VOLUME I

DOCUMENTATION
FOR
THE VIRGINIA STATE CORPORATION COMMISSION'S PRODUCTION COST SIMULATION MODEL

Prepared by

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The Ohio State University
Columbus, Ohio

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FOREWORD

This report was prepared for the Virginia State Corporation Commission. Any opinions expressed herein are solely those of the authors and do not necessarily reflect the opinions nor the policies of the National Regulatory Research Institute or the Virginia State Corporation Commission.

The NRRI is making this report available to those concerned with state utility regulatory issues, since the subject matter presented here is believed to be of timely interest to regulatory agencies and to others concerned with utilities regulation.

The NRRI appreciates the cooperation of the staff of the Virginia State Corporation Commission with the authors in preparing this study.

Dr. Douglas N. Jones
Director

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PREFACE

Pursuant to recent legislation (code of Virginia, Section 55-249.6) the staff of the Virginia State Corporation Commission (VSCC) has been developing a reporting and monitoring system in order to evaluate the fuel purchase costs and fuel usage practices of the electric utilities serving the Commonwealth of Virginia.

Part of the development of this system has been carried out under contract with The National Regulatory Research Institute (NRRI). A portion of the work performed by the Institute has been the development of a Production Cost Simulation (PCS) computer mode. This manual contains a description and the documentation for the PCS model.

The PCS model projects energy production by generating unit as a function of the unit's equivalent availability, capacity, loading position and the energy supply demands on the system. From the projected energy generation values parameters such as thermal energy consumption, fuel expense, average heat rate, capacity factor and average fuel expense are calculated for each unit and totaled or averaged for the system. The results of these calculations are reported on a monthly, quarterly and study period basis.

The documentation for the PCS model is provided in two volumes.

Volume I is divided into two sections. The first section gives a description of the model. It is designed to provide the reader with an overview of the model's calculation methodology and uses. The second section provides a detailed description of the programming aspects of the model. It is designed for the user and programmer. Volume II contains three of five appendices to this manual.

Further information about the model can be obtained from:

NRRI
2130 Neil Avenue
Columbus, Ohio 43210

ACKNOWLEDGEMENT

The developers of the PCS model wish to acknowledge the Virginia State Corporation Commission staff for their valuable assistance.

The support of Commissioners Preston C. Shannon, Junie L. Bradshaw and Thomas P. Harwood, Jr., is gratefully acknowledged.

PART I
DESCRIPTION OF THE PCS MODEL

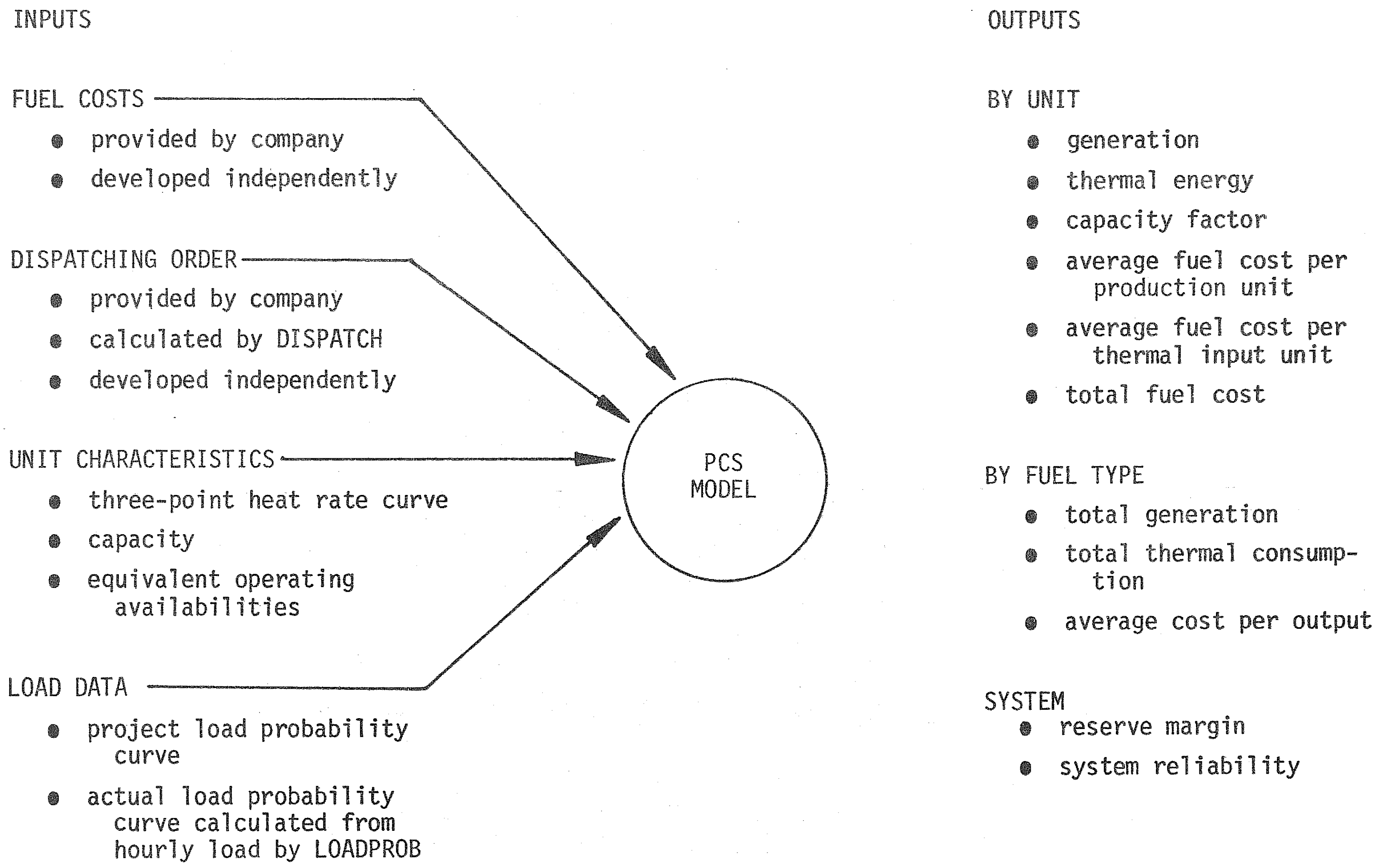
Introduction

The PCS model is comprised of three separate operating modules. the main module, which is referred to as the PCS module, calculates the projected energy generation of each unit as a function of the unit's equivalent availability, capacity, dispatching order and the energy demands on the generating system. These factors as well as heat rate and fuel costs are provided as input to the module[+]. The other two modules are used to calculate input information for the PCS module. One module, DISPATCH, is a dispatching routine which develops a loading order for the generating system so as to minimize cost subject to a minimum load demand value and a spinning reserve margin constraint*. The other module, LOADPROB, is used to calculate a load probability curve from hourly load data.

Figure 1 shows the inputs and their sources for the PCS model and the outputs from the model. Contained in the balance of this section are descriptions of each module and the data files necessary to operate the model.

[+] Contained within most production cost simulation models is the development of a dispatching order. The PCS module requires an input dispatching order. By separating the production projection from the dispatching calculation, the model is easier to use and less expensive to operate.

*The intent of the DISPATCH module is to provide the analyst with a first order dispatching sequence if the utility does not provide one or an alternative loading order.



INPUTS

FUEL COSTS
- provided by company
- developed independently

DISPATCHING ORDER
- provided by company
- calculated by DISPATCH
- developed independently

UNIT CHARACTERISTICS
- three-point heat rate curve
- capacity
- equivalent operating availabilities

LOAD DATA
- project load probability curve
- actual load probability curve calculated from hourly load by LOADPROB

OUTPUTS

BY UNIT
- generation
- thermal energy
- capacity factor
- average fuel cost per production unit
- average fuel cost per thermal input unit
- total fuel cost

BY FUEL TYPE
- total generation
- total thermal consumption
- average cost per output

SYSTEM
- reserve margin
- system reliability

FIGURE 1 PCS Inputs and Outputs

PCS Module

The PCS module can be viewed as having four major operation sections. They are the following:

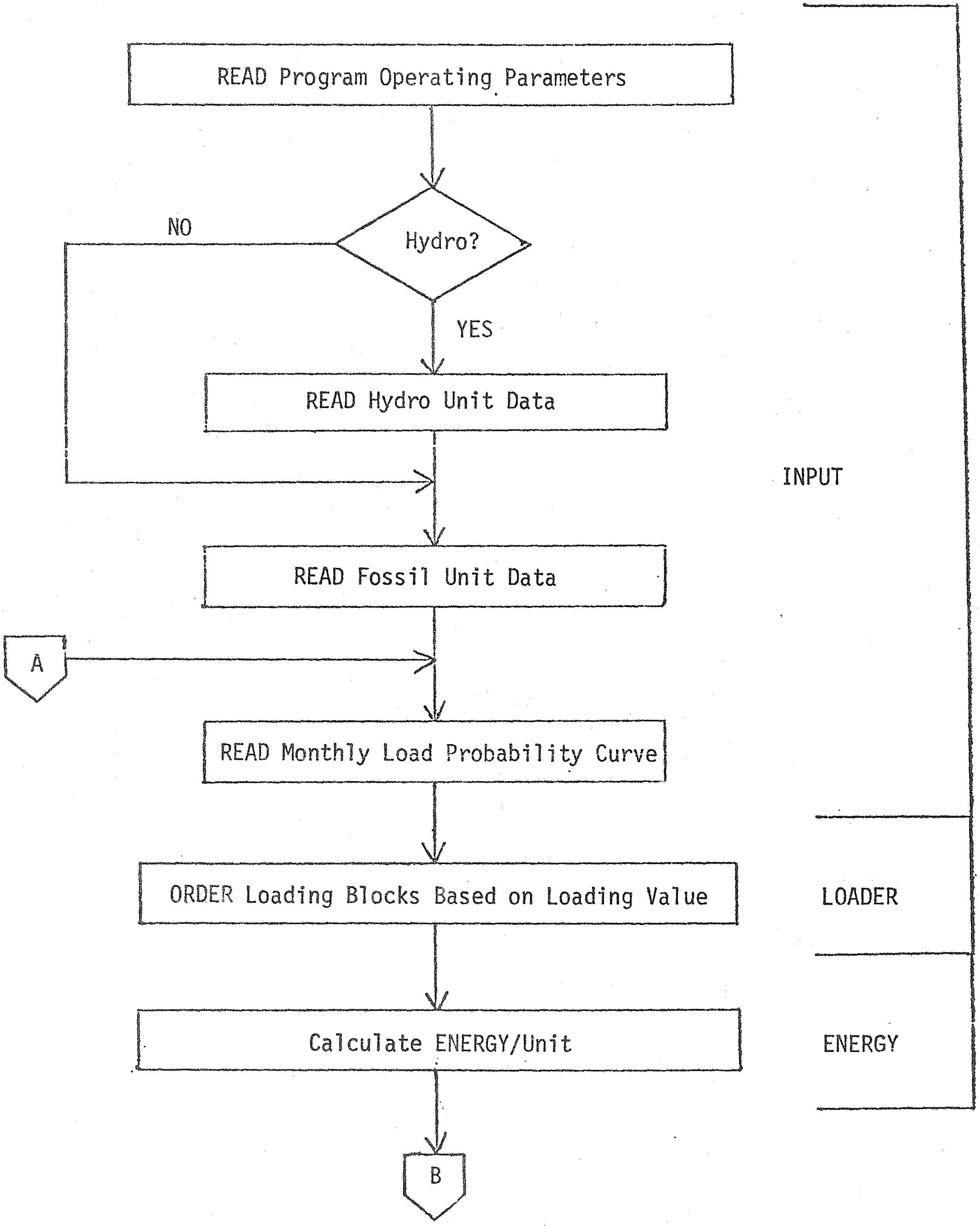
1. INPUT Section -- unit operational and fuel data and system load data are accessed by the program through this section.
2. LOADING Section - the dispatching order of the units is established in this section.
3. ENERGY Section - the projection calculation is performed in this section using a probabilistic technique which is described later in this text.
4. REPORT Section - the output from the model is reported on a monthly, quarterly and study period basis.

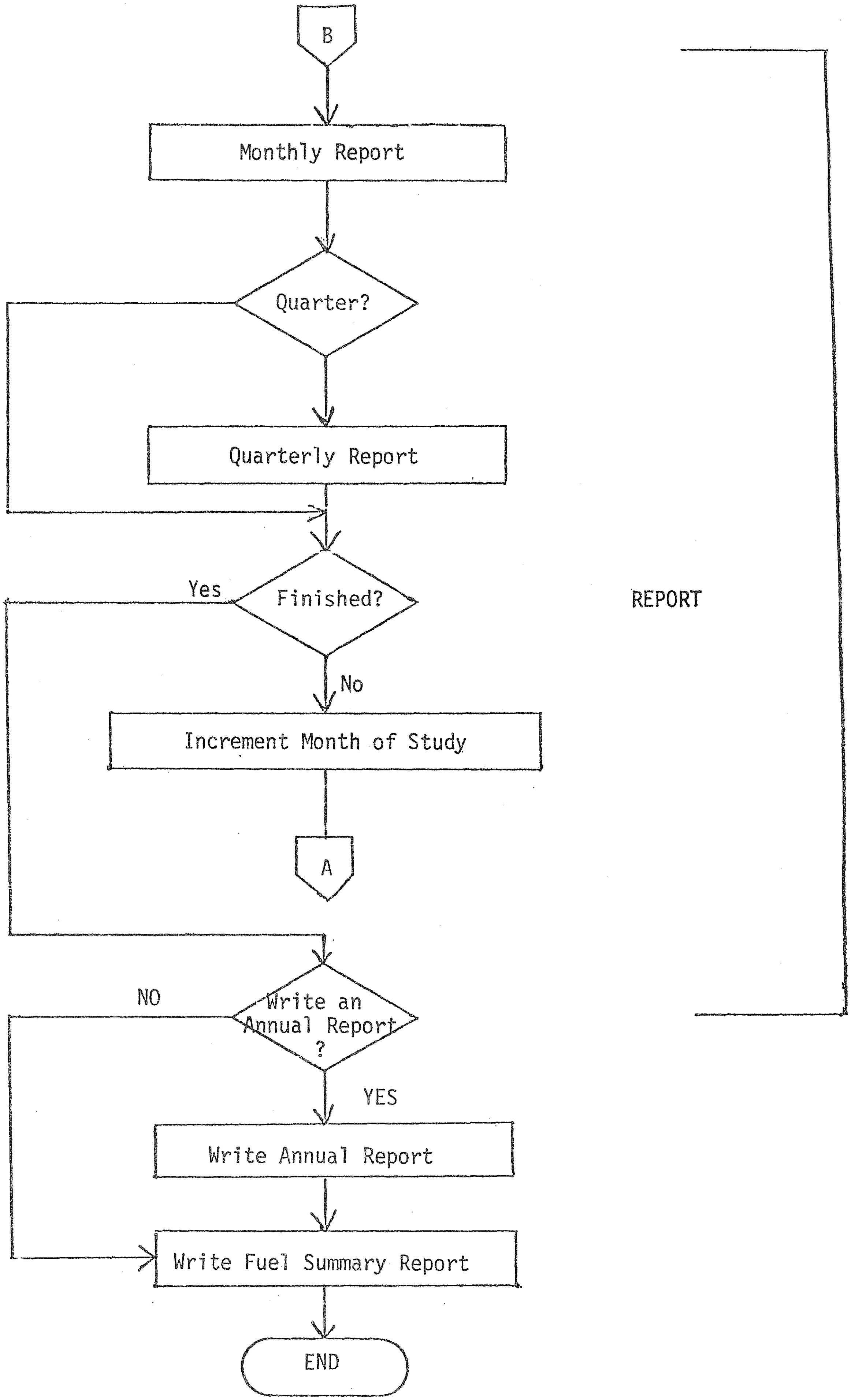
Figure 2 shows the generalized flow diagram of this module with the four operational sections identified.

The data necessary to operate the PCS model is organized into four groups. They are:

1. Unit Operational and Fuel Data for Fossil and Nuclear Units - this file contains unit operational data and fuel cost information data. The data are reported on a monthly basis.
2. Unit Operational Data for the Hydro Units - this file contains monthly capacity and projected generation for hydro units.
3. Load Data - the model requires monthly load data in the form of a load probability curve.

Figure 2: Flow Diagram of the PCS Module




B
Monthly Report
Quarter?
Quarterly Report
Yes
Finished?
No
Increment Month of Study
A
NO
Write an Annual Report ?
YES
Write Annual Report
Write Fuel Summary Report
END
REPORT

4. User Supplied Data - the model has operational options which the user chooses during execution.

INPUT Section

This section reads the operational and fuel data for each unit for the twelve months of the year. It then stores these values in the appropriate computer variable locations.

In order to calculate the energy generation of each unit the monthly load probability curve is entered into the program through this section.

The user specified operating parameters are also specified through this section.

LOADER Section

The LOADER section of the module orders the loading blocks of each unit by ascending dispatching number. The PCS model is designed to handle unit dispatching with up to three loading steps. That is, each unit can be dispatched in one, two or three loading steps. When a unit is single step dispatched it is put on line at full power. When it is dispatched in two steps it is first loaded to a minimum load capacity then to full capacity. Three step loading is accomplished by first dispatching the unit to a minimum capacity, then to an intermediate capacity and finally to full power.

In this section, the loading order of each generating unit is established. This is accomplished by the loading of each loading step based on an order determined externally to the model and supplied as input to the model as part of the unit operational and fuel data file. This allows the utility company to specify the expected loading order of the units. At times, placing higher cost units earlier in the loading order may better model physical constraints on the system such as environmental consideration.

The use of the DISPATCH module to establish a loading order is discussed in a later section.

ENERGY Section

The purpose of the ENERGY section is to calculate the expected megawatt-hour generation of each unit on line during the month. This calculation is the essence of the PCS model. Also calculated in ENERGY are the loss-of-load probability (LOLP) and the amount of expected energy that the generating system cannot supply to meet the demand.

The energy generated by each unit is calculated by the probabilistic simulation method, which is essentially the same as that developed by Booth[+] and then adapted for use in the WASP program*, except that the load probability curves are expressed by piecewise linear functions rather than Fourier series. A simplified derivation of the calculation method follows.

The generating units of the utility being studied are dispatched to meet the required generation needs of the system as expressed by the load probability curve shown in Figure 3. Assume that the generating system under consideration has N units which are dispatched in one load step in order of their unit numbers to meet the energy demands on the system. Figure 4 illustrates this situation. Suppose, also, for illustrative purposes that each unit is available at all times during the study period.

[+] Booth, R. R., "Power System Simulation Model Based on Probability Analysis," IEEE Trans. on Power Apparatus and Systems, Vol. PAS-91, No. 1, pp 62-69 (Jan.-Feb. 1972).

* Jenkins, R. T., and D. S. Joy, "Wien Automic System Planning Package (WASP) - An Electric Utility Optimal Generation Expansion Planning Computer Code," ORNL 4945, Oak Ridge National Laboratory, Oak Ridge Tennessee, July 1974.

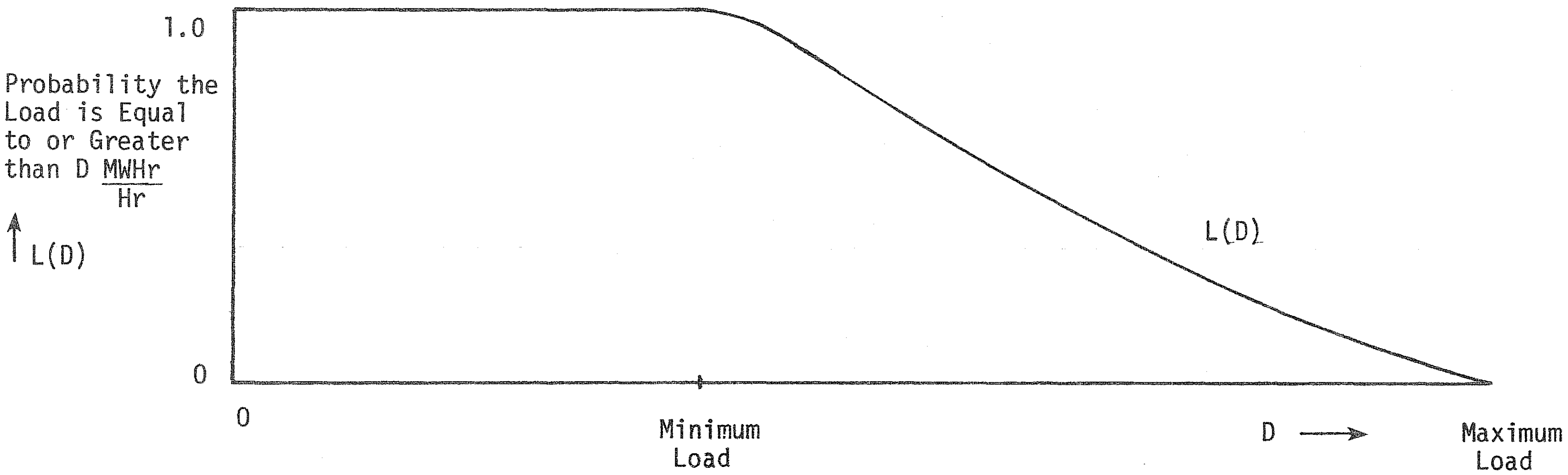


Figure 3 Load Probability Curve

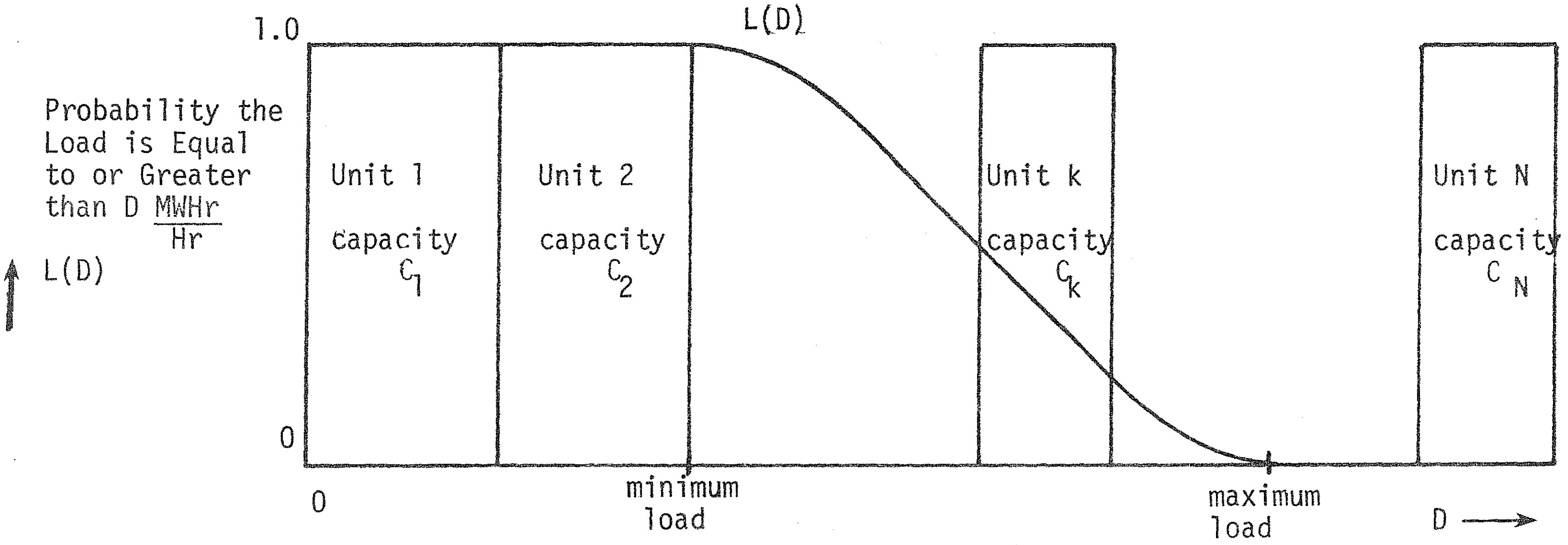


Figure 4 Load Probability Curve with Generating Units Dispatched to Meet the Load

The expected energy output of each unit is the area of intersection of the unit's location in the loading order and the load probability curve. Expressed in mathematical terms the expected energy generation of each unit is

$$ENG_k = T_p p_k \int_{\sum_{j=1}^{k-1} C_j}^{\sum_{j=1}^{k} C_j} L_o(D)\, dD \qquad (1)$$

where p_k is the availability of the k^{th} unit (for this case p_k=1.0), ENG_k is the expected generation of the k^{th} unit, T_p is the number of the hours in the study period, and C_j is the megawatt capacity of the j^{th} unit in the loading order.

If all units in an operating system were available 100% of the time the calculation of expected generation would be straightforward and simple. However, units are available less than 100% during a study period. This effect must be accounted for.

Assume that the availability of Unit 1 becomes zero. Physically the other operating units would shift up (to the left) in the loading order to compensate for the lost generation from Unit 1. The expected generation of the remaining units, assuming a 100% availability, can be calculated using Equation 1 with the modification to the limits of integration based on the fact that Unit 1 is not available. Mathematically the unavailability of Unit 1 can be accounted for in two ways. The first involves removing Unit 1 from the loading order, then dispatching the remaining units against the load probability curve. The second method is to shift the load probability curve to the right by the capacity of Unit 1. This is illustrated in Figure 5. The expected generation of the remaining units can be calculated by integrating the curve $L_o(D-C_1)$ over their loading range.

In reality all units have an availability range between zero and 100%. To account for this an equivalent load probability curve is defined which weights the percentage of time that a unit is on- and off-line. In the case of Unit 1 the equivalent load probability curve is defined by

$$L_1(D) = p_1 L_o(D) + (1-p_1)\ L_o(D-C_1) \qquad (2)$$

where p_1 is the availability of Unit 1 expressed as a fraction, $L_o(D)$ is the original load probability curve, and $L_1(D)$ is the equivalent load probability curve which is created because of the unavailability of Unit 1. Figure 6 illustrates this curve.

The expected energy generation for Unit 2 is calculated using the equivalent load probability curve $L_1(D)$ in Equation 1.

The equivalent load probability curve, which expresses the effect of the absence of Unit 2 on the expected generation of units in the loading order after Unit 2, is

$$L_2(D) = p_2 L_1(D) + (1-p_2)\ L_1(D-C_2) \qquad (3)$$

Equation 3 can be written in the general form which expresses the k^{th} equivalent load probability curve as

$$L_k(D) = p_k\ L_{k-1}(D) + (1-p_k)\ L_{k-1}(D-C_k) \qquad (4)$$

The expected energy generation of the k^{th} units is the area of intersection of the k^{th} unit's position in the loading order with the $L_{k-1}(D)$

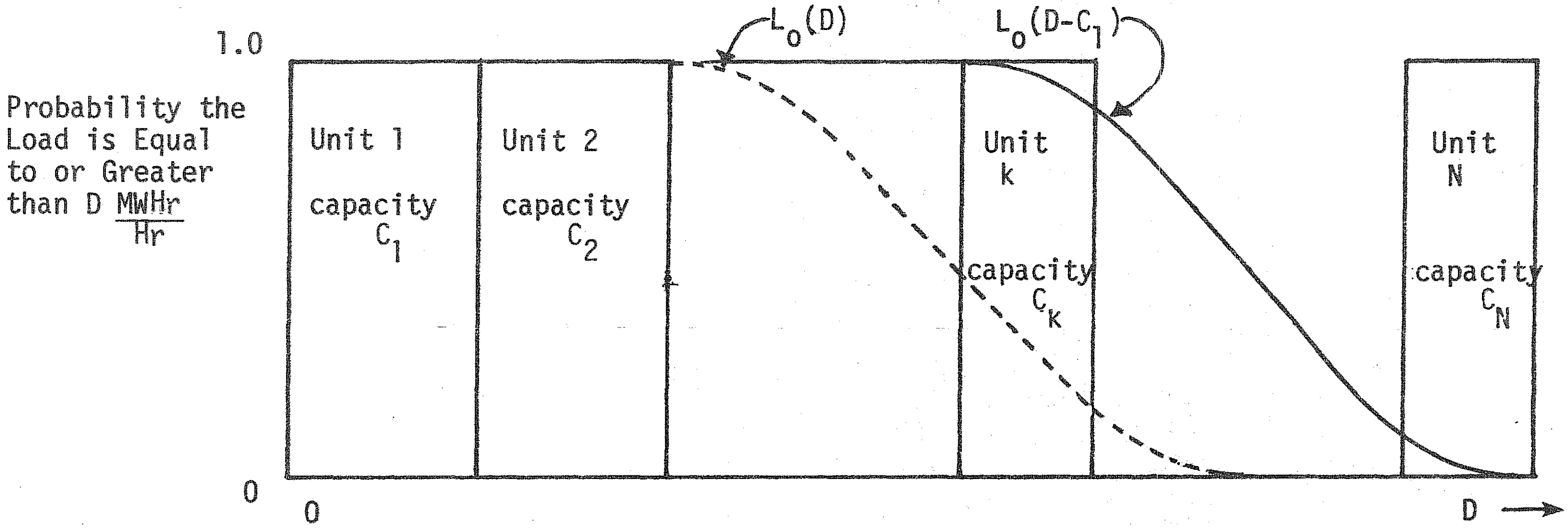


Figure 5 Load Probability Curve Shifted by the Capacity of Unit 1

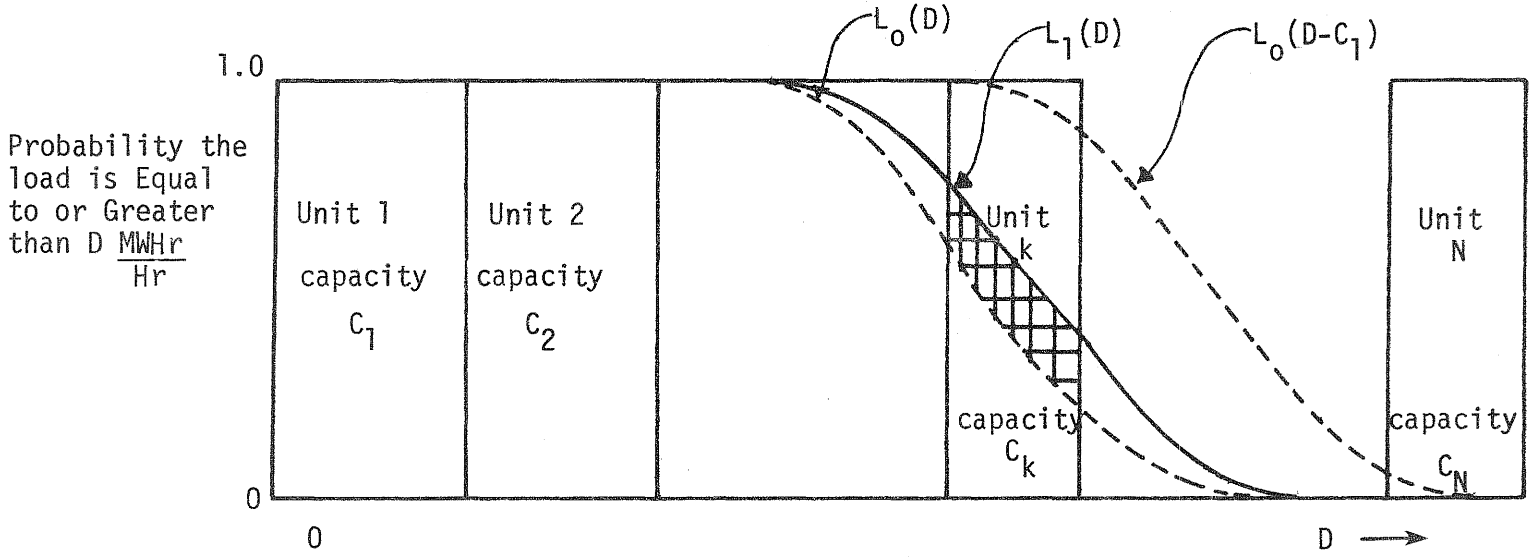


Figure 6 Equivalent Load Probability Curve

equivalent load probability curve times the availability of the k^{th} unit, p_k, and times the number of hours in the period. Expressed mathematically this is

$$ENG_k = T_p \, p_k \int_{\sum_{j=1}^{k-1} C_j}^{\sum_{j=1}^{k} C_j} L_{k-1}(D) \, dD \qquad (5)$$

Using the equivalent load probability curve for the N^{th} unit, the amount of expected unserved energy and the loss-of-load probability are calculated as shown in Figure 7. The shaded area of the curve $L_n(D)$ is the area of the curve which does not intersect with any of the units in the generating system. This then is the energy which is to be supplied by the utility but cannot be supplied by the generating system. The loss-of-load probability is the value of $L_N(D)$ at D equal to system generating capacity.

The unserved energy can be calculated from

$$UNENG = T_p \int_{SYSCAP}^{\infty} L_N(D) \, dD \qquad (6)$$

or more simply from

$$UNENG = T_p \int_{o}^{\infty} L_o(D) \, dD - \sum_{j=1}^{N} ENG_j \qquad (7)$$

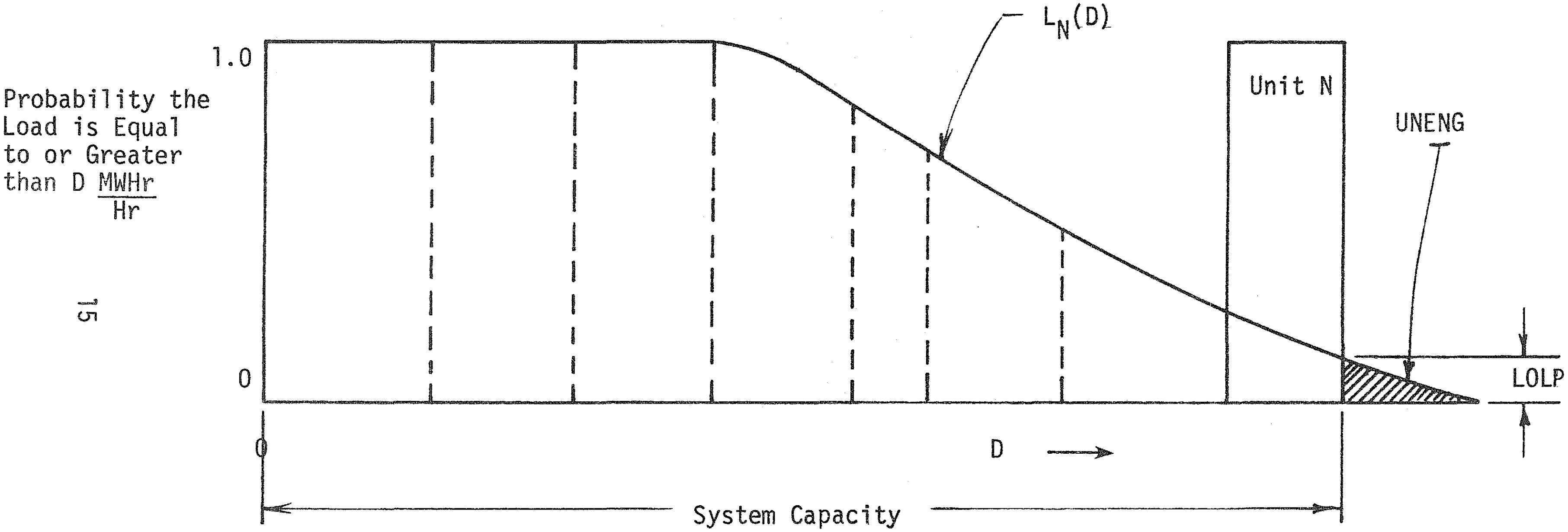


Figure 7 Unserved Energy and LOLP

Where the first term in Equation 7 is the total energy the system must supply and the second term is the total energy generated by the N generating units. The PCS model calculates unserved energy using Equation 7.

The above derivation lacks completeness in that each unit is dispatched in one load step. The method as presented can be applied to multiple loading steps if one assumes that the availability of any loading block is independent of any other block. In reality this is not the case. In order to model reality a deconvolution technique is utilized. A detailed derivation of the deconvolution technique and the total technique is given in Appendix A.

REPORT Section

The REPORT section provides the model's output information to the user. The parameters printed by the REPORT section consist of echoing some operational parameters and fuel cost parameters that were read into the model by the INPUT section as well as parameters which can be calculated as a multiple of energy generation.

Reports are printed on a monthly, quarterly and period of study basis. The user can select the frequency of reports. Figures 8 and 9 show sample output reports. Figure 10 shows the default report which is a summary for the study period of fuel usage by month.

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    THE VIRGINIA STATE CORPORATION COMMISSION'S
    PRODUCTION COST SIMULATION (PCS) MODEL

    STUDY TITLE:  LOADING-3B 3C 3P 1H  VEPCO 1979 PLANT AND  REVISED LOAD DATA


                                         VIRGINIA ELECTRIC POWER CO.

                                       EXPECTED UNIT OPERATING CHARACTERISTICS DURING
                                                        JAN, 1979
                                AVERAGE TOTAL                                           OPERATING          WEIGHTED
                                  FUEL   FUEL   THERMAL    ELECTRIC   AVERAGE  CAPACITY  AVAIL-    UNIT    AVERAGE       LAMDAS
                     LOAD  FUEL   COST   COST    ENERGY   GENERATION HEAT RATE  FACTOR  ABILITY  CAPACITY FUEL COST    HL  3Q  FL
    UNIT NAME        TYPE  TYPE ($/MWH) ($000)  (MMBTU)      (MWH)   (BTU/KWH)  (PCT)    (PCT)     (MW)  (CTS/MMBTU)

CUSHAW HYDRO         HYDR  HYDR  0.0       0.0         0.       714.        0.   24.0  100.0          4.      0.0       0   0   1
NORTH ANNA 1         BASE  NUCL  4.76   2532.3   6206566.    531604.    11675.   78.8   78.9        907.     40.80      4  15  16
SURRY 1              BASE  NUCL  3.93   2040.3   6004349.    519214.    11564.   90.0   90.5        775.     33.98      5  17  18
SURRY 2              BASE  NUCL  4.98   2766.1   6428365.    555664.    11569.   96.4   97.8        775.     43.03      6  22  23
MT. STORM 3          BASE  COAL 12.25   3807.4   3369372.    310858.    10839.   74.6   77.3        560.    113.00      7  24  27
MT. STORM 1          BASE  COAL            0.0         0.         0.                         0.0        553.
MT. STORM 2          BASE  COAL 11.91   3524.5   3118986.    295867.    10542.   71.9   75.2        553.    113.00      9  26  29
PURCHSE POWER AEP    HYDR  HYDR  0.0       0.0         0.    415950.        0.   69.9  100.0        800.      0.0       0   0  10
BREMO 4              BASE  COAL 15.68   1666.0   1067975.    106252.    10051.   87.1   92.4        164.    156.00     11  30  31
BREMO 3              CYCL  COAL 18.83    915.4    586800.     48626.    12068.   90.8   97.2         72.    156.00     12  32  34
CHESTERFIELD 6       CYCL  COAL 20.04   3038.0   1651069.    151572.    10893.   31.0   35.3        658.    184.00     13  36  37
CHESTERFIELD 5       CYCL  COAL 20.83    696.0    378274.     33416.    11320.   13.5   14.9        333.    184.00     14  33  35
YORKTOWN 1           BASE  HOIL 20.21   2228.7   1125615.    110256.    10209.   89.3  100.0        166.    198.00     21  38  39
ROANOKE RAPIDS       HYDR  HYDR  0.0       0.0         0.     58755.        0.   79.0  100.0        100.      0.0       0   0  30
GASTON               HYDR  HYDR  0.0       0.0         0.     55181.        0.   33.0  100.0        225.      0.0       0   0  35
YORKTOWN 3           BASE  HOIL 20.12   4494.7   2270077.    223406.    10161.   36.7   54.0        818.    198.00     40  41  42
PORTSMOUTH 3         BASE  HOIL 18.16    949.9    524796.     52297.    10035.   43.4   78.3        162.    181.00     43  44  59
PORTSMOUTH 4         BASE  HOIL 18.87     28.7     15859.      1521.    10424.    0.9    1.7        233.    181.00     45  46  58
POSSUM POINT 4       BASE  HOIL 17.77   1806.7   1032420.    101653.    10156.   58.6   97.9        233.    175.00     47  48  49
POSSUM POINT 5       CYCL  HOIL 24.38   6172.6   2529773.    253235.     9990.   42.3   97.0        805.    244.00     50  51  52
YORKTOWN 2           CYCL  HOIL 22.15    485.4    245127.     21914.    11186.   17.3   60.4        170.    198.00     53  54  63
CHESTERFIELD 4       BASE  HOIL            0.0         0.         0.                         0.0        166.
POSSUM POINT 3       BASE  HOIL 18.65    360.1    205790.     19313.    10655.   25.7   93.6        101.    175.00     60  61  62
PORTSMOUTH 1         BASE  HOIL 22.05    354.7    195951.     16087.    12181.   21.4   88.3        101.    181.00     64  65  66
CHESTERFIELD 3       BASE  HOIL 20.92    312.6    168987.     14943.    11309.   20.1   91.4        100.    185.00     67  68  69
PORTSMOUTH 2         CYCL  HOIL 20.12    277.3    153212.     13783.    11116.   18.3   92.7        101.    181.00     70  71  72
POSSUM POINT 2       CYCL  HOIL 22.80    192.0    109699.      8421.    13026.   16.4   92.4         69.    175.00     73  74  77
POSSUM POINT 1       CYCL  HOIL 22.27    202.8    115912.      9107.    12728.   16.5   99.6         74.    175.00     75  76  81
CHESTERFIELD 2       CYCL  HOIL 26.46    193.0    104344.      7295.    14303.   13.4   86.2         73.    185.00     78  79  80
CHESTERFIELD 1       CYCL  HOIL 30.31    127.8     69072.      4216.    16383.   10.1   71.2         56.    185.00     82  83  84
MT. STORM ICEN 1     PEAK  GASO            0.0         0.         0.                         0.0         12.
LOWMOOR ICEN 1-4     PEAK  LOIL 47.85    183.0     61204.      3824.    16005.    8.6   63.6         60.    299.00     94  95  96
NORTHERN NECKICEN1-4 PEAK  LOIL 47.84    185.1     61913.      3869.    16001.    8.1   63.6         64.    299.00     97  98  99
SURRY ICEN 1,2       PEAK  LOIL 50.85    109.7     36685.      2157.    17008.    7.8   63.6         37.    299.00    100 101 102
POSSUM POINT ICEN1-6 PEAK  LOIL 46.10    197.4     66004.      4281.    15419.    7.4   63.6         78.    299.00    103 104 105
PORTSMOUTH ICEN 1346 PEAK  LOIL 50.89    155.4     51981.      3054.    17020.    6.8   63.6         60.    299.00    106 111 112
PORTSMOUTH ICEN 7-10 PEAK  LOIL 50.89    209.2     69981.      4112.    17020.    6.6   63.6         84.    299.00    107 113 114
KITTY HAWK ICEN 1,2  PEAK  LOIL 54.66    110.6     36975.      2023.    18280.    6.2   63.6         44.    299.00    115 116 117
TOTALS                          11.74  40323.4  38062880.   3964396.    11085.   55.4              9615.    105.94
UNSERVED ENERGY       (MWH)      39442.
TOTAL ENERGY REQUIRED (MWH)    4003838.
```

Figure 8 Unit Projected Generation and Fuel Cost Information

```
JAN ,1979--DEC ,1979 PROJECTED GENERATION AND FUEL USE SUMMARY
FOR VIRGINIA ELECTRIC POWER CO.

SYSTEM PARAMETERS BY FUEL TYPE:

                THERMAL       ELECTRIC                    AVERAGE     AVERAGE
                ENERGY         ENERGY       FUEL COST    HEAT RATE     COST
                (MMBTU)        (MWH)         ($000)     (BTU/KWH)    ($/MWH)

      COAL    165022688.     14971061.      236365.      11023.       15.79
      NUCL    167947552.     14450350.       66249.      11622.        4.58
      LOIL      9310090.       558842.       30669.      16660.       54.88
      HOIL    108123952.     10543981.      264253.      10255.       25.06
      GASO       235787.        12866.         789.      18327.       61.36
      HYDR                     817760.
      TOTALS  450636288.     41354576.      598325.      11117.       14.76
SYSTEM PARAMETERS BY LOAD TYPE:

                THERMAL       ELECTRIC                    AVERAGE     AVERAGE
                ENERGY         ENERGY       FUEL COST    HEAT RATE     COST
                (MMBTU)        (MWH)         ($000)     (BTU/KWH)    ($/MWH)

      BASE    353598464.     31964608.      372348.      11062.       11.65
      CYCL     87495408.      8000725.      194518.      10936.       24.31
      PEAK      9545877.       571707.       31458.      16697.       55.03
      HYDR                     817760.
      TOTALS  450636288.     41354576.      598325.      11117.       14.76

SYSTEM GENERATION PARAMETERS:

TOTAL THERMAL ENERGY       (MMBTU)  450636288.
TOTAL ELECTRICAL GENERATION (MWH)    41354576.
TOTAL FUEL COST             ($000)     598325.
TOTAL UNSERVED ENERGY        (MWH)    1404350.
TOTAL ENERGY REQUIRED        (MWH)   42758912.
```

Figure 9 System Projected Generation and Fuel Information

```
JAN, 1979 -- DEC, 1979 MONTHLY FUEL USAGE SUMMARY
FOR VIRGINIA ELECTRIC POWER CO.

                      JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP      OCT      NOV      DEC      TOTL

COAL
  ENERGY  (GWH)       947.     950.    1090.    1138.    1090.    1006.    1413.    1297.    1242.     899.     845.    1163.   13080.
  COST  (KILO$)     13647.   15086.   17435.   15098.   14799.   14921.   19965.   18431.   17963.   12301.   11703.   16995.  188345.
  COST  ($/MWH)      14.42    15.88    15.99    13.26    13.57    14.83    14.13    14.21    14.47    13.68    13.85    14.62    14.40

NUCL
  ENERGY  (GWH)      1606.    1052.     830.       0.     562.     597.     600.     498.     484.     905.    1299.    1820.   10252.
  COST  (KILO$)      7339.    4603.    3744.       0.    2675.    2846.    2858.    2272.    2208.    3798.    5664.    8311.   46317.
  COST  ($/MWH)       4.57     4.37     4.51      0.0     4.76     4.76     4.76     4.57     4.57     4.20     4.36     4.57     4.52

LOIL
  ENERGY  (GWH)        23.      59.      36.      47.      31.      66.      42.      82.      72.      25.      17.       9.     509.
  COST  (KILO$)      1150.    3046.    2058.    2759.    1929.    5168.    3227.    6272.    5313.    1866.    1319.     707.   34816.
  COST  ($/MWH)      49.33    51.38    57.13    58.16    63.19    77.79    77.51    76.73    73.98    76.02    77.30    79.05    68.42

HOIL
  ENERGY  (GWH)       857.    1325.     955.    1215.     797.    1064.    1113.    1203.     745.     731.     595.     334.   10934.
  COST  (KILO$)     18187.   28835.   23471.   31964.   21050.   31542.   38090.   43182.   26568.   26662.   21913.   12540.  324003.
  COST  ($/MWH)      21.21    21.76    24.57    26.32    26.42    29.64    34.22    35.91    35.67    36.49    36.82    37.49    29.63

GASO
  ENERGY  (GWH)         0.       0.       0.       2.       1.       2.       1.       2.       2.       1.       1.       0.      12.
  COST  (KILO$)         0.       0.       0.     112.      82.     202.     128.     173.     153.      57.      41.      22.     969.
  COST  ($/MWH)        0.0      0.0      0.0    71.03    77.75    97.34    96.95    69.51    68.64    68.64    69.80    71.41    77.77

HYDR
  ENERGY  (GWH)       531.     337.     332.     592.     630.     520.     586.     633.     611.     637.     623.     618.    6648.
  COST  (KILO$)         0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.       0.
  COST  ($/MWH)        0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0


TOTALS FOR FUELS:
 GENERATED
  ENERGY (GWH)       3964.    3724.    3243.    2994.    3110.    3256.    3755.    3714.    3155.    3197.    3379.    3944.   41435.
 COST  (KILO$)      40323.   51570.   46708.   49933.   40535.   54679.   64267.   70330.   52206.   44685.   40639.   38576.  594450.
 COST  ($/MWH)       11.74    15.23    16.04    20.79    16.34    19.98    20.28    22.83    20.52    17.46    14.74    11.60    17.09

UNSERVED
 ENERGY  (GWH)         39.     142.      77.      87.      50.     204.     116.     286.     234.      43.      30.      15.     184.

TOTAL
 ENERGY  (GWH)       4004.    3866.    3320.    3081.    3160.    3460.    3870.    4000.    3389.    3240.    3410.    3959.   41619.
```

Figure 10 Fuel Usage Summary by Month for the Study Period

DISPATCH Module

The DISPATCH module is a separate program which to a first order approximation develops an economic dispatching order subject to a minimum capacity on-line constraint. This module is used to provide the user with an alternative loading to that provided as part of the generating unit files or an initial loading order.

A flow diagram of the DISPATCH model is shown in Figure 11. The module uses the hydro and fossil/nuclear plant files as input. Information contained in these files is used to calculate a dispatching cost for each fossil and nuclear unit loading step. If hydro units exist in the generating system, additional costing information is requested by the programs for each month.

For each month, the program requests the minimum amount of capacity that is to be on-line. This value is used to simulate the backing off of base loaded units to meet night time loads (minimum) loads. The program loads the first loading blocks of the least costly units until the minimum load is reached.

If a unit has zero equivalent availability for the month its capacity is not included in the capacity on-line which meets the minimum loading requirements. However, that unit is positioned in the loading order based on its cost.

Having met the minimum loading requirement, the program proceeds to load the remaining loading steps. This is accomplished by first combining the information contained in the loading array by load step into one cost array, one unit array and one load step array. The unit array and the load step array are ordered by increasing cost using the cost array.

At this point the remaining load steps are ordered by cost; however, the loading order may now imply the physically impossible situation where the loading steps for a single unit are not in numerical sequence. The program adjusts the cost-ordered loading sequence to ensure that the physical loading sequence is correct.

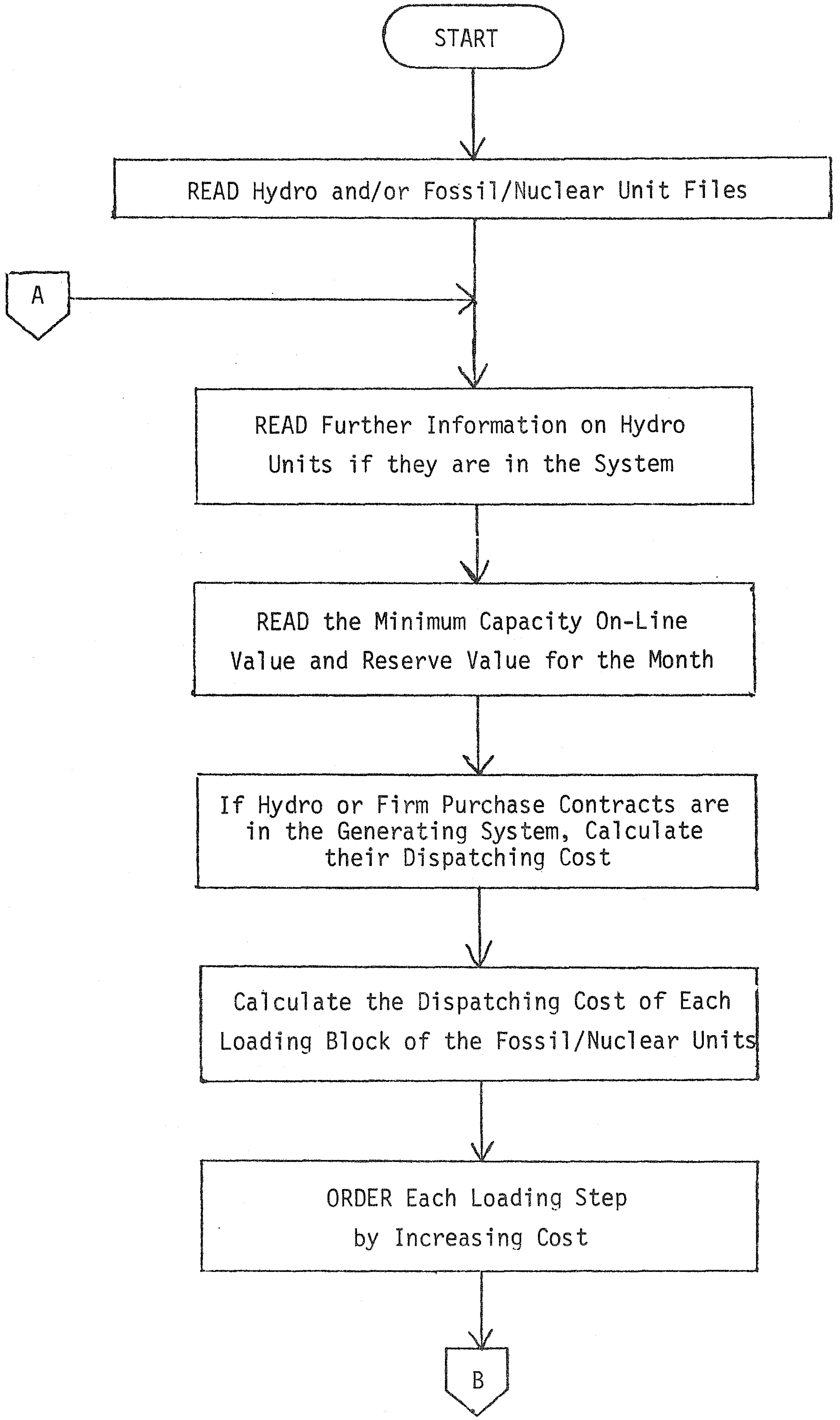
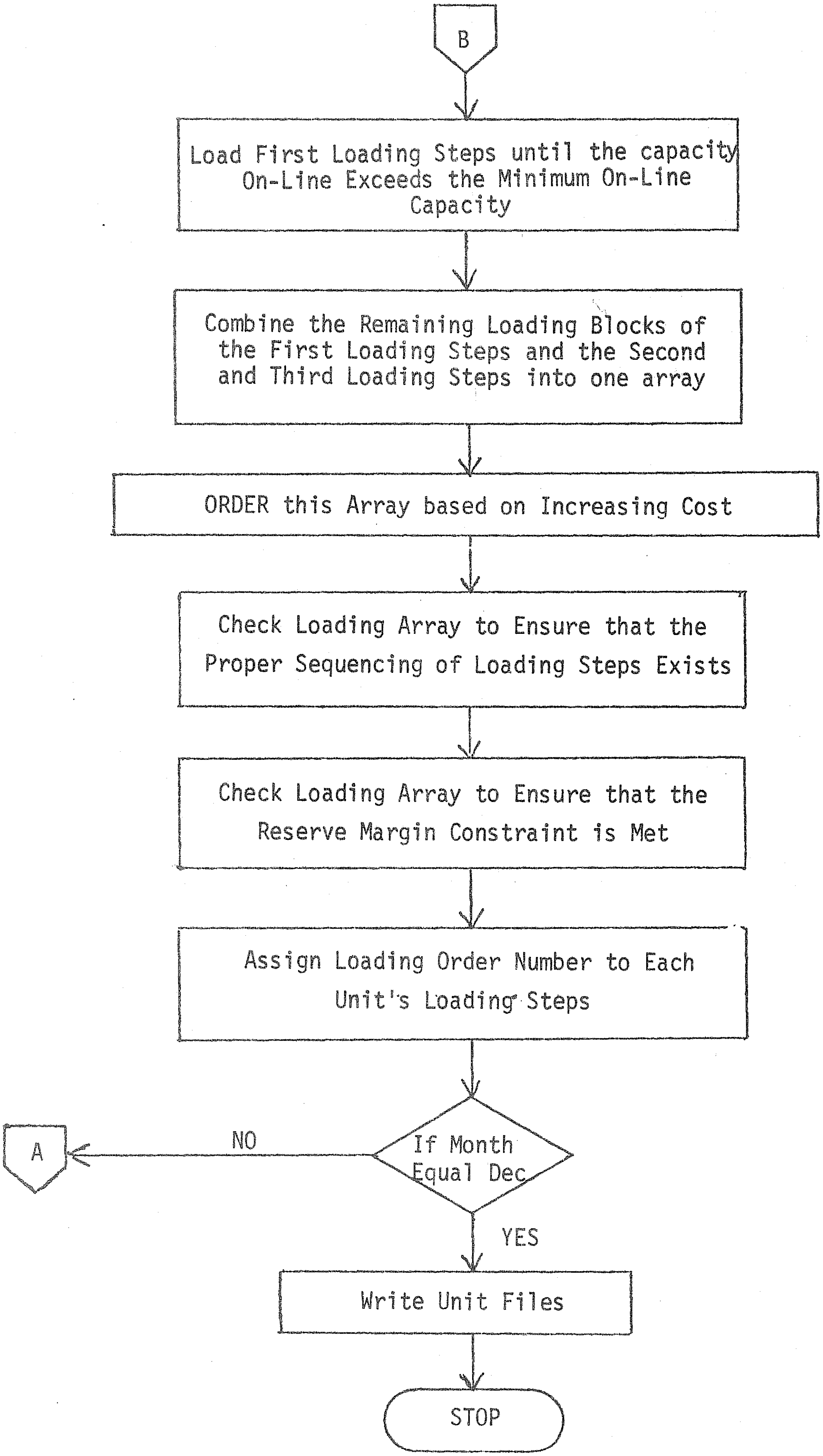


Figure 11 Flow Diagram of the DISPATCH Module


B
Load First Loading Steps until the capacity On-Line Exceeds the Minimum On-Line Capacity
Combine the Remaining Loading Blocks of the First Loading Steps and the Second and Third Loading Steps into one array
ORDER this Array based on Increasing Cost
Check Loading Array to Ensure that the Proper Sequencing of Loading Steps Exists
Check Loading Array to Ensure that the Reserve Margin Constraint is Met
Assign Loading Order Number to Each Unit's Loading Steps
If Month Equal Dec
NO
A
YES
Write Unit Files
STOP

Finally, the loading order is adjusted subject to the reserve margin constraint. This constraint is designed to keep the available generating reserve on-line above the reserve margin value entered by the user. When the available reserve value drops below the reserve constraint the program searches the loading order to find the first loading block of a unit. This block is then loaded to increase the available reserve. If all the first loading steps have been dispatched, this constraint cannot be met and, the remaining load steps are then dispatched without regard to reserve.

The loading of each step having been completed, loading positive numbers are assigned to each load step of each unit. The first block loaded is assigned the number five. The second is assigned the number ten. Subsequent steps are incremented by five. Avoiding consecutive numbers allows for ease of adjusting load positions at the user's discretion.

The above process is carried out for each month of the year. After this is accomplished the fossil/nuclear file and the hydro file are written to disk space as new files. This allows the user to maintain the old files with their loading orders.

LOAD PROBABILITY Module

The purpose of the LOAD PROBABILITY module is to calculate a load probability curve for each month from hourly load data. This module is to be used when the utility can supply the hourly load data in the format defined by the Edison Electric Institute.

The flow diagram of the module is shown in Figure 12. The module reads the hourly loads for the period. These load values are stored in an array which views the year as twelve months, each having 31 days. Days which do not exist have zero loads which the program bypasses.

Having read the hourly loads the program calculates the load probability curve for each month in the study period. The load probability curve provides the information on the portion of time the load represented by the hourly loads meets or exceed a given value. Representative load probability curves are shown in the section of this manual which describes the PCS module.

When the load probability curve is calculated it is written to disk space for use in the PCS module.

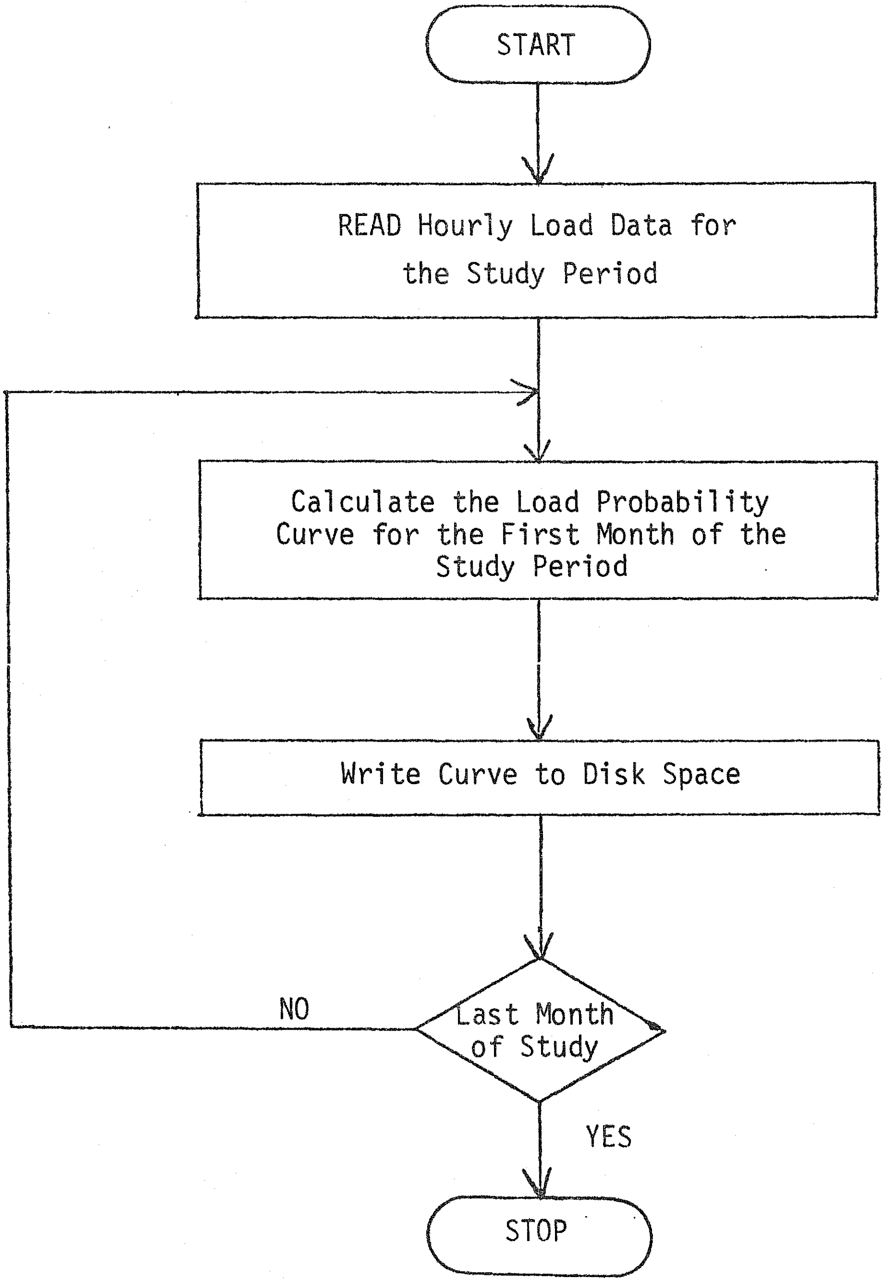


Figure 12 Flow Diagram of the LOAD PROBABILITY Module

INPUT Files

Unit Operational and Fuel Data Files

These data are divided into two separate files, one for fossil and nuclear units and the other for hydro units.

Each file contains unit operation data. The data in this file is used by the LOADER, ENERGY and REPORT sections of the PCS module. For each generating unit there are 13 records or computer cards containing information. The first record contains information about the unit, which does not change from month to month. The following 12 records contain monthly operating information. One record is used for each month.

Figure 13 shows the format for the fossil unit file. Figure 14 shows the format for the hydro unit file. Appendix B contains a description of the data elements.

Load Data Files

The PCS module requires that the load data be presented in the format of a load probability curve. This curve expresses the fraction of time the load meets or exceeds a given load value. The LOADPROB module is used to calculate the load probability curve from hourly loads in the format used to report these loads to the Edison Electric Institute.

VIRGINIA STATE CORPORATION COMMISSION'S PRODUCTION COST SIMULATION (PCS) MODEL REPORTING FORM

NUCLEAR AND FOSSIL UNIT DATA FILE

COMPANY	
UNIT NAME	DATE

												FUELS					ON-LINE			OFF-LINE				ANNUAL				CAPACITY						
C N		VSCC NUMBER		UNIT NAME		FRAC. OWNED		UT		LT		P		A		I	MO		YEAR	MO		YEAR		EQUIV. AVAIL		CAPACITY COST		WIN		SUM				
*	X		X		X		X		X		X		X		X			X			X		X		X		X		X					

						CAPACITY AND HEAT RATE BY LOADING BLOCK										MONTHLY		FUEL COST				FRAC.		DISPATCHING ORDER BY LOADING BLOCK			
						BLOCK 1				BLOCK 2				BLOCK 3		EQUIV.						GEN.					
	MO		YR		VSCC NUMBER	MW1		HTRT1		MW2		HTRT2		MW3		HTRT3		AVAIL.		PRIMARY		SECONDARY		BY PRI.		BK1		BK2		BK3
*	1	X		X		X		X		X		X		X		X		X		X		X		X		X		X
*	2	X		X		X		X		X		X		X		X		X		X		X		X		X		X
*	3	X		X		X		X		X		X		X		X		X		X		X		X		X		X
*	4	X		X		X		X		X		X		X		X		X		X		X		X		X		X
*	5	X		X		X		X		X		X		X		X		X		X		X		X		X		X
*	6	X		X		X		X		X		X		X		X		X		X		X		X		X		X
*	7	X		X		X		X		X		X		X		X		X		X		X		X		X		X
*	8	X		X		X		X		X		X		X		X		X		X		X		X		X		X
*	9	X		X		X		X		X		X		X		X		X		X		X		X		X		X
*	10	X		X		X		X		X		X		X		X		X		X		X		X		X		X
*	11	X		X		X		X		X		X		X		X		X		X		X		X		X		X
*	12	X		X		X		X		X		X		X		X		X		X		X		X		X		X

* Key punch only the lines marked with an asterisk.

X Represents a blank.

Figure 13 Nuclear and Fossil Unit Data File Format

VIRGINIA STATE CORPORATION COMMISSION'S PRODUCTION COST SIMULATION (PCS) MODEL REPORTING FORM

COMPANY

UNIT

DATE

HYDRO UNIT DATA FILE

			VSCC				FRAC										ON-LINE				OFF-LINE				CAPACITY		CAPACITY			
	C N		NUMBER		UNIT NAME		OWNED		UT		LT		HT		P		MO		YEAR		MO		YEAR		COST		MAX		MIN	
*		X		X		X		X		X		X		X		X		X		X		X		X		X		X		X

					VSCC		CAPACITY LOADING BLOCKS						DISPATCHING ORDER						GENERATION		PUMPING		AVE. PUMP.	
	MO		YR		NUMBER		MW1		MW2		MW3		BK1		BK2		BK3		BY UNIT		ENERGY		COST	
*	1	X		X		X		X		X		X		X		X		X		X		X	.	X
*	2	X		X		X		X		X		X		X		X		X		X		X	.	X
*	3	X		X		X		X		X		X		X		X		X		X		X	.	X
*	4	X		X		X		X		X		X		X		X		X		X		X	.	X
*	5	X		X		X		X		X		X		X		X		X		X		X	.	X
*	6	X		X		X		X		X		X		X		X		X		X		X	.	X
*	7	X		X		X		X		X		X		X		X		X		X		X	.	X
*	8	X		X		X		X		X		X		X		X		X		X		X	.	X
*	9	X		X		X		X		X		X		X		X		X		X		X	.	X
*	10	X		X		X		X		X		X		X		X		X		X		X	.	X
*	11	X		X		X		X		X		X		X		X		X		X		X	.	X
*	12	X		X		X		X		X		X		X		X		X		X		X	.	X

* Key punch only the lines marked with an asterisk.

X Represents a blank.

Figure 14 Hydro Unit Data File Format

The load probability information is provided on a monthly basis in the format shown in Figure 15. The first record for each month gives the month, year, minimum load, maximum load, number of data points to follow and the total generation expressed by the curve. The following records list the y-axis data points, where the first value of 1.000000 corresponds to the minimum load. The last value corresponds to the peak maximum demand during the month. All y-axis values between the first and last are based on uniformly spaced x-axis values. The load spacing is calculated from

$$\text{DELTA} = \frac{(\text{MAXLOAD - MINLOAD})}{\text{POINTS - 1}} \tag{8}$$

where MAXLOAD is the maximum load for the month, MINLOAD is the minimum load for the month and POINTS is the number of points in the curve. For example, the x-axis load spacing (DELTA) for January as shown in Figure 11 is 88.69 MW. The PCS model uses the calculated value of DELTA to calculate the x-axis values of the load probability curve.

User Supplied Data

The user must supply information to the PCS model in order to specify calculation options and provide headings for tables. Listed below is the information the PCS module requires.

```
ENTER THE STUDY TITLE
ENTER COMPANY NAME
ENTER FIRST MONTH OF STUDY (1-12)
ENTER FIRST YEAR OF STUDY
ENTER LAST MONTH OF STUDY  (1-12)
ENTER LAST YEAR OF STUDY
ARE THERE HYDRO UNITS ? (T OR F)
ENTER # LOADING STEPS FOR BASE, CYCLE, & PEAK
ENTER FILE NUMBER FOR OUTPUT REPORTS
REPORT OPTION ? (1-3)
     1 ALL REPORTS
     2 QUARTERLY AND ANNUAL REPORTS
     3 ANNUAL REPORT AND MONTHLY FUEL SUMMARY
     4 MONTHLY FUEL SUMMARY ONLY
```

```
   A  B    C  D        E        F        G

   1 79   50 3024.   7370.    744. 3951534.
  1.000000.9946236.9919354.9892473.9838709.9811828.9717742.9623656.9502688.9435484
  .9381720.9274193.9166666.9032258.8790323.8534946.8239247.8010752.7674731.7338709
H .7096774.6854838.6545699.6276882.5994623.5698925.5322580.4784946.4422043.4045699
  .3709677.3319892.2836021.2500000.2190860.1774193.1451613.1182795.0940860.0793011
  .0524194.0430108.0322581.0201613.0188172.0147849.0120968.0040323.0013441.0013441
```

A - Month

B - Year

C - Number of Points in the Load probability curve

D - Minimum Load

E - Maximum load

F - Number of hours in the month

G - Megawatt hours represented by the curve

H - Load probability values

Figure 15. Load Probability Curve Data

PART II

PCS Model Programs

PCS Module Execution

The PCS module was developed on the Ohio State University's Amdahl 470 computer system, where it was compiled using Fortran H extended. The IBM-compatible operating system allows either batch processing or on-line execution using the Time-Sharing Option (TSO). A representative set of batch-processing instructions is shown in Figure 16, while the corresponding interactive commands are shown in Figure 17. Note that interactive users may wish to allocate FT04F001 to their terminal's keyboard for direct control over the execution parameters, in lieu of allocating it to a disk file. For the logical record length, field definitions, and data content of the other three input files (HYDRO.UNIT.DATA, FOSSIL.NUCLEAR.UNIT.DATA, and LOAD.PROB.DATA), please refer to the file descriptions in Part I of this manual.

DISPATCH Module Execution

The DISPATCH module can be executed either in batch or interactive mode. Figure 18 lists the JCL used at The Ohio State University computer center. Figure 19 lists the TSO commands needed to operate the module.

LOAD PROBABILITY Module Execution

As with the PCS and DISPATCH module the LOAD PROBABILITY module can be executed in batch or interactively. The JCL and TSO command for this module are shown in Figures 20 and 21.

```
 PCS.CNTL
// MSGCLASS=A,REGION=256K,TIME=2
/*JOBPARM DISKIO=4000,LINES=12000,COPIES=1
//S1 EXEC PROC=FORTXCLG,PARM.FORT='XREF,NODECK,OPT(0)',TIME.GO=(1,15)
//SYSPRINT DD SYSOUT=A
//FORT.SYSIN DD DSN=PCS.FORT,DISP=SHR
//GO.FT06F001 DD SYSOUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=665,BUFNO=1)
//GO.FT04F001 DD DSN=USER.INPUT.DATA,DISP=SHR
//GO.FT11F001 DD DSN=HYDRO.UNIT.DATA,DISP=SHR
//GO.FT12F001 DD DSN=FOSSIL.NUCLEAR.UNIT.DATA,DISP=SHR
//GO.FT13F001 DD DSN=LOAD.PROB.DATA,DISP=SHR
//
```

Figure 16 JCL for PCS Module

```
  PCS.CLIST
 PROC 0 TIME(,5)
 TIME
 FREE F(FT04F001 FT06F001 FT11F001 FT12F001 FT13F001)
 ALLOC F(FT04F001) DA(USER.INPUT.DATA) SHR
 ALLOC F(FT06F001) DA(*)
 ALLOC F(FT11F001) DA(HYDRO.UNIT.DATA) SHR
 ALLOC F(FT12F001) DA(FOSSIL.NUCLEAR.UNIT.DATA) SHR
 ALLOC F(FT13F001) DA(LOAD.PROB.DATA) SHR
 FORT PCS.FORT
 LOADGO PCS.OBJ FORTLIB
```

Figure 17 TSO Commands for PCS Module

```
 FORT.CNTL(DISPATCH)
// MSGCLASS=A,REGION=256K
/*JOBPARM DISKIO=4000,LINES=12000
//S1 EXEC PROC=FORTXCLG,PARM.FORT='XREF,NODECK,OPT(0)'
//FORT.SYSIN DD DSN=DISPATCH.FORT,DISP=SHR,
//   DCB=(RECFM=FB,LRECL=80,BLKSIZE=400)
//*  UNIT 5 IS FOR USER SUPPLIED DATA *//
//GO.FT05F001 DD DSN=DISPATCH.USER.INPUT.DATA,DISP=SHR
//* UNITS 11 AND 12 ARE FOR INPUT FROM EXISTING UNIT FILES
//GO.FT11F001 DD DSN=OLD.HYDRO.DATA,DISP=SHR,
//   DCB=(RECFM=FB,LRECL=80,BLKSIZE=400)
//GO.FT12F001 DD DSN=OLD.FOSSIL.NUCLEAR.DATA,DISP=SHR,
//   DCB=(RECFM=FB,LRECL=80,BLKSIZE=400)
//* UNITS 20 AND 21 ARE FOR THE OUTPUT OF THE NEW UNIT FILES
//GO.FT20F001 DD DSN=NEW.HYDRO.DATA,DISP=NEW,
//   DCB=(RECFM=FB,LRECL=80,BLKSIZE=400)
//GO.FT21F001 DD DSN=NEW.FOSSIL.NUCLEAR.DATA,DISP=NEW,
//   DCB=(RECFM=FB,LRECL=80,BLKSIZE=400)
//
```

Figure 18 JCL for DISPATCH Module

```
 DISPATCH.TSO.CLIST
FREE F(FT05F001,FT11F001,FT12F001,FT20F001,FT21F001)
ATTRIB ONE LRECL(80) RECFM(F,B) BLKSIZE(400)
ALLOC F(FT05F001) DA(DISPATCH.USER.INPUT.DATA)
ALLOC F(FT11F001) DA(OLD.HYDRO.DATA)
ALLOC F(FT12F001) DA(OLD.FOSSIL.NUCLEAR.DATA)
ALLOC F(FT20F001) DA(NEW.HYDRO.DATA) NEW USING(ONE)
ALLOC F(FT21F001) DA(NEW.FOSSIL.NUCLEAR.DATA) NEW USING(ONE) -
    TRACKS SPACE(1,1) CATALOG
FORT DISPATCH.FORT
LOADGO DISPATCH.OBJ FORTLIB
```

Figure 19 TSO Commands for DISPATCH Module

```
 LOADPROB.CNTL
00010 // MSGCLASS=A,REGION=256K
00020 /*JOBPARM DISKIO=2000
00030 //S1 EXEC PROC=FORTXCLG,PARM.FORT='XREF,NODECK,OPT(0)'
00040 //FORT.SYSIN DD DSN=LOADPROB.FORT,DISP=SHR
00050 //* UNIT 10 IS FOR HOURLY LOAD DATA
00060 //GO.FT10F001 DD DSN=HOURLY.LOAD.DATA,DISP=SHR
00070 //* UNIT 15 IS FOR THE LOAD PROB OUTPUT
00080 //GO.FT15F001 DD DSN=LOAD.PROB.OUTPUT.DATA,DISP=NEW,
00090 //     DCB=(RECFM=FB,LRECL=80,BLKSIZE=400)
00100 //
```

Figure 20 JCL for LOAD PROBABILITY Module

```
 LOADPROB.TSO.CLIST
00010 FREE F(FT15F001,FT10F001)
00011 ATTRIB ONE LRECL(80) RECFM(F,B) BLKSIZE(400)
00030 ALLOC F(FT10F001) DA(HOURLY.LOAD.DATA) OLD
00040 ALLOC F(FT15F001) DA(LOAD.PROB.OUTPUT.DATA) NEW TRACKS SPACE(1,1) -
00041       USING(ONE) CATALOG
00050 FORT LOADPROB.FORT
00060 LOADGO LOADPROB.OBJ FORTLIB
```

Figure 21 TSO Commands for LOAD PROBABILITY Module

PCS Module Routines

The PCS module contains a Main routine and 27 subroutines. Figure 22 shows the name of each subroutine in their calling sequence.

This section contains a description of each subroutine, a list of variables and their definitions, and a flow chart for each one. Appendix C contains a complete source listing of the PCS module.

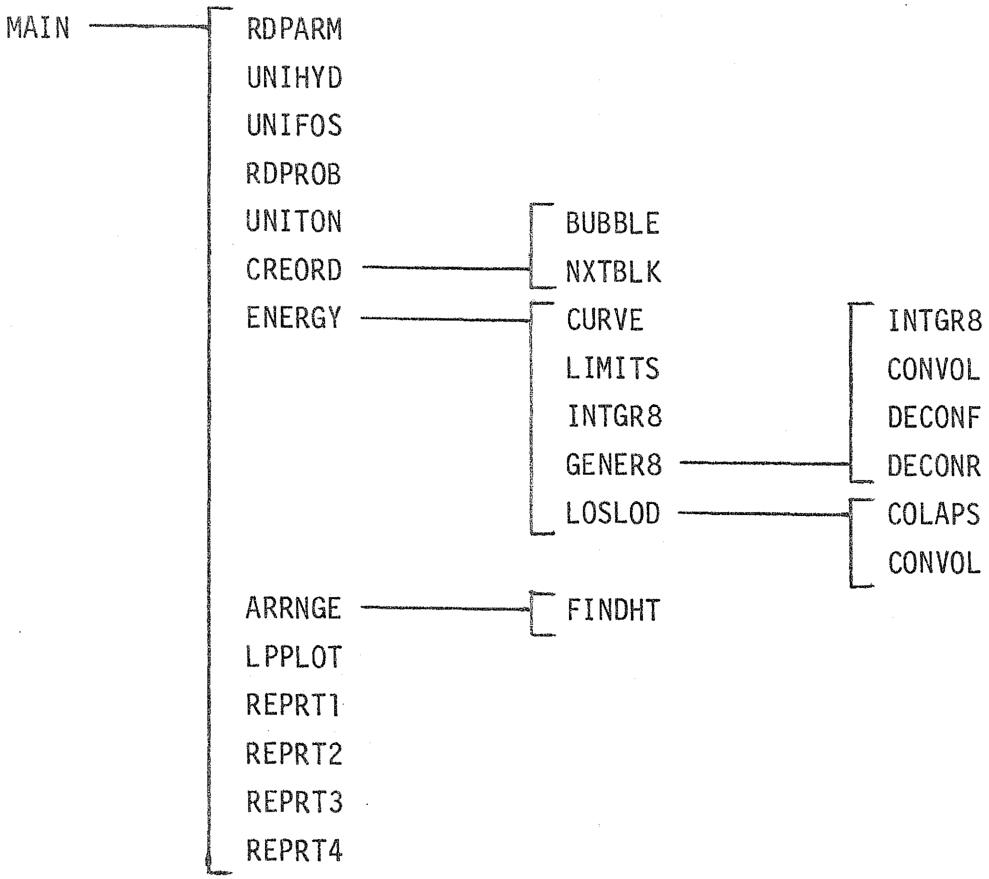


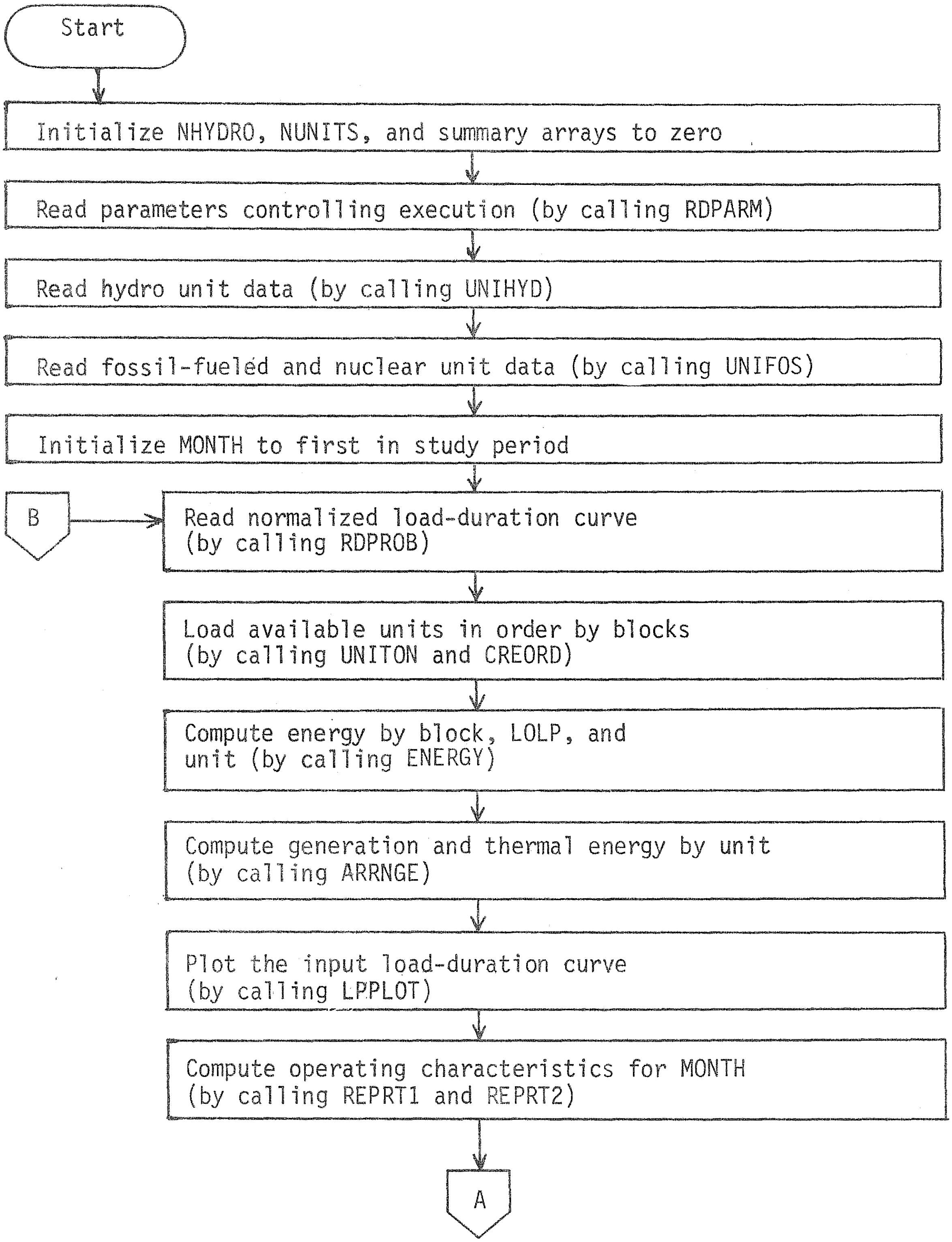
Figure 22 PCS Module Subroutines in the Sequence Called

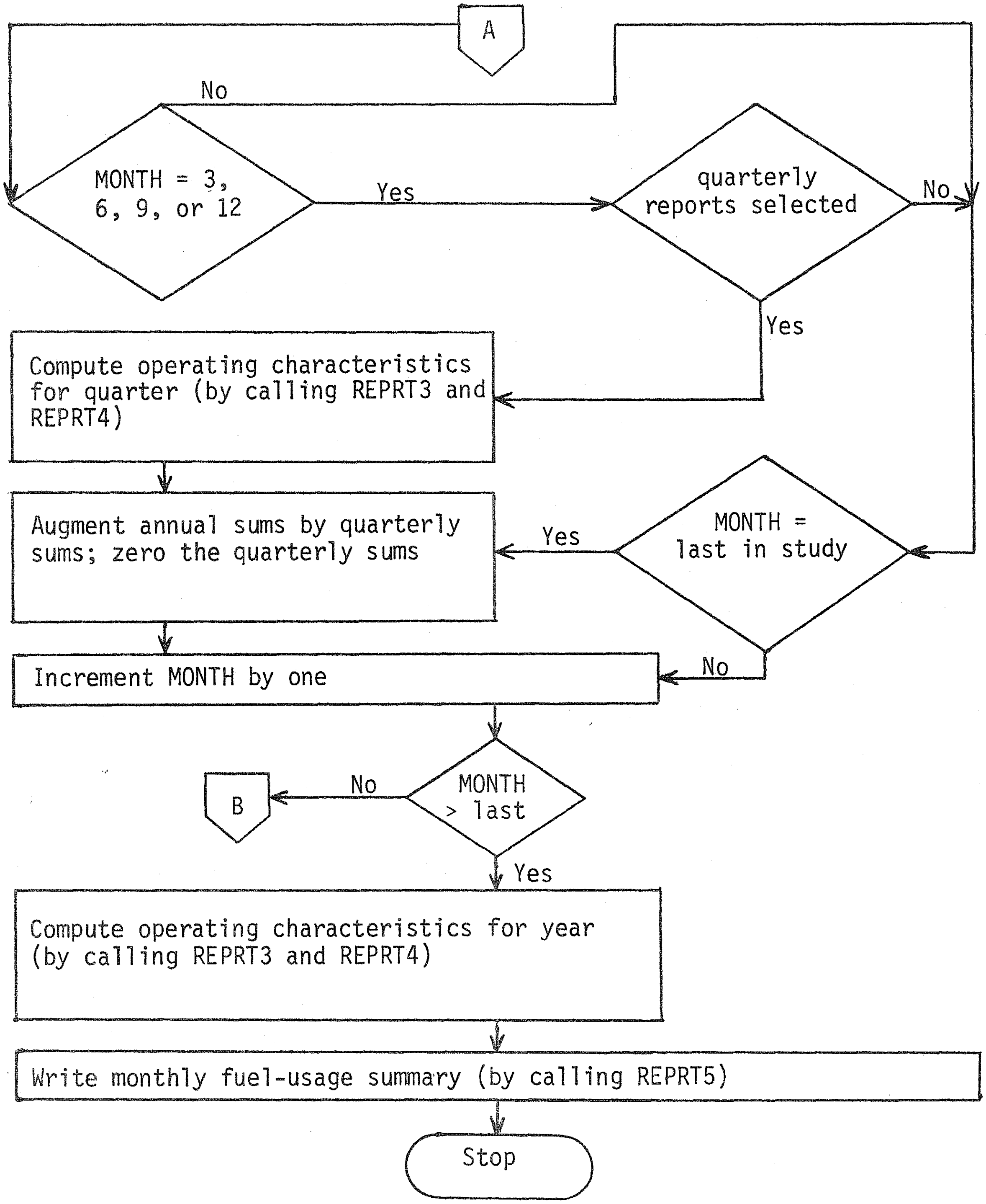
MAIN Routine

This program serves to structure the execution of computation in a concise, straightforward sequence. Following the definition of each global variable's type and dimension, summary variables are initialized and operating characteristics are read for each generating unit. The monthly loop controls the computation and reporting of each unit's operating characteristics. The annual reports and monthly fuel-usage summary are generated once at the conclusion of the study period.

Since the annual sums are initialized only once, and the generating units' input data are read for only twelve months, the program in its present configuration is not appropriate for study periods spanning more than one calendar year. With care taken to control the amount of generation-unit data read each year, a multi-year loop could be added if longer study periods are desired.

MAIN


Start
Initialize NHYDRO, NUNITS, and summary arrays to zero
Read parameters controlling execution (by calling RDPARM)
Read hydro unit data (by calling UNIHYD)
Read fossil-fueled and nuclear unit data (by calling UNIFOS)
Initialize MONTH to first in study period
B
Read normalized load-duration curve (by calling RDPROB)
Load available units in order by blocks (by calling UNITON and CREORD)
Compute energy by block, LOLP, and unit (by calling ENERGY)
Compute generation and thermal energy by unit (by calling ARRNGE)
Plot the input load-duration curve (by calling LPPLOT)
Compute operating characteristics for MONTH (by calling REPRT1 and REPRT2)
A

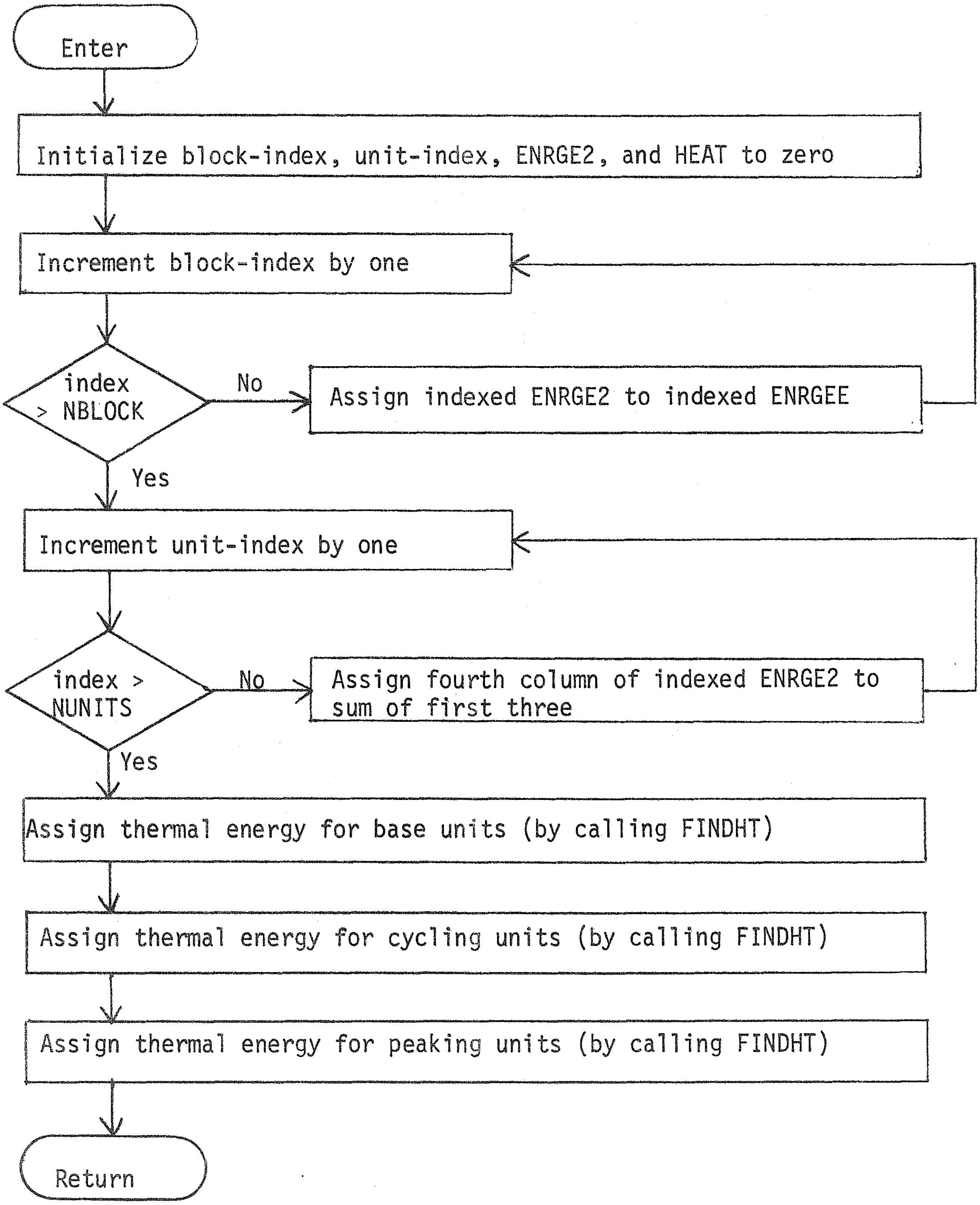

A
No
MONTH = 3, 6, 9, or 12
Yes
quarterly reports selected
No
Yes
Compute operating characteristics for quarter (by calling REPRT3 and REPRT4)
Augment annual sums by quarterly sums; zero the quarterly sums
Yes
MONTH = last in study
No
Increment MONTH by one
B
No
MONTH > last
Yes
Compute operating characteristics for year (by calling REPRT3 and REPRT4)
Write monthly fuel-usage summary (by calling REPRT5)
Stop

```
C=======================================================================
C
C   ROUTINE:            **** M A I N ****
C
C   REQUIREMENTS:
C     I/O UNITS TO BE ALLOCATED BY JOB CONTROL:
C     HYUNIT    LOGICAL UNIT (11) FROM WHICH TO READ HYDRO INFO
C     PFUNIT    LOGICAL UNIT (12) FROM WHICH TO READ FOSSIL INFO
C     PBUNIT    LOGICAL UNIT (13) FROM WHICH TO READ LOAD-PROBABILITIES
C     SUNIT     LOGICAL UNIT TO WHICH TO WRITE ALL REPORTS SELECTED
C               ACCORDING TO OPTION IN ROUTINE RDPARM;
C               LOGICAL UNITS MUNIT, QUNIT, AND AUNIT ARE SET EITHER
C               TO ZERO OR TO SUNIT ACCORDING TO OPTION
C
C   ROUTINES CALLED:
C     RDPARM    UNIHYD    UNIFOS    RDPROB
C     UNITON    CREORD    ENERGY    ARRNGE    LPPLOT
C     REPRT1    REPRT2    REPRT3    REPRT4    REPRT5
C
C
C   AUTHOR:
C     NATIONAL REGULATORY RESEARCH INSTITUTE, MARCH 1979
C
C   LAST REVISED:  10/79
C
C=======================================================================
```

ARRNGE Routine

This routine rearranges the generation (ENRGEE) from a single-column array by order of block loaded, to a three-column representation (ENRGE2) with columns ordered by block-level and rows ordered by unit-number. The fourth column of ENRGE2 is reserved for the total generation by unit. Preparatory to writing reports, the thermal energy input requirements are calculated for each of the categories of thermal units: base, cycling, and peaking.

ARRNGE

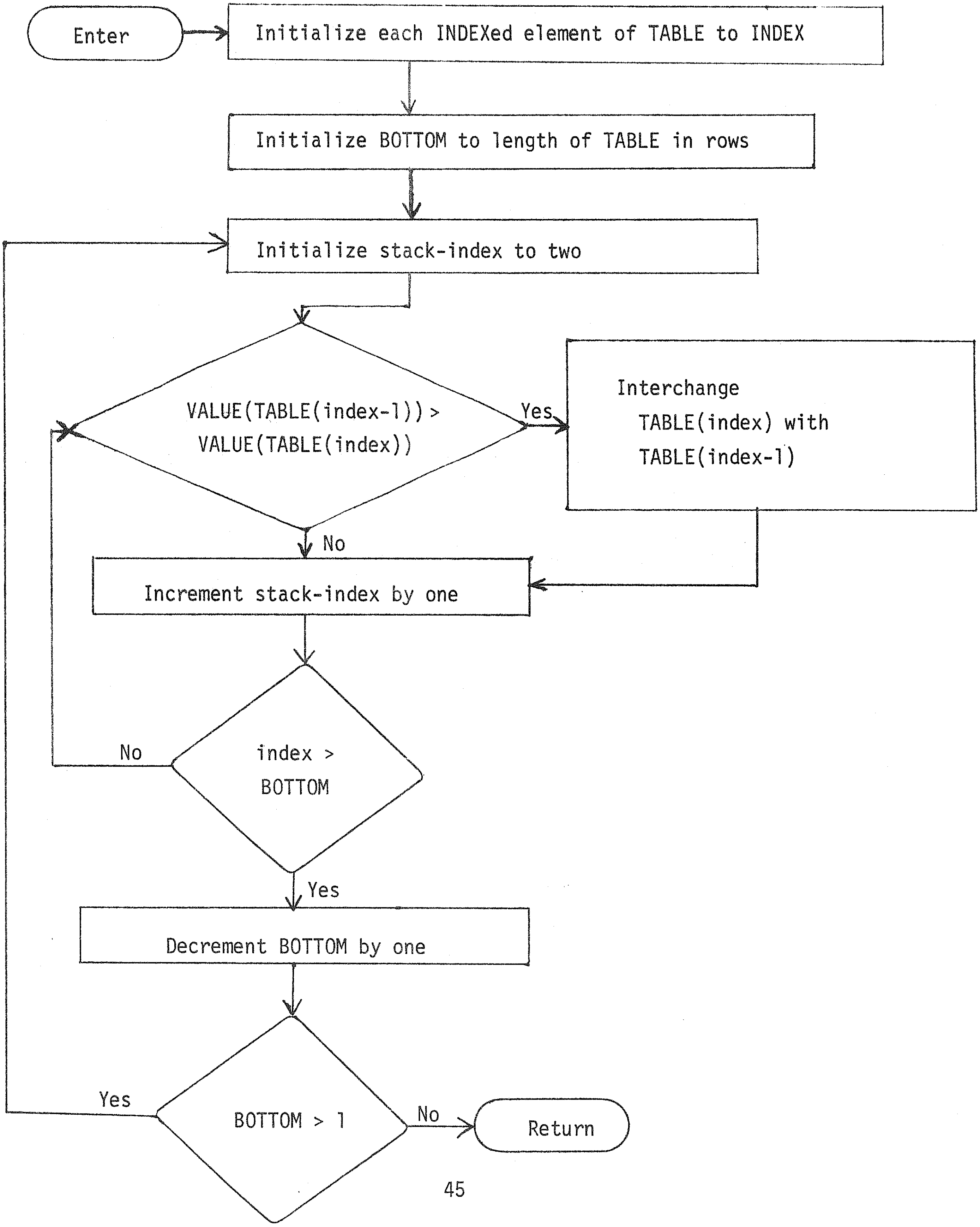

Enter
Initialize block-index, unit-index, ENRGE2, and HEAT to zero
Increment block-index by one
index > NBLOCK
No
Assign indexed ENRGE2 to indexed ENRGEE
Yes
Increment unit-index by one
index > NUNITS
No
Assign fourth column of indexed ENRGE2 to sum of first three
Yes
Assign thermal energy for base units (by calling FINDHT)
Assign thermal energy for cycling units (by calling FINDHT)
Assign thermal energy for peaking units (by calling FINDHT)
Return

```
C=======================================================================
C
C  ROUTINE:          **** A R R N G E ****
C
C  PURPOSE:
C    TO ARRANGE THE GENERATED ENERGY (WHICH IS IN ORDER BY LOADING BLOCK
C    IN ARRAY ENRGEE) BY UNIT IN ORDER OF LOADING, AND TO COMPUTE THE
C    THERMAL ENERGY REQUIREMENTS OF EACH BLOCK LOADED
C
C  INPUT VARIABLES:
C    NBLOCK    NUMBER OF BLOCKS LOADED
C    UNIT      LOADING ORDER OF UNITS
C    BLOCK     LOADING ORDER OF BLOCKS
C    ENRGEE    ENERGY GENERATED BY EACH BLOCK, IN MWH
C    NUNITS    NUMBER OF UNITS LOADED
C    IDBASE    INDEX OF BASE-LOADED UNITS, IN THE ORDER READ
C    NBASE     NUMBER OF BASE-LOADED UNITS LOADED
C    NBSTEP    NUMBER OF LOADING-STEPS USED FOR BASE UNITS
C    IDCYCL    INDEX OF CYCLING UNITS, IN THE ORDER READ
C    NCYCL     NUMBER OF CYCLING UNITS LOADED
C    NCSTEP    NUMBER OF LOADING-STEPS USED FOR CYCLING UNITS
C    IDPEAK    INDEX OF PEAKING UNITS, IN THE ORDER READ
C    NPEAK     NUMBER OF PEAKING UNITS LOADED
C    NPSTEP    NUMBER OF LOADING-STEPS USED FOR PEAKING UNITS
C    HEATR1    HEAT RATE IN BTU/KWH OF FIRST BLOCK, BY UNIT
C    HEATR2    HEAT RATE IN BTU/KWH OF SECOND BLOCK, BY UNIT
C    HEATR3    HEAT RATE IN BTU/KWH OF THIRD BLOCK, BY UNIT
C
C  OUTPUT VARIABLES:
C    ENRGE2    ENERGY GENERATED BY UNITS, BY COLUMNS:  1-FIRST BLOCK,
C              2-SECOND BLOCK, 3-THIRD BLOCK, 4-TOTAL FOR UNIT
C    HEAT      THERMAL ENERGY REQUIREMENTS BY UNITS, BY COLUMNS:
C              1-FIRST BLOCK, 2-SECOND BLOCK, 3-THIRD BLOCK,
C              4-TOTAL FOR UNIT
C
C  ROUTINES CALLED:
C    FINDHT
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

BUBBLE Routine

As implied by its name, this routine performs a bubble-sort on the elements of array VALUES. By using an index array TABLE for the manipulations of order, the sorting operation leaves VALUES intact. Upon initialization, TABLE contains the ordered set of integers (1, 2, 3, ... , LENGTH); upon exit, it contains the set of row-indices ordered by ascending value of elements in VALUE. Thus the first element of TABLE is the row index of the smallest element in VALUE, and the last is the row index of the largest.

BUBBLE

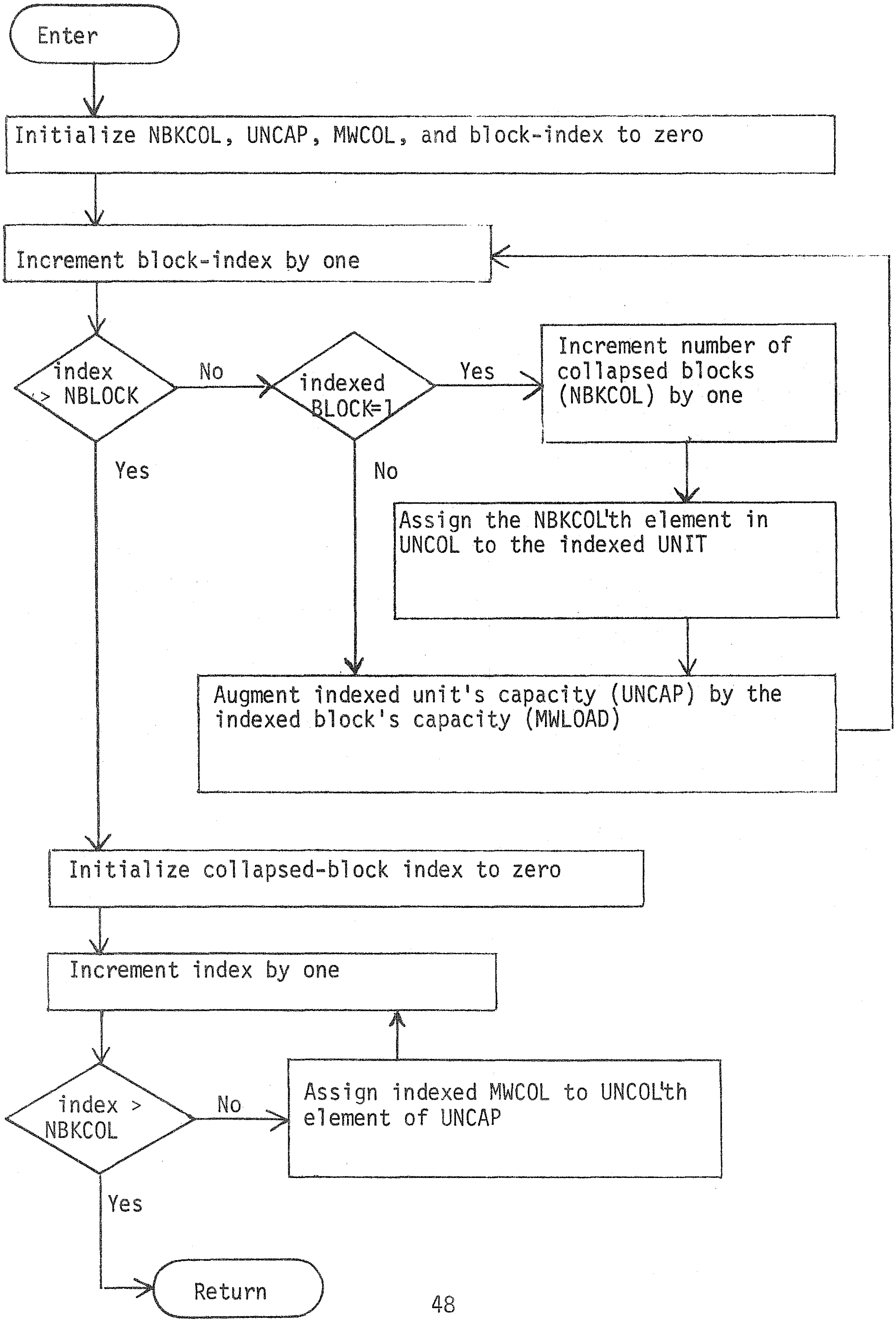

Enter
Initialize each INDEXed element of TABLE to INDEX
Initialize BOTTOM to length of TABLE in rows
Initialize stack-index to two
VALUE(TABLE(index-1)) >
VALUE(TABLE(index))
Yes
Interchange
TABLE(index) with
TABLE(index-1)
No
Increment stack-index by one
No
index >
BOTTOM
Yes
Decrement BOTTOM by one
Yes
BOTTOM > 1
No
Return

```
C=====================================================================
C
C  ROUTINE:          **** B U B B L E ****
C
C  PURPOSE:
C    GIVEN THE ARRAY VALUES, BUBBLE CREATES AN ARRAY TABLE,
C    WHICH IS A POINTER TO EACH LOCATION IN THE VALUE ARRAY
C
C  INPUT VARIABLES:
C    VALUES     LAMBDA-VALUES TO BE SORTED
C    LENGTH     NUMBER OF VALUES
C    COL        COLUMN OF TABLE TO USE
C    MONTH      MONTH OF STUDY
C
C  OUTPUT VARIABLES:
C    TABLE      INDICES SHOWING SORTED ORDER OF THE ARRAY VALUES
C               (RANGES FROM 1 TO LENGTH)
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=====================================================================
```

COLAPS Routine

This routine adds generation capacities across blocks of each unit, returning the sums in the collapsed capacity (MWCOL) array. The array elements are ordered by considering only the lambda-values of the first block of each unit; higher-blocks' lambdas are ignored.

COLAPS

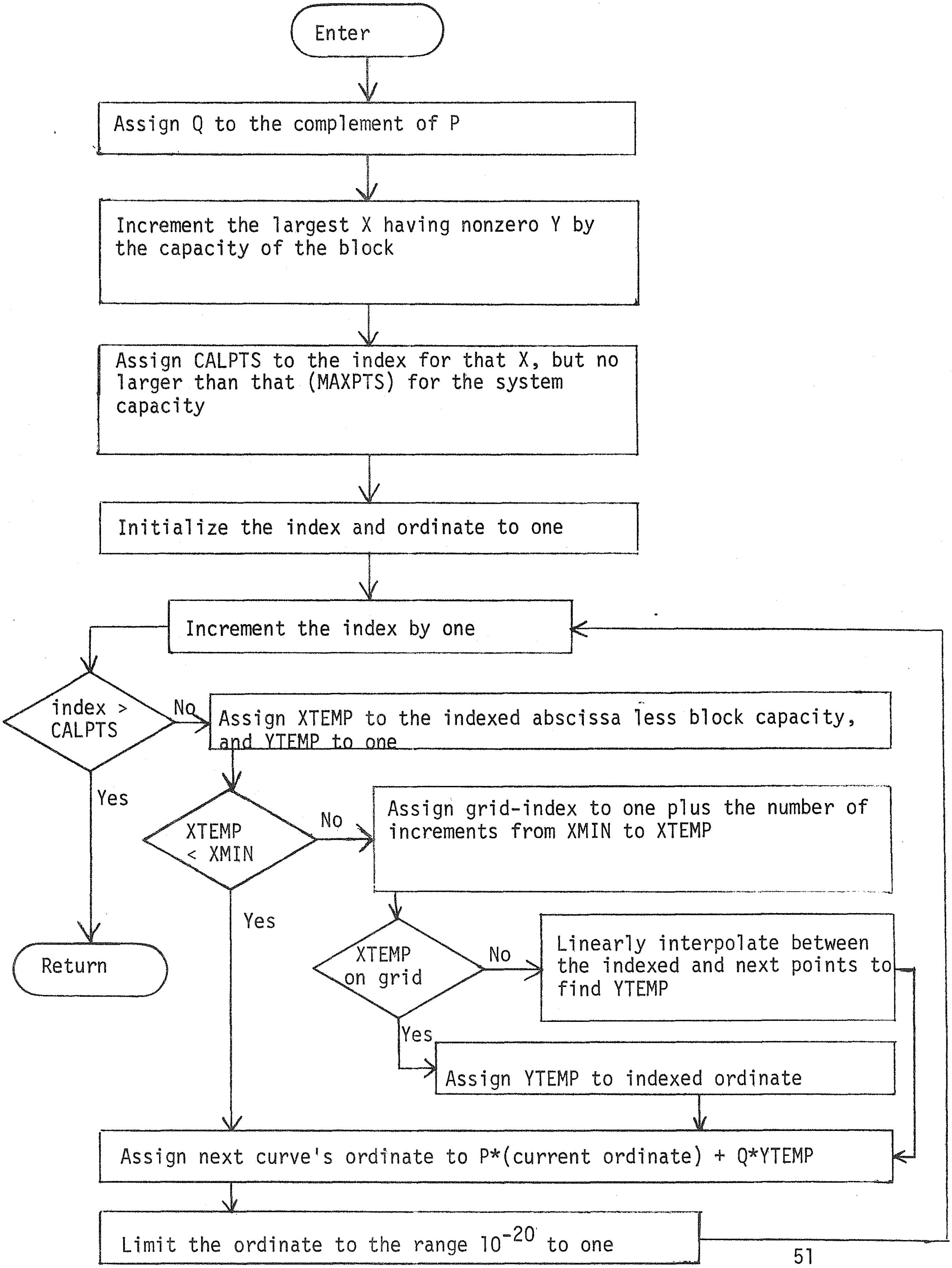

Enter
Initialize NBKCOL, UNCAP, MWCOL, and block-index to zero
Increment block-index by one
index <> NBLOCK
No
indexed BLOCK=1
Yes
Increment number of collapsed blocks (NBKCOL) by one
Yes
No
Assign the NBKCOL'th element in UNCOL to the indexed UNIT
Augment indexed unit's capacity (UNCAP) by the indexed block's capacity (MWLOAD)
Initialize collapsed-block index to zero
Increment index by one
index > NBKCOL
No
Assign indexed MWCOL to UNCOL'th element of UNCAP
Yes
Return

```
C=======================================================================
C
C  ROUTINE:          **** C O L A P S ****
C
C  INPUT VARIABLES:
C    MWBLOK    CAPACITY BY BLOCKS LOADED
C    UNIT      LOADING ORDER OF UNITS
C    BLOCK     LOADING ORDER OF BLOCKS
C    NBLOCK    NUMBER OF BLOCKS TO LOAD
C
C  OUTPUT VARIABLES:
C    UNCOL     COLLAPSED LOADING ORDER ARRAY
C    NBKCOL    NUMBER OF BLOCKS IN THE COLLAPSED ORDER
C    SYSCAP    TOTAL SYSTEM CAPACITY IN MW
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE, MAY 1979
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

CONVOL Routine

This routine performs the convolution of two cumulative probability distribution functions, one of which is the current normalized equivalent load-duration curve. It is normalized in that ordinates (duration) are on the range from zero to one, inclusive. The other function is the capacity outage distribution, which has discontinuous jumps of P at zero capacity and 1-P at a capacity (abscissa) of CAP. The simplification afforded by the outage distribution's derivative vanishing at all but two points, is evident in the routine's algorithm: at any abscissa X, the ordinate Y (NEXT) after convolution is the sum of P times the ordinate Y (CURRNT) before convolution, and (1-P) times the ordinate Y (CURRNT) evaluated at that abscissa less the capacity CAP. For negative abscissas, the current curve is defined with unit ordinates. Since a single ordinate may be the result of multiple convolutions, each involving the product of numbers less than one, underflow is possible; it is avoided by rounding all ordinates less than 10^{-10} to zero.

CONVOL

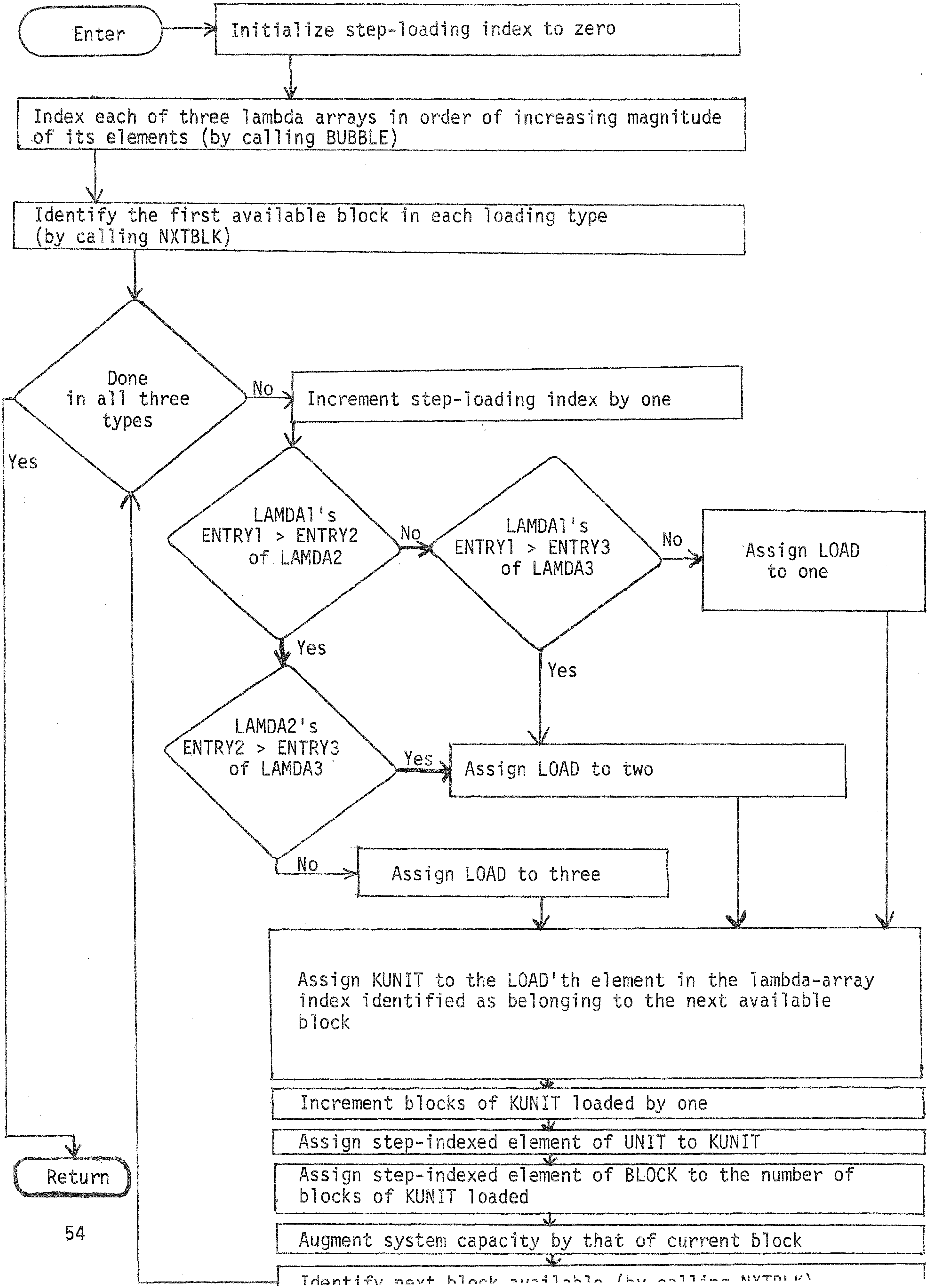

Enter
Assign Q to the complement of P
Increment the largest X having nonzero Y by the capacity of the block
Assign CALPTS to the index for that X, but no larger than that (MAXPTS) for the system capacity
Initialize the index and ordinate to one
Increment the index by one
index > CALPTS
No
Assign XTEMP to the indexed abscissa less block capacity, and YTEMP to one
Yes
XTEMP < XMIN
No
Assign grid-index to one plus the number of increments from XMIN to XTEMP
Yes
Return
XTEMP on grid
No
Linearly interpolate between the indexed and next points to find YTEMP
Yes
Assign YTEMP to indexed ordinate
Assign next curve's ordinate to P*(current ordinate) + Q*YTEMP
Limit the ordinate to the range 10^-20 to one

```
C======================================================================
C
C  ROUTINE:           **** C O N V O L ****
C
C  PURPOSE:
C    TO FORM A NEW EQUIVALENT LOAD-DURATION CURVE (Y) BY CONVOLUTION
C
C  INPUT VARIABLES:
C   *Y          ORDINATES OF THE LOAD-PROBABILITY CURVE
C    X          ABSCISSAS OF THE LOAD-PROBABILITY CURVE
C    XMIN       MAXIMUM VALUE OF X FOR WHICH Y=1
C    XNZERO     MAXIMUM VALUE OF X FOR WHICH Y IS NON-ZERO
C    NPTS       LENGTH OF COLUMNS IN ARRAY Y
C    DELTA      STEP-SIZE FOR THE X-AXIS
C    CURRNT     1 IF CURRENT COLUMN OF ORDINATES IS IN Y(*,1)
C               2 IF CURRENT COLUMN OF ORDINATES IS IN Y(*,2)
C    NEXT       1 IF NEXT COLUMN OF ORDINATES IS IN Y(*,1)
C               2 IF NEXT COLUMN OF ORDINATES IS IN Y(*,2)
C    CAP        CAPACITY OF BLOCK INVOKING THE CONVOLUTION, IN MW
C    PAVAIL     AVAILABILITY PROBABILITY OF UNIT
C    MAXPTS     MAXIMUM NUMBER OF ORDINATES TO COMPUTE FOR NEXT CURVE
C
C   *VARIABLE IS BOTH INPUT/OUTPUT
C
C  ALGORITHM:
C    CHRISTOS POSEIDON
C    CHAPTER 4 OF PHD DISSERTATION (UNPUBLISHED 1979)
C    THE OHIO STATE UNIVERSITY
C    DEPARTMENT OF NUCLEAR ENGINEERING
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE, 2/16/79
C
C  LAST REVISED:  10/79
C
C======================================================================
```

CREORD Routine

This routine steps through all available blocks in order of successive loading. At each step of the loading, one available block is identified from each of the three load-level categories. That block of the three having the lowest-value lambda is counted as loaded, and the next available block of the same load-level category is identified by the call to NXTBLK. When each of the three columns of lambdas is exhausted, the loading loop is complete.

CREORD



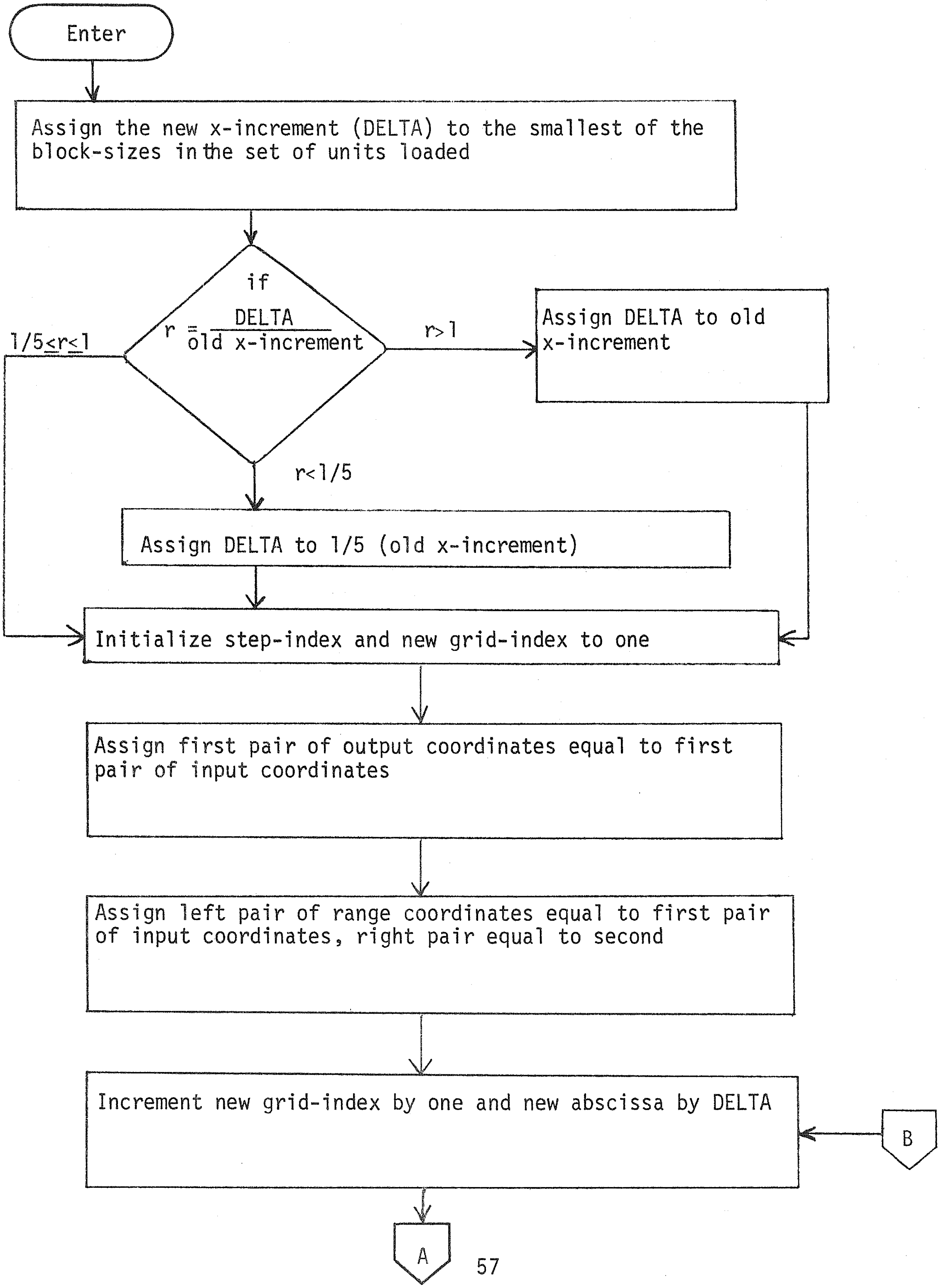
Enter
Initialize step-loading index to zero
Index each of three lambda arrays in order of increasing magnitude of its elements (by calling BUBBLE)
Identify the first available block in each loading type (by calling NXTBLK)
Done in all three types
No
Yes
Increment step-loading index by one
LAMDA1's ENTRY1 > ENTRY2 of LAMDA2
No
LAMDA1's ENTRY1 > ENTRY3 of LAMDA3
No
Assign LOAD to one
Yes
Yes
LAMDA2's ENTRY2 > ENTRY3 of LAMDA3
Yes
Assign LOAD to two
No
Assign LOAD to three
Assign KUNIT to the LOAD'th element in the lambda-array index identified as belonging to the next available block
Increment blocks of KUNIT loaded by one
Assign step-indexed element of UNIT to KUNIT
Assign step-indexed element of BLOCK to the number of blocks of KUNIT loaded
Augment system capacity by that of current block
Identify next block available (by calling NXTBLK)
Return

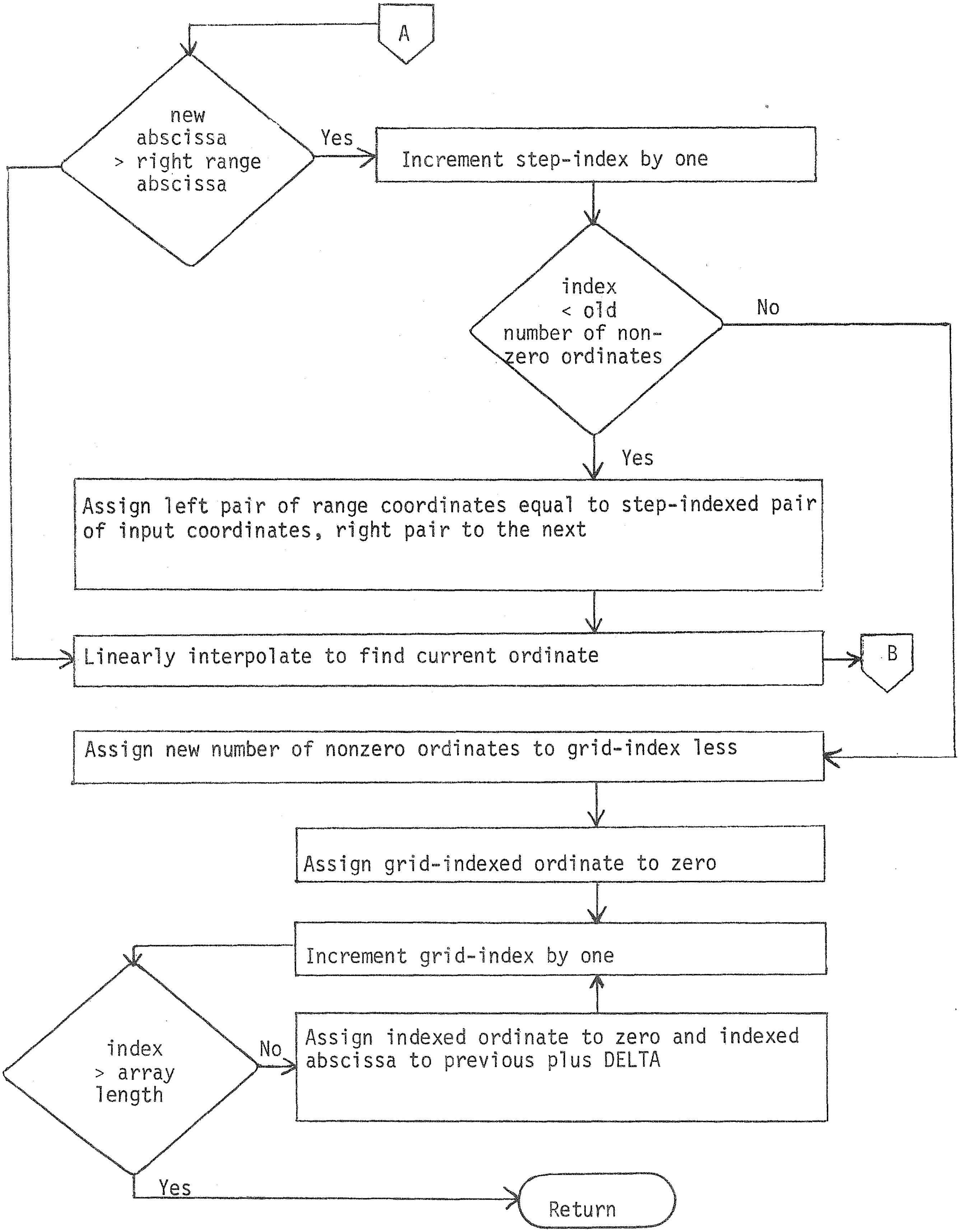
```
C=======================================================================
C
C  ROUTINE:          **** C R E O R D ****
C
C  PURPOSE:
C    TO CREATE A LOADING ORDER FOR THE SYSTEM AND TO FIND THE SYSTEM
C    CAPACITY.  THE LOADING ORDER IS CREATED BY LOADING THE NEXT
C    UNIT WHICH CORRESPONDS TO THE SMALLEST UNUSED LAMBDA VALUE.
C    AS BLOCKS OF UNITS ARE LOADED, THE UNIT LOADED IS RECORDED,
C    AN ARRAY OF BLOCK LOADING ORDER IS FORMED, THE BLOCK CAPACITY IS
C    RECORDED, AND THE TOTAL SYSTEM CAPACITY IS INCREMENTED.
C
C  INPUT VARIABLES:
C    AVAIL      .TRUE. IF UNIT IS AVAILABLE TO GO ON-LINE
C               .FALSE. IF UNIT IS NOT AVAILABLE TO GO ON-LINE
C    LAMDA1     FIRST BLOCK'S ORDINAL FOR LOADING
C    LAMDA2     SECOND BLOCK'S ORDINAL FOR LOADING
C    LAMDA3     THIRD BLOCK'S ORDINAL FOR LOADING
C    NUNITS     LENGTH OF LAMDA1, LAMDA2, LAMDA3 & AVAIL
C    MONTH      MONTH OF STUDY PERIOD
C    BLKCAP     CUMULATIVE BLOCK CAPACITIES FOR EACH UNIT, IN MW
C
C  OUTPUT VARIABLES:
C    UNIT       UNIT LOADING ORDER
C    BLOCK      BLOCK LOADING ORDER
C    MWBLOK     CAPACITY OF BLOCKS LOADED, IN MW
C    K          NUMBER OF LOADING STEPS
C    SYSCAP     SYSTEM CAPACITY IN MW
C
C
C  ROUTINES CALLED:
C    BUBBLE   NXTBLK
C
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

CURVE Routine

This routine simply transfers the input load-duration curve (with x, y coordinates XAXIS1, ELC) to a new grid of coordinate pairs (XAXIS, ELCSVE). The grid increment DELTA is chosen as the smallest of the block capacities, and is further restricted to be in the range 20% to 100% of the spacing between abscissas of the input curve. Linear interpolation is used to assign ordinates to the new grid of points. Beyond the first zero on the input curve, corresponding output ordinates are assigned zero values. The number of non-zero ordinates (NZPNTS) is revised to describe the output array ELCSVE.

CURVE


Enter
Assign the new x-increment (DELTA) to the smallest of the block-sizes in the set of units loaded
if
r = DELTA / old x-increment
1/5≤r≤1
r>1
Assign DELTA to old x-increment
r<1/5
Assign DELTA to 1/5 (old x-increment)
Initialize step-index and new grid-index to one
Assign first pair of output coordinates equal to first pair of input coordinates
Assign left pair of range coordinates equal to first pair of input coordinates, right pair equal to second
Increment new grid-index by one and new abscissa by DELTA
B
A


A
new abscissa > right range abscissa
Yes
Increment step-index by one
index < old number of non-zero ordinates
No
Yes
Assign left pair of range coordinates equal to step-indexed pair of input coordinates, right pair to the next
Linearly interpolate to find current ordinate
B
Assign new number of nonzero ordinates to grid-index less
Assign grid-indexed ordinate to zero
Increment grid-index by one
index > array length
No
Assign indexed ordinate to zero and indexed abscissa to previous plus DELTA
Yes
Return

```
C=======================================================================
C
C  ROUTINE:            **** C U R V E ****
C
C  PURPOSE:
C    GIVEN THE LOAD-PROBABILITY CURVE ELC, TO CREATE THE CURVE
C    ELCSVE WHICH IS UNIFORMLY SPACED ON THE X-AXIS BASED ON THE
C    SMALLEST LOADING BLOCK IN ARRAY MWBLOK
C
C  INPUT VARIABLES:
C    ELC        ORDINATES OF UNMODIFIED LOAD-PROBABILITY CURVE
C    XAXIS      VALUES FOR LOAD-PROBABILITY CURVE ABSCISSAS
C    MWBLOK     CAPACITY OF BLOCKS LOADED, IN MW
C    NBLOCK     NUMBER OF BLOCKS TO LOAD
C    ELDCPT     NUMBER OF POINTS IN ARRAYS ELCSVE AND XAXIS
C   *NZPNTS     NUMBER OF NON-ZERO ORDINATES IN ELCSVE
C
C   *VARIABLE IS BOTH INPUT/OUTPUT
C
C  OUTPUT VARIABLES:
C    ELCSVE     LOAD-PROBABILITY ORDINATES ON THE NEW GRID,
C               FOR ABSCISSAS BETWEEN BASE LOAD AND PEAK LOAD (INCL)
C    XAXIS      LOAD-PROBABILITY ABSCISSAS ON THE NEW GRID
C    DELTA      STEP-SIZE FOR XAXIS ARRAY
C
C  INTERNAL VARIABLES:
C    XLEFT,XRIGHT  X-AXIS INTERPOLATION END-POINTS
C    YLEFT,YRIGHT  Y-AXIS INTERPOLATION END-POINTS
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE, MAY 1979
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

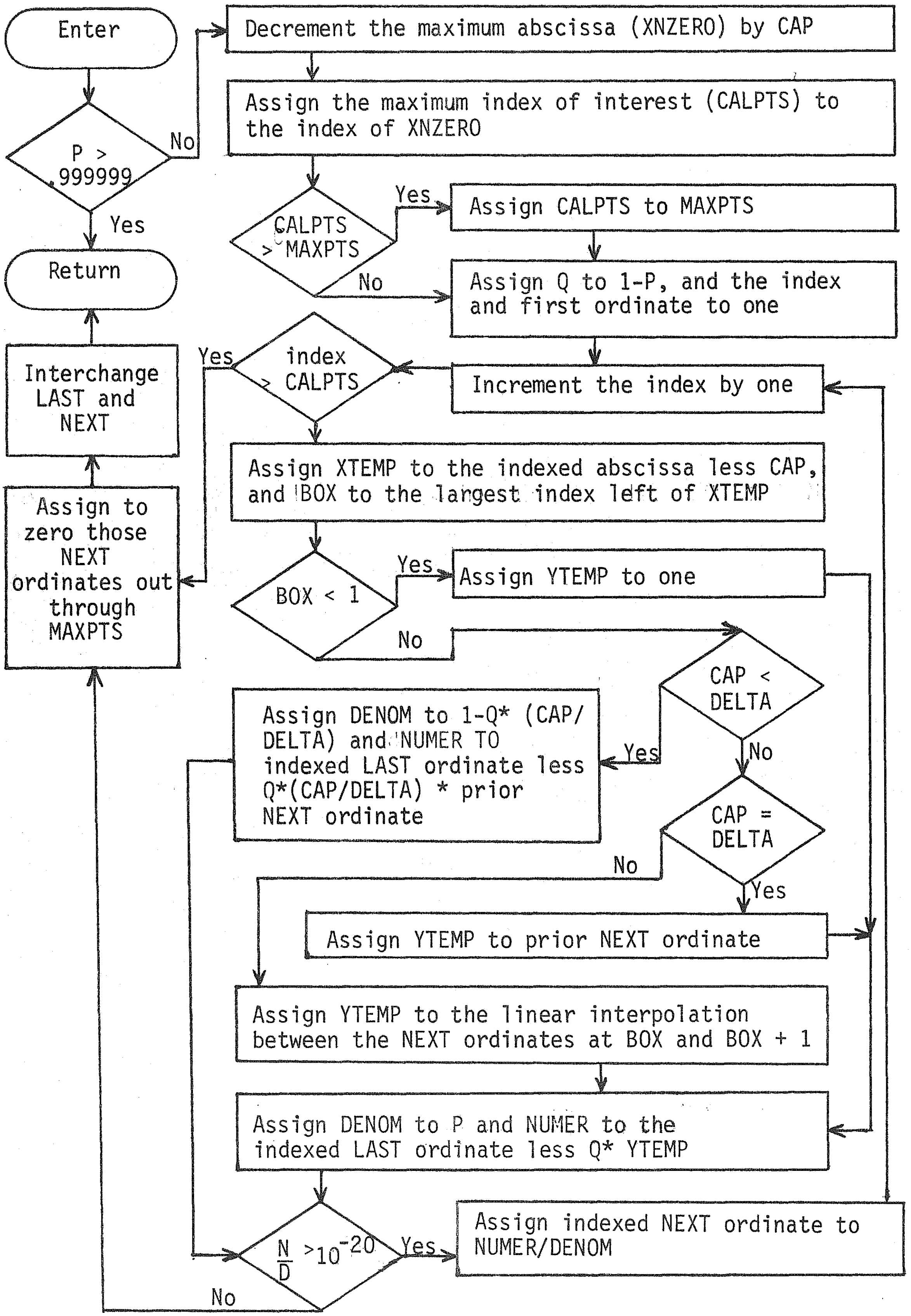
DECONF Routine

This routine performs the deconvolution of an aggregate capacity outage distribution function from the cumulative load probability distribution function stored in the LAST column of array Y. The aggregation is over blocks which operate or fail as a unit. Ordinates of the resultant function are stored in the NEXT column. The general equation used is that derived for the convolution process, but solved explicitly for the ordinates prior to convolution. Since the NEXT ordinates are computed recursively in ascending (forward) sequence of abscissas, errors due to roundoff in the early steps of the recursion process propagate with coefficient - Q/P; hence the process is unstable for availabilities (P) less than one-half. Use of double-precision merely delays the onset of significant error. The deconvolution of blocks with low availability is properly handled in a numerically stable manner by rearranging the equation such that the error propagates with coefficient - P/Q, as in the DECONR routine.

Those aggregate blocks having capacity (CAP) less than the grid-increment (DELTA) require the solution of an implicit equation for the NEXT ordinate. In all cases, ordinates are restricted to fall between unity and a positive threshold large enough to preclude underflow. The computation loop is aborted at the first violation of this threshold, and all remaining points are assigned to zero. To preserve the non-increasing characteristic of a valid load-probability distribution, each ordinate is restricted to be no greater than that to its left.

Each non-trivial execution of this routine causes the interchange of the numeric values in the LAST and NEXT variables, so that the ordinates just computed will be considered by the calling routine as the currently appropriate load-probability function.

DECONF

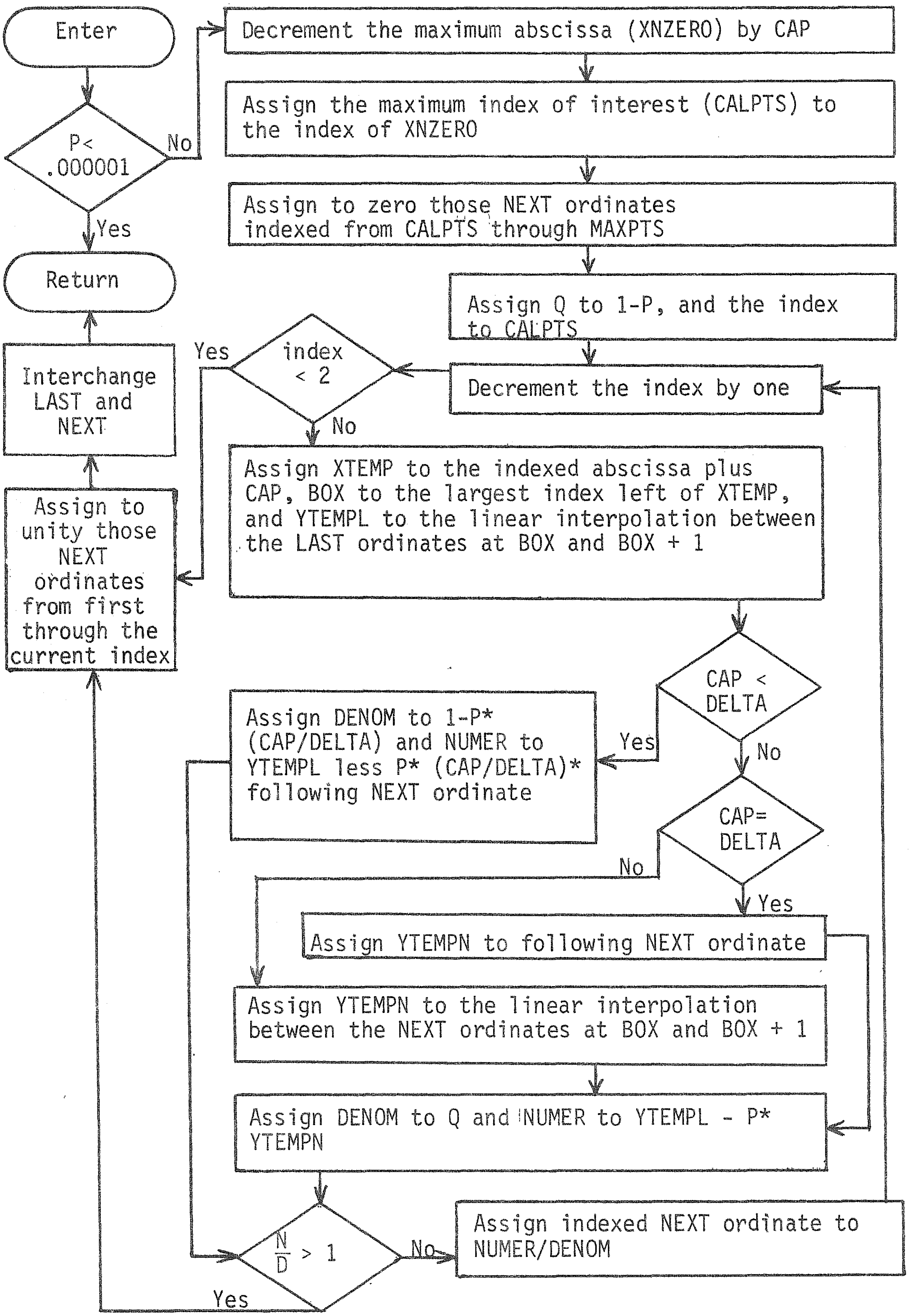

Enter
P > 999999
No
Yes
Return
Decrement the maximum abscissa (XNZERO) by CAP
Assign the maximum index of interest (CALPTS) to the index of XNZERO
CALPTS > MAXPTS
Yes
No
Assign CALPTS to MAXPTS
Assign Q to 1-P, and the index and first ordinate to one
Increment the index by one
index > CALPTS
Yes
Interchange LAST and NEXT
Assign to zero those NEXT ordinates out through MAXPTS
Assign XTEMP to the indexed abscissa less CAP, and BOX to the largest index left of XTEMP
BOX < 1
Yes
No
Assign YTEMP to one
CAP < DELTA
Yes
No
Assign DENOM to 1-Q* (CAP/DELTA) and NUMER TO indexed LAST ordinate less Q*(CAP/DELTA) * prior NEXT ordinate
CAP = DELTA
No
Yes
Assign YTEMP to prior NEXT ordinate
Assign YTEMP to the linear interpolation between the NEXT ordinates at BOX and BOX + 1
Assign DENOM to P and NUMER to the indexed LAST ordinate less Q* YTEMP
N/D >10^-20
Yes
No
Assign indexed NEXT ordinate to NUMER/DENOM

```
C========================================================================
C
C  ROUTINE:           **** D E C O N F ****
C
C  PURPOSE:
C    TO REMOVE THE EFFECTS OF PRIOR-LOADED BLOCKS OF THE SAME
C    UNIT ON THE SHAPE OF THE LOAD-PROBABILITY CURVE, BY DECONVOLUTION
C    FROM LEFT TO RIGHT USING YNEXT(X)=(YLAST(X)-Q*YNEXT(X-CAP))/P
C
C  INPUT VARIABLES:
C   *Y         ORDINATES OF THE LOAD-PROBABILITY CURVE
C    X         ABSCISSAS OF THE LOAD-PROBABILITY CURVE
C    XMIN      MAXIMUM VALUE OF X FOR WHICH Y=1
C    DELTA     STEP-SIZE FOR THE X-AXIS
C    LAST      1 IF CURRENT COLUMN OF ORDINATES IS IN Y(*,1)
C              2 IF CURRENT COLUMN OF ORDINATES IS IN Y(*,2)
C    NEXT      1 IF NEXT COLUMN OF ORDINATES IS IN Y(*,1)
C              2 IF NEXT COLUMN OF ORDINATES IS IN Y(*,2)
C    CAP       CAPACITY OF PREVIOUS BLOCKS TO BE DECONVOLVED
C    P         AVAILABILITY OF UNIT
C    NPTS      LENGTH OF COLUMNS OF ARRAY Y
C    MAXPTS    MAXIMUM NUMBER OF ORDINATES TO COMPUTE FOR NEXT CURVE
C    XNZERO    MAXIMUM VALUE OF X FOR WHICH Y IS NON-ZERO
C
C   *VARIABLE IS BOTH INPUT/OUTPUT
C
C  ALGORITHM:
C    (NUMERICALLY STABLE FOR P>0.5)
C    CHRISTOS POSEIDON
C    CHAPTER 4 OF PHD DISSERTATION (UNPUBLISHED 1979)
C    THE OHIO STATE UNIVERSITY
C    DEPARTMENT OF NUCLEAR ENGINEERING
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C========================================================================
```

DECONR Routine

This routine is syntactically similar to DECONF, as it performs deconvolution according to the same basic equation. Here, however, the NEXT ordinates are computed recursively in descending (reverse) sequence of abscissas so that roundoff errors do not propagate; this routine is called only when the propagation coefficient (-P/Q) is of fractional magnitude. The reversed processing order implies the following differences from the forward order: no check is needed for negative indices, since the aggregate block capacity is added to indexed abscissas instead of subtracted; the loop is aborted at the first computed ordinate greater than unity; and each ordinate is restricted to be no less than that to its right.

DECONR

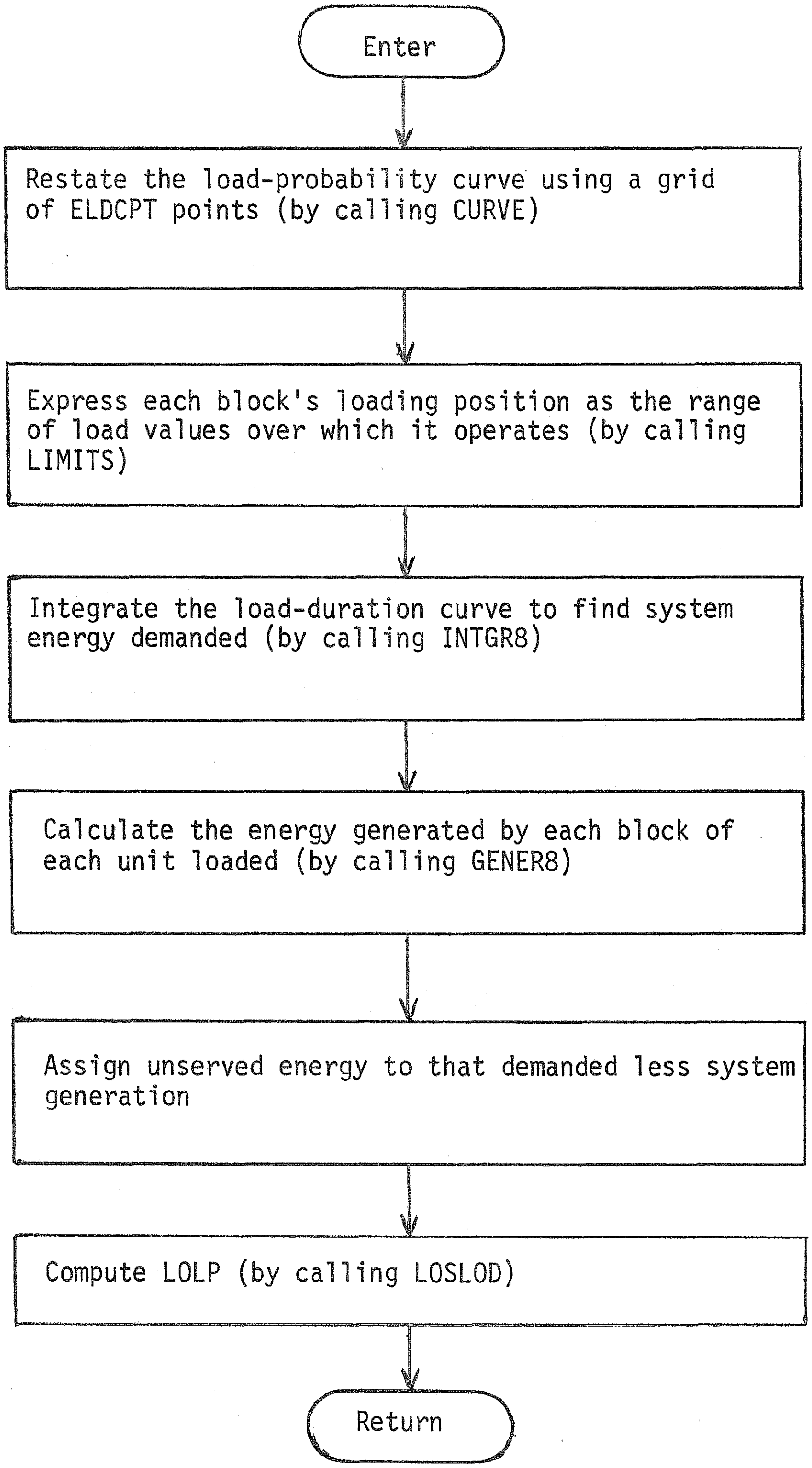

Enter
P< .000001
No
Yes
Return
Decrement the maximum abscissa (XNZERO) by CAP
Assign the maximum index of interest (CALPTS) to the index of XNZERO
Assign to zero those NEXT ordinates indexed from CALPTS through MAXPTS
Assign Q to 1-P, and the index to CALPTS
Decrement the index by one
index < 2
Yes
No
Interchange LAST and NEXT
Assign to unity those NEXT ordinates from first through the current index
Assign XTEMP to the indexed abscissa plus CAP, BOX to the largest index left of XTEMP, and YTEMPL to the linear interpolation between the LAST ordinates at BOX and BOX + 1
CAP < DELTA
Yes
No
Assign DENOM to 1-P* (CAP/DELTA) and NUMER to YTEMPL less P* (CAP/DELTA)* following NEXT ordinate
CAP= DELTA
No
Yes
Assign YTEMPN to following NEXT ordinate
Assign YTEMPN to the linear interpolation between the NEXT ordinates at BOX and BOX + 1
Assign DENOM to Q and NUMER to YTEMPL - P* YTEMPN
N/D > 1
No
Yes
Assign indexed NEXT ordinate to NUMER/DENOM

```
C=============================================================================
C
C  ROUTINE:          **** D E C O N R ****
C
C  PURPOSE:
C    TO REMOVE THE EFFECTS OF PRIOR-LOADED BLOCKS OF THE SAME
C    UNIT ON THE SHAPE OF THE LOAD-PROBABILITY CURVE, BY DECONVOLUTION
C    FROM RIGHT TO LEFT USING YNEXT(X)=(YLAST(X+CAP)-P*YNEXT(X+CAP))/Q
C
C  INPUT VARIABLES:
C   *Y          ORDINATES OF THE LOAD-PROBABILITY CURVE
C    X          ABSCISSAS OF THE LOAD-PROBABILITY CURVE
C    XMIN       MAXIMUM VALUE OF X FOR WHICH Y=1
C    DELTA      STEP-SIZE FOR THE X-AXIS
C    LAST       1 IF CURRENT COLUMN OF ORDINATES IS IN Y(*,1)
C               2 IF CURRENT COLUMN OF ORDINATES IS IN Y(*,2)
C    NEXT       1 IF NEXT COLUMN OF ORDINATES IS IN Y(*,1)
C               2 IF NEXT COLUMN OF ORDINATES IS IN Y(*,2)
C    CAP        CAPACITY OF PREVIOUS BLOCKS TO BE DECONVOLVED
C    P          AVAILABILITY OF UNIT
C    NPTS       LENGTH OF COLUMNS OF ARRAY Y
C    MAXPTS     MAXIMUM NUMBER OF ORDINATES TO COMPUTE FOR NEXT CURVE
C    XNZERO     MAXIMUM VALUE OF X FOR WHICH Y IS NON-ZERO
C
C   *VARIABLE IS BOTH INPUT/OUTPUT
C
C  ALGORITHM:
C    (NUMERICALLY STABLE FOR P<0.5)
C    COMPLEMENT OF THAT IN ROUTINE DECONF
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE, OCTOBER 1979
C
C=============================================================================
```

ENERGY Routine

This routine supervises calculations of monthly energy-related values that form the basis of the production-cost reports: system-wide energy demanded, unserved energy, and the energy generated by each block loaded. The system's generation reliability (LOLP) is computed using single-block loading to minimize errors in the convolution process and to reflect the full availability of hydro units in meeting peak demands.

ENERGY

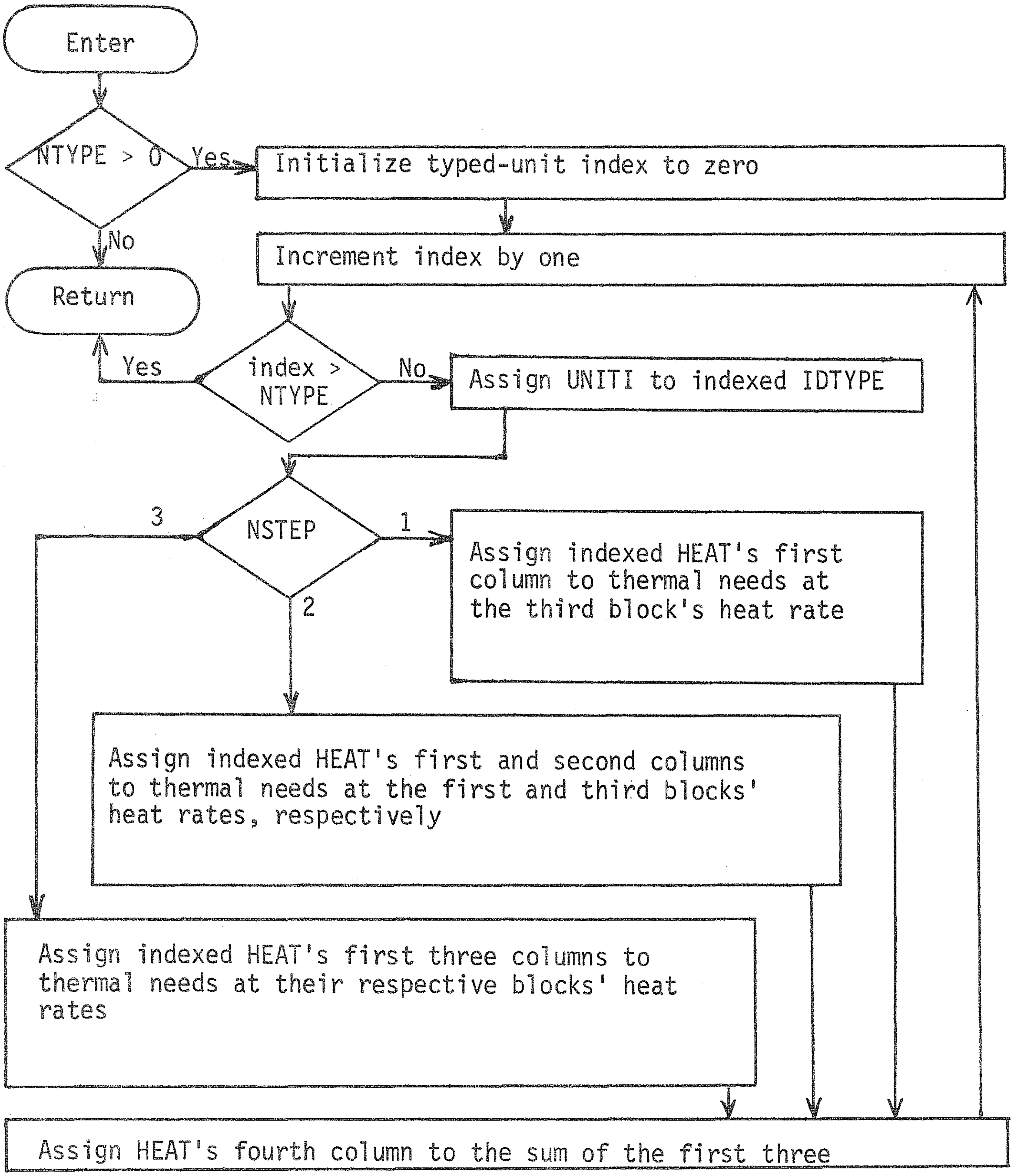

Enter
Restate the load-probability curve using a grid of ELDCPT points (by calling CURVE)
Express each block's loading position as the range of load values over which it operates (by calling LIMITS)
Integrate the load-duration curve to find system energy demanded (by calling INTGR8)
Calculate the energy generated by each block of each unit loaded (by calling GENER8)
Assign unserved energy to that demanded less system generation
Compute LOLP (by calling LOSLOD)
Return

```
C=======================================================================
C
C   ROUTINE:            **** E N E R G Y ****
C
C   PURPOSE:
C     GIVEN A SYSTEM LOAD-PROBABILITY CURVE (ELC), TO PROJECT THE ENERGY
C     GENERATED BY EACH UNIT IN THE SYSTEM, RELIABILITY (LOLP),
C     AND THE AMOUNT OF PURCHASED POWER NEEDED TO MEET SYSTEM DEMANDS.
C
C   INPUT VARIABLES:
C     ELC        ORDINATES OF UNMODIFIED LOAD-PROBABILITY CURVE
C     XAXIS1     VALUES FOR LOAD-PROBABILITY CURVE ABSCISSAS
C     ELCPTS     NUMBER OF POINTS IN ELC AND XAXIS1
C     UNIT       LOADING ORDER OF UNITS
C     BLOCK      LOADING ORDER OF BLOCKS
C     MWBLOK     CAPACITY OF BLOCKS LOADED, IN MW
C     EAVAIL     EFFECTIVE AVAILABILITY BY UNIT
C     NBLOCK     NUMBER OF BLOCKS TO LOAD
C     SYSCAP     TOTAL SYSTEM CAPACITY IN MW
C     HOURS      NUMBER OF HOURS IN STUDY PERIOD
C     MONTH      MONTH OF STUDY
C     HYDROS     LOGICAL FOR CONDITION OF HYDROS IN SYSTEM
C     UNTYPE     TYPE OF GENERATION UNIT: 1-STEAM FOSSIL, 2-STEAM NUCLEAR,
C                3-I.C. ENGINE, 4-GAS TURBINE, 5-JET ENGINE, 6-HYDRO,
C                7-PUMPED STORAGE
C     UNGEN      THE EXPECTED GENERATION BY EACH HYDRO UNIT
C     IDHYDRO    LOCATION OF THE HYDRO UNIT IN THE ORDER READ
C     NHYDRO     NUMBER OF HYDRO UNITS
C
C   OUTPUT VARIABLES:
C     LOLP       LOSS OF LOAD PROBABILITY (0 < LOLP < 1)
C     SYSGEN     TOTAL SYSTEM ENERGY
C     UNSERV     UNSERVED ENERGY
C     ENRGEE     ENERGY BY BLOCK LOADED
C
C   VARIABLES INTERNAL TO ENERGY AND THE SUBROUTINES IT CALLS:
C     ELDC       ORDINATES OF CALCULATED LOAD PROBABILITY CURVE
C     XAXIS      THE X AXIS DEMAND VALUES FOR ELDC & ELCSVE
C     ELCSVE     ORDINATES OF THE NEW LOAD PROBABILITY
C                CURVE COMPUTED IN SUBROUTINE CURVE
C     ELDCPT     NUMBER OF POINTS IN ARRAYS ELDC, XAXIS, AND ELCSVE
C     NZPNTS     NUMBER OF NON-ZERO ORDINATES IN ELCSVE
C
C   ROUTINES CALLED:
C     CURVE   LIMITS   INTGR8   GENER8   LOSLOD
C
C
C   AUTHOR:
C     NATIONAL REGULATORY RESEARCH INSTITUTE, 2/22/79
C
C   LAST REVISED:  10/79
C
C=======================================================================
```

FINDHT Routine

This routine simply computes the thermal-energy requirements (HEAT) array to correspond with the specified heat-rate for each block and the electrical energy generated by that block. Since thermal energy is reported in millions of British thermal units (MBTU), a conversion factor of .001 is included to cancel the units on the other factors: (BTU/KWH) * (MWH) = KBTU * (MBTU/(1000 * KBTU)) = .001 MBTU. Here M is consistently used to represent million (mega-), in distinction from the confusing convention of using MMBTU for million BTU.

FINDHT


Enter
NTYPE > 0
Yes
No
Return
Initialize typed-unit index to zero
Increment index by one
index > NTYPE
Yes
No
Assign UNITI to indexed IDTYPE
NSTEP
1
2
3
Assign indexed HEAT's first column to thermal needs at the third block's heat rate
Assign indexed HEAT's first and second columns to thermal needs at the first and third blocks' heat rates, respectively
Assign indexed HEAT's first three columns to thermal needs at their respective blocks' heat rates
Assign HEAT's fourth column to the sum of the first three

```
C=====================================================================
C
C  ROUTINE:          **** F I N D H T ****
C
C  PURPOSE:
C    TO CALCULATE THE THERMAL ENERGY FOR BLOCKS OF A GIVEN LOADING
C    TYPE AND THE TOTAL THERMAL ENERGY FOR THE UNIT.
C
C  INPUT VARIABLES:
C    IDTYPE    INDEX OF UNITS OF SPECIFIED TYPE, IN THE ORDER READ
C    NTYPE     NUMBER OF UNITS LOADED OF SPECIFIED TYPE
C    NSTEP     NUMBER OF LOADING-STEPS USED FOR THIS LOADING TYPE
C    HEATR1    HEAT RATE IN BTU/KWH OF FIRST BLOCK, BY UNIT
C    HEATR2    HEAT RATE IN BTU/KWH OF SECOND BLOCK, BY UNIT
C    HEATR3    HEAT RATE IN BTU/KWH OF THIRD BLOCK, BY UNIT
C    ENRGE2    ENERGY GENERATED BY UNITS, BY COLUMNS:  1-FIRST BLOCK,
C              2-SECOND BLOCK, 3-THIRD BLOCK, 4-TOTAL FOR UNIT
C
C  OUTPUT VARIABLES:
C    HEAT      THERMAL ENERGY REQUIREMENTS BY UNITS, BY COLUMNS:
C              1-FIRST BLOCK, 2-SECOND BLOCK, 3-THIRD BLOCK,
C              4-TOTAL FOR UNIT
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=====================================================================
```

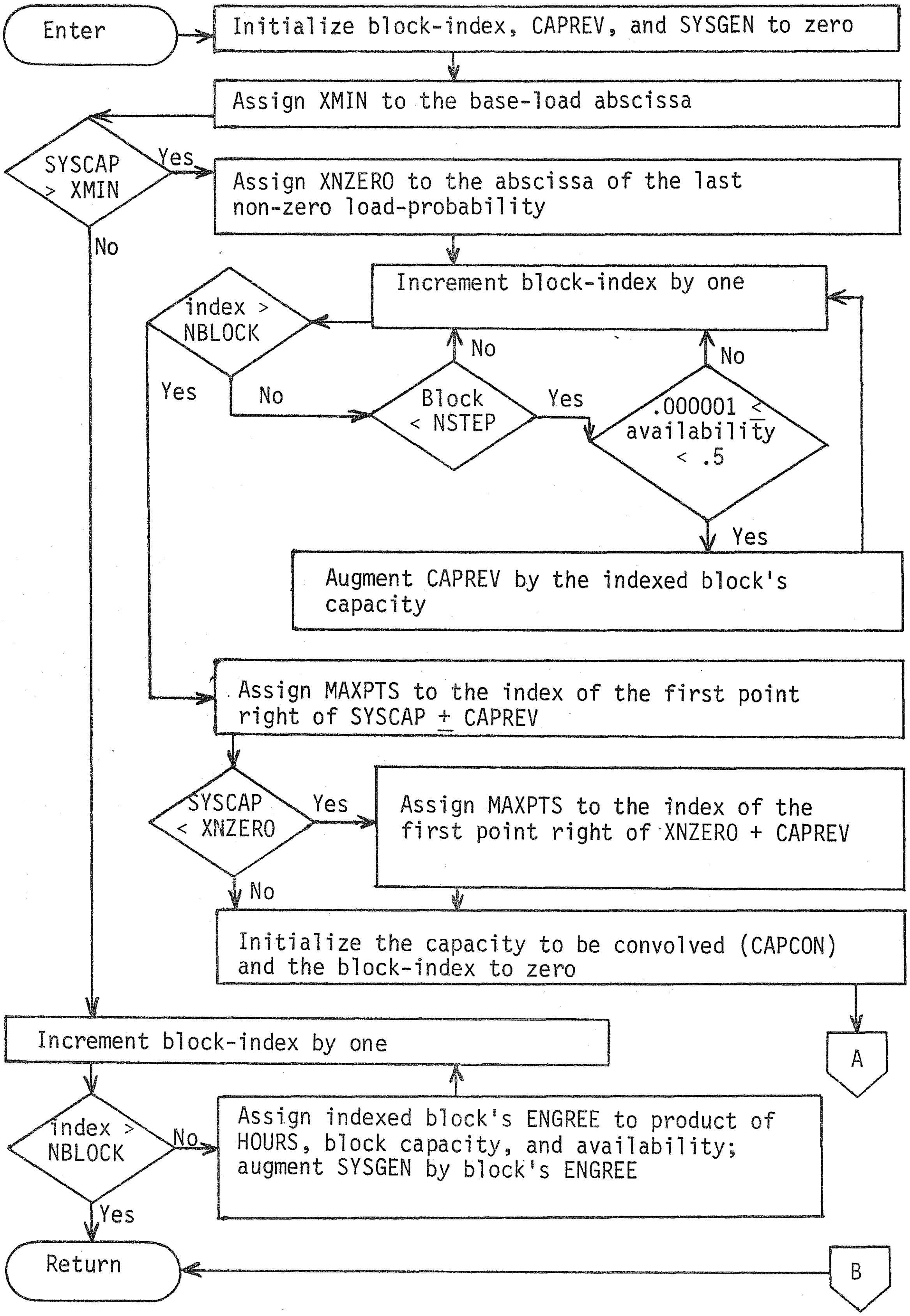
GENER8 Routine

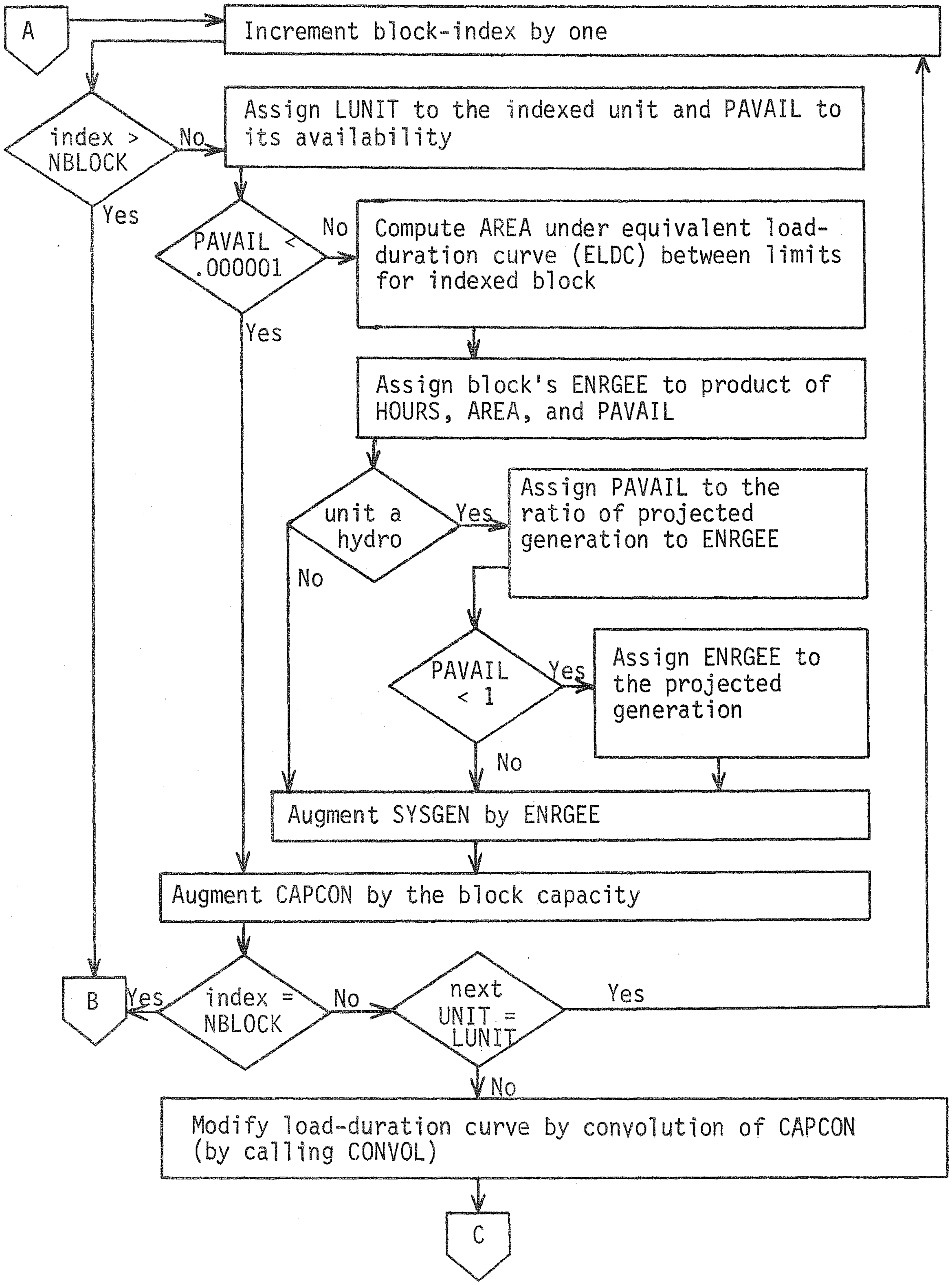
This routine is responsible for the computation of the electrical energy generated by each block in the loading order. The load-duration curve appropriate for the integration of a block's energy is that original load-duration curve modified by the convolution of the outage distribution functions of all independent blocks that had been loaded prior to the current blocks. The requirement of independence means that all prior-loaded blocks which operate or fail as a unit with the current block, must have their outage distribution functions ignored in the computation of the current block's energy. Since the routine stores the cumulative effects of all prior-loaded blocks' outages in the current column of the equivalent load-duration curve (ELDC) array, and since convolution is a commutative (order-independent) operation, deconvolution may be invoked to remove outage effects from prior-loaded blocks of the current unit. Following the energy calculation for a unit's secondary or tertiary blck, that block's capacity is aggregated with the sum capacity of the units' prior-loaded blocks for the convolution, regardless of adjacency of blocks. Appropriate steps have been taken to avoid convolution and deconvolution for blocks with unit or zero availability (since, in neither case should the ELDC be affected) and to treat adjacent blocks of a common unit as an aggregate for the purposes of convolution.

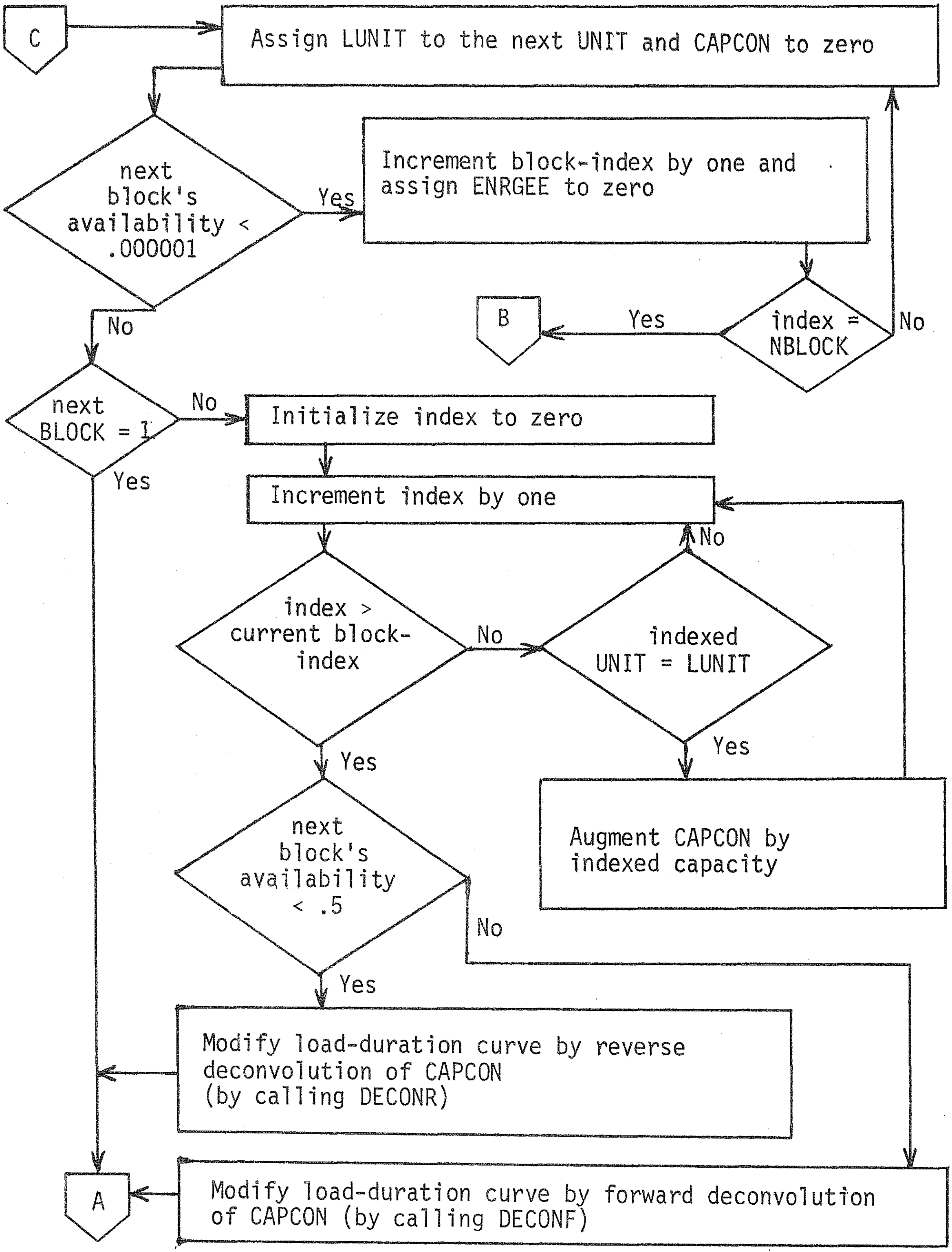
The avoidance of deconvolution for the first block of any unit inplies that blocks within a single unit must be loaded in ascending order; neither the second nor third block may have a lambda value lower than the first block's lambda.

The early return due to base-load (XMIN) exceeding system capacity (SYSCAP) is included for use with degenerate cases of input data; it is not expected to be exercised by normal utility system's data. Since the load-duration curve had been normalized to one (time unit), the area under any portion of its base-load section is simplified to the range of integration.

GENER8


Enter
Initialize block-index, CAPREV, and SYSGEN to zero
Assign XMIN to the base-load abscissa
SYSCAP > XMIN
Yes
No
Assign XNZERO to the abscissa of the last non-zero load-probability
Increment block-index by one
index > NBLOCK
Yes
No
Block < NSTEP
No
Yes
.000001 ≤ availability < .5
No
Yes
Augment CAPREV by the indexed block's capacity
Assign MAXPTS to the index of the first point right of SYSCAP ± CAPREV
SYSCAP < XNZERO
Yes
No
Assign MAXPTS to the index of the first point right of XNZERO + CAPREV
Initialize the capacity to be convolved (CAPCON) and the block-index to zero
A
Increment block-index by one
index > NBLOCK
No
Yes
Assign indexed block's ENGREE to product of HOURS, block capacity, and availability; augment SYSGEN by block's ENGREE
Return
B


A
Increment block-index by one
index > NBLOCK
No
Assign LUNIT to the indexed unit and PAVAIL to its availability
Yes
PAVAIL < .000001
No
Compute AREA under equivalent load-duration curve (ELDC) between limits for indexed block
Yes
Assign block's ENRGEE to product of HOURS, AREA, and PAVAIL
unit a hydro
Yes
Assign PAVAIL to the ratio of projected generation to ENRGEE
No
PAVAIL < 1
Yes
Assign ENRGEE to the projected generation
No
Augment SYSGEN by ENRGEE
Augment CAPCON by the block capacity
B
Yes
index = NBLOCK
No
next UNIT = LUNIT
Yes
No
Modify load-duration curve by convolution of CAPCON (by calling CONVOL)
C

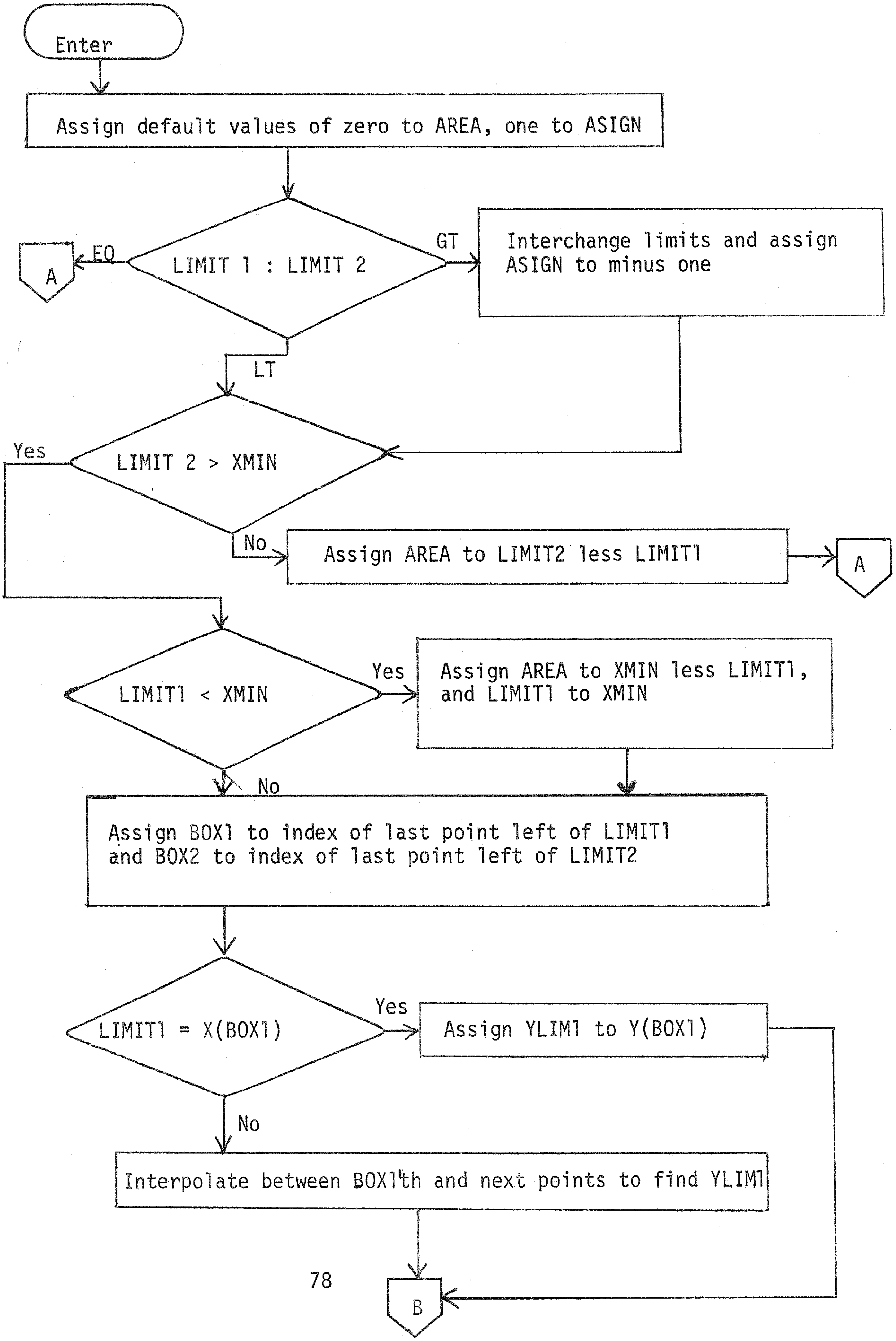

C
Assign LUNIT to the next UNIT and CAPCON to zero
next block's availability < .000001
Yes
Increment block-index by one and assign ENRGEE to zero
No
B
Yes
index = NBLOCK
No
next BLOCK = 1
No
Initialize index to zero
Yes
Increment index by one
No
index > current block-index
No
indexed UNIT = LUNIT
Yes
Yes
Augment CAPCON by indexed capacity
next block's availability < .5
No
Yes
Modify load-duration curve by reverse deconvolution of CAPCON (by calling DECONR)
A
Modify load-duration curve by forward deconvolution of CAPCON (by calling DECONF)

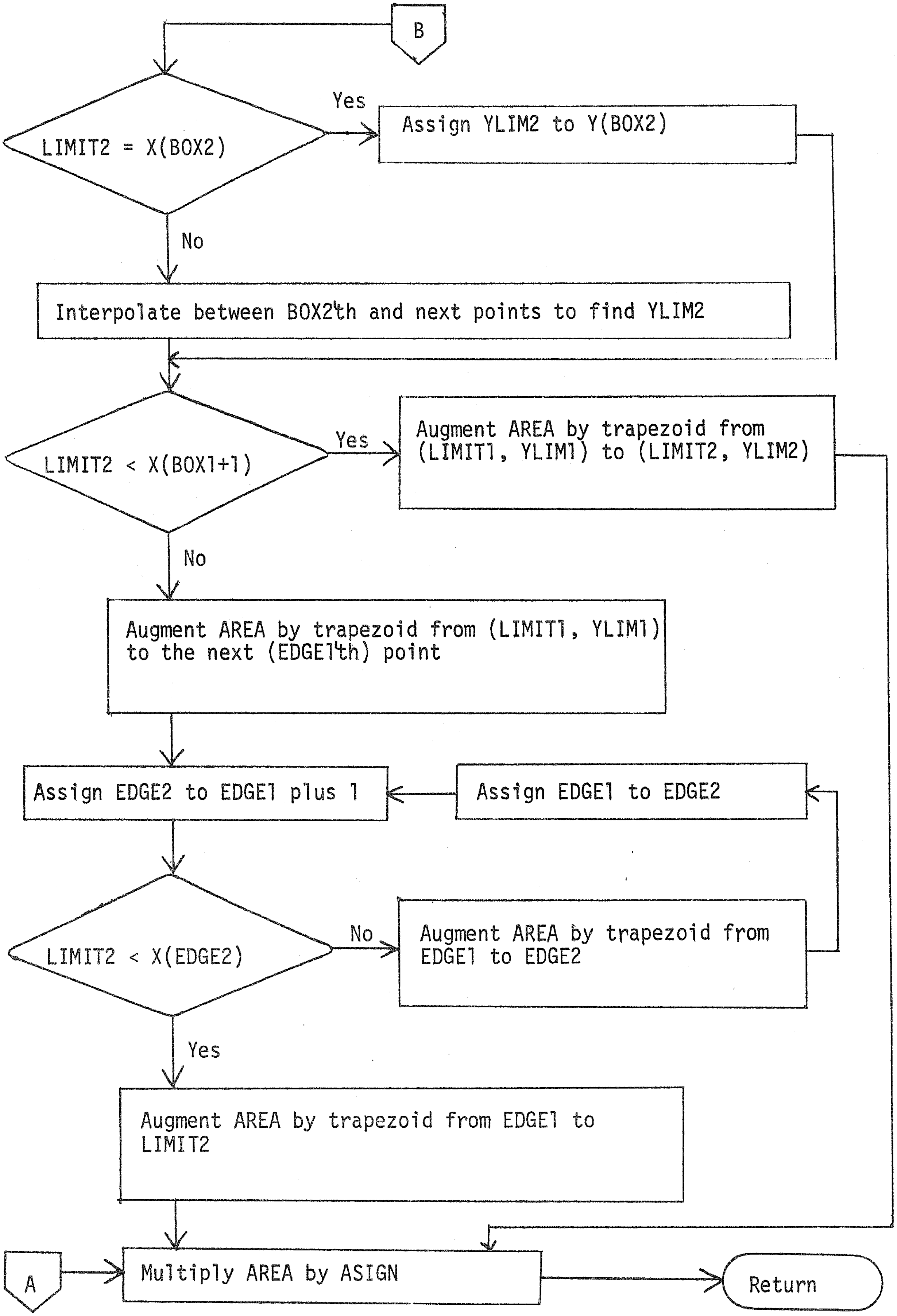
```
C=======================================================================
C
C  ROUTINE:          **** G E N E R 8 ****
C
C  PURPOSE:
C    TO CALCULATE GENERATION IN MWH FOR EACH BLOCK LOADED
C
C  INPUT VARIABLES:
C    ELDC       ORDINATES OF CALCULATED LOAD-PROBABILITY CURVE
C    XAXIS      ORDINATES OF LOAD-PROBABILITY CURVE
C    DELTA      STEP-SIZE FOR ARRAY XAXIS
C    EAVAIL     EFFECTIVE AVAILABILITY BY UNIT
C    MONTH      MONTH OF STUDY
C    UNIT       LOADING ORDER OF UNITS
C    MWBLOK     CAPACITY OF BLOCKS LOADED, IN MW
C    BLOCK      LOADING ORDER OF BLOCKS
C    NBLOCK     NUMBER OF BLOCKS TO LOAD
C    LIMITA     LEFT-HAND INTEGRATION LIMITS BY BLOCK
C    LIMITB     RIGHT-HAND INTEGRATION LIMITS BY BLOCK
C    HOURS      NUMBER OF HOURS IN MONTH
C    ELDCPT     NUMBER OF POINTS IN ARRAYS ELDC AND XAXIS
C    NZPNTS     NUMBER OF NON-ZERO ORDINATES IN ELDC'S COLUMNS
C    UNLOAD     LOADING TYPE OF UNIT:  1-BASE, 2-CYCLING, 3-PEAKING,
C               4-HYDRO
C    NSTEP      NUMBER OF LOADING STEPS FOR THE FOUR TYPES OF UNITS
C
C  OUTPUT VARIABLES:
C    ENRGEE     GENERATION OF EACH BLOCK, IN MWH
C    SYSGEN     TOTAL SYSTEM GENERATION, IN MWH
C
C  ROUTINES CALLED:
C    INTGR8   CONVOL   DECONF   DECONR
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE, MAY 1979
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

INTGR8 Routine

This routine performs trapezoidal integration of the area under the curve Y(X), where X(I) and Y(I,J) are both arrays of coordinates; the second subscript on Y allows reference to more than one curve by the calling statement. Since the ordinates for abscissas from zero through XMIN are assumed to be unity, the area of integrals over portions of that range is simply the difference of the integration limits. Beyond XMIN, the piecewise-linear representation of the curve justifies the sufficiency of the trapezoidal approach. Each trapezoid is no wider than the increment between values of X; for integration limits non-coincident with the x-grid, linear interpolation is used to compute the corresponding ordinates.

INTGR8


Enter
Assign default values of zero to AREA, one to ASIGN
LIMIT 1 : LIMIT 2
EQ
A
GT
Interchange limits and assign ASIGN to minus one
LT
LIMIT 2 > XMIN
Yes
No
Assign AREA to LIMIT2 less LIMIT1
A
LIMIT1 < XMIN
Yes
Assign AREA to XMIN less LIMIT1, and LIMIT1 to XMIN
No
Assign BOX1 to index of last point left of LIMIT1 and BOX2 to index of last point left of LIMIT2
LIMIT1 = X(BOX1)
Yes
Assign YLIM1 to Y(BOX1)
No
Interpolate between BOX1'th and next points to find YLIM1
B

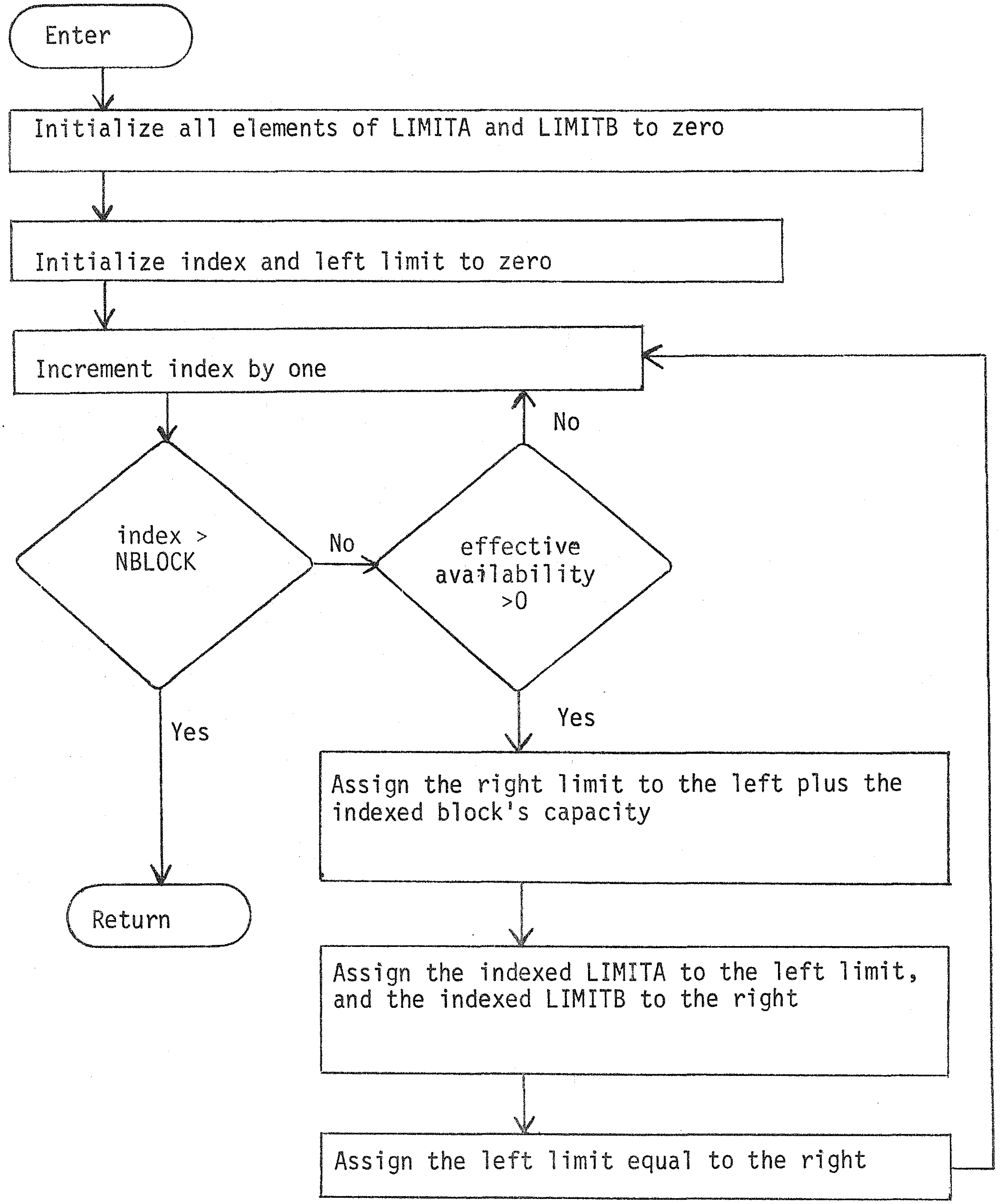

B
LIMIT2 = X(BOX2)
Yes
Assign YLIM2 to Y(BOX2)
No
Interpolate between BOX2th and next points to find YLIM2
LIMIT2 < X(BOX1+1)
Yes
Augment AREA by trapezoid from (LIMIT1, YLIM1) to (LIMIT2, YLIM2)
No
Augment AREA by trapezoid from (LIMIT1, YLIM1) to the next (EDGE1th) point
Assign EDGE2 to EDGE1 plus 1
Assign EDGE1 to EDGE2
LIMIT2 < X(EDGE2)
No
Augment AREA by trapezoid from EDGE1 to EDGE2
Yes
Augment AREA by trapezoid from EDGE1 to LIMIT2
A
Multiply AREA by ASIGN
Return

```
C===============================================================================
C
C   ROUTINE:           **** I N T G R 8 ****
C
C   PURPOSE:
C     TO FIND THE AREA UNDER THE CURVE Y(X) FROM LIMITA TO LIMITB
C
C   INPUT VARIABLES:
C     Y           ORDINATES OF THE LOAD-PROBABILITY CURVE TO BE INTEGRATED
C     CURRNT      IF 1, USE THE CURVE IN Y(*,1)
C                 IF 2, USE THE CURVE IN Y(*,2)
C     NPTS        NUMBER OF VALUES IN ONE COLUMN OF Y
C     X           ABSCISSAS OF THE LOAD-PROBABILITY CURVE
C     XMIN        MAXIMUM VALUE OF X FOR WHICH Y=1
C     DELTA       STEP-SIZE FOR THE X-AXIS
C     LIMITA      ABSCISSA WHERE INTEGRATION BEGINS
C     LIMITB      ABSCISSA WHERE INTEGRATION ENDS
C
C   OUTPUT VARIABLES:
C     AREA        AREA UNDER Y FROM LIMITA TO LIMITB
C
C   NOTES:
C     ROUTINE WILL HANDLE THE FOLLOWING CONDITIONS DIFFERENTLY
C
C         LIMIT1 < LIMIT2
C         LIMIT1 = LIMIT2
C         LIMIT1 > LIMIT2
C
C   AUTHOR:
C     NATIONAL REGULATORY RESEARCH INSTITUTE
C
C   LAST REVISED:  10/79
C
C===============================================================================
```

LIMITS Routine

This routine steps through the blocks of units in the loading order, assigning left and right load-axis end-points for later use as the range of integration for each block. The end-points are defined as the extremes of system demand over which the block would be partially loaded.

LIMITS


Enter
Initialize all elements of LIMITA and LIMITB to zero
Initialize index and left limit to zero
Increment index by one
index > NBLOCK
No
effective availability >0
No
Yes
Yes
Return
Assign the right limit to the left plus the indexed block's capacity
Assign the indexed LIMITA to the left limit, and the indexed LIMITB to the right
Assign the left limit equal to the right

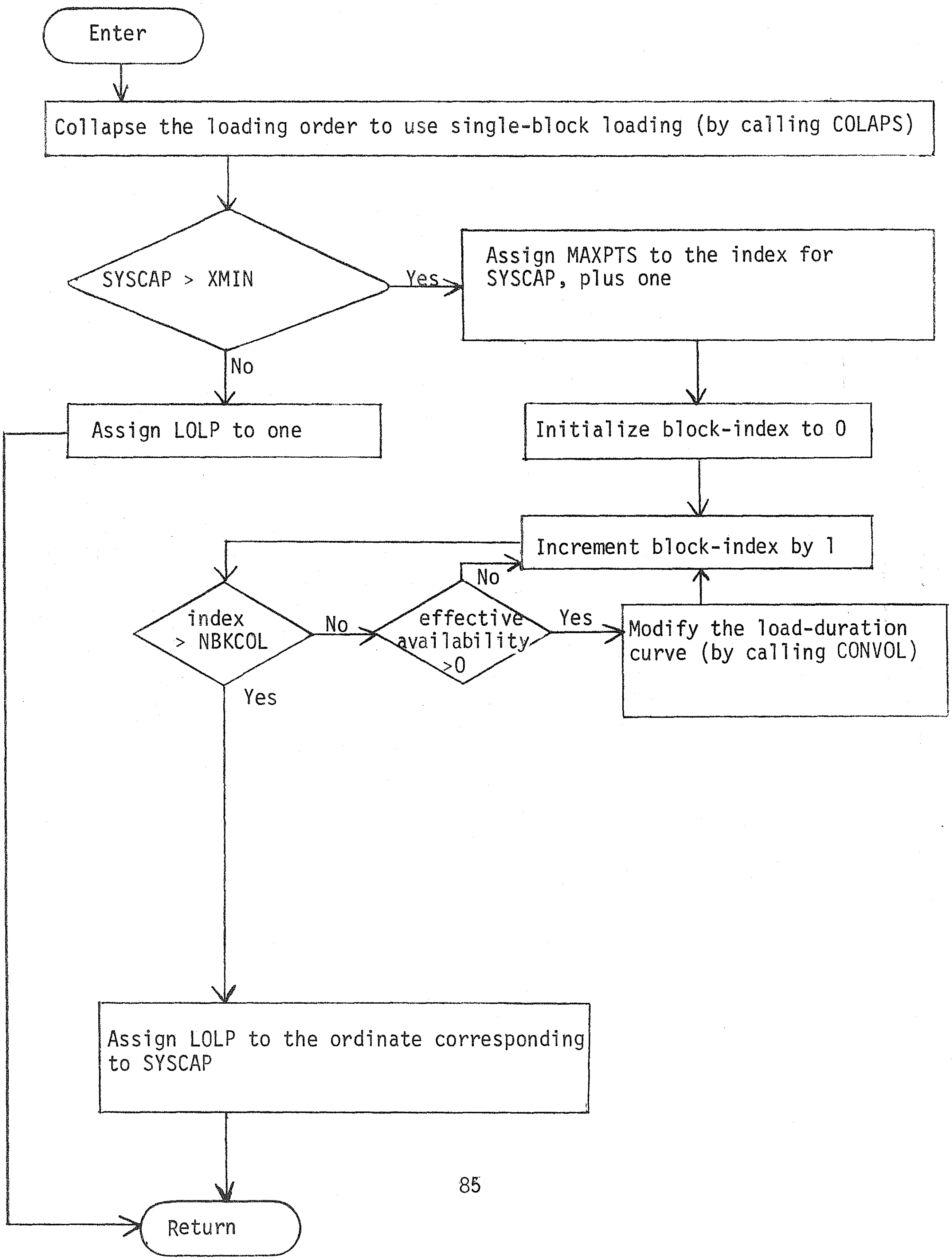
```
C=======================================================================
C
C  ROUTINE:          **** L I M I T S ****
C
C  PURPOSE:
C    TO FIND AND STORE THE LIMITS OF INTEGRATION FOR
C    EACH LOADING BLOCK OF EACH UNIT
C
C  INPUT VARIABLES:
C    MWBLOK    CAPACITY OF BLOCKS LOADED, IN MW
C    NBLOCK    NUMBER OF BLOCKS TO LOAD
C    UNIT      LOADING ORDER OF UNITS
C    BLOCK     LOADING ORDER OF BLOCKS
C    EAVAIL    EFFECTIVE AVAILABILITY BY UNIT
C    MONTH     MONTH OF STUDY
C    SYSCAP    TOTAL SYSTEM CAPACITY IN MW
C
C  OUTPUT VARIABLES:
C    LIMITA    LEFT-HAND INTEGRATION LIMIT
C    LIMITB    RIGHT-HAND INTEGRATION LIMIT
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE, MAY 1979
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

LOSLOD Routine

This routine computes the system reliability (or loss-of-load probability, LOLP) as that ordinate on the system's equivalent load-duration curve (ELDC) corresponding to an abscissa equal to system capacity. Although the system's ELDC had been developed in routine GENER8, the treatment of hydro units as having limited availability and the multi-block loading used with deconvolution of lower-order units resulted in distortions of the curve's shape. To avoid such distortions, the system's ELDC is regenerated from the original curve (ELCSVE), incorporating each unit (up to three blocks operating or failing together) by a single convolution (call to CONVOL). This is accomplished by collapsing the loading-order to that implied by single-block loading, then cycling through the number of aggregate blocks (NBKCOL), modifying the ELDC at each pass.

The early return with LOLP assigned to one is included for use with degenerate cases of input data; it is not expected to be exercised by normal utility systems' data.

LOSLOD

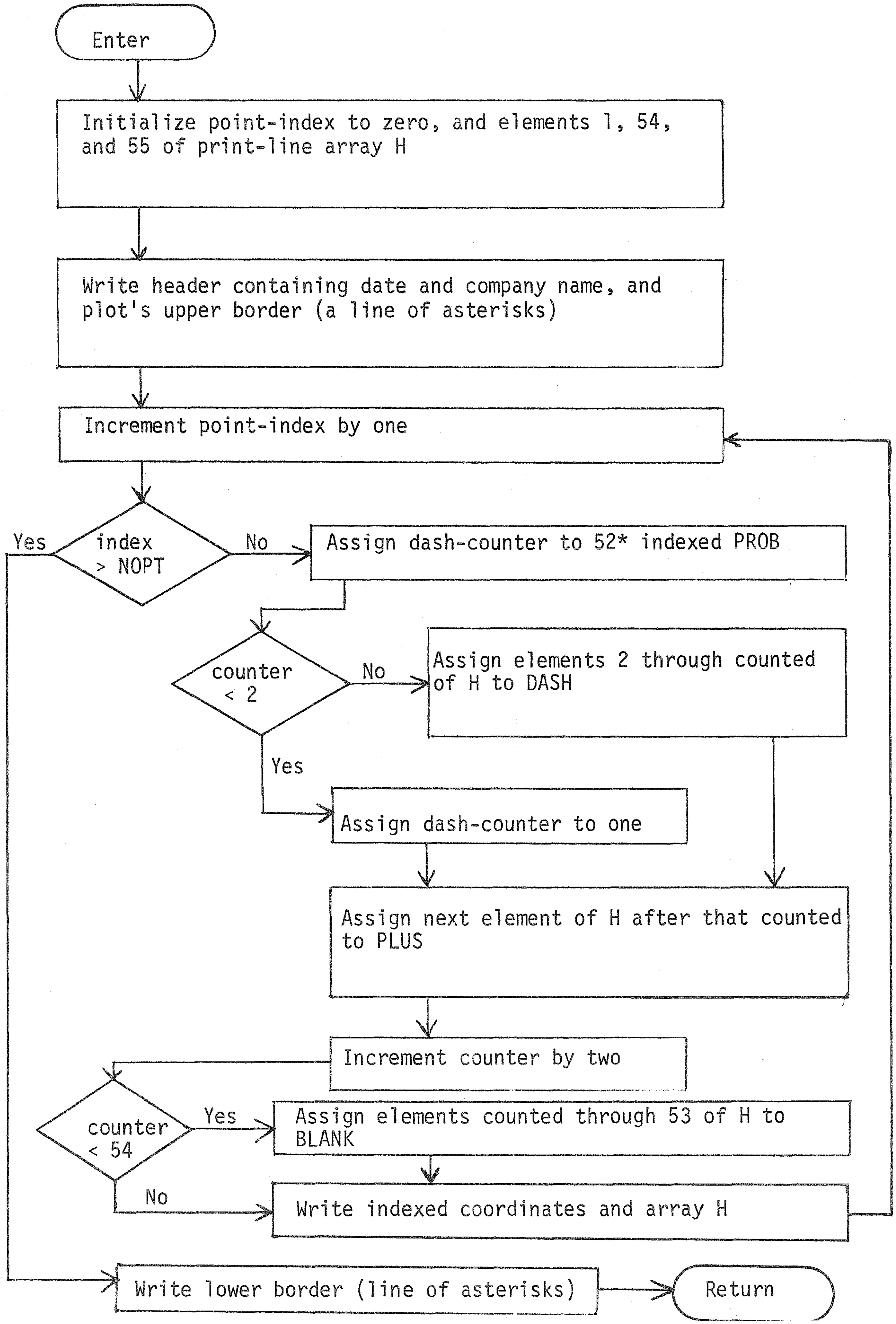

Enter
Collapse the loading order to use single-block loading (by calling COLAPS)
SYSCAP > XMIN
Yes
Assign MAXPTS to the index for SYSCAP, plus one
No
Assign LOLP to one
Initialize block-index to 0
Increment block-index by 1
No
index > NBKCOL
No
effective availability >0
Yes
Modify the load-duration curve (by calling CONVOL)
Yes
Assign LOLP to the ordinate corresponding to SYSCAP
Return

```
C=======================================================================
C
C  ROUTINE:          **** L O S L O D ****
C
C  PURPOSE:
C    TO CALCULATE THE LOSS-OF-LOAD PROBABILITY FOR THE GENERATING SYSTEM
C
C  INPUT VARIABLES:
C    ELDC       ORDINATES OF CALCULATED LOAD-PROBABILITY CURVE
C    DELTA      STEP-SIZE FOR THE X-AXIS
C    XAXIS      VALUES FOR LOAD-PROBABILITY CURVE ABSCISSAS
C    ELDCPT     NUMBER OF POINTS IN ARRAYS ELDC AND XAXIS
C    NZPNTS     NUMBER OF NON-ZERO ORDINATES IN ELDC
C    UNIT       LOADING ORDER OF UNITS
C    BLOCK      LOADING ORDER OF BLOCKS
C    MWBLOK     CAPACITY OF BLOCKS LOADED, IN MW
C    EAVAIL     EFFECTIVE AVAILABILITY BY UNIT
C    NBLOCK     NUMBER OF BLOCKS TO LOAD
C    SYSCAP     TOTAL SYSTEM CAPACITY IN MW
C    MONTH      MONTH OF STUDY
C    CURRNT     1 IF CURRENT COLUMN OF ORDINATES IS IN Y(*,1)
C               2 IF CURRENT COLUMN OF ORDINATES IS IN Y(*,2)
C    NEXT       1 IF NEXT COLUMN OF ORDINATES IS IN Y(*,1)
C               2 IF NEXT COLUMN OF ORDINATES IS IN Y(*,2)
C
C  OUTPUT VARIABLES:
C    LOLP       LOSS OF LOAD PROBABILITY (0 < LOLP < 1)
C
C  INTERNAL VARIABLES:
C    UNCOL      LOADING ORDER ARRAY COLLAPSED BY SINGLE-BLOCK UNITS
C    NBKCOL     NUMBER OF BLOCKS IN THE COLLAPSED ORDER
C    BOX        ARRAY POSITION WHERE SYSTEM CAPACITY FALLS
C    K          INDEX USED FOR BLOCK-LOOPING
C    MAXPTS     MAXIMUM NUMBER OF ORDINATES TO BE CALCULATED
C    PAVAIL     UNIT AVAILABILITY
C    XNZERO     MAXIMUM ABSCISSA FOR WHICH Y IS NOT ZERO
C
C  ROUTINES CALLED:
C    COLAPS   CONVOL
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE, MAY 1979
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

LPPLOT Routine

This routine generates a crude plot of the NOPT coordinates on the unmodified load-probability curve as passed by routine RDPROB. Each coordinate-pair is printed on the same line as a sequence of one asterisk (STAR) and hyphens (DASH) representing the magnitude of the ordinate (PROB). The hyphens are terminated by a plus-sign (PLUS) in the position (J) corresponding to the smallest integer exceeding 52 times the ordinate. Thus a plus-sign preceded by an asterisk and no hyphens would be printed for an ordinate of zero; for an ordinate of 0.499, twenty-four hyphens would precede the plus-sign; for 0.500, twenty-five hyphens. If the left-hand column of asterisks is considered the x-axis (corresponding to zero probability for a continuous curve), the subjective effect of the plus-sign assignment is to overstate the ordinates by up to one increment. To read the plot accurately, one must recall the assignment algorithm, which effectively locates the ordinate only as lying somewhere on the range of one increment preceding the plus-sign. If great significance will be placed on the plotted points, one may remove the subjective bias by subtracting 0.5 in the dash-counter assignment statement. If the resultant dash-counter (IN) is less than one, the flow should branch directly to the plus-sign assignment. This would, more conventionally, represent zero ordinates by a plus-sign in the first possible position, overwriting the asterisk.

LPPLOT

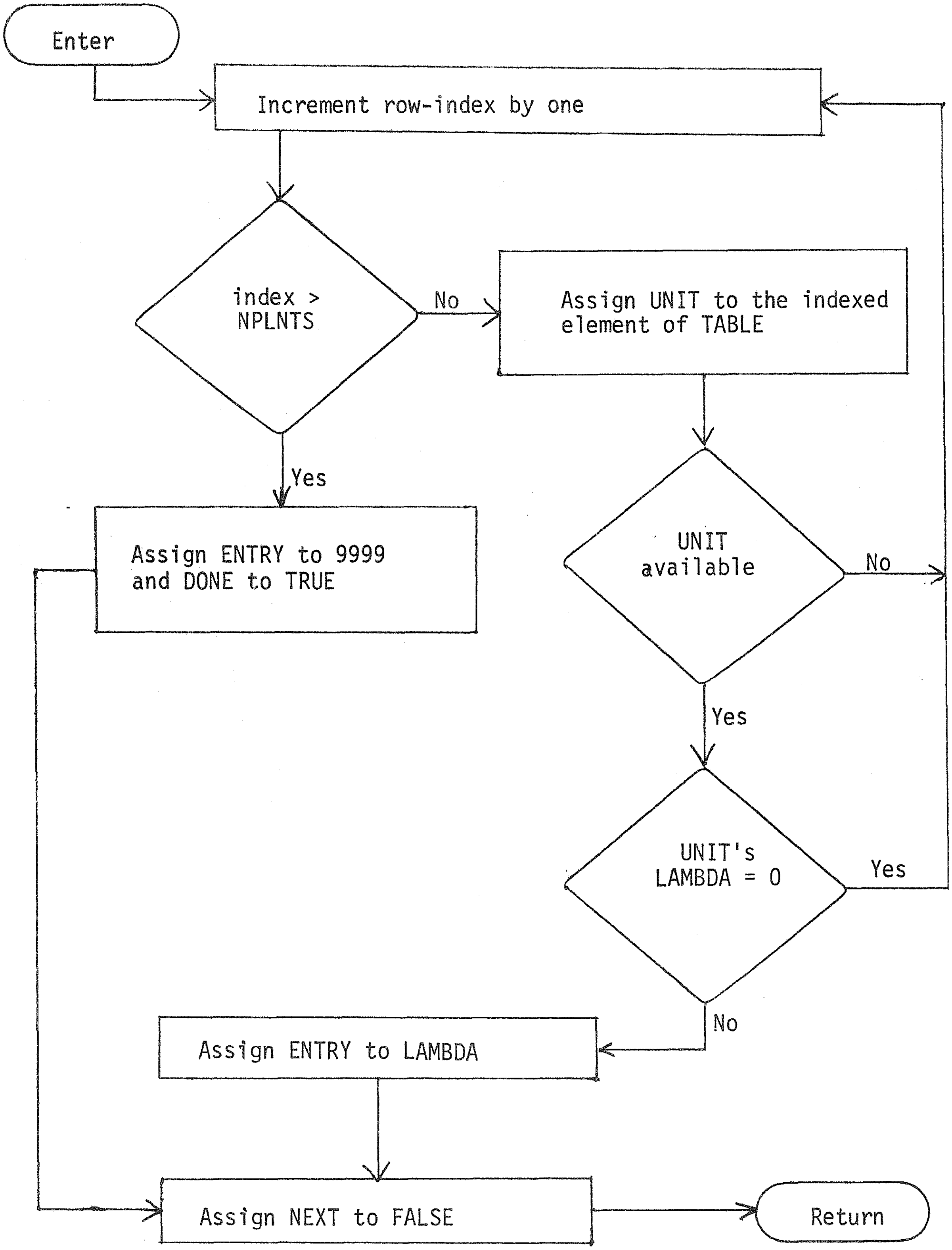

Enter
Initialize point-index to zero, and elements 1, 54, and 55 of print-line array H
Write header containing date and company name, and plot's upper border (a line of asterisks)
Increment point-index by one
index > NOPT
Yes
No
Assign dash-counter to 52* indexed PROB
counter < 2
No
Assign elements 2 through counted of H to DASH
Yes
Assign dash-counter to one
Assign next element of H after that counted to PLUS
Increment counter by two
counter < 54
Yes
Assign elements counted through 53 of H to BLANK
No
Write indexed coordinates and array H
Write lower border (line of asterisks)
Return

```
C=======================================================================
C
C  ROUTINE:          **** L P P L O T ****
C
C  PURPOSE:
C    TO PLOT THE LOAD-PROBABILITY CURVE USING NOPT POINTS
C
C  INPUT VARIABLES:
C    LODVAL    X-AXIS LOAD VALUES
C    PROB      Y-AXIS PROBABILITY VALUES
C    NOPT      NUMBER OF  (NON-ZERO) POINTS TO BE PLOTTED
C    MONTH     MONTH OF STUDY (1-12)
C    IYEAR     YEAR OF STUDY
C    COMPNA    COMPANY NAME
C    FILE      LOGICAL UNIT ON WHICH POINTS ARE TO BE PLOTTED
C
C  NOTES:
C    ADAPTED FROM AN EARLIER VERSION FOR THE PUBLIC UTILITIES COMMISSIO
C    OF OHIO
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

NXTBLK Routine

This routine simply scans forward in the array TABLE until a unit is found which is available during the current month and has non-zero priority (LAMDA). When the COL column of TABLE is exhausted, the value of ENTRY is returned as 9999 to allow it to function in the numerical comparisons of CREORD without the possibility of being the smallest among the three considered.

NXTBLK


Enter
Increment row-index by one
index > NPLNTS
No
Assign UNIT to the indexed element of TABLE
Yes
Assign ENTRY to 9999 and DONE to TRUE
UNIT available
No
Yes
UNIT's LAMBDA = 0
Yes
No
Assign ENTRY to LAMBDA
Assign NEXT to FALSE
Return

```
C=======================================================================
C
C  ROUTINE:             **** N X T B L K ****
C
C  PURPOSE:
C    TO FIND THE NEXT AVAILABLE BLOCK WHICH IS TO BE LOADED.
C    THE CONDITIONS FOR BEING LOADED ARE THAT THE CORRESPONDING
C    LAMBDA VALUE MUST NOT EQUAL 0 AND THAT THE BLOCK MUST BE
C    AVAILABLE DURING THIS SECTION OF THE STUDY.
C
C  INPUT VARIABLES:
C    AVAIL      .TRUE. IF UNIT IS AVAILABLE
C               .FALSE. IF UNIT IS NOT AVAILABLE
C    NUNITS     LENGTH OF AVAIL, TABLE & LAMBDA
C    TABLE      INDEX TABLE TO BE SEARCHED
C    LAMBDA     BLOCKS' LOADING-ORDER INDICES
C    POINTR     ROW IN TABLE WHERE THE SEARCH BEGINS
C    COL        COLUMN OF TABLE TO USE
C    MONTH      MONTH OF STUDY PERIOD
C
C  OUTPUT VARIABLES:
C    DONE       .TRUE. IF NO MORE BLOCKS TO LOOK FOR IN TABLE
C               .FALSE. IF MORE BLOCKS STILL UNLOADED
C    NEXT       .FALSE. TO INDICATE THAT THIS ROUTINE WAS CALLED
C    POINTR     UPDATED ROW-LOCATION OF THE CURRENT BLOCK
C    ENTRY      VALUE OF THE LAMBDA FOR THE UNIT
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE, FEBRUARY 1979
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

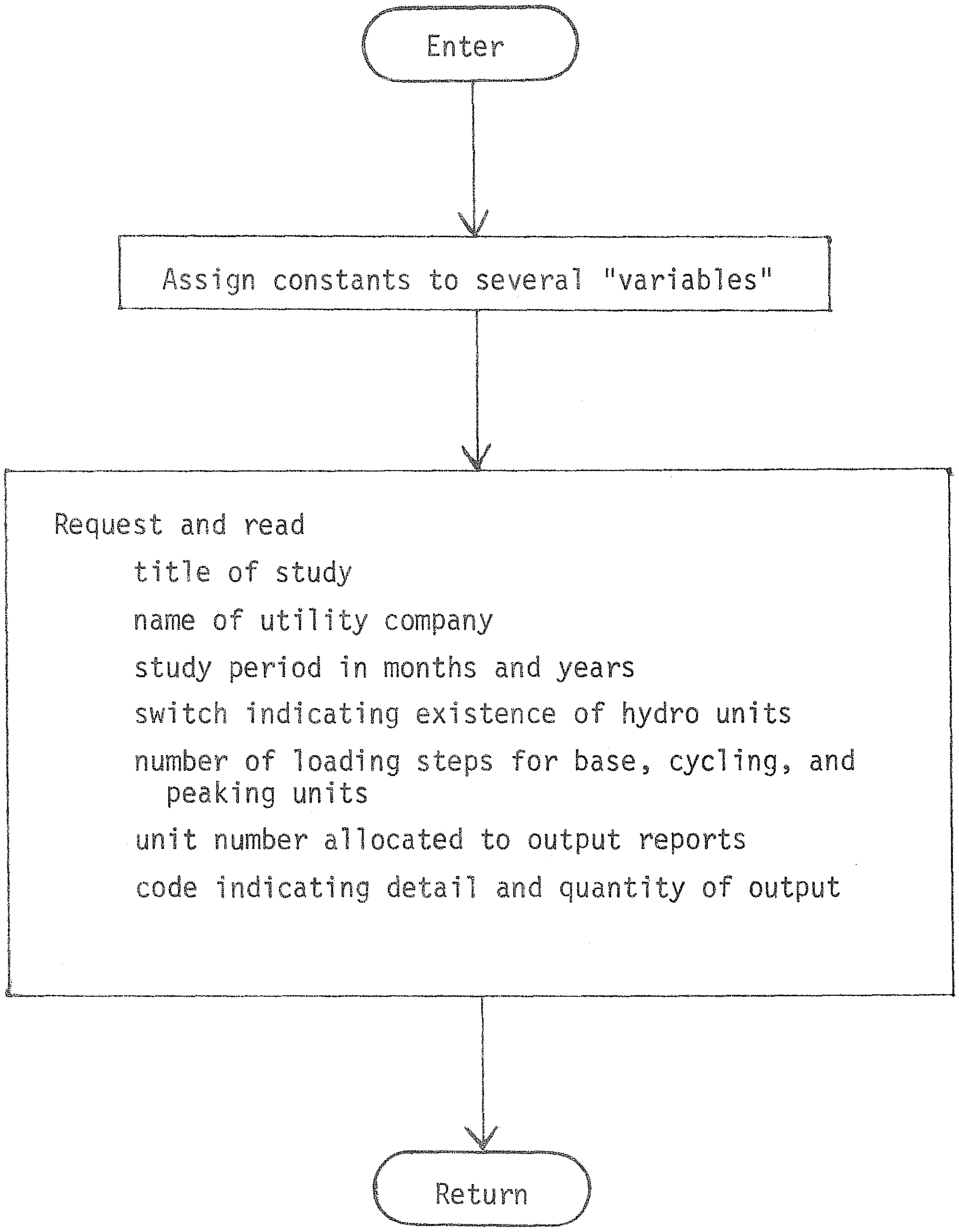
RDPARM Routine

This routine currently uses a machine-dependent free-form READ statement (interpreting blanks and commas as field delimiters) for several variables. To eliminate ambiguity in some of the field-widths expected, and to allow operation at other installations, recommended formats and corresponding numeric examples are given for these variables:

MONTH1	I2	01
YEAR1	I4	1977
MONTH2	I2	06
YEAR2	I4	1978
NBSTEP, NCSTEP, NPSTEP	3I2	030303
SUNIT	I2	15
OPTION	I1	2

Note that the current program array dimensions limit the number of loading steps (NBSTEP, NCSTEP, NPSTEP) to three.

RDPARM

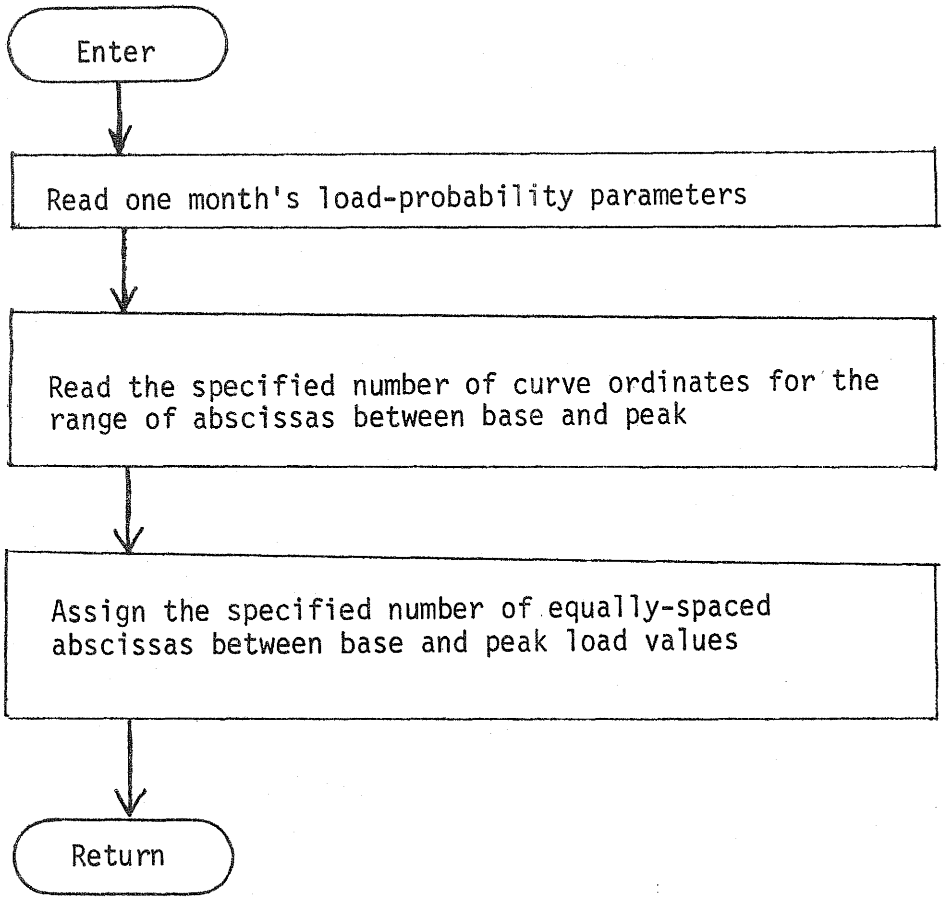

Enter
Assign constants to several "variables"
Request and read
title of study
name of utility company
study period in months and years
switch indicating existence of hydro units
number of loading steps for base, cycling, and peaking units
unit number allocated to output reports
code indicating detail and quantity of output
Return

```
C======================================================================
C
C  ROUTINE:           **** R D P A R M ****
C
C  PURPOSE:
C    TO READ IN THE PROGRAM PARAMETERS DESCRIBED IN THE OUTPUT
C    SECTION BELOW
C
C  INPUT VARIABLES:
C    NONE
C
C  OUTPUT VARIABLES:
C    HYDROS     .FALSE. IF NO HYDRO UNITS
C               .TRUE. IF HYDRO UNIT INFORMATION IS TO BE READ
C    HYUNIT     LOGICAL UNIT FROM WHICH TO READ HYDRO INFO
C    PFUNIT     LOGICAL UNIT FROM WHICH TO READ FOSSIL INFO
C    PBUNIT     LOGICAL UNIT FROM WHICH TO READ LOAD-PROBABILITY CURVE
C    MUNIT      LOGICAL UNIT TO WHICH TO WRITE MONTHLY REPORT
C    QUNIT      LOGICAL UNIT TO WHICH TO WRITE QUARTERLY REPORT
C    AUNIT      LOGICAL UNIT TO WHICH TO WRITE ANNUAL REPORT
C    SUNIT      LOGICAL UNIT TO WHICH TO WRITE FUEL-USAGE SUMMARY
C    MONTH1     FIRST MONTH OF STUDY
C    MONTH2     LAST MONTH OF STUDY
C    YEAR1      FIRST YEAR OF STUDY
C    YEAR2      LAST YEAR OF STUDY
C    NBSTEP     NUMBER OF BASE UNIT LOADING STEPS
C    NCSTEP     NUMBER OF CYCLE UNIT LOADING STEPS
C    NPSTEP     NUMBER OF PEAKER UNIT LOADING STEPS
C    COMPNA     COMPANY NAME
C
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C======================================================================
```

RDPROB Routine

The NOPT ordinates on the monthly load-probability curve read by this routine must correspond to NOPT (implicit) load values equally spaced between the base and peak values, inclusive. In addition to the coordinates for the probability curve, the routine returns values, as read, for the number of hours covered and the energy generation in the current month.

RDPROB


Enter
Read one month's load-probability parameters
Read the specified number of curve ordinates for the range of abscissas between base and peak
Assign the specified number of equally-spaced abscissas between base and peak load values
Return

```
C=======================================================================
C
C  ROUTINE:              **** R D P R O B ****
C
C  PURPOSE:
C    TO READ THE LOAD PROBABILITY DATA SUPPLIED BY THE COMPANY AND TO
C    CALCULATE THE LOAD VALUES FOR EACH INPUT VALUE.
C
C  INPUT VARIABLES:
C    PBUNIT    LOGICAL UNIT FROM WHICH TO READ THE LOAD-PROBABILITY DATA
C    HRSIP     HOURS IN EACH PERIOD COVERED
C    GENMO     ENERGY GENERATION IN EACH PERIOD
C
C  OUTPUT VARIABLES:
C    LODVAL    X-AXIS LOAD VALUES
C    PROB      Y-AXIS PROB VALUES
C    NOPT      NUMBER OF DATA POINTS
C    BASE      BASE LOAD FOR EACH PERIOD
C    PEAK      PEAK LOAD FOR EACH PERIOD
C    DELTA     LOAD VALUE INCREMENT
C    IFLAG     0 IF CURVE WAS READ FROM PBUNIT
C              1 IF CURVE WAS NOT ON UNIT PBUNIT
C
C  NOTES:
C     THE PROGRAM WILL END ABNORMALLY IF AN END-OF-FILE IS
C     ENCOUNTERED PREMATURELY.
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

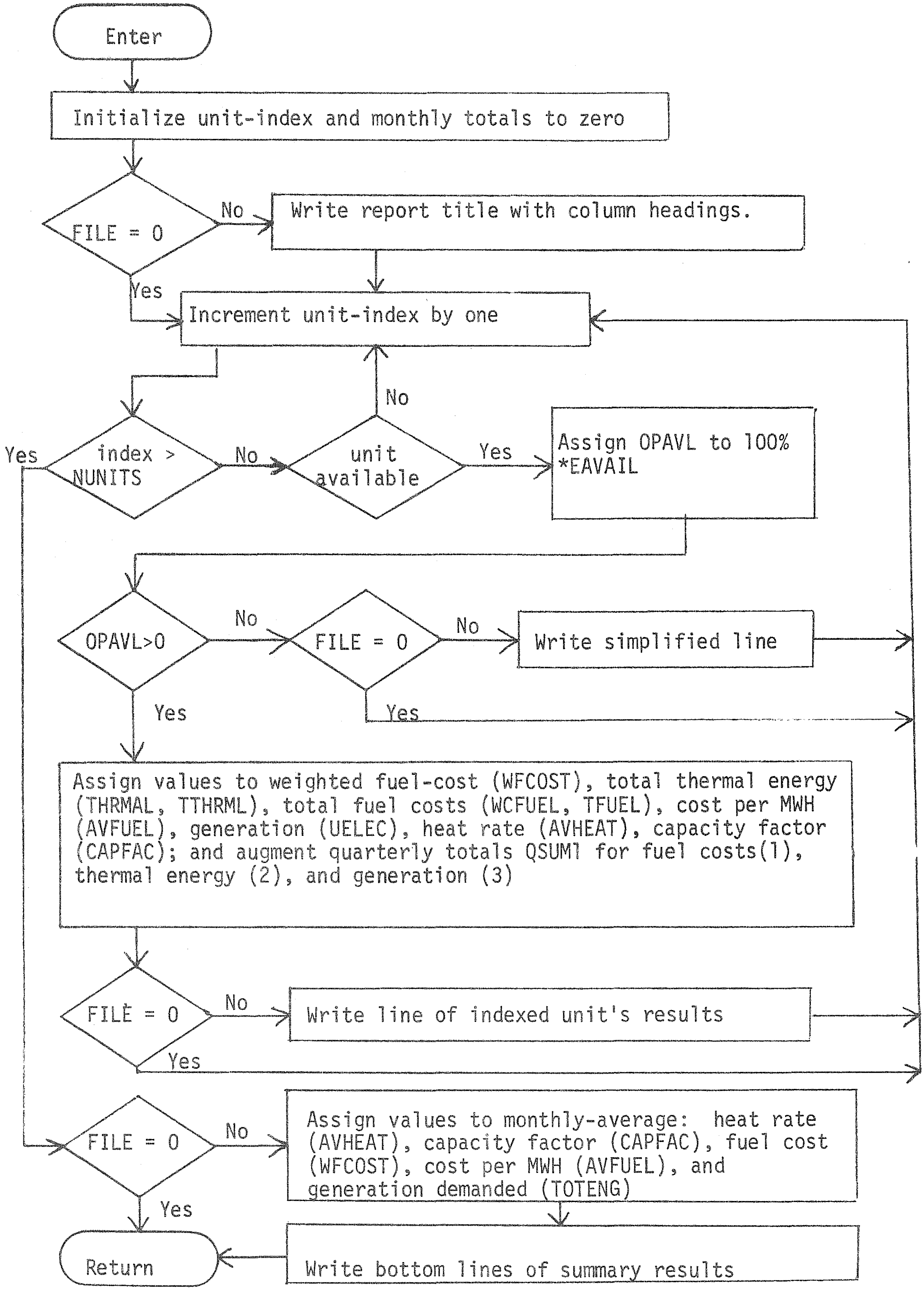
REPRT1 Routine

This routine computes unit operating characteristics during the specified month. If the output unit (FILE) is not zero, the results are printed. In either case, quarterly sums (QSUM1 columns) are augmented for possible use in other reports.

The scale factors used in the assignments deserve explanation. In the table following, M is consistently used to represent million.

units of contributing factors		numeric factor		units carried	variable assigned
(MBTU) * (¢/MBTU)	=	.00001	*	(K$)	TFUEL
(K$)/(MWH)	=	1000	*	($/MWH)	AVFUEL
(MBTU)/(MWH)	=	1000	*	(BTU/KWH)	AVHEAT
none	=	100	*	(%)	OPAVL
(MWH)/((MW)*(H))	=	100	*	(%)	CAPFAC

REPRT1


Enter
Initialize unit-index and monthly totals to zero
FILE = 0
No
Write report title with column headings.
Yes
Increment unit-index by one
Yes
index > NUNITS
No
unit available
No
Yes
Assign OPAVL to 100% *EAVAIL
OPAVL>0
No
FILE = 0
No
Write simplified line
Yes
Yes
Assign values to weighted fuel-cost (WFCOST), total thermal energy (THRMAL, TTHRML), total fuel costs (WCFUEL, TFUEL), cost per MWH (AVFUEL), generation (UELEC), heat rate (AVHEAT), capacity factor (CAPFAC); and augment quarterly totals QSUM1 for fuel costs(1), thermal energy (2), and generation (3)
FILE = 0
No
Write line of indexed unit's results
Yes
FILE = 0
No
Assign values to monthly-average: heat rate (AVHEAT), capacity factor (CAPFAC), fuel cost (WFCOST), cost per MWH (AVFUEL), and generation demanded (TOTENG)
Yes
Return
Write bottom lines of summary results

```
C=====================================================================
C
C  ROUTINE:          **** R E P R T 1 ****
C
C  PURPOSE:
C    TO WRITE A MONTHLY REPORT OF THE EXPECTED UNIT OPERATING
C    CHARACTERISTICS; ALSO, TO ROLL MONTHLY VALUES FOR EACH
C    UNIT INTO ARRAY QSUM1, WHICH WILL BE USED TO
C    PRINT AND CALCULATE VALUES IN REPRT3.
C
C  INPUT VARIABLES:
C    PBTUCT    COST OF PRIMARY FUEL IN CENTS/MEGA-BTU
C    ABTUCT    COST OF ALTERNATE FUEL IN CENTS/MEGA-BTU
C    PGENFC    FRACTION OF GENERATION USING PRIMARY FUEL
C    ENRGE2    ENERGY GENERATED BY EACH UNIT OVER THE MONTH
C    AVAIL     .TRUE. IF UNIT WAS AVAILABLE DURING STUDY
C              .FALSE. IF UNIT WAS NOT AVAILABLE DURING STUDY
C    BLKCAP    CUMULATIVE BLOCK CAPACITIES FOR EACH UNIT, IN MW
C    HRSIP     NUMBER OF HOURS IN STUDY PERIOD
C    YEAR      YEAR OF STUDY (FOUR-DIGIT)
C    MONTH     MONTH OF STUDY
C    NUNITS    NUMBER OF UNITS LOADED
C    UNAME     NAMES OF GENERATING UNITS
C    COMPNA    COMPANY NAME
C    FILE      LOGICAL UNIT TO WHICH REPORT IS TO BE WRITTEN
C    EAVAIL    EFFECTIVE AVAILABILITY
C    UNIT      LOADING ORDER OF UNITS
C    TITLE     STUDY DESCRIPTION
C
C  OUTPUT VARIABLES:
C    QSUM1     QUARTERLY TOTALS BY UNITS, BY COLUMNS:  1-FUEL COSTS,
C              2-THERMAL ENERGY, 3-ELECTRIC GENERATION
C    TTHRML    TOTAL THERMAL ENERGY FOR THIS MONTH
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=====================================================================
```

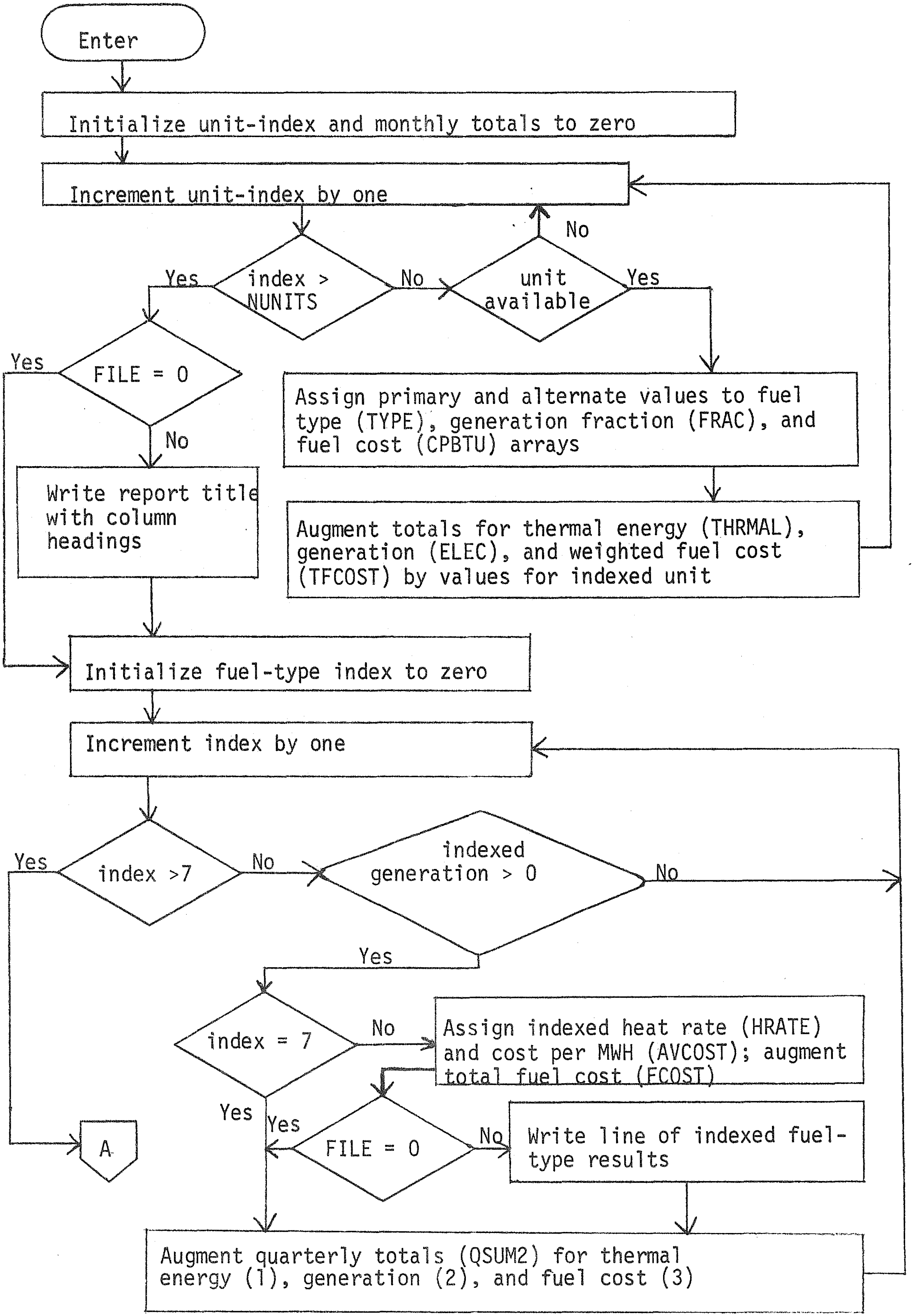
REPRT2 Routine

This routine computes the specified month's fuel-usage characteristics from two aspects of the generation system, segmenting it first by the seven fuel types and secondly by the four types of loading. If the output unit (FILE) is not zero, the results are printed. In either case, quarterly sums (arrays QSUM2 and QSUM3) are augmented for possible use in other reports. In conclusion, a line of parameters characterizing the system load is printed: capacity, base and peak loads, load and capacity factors, reserve margin, generated and unserved energy values, and generation reliability. To avoid apparent discrepancies due to single-precision arithmetic, the fuel-usage parameters averaged across fuel types are used as surrogates for those averaged across loading types.

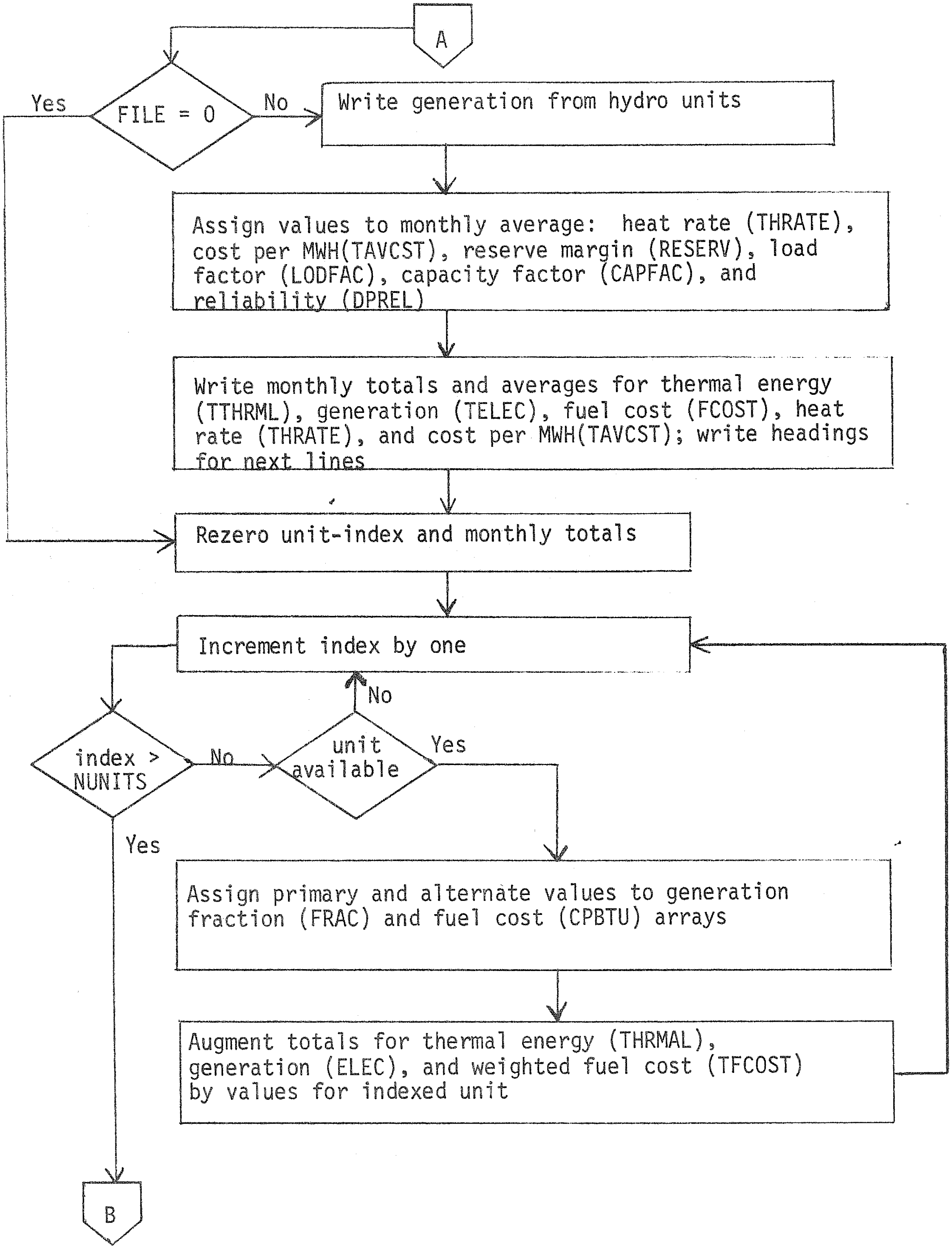
The scale factors used in the assignments deserve explanation. In the table following, M is consistently used to represent million.

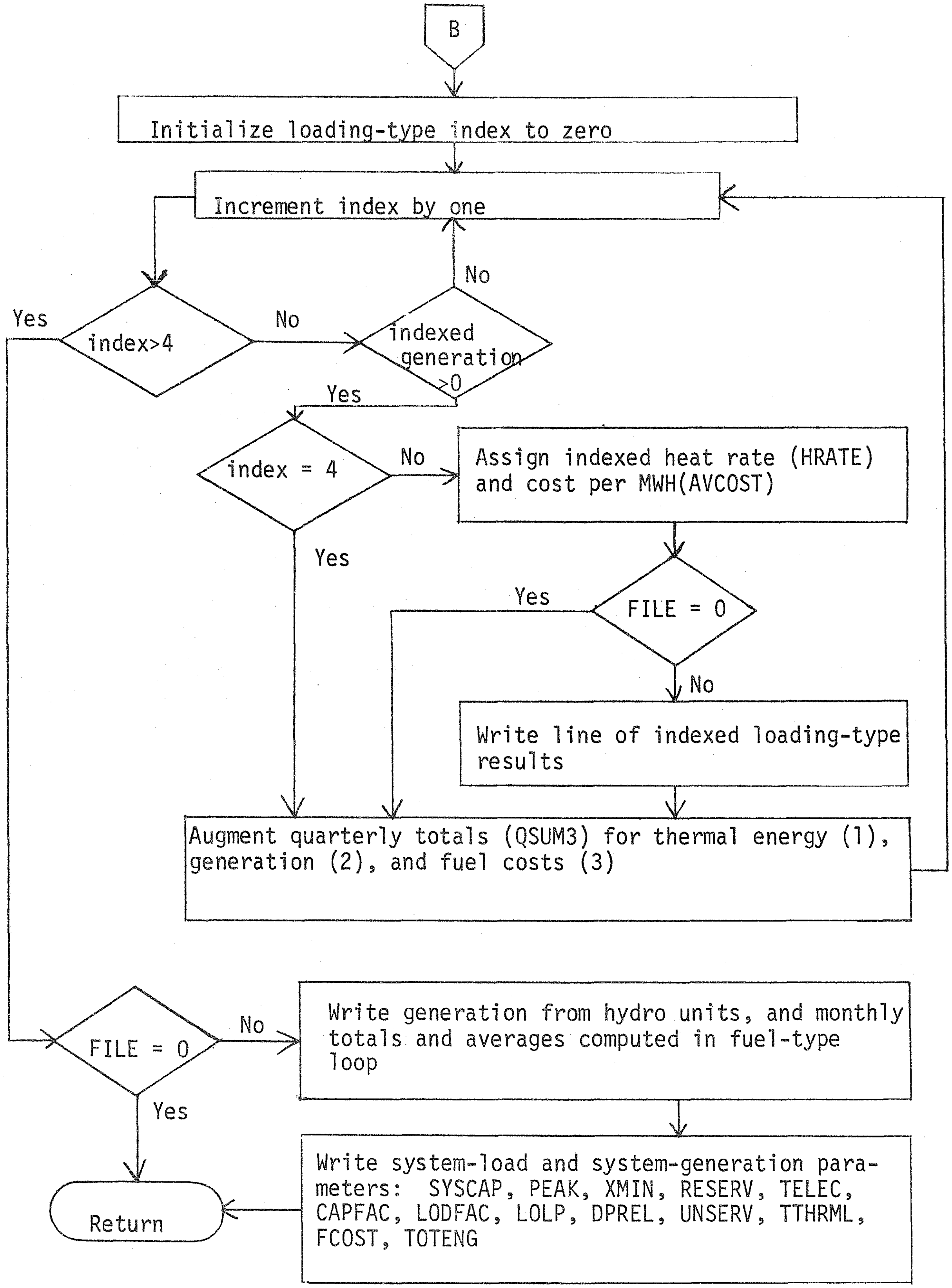
units of contributing factors		numeric factor		units carried	variable assigned
(¢/MBTU) * (MBTU)	=	.00001	*	(K$)	TFCOST
(K$)/(MWH)	=	1000	*	($/MWH)	AVCOST
(MBTU)/(MWH)	=	1000	*	(BTU/KWH)	HRATE
(MWH)/((MW)*(H))	=	100	*	(%)	LODFAC
(MWH)/((MW)*(H))	=	100	*	(%)	CAPFAC

REPRT2



Enter
Initialize unit-index and monthly totals to zero
Increment unit-index by one
No
Yes
index > NUNITS
No
unit available
Yes
Yes
FILE = 0
No
Assign primary and alternate values to fuel type (TYPE), generation fraction (FRAC), and fuel cost (CPBTU) arrays
Write report title with column headings
Augment totals for thermal energy (THRMAL), generation (ELEC), and weighted fuel cost (TFCOST) by values for indexed unit
Initialize fuel-type index to zero
Increment index by one
Yes
index >7
No
indexed generation > 0
No
Yes
index = 7
No
Assign indexed heat rate (HRATE) and cost per MWH (AVCOST); augment total fuel cost (FCOST)
Yes
Yes
FILE = 0
No
Write line of indexed fuel-type results
A
Augment quarterly totals (QSUM2) for thermal energy (1), generation (2), and fuel cost (3)


A
FILE = 0
Yes
No
Write generation from hydro units
Assign values to monthly average: heat rate (THRATE), cost per MWH(TAVCST), reserve margin (RESERV), load factor (LODFAC), capacity factor (CAPFAC), and reliability (DPREL)
Write monthly totals and averages for thermal energy (TTHRML), generation (TELEC), fuel cost (FCOST), heat rate (THRATE), and cost per MWH(TAVCST); write headings for next lines
Rezero unit-index and monthly totals
Increment index by one
No
index > NUNITS
No
unit available
Yes
Yes
Assign primary and alternate values to generation fraction (FRAC) and fuel cost (CPBTU) arrays
Augment totals for thermal energy (THRMAL), generation (ELEC), and weighted fuel cost (TFCOST) by values for indexed unit
B


B
Initialize loading-type index to zero
Increment index by one
index>4
Yes
No
indexed generation >0
No
Yes
index = 4
No
Assign indexed heat rate (HRATE) and cost per MWH(AVCOST)
Yes
FILE = 0
Yes
No
Write line of indexed loading-type results
Augment quarterly totals (QSUM3) for thermal energy (1), generation (2), and fuel costs (3)
FILE = 0
No
Write generation from hydro units, and monthly totals and averages computed in fuel-type loop
Yes
Write system-load and system-generation parameters: SYSCAP, PEAK, XMIN, RESERV, TELEC, CAPFAC, LODFAC, LOLP, DPREL, UNSERV, TTHRML, FCOST, TOTENG
Return

```
C=====================================================================
C
C  ROUTINE:           **** R E P R T 2 ****
C
C  PURPOSE:
C    TO WRITE A REPORT THAT SUMMARIZES THE SYSTEM PARAMETERS
C    BY FUEL TYPE AND UNIT LOADING TYPE; ALSO, TO ROLL QUARTERLY
C    TOTALS BY FUEL TYPE AND LOADING TYPE INTO QSUM2 AND QSUM3
C    RESPECTIVELY.
C
C  INPUT VARIABLES:
C    SYSCAP     SYSTEM CAPACITY IN MW, BY MONTH
C    PEAK       SYSTEM PEAK LOADS IN MW, BY MONTH
C    LOLP       LOSS-OF-LOAD PROBABILITY, BY MONTH
C    HRSIP      HOURS IN A STUDY MONTH
C    UNSERV     UNSERVED ENERGY IN MWH, BY MONTH
C    PGENFC     FRACTION OF ENERGY GENERATED BY PRIMARY FUEL, BY MONTH
C    PBTUCT     COST OF PRIMARY FUEL, IN CENTS/MEGA-BTU
C    ABTUCT     COST OF ALTERNATE FUEL, IN CENTS/MEGA-BTU
C    PRIFUL     PRIMARY FUEL TYPE FOR UNIT
C    ALTFUL     ALTERNATE FUEL TYPE FOR UNIT
C    MONTH      MONTH OF STUDY
C    FILE       LOGICAL UNIT TO WHICH REPORT IS TO BE WRITTEN
C    ENRGE2     ENERGY GENERATED BY UNITS, BY COLUMNS:  1-FIRST BLOCK,
C               2-SECOND BLOCK, 3-THIRD BLOCK, 4-TOTAL FOR UNIT
C    HEAT       THERMAL ENERGY REQUIREMENTS BY UNITS, BY COLUMNS:
C               1-FIRST BLOCK, 2-SECOND BLOCK, 3-THIRD BLOCK,
C               4-TOTAL FOR UNIT
C    NUNITS     NUMBER OF UNITS IN STUDY
C    AVAIL      .TRUE. IF UNIT WAS AVAILABLE
C               .FALSE. IF UNIT WAS NOT AVAILABLE
C    COMPNA     NAME OF COMPANY
C    YEAR       YEAR OF STUDY
C    TTHRML     TOTAL THERMAL ENERGY FOR THIS MONTH
C    UNTYPE     LOADING TYPE OF UNIT
C    XMIN       BASE LOAD IN MW
C
C  OUTPUT VARIABLES:
C    MSUM2      MONTHLY ELECTRIC AND COST TOTALS BY FUEL TYPE
C    QSUM2      QUARTERLY THERMAL, ELECTRIC, AND COST TOTALS BY
C               FUEL TYPE
C    QSUM3      QUARTERLY THERMAL, ELECTRIC, AND COST TOTALS BY
C               LOADING TYPE
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=====================================================================
```

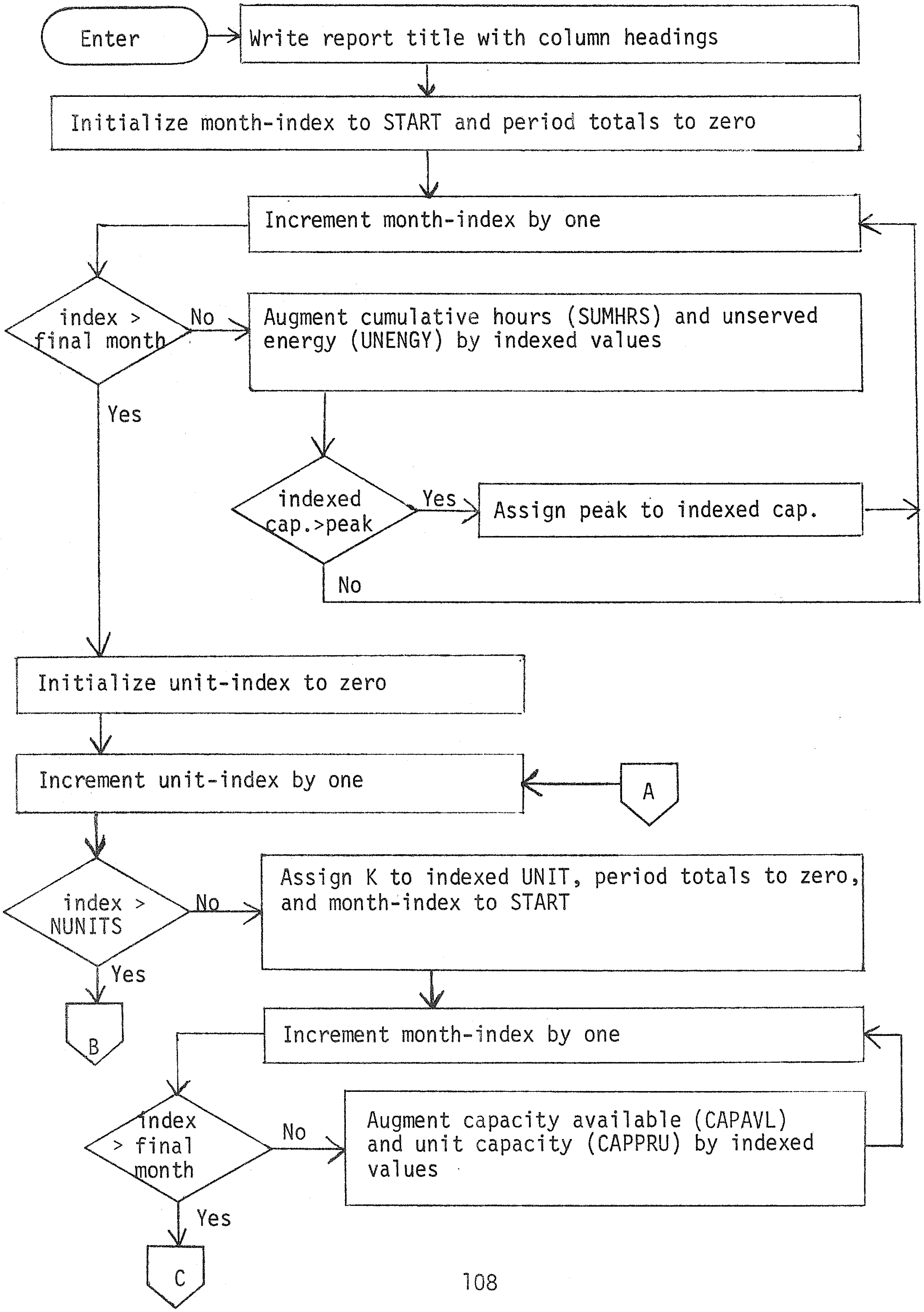
REPRT3 Routine

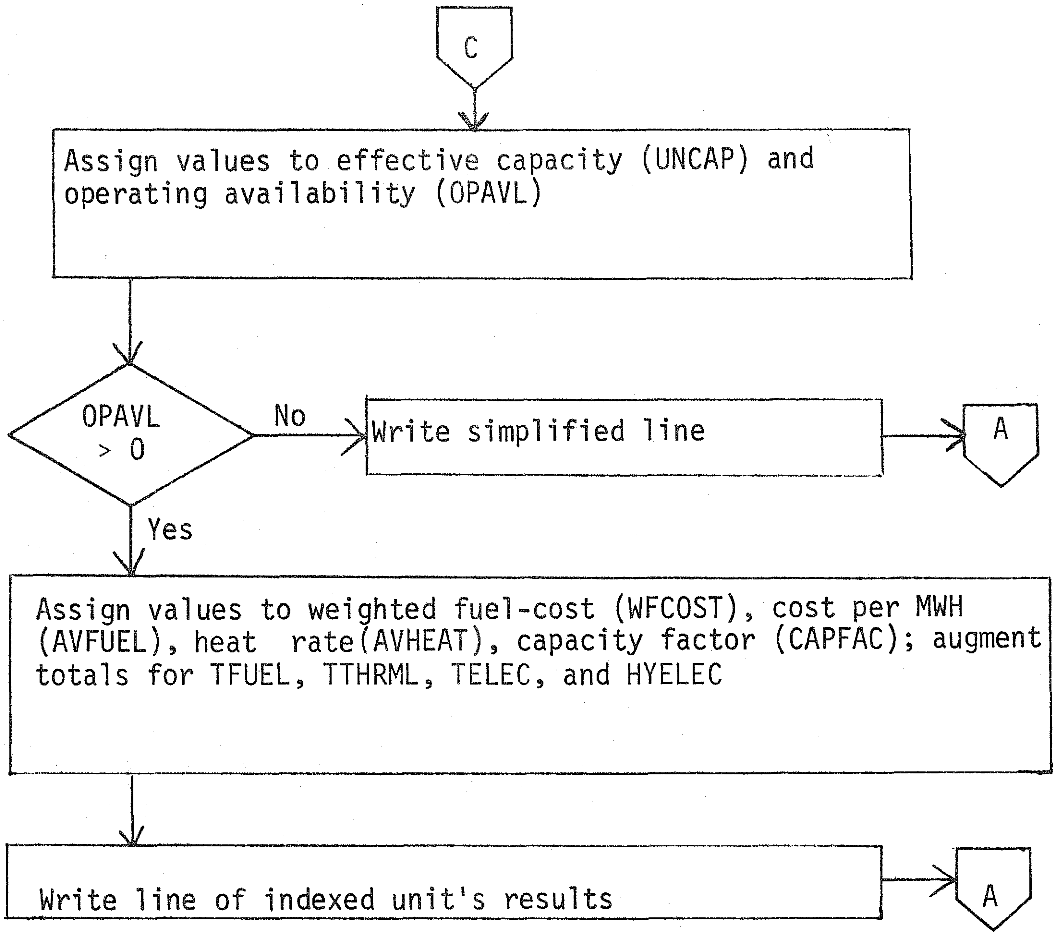
This routine computes unit operating characteristics over the specified period (from START to MONTH), usually a year or quarter thereof. Previously-computed data passed via array SUM1 (from routine REPRT1 if QSUM1, from MAIN program if ASUM1) are used with other unit-indexed arrays (EAVAIL and COWNMW).

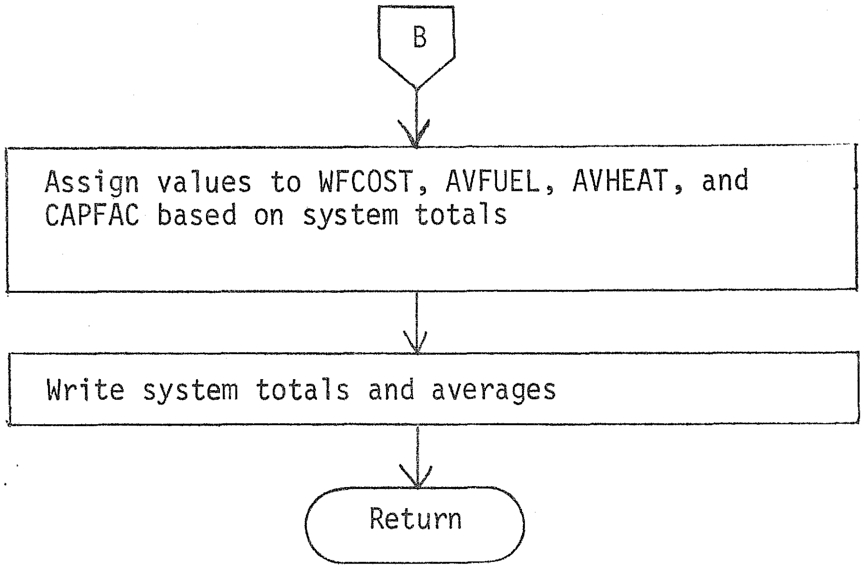
The scale factors used in the assignments deserve explanation. In the table following, M is consistently used to represent million.

units of contributing factors		numeric factor		units carried	variable assigned
(K$)/(MBTU)	=	100,000	*	(¢/MBTU)	WFCOST
(K$)/(MWH)	=	1000	*	($/MWH)	AVFUEL
(MBTU)/(MWH)	=	1000	*	(BTU/KWH)	AVHEAT
(MWH)/(MWH)	=	100	*	(%)	CAPFAC

REPRT3


Enter
Write report title with column headings
Initialize month-index to START and period totals to zero
Increment month-index by one
index > final month
No
Augment cumulative hours (SUMHRS) and unserved energy (UNENGY) by indexed values
Yes
indexed cap.>peak
Yes
Assign peak to indexed cap.
No
Initialize unit-index to zero
Increment unit-index by one
A
index > NUNITS
No
Assign K to indexed UNIT, period totals to zero, and month-index to START
Yes
B
Increment month-index by one
index > final month
No
Augment capacity available (CAPAVL) and unit capacity (CAPPRU) by indexed values
Yes
C


C
Assign values to effective capacity (UNCAP) and operating availability (OPAVL)
OPAVL > 0
No
Write simplified line
A
Yes
Assign values to weighted fuel-cost (WFCOST), cost per MWH (AVFUEL), heat rate(AVHEAT), capacity factor (CAPFAC); augment totals for TFUEL, TTHRML, TELEC, and HYELEC
Write line of indexed unit's results
A


B
Assign values to WFCOST, AVFUEL, AVHEAT, and CAPFAC based on system totals
Write system totals and averages
Return

```
C=========================================================================
C
C  ROUTINE:            **** R E P R T 3 ****
C
C  PURPOSE:
C    TO WRITE A REPORT OF THE EXPECTED UNIT OPERATING CHARACTERISTICS
C    ON A QUARTERLY AND AN ANNUAL BASIS
C
C  INPUT VARIABLES:
C    SUM1      BY COLUMNS:  TOTAL FUEL COST, ELECTRIC AND THERMAL
C              ENERGY GENERATION
C    WFCOST    WEIGHTED-AVERAGE FUEL COST, IN CENTS/MEGA-BTU
C    AVFUEL    AVERAGE FUEL COST, IN DOLLARS/MWH
C    AVHEAT    AVERAGE HEAT RATE
C    CAPFAC    CAPACITY FACTOR
C    START     STARTING MONTH OF REPORT PERIOD
C    BLKCAP    CUMULATIVE BLOCK CAPACITIES FOR EACH UNIT, IN MW
C    HRSIP     HOURS IN STUDY PERIOD
C    YEAR      YEAR OF STUDY
C    MONTH     MONTH OF STUDY
C    NUNITS    NUMBER OF UNITS IN STUDY
C    UNAME     NAMES OF GENERATING UNITS
C    COMPNA    COMPANY NAME
C    FILE      LOGICAL UNIT TO WHICH REPORT IS TO BE WRITTEN
C    EAVAIL    EFFECTIVE AVAILABILTY
C    UNIT      LOADING ORDER OF UNITS
C    PRIFUL    PRIMARY FUEL TYPE
C    UNLOAD    LOADING TYPE OF UNIT
C    TITLE     STUDY DESCRIPTION
C    SYSTMW    SYSTEM CAPACITY IN MW
C    UNSERV    UNSERVED ENERGY IN MWH
C
C  OUTPUT VARIABLES:
C    TELEC     CUMULATIVE GENERATION IN MWH
C    TTHRML    CUMULATIVE THERMAL ENERGY IN MEGA-BTU
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=========================================================================
```

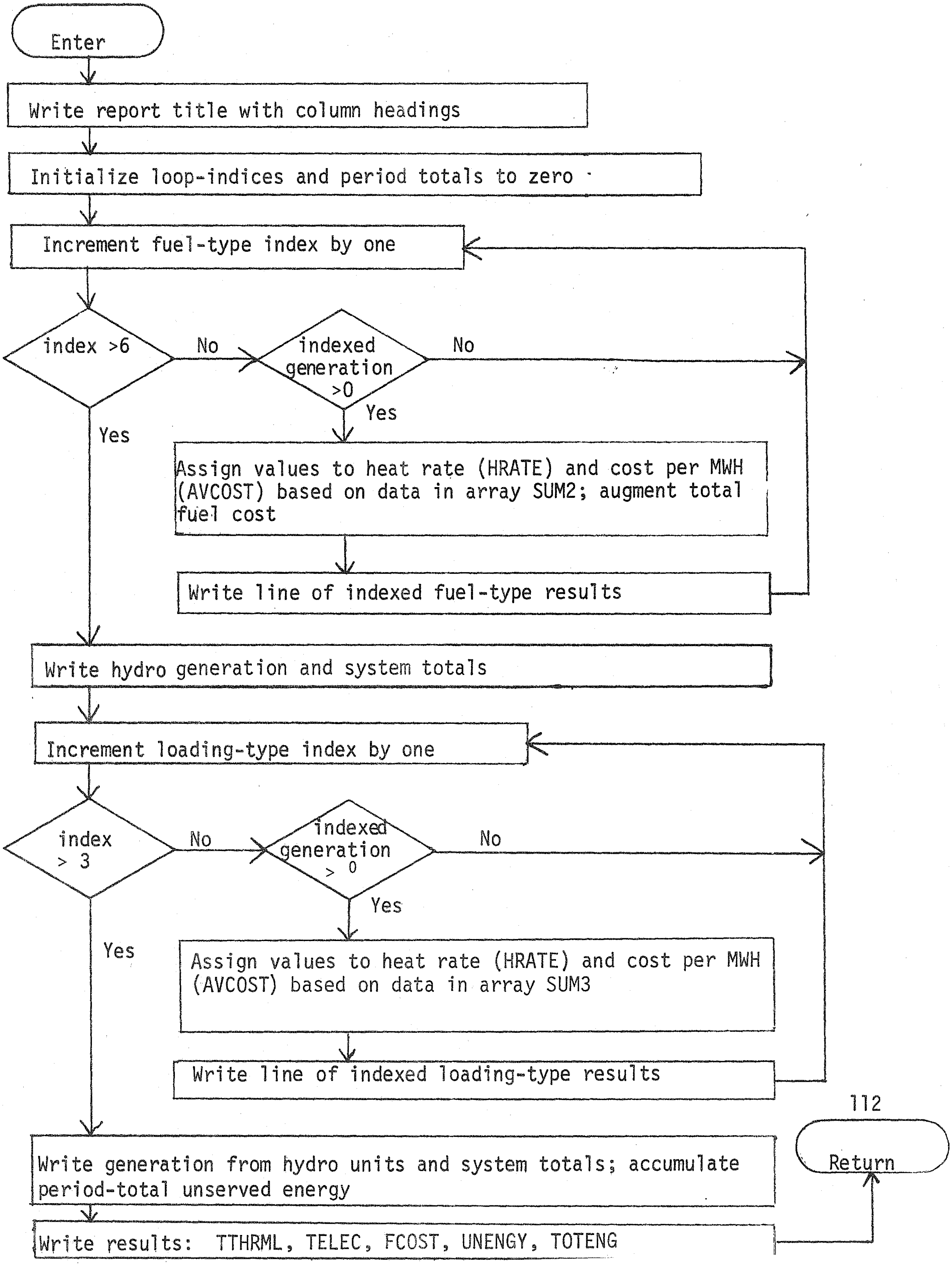
REPRT4 Routine

This routine computes the fuel-usage characteristics over the specified period (from START to MONTH) from two aspects of the generation system, segmenting it first by the seven fuel types and secondly by the four types of loading. Previously-computed data passed via arrays SUM2 and SUM3 (from routine REPRT2 if a quarterly period, from MAIN program if annual) are used.

The scale factors used in the assignments deserve explanation. In the table following, M is consistently used to represent million.

units of contributing factors		numeric factor		units carried	variable assigned
(MBTU)/(MWH)	=	1000	*	(BTU/KWH)	HRATE
(K$)/(MWH)	=	1000	*	($/MWH)	AVCOST

REPRT4

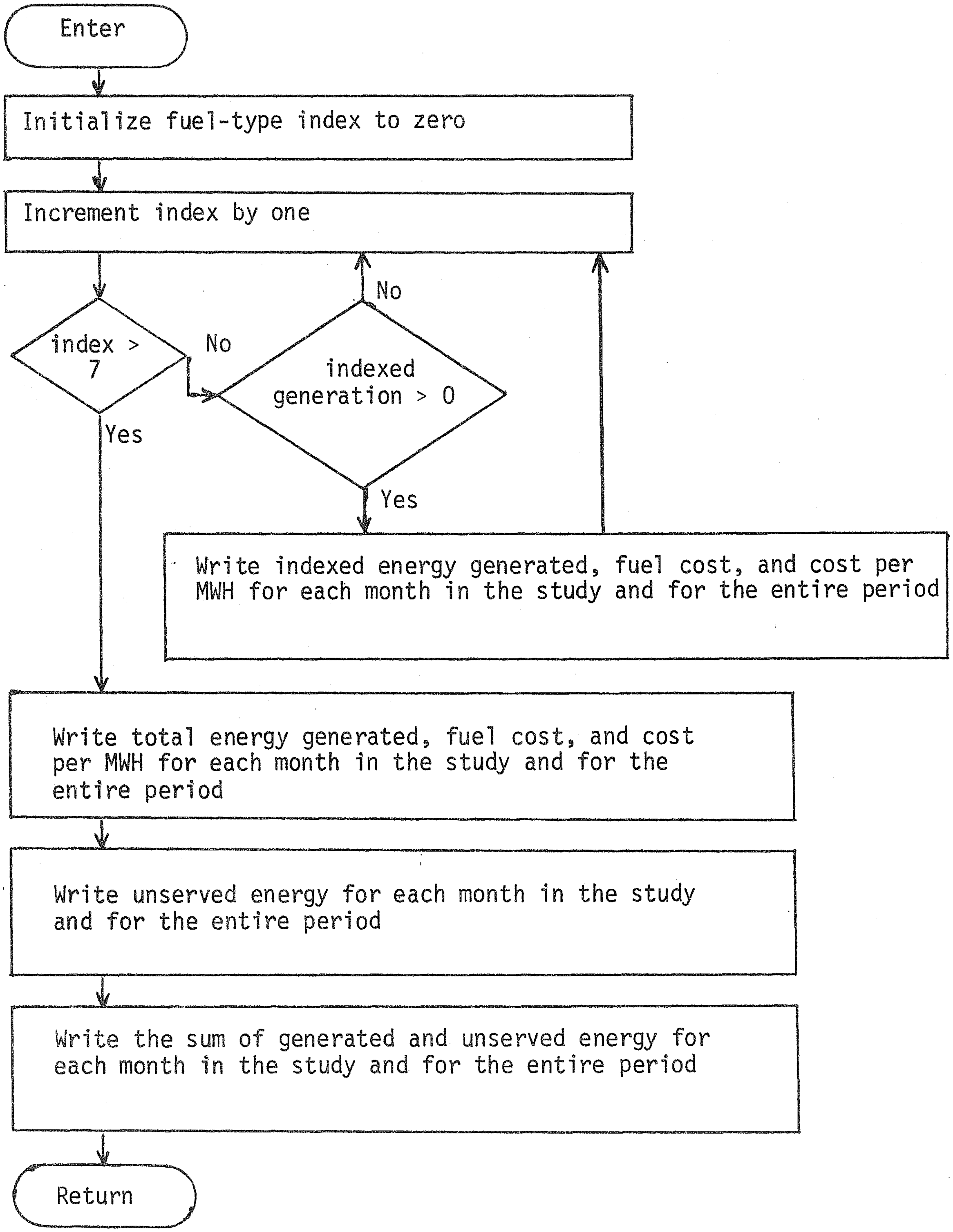

Enter
Write report title with column headings
Initialize loop-indices and period totals to zero
Increment fuel-type index by one
index >6
No
indexed generation >0
No
Yes
Yes
Assign values to heat rate (HRATE) and cost per MWH (AVCOST) based on data in array SUM2; augment total fuel cost
Write line of indexed fuel-type results
Write hydro generation and system totals
Increment loading-type index by one
index > 3
No
indexed generation > 0
No
Yes
Yes
Assign values to heat rate (HRATE) and cost per MWH (AVCOST) based on data in array SUM3
Write line of indexed loading-type results
Write generation from hydro units and system totals; accumulate period-total unserved energy
Write results: TTHRML, TELEC, FCOST, UNENGY, TOTENG
Return

```
C=======================================================================
C
C  ROUTINE:            **** R E P R T 4 ****
C
C  PURPOSE:
C    TO WRITE A REPORT SUMMARIZING GENERATION AND FUEL USAGE BY FUEL
C    TYPE AND LOADING TYPE ON A QUARTERLY AND ANNUAL BASIS.
C
C  INPUT VARIABLES:
C    UNSERV    UNSERVED ENERGY BY MONTH
C    START     FIRST MONTH OF STUDY PERIOD
C    MONTH     FINAL MONTH OF STUDY PERIOD
C    FILE      LOGICAL UNIT TO WHICH REPORT IS TO BE WRITTEN
C    SUM2      THERMAL, ELECTRIC, AND COST TOTALS BY FUEL TYPE
C    SUM3      THERMAL, ELECTRIC, AND COST TOTALS BY LOADING TYPE
C    COMPNA    COMPANY NAME
C    YEAR      YEAR OF STUDY
C    TELEC     TOTAL GENERATION IN MWH
C    TTHRML    TOTAL THERMAL ENERGY IN MEGA-BTU
C
C  OUTPUT VARIABLES:
C    FCOST     TOTAL FUEL COST IN THOUSANDS OF DOLLARS
C    TAVCST    TOTAL AVERAGE FUEL COST IN DOLLARS/MWH
C    UNENGY    TOTAL UNSERVED ENERGY, IN MWH
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

REPRT5 Routine

This routine simply and concisely restates the fuel-usage as computed in other report routines for each month covered by the study period, and for the entire period. Supporting data on generated and unserved energy are printed. The numeric factor of 1000 is included in the average-cost calculation to convert from (K$)/(MWH) to ($/MWH) units.

REPRT5


Enter
Initialize fuel-type index to zero
Increment index by one
index > 7
No
Yes
indexed generation > 0
No
Yes
Write indexed energy generated, fuel cost, and cost per MWH for each month in the study and for the entire period
Write total energy generated, fuel cost, and cost per MWH for each month in the study and for the entire period
Write unserved energy for each month in the study and for the entire period
Write the sum of generated and unserved energy for each month in the study and for the entire period
Return

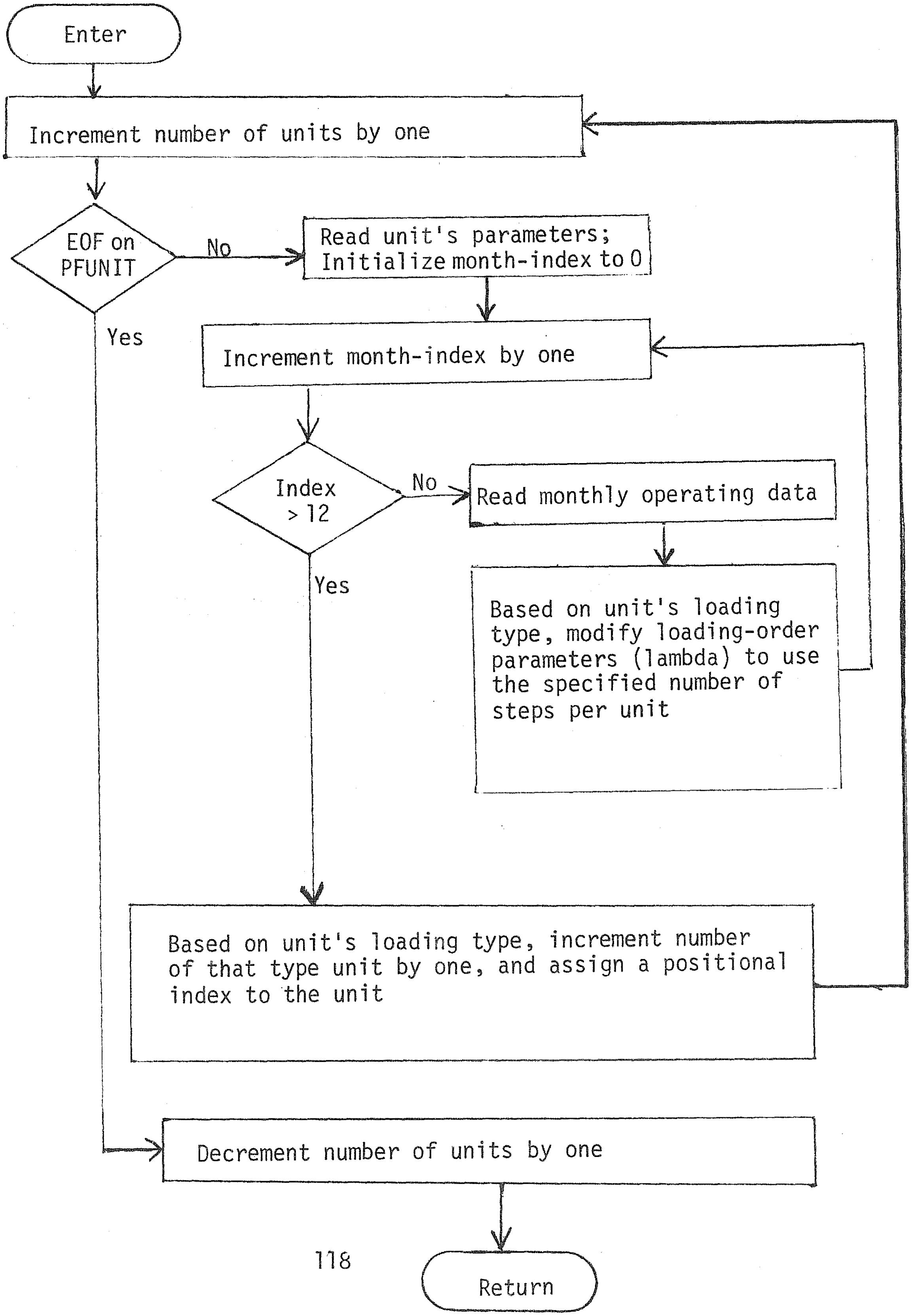
```
C=======================================================================
C
C  ROUTINE:          **** R E P R T 5 ****
C
C  PURPOSE:
C    TO WRITE A REPORT SUMMARIZING MONTHLY FUEL USAGE.
C
C  INPUT VARIABLES:
C    UNSERV     UNSERVED ENERGY BY MONTH, IN MWH
C    UNENGY     TOTAL UNSERVED ENERGY, IN MWH
C    MONTH1     FIRST MONTH OF STUDY PERIOD
C    MONTH      FINAL MONTH OF STUDY PERIOD
C    FILE       LOGICAL UNIT TO WHICH REPORT IS TO BE WRITTEN
C    MSUM2      MONTHLY ELECTRIC AND COST TOTALS BY FUEL TYPE
C    ASUM2      ANNUAL THERMAL, ELECTRIC, AND COST TOTALS BY FUEL TYPE
C    COMPNA     COMPANY NAME
C    YEAR       YEAR OF STUDY
C    TELEC      TOTAL GENERATION IN MWH
C    FCOST      TOTAL FUEL COST IN THOUSANDS OF DOLLARS
C    TAVCST     RATIO OF TOTAL FUEL COST TO TOTAL GENERATION, IN $/MWH
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

UNIFOS Routine

This routine reads data values for nuclear and fossil-fueled generating units primarily (outer-loop) by unit and secondarily (inner-loop) by month within the study year. Each such unit's loading type is here restricted to 1, 2, or 3 to indicate base, cycling, or peaking, respectively; type 4 (hydro) is disallowed. Thus the loading type determines the branching which assigns the number of loading steps per unit (NSTEP) and the branching for counting and indexing each unit.

The three lambda arrays (LAMDA1, LAMDA2, LAMDA3) as read indicate the dispatch priorities, a block having a lower-value lambda being loaded prior to one with a higher value. In general, all three arrays will be specified by the input data, yet the analyst may want to make a run using only one or two loading steps per unit. This option having been specified independently across loading types by parameters NBSTEP, NCSTEP, and NPSTEP (one of which is assigned to local variable NSTEP), the lambda arrays are used unaltered if NSTEP is three. For NSTEP equal to two, the priority for the full-load block (in LAMDA3) is assigned to that specified for the next lower-order block (in LAMDA2), and LAMDA2 is assigned to aero, so that each unit is priority-loaded in two steps. For NSTEP equal to one, the priority for the full-load block is assigned to that specified for the lowest block (in LAMDA1), and both LAMDA2 and LAMDA1 are assigned to zero, so that each unit is fully-loaded according to the lowest-order priorities.

UNIFOS


Enter
Increment number of units by one
EOF on PFUNIT
No
Yes
Read unit's parameters; Initialize month-index to 0
Increment month-index by one
Index > 12
No
Yes
Read monthly operating data
Based on unit's loading type, modify loading-order parameters (lambda) to use the specified number of steps per unit
Based on unit's loading type, increment number of that type unit by one, and assign a positional index to the unit
Decrement number of units by one
Return

```
C===========================================================================
C
C  ROUTINE:          **** U N I F O S ****
C
C  PURPOSE:
C    TO READ THE NUCLEAR- AND FOSSIL-FUELED UNITS' DATA FROM LOGICAL
C    UNIT PFUNIT.  THE OPERATION CHARACTERISTICS ARE READ AND STORED FOR
C    EACH MONTH OF THE STUDY.  ALSO THE UNIT CAPACITY AVAILABLE TO THE
C    COMPANY IS CALCULATED.
C
C  INPUT VARIABLES:
C    PFUNIT    LOGICAL UNIT FROM WHICH UNIT INFORMATION IS READ
C    IYEAR     FOUR-DIGIT STUDY-YEAR
C    NBSTEP    NUMBER OF LOADING STEPS FOR BASE UNITS
C    BCSTEP    NUMBER OF LOADING STEPS FOR CYCLING UNITS
C    NPSTEP    NUMBER OF LOADING STEPS FOR PEAKING UNITS
C
C  OUTPUT VARIABLES:
C    AUPAVL    ANNUAL UNIT PRODUCTION AVAILABILITY
C    CAPCST    CAPITAL COST OF UNIT IN DOLLARS PER INSTALLED KW
C    VSCCNO    UNIT NUMBER ASSIGNED BY VSCC
C    UNAME     UNIT NAME
C    FRAOWN    FRACTION OF UNIT OWNED BY COMPANY
C    UNTYPE    THE CLASSIFICATION OF THE UNIT:
C                                 1-STEAM FOSSIL, 2-STEAM NUCLEAR,
C                                 3-I.C. ENGINE, 4-GAS TURBINE,
C                                 5-JET ENGINE, 6-HYDRO,
C                                 7-PUMPED STORAGE
C    UNLOAD    UNIT LOADING TYPE: 1-BASE, 2-CYCLING, 3-PEAKING, 4-HYDRO
C    PRIFUL    PRIMARY FUEL USED BY EACH UNIT:
C                  1-COAL        5-NATURAL GAS
C                  2-NUCLEAR     6-GASOLINE
C                  3-LIGHT OIL   7-WATER
C                  4-HEAVY OIL   0-NONE
C    ALTFUL    ALTERNATE FUEL USED BY EACH UNIT, AS IN PRIFUL
C    IGFUEL    IGNITION FUEL USED BY EACH UNIT, AS IN PRIFUL
C    ONLIMO    THE MONTH THAT THE UNIT WENT INTO COMMERCIAL SERVICE
C    ONLIYR    THE YEAR THE UNIT WENT INTO SERVICE
C    OFLIMO    THE LAST MONTH THE UNIT IS EXPECTED TO REMAIN IN SERVICE
C    OFLIYR    THE LAST YEAR THE UNIT IS EXPECTED TO REMAIN IN SERVICE
C    UNETCP    UNLIMITED NET CAPACITY OF UNIT
C    LNETCP    LIMITED NET CAPACITY OF UNIT
C    HEATR1    HEAT RATE FOR FIRST BLOCK, IN BTU/KWH
C    HEATR2    HEAT RATE FOR SECOND BLOCK, IN BTU/KWH
C    HEATR3    HEAT RATE FOR THIRD BLOCK, IN BTU/KWH
C    EAVAIL    EFFECTIVE AVAILABILITY
C    BLKCAP    CUMULATIVE BLOCK CAPACITIES FOR EACH UNIT, IN MW
C    PBTUCT    PRIMARY FUEL COST IN CENTS/MEGA-BTU
C    ABTUCT    COST OF ALTERNATE FUEL IN CENTS PER MEGA-BTU
C    LAMDA1    LOADING PRIORITY FOR THE UNIT'S FIRST BLOCK
C    LAMDA2    LOADING PRIORITY FOR THE UNIT'S SECOND BLOCK
C    LAMDA3    LOADING PRIORITY FOR THE UNIT'S THIRD BLOCK
C    PGENFC    FRACTION OF GENERATION USING PRIMARY FUEL
C    IDBASE    LOCATION OF EACH BASE UNIT IN THE ORDER OF READING
C    IDCYCL    LOCATION OF EACH CYCLING UNIT IN THE ORDER OF READING
C    IDPEAK    LOCATION OF PEAKING UNITS IN THE ORDER OF READING
C    NBASE     THE NUMBER OF BASE UNITS
C    NCYCL     THE NUMBER OF CYCLING UNITS
C    NPEAK     THE NUMBER OF PEAKING UNITS
C    NUNITS    THE TOTAL NUMBER OF UNITS
```

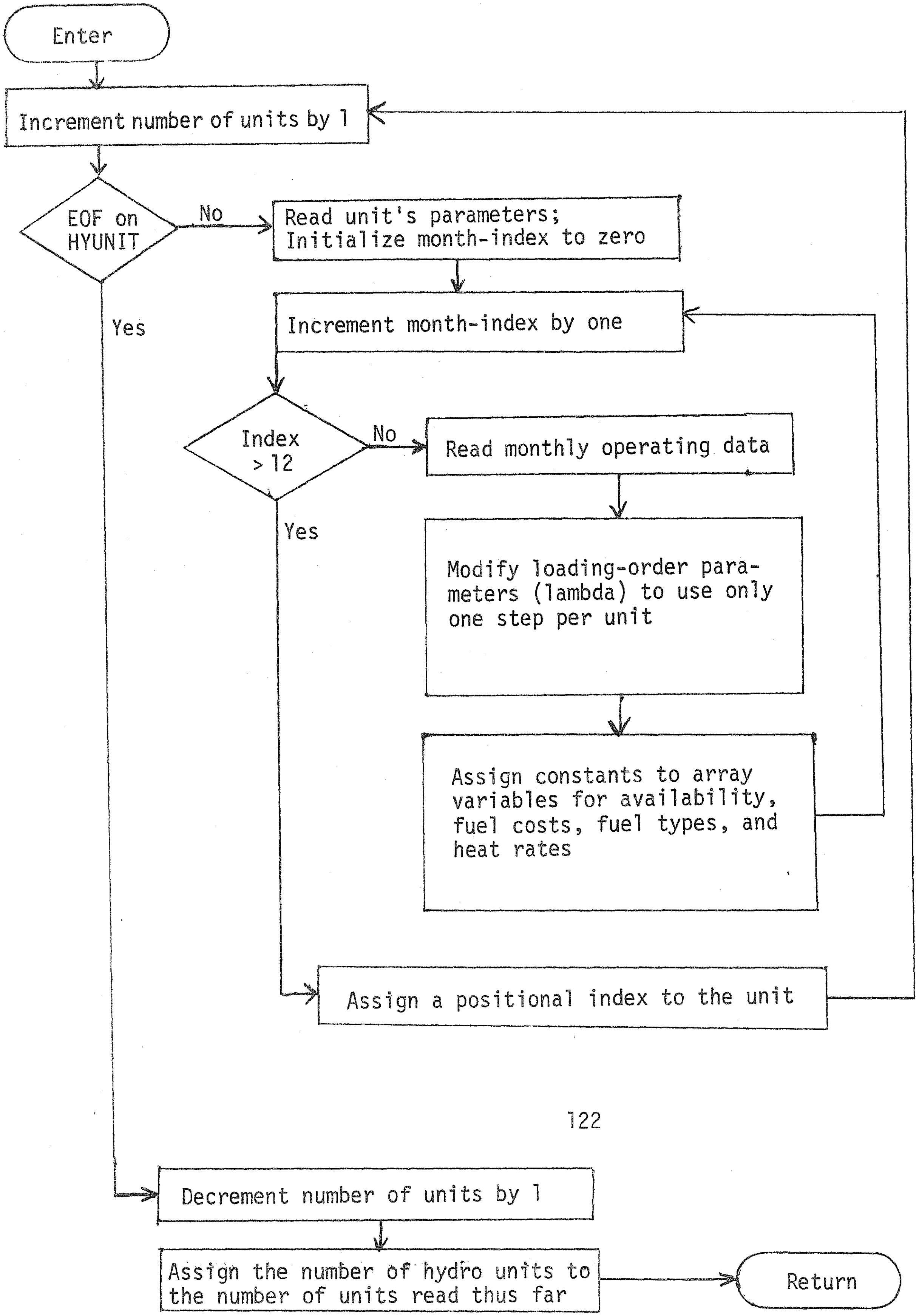
```
C
C  NOTES:
C    PROGRAM WILL END ABNORMALLY SHOULD AN UNEXPECTED EOF
C    OCCUR OR IF THE YEAR ON FILE DOES NOT MATCH THAT ANTICIPATED.
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=======================================================================
```

UNIHYD Routine

This routine reads and assigns data values for hydro generating units primarily (outer-loop) by unit and secondarily (inner-loop) by month within the study year. Hydro units are assigned availabilities of one (100%). Since no fuel is consumed, the heat rates and fuel costs are assigned to zero.

The three lambda arrays (LAMDA1, LAMDA2, LAMDA3) as read indicate the dispatch priorities, a block having a lower-value lambda being loaded prior to one with a higher value. In general, all three arrays will be specified by the input data, yet the program requires using only one loading step per hydro unit. This having been specified by parameter NHSTEP, the lambda arrays are altered: the priority for the full-load block is assigned to that specified for the lowest block (in LAMDA1), and both LAMDA2 and LAMDA1 are assigned to zero, so that each unit is fully-loaded according to the lowest-order priorities.

UNIHYD

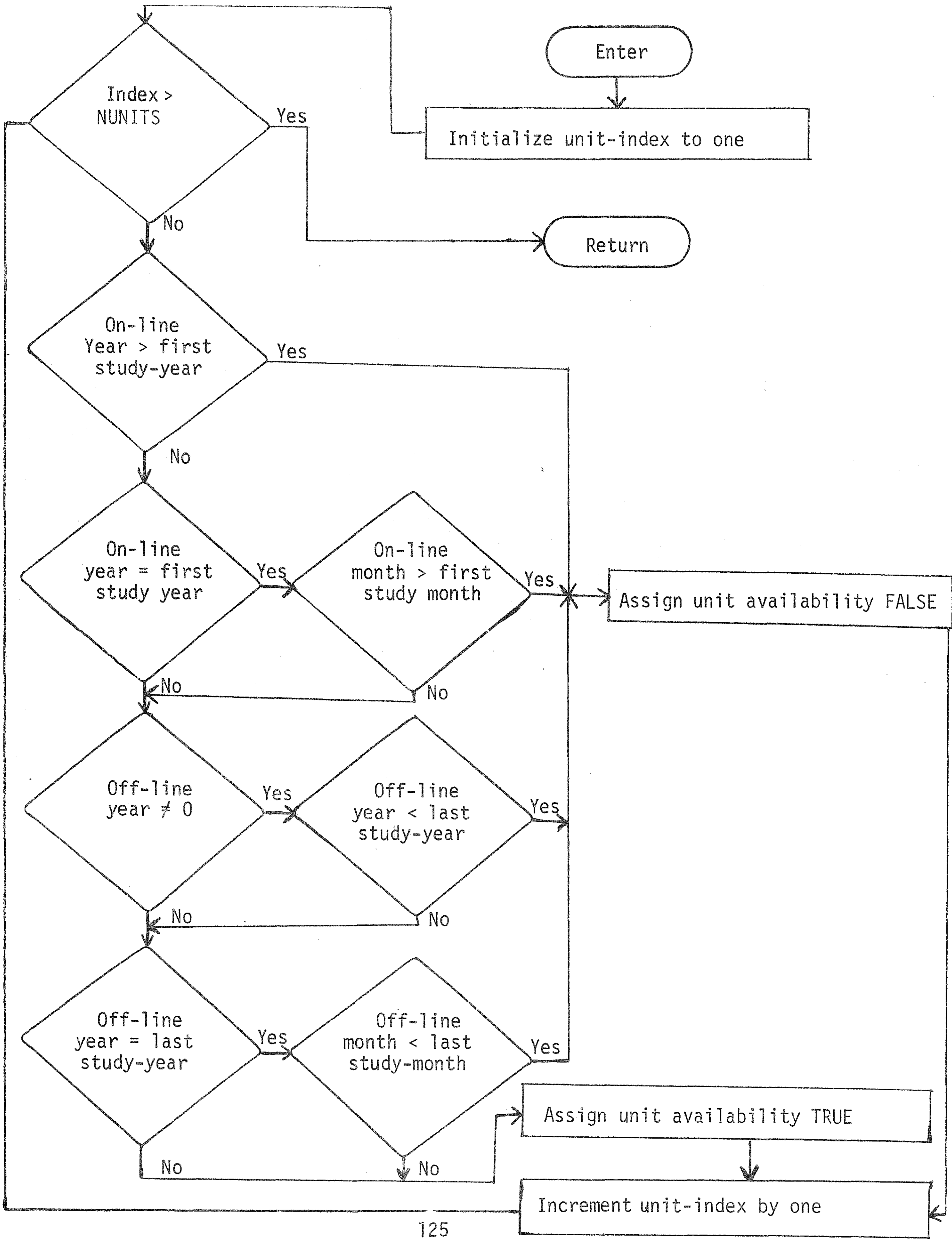

Enter
Increment number of units by 1
EOF on HYUNIT
No
Yes
Read unit's parameters; Initialize month-index to zero
Increment month-index by one
Index > 12
No
Yes
Read monthly operating data
Modify loading-order parameters (lambda) to use only one step per unit
Assign constants to array variables for availability, fuel costs, fuel types, and heat rates
Assign a positional index to the unit
Decrement number of units by 1
Assign the number of hydro units to the number of units read thus far
Return

```
C=========================================================================
C
C  ROUTINE:           **** U N I H Y D ****
C
C  PURPOSE: TO READ THE HYDRO UNIT DATA FROM UNIT HYUNIT AND STORE
C    THEM BY UNIT AND MONTH
C
C
C  INPUT VARIABLES:
C    HYUNIT   LOGICAL UNIT FROM WHICH HYDRO INFORMATION IS READ
C    IYEAR    FOUR-DIGIT STUDY-YEAR
C    NHSTEP   NUMBER OF LOADING STEPS FOR HYDRO UNITS
C
C  OUTPUT VARIABLES:
C    VSCCNO    UNIT ID NUMBER
C    UNAME     NAME OF UNIT
C    FRAOWN    FRACTION OWNED BY COMPANY
C    UNTYPE    TYPE OF GENERATION UNIT: 1-STEAM FOSSIL, 2-STEAM NUCLEAR,
C              3-I.C. ENGINE, 4-GAS TURBINE, 5-JET ENGINE, 6-HYDRO,
C              7-PUMPED STORAGE
C    UNLOAD    LOADING TYPE OF UNIT:  1-BASE, 2-CYCLE, 3-PEAK, 4-HYDRO
C    HYTYPE    TYPE OF HYDRO UNIT:  1-RUN OF RIVER, 2-STORAGE, 3-PUMPED
C              STORAGE
C    PRIFUL    PRIMARY FUEL FOR UNIT:  1-COAL, 2-NUCLEAR, 3-LIGHT OIL,
C              4-HEAVY OIL, 5-NATURAL GAS, 6-GASOLINE, 7-WATER, 0-NONE
C    ONLIMO    ON-LINE MONTH FOR UNIT
C    ONLIYR    ON-LINE YEAR FOR UNIT
C    OFLIMO    OFF-LINE MONTH FOR UNIT
C    OFLIYR    OFF-LINE YEAR FOR UNIT
C    AUPAVL    ANNUAL UNIT PRODUCTION AVAILABILITY
C    CAPCST    CAPACITY COST
C    UNETCP    UNLIMITED NET CAPACITY OF UNIT
C    LNETCP    LIMITED NET CAPACITY OF UNIT
C    LAMDA1    LOADING PRIORITY FOR THE UNIT'S FIRST BLOCK
C    LAMDA2    LOADING PRIORITY FOR THE UNIT'S SECOND BLOCK
C    LAMDA3    LOADING PRIORITY FOR THE UNIT'S THIRD BLOCK
C    NUNITS    CURRENT NUMBER OF UNITS IN SYSTEM
C    NHYDRO    NUMBER OF HYDRO UNITS IN SYSTEM
C    IDHYDR    LOCATION OF EACH UNIT IN THE ORDER OF READING
C    ALTFUL    ALTERNATE FUEL CODE, AS IN PRIFUL
C    IGFUEL    IGNITION FUEL CODE, AS IN PRIFUL
C    UNGEN     PROJECTED GENERATION OF EACH UNIT, IN MWHRS
C    BLKCAP    CUMULATIVE BLOCK CAPACITIES FOR EACH UNIT, IN MW
C    EAVAIL    EFFECTIVE AVAILABILITY
C    HEATR1    HEAT RATE FOR FIRST BLOCK, IN BTU/KWH
C    HEATR2    HEAT RATE FOR SECOND BLOCK, IN BTU/KWH
C    HEATR3    HEAT RATE FOR THIRD BLOCK, IN BTU/KWH
C    PBTUCT    COST OF PRIMARY FUEL IN CENTS/MEGA-BTU
C    ABTUCT    COST OF ALTERNATE FUEL IN CENTS/MEGA-BTU
C    PGENFC    FRACTION OF GENERATION USING PRIMARY FUEL
C
C  AUTHOR:
C    NATIONAL REGULATORY RESEARCH INSTITUTE
C
C  LAST REVISED:  10/79
C
C=========================================================================
```

UNITON Routine

To meet the availability criteria, this routine requires that a plant (unit) have its date of on-line transfer no later than the first month of the first study-year, and its date of off-line transfer no earlier than the last month of the last study-year. As called, however, the routine has the first and last study-years identical, as are the first and last study-months. In practice, then, the criteria degenerate to simply having the current (study) month and year date no earlier than the date of on-line transfer and no later than the date of off-line transfer. Logic requires that the month of off-line transfer be specified as the last full month during which the unit is expected to be in service.

UNITON



Enter
Initialize unit-index to one
Index > NUNITS
Yes
No
Return
On-line Year > first study-year
Yes
No
On-line year = first study year
Yes
No
On-line month > first study month
Yes
No
Assign unit availability FALSE
Off-line year ≠ 0
Yes
No
Off-line year < last study-year
Yes
No
Off-line year = last study-year
Yes
No
Off-line month < last study-month
Yes
No
Assign unit availability TRUE
Increment unit-index by one

```
C=======================================================================
C
C   ROUTINE:             **** U N I T O N ****
C
C   PURPOSE:
C     TO FILL AN ARRAY (AVAIL) WITH LOGICAL (TRUE/FALSE)
C     VALUES INDICATING WHETHER A PARTICULAR UNIT IS ONLINE
C     FOR THE MONTH OF STUDY.
C
C   INPUT VARIABLES:
C     MOLOW     BEGINNING MONTH OF STUDY
C     YRLOW     BEGINNING YEAR OF STUDY (LAST 2 DIGITS)
C     MOHIGH    ENDING MONTH OF STUDY
C     YRHIGH    ENDING YEAR OF STUDY (LAST 2 DIGITS...I.E. 1976 => 76)
C     NUNITS    NUMBER OF UNITS TO CHECK
C     ONLIMO    MONTH THE UNIT WENT INTO SERVICE
C     ONLIYR    YEAR THE UNIT WENT INTO SERVICE
C     OFLIMO    LAST MONTH THE UNIT IS EXPECTED IN SERVICE
C     OFLIYR    LAST YEAR THE UNIT IS EXPECTED IN SERVICE
C
C   OUTPUT VARIABLES:
C     AVAIL     .TRUE. IF UNIT IS AVAILABLE
C               .FALSE. IF UNIT IS NOT AVAILABLE
C
C   AUTHOR:
C     NATIONAL REGULATORY RESEARCH INSTITUTE
C
C   LAST REVISED:  10/79
C
C=======================================================================
```

DISPATCH MODULE ROUTINES

The DISPATCH module contains a MAIN routine and 9 subroutines. Figure 23 shows the name of each subroutine and the calling sequence.

This section contains a description of each subroutine and a flow chart for each one.

MAIN Routine

The MAIN routine of the DISPATCH module carries out more than the normal control function. Except for a few subroutines the function of DISPATCH is performed in the MAIN routine.

The concept of the DISPATCH module is to calculate a loading order based on some first order constraints. These constraints are

1. The first loading blocks of the available units are loaded by increasing cost until a minimum load value is reached. This allows in a simplistic way to simulate the backing-off of units during night time.
2. Maintaining an on-line reserve margin.

The values that these constraints use are entered by the user. The imaginative use of these values will lead to some interesting dispatching orders.

The MAIN routine performs the following functions:

1. read user information;
2. read plant data;
3. if hydro units are in the system it determines the type of units;
4. if hydro units are in the systen the appropriate fuel costs are calculated;
    - run of river zero costs
    - pumped storage loss factor times average pumping cost
    - river storage relative cost provided by user
    - contract cost on data file

5. determine the cost of each fossil and nuclear loading block;
6. order the first, second and third loading step by cost within each group;
7. load the first blocks of the units until the minimum load condition is met;
8. order all the unloaded steps by cost;
9. check and correct for improper sequencing of a unit's loading blocks;
10. load the unload blocks subject to the reserve constraint;
11. assign relative dispatching values to each loading step. These values are in increments of five, thus providing ease of shifting the loading order based on other constraints.
12. write the new plant files.

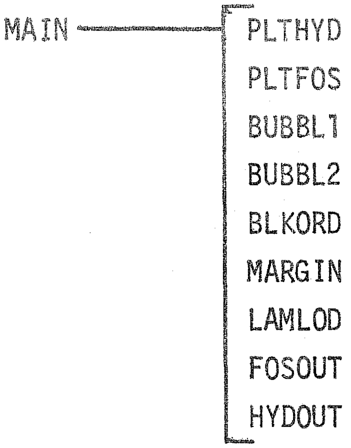
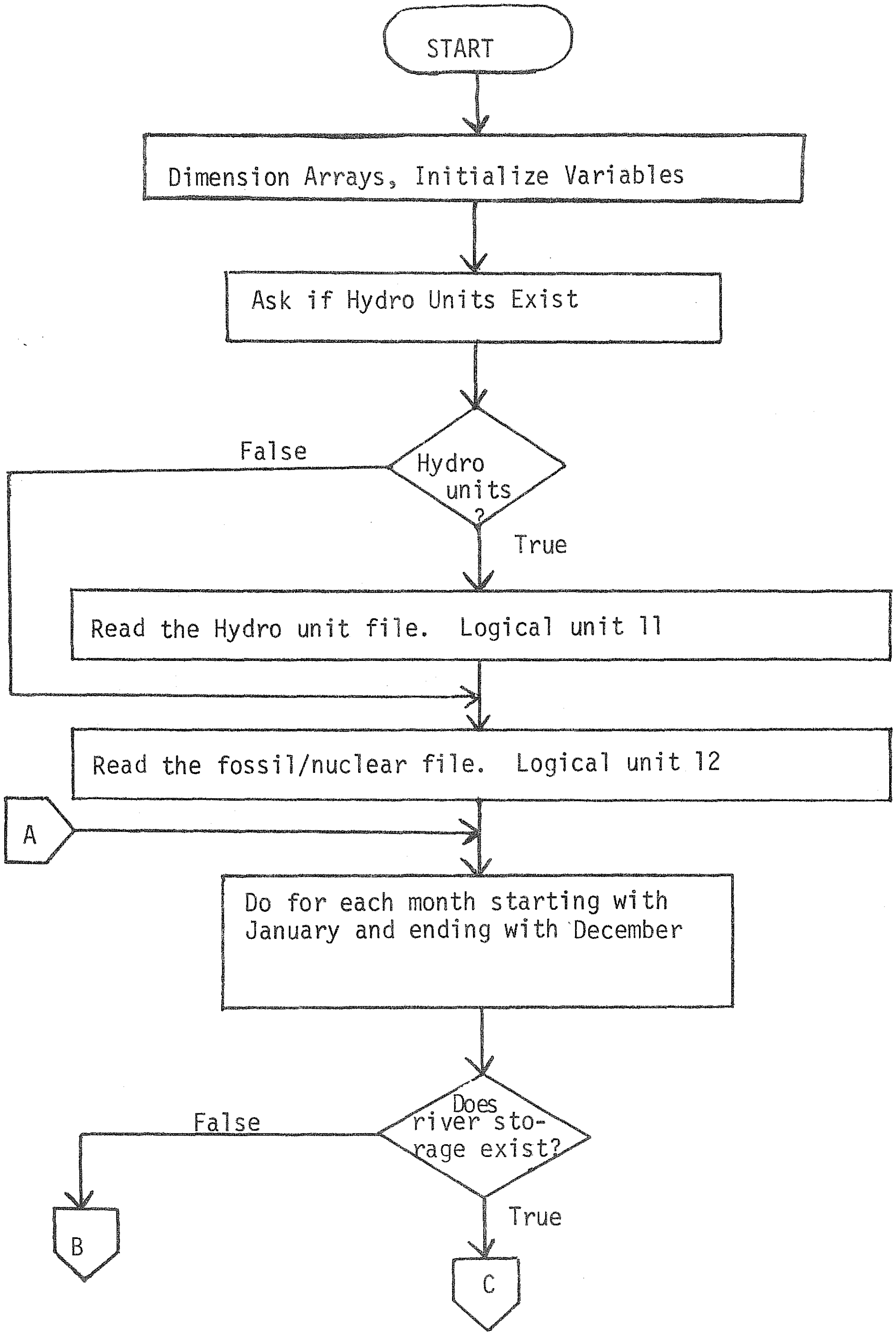
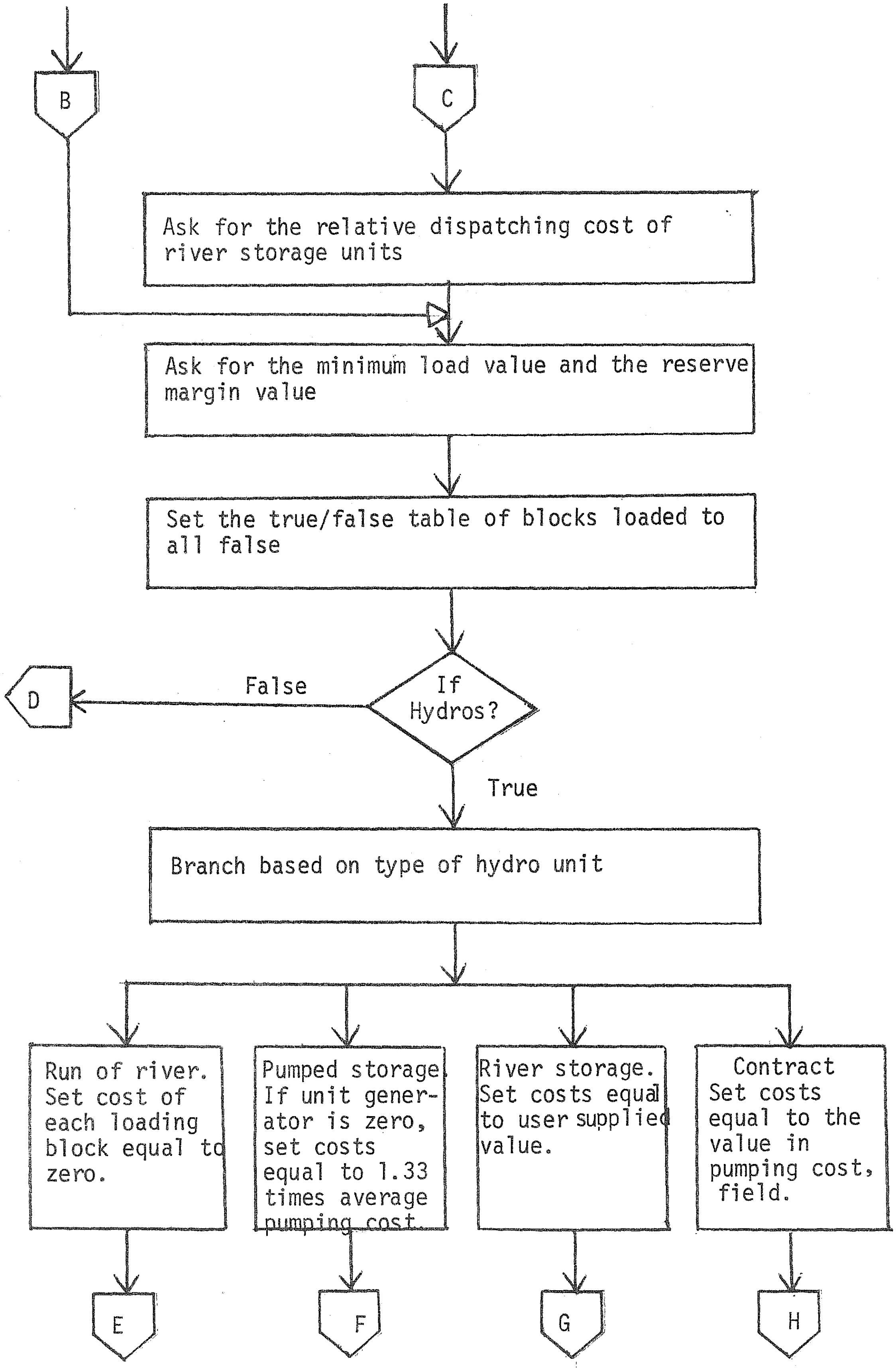
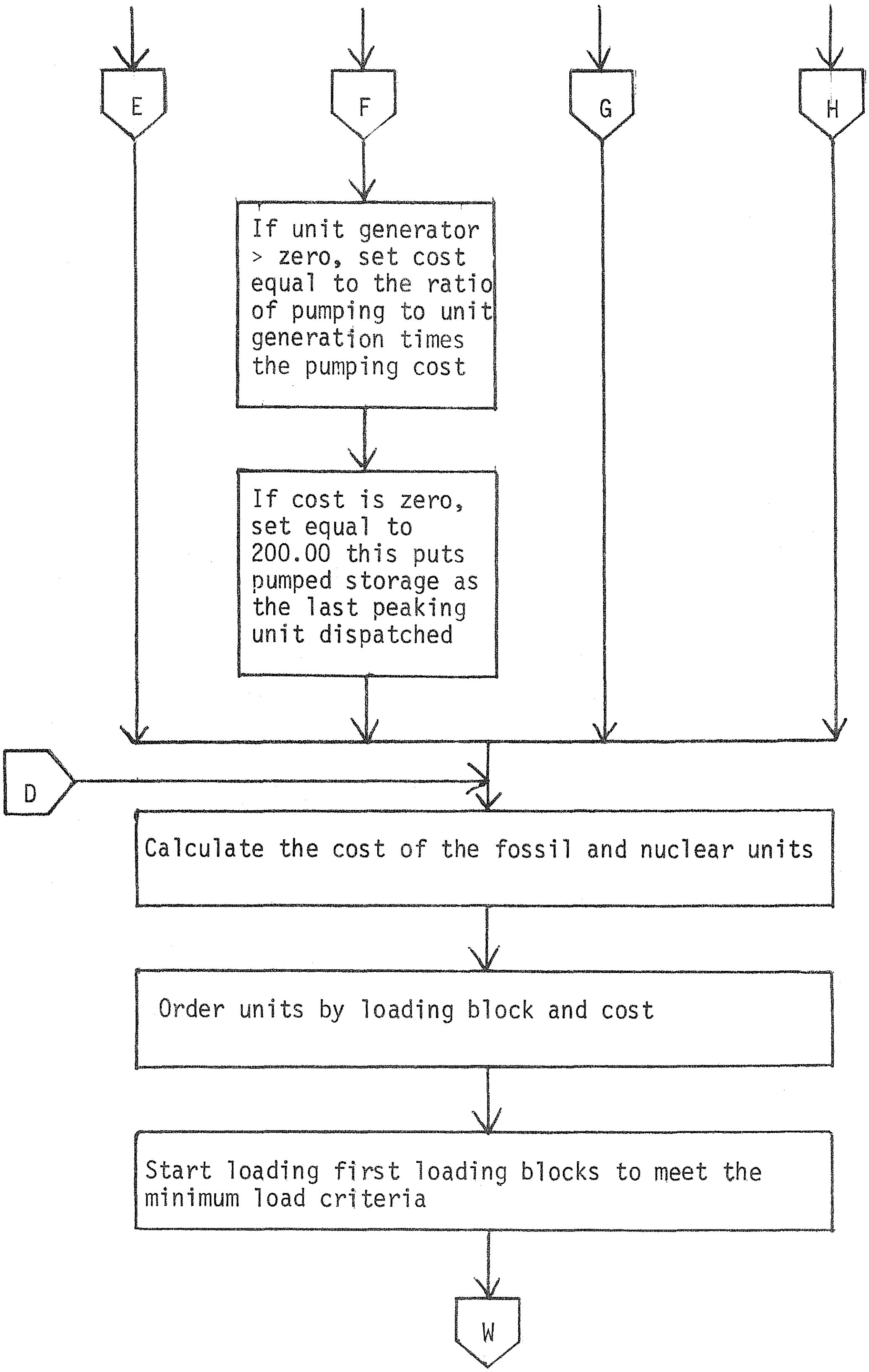


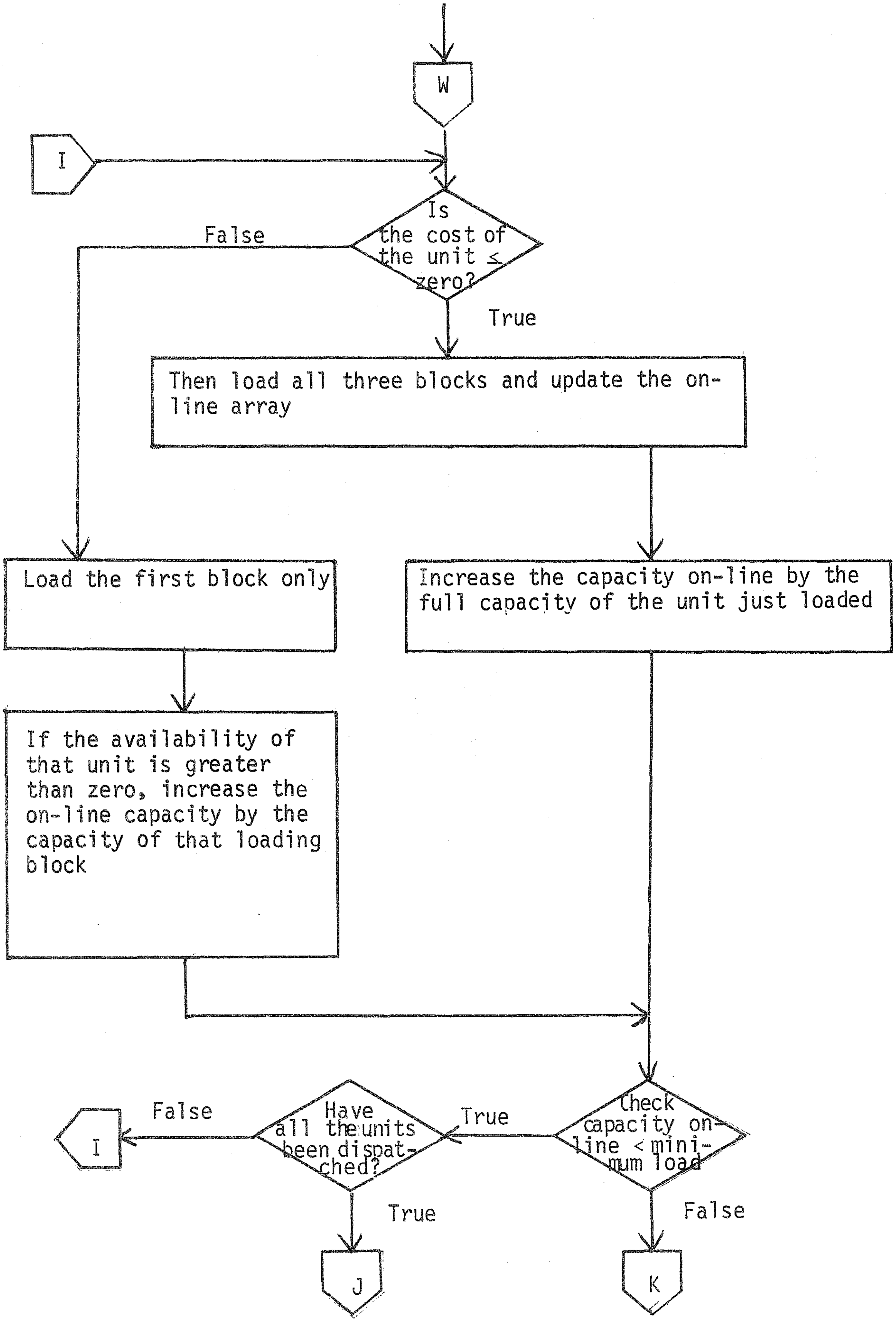
Figure 23 DISPATCH Module Subroutines in the Sequence Called

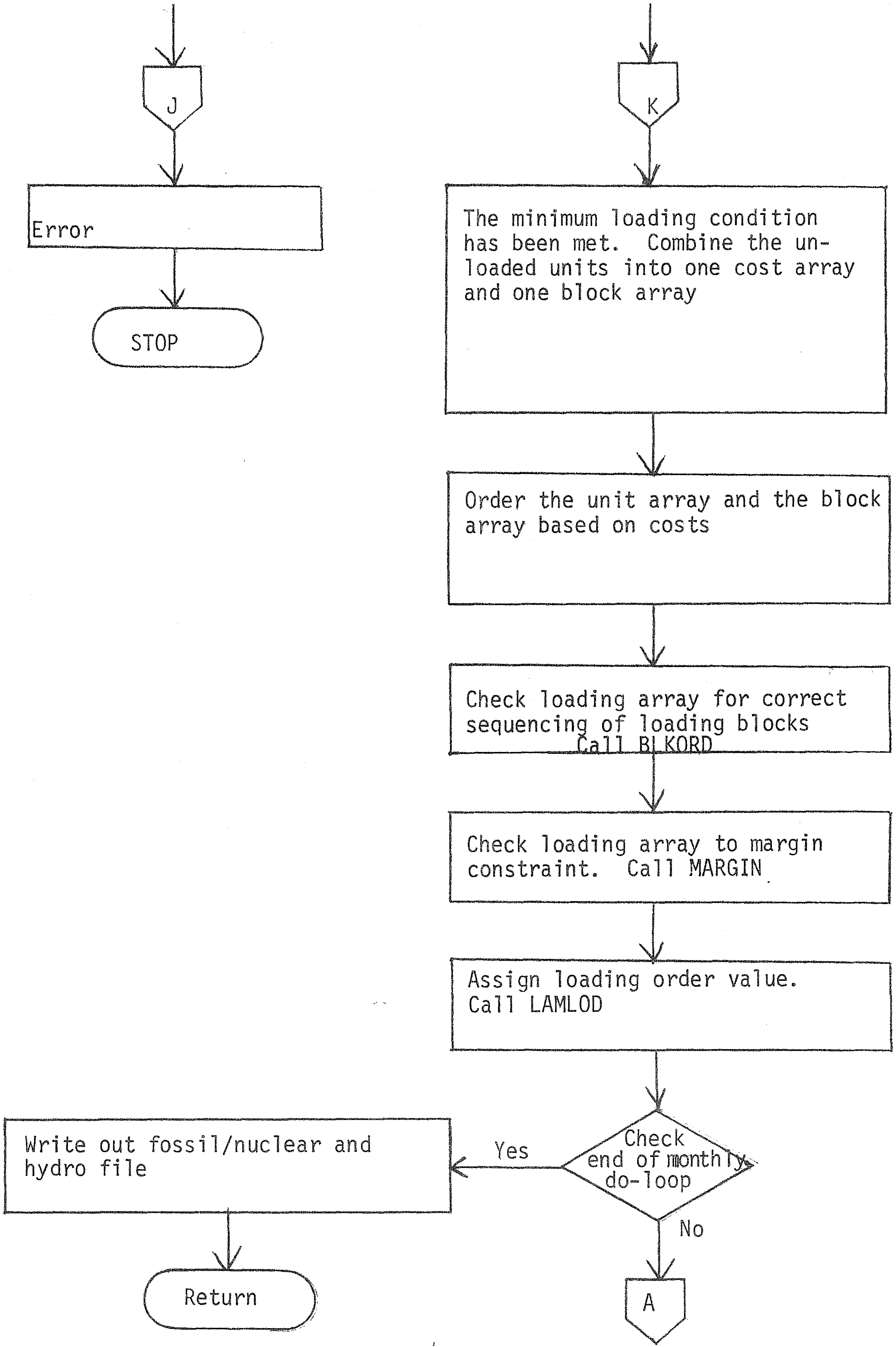
MAIN ROUTINE




B
C
Ask for the relative dispatching cost of river storage units
Ask for the minimum load value and the reserve margin value
Set the true/false table of blocks loaded to all false
If Hydros?
False
D
True
Branch based on type of hydro unit
Run of river. Set cost of each loading block equal to zero.
Pumped storage. If unit generator is zero, set costs equal to 1.33 times average pumping cost.
River storage. Set costs equal to user supplied value.
Contract Set costs equal to the value in pumping cost, field.
E
F
G
H


E
F
G
H
If unit generator > zero, set cost equal to the ratio of pumping to unit generation times the pumping cost
If cost is zero, set equal to 200.00 this puts pumped storage as the last peaking unit dispatched
D
Calculate the cost of the fossil and nuclear units
Order units by loading block and cost
Start loading first loading blocks to meet the minimum load criteria
W

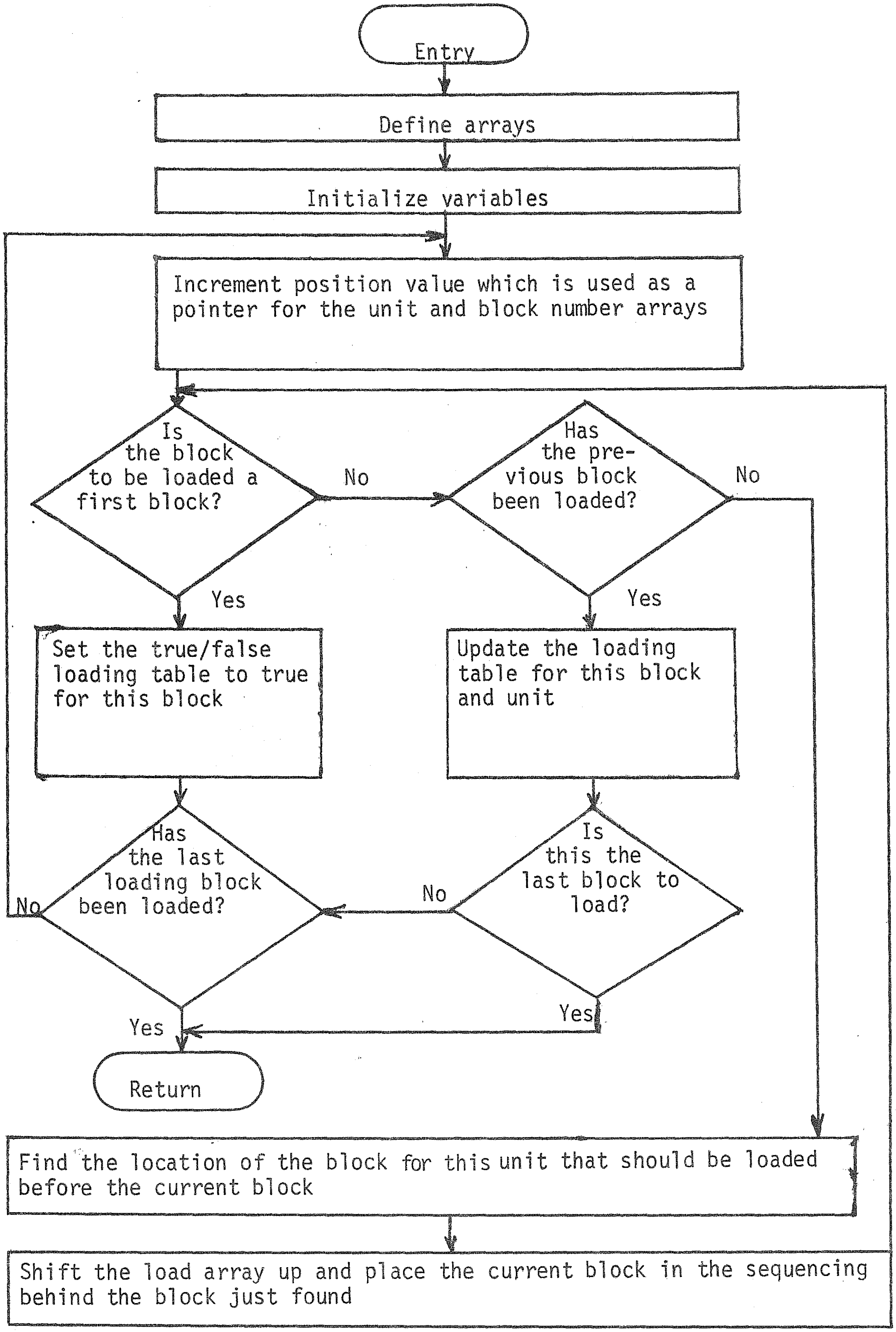

W
I
Is the cost of the unit ≤ zero?
False
True
Then load all three blocks and update the on-line array
Load the first block only
Increase the capacity on-line by the full capacity of the unit just loaded
If the availability of that unit is greater than zero, increase the on-line capacity by the capacity of that loading block
Check capacity on-line < minimum load
True
False
Have all the units been dispatched?
False
True
I
J
K


J
Error
STOP
K
The minimum loading condition has been met. Combine the unloaded units into one cost array and one block array
Order the unit array and the block array based on costs
Check loading array for correct sequencing of loading blocks Call BLKORD
Check loading array to margin constraint. Call MARGIN
Assign loading order value. Call LAMLOD
Check end of monthly do-loop
Yes
Write out fossil/nuclear and hydro file
Return
No
A

BLKORD Routine

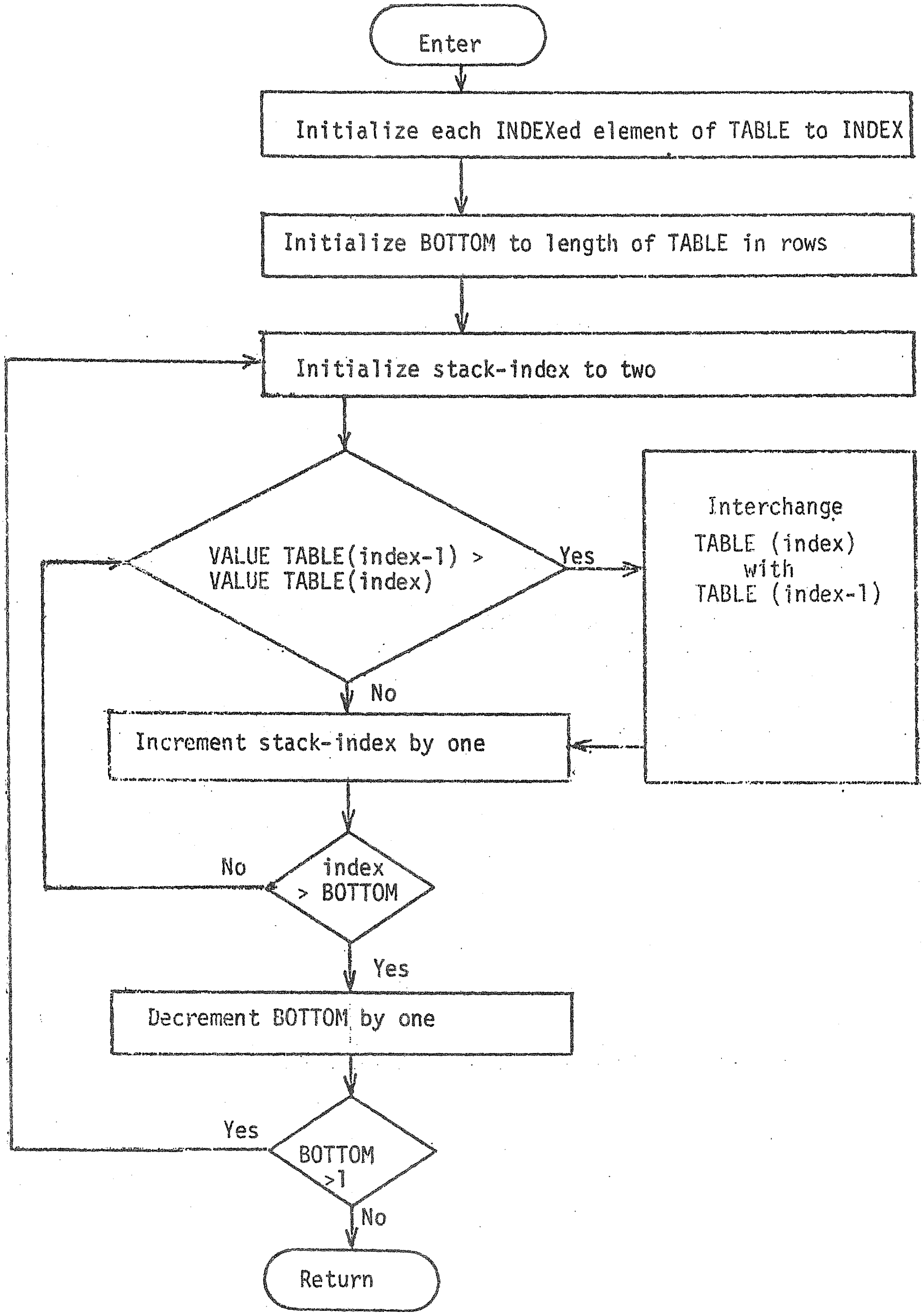
The function of this routine is to make sure that the units are loaded in their proper physical order. That is, block one is loaded before block two and three, etc.

BLKORD


Entry
Define arrays
Initialize variables
Increment position value which is used as a pointer for the unit and block number arrays
Is the block to be loaded a first block?
No
Has the previous block been loaded?
No
Yes
Yes
Set the true/false loading table to true for this block
Update the loading table for this block and unit
Has the last loading block been loaded?
No
No
Is this the last block to load?
Yes
Yes
Return
Find the location of the block for this unit that should be loaded before the current block
Shift the load array up and place the current block in the sequencing behind the block just found

BUBBL1 Routine

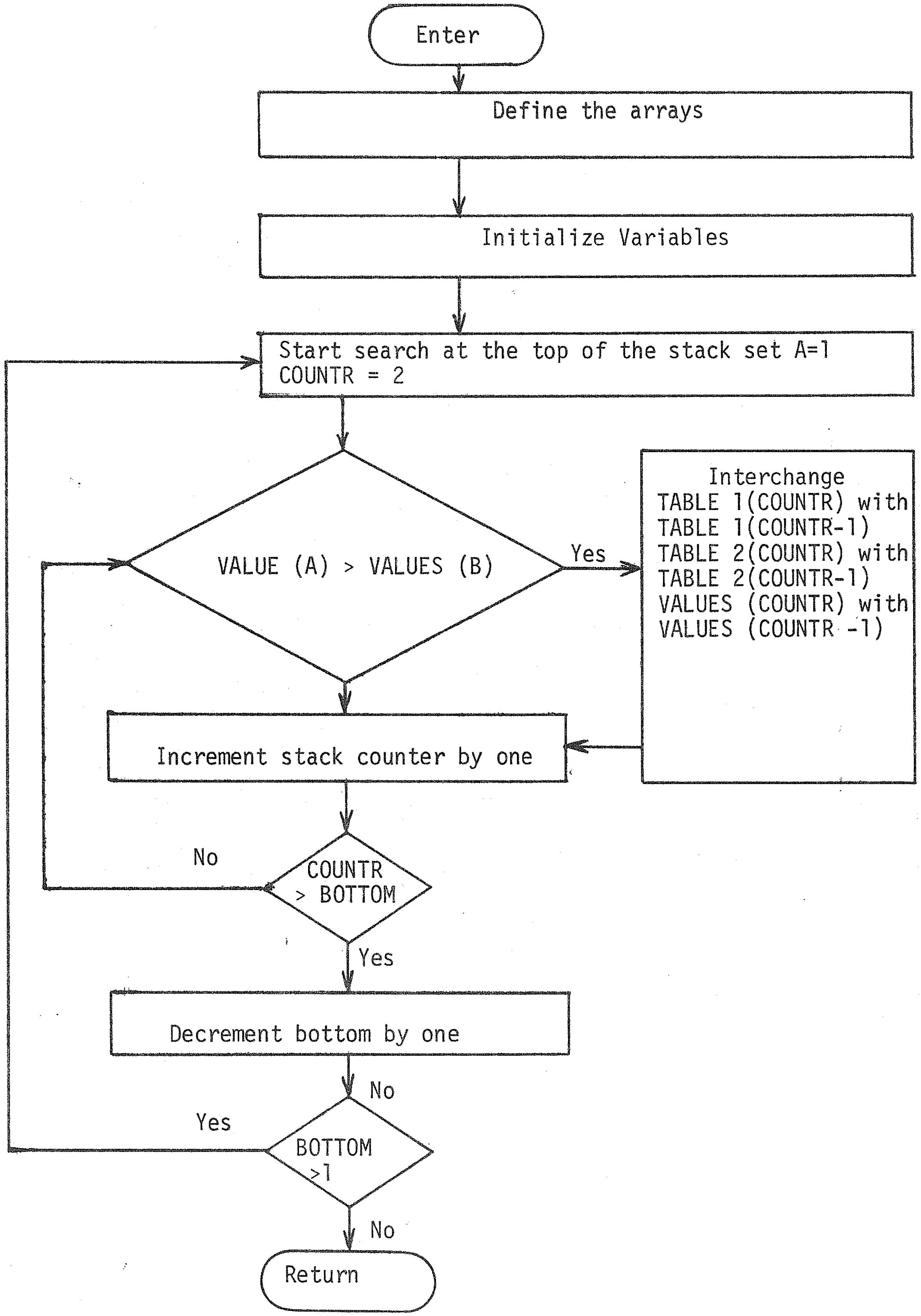
This routine orders the array TABLE by the values in the array VALUES. It is designed to order the loading blocks by increasing cost.


Enter
Initialize each INDEXed element of TABLE to INDEX
Initialize BOTTOM to length of TABLE in rows
Initialize stack-index to two
VALUE TABLE(index-1) >
VALUE TABLE(index)
Yes
Interchange
TABLE (index)
with
TABLE (index-1)
No
Increment stack-index by one
No
index
> BOTTOM
Yes
Decrement BOTTOM by one
Yes
BOTTOM
>1
No
Return

BUBBL2 Routine

This routine orders the two arrays TABLE1 and TABLE2 by the values in array VALUES.

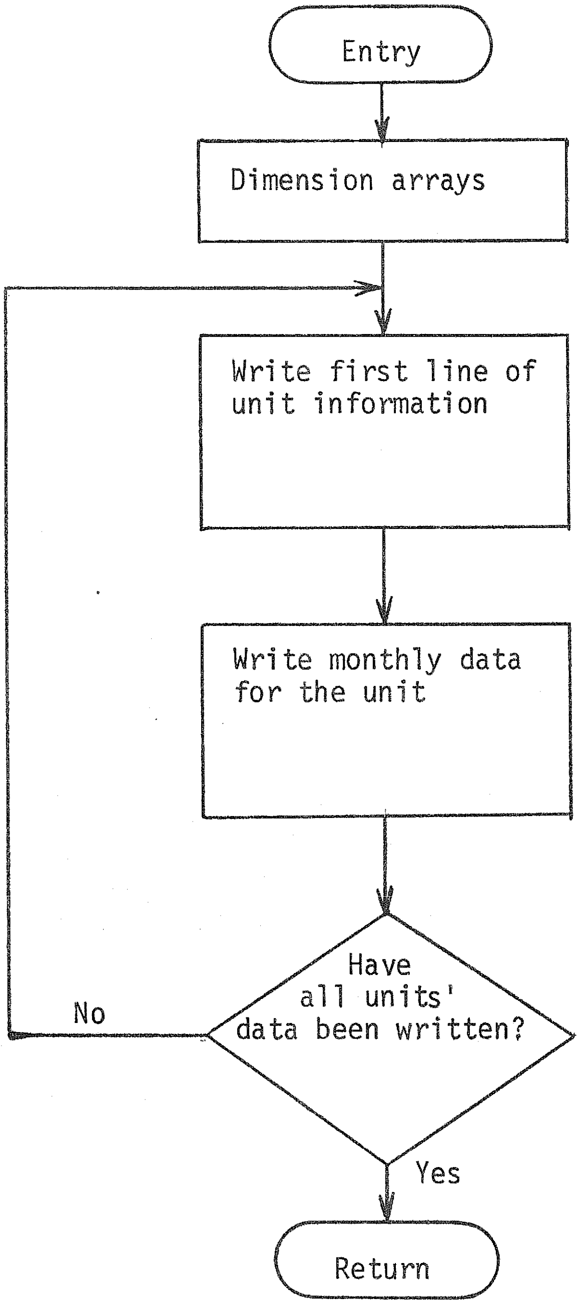
BUBBL2


Enter
Define the arrays
Initialize Variables
Start search at the top of the stack set A=1
COUNTR = 2
VALUE (A) > VALUES (B)
Yes
Interchange
TABLE 1(COUNTR) with
TABLE 1(COUNTR-1)
TABLE 2(COUNTR) with
TABLE 2(COUNTR-1)
VALUES (COUNTR) with
VALUES (COUNTR -1)
Increment stack counter by one
No
COUNTR
> BOTTOM
Yes
Decrement bottom by one
No
Yes
BOTTOM
>1
No
Return

FOSOUT Routine

This subroutine is used to write the fossil/nuclear file to logical unit 20.

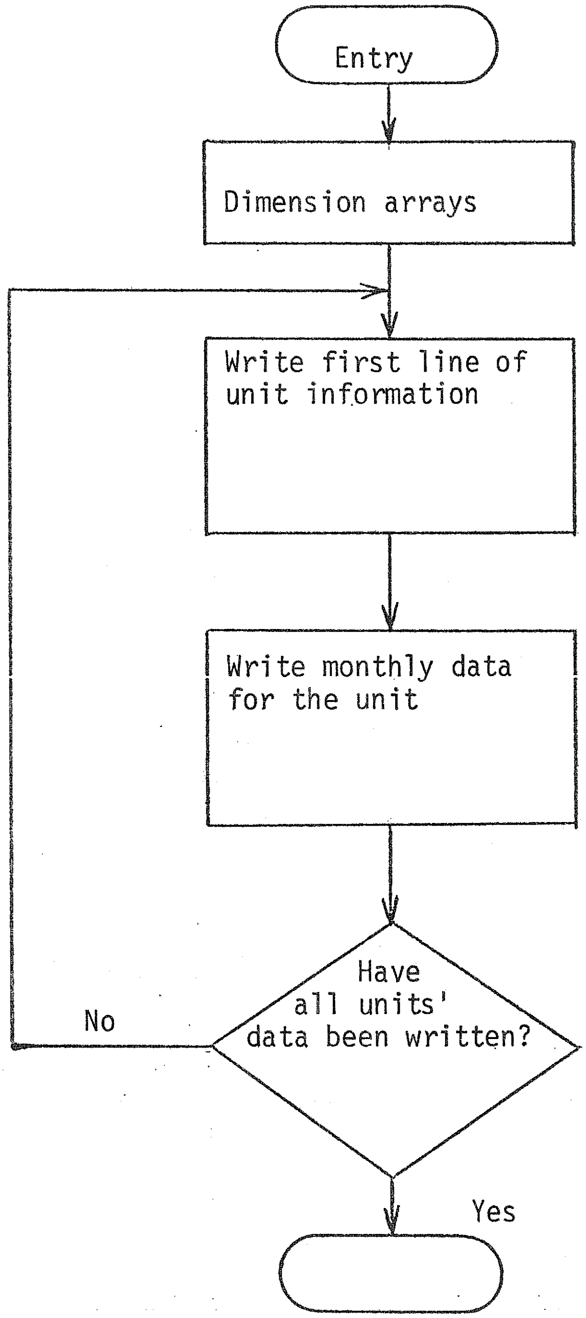
FOSOUT


Entry
Dimension arrays
Write first line of unit information
Write monthly data for the unit
Have all units' data been written?
No
Yes
Return

HYDOUT Routine

This routine writes the hydro file, if there is one, to logical unit 21.

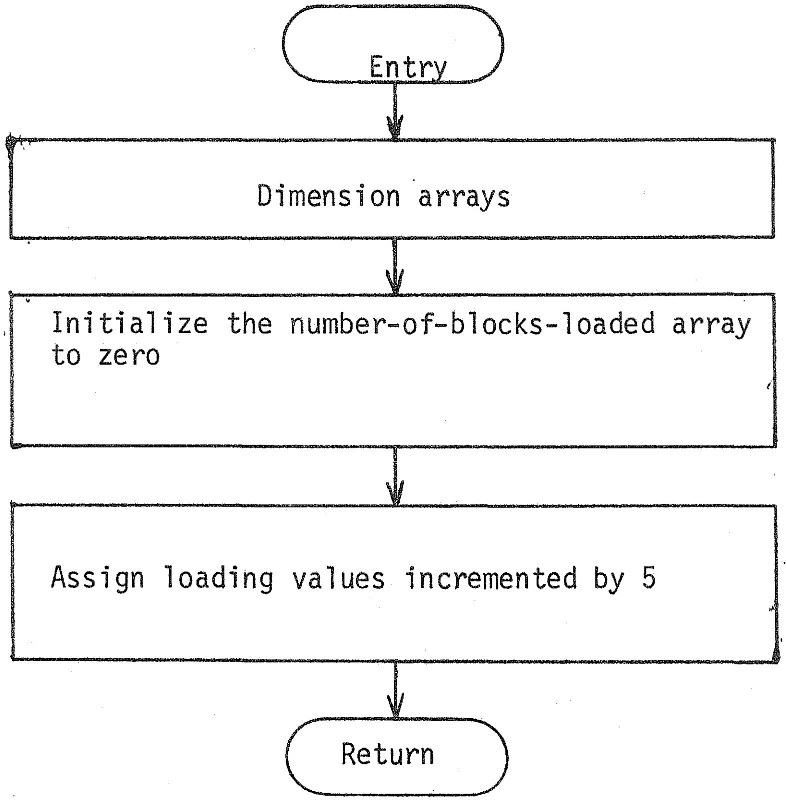
HYDOUT


Entry
Dimension arrays
Write first line of unit information
Write monthly data for the unit
Have all units' data been written?
No
Yes

LAMLOD

This routine assigns the loading order values to the generating units using increments of five.

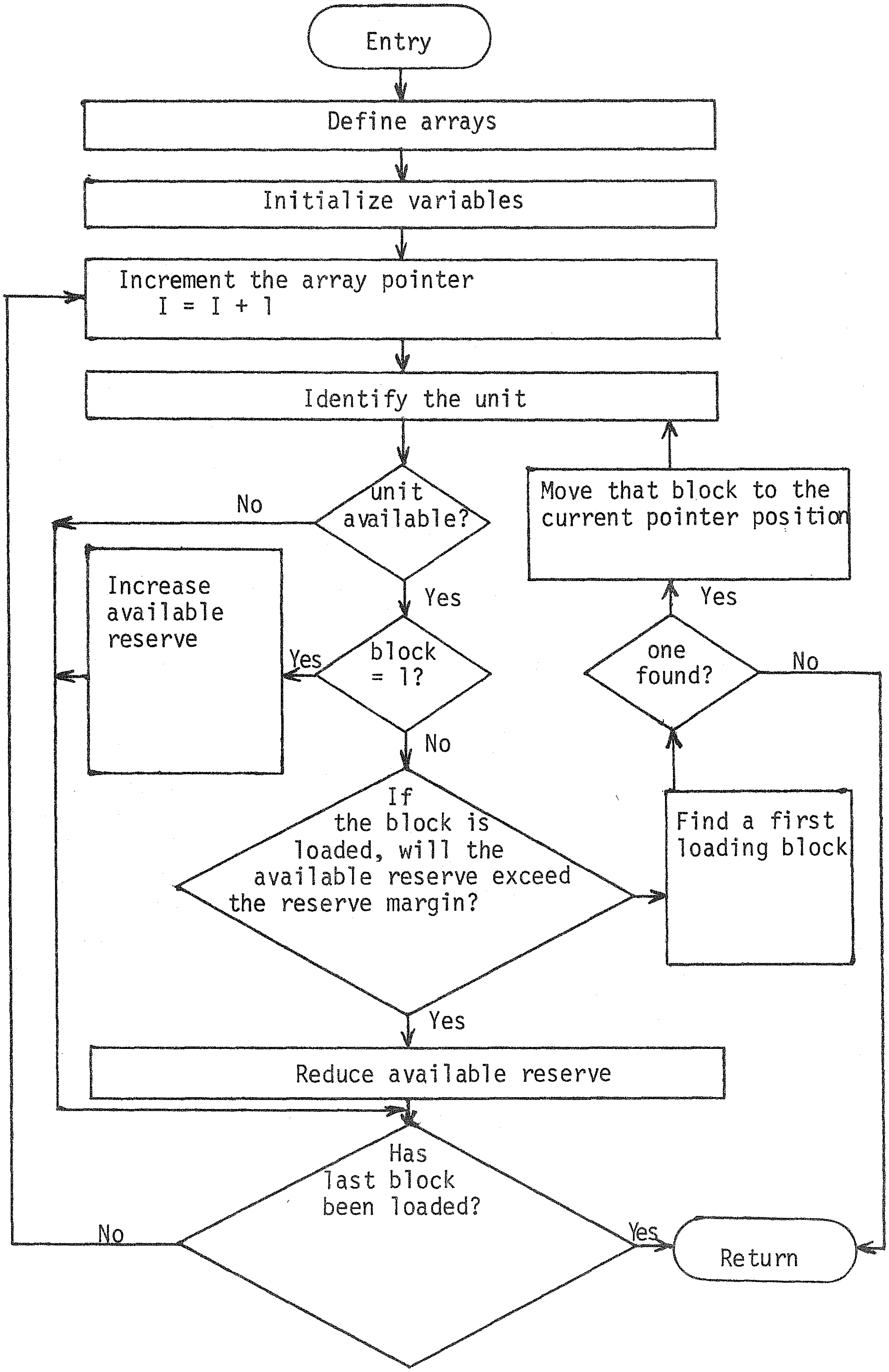
LAMLOD


Entry
Dimension arrays
Initialize the number-of-blocks-loaded array to zero
Assign loading values incremented by 5
Return

MARGIN Routine

The MARGIN routine loads capacity subject to keeping the available reserve above the user-defined reserve margin. When a loading step is put on line that would cause the available reserve to drop below the reserve margin, the program looks for the next first loading block of a unit and loads it. This causes the available reserve to be increased. If all first loading blocks have been loaded, control is returned to the MAIN routine since the reserve margin constraint can not be satisfied.

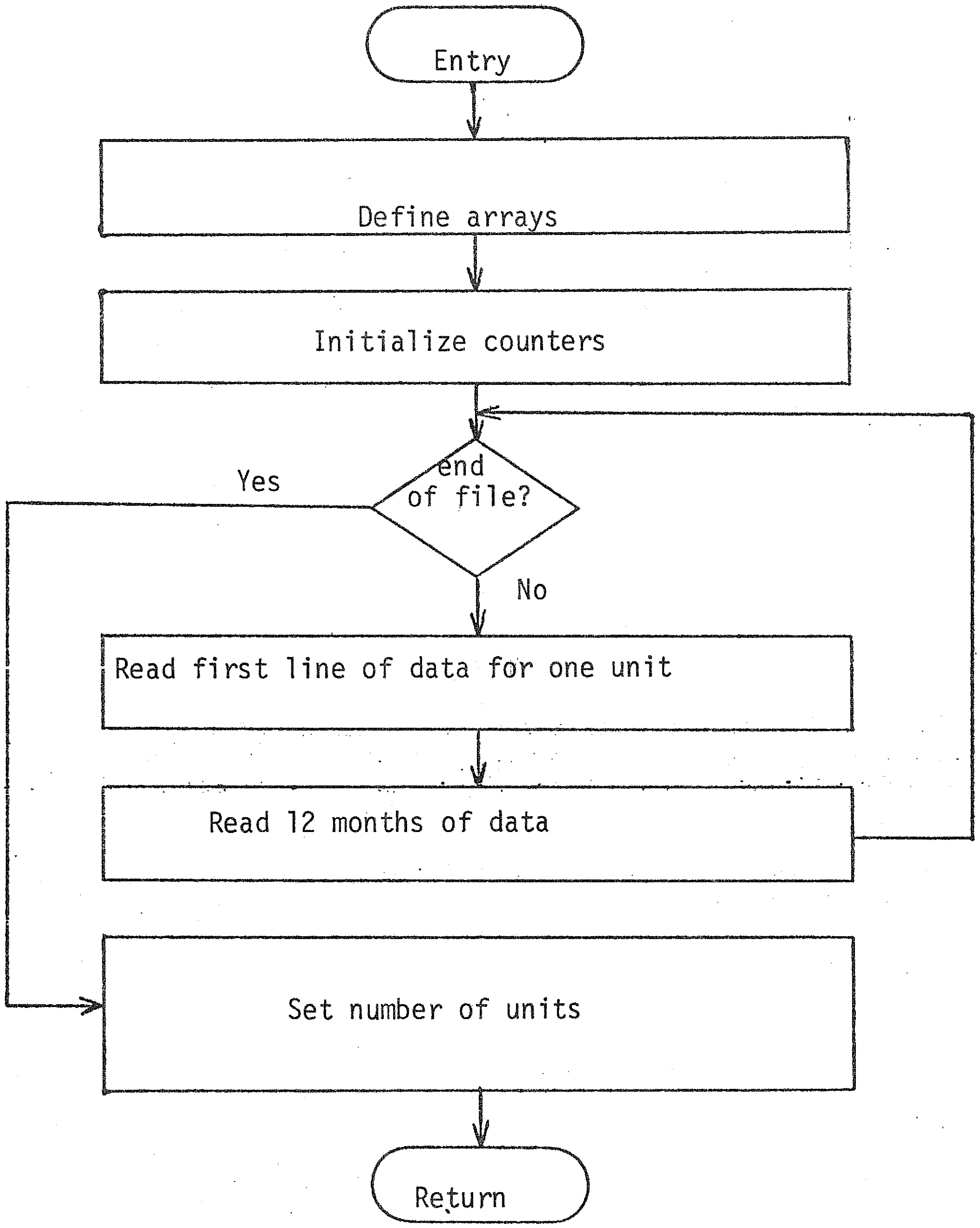
MARGIN


Entry
Define arrays
Initialize variables
Increment the array pointer
I = I + 1
Identify the unit
unit available?
No
Yes
Increase available reserve
block = 1?
Yes
No
If the block is loaded, will the available reserve exceed the reserve margin?
Yes
Reduce available reserve
Has last block been loaded?
No
Yes
Return
Find a first loading block
one found?
Yes
No
Move that block to the current pointer position

PLTFOS Routine

This routine reads the fossil/nuclear plant file from logical unit 12.

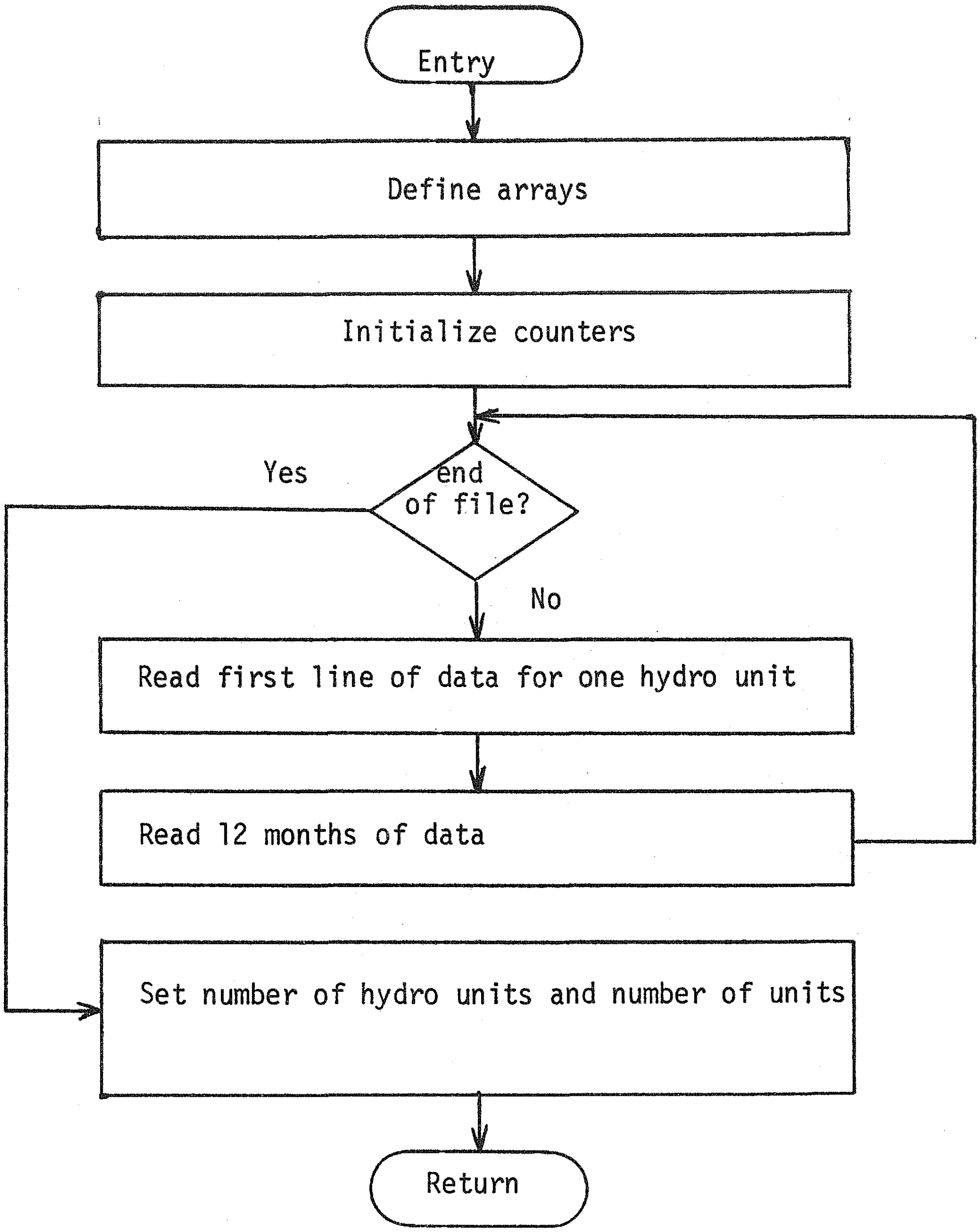
PLTFOS


Entry
Define arrays
Initialize counters
end of file?
Yes
No
Read first line of data for one unit
Read 12 months of data
Set number of units
Return

PLTHYD Routine

This routine reads the hydro file from logical unit 11.

PLTHYD


Entry
Define arrays
Initialize counters
end of file?
Yes
No
Read first line of data for one hydro unit
Read 12 months of data
Set number of hydro units and number of units
Return

LOAD PROBABILITY MODULE ROUTINES

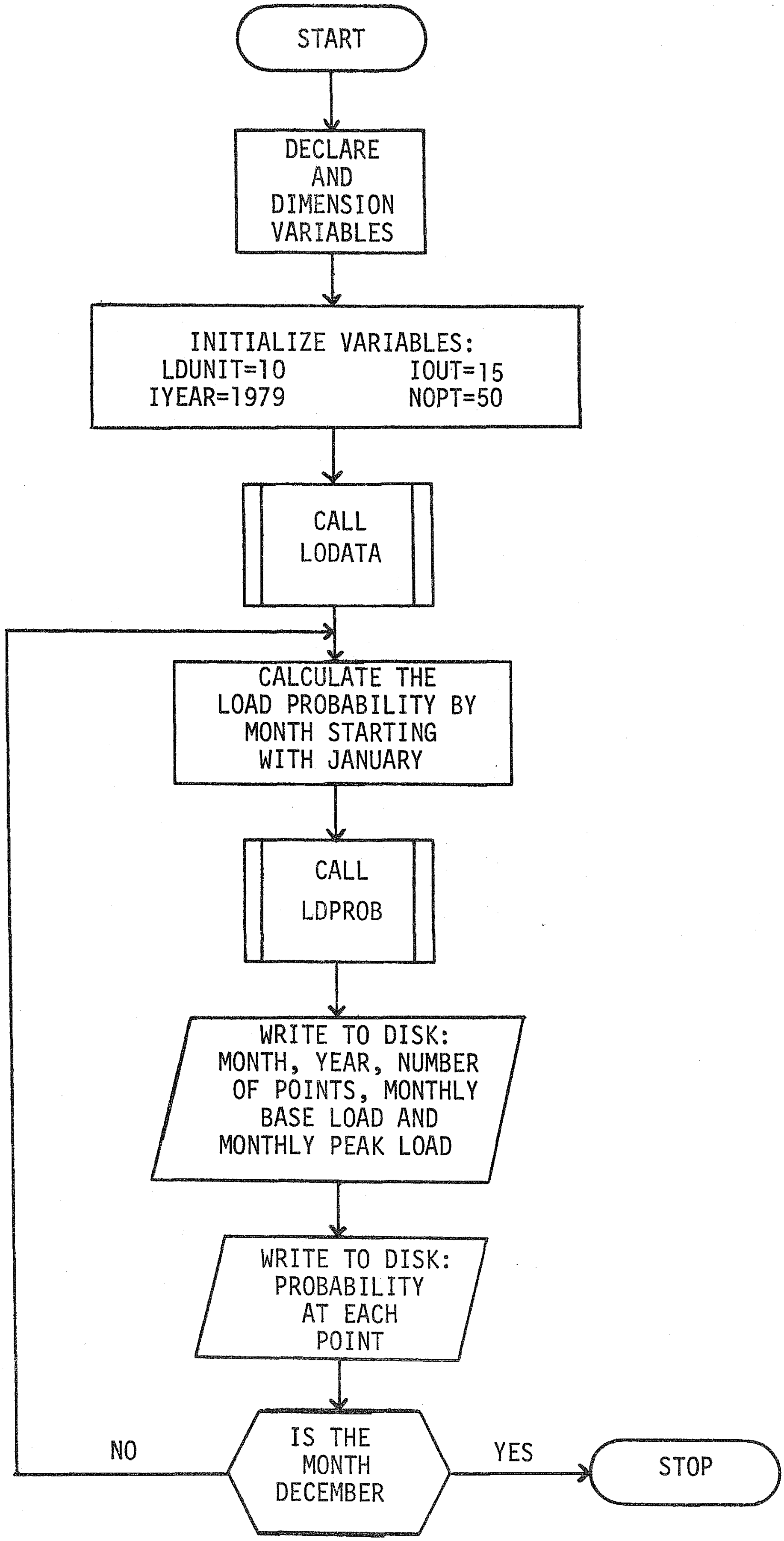
MAIN Routine

The MAIN portion of this module is to act as a control routine. It calls the two subroutines, LODATA and LOPROB, and writes the calculated load probability curve to the appropriate file.

The input logical file number is 10 for the hourly load data. The output file is number 15. These numbers can be changed by changing the values of variables LDUNIT and IOUT in the MAIN routine.

The number of points on the load probability curve is 50. This is a sufficient number of points for the PCS module. Up to 200 points can be calculated, but this number of points would greatly increase the calculation time of the PCS module but not necessarily increase the accuracy of the calculation.

MAIN


START
DECLARE AND DIMENSION VARIABLES
INITIALIZE VARIABLES:
LDUNIT=10
IOUT=15
IYEAR=1979
NOPT=50
CALL LODATA
CALCULATE THE LOAD PROBABILITY BY MONTH STARTING WITH JANUARY
CALL LDPROB
WRITE TO DISK: MONTH, YEAR, NUMBER OF POINTS, MONTHLY BASE LOAD AND MONTHLY PEAK LOAD
WRITE TO DISK: PROBABILITY AT EACH POINT
NO
IS THE MONTH DECEMBER
YES
STOP

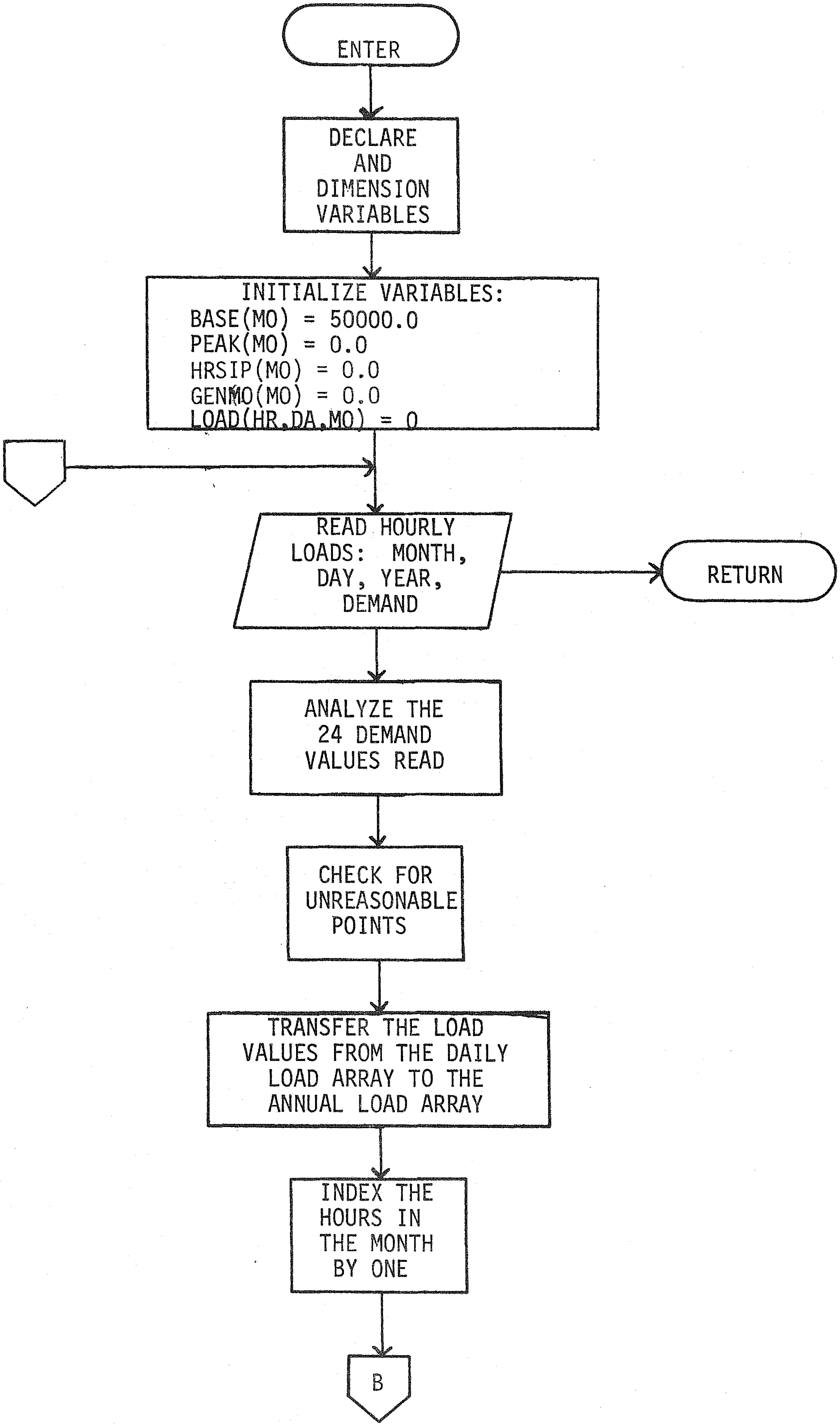
LODATA Routine

The function of this routine is to read and store the hourly load values for future use by the LDPROB routine.

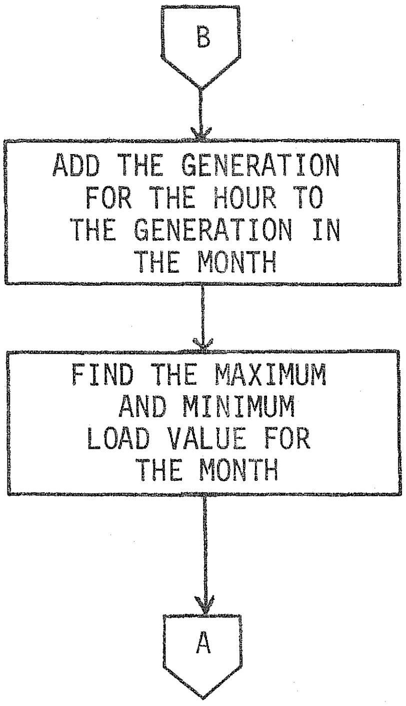
The load values are read one day at a time from logical unit LDUNIT, which is defined in the MAIN routine as 10. These values are then stored in the array LOAD, which represents the year as 12 months each having 31 days with 24 hours. Subsequent reading of this array by-passes zero load values.

Also calculated in this routine are the number of hours in the month, HRSIP, the generation in the month, GENMO, the peak load of the month, PEAK(MO), and the minimum load for the month, BASE(MO).

LODATA



ENTER
DECLARE AND DIMENSION VARIABLES
INITIALIZE VARIABLES:
BASE(MO) = 50000.0
PEAK(MO) = 0.0
HRSIP(MO) = 0.0
GENMO(MO) = 0.0
LOAD(HR,DA,MO) = 0
READ HOURLY LOADS: MONTH, DAY, YEAR, DEMAND
RETURN
ANALYZE THE 24 DEMAND VALUES READ
CHECK FOR UNREASONABLE POINTS
TRANSFER THE LOAD VALUES FROM THE DAILY LOAD ARRAY TO THE ANNUAL LOAD ARRAY
INDEX THE HOURS IN THE MONTH BY ONE
B


B
ADD THE GENERATION FOR THE HOUR TO THE GENERATION IN THE MONTH
FIND THE MAXIMUM AND MINIMUM LOAD VALUE FOR THE MONTH
A

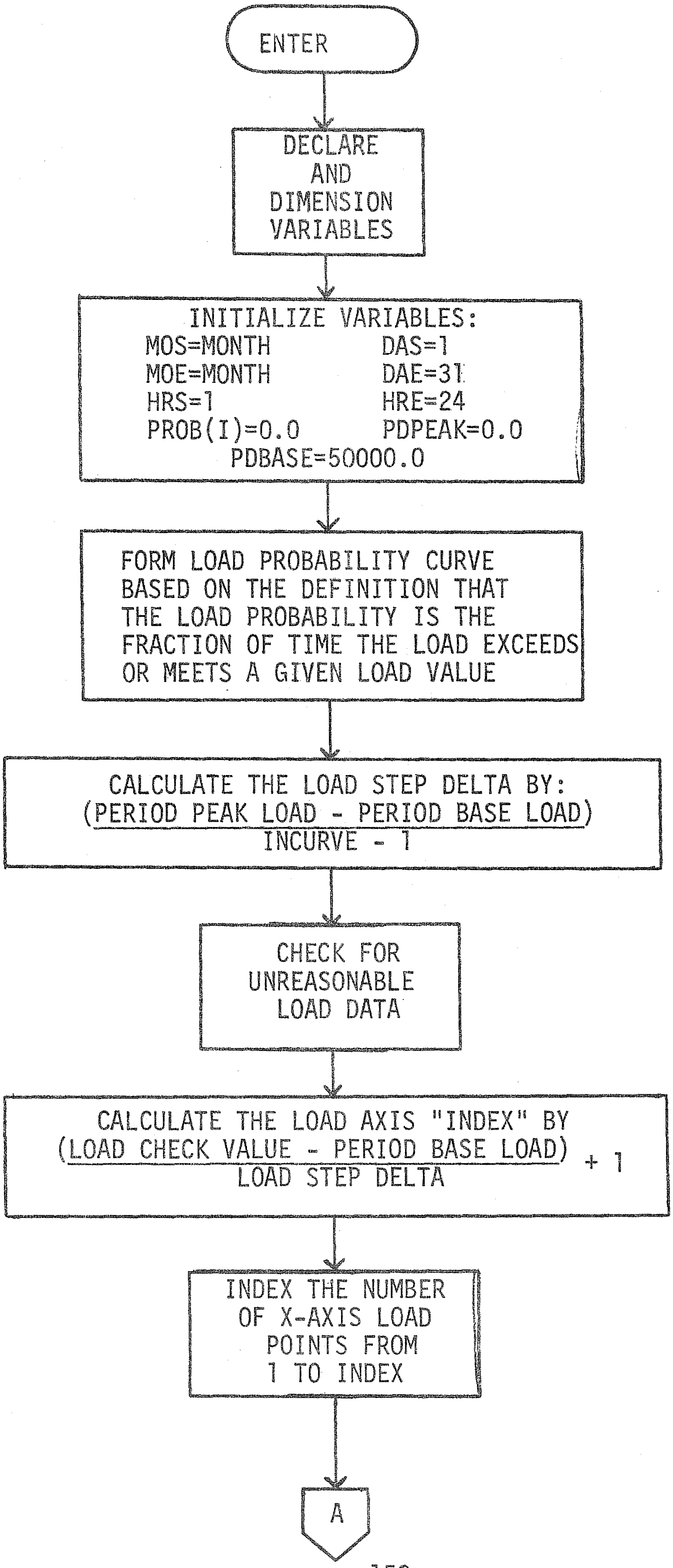
LDPROB Routine

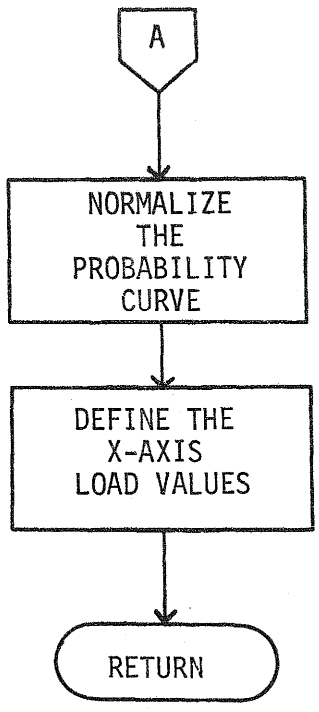
The LDPROB routine calculates the load probability curve based on the hourly loads. The function of this routine is to calculate the load probability curve on a monthly basis for all the days and hours in the month. However, the programming is such that with some changes the load probability curve can be calculated for a variable time period.

The curve is calculated by identifying where the load value would be on the load x-axis of the curve. The y-axis values are incremented by one from the first point to the point where the load value falls. This physically means that for all load values less than or equal to the current value, the load was greater than or equal to the loads for one hour. This process continues until all the non-zero loads for the month have been processed.

The curve is then normalized to the number of hours during which the load is at or above the minimum load. Although not used by the module, the load-axis values are calculated.

LDPROB


ENTER
DECLARE AND DIMENSION VARIABLES
INITIALIZE VARIABLES:
MOS=MONTH
DAS=1
MOE=MONTH
DAE=31
HRS=1
HRE=24
PROB(I)=0.0
PDPEAK=0.0
PDBASE=50000.0
FORM LOAD PROBABILITY CURVE BASED ON THE DEFINITION THAT THE LOAD PROBABILITY IS THE FRACTION OF TIME THE LOAD EXCEEDS OR MEETS A GIVEN LOAD VALUE
CALCULATE THE LOAD STEP DELTA BY:
(PERIOD PEAK LOAD - PERIOD BASE LOAD) / INCURVE - 1
CHECK FOR UNREASONABLE LOAD DATA
CALCULATE THE LOAD AXIS "INDEX" BY
(LOAD CHECK VALUE - PERIOD BASE LOAD) / LOAD STEP DELTA + 1
INDEX THE NUMBER OF X-AXIS LOAD POINTS FROM 1 TO INDEX
A


A
NORMALIZE THE PROBABILITY CURVE
DEFINE THE X-AXIS LOAD VALUES
RETURN

APPENDIX A

A Detailed Description of the PCS Module Algorithms

This appendix is Chapter 4 of

Development of Methodologies and Evaluation of the Effects of Load Management and Plant Availability Improvements on the Fuel Cost and Reliability of an Electric Utility System

A
Dissertation

by

Christos Poseidon, Ph.D.
The Ohio State University

March, 1979

CHAPTER 4

METHODOLOGY FOR THE CALCULATION OF FUEL COST AND SYSTEM RELIABILITY

4.1 Introduction

The basic tool used for fuel costing and reliability calculations in this work is the MARC-IIIB Code previously developed at The Ohio State University [27]. For application of this code to various aspects of the present study, several modifications of this code were made to improve its accuracy and its efficiency. The objective of this chapter is to describe the basic algorithms of the MARC-IIIB Code and the modifications.

The probabilistic simulation used by the MARC Code for production costing and reliability calculations was originally developed by Baleriaux et al and later used by Booth, and adopted in the WASP (Wien Automatic System Planning) by Joy and Jenkins [10-14]. The major difference in the application of probabilistic simulation between MARC-IIIB and WASP is that in the former the load duration curve is expressed as a piece-wise linear function whereas in the latter it is represented by a Fourier series. Reliability can be calculated more accurately using piece-wise linear functions [16].

The author's most significant contribution in this chapter is the development of a new technique of probabilistic simulation which is approximate but reduces computing time substantially. The second contribution of the author is the presentation of an analysis for multiple-block representation of generating units and the incorporation of two-block representation into the MARC-IIIB Code. In the MARC-IIIB Code the load duration curve is represented by a piece-wise linear function. The possibility of using two-block representation in conjunction with piece-wise linear functions was doubted by the authors of WASP [17] but the validity of the approach is shown in Section 4.3.

The basic aspects of probabilistic simulation using load duration curves are reported elsewhere [13,14]. However, it is necessary to outline the method before the author's modifications are described. This is done in Section 4.2. In Section 4.3 the algorithm for multiple-block representation of generating units is described, and applications are made to test its validity. The calculation of energy generation by multiple-block units makes use of the technique of deconvolution. The usefulness of this technique in a different application is demonstrated in Appendix C. In that application deconvolution is used to calculate the effect of each unit to system reliability. The new technique of approximate probabilistic simulation is described in Section 4.4. In Section 4.5 other important aspects of the MARC Code are discussed.

4.2 Probabilistic Simulation with One Loading Block Representation of Generating Units

With probabilistic simulation, the expected amount of energy generation by each unit is calculated using the system load duration curve, the availability probability of each unit and the loading order of the system's units. The total fuel cost is then calculated. In this method two indices of reliability may be defined. These are the "Loss-of-Load Probability", (LOLP), and the "Unserved Energy" The first index, LOLP, signifies the amount of time that the system cannot satisfy the demand. It is frequently expressed as a fraction (or percentage) of the period of study, or in days per year. The second index, unserved energy, signifies the total amount of energy that the system will be unable to serve in the period of study. Unserved energy is expressed in MWh. Neither of the above indices contain any information about the frequency of the system's inability to serve the demand. Both of these indices, however, can be used to evaluate the effect of various parameters on system reliability such as changes in load and unit availability.

In the remainder of this section fundamental aspects of probabilistic simulation for one-block units are discussed.

The method of probabilistic simulation is developed using the concepts of load duration, unit loading order, and unit availability probability.

Load duration is the number of hours in a period that the load on the system is equal to or exceeds a given load level. A load duration curve can be calculated using known or forecasted system hourly loads. A typical load duration curve is shown in Figure 4.1.

In this chapter the loading order of units will be assumed to be known. The loading order of units may be decided according to various strategies. Criteria which determine loading order usually include

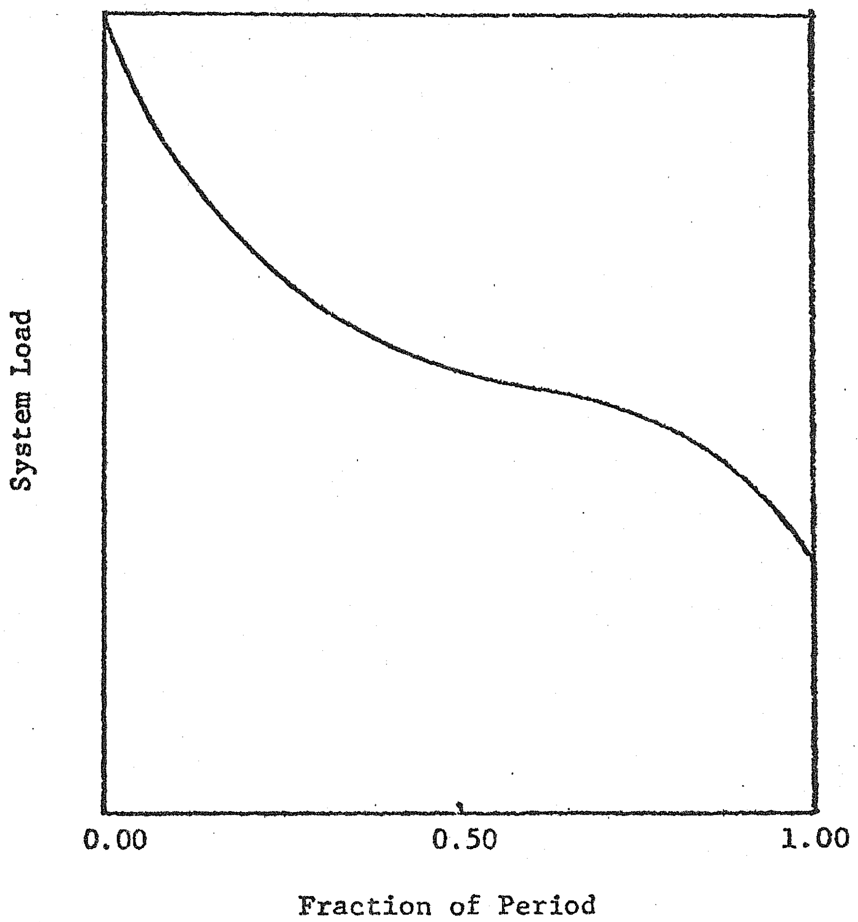


Figure 4.1 A Typical Load Duration Curve

reliability, economic and environmental factors. These factors may be weighted according to the amount of time that a unit is expected to operate in a given day. A more complete discussion of the method used to determine loading order in this work is given in Section 4.5.1.

For purposes of probabilistic simulation unit availability is defined as the "probability that a unit is able to generate electricity when needed" [14]. Frequently, this probability is defined in terms of the forced outage rate, and it is assumed that a unit can be either fully available or fully unavailable. The forced outage rate is defined as:

$$\mathrm{FOR} = \frac{\text{Forced Outage Hours}}{\text{Service Hours} + \text{Forced Outage Hours}} \times 100 \qquad (4.1)$$

Availability probability is then defined as

$$p = 1 - \frac{\mathrm{FOR}}{100} \qquad (4.2)$$

The definitions expressed by Eq. (4.1) and (4.2) are sufficient for the discussion of the principle of probabilistic simulation. In practical applications, however, partial deratings and maintenance outages are also considered in the definition of p. A more complete discussion about the definition of p in the present work is given in Section 4.5.2.

Assume that in a given time period, T hours, the loading order of N units of a system is

$$C_1, C_2, C_3, \ldots\ldots C_N$$

where C_i is the capacity (MW) of the i^{th} unit. We denote the availability probability of unit i by p_i. The probability that unit i is unavailable is

$$q_i = 1 - p_i \tag{4.3}$$

Here it is assumed that a unit is either fully available or fully unavailable. Assuming that the availability probability of each unit is 1, the energy generation of unit i in a period of time T may be calculated by

$$E_i = T \int_{a_i}^{b_i} L(x)\, dx \tag{4.4}$$

where

E_i = Energy generation of unit i, MWh

$L(x)$ = The "inverted", normalized, system load duration curve

T = The number of hours in the period

$$a_i = \sum_{j=1}^{j=i-1} C_j \text{ ,MW} \quad , \quad a_1 = 0$$

$$b_i = a_i + C_i\text{, MW}$$

The inverted load duration curve, L(x), and the amount of energy produced by unit i are illustrated in Figure 4.2.

If, however, $p_i \neq 1$, a load probability distribution function must be calculated for each unit. The load probability distribution

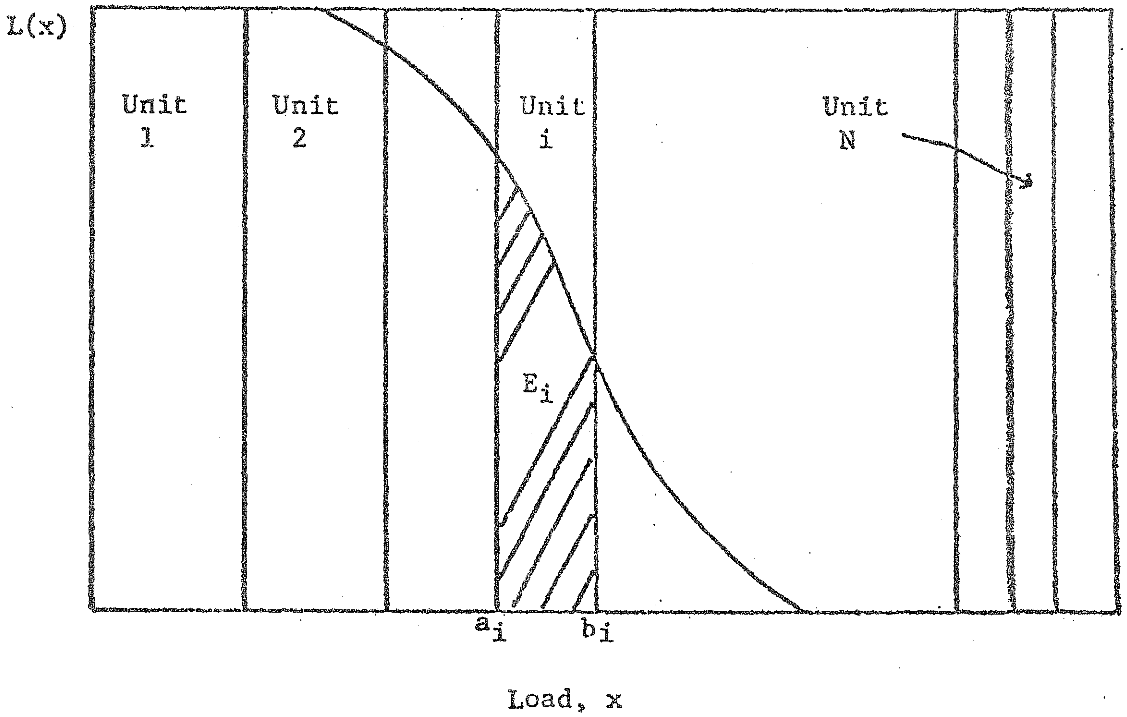


Figure 4.2 A Typical Inverted Load Duration Curve

for each unit depends on the system load distribution, L(x), and on the availability probability and capacity of each unit with higher loading priority. For the first loaded unit, the load probability distribution function is equal to L(x). The load probability distribution function for the remaining units can be found recursively by the following argument.

The energy generated by unit 1 is

$$E_1 = p_1 T \int_0^{C_1} L(x)dx \tag{4.5}$$

where T is the length of the period in hours, x is in MW, and E_1 is in MWh. The amount of energy generated by unit 2 when unit 1 is available is

$$E_{21} = p_1 p_2 T \int_{C_1}^{C_1+C_2} L(x)dx \tag{4.6}$$

The amount of energy generated by unit 2 when unit 1 is not available is

$$E_{22} = q_1 p_2 T \int_0^{C_2} L(x)dx \tag{4.7}$$

Thus, the total amount of energy generated by unit 2 is given by

$$E_2 = E_{21} + E_{22}$$

By rearranging Eq. (4.6) and (4.7), it is seen that E_2 can also be expressed as

$$E_2 = p_2 T \int_{C_1}^{C_1+C_2} EL_1(x)dx \tag{4.8}$$

where

$$EL_1(x) = p_1 L(x) + q_1 L(x-C_1) \tag{4.9}$$

The function $EL_1(x)$ represents the load probability distribution function for unit 2. The remaining functions $EL_i(x)$ can be found similarly. These functions have been called "Equivalent Load Duration Curves", (ELDC). The concept of the ELDC facilitates the calculation of E_i because $EL_i(x)$ can be found by the general recursion relation

$$EL_i(x) = p_i EL_{i-1}(x) + q_i EL_{i-1}(x-C_i) \tag{4.10}$$

$$i = 1, 2, \ldots N$$

where

$$EL_0(x) = L(x)$$

Using Eq. (4.10) the amount of energy generated by unit i, E_i, is calculated by

$$E_i = p_i T \int_{a_i}^{b_i} EL_{i-1}(x)\, dx \tag{4.11}$$

$$i = 1, 2, \ldots N$$

where

$$a_i = \sum_{j=1}^{j=i-1} C_j \quad , \quad a_1 = 0$$

and

$$b_i = a_i + C_i$$

$$EL_0(x) = L(x)$$

A set of ELDC's is illustrated in Figure 4.3.

The last ELDC, $EL_N(x)$, includes the effect of outages of unit N. LOLP and Unserved Energy are calculated by

$$\text{LOLP} = EL_N\ (B) \tag{4.12}$$

$$\text{Unserved Energy} = T \int_B^{\infty} EL_N(x)dx \tag{4.13}$$

where

$$B = \sum_{i=1}^{N} C_i$$

The LOLP and Unserved Energy are also illustrated in Figure 4.3.

4.3 Multiple-Block Representation of Generating Units

The loading order of units as specified in Section 4.2 assumes that each unit is loaded to full capacity in one step. In the actual situation, depending upon a system's constrains and objectives (i.e., spinning reserve requirements, economic factors), a unit may be

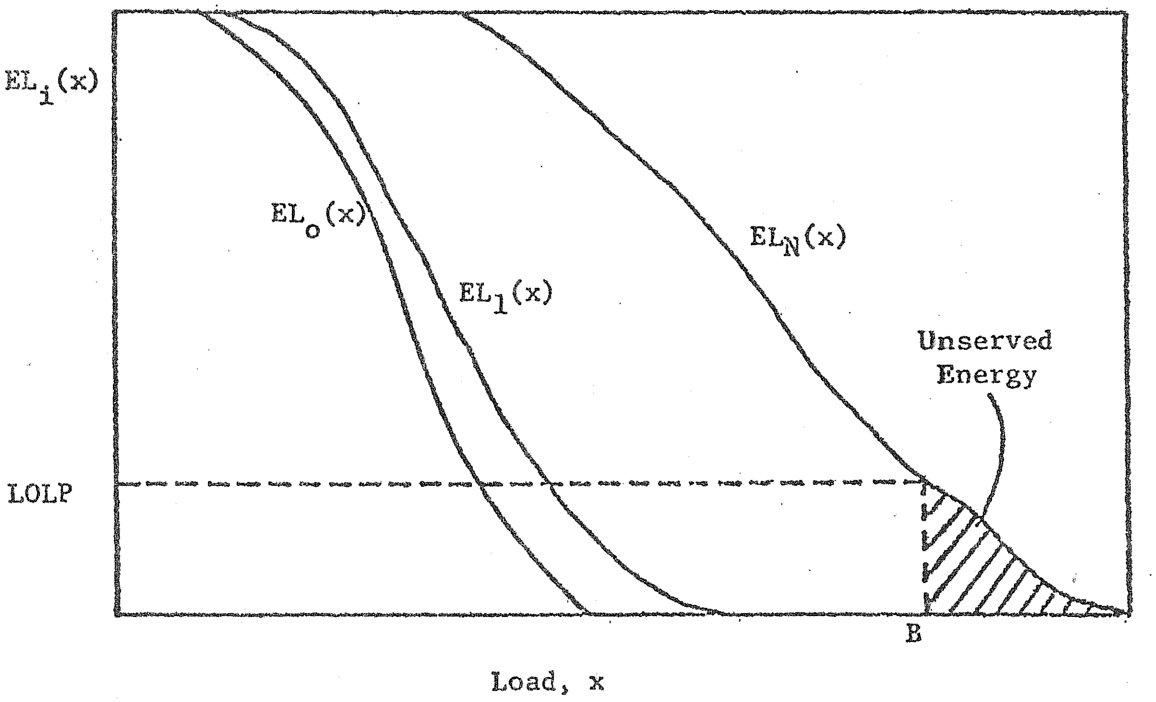


Figure 4.3 A Set of Equivalent Load Duration Curves

loaded up to a certain fraction of its capacity and then a different unit may be loaded before the previous unit is loaded to full capacity. In addition, assuming that suitable outage data are available, partial outages may be simulated by assigning different availability probabilities to different blocks of the same unit. It is, therefore, desirable to provide the MARC Code with the capability of multiple block representation of generating units.

Basic concepts which are useful for multiple loading block representation have been reported in [18,19]. Two block unit representation in conjunction with Fourier series representation of the load duration curve has been used in the WASP Code [15]. In this section the algorithm of multiple block representation is described and applications in conjunction with a piece-wise linear load duration curves are made. The use of piece-wise linear curves has been shown to lead to a more accurate calculation of system reliability [16].

4.3.1 Algorithm of Multiple Block Representation

For simplicity of explanation in the following derivation it is assumed that only one unit in the system is loaded in two steps (2-block representation). Further, it is assumed that both blocks have the same availability probability. At the end of this section the algorithm will be generalized to include units loaded in multiple steps and units with different availability probabilities assigned to each block.

A system is considered consisting of N units. The loading order of units and blocks is C_1, C_2, ..., C_{j-1}, C_{j1}, C_{j+1}, ..., C_k, C_{j2}, C_h, C_{h+1}, ..., C_N where C_i represents the capacity of block i. The series above indicates that units 1 through j-1 are represented by only one block. Unit j is represented by two blocks with capacities C_{j1} and C_{j2} of which only C_{j1} is loaded immediately after C_{j-1}. Following C_{j1}, the one-block units C_{j+1} through C_k are loaded, then C_{j2} is loaded, and then each of the remaining one-block units are loaded. The ELDC corresponding to each block (or unit) are termed EL_o, EL_1, ..., EL_{j-2}, EL_{j-1}, EL_j, ..., EL_{k-1}, EL_k, EL_{h-1}, EL_h, ..., EL_{N-1}. The ELDC for blocks 1, 2, ... k are calculated according to the procedure of Section 4.2 as

$$\begin{aligned} EL_0 (x) &= L(x) \\ EL_1 (x) &= p_1 EL_0(x) + q_1 EL_0(x-C_1) \qquad (4.14) \\ &\vdots \\ EL_{k-1}(x) &= p_{k-1} EL_{k-2}(x) + q_{k-1} EL_{k-2}(x-C_{k-1}) \end{aligned}$$

Energy generation by blocks 1, 2, ... k is calculated using Eq. (4.14) as

$$E_n = p_n T \int_{a_n}^{b_n} EL_{n-1}(x)dx \qquad (4.15)$$

$$n = 1, 2, \ldots k$$

where

$$a_n = \sum_{m=1}^{m=n-1} C_m, \; a_1 = 0$$

$$b_n = a_n + C_n$$

If the same procedure were to be used to calculate the ELDC for C_{j2} and the amount of energy generated by C_{j2}, E_{j2}, this ELDC would include the effects of outages of C_{j1}, and the calculated energy generation would include energy generated by block j_2 in replacement of block j_1 when j_1 was unavailable. This is physically impossible since it has been assumed here that when j_1 is on outage j_2 must also be on outage. The effect of outages of block C_{j1} can be removed (deconvolved) from the load probability distribution for C_j2, $EL_k(x)$, by using the expression

$$\tilde{EL}_k(x) = \frac{EL_k(x) - q_j \tilde{EL}_k(x-C_{j1})}{p_j} \tag{4.16}$$

Equation (4.16) expresses the load probability distribution function if the effects of outages of C_{j1} are not included. The energy generated by j_2 is calculated by

$$E_{j2} = p_j T \int_{a_{j2}}^{b_{j2}} \tilde{EL}_k(x)\,dx \tag{4.17}$$

where $\widetilde{EL}_k(x)$ is the modified distribution function,

and

$$a_{j2} = \sum_{m=1}^{m=k} C_m \, ,$$

$$b_{j2} = a_{j2} + C_{j2}$$

For the calculation of the energy generation of subsequent units, the effect of the outages of (the total) unit C_j must be included in the distributions $EL_{h-1}(x)$, $EL_h(x)$, ..., $EL_N(x)$. Because of the recursive character of these functions, it is sufficient that the effect of outages of unit C_j be included in $EL_{h-1}(x)$. Thus,

$$EL_{h-1}(x) = p_j \tilde{EL}_k(x) + q_j \tilde{EL}_k(x-C_j) \tag{4.18}$$

where $C_j = C_{j1} + C_{j2}$

Using Eq. (4.18)

$$E_h = p_h T \int_{a_h}^{b_h} EL_{h-1}(x)dx \tag{4.19}$$

where

$$a_1 = \sum_{m=1}^{m=h-1} C_m ,$$

and

$$b_h = a_h + C_h$$

the ELDC for the remaining units can be calculated as in Section 4.2. When more than one unit is represented by two blocks, the above procedure can be applied to each such unit.

It is now supposed that the probability of operation at full capacity is p_1, at a derated capacity, C_{j1}, is p_2, and of unavailability is q so that

$$p_1 + p_2 + q = 1.0$$

Therefore,

$$p_{j1} = p_1 + p_2,$$

$$q_{j1} = q,$$

$$p_{j2} = p_1$$

The energy of the second block, capacity C_{j2}, must be calculated using $\widehat{EL}_k(x)$ which does not include the effects of outage of the first block, and is given by Eq. (4.16). For subsequent ELDC, the two blocks may be included into the distribution using

$$EL_{h-1}(x) = p_1\widehat{EL}_k(x) + p_2\widehat{EL}_k(x-C_{j2}) + q\ \widehat{EL}_k(x-C_{j1}-C_{j2}) \qquad (4.20)$$

A plant may be loaded in more than two steps. In this case the calculation of energy generation can be made more accurately by multiple-block representation of plants in probabilistic simulation. Multiple block representation has been discussed in Reference [18]. In the following algorithm it is assumed that unit j is divided into n loading blocks, and that the availability probability of all blocks of unit j is the same (p_j). For simplicity of notation the ELDC for the M+1th block of junit j before removing the effects of outages of the first M blocks of j is termed as Y_1. The ELDC after removing the effects of these blocks is termed as $\tilde{Y}_1$. The ELDC for the unit (or block) which follows the M+1th block of unit j in loading order is termed as Y_2. Assuming the same availability probability (2-state model) for all blocks of j,

$$\tilde{Y}_1(x) = \frac{Y_1(x) - q_j\tilde{Y}_1(x-\sum_{i=1}^{i=M} C_{ji})}{p_j} \qquad (4.21)$$

and

$$Y_2(x) = p_j\tilde{Y}_1(x) + q_j\tilde{Y}_1(x-\sum_{i=1}^{i=M+1} C_{ji}) \qquad (4.22)$$

The function $\widetilde{EL}_k(x)$ in Eq. (4.16) is formed from pre-calculated values of the same function. Numerically, Eq. (4.16) is written as

$$\tilde{EL}_k(x_i) = \frac{EL_k\ (x_i) - q_j \tilde{EL}_k(x_i - C_{j1})}{p_j} \tag{4.23}$$

where i indicates a point on the load axis. If, however,

$$C_{ji} < x_i - x_{i-1}$$

$\widetilde{EL}_k(x_i)$ cannot be calculated in terms of $\widetilde{EL}_k(x_i - C_{j1})$. In this case $\widetilde{EL}_k(x_i)$ is calculated as follows [28]. Because $\tilde{EL}_k$ is a piece-wise linear function, $\widetilde{EL}_k(x_i)$ and $\widetilde{EL}_k(x_{i-1})$ are points on a straight line. Thus, by interpolation

$$\tilde{EL}_k(x_i - C_{j1}) = \frac{x_{i-1} - x_i + C_{j1}}{x_{i-1} - x_i}\,\tilde{EL}_k(x_i) - \frac{C_{j1}}{x_{i-1} - x_i}\,\tilde{EL}_k(x_{i-1}) \tag{4.24}$$

By introducing Eq. (4.24) into Eq. (4.23), $\widetilde{EL}_k(x-C_{j1})$ is eliminated and Eq. (4.24) is then solved for $\widetilde{EL}_k(x_i)$.

4.3.2 Numerical Evaluation

The two-block representation algorithm was incorporated into the MARC-IIIB Code, for the case of equal availability probabilities (2-state model) of both blocks of the same unit. A listing of the algorithm is provided in Appendix B. This algorithm was validated using three tests. In the first test, the function $\widetilde{EL}_k(x)$ was first calculated according to the algorithm described, and then it was recalculated omitting block j_1. The two functions were found to be equal at all points. In some cases, however, computer truncation error was observed. This error was eliminated by using "double precision". This test proves that Eq. (4.16) produces the correct function, $\tilde{EL}_k(x)$ when block j1 is removed from the distribution $EL_k(x)$. In the second test, the energy generated by block j2 was calculated by first considering j2 as the second block of unit j, and then by considering j2 as an independent unit. In both cases j1 and j2 were assigned the same availability probability. It was found that in the first case the energy generation of j2 was less. This result agrees with what would be expected, since in the second case, block j2 can generate additional energy in replacement of j1, when j1 is on outage. In the third test, the energy generation of unit h (the next one to j2 in loading order) was calculated by first considering j1 and j2 as blocks of the same unit and then by considering one unit with capacity C_j, $C_j = C_{j1} + C_{j2}$. In both cases the calculated energy generation of unit h was the same. This result agrees with what was expected, since the amount of energy generated by unit h (and hence system reliability) are independent of whether unit j is loaded in one or two steps.

An additional application of deconvolution is discussed in Appendix C.

4.4 A New Technique of Approximate Probabilistic Simulation: Group Representation of Generating Units

Certain types of studies, such as the expansion planning of a generating system or the evaluation of different levels of availability improvements or load management on system economics, frequently require the repetitive application of probabilistic simulation. In such studies, a large number of alternative scenarios must be evaluated for generating cost and reliability comparisons. Such evaluations require the computation of a large number of ELDC. For this reason, a large fraction of the computing cost associated with such studies is due to the repetitive application of the probabilistic simulation method. It is, therefore, desirable to develop techniques whereby this cost will be reduced.

In this section a new technique of probabilistic simulation devised by the author is presented [20]. With this technique energy generation, LOLP, and unserved energy are calculated at a reduced computational time and cost. This technique consists of aggregating individual generating units into groups of units and then applying the method of probabilistic simulation to groups of units. Thus, instead of calculating an ELDC for each unit, only one such is calculated for each group. As a result, a substantial reduction in computational time is observed.

4.4.1 Algorithm of Group Representation

Consider a system of N units the loading order of which is

$$C_1, C_2, \ldots C_N$$

where C_i is the capacity of unit i. The availability probability of unit i is p_i. In the present grouping technique the N units are aggregated into groups with the loading order within each group and between groups maintained. ELDC are constructed only for groups of units and not for each unit. This is done by an appropriate definition of group capacity and group availability probability. Once such group parameters are defined, a group is treated as an "equivalent" unit in the standard probabilisitc simulation. A group may contain any number of units.

The system load duration curve is denoted by L(x), while the ELDC for group j by $ELG_{j-1}(x)$. The function $ELG_{j-1}(x)$ and the position of group j in loading order are shown in Figure 4.4. The capacities of the n units of group j are denoted by

$$C_1{}^j, C_2{}^j, \ldots C_n{}^j$$

The group capacity is defined as the sum of the capacities of the units in group j. Group availability probability is defined here as

$$p^j = \frac{\text{Energy generated by group j in period T}}{\text{Energy required from group j in period T}} \qquad (4.25)$$

The calculation of P^j is described later in this section. Using the definition of Eq. (4.25), the ELDC for group j+1, $ELG_j(x)$, is calculated by

$$ELG_j(x) = P^j \; ELG_{j-1}(x) + Q^j \; ELG_{j-1}(x - GRC_j) \qquad (4.26)$$

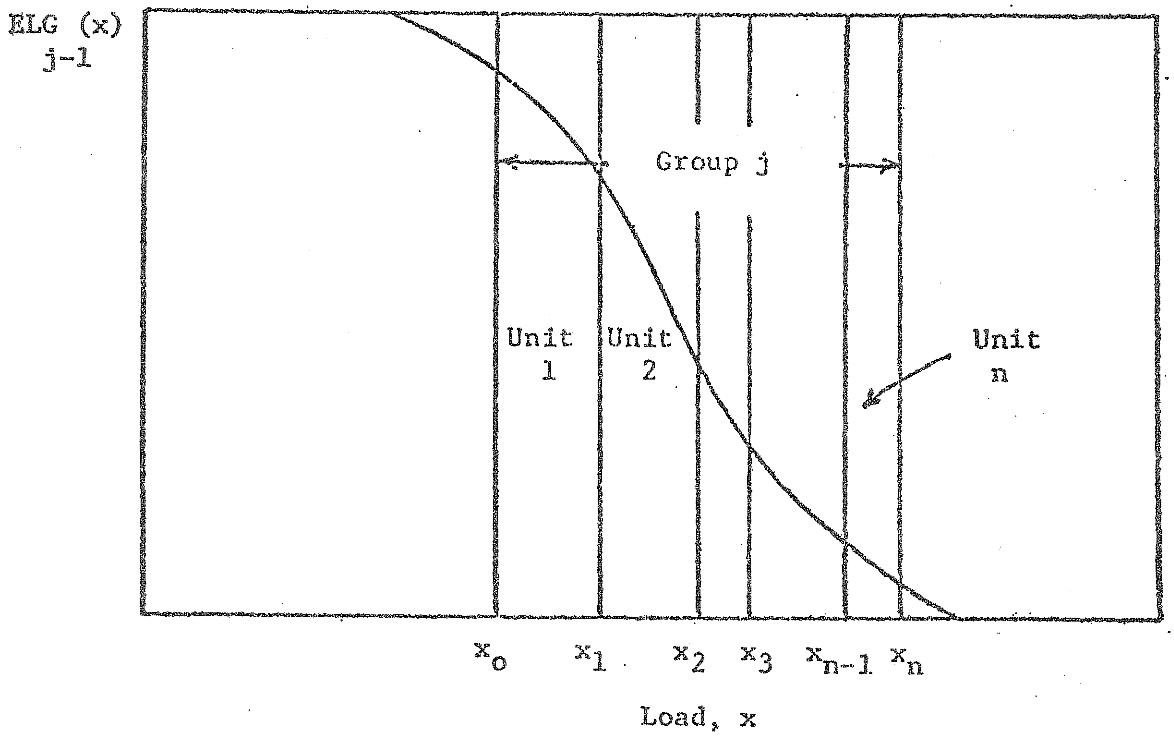


Figure 4.4 The Equivalent Load Duration Curve for Group j

where

$$Q^j = 1 - P^j ,$$

$$GRC_j = \sum_{i=1}^{i=n} C_i^j ,$$

and

$$ELG_0(x) = L(x)$$

The group availability probability, P^j, is calculated concurrently with the energy of the units in group j as follows. Group j contains n units. Initially, the first two units of the group are considered. The capacities of these units are C_1^j and C_2^j, and their availability probabilities are p_1^j and p_2^j respectively. The expected energy generation of these units is

$$E_1^j = p_1^j \, T \int_{x_0}^{x_1} ELG_{j-1}(x)dx \qquad (4.27)$$

and

$$E_2^j = p_1^j p_2^j \, T \int_{x_1}^{x_2} ELG_{j-1}(x)dx + q_1^j p_2^j \, T \int_{x_0}^{x_0+C_2^j} ELG_{j-1}(x)dx \qquad (4.28)$$

respectively. In Eq. (4.27) and (4.28), $ELG_{j-1}(x)$ is the ELDC for group j. The limits of the integrals in Eq. (4.27) and (4.28) are shown in Figure 4.4. Next, unit 1 and unit 2 are combined and represented by an equivalent unit having capacity $C_1^j + C_2^j$ and equivalent availability P^j_{12} given by

$$P_{12}^{j} = \frac{(E_1^j + E_2^j)}{\displaystyle\int_{x_0}^{x_2} ELG_{j-1}(x)\,dx} \tag{4.29}$$

The energy generated by the third unit is calculated by the same procedure as for E_2^j in Eq. (4.28):

$$E_3^j = P_{12}^j \, p_3^j \, T \int_{x_2}^{x_3} ELG_{j-1}(x)\,dx + Q_{12}^j \, p_3^j \, T \int_{x_0}^{x_0 + C_3^j} ELG_{j-1}(x)\,dx \tag{4.30}$$

Next, units 1, 2 and 3 are combined and represented by an equivalent unit of capacity $C_1^{\,j} + C_3^{\,j}$ and equivalent availability $P_{123}^{\,j}$ given by

$$P_{123}^{\,j} = \frac{(E_1^j + E_2^j + E_3^j)}{\displaystyle\int_{x_0}^{x_3} ELG_{j-1}(x)\,dx} \tag{4.31}$$

This procedure is repeated until the last unit in the group is included. Then the group availability probability, P^j, is set equal to $P_{12\ldots n}^{\,j}$. The LOLP and unserved energy are calculated as in the standard technique using $ELG_N(x)$.

As seen from Eq. (4.27) through (4.31), the calculation of each $P^j{}_{12\ \ldots j}$, $2 \leq k \leq n$, requires the evaluation of two integrals but does not require the calculation of ELDC for individual units. Therefore, this procedure reduces computing time. However, a disadvantage is that the approximation which is used for the calculation of $E_3{}^j$, as well as for $E_4{}^j$, etc., introduces an error which propagates and affects the accuracy of all the remaining computations. As the number of units in each group increases, the computing time savings increases while the error also increases. This error is, however, smaller if the capacity of units in a group is small. This is particularly important in dealing with peaking units because their capacities are very small and their contribution to the system's energy generation is very small while the computing time needed for the computation of their ELDC is the same as for larger units.

4.4.2 Numerical Evaluation

In order to test the validity of the proposed technique and its effectiveness in reducing computing time, the technique was implemented into a generating system simulation program and applied to a test system. A listing of this program is provided in Appendix D. A piece-wise linear interpolation method is used in the program to represent ELDC. The reduction in computing time and error relative to the standard technique are evaluated for different ways of grouping of the generating units. The capacity of each unit owned by the utility and the availability probability of each unit are listed in loading order in Table 4.1. The inverted load duration curve of the system in the period of simulation is shown in Figure 4.5. The cases of grouping to which the technique was applied are shown in Table 4.2. Case 1 is the reference case where no grouping is used. In Cases 2 through 5, the last 11 units, namely unit 19 through 29, are combined into 4, 3, 2 and 1 groups, respectively. The boundary between two adjacent groups is shown by a dotted horizontal bar in Table 4.2. In Cases 6 through 9, the last 20 units, namely units 10 through 29, are combined into 9, 7, 5 and 4 groups, respectively.

TABLE 4.1

SYSTEM PLANT PARAMETERS

Unit Number	Unit Capacity, MW.	Availability Probability
1	218.50	0.67
2	180.00	0.89
3	202.30	0.83
4	204.75	0.79
5	204.75	0.78
6	204.75	0.80
7	132.00	0.86
8	140.00	0.84
9	140.00	0.84
10	67.00	0.95
11	61.00	0.95
12	60.00	0.93
13	67.00	0.92
14	67.00	0.92
15	67.00	0.95
16	14.00	0.74
17	11.00	0.84
18	149.00	0.84
19	14.00	0.79
20	3.85	0.90
21	28.00	0.93
22	21.00	0.89
23	17.00	0.93
24	17.00	0.95
25	17.00	0.93
26	17.00	0.93
27	21.00	0.87
28	21.00	0.91
29	8.00	1.00*

*purchase power contract

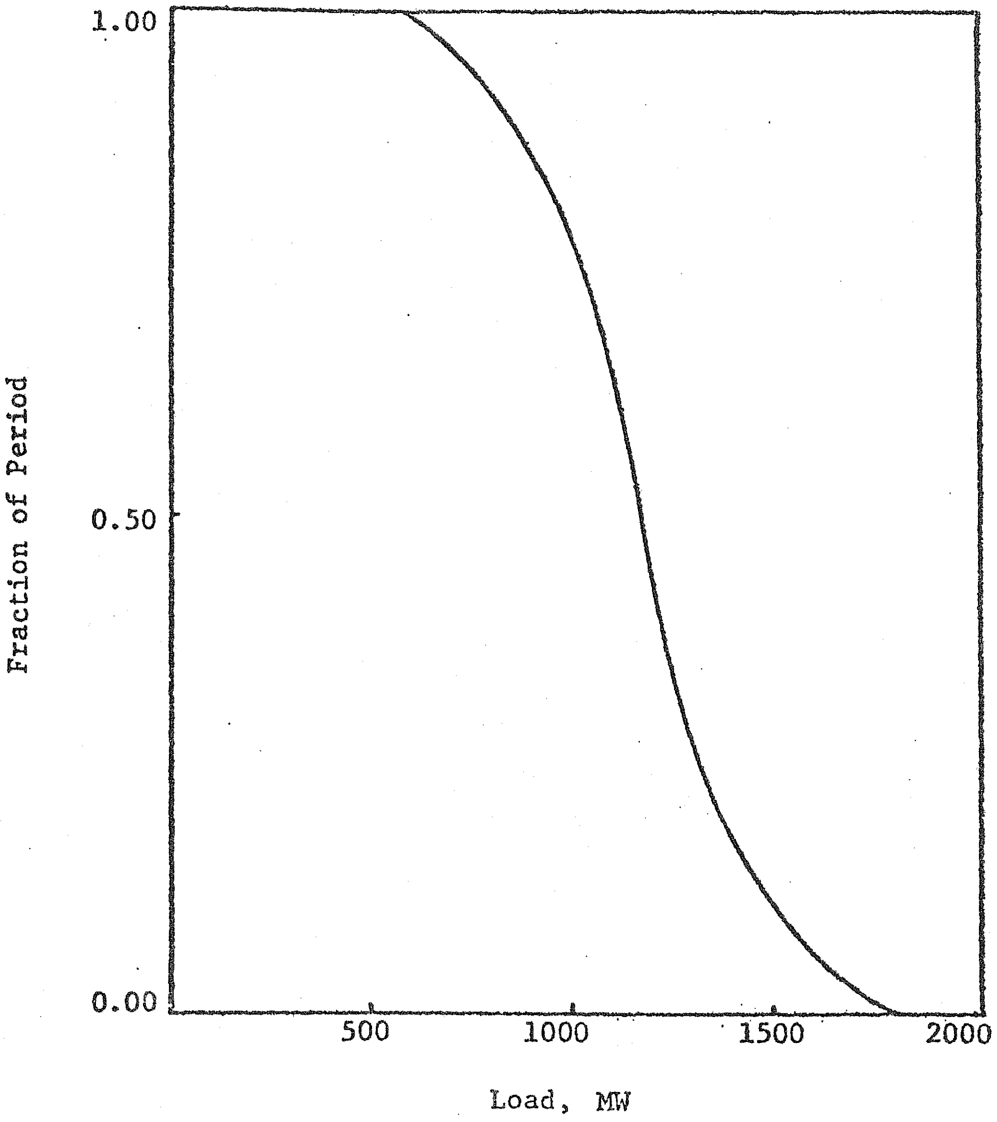


Figure 4.5 The Inverted Load Duration Curve of the System Considered

TABLE 4.2

ARRANGEMENT OF UNITS ACCORDING TO NINE DIFFERENT

GROUPING SCHEMES

(Each Entry Represents the Capacity of a Group in MW)

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
No. of Groups	29	22	21	20	19	18	16	14	13
	218.50	218.50	218.50	218.50	218.50	218.50	218.50	218.50	218.50
	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00
	202.30	202.30	202.30	202.30	202.30	202.30	202.30	202.30	202.30
	204.75	204.75	204.75	204.75	204.75	204.75	204.75	204.75	204.75
	204.75	204.75	204.75	204.75	204.75	204.75	204.75	204.75	204.75
	204.75	204.75	204.75	204.75	204.75	204.75	204.75	204.75	204.75
	132.00	132.00	132.00	132.00	132.00	132.00	132.00	132.00	132.00
	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00
	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00
	67.00	67.00	67.00	67.00	67.00	128.00	128.00		
	61.00	61.00	61.00	61.00	61.00			188.00	255.00
	60.00	60.00	60.00	60.00	60.00	127.00	127.00		
	67.00	67.00	67.00	67.00	67.00				
	67.00	67.00	67.00	67.00	67.00	134.00	134.00	201.00	
	67.00	67.00	67.00	67.00	67.00				308.00
	14.00	14.00	14.00	14.00	14.00	25.00	25.00		
	11.00	11.00	11.00	11.00	11.00			174.00	
	149.00	149.00	149.00	149.00	149.00	149.00	149.00		
	14.00								
	3.85	48.85	48.85			48.85			
	28.00			83.85			83.85	83.85	83.85
	21.00								
	17.00	55.00	72.00		187.85	55.00			
	17.00								
	17.00								
	17.00	55.00		101.00		55.00			101.00
	21.00						101.00	101.00	
	21.00	29.00	67.00			29.00			
	8.00								

Entries in Table 4.2 show the capacity of each group in Cases 1 through 9.

The error relative to Case 1 in the calculated energy generation by each unit, is shown in Table 4.3. By observing Cases 2 through 5 in Table 4.3, the following tendencies may be recognized. First, the amount of error increases as the size of groups increases, i.e., the errors in Case 5 are larger than those in Cases 2 through 4. Second, the error increases in the loading order, although this rule does not strictly apply. Those two tendencies are observed also in Cases 6 through 9. By comparing Cases 2 and 6, where the grouping schemes for units 19 through 29 are identical, it can be seen that grouping units in an early loading order increases the errors for the units in a later loading order. Similar comparisons may be made between Cases 4 and 7, or Cases 4 and 8 or Cases 4 and 9.

The last row of Table 4.3 shows the percent error in the total energy generation calculated for each case. This error is less than or equal to 0.01% for all the grouping schemes tested. This high accuracy in the total energy generation is due to the fact that only relatively small units, whose contribution to the total energy generation is small because of their small capacities as well as their low loading priorities, are grouped.

Figure 4.6 shows the error in LOLP as well as the computing time for each case relative to the reference case. The CPU time for Case 2 is approximately 70% of Case 1, (or 30% saving) while that for Case 9 is 34% (or 66% saving). The error in LOLP for Cases 2 through 5 is less than 1%, while the error for Cases 6 through

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TABLE 4.3

PERCENT ERROR IN THE CALCULATION OF ENERGY GENERATION

(Blank entries indicate no grouping. Boxes indicate groups of units).

Case Number	1	2	3	4	5	6	7	8	9
Number of Groups	29	22	21	20	19	18	16	14	13
Unit Number									
10						0.0	0.0	0.0	0.0
11						0.0	0.0	0.0	0.0
12						-0.1	-0.1	-0.1	-0.1
13						-0.1	-0.1	-0.3	-0.3
14						-0.5	-0.5	-0.5	-1.2
15						-0.1	-0.1	-0.4	-0.7
16						0.0	0.0	-0.4	-0.3
17						0.0	0.0	-0.4	-0.4
18						0.0	0.0	-0.1	0.0
19		0.0	0.0	0.0	0.0	0.6	0.6	0.2	-1.9
20		0.0	0.0	0.0	0.0	0.7	0.7	0.3	-1.7
21		0.0	0.0	0.0	0.0	0.8	0.8	0.7	-1.2
22		-0.1	-0.1	-0.1	-0.1	0.8	0.8	1.2	-0.3
23		-0.1	-0.1	-0.1	-0.1	0.8	0.6	1.2	0.1
24		-0.1	-0.1	-0.3	-0.3	0.7	0.5	1.3	0.8
25		-0.1	-0.1	-0.3	-0.4	0.7	0.6	1.5	1.7
26		-0.1	-0.2	-0.2	-0.4	1.0	0.9	1.7	2.7
27		-0.1	-0.1	-0.1	-0.5	1.2	1.2	2.1	3.7
28		-0.1	-0.1	-0.2	-0.7	1.5	1.4	2.6	4.8
29		-0.1	-0.2	-0.3	-0.9	1.7	1.6	3.1	5.6
Error in Total Energy, %		< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01

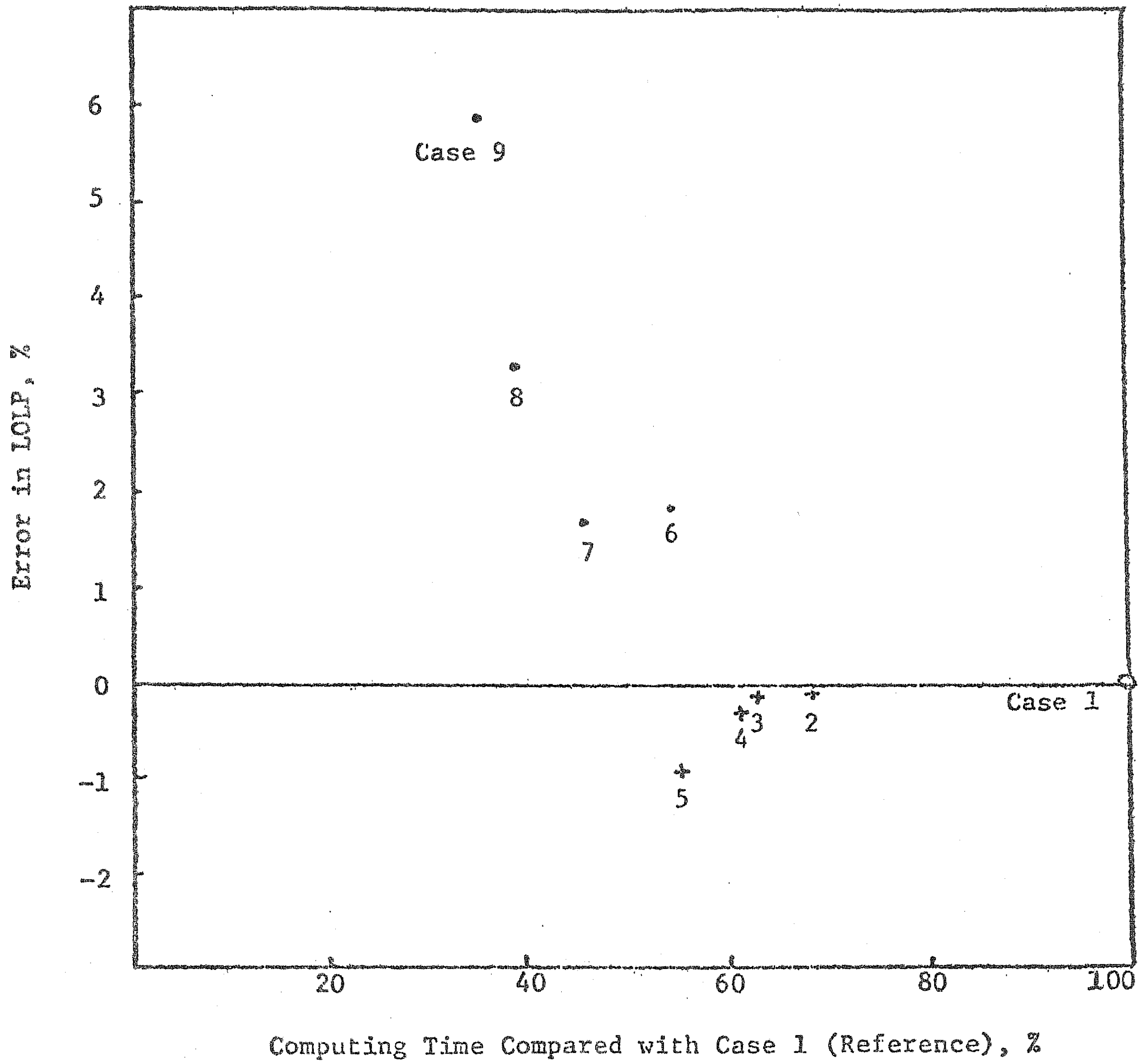

Figure 4.6 Computing Time and Error in LOLP

9 is spread between 1% and 6%. The error in LOLP less than 10% is considered to be small in system planning because a projected LOLP for any given system is subject to much greater error due to uncertainty in load forecasting and outage rates.

4.4.3 Conclusion

An algorithm to combine generating units into large equivalent units was derived in conjunction with probabilistic simulation of generating system operation. Test results show that the number of ELDC to be calculated in a probabilistic simulation can be easily reduced with a computing time saving of 30% to 70% without introducing a significant amount of error. The proposed method is most successfully used to increase the computing efficiency in dealing with small peaking units whose contribution to the system is minimal but for which it takes the same computational cost to form individual ELDC as it does for larger units.

The computational costs are compared based on the probabilistic simulation using the piece-wise polynomial representation of ELDC's. If another type of expansion of ELDC's is used, the amount of computing cost saving by the grouping scheme will be different. Nevertheless, the effectiveness of the grouping method is not affected by the type of the mathematical representation of ELDC's in the computer program.

4.5 Implementation of the Method of Probabilistic Simulation for Fuel Costing and Reliability Calculations

The methodologies described in Sections 4.2, 4.3 and 4.4 have been implemented into computer programs for the calculation of fuel costs and system reliability. The methods of Section 4.2 and 4.3 are incorporated into the MARC Code. The grouping technique has been incorporated into a different program, similar to MARC. Both of these programs require similar data. For this section such data requirements and certain auxiliary techniques for the implementation of probabilistic simulation are discussed.

Implementation of probabilistic simulation techniques requires knowledge of expected system loads, loading order of units, and availability probabilities. The estimation of expected loads is a forecasting problem and will not be addressed in this work. The discussion in this section will focus on

(1) A technique for the determination of the loading order of units, and

(2) A technique for the determination of unit availability probability.

The author has contributed to the development of the second technique.

4.5.1 Determination of the Loading Order of Units

The method of probabilistic simulation requires as its input the specification of the loading order of units. This order is assumed to be fixed in each interval (period) of study. When the loading order is not provided by the input, an auxiliary technique is used to generate the loading order. This auxiliary technique simulates unit commitment based on the criterion of maintaining sufficient spinning reserve to overcome the (single) contingency of the largest committed unit. Such unit may be divided into up to two blocks (segments). Base units are committed first, cycling units next, and peaking units last. Within each of these three groups (Base, Cycling, Peaking), dispatching is performed based on the order of increasing fuel cost [27].

4.5.2 Determination of Unit Availability Probability

The method of probabilistic simulation requires as its input the probability that a unit will be available to operate when needed (availability probability). A unit may be partially or fully unavailable either due to failure of one of its components or because of scheduled (or planned) maintenance.

A measure of unavailability due to failure is the Equivalent Forced Outage Rate, EFOR, defined in Reference [24] as:

$$EFOR = \frac{FOH + EFOH}{FOH + EFOH + SH} \times 100 \qquad (4.32)$$

where FOH = forced outage hours

$EFOH = \frac{\Sigma \text{forced partial outage hours} \times \text{size of reduction}}{\text{maximum dependable capacity}}$,

SH = the total number of hours the unit was actually operated with breakers closed to the station bus.

By defining the probability of failure, q, to be identical with $\frac{EFOR}{100}$, the probability that a unit will not be unavailable due to failure when called upon, P_f, is

$$P_f = 1 - q \qquad (4.33)$$

It is assumed here that a unit can be either fully available or fully unavailable. For the context of probabilistics simulation, forced outages are regarded as randomly distributed. Thus, q is regarded as a constant throughout each period of study.

A unit which is on maintenance must not be included in the capacity of the system during the period of maintenance. However, because it is impractical to coordinate the periods of simulation with the periods of maintenance, an alternative technique is used. Maintenance time is assumed to be uniformly distributed throughout each period of simulation. (In this work the typical duration of a period is on the order of three months.) Thus, if a unit has m days of maintenance in a period of K days, the "maintenance outage probability" of this unit in the particular period is defined to be equal to $\frac{m}{K}$. The probability that this unit will not be on maintenance in the same period, P_m, is defined as

$$P_m = 1 - \frac{m}{K} \tag{4.34}$$

Using Equations (4.33) and (4.34), availability probability is calculated in this study by

$$P = (1-q)\ (1 - \frac{m}{K}) \tag{4.35}$$

When the maintenance schedule is not known, it is simulated in this study as follows: The total maintenance space required in the year, MS, is defined as

$$MS = \sum_{i=1}^{N} C_i\ D_i \tag{4.36}$$

where

MS = the total maintenance space required, MWh

C_i = the capacity of unit i, MW

D_i = the number of hours required for maintenance of unit i in the year,

N = the total number of units in the system.

The quantity MS is allocated to each period of the year based on the criterion of equalizing reserves between periods. The maintenance space allocated to each period is further allocated to each type of (base, cycling, peaking) unit so that the fraction of the maintenance space allocated to each type of unit in each period is equal to the fraction of maintenance space of the period to the total maintenance space in the year. The maintenance space allocated to each type of unit in each period is further allocated to each unit in the order of unit capacity [27].

4.6 Summary

In this chapter techniques of probabilistic simulation of generating system operation were developed. Probabilistic simulation is used by the MARC computer program to calculate energy generation and system reliability in the evaluations of Chapter 5. In the MARC program the load duration curve is represented by a piece-wise linear function and generating units are represented by two blocks.

Algorithms of probabilistic simulation which were developed in this chapter include:

1. one-block representation of generating units,
2. multiple-block representation of generating units,
3. two-state model of availability probability,
4. three-state model of availability probability.

A new technique of probabilistic simulation suitable for repetitions application of probabilistic simulation was developed. This technique is approximate but it was shown to reduce computing time by up to 66% with error in the LOLP spread between 0 and 6% and insignificant error in the calculation of energy generation.

Implementation of probabilistic simulation in the MARC code was discussed with emphasis on the algorithms for the determination of plant loading order and availability probability.

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APPENDIX B

Description of Data Elements in the Unit Data Files

FOSSIL AND NUCLEAR UNIT
DATA ELEMENT DESCRIPTIONS
ANNUAL INFORMATION

DATA ELEMENT NOTATION	DATA DESCRIPTIONS
CN	A single digit company number 1 = Appalachian Power Company, 2 = Delmarva Power and Light Company, 3 = Potomac Edison Company, 4 = Potomac Electric Power Company, 5 = Virginia Electric Power Company
VSCC NUMBER	The six digit unit identification number which uniquely identifies the unit relative to all units of companies serving Virginia is listed. This number will be assigned.
UNIT NAME	The unique name of the unit up to 20 characters is given left justified in the field.
FRAC OWNED	The fraction of the unit owned or leased by the reporting company is given. This number is calculated based on the maximum dependable capacity of the unit such that the maximum capacity available to the reporting company is the fraction of unit ownership times the maximum capacity of the unit. Field length is four characters including the decimal point.
UT	The type of unit is given. Enter one of the following numbers: 1 steam-fossil 2 steam-nuclear 3 diesel 4 gas turbine 5 jet engine
LT	The unit loading type is given. Enter one of the following numbers: 1 Base 2 Intermediate (Cycling) 3 Peaking
FUELS	
P	The primary fuel used by the unit for generation is reported. Enter one of the following numbers:

	1 coal 2 nuclear 3 light oil (No. 2) 4 heavy oil (No. 4 and 6) 5 natural gas 6 gasoline/jet fuel 9 other
A	The alternate or secondary fuel used for generation is listed. Enter one of the following numbers: 1 coal 2 nuclear 3 light oil (No. 2) 4 heavy oil (No. 4 and 6) 5 natural gas 6 gasoline/jet fuel 9 other 0 no alternate fuel used
I	The fuel used for ignition is listed. Enter the appropriate number from the above list.
ON-LINE MO	The month that the unit went into commercial service is given. Enter 01-12
YR	The year that the unit went into commercial service is given. Enter four digits of the year.
OFF-LINE MO	The month that the unit is expected to be retired from commercial service is listed. If not known, enter 12.
YR	The year that the unit is expected to be retired from commercial service is given. If not known, enter 1999.
ANNUAL EQUIV AVAIL	The annual unit equivalent availability factor is given for the reporting year. The equivalent availability (EEI definitions) is defined using, $EA = \frac{AH - (EFOH + ESOH)}{PH}$, where AH is equal to service hours plus reserve shutdown hours, EFOH is the equivalent forced outage hours $EFOH = \frac{\sum_{\forall i} TFO_i * SFO_i}{MDC}$

where TFO_i is the length in hours of the i^{th} capacity derating, SFO_i is the size in MW of the i^{th} capacity derating where the product of TFO_i and SFO_i summed over all such partial forced outages, and MDC is the unit's maximum depen-capacity in MW; ESOH is the equivalent scheduled outage hours

$$ESOH = \frac{\sum_{\forall j} (TOS_j * SSO_j)}{MDC}$$

where TSO_j is the length of the j^{th} derating due to planned or scheduled outage in hours; SSO_j is the size of the corresponding derating in MW. PH is the number of hours in the period. Field length is four characters including decimal point.

CAPACITY COST	The capacity cost of the unit expressed in dollars per KW is given. This number is calculated by dividing the cost of the unit (land and land rights plus structure and improvements plus equipment costs) by the nameplate rating of the unit expressed in KW. In the case of nuclear plants this cost does not include the cost of the initial fuel loading. Field length is four characters (right justified in its field).
CAPACITY WIN	The maximum dependable capacity in MW which the unit can produce over a four hour or longer period of time under minimum ambient restrictions. Field length is four characters (right justified in its field).
SUM	The maximum dependable capacity in MW modified for ambient limitations for a specified period of the year. Field length is four characters (right justified in its field).

FOSSIL AND NUCLEAR UNIT
DATA ELEMENT DESCRIPTIONS
MONTHLY INFORMATION

DATA ELEMENT NOTATION	DATA DESCRIPTIONS
MO	The two digits of the reporting month are given.
YR	The last two digits of the reporting year are given.
VSCC NUMBER	The unit identification number is given.
CAPACITY AND HEAT RATE BY LOADING BLOCK	The heat rate curve of each unit is represented at three points MW1, MW2 and MW3 (in MW), as HTRT1, HTRT2 and HTRT3, (in Btu/kwh), respectively. MW1 represents the minimum (flame-out) load, MW3 the maximum dependable capacity, and MW2 an intermediate point. The field length for each of MW1 and MW2 is three characters, for MW3 is four characters (right justified each value), and for each of HTRT1, HTRT2 and HTRT3 is five characters. When a unit's heat rate curve is not available set MW1 = 1/2 MW3 and MW2 = 3/4 MW3, and set HTRT1, HTRT2 and HTRT3 equal to the heat rate at maximum dependable capacity.
MONTHLY EQUIV AVAIL	The equivalent availability for the unit for the reporting month. This value is calculated using the same technique as the annual equivalent availability and outage data for the reporting month. Field length is four characters including decimal point.
FUEL COST	The weighted average fuel cost burned in the unit during the reporting month in ¢/10^6Btu is reported for the
PRIMARY	primary fuel and the
SECONDARY	alternate fuel
	to the nearest hundredth of a cent. For each of the numbers field length is six characters.

FRAC GEN BY PRI	The fraction of energy generation by the unit attributed to the primary fuel. Field length is four characters including decimal point.
DISPATCHING ORDER BY LOADING BLOCK	Each unit is loaded in three steps (loading blocks) of capacity MW1, MW2 - MW1, and MW3 MW2. The values BK1, BK2 and BK3 represent the relative loading order of each block in the system dispatching for the reporting month. Field length for each of BK1, BK2 and BK3 is three characters and is right justified in the field. Representation of loading in less than three steps can be made by numbering the adjacent blocks consecutively.

HYDRO UNIT
DATA ELEMENT DESCRIPTIONS
ANNUAL INFORMATION

DATA ELEMENT NOTATION	DATA DESCRIPTIONS
CN	A single digit company number 1 = Appalachian Power Company, 2 = Delmarva Power and Light Company, 3 = Potomac Edison Company, 4 = Potomac Electric Power Company, 5 = Virginia Electric Power Company
VSCC NUMBER	The six digit unit identification number which uniquely identifies the unit relative to all units of companies serving Virginia is listed. This number will be assigned.
UNIT NAME	The unique name of the unit up to 20 characters is given.
FRAC OWNED	The fraction of the unit owned or leased by the reporting company is given. This number is calculated based on the maximum dependable capacity of the unit such that the maximum capacity available to the reporting company is the fraction of unit ownership times the maximum capacity of the unit. Field length is four characters.
UT	The type of unit is given. Enter "6"
LT	The unit loading type is given. Enter "4"
HT	The type of hydro unit is given. Enter one of the following numbers: 1 run-of-river 2 pumped storage 3 river reservoir
P	The primary fuel used by the unit for generation is reported. Enter "7"
ON-LINE MO	The month that the unit went into commercial service is given. Enter 01-12.

YR	The year that the unit went into commercial service is given. Enter four digits of the year.
OFF-LINE MO	The month that the unit is expected to be retired from commercial service is listed. If not known, enter 12.
YR	The year that the unit is expected to be retired from commercial service is given. If not known, enter 1999.
CAPACITY COST	The capacity cost of the unit expressed in dollars per KW is given. This number is calculated by dividing the cost of the unit (land and land rights plus structure and improvements plus equipment costs) by the nameplate rating of the unit expressed in KW. Field length is four characters.
CAPACITY MAX	The maximum dependable capacity in MW which the unit can produce subject to the most favorable flow conditions. Field length is four characters.
MIN	The minimum dependable capacity in MW. Field length is four characters.

HYRDRO UNIT
DATA ELEMENT DESCRIPTIONS
MONTHLY INFORMATION

DATA ELEMENT NOTATION	DATA DESCRIPTIONS
MO	The two digits of the reporting month are given.
YR	The last two digits of the reporting year are given.
VSCC NUMBER	The unit identification number is given. Field length is six characters.
CAPACITY LOADING BLOCKS	MW1, MW2 and MW3 represent loading points of the unit and BK1, BK2 and BK3 the order of loading of blocks in the system dispatching table (see discussion in data description for Fossil and Nuclear units). Field length for each of MW1,MW2 and MW3 is four characters (right justified in the field).
DISPATCHING ORDER BY LOADING BLOCK	Each unit is loaded in three steps (loading blocks) of capacity MW1, MW2 - MW1, and MW3 MW2. The values BK1, BK2 and BK3 represent the relative loading order of each block in the system dispatching for the reporting month. Field length for each of BK1, BK2 and BK3 is three characters and is right justified in the field. Representation of loading in less than three steps can be made by numbering the adjacent blocks consecutively.
GENERATION BY UNIT	The net generation of the unit is reported in MWh. Field length is seven characters (right justified in the field).
PUMPING ENERGY	If the unit is a pumped storage unit the amount of energy in MWh used for pumping water uphill is reported. Field length is seven characters (right justified in the field).

AVE PUMP COSTS	For a pumped storage unit the average cost of the energy used for pumping the water uphill in $/MWh to the nearest cent is reported. Field length is six characters including decimal point.