing and is calculated by

$$UNC = 0.1 \times \left(\frac{1}{WART}\right)^{0.73} \tag{6.2}$$

where WART = ratio of water to air flow rates.

The total tower height required is the sum of the sum of the chimney height required for the pressure differential, the packing height, the height of the spray nozzles above the packing, and the air inlet opening height. This is expressed as

$$THT = \frac{TPDP \times VHDI}{DIN - DOUT} \tag{6.3}$$

where TPDP = total pressure drop (air inlet velocity heads)

VHDI = inlet velocity head (lbf/ft^2)

DIN, DOUT = inlet and exit air density (lbm/ft^3)

The capital cost of the tower is calculated from data on British towers (Ref. 11) modified slightly to reflect United States prices. The resulting equation for the capital is

$$CAPCOS = 3.4 \times 10^5 \times (HTDIA)^{.17} \qquad (6.4)$$

where HTDIA = height of tower times diameter of tower.

6.4 Flow Diagram

The flow diagram for the design portion of the subroutine SUBNDW is the same as that for the mechanical draft system subroutine SUBMDW, Figure 5.3. The off-design flow diagram is essentially the same as the off-design diagram for the cooling pond system, Figure 4.2. Therefore, neither flow diagram is included in this section.

6.5 Results

The results using the data of all four data sets are shown in Tables 6.1 through 6.4. The description of the results is the same as for the preceding cooling systems with the exceptions noted below.

PRESSURE DROP - total air pressure drop through the tower (lbf/ft^2)

TOWER HEIGHT - total height of the tower including opening and packing (ft)

TOWER DIAMETER - base diameter of the tower (ft)

TOWER CHARACTERISTIC - the total tower characteristic (Ref. 6)

In the variable ambient conditions error messages,

CHAR - tower characteristic required

THT - tower height required

A fatal error message may occur within the off-design calculations for closed systems when the cooling system cannot reject the required heat at any condenser temperature between the specified limits. A particular case would be if the condenser temperature and ambient temperatures are the same as the "design" conditions, but the power plant is "operating" slightly off design and is less efficient (the heat rate for 100% capacity is slightly higher than for "design").

Table 6.1

NATURAL DRAFT TOWER RESULTS USING SUBD1
(SPECIFIED CONDENSER, TOPPING)

```
----- NATURAL DRAFT WET TOWER -----

THE DESIGN VALUES AND COSTS ARE -


Q REJECT =9.181E 08 BTU/HR  AT T CONDENSER =  100
FAN POWER =     0E 00 HP      PUMP POWER =1.454E 03 HP
H2O EVAP =3.546E 00 CFS (8.677E 05 LB/HR)
H2O BLOWDOWN =9.390E-01 CFS (2.298E 05 LB/HR)
AIR FLOW RATE =4.859E 07 LB/HR
PRESSURE DROP =  1.2    COND FLOW =4.200E 07
   RANGE =  12      APPROACH =  10
TOWER HEIGHT =   470   TOWER DIAMETER =  315
WATER LOADING =    538 LBM/HR-FT2
TOWER CHARACTERISTIC = 1.38      PACKING HEIGHT=12.41

Q REJ TOWER =5.061E 08 BTU/HR

CAPITAL COST =2.573E 06 DOLLARS
CONDENSER AND PUMP COST =     0E 00 DOLLARS/KW
OPERATING COST =  .013 MILLS/KW-HR
MAINTENANCE COST =  .014 MILLS/KW-HR
CONDENSER SYSTEM COST =     0 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .000 MILLS/KW-HR

  TOTAL SYSTEM COST =  .242 MILLS/KW-HR


VARIABLE AMBIENT CONDITIONS


     FOR CAP =1.00,     T WB =   60, AND  TC =  92
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP =1.00,      T WB =  70, AND   TC =  92
T DIS EXCEEDS T DIS MAX - CONTINUING

     FOR CAP = .80,      T WB =  70, AND   TC =  85
T DIS EXCEEDS T DIS MAX - CONTINUING

     FOR CAP = .80,      T WB =  70, AND   TC =  90
T DIS EXCEEDS T DIS MAX - CONTINUING
```

Table 6.1 (Concluded)

```
     FOR CAP = .60,     T WB =   60,  AND  TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .60,      T WB =  70, AND   TC =  80
T DIS EXCEEDS T DIS MAX - CONTINUING

     FOR CAP = .60,      T WB =  70, AND   TC =  85
T DIS EXCEEDS T DIS MAX - CONTINUING

     FOR CAP = .25,     T WB =   60,  AND  TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .25,     T WB =   70,  AND  TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .25,     T WB =   70,  AND  TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE


  WITH THE VARIOUS AMBIENT TEMPERATURES
  THE COSTS ARE -

OPERATING COST =  .013 MILLS/KW-HR
DIFFERENTIAL FUEL COST =-0.000 MILLS/KW-HR

TOTAL SYSTEM COST =  .241 MILLS/KW-HR
```

Table 6.2

NATURAL DRAFT TOWER RESULTS USING SUBD2
(SPECIFIED CONDENSER, CLOSED SYSTEM)

```
        ----- NATURAL DRAFT WET TOWER -----

     THE DESIGN VALUES AND COSTS ARE -


Q REJECT =9.454E 08 BTU/HR  AT T CONDENSER =  120
FAN POWER =     0E 00 HP      PUMP POWER =1.200E 03 HP
H20 EVAP =3.537E 00 CFS (8.654E 05 LB/HR)
H20 BLOWDOWN =9.669E-01 CFS (2.366E 05 LB/HR)
AIR FLOW RATE =2.114E 07 LB/HR
PRESSURE DROP =  1.5    COND FLOW =4.200E 07
   RANGE =  23     APPROACH =  20
TOWER HEIGHT =   235   TOWER DIAMETER =  207
WATER LOADING =   1250 LBM/HR-FT2
TOWER CHARACTERISTIC =  .96     PACKING HEIGHT=15.80

CAPITAL COST =2.129E 06 DOLLARS
CONDENSER AND PUMP COST =     0E 00 DOLLARS/KW
OPERATING COST =  .011 MILLS/KW-HR
MAINTENANCE COST =  .012 MILLS/KW-HR
CONDENSER SYSTEM COST =     0 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .010 MILLS/KW-HR

  TOTAL SYSTEM COST =  .211 MILLS/KW-HR


            VARIABLE AMBIENT CONDITIONS


     FOR CAP = .25,     T WB =   70,  AND  TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

     FOR CAP = .25,     T WB =   70,  AND  TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE

  WITH THE VARIOUS AMBIENT TEMPERATURES
  THE COSTS ARE -

OPERATING COST =  .011 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .008 MILLS/KW-HR

TOTAL SYSTEM COST =  .207 MILLS/KW-HR
```

Table 6.3

NATURAL DRAFT TOWER RESULTS USING SUBD3
("DESIGN" CONDENSER, TOPPING)

```
----- NATURAL DRAFT WET TOWER -----
THE DESIGN VALUES AND COSTS ARE -


Q REJECT =9.454E 08 BTU/HR  AT T CONDENSER =  120
FAN POWER =     0E 00 HP      PUMP POWER =8.841E 02 HP
H2O EVAP =3.542E 00 CFS (8.667E 05 LB/HR)
H2O BLOWDOWN =9.669E-01 CFS (2.366E 05 LB/HR)
AIR FLOW RATE =2.879E 07 LB/HR
PRESSURE DROP =  1.2    COND FLOW =2.380E 07
   RANGE =  30     APPROACH =  10
TOWER HEIGHT =   271   TOWER DIAMETER =  182
WATER LOADING =    911 LBM/HR-FT2
TOWER CHARACTERISTIC = 1.78     PACKING HEIGHT=15.51

Q REJ TOWER =7.074E 08 BTU/HR

CAPITAL COST =2.135E 06 DOLLARS
CONDENSER AND PUMP COST =5.093E 00 DOLLARS/KW
OPERATING COST =  .008 MILLS/KW-HR
MAINTENANCE COST =  .012 MILLS/KW-HR
CONDENSER SYSTEM COST =  .091 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .010 MILLS/KW-HR

  TOTAL SYSTEM COST =  .300 MILLS/KW-HR


              VARIABLE AMBIENT CONDITIONS


     FOR CAP =1.00,      T WB =  70, AND   TC = 110
T DIS EXCEEDS T DIS MAX - CONTINUING

     FOR CAP = .80,      T WB =  70, AND   TC = 100
T DIS EXCEEDS T DIS MAX - CONTINUING

     FOR CAP = .80,      T WB =  70, AND   TC = 106
T DIS EXCEEDS T DIS MAX - CONTINUING

     FOR CAP = .60,      T WB =  70, AND   TC =  92
T DIS EXCEEDS T DIS MAX - CONTINUING

     FOR CAP = .60,      T WB =  70, AND   TC =  97
T DIS EXCEEDS T DIS MAX - CONTINUING

     FOR CAP = .25,    T WB =   60,  AND  TC =  79
PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE
```

Table 6.3 (Concluded)

```
     FOR CAP = .25,      T WB =  70, AND    TC =  79
T DIS EXCEEDS T DIS MAX - CONTINUING

     FOR CAP = .25,      T WB =  70, AND    TC =  83
T DIS EXCEEDS T DIS MAX - CONTINUING

  WITH THE VARIOUS AMBIENT TEMPERATURES
  THE COSTS ARE -

OPERATING COST =  .008 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .004 MILLS/KW-HR



TOTAL SYSTEM COST =  .293 MILLS/KW-HR
```

Table 6.4

NATURAL DRAFT TOWER RESULTS USING SUBD4
("DESIGN" CONDENSER, CLOSED SYSTEM)

```
----- NATURAL DRAFT WET TOWER -----

THE DESIGN VALUES AND COSTS ARE -


Q REJECT =9.454E 08 BTU/HR  AT T CONDENSER =  120
FAN POWER =    0E 00 HP     PUMP POWER =1.140E 03 HP
H2O EVAP =3.546E 00 CFS (8.678E 05 LB/HR)
H2O BLOWDOWN =9.669E-01 CFS (2.366E 05 LB/HR)
AIR FLOW RATE =3.042E 07 LB/HR
PRESSURE DROP =  1.4    COND FLOW =2.980E 07
   RANGE =  32      APPROACH =   8
TOWER HEIGHT =   315   TOWER DIAMETER =  215
WATER LOADING =    820 LBM/HR-FT2
TOWER CHARACTERISTIC = 2.17     PACKING HEIGHT=21.33

CAPITAL COST =2.253E 06 DOLLARS
CONDENSER AND PUMP COST =5.759E 00 DOLLARS/KW
OPERATING COST =  .011 MILLS/KW-HR
MAINTENANCE COST =  .013 MILLS/KW-HR
CONDENSER SYSTEM COST =  .104 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .010 MILLS/KW-HR

  TOTAL SYSTEM COST =  .326 MILLS/KW-HR


            VARIABLE AMBIENT CONDITIONS


  WITH THE VARIOUS AMBIENT TEMPERATURES
  THE COSTS ARE -

OPERATING COST =  .010 MILLS/KW-HR
DIFFERENTIAL FUEL COST =  .008 MILLS/KW-HR

TOTAL SYSTEM COST =  .323 MILLS/KW-HR
```

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APPENDIX

Glossary of Variable Names

ACFM	Air Flow Rate (ft^3/min)
ACOND	Condenser Area (ft^2)
AFLR	Air Flow Rate (lbm/hr)
AFLR1	AFLR corresponding to TOTCS1
ALDG	Air Loading (mass velocity) (lbm/ft^2-hr)
ALDGE	An Equivalent Air Mass Flow Rate (lbm/hr-ft^2)
ALPACT	The Actual ALPHA
ALPHA	Exponent for Exponential Temperature Decay
ALPHA1	Exponent for Exponential Temperature Decay
AMBDFC (I)	Differential Fuel Cost for Operation at CAP (I) (mills/kwhr)
AMBOPC (I)	Operating Cost at CAP(I) (mills/kwhr)
AMBRH (J)	Off Design Relative Humidities (%/100)
AMRAD	Off Design Absorbed Radiation (Btu/ft^2-day)
AMWIND	Off Design Wind Velocity (mph)
ANFCR	Annual Fixed Charge Rate (%/100)
APPR	Approach - temperature difference between outlet water and wet bulb (° F)
APPR1	APPR corresponding to TOTCS1
APSAT	Water Vapor Partial Pressure (psi)
AREAC	Condenser Area for Specified Condenser (ft^2)
AREAP	Cooling Pond Area (acre)
AREAP1	AREAP corresponding to TOTCS1
AVDFCS	Average Off Design Differential Fuel Cost (mills/kwhr)
AVOPCS	Average Off Design Operating Cost (mills/kwhr)
AVTCST	Average Off Design Total Cost (mills/kwhr)
BETA	The derivative of the saturation pressure with respect to temperature, evaluated at the equilibrium temperature (psi/° F)
BOWRAT	Bowen Ratio-Ratio of Conduction to Evaporation Heat Transfer
BSA	Base Area of Tower (ft^2)
CAIR	Heat Capacity Rate (Btu/hr° F)
CAP(I)	Plant Capacity (%/100)
CAPCOS	Capital Cost ($)

CAPCS1	CAPCOS corresponding to TOTCS1
CAPFAC	Average Power Plant Capacity Factor (%/100)
CCPKW	Plant Capital Cost ($/kw)
CHAR	Tower Characteristic
CHAR1	CHAR corresponding to TOTCS1
CHEAD	Friction Pressure Drop in the Condenser (water side)
CKWHRS	Total Power Output per year during which the cooling system is used (kwhr/yr)
CO1	Total Enthalpy Rise of Air Through Tower (Btu/lbm)
COLPCT(I)	Percent of Operating Time, TOTLD(I), that cooling system is used (%/100)
CONCR	Ratio of Circulation Water to Raw-Water Minerals Concentration
CONCST	Condenser Cost ($)
COSMA1	COSMA1 corresponding to TOTCS1
COSMAI	Maintenance Cost (mills/kwhr)
COSPK1	COSPKW corresponding to TOTCS1
COSPKW	Specific Capital Cost ($/kw)
CWB	Wet Bulb Factor
DECKHT	Deck Spacing (ft)
DELF1	DELFC corresponding to TOTCS1
DELFC	Differential Fuel Cost (mills/kwhr)
DELHR	Change in Heat Rate (Btu/kwhr)
DELHS	Change in Saturation Enthalpy (Btu/lbm)
DELP	Packing Pressure Drop (inches of water)
DEPTH	Condenser Depth (ft)
DFCOD	Off Design Differential Fuel Cost (mills/kwhr)
DH	Net Heat Transfer Rate from water to air - will be zero when the equilibrium temperature is substituted into its defining equation (Btu/ft^2-day)
DHM, DHP	The Heat Transfer Rate from water to air when the water is 1° F below and above the equilibrium temperature (assumed or actual) (Btu/ft^2-day)
DHPRIM	The Derivative of DH with Respect to Temperature (Btu/day ft^2-° F)
DIA	Tower Diameter (at base) (ft)

DIA1	DIA corresponding to TOTCS1
DIN	Inlet Air Density (lbm/ft^3)
DOUT	Exit Air Density (lbm/ft^3)
DP1	DELP corresponding to TOTCS1
DT1	Condenser Temperature Difference = TC - T2 (° F)
DT2	Condenser Temperature Difference (approach) = TC -T1 (° F)
DTLGM	Log Mean Temperature Difference (° F)
DTRIV	Change in total "mixed" river temperature between upstream and just downstream of condenser (° F)
ECOF	Evaporation Coefficient ($Btu/ft^2 day$ mm Hg)
FANEF	Fan Efficiency (%/100)
FCFS	Condenser Flow (ft^3/sec)
FLOW	Condenser flow (lbm/hr)
FLOW1	FLOW corresponding to TOTCS1
FUCST	Fuel Cost (¢/million Btu)
FUDGE	An Intermediate Cost Factor
GPM	Condenser Flow Rate (gal/min)
GPM1	GPM corresponding to TOTCS1
GPMT	Total Flow Rate (gal/min)
H(T)	Saturation Enthalpy at Temperature T (Btu/lbm)
H1	Saturation Enthalpy corresponding to the Wet Bulb Temperature (Btu/lbm)
H2	Saturation Enthalpy corresponding to TAXT (except SUBEVAP) -- SUBEVAP only - Exit Air Enthalpy (Btu/lbm)
HDR	Ratio of Tower Height to Diameter
HDR1	HOVD Corresponding to TOTCS1
HDRMAX	Specified Maximum HOVD
HEATR	Net heat rate (Btu/kwhr)
HOUT	Saturation Enthalpy corresponding to Outlet Air Temperature (Btu/lbm)
HPF1	HPFAN corresponding to TOTCS1
HPFAN	Fan Power (hp)
HPP1	HPPMP corresponding to TOTCS1
HPPMP	Pumping Power (hp)

HR(I, J)	Net Heat Rate Corresponding to HRP(I, J) (Btu/kwhr)
HRBASE	Base net heat rate corresponding to PCBASE (Btu/kwhr)
HRCOF2(I), HRCOF1(I) HRCOFϕ(I)	Quadratic Heat Rate Coefficients such that HEAT RATE= HRCOF2(I) x $(TC)^2$ + HRCOF1(I) x (TC) + HRCOFϕ
HRP (I, J)	Condenser Pressure for each Heat Rate Point. THR(I, J) at each CAP(J) (in. Hg.)
HTDIA	Tower Height times Tower Diameter (ft^2)
HWB1	H1 corresponding to TOTCS1
IREAD	Program Read Control Number
ISUB	Program Subroutine Control Number
IRITE	Program Print Out Control Number
IWL	Number of Iterations on WLOAD
NCAPS	Number of Plant Capacities (exclusive of "design" capacity)
NCAPS1	Subscript meaning "Design" Value
NH2O	Type of Cooling Water Used (-1= seawater, 0= untreated fresh water, + 1= treated fresh water)
NHRPTS (I)	Number of Heat Rates Input at each CAP(I)
NSPCON	Whether or not Condenser is Specified (0= no, 1= yes)
NSUBS(I)	Subroutine Control Flags
NSYSOP	Type of Cooling System Operation (0= closed cycle, 2= topping)
NTAMB	Number of Ambient Temperatures
NTCOD	An Index of the Condenser Temperature has been Incremented
OPCOD	Off Design Operating Cost (mills/kwhr)
OPCOS	Operating Cost (mills/kwhr)
OPCS1	OPCOS corresponding to TOTCS1
OPHT	Tower Inlet Air Opening Height (ft)
OPHT1	OPHT corresponding to TOTCS1
P(T)	Saturation Pressure a T (psia)
PBAR	Atmospheric Pressure (= 14.696 psi)

PCBASE	Base Condenser Pressure (in. Hg.)
PCMAX(I)	Maximum Condenser Pressure for CAP (I) (in. Hg.)
PCMIN(I)	Minimum Condenser Pressure for CAP (I) (in. Hg.)
PCTAMB (I,J)	Percent of Cooling System Use Time, (COLPCT(J) x TOTLD(J)), at each CAP(I) that the system operates at the specified ambient temperatures (TAMDB(J), TAMWB(J)) (%/100)
PHEAD	Frictional Pumping Head (ft.)
PHT	Packing Height (ft)
PKWA	Packing Pressure drop with zero water flow (velocity heads/ft)
PKWB	Slope of packing pressure drop versus water loading curve (hr ft velocity heads/lbm)
PLAC	Cost of Condenser Cooling Water Ducting ($/kw)
PLAC1	PLAC corresponding to TOTCS1
PLANA	Tower Plan Area (ft^2)
PLANA1	PLANA corresponding to TOTCS1
PLUMEW	Plume Width (ft)
PLUMT	Plume Temperature (° F)
PMPCST	Pumping Cost (mills/kwhr)
PMPEF	Pump Efficiency (%/100)
PPK	Pressure Drop Across Packing (inlet velocity heads)
PPK1	PPK corresponding to TOTCS1
PRPAGR	Cost of Land and Pond Construction ($/acre)
PSIZE	Rated Plant Output (MW)
PSP	Air Pressure Drop Across Water Spray (inlet velocity heads)
PV	Partial Pressure of Water Vapor (psia)
PWCST	Power cost (for auxiliaries) (mills/kwhr)
QCON	Condenser Water Flow (ft^3/sec)
QLAT	Latent (evaporation) Heat Transfer (Btu/hr)
QREJ	Heat Rejected by Power Plant (Btu/hr)

QREJT	Heat Rejected by Cooling System (Btu/hr)
QRJ1	QREJ corresponding to TOTCS1
QRJT1	QREJT corresponding to TOTCS1
RA	Condenser or cooling System Range (° F)
RA1	RA corresponding to TOTCS1
RAD	Absorbed Radiation (Btu/ft^2 day)
RDH1	Inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at T2 + 0.1 (T1 - T2) (lbm/Btu)
RDH2	Inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at T2 + 0.4 (T1 - T2) (lbm/Btu)
RDH3	Inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at T1 - 0.4 (T1 - T2) (lbm/Btu)
RDH4	Inverse of the difference between saturation enthalpy and actual enthalpy, evaluated at T1 - 0.1 (T1 - T2) (lbm/Btu)
SPFLOW	Condenser Water Flow Rate for Specified Condenser (lbm/hr)
SPHT	Distance of Spray nozzles above packing (ft.)
SYS1	SYSCST corresponding to TOTCS1
SYSCST	Condenser System Cost (mills/kwhr)
T1	Temperature of Water out of Condenser (into cooling system) (° F)
T11	T1 corresponding to TOTCS1
T2	Temperature of Water into Condenser (from cooling system) (° F)
T21	T2 corresponding to TOTCS1
TA	Air Temperature (° F)
TAMDB(J)	Off Design Dry Bulb Temperature (° F)
TAMRV(J)	Off Design River of Estuary Temperature (° F)
TAMWB(J)	Off Design Wet Bulb Temperature (° F)

TAVH2O	Available Water Temperature (° F)
TAXT	Average of Inlet and Outlet Water Temperatures (° F)
TAXT1	TAXT corresponding to TOTCS1
TC	Condenser Temperature (° F)
TC1	TC corresponding to TOTCS1
TCALC	Equilibrium Temperature (° F)
TCALC1	TCALC corresponding to TOTCS1
TCBASE	Base Condenser Temperature (° F)
TCMAX(I)	Maximum Condenser Pressure at CAP(I) (° F)
TCMIN(I)	Minimum Condenser Temperature at CAP(I) (° F)
TDB	Design Dry Bulb Temperature (° F)
TDFMIL	Total Differential Fuel Cost for Each Capacity (mills)
TDISMX	Maximum Water Discharge Temperature (° F)
TG	An Initial Guess at the Equilibirum Temperature (° F)
THR(I, J)	Condenser Saturation Temperature corresponding to HRP(I, J) (° F)
THT	Total Tower height (ft)
THT1	THT corresponding to TOTCS1
TKWHRS	Total Power Output per Year (kwhr/yr)
TNEW	A New Guess at the Equilibirum Temperature (° F)
TOPMIL	Total Operating Cost for each Capacity (mills)
TOTCOS	Total System Cost (mills/kwhr)
TOTCS1	The Minimum Total System Cost calculated up to that point in the Program (mills/kwhr)
TOTHP	Total Auxiliary Power Required for Cooling System (hp)
TOTLD(I)	Hours per year Operating at each corresponding Capacity CAP(I) (hrs/yr)
TOUTS	Saturation Temperature of Outlet Air (° F)
TPDP	Total Pressure Drop (inlet velocity heads)
TPDP1	TPDP corresponding to TOTCS1
TPIX	Inlet and exit turning losses plus friction loss (inlet velocity heads)

TURBHR(I, J)	Net Heat Rate corresponding to HRP(I, J) for each CAP(I) (Btu/kwhr)
TWAV	Average Water Temperature (° F)
TWB	Design Wet Bulb Temperature (° F)
TWREAL	River Temperature XI Downstream from Plant if no heat were added at plant (° F)
TXDIST	"Mixed" river temperature XI Downstream from Plant (° F)
TZERO	"Mixed" river temperature just downstream of condenser (° F)
UA	Heat Transfer Coefficient times Area (Btu/hr° F)
UA1	UA corresponding to TOTCS1
UALL	Overall Heat Transfer Coefficient (Btu/hr-ft^2-° F)
UNC	Characteristic per foot of packing
UOVALL	Overall Heat Transfer Coefficient for Specified Condenser (Btu/hr-ft^2-° F)
USEFAC	Average Cooling Use Factor (%/100)
VELRIV	River Velocity (ft/day)
VHDI	Inlet Velocity Head (lbf/ft^2)
VIN	Air Inlet Velocity (ft/sec)
WACT	Specific Humidity
WART	Ratio of Water Flow to Air Flow
WART1	WART corresponding to TOTCS1
WBDWN	Water Flow Needed for Blowdown (lbm/hr)
WBDWN1	WBDWN corresponding to TOTCS1
WCOFA, WCOFB	Coefficients such that ECOF = WCOFA + WCOFB x WIND
WEVAP	Water Evaporation Rate (lbm/hr)
WEVAP1	WEVAP corresponding to TOTCS1
WIDTH	Width of River or Estuary (ft)
WIND	Wind Speed (mph)
WLMTD	Log Mean Temperature of Cooling Pond (° F)
WLOAD	Water Loading (lbm/hr/ft^2)
WLOAD1	WLOAD corresponding to TOTCS1
WNEED	Total Makeup Water Required (lbm/hr)

WNEED1	WNEED corresponding to TOTCS1
XI	Distance Downstream from Plant (mi)
XK	Energy Exchange Coefficient (Btu/day ft-° F)
XK (IK)	Cooling Factor defined in Figure 5.1
XK1	XK(IK) corresponding to TOTCS1

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      PROGRAM MAINFWP
      COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLD(5),
     X COLPCT(5),TCMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),
     X HRCOF2(6),HRCOF1(6),HRCOF0(6),TDB,TWB,RH,TAVH2O,TCBASE,
     X NTAMB,AMBDFC(5),AMBOPC(5),TAMDB(5),TAMWB(5),AMBRH(5),
     X TAMRV(5),PCTAMB(5,5),NSYSOP,TDISMX,NSPCON,UOVALL,AREAC,SPFLOW,
     X NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,IRITE,IREAD,
     *  AMWIND(5),AMRAD(5),WIND,RAD
      DIMENSION NHRPTS(6),HRP(6,6),THR(6,6),TURBHR(6,6),
     X  HR(6,6),NSUBS(5)
      IRITE=31
      IREAD=30
  200 FORMAT(5F10.0,I10)
  201 FORMAT(6F10.2)
  202 FORMAT(6F10.0)
  203 FORMAT(7I10)
  204 FORMAT(6F10.0,2I10)
  205 FORMAT(F10.0,2I10,4F10.0)
      READ(IREAD,200)PSIZE,CCPKW,ANFCR,FUCST,PRPAGR,NCAPS
      NCAPS1=NCAPS+1
      READ(IREAD,201) (CAP(I),I=1,5)
      READ(IREAD,202) (TOTLD(I),I=1,5)
      READ(IREAD,201) (COLPCT(I),I=1,5)
      READ(IREAD,203) (NHRPTS(I),I=1,6)
      READ(IREAD,201) (PCMIN(I),I=1,6)
      READ(IREAD,201) (PCMAX(I),I=1,6)
      NNCAP=NCAPS
      IF(NHRPTS(NCAPS1) .GT. 0) NNCAP=NNCAP+1
      DO 210 I=1,NNCAP
       READ(IREAD,201)  (HRP(I,J),J=1,6)
  210 READ(IREAD,202) (TURBHR(I,J),J=1,6)
C
C
      READ(IREAD,204)TDB,TWB,TAVH2O,PCBASE,WIND,RAD,NH2O,NTAMB
C
      READ(IREAD,202) (TAMDB(I),I=1,NTAMB)
      READ(IREAD,202) (TAMWB(I),I=1,NTAMB)
      READ(IREAD,202) (TAMRV(I),I=1,NTAMB)
      READ(IREAD,202) (AMWIND(I),I=1,NTAMB)
      READ(IREAD,202) (AMRAD(I),I=1,NTAMB)
C
      DO 216 I=1,NCAPS
  216  READ(IREAD,201) (PCTAMB(I,J),J=1,NTAMB)
C
      READ(IREAD,205)WIDTH,NSYSOP,NSPCON,TDISMX,UOVALL,AREAC,SPFLOW
      READ(IREAD,203) (NSUBS(I),I=1,5)
C
C          LOAD DURATION HOURS CHECK - TO STATEMENT 246
      TOTDUR=0.0
      DO 243 I=1,NCAPS
      TOTAM=0.0
C          PERCENT AMBIENT TIME CHECK - TO STATEMENT 242
      DO 238 J=1,NTAMB
  238  TOTAM=TOTAM+PCTAMB(I,J)
      IF( TOTAM .EQ. 1.) GO TO 242
      WRITE(IRITE,239)I
C          CALC OF RELATIVE HUMIDITY - RH AND AMBRH
  239  FORMAT(# TOT PCT AMBIENT HRS NOT = 1.0 FOR CAP NO#,I2)
      GO TO 500
  242  CONTINUE
      TOTDUR=TOTDUR+TOTLD(I)
  243  CONTINUE
```

```
      IF (TOTDUR .EQ. 8760.)GO TO 246
      WRITE(IRITE,244)
  244 FORMAT(≠ TOT LD HRS NOT = 8760 ≠)
      GO TO 500
  246 CONTINUE
C
      PBAR=14.696
      PV=P(TWB)-(((PBAR-P(TWB))*(TDB-TWB))/(2800.-1.3*TWB))
      RH=PV/P(TDB)
      DO 20 I=1,NTAMB
   20 AMBRH(I)=(P(TAMWB(I))-(((PBAR-P(TAMWB(I)))*
     X (TAMDB(I)-TAMWB(I)))/(2831.-1.43*TAMWB(I))))/P(TAMDB(I))
C
C          QUADRADIC CURVE FIT OF HEAT RATES (TO STATEMENT
      NNCAP=NCAPS
      CAP(NCAPS1)=1.
      IF(NHRPTS(NCAPS1) .GT. 0) NNCAP=NNCAP+1
      DO 9 I=1,NNCAP
      IF(NHRPTS(I) .GT. 2) GO TO 7
      WRITE(IRITE,6)I
    6 FORMAT(≠ LESS THAN 3 HEAT RATES FOR CAP NO ≠,I2)
      GO TO 500
    7 X1=0.$X2=0.$X3=0.$X4=0.$XY=0.$X2Y=0.$Y1=0.
      M2=NHRPTS(I)
      DO 8 J=1,M2
C
      HR(I,J)=TURBHR(I,J)
C
C          CALC OF TSAT FROM PRESS. (IN. HG)
      BLOG=ALOG(HRP(I,J))
      THR(I,J)=79.035793+30.462409*BLOG+1.9740416*
     X (BLOG)**2+0.13124035*(BLOG)**3
      X1=THR(I,J)+X1
      X2=(THR(I,J)**2)+X2
      Y1=HR(I,J)+Y1
      X3=(THR(I,J)**3)+X3
      X4=(THR(I,J)**4)+X4
      XY=XY+THR(I,J)*HR(I,J)
    8 X2Y=X2Y+(THR(I,J)**2)*HR(I,J)
      B=NHRPTS(I)
      DEN=X4*(B*X2-X1**2)-X3*(B*X3-X2*X1)+X2*(X3*X1-X2**2)
      ANUM=X2Y*(B*X2-X1**2)-X3*(B*XY-X1*Y1)+X2*(XY*X1-X2*Y1)
      BNUM=X4*(B*XY-X1*Y1)-X2Y*(B*X3-X2*X1)+X2*(X3*Y1-XY*X2)
      CNUM=X4*(X2*Y1-XY*X1)-X3*(X3*Y1-XY*X2)+X2Y*(X3*X1-X2**2)
      HRCOF2(I)=ANUM/DEN
      HRCOF1(I)=BNUM/DEN
      HRCOF0(I)=CNUM/DEN
    9 CONTINUE
C
C          MAKING DESIGN HR = 100PCT CAPACITY HR (IF NOT SPECIFIED)
      IF(NHRPTS(NCAPS1) .GT. 0) GO TO 45
      DO 40 I=1,NCAPS
      IF(CAP(I) .EQ. 1.) GO TO 42
   40 CONTINUE
      WRITE(IRITE,41)
   41 FORMAT(≠ NO 100 PCT CAPACITY OR DESIGN HR≠)
      GO TO 500
   42 HRCOF2(NCAPS1)=HRCOF2(I)
      HRCOF1(NCAPS1)=HRCOF1(I)
      HRCOF0(NCAPS1)=HRCOF0(I)
      PCMIN(NCAPS1)=PCMIN(I)
      PCMAX(NCAPS1)=PCMAX(I)
```

```
   45  CONTINUE
C
      DO 11 I=1,NCAPS1
      BLOG=ALOG(PCMIN(I))
      TCMIN(I)=79.035793+30.462409*BLOG+1.9740416*
     X (BLOG)**2+0.13124035*(BLOG)**3
      BLOG=ALOG(PCMAX(I))
   11   TCMAX(I)=79.035793+30.462409*BLOG+1.9740416*
     X (BLOG)**2+0.13124035*(BLOG)**3
      BLOG=ALOG(PCBASE)
      TCBASE=79.035793+30.462409*BLOG+1.9740416*
     X (BLOG)**2+0.13124035*(BLOG)**3
C
C          CALC OF AVG CAPACITY FACTOR AND COOLING USE FACTOR
      TKWHRS=0.0
      CKWHRS=0.0
      DO 47 I=1,NCAPS
      TKWHRS=TKWHRS+(CAP(I)*TOTLD(I))
   47  CKWHRS=CKWHRS+(CAP(I)*TOTLD(I)*COLPCT(I))
      CAPFAC=TKWHRS/8760.
      USEFAC=CKWHRS/TKWHRS
C
C
      DO 60 ISUB=1,5
      IF(NSUBS(ISUB).EQ.0)GO TO 60
      GO TO (50,70,72,74,76)ISUB
   50 WRITE(IRITE,350)PSIZE,CCPKW,ANFCR,FUCST,PRPAGR
  350 FORMAT(1H1,10X,≠-----PRINTOUT OF INPUT DATA-----≠
     X    /1H04X,≠PSIZE     CAP $     ANFCR     FUEL $     PRPAGR≠, /,
     X5X,F5.0,F9.0,F8.2,F9.0,F10.0//)
C
      WRITE(IRITE,360)(CAP(I),I=1,NCAPS)
      WRITE(IRITE,361)(TOTLD(I),I=1,NCAPS)
      WRITE(IRITE,362)(COLPCT(I),I=1,NCAPS)
      WRITE(IRITE,363)(PCMIN(I),I=1,NCAPS1)
      WRITE(IRITE,364)(TCMIN(I),I=1,NCAPS1)
      WRITE(IRITE,365)(PCMAX(I),I=1,NCAPS1)
      WRITE(IRITE,366)(TCMAX(I),I=1,NCAPS1)
  360  FORMAT(5X,≠CAPACITIES AND CORRESPONDING DATA≠,/, 7X,    ≠(EXTRA V
     XALUES ARE DESIGN DATA)≠,//, 3X,≠CAPACITY -     ≠,5F7.2)
  361 FORMAT(≠    HRS/YEAR -      ≠,5F7.0)
  362 FORMAT(≠    PCT COOLING -  ≠,5F7.2)
  363 FORMAT(≠    MIN P COND -    ≠,6F7.2)
  364 FORMAT(≠    MIN T COND -    ≠,6F7.2)
  365 FORMAT(≠    MAX P COND -    ≠,6F7.2)
  366 FORMAT(≠    MAX T COND -    ≠,6F7.2)
C
      WRITE(IRITE,370)CAPFAC,USEFAC
  370  FORMAT(5X,≠CAPACITY FACTOR =≠,F5.2,/,5X,≠COOLING USE FACTOR =≠
     X ,F5.2,//)
C
      WRITE(IRITE,403)
  403  FORMAT(5X,≠COND PRESS AND CORRESPONDING DATA AT EACH CAPACITY
     X≠)
      DO 407 I=1,NCAPS
      WRITE(IRITE,404) CAP(I)
  404  FORMAT(/2X,≠CAPACITY =≠,F4.2)
C
      M2=NHRPTS(I)
      WRITE(IRITE,405)  (HRP(I,J),J=1,M2)
  405  FORMAT(3X,≠PRESSURE -     ≠,6F8.2)
C
```

```
  407 WRITE(IRITE,406) (TURBHR(I,J),J=1,M2)
  406  FORMAT(3X,≠T HEAT RATE -  ≠,6F8.0)
C
      M2=NHRPTS(NCAPS1)
      IF(M2 .EQ. 0) GO TO 412
      WRITE(IRITE,409)(HRP(NCAPS1,J),J=1,M2)
  409  FORMAT(//5X,≠DESIGN VALUES (CAPACITY = PLANT SIZE)≠,//, 3X,   ≠PR
     XESSURE -     ≠,6F8.2,/)
      WRITE(IRITE,410)(TURBHR(NCAPS1,J),J=1,M2)
  410  FORMAT(3X,≠T HEAT RATE -  ≠,6F8.0,/)
C
  412  WRITE(IRITE,413)TDB,TWB,WIND,RAD,TAVH2O,NH2O
  413 FORMAT(≠0   DRY BULB T    WET BULB T    WIND SPEED    RADIATION≠/
     X  F12.0,F14.0,F13.1,F14.0/≠0   AVAIL H2O T    TYPE AVAILABLE H2O≠/
     X  F13.0,I16)
C
      WRITE(IRITE,429)PCBASE,TCBASE
  429  FORMAT(3X,≠BASE P COND      BASE T COND≠,/,7X,F6.2,8X,F6.1//)
      WRITE(IRITE,414)(TAMDB(I),I=1,NTAMB)
  414  FORMAT(1H14X≠VARIABLE AMBIENT TEMPERATURES≠,//3X,≠DRY BULB -  ≠
     X  5F7.0,/)
      WRITE(IRITE,415)(TAMWB(I),I=1,NTAMB)
  415  FORMAT(3X,≠WET BULB -  ≠,5F7.0,/)
      WRITE(IRITE,416)(TAMRV(I),I=1,NTAMB)
  416  FORMAT(3X,≠RIVER -     ≠,5F7.0,/)
      WRITE(IRITE,1417)(AMWIND(I),I=1,NTAMB)
 1417 FORMAT(≠   WIND≠8X,5F7.1)
      WRITE(IRITE,1418)(AMRAD(I),I=1,NTAMB)
 1418 FORMAT(≠   RADIATION   ≠5F7.0)
C
      WRITE(IRITE,417)
  417  FORMAT(//5X,≠PERCENT OF COOLING SYSTEM TIME AT ABOVE≠,/,
     X 8X,≠AMBIENT CONDITIONS≠,/)
      DO 418 I=1,NCAPS
  418  WRITE(IRITE,419)CAP(I),(PCTAMB(I,J),J=1,NTAMB)
  419  FORMAT(/3X,≠CAP = ≠,F4.2,≠ -≠,5F7.2)
C
      WRITE(IRITE,420)WIDTH,NSYSOP,NSPCON
  420  FORMAT(//5X,    ≠RIVER WIDTH    TYPE COOLING(2=TOPPING)    COND S
     XPECIFIED(1=YES)≠,/, 5X,F8.0,14X,I2,24X,I2,/)
C
      IF(NSYSOP-2)424,421,424
  421   WRITE(IRITE,422)TDISMX
  422  FORMAT( 3X,≠MAX DISCHARGE TEMP = ≠,F4.0/)
C
  424  IF(NSPCON-1)428,425,428
  425  WRITE(IRITE,426)UOVALL,AREAC,SPFLOW
  426  FORMAT(5X,≠CONDENSER SPECIFICATIONS≠,/, 3X,≠OVERALL U = ≠,F6.
     X0,/, 3X,≠TUBE AREA = ≠,E9.4,/, 3X,≠H2O FLOW = ≠,F9.4,//)
C
  428  CONTINUE
      GO TO 60
C
   70 CALL SUBPOLU
      GO TO 60
   72  CALL SUBPOND
      GO TO 60
   74  CALL SUBMDW
      GO TO 60
   76  CALL SUBNDW
   60 CONTINUE
  500  END
```

```
      SUBROUTINE SUBPOLU
      COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLD(5), COLPCT(5),TC
     XMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),  HRCOF2(6),HRCOF1(6),HRCOFO(6),
     XTDB,TWB,RH,TAVH2O,TCBASE,  NTAMB,AMBDFC(5),AMBOPC(5),TAMDB(5),TAMW
     XB(5),AMBRH(5),  TAMRV(5),PCTAMB(5,5),NSYSOP,TDISMX,NSPCON,UOVALL,A
     XREAC,SPFLOW,  NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,IRITE,IREAD
      WIND=8.8
      QFLRIV=7000.
      DEPTH=10.
      RAD=5580.
      PMPEF=0.8
      TOTCS1=1.E3
C
C          CALCULATION OF THE EQULIBRIUM TEMPERATURE, TCALC, TO
C          STATEMENT 1 -- EQUATION TAKEN FROM EDINGER
      WCOFA=0.
      WCOFB=15
      ECOF=WCOFA+WCOFB*WIND
      TA=TDB
      TG=TDB
    7 DH=RAD-1801.*(TG/460.+1.)**4-ECOF*51.7*(P(TG)-RH*P(TA)) -.26*ECO
     XF*(TG-TA)
      DHP=RAD-1801.*((TG+1.)/460.+1.)**4-ECOF*51.7*(P(TG+1.)-RH*P(TA)) -
     X.26*ECOF*(TG+1.-TA)
      DHM=RAD-1801.*((TG-1.)/460.+1.)**4-ECOF*51.7*(P(TG-1.)-RH*P(TA)) -
     X.26*ECOF*(TG-1.-TA)
      DHPRIM=(DHP-DHM)/2.
      IF(ABS(DH)-1.)1,2,2
    2 TNEW=TG-DH/DHPRIM
      TG=TNEW
      GO TO 7
    1 TCALC=TG
      BETA=51.7*(P(TCALC+1.)-P(TCALC-1.))/2.
      XK=15.7+(0.26+BETA)*ECOF
      TC=TCMIN(NCAPS+1)
  100 CONTINUE
      IF(NSPCON-1)30,40,30
   40 CALL PAFCST(NCAPS+1,TC,PWCST,DELFC,QREJ)
      DT2=(QREJ/SPFLOW)/(EXP(UOVALL*AREAC/SPFLOW)-1.)
      DT1=DT2+QREJ/SPFLOW
      T1=TC-DT2
      T2=TC-DT1
      IF(NSYSOP-2)41,46,41
   41   IF(DT1-(TC-TAVH2O))45,45,151
   30 DT2=5.
      IF(NSYSOP-2)31,46,31
   31 T2=TAVH2O
      GO TO 51
   46 WRITE(IRITE,50)
   50 FORMAT(/#CANNOT HAVE TOPPING WITH STRAIGHT CONDENSER COOLING#)
      GO TO 400
   51 CALL PAFCST(NCAPS+1,TC,PWCST,DELFC,QREJ)
   45 CALL COND(TC,T2,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,
     *  COSPKW)
      RA=T1-T2
      IF(NH2O)13,14,15
C          PLAC- COST PER KW FOR WATER DUCTING
   13 PLAC=1.5
      GO TO 16
   14 PLAC=1.25
      GO TO 16
   15 PLAC=1.0
```

```
 16  CONTINUE
     IF(NSPCON.EQ.1)PLAC=0.0
     SYSCST=SYSCST+PLAC*ANFCR/(CAPFAC*8.76)
C        ASSUME 5 FT OF PUMPING HEAD (FRICTION)
     PHEAD=5.
     HPPMP=GPM*PHEAD/(3960.*PMPEF)
     CAPCOS=0.0
     OPCOS=(HPPMP*.7457/(PSIZE*1000.))*PWCST
     COSMAI=.001*CAPCOS/(PSIZE*1000.)+.1*OPCOS+.01*SYSCST
     TOTCOS=SYSCST+DELFC+OPCOS+COSMAI
     IF(TOTCOS-TOTCS1)154,156,156
156  IF(NSPCON.EQ.1)GO TO 190
151  TC=TC+1.
     IF(TC-TCMAX(NCAPS+1))100,100,190
154  RA1=RA
     T11=T1
     T21=T2
     SYS1=SYSCST
     CAPCS1=CAPCOS
     COSPK1=COSPKW
     OPCS1=OPCOS
     COSMA1=COSMAI
     PLAC1=PLAC
     HPF1=0.
     HPP1=HPPMP
     DELF1=DELFC
     TCALC1=TCALC
     QRJ1=QREJ
     FLOW1=FLOW
     FCFS=FLOW1/224700.
     GPM1=GPM
     UA1=UA
     TC1=TC
     TOTCS1=TOTCOS
     GO TO 156
190  IF(TOTCS1-1.E3)200,195,200
195  WRITE(IRITE,196)TC,T1,RA
196  FORMAT(/3X,   ≠FOR THE GIVEN CONDITIONS A SOLUTION CANNOT BE FOUN
    XD≠,/,3X,≠TC =≠,F5.0,≠   T1 =≠,F5.0,≠    RA =≠,F5.0)
     GO TO 400
200  CONTINUE
     WRITE(IRITE,212)
212  FORMAT(≠1≠15X≠-----STRAIGHT CONDENSER COOLING-----≠,/)
     IF(NH2O)220,228,230
220  WRITE(IRITE,197)
197  FORMAT(20X≠(WITH SEA WATER)≠//)
     GO TO 23
228  WRITE(IRITE,198)
198  FORMAT(20X≠(WITH UNTREATED FRESH WATER)≠//)
     GO TO 23
230   WRITE(IRITE,157)
157  FORMAT(20X≠(WITH TREATED FRESH WATER)≠//)
 23 WRITE(IRITE,227)QRJ1,TC1,FCFS,FLOW1,HPP1,TCALC1,RA1
227  FORMAT(10X≠THE DESIGN VALUES AND COSTS ARE -≠,//,3X≠Q REJECT =
    X≠,E9.4,≠ BTU/HR  AT T CONDENSER =≠,F4.0,/,3X≠CONDENSER FLOW =≠,E9.
    *  4,≠ CFS (≠E9.
    X4,≠ LB/HR)   PUMP POWER =≠,E9.4,≠ HP≠,/,3X≠EQULIBRIUM TEMP =≠,F4.0
    X,≠         RANGE =≠,F4.0,/)
     CALL PRTDS2(CAPCS1,OPCS1,COSMA1,SYS1,DELF1,TOTCS1,COSPK1)
     WRITE(IRITE,302)
302  FORMAT(//15X≠--RIVER TEMPERATURES--≠,//,
    X1X,14HDISTANCE-MILES,3X,17HSTREAM TEMP DEG.F, 3X,17HPLUME TEMP.-DE
```

```
     XG.F ,3X,14HPLUME WIDTH-MI,/19X,8HNO PLANT,2X,5HMIXED,//)
C          CALC OF PLUME TEMPS AND WIDTH AND RIVER TEMPS- TO STAT 22
      VELRIV=(QFLRIV/(WIDTH*DEPTH))*3600.*24.
      DTRIV=(QRJ1/QFLRIV)/(3600.*62.4)
      TZERO=TAVH2O+DTRIV
      I=-1
  307 I=I+1
      IF(I.EQ.11)I=20
      XI=I
      QCON=FLOW1/(3600.*62.4)
      C1=ALOG(QFLRIV/(QFLRIV-QCON))
      PLUMEW=WIDTH*(1.-EXP(-(XI/2.+C1)))
      ALPHA1=-((XK*XI*5280.)/(62.4*DEPTH*VELRIV))
      TXDIST=(TZERO-TCALC)*EXP(ALPHA1)+TCALC
      TWREAL=(TAVH2O-TCALC)*EXP(ALPHA1)+TCALC
      PLUMEW=PLUMEW/5280.
      PLUMT=((TXDIST-TWREAL)/(1.-EXP(-(XI/2.+C1))))+TWREAL
      WRITE(IRITE,308)XI,TWREAL,TXDIST,PLUMT,PLUMEW
  308  FORMAT(6X,F5.1,6X,F6.2,4X,F6.2,5X,F6.2,11X,F6.4)
      IF(I.LT.20)GO TO 307
      WRITE(IRITE,330)
  330  FORMAT(//15X,≠VARIABLE AMBIENT CONDITIONS≠/)
      IF(NTAMB.EQ.0)GO TO 400
      TOPMIL=0.0
      TDFMIL=0.0
      DO 350 I=1,NCAPS
      IF(CAP(I).EQ.0.)GO TO 350
      AMBOPC(I)=0.0
      AMBDFC(I)=0.0
      DO 340 J=1,NTAMB
      IF(PCTAMB(I,J).EQ.0.)GO TO 340
      TC=TCMIN(I)
      NTCOD=0
  301  CALL PAFCST(I,TC,PWCST,DFCOD,QREJ)
      DT2=(QREJ/FLOW1)/(EXP(UA1/FLOW1)-1.)
      DT1=DT2+QREJ/FLOW1
      T1=TC-DT2
      T2=TC-DT1
      IF(T2-TAMRV(J))304,305,310
  305  NTCOD=1
      GO TO 310
  304  TC=TC+1.
      NTCOD=1
      IF(TC .LT. TCMAX(I))GO TO 301
      WRITE(IRITE,309)PCMAX(I),CAP(I),TAMWB(J)
  309  FORMAT(/,3X,≠CONDENSER PRESS MUST EXCEED THE GIVEN MAX OF≠,/ 8
     XX,F4.2,≠ FOR THE CAPACITY OF≠,F4.2,≠ AT T WET BULB =≠,F5.0,/,3X,≠P
     XROGRAM DISCONTINUING≠)
      GO TO 400
  310  IF(NTCOD.GT.0)GO TO 315
      WRITE(IRITE,312)CAP(I),TAMWB(J),TC
  312  FORMAT(/8X,≠FOR CAP =≠,F4.2,≠,     T WB =≠,F5.0,≠,  AND  TC =≠,
     XF4.0,/,3X≠PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE≠)
      IF(DFCOD.GT.0.)DFCOD=0.0
  315  CONTINUE
      OPCOD=(HPP1*.7457/(PSIZE*1000.))*PWCST
      AMBOPC(I)=AMBOPC(I)+OPCOD*PCTAMB(J)
      AMBDFC(I)=AMBDFC(I)+DFCOD*PCTAMB(J)
  340  CONTINUE
      TOPMIL=TOPMIL+AMBOPC(I)*TOTLD(I)*COLPCT(I)*CAP(I)
      TDFMIL=TDFMIL+AMBDFC(I)*TOTLD(I)*COLPCT(I)*CAP(I)
  350  CONTINUE
```

```
      AVOPCS=TOPMIL/TKWHRS
      AVDFCS=TDFMIL/TKWHRS
      AVTCST=AVOPCS+AVDFCS+SYS1+COSMA1
      CALL PRTOD(AVOPCS,AVDFCS,AVTCST)
  400 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SUBPOND
      COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLD(5), COLPCT(5),TC
     XMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),  HRCOF2(6),HRCOF1(6),HRCOF0(6),
     XTDB,TWB,RH,TAVH2O,TCBASE,  NTAMB,AMBDFC(5),AMBOPC(5),TAMDB(5),TAMW
     XB(5),AMBRH(5),  TAMRV(5),PCTAMB(5,5),NSYSOP,TDISMX,NSPCON,UOVALL,A
     XREAC,SPFLOW,  NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,IRITE,IREAD,
     *  AMWIND(5),AMRAD(5),WIND,RAD
      PMPEF=0.8
      TOTCS1=1.E3
C          CALC OF EQULIBRIUM TEMPERATURE
      WCOFA=0.
      WCOFB=15.
      ECOF=WCOFA+WCOFB*WIND
      TA=TDB
      TG=TDB
    7  DH=RAD-1801.*(TG/460.+1.)**4-ECOF*51.7*(P(TG)-RH*P(TA)) -.26*ECO
     XF*(TG-TA)
      DHP=RAD-1801.*((TG+1.)/460.+1.)**4-ECOF*51.7*(P(TG+1.)-RH*P(TA)) -
     X.26*ECOF*(TG+1.-TA)
      DHM=RAD-1801.*((TG-1.)/460.+1.)**4-ECOF*51.7*(P(TG-1.)-RH*P(TA)) -
     X.26*ECOF*(TG-1.-TA)
      DHPRIM=(DHP-DHM)/2.
      IF(ABS(DH)-1.)1,2,2
    2  TNEW=TG-DH/DHPRIM
      TG=TNEW
      GO TO 7
    1  TCALC=TG
      BETA=51.7*(P(TCALC+1.)-P(TCALC-1.))/2.
      XK=15.7+(0.26+BETA)*ECOF
      TC=TCMIN(NCAPS+1)
  100  CONTINUE
      IF(NSPCON-1)30,40,30
   40  CALL PAFCST(NCAPS+1,TC,PWCST,DELFC,QREJ)
      DT2=(QREJ/SPFLOW)/(EXP(UOVALL*AREAC/SPFLOW)-1.)
      DT1=DT2+QREJ/SPFLOW
      T1=TC-DT2
      IF(NSYSOP-2)44,41,44
   41  IF(TDISMX.LT.TCALC)GO TO 197
      IF(DT1-(TC-TAVH2O))15,15,42
   42  IF(TC-TCMAX(NCAPS+1))13,190,190
   13  TC=TC+1
      GO TO 40
   15  T2=TDISMX
      RA=T1-T2
      IF(RA.LT.0.)GO TO 190
      GO TO 46
   44  T2=TC-DT1
      IF(T2-TCALC)151,151,45
   30  DT2=5.
      IF(NSYSOP-2)31,32,31
   31   T2=TCALC+1.
      GO TO 50
   32  IF(TDISMX.LT.TCALC)GO TO 197
      T2=TDISMX
   50  IF((TC-DT2)-T2)151,151,51
   51  CALL PAFCST(NCAPS+1,TC,PWCST,DELFC,QREJ)
      IF(NSYSOP-2)45,46,45
   45  CALL COND(TC,T2,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,COSPKW)
      QREJT=QREJ
      GO TO 47
   46  CALL COND(TC,TAVH2O,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,COSPKW)
      QREJT=QREJ*(T1-T2)/(T1-TAVH2O)
```

```
47  RA=T1-T2
    ALPHA=-ALOG((T2-TCALC)/(T1-TCALC))
    AREAP=24.*ALPHA*FLOW/(XK*43560.)
C        ALOG MEAN T DIF BETWEEN AIR AND WATER
    IF(T2-TDB)48,48,49
48  WLMTD=(T1+T2)/2.-TDB
    GO TO 53
49  WLMTD=(T1-T2)/ALOG((T1-TDB)/(T2-TDB))
C        BOWEN RATIO - RATIO OF CONDUCTION TO EVAPORATION
C     HEAT TRANSFER - MODIFIED FROM EDINGER AND GEYER
53  TWAV=(T1+T2)/2.
    BOWRAT=.26*WLMTD/(51.7*(P(TWAV)-RH*P(TDB)))
    QLAT=(QREJT-(.173E-8*((T1+T2)/2.+460.)**4-RAD/24.)*AREAP*
   * 43560.)/(1.+BOWRAT)
    WEVAP=QLAT/970.3
    GPMT=GPM+WEVAP/(8.34*60.)
C        ASSUME 30 FT OF PUMPING HEAD (FRICTION)
    PHEAD=30.
    HPPMP=GPMT*PHEAD/(3960.*PMPEF)
    CAPCOS=AREAP*PRPAGR
    DELFC=DELFC*USEFAC
    OPCOS=(HPPMP*.7457/(PSIZE*1000.))*PWCST*USEFAC
    COSMAI=.001*CAPCOS/(PSIZE*1000.)+.1*OPCOS+.01*SYSCST
    TOTCOS=(CAPCOS*ANFCR)/(PSIZE*1000.*CAPFAC*8.76) +OPCOS +COSMAI+SYS
   XCST+DELFC
    IF(TOTCOS-TOTCS1)154,156,156
156 IF(NSPCON.EQ.1)GO TO 157
    IF(NSYSOP.EQ.2)GO TO 151
    T2=T2+1.
    GO TO 50
157 IF(NSYSOP.EQ.2)GO TO 190
151 TC=TC+1.
    IF(TC-TCMAX(NCAPS+1))100,100,190
154 RA1=RA
    AREAP1=AREAP
    T11=T1
    T21=T2
    SYS1=SYSCST
    CAPCS1=CAPCOS
    COSPK1=COSPKW
    OPCS1=OPCOS
    COSMA1=COSMAI
    AFLR1=0.
    HPF1=0.
    HPP1=HPPMP
    DELF1=DELFC
    TCALC1=TCALC
    QRJ1=QREJ
    QRJT1=QREJT
    FLOW1=FLOW
    GPM1=GPM
    UA1=UA
    WEVAP1=WEVAP
    TC1=TC
    TOTCS1=TOTCOS
    GO TO 156
190 IF(TOTCS1-1.E3)200,195,200
195 WRITE(IRITE,196)TC,T1,RA
196 FORMAT(/3X,≠FOR THE GIVEN CONDITIONS A SOLUTION CANNOT BE FOUN
   XD≠,/,3X,≠TC =≠,F5.0,≠   T1 =≠,F5.0,≠    RA =≠,F5.0)
    GO TO 400
197 WRITE(IRITE,198)
```

```
198  FORMAT(/,3X,≠MAX DIS T LESS THAN EQULIBRIUM T≠)
     GO TO 400
200  CONTINUE
     WRITE(IRITE,212)
212  FORMAT(≠1≠,15X,≠----- COOLING POND -----≠,//, 10X,  ≠THE DESIGN V
    XALUES AND COSTS ARE -≠,//)
     CALL PRTDS1(QRJ1,TC1,HPF1,HPP1,WEVAP1,WBDWN1,AFLR1)
     WRITE(IRITE,227)FLOW1,T11,RA1,TCALC1,AREAP1
227  FORMAT(3X,≠COND FLOW =≠,E9.4,≠    T IN =≠,F4.0,≠     RANGE =≠
    X,F4.0,/,3X,≠EQULIBRIUM TEMP =≠,F4.0,≠     POND AREA =≠,F8.0,
    X≠ ACRES≠)
     IF(NSYSOP-2)230,228,230
228  WRITE(IRITE,229)QRJT1
229  FORMAT(/3X,≠Q REJ POND =≠,E9.4,≠ BTU/HR≠)
230  CALL PRTDS2(CAPCS1,OPCS1,COSMA1,SYS1,DELF1,TOTCS1,COSPK1)
     WRITE(IRITE,330)
330  FORMAT(//15X,≠VARIABLE AMBIENT CONDITIONS≠/)
     IF(NTAMB.EQ.0)GO TO 400
     TOPMIL=0.0
     TDFMIL=0.0
     DO 350 I=1,NCAPS
     IF(CAP(I).EQ.0.)GO TO 350
     AMBOPC(I)=0.0
     AMBDFC(I)=0.0
     DO 340 J=1,NTAMB
     IF(PCTAMB(I,J).EQ.0.)GO TO 340
     TC=TCMIN(I)
     NTCOD=0
     TA=TAMDB(J)
     TG=TA
     RAD=AMRAD(J)
     ECOF=WCOFA+WCOFB*AMWIND(J)
 20  DH=RAD-1801.*(TG/460.+1.)**4-ECOF*51.7*(P(TG)-AMBRH(J)* P(TA))-
    X.26*ECOF*(TG-TA)
     DHP=RAD-1801.*((TG+1.)/460.+1.)**4-ECOF*51.7*(P(TG+1.)-AMBRH(J)*
    XP(TA))-.26*ECOF*(TG+1.-TA)
     DHM=RAD-1801.*((TG-1.)/460.+1.)**4-ECOF*51.7*(P(TG-1.)-AMBRH(J)*
    XP(TA))-.26*ECOF*(TG-1.-TA)
     DHPRIM=(DHP-DHM)/2.
     IF(ABS(DH)-1.)21,22,22
 22  TNEW=TG-DH/DHPRIM
     TG=TNEW
     GO TO 20
 21  TCALC=TG
     BETA=51.7*(P(TCALC+1.)-P(TCALC-1.))/2.
     XK=15.7+(.26+BETA)*ECOF
     ALPACT=(AREAP1*XK*43560.)/(24.*FLOW1)
301  CALL PAFCST(I,TC,PWCST,DFCOD,QREJ)
     DT2=(QREJ/FLOW1)/(EXP(UA1/FLOW1)-1.)
     DT1=DT2+QREJ/FLOW1
     T1=TC-DT2
     T2=TC-DT1
     IF(NSYSOP-2)316,303,316
316  IF(T2-TCALC)304,304,302
303  IF(T2-TAMRV(J))304,305,306
305  NTCOD=1
     GO TO 306
306  T2=TCALC+(T1-TCALC)/EXP(ALPACT)
     IF(T2-TDISMX)310,310,307
307  WRITE(IRITE,308)CAP(I),TAMWB(J),TC,T2
308  FORMAT(/8X≠FOR CAP =≠,F4.2,≠,     T WB =≠,F4.0,≠, AND   TC =≠
    X,F4.0,/,3X≠T DIS EXCEEDS TDIS MAX - CONTINUING≠)
```

```
      GO TO 315
302   ALPHA=-ALOG((T2-TCALC)/(T1-TCALC))
      IF(ALPHA.LT.ALPACT)GO TO 310
304   TC=TC+1.
      NTCOD=1
      IF(TC .LT. TCMAX(I))GO TO 301
      WRITE(IRITE,309)CAP(I),J
309   FORMAT(≠-*****THE POND IS ESSENTIALLY TOO SMALL FOR≠,F4.2,
     *  ≠ CAPACITY AND AMBIENT NO.≠,I2/≠ PROGRAM DISCONTINUING≠)
      GO TO 400
310   IF(NTCOD.GT.0)GO TO 315
      WRITE(IRITE,312)CAP(I),J
312   FORMAT(≠0THE POND IS LARGER THAN NECESSARY FOR≠,F4.2,≠ CAPACITY≠,
     *  ≠ AND AMBIENT NO.≠,I2/
     *≠ COMPUTING COSTS ASSUMING MOST EFFICIENT CONDITION (PC=PCMIN)≠)
      IF(DECOD.GT.0.)DFCOD=0.0
315   CONTINUE
      OPCOD=(HPP1*.7457/(PSIZE*1000.))*PWCST
      AMBOPC(I)=AMBOPC(I)+OPCOD*PCTAMB(J)
      AMBDFC(I)=AMBDFC(I)+DFCOD*PCTAMB(J)
340   CONTINUE
      TOPMIL=TOPMIL+AMBOPC(I)*TOTLD(I)*COLPCT(I)*CAP(I)
      TDFMIL=TDFMIL+AMBDFC(I)*TOTLD(I)*COLPCT(I)*CAP(I)
350   CONTINUE
      AVOPCS=TOPMIL/TKWHRS
      AVDFCS=TDFMIL/TKWHRS
      AVTCST=(CAPCS1*ANFCR)/(PSIZE*1000.*CAPFAC*8.76) +AVOPCS+AVDFCS+SYS
     X1+COSMA1
      CALL PRTOD(AVOPCS,AVDFCS,AVTCST)
400   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SUBMDW
      COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP[illegible]
     X COLPCT(5),TCMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),
     X  HRCOF2(6),HRCOF1(6),HRCOF0(6),TDB,TWB,RH,TAVH2O,TCBASE,
     X  NTAMB,AMBDFC(5),AMBOPC(5),TAMDB(5),TAMWB(5),AMBRH(5),
     X  TAMRV(5),PCTAMB(5,5),NSYSOP,TDISMX,NSPCON,UOVALL,AREAC,SPFLOW,
     X  NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,IRITE,IREAD
      DIMENSION XK(20)
      FANEF=0.8
      PMPEF=0.8
      TOTCS1=1.E3
      TC=TCMIN(NCAPS+1)
 100  CONTINUE
      IF(NSPCON-1)30,40,30
  40  CALL PAFCST(NCAPS+1,TC,PWCST,DELFC,QREJ)
      DT2=(QREJ/SPFLOW)/(EXP(UOVALL*AREAC/SPFLOW)-1.)
      DT1=DT2+QREJ/SPFLOW
      T1=TC-DT2
      IF(NSYSOP-2)44,41,44
  41  IF(DT1-(TC-TAVH2O))15,15,42
  42  IF(TC-TCMAX(NCAPS+1))13,190,190
  13  TC=TC+1
      GO TO 40
  15  T2=TDISMX
      APPR=T2-TWB
      IF(APPR.LT.7.)GO TO 190
      IF(APPR.GT.20.)GO TO 190
      RA=T1-T2
      IF(RA.LT.10.)GO TO 190
      GO TO 46
  44  T2=TC-DT1
      APPR=T2-TWB
      IF(APPR.LT.7.)GO TO 151
      IF(APPR.GT.20.)GO TO 190
      GO TO 45
  30  IF(NSYSOP-2)31,32,31
  31  APPR=7.
  50  T2=TWB+APPR
      IF(TC-T2)151,151,51
  32  T2=TDISMX
      APPR=T2-TWB
      IF(APPR.LT.7.)GO TO 190
      IF(APPR.GT.20.)GO TO 190
  51  DT2=5.
      CALL PAFCST(NCAPS+1,TC,PWCST,DELFC,QREJ)
      IF(NSYSOP-2)45,46,45
  45  CALL COND(TC,T2,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,
     *  COSPKW)
      QREJT=QREJ
      GO TO 47
  46  CALL COND(TC,TAVH2O,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,
     *  COSPKW)
      QREJT=QREJ*(T1-T2)/(T1-TAVH2O)
  47  RA=T1-T2
      IF(RA.LT.10.)GO TO 151
      TAXT=(T1+T2)/2.
      H1=H(TWB)
      H2=H(TAXT)
      AFLR=QREJT/(H2-H1)
      WACT=RH*(.622*P(TDB))/(14.696-P(TDB))
      APSAT=(WACT*14.696)/(.622+WACT)
      DIN=144.*(14.696-APSAT)/(53.35*(TDB+460.))
```

```
      WART=FLOW/AFLR
      T3=T2+.1*RA
      T4=T2+.4*RA
      T5=T1-.4*RA
      T6=T1-.1*RA
      CO1=WART*RA
      RDH1=1./(H(T3)-H1-.1*CO1)
      RDH2=1./(H(T4)-H1-.4*CO1)
      RDH3=1./(H(T5)-H2+.4*CO1)
      RDH4=1./(H(T6)-H2+.1*CO1)
      CHAR=(RA/4.)*(RDH1+RDH2+RDH3+RDH4)
C
C          PACKING HEIGHT FROM FRAAS + OZISIK - DECK NUMBER 1
      DECKHT =2.
      PHT=DECKHT*(CHAR-.07)/(.103*WART**(-.54))
C           WATER LOADING = 2500
      WLOAD=2500.
      PLANA=FLOW/WLOAD
C           AIR LOADING OR G
      ALDG=AFLR/PLANA
      ALDGE=ALDG+3500.
C
C          PRESSURE DROP (INCHES OF WATER) FROM FRAAS AND OZISIK
      DELP=((PHT/DECKHT)*.0675/DIN)*(0.4E-8*ALDG**2 +.1E-12*2500.*ALDGE*
     X*2*2.62)
      RANGE=RA
      IK=APPR
      IF(GPM)210,210,11
C          CALK OF K FACTOR - LOCKHART ET AL
   11 IF(IK-7)370,7,1
    1 IF(IK-20)2,2,370
    2 IF(IK-10)6,5,5
    6  GO TO (8,9),(IK-7)
    7  XK(7)=.42626139+.30755494*RANGE-.83222851E-02*RANGE**2+.14
     X130379E-03*RANGE**3-.87533682E-06*RANGE**4
      GO TO 25
    8  XK(8)=.53003286+.26855945*RANGE-.71968070E-02*RANGE**2+.12
     X092005E-03*RANGE**3-.73568322E-06*RANGE**4
      GO TO 25
    9  XK(9)=.27667081+.27125055*RANGE-.75042365E-02*RANGE**2+.12
     X884963E-03*RANGE**3-.80021960E-06*RANGE**4
      GO TO 25
    5  AA=APPR/2.
      Z=0.
      IA=AA
      AB=IA
      IF(AB.EQ.AA)GO TO (10,12,14,16,18,20),(AB-4.)
      GO TO (10,12,14,16,18),(AB-4.)
   21  Z=2.
      GO TO (12,14,16,18,20),(AB-4.)
   10  XK(10)=.87557520E-01+.25976379*RANGE-.69589515E-02*RANGE**2
     X +.11542869E-03*RANGE**3-.69832755E-06*RANGE**4
      IF(AB.EQ.AA)GO TO 25
      IF(Z-2.)21,23,21
   12  XK(12)=.30755983E-02+.22692621*RANGE-.57515664E-02*RANGE**2
     X +.89248959E-04*RANGE**3-.50381046E-06*RANGE**4
      IF(AB.EQ.AA)GO TO 25
      IF(Z-2.)21,23,21
   14  XK(14)=-.33616133+.22612638*RANGE-.57931043E-02*RANGE**2
     X+.89896029E-04*RANGE**3-.50893025E-06*RANGE**4
      IF(AB.EQ.AA)GO TO 25
      IF(Z-2.)21,23,21
```

```
 16   XK(16)=-.43379805+.20785695*RANGE-.51672632E-02*RANGE**2
     X+.77053656E-04*RANGE**3-.42119093E-06*RANGE**4
      IF(AB.EQ.AA)GO TO 25
      IF(Z-2.)21,23,21
 18   XK(18)=-.91434163+.23827008*RANGE-.66801246E-02*RANGE**2
     X+.10604073E-03*RANGE**3-.61338627E-06*RANGE**4
      IF(AB.EQ.AA)GO TO 25
      IF(Z-2.)21,23,21
 20   XK(20)=-.12250402E+01+.25793956*RANGE-.7655059E-02*RANGE**2
     X  +.12169709E-03*RANGE**3-.70610963E-06*RANGE**4
      IF(AB.EQ.AA)GO TO 25
      IF(Z-2.)21,23,21
 23   XK(IK)=(XK(IK-1)+XK(IK+1))/2.
 25   CONTINUE
      CWB=.7+EXP(4.17-.0767*TWB)
      DELHS=QREJT/AFLR
      HOUT=H1+DELHS
      TOUTS=.99674408E1+.24105952E1*HOUT-.22686654E-1*HOUT**2  + .102553
     X04E-3*HOUT**3-.14174090E-6*HOUT**4
      QLAT=QREJT-AFLR*.24*(TOUTS-TDB)
      WEVAP=QLAT/970.3
      CONCR=5.
C          WATER FOR BLOWDOWN
      WBDWN=(.06*QREJT*62.4)/(500.*7.48*(CONCR-1.))
      WNEED=WEVAP+WBDWN
      GPMT=GPM+WNEED/(8.34*60.)
      FUDGE=GPMT*XK(IK)*CWB
C          LOCKHART SAYS COST = 2*FUDGE BUT CONVERSES COSTS ARE
C          ABOUT 2*LOCKHARTS - USE AVG. = 3*FUDGE
      CAPCOS=3.*FUDGE
      ACFM=AFLR/(60.*DIN)
      HPFAN=(ACFM*DELP*5.2)/(33000.*FANEF)
      HPPMP=GPMT*(PHT+10.)/(3960.*PMPEF)
      TOTHP=HPFAN+HPPMP
      DELFC=DELFC*USEFAC
      OPCOS=(TOTHP*.7457/(PSIZE*1000.))*PWCST*USEFAC
      COSMAI=.001*CAPCOS/(PSIZE*1000.)+.1*OPCOS+.01*SYSCST
      TOTCOS=(CAPCOS*ANFCR)/(PSIZE*1000.*CAPFAC*8.76) +OPCOS
     X +COSMAI+SYSCST+DELFC
      IF(TOTCOS-TOTCS1)154,156,156
156   IF(NSPCON.EQ.1)GO TO 157
      IF(NSYSOP.EQ.2)GO TO 151
      APPR=APPR+1.
      IF(APPR-20.)50,50,151
157   IF(NSYSOP.EQ.2)GO TO 190
151   TC=TC+1.
      IF(TC-TCMAX(NCAPS+1))100,100,190
154   RA1=RA
      CHAR1=CHAR
      PHT1=PHT
      PLANA1=PLANA
      AFLR1=AFLR
      DP1=DELP
      APPR1=APPR
      HWB1=H1
      SYS1=SYSCST
      CAPCS1=CAPCOS
      COSPK1=COSPKW
      OPCS1=OPCOS
      COSMA1=COSMAI
      THP1=TOTHP
      HPF1=HPFAN
```

```
      HPP1=HPPMP
      DELF1=DELFC
      QRJ1=QREJ
      QRJT1=QREJT
      FLOW1=FLOW
      GPM1=GPM
      WART1=WART
      UA1=UA
      WEVAP1=WEVAP
      WBDWN1=WBDWN
      WNEED1=WNEED
      TC1=TC
      XK1=XK(IK)
      TOTCS1=TOTCOS
      GO TO 156
190   IF(TOTCS1-1.E3)200,195,200
195   WRITE(IRITE,196)TC,APPR,RA
196   FORMAT(/3X,≠FOR THE GIVEN CONDITIONS A SOLUTION CANNOT BE
     X FOUND≠,/,3X,≠TC =≠,F5.0,≠     APPR =≠,F5.0,≠     RA =≠,F5.0)
      GO TO 400
200   CONTINUE
210   WRITE(IRITE,212)
212   FORMAT(≠1≠,15X,≠----- MECHANICAL DRAFT WET TOWER -----≠,//, 10
     XX,≠THE DESIGN VALUES AND COSTS ARE -≠,//)
      CALL PRTDS1(QRJ1,TC1,HPF1,HPP1,WEVAP1,WBDWN1,AFLR1)
      WRITE(IRITE,227)DP1,FLOW1,RA1,APPR1
227   FORMAT(3X,≠PRESSURE DROP =≠,F5.2,≠     COND FLOW =≠,E9.4,/,
     X 3X≠RANGE =≠,F4.0,≠      APPROACH =≠,F4.0)
      IF(NSYSOP-2)230,228,230
228   WRITE(IRITE,229)QRJT1
229   FORMAT(/3X,≠Q REJ TOWER =≠,E9.4,≠ BTU/HR≠)
230   CALL PRTDS2(CAPCS1,OPCS1,COSMA1,SYS1,DELF1,TOTCS1,COSPK1)
      WRITE(IRITE,330)
330   FORMAT(//15X,≠VARIABLE AMBIENT CONDITIONS≠/)
      IF(NTAMB.EQ.0)GO TO 400
      TOPMIL=0.0
      TDFMIL=0.0
      DO 350 I=1,NCAPS
      IF(CAP(I).EQ.0.)GO TO 350
      AMBOPC(I)=0.0
      AMBDFC(I)=0.0
      DO 340 J=1,NTAMB
      IF(PCTAMB(I,J).EQ.0.)GO TO 340
      TC=TCMIN(I)
      NTCOD=0
301   CALL PAFCST(I,TC,PWCST,DFCOD,QREJ)
      DT2=(QREJ/FLOW1)/(EXP(UA1/FLOW1)-1.)
      DT1=DT2+QREJ/FLOW1
      T1=TC-DT2
      T2=TC-DT1
      IF(NSYSOP-2)316,303,316
316   IF(T2-TAMWB(J))304,304,302
303   IF(T2-TAMRV(J))304,305,306
305   NTCOD=1
306   T2=TDISMX
      IF(T2.GT.TAMWB(J))GO TO 302
      WRITE(IRITE,313)TAMWB(J)
313   FORMAT(3X≠T DIS MAX LESS THAN(OR =) T WB =≠,F4.0,/,
     X 3X≠REQUIRES NEGATIVE APPROACH - DISCONTINUING≠)
      GO TO 400
302   TAXT=(T1+T2)/2.
      RA=T1-T2
```

```
      T3=T2+.1*RA
      T4=T2+.4*RA
      T5=T1-.4*RA
      T6=T1-.1*RA
      CO1=WART1*RA
      H1=H(TAMWB(J))
      H2=H(TAXT)
      RDH1=1./(H(T3)-H1-.1*CO1)
      RDH2=1./(H(T4)-H1-.4*CO1)
      RDH3=1./(H(T5)-H2+.4*CO1)
      RDH4=1./(H(T6)-H2+.1*CO1)
      CHAR=(RA/4.)*(RDH1+RDH2+RDH3+RDH4)
      IF(CHAR .LT. CHAR1) GO TO 310
      IF(NSYSOP-2)304,307,304
307   WRITE(IRITE,308)CAP(I),TAMWB(J),TC
308   FORMAT(/8X≠FOR CAP =≠,F4.2,≠,       T WB =≠,F4.0,            ≠, AND
     X   TC =≠,F4.0,/,3X≠T DIS EXCEEDS TDIS MAX - CONTINUING≠)
      GO TO 315
304   TC=TC+1.
      NTCOD=1
      IF(TC .LT. TCMAX(I))GO TO 301
      WRITE(IRITE,309)PCMAX(I),CAP(I),TAMWB(J)
309   FORMAT(/,3X,≠CONDENSER PRESS MUST EXCEED THE GIVEN MAX OF≠,/ 8
     XX,F4.2,≠ FOR THE CAPACITY OF≠,F4.2,≠ AT T WET BULB =≠,F5.0,/,3X,≠
     XPROGRAM DISCONTINUING≠)
      GO TO 400
310   IF(NTCOD.GT.0)GO TO 315
      WRITE(IRITE,312)CAP(I),TAMWB(J),TC
312   FORMAT(/8X,≠FOR CAP =≠,F4.2,≠,       T WB =≠,F5.0,≠,   AND
     X  TC =≠,F4.0,/,3X≠PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE≠)
      IF(DFCOD.GT.0.)DFCOD=0.0
315   CONTINUE
      OPCOD=(THP1*.7457/(PSIZE*1000.))*PWCST
      AMBOPC(I)=AMBOPC(I)+OPCOD*PCTAMB(J)
      AMBDFC(I)=AMBDFC(I)+DFCOD*PCTAMB(J)
340   CONTINUE
      TOPMIL=TOPMIL+AMBOPC(I)*TOTLD(I)*COLPCT(I)*CAP(I)
      TDFMIL=TDFMIL+AMBDFC(I)*TOTLD(I)*COLPCT(I)*CAP(I)
350   CONTINUE
      AVOPCS=TOPMIL/TKWHRS
      AVDFCS=TDFMIL/TKWHRS
      AVTCST=(CAPCS1*ANFCR)/(PSIZE*1000.*CAPFAC*8.76) +AVOPCS+AVDFCS+SYS
     X1+COSMA1
      CALL PBTOD(AVOPCS,AVDFCS,AVTCST)
      GO TO 400
370   WRITE(IRITE,371) APPR
371   FORMAT(≠ APPROACH=≠,F7.1,≠ NO CURVES - RUN ABORTED≠)
      GO TO 400
400   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SUBNDW
      COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLD(5), COLPCT(5),TC
     XMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),  HRCOF2(6),HRCOF1(6),HRCOFO(6),
     XTDB,TWB,RH,TAVH2O,TCBASE,  NTAMB,AMBDFC(5),AMBOPC(5),TAMDB(5),TAMW
     XB(5),AMBRH(5),  TAMRV(5),PCTAMB(5,5),NSYSOP,TDISMX,NSPCON,UOVALL,A
     XREAC,SPFLOW,  NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,IRITE,IREAD
      PI=3.14159
      PMPEF=0.8
      TOTCS1=1.E3
      HDRMAX=1.5
      IWL=0
      TC=TCMIN(NCAPS+1)
  100 CONTINUE
      IF(NSPCON-1)30,40,30
   40 CALL PAFCST(NCAPS+1,TC,PWCST,DELFC,QREJ)
      DT2=(QREJ/SPFLOW)/(EXP(UOVALL*AREAC/SPFLOW)-1.)
      DT1=DT2+QREJ/SPFLOW
      T1=TC-DT2
      IF(NSYSOP-2)44,41,44
   41 IF(DT1-(TC-TAVH2O))15,15,42
   42 IF(TC-TCMAX(NCAPS+1))13,190,190
   13 TC=TC+1
      GO TO 40
   15 T2=TDISMX
      APPR=T2-TWB
      IF(APPR.LT.7.)GO TO 190
      IF(APPR.GT.20.)GO TO 190
      RA=T1-T2
      IF(RA.LT.10.)GO TO 190
      GO TO 46
   44 T2=TC-DT1
      APPR=T2-TWB
      IF(APPR.LT.7.)GO TO 151
      IF(APPR.GT.20.)GO TO 190
      GO TO 45
   30 IF(NSYSOP-2)31,32,31
   31 APPR=7.
   50 T2=TWB+APPR
      IF(TC-T2)151,151,51
   32 T2=TDISMX
      APPR=T2-TWB
      IF(APPR.LT.7.)GO TO 190
      IF(APPR.GT.20.)GO TO 190
   51 DT2=5.
      CALL PAFCST(NCAPS+1,TC,PWCST,DELFC,QREJ)
      IF(NSYSOP-2)45,46,45
   45 CALL COND(TC,T2,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,
     * COSPKW)
      QREJT=QREJ
      GO TO 47
   46 CALL COND(TC,TAVH2O,QREJ,PWCST,DT2,T1,UA,FLOW,GPM,SYSCST,
     * COSPKW)
      QREJT=QREJ*(T1-T2)/(T1-TAVH2O)
   47 RA=T1-T2
      IF(RA.LT.10.)GO TO 151
      WLOAD=1250.
      IWL=0
C        INITIAL WATER LOADING  1250 LBM/FT2/HR
   48 CONTINUE
      BSA=FLOW/WLOAD
      DIA=SQRTF(4.*BSA/3.14159)
C        TAXT - AIR EXIT TEMP - FRAAS + OZISIK
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```
      TAXT=(T1+T2)/2.
      H1=H(TWB)
      H2=H(TAXT)
      AFLR=QREJ/(H2-H1)
      WART=FLOW/AFLR
C         CALC OF CHAR(TOTAL REQUIRED TOWER CHARACTERISTIC) FROM CTI
      T3=T2+0.1*RA
      T4=T2+0.4*RA
      T5=T1-0.4*RA
      T6=T1-0.1*RA
      CO1=WART*RA
      RDH1=1./(H(T3)-H1-0.1*CO1)
      RDH2=1./(H(T4)-H1-0.4*CO1)
      RDH3=1./(H(T5)-H2+0.4*CO1)
      RDH4=1./(H(T6)-H2+0.1*CO1)
      CHAR=(RA/4.)*(RDH1+RDH2+RDH3+RDH4)
C         UNC - CHAR/FT OF PACKING FROM LOWE + CHRISTE
      UNC=0.1*(1./WART)**0.73
      PHT=CHAR/UNC
C          WACT - ACTUAL HUMIDITY
      WACT=RH*(0.622*P(TDB))/(14.696-P(TDB))
      APSAT=(WACT*14.696)/(0.622+WACT)
      DIN=144.*(14.696-APSAT)/(53.35*(TDB+460.))
      DOUT=(144.*(14.696-P(TAXT)))/(53.35*(TAXT+460.))
C          VIN - INLET VELOCITY
      VIN=5.
C         VHDI - INLET VEL HEAD
      VHDI=(VIN**2)*DIN/64.4
      OPHT=(AFLR/3600.)/(PI*DIA*DIN*VIN)
C            SPRAY NOZZLES ASSUMED 4 FT ABOVE PACKING
C         PPK - DEL P OF PACKING (VEL HEADS/FT)
C         ASSUMED LINEAR FUNCTION OF WLOAD - SEE LOWE + CHRISTIE
      PKWA=.5
      PKWB=2.5E-4
      PPK=PHT*(PKWA+PKWB*WLOAD)
C         PSP - DEL P OF SPRAY
      PSP=0.16*(OPHT+4.)*WART**1.32
C         INLET + EXIT TURNING LOSSES + FRICTION LOSS = TPIX VEL HDS
      TPIX=28.5
      TPDP=PPK+PSP+TPIX
      DELP=TPDP*VHDI
      THT=DELP/(DIN-DOUT)
      HDR=THT/DIA
      IF(HDR.LE.HDRMAX)GO TO 120
      WLOAD=.9*WLOAD
      IWL=IWL+1
      IF(IWL.LE.10)GO TO 48
  120 HTDIA=THT*DIA
      CAPCOS=3.4E5*(HTDIA**.17)
      CONCR=5.
      TOUTS=.99674408E1+.24105952E1*H2-.22686654E-1*H2**2  +.10255304E-3
     X*H2**3-.14174090E-6*H2**4
      QLAT=QREJ-AFLR*.24*(TOUTS-TDB)
      WEVAP=QLAT/970.3
      WBDWN=(.06*QREJ*62.4)/(500.*7.48*(CONCR-1.))
      WNEED=WEVAP+WBDWN
      HPPMP=(GPM*(PHT+4.+OPHT))/(3960.*PMPEF)
      OPCOS=(HPPMP*.7457/(PSIZE*1000.))*PWCST*USEFAC
      DELFC=DELFC*USEFAC
      COSMAI=.001*CAPCOS/(PSIZE*1000.)+.1*OPCOS+.01*SYSCST
      TOTCOS=(CAPCOS*ANFCR)/(PSIZE*1000.*CAPFAC*8.76) +OPCOS
     X +COSMAI+SYSCST+DELFC
```

```
      IF(TOTCOS-TOTCS1)154,156,156
156   IF(NSPCON.EQ.1)GO TO 157
      IF(NSYSOP.EQ.2)GO TO 151
      APPR=APPR+1.
      IF(APPR-20.)50,50,151
157   IF(NSYSOP.EQ.2)GO TO 190
151   TC=TC+1.
      IF(TC-TCMAX(NCAPS+1))100,100,190
154   RA1=RA
      CHAR1=CHAR
      PHT1=PHT
      PPK1=PPK
      AFLR1=AFLR
      APPR1=APPR
      HWB1=H1
      SYS1=SYSCST
      CAPCS1=CAPCOS
      COSPK1=COSPKW
      OPCS1=OPCOS
      COSMA1=COSMAI
      HPF1=0.0
      HPP1=HPPMP
      DELF1=DELFC
      QRJ1=QREJ
      QRJT1=QREJT
      FLOW1=FLOW
      GPM1=GPM
      WART1=WART
      UA1=UA
      WEVAP1=WEVAP
      WBDWN1=WBDWN
      WNEED1=WNEED
      TC1=TC
      DIA1=DIA
      THT1=THT
      TAXT1=TAXT
      OPHT1=OPHT
      TPDP1=TPDP
      DP1=DELP
      TOTCS1=TOTCOS
      WLOAD1=WLOAD
      HDR1=HDR
      GO TO 156
190   IF(TOTCS1-1.E3)200,195,200
195   WRITE(IRITE,196)TC,APPR,RA
196   FORMAT(/3X,   ≠FOR THE GIVEN CONDITIONS A SOLUTION CANNOT BE FOUN
     XD≠,/,3X,≠TC =≠,F5.0,≠    APPR =≠,F5.0,≠    RA =≠,F5.0)
      GO TO 400
200   CONTINUE
      WRITE(IRITE,212)
212   FORMAT(≠1≠,15X,≠------ NATURAL DRAFT WET TOWER ------≠,//, 10X,≠
     XTHE DESIGN VALUES AND COSTS ARE -≠,//)
      CALL PRTDS1(QRJ1,TC1,HPF1,HPP1,WEVAP1,WBDWN1,AFLR1)
      WRITE(IRITE,227)DP1,FLOW1,RA1,APPR1,THT1,DIA1,WLOAD1,CHAR1,PHT1
227   FORMAT(3X,≠PRESSURE DROP =≠,F5.1,≠    COND FLOW =≠,E9.4,/, 3X≠
     XRANGE =≠,F4.0,≠    APPROACH =≠,F4.0,/,3X≠TOWER HEIGHT =≠,F6.0,
     X  ≠   TOWER DIAMETER =≠F5.0/≠   WATER LOADING =≠F7.0,≠ LBM/HR-FT2≠
     X/ ≠   TOWER CHARACTERISTIC =≠F5.2,≠     PACKING HEIGHT=≠F5.2)
      IF(NSYSOP-2)230,228,230
228   WRITE(IRITE,229)QRJT1
229   FORMAT(/3X,≠Q REJ TOWER =≠,E9.4,≠ BTU/HR≠)
230   CALL PRTDS2(CAPCS1,OPCS1,COSMA1,SYS1,DELF1,TOTCS1,COSPK1)
```

```
      IF(HDR1.LE.HDRMAX)GO TO 140
      WRITE(IRITE,125)HDR1,HDRMAX
  125 FORMAT(≠0  NOTE--H/D=≠F5.2,≠ WHICH IS GREATER THAN≠,
     X ≠ H/DMAX=≠F5.2//)
  140 CONTINUE
      WRITE(IRITE,330)
  330  FORMAT(//15X,≠VARIABLE AMBIENT CONDITIONS≠/)
      IF(NTAMB.EQ.0)GO TO 400
      TOPMIL=0.0
      TDFMIL=0.0
      DO 350 I=1,NCAPS
      IF(CAP(I).EQ.0.)GO TO 350
      AMBOPC(I)=0.0
      AMBDFC(I)=0.0
      DO 340 J=1,NTAMB
      IF(PCTAMB(I,J).EQ.0.)GO TO 340
      TC=TCMIN(I)
      NTCOD=0
  301  CALL PAFCST(I,TC,PWCST,DFCOD,QREJ)
      DT2=(QREJ/FLOW1)/(EXP(UA1/FLOW1)-1.)
      DT1=DT2+QREJ/FLOW1
      T1=TC-DT2
      T2=TC-DT1
      IF(NSYSOP-2)316,303,316
  316  IF(T2-TAMWB(J))304,304,320
  303  IF(T2-TAMRV(J))304,305,306
  305  NTCOD=1
  306  T2=TDISMX
      IF(T2.GT.TAMWB(J))GO TO 320
      WRITE(IRITE,313)TAMWB(J)
  313  FORMAT(3X≠T DIS MAX LESS THAN(OR =) T WB =≠    ,F4.0,/, 3X≠REQUIR
     XES NEGATIVE APPROACH - DISCONTINUING≠)
      GO TO 400
  321  IF(NSYSOP-2)304,307,304
  307  WRITE(IRITE,308)CAP(I),TAMWB(J),TC
  308  FORMAT(/8X≠FOR CAP =≠,F4.2,≠,      T WB =≠,F4.0,≠, AND    TC =≠
     X ,F4.0/3X,≠T DIS EXCEEDS T DIS MAX - CONTINUING≠)
      GO TO 315
  304  TC=TC+1.
      NTCOD=1
      IF(TC .LT. TCMAX(I))GO TO 301
      WRITE(IRITE,309)PCMAX(I),CAP(I),TAMWB(J)
  309  FORMAT(/,3X,≠CONDENSER PRESS MUST EXCEED THE GIVEN MAX OF≠,/ 8
     XX,F4.2,≠ FOR THE CAPACITY OF≠,F4.2,≠ AT T WET BULB =≠,F5.0,/,3X,≠P
     XROGRAM DISCONTINUING≠)
      GO TO 400
  320  WACT=AMBRH(J)*(.622*P(TAMDB(J)))/(14.696-P(TAMDB(J)))
      APSAT=WACT*14.696/(.622+WACT)
      DIN=144.*(14.696-APSAT)/(53.35*(TAMDB(J)+460.))
      TAXT=(T1+T2)/2.
      RA=T1-T2
      H1=H(TAMWB(J))
      H2=H(TAXT)
      DOUT=(144.*(14.696-P(TAXT)))/(53.35*(TAXT+460.))
      AFLR=QREJ/(H2-H1)
      VIN=(AFLR/3600.)/(PI*DIA1*OPHT1*DIN)
      WART=FLOW1/AFLR
      PSP=.16*(OPHT+4.)*WART**1.32
      TPDP=PPK1+PSP+TPIX
      VHDI=(VIN**2)*DIN/64.4
      THT=(TPDP*VHDI)/(DIN-DOUT)
      IF(THT-THT1.GT.5.)GO TO 321
```

```
      IF(NTCOD.GT.0)GO TO 315
      WRITE(IRITE,312)CAP(I),TAMWB(J),TC
  312 FORMAT(/8X,≠FOR CAP =≠,F4.2,≠,     T WB =≠,F5.0,≠,  AND  TC =≠,
     X F4.0/≠   PC LESS THAN PC MIN - ASSUME PC MIN - CONTINUE≠)
      IF(DFCOD.GT.0.)DFCOD=0.0
  315 CONTINUE
      OPCOD=(HPP1*.7457/(PSIZE*1000.))*PWCST
      AMBOPC(I)=AMBOPC(I)+OPCOD*PCTAMB(J)
      AMBDFC(I)=AMBDFC(I)+DFCOD*PCTAMB(J)
  340 CONTINUE
      TOPMIL=TOPMIL+AMBOPC(I)*TOTLD(I)*COLPCT(I)*CAP(I)
      TDFMIL=TDFMIL+AMBDFC(I)*TOTLD(I)*COLPCT(I)*CAP(I)
  350 CONTINUE
      AVOPCS=TOPMIL/TKWHRS
      AVDFCS=TDFMIL/TKWHRS
      AVTCST=(CAPCS1*ANFCR)/(PSIZE*1000.*CAPFAC*8.76) +AVOPCS+AVDFCS+SYS
     X1+COSMA1
      CALL PRTOD(AVOPCS,AVDFCS,AVTCST)
      GO TO 400
  400 CONTINUE
      RETURN
      END
```

```
 SUBROUTINE PAFCST(I,TC,PWCST,DELFC,QREJ)
 COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLD(5),
X COLPCT(5),TCMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),
X  HRCOF2(6),HRCOF1(6),HRCOF0(6),TDB,TWB,RH,TAVH2O,TCBASE,
X  NTAMB,AMBDFC(5),AMBDPC(5),TAMDB(5),TAMWB(5),AMBRH(5),
X  TAMRV(5),PCTAMB(5,5),NSYSOP,TDISMX,NSPCON,UOVALL,AREAC,SPFLOW,
X  NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,IRITE,IREAD
 HRBASE=HRCOF2(I)*TCBASE**2+HRCOF1(I)*TCBASE+HRCOF0(I)
 HEATR=HRCOF2(I)*TC**2+HRCOF1(I)*TC+HRCOF0(I)
 QREJ=(HEATR-3413.)*PSIZE*CAP(I)*1000.
 DELHR=HEATR-HRBASE
 DELFC=FUCST*DELHR*1.E-5
 PWCST=FUCST*HEATR*1.E-5+(CCPKW*ANFCR)/(CAPFAC*8.76)
 RETURN
 END
```

```
      SUBROUTINE COND(TCOND,TIN,QREJ,PWCST,DT2,TOUT,UA,FLOW,GPM,
     *  SYSCST,COSPKW)
      COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLD(5),
     X COLPCT(5),TCMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),
     X  HRCOF2(6),HRCOF1(6),HRCOF0(6),TDB,TWB,RH,TAVH2O,TCBASE,
     X  NTAMB,AMBDFC(5),AMBOPC(5),TAMDB(5),TAMWB(5),AMBRH(5),
     X  TAMRV(5),PCTAMB(5,5),NSYSOP,TDISMX,NSPCON,UOVALL,AREAC,SPFLOW,
     X  NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,IRITE,IREAD
      PMPEF=.8
      IF(NSPCON.EQ.1)GO TO 30
C           VARIATION OF HEAT TRANSFER COEFFICIENT, UALL, WITH TYPE
C           OF WATER
      IF(NH2O)20,10,15
   10  UALL=340.
      GO TO 25
   15  UALL=420.
      GO TO 25
   20  UALL=250.
   25  CONTINUE
      DT1=TCOND-TIN
      TOUT=TCOND-DT2
      DELT=TOUT-TIN
C           ALOG MEAN TEMPERATURE DIFFERENCE, LMTD
      DTLGM=(DT1-DT2)/(ALOG(DT1/DT2))
      ACOND=QREJ/(DTLGM*UALL)
      UA=UALL*ACOND
      CONCST=20.*(ACOND*1.05)**.9
C           65 PERCENT INCREASE IN MATERIAL COSTS IF SALT WATER USED
      IF(NH2O.LT.0)CONCST=CONCST*1.65
      FLOW=QREJ/DELT
      GPM=FLOW/(8.34*60.)
C          ASSUME 35 FT OF HEAD
      CHEAD=35.
      PMPCST=(GPM*CHEAD*.7457*PWCST)/(3960.*PMPEF*PSIZE*1000.)
C           1 DOLLAR PER GPM FOR COST OF PUMPS
      COSPKW=(CONCST+1.*GPM)/(PSIZE*1.E3)
      SYSCST=(COSPKW*ANFCR)/(CAPFAC*8.76)+PMPCST
      GO TO 50
   30  UA=UOVALL*AREAC
      FLOW=SPFLOW
      GPM=FLOW/(8.34*60.)
      SYSCST=0.0
   50  RETURN
      END
```

```
      SUBROUTINE PRTDS1(QREJ,TC,HPF,HPP,WEV,WBD,AFLR)
      COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLD(5), COLPCT(5),TC
     XMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),  HRCOF2(6),HRCOF1(6),HRCOFO(6),
     XTDB,TWB,RH,TAVH2O,TCBASE,  NTAMB,AMBDFC(5),AMBOPC(5),TAMDB(5),TAMW
     XB(5),AMBRH(5),  TAMRV(5),PCTAMB(5,5),NSYSOP,TDISMX,NSPCON,UOVALL,A
     XREAC,SPFLOW,  NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,IRITE,IREAD
      WEVCFS=WEV/244700.
      WBDCFS=WBD/244700.
      WRITE(IRITE,10)QREJ,TC,HPF,HPP,WEVCFS,WEV,WBDCFS,WBD,AFLR
   10 FORMAT(/,3X,≠Q REJECT =≠,E9.4,≠ BTU/HR  AT T CONDENSER =≠, F5.0
     X,/,3X,≠FAN POWER =≠,E9.4,≠ HP     PUMP POWER =≠,E9.4,≠ HP≠,/, 3X,≠
     *H2O EVAP =≠,E9.4,≠ CFS (≠,E9.4,≠ LB/HR)≠/
     *  ≠    H2O BLOWDOWN =≠,E9.4,≠ CFS (≠,E9.4,≠ LB/HR)≠/
     *  ≠    AIR FLOW RATE =≠,E9.4,≠ LB/HR≠)
      RETURN
      END
```

```
      SUBROUTINE PRTDS2(CAPCOS,OPCOS,COSMAI,SYSCOS,DELFC,TOTCOS,COSPKW)
      COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLD(5), COLPCT(5),TC
     XMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),  HRCOF2(6),HRCOF1(6),HRCOF0(6),
     XTDB,TWB,RH,TAVH2O,TCBASE,  NTAMB,AMBDFC(5),AMBOPC(5),TAMDB(5),TAMW
     XB(5),AMBRH(5),  TAMRV(5),PCTAMB(5,5),NSYSOP,TDISMX,NSPCON,UOVALL,A
     XREAC,SPFLOW,  NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,IRITE,IREAD
      WRITE(IRITE,10) CAPCOS,COSPKW,OPCOS,COSMAI,SYSCOS,DELFC,TOTCOS
   10 FORMAT(≠0  CAPITAL COST =≠,E9.4,≠ DOLLARS≠/≠   CONDENSER AND PUMP
     *COST =≠,E9.4,≠ DOLLARS/KW≠/≠   OPERATING COST =≠,
     X       F6.3,≠ MILLS/KW-HR≠,/, 3X,≠MAINTENANCE COST =≠,F6.3,≠ MILLS
     X/KW-HR≠,/, 3X,≠CONDENSER SYSTEM COST =≠,F6.3,≠ MILLS/KW-HR≠,/, 3X,
     X≠DIFFERENTIAL FUEL COST =≠,F6.3,≠ MILLS/KW-HR≠,//, 3X,≠  TOTAL SYS
     XTEM COST =≠,F6.3,≠ MILLS/KW-HR≠/)
      RETURN
      END
```

```
      SUBROUTINE PRTCD(OPCOD,DFCOD,TCOD)
      COMMON PSIZE,CCPKW,ANFCR,FUCST,NCAPS,CAP(6),TOTLD(5), COLPCT(5),TC
     XMIN(6),PCMIN(6),TCMAX(6),PCMAX(6),  HRCOF2(6),HRCOF1(6),HRCOFO(6),
     XTDB,TWB,RH,TAVH2O,TCBASE,  NTAMB,AMBDFC(5),AMBOPC(5),TAMDB(5),TAMW
     XB(5),AMBRH(5),  TAMRV(5),PCTAMB(5,5),NSYSOP,TDISMX,NSPCON,UOVALL,A
     XREAC,SPFLOW,  NH2O,WIDTH,PRPAGR,CAPFAC,USEFAC,TKWHRS,IRITE,IREAD
      WRITE(IRITE,10) OPCOD,DFCOD,TCOD
   10 FORMAT(/5X,≠WITH THE VARIOUS AMBIENT TEMPERATURES≠,/,
     X 5X,≠THE COSTS ARE -≠,//,
     X 3X,≠OPERATING COST =≠,F6.3,≠ MILLS/KW-HR≠,/,
     X 3X,≠DIFFERENTIAL FUEL COST =≠,F6.3,≠ MILLS/KW-HR≠,/,
     X /,3X,≠TOTAL SYSTEM COST =≠,F6.3,≠ MILLS/KW-HR≠)
      RETURN
      END
```

```
      FUNCTION H(T)
      H    =21.572142-.93539227*T+.28365243E-01*T**2 -.26605772E-03*T**3+
     X.12608996E-05*T**4
      RETURN
      END
```

```
 FUNCTION P(T)
 P    =.16818166E-1+.14461089E-2*T+.83460247E-5*T**2+.4987537E-6
X *T**3-.20658843E-9*T**4+.22620224E-10*T**5
 RETURN
 END
```

DATA SUBD1

200	150	.12	10	1000	5		
100	80	60	25	0			
5150	1750	800	700	360			
80	70	50	30	15			
3	3	4	3	3	5		
150	100	100	100	100	150		
350	400	400	450	450	350		
150	250	350					
7987	8037	8153					
100	200	300					
7974	8025	8174					
100	200	300	350				
8055	8195	8430	8543				
100	200	300					
8828	9381	9815					
100	200	300					
0	0	0					
150	200	250	300	350			
8000	8009	8042	8089	8151			
85	75	75	1.5	10	4000	-1	3
70	80	85					
60	70	70					
60	65	70					
10	10	10					
4000	4000	4000					
25	25	50					
30	30	40					
40	30	30					
50	25	25					
00	00	100					
2000	2	1	85	350	2.76E5	4.2E7	
1		1	1	1			

DATA SUBD2

200	150	.12	10	1000	5		
100	80	60	25	0			
5150	1750	800	700	360			
80	70	50	30	15			
3	3	4	3	3	5		
150	100	100	100	100	150		
350	400	400	450	450	350		
150	250	350					
7987	8037	8153					
100	200	300					
7974	8025	8174					
100	200	300	350				
8055	8195	8430	8543				
100	200	300					
8828	9381	9815					
100	200	300					
0	0	0					
150	200	250	300	350			
8000	8009	8042	8089	8151			
85	75	75	1.5	10	4000	0	3
70	80	85					
60	70	70					
60	65	70					
10	10	10					
4000	4000	4000					
25	25	50					
30	30	40					
40	30	30					
50	25	25					
00	00	100					
2000	0	1		350	2.76E5	4.2E7	
1	1	1	1	1			

DATA SUBD3

200	150	.12	10	5000	5		
100	80	60	25	0			
5150	1750	800	700	360			
80	70	50	30	15			
3	3	4	3	3	5		
150	100	100	100	100	150		
350	400	400	450	450	350		
150	250	350					
7987	8037	8153					
100	200	300					
7974	8025	8174					
100	200	300	350				
8055	8195	8430	8543				
100	200	300					
8828	9381	9815					
100	200	300					
0	0	0					
150	200	250	300	350			
8000	8009	8042	8089	8151			
85	75	75	1.5	10	4000	0	3
70	80	85					
60	70	70					
60	65	70					
10	10	10					
4000	4000	4000					
25	25	50					
30	30	40					
40	30	30					
50	25	25					
00	00	100					
2000	2	0	85				
1		1	1	1			

DATA SUBD4

200	150	.12	10	5000	5		
100	80	60	25	0			
5150	1750	800	700	360			
80	70	50	30	15			
3	3	4	3	3	5		
150	100	100	100	100	150		
350	400	400	450	450	350		
150	250	350					
7987	8037	8153					
100	200	300					
7974	8025	8174					
100	200	300	350				
8055	8195	8430	8543				
100	200	300					
8828	9381	9815					
100	200	300					
0	0	0					
150	200	250	300	350			
8000	8009	8042	8089	8151			
85	75	75	1.5	10	4000	0	3
70	80	85					
60	70	70					
60	65	70					
10	10	10					
4000	4000	4000					
25	25	50					
30	30	40					
40	30	30					
50	25	25					
00	00	100					
2000	0	0					
1	1	1	1	1	1		

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27 *Abstract*

A computer program is described for calculation of both cooling system and power plant cost and the determination of the minimum total cost for a given set of parameters. To this end the effect of various design parameters have been studied to determine which have significant effects on the performance of the various cooling schemes and which are important to power plant costs. Design equations based on these parameters are incorporated into a computer program through which the minimum total cost is calculated.

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