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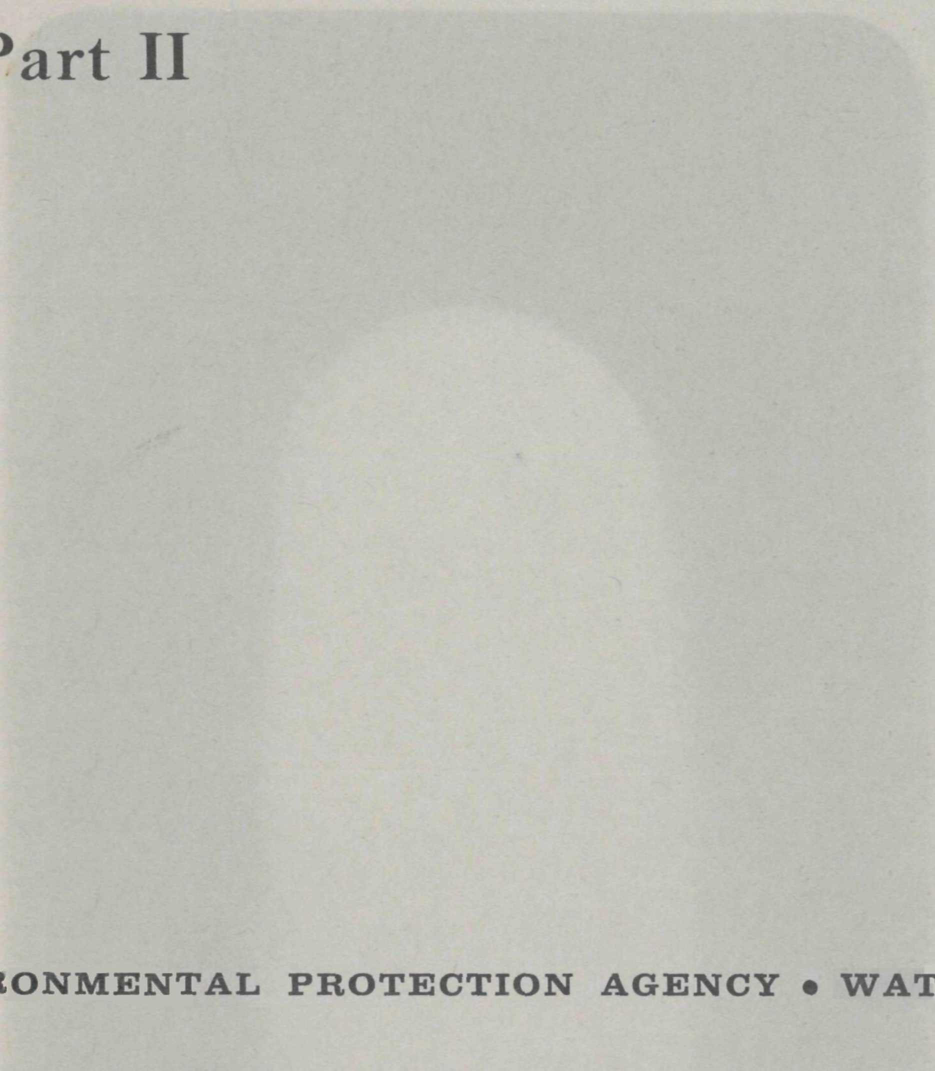
RESEARCH ON DRY - TYPE COOLING TOWERS FOR THERMAL ELECTRIC GENERATION

Part II



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RESEARCH ON DRY-TYPE COOLING TOWERS FOR

THERMAL ELECTRIC GENERATION: PART II

Computer Program Descriptions

by

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for the

WATER QUALITY OFFICE

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TABLE OF CONTENTS

DRY COOLING TOWER OPTIMIZATION COMPUTER PROGRAMS

GENERAL

The study of dry-type cooling towers as described in the report Research on Dry-Type Cooling Towers for Thermal Electric Generation was facilitated by the development of two computer programs to aid in the analysis of the large quantity of data. The writeup herein describes the two programs in detail and provides instructions for their operation.

The computer used was a CDC 6400 in the timesharing system of United Computing Systems, Inc., of Kansas City, Missouri. Input was by paper tape on a remote teletype terminal. Remote and local batch output by terminal was possible; however, remote batch was primarily used due to the large amount of output information. The programs were coded in FORTRAN IV.

The physical dimensions of a natural-draft dry cooling tower and its capital cost are evaluated by the program titled "TOWSIZ". The economically optimum dry cooling system is determined by the program titled "OPTDCT".

ECONOMIC OPTIMIZATION PROGRAM "OPTDCT"

The purpose of the program OPTDCT is to determine, for a given set of conditions at a particular location, the economically optimum dry-type cooling system for a large thermal-electric generating plant.

The size of the dry cooling system is a function of the initial temperature difference (ITD) which is the difference between the turbine exhaust steam temperature and the ambient air temperature. The economically optimum dry cooling system for a specific set of conditions is that which results in the lowest total annual cost.

The annual costs which are affected by the ITD of the dry cooling system and which, therefore, must be considered in the economic optimization analysis are the annual capital costs, operation and maintenance costs, total generating plant fuel costs, auxiliary power costs and the cost of replacing generating capacity lost at high ambient air temperatures.

The economic optimization program OPTDCT requires the input from two external data files, TURBIN and SITEXX. All other data required for the analysis are either in data statements within the program or are created by the program and then stored in arrays.

The data file TURBIN contains the following data pertaining to the turbine: nameplate rating; type of fuel (fossil or nuclear); the design heat rejection; limiting values for the operating back pressure; the turbine output for back pressure from 1.0 inch Hg to 18.0 inches Hg in steps of 0.5 inches; and corresponding values of turbine heat rate, station heat rate and heat rejection for the three turbine operating conditions of full throttle, 3/4 load and 1/2 load.

The data file SITEXX contains the following site related information: site name, elevation, reason of peak electrical demand, fuel costs, fixed-charge rates, a construction cost multiplier, the capital cost per kw for peaking units, a cutoff temperature used in determining when the peaking unit is operated, the capital cost per kw for auxiliary power, operation and maintenance cost data and ambient air temperature duration data for the site.

Description of Program "OPTDCT"

The following is a detailed section by section explanation of the computer program. A glossary of terms, used in the program, can be found in Appendix E.

The first section of the program, ending at line 01080, contains declaration, data and comment statements. The data within this section does not change with the exception of the following: AUX100 data line no. 00360, KWAX data line no. 00440, CAPCST data lines 00960-01020, and the TOWER data line no. 01060. These blocks of data have to correspond to the tower and turbine being analyzed. A further explanation of the above mentioned data is in the section on operating instructions.

The next section, line 01100 to line 01260, is the section that creates the air temperature and back pressure arrays. The first part creates the 32 values of air temperature starting at 117°F and decreasing by 5° increments to −38°F. The second part creates the back pressure data. These values start at 1.0 inch Hg and go to 18.0 inches Hg by 0.5 inch increments.

In the section beginning on line 01260 and ending on line 01580 the turbine data from file TURBIN is read into the program. Also within this section the nominal generation for the given set of operating conditions is calculated. This is done in the statements on lines 01320 and 01340.

After the first eight lines of data have been read into the program, the data check subroutine (DATCHK) is called and the data is checked to see if the right number of values have been read. The next fifteen lines of data are read and the subroutine is called again. This is done until all of the turbine data has been read into the program.

The next section of the program reads in the site data. An explanation of how the site data files are set up is contained in the section on data files. After the site data is read, subroutine DATCHK is called again to verify that the correct number of values were read into the program.

Also within this section, an indicator (IWSP) is set up to direct the computer to the different calculations which are involved with the different peaking periods. This section also finds the air temperatures corresponding to the first and last non-zero temperature durations.

The site identification data is written to the output file in the next section. This starts at line 02520 and ends at line 03040.

The section starting with line 03060 sets up variables that are used in calculating operating costs. These variables are used later in the program, mostly in table look-up calculations.

The next section of the program deals with capital cost. The computer picks the capital cost for a specific ITD and elevation of the site being analyzed from a table of capital costs.

The capital cost is then multiplied by the construction cost index for the site.

The next section, line 03580 through line 03820, initializes variables that are accumulative. These variables are cumulative for each different ITD.

Starting at line 03900, the coefficient A is determined in the equation ITD = A*HREJ**Z. The value of the exponent Z used in the program was .75 for a natural-draft tower and .91 for a mechanical-draft tower.

The calculations to find the operating back pressure for the different air temperatures and for the different turbine loadings begin at line 04000. The back pressures are found by the method of successive approximations and are calculated from line 04120 to line 04660. A limitation has been set on the number iterations it takes to arrive at the turbine operating back pressure. If the limitation is exceeded then the operating back pressure is set equal to the allowable maximum. If the back pressure is found before the limitation is reached, the computer then checks to see if it is within the designated limit. If the back pressure is within the maximum and minimum limitations, then that pressure is used to determine the power output of the turbine and also its heat rate.

If the back pressure is not within the limiting values, the turbine operation is adjusted to operate within the designated limits. These calculations are made between lines 04680 and 04780.

In the section beginning at line 04800 the annual fuel consumption (Btu) is calculated. This value is calculated from the operating station heat rate and reflects the ambient air temperatures during the year and the generating plant loading assumptions.

Starting at line 05000, the auxiliary power requirements for the varying ITD's and air temperatures are calculated. The program is directed to the appropriate calculations depending upon the type of tower (natural draft or mechanical draft). Auxiliary power and energy requirements for a mechanical-draft tower are calculated between lines 05020 and 05440. Natural draft auxiliary power and energy requirements are calculated between lines 05480 and 05540.

The next section beginning at line 05560 is the section in which the loss or gain of capacity is calculated. If the operating back pressure is greater than 3-1/2 inches Hg, then there is a loss of capacity and the amount is calculated in the part beginning at line 05760. If there is a gain, the amount is calculated in the part beginning at line 05620.

The loss of capacity occurring at the temperature equalled or exceeded 10 hours per year is calculated on line 05960.

The next section of the program, beginning at line 06080, writes into the output file the information identifying each run.

The section beginning at line 06240 writes into the output file the column headings for the program results.

The last section of the program, starting at line 06560, calculates the total annual cost. This annual cost data is then searched by the computer to find the minimum annual cost and therefore the optimum ITD. After the optimum ITD is found the results are placed in the output file.

The remainder of the program consists of two subroutines used by the main program. These subroutines, DATCHK and TBLUQ, are described in the next two sections.

General Description of Subroutine "DATCHK"

The purpose of this subroutine is to check if the correct number of values of data have been read into the main program. This check is accomplished by testing to see if the data check number, 1.0E50, is in its proper place within the data file.

Data check numbers can be found on lines 00180, 00340, 00500, and 00660 in the turbine data file TURBIN and on line 250 in the site data file. After the data preceding the data check number is read into the program, subroutine DATCHK is called and it tests to see if 1.0E50 is in its proper place. If there are some data missing or if there are extra data within the file, the subroutine will read some other number than 1.0E50. Thus, not finding the data check number it prints out an error message, indicating that the data has an incorrect number of values. The message printed out by the computer is the name of the data file it is reading and also the line of data that it read instead of the data check number.

After the message is printed out, the data file is reread by the subroutine to find the data check number. After finding this number, the data file has been placed in the proper position so that the remaining data can be read without the error being carried through the file.

General Description of Subroutine "TBLUQ"

This routine is used to interpolate values from tables created by the program or tables entered in data statements. It uses the method of determinant solution of two second order equations.

The first variable in the call is a reference to the first column of the table, which is specified as the second argument. The subroutine first determines whether the requested value lies within the limits of the specified table column. If it does, processing proceeds to the table search.

If the specified value is outside the column entry the program determines whether it is above or below the table and sets indicators to extrapolate from the appropriate end of the table. A return error flag is set and control is transferred to the interpolation calculation.

The table search looks for successive elements of the reference column whose values lie on either side of the requested value. Should an entry in the reference column exactly equal the requested value, the corresponding entry from the look-up column, the third argument, is returned as the subroutine value. Otherwise the table search finds two bracketing values and checks whether they are the first values in the table. If they are, they are used in conjunction with the third variable for interpolation. If they are not the first values, the bracketing values together with the table entry preceding them are used for interpolation.

Description of Data File "TURBIN"

This external input file contains the data pertaining to the turbine performance for varying back pressures for program OPTDCT. Sample data for the fossil-fueled and nuclear-fueled turbines are in Tables 5-B and 6-B of Appendix B.

The first section of the data file TURBIN, starts with the nameplate capacity of the generator (kw) and the type of fuel, specified as either FOSSIL or NUCLEAR. Line 00110 is the nominal heat rejection of the turbine in thousands of Btu per hour. Line 00120 contains the minimum and maximum values of back pressure (inches Hg) at which the turbine is allowed to operate.

The next section, starting with line 00130, contains the 35 values of full throttle generation (kw). These values correspond to back pressures from 1.0 inch Hg to 18.0 inches Hg in 0.5 inch increments. This set of data is followed by the data check number on line 00180.

The next three sections, starting with lines 00190, 00350, and 00510 constitute the main body of the file. These sections correspond to the turbine operating conditions of full throttle, 3/4 load and 1/2 load, respectively. Each section ends with the data check number 1.0E50. This enables the program to check for the correct number of values.

Each section contains three sets, 35 values each of turbine heat rates (Btu/kwh), plant heat rates (Btu/kwh), and heat rejection (10^6 Btu/hr) at various back pressures. The back pressures correspond to the array of back pressures set up in the main program.

Description of Data File "SITEXX" (1)

The SITEXX data file contains the data for each location that the economic optimization program analyzes. Each file consists of 16 lines of data, the last line of data being the data check number. A sample of a site data file is shown in Table 7-B of Appendix B.

The first three lines of data include the site name, elevation and the season of peak electrical demands. The name of the site has been limited to thirty characters. The elevation is in feet above sea level and the period of peak demand is either summer or winter.

The next line of data, line 130, includes the number of base plant fuel costs to be used in the analysis followed by the fuel costs in cents per million Btu. The program is presently set up to take a maximum of three such fuel costs, but this number can be increased by changing the array dimension.

Line 140 includes the number of fixed-charge rates to be used in the analysis followed by the fixed-charge rates. This line of data has been set for a maximum of five fixed-charge rates. It can be increased in the same manner as the number of fuel costs. These values are entered as percentages.

---

(1) Where SITEXX is a file name of SITE01, SITE02, through SITE 27.

The next two lines, 150 and 160, are the capital cost multiplier and the capital cost of the peaking unit in dollars per kw respectively.

Line 170 contains the fixed-charge rates applicable to the peaking unit. The same number of values are entered on this line as are entered on line 140. These values are also entered as percentages.

The next four lines of data contain the peaking unit fuel costs in cents per million Btu (line 180), the cutoff temperature for peaking generation in ^{o}F (line 190), the capital cost of providing auxiliary power requirements in dollars per kw (line 200) and the operating and maintenance cost as a percentage of the capital cost (line 210). The number of peaking unit fuel costs corresponds to the number of base plant fuel costs.

The next three lines of data (220, 230, 240) contain the 32 values of temperature durations. These values are the percent of time during a year that the corresponding air temperatures are expected to occur. The air temperatures correspond to the array of air temperatures which are created in the main program.

The last line (250) contains the data check number 1.0E50.

Format of External Data Files

Data input files TURBIN and SITEXX are desequenced files. These files cannot have line numbers. The program reads each line starting with the first character. The data files shown in Appendix B have line numbers. These are used only to enter the data files in the computer and are used, in this case, only as reference numbers. Once the files are entered in the computer they are desequenced.

Output Data File

Output file OPTOUT will contain the results of the computer runs. This file must be created before the runs are made. To obtain the results from this file, list file OPTOUT.

Operating Instructions for "OPTDCT"

Before running the computer program there are several items that need to be checked to see if the data corresponds to the turbine and cooling system being analyzed. The items that need to be checked are:

1. Auxiliary data
2. Capital cost data
3. Type of tower
4. Turbine data
5. Tower characteristics equations
6. Capital cost multipliers
7. Capital cost of auxiliary power requirements

The auxiliary power requirements data should correspond to the type of cooling tower (natural or mechanical draft) and the type of fuel (fossil or nuclear). The auxiliary power requirements for each of the towers and turbine units are shown in Tables 1-B and 2-B of Appendix B. These values correspond to ITD's of 30°F through 80°F in 10° increments. The values of auxiliary power requirements for a mechanical-draft tower are entered on line 00360 and the values for a natural-draft tower are entered on line 00440.

The mechanical-draft cooling tower data are entered in the following form using data for a fossil-fueled unit:

```
DATA AUX100/32000.,26000.,21000.,17000.,14000.,12000./
```

The natural-draft cooling tower data are entered in the following form, again using data for a fossil-fueled unit:

```
DATA KWAX/12000.,9000.,7000.,6000.,5000.,4000./
```

The auxiliary data (AUXTMP) on lines 00380, 00400, and 00420 do not change. The values in the program listing (Appendix A) are generalized due to their proprietary nature. Contact the manufacturer for specific information. These values represent the air temperatures associated with the minimum (53%) and maximum (100%) proportion of full auxiliary power requirements corresponding to ITD values of 30°F to 80°F in 10° increments for a mechanical-draft tower. They also correspond to full throttle, 3/4 load and 1/2 load operations of the turbine.

The capital cost data, shown in Tables 1-B and 2-B of Appendix B, correspond to the type of turbine and also to the type of cooling system. Depending upon the type of tower and turbine being analyzed the corresponding capital cost must be used. The data are entered on lines 00960, 00980, 01000, and 01020 in the following form:

```
DATA CAPCST/32610000.,22880000.,17200000.,14090000.,
+12040000.,10280000.,36150000.,24430000.,18220000.,
+14700000.,12500000.,10600000.,40500000.,26850000.,
+19770000.,15740000.,13260000.,11100000./
```

The data for sea level elevation is entered first, followed by the data for elevation of 3,000 feet and 6,000 feet. These data represent three curves of capital cost versus ITD for the three elevations.

The type of tower being analyzed is entered on line 01060 in the following forms:

```
DATA TOWER/8HNATURALb,8HDRAFTbbb/
                or
DATA TOWER/8HMECHANIC,8HALbDRAFT/
```

These data are used later in the program in the output as well as in directing the program to the auxiliary calculations that are associated with the type of tower being analyzed.

The data file, TURBIN, containing the turbine data, corresponds to the type of turbine that is being analyzed, either a fossil- or nuclear-fueled unit. These data, along with the tower data determine the type of analysis that will be made. The remaining data used in the calculations corresponds to these two sets of data.

The last item to be checked in the main program is the exponent in the tower operating characteristics equations. The exponent must correspond to the type of tower being used. The value of the exponent is 0.75 for natural draft and 0.91 for mechanical draft. The three equations involving the exponent change are on lines 03680, 04140, and 04760. These equations are as follows for a natural-draft tower:

```
03680 A = THETA/HREJD**.75
04140 110 SATT = AIRT(NT) + A*HRJ**.75
04760 HREJMX = (PLITD*A)**(1./.75)
```

The last two items to be checked are in the site data. The first is the capital cost multiplier and the second is the auxiliary capital cost.

The capital cost multiplier is to allow for variations in construction costs due to local conditions. In areas subject to hurricane winds the construction cost will be greater due to the requirement for stronger structures to resist the forces of these winds. Therefore, a capital cost multiplier is used to provide for the resulting increase in costs. The adjustment for hurricane winds is applied only to the analysis of a natural-draft tower. The mechanical-draft towers are not sufficiently affected by the high velocity winds to warrant an increase in the multiplier above the normal construction cost index for that particular area.

The last item to be checked is the capital cost of auxiliary power. This value depends on the type of unit (fossil- or nuclear-fueled). The capital cost of auxiliary power is assumed to be $150/kw for a fossil-fueled unit and is assumed to be $225/kw for a nuclear-fueled unit.

After checking the above listed items, the program is ready to be run. Each time that a different tower or turbine is used, the above checks must be repeated to insure that the correct data is in the program.

"OPTDCT" Flow Chart Description (1)

1. Dimension variables for tables, temporary storage, etc. Define constants and tables which are not dependent on the site or type of turbine.

Constants:	Tables:
OPHRS	AUX100 vs. TBLITD
HRSPYR	AUXTMP vs. TBLITD vs. PCTLOD
ASTER	KWAX vs. TBLITD
TOWER	P vs. T
SITENO	PCTTIM vs. PCTLD
	CAPCST vs. TBLITD vs. TBLELV

Define ambient air temperatures for table of ambient air temperature vs. annual duration, in percent, of that temperature ($\pm 2^{o}$F). AIRT ranges from 117^{o}F down to -38^{o}F in steps of 5^{o}F.

Define turbine exhaust pressures to associate with values at turbine heat rate, plant heat rate, heat rejected by turbine, and full throttle kw which are read from the turbine file. BP (back pressure) values range from 1.0 inch Hg to 18.0 inches Hg in steps of 0.5 inch Hg.

2. Read the characteristics of the turbine used. This includes the rated kw, whether fossil or nuclear, the design heat rejection and the minimum and maximum back pressure allowable for operating the turbine. Also included are values for tables of back pressure vs. full throttle kw, and values for full throttle, 75% load and 50% load for tables of back pressure vs. net heat rate, gross heat rate and heat rejection.

3. In several specific places the number 1.0E50 must be put into the data file. A subroutine DATCHK is called to check that these numbers are in the correct place in the data file. If they are not in the correct place, there are too many or too few values in the data file. In this case the subroutine prints an error message indicating the data file and the location in the file where the error occurred.

(1) Numbers on these pages correspond to numbers on the flow chart blocks in Appendix D.

4. The nominal annual mwh is the amount which could be produced if operated at the given conditions of load and amount of time specified for that load.

5. Start a loop to cycle through each of the different sites printing a complete set of output for each.

6. Read the information from the appropriate site file. This should include all information that might change for different locations. Included is the name of the site, the elevation, whether winter or summer peak, the fuel costs, fixed-charge rates, capital cost multiplier, cutoff temperature for peak generation, operation and maintenance percentage, and the duration in percent of a year associated with each of the temperatures in AIRT.

7. Set an indicator for applicable winter or summer peaking period.

8. Find the first and last non-zero temperature durations and set a pointer to each so that later processing can be confined to meaningful values.

9. Call the subroutine DATCHK while reading the site file to verify that the right number of values are on the file.

10. Output information which identifies the site being processed, the type of turbine, the type of dry cooling tower, the turbine operating hours per year and the three combinations of percent time at a given percent load which describe the annual demand on the turbine. All output except for error message is done indirectly; i.e., it is written onto a data file during the execution of the program and then the data file is tested after the program is finished.

11.12. 13.14. Compute several values for later use in interpolation of tables through the use of subroutine TBLUQ. These include values of kw load for the maximum operating back pressure, kw load for the actual operating back pressure, heat rejected by the turbine at the maximum operating back pressure, the hours duration of the three highest temperatures, and the three highest temperatures at that site. TBLUQ is a function subprogram that, given a value in one column of a table, returns the corresponding value from the second column of the table. If the given value is between values in the table, a quadratic interpolation is done to arrive at the value to be returned.

15. Find the air temperature which is equalled or exceeded 10 hours per year. Use TBLUQ and the three valued table just computed of DUR vs. AIR.

16. Set up a loop to perform the basic calculations with each ITD from 30°F to 80°F in 1° increments.

17. Convert the integer ITD into an equivalent real value THETA. The integer I is the subscript which corresponds to each ITD. I ranges in value from 1 to 51 in increments of 1.

18. Do two sets of table look-ups using TBLUQ to determine the capital cost of the cooling system which is a function of both elevation and ITD. This table is different for natural- and mechanical-draft towers and is determined outside of this program.

19. Multiply capital cost by capital cost multiplier.

20. The coefficient A must be calculated for each ITD. The given ITD and design heat rejection are used to calculate A. Z is a given exponent and is 0.75 for natural-draft towers and 0.91 for mechanical-draft towers. Once A is computed this equation will give the ITD of a given tower for all heat rejection values.

21. Set up loop to cycle through each of the three loading conditions of percent time vs. percent load.

22. Set up loop to cycle through each of the air temperatures between the highest and lowest recorded at the given site.

23. Initialize iteration counter and two variables used for back pressures. OPBP is initialized at BPMIN (minimum back pressure) because if the operating BP is less than BPMIN it is possible to skip out of the loop before OPBT is computed. Skip to block 29 which calculates the heat rejected from the turbine.

24.-32. This group of blocks involves an iterative procedure to arrive at the actual operating back pressure. Essentially what must be found is the intersection of the turbine characteristic curve for the given load and the cooling tower characteristic curve for the given air temperature. Both the turbine and cooling tower curves are in terms of heat rejection vs. back pressure. The turbine curve is arrived at from a table of values from the turbine data file and the cooling tower curve is arrived at by using the equation Part Load ITD = A x (Heat Rejection)^Z, the ambient air temperature and the relation between saturation temperature and saturation pressure.

The solution is arrived at by first assuming a back pressure (the minimum back pressure is used for a starting value). For this back pressure and the given load the turbine will produce a certain amount of heat rejection.

This heat rejection is used to calculate the part load ITD of the cooling system. Adding the ambient air temperature and the ITD gives the saturated steam temperature. This temperature corresponds to a saturated steam pressure which is exhaust back pressure of the turbine. If the preceding back pressure and the newly derived back pressure are within 0.01 inch Hg of each other then that is the back pressure which is used in the analysis. If the two values differ by more than 0.01 inch Hg then the newly calculated back pressure is used as the starting point of the calculation. If after 15 iterations a solution has not been found, an error message is printed, the last back pressure calculated is used and processing continues.

33.34. If the calculated back pressure is less than the minimum, make it equal to the minimum.

35. In order to calculate energy requirements, it is necessary to calculate the total number of hours of the year that the plant runs at the given load and air temperature.

36. Check to see if the calculated back pressure is greater than the maximum allowed for the turbine and if so, the turbine output must be decreased to an allowable level. Transfer to block 39 to do this.

37. For the computer back pressure, find the maximum possible output in kw of the turbine.

38. Compare the maximum possible output with that required and use the smaller as the actual turbine output. Skip to block 41.

39. If the calculated back pressure exceeds the maximum, then plant output is limited by the amount of heat the cooling system can reject at the maximum back pressure. Calculate this heat rejection by using the maximum back pressure to arrive at a corresponding saturation temperature; this temperature minus the air temperature gives the maximum part load ITD which is possible; from this part load ITD the corresponding heat rejection can be determined using the equation:

$$\text{Heat Rejection} = \left(\frac{\text{Part Load ITD}}{A}\right)^{(1/Z)}$$

40. By doing a table look-up (with TBLUQ) in a table of heat rejection vs. load at the maximum back pressure and using the calculated heat rejection as one value in the table, the maximum turbine output can be found.

41. The station heat rate may now be found from the table of station heat rate vs. back pressure vs. load, by four calls to TBLUQ – three calls to build a table of load vs. station heat rate for a constant back pressure and another call to find the station heat rate for given load.

42. Calculate and accumulate the total annual fuel requirement (Btu). The Btu requirements for each load and temperature combination are calculated from the station heat rate multiplied by the total hours for that condition, and then added to the previous subtotal.

43. The next few blocks calculate the auxiliary power and energy requirements. These steps differ depending on whether the tower is natural or mechanical draft. This block tests to see if the tower is natural draft and skips to 47 if it is.

44. The maximum auxiliary power requirement for each ITD is found by interpolating a table of auxiliary power requirements vs. ITD

45. A linear interpolation of another table gives the percent of maximum auxiliary power requirement used for a given air temperature, ITD and load.

46. Compute the annual auxiliary kwh for mechanical draft by applying the above percentage to the product of the maximum auxiliary power requirement computed in block 44 and the number of hours per year at this condition. Skip to block 49.

47. Determine the auxiliary power requirements for the natural-draft tower by a call to TBLUQ using the ITD given and the table of ITD vs. KWAX.

48. Compute the auxiliary energy requirements by multiplying the auxiliary power requirements by the number of hours at the given conditions.

49. Calculate and accumulate the total energy produced by the turbine. The energy produced at the given conditions is computed by multiplying the kw produced by the turbine times the number of hours at the given conditions.

50. If, at full throttle, the amount produced by the turbine is different than the nameplate capacity, then a gain or loss of capacity and energy must be computed.

51.55. If there is a net gain, calculate that gain in kwh and Btu. The kwh gain is calculated by taking the difference between the actual amount produced and the amount required, times the number of hours at the given conditions. The associated Btu requirement is computed by taking the kwh gain times the calculated station heat rate. A gain may only occur if the demand is 100% of nameplate and the turbine can produce more than that amount. Skip to block 56.

52. If there is a loss, check whether the air temperature is above or below the cutoff temperature.

53. If below the cutoff temperature, calculate the energy (kwh x hrs) and store in KWHBLO. Skip to block 57.

54. If above the cutoff temperature, calculate the energy and store in KWHABV.

56. If processing one of the three highest temperatures, save the amount of power loss or gain for later interpolation.

57.58. Go to next lower temperature and its duration, until all non-zero durations have been used, then go back to block 23.

59.60. After making the calculations for all temperatures for a given load go to the net load condition until calculations have been made for all load conditions.

61. The total energy produced in a year has now been calculated for the plant. Save this value for each ITD.

62. Determine the capacity loss which occurs at the air temperature equalled or exceeded 10 hours per year by interpolation of a table of the three highest air temperatures and the corresponding kw losses or gains for those temperatures.

63.64. All values which vary with ITD, for a given site and ITD, have now been calculated and stored in arrays. Calculate the same values for the next higher ITD until values have been computed for all ITD values up to and including $80^{\circ}F$.

65. Set up counter to calculate annual costs using each of the fuel costs. Up to three fuel costs may be used for each site.

66. Set up another counter to calculate the annual costs for each of the five different fixed-charge rates.

67. Write the headings on the output file for the page of outputs. Along with the column headings, the capital cost factors, the fuel costs, and the capital costs per kw for peaking and auxiliary power are outputted inorder to identify the case being run.

68.69. Set up loop to calculate and output annual costs and intermediate results for each ITD.

70. The annual cost which is associated with the capital cost of the cooling system is equal to the capital cost multiplied by the fixed-charge rate.

71. Calculate the operation and maintenance cost of the cooling system (which is a percentage of the total capital cost) and add this cost to the total annual cost.

72. Compute the total annual cost of fuel by taking total annual Btu times the fuel cost per million Btu.

73.74. Check whether peak is in winter or summer. For a summer peak compute
75. the capital cost of replacing the lost capacity and a cost for the energy lost. For a winter peak, compute only the penalty for the lost energy since the peak system demand would not occur during the months when the capacity losses would occur. The capital cost of replacement capacity is computed as the capacity loss which occurs at the air temperature equalled or exceeded 10 hours per year times a cost in $/kw for peaking power to replace it, plus an operation and maintenance cost assumed as a $1.20 per kw loss.

The operating cost is determined by multiplying the energy lost by the appropriate heat rate and the appropriate fuel cost. This cost is divided into two parts, operating cost associated with energy lost above the cutoff temperature and operating cost associated with energy lost below the cutoff temperature. Above the cutoff temperature the lost energy was replaced by a peaking unit; thus a higher heat rate and a higher fuel cost was used. Below the cutoff temperature the lost energy was assumed to be replaced by another large base load unit; thus the base load unit heat rate and fuel cost were used.

76. Add the capital and operating costs for the penalty to get the total penalty cost.

77. Add the kwh below the cutoff temperature to the kwh above the cutoff temperature to get the total energy loss.

78. Capital cost of auxiliary power is computed by taking the maximum auxiliary power required times the $/kw cost of auxiliary power. The operating cost of the auxiliaries is the auxiliary energy in kwh times the average plant fuel cost in mills/kwh plus an operation and maintenance cost. The total annual cost of the auxiliary power and energy is the sum of the capital cost times a fixed-charge rate plus the operating cost.

79. The annual cost of the cooling system is the summation of: annual capital cost of the cooling system including an operation and maintenance charge, the annual cost of the total plant fuel, the annual cost of replacing capacity and energy losses due to high turbine back pressure, the annual cost of auxiliary power and energy, and the credit given for the generation of excess energy.

78.79. The optimum total annual cost is to be flagged in each case. Therefore, a test must be made to save the lowest total annual cost and test with the next one calculated. The ITD of the optimum value is also saved.

82. For each ITD the following values are saved on a temporary file for later output:

a. ITD
b. Actual mwh produced
c. Credit energy in mwh
d. Penalty energy in mwh
e. Auxiliary energy in mwh
f. Capacity lost in kw
g. Auxiliary power in kw
h. Annual capital and operation and maintenance cost of the dry cooling system
i. Annual cost of total plant fuel
j. Amount credited due to excess energy
k. Cost of replacing capacity and energy cost
l. Cost of auxiliaries
m. Total annual dollar cost
n. Total annual cost in mills/kwh

81.82. Go back to block 68 and process with next ITD until ITD = 80°F; then continue on.

85. Copy the temporary data file onto the permanent output file and look for the ITD with the minimum annual cost. Before copying the line of data associated with the optimum ITD, write the word "OPTIMUM" to indicate that the next line is the optimum condition.

86.87. Calculate a whole new set of output values with a different fixed-charge rate until all five fixed-charge rates have been used.

88.89. Calculate another set of five pages of output using the second set of fuel costs, and the final set using the last set of fuel costs. This means that there will be fifteen combinations of fixed-charge rates and fuel costs for each site.

90.91. Now that all information for one site has been written onto the output file go back and do the same thing with the next site until all 27 sites have been processed. Once the program execution is finished the output file is listed to obtain a printed copy of the printout.

TOWER OPTIMIZATION PROGRAM "TOWSIZ"

Program TOWSIZ computes the physical dimensions of a natural-draft dry-type cooling tower and evaluates the capital cost of constructing the tower.

Six basic design parameters are required by the program as input. These values are the ITD, range, heat rejection, water flow, ambient air temperature and elevation. Using these parameters, the program evaluates a number of intermediate variables which contribute to the computation of the tower size (height, top diameter and bottom diameter).

After sizing the tower the program evaluates the capital cost of the cooling system. The capital cost is divided into the areas of tower structure, condenser, piping and valves and controls. The tower structure cost is the make-up of stack, shed and coil costs. Piping and valves includes the cost for piping, valves, circulating water pumps, cooling system filler pump and storage tank.

Within the subheading of structure costs, the dollar value of the tower itself is found by interpolation between curves for three evaluated tower diameters. The shed cost is evaluated from the area difference between the base diameter and top diameter charged at $7.60 per square foot. Coil cost is evaluated at $14,500 per coil.

Condenser cost is arrived at from a table of cost vs. heat rejection.

The costs of piping, valves, pumps, and storage tanks are computed in subroutine TWRPIP. They are developed by computing the water flow needed to reject the amount of heat produced by the plant at its design point. From the GPM required, the pipe and valve sizes and quantity of each are determined. The number of pumps to handle the flow is figured and the required storage capacity is calculated. From cost tables in the subroutine, the costs of the above items are figured and then summed. $500,000 is included for controls.

Description of Program "TOWSIZ"

The first section of the program ending at line 02380 contains declaration, data and comments statements. The data within this section do not change.

Beginning at line 02400, the intermediate results for determining the tower size is computed. After the intermediate results are calculated, the actual physical size of the tower is computed. Results are the tower height, upper diameter, bottom diameter and the water flow rate.

The next section beginning at line 03340 calculates the capital cost of the cooling system. The stack, shed, and coil costs are calculated. These constitute the structure costs. Then the condenser cost is calculated beginning at line 03540.

Line 03620 is the statement which calls routine TWRPIP. This routine calculates the costs of pipes, valves, circulating water pumps, filler pumps and storage tank costs.

The section beginning on line 03640 and ending on line 04140 prints out the results of the tower sizing program. A sample of the printout is shown in Appendix C. Each line of data in data file SIZDAT will result in a size and cost analysis of a cooling system for the specified data.

Description of Subroutine "TBLUQ"

This subroutine is identical to the one in the economic optimization program. See prior description beginning on page 8.

General Description of Subroutine "TWRPIP"

This routine is used to calculate the cost of piping, valves, pumps, and storage facilities. This routine uses subroutine PIPSIZ to calculate the size of pipes and valves.

Once the sizes of the pipe and valves are determined, subroutine TWRPIP calculates the quantity of each that is required and their costs. After calculating all the piping and valve costs, the pumping requirements are calculated. After arriving at the pumping costs, the cost of water storage facilities are calculated.

These costs of piping, valves, pumps and storage are then summed and added to the other cooling system costs.

General Description of Subroutine "PIPSIZ"

This routine calculates the size of the pipe required for a given water flow rate. After the pipe size is calculated, the corresponding pipe and valve costs are determined from a table of pipe and valve costs.

Description of Data File "SIZDAT"

This external data file is used by program TOWSIZ. A sample is shown in Appendix B. There are six values on each line. The first value is the initial temperature difference followed by water cooling range, heat rejection, water flow, ambient air temperature and elevation. Each line of the file has corresponding data. There is no maximum limit set on the number of lines of data within the file.

This data file is a desequenced file. The file is created with line numbers. When it is entered into the computer it is desequenced. The file is read line by line until the last line of data is read. On completion of reading the last line, the execution of the program is terminated.

Output Data

A sample of the output data is shown in Appendix C. The listing shows input data for the particular run, the physical dimensions of the cooling tower and its costs, the condenser cost, piping facilities cost, the cost of controls and the total cooling system cost, including contingencies.

Operating Instruction for "TOWSIZ"

The program is ready to run once it and the data file SIZDAT are in the computer. Check to make sure the data file has been desequenced.

"TOWSIZ" Flow Chart Description (1)

1.01 Data statements are used in the program to define data tables in the program which will be used to perform interpolation for various computations. Included are tables of stack diameter, stack height, stack cost, temperature ranges, ambient air temperature height adjustment factors, altitudes, altitude height adjustment factors, air flow, heat rejection, pressure drop across the coil and water flow.

1.02 Values of entered heat rejection and pressure drop tables are scaled to proper dimensions for program use.

1.04 The input variables, initial temperature difference, range, heat rejection, G_o, ambient air temperature and elevation, are read for one case from one line of the data file named "SIZDAT".

(1) Numbers on these pages correspond to the numbers on flow chart blocks.

1.05 The number of cooling columns is calculated by dividing condenser flow by G_o. A temporary variable is then set to the remainder of the number of coils divided by four. If the remainder is zero the calculated number of coils is used. If it is not zero the number of coils is increased to the next number evenly divisible by four. This action is taken to ensure the number of deltas, which is one half the number of columns will be an even number.

1.06 Seven curves of heat rejection versus air flow have been entered for seven different values of water flow. The program compares the entered value of water flow with the acceptable values corresponding to the curves. If no match is found an error message is printed in block 1.07. A match branches to block 1.10.

1.07 The following message is printed: G_o = XXXXX NO CORRESPONDING CURVE. Case aborted.

1.08 If there is still data in the input file, the program initiates the new case. When no data is left, the program terminates.

1.10 Subroutine TBLUQ is called. If the error flag for data outside tables is set in the subroutine, the main program will branch to block 1.11. A normal subroutine execution will lead to block 1.12.

1.11 The following message is printed: L_o OUTSIDE TABLE. Processing continues.

1.12 Pressure drop across the coil is found using air flow looking into air flow and pressure drop tables.

1.13, 1.14, 1.15 Velocities and losses are calculated.

1.16 Ambient air temperature is used to reference a table of temperatures and adjustment factors; the reference temperature of 50.0° is used in the same way; the site elevation references a table of elevations and adjustment factors. The result of these calls to TBLUQ is a set of factors which are used to adjust the tower draft height according to varying air densities at temperatures other than 50.0° and elevations other than sea level.

1.17 Apply the factors from block 1.16 to calculate adjusted draft height and add 80.0 feet to obtain total tower height.

1.18 The final air temperature is used to find an adjustment factor for the tower upper area.

1.19 Compute the tower upper area and diameter and lower diameter.

1.20 Test to find if lower diameter is less than upper diameter. If not, go to 1.22, otherwise go to 1.21.

1.21 Set lower diameter equal to upper diameter. Continue at 1.22.

1.22 The program finds two successive entries in a table of stack diameters which bracket the calculated upper diameter. When these are found, go to step 1.24. If no such entries are found, move to 1.23.

1.23 The following error message is printed: UPPER DIAMETER XXXX OUTSIDE OF TABLES. Control is sent to block 1.08.

1.24 Routine TBLUQ is called twice, once for each of the two diameters found in step 1.22, using the total calculated tower height to find a tower cost for each of the two diameters.

1.25 The calculated upper diameter is used to perform a linear interpolation between the calculated costs from step 1.24.

1.26 The roof cost is calculated as the difference between the cross-sectional areas of the top and bottom stack diameters times $7.60 per square foot.

1.27 Basic condenser costs are provided to the program in a table of water cooling range vs. condenser cost in dollars per 10^9 Btu per hour. The range is used through TBLUQ to find a basic condenser cost which is multiplied by the heat rejection in 10^9 Btu per hour to get total condenser cost.

1.28 The number of deltas is one half the number of cooling columns.

1.29 Call Subroutine TWRPIP to compute all piping and associated costs.

1.30 Print out summary for sizing and cost evaluation.

Subroutine "TBLUQ" Flow Chart Description

2.01 Checks to see if value is within the given table of values.

2.02 If value is not in table it checks to see if the value is less than the smallest value in the table.

2.03 If value is less than the smallest value then it uses the first three values to extrapolate for the desired value.

2.04 If value is not in the table it checks to see if the value is greater than the largest table value.

2.05 If value is greater than the largest table value then it uses the last three table values to extrapolate.

2.06 Sets an error flag for any value outside the table.

2.07 Checks to see if value is equal to a table entry.

2.08 If value equals table value then it returns corresponding entry.

2.09, 2.10 Checks for exact location in the table.

2.11, 2.12, 2.13, 2.14 Uses three table entries to evaluate the value being looked up. If value is between the first and second table entry then it uses the first three entries for the evaluations. If value is between last two table entries it uses last three table entries. Anywhere else in the table it uses the two table values preceding and the one following the value.

2.15 Value is evaluated for from appropriate table values and returned to program.

Subroutine "TWRPIP" Flow Chart Description

3.01 Calculate the water flow rate required for the transfer of the heat produced by the turbine. This flow rate establishes the size and number of supply lines required to pipe the water to the cooling tower.

3.02, 3.05, 3.09, 3.12, 3.16 Subroutine "PIPSIZ" is called to calculate the diameters of the pipe and also pick the corresponding pipe and valve costs from a table of pipe and valve costs.

3.03, 3.06, 3.10, 3.13, 3.17 Calculate the quantity of pipe and valves required and the cost.

3.04 Calculate the water flow rate for the header lines.

3.07 Calculate the number of cooling deltas per tower sector.

3.08 Calculate the water flow rate for the sector drain pipe.

3.11 Calculate the water flow rate for the filler water pipes.

3.14 Calculate the number of bypass valves and their cost.

3.15 Calculate the water flow rate for the emergency drain pipe.

3.18 Calculate the number of circulating water pump setups and their cost.

3.19 Calculate the cost of filler pumps.

3.20 Calculate storage tank costs from a curve of gpm vs. tank cost.

3.21 Sum up the costs of piping, valves, pumps and storage tanks.

Subroutine "PIPSIZ" Flow Chart Description

4.01 Calculate the pipe size from the water flow rate.

4.02 Check to see if the diameter is less than or equal to the maximum size in the table of pipe size vs. cost. If it is less than or equal to the maximum, the program proceeds to 4.04.

4.03 If diameter is greater than maximum, add on another line and proceed to 4.01.

4.04 Find corresponding pipe and valve cost from table of pipe size vs. pipe and valve cost.

APPENDIX A

PROGRAM LISTINGS

ECØNØMIC ØPTIMIZATIØN PRØGRAM "ØPTDCT"

```
PRØGRAM ØPTDCT(ØUTPUT,TAPE1,TAPE2,TAPE3,TAPE4)
REAL KW,KWH,NHR,KWLØS(3),KWHABV(51),KWHBLØ(51)
REAL TØTCAP(51),CRDBTU(51),TØTBTU(51),SITENØ(27)
REAL KWLØSS(51),DUR(3),KWHLØS,CCFGT(5)
REAL MILPKW,MWH(51),LØAD(3),HREJT(3)
REAL PCTLØD(3),TBLITD(6),AUXKWH(51)
REAL AUXKW(51),LØAD1(3)
REAL KWHGAN(51),TEMP(3),KWAX(6)
DIMENSIØN P(56),T(56),AIRT(32),TDUR(32),SITE(5),FULCST(3)
DIMENSIØN BP(35),FTKW(35),GHR(35,3),HREJ(35,3),CCF(5),AUXTEM(2)
DIMENSIØN PCTTIM(3),PCTLD(3),PFCST(3),TBLELV(3),CAPCST(6,3)
DIMENSIØN TØWER(2),AUX100(6),AUXTMP(2,6,3),B(3),AIR(3)
** AUXILIARY DATA CØRRESPØNDS TØ FØSSIL ØR NUCLEAR FUELED UNIT
DATA AUX100 /48000.,39000.,32000.,26000.,22000.,18000./
DATA AUXTMP /55.,65.,45.,55.,30.,45.,15.,35.,5.,25.,-20.,15.,
+  60.,70.,50.,60.,45.,55.,35.,45.,25.,40.,15.,30.,
+  70.,75.,65.,75.,55.,65.,50.,60.,40.,55.,30.,50./
DATA KWAX /19000.,14000.,11000.,9000.,8000.,7000./
DATA SITENØ / 6HSITE01,6HSITE02,6HSITE03,6HSITE04,6HSITE05,
+  6HSITE06,6HSITE07,6HSITE08,6HSITE09,6HSITE10,6HSITE11,
+  6HSITE12,6HSITE13,6HSITE14,6HSITE15,6HSITE16,6HSITE17,
+  6HSITE18,6HSITE19,6HSITE20,6HSITE21,6HSITE22,6HSITE23,
+  6HSITE24,6HSITE25,6HSITE26,6HSITE27 /
** STEAM TABLE DATA (SATURATIØN TEMPERATURES AND PRESSURES)
DATA P /.2,.3,.4,.5,.6,.7,.8,.9,1.0,1.1,1.2,1.3,1.4,1.5,
+  1.6,1.7,1.8,1.9,2.0,2.1,2.2,2.3,2.4,2.5,2.6,2.7,2.8,2.9,
+  3.0,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,14.,15.,16.,17.,18.,
+  19.,20.,21.,22.,23.,24.,25.,26.,27.,28.,29.,29.921 /
DATA T / 34.57,44.96,52.64,58.80,63.96,68.41,72.32,75.84,79.03,
+  81.96,84.64,87.17,89.51,91.72,93.81,95.78,97.65,99.43,
+  101.14,102.77,104.33,105.85,107.30,108.71,110.06,111.37,
+  112.63,113.86,115.06,125.43,133.76,140.78,146.86,152.24,157.09,
+  161.49,165.54,169.28,172.78,176.05,179.14,182.05,184.82,187.45,
+  189.96,192.37,194.68,196,90,199.03,201.09,203.08,205.00,206.87,
+  208.67,210.43,212.00 /
DATA PCTTIM / 50.,50.,0. /
DATA PCTLD / 100.,75.,50. /
DATA PCTLØD / 100.,75.,50. /
DATA ØPHRS / 7500. /
DATA HRSPYR / 8760. /
DATA ASTER / 2H** /
DATA TBLITD / 30.,40.,50.,60.,70.,80. /
** CAPITAL CØST DATA FØR VARIØUS ITD'S AND ELEVATIØNS
DATA CAPCST/50000000.,36080000.,26920000.,21530000.,17720000.,
+15870000.,54800000.,37840000.,28210000.,22340000.,22340000.,
+18160000.,16220000.,60000000.,41250000.,29890000.,23670000.,
+19100000.,16810000./
DATA TBLELV /0.,3000.,6000. /
DATA TOWER/8HNATURAL ,8HDRAFT   /
CALL RETR (1,6HOPTOUT)
```

```
** SET UP AIR TEMPERATURES IN ARRAY *AIRT*
DØ 10 I = 1,32
AIRT(I) = 122-I*5
10 CØNTINUE
** SET UP BACK PRESSURE ARRAY
DØ 15 I = 1,35
BP(I) = (I+1.)/2.
15 CONTINUE
** READ TURBINE DATA FRØM FILE *TURBIN*
CALL RETR (2,6HTURBIN)
READ (2,) KW,ITYPE,HREJD,BPMIN,BPMAX
KWH = KW*ØPHRS*(PCTTIM(1)*PCTLD(1)+PCTTIM(2)*PCTLD(2)+
+  PCTTIM(3)*PCTLD(3))/1.0E4
TMWH = KWH/1000.
** READ FULL THRØTTLE KW
READ (2,) (FTKW(I),I=1,35)
CALL DATCHK(2)
** READ NET HEAT RATE, GRØSS HEAT RATE, AND HEAT REJECTIØN FØR
**   FULL THRØTTLE, 75 O/O LØAD, AND 50 O/O LØAD
DØ 20 IL = 1,3
READ (2,) (NHR,I=1,35)
READ (2,) (GHR(I,IL),I=1,35)
READ (2,) (HREJ(I,IL),I=1,35)
CALL DATCHK(2)
20 CØNTINUE
** READ SITE DEPENDENT INFØRMATIØN FRØM FILE *SITE*
DØ 500 ISITE = 1,27
CALL RETR (3,SITENØ(ISITE))
** READ SITE NAME
READ (3,30) SITE
30 FØRMAT (5A6)
** READ IN SITE ELEVATIØN
READ (3,) ELEV
** READ IN WHETHER WINTER ØR SUMMER PEAKING PERIØD
READ (3,) PEAK
IWSP = 0
IF (PEAK.EQ.6HWINTER) IWSP = 1
IF (PEAK.EQ.6HSUMMER) IWSP = 2
IF (IWSP.EQ.0) PRINT,
+ *PEAKING PERIØD NØT 'SUMMER' ØR 'WINTER'*
** READ IN THE NUMBER ØF DIFFERENT BASE FUEL CØST AND THE
**   VARIØUS BASE FUEL CØST
READ (3,) NFUL,(FULCST(I),I=1,NFUL)
** READ IN THE NUMBER ØF DIFFERENT CAPITAL CØST FACTØRS AND THE
**   VARIØUS CAPITAL CØST FACTØRS
READ (3,) NCCF,(CCF(I),I=1,NCCF)
** READ IN CAPITAL CØST MULTIPLIER
READ (3,) CCM
** READ IN PEAKING CAPITAL CØST
READ (3,) PCCST
```

```
** READ CAPITAL CØST FACTØRS FØR GAS TURBINE
READ (3,) (CCFGT(I),I=1,NCCF)
** READ IN PEAKING FUEL CØST
READ (3,) (PFCST(I),I=1,NFUL)
**READ IN CUTOFF TEMPERATURE FØR PEAK GENERATIØN
READ (3,) CUTØFF
** READ IN CØST/KW FØR AUXILIARIES
READ (3,) CPKWAX
**  READ IN ØPERATIØN AND MAINTENANCE PERCENTAGE
READ (3,) OAMCT
** READ IN TABLE ØF TEMPERATURE DURATIØNS
READ (3,) (TDUR(I),I=1,32)
** FIND FIRST AND LAST NON-ZERO TEMPERATURE DURATIØNS
DØ 32 NT = 1,32
IF (TDUR(NT).NE.0.0) GØ TØ 33
32 CONTINUE
33 NTL = NT
DØ 35 NT = 1,32
IF (TDUR(NT).NE.0.0) NTU = NT
35 CONTINUE
CALL DATCHK(3)
** WRITE OUT SITE IDENTIFYING DATA
WRITE (1,360) SITE
360 FORMAT (//*SITE - *5A6)
WRITE (1,361) ELEV
361 FORMAT (*ELEVATIØN -*F5.0* FEET ABØVE SEA LEVEL*)
WRITE (1,362) PEAK
362 FORMAT(*PEAK PERIØD - *A6)
WRITE (1,364) KW,ITYPE
364 FORMAT (*TURBINE -*,F7.0,* KW *A7* UNIT*)
WRITE (1,365) ØPHRS,PCTTIM(1),(PCTLD(I),PCTTIM(I),I=2,3)
365 FORMAT (*  IN OPERATIØN -*F5.0* HRS/YR*/
+  *  AT FULL THRØTTLE*,F4.0* 0/0 ØF THE TIME*
+  2(/*  AT*F4.0* 0/0 LOAD*F5.0* 0/0 ØF THE TIME*))
WRITE (1,363) TMWH
363 FORMAT (*TOTAL ANNUAL ENERGY -*F8.0* MWH NØMINAL*)
WRITE (1,368) TØWER
368 FØRMAT (*TØWER - *2A8)
WRITE (1,931) OAMCT
931 FORMAT(*COOLING SYSTEM ØPERATIØN AND MAINTENANCE CØST -*
+F5.2* 0/0*)
WRITE (1,366) HREJD,ASTER
366 FØRMAT (*DESIGN HEAT REJECTIØN -*,F5.0,* X 10*A2*6 BTU/HR*)
WRITE (1,367) CCM
367 FØRMAT (*CAPITAL COST MULTIPLIER -*F5.2)
WRITE (1,468)CUTOFF
468 FORMAT(*CUTØFF TEMPERATURE FØR PEAKING GENERATIØN -*F4.0
+** F*)
** SET UP VARIABLES USED IN CALCULATING ØPERATING CØSTS
LØAD(1)=TBLUQ(BPMAX,BP,FTKW,35)
```

```
LØAD(2) = KW*.75
LØAD(3) = KW*.50
LØAD1(2) = LØAD(2)
LØAD1(3) = LØAD(3)
HREJT(1) = TBLUQ(BPMAX,BP,HREJ(1,1),35)
HREJT(2) = TBLUQ(BPMAX,BP,HREJ(1,2),35)
HREJT(3) = TBLUQ(BPMAX,BP,HREJ(1,3),35)
DUR(1) = TDUR(NTL)*HRSPYR/100.
DUR(2) = DUR(1)+TDUR(NTL+1)*HRSPYR/100.
DUR(3) = DUR(2)+TDUR(NTL+2)*HRSPYR/100.
AIR(1) = AIRT(NTL)
AIR(2) = AIRT(NTL+1)
AIR(3) = AIRT(NTL+2)
AIR10 = TBLUQ(10.,DUR,AIR,3)
** CALCULATE CAPITAL CØST FØR EACH THETA CØRRESPØNDING
**     TØ SITE ELEVATIØN
DØ 200 ITD = 30,80
I = ITD-29
THETA = ITD
DØ 1501 IK = 1,3
1501 B(IK) = TBLUQ(THETA,TBLITD,CAPCST(1,IK),6)
TØTCAP(I) = TBLUQ(ELEV,TBLELV,B,3)
** ADJUST CAPITAL CØST FØR SITE LØCATIØN
TØTCAP(I) = TØTCAP(I)*CCM
** INITIALIZE ACCUMULATIVE VARIABLES
TØTBTU(I) = 0.0
CRDBTU(I) = 0.0
KWHBLØ(I) = 0.0
KWHABV(I) = 0.0
KWHGAN(I) = 0.0
AUXKW(I) = 0.0
AUXKWH(I) = 0.0
KWH = 0.0
IT = 0
KWLØS(1) = 0.
KWLØS(2) = 0.
KWLØS(3) = 0.
** DETERMINE CØEFFICIENT ØF "A" ØF EQUATIØN: THETA = A*HREJ**Z
** EXPØNENT "Z" CØRRESPØNDS TØ TØWER TYPE,
**     NATURAL DRAFT  Z = .75    MECHANICAL DRAFT  Z = .91
A = THETA/HREJD**.75
** DETERMINE ØPERATING BACK PRESSURE AS INTERSECTIØN ØF THE
**     CURVES ØF HEAT REJECTIØN VS. BACK PRESSURE FØR THE
**     TØWER AT A GIVEN AIR TEMPERATURE AND FØR THE TURBIN
**     AT A GIVEN LØAD
DØ 150 IL = 1,3
DØ 145 NT = NTL,NTU
ITER = 0
BPT = 0.0
ØPBP = BPMIN
```

```
GØ TØ 117
110 SATT = AIRT(NT)+A*HRJ**.75
IF (SATT-75.) 120,115,115
115 SATP = TBLUQ(SATT,T,P,56)
ØPBP = SATP
IF (ABS(ØPBP-BPT).LT.0.01) GØ TØ 120
BPT = ØPBP
117 TEMP(1) = TBLUQ(ØPBP,BP,HREJ(1,1),35)
TEMP(2) = TBLUQ(ØPBP,BP,HREJ(1,2),35)
TEMP(3) = TBLUQ(ØPBP,BP,HREJ(1,3),35)
HRJ = TBLUQ(PCTLD(IL),PCTLØD,TEMP,3)
ITER = ITER+1
IF (ITER.GT.15) PRINT,*MØRE THAN 15 ITERATIØNS TØ FIND*,
+  * ØPERATING BACK PRESSURE *,/,ITD,AIRT(NT),ØPBP,HRJ
IF (ITER.GT.15) GØ TØ 120
GØ TØ 110
** MAKE ØPERATING BACK PRESSURE NØT LESS THAN THE MINIMUM
**   SPECIFIED IN THE FILE *TURBIN*
120 ØPBP = AMAX1(ØPBP,BPMIN)
** CALCULATE THE NUMBER ØF HØURS AT THE GIVEN LØAD AND TEMPERATURE
HRS = ØPHRS*TDUR(NT)*PCTTIM(IL)/1.0E4
** DETERMINE KW LEVEL ØF ØPERATIØN PØSSIBLE
BPT = AMIN1(ØPBP,BPMAX)
FTKWT = TBLUQ(BPT,BP,FTKW,35)
IF (ØPBP.GT.BPMAX) GØ TØ 122
IF (PCTLD(IL).EQ.100.) TKW = FTKWT
IF (PCTLD(IL).LT.100.) TKW = PCTLD(IL)*KW/100.
IF (TKW.GT.FTKWT) TKW = FTKWT
GØ TØ 126
** ADJUST KW LEVEL IF BACK PRESSURE GREATER THAN ALLØWABLE
122 SATT = TBLUQ(BPMAX,P,T,56)
PLITD = SATT-AIRT(NT)
HREJMX = (PLITD/A)**(1./.75)
TKW = TBLUQ(HREJMX,HREJT,LØAD,3)
ØPBP = BPMAX
** CALCULATE THE TØTAL YEARLY BTU'S CØNSUMED FØR EACH ØF THE
**    THREE LØADINGS ØF 100, 75, AND 50 0/0
** DETERMINE GRØSS HEAT RATE FØR CALCULATED BACK PRESSURE
126 TEMP(1) = TBLUQ(ØPBP,BP,GHR(1,1),35)
TEMP(2) = TBLUQ(ØPBP,BP,GHR(1,2),35)
TEMP(3) = TBLUQ(ØPBP,BP,GHR(1,3),35)
LØAD1(1) = TBLUQ(ØPBP,BP,FTKW,35)
ØPGHR = TBLUQ(TKW,LØAD1,TEMP,3)
TØTBTU(I) = TØTBTU(I)+ØPGHR*HRS*TKW
** DETERMINE AUXILIARY PØWER REQUIREMENTS FØR THE VARYING THETAS
IF (TØWER(1).EQ.8HNATURAL ) GØ TØ 1320
** AUXILIARY CALCULATIØNS FØR MECHANICAL DRAFT TØWER
FULAUX = TBLUQ(THETA,TBLITD,AUX100,6)
DØ 1210 IJ = 1,5
IF ((THETA.GE.TBLITD(IJ)).AND.(THETA.LE.TBLITD(IJ+1))) GØ TØ 1220
```

```
1210 CØNTINUE
PAUSE 4910
1220 IJ1 = IJ+1
IJ2 = IJ
AUXTEM(1) = AUXTMP(1,IJ2,IL)-(((THETA-TBLITD(IJ))/10.)*
+  (AUXTMP(1,IJ2,IL)-AUXTMP(1,IJ1,IL)))
AUXTEM(2) = AUXTMP(2,IJ2,IL)-(((THETA-TBLITD(IJ))/10.)*
+  (AUXTMP(2,IJ2,IL)-AUXTMP(2,IJ1,IL)))
IF (AIRT(NT).LE.AUXTEM(1)) GØ TØ 1240
IF (AIRT(NT).GE.AUXTEM(2)) GØ TØ 1250
PCT = 0.53+0.47*((AIRT(NT)-AUXTEM(1))/(AUXTEM(2)-AUXTEM(1)))
GØ TØ 1260
1240 PCT = 0.53
GØ TØ 1260
1250 PCT = 1.00
GØ TØ 1260
1260 AUXKWH(I) = AUXKWH(I) +FULAUX*PCT*HRS
AUXKW(I) = FULAUX
GØ TØ 1290
** AUXILIARY CALCULATIØNS FØR NATURAL DRAFT TØWER
1320 AUXKW(I) = TBLUQ(THETA,TBLITD,KWAX,6)
AUXKWH(I) = AUXKWH(I)+AUXKW(I)*HRS
1290 KWH = KWH + TKW*HRS
** CALCULATE LØSS ØR GAIN ØF CAPACITY
CAPLØS = KW*PCTLD(IL)/100.-TKW
IF (CAPLØS.GT.0.0) GØ TØ 130
** GAIN IN CAPACITY CALCULATIØNS
KWHGAN(I) = KWHGAN(I)-CAPLØS*HRS
CRDBTU(I) = CRDBTU(I)-CAPLØS*HRS*ØPGHR
132 IT = IT+1
IF (IT.GT.3) GØ TØ 145
KWLØS(IT) = CAPLØS
GØ TØ 145
** LØSS ØF CAPACITY CALCULATIØNS
130 IF(AIRT(NT).GE.CUTØFF) GØ TØ 131
KWHBLØ(I) = KWHBLØ(I) + CAPLØS*HRS
GØ TØ 132
131 KWHABV(I) = KWHABV(I)+CAPLØS*HRS
GØ TØ 132
145 CØNTINUE
150 CØNTINUE
MWH(I) = KWH/1000.
** CALCULATE LØSS ØF CAPACITY AT THE 10 HØUR AIR TEMPERATURE
KWLØSS(I) = TBLUQ(AIR10,AIR,KWLØS,3)
IF ((KWLØS(2)+KWLØS(3)).EQ.0.0.AND.DUR(1).LT.10.) KWLØSS(I) = 0.0
200 CØNTINUE
DØ 450 K = 1,NFUL
DØ 450 J = 1,NCCF
** WRITE ØUT INFØRMATIØN IDENTIFYING EACH RUN
WRITE (1,370) CCF(J),CCFGT(J),CCF(J),FULCST(K),ASTER,PFCST(K),
+  ASTER,PCCST,CPKWAX
```

```
06120 370 FØRMAT(*CAPITAL CØST FACTØRS:*9X*PLANT -*F3.0* O/O*3X*PEAKING*
06140+** CAPACITY -*F3.0* O/O*3X*AUXILIARIES -*F3.0* O/O*/*PLANT FUEL *
06160+**CØST -*F3.0* CENTS/10*A2*6 BTU*10X*PEAKING FUEL CØST -*F3.0
06180+** CENTS/10*A2*6 BTU*/*PEAKING CAPITAL CØST -*F4.0* $/KW*16X
06200+**AUXILIARY CAPITAL CØST -*F4.0* $/KW*/)
06220** WRITE ØUT CØLUMN HEADINGS FØR THE DATA ØUTPUT
06240 WRITE (1,380)
06260 380 FØRMAT(68X*ANNUAL*/68X*CAPITAL*3X*ANNUAL*/17X*EXCESS*45X*AND *
06280+**Ø+M*4X*FUEL*
06300+33X*TØTAL ANNUAL*/*INIT.*3X*GRØSS*4X*ENERGY*47X*CØST*5X*CØST*3X
06320+**CREDIT*23X*CØST ØF CØØLING*/*TEMP.*3X*ENERGY*3X*DUE TØ*2X*CAPACI*
06340+**TY*21X*MAXIMUM*8X*ØF DRY*5X*ØF*5X*FØR*3X*CAPACITY*13X*SYSTEM AND*
06360+** TØTAL*/*DIFF.*3X*800 MW*4X*EXTRA*3X*PENALTY*1X*AUXILIARY*1X*LØS*
06380+**S ØF*2X*AUXILIARY*6X*CØØLING*3X*800 MW*2X*EXCESS*2X*PENALTY*1X
06400+**AUXILIARY*6X*PLANT FUEL*/*(DEG)*4X*UNIT*3X*CAPACITY*2X*ENERGY*3X
06420+**ENERGY*3X*CAPACITY*3X*POWER*9X*SYSTEM*4X*UNIT*3X*ENERGY*
06440+3X*CØST*5X
06460+**CØST*5X*==================*/*( F )*,4(4X*(MWH)*),5X*(KW)*6X*(KW)*
06480+11X*($)*6X*($)*,2(5X*($)*),6X*($)*8X*($)*2X*(MILL/KWH)*)
06500 ITD = 29
06520 TANT = 1.0E50
06540 REWIND 4
06560 DØ 425 I = 1,51
06580 ITD = ITD+1
06600** DETERMINE ANNUAL CAPITAL CØSTS FØR EACH CAPITAL CØST FACTØR
06620 ANNCAP = TØTCAP(I)*CCF(J)/100.
06640 ØPMAT = TØTCAP(I)*OAMCT/100.
06660 ACCAØM = ANNCAP+ØPMAT
06680** CALCULATE TØTAL FUEL CØST FØR THE AMØUNT ØF BTU'S USED
06700**   FØR THAT YEAR CØMBINED WITH THE DIFFERENT FUEL CØSTS
06720 ANNFUL = TØTBTU(I)*FULCST(K)/1.0E8
06740** CALCULATE CREDIT FØR EXCESS ENERGY PRØDUCED
06760 CREDIT = CRDBTU(I)*FULCST(K)/1.0E8
06780**CALCULATE CAPACITY LØSS CHARGES
06800 IF (IWSP.EQ.1) GØ TØ 137
06820** SUMMER PEAKING CAPACITY LØSS CHARGES
06840 PENCAP = KWLØSS(I)*PCCST*CCFGT(J)/100.+1.2*KWLØSS(I)
06860 PENØPR= KWHABV(I)*15.*PFCST(K)/1.0E5+(KWHBLØ(I)/1.0E4)*
06880+ (FULCST(K)+1.)
06900 GØ TØ 138
06920** WINTER PEAKING CAPACITY LØSS CHARGES
06940 137 PENCAP = 0.0
06960 PENØPR = ((KWHABV(I)+KWHBLØ(I))/1.0E4)*(FULCST(K)+1.)
06980** SUMMATIØN ØF CAPACITY LØSS CHARGES
07000 138 PENLTY = PENCAP+PENØPR
07020 KWHLØS = KWHABV(I)+KWHBLØ(I)
07040**CALCULATE AUXILIARY PØWER REQUIREMENT CHARGES
07060** ASSUME Ø AND M CHARGES ARE .10 MILLS/KWH
07080 390 ØNM = .10
```

```
AUXCAP = AUXKW(I)*CPKWAX
** CALCULATE MILLS/KWH FIGURE FØR AUXILIARY KWH
FCSTAX = ANNFUL/MWH(I)+ØNM
AUXØPR = AUXKWH(I)*FCSTAX/1000.
AUXCST = AUXCAP*CCF(J)/100.+AUXØPR
** COMBINE ØPERATING CØSTS AND CAPITAL CØSTS FØR CØRRESPØNDING
**   THETAS
TANCST = ACCAOM+ANNFUL+PENLTY+AUXCST-CREDIT
MILPKW = TANCST/TMWH
** CHANGE ENERGY VALUES TØ MWH
KWHLØS = KWHLØS/1000.
TAXKWH = AUXKWH(I)/1000.
TKWHGN = KWHGAN(I)/1000.
** DETERMINE THE ØPTIMUM ITD
IF(TANT.LT.TANCST) GØ TØ 3
TANT = TANCST
ISAVE = ITD
** WRITE DATA IN ØUTPUT FILE
3 WRITE(4,420)ITD,MWH(I),TKWHGN,KWHLØS,TAXKWH,KWLØSS(I),
+    AUXKW(I),ACCAØM,ANNFUL,CREDIT,PENLTY,AUXCST,TANCST,MILPKW
420 FØRMAT (I4,F11.0,3F9.0,2F10.0,F14.0,F9.0,F7.0,F9.0,
+    F10.0,F12.0,F8.4)
425 CØNTINUE
REWIND 4
DØ 1020 I=1,51
READ (4,420)ITD,MWH(I),TKWHGN,KWHLØS,TAXKWH,KWLØSS(I),
+ AUXKW(I),ACCAØM,ANNFUL,CREDIT,PENLTY,AUXCST,TANCST,MILPKW
IF (ITD.NE.ISAVE) GØ TØ 1020
WRITE (1,611)
611 FØRMAT (*ØPTIMUM:*)
1020 WRITE (1,420)ITD,MWH(I),TKWHGN,KWHLØS,TAXKWH,KWLØSS(I),
+ AUXKW(I),ACCAØM,ANNFUL,CREDIT,PENLTY,AUXCST,TANCST,MILPKW
450 CØNTINUE
500 CØNTINUE
ENDFILE 1
REWIND 1
CALL REPL (1,6HØPTØUT)
STØP
END
** DATA FILE CHECK SUBRØUTINE
SUBRØUTINE DATCHK(NFIL)
DIMENSIØN LINE(24)
INTEGER FILE(3),ICNT(3)
DATA FILE /6HSPVSST,6HTURBIN,6HSITE  /
READ (NFIL,) DATA
ICNT(NFIL) = ICNT(NFIL)+1
IF (DATA-1.0E50) 20,10,20
10 RETURN
20 BACKSPACE NFIL
READ (NFIL,30) LINE
```

```
30 FØRMAT (24A3)
PRINT 40,LINE,FILE(NFIL)
40 FØRMAT (/24A3/*ERRØR IN READING FILE *A6* - ABØVE LINE*
+ * SHØULD BE DATA CHECK NUMBER (1.0E50)*/)
REWIND NFIL
NCNT = ICNT(NFIL)
DØ 50 I = 1,NCNT
45 READ (NFIL,) DATA
IF (DATA-1.0E50) 45,50,45
50 CØNTINUE
RETURN
END
** TABLE LØØKUP SUBRØUTINE USING A CURVILINEAR INTERPØLATIØN
**TABLE LØØKUP RØUTINE USING A DETERMINANT SØLUTIØN ØF TWØ
** SECØND ØRDER EQUATIØNS
DIMENSIØN XT(100),YT(100)
IF ((XT(1)-X)*(XT(NVAL)-X)) 3,3,2
2 IF (ABS(X-XT(1)).LT.ABS(X-XT(NVAL))) N = 1
IF (ABS(X-XT(1)).GT.ABS(X-XT(NVAL))) N = NVAL-2
GØ TØ 25
3 N = NVAL-1
DØ 10 I = 1,N
IF(X.NE.XT(I)) GØ TØ 5
TBLUQ = YT(I)
RETURN
5 IF ((X.GT.XT(I)).AND.(X.LT.XT(I+1))) GØ TØ 15
IF ((X.LT.XT(I)).AND.(X.GT.XT(I+1))) GØ TØ 15
10 CØNTINUE
N = NVAL-2
GØ TØ 25
15 IF (I-3) 16,20,20
16 N = 1
GØ TO 25
20 N = I-1
25 X1 = XT(N)
X2 = XT(N+1)
X3 = XT(N+2)
Y1 = YT(N)
Y2 = YT(N+1)
Y3 = YT(N+2)
X1S = X1*X1
X2S = X2*X2
X3S = X3*X3
DET = X2S*X3-X3S*X2-X1S*X3+X3S*X1+X1S*X2-X2S*X1
A = (Y2*X3-X2*Y3-Y1*X3+Y3*X1+Y1*X2-Y2*X1)/DET
B = (X2S*Y3-X3S*Y2-X1S*Y3+X3S*Y1+X1S*Y2-X2S*Y1)/DET
C = (Y1*(X2S*X3-X3S*X2)-Y2*(X1S*X3-X3S*X1)+Y3*(X1S*X2-X2S*X1)
+ )/DET
TBLUQ = A*X*X+B*X+C
RETURN
END
```

TØWER ØPTIMIZATIØN PRØGRAM "TØWSIZ"

```
PRØGRAM TØWSIZ(TAPE1,ØUTPUT)
C     DRY CØØLING TØWER SIZING AND CØST EVALUATIØN PRØGRAM
C          6/30/70     PJB
C
C
C     PRØGRAM PARAMETERS
C     NAME      USE
C     ITD       INITIAL TEMPERATURE DIFFERENCE
C     RANGE     TEMP CHANGE ØF CØNDENSATE
C     HTREJ     HEAT REJECTIØN
C     GO
C     AMAIRT    AMBIENT AIR TEMPERATURE
C     ELEV      ELEVATIØN
C     CØNDF     CØNDENSATE FLØW
C     N         NUMBER ØF CØLUMNS
C     QO
C     CURVGO    (7)  TABLE ØF CØNSTANT GO TØ IDENTIFY CURVE 1
C     LO
C     Q1TBL      (31,7)  TABULAR CØØRDINATES FRØM CURVE 1 PLØT
     LØTBL     31)   LO FØR CURVE 1 AND DELTAP
C     DELTAP    CØIL LØSS
C     DPTBL      (31)    TABLE ØF DELTAP VALUES
C     AEXIT     AIR EXIT VELØCITY
C     EXITV     CØNSTANT (20 FT/SEC) EXIT VELØCITY
C     EXITLS    EXIT LØSSES
C     DRFTLS    DRAFT LØSSES
C     TØTLØS    TØTAL LØSSES
C     AIRHT     AIR HEAT GAIN
C     AIRDLT    AIR TEMPERATURE INCREASE
C     FAIRTM    FINAL AIR TEMPERATURE
C     DRAFTH    DRAFT HEIGHT
C     ADRFTH    ADJUSTED DRAFT HEIGHT
C     TØTALH    TØTAL DRAFT HEIGHT
C     ADRT      AIR DENSITY RATIØ - TEMPERATURE
C     ADRA      AIR DENSITY RATIØ - ELEVATIØN
C     TEMPS     (  )  TEMPERATURE TABLE
C     TFACTR    (  )  TEMP DENSITY RATIØ TABLE
C     HEIGHT    (  )  ALTITUDE TABLE
C     AFACTR    (  )  ALTITUDE DENSITY RATIØ TABLE
C     UPAREA    AREA ØF TØWER TØP
C     UPDIAM    DIAM ØF TØWER TØP
C     LØWDIA    DIAM ØF TØWER BØTTØM
C
C
INTEGER STPTS(4)
REAL N,LO
REAL LOTBL,LØWDIA
REAL ITD
DIMENSIØN CURVGO(7),Q1TBL(31,7),LOTBL(31),DPTBL(31)
DIMENSIØN IENTR(7)
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DIMENSIØN TEMPS(18),TFACTR(18),HEIGHT(24),AFACTR(24)
DIMENSION STDIAM(4),STKHT(5,4),STKCST(5,4),RTEMP(6),CNDCST(6)
DIMENSION DUMMY(31)
COMMON JJ
CØMMØN HTREJ,RANGE,DELTAS,LØWDIA,TPCST,TVCST,PCØST,FPCST
CØMMØN STCST,TØTPCS,GPM
EQUIVALENCE(DUMMY(1),Q1TBL(1,7))
DATA STDIAM/217.,312.,460.,550./
DATA STKHT/120.,240.,387.,527.,793.,126.,283.,463.,603.,
+800.,126.,283.,463.,603.,813.,200.,400.,600.,800.,0.0/
DATA STKCST/272466.,574247.,897032.,1470194.,3111314.,361950.,
+894091.,1565409.,2314192.,3971000.,516062.,1264230.,2067594.,
+3326040.,5360366.,980000.,2050000.,3730000.,5980000.,0./
DATA STPTS/5,5,5,4/
DATA RTEMP/5.0,10.0,20.0,30.0,40.0,50.0/
DATA CNDCST/273000.,256000.,228000.,208000.,190000.,167000./
DATA TEMPS /-20.,-10.,0.,10.,20.,30.,40.,50.,60.,70.,80.,
+90.,100.,110.,120.,130.,140.,150./
DATA TFACTR /1.197,1.175,1.171,1.125,1.102,1.078,1.057,1.037,
+1.018,1.00,.986,.962,.944,.933,.914,.899,.884,.870/
DATA HEIGHT /0.,400.,800.,1200.,1600.,2000.,2400.,2800.,3200.,
+3600.,4000.,4400.,4800.,5200.,5600.,6000.,6400.,6800.,7200.,
+7600.,8000.,8400.,8800.,9200./
DATA AFACTR /1.,.985 ,.972,.958,.944,.93,.917,.904,.891,.878,
+.864,.852,.832,.826,.813,.802,.788,.776,.755,.754,.743,.73,.719,
+.708/
DATA IENTR /31,31,31,31,27,27,31/
DATA LOTBL /200.,210.,220.,230.,240.,250.,260.,270.,280.,290.,
+300.,310.,320.,330.,340.,350.,360.,370.,380.,390.,
+400.,410.,420.,430.,440.,450.,460.,470.,480.,490.,500./
DATA Q1TBL /35.6,36.6,37.8,38.8,39.9,41.,42.1,43.2,44.3,45.3,
+46.4,47.4,48.4,49.2,50.1,51.,51.8,52.6,53.4,54.2,54.9,55.6,
+56.3,57.,57.6,58.2,58.8,59.4,60.,60.6,61.2,
+34.6,35.5,36.6,37.7,38.7,39.8,40.8,41.7,42.7,43.6,44.5,
+45.3,46.1,46.8,47.5,48.3,49.0,49.6,50.3,51.0,51.6,52.2,
+52.8,53.4,54.0,54.6,55.2,55.8,56.3,56.8,57.4,
+33.7,34.7,35.7,36.7,37.7,38.6,39.6,40.5,41.4,42.3,43.1,
+43.9,44.7,45.4,46.1,46.8,47.5,48.1,48.7,49.3,49.9,50.4,
+51.0,51.6,52.2,52.7,53.2,53.8,54.3,54.8,55.3,
+33.1,34.0,34.9,35.8,36.7,37.6,38.4,39.3,40.1,40.8,41.6,
+42.3,43.0,43.7,44.4,45.0,45.6,46.2,46.7,47.2,47.7,48.3,
+48.8,49.3,49.8,50.3,50.8,51.3,51.7,52.1,52.5,
+32.2,33.0,33.9,34.8,35.6,36.4,37.2,38.0,38.7,39.4,40.2,
+40.8,41.4,42.0,42.6,43.2,43.8,44.3,44.8,45.2,45.6,46.0,
+46.5,46.9,47.3,47.6,48.0,48.4,48.8,49.1,49.4,
+31.0,31.7,32.4,33.1,33.7,34.4,35.1,35.8,36.4,37.0,37.6,
+38.2,38.8,39.3,39.8,40.3,40.7,41.1,41.5,41.9,42.3,42.7,
+43.1,43.4,43.8,44.1,44.4,0.,0.,0.,0./
DATA DUMMY/25.9,26.4,26.9,27.3,27.8,28.2,28.6,29.0,29.5,29.9,30.3,
+30.6,30.9,31.2,31.5,31.7,31.9,32.2,32.4,32.5,32.7,32.9,
+33.1,33.2,33.4,33.6,33.7,33.8,34.0,35.1,35.2 /
```

```
DATA DPTBL /18.5,18.7,18.9,19.1,19.3,19.5,19.7,19.9,20.1,
+20.3,20.6,20.8,21.0,21.2,21.4,21.6,21.8,22.0,22.3,22.5,
+22.8,23.0,23.2,23.4,23.7,24.0,24.3,24.6,24.8,25.2,25.5 /
DATA CURVGO/264480.,220400.,198360.,176320.,154280.,132240.,
+88160./
DATA EXITV/20.0/
DATA CONTRL/500000./
CALL RETR(1,6HSIZDAT)
DØ 20 K=1,31
DØ 10 L=1,7
10 Q1TBL(K,L)=Q1TBL(K,L)*1000.
20 DPTBL(K)=DPTBL(K)-16.0
C     INPUT BASIC SIZING AND CØST EVALUATIØN DATA
50 READ (1,) ITD,RANGE,HTREJ,GO,AMAIRT,ELEV
C     CØMPUTE INTERMEDIATE SIZING DATA
CONDF=HTREJ/RANGE
N=CONDF/GO
TEMP=AMOD(N,4.0)
IF (TEMP.NE.0.0) N=N-TEMP+4.0
QO=(HTREJ/N)*0.252
Q1=QO/(ITD*0.55555)
90 DØ 100 I=1,7
IF (GO.EQ.CURVGO(I)) GØ TØ 110
100 CONTINUE
PRINT,*GO =*,GO,* NO CØRRESPØNDING CURVE. CASE ABØRTED.*
GØ TØ 9000
110 ICURV=I
LO=TBLUQ(Q1,Q1TBL(1,ICURV),LOTBL,IENTR(ICURV),NFLAG)
IF (NFLAG.EQ.2) PRINT,*LO ØUTSIDE TABLE*
DELTAP=TBLUQ(LO,LOTBL,DPTBL,31,NFLAG)/25.4
AEXIT=EXITV
EXITLS=((AEXIT/4005.)*60.0)**2
DRFTLS=0.15*EXITLS
TOTLOS=DELTAP+EXITLS+DRFTLS
AIRHT=QO/(LO*555.408)
AIRDLT=AIRHT/0.24
FAIRTM=50.0+AIRDLT
DRAFTH=TOTLOS/(7.659*(1.0/510.-1.0/(AIRDLT+510.)))
ADRT=TBLUQ(AMAIRT,TEMPS,TFACTR,18,NFLAG)
ADRT1=TBLUQ(50.0,TEMPS,TFACTR,18,NFLAG)
ADRA=TBLUQ(ELEV,HEIGHT,AFACTR,24,NFLAG)
ADRFTH=DRAFTH*((ADRT1/ADRT)**3)*((1.0/ADRA)**2)
TØTALH=ADRFTH+80.0
ADRT=TBLUQ(FAIRTM,TEMPS,TFACTR,18)
UPAREA=N*LO/(ADRT*AEXIT)*8.174
UPDIAM=(UPAREA*1.2732)**0.5
LØWDIA=3.28*(0.717+0.899*(N/4.0))
IF (LØWDIA.LT.UPDIAM)  LØWDIA=UPDIAM
```

```
C      COST EVALUATION SEGMENT
C      VARIABLE    USE
C      STDIAM      (3)  TABLE OF CØST EVALUATION TØWER SIZES
C      STKHT       (3,5)  TABLE ØF STACK HEIGHTS
C      STKCST      (3,5)  TABLE OF STACK CØSTS
C      STACK       EVALUATEED CØST ØF STACK
C      DROOF       EVALUATED COST OF DELTA RØØF
C      COILS       COST ØF CØØLING CØILS
C      RTEMP       (6)  TEMP RANGE TABLE FØR CØNDENSER CØSTS
C      CNDCST      (6)  CØST TABLE FØR CØNDENSER EVALUATIØN
C      CPBTU      CØNDENSER CØST PER BILLIØN BTU
C      DNDNSR      TØTAL CØNDENSER CØST
C       TØWER STRUCTURE
DO 2000 I=1,3
IF ((UPDIAM.GE.STDIAM(I)).AND.(UPDIAM.LE.STDIAM(I+1))) GO TØ 2010
2000 CONTINUE
PRINT,*UPPER DIAMETER = *,UPDIAM,*  OUTSIDE ØF TABLES*
GØ TO 9000
2010 A1=TBLUQ(TØTALH,STKHT(1,I),STKCST(1,I),STPTS(I),NFLAG)
A2=TBLUQ(TOTALH,STKHT(1,I+1),STKCST(1,I+1),STPTS(I+1),NFLAG)
STACK=A1+(A2-A1)*((UPDIAM-STDIAM(I))/(STDIAM(I+1)-STDIAM(I)))
DRØØF=0.78539*(LOWDIA**2-UPDIAM**2)*7.60
CØILS=14500.*N/2.
C      CONDENSER COST
CPBTU=TBLUQ(RANGE,RTEMP,CNDCST,6,NFLAG)
CNDNSR=CPBTU*(HTREJ/1.0E09)
DELTAS=N/2.0
CALL TWRPIP
PRINT 1001,ITD,RANGE,HTREJ,GO,AMAIRT,ELEV,TØTALH,UPDIAM,LØWDIA,GPM
1001 FORMAT(/////70(*-*)/*DRY COOLING TØWER SIZING AND CØST *
+*EVALUATIØN*///*DESIGN PARAMETERS*//9X*ITD = *F5.0,5X*RANGE = *
+F5.0/9X*HEAT REJECTIØN = *E9.1/9X*WATER FLØW PER HØUR = *E10.1/
+9X*AMBIENT AIR TEMP = *F5.0,4X*ELEVATIØN = *F7.0////*TØWER SIZING*
+//9X*TOWER HEIGHT = *F6.1/9X*UPPER DIAMETER = *F6.1/9X*BØTTØM *
+*DIAMETER = *F6.1/9X*GALLØNS PER MINUTE = *F9.0)
TTØWER=STACK+DROOF+COILS
PRINT 1002,STACK,DROOF,COILS,TTØWER,CNDNSR
1002 FORMAT (///*COST EVALUATIØN*/4X*TØWER STRUCTURE*//9X
+*STACK COST*8X,F11.0/9X*SHED COST*9X,F11.0/9X*CØIL CØST*9X,
+F11.0//9X*TOTAL STRUCTURE*12X,F11.0///4X*CØNDENSER*//
+9X*CØNDENSER CØST*13X,F11.0)
TØT=TØTPCS+TTØWER+CNDNSR+CONTRL
PRINT 1003,TPCST,TVCST,PCOST,FPCST,STCST,TØTPCS,CØNTRL,TØT
1003 FØRMAT (///4X*PIPING, VALVES, ETC.*//9X*PIPE CØST*9X,F11.0/
+9X,*VALVE CØST*8X,F11.0/9X*PUMP CØST*9X,F11.0/9X*FILLER PUMP CØST*
+2X,F11.0/9X*STØRAGE TANK CØST *F11.0//9X*TØTAL PIPING FACIL*
+*ITIES*4X,F11.0//4X*CONTROLS*//9X*CONTRØL CØST*15X,F11.0///
+*CØMPLETE TØWER FACILITIES*///9X*TØTAL TØWER CØST*9X,F13.0//)
TØT=TØT*1.25
PRINT 1004,TØT
1004 FØRMAT (*TØTAL TØWER CØST AND CØNTINGENCIES*F13.0///70(*-*))
```

```
9000 IF (ENDFILE 1) 9100,50
9100 STØP
END
FUNCTIØN TBLUQ (X,XT,YT,NVAL,NFLAG)
DIMENSIØN XT(100),YT(100)
IF ((XT(1)-X)*(XT(NVAL)-X)) 3,3,2
2 IF (ABS(X-XT(1)).LT.ABS(X-XT(NVAL))) N = 1
IF (ABS(X-XT(1)).GT.ABS(X-XT(NVAL))) N = NVAL-2
NFLAG=2
GØ TØ 25
3 N = NVAL-1
NFLAG=1
DØ 10 I = 1,N
IF (X.NE.XT(I)) GØ TØ 5
TBLUQ = YT(I)
RETURN
5 IF ((X.GT.XT(I)).AND.(X.LT.XT(I+1))) GØ TØ 15
IF ((X.LT.XT(I)).AND.(X.GT.XT(I+1))) GØ TØ 15
10 CØNTINUE
N = NVAL-2
GØ TØ 25
15 IF (I-3) 16,20,20
16 N = 1
GØ TØ 25
20 N = I-1
25 X1 = XT(N)
X2 = XT(N+1)
X3 = XT(N+2)
Y1 = YT(N)
Y2 = YT(N+1)
Y3 = YT(N+2)
X1S = X1*X1
X2S = X2*X2
X3S = X3*X3
DET = X2S*X3-X3S*X2-X1S*X3+X3S*X1+X1S*X2-X2S*X1
A = (Y2*X3-X2*Y3-Y1*X3+Y3*X1+Y1*X2-Y2*X1)/DET
 B = (X2S*Y3-X3S*Y2-X1S*Y3+X3S*Y1+X1S*Y2-X2S*Y1)/DET
C = (Y1*(X2S*X3-X3S*X2)-Y2*(X1S*X3-X3S*X1)+Y3*(X1S*X2-X2S*X1)
+ )/DET
TBLUQ = A*X*X+B*X+C
RETURN
END
SUBRØUTINE TWRPIP
DIMENSIØN NØDEL(1),BTUPHR(1),RANGE(1),ITD(1)
REAL ITD,NØDEL,NØLEV,NSECPL,NDELPL,NMSL,MPS,MPD,MVD,MPLEN
REAL MPCST,MVCST,NMVAL,NHSL,NHV,NDV,NFV,NBPV,NEDL,NEDVAL
CØMMØN JJ
CØMMØN BTUPHR,RANGE,NØDEL,BDIAFT,TPCST,TVCST,PCØST,FPCST,
+STCST,TØTAL,GPM
DATA DELHI,PI/65.6,3.14159/
```

```
DATA GAPDEL,NØLEV,NSECPL/448.,2.,4./
DØ 200 IR = 1,1
NDELPL = NØDEL(IR)/NØLEV
JJ=1
GPM = BTUPHR(IR)/(RANGE(IR)*8.337*60.)
GPMPL = GPM/NØLEV
CALL PIPSIZ(GPMPL,NMSL,MPS,MPD,MVD)
TNMSL = NMSL*NØLEV
MPLEN = 2.*400.*TNMSL+DELHI*(NØLEV-1.)*NMSL
MPCST = MPLEN*MPD
NMVAL = 2.*TNMSL
MVCST = NMVAL*MVD
JJ=2
HGPM = GPM/(NØLEV*NSECPL)
CALL PIPSIZ(HGPM,NHSL,HPS,HPD,HVD)
IF (NHSL.GT.1.)16,20
16 PRINT,/,*TØØ MANY HEADER LINES*
GØ TØ 200
20 HPLEN = (BDIAFT + 3.55)*(1.+PI/2.)*NØLEV*NSECPL
HPCST = HPLEN*HPD
NHV = 4.*NSECPL*NØLEV
HVCST = NHV*HVD
DELPSE = NØDEL/(NØLEV*NSECPL)
DGPM = DELPSE*GAPDEL
CALL PIPSIZ(DGPM,NDL,DPS,DPD,DVD)
DPLEN = BDIAFT*NSECPL*NØLEV
DPCST = DPLEN*DPD
NDV = 2.*NSECPL*NØLEV
DVCST = NDV*DVD
FGPM = DGPM/10.
CALL PIPSIZ(FGPM,NFL,FPS,FPD,FVD)
FPLEN = DPLEN
FPCST = FPLEN*FPD
NFV = NDV
FVCST = NFV*FVD
NBPV = NMVAL/2.
BPVALS = MPS
BPVALD = MVD
BPVCST = NBPV*BPVALD
EDGPM = GPM/TNMSL/4.
CALL PIPSIZ(EDGPM,NEDL,EDPS,EDPD,EDVD)
NEDL = TNMSL
EDPLEN = BDIAFT*.75*NEDL
EDPCST = EDPLEN*EDPD
NEDVAL = NEDL
EDVCST = NEDVAL*EDVD
IPSETS = GPM/85000.+1.5
PCØST = IPSETS*300000.
IFPSET = FGPM/5500.+2.
FPCST = IFPSET*20000.
```

```
STLBS = 12360.7+.16912*GPM
STCST = STLBS*.5
TPCST = MPCST+HPCST+DPCST+FPCST+EDPCST
TVCST = MVCST+HVCST+DVCST+FVCST+EDVCST+BPVCST
TPVCST= TPCST+TVCST
TØTAL = TPVCST+PCØST+FPCST+STCST
200 CØNTINUE
RETURN
END
SUBRØUTINE PIPSIZ(GPM,NØL,PDIA,DPRFT,DPRVAL)
REAL NØL,NSL
CØMMØN JJ
DIMENSIØN PSIZE(14),DPFT(2,14),DPVAL(14)
DATA PSIZE/18.,22.,24.,26.,32.,36.,42.,48.,54.,60.,72.,84.,96.,
+108./
DATA DPFT/31.,45.,32.,49.,33.,51.,36.,57.,40.,64.,42.,69.,52.,84.,
+57.,93.,69.,109.,76.,121.,102.,155.,117.,178.,134.,203.,161.,238./
DATA DPVAL/2960.,5350.,3720.,7330.,10480.,6380.,12670.,
+14520.,18650.,23650.,31280.,41370.,59340.,70920./
NSL = 1.
10 DIA = SQRT(3.55E-4*GPM/NSL)*12.
IF(DIA.LE.108.)GØ TØ 20
NSL = NSL+1
GØ TØ 10
20 DØ 30 I = 1,14
IF(DIA.LE.PSIZE (I)) GØ TØ 40
30 CØNTINUE
I = 14
40 NØL =NSL
PDIA = PSIZE(I)
DPRFT = DPFT(JJ,I)
DPRVAL = DPVAL(I)
RETURN
END
```

APPENDIX B

SAMPLE DATA

TABLE 1-B

Auxiliary Power Requirements for 800-Mw Natural-Draft, Dry-Type Cooling Tower

ITD (°F)	Fossil-Fueled Turbine (kw)	Nuclear-Fueled Turbine (kw)
30	12,000	19,000
40	9,000	14,000
50	7,000	11,000
60	6,000	9,000
70	5,000	8,000
80	4,000	7,000

TABLE 2-B

Auxiliary Power Requirements for 800-Mw Mechanical-Draft, Dry-Type Cooling Tower

ITD (°F)	Fossil-Fueled Turbine (kw)	Nuclear-Fueled Turbine (kw)
30	32,000	48,000
40	26,000	39,000
50	21,000	32,000
60	17,000	26,000
70	14,000	22,000
80	12,000	18,000

TABLE 3-B

Capital Costs for 800-Mw Natural-Draft, Dry-Type Cooling Tower

FOSSIL UNIT

ITD (°F)	Elevation Sea Level	3,000 Ft.	6,000 Ft.
30	$32,610,000	$36,150,000	$40,500,000
40	22,880,000	24,430,000	26,850,000
50	17,200,000	18,220,000	19,770,000
60	14,090,000	14,700,000	15,740,000
70	12,040,000	12,500,000	13,260,000
80	10,280,000	10,600,000	11,100,000

NUCLEAR UNIT

ITD (°F)	Elevation Sea Level	3,000 Ft.	6,000 Ft.
30	$50,000,000	$54,800,000	$60,000,000
40	36,080,000	37,840,000	41,250,000
50	26,920,000	28,210,000	29,890,000
60	21,530,000	22,340,000	23,670,000
70	17,720,000	18,160,000	19,100,000
80	15,870,000	16,220,000	16,810,000

TABLE 4-B

Capital Costs for 800-Mw Mechanical-Draft, Dry-Type Cooling Tower

FOSSIL UNIT

ITD (°F)	Elevation Sea Level	3,000 Ft.	6,000 Ft.
30	$23,920,000	$24,460,000	$25,120,000
40	20,000,000	20,450,000	21,000,000
50	16,400,000	16,770,000	17,220,000
60	13,280,000	13,580,000	13,940,000
70	10,960,000	11,210,000	11,510,000
80	9,720,000	9,940,000	10,210,000

NUCLEAR UNIT

ITD (°F)	Elevation Sea Level	3,000 Ft.	6,000 Ft.
30	$35,280,000	$36,070,000	$37,040,000
40	29,480,000	30,140,000	30,950,000
50	24,120,000	24,660,000	25,330,000
60	19,640,000	20,080,000	20,620,000
70	16,160,000	16,520,000	16,970,000
80	14,240,000	14,560,000	14,950,000

TABLE 5-B

"TURBIN" Data File
(Fossil Fuel)

```
00100 800000.   FOSSIL
00110 4000.
00120 1.0,18.0
00130 809975.,809470.,808966.,806917.,803960.,800000.,795591.
00140 790268.,784068.,777499.,771039.,765135.,759588.,754034.
00150 748560.,743249.,738182.,733183.,728251.,723385.,718584.
00160 713846.,709170.,704555.,700377.,696249.,692168.,688136.
00170 684150.,680209.,676314.,672533.,668657.,664961.,661170.
00180 1.0E50
00190 8100.,8105.,8110.,8130.,8161.,8201.,8247.
00200 8302.,8368.,8439.,8509.,8575.,8638.,8701.
00210 8765.,8827.,8888.,8949.,9009.,9070.,9130.
00220 9191.,9252.,9312.,9368.,9423.,9479.,9534.
00230 9590.,9645.,9701.,9756.,9812.,9867.,9923.
00240 9000.,9006.,9011.,9034.,9068.,9112.,9163.
00250 9225.,9298.,9376.,9455.,9528.,9597.,9668.
00260 9739.,9808.,9876.,9943.,10010.,10078.,10145.
00270 10212.,10280.,10347.,10409.,10470.,10532.,10594.
00280 10655.,10717.,10779.,10840.,10902.,10963.,11026.
00290 3797.,3798.,3800.,3807.,3817.,3831.,3846.
00300 3864.,3885.,3907.,3929.,3950.,3968.,3987.
00310 4006.,4024.,4042.,4059.,4075.,4092.,4108.
00320 4125.,4141.,4156.,4171.,4185.,4199.,4212.
00330 4226.,4239.,4253.,4266.,4279.,4291.,4304.
00340 1.0E50
00350 8213.,8218.,8238.,8271.,8311.,8373.,8450.
00360 8525.,8600.,8673.,8743.,8811.,8875.,8938.
00370 8998.,9057.,9115.,9174.,9231.,9289.,9345.
00380 9398.,9452.,9506.,9560.,9607.,9662.,9710.
00390 9760.,9809.,9859.,9908.,9955.,10005.,10052.
00400 9126.,9132.,9153.,9190.,9235.,9303.,9389.
00410 9473.,9556.,9637.,9714.,9790.,9861.,9932.
00420 9998.,10063.,10128.,10193.,10257.,10321.,10383.
00430 10442.,10502.,10562.,10622.,10675.,10735.,10789.
00440 10844.,10899.,10954.,11009.,11061.,11117.,11168.
00450 2880.,2883.,2895.,2915.,2939.,2976.,3022.
00460 3067.,3112.,3156.,3198.,3239.,3277.,3315.
00470 3351.,3386.,3421.,3456.,3491.,3526.,3559.
00480 3591.,3623.,3656.,3688.,3716.,3749.,3778.
00490 3808.,3838.,3867.,3897.,3925.,3955.,3983.
00500 1.0E50
00510 8642.,8681.,8727.,8799.,8911.,9014.,9115.
00520 9212.,9300.,9387.,9473.,9555.,9632.,9709.
00530 9784.,9856.,9923.,9994.,10062.,10126.,10191.
00540 10254.,10315.,10375.,10434.,10493.,10550.,10608.
00550 10662.,10717.,10773.,10825.,10876.,10929.,10979.
00560 9602.,9645.,9697.,9777.,9901.,10016.,10128.
00570 10236.,10333.,10430.,10525.,10616.,10703.,10788.
00580 10871.,10951.,11026.,11104.,11180.,11251.,11323.
00590 11393.,11461.,11527.,11594.,11659.,11723.,11787.
00600 11846.,11908.,11970.,12028.,12094.,12144.,12199.
00610 2091.,2107.,2126.,2154.,2199.,2240.,2281.
00620 2320.,2355.,2390.,2424.,2457.,2488.,2518.
00630 2548.,2577.,2604.,2632.,2659.,2685.,2711.
00640 2736.,2761.,2785.,2809.,2832.,2855.,2878.
00650 2899.,2922.,2944.,2965.,2985.,3006.,3026.
00660 1.0E50
```

TABLE 6-B

"TURBIN" Data File
(Nuclear Fuel)

```
00100 800000.  NUCLEAR
00110 6000.
00120 2.0,18.0
00130 813687.,813687.,813687.,811636.,807175.,800000.,789884.
00140 778425.,768844.,759427.,750978.,742715.,733924.,726030.
00150 717688.,710078.,704520.,698465.,692455.,687169.,681962.
00160 677381.,672321.,667869.,663475.,659710.,654910.,651748.
00170 648617.,644968.,641410.,638377.,635373.,631871.,627937.
00180 1.0E50
00190 10390.,10390.,10390.,10416.,10474.,10568.,10703.
00200 10861.,10996.,11132.,11257.,11383.,11519.,11644.
00210 11780.,11906.,12000.,12104.,12209.,12303.,12397.
00220 12481.,12574.,12658.,12742.,12815.,12909.,12971.
00230 13034.,13108.,13180.,13243.,13306.,13379.,13463.
00240 10390.,10390.,10390.,10416.,10474.,10568.,10703.
00250 10861.,10996.,11132.,11257.,11383.,11519.,11644.
00260 11780.,11906.,12000.,12104.,12209.,12303.,12397.
00270 12481.,12574.,12658.,12742.,12815.,12909.,12971.
00280 13034.,13108.,13180.,13243.,13306.,13379.,13463.
00290 5677.,5677.,5677.,5684.,5699.,5724.,5758.
00300 5797.,5830.,5862.,5891.,5919.,5949.,5976.
00310 6005.,6031.,6050.,6070.,6091.,6109.,6127.
00320 6142.,6159.,6175.,6190.,6203.,6219.,6230.
00330 6240.,6253.,6265.,6275.,6286.,6298.,6311.
00340 1.0E50
00350 10535.,10535.,10552.,10596.,10667.,10789.,10967.
00360 11152.,11301.,11441.,11567.,11697.,11835.,11961.
00370 12093.,12215.,12307.,12409.,12510.,12600.,12688.
00380 12761.,12846.,12922.,13003.,13065.,13157.,13211.
00390 13264.,13330.,13395.,13450.,13499.,13567.,13637.
00400 10535.,10535.,10552.,10596.,10667.,10789.,10967.
00410 11152.,11301.,11441.,11567.,11697.,11835.,11961.
00420 12093.,12215.,12307.,12409.,12510.,12600.,12688.
00430 12761.,12846.,12922.,13003.,13065.,13157.,13211.
00440 13264.,13330.,13395.,13450.,13499.,13567.,13637.
00450 4273.,4273.,4284.,4310.,4352.,4425.,4532.
00460 4644.,4733.,4817.,4892.,4970.,5053.,5129.
00470 5208.,5281.,5336.,5398.,5458.,5512.,5565.
00480 5609.,5660.,5705.,5754.,5791.,5847.,5879.
00490 5911.,5950.,5989.,6022.,6051.,6093.,6134.
00500 1.0E50
00510 11085.,11128.,11181.,11273.,11437.,11615.,11830.
00520 12051.,12221.,12384.,12532.,12684.,12846.,12994.
00530 13149.,13293.,13398.,13518.,13635.,13736.,13837.
00540 13924.,14020.,14103.,14193.,14269.,14368.,14432.
00550 14490.,14564.,14637.,14695.,14748.,14821.,14895.
00560 11085.,11128.,11181.,11273.,11437.,11615.,11830.
00570 12051.,12221.,12384.,12532.,12684.,12846.,12994.
00580 13149.,13293.,13398.,13518.,13635.,13736.,13837.
00590 13924.,14020.,14103.,14193.,14269.,14368.,14432.
00600 14490.,14564.,14637.,14695.,14748.,14821.,14895.
00610 3069.,3086.,3107.,3144.,3210.,3281.,3367.
00620 3455.,3523.,3588.,3648.,3708.,3773.,3832.
00630 3894.,3952.,3994.,4042.,4089.,4129.,4170.
00640 4204.,4243.,4276.,4312.,4343.,4382.,4408.
00650 4431.,4460.,4490.,4513.,4534.,4563.,4593.
00660 1.0E50
```

TABLE 7-B

"SITEXX" Data File

```
100 DENVER COLORADO
110 5300
120 SUMMER
130 3,20.,30.,35.
140 5,8.,10.,12.,15.,18.
150 .95
160 100.
170 8.,10.,12.,15.,18.
180 40.,40.,40.
190 0.0
200 150.
210 1.0
220 0.,0.,0.,.01,.11,1.18,2.69,3.79,4.98,6.26,7.80,8.93
230 8.34,7.73,8.03,7.89,8.18,8.22,6.31,4.09,2.46
240 1.36,.89,.41,.25,.07,.01,0.,.01,0.,0.,0.
250 1.0E50
```

TABLE 8-B

"SIXDAT" Data File

```
57., 28.5, 5.0E09, 220400., 50., 600.
57., 28.5, 5.0E09, 220400., 75., 600.
57., 28.5, 5.0E09, 220400., 95., 600.
62., 31.0, 5.0E09, 220400., 50., 600.
62., 31.0, 5.0E09, 220400., 75., 600.
62., 31.0, 5.0E09, 220400., 95., 600.
```

APPENDIX C

OUTPUT SAMPLES

TABLE 3-C

Tower Sizing Program "TOWSIZ"

Dry Cooling Tower Sizing and Cost Evaluation

Design Parameters

ITD = 40°F   Range = 20°F
Heat Rejection = 4.0E+09 Btu/hr.
Water Flow per Hour = 2.2E+05
Ambient Air Temp = 50°F   Elevation = 0 ft.

Tower Sizing

Tower Height =	631.4 ft.
Upper Diameter =	421.8 ft.
Bottom Diameter =	671.7 ft.
Gallons per Minute =	399824

Cost Evaluation

Tower Structure		
Stack Cost	$3311729	
Shed Cost	1631071	
Coil Cost	6583000	
Total Structure		$11525799
Condenser		
Condenser Cost		$ 912000
Piping, Valves, etc.		
Pipe Cost	$2383132	
Valve Cost	1309700	
Pump Cost	1800000	
Filler Pump Cost	40000	
Storage Tank Cost	39989	
Total Piping Facilities		$ 5362921
Controls		
Control Cost		$ 500000
Complete Tower Facilities		
Total Tower Cost		$18300721
Total Tower Cost and Contingencies		$22875901

TABLE 1-C

Program OPTDCT Output

SITE - DENVER, COLORADO
ELEVATION - 5300 FEET ABOVE SEA LEVEL
PEAK PERIOD - SUMMER
TURBINE - 800000 KW FOSSIL UNIT
IN OPERATION - 7500 HRS/YR
AT FULL THROTTLE 50 0/0 OF THE TIME
AT 75 0/0 LOAD 50 0/0 OF THE TIME
AT 50 0/0 LOAD 0 0/0 OF THE TIME
TOTAL ANNUAL ENERGY - 5250000 MWH NOMINAL
TOWER - NATURAL DRAFT
COOLING SYSTEM OPERATION AND MAINTENANCE COST - 1.00 0/0
DESIGN HEAT REJECTION - 4000 X 10**6 BTU/HR
CAPITAL COST MULTIPLIER - .95
CUTOFF TEMPERATURE FOR PEAKING GENERATION - 0 F

TABLE 2-C

Program OPTDCT Output

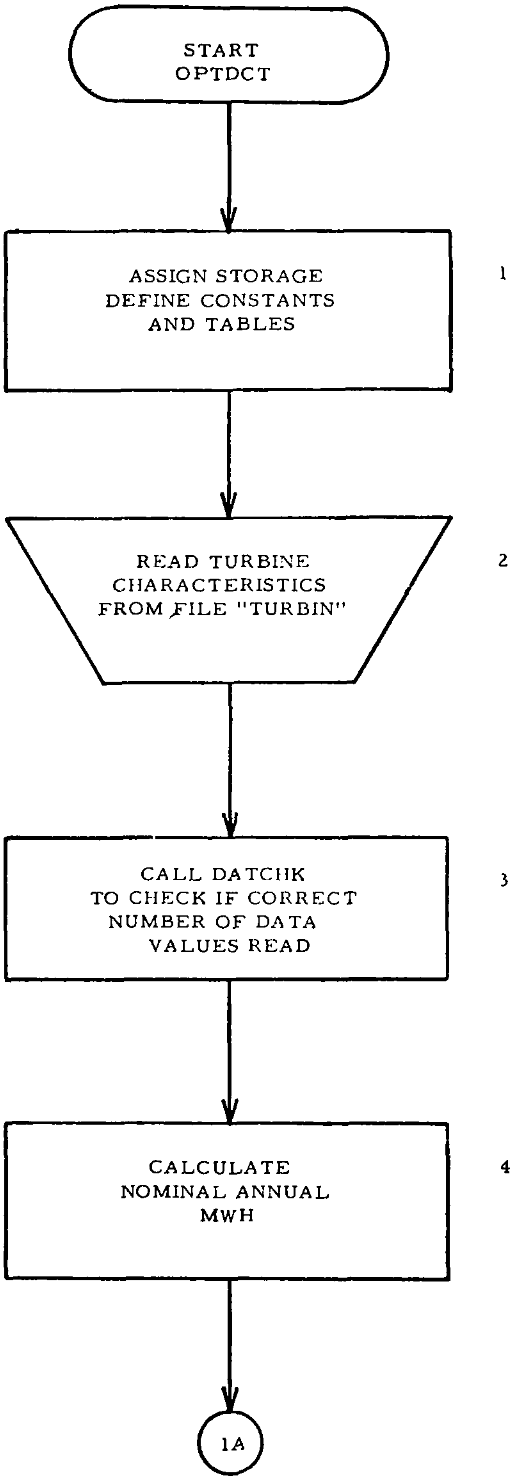
CAPITAL COST FACTORS: PLANT - 8 0/0 PEAKING CAPACITY - 8 0/0 AUXILIARIES - 8 0/0
PLANT FUEL COST - 20 CENTS/10**6 BTU PEAKING FUEL COST - 40 CENTS/10**6 BTU
PEAKING CAPITAL COST - 100 $/KW AUXILIARY CAPITAL COST - 150 $/KW

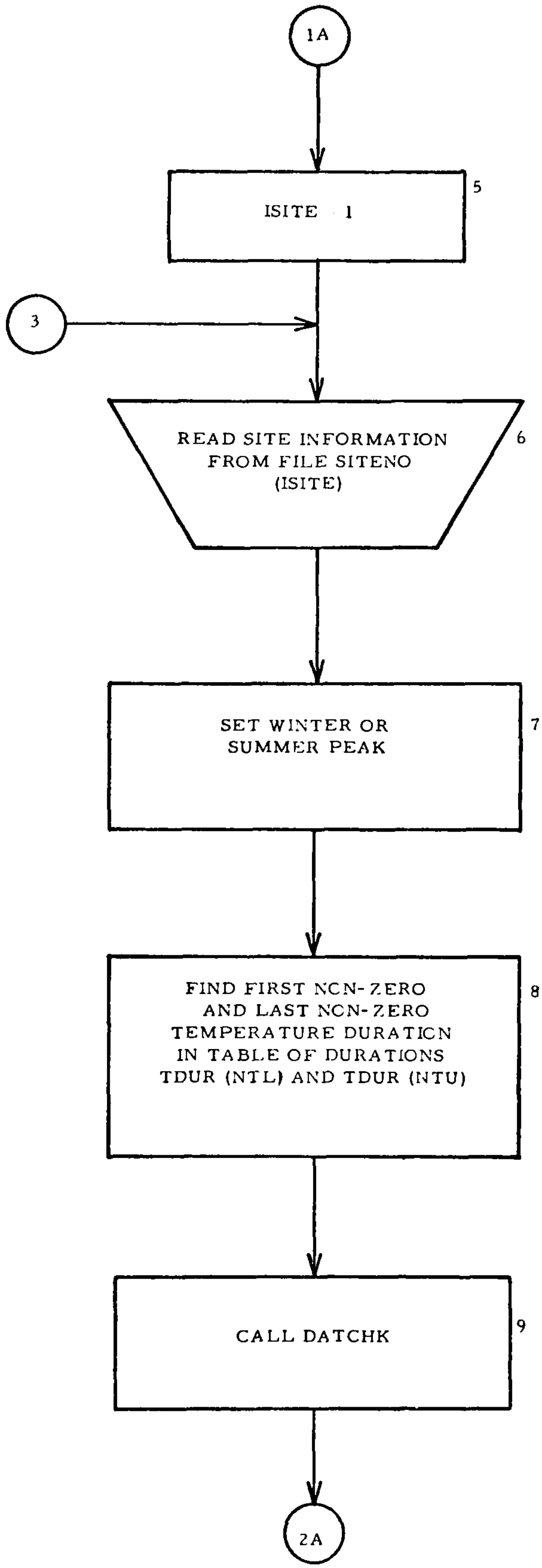
INIT. TEMP. DIFF. (DEG) (F)	GROSS ENERGY 800 MW UNIT (MWH)	EXCESS ENERGY DUE TO EXTRA CAPACITY (MWH)	CAPACITY PENALTY ENERGY (MWH)	AUXILIARY ENERGY (MWH)	LOSS OF CAPACITY (KW)	MAXIMUM AUXILIARY POWER (KW)	ANNUAL CAPITAL AND O+M COST OF DRY COOLING SYSTEM ($)	ANNUAL FUEL COST OF 800 MW UNIT ($)	CREDIT FOR EXCESS ENERGY ($)	CAPACITY PENALTY COST ($)	AUXILIARY COST ($)	TOTAL ANNUAL COST OF COOLING SYSTEM AND TOTAL PLANT FUEL ($)	(MILL/KWH)
30	5284576	34619	44	93375	5474	12458	3369773	9577609	62349	50619	327968	13263620	2.5264
31	5284268	34354	86	90624	6636	12083	3232406	9577954	61873	61569	318321	13128377	2.5006
32	5283928	34058	130	87966	7877	11729	3100475	9578330	61342	73249	309001	12999713	2.4761
33	5283562	33739	177	85401	9199	11387	2973981	9578736	60769	85692	300008	12877647	2.4529
34	5283169	33395	226	82929	10605	11057	2852923	9579173	60151	98917	291342	12762203	2.4309
35	5282746	33051	306	80550	12095	10740	2737302	9579633	59534	113110	283003	12653514	2.4102
36	5282280	32727	447	78264	13677	10435	2627117	9580135	58953	128515	274991	12551806	2.3908
37	5281763	32360	597	76071	15354	10143	2522369	9580682	58294	144837	267307	12456902	2.3727
38	5281208	31962	754	73971	17108	9863	2423057	9581274	57578	161919	259950	12368622	2.3559
39	5280616	31535	919	71964	18912	9595	2329182	9581913	56811	179503	252921	12286708	2.3403
40	5279978	31093	1115	70050	20789	9340	2240743	9582598	56016	197951	246218	12211493	2.3260
41	5279287	30712	1425	68229	22742	9097	2157740	9583326	55332	217779	239843	12143357	2.3130
42	5278521	30274	1752	66501	24693	8867	2080174	9584104	54545	237692	233796	12081221	2.3012
43	5277700	29797	2097	64866	26672	8649	2008045	9584938	53689	257967	228077	12025338	2.2905
44	5276828	29287	2459	63324	28687	8443	1941352	9585834	52771	278677	222685	11975776	2.2811
45	5275892	28735	2843	61875	30696	8250	1880095	9586793	51776	299465	217620	11932196	2.2728
46	5274891	28301	3409	60519	32688	8069	1824275	9587820	50997	321185	212884	11895166	2.2657
47	5273797	27801	4004	59256	34662	7901	1773891	9588916	50100	342909	208476	11864091	2.2598
48	5272630	27258	4628	58086	36641	7745	1728944	9590061	49125	364863	204395	11839139	2.2551
49	5271398	26677	5279	57009	38627	7601	1689434	9591281	48078	387045	200643	11820324	2.2515
50	5270088	26048	5960	56025	40610	7470	1655359	9592576	46945	409370	197219	11807579	2.2491
51	5268699	25545	6847	54878	42689	7317	1610668	9593954	46042	433822	193223	11785625	2.2449
52	5267205	25008	7803	53778	44844	7170	1568494	9595423	45076	459381	189392	11767613	2.2415
53	5265621	24423	8802	52724	47054	7030	1528837	9596982	44023	485706	185725	11753228	2.2387
54	5263957	23793	9836	51717	49297	6896	1491698	9598606	42890	512550	182223	11742187	2.2366
55	5262208	23118	10909	50756	51585	6767	1457077	9600310	41671	540037	178885	11734637	2.2352
OPTIMUM:													
56	5260358	22563	12205	49842	53899	6646	1424973	9602104	40673	569101	175712	11731217	2.2345
57	5258395	22029	13634	48974	56235	6530	1395387	9604011	39713	599167	172704	11731555	2.2346
58	5256322	21440	15117	4815[illegible]	58586	6420	1368318	9606030	38653	629692	169861	11735248	2.2353
59	5254154	20804	16650	47378	60941	6317	1343767	9608163	37508	660558	167183	11742164	2.2366
60	5251891	20125	18234	46650	63327	6220	1321734	9610391	36283	692010	164669	11752521	2.2386
61	5249505	19542	20038	45861	65784	6115	1295420	9612689	35233	725437	161943	11760255	2.2400
62	5246998	19047	22049	45099	68286	6013	1270388	9615115	34344	760526	159312	11770998	2.2421
63	5244362	18494	24132	44364	70833	5915	1246638	9617668	33349	796457	156778	11784193	2.2446
64	5241614	17895	26281	43656	73432	5821	1224170	9620358	32270	833261	154341	11799860	2.2476
65	5238758	17258	28499	42975	76100	5730	1202983	9623196	31120	871119	151999	11818177	2.2511
66	5235767	16665	30898	42321	78818	5643	1183078	9626171	30051	910515	149755	11839467	2.2551
67	5232639	16201	33561	41694	81571	5559	1164454	9629209	29217	951824	147606	11863876	2.2598
68	5229364	15674	36310	41094	84409	5479	1147112	9632401	28271	994421	145554	11891218	2.2650
69	5225958	15102	39144	40521	87311	5403	1131052	9635733	27241	1038128	143599	11921271	2.2707
70	5222434	14492	42058	39975	90253	5330	1116274	9639244	26141	1082674	141741	11953792	2.2769
71	5218761	13881	45120	39402	93236	5254	1097206	9642916	25039	1128492	139789	11983366	2.2825
72	5214939	13432	48493	38847	96253	5180	1078408	9646784	24231	1176485	137900	12015346	2.2886
73	5210950	12915	51965	38309	99114	5108	1059878	9650733	23302	1223642	136074	12047025	2.2947
74	5206822	12353	55530	37788	101953	5038	1041617	9654838	22289	1271148	134309	12079623	2.3009
75	5202557	11749	59192	37284	104879	4971	1023626	9659105	21201	1320040	132606	12114175	2.3075
76	5198139	11106	62966	36798	107874	4906	1005902	9663554	20040	1370237	130966	12150619	2.3144
77	5193561	10678	67117	36329	110906	4844	988448	9668221	19271	1423034	129388	12189820	2.3219
78	5188826	10189	71363	35877	113986	4784	971263	9673140	18392	1476850	127874	12230734	2.3297
79	5183939	9655	75716	35442	117161	4726	954346	9678181	17430	1532178	126421	12273697	2.3378
80	5178903	9080	80177	35025	120375	4670	937698	9683345	16393	1588507	125031	12318188	2.3463

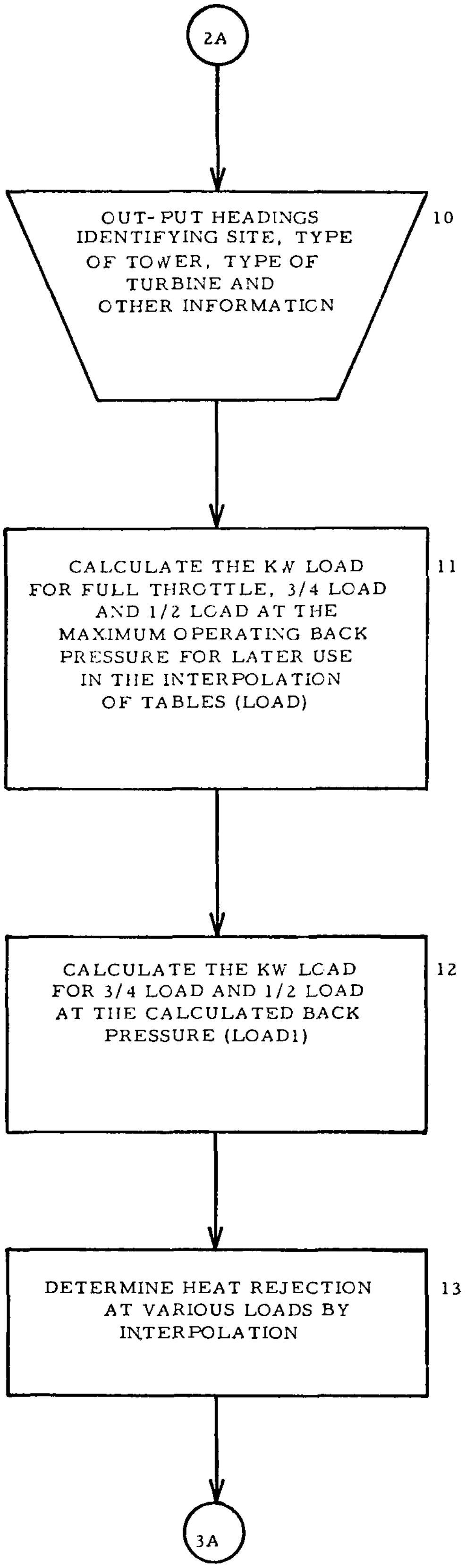
APPENDIX D

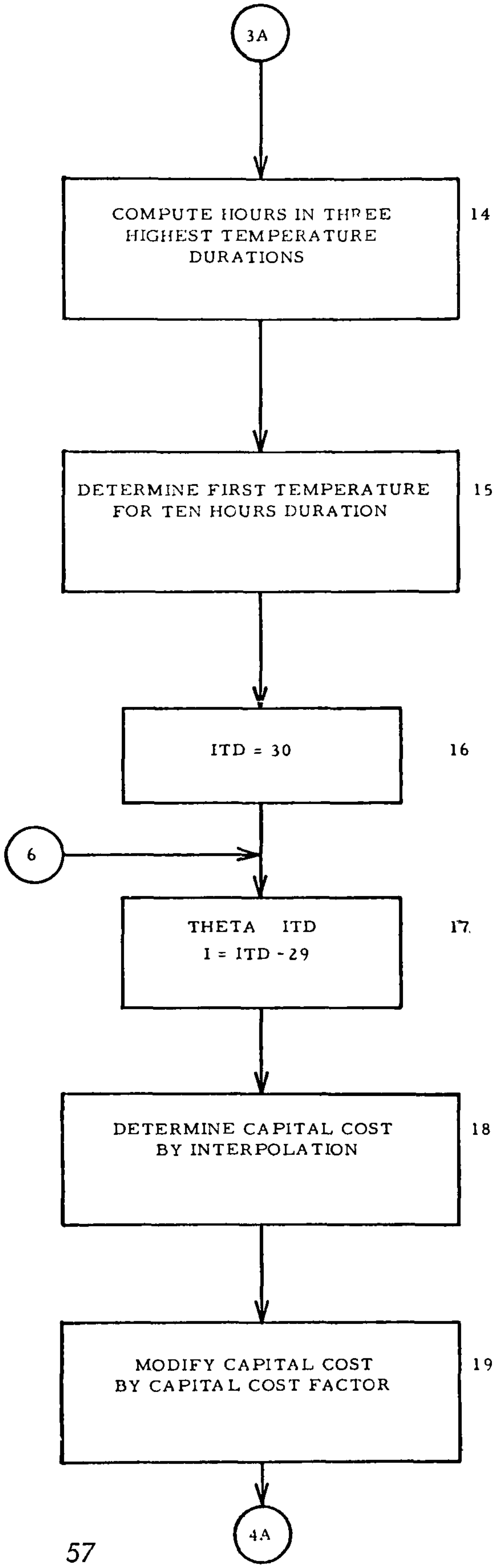
FLOW CHARTS

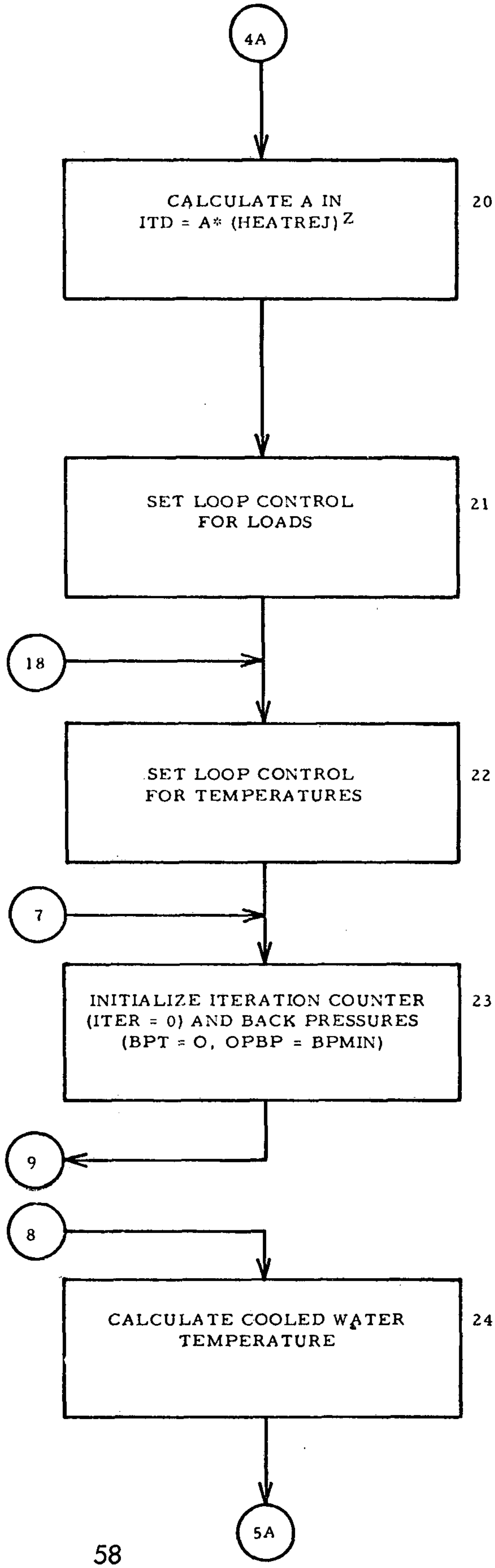
FLOW CHART OF PROGRAM "OPTDCT"

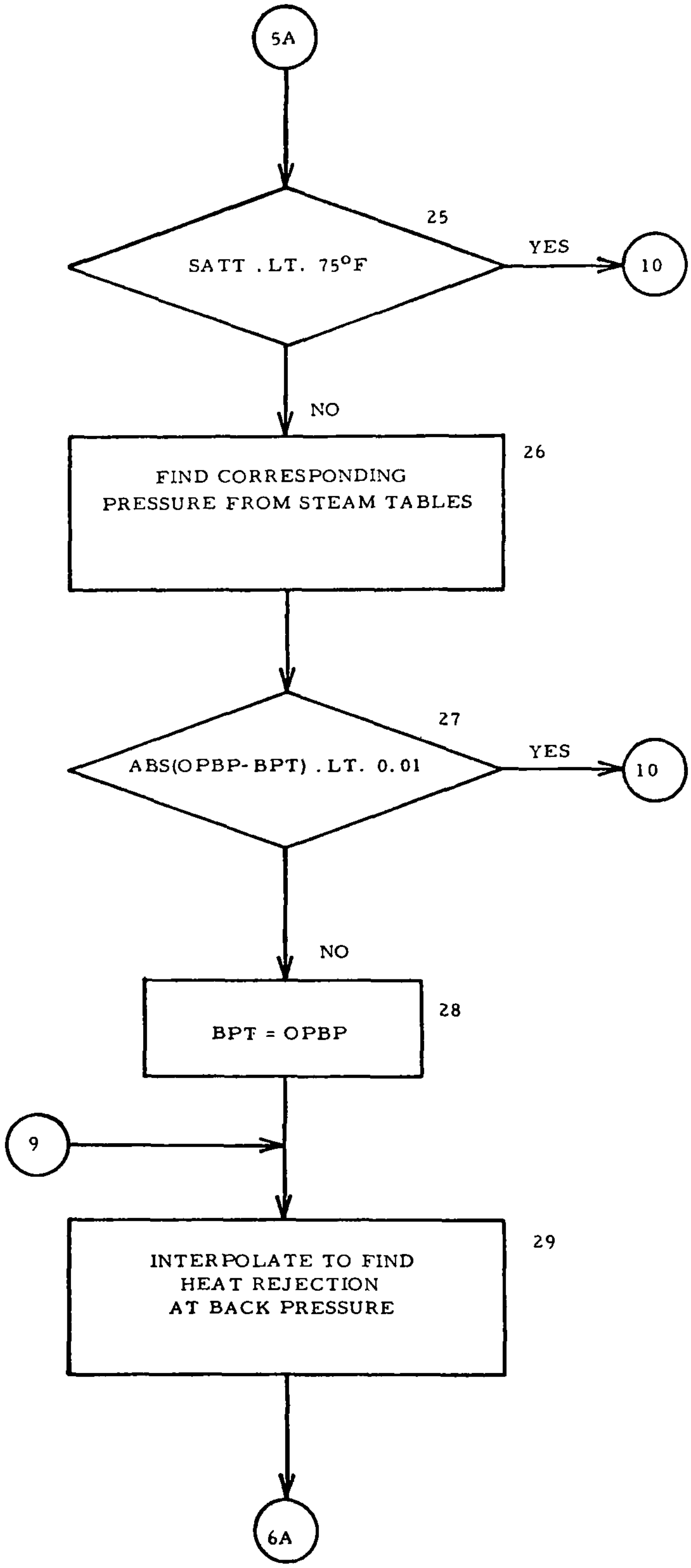


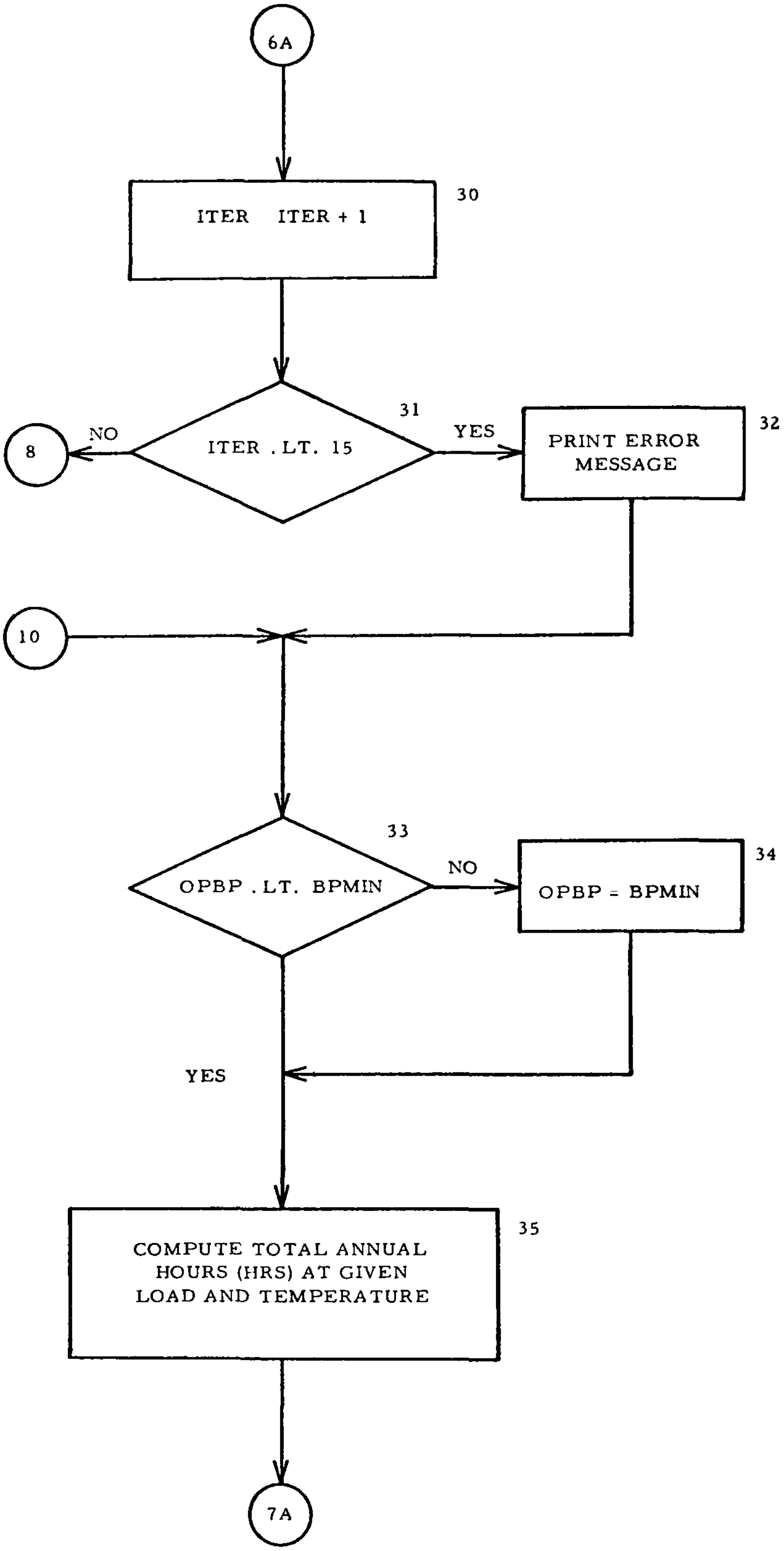

1A
ISITE 1
5
3
READ SITE INFORMATION FROM FILE SITENO (ISITE)
6
SET WINTER OR SUMMER PEAK
7
FIND FIRST NON-ZERO AND LAST NON-ZERO TEMPERATURE DURATION IN TABLE OF DURATIONS TDUR (NTL) AND TDUR (NTU)
8
CALL DATCHK
9
2A

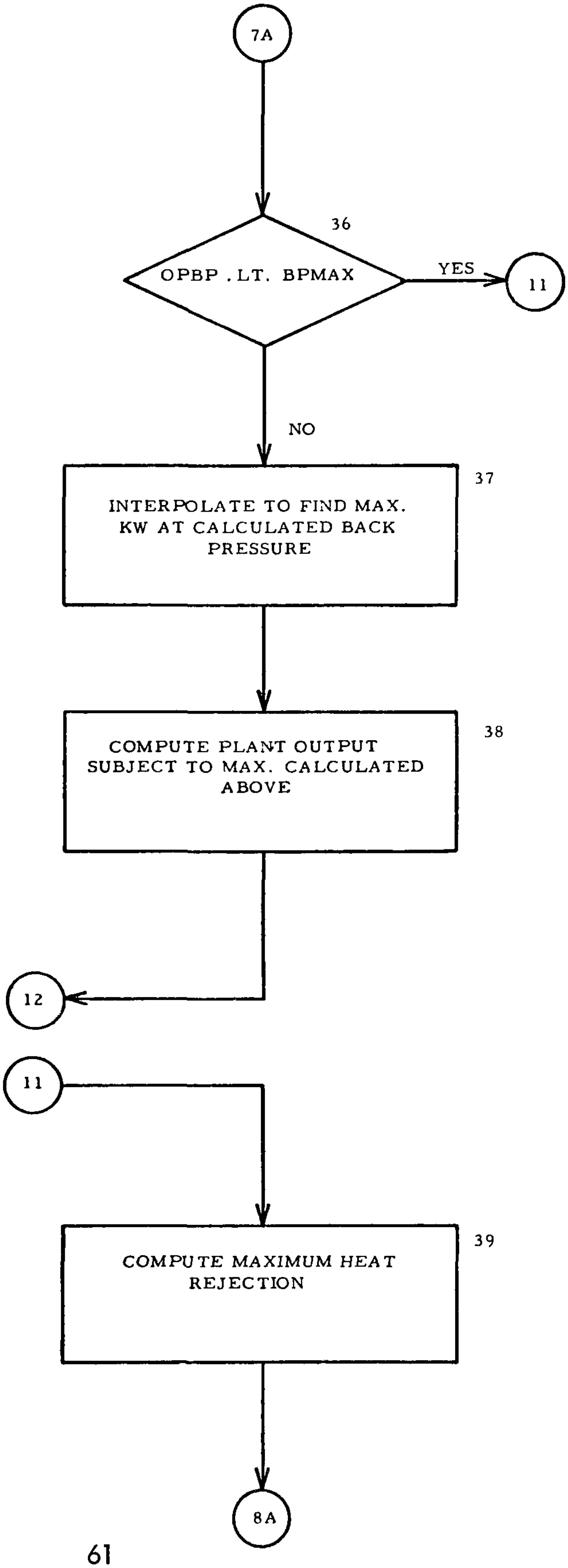

2A
OUT-PUT HEADINGS IDENTIFYING SITE, TYPE OF TOWER, TYPE OF TURBINE AND OTHER INFORMATION
10
CALCULATE THE KW LOAD FOR FULL THROTTLE, 3/4 LOAD AND 1/2 LOAD AT THE MAXIMUM OPERATING BACK PRESSURE FOR LATER USE IN THE INTERPOLATION OF TABLES (LOAD)
11
CALCULATE THE KW LOAD FOR 3/4 LOAD AND 1/2 LOAD AT THE CALCULATED BACK PRESSURE (LOAD1)
12
DETERMINE HEAT REJECTION AT VARIOUS LOADS BY INTERPOLATION
13
3A


3A
COMPUTE HOURS IN THREE HIGHEST TEMPERATURE DURATIONS
14
DETERMINE FIRST TEMPERATURE FOR TEN HOURS DURATION
15
ITD = 30
16
6
THETA ITD
I = ITD - 29
17
DETERMINE CAPITAL COST BY INTERPOLATION
18
MODIFY CAPITAL COST BY CAPITAL COST FACTOR
19
4A

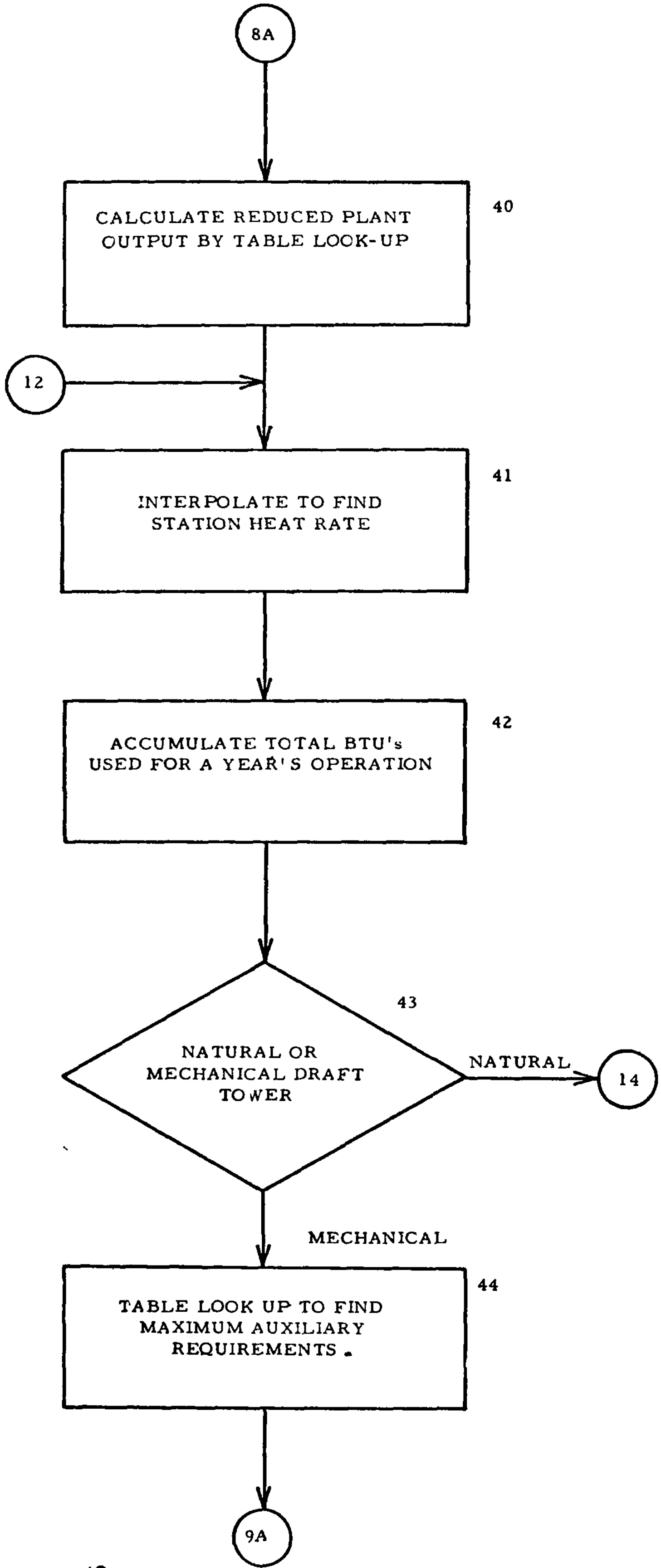

4A
CALCULATE A IN
ITD = A* (HEATREJ) Z
20
SET LOOP CONTROL
FOR LOADS
21
18
SET LOOP CONTROL
FOR TEMPERATURES
22
7
INITIALIZE ITERATION COUNTER
(ITER = 0) AND BACK PRESSURES
(BPT = O, OPBP = BPMIN)
23
9
8
CALCULATE COOLED WATER
TEMPERATURE
24
5A

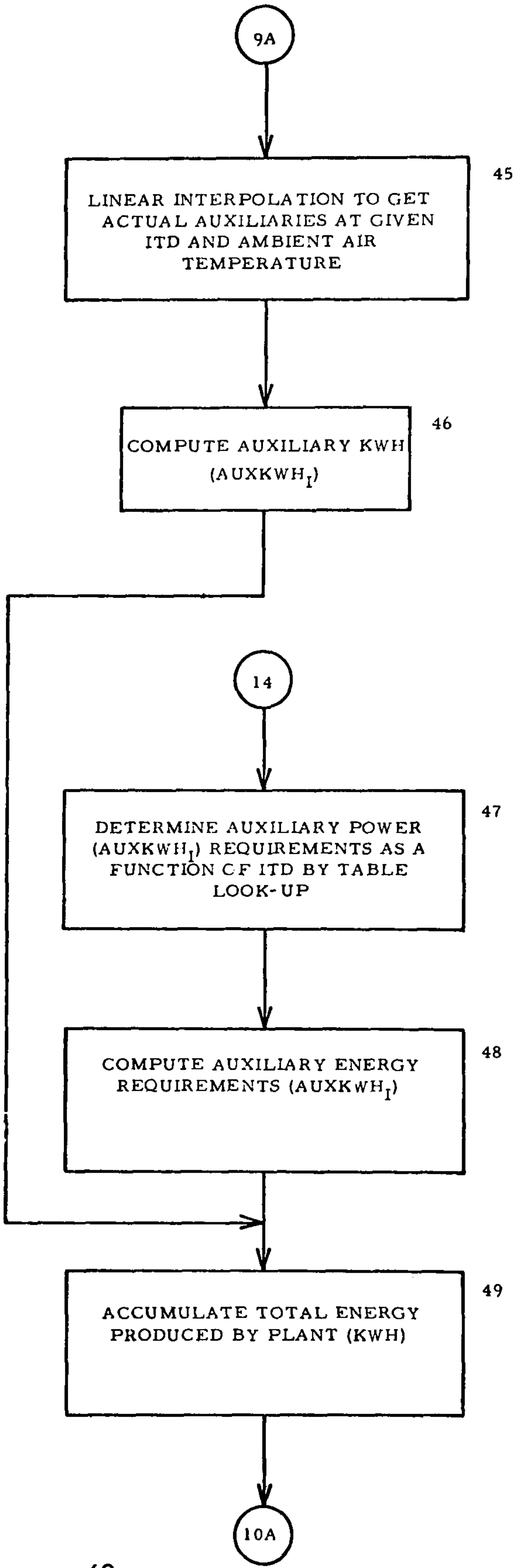

5A
25
SATT .LT. 75°F
YES
10
NO
26
FIND CORRESPONDING
PRESSURE FROM STEAM TABLES
27
ABS(OPBP-BPT) .LT. 0.01
YES
10
NO
28
BPT = OPBP
9
29
INTERPOLATE TO FIND
HEAT REJECTION
AT BACK PRESSURE
6A

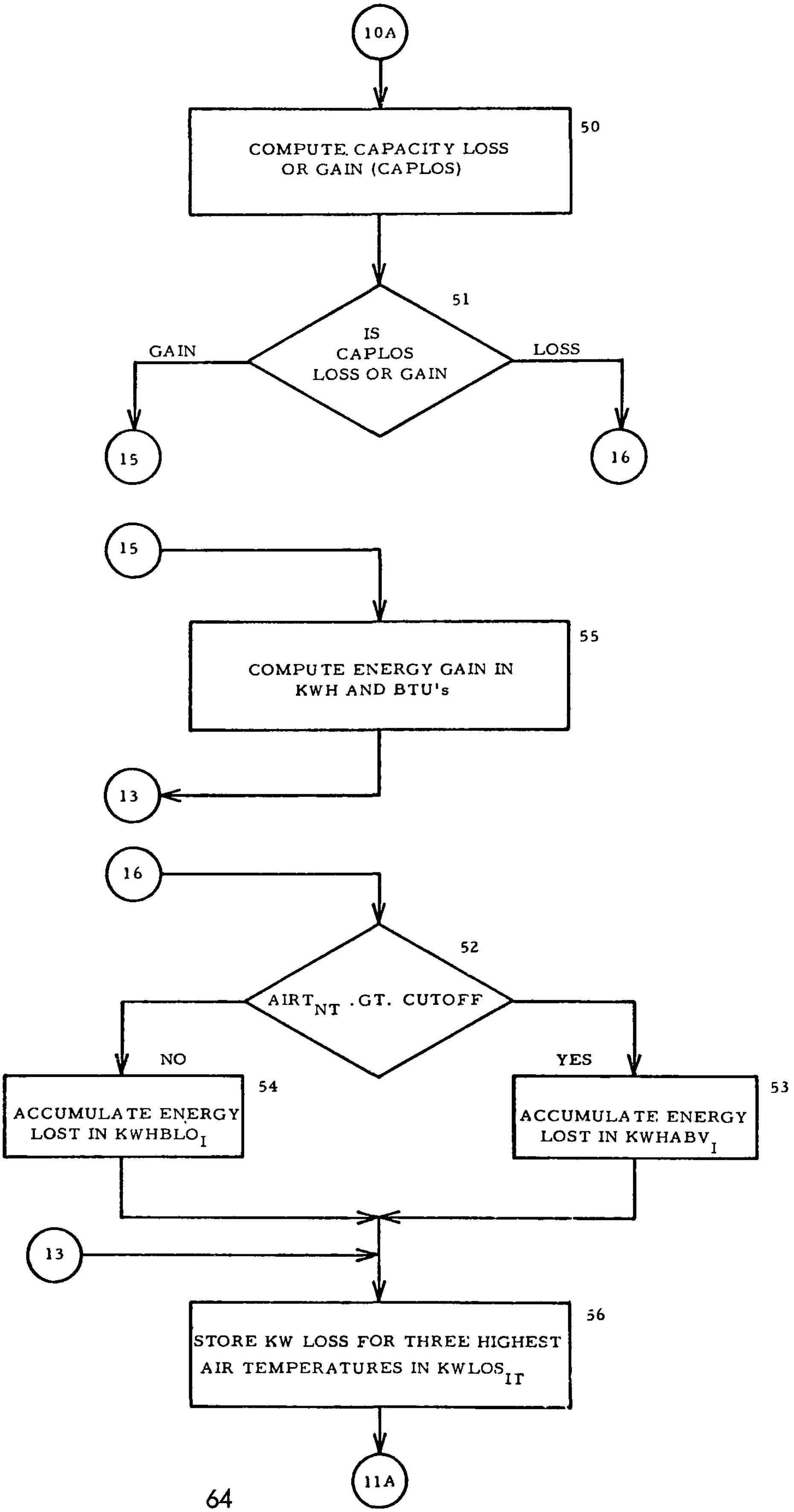

6A
30
ITER ITER + 1
31
NO
8
ITER .LT. 15
YES
32
PRINT ERROR MESSAGE
10
33
OPBP .LT. BPMIN
NO
34
OPBP = BPMIN
YES
35
COMPUTE TOTAL ANNUAL HOURS (HRS) AT GIVEN LOAD AND TEMPERATURE
7A

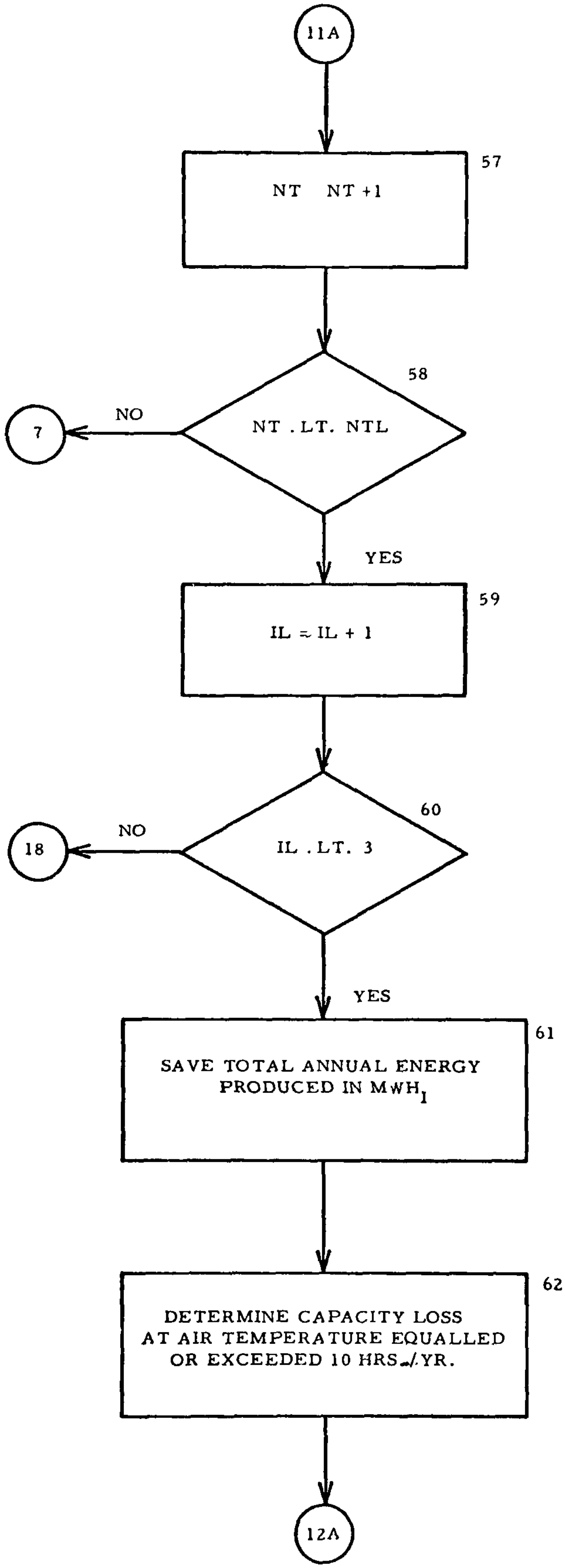


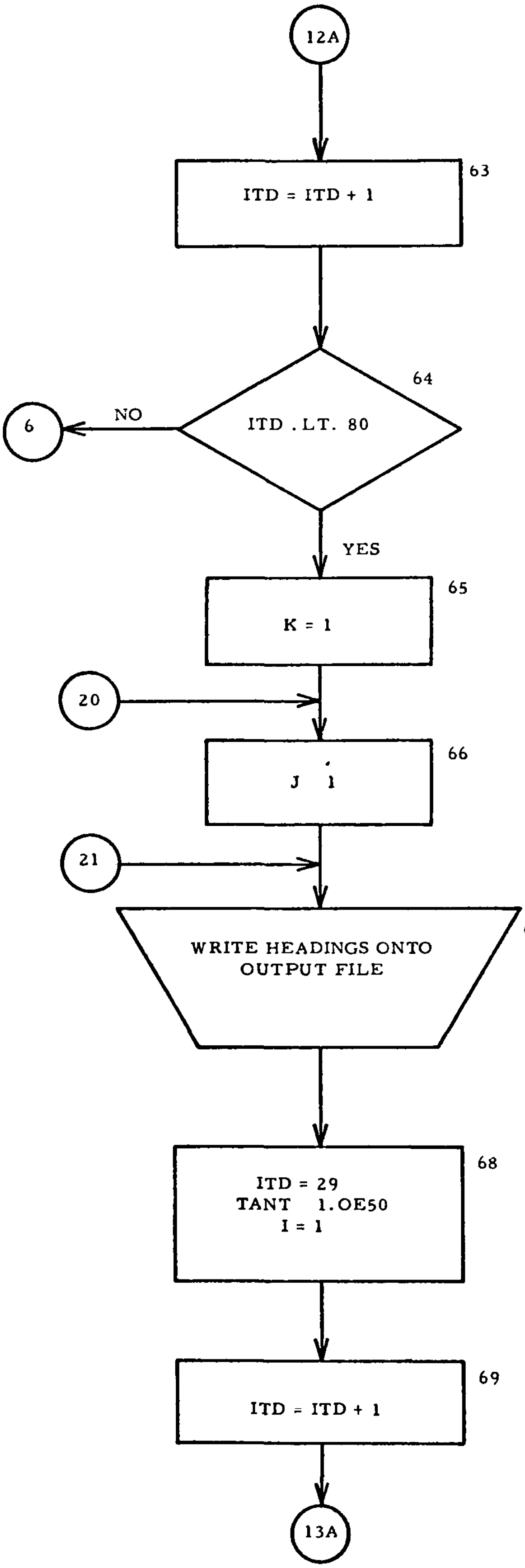
7A
36
OPBP .LT. BPMAX
YES
11
NO
37
INTERPOLATE TO FIND MAX. KW AT CALCULATED BACK PRESSURE
38
COMPUTE PLANT OUTPUT SUBJECT TO MAX. CALCULATED ABOVE
12
11
39
COMPUTE MAXIMUM HEAT REJECTION
8A


8A
CALCULATE REDUCED PLANT OUTPUT BY TABLE LOOK-UP
40
12
INTERPOLATE TO FIND STATION HEAT RATE
41
ACCUMULATE TOTAL BTU's USED FOR A YEAR'S OPERATION
42
NATURAL OR MECHANICAL DRAFT TOWER
43
NATURAL
14
MECHANICAL
TABLE LOOK UP TO FIND MAXIMUM AUXILIARY REQUIREMENTS.
44
9A

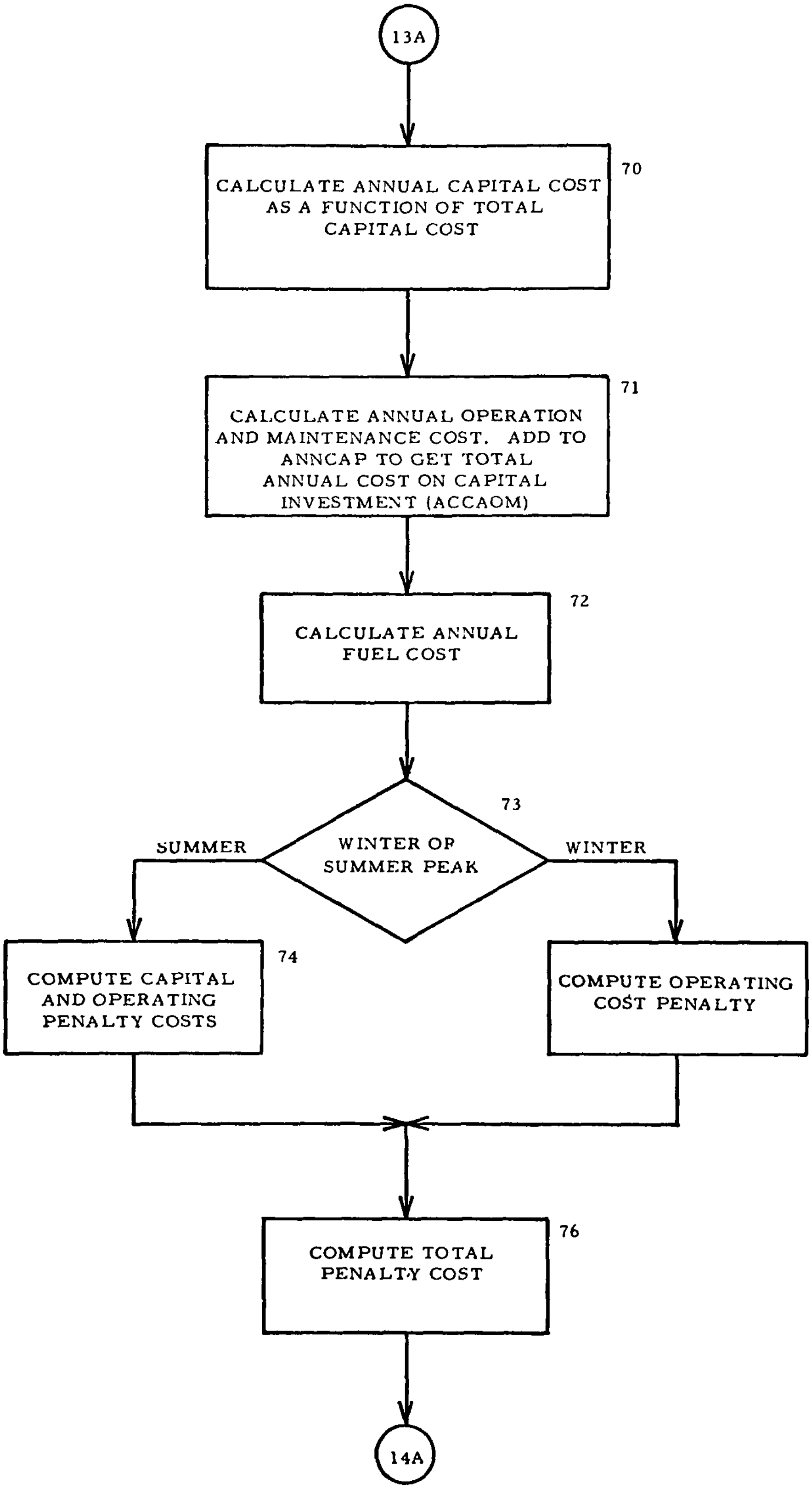

9A
LINEAR INTERPOLATION TO GET ACTUAL AUXILIARIES AT GIVEN ITD AND AMBIENT AIR TEMPERATURE
45
COMPUTE AUXILIARY KWH ($AUXKWH_I$)
46
14
DETERMINE AUXILIARY POWER ($AUXKWH_I$) REQUIREMENTS AS A FUNCTION OF ITD BY TABLE LOOK-UP
47
COMPUTE AUXILIARY ENERGY REQUIREMENTS ($AUXKWH_I$)
48
ACCUMULATE TOTAL ENERGY PRODUCED BY PLANT (KWH)
49
10A

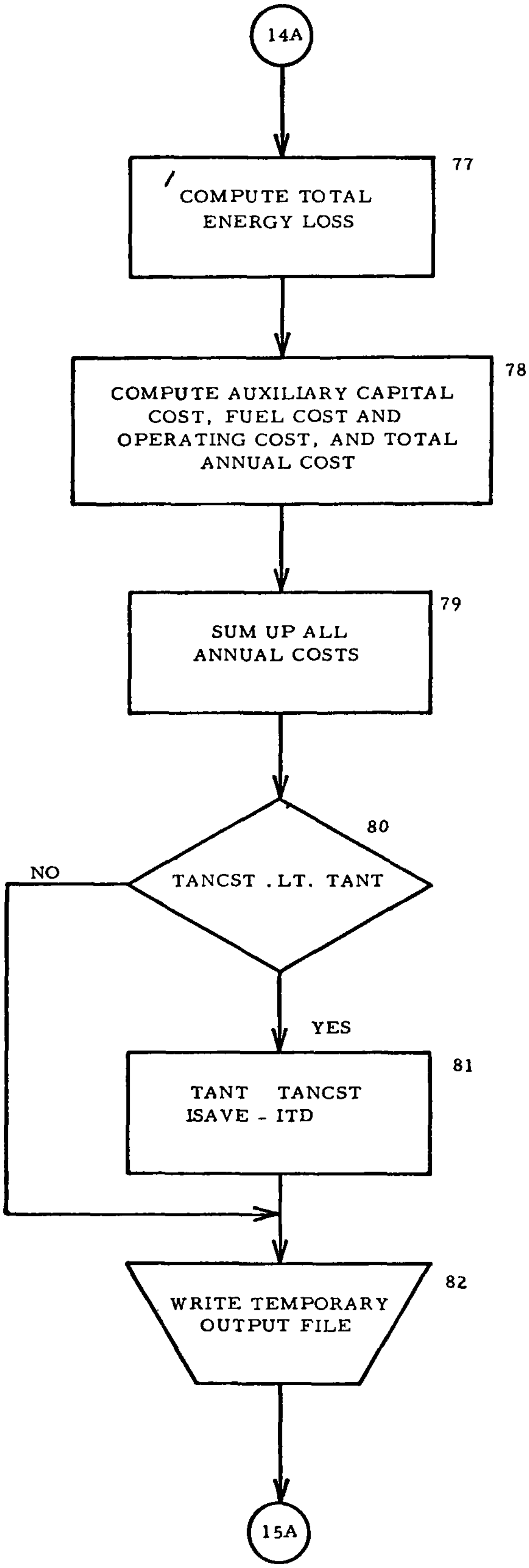

10A
COMPUTE CAPACITY LOSS OR GAIN (CAPLOS)
50
IS CAPLOS LOSS OR GAIN
51
GAIN
LOSS
15
16
15
COMPUTE ENERGY GAIN IN KWH AND BTU's
55
13
16
AIRT$_{NT}$ .GT. CUTOFF
52
NO
YES
ACCUMULATE ENERGY LOST IN KWHBLO$_I$
54
ACCUMULATE ENERGY LOST IN KWHABV$_I$
53
13
STORE KW LOSS FOR THREE HIGHEST AIR TEMPERATURES IN KWLOS$_{IT}$
56
11A

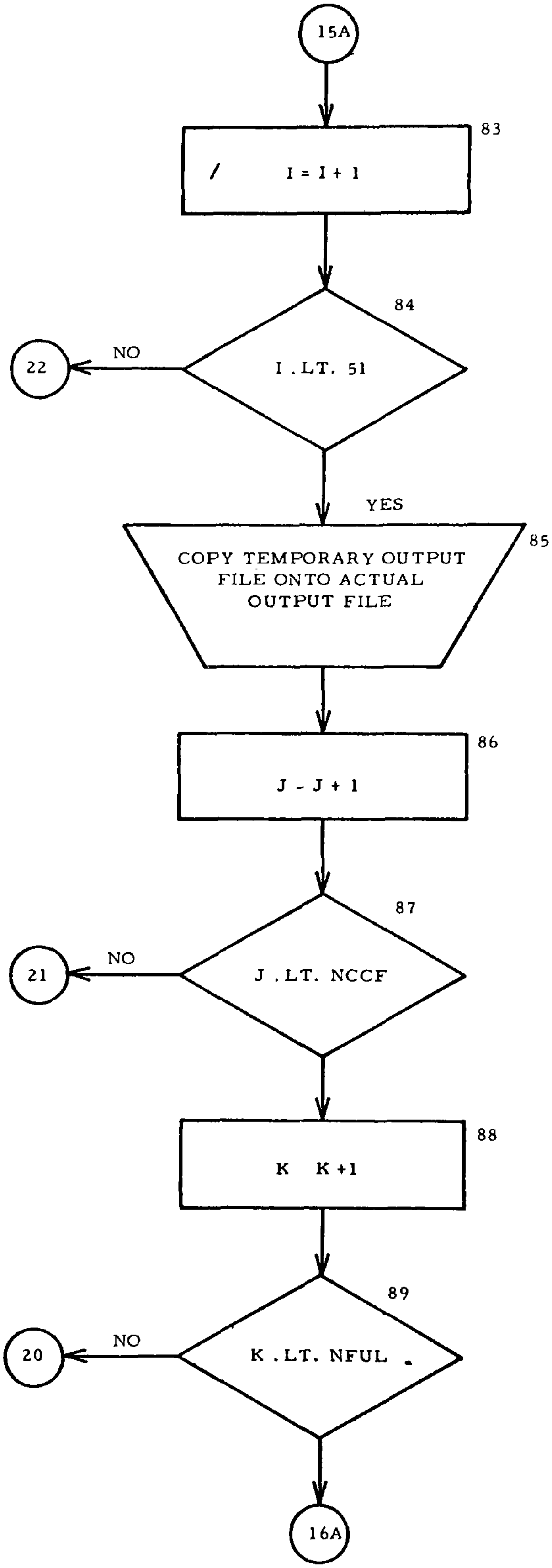

11A
NT NT +1
57
NT .LT. NTL
58
NO
7
YES
IL = IL + 1
59
IL .LT. 3
60
NO
18
YES
SAVE TOTAL ANNUAL ENERGY PRODUCED IN MWH_I
61
DETERMINE CAPACITY LOSS AT AIR TEMPERATURE EQUALLED OR EXCEEDED 10 HRS./YR.
62
12A

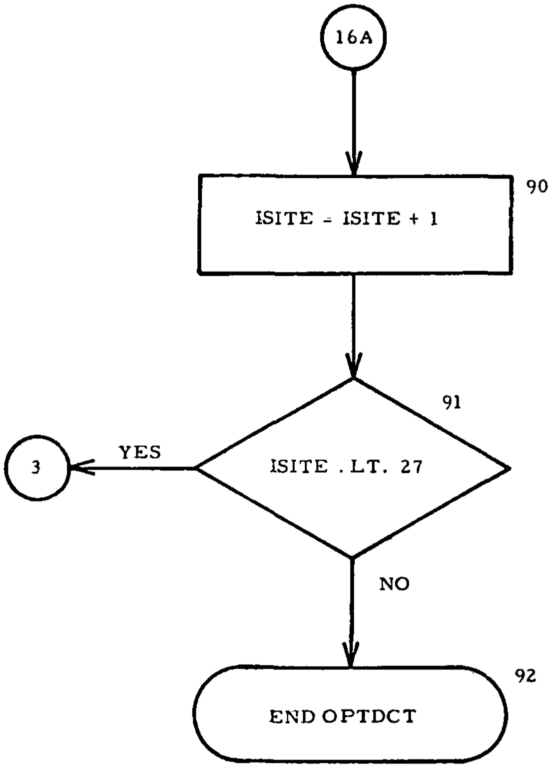


12A
ITD = ITD + 1
63
ITD .LT. 80
64
NO
6
YES
K = 1
65
20
J 1
66
21
WRITE HEADINGS ONTO
OUTPUT FILE
67
ITD = 29
TANT 1.OE50
I = 1
68
ITD = ITD + 1
69
13A

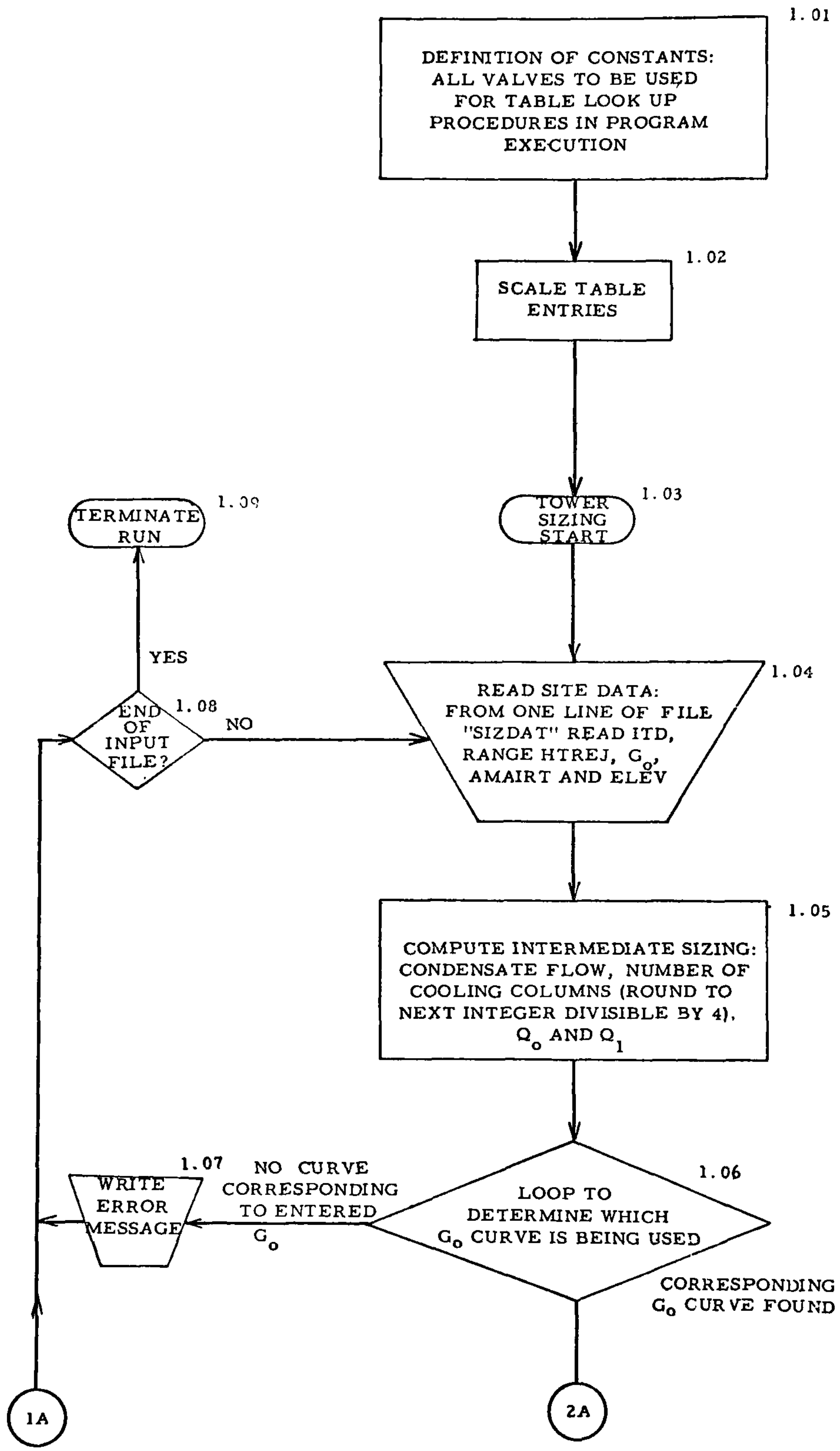

13A
CALCULATE ANNUAL CAPITAL COST AS A FUNCTION OF TOTAL CAPITAL COST
70
CALCULATE ANNUAL OPERATION AND MAINTENANCE COST. ADD TO ANNCAP TO GET TOTAL ANNUAL COST ON CAPITAL INVESTMENT (ACCAOM)
71
CALCULATE ANNUAL FUEL COST
72
WINTER OR SUMMER PEAK
73
SUMMER
WINTER
COMPUTE CAPITAL AND OPERATING PENALTY COSTS
74
COMPUTE OPERATING COST PENALTY
75
COMPUTE TOTAL PENALTY COST
76
14A

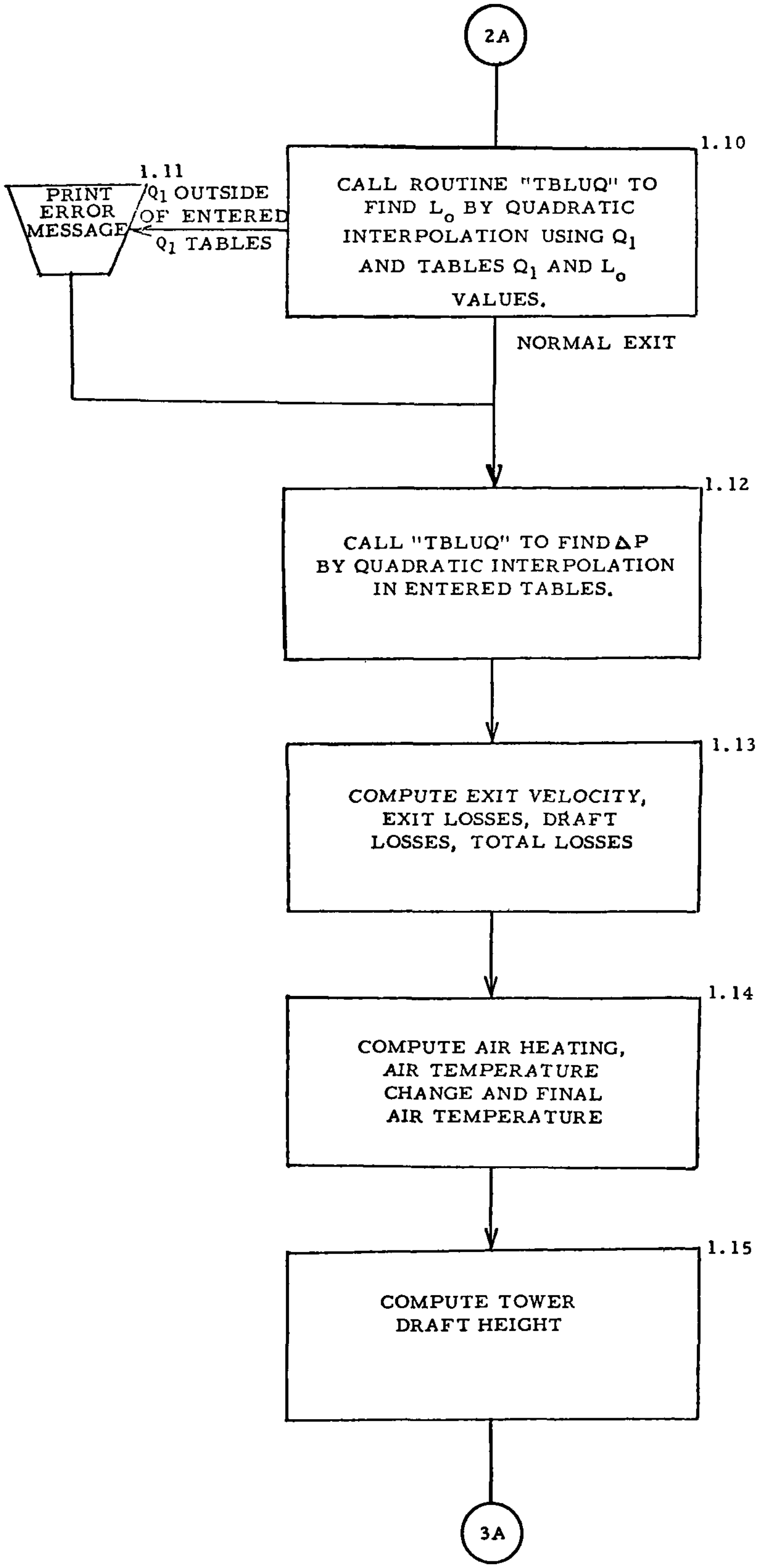

14A
77
COMPUTE TOTAL ENERGY LOSS
78
COMPUTE AUXILIARY CAPITAL COST, FUEL COST AND OPERATING COST, AND TOTAL ANNUAL COST
79
SUM UP ALL ANNUAL COSTS
80
TANCST .LT. TANT
NO
YES
81
TANT TANCST
ISAVE - ITD
82
WRITE TEMPORARY OUTPUT FILE
15A

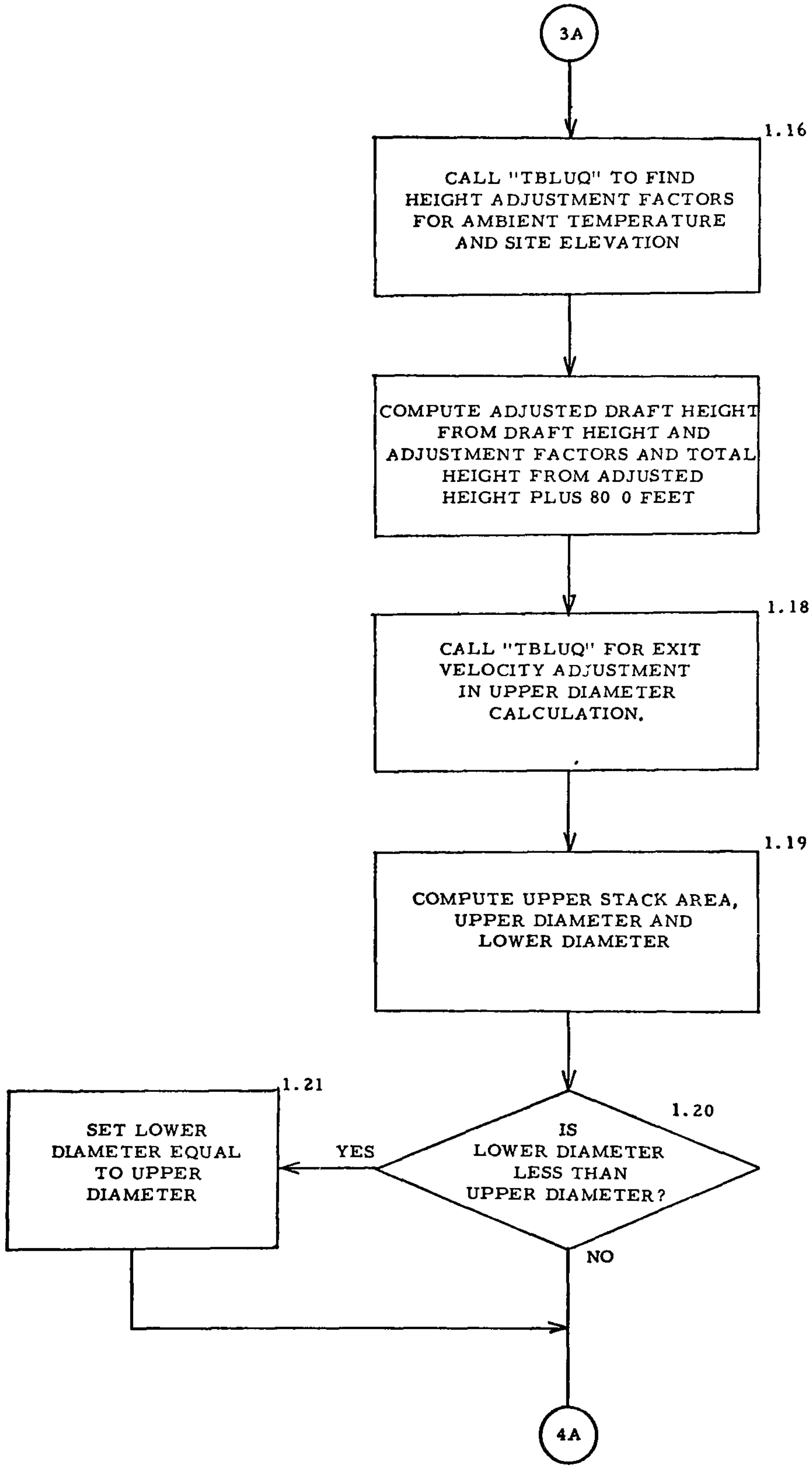

15A
83
I = I + 1
84
NO
22
I .LT. 51
YES
85
COPY TEMPORARY OUTPUT FILE ONTO ACTUAL OUTPUT FILE
86
J - J + 1
87
NO
21
J .LT. NCCF
88
K K +1
89
NO
20
K .LT. NFUL
16A

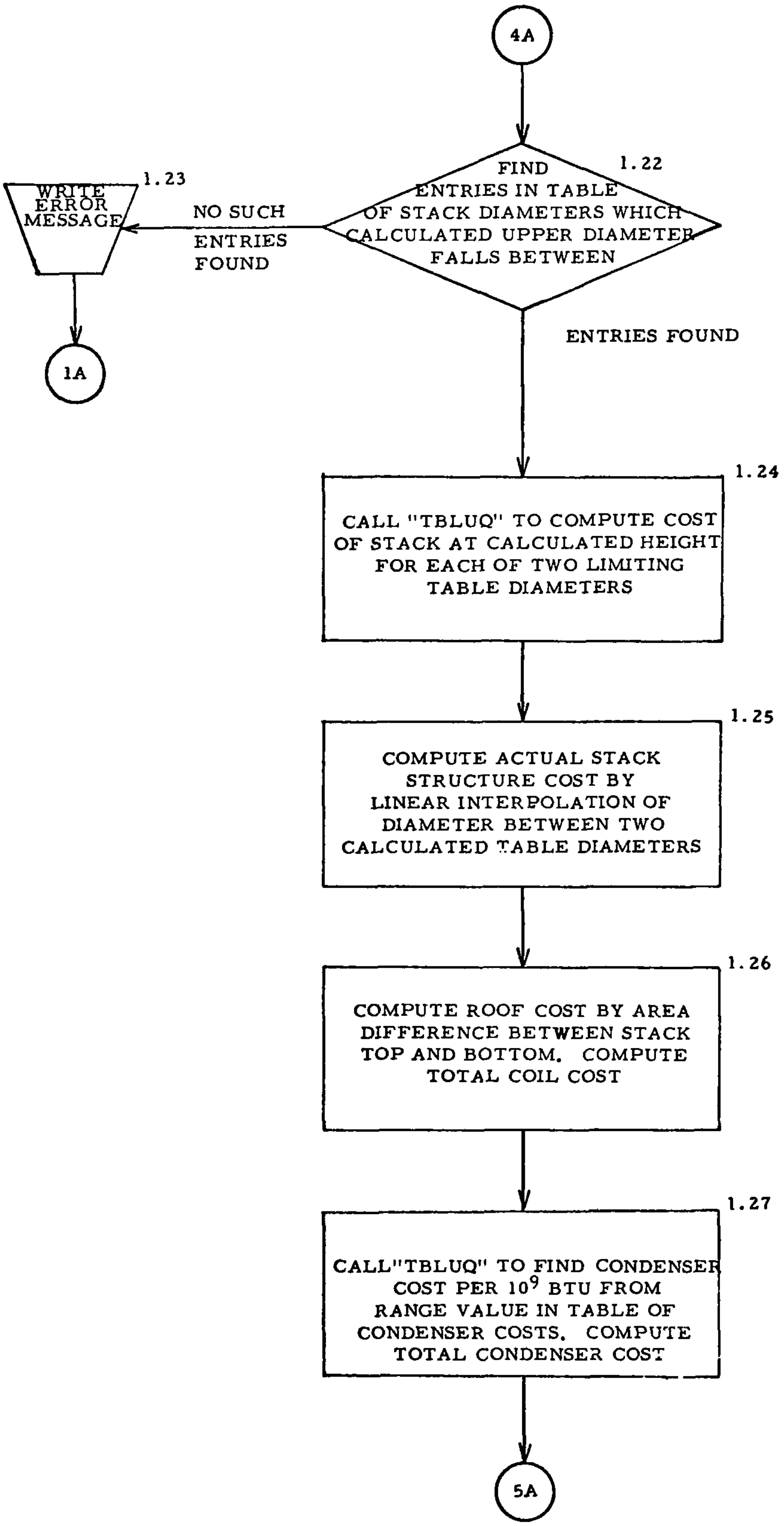

16A
ISITE = ISITE + 1
90
91
YES
3
ISITE .LT. 27
NO
92
END OPTDCT

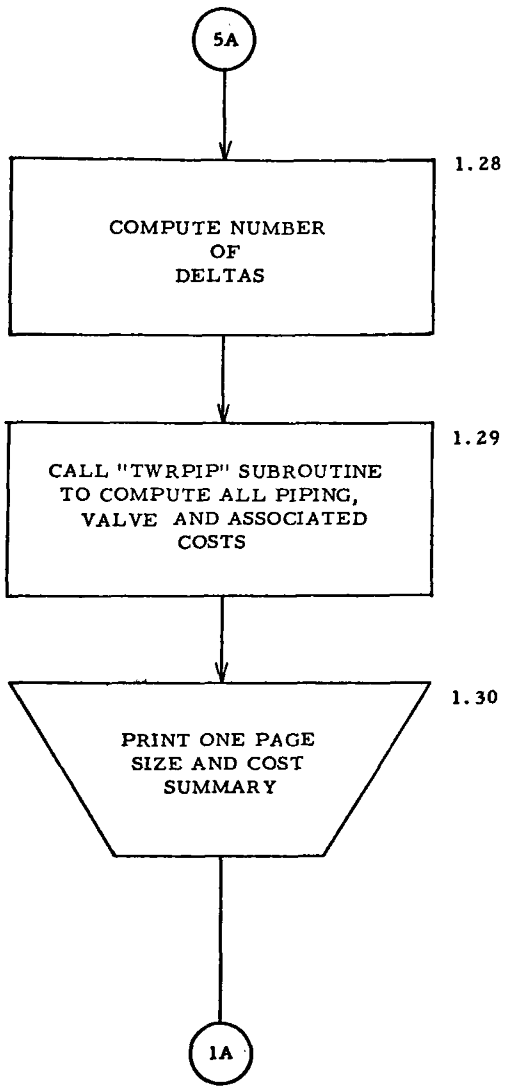
FLOW CHART OF PROGRAM "TOWSIZ"



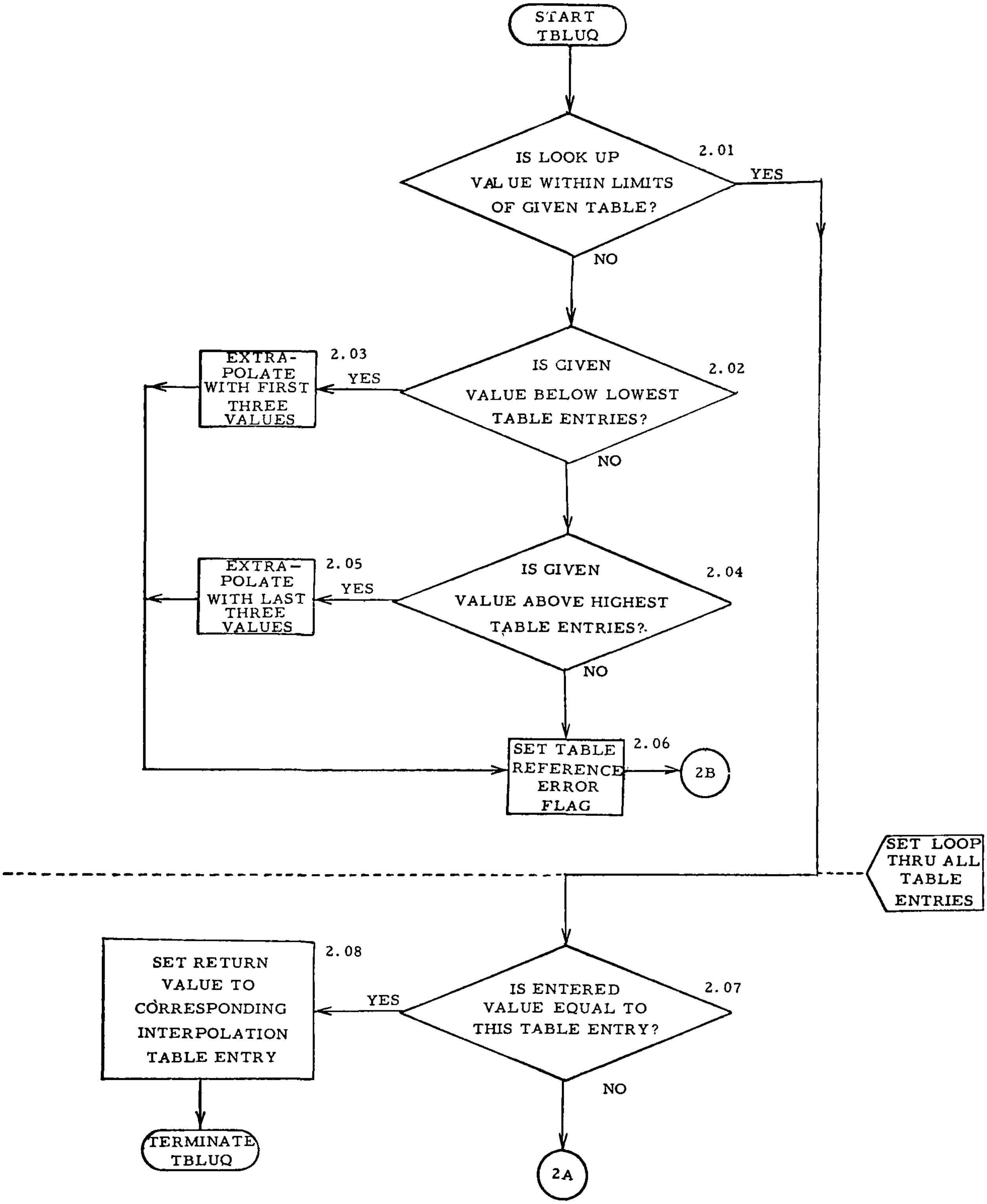

2A
1.10
CALL ROUTINE "TBLUQ" TO FIND L_o BY QUADRATIC INTERPOLATION USING Q_1 AND TABLES Q_1 AND L_o VALUES.
1.11
Q_1 OUTSIDE OF ENTERED Q_1 TABLES
PRINT ERROR MESSAGE
NORMAL EXIT
1.12
CALL "TBLUQ" TO FIND ΔP BY QUADRATIC INTERPOLATION IN ENTERED TABLES.
1.13
COMPUTE EXIT VELOCITY, EXIT LOSSES, DRAFT LOSSES, TOTAL LOSSES
1.14
COMPUTE AIR HEATING, AIR TEMPERATURE CHANGE AND FINAL AIR TEMPERATURE
1.15
COMPUTE TOWER DRAFT HEIGHT
3A

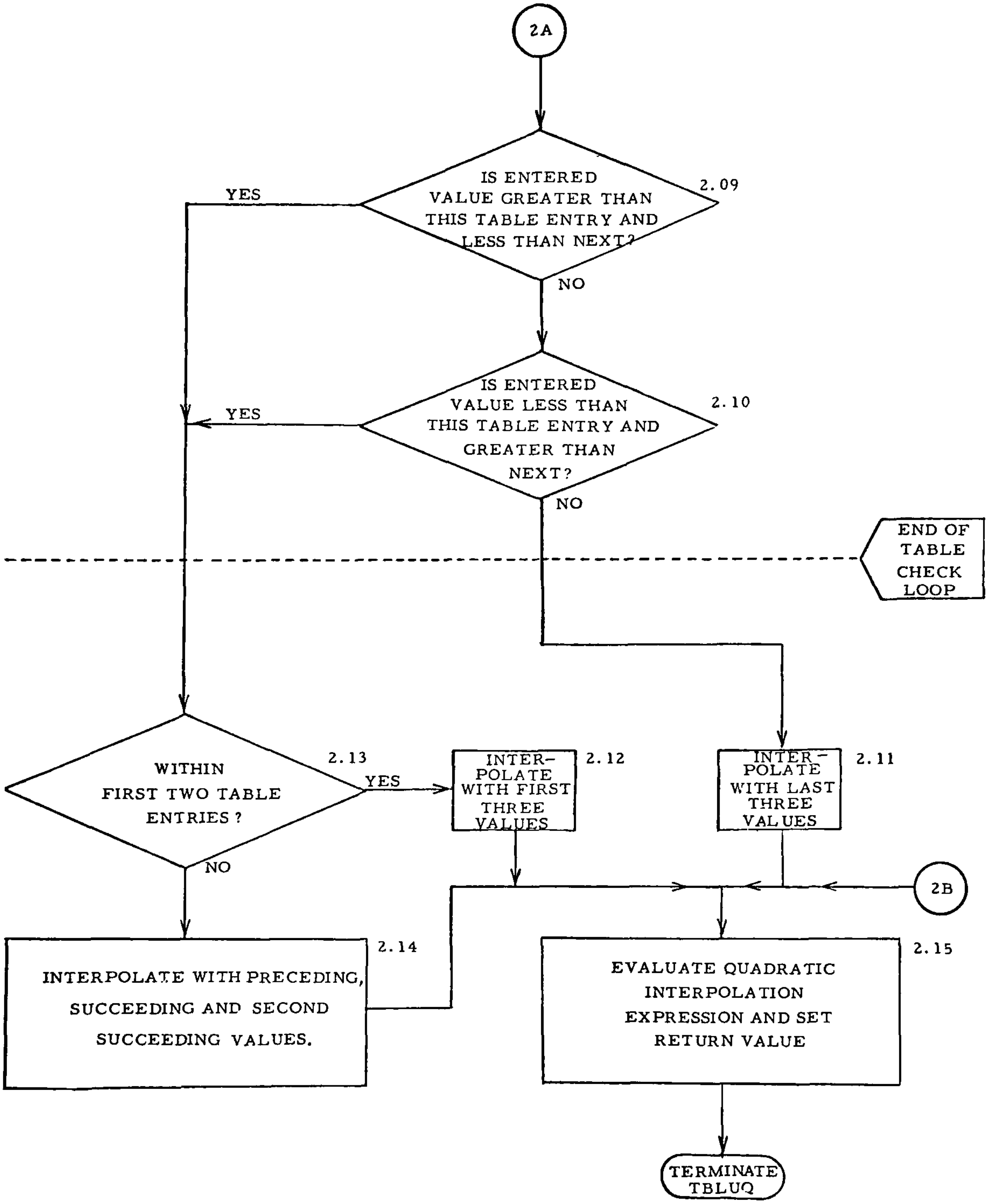

3A
1.16
CALL "TBLUQ" TO FIND HEIGHT ADJUSTMENT FACTORS FOR AMBIENT TEMPERATURE AND SITE ELEVATION
COMPUTE ADJUSTED DRAFT HEIGHT FROM DRAFT HEIGHT AND ADJUSTMENT FACTORS AND TOTAL HEIGHT FROM ADJUSTED HEIGHT PLUS 80 0 FEET
1.18
CALL "TBLUQ" FOR EXIT VELOCITY ADJUSTMENT IN UPPER DIAMETER CALCULATION.
1.19
COMPUTE UPPER STACK AREA, UPPER DIAMETER AND LOWER DIAMETER
1.20
IS LOWER DIAMETER LESS THAN UPPER DIAMETER?
YES
NO
1.21
SET LOWER DIAMETER EQUAL TO UPPER DIAMETER
4A


4A
FIND ENTRIES IN TABLE OF STACK DIAMETERS WHICH CALCULATED UPPER DIAMETER FALLS BETWEEN
1.22
NO SUCH ENTRIES FOUND
WRITE ERROR MESSAGE
1.23
1A
ENTRIES FOUND
CALL "TBLUQ" TO COMPUTE COST OF STACK AT CALCULATED HEIGHT FOR EACH OF TWO LIMITING TABLE DIAMETERS
1.24
COMPUTE ACTUAL STACK STRUCTURE COST BY LINEAR INTERPOLATION OF DIAMETER BETWEEN TWO CALCULATED TABLE DIAMETERS
1.25
COMPUTE ROOF COST BY AREA DIFFERENCE BETWEEN STACK TOP AND BOTTOM. COMPUTE TOTAL COIL COST
1.26
CALL"TBLUQ" TO FIND CONDENSER COST PER 10^9 BTU FROM RANGE VALUE IN TABLE OF CONDENSER COSTS. COMPUTE TOTAL CONDENSER COST
1.27
5A

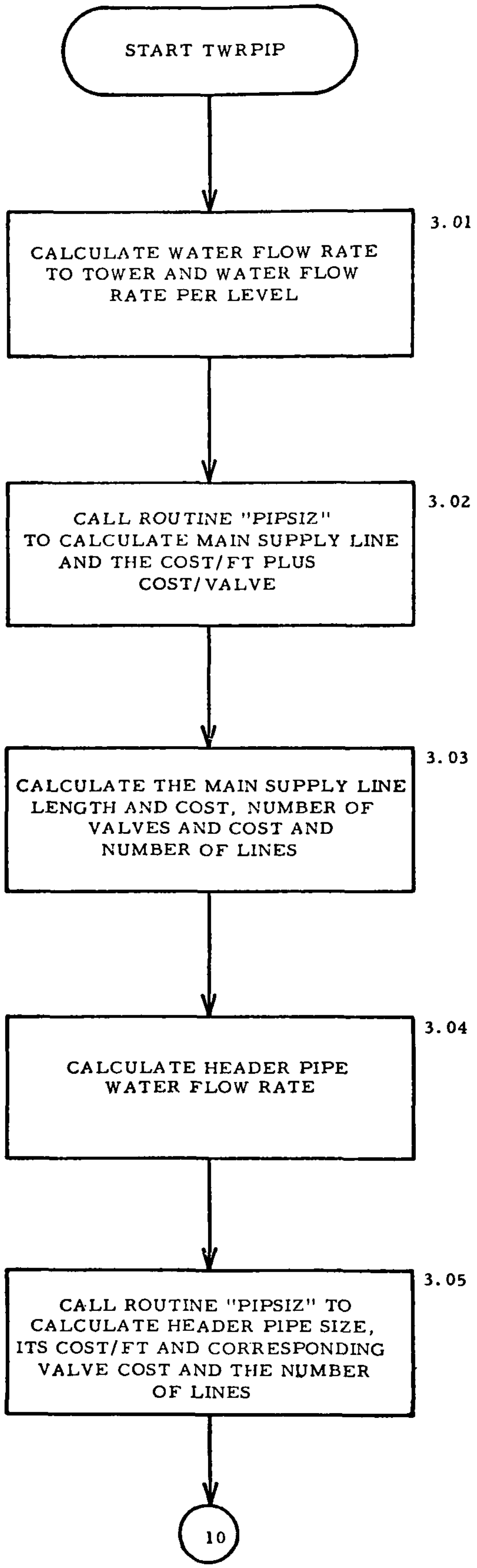

5A
1.28
COMPUTE NUMBER
OF
DELTAS
1.29
CALL "TWRPIP" SUBROUTINE
TO COMPUTE ALL PIPING,
VALVE AND ASSOCIATED
COSTS
1.30
PRINT ONE PAGE
SIZE AND COST
SUMMARY
1A

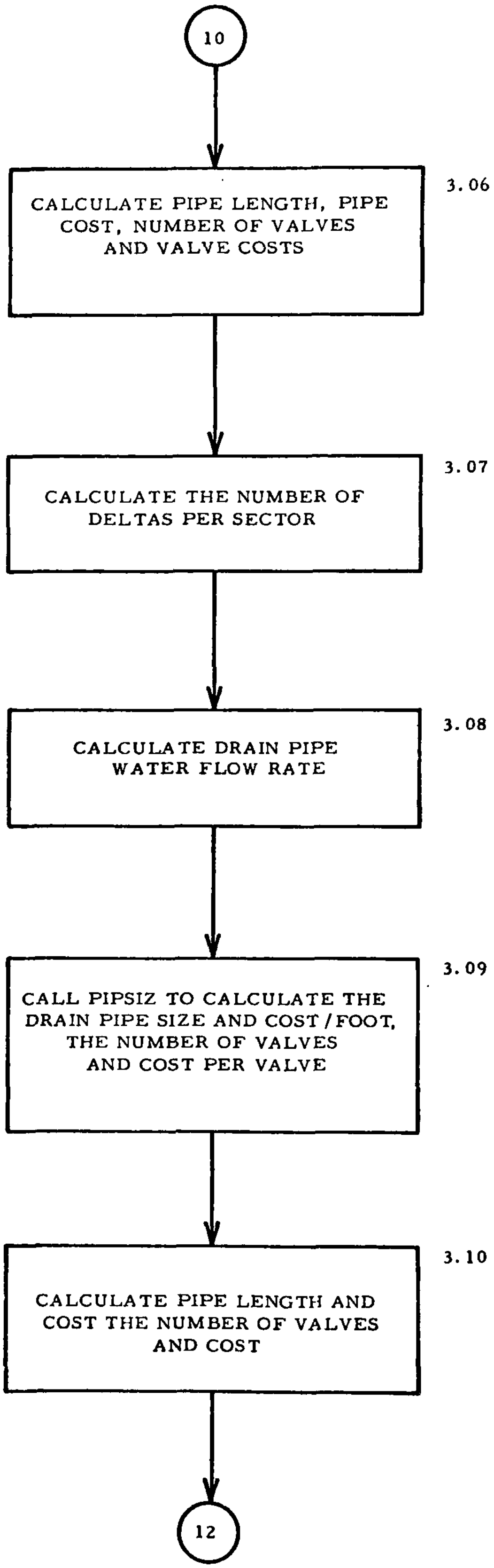
FLOW CHART OF FUNCTION "TBLUQ"

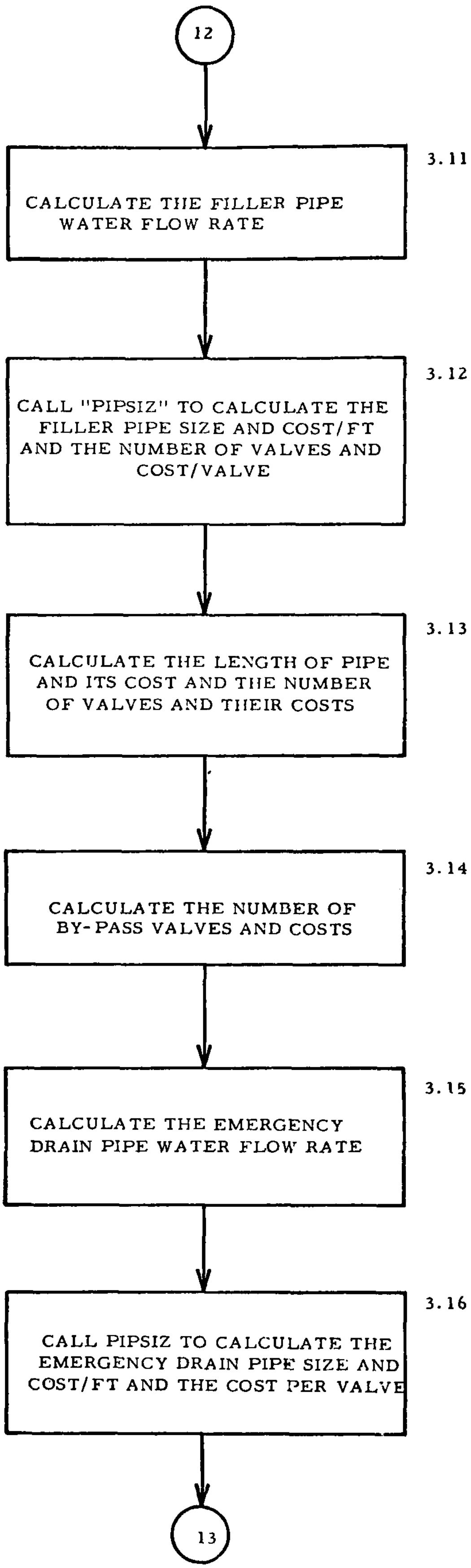


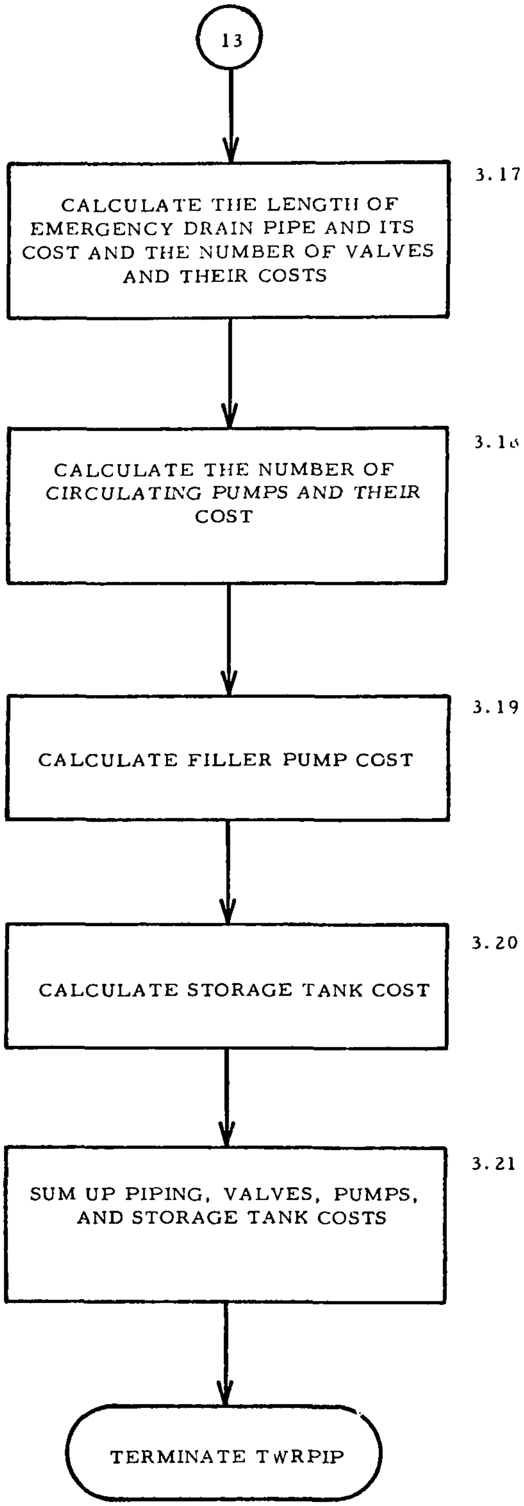

2A
IS ENTERED VALUE GREATER THAN THIS TABLE ENTRY AND LESS THAN NEXT?
2.09
YES
NO
IS ENTERED VALUE LESS THAN THIS TABLE ENTRY AND GREATER THAN NEXT?
2.10
YES
NO
END OF TABLE CHECK LOOP
WITHIN FIRST TWO TABLE ENTRIES ?
2.13
YES
NO
INTER-POLATE WITH FIRST THREE VALUES
2.12
INTER-POLATE WITH LAST THREE VALUES
2.11
2B
INTERPOLATE WITH PRECEDING, SUCCEEDING AND SECOND SUCCEEDING VALUES.
2.14
EVALUATE QUADRATIC INTERPOLATION EXPRESSION AND SET RETURN VALUE
2.15
TERMINATE TBLUQ

FLOW CHART OF SUBROUTINE "TWRPIP"

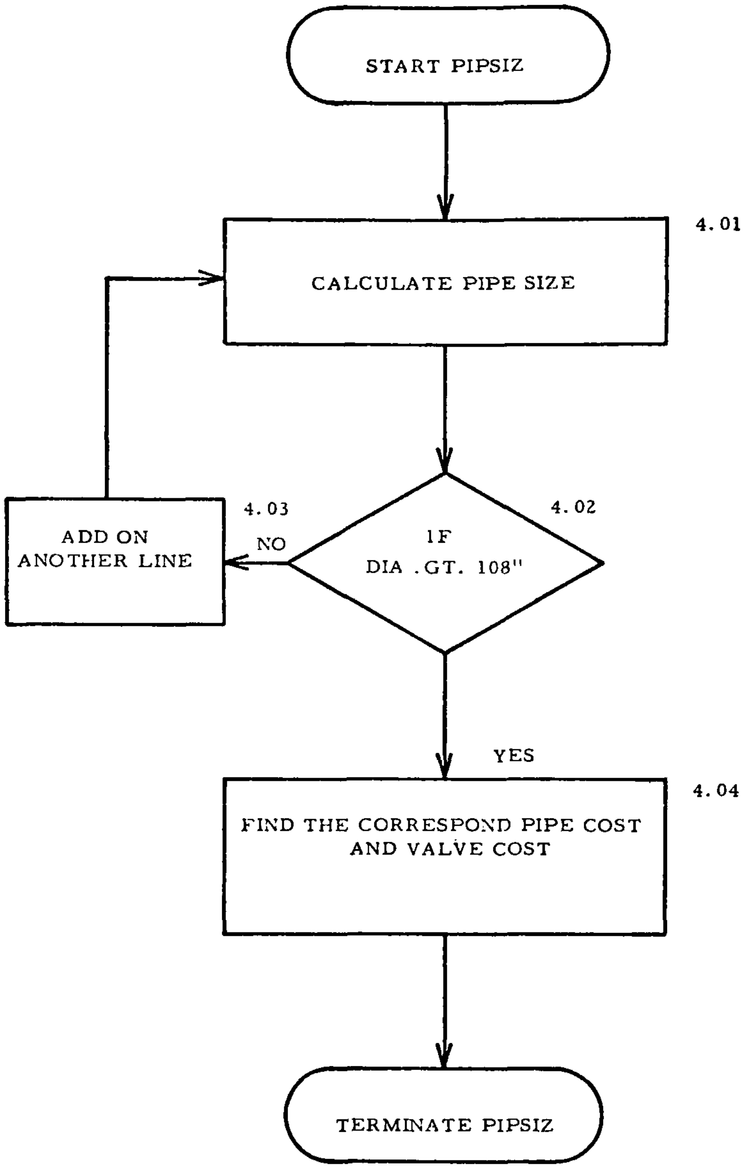



10
3.06
CALCULATE PIPE LENGTH, PIPE COST, NUMBER OF VALVES AND VALVE COSTS
3.07
CALCULATE THE NUMBER OF DELTAS PER SECTOR
3.08
CALCULATE DRAIN PIPE WATER FLOW RATE
3.09
CALL PIPSIZ TO CALCULATE THE DRAIN PIPE SIZE AND COST / FOOT, THE NUMBER OF VALVES AND COST PER VALVE
3.10
CALCULATE PIPE LENGTH AND COST THE NUMBER OF VALVES AND COST
12


12
3.11
CALCULATE THE FILLER PIPE WATER FLOW RATE
3.12
CALL "PIPSIZ" TO CALCULATE THE FILLER PIPE SIZE AND COST/FT AND THE NUMBER OF VALVES AND COST/VALVE
3.13
CALCULATE THE LENGTH OF PIPE AND ITS COST AND THE NUMBER OF VALVES AND THEIR COSTS
3.14
CALCULATE THE NUMBER OF BY-PASS VALVES AND COSTS
3.15
CALCULATE THE EMERGENCY DRAIN PIPE WATER FLOW RATE
3.16
CALL PIPSIZ TO CALCULATE THE EMERGENCY DRAIN PIPE SIZE AND COST/FT AND THE COST PER VALVE
13


13
CALCULATE THE LENGTH OF EMERGENCY DRAIN PIPE AND ITS COST AND THE NUMBER OF VALVES AND THEIR COSTS
3.17
CALCULATE THE NUMBER OF CIRCULATING PUMPS AND THEIR COST
3.18
CALCULATE FILLER PUMP COST
3.19
CALCULATE STORAGE TANK COST
3.20
SUM UP PIPING, VALVES, PUMPS, AND STORAGE TANK COSTS
3.21
TERMINATE TWRPIP

FLOW CHART OF SUBROUTINE "PIPSIZ"



APPENDIX E

GLOSSARY

Glossary of Terms Used in the Cooling Tower Optimization Program "OPTDCT"

A - The coefficient of the equation

$$ITD = A \times (\text{Heat Rejection } 10^6 \text{ Btu/hr})^Z$$

which defines the operating characteristics of a dry cooling tower.

ABS - Absolute, Library function of the computer.

ACCAOM - Annual capital cost and operating and maintenance costs.

AIR - Variable used to store the three highest non-zero ambient air temperatures for each site.

AIR10 - Variable used to store the air temperature which is equalled or exceeded ten hours per year. (Sometimes called "the ten hour air temperature".)

AIRT - An array that contains air temperatures corresponding to the table of durations in the site data. Values from 117°F to −38°F in 5° increments (117°, 112°, 107°, ...−28°, −33°, −38°).

AMAX1 - Maximum, Library function of the computer.

AMIN1 - Minimum, Library function of the computer.

ANNCAP - Annual capital cost determined by applying the appropriate (fixed-charge rate) to the total capital cost for the given ITD.

ANNFUL - Annual fuel cost determined by applying the appropriate unit cost of fuel to the total Btu's used for the given ITD.

ASTER - Variable used only in output format indicating a number raised to a power.

AUX100 - Table of full auxiliary power requirements vs. ITD for mechanical-draft towers.

AUXCAP - The capital cost of auxiliary power required in dollars.

AUXCST - The total annual cost for the auxiliary power and energy necessary to the cooling system.

AUXKW - The maximum power needed for the cooling system auxiliaries (pumps and fans).

AUXKWH - Variable used to store the energy value for the auxiliary requirements of the cooling system.

AUXOPR - Annual operating cost incurred in supplying the necessary auxiliary energy.

AUXTEM - Variable used to store the maximum and minimum air temperature used in calculating the percentage of full auxiliary power requirements for a mechanical-draft tower for a given ITD.

AUXTMP - Table of air temperatures corresponding to the maximum (100%) and minimum (53%) percentage of full auxiliary power requirements for a mechanical-draft tower.

B - Variable used for temporary storage of capital costs for a given ITD corresponding to elevations of sea level, 3,000 and 6,000 feet.

BP - An array which contains a table of back pressures which cover the range of operation from 1.0 inch Hg to 18.0 inches Hg in steps of .5 inch Hg. Corresponds to values of full throttle kw, station heat rate, and heat rejected to the cooling system. From the turbine data file.

BPMAX - Maximum allowable turbine back pressure (inches Hg).

BPMIN - Minimum allowable turbine back pressure (inches Hg).

BPT - Variable used for temporary storage of the calculated back pressure used in the calculations for finding the operating back pressure of the turbine.

CAPCST - Variable used for storing and calculating the capital costs of the cooling system

CAPLOS - Variable used in the calculation of the loss or gain of capacity (kw) resulting from turbine operation above or below a back pressure of 3-1/2 inches Hg.

CCF - The capital cost factors (fixed-charge rates) applied to the cooling system capital cost represents annual cost.

CCFGT - Capital cost factors (fixed-charge rates) applied to the capital cost of peaking units used to replace capacity losses.

CCM - Capital cost multiplier. This variable is used to adjust for variations in construction cost.

CPWAX - Capital cost (in \$/kw) of providing auxiliary power. (\$150/kw for fossil-fueled units and \$225/kw for nuclear-fueled units).

CRDBTU - Array used to retain the Btu of excess energy. Excess energy is produced only under full throttle operation at back pressures below 3.5 inches Hg and in the energy resulting from power production in excess of 800 mw. One value per given ITD.

CREDIT - Annual credit, in dollars, determined by applying the appropriate fuel cost CRDBTU.

CUTOFF - The air temperature at or above that at which the lost power and energy is replaced by a peaking unit.

DUR - Variable used to retain the first three non-zero temperature durations corresponding to the three highest temperatures for each site.

ELEV - Elevation (feet above sea level) of each site being studied.

FCSTAX - Variable used for the incremental cost (mills/kwh) auxiliary energy. This cost is the annual plant fuel in mills/kwh plus an operation and maintenance allowance of 0.1 mill/kwh.

FTKW - An array containing the full throttle capabilities of the turbine corresponding to bac, pressures from 1.0 inch Hg to 18.0 inches Hg in 0.5 inch steps.

FTKWT - Variable used for temporary storage of full throttle output of the turbine corresponding to the actual operating back pressure.

FULAUX - Variable used to store the full auxiliary power requirements (100%) for a given ITD for a mechanical-draft tower.

FULCST - The fuel cost for 800-mw unit for the given site in ¢/10^6 Btu.

GHR - Plant heat rate with a value corresponding to each value of back pressure.

HREJ - Heat rejected by the turbine with a value corresponding to each value of GHR.

HREJD - Design heat rejection of the turbine (4×10^9 Btu/hr for a fossil unit or 6×10^9 Btu/hr for a nuclear unit).

HREJMX - Maximum heat rejection obtainable when the turbine is backed down to operate within its prescribed limits.

HREJT - Heat rejection associated with the maximum allowable back pressure for the three operating levels of full throttle, 3/4 load and 1/2 load.

HRJ - Temporary value of heat rejected by the turbine for use in determining the operating back pressure.

HRS - Number of hours of operation for a given load (PCTTIM) at a given air temperature (TDUR) based on the number of operating hours per year (OPHRS).

HRSPYR - The number of hours in a year. Assumed to be 8,760.

I - Variable subscript corresponding to values of ITD (I = 1, ITD = 30; I = 2, ITD = 31; etc.).

IJ, IJ2 - Variable subscript corresponding to curves of percent of full auxiliary power requirement vs. ambient air temperature for different ITD for a mechanical-draft tower.

IJ1 - Variable subscript corresponding to the curve IJ + 1 of percent of full auxiliary power requirement vs. air temperature for a mechanical-draft tower.

IK - Variable subscript associated with the capital cost curves corresponding to elevations of sea level, 3,000 feet, and 6,000 feet.

IL - Subscript used to cycle through the three combinations of percent load (PCTLD) and percent time (PCTTIM).

ISAVE - Variable used to store the optimum ITD for each run.

ISITE	-	Variable subscript used to denote the site on which the program is operating.
IT	-	Variable subscript used to associate the loss or gain of capacity with the first three non-zero temperature durations.
ITD, THETA	-	Variable used interchangeably to indicate the *initial temperature* difference which is the difference between the saturation temperature of the condensing steam and the ambient dry-bulb air temperature.
ITER	-	Variable used as a counter to keep track of the number of iterations needed to converge the operating back pressure.
ITYPE	-	The name of the basic type of fuel used for the turbine, either fossil or nuclear.
IWSP	-	Variable indicator relating to the peaking period for the site. Peaking period being either winter (IWSP = 1) or summer (IWSP = 2).
J	-	Variable subscript used to denote the appropriate capital cost factor (fixed-charge rate) and capital cost factor for gas turbine associated with each run.
K	-	Variable subscript used to denote the appropriate plant fuel cost and peaking fuel cost associated with each run.
KW	-	Turbine nameplate rating in kw.
KWAX	-	Array of auxiliary power requirements for the natural-draft tower. Six values corresponding to ITD values of 30°F, 40°F, 50°F, 60°F, 70°F and 80°F.
KWH	-	Variable used twice, first for calculating the nominal energy produced by the plant (kwh) and secondly for calculating the energy produced under given conditions (kwh).
KWHABV	-	The total energy loss occurring when the ambient air temperature is equal to or above the cutoff temperature. One value for each ITD (kwh).
KWHBLO	-	The total energy loss occurring when the ambient air temperature is below the cutoff temperature. One value for each ITD (kwh).

KWHGAN - The excess energy produced when operating at full throttle and below 3-1/2 inches Hg back pressure. One value for each ITD (kwh).

KWHLOS - The energy lost when operating at full throttle and above 3-1/2 inches Hg back pressure. One value for each ITD (kwh).

KWLOS - Variable used in calculating the loss of capacity (KWLOSS) at the ten hour air temperature. One value, in kw, for each of the three highest air temperatures.

KWLOSS - The lost capacity associated with the ten hour air temperature. One value, in kw, for each ITD.

LOAD - The turbine output in kw corresponding to the maximum allowable back pressure and the appropriate load condition (full throttle, 3/4 load and 1/2 load).

LOAD1 - Three values of turbine output, the first value being the output at the actual operating back pressure at full throttle and the remaining two values corresponding to the output at the maximum allowable back pressure for 3/4 load and 1/2 load operation respectively.

MILPKW - Total annual cost of the cooling system and total plant fuel cost. One value for each ITD (mills/kwh).

MWH - Variable used to retain the amount of energy actually produced by the turbine for a given set of operating conditions.

NCCF - The number of capital cost factors (fixed-charge rates) to be used for each site.

NFUL - The number of base fuel costs and the number of peaking fuel costs to be used for each site.

NHR - Net heat rate of turbine. Not used in program calculations but used to skip over net heat rate values on data file (Btu/kwh) in order to leave data file general.

NT - Variable subscript used to denote the 32 values of temperature duration and air temperatures.

NTL - Subscript of the first non-zero temperature duration in the array TDUR.

NTU	-	Subscript of the last non-zero temperature duration in the array TDUR
OAMCT	-	Operating and maintenance cost as a percentage of capital cost.
ONM	-	Variable operation and maintenance cost (mills/kwh).
OPBP	-	Actual operating back pressure of the turbine for a given set of conditions.
OPGHR	-	Actual operating station heat rate of the turbine for a given set of conditions.
OPHRS	-	The number of hours per year of plant operation.
OPMAT	-	Operation and maintenance cost.
OPTDCT	-	Optimization of Dry Cooling Towers. The name of the program.
OPTOUT	-	The name of the file in which the program results are stored.
P	-	An array which contains the saturation pressures for a table of saturation temperatures (°F) vs. saturation pressures (inches Hg).
PAUSE	-	Library subroutine used if the program does not function correctly.
PCCST	-	Peaking unit capital cost ($/kw).
PCT	-	Percent of full auxiliary power requirement for a mechanical-draft tower for a given ITD, air temperature and load.
PCTLD	-	Percent load at which the turbine is operating; i.e., 100% for full throttle, 75% for 3/4 load, and 50% for 1/2 load.
PCTLOD	-	The three operating conditions of the turbine; 100% for full throttle, 75% for 3/4 load and 50% for 1/2 load.
PCTTIM	-	The percent of time the turbine will be operating at a specific load level.
PEAK	-	Peaking period for each site (summer or winter).

PENCAP - Annual capital cost of replacing the generating capacity lost at the air temperature that is equalled or exceeded ten hours per year.

PENLTY - The annual cost of replacing capacity and energy losses. PENLTY = PENCAP + PENOPR.

PENOPR - Annual operating cost related to the replacement of the energy lost due to operation at back pressures in excess of 3-1/2 inches Hg.

PFCST - Peaking unit fuel cost (¢/10^6 Btu).

PLITD - Part load ITD.

SATP - Saturation pressure (inches Hg).

SATT - Saturation temperature (°F).

SITE - Variable used to store the site names.

SITENO - An array that contains the names of the 27 data files containing site information. SITE01, SITE02, ..., SITE 27.

T - An array which contains the saturation temperatures for a table of saturation temperatures (°F) vs. saturation pressures (inches Hg).

TANCST - Total annual cost of the cooling system and total plant fuel ($).

TANT - Variable used in finding the optimum ITD.

TAXKWH - Auxiliary energy in mwh.

TBLELV - Table of elevations (0, 3,000, and 6,000 feet above sea level).

TBLITD - Table of ITD from 30°F to 80°F in 10° increments.

TBLUQ - Table look-up subroutine used in the program.

TDUR - Temperature durations in the site data. These durations are the percent of time during a year that the ambient air temperature is within a given 5° range.

TEMP - Temporary variable used for storage in several locations in the program.

TKW	-	The maximum output of the turbine under a given set of conditions within the limiting values.
TKWGAN	-	Excess energy, in mwh, produced when operating at full throttle and below 3-1/2 inches Hg back pressure.
TMWH	-	Nominal annual energy, in mwh, produced by the 800-mw generating plant for the given loading assumptions.
TOTBTU	-	The total annual fuel consumption, in Btu, for the given loading assumptions.
TOTCAP	-	Capital cost corresponding to site elevation and ITD.
TOWER	-	Variable containing the type of tower used in the cooling system, either "Natural Draft" or "Mechanical Draft".
TURBIN	-	Name of the data file containing the turbine data.

Glossary of Terms Used in Subroutine "DATCHK"

DATCHK	-	Data check, name of the subroutine.
FILE	-	Variable containing the names of the data files.
INCT	-	Variable used as a counter.
NFIL	-	The number of the tape the data file is on.
SITE	-	Name of the file containing the site data.
SPVSST	-	Variable used to hold space for a file name that could be inserted at a later date.
TURBIN	-	Name of the file containing the turbine data.

Glossary of Terms Used in Subroutine "TBLUQ"

A	-	Coefficient of X^2 in the equation $TBLUQ = AX^2 + BX + C$.
ABS	-	Library function used to find the absolute value of a number or function.
B	-	Coefficient of X in the equation $TBLUQ = AX^2 + BX + C$.
C	-	Constant in the equation $TBLUQ = AX^2 + BX + C$.
DET	-	Variable used in the calculation of A, B, and C.
I	-	Subscript.
N	-	Subscript.
NVAL	-	Number of X and Y values in the table which the value is being sought.
TBLUQ	-	Name of the subroutine and the value which is being sought.
X	-	The variable for a corresponding Y value.
X1,X2,X3	-	The three X values used in the interpolation from the table of values being used.
X1S,X2S, X3S	-	The X1, X2, and X3 values squared, respectively.
XT	-	The table of X values being used.
Y1,Y2,Y3	-	The three Y values used in the interpolation from the table of values being used.
YT	-	The table of Y values being used.

Glossary of Terms Used in the
Tower Optimization Program
"TOWSIZ"

ADRA	-	Air density ratio - elevation.
ADRFTH	-	Adjusted draft height.
ADRT	-	Air density ratio - temperature.
AEXIT	-	Air exit velocity.
AFACTR	-	Altitude density ratio table.
AIRDLT	-	Air temperature increase.
AIRHT	-	Air heat gain.
AMAIRT	-	Ambient air temperature.
CNDCST	-	Table of condenser costs.
COILS	-	Cost of heat exchangers.
CONDF	-	Condensate flow.
CPBTU	-	Condenser cost per billion Btu per hour.
CURVGO	-	Table of water flows.
DELTAP	-	Coil losses.
DNDNSR	-	Table of condenser cost.
DPTBL	-	Table of coil losses.
DRAFTH	-	Draft height
DRAFTLS	-	Draft losses.
DROOF	-	Cost of delta roof.
ELEV	-	Elevation.

EXITLS - Exit losses.

EXITV - Exit velocity (20 fps).

FAIRTNI - Final air temperature.

G0 (G_o) - Water flow (lbs./hr.).

HEIGHT - Table of altitudes.

HTREJ - Heat rejection.

ITD - Initial temperature difference.

L0 (L_o) - Air flow (metric tons/hr.).

L0TBL - Table of values of air flow.

LOWDIA - Bottom diameter of tower.

N - Number of heat exchanger columns.

P - Pressure drop across the coil.

Q0 (Q_o) - Heat rejection per hour per column (Btu).

Q1 (Q_1) - Heat rejection per hour per degree of ITD.

Q1TBL - Table of values of heat rejection per hour per column per degree ITD.

RANGE - Temperature change of condensate.

RTEMP - Temperature range table for condenser cost.

STACK - Cost of stack.

STDIAM - Table of tower stack diameters.

STKCST - Table of stack costs.

STKHT - Table of stack heights.

TEMPS - Temperature table.

TFACTR - Temperature density ratio table.

TOTALH - Total draft height.

TOTLOS - Total losses.

UPAREA - Tower area at top.

OPDIAM - Top diameter of tower.

Glossary of Terms Used in Subroutine "TWRPIP"

BDIAFT	-	Diameter of the base of the cooling tower.
BPVALD	-	Cost per valve for bypass valves.
BPVALS	-	Bypass valve size (inches).
BPVCST	-	Bypass valve cost ($).
BTUPHR	-	Btu per hour.
DELHI	-	Delta Height (ft.).
DELPSE	-	Number of deltas per sector.
DGPM	-	Drain flow rate (gpm)
DPCST	-	Drain pipe cost ($).
DPD	-	Unit cost of drain pipe ($/ft.).
DPFT	-	Table of pipe cost ($/ft.).
DPLEN	-	Length of drain pipe (ft.).
DPRFT	-	Pipe cost corresponding to pipe size ($/ft.).
DPRVAL	-	Valve cost corresponding to valve size ($/valve).
DVCST	-	Drain valve cost ($).
DVD	-	Unit cost of drain valves ($/valve).
EDGPM	-	Rate at which water must be drained in case of an emergency (gpm).
EDPCST	-	Cost of emergency drain pipe ($).
EDPLEN	-	Emergency drain pipe length (ft.).
EDVCST	-	Emergency drain valve cost ($).

EDVD	-	Cost per valve for emergency drain valves ($).
FGPM	-	Flow rate at which cooling system is filled (gpm).
FPCST	-	Filler pipe cost ($).
FPD	-	Cost per foot for filler pipe ($/ft.).
FPLEN	-	Length of filler pipe (ft.).
FVCST	-	Filler valve cost ($).
GAPDEL	-	Gallons of water per delta.
GPM	-	Flow rate for cooling condensate (gpm).
GPMPL	-	Flow rate per level (gpm).
HGPM	-	Flow rate in header pipes (gpm).
HPCST	-	Header pipe cost ($).
HPD	-	Cost per foot of header pipe ($/ft.).
HPLEN	-	Length of header pipe (ft.).
HVD	-	Cost per valve for header valves ($).
HVCST	-	Cost of header valves ($).
IFPSET	-	Number of filler pumps required.
IPSETS	-	Number of circulating pumps required.
MPCST	-	Cost of main supply line pipe ($).
MPP	-	Cost per foot for main supply line ($/ft.).
MPLEN	-	Length of supply line (ft.).
MPS	-	Size of main supply line (inches).
MVCST	-	Cost of main supply line valves ($).
MVD	-	Cost per valve for main supply line valves ($).

NBPV	-	Number of bypass valves.
NDELPL	-	Number of deltas per level.
NDV	-	Number of drain valves.
NEDL	-	Number of emergency drain lines.
NEDVAL	-	Number of emergency drain valves.
NFV	-	Number of filler line valves.
NHSL	-	Number of header supply lines.
NHV	-	Number of header valves.
NMSL	-	Number of main supply lines.
NMVAL	-	Number of main supply line valves.
NODEL	-	Number of cooling deltas.
NOL	-	Number of lines.
NOLEV	-	Number of levels of cooling deltas.
NSECPL	-	Number of sectors per level.
NSL	-	Number of supply lines.
PCOST	-	Circulating water pump cost ($).
PDIA	-	Diameter of the different pipe (inches).
PI	-	3.14159.
PIPSIZ	-	Name of subroutine that calculates diameter.
PSIZE	-	Table of pipe sizes (inches).
STCST	-	Storage tank cost ($).
STLBS	-	Weight of storage tank (lbs.).
TNMSL	-	Total number of main supply lines.

TPCST	-	Total pipe cost ($).
TPVCST	-	Total pipe and valve cost ($).
TVCST	-	Total valve cost ($).