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REFCO-83 User's Manual

J. G. Delene
O. W. Hermann

Prepared for the U.S. Nuclear Regulatory Commission
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REFCO-83 USER'S MANUAL

J. G. Delene*
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ABSTRACT

The computer code REFCO-83 utilizes a discounted cash flow (DCF) analysis procedure to calculate batch cycle, and lifetime levelized nuclear fuel cycle costs. This code is an updated version of the REFCO computer code originally written in the early 1970s. The basic methodology and procedures were retained; however, extensive modifications were made to the input and data handling procedures. Several computational procedures were updated to make the code more versatile and to simulate recent events such as the provisions of the Nuclear Waste Policy Act of 1982.

This report is a user's guide for the revised REFCO code. It contains a description of the code methodology, a cost data base, a discussion of the general code structure, the code input instructions, and sample cases.

KEYWORDS: Nuclear fuel cycle, nuclear fuel costs, computer code.

1. INTRODUCTION

The computer code REFCO (Reactor Fuel Code) was originally written¹ in the early 1970s. Since then the code has been revised extensively, and some of these early revisions have been reported.^{2,3} Other extensive revisions, which were never documented, occurred during the Non-proliferation Alternative Systems Assessment Program⁴ (NASAP) where a versatile fuel cycle cost code capable of handling many different fuel types was needed.

Recently the REFCO code has again been revised. The basic methodology and procedures were retained; however, extensive modifications were made to the input and data handling procedures to facilitate use, and several other procedures were updated. Default reference data are now provided in reference data files, which are easily modified if the program is to be run with alternate assumptions.

Other procedural changes include a system for the automatic modification of the mass flow vs time data to simulate operation at capacity

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factors other than the reference value. Also, the current code allows either expensing or capitalization of fuel costs whereas the previous versions only allowed capitalization. In addition a waste disposal cost, which is proportional to power production, has been added to simulate the provisions of the Nuclear Waste Policy Act of 1982.

This report is a user's guide for the revised REFCO code. It contains a description of the code methodology, a cost data base, a discussion of the general code structure, the code input instructions, and sample cases.

The computer code REFCO-83 is written in FORTRAN IV for the IBM 360, 370, and 3033 machines. The computer core required is less than 270 k bytes for the MVS operating system (300 k bytes for MVT), and computer running time for a single calculation will require only a few seconds.

The REFCO-83 program and cost models can be obtained from the National Energy Software Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439.

2. METHODOLOGY

The nuclear fuel cost is composed of many separate subcosts, which are related to the various fuel cycle materials, service requirements, and credits received for residual fuel materials. The cash payments related to these fuel cycle requirements occur at different times relative to power production. Fuel is loaded and unloaded in batches, each batch having different cash flow requirements caused by both composition differences from batch to batch and by changes in the prices of fuel commodities and services.

2.1 Discounted Cash Flow

The REFCO code uses discounted cash flow (DCF) methods to solve for a levelized cost of energy. The DCF analysis establishes an energy "cost" associated with the fuel by requiring that the revenues from the sale of energy be adequate to pay the required return on outstanding capital, to pay all expenses including taxes, and to retire the outstanding investment to zero by the end of the economic life of the set of fuel investments.

In the REFCO program, the DCF procedure is applied on a "batchwise" basis for each subcost item or component; that is, levelized fuel subcosts are calculated for each discrete batch of fuel elements loaded into the reactor. A fuel batch is defined as a set of fuel elements with a specific charge and discharge time and with the same fuel composition at the time of charge. In the current revisions to REFCO the fuel payments may be either capitalized or expensed. If they are capitalized, the tax deduction is spread over the life of the fuel in the reactor, proportionally with the power produced. If the payment is expensed, the tax deduction is taken immediately or with a set time lag. The capitalization of a fuel cycle back end credit (such as recovered uranium or plutonium) means that these credits are treated as the salvage value of a capitalized investment. The batch levelized fuel cycle cost is the cost of energy such that the sales revenue from the energy produced by the batch during its in-core residence recovers all batch costs including taxes and carrying charges.

The basic equation solved by REFCO for the levelized fuel cycle cost is given by

$$\bar{p} = \frac{\frac{1}{1-r} \int I_t e^{-X't} dt - \frac{r}{1-r} \int D_t^T e^{-X't} dt + \int O_t e^{-X't} dt}{\int S_t e^{-X't} dt} \quad (2.1)$$

The derivation leading to this equation is described in Appendix A of this report. Terms are defined in Table A.1. The capitalized investments, I_t , and the expensed operating costs, O_t (other than waste disposal), are paid for at discrete times corresponding to the refueling period plus or minus a lead or lag time. Thus, these items will appear

in the numerator of the equation as delta functions, having values only at discrete times.

Energy, however, is produced continuously. The revenues from the sale of this energy will usually lag production. The integral in the denominator will thus become

$$\int_{t_i + \text{SLG}}^{t_o + \text{SLG}} S_t e^{-X't} dt \quad (2.2)$$

where

t_i = time energy production begins (time fuel enters core),
 t_o = time energy production ends (time fuel is removed from core),
 and
 SLG = lag time for revenue collection.

In addition to power production, the tax depreciation term, D_t^T , and the waste fund payment (expensed and included in O_t) are treated as continuous functions since they are related to revenues received and power production.

The levelized fuel cost equation is applied to each batch and cost item separately so that levelized costs are obtained for each cost item, k , in each batch, B . The total levelized cost for a fuel batch is the sum of the component levelized costs for the particular batch.

$$\bar{P}_B = \sum_k \bar{P}_{k,B} \quad (2.3)$$

The lifetime levelized cost is the cumulative batch levelized cost over the reactor life. This is obtained by summing the numerator and denominator in Eq. 2.1 separately and then taking the ratio of the resulting sums.

$$\text{TOP} = \sum_{\text{all batches}} \sum_{\text{cost items}} \left[\frac{1}{1-r} \int I_t e^{-X't} dt - \frac{1}{1-r} \int D_t^T e^{-X't} dt + \int O_t e^{-X't} dt \right] \quad (2.4)$$

$$\text{BOT} = \sum_{\text{all batches}} \left[\int S_t e^{-X't} dt \right] \quad (2.5)$$

$$\bar{P} = \frac{\text{TOP}}{\text{BOT}} \quad (2.6)$$

Cycle levelized costs are also calculated. A cycle is the period of time between refuelings and is composed of several batches in various stages of irradiation. The levelized fuel cost, \bar{P}_{cj} , for any cycle, is calculated by summing the discounted revenue streams obtained for each batch irradiated in the cycle and then dividing this sum by the discounted batch energies produced in the cycle.

$$\bar{P}_{cj} = \frac{\sum_{B \in j} \int e^{-X't} \bar{P}_B S_{B,j} dt}{\sum_{B \in j} \int e^{-X't} S_{B,j} dt} \quad (2.7)$$

where

\bar{P}_B is the batch levelized cost for a batch present during cycle j ,
 $S_{B,j}$ is the energy generated by batch B during cycle j , and
 $B \in j$ indicates that the sum is over all batches B contained in cycle j .

2.2 Constant and Current Dollar Costs

To properly account for the effect of income taxes, all calculations in REFCO are done using "then" current dollars, including price escalations caused by inflation. The levelized cost obtained using the previously discussed methodology is a current dollar levelized cost. Although this equivalent cost remains constant in time, the value of money changes due to inflation, thus this levelized cost is in no single year's buying power. A constant dollar levelized cost is a cost which keeps the same buying power in terms of a reference year's dollar.

The relationship between constant and current dollar levelized price is discussed in the Ref. 5. The equation used to adjust from the current dollar levelized cost to the constant dollar levelized cost is

$$\bar{P}_o = (1+i)^{-L} \bar{P} \frac{\sum_{\text{cycles } j} \int S_j e^{-X't} dt}{\sum_{\text{cycles } j} \int S_j e^{-X'_A t} dt} \quad (2.8)$$

where

S_j = energy produced in cycle j ,
 X'_A = the exponential discount rate reduced by the rate of inflation, i , or
 $X'_A = \ln(1+X) - \ln(1+i)$.

2.3 Capacity Factor Adjustments

The reactor input and output mass flows used by REFCO are for specified cycle (reload) times at a specified capacity factor. The reference PWR mass flows are for a 75% capacity factor and annual reloading. An alternate constant capacity factor or year-by-year capacity factors may be specified. The adjustments to the specified capacity factors are made by keeping the fuel burnup in the individual batches constant. This approximately maintains the physics characteristics of the burnup with the possible exception of the decay of some higher isotope number plutonium. The capacity factor adjustment is then made by changing the individual cycle times. Equilibrium fuel batches are added or subtracted from the mass flow set to maintain the approximate reactor life specified. The final core batches are maintained so as to preserve the characteristics of the final discharge.

As an example for mass balances developed for 75% capacity factor and annual reloading, an adjustment to a constant lifetime capacity factor of 65% would lengthen the cycle length by a factor of 1.154 (75/65). The 30-year reactor lifetime then would use four fewer batches of fuel than if the reactor were run for 30 years at 75% capacity factor.

2.4 Waste Disposal Cost

The Nuclear Waste Policy Act of 1982 provides for the collection of a fee from utilities as nuclear electricity is produced. This fee was set initially at 1 mill/kWh, but there is provision in the act to adjust the fee from time to time to meet projected program costs.

In the REFCO program, a base price and escalation rate may be specified for this cost. The cash flow for waste disposal is assumed to be continuous in the same way that the receipt of revenue from electric sales is assumed to be continuous. The same lag time between electric generation and cash flow is used for the waste disposal cost as is used for the electric sales revenue. In addition the waste disposal unit cost (mills/kWh) is assumed to change continuously at its escalation rate. The actual changes in the waste disposal cost will of course occur discretely as will the payments to the fund. The continuous method used here is consistent with the revenue and tax assumptions and is a reasonable approximation to an uncertain future.

The operating cost term for the waste disposal cost from Eq. (2.1) for a fuel batch loaded at time t_1 and removed at time t_0 becomes

$$\int_{t_1}^{t_0 + SLG} e^{-X't} dt = \int_{t_1 + SLG}^{t_0 + SLG} S_t e^{-X'_w t} dt \quad (2.9)$$

where

P_w = the reference price for waste disposal at reactor startup,

$X_w = \ln(1 + X) - \ln(1 + e_w)$, and

e_w = escalation rate for waste disposal price.

3. REFERENCE DATA BASE

The data base used for the default values for the REFCO code was taken from the Nuclear Energy Cost Data Base (NECDB) described in Ref. 5. Table 3.1 summarizes the recommended financial and technical parameters, Table 3.2 gives fuel component costs, Table 3.3 lists the PWR load and discharge mass flows, and Table 3.4 gives the default lead and lag times and process losses. A complete discussion of the sources of the information in Tables 3.1-3.4 is contained in the NECDB.

Table 3.1. Technical and financial parameters

Reactor plant size, MW(e)	1210
Capacity factor, %	65
Thermal efficiency, %	32
Startup year	1995
Economic life, years	30
Enrichment plant tails assay, %	0.2
Reference year for cost information	1982
Average inflation rate, %/year	6
Capitalization, %	
Debt	51
Equity (including preferred stock)	49
Return on capitalization, %/year	
Debt interest	10
Equity return	13.8
Average cost of money, %/year	11.9
Federal income tax rate, %/year	46
State income tax rate, %/year	4
Effective cost of money, %/year	9.4
Exponential discount rate, %/year	9.0

Table 3.2 Nuclear fuel cost parameters

<u>Component prices, 1982 dollars</u>	
U ₃ O ₈ , \$/lb	32
Conversion, \$/kgU	8
Enrichment, \$/SWU	130
Low-enriched uranium fabrication, \$/kg HM	180
Spent fuel disposal, mills/kWh	1
<u>Escalation rates, ^a %/year</u>	
Uranium price	9.18
Other costs	6

^aEscalation rates including the 6%/year general inflation rate.

Table 3.3. PWR low-enriched uranium-fueled reactor^a charge and discharge data

Batch number	Charge data			Discharge data				
	Time (yr)	Total uranium (kg)	U-235 (kg)	Time ^b (yr)	Total uranium (kg)	U-235 (kg)	Total Pu (kg)	Fissile Pu (kg)
1	0.0	34119	565	1.0	33457	243	203	157
2	0.0	32235	711	2.0	31243	214	244	176
3	0.0	32962	925	3.0	31657	244	289	206
4	1.0	34119	1071	4.0	32708	304	311	227
5	2.0	34545	1028	5.0	33101	271	317	228
6	3.0	34119	984	6.0	32728	261	309	223
7	4.0	34119	1058	7.0	32703	295	311	226
8	5.0	34545	1026	8.0	33115	274	315	228
9	6.0	34119	1028	9.0	32704	278	311	225
10	7.0	34119	1028	10.0	32704	278	311	225
11	8.0	34545	1041	11.0	33112	282	315	228
Batch numbers 9-11 repeat until final core is reached								
30	27.0	34119	1028	30.0	32704	278	311	225
31	28.0	34119	1028	30.0	33251	429	248	190
32	29.0	34545	1041	30.0	33651	661	161	136

^a1210 MW(e), 31.9% thermal efficiency.

^bNominal times measured from reactor startup for 75% capacity factor.

Table 3.4. Fuel cycle lead and lag times
and fissile material losses

	Initial core	Reloads
Lead time years, prior to startup		
U ₃ O ₈ purchase	1.75	1.00
Conversion to UF ₆	1.42	0.67
Enrichment	1.25	0.50
Fabrication	0.50	0.25
Lag time, years after discharge		
Spent fuel disposal	5.0	
Collection of revenue or payment of waste disposal cost	0.5	
Fissile material losses, %		
Conversion and enrichment	0.5	
Fabrication	1.0	

4. BASIC CONSIDERATIONS IN USING REFCO

There are several basic considerations in using REFCO that may aid the user in preparing input. The accessing of data from the Reference Parameters File, for example, should enhance the ease of preparing input. Also, the types of input controls to the cost analysis calculation should be considered prior to using the input descriptions in the following section.

4.1 Form of User Input Data

An outline of the user input data follows:

- A. Card with signal for "card image edit" of input
- B. Case data
 - 1. Fuel cycle model request card
 - 2. Case title card
 - 3. NAMELIST data (rules in Appendix B)
- C. Subsequent cases: repeat B for each case

4.2 The Reference Parameters File Using Minimum Input

There are three methods for supplying the case input data:

- 1. Supply the data as user input only.
- 2. Use only the data of a requested Fuel Cycle Model contained in the Reference Parameters File.
- 3. First, access the data of a Fuel Cycle Model from the Reference Parameters File and follow with user input for required data modifications.

The second method produces the "reference case" pertaining to the specified Fuel Cycle Model.

The use of the third method implies that the user has satisfactory knowledge of the input reference parameters for a specific Fuel Cycle Model. These data are available from two types of edits:

- 1. The data can be directly obtained by executing the code and requesting an edit of the Reference Parameters File (see IEDIT = 1 in Sect. 5.4.1). The edit of the PWR Once-Through Fuel Cycle Model is listed in Appendix C.
- 2. A reference case using a Fuel Cycle Model may be executed, with the option selected for printing input used by the code (see IPRINT = 1 in Sect. 5.4.1). For this procedure, all scalar input parameters are printed. Array data are printed, either as input, or the data is processed to an expanded form and printed. Thus, when the user is modifying certain array data, obtaining the direct file edit (IEDIT =1) is advisable.

4.3 Supplying Data as User Input Only

There may be cases in which the user wants to supply all of the input data and not use any of the reference file fuel cycle models. In this case, the Reference Parameters File data definition card is not required in the Job Control Language (see Sect. 6.5).

All input variables are initialized to default values by the code. These default values are shown in parentheses following each parameter description in Sect. 5. However, the user should be aware that the Reference Parameters File data, when requested, will override the code default values.

4.4 Altering Data in the Execution of Multiple Cases

In multiple cases, all input data of a previous case are retained as default data for the next case. The desired input changes are all the input necessary. This is similar to modifying Fuel Cycle Model data. However, if a Fuel Cycle Model is requested it will always override the default values from the previous case.

4.5 Deleting Data in Single or Final Cases

If NAMELIST data are not required in a single or final case, the input may end with either the title card or the Fuel Cycle Model request card. Although a NAMELIST is required in all other cases, the NAMELIST may be void of data items. Also, if the reference case for the PWR Once-Through Fuel Cycle Model is to be executed, user input is not required.

4.6 Fuel Cycle Cost Components in REFCO

A fuel cycle cost component (referred to as a "component") is considered to be any fuel material purchase, processing cost, or discharge material credit in the complete fuel cycle. The following cost components are available in REFCO:

1. Thorium purchase
2. Plutonium purchase
3. ^{233}U purchase
4. U_3O_8 purchase
5. Conversion of U_3O_8 to UF_6 processing cost
6. Uranium enrichment cost
7. Fuel fabrication cost
8. Back end processing cost
9. Waste disposal fee, or a second back end cost
10. Thorium credit
11. Plutonium credit

12. ^{233}U credit
13. U_{308} credit from reprocessed uranium
14. Conversion credit from reprocessed uranium
15. Enrichment credit from reprocessed uranium

4.7 Selecting the Cost Components of the Fuel Cycle

The various types of reactor fuel cycles require different cost components. There are two input options and two types of parameters that are applied in determining which cost components are to be included in the fuel cycle cost.

Credits from reprocessed uranium are included if the option signal CREDOP = 0 (see Sect. 5.4.1). Also, there are two types of parameters which are always required in accounting for a component of the fuel cycle cost: (1) the unit price and (2) the quantity of the component required. Both of these types of data are input or computed from input.

When both price and material quantities are input, and if required, the recycle credit is requested, the component is included in the cost. Usually, a component is excluded by simply setting its price to zero. Credit for reprocessed uranium is excluded by setting CREDOP = 1. In other cases, where a type of material is purchased for fuel but no credit is allowed for the discharged material, the quantity of discharged material should be set equal to zero.

REFCO computes fuel cycle costs separately for each batch of fuel. Thus, the selection of fuel cycle components on a batch basis can be accomplished by proper input of the mass balance data associated with each batch (see Sect. 5.5.2). The code has provision for reactors containing two different types of fuel assemblies. The input for such cases requires the two types of fabrication prices and possibly reprocessing costs, the corresponding two sets of mass balance data, and the proper duplication of cycle operation times for the corresponding batches (see TIME in Sect. 5.5.3).

4.8 Repetitive Input Simplified

Many code parameters may be varied with time. Frequently, after either the first value or first few values, the data remain constant. The code allows the user to stop entering data into certain arrays and computes the repeated data. Input parameter descriptions for which the "repetitive data computation" is permitted are signified by "Rep-Data-Comp." in Sect. 5. The last value entered as input is then repeated for the remaining data in the array. Different methods are used in the cases of prices and mass balance parameters. For the case of prices, the remaining component unit prices are computed by adjusting the last input price, using a cost escalation factor also given as input. In the case of mass balances, sets of equilibrium batches are repeated. The input details for mass balance data are explained in the input description.

4.9 Reactor Operating History and Mass Balance Data

The cost analysis calculation requires data for fuel charges and discharges and the delivered electrical energy, in addition to the reactor operating periods associated with these parameters. These types of input data are commonly referred to as mass balances and operating histories. The options in REFCO permit the user to avoid the conversion of large amounts of data. The methods and definitions of terms in explaining these options are presented here.

Each fuel batch is a set of fuel elements with a specific charge and discharge time and the same composition. An operating cycle is the period between consecutive fuel loadings. Each batch resides within the reactor for a specific number of cycles.

There are six basic types of parameters required by REFCO in describing the mass balance and operating history:

1. Fuel masses charged to each batch
2. Fuel masses discharged from each batch
3. Energy delivered by each batch
4. Cycle operating time points
5. The cycle number when each batch is loaded (at start)
6. Number of cycles each batch resides in the core

While the input of the six basic parameters is sufficient, variations in these input requirements are explained below.

4.9.1 Constant energy delivered per cycle

The option, ENCALC = 1, permits the input of a constant energy delivered per cycle, CYCKW, and a constant number of cycles that an equilibrium batch resides in the core, STAY. Parameter types 3, 5, and 6, above, are not required when using this option.

4.9.2 Burnup used in computing energy delivered

Another option, ENGYOP = 0, allows the user to input burnup per unit weight of each batch and weight per batch. By using the thermal efficiency, THEFF, of the reactor, the code computes the energy delivered by each batch. When this option is used, parameter type 3 is not required.

4.9.3 Distribution of cycle energies for each batch

After any of the above methods is used to supply data for either the total energy delivered by a cycle or batch, another option, ENDIST = 0, permits the input of the distribution of the energy delivered in each cycle by each batch of fuel. The cycle energies are used for computing the energy distribution between cycles in the batch, with the final cycle energies normalized to produce the total batch energies derived by

one of the above methods. When this option is not used, energies are divided equally for all cycles of the batch.

4.9.4 Cycle time points computed from capacity factors

There are two parameters, in addition to the six listed above, that may be associated with the reference mass balance data: (1) the reference cycle time lengths and (2) the reference capacity factors of each cycle. While cycle time lengths are typically equal to one year, they may vary in the code input by specifying RCYCL.

The option, TIMPTS, permits the cycle reload times to be either input or computed from the capacity factors required in the case. This option allows the mass balances and operating times based upon one set of capacity factors to be used with an alternate set of capacity factors. If the set of desired capacity factors is the same as the set of reference capacity factors, the computed cycle time points will be identical to the reload times for the reference mass balance data.

4.10 Capitalized or Expensed Tax Treatment

The tax treatment of a component cost or credit is different depending on whether it is capitalized or expensed (see Sect. 2). An array, INC, is used to select the tax treatment for each component. Also, a method may be selected for the waste disposal cost in which it is expensed as a fee which is proportional to the amount of electricity sold. In the reference PWR Once-Through Model this method is selected for waste disposal, all other costs or credits associated with the discharged fuel are expensed, and all costs associated with the charged fuel (front end costs) are capitalized. Credits are treated as negative expenses in Eq. (2.1) if the expense option is selected. The capitalization of a fuel cycle back end credit means that these credits are treated as the salvage value of a capitalized investment.

5. REFCO INPUT DESCRIPTION

It will be helpful to the user to have read Sect. 4 before preparing input to REFCO. In particular, familiarity with subsections on the form of input data and the use of the Reference Parameters File is recommended. The help from reading other subsections depends upon the intended use of the code. The general rules for NAMELIST input are given in Appendix B. While the method of using or adding data to the Reference Parameters File is described here, the general updating or copying of data to a new file is explained in Appendix D. Also, a supplementary back end subdivision feature is given in Appendix F.

The input items must be in the order of the following descriptions. Data items in a NAMELIST, however, may be in any order. After each data variable name, the condition specifying its requirement is given. The code default value of the variable is shown in parentheses, or when not specified, array data are initialized to zero. The input in Sects. 5.1-5.3 is always necessary to run a case. Input of the NAMELIST data is necessary only to construct a new fuel cycle model or to change parameters from an old model.

5.1 Signal for Card Image Edit of Input

Format of data card: FORMAT(I1)

INEDIT - always required (0):
 = 0, no edit requested;
 = 1, all user input data cards printed.

When an edit is requested, the Job Control Language must include a proper scratch data set definition of unit No. 10 (see Sect. 6.5).

5.2 Case Request Card for Fuel Cycle Model

Format of data card: FORMAT (A8, 2I4) (Card is blank when not using or making a Fuel Cycle Model.)

LIBNAM - 8 characters or blanks:
 = blank (not input), no Fuel Cycle Model requested;
 = 8 character name, the name of a Fuel Cycle Model to either use or make in the Reference Parameters File. The file model data is always accessed if there is a Fuel Cycle Model named with the characters input for LIBNAM and NEWLIB = 0. If the model is not in the file and NEWLIB = 1, a model containing all of the case data is added to the file and named with the input for LIBNAM. When a name is not spelled correctly and NEWLIB = 0, the input name is printed and the job stops. Also, if it is desired to access one

model and change the data to make a new model, another case must be added in which the name input for LIBNAM is the new model name and NEWLIB = 1. (The default is LIBNAM = PWR-OT1b, where b is a blank and "0" is the letter O. The default is used only when a card is omitted. See the above meaning for LIBNAM = blank.)

- LIBNUM - required only if LIBNAM is not blank:
 = Logical unit no. of Reference Parameters data set. (20)
- LSTART- required only when making the first Fuel Cycle Model on a new Reference Parameters File (0):
 = 9999, flag for making first model in new file;
 ≠ 9999, flag when not making first model.

5.3 Case Title Card

Format of card: (13A4)
 DES - case title, in 52 characters.

In the final case input, either the title card or both the model request card and title card may be omitted when the NAMELIST is not required.

5.4 Case Input Constants - NAMELIST/IN/

Start NAMELIST/IN/ as:

&IN (Always start in column 2 and follow with a blank.)

For all data items, input the variable name, the equal sign, the input value, and immediately follow with a comma. There may be any number of blanks or none between data items. When starting a new card, do not use the first column or split a data item between two cards. Data may extend to column 80. Note that no names contain a zero, only the letter "0", and & is the "and" sign. See Appendix B for further details of NAMELIST input.

5.4.1 Option signals

Code input requires either the option signals listed here or the defaults, unless stated otherwise.

MILKWH - units of printed cost rates (0):
 = 0, mills per kilowatt hour;
 = 1, cents per million Btu generated.

- PRCOPT - price data option (0):
- = 0, price data are input as a function of the start of each year. The prices for materials and services used in fuel cycle are found by a linear interpolation with time;
 - = 1, price data are input as a function of batch load times;
 - = 2, price data for material and services used in a batch are input directly.
- ESCOPT - escalation factor (see Sect. 5.4.4) option (1):
- = 0, no price escalation is used;
 - = 1, price escalation factors are used.
- CREDOP - recycle credit allowance (see Sect. 4.7) option (1):
- = 0, credit is given for recovered uranium feed and separative work from reprocessed fuel;
 - = 1, no credit is given.
- TOTLHM - option for computing total masses (see Sects. 4.9 and 4.9.4) (1):
- = 0, total masses in fabrication and reprocessing are computed internally by sum of isotopic constituents;
 - = 1, total masses input in mass balances.
- TIMPTS - method of supplying cycle time points (see Sect. 4.9.4) option (1):
- = 0, cycle operating time points, TIME, are input;
 - = 1, cycle time points computed from reference cycle lengths, RCYCL, reference capacity factors, CFR, associated with mass balance data, and capacity factors, CF, of case input.
- ENGYOP - batch energy input (see Sect. 4.9.2) option (1):
- = 0, energy delivered is computed from fuel burnup, BBURN, batch loading, BHVMET, and thermal efficiency, THEFF;
 - = 1, input (see BTOKWH or CYCKW) in 10^9 kWh;
 - = 2, input (see BTOKWH or CYCKW) in 10^{14} Btu.
- ENCALC - constant energy input option, (required if ENGYOP > 0) (1):
- = 0, each batch energy input;
 - = 1, batch energies computed from constant cycle energy input, CYCKW, and cycles per batch input, STAY. Also, data for arrays NPTOT and NTA are computed. Option not used if ENGYOP = 0. (See Sect. 4.9.1.)
- ENDIST - type of cycle energy distribution for batch (see Sect. 4.9.3) (1):
- = 0, cycle energy distribution input, ENi (see Sect. 5.6);
 - = 1, energy divided equally between cycles.
- MCOMP - option for adding back end components (see Appendix F) (0):
- = 0, option not requested;
 - \leq 6, number of back end components replacing component number 8 in Sect. 4.6.
- IPRINT - print option for input data used (see Sect. 6.4) (1):
- = 0, do not print;
 - = 1, print all input data from user input or Reference Parameters File.

- OUTOPT - edit level of printed results (see Sect. 6.4) (1):
- = -2, prints a single summary page;
 - = -1, prints 3 additional summary pages including levelized cost by batch, and cumulative levelized cost by component;
 - = 0, prints the above plus electrical energy produced, levelized cost per cycle, and the component breakdown of levelized cost as direct and carrying charges, as cost per batch, and as cumulative cost by batch;
 - = 1, prints the above plus a cost account per batch for all components, listing the year of cost or credit, quantity, price, current cost, present worth, and cumulative capitalized and expensed costs.
- NEWLIB - option for making new Fuel Cycle Model in Reference Parameters File (0):
- = 0, do not make new Fuel Cycle Model;
 - = 1, after all user input data are read, the input or default values are saved in a new Fuel Cycle Model named LIBNAM in Reference Parameters File. These parameters include all of the data that can be supplied by NAMELIST/IN/ or /EDIST/ with the exceptions of NEWLIB, MCOMP, IPRINT, and IEDIT, which must always be input to current cases. When NEWLIB = 1 and the name input for LIBNAM is already in the file, the code prints an error message and terminates job.
- IEDIT - option for editing the Reference Parameters File (0):
- = 0, do not edit;
 - = 1, edit, listing all data of all Fuel Cycle Models in Reference Parameters file;
 - = -1, edit, as above, for job with no REFCO cost analysis case requested.

5.4.2 Reactor design and operation parameters

All remaining input is floating point except where noted.

- POWMWE - reactor design capacity in MW(e). (1210.)
- YRSTRT - year in which reactor begins operation. (1995.)
- RLIFE - reactor lifetime in years. (30.)
- THEFF - thermal efficiency of reactor. (0.319)

The following two data items are required if TIMPTS = 0:

- NBMAX - integer ≤ 70 , total number of batches used during reactor lifetime. Each batch is the total fuel loaded at the beginning of each operating cycle. Most fuel cycle component data are input by batch. (28)
- NPMAX - integer ≤ 120 , total number of reactor operating periods or cycles. Levelized costs are computed by cycles and batches. (26)

5.4.3 Tax, debt, and insurance constants

DNB - fraction of capital from debt. (0.51)
 RRB - annual interest rate on debt. (0.10)
 RRE - annual after-tax earning rate on equity. (0.138)
 TXR - federal income tax rate. (0.46)
 STX - state income tax rate. (0.04)
 SGR - state tax rate on gross revenues. (0.)
 PTR - property tax rate on fuel. (0.)
 PIR - property insurance rate on fuel. (0.)
 FCORTX - fraction of the core assessed for property tax. (0.)

5.4.4 Inflation and price escalation rates

RATINF - general rate of inflation. (0.06)

Following are escalation factors for the component cost specified:

ESCU33 - ^{233}U . (0.06)
 ESCUR - U308. (0.0918)
 ESCCV - conversion of U308 to UF₆. (0.06)
 ESCSWU - separative work. (0.06)
 ESCFB1 - type 1 fuel assembly fabrication. (0.06)
 ESCFB2 - type 2 fuel assembly fabrication. (0.06)
 ESCBE1 - back end (i.e., reprocessing). (0.06)
 ESCBE2 - waste disposal charge. (0.06)
 ESCTLS - depleted UF₆ tails of separation plant. (0.06)
 ESCPU - plutonium. (0.06)
 ESCTH - thorium. (0.06)

These factors are the annual escalation rates of each component cost, when PRCOPT < 2. However, the factors are the escalation of prices between consecutive batches, when PRCOPT = 2.

5.4.5 Economic losses (%) in processes

FABLTH - thorium fabrication. (1.)
 FABLPU - fissile plutonium fabrication. (1.)
 FABLU3 - ^{233}U fabrication. (1.)
 CVLOSS - U308 to UF₆ conversion. (0.5)
 FABLOS - uranium fabrication. (1.)
 REPLU3 - recovered ^{233}U . (1.)
 REPLTH - recovered thorium. (1.)
 REPLPU - plutonium reprocessing. (1.)
 REPLU5 - ^{235}U reprocessing. (1.)

5.4.6 Reference constants and other data

- UASSAY - weight fraction of ^{235}U in natural uranium. (0.00711)
 ALAG - lag time, in years, for revenue received. (0.5)
 NYCOST - integer, year price data starts. (1982)
 TREF - reference year (as a floating point number) for which the constant dollar cost is computed. (1983.0)

The following two data items are required if ENCALC = 1, signifying constant cycle energy:

- CYCKW - total energy delivered, in 10^9 kWh (when ENGYOP < 2), or produced, in 10^{14} Btu (when ENGYOP = 2) by each cycle. (7.96)
 STAY - number of cycles that an equilibrium batch (with normal design burnup) resides in core. Also, STAY is required if NBR < NBMAX in mass balance data in Sect. 5.5.2. (3.0)

The following parameter is optional (see XT in Sect. 5.5.2):

- TAILS - constant weight fraction of ^{235}U in enrichment plant tails. (0.002)

5.5 Case Input Array Data - NAMELIST/IN/

Most of the array input is contained in &IN. Another array, contained in &ENDIST, is discussed in Sect. 5.6. Appendix F discusses subdividing the back end cost component where NAMELIST/COMP/ is used.

5.5.1 Prices, lead/lag times, and tax signals

- PRICE(M,N) - unit prices of fuel cycle component materials or services. Values, for each N, may pertain to either years (PRCOPT < 2) starting in NYCOST (see Sect. 5.4.6) or batches (PRCOPT = 2). While the code must use prices extending through the entire reactor life time, the input may terminate at any N greater or equal to 1. If the data are terminated, the component prices for subsequent N are computed by applying the price escalation factor to the last price given for each component (see Sect. 5.4.4). N may not exceed 120. The indices M, the corresponding components, and the cost units are:
- 1, thorium, \$/kg Th
 - 2, plutonium, \$/kg fissile Pu
 - 3, ^{233}U , \$/kg ^{233}U
 - 4, U₃O₈, \$/lb U₃O₈
 - 5, conversion, \$/kg U
 - 6, separative duty of enrichment, \$/kg SWU
 - 7, fabrication (type 1), \$/kg heavy metal
 - 8, reprocessing, \$/kg heavy metal

- 9, fabrication (type 2), \$/kg heavy metal
- 10, waste disposal, mills/kWh [INC(9) = -1]; or, back end (type 2), \$/kg heavy metal [INC(9) \geq 0]
- 11, cost of depleted tails, \$/kg U
- 12, not used, but an entry for M = 12 is required, since dimension is (12, 120).

TLEAD(K,NY) - lead time prior to fuel loading or lag time after fuel discharge in years for payment for materials or services. The initial series, NY = 1, pertains to batches in the initial core loading. Data for NY > 1 are for batches loaded in subsequent cycles. If input is terminated, data for omitted batches remain the same as the last batch input. TLEAD is positive for lead times and is referenced to the start of fuel irradiation. TLEAD is negative for lag times and is referenced to the discharge of fuel. The dimensions of TLEAD are (13, 120). When K < 7, TLEAD(K,NY) are the lead times for component prices as specified for M < 7 in the array PRICE (M,N). The other indices K, the type of required lead or lag time, and the corresponding components are:

- 7, lead, fabrication (for type input to case)
 - 8, lag, reprocessing (not waste disposal)
 - 9, lag, thorium sale
 - 10, lag, plutonium sale
 - 11, lead, purchase of depleted UF₆ tails
 - 12, lag, ²³³U sale
 - 13, lag, ²³⁵U credit
- ALAG (see Sect. 5.4.6) is used for the waste disposal fee payment lag time

INC(L) - tax treatment for fuel cycle component L:
 = 0, cost is expensed;
 = 1, cost is capitalized;
 = -1, fee/kWh is expensed [for use with waste disposal cost, INC(9), only].

The components corresponding to L are listed in Sect. 4.6. The default values are INC(L) = 1 for the fuel cycle front end costs (L = 1-7), and INC(L) = 0 for the fuel cycle back end costs and credits with the exception that for waste disposal INC(9) = -1. Component No. 9 applies to waste disposal, if INC(9) = -1. Otherwise, it applies to back end (type 2) costs, such as reprocessing a second type of fuel.

5.5.2 Mass balances and associated parameters

Several arrays named BALi are input.

BALi(M) - mass charge and discharge data (in kg) for batch i, where i ranges from i = 1 to i = NBMAX (see Sect. 5.4.2). Note that "i" is part of each variable name input and must be one character when i < 10. The user may input data for

up to all the NBMAX batches required. If an insufficient number of batches is available, the code will add batches. If too many batches are input, the code will remove batches. The final batches input (last "STAY" number of batches) will be the final core batches. The code will assume that the previous "STAY" batches are equilibrium batches. This set of batches will be repetitively added or subtracted in order of insertion (reverse order for removal) until the correct number of batches is obtained. The indices M and the corresponding material charged or discharged, in kg, are:

- 1, total uranium charged
- 2, ^{235}U charged
- 3, total plutonium charged
- 4, fissile plutonium charged
- 5, total thorium charged
- 6, ^{233}U charged
- 7, total heavy metal fabricated, if TOTLHM = 1
- 8, total uranium discharged
- 9, ^{235}U discharged
- 10, total plutonium discharged
- 11, fissile plutonium discharged
- 12, total thorium discharged
- 13, ^{233}U discharged
- 14, total heavy metal reprocessed, if TOTLHM = 1

The following data, associated with mass balances, must always be input if TIMPTS = 1:

- RCYCL(N) - reference operating cycle lengths associated with mass balance data. Indices N vary from N = 1 to N = NPMAX, the total number of operating cycles (see Sect. 5.4.2). When input terminates at $N < \text{NPMAX}$, the last nonzero value is repeated. The default value of RCYCL(1) is 1.0 year. ("Rep-Data-Comp.," as defined in Sect. 4.8.)
- CFR(N) - reference capacity factors (fraction) used in computing mass balances. Indices N have same meaning as for RCYCL.

The following data, associated with mass balances, must always be input if either ENGYOP = 0 or ENCALC = 0:

- NPTOT(I) - total number of cycles that batch I resides in core, where I = 1 in BALi arrays. If ENCALC = 1, the code constructs NPTOT data as follows: 1, 2, ..., STAY, (with STAY repeated $\text{NBMAX} - 2 * \text{STAY} + 2$ times) ..., STAY, ..., 2, 1.
- NPA(I) - number of the cycle when batch i is loaded (at start of cycle), where I = 1 in BALi arrays. If ENCALC = 1, STAY number of batches is charged at the first cycle and $\text{NPA}(I) = I - \text{STAY} + 1$ for all other batches.

The following optional array permits the enrichment plant tails assay to vary by batch. Also, see TAILS in Sect. 5.4.6.

XT(I) - weight fraction of ^{235}U in enrichment plant tails for batch I. When not input or zero, code sets XT(I) = TAILS.

Another optional array permits the use of two different types of fuel assembly fabrications and, possibly, back end processes [see INC(9) in Sect. 5.5.1]. If two types of fuel (requiring two types of fabrication) are loaded at the same times, separate fuel batches are required and the cycle time points input for array TIME (see Sect. 5.5.3) must be repeated for each batch. Also, note that cases for more than two types of assemblies may be computed properly as separate cases, where the total levelized cost is the sum of that computed for each case.

NTYPE(I) - equals either "1" or "2" for batch I, denoting the type of fabrication cost and possible back end cost in array PRICE (see Sect. 5.5.1). When not input or zero, the code sets NTYPE(I) = 1.

5.5.3 Reactor operating history variables

BBURN(I) - total burnup for batch I in MWd (thermal) per metric ton heavy metal; required only if ENGYOP = 0.

BHVMET(I) - total metric tons of heavy metal in batch I; required only if ENGYOP = 0.

BTOKWH(I) - energy produced by batch I; if ENGYOP = 1, BTOKWH(I) is the electrical energy delivered per batch, in 10^9 kWh; if ENGYOP = 2, BTOKWH(I) is the thermal energy produced per batch, in 10^{14} Btu. BTOKWH is required only if ENGYOP > 0 and ENCALC = 0. If ENDIST = 0, see Sect. 5.6 for distribution of the batch energy by cycles.

Note that the three above input arrays are not used when ENGYOP > 0 and ENCALC = 1, since these settings of option signals permit a constant energy per cycle to be computed from CYCKW and STAY (see Sect. 5.4.6).

Section 5.5.2 discussed the inputs associated with the reference mass balance set. As discussed in Sects. 2 and 4.9, REFCO has the ability to adjust the reference input data to alternate system capacity factors. The following information relates to the setting of the time a batch of fuel remains in the reactor core.

TIME(J) - pairs of starting and ending time points relative to TIME(1), for each cycle N, where N ranges from N = 1 to N = NPMAX (see Sect. 5.4.2); required if TIMPTS = 0. Always set TIME(1) = 0.0; TIME(J) is the starting time for cycle N if J = 2*N - 1, or the ending time if J = 2*N. The use of two types of fuel elements in the reactor is simulated by repeating the cycle time points in TIME to correspond to the batches of each type in the

mass balance data (see BAL_i and NTYPE in Sect. 5.5.2). The code requires either TIME or CF, CFR, and RYCL to be input.

CF(N) - capacity factors (fraction) for each year N in the case, where N ranges from N = 1 to N = RLIFE (see Sect. 5.4.2). Use of CF requires the reference data RYCL and CFR (see Sect. 5.5.2); required only if TIMPTS = 1.

The NAMELIST/IN/ must always be terminated by &END. This terminates the description of input that is always required to run a case (except for void data cases, see Sect. 4.5). This information is contained in the cost model described in Appendix C. Section 5.6 pertains to data that should be included only for a specific option.

5.6 Other Optional Input - NAMELIST/EDIST/

The following is required only if ENDIST = 0, where a number of arrays named EN_i are input:

EN_i(M) - relative energies per cycle $M \leq 10$ for each batch *i*, where *i* ranges from *i* = 1 to *i* = NBMAX (see Sect. 5.4.2). As for BAL_i, "i" is part of the variable name input and must be one character when *i* < 10. The indices M range from M = 1 for the first cycle in which a batch is in the core to M = NPTOT(*i*) (see Sect. 5.5.2). While the energies per cycle may be either the actual energies or simply distributions relative to other EN_i(M) for the same batch, the code will always normalize the EN_i data to the total energy of the batch. These energies of the batch are derived from either BTOKWH, BBURN, and BHVMET (see Sect. 5.5.3) or CYCKW and STAY (see Sect. 5.4.6).

When EN_i data are required, always precede it with &EDIST (starting in column 2) and terminate with &END to end case data.

5.7 Default Values for Additional Cases

Add any additional cases as described above, starting in Sect. 5.2 with the Fuel Cycle Model request card. Note that only modifications to the data of the last case are required, since all data are retained as new defaults for all input. Of course, data supplied from the Reference Parameters File override these data. Also, an additional case may be used for adding a Fuel Cycle Model to the reference file.

6. SAMPLE CASES

The user input data required in executing three cases are presented here. If the user does not have a Reference Parameters File, the last case could be run first to produce the data set applied in the first two cases.

6.1 Case Using the Reference Parameters File

Execute a case using the PWR-OT1 Fuel Cycle Model unmodified. Edit the input cards and all processed input data. Print complete results, as specified by the data in the model requested. This allows NAMELIST data to be omitted from input. Supply a title card.

The complete user input is:

```
1
PWR-OT1
REFERENCE PWR-ONCE-THROUGH CASE
See Sect. 6.4, Figs. 6.1-6.12, for sample printout of the case.
```

6.2 Modifying Reference File Data

Execute a case in which the reference model PWR-OT1 is modified with a general inflation rate and price escalation factors of 0.04 and reactor capacity factors equal to 75%.

ORNL-DWG 84-5665 ETD

* EDIT OF INPUT *

```
1
PWR-OT1
REFERENCE PWR-ONCE-THROUGH CASE
```

NAMES OF REACTOR-CYCLE MODELS
IN
THE REFERENCE FUEL-CYCLE-PARAMETERS FILE

PWR-OT1 , APPLIED IN THIS CASE

Fig. 6.1. Input card image edit and reference file contents.

INPUT DATA REFERENCE PWR-ONCE-THROUGH CASE

DESIGN CAPACITY OF REACTOR, MWE = 1210.000
 YEAR IN WHICH REACTOR BEGINS OPERATION, YESTRT = 1995.000
 REACTOR LIFETIME (YEARS), NLIPE = 30.000
 THERMAL EFFICIENCY OF REACTOR, THEFF = 0.319
 TOTAL NUMBER OF BATCHES OF FUEL, NBMAX = 28
 TOTAL NUMBER OF OPERATING PERIODS, NPMAX = 26

OPTIONS SELECTED FOR CASE

MILKW = 0, 0/1COMPUTED COSTS: MILLS PER KWH / CENTS PER MILLION BTU.
 PRCPPT = 0, 0/1/2PRICES USED: BY YEAR, INTERPOLATED WITH TIME / BY START OF YEAR / BY BATCH.
 ESCOPT = 1, 0/1ESCALATION FACTORS ARE NOT USED / ARE USED.
 CHEDOP = 1, 0/1URANIUM FEED AND SEPARATIVE WORK: CREDIT GIVEN / NO CREDIT.
 TOTLTH = 1, 0/1TOTAL MASSES IN FERRITATION AND REPROCESSING ARE COMPUTED / INPUT IN MASS BALANCE DATA.
 TIMPS = 1, 0/1START TIME OF CYCLES: INPUT / COMPUTED FROM CAPACITY FACTORS.
 ENGTOP = 1, 0/1/2BATCH ENERGIES FROM INPUT: SUENUP AND LOADING / ENERGY IN 10**14 BTU.
 ENCALC = 1, 0/1(IF ENGYOP>0) BATCH ENERGIES: AS INPUT / AS COMPUTED FROM CONSTANT CYCLE ENERGY, CYCKW.
 ENDISP = 1, 0/1CYCLE ENERGY FOR EACH BATCH: DISTRIBUTION INPUT / DIVIDED EQUALLY.
 IPRINT = 1, 0/1PRINT TABLES OF INPUT DATA USED: NO / YES.
 OUTDPT = -1, -2/-1/0/1 ..EDIT LEVEL OF PRINTED RESULTS: SINGLE PAGE / 4 SUMMARY PAGES / ALL EXCEPT BATCH COSTS / COMPLETE.
 NEWLIB = 0, 0/1REDUCE NEW FUEL-CYCLE MODEL IN REFERENCE PARAMETERS FILE: NO / YES.
 IEDIT = 0, -1/0/1EDIT REFERENCE PARAMETERS FILE: YES (NO CASE INPUT) / NO / YES (AFTER CASE).

COST TREATMENT IN COMPUTING TAXES

I	COMPONENT	INC(I)	TYPE OF COST
1	TR PURCHASE	1	CAPITALIZED
2	PU PURCHASE	1	CAPITALIZED
3	0233 PURCHASE	1	CAPITALIZED
4	0308 PURCHASE	1	CAPITALIZED
5	CONVERSION	1	CAPITALIZED
6	ENRICHMENT	1	CAPITALIZED
7	FABRICATION	1	CAPITALIZED
8	BACK END	0	EXPENSED
9	WASTE DISPOSAL	-1	EXPENSED, PROPORTIONAL TO POWER
10	TR CREDIT	0	EXPENSED
11	PU CREDIT	0	EXPENSED
12	0233 CREDIT	0	EXPENSED
13	0308 CREDIT	0	EXPENSED
14	CONV CREDIT	0	EXPENSED
15	ENRICH CREDIT	0	EXPENSED

Fig. 6.2. Input edit of reactor design data and option signals.

INPUT DATA REFERENCE PWR-ORCE-THROUGH CASE

TAX CONSTANTS

FRACTION OF CAPITAL IN BONDS, DBS = 0.51000
 ANNUAL INTEREST RATE ON DEBT, RDB = 0.10000
 ANNUAL AFTER-TAX EARNING RATE ON EQUITY, REE = 0.11900
 FEDERAL INCOME TAX RATE, TIR = 0.46000
 STATE INCOME TAX RATE, STX = 0.04000
 STATE GROSS REVENUES TAX RATE, SGR = 0.0
 PROPERTY TAX RATE, PTR = 0.0
 PROPERTY INSURANCE RATE, PIR = 0.0
 FRACTION OF CORE VALUE FOR TAX ASSESSMENT, FORTK = 0.0

PRICE ESCALATION FACTORS

GENERAL RATE OF INFLATION = 0.0600
 U308 PRICE ESCALATION FACTOR = 0.0918
 U308-UF6 CONVERSION COST ESCALATION FACTOR = 0.3600
 SEPARATIVE WORK COST ESCALATION FACTOR = 0.3600
 FABRICATION COST ESCALATION FACTOR, TYPE-1 = 0.0600
 BACK END COST ESCALATION FACTOR = 0.0600
 PLUTONIUM CREDIT PRICE ESCALATION FACTOR = 0.0600
 DEPLETED UF6 TAILS PRICE ESCALATION FACTOR = 0.3600
 FABRICATION COST ESCALATION FACTOR, TYPE-2 = 0.0600
 WASTE DISPOSAL COST ESCALATION FACTOR = 0.0600

ECONOMIC (%) LOSSES IN PROCESSES

THORIUM FABRICATION = 1.00
 FISSILE PLUTONIUM FABRICATION = 1.00
 U233 FABRICATION = 1.00
 U308-UF6 CONVERSION = 0.50
 URANIUM FABRICATION = 1.00
 RECOVERED U233 = 1.00
 RECOVERED THORIUM = 1.00
 PLUTONIUM REPROCESSING = 1.00
 U235 REPROCESSING = 1.00

OTHER INPUT PARAMETERS

WEIGHT % U235 OF NATURAL URANIUM, UASSAY = 0.00711
 YEARS LAG TIME FOR REVENUE RECEIVED, ALAG = 0.500
 NUMBER OF YEARS OF LEAD/LAG TIME DATA, NYMAX = 2
 NUMBER OF YEARS OF PRICE DATA, NPRICE = 1
 REFERENCE YEAR FOR CONSTANT DOLLAR COST, TRZF = 1982.30
 YEAR LEAD/LAG/PRICE DATA STARTS, WYCOST = 1982
 CONSTANT CYCLE ENERGY (10**9 KWH), CYCKW = 7.9600
 NUMBER OF CYCLES FOR EQUILIBRIUM BATCHES, STAY = 3.

LEAD AND LAG TIMES FOR PAYMENTS, YEARS

YEAR	BUY TH	BUY PU	BUY U233	BUY U308	CONV	ENRICH	FABR	END	TH SALE	PU SALE	TAILS	U233 SALE	U235 CRED
1	0.0	0.0	0.0	1.75	1.42	1.25	0.50	-5.00	0.0	0.0	0.3	0.0	0.0
2	0.0	0.0	0.0	1.00	0.57	0.50	0.25	-5.00	0.0	0.0	0.3	0.0	0.0

SUBSEQUENT YEARS ARE IDENTICAL TO LAST YEAR PRINTED

Fig. 6.3. Input edit of case constants and lead or lag times.

INPUT DATA REFERENCE PWR-ONCE-THROUGH CASE

PRICE DATA ENTERED BY YEARS

YEAR	TH (\$/KGTH)	FIPU (\$/KGFP)	U233 (\$/KGU3)	U308 (\$/LBU)	CONV (\$/KGU)	ENRICHMENT (\$/KG SWU)	FABR 1 (\$/KGHM)	END 1 (\$/KGHM)	FABR 2 (\$/KGHM)	DISPOSAL (MILLS/KWH)	TAILS (\$/KGU)
1982	0.0	0.0	0.0	32.20	8.00	130.00	180.00	0.0	0.0	1.00	0.0
1983	0.0	0.0	0.0	35.16	8.48	137.80	190.80	0.0	0.0	1.06	0.0
1984	0.0	0.0	0.0	38.38	8.99	146.07	202.25	0.0	0.0	1.12	0.0
1985	0.0	0.0	0.0	41.91	9.53	154.83	214.38	0.0	0.0	1.19	0.0
1986	0.0	0.0	0.0	45.75	10.10	164.12	227.24	0.0	0.0	1.26	0.0
1987	0.0	0.0	0.0	49.95	10.71	173.97	240.88	0.0	0.0	1.34	0.0
1988	0.0	0.0	0.0	54.54	11.35	184.41	255.33	0.0	0.0	1.42	0.0
1989	0.0	0.0	0.0	59.55	12.03	195.47	270.65	0.0	0.0	1.50	0.0
1990	0.0	0.0	0.0	65.01	12.75	207.20	286.89	0.0	0.0	1.59	0.0
1991	0.0	0.0	0.0	70.98	13.52	219.63	304.10	0.0	0.0	1.69	0.0
1992	0.0	0.0	0.0	77.50	14.33	232.81	322.35	0.0	0.0	1.79	0.0
1993	0.0	0.0	0.0	84.61	15.19	246.78	341.69	0.0	0.0	1.90	0.0
1994	0.0	0.0	0.0	92.38	16.10	261.58	362.19	0.0	0.0	2.01	0.0
1995	0.0	0.0	0.0	100.86	17.06	277.28	383.92	0.0	0.0	2.13	0.0
1996	0.0	0.0	0.0	110.12	18.09	293.91	406.96	0.0	0.0	2.26	0.0
1997	0.0	0.0	0.0	120.23	19.17	311.55	431.37	0.0	0.0	2.40	0.0
1998	0.0	0.0	0.0	131.26	20.32	330.24	457.26	0.0	0.0	2.54	0.0
1999	0.0	0.0	0.0	143.31	21.54	350.05	484.69	0.0	0.0	2.69	0.0
2000	0.0	0.0	0.0	156.47	22.83	371.06	513.77	0.0	0.0	2.85	0.0
2001	0.0	0.0	0.0	170.83	24.20	393.32	544.60	0.0	0.0	3.03	0.0
2002	0.0	0.0	0.0	186.51	25.66	416.92	577.27	0.0	0.0	3.21	0.0
2003	0.0	0.0	0.0	203.64	27.20	441.93	611.91	0.0	0.0	3.40	0.0
2004	0.0	0.0	0.0	222.33	28.83	468.45	648.62	0.0	0.0	3.60	0.0
2005	0.0	0.0	0.0	242.74	30.56	496.56	687.54	0.0	0.0	3.82	0.0
2006	0.0	0.0	0.0	265.02	32.39	526.35	728.79	0.0	0.0	4.05	0.0
2007	0.0	0.0	0.0	289.35	34.33	557.93	772.52	0.0	0.0	4.29	0.0
2008	0.0	0.0	0.0	315.91	36.39	591.40	818.87	0.0	0.0	4.55	0.0
2009	0.0	0.0	0.0	344.92	38.58	626.89	868.00	0.0	0.0	4.82	0.0
2010	0.0	0.0	0.0	376.58	40.89	664.50	920.08	0.0	0.0	5.11	0.0
2011	0.0	0.0	0.0	411.15	43.35	704.37	975.28	0.0	0.0	5.42	0.0
2012	0.0	0.0	0.0	448.89	45.95	746.63	1033.80	0.0	0.0	5.74	0.0
2013	0.0	0.0	0.0	490.10	48.70	791.43	1095.83	0.0	0.0	6.09	0.0
2014	0.0	0.0	0.0	535.09	51.63	838.91	1161.57	0.0	0.0	6.45	0.0
2015	0.0	0.0	0.0	584.21	54.72	889.25	1231.27	0.0	0.0	6.84	0.0
2016	0.0	0.0	0.0	637.84	58.01	942.60	1305.14	0.0	0.0	7.25	0.0
2017	0.0	0.0	0.0	696.39	61.49	999.16	1383.45	0.0	0.0	7.69	0.0
2018	0.0	0.0	0.0	760.32	65.18	1059.10	1466.45	0.0	0.0	8.15	0.0
2019	0.0	0.0	0.0	830.12	69.09	1122.65	1554.44	0.0	0.0	8.64	0.0
2020	0.0	0.0	0.0	906.32	73.23	1190.01	1647.70	0.0	0.0	9.15	0.0
2021	0.0	0.0	0.0	989.53	77.63	1261.41	1746.57	0.0	0.0	9.70	0.0
2022	0.0	0.0	0.0	1080.36	82.28	1337.09	1851.36	0.0	0.0	10.29	0.0
2023	0.0	0.0	0.0	1179.54	87.22	1417.31	1962.44	0.0	0.0	10.90	0.0
2024	0.0	0.0	0.0	1287.82	92.45	1502.35	2080.18	0.0	0.0	11.56	0.0

SUBSEQUENT YEARS ARE IDENTICAL TO LAST YEAR PRINTED
EXCEPT FOR ESCALATION

Fig. 6.4. Price edit from processed input data.

INPUT DATA REFERENCE PWR-ONCE-THROUGH CASE

CAPACITY FACTOR AND CYCLE LENGTH DATA

<u>REFERENCE PARAMETERS FILE</u>			<u>CASE INPUT DATA AND MODIFIED CYCLE LENGTHS</u>				<u>CYCLE TIME BOUNDRIES</u>	
<u>CYCLE</u>	<u>CAPACITY FACTOR</u>	<u>LENGTH (YEARS)</u>	<u>YEAR</u>	<u>CAPACITY FACTOR</u>	<u>CYCLE</u>	<u>LENGTH (YEARS)</u>	<u>START</u>	<u>END</u>
1	0.75	1.000	1	0.65	1	1.154	0.0	1.15
2	0.75	1.000	2	0.65	2	1.154	1.15	2.31
3	0.75	1.000	3	0.65	3	1.154	2.31	3.46
4	0.75	1.000	4	0.65	4	1.154	3.46	4.62
5	0.75	1.000	5	0.65	5	1.154	4.62	5.77
6	0.75	1.000	6	0.65	6	1.154	5.77	6.92
7	0.75	1.000	7	0.65	7	1.154	6.92	8.08
8	0.75	1.000	8	0.65	8	1.154	8.08	9.23
9	0.75	1.000	9	0.65	9	1.154	9.23	10.38
10	0.75	1.000	10	0.65	10	1.154	10.38	11.54
11	0.75	1.000	11	0.65	11	1.154	11.54	12.69
12	0.75	1.000	12	0.65	12	1.154	12.69	13.85
13	0.75	1.000	13	0.65	13	1.154	13.85	15.00
14	0.75	1.000	14	0.65	14	1.154	15.00	16.15
15	0.75	1.000	15	0.65	15	1.154	16.15	17.31
16	0.75	1.000	16	0.65	16	1.154	17.31	18.46
17	0.75	1.000	17	0.65	17	1.154	18.46	19.62
18	0.75	1.000	18	0.65	18	1.154	19.62	20.77
19	0.75	1.000	19	0.65	19	1.154	20.77	21.92
20	0.75	1.000	20	0.65	20	1.154	21.92	23.08
21	0.75	1.000	21	0.65	21	1.154	23.08	24.23
22	0.75	1.000	22	0.65	22	1.154	24.23	25.38
23	0.75	1.000	23	0.65	23	1.154	25.38	26.54
24	0.75	1.000	24	0.65	24	1.154	26.54	27.69
25	0.75	1.000	25	0.65	25	1.154	27.69	28.85
26	0.75	1.000	26	0.65	26	1.154	28.85	30.00
			27	0.65				
			28	0.65				
			29	0.65				
			30	0.65				

Fig. 6.5. Cycle time edit from input data.

INPUT DATA REFERENCE PWR-ONCE-THROUGH CASE

ENERGY DELIVERED PER BATCH BY CYCLES

(STARTING AT THE FIRST CYCLE THE BATCH IS IN THE CORE)

BATCH	ENERGY/CYCLE (10**9 KWH)		
1	2.6533		
2	2.6533	2.6533	
3	2.6533	2.6533	2.6533
4	2.6533	2.6533	2.6533
5	2.6533	2.6533	2.6533
6	2.6533	2.6533	2.6533
7	2.6533	2.6533	2.6533
8	2.6533	2.6533	2.6533
9	2.6533	2.6533	2.6533
10	2.6533	2.6533	2.6533
11	2.6533	2.6533	2.6533
12	2.6533	2.6533	2.6533
13	2.6533	2.6533	2.6533
14	2.6533	2.6533	2.6533
15	2.6533	2.6533	2.6533
16	2.6533	2.6533	2.6533
17	2.6533	2.6533	2.6533
18	2.6533	2.6533	2.6533
19	2.6533	2.6533	2.6533
20	2.6533	2.6533	2.6533
21	2.6533	2.6533	2.6533
22	2.6533	2.6533	2.6533
23	2.6533	2.6533	2.6533
24	2.6533	2.6533	2.6533
25	2.6533	2.6533	2.6533
26	2.6533	2.6533	2.6533
27	2.6533	2.6533	
28	2.6533		

Fig. 6.6. Edit of energy delivered per batch by cycles.

CALCULATED BATCH COSTS, MILLIONS OF \$ REFERENCE PWR-ONCE-THROUGH CASE

COSTS FOR BATCH NUMBER 1 TYPE= 1 CHARGED AT TIME = 1995.00 DISCHARGED AT TIME = 1996.15									
	TIME	YEAR	QUANTITY	PRICE	\$ MILLION	PW FACTOR	PW COST	CUM PW CAP	CUM PW EXP
TH COST	0.0	1995.00	0.0	0.0	0.0	1.00000	0.0	0.0	0.0
PU COST	0.0	1995.00	0.0	0.0	0.0	1.00000	0.0	0.0	0.0
U233 COST	0.0	1995.00	0.0	0.0	0.0	1.00000	0.0	0.0	0.0
U308 COST	-1.75	1993.25	98688.94	86.55	22.209	1.17036	25.992	25.992	0.0
CONV COST	-1.42	1993.58	98688.88	15.71	1.551	1.13615	1.762	27.754	0.0
ENRICHMENT	-1.25	1993.75	52345.73	257.88	13.499	1.11892	15.104	42.858	0.0
FAB COST	-0.50	1994.50	34463.61	373.06	12.857	1.04597	13.448	56.306	0.0
BACK END 1	6.15	2001.15	33660.00	0.0	0.0	0.57511	0.0	56.306	0.0
WASTE DISP	0.0	1995.00	33660.00	2.13	6.027	0.57511	5.470	56.306	5.470
SALE TH	1.15	1996.15	0.0	0.0	0.0	0.90147	0.0	56.306	5.470
SALE FIPU	1.15	1996.15	155.43	0.0	0.0	0.90147	0.0	56.306	5.470
SALE U233	1.15	1996.15	0.0	0.0	0.0	0.90147	0.0	56.306	5.470
U308 CD	1.15	1996.15	0.0	111.67	0.0	0.90147	0.0	56.306	5.470
CONV CD	1.15	1996.15	0.0	18.25	0.0	0.90147	0.0	56.306	5.470
ENRICH CD	1.15	1996.15	0.0	296.63	0.0	0.90147	0.0	56.306	5.470
TOTAL COST					56.142		61.777	56.306	5.470
COSTS FOR BATCH NUMBER 2 TYPE= 1 CHARGED AT TIME = 1995.00 DISCHARGED AT TIME = 1997.31									
	TIME	YEAR	QUANTITY	PRICE	\$ MILLION	PW FACTOR	PW COST	CUM PW CAP	CUM PW EXP
TH COST	0.0	1995.00	0.0	0.0	0.0	1.00000	0.0	56.306	5.470
PU COST	0.0	1995.00	0.0	0.0	0.0	1.00000	0.0	56.306	5.470
U233 COST	0.0	1995.00	0.0	0.0	0.0	1.00000	0.0	56.306	5.470
U308 COST	-1.75	1993.25	128442.56	86.55	28.904	1.17036	33.829	90.135	5.470
CONV COST	-1.42	1993.58	128442.56	15.71	2.018	1.13615	2.293	92.428	5.470
ENRICHMENT	-1.25	1993.75	85093.00	257.88	21.944	1.11892	24.553	116.982	5.470
FAB COST	-0.50	1994.50	32560.58	373.06	12.147	1.04597	12.705	129.687	5.470
BACK END 1	7.31	2002.31	31487.00	0.0	0.0	0.51845	0.0	129.687	5.470
WASTE DISP	0.0	1995.00	31487.00	2.13	12.473	0.51845	10.744	129.687	16.214
SALE TH	2.31	1997.31	0.0	0.0	0.0	0.81266	0.0	129.687	16.214
SALE FIPU	2.31	1997.31	174.24	0.0	0.0	0.81266	0.0	129.687	16.214
SALE U233	2.31	1997.31	0.0	0.0	0.0	0.81266	0.0	129.687	16.214
U308 CD	2.31	1997.31	0.0	123.62	0.0	0.81266	0.0	129.687	16.214
CONV CD	2.31	1997.31	0.0	19.53	0.0	0.81266	0.0	129.687	16.214
ENRICH CD	2.31	1997.31	0.0	317.30	0.0	0.81266	0.0	129.687	16.214
TOTAL COST					77.487		84.125	129.687	16.214

Fig. 6.7. Detailed accounting of component cost per batch.

RESULTS REFERENCE PWR-ONCE-THROUGH CASE

FACTORS IN LEVELIZED COST CALCULATION

DNB FRACTION OF CAPITAL IN BONDS = 0.51000
 RRB ANNUAL INTEREST RATE ON DEBT = 0.10000
 RRE ANNUAL AFTER-TAX EARNING RATE ON EQUITY = 0.13800
 TXR FEDERAL INCOME TAX RATE = 0.46000
 STX STATE INCOME TAX RATE = 0.04000
 SGR STATE GROSS REVENUES TAX RATE = 0.0
 TXRM COMBINED TAX RATE = $TXR + STX - TXR * STX$ = 0.48160
 TXRE COMBINED TAX RATE = $(1. - TXR) * (STX + SGR - STX * SGR) + TXR$ = 0.48160
 RRA AVERAGE COST OF MONEY = $DNB * RRB + (1. - DNB) * RRE$ = 0.11862
 BRV EFFECTIVE COST OF MONEY = $DNB * RRB * (1. - TXRM) + (1. - DNB) * RRE$ = 0.09406
 PCRF ANNUAL FIXED CHARGE RATE ON FUEL = 0.17341
 G EQUIVALENT INTEREST RATE FOR CONTINUOUS DISCOUNTING = $ALOG(1. + BRV)$ = 0.08989
 PWELEC TOTAL PRESENT-WORTHED ELECTRICITY PRODUCED = 68.42
 PWPTY TOTAL PRESENT WORTH OF PROPERTY TAXES AND INSURANCE = 0.0
 PWDDUC TOTAL PRESENT WORTH OF TAX DEPRECIATION = 1847.6
 PWCAPS TOTAL PRESENT WORTH OF CAPITALIZED FUEL COSTS = 2398.5
 PWEXPS TOTAL PRESENT WORTH OF EXPENSED FUEL COSTS = 280.6
 TOP = $(1. - TXRM) * (PWEXPS + PWPTY) - TXRM * PWDDUC + PWCAPS$ = 1654.2
 BOT = $(1. - TXRE) * PWELEC$ = 35.470
 ADJ RATIO OF CONSTANT TO CURRENT DOLLAR COST = 0.2438
 ***** LEVELIZED FUEL CYCLE COST:
 FCOST COST, IN CURRENT DOLLARS (AS PAID) = TOP / BOT = 46.636 (MILLS/KWH)
 CCOST COST, IN CONSTANT (1982) DOLLARS = $PCOST * ADJ$ = 11.371 (MILLS/KWH)

Fig. 6.8. Summary of levelized cost calculation.

RESULTS REFERENCE PWR-ONCE-THROUGH CASE

(COST IN MILLS/KWH)

LEVELIZED ENERGY COST FOR EACH CYCLE

CYCLE	ENERGY	PW REV REQ	LEVEL COST	CUM LVL COST
1	7.960	193.528	24.31	24.31
2	7.960	182.262	22.90	23.64
3	7.960	194.820	24.47	23.89
4	7.960	211.778	26.61	24.47
5	7.960	229.701	28.86	25.17
6	7.960	249.331	31.32	25.95
7	7.960	274.201	34.45	26.82
8	7.960	295.309	37.10	27.69
9	7.960	322.626	40.53	28.60
10	7.960	350.683	44.06	29.53
11	7.960	381.300	47.90	30.47
12	7.960	415.090	52.15	31.43
13	7.960	451.523	56.72	32.40
14	7.960	491.268	61.72	33.38
15	7.960	535.242	67.24	34.37
16	7.960	582.785	73.21	35.37
17	7.960	634.800	79.75	36.37
18	7.960	692.295	86.97	37.38
19	7.960	754.382	94.77	38.40
20	7.960	822.224	103.29	39.42
21	7.960	897.337	112.73	40.44
22	7.960	978.671	122.95	41.46
23	7.960	1067.814	134.15	42.49
24	7.960	1161.635	145.93	43.51
25	7.960	1432.406	179.95	44.72
26	7.960	2287.610	287.39	46.64

Fig. 6.9. Levelized energy cost for each cycle.

RESULTS REFERENCE PVE-ONCE-THROUGH CASE

COST BREAKDOWN BY BATCHES (MILLS/KWH)

BATCH	DIRECT CHARGES										CARRYING CHARGE			TOTAL										
	TH	PU	U233	U308	CONV	SWU	FABR	BACK	END	DISP	TR	CR	PU		CP	U233	CR	U308	CR	CONV	CF	SMJ	CR	CHARGE
1	0.0	0.0	0.0	8.37	0.58	5.09	4.85	0.0	2.27	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	8.64	29.80
2	0.0	0.0	0.0	5.45	0.38	4.14	2.29	0.0	2.35	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	7.76	21.86
3	0.0	0.0	0.0	4.82	0.34	4.19	1.56	0.0	2.43	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	7.93	21.28
4	0.0	0.0	0.0	6.66	0.44	5.75	1.75	0.0	2.60	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	8.35	25.55
5	0.0	0.0	0.0	7.05	0.45	5.75	1.90	0.0	2.78	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	8.67	26.59
6	0.0	0.0	0.0	7.45	0.46	5.78	2.00	0.0	2.98	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	9.00	27.67
7	0.0	0.0	0.0	8.91	0.53	6.91	2.14	0.0	3.18	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	10.63	32.31
8	0.0	0.0	0.0	9.53	0.55	7.01	2.32	0.0	3.41	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	11.19	33.99
9	0.0	0.0	0.0	10.57	0.59	7.57	2.45	0.0	3.64	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	12.22	37.04
10	0.0	0.0	0.0	11.70	0.63	8.10	2.62	0.0	3.90	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	13.32	40.26
11	0.0	0.0	0.0	13.11	0.68	8.77	2.84	0.0	4.17	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	14.71	44.28
12	0.0	0.0	0.0	14.34	0.72	9.26	3.00	0.0	4.46	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	15.85	47.62
13	0.0	0.0	0.0	15.86	0.77	9.90	3.21	0.0	4.77	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	17.29	51.80
14	0.0	0.0	0.0	17.78	0.83	10.73	3.48	0.0	5.10	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	19.11	57.32
15	0.0	0.0	0.0	19.42	0.88	11.33	3.67	0.0	5.45	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	20.99	61.35
16	0.0	0.0	0.0	21.48	0.94	12.12	3.93	0.0	5.83	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	22.48	66.78
17	0.0	0.0	0.0	24.09	1.02	13.13	4.25	0.0	6.24	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	24.97	73.59
18	0.0	0.0	0.0	26.33	1.08	13.86	4.49	0.0	6.67	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	26.84	79.27
19	0.0	0.0	0.0	29.14	1.15	14.82	4.80	0.0	7.13	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	29.33	86.29
20	0.0	0.0	0.0	32.66	1.25	16.03	5.20	0.0	7.63	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	32.47	95.26
21	0.0	0.0	0.0	35.68	1.32	16.96	5.50	0.0	8.16	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	35.95	102.67
22	0.0	0.0	0.0	39.47	1.41	18.14	5.88	0.0	8.73	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	38.33	111.95
23	0.0	0.0	0.0	44.23	1.53	19.65	6.27	0.0	9.34	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	42.46	123.57
24	0.0	0.0	0.0	48.36	1.61	20.75	6.72	0.0	9.98	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	45.90	133.32
25	0.0	0.0	0.0	53.52	1.73	22.19	7.19	0.0	10.68	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	50.24	145.55
26	0.0	0.0	0.0	59.24	1.85	23.73	7.69	0.0	11.42	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	55.01	158.93
27	0.0	0.0	0.0	66.31	2.00	26.08	8.34	0.0	12.20	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	71.88	235.37
28	0.0	0.0	0.0	220.28	6.41	82.50	26.71	0.0	12.20	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	119.74	467.86

Fig. 6.10. Component cost breakdown by batch.

RESULTS REFERENCE PWR-ONCE-THROUGH CASE

CUMULATIVE BATCHWISE LEVELIZED COST BREAKDOWN (MILLS/KWH)

BATCH	TH	PU	U233	U308	CONV	SWU	FABR	BACK END	DISP	TH CR	PU CR	U233 CR	U308 CR	CONV CR	SWU CR	TOTAL
1	0.0	0.0	0.0	13.03	0.87	7.37	6.26	0.0	2.27	0.0	0.0	0.0	0.0	0.0	0.0	29.80
2	0.0	0.0	0.0	10.51	0.70	6.80	4.27	0.0	2.32	0.0	0.0	0.0	0.0	0.0	0.0	24.60
3	0.0	0.0	0.0	9.67	0.64	6.95	3.36	0.0	2.37	0.0	0.0	0.0	0.0	0.0	0.0	22.99
4	0.0	0.0	0.0	10.05	0.66	7.51	3.12	0.0	2.44	0.0	0.0	0.0	0.0	0.0	0.0	23.77
5	0.0	0.0	0.0	10.37	0.67	7.78	3.05	0.0	2.51	0.0	0.0	0.0	0.0	0.0	0.0	24.38
6	0.0	0.0	0.0	10.67	0.68	7.95	3.04	0.0	2.58	0.0	0.0	0.0	0.0	0.0	0.0	24.91
7	0.0	0.0	0.0	11.17	0.70	8.28	3.05	0.0	2.66	0.0	0.0	0.0	0.0	0.0	0.0	25.85
8	0.0	0.0	0.0	11.63	0.71	8.53	3.09	0.0	2.73	0.0	0.0	0.0	0.0	0.0	0.0	26.69
9	0.0	0.0	0.0	12.12	0.73	8.79	3.13	0.0	2.81	0.0	0.0	0.0	0.0	0.0	0.0	27.57
10	0.0	0.0	0.0	12.62	0.75	9.04	3.19	0.0	2.88	0.0	0.0	0.0	0.0	0.0	0.0	28.48
11	0.0	0.0	0.0	13.16	0.77	9.30	3.25	0.0	2.96	0.0	0.0	0.0	0.0	0.0	0.0	29.43
12	0.0	0.0	0.0	13.69	0.79	9.55	3.31	0.0	3.04	0.0	0.0	0.0	0.0	0.0	0.0	30.37
13	0.0	0.0	0.0	14.24	0.80	9.80	3.37	0.0	3.11	0.0	0.0	0.0	0.0	0.0	0.0	31.32
14	0.0	0.0	0.0	14.81	0.82	10.05	3.44	0.0	3.19	0.0	0.0	0.0	0.0	0.0	0.0	32.31
15	0.0	0.0	0.0	15.38	0.84	10.30	3.50	0.0	3.26	0.0	0.0	0.0	0.0	0.0	0.0	33.29
16	0.0	0.0	0.0	15.97	0.86	10.54	3.57	0.0	3.34	0.0	0.0	0.0	0.0	0.0	0.0	34.27
17	0.0	0.0	0.0	16.57	0.88	10.78	3.64	0.0	3.41	0.0	0.0	0.0	0.0	0.0	0.0	35.28
18	0.0	0.0	0.0	17.18	0.90	11.02	3.71	0.0	3.48	0.0	0.0	0.0	0.0	0.0	0.0	36.28
19	0.0	0.0	0.0	17.79	0.92	11.25	3.77	0.0	3.56	0.0	0.0	0.0	0.0	0.0	0.0	37.29
20	0.0	0.0	0.0	18.43	0.93	11.49	3.84	0.0	3.63	0.0	0.0	0.0	0.0	0.0	0.0	38.32
21	0.0	0.0	0.0	19.06	0.95	11.72	3.91	0.0	3.70	0.0	0.0	0.0	0.0	0.0	0.0	39.33
22	0.0	0.0	0.0	19.70	0.97	11.94	3.98	0.0	3.77	0.0	0.0	0.0	0.0	0.0	0.0	40.35
23	0.0	0.0	0.0	20.36	0.99	12.16	4.04	0.0	3.84	0.0	0.0	0.0	0.0	0.0	0.0	41.39
24	0.0	0.0	0.0	21.01	1.01	12.38	4.11	0.0	3.90	0.0	0.0	0.0	0.0	0.0	0.0	42.41
25	0.0	0.0	0.0	21.67	1.02	12.60	4.17	0.0	3.97	0.0	0.0	0.0	0.0	0.0	0.0	43.44
26	0.0	0.0	0.0	22.34	1.04	12.80	4.24	0.0	4.04	0.0	0.0	0.0	0.0	0.0	0.0	44.46
27	0.0	0.0	0.0	23.05	1.06	13.03	4.31	0.0	4.08	0.0	0.0	0.0	0.0	0.0	0.0	45.52
28	0.0	0.0	0.0	23.80	1.08	13.28	4.38	0.0	4.10	0.0	0.0	0.0	0.0	0.0	0.0	46.64

Fig. 6.11. Cumulative batchwise levelized cost with component breakdown.

RESULTS REFERENCE PWR-ONCE-THROUGH CASE

TOTAL LEVELIZED COSTS OVER REACTOR LIFETIME. BY COMPONENT, (MILLS/KWH)

	CONSTANT DOLLARS (1982)	CURRENT DOLLARS
TH PURCHASE	0.0	0.0
PU PURCHASE	0.0	0.0
U233 PURCHASE	0.0	0.0
U308 PURCHASE	5.80	23.80
CONVERSION	0.26	1.08
ENRICHMENT	3.24	13.28
FABRICATION	1.07	4.38
BACK END	0.0	0.0
WASTE DISPOSAL	1.00	4.10
TH CREDIT	0.0	0.0
PU CREDIT	0.0	0.0
U233 CREDIT	0.0	0.0
U308 CREDIT	0.0	0.0
CONV CREDIT	0.0	0.0
ENRICH CREDIT	0.0	0.0
TOTAL	11.37	46.64

Fig. 6.12. Component levelized cost over reactor life.

The complete user input is:

```

1
PWR-OT1
PWR-ONCE-THROUGH WITH 4% INFLATION, 75% CAP. FACT.
  &IN RATINF=0.04, ESCUR=0.04, ESCCV=0.04,
  ESCSWU=0.04, ESCFBI=0.04, ESCBEL=0.04,
  CF=30*0.75, &END

```

With these modifications, the levelized fuel cycle cost is reduced to 23.23 mills/kWh in current dollars and 9.20 mills/kWh in constant 1982 dollars (not shown).

6.3 Large Data Input Saved in Reference File

Execute a case where the "PWR-OT1" model data are supplied by user input and the data are saved as a reference Fuel Cycle Model in a new Reference Parameters File. Also, edit the file. See Appendix C and code defaults in preparing case data.

The minimum sufficient set of user input is given in Table 6.1.

Table 6.1. Minimum input to create reference case

```

PWR-OT1      9999
REFERENCE PWR-ONCE-THROUGH CASE
&IN NEWLIB=1, IED=1,
  TLEAD=3*0.0, 1.75, 1.42, 1.25, 0.50, -5.0,
        8*0.0, 1.00, 0.67, 0.50, 0.25, -5.0,
  PRICE=3*0.0, 32.2, 8., 130., 180., 0., 0., 1.,
CFR(1)=0.75, CF(1)=0.65,
BAL1= 34119.00, 565.0, 0.0, 0.0, 0.0, 0.0, 34119.00,
      33457.00, 243.0, 203.0, 157.0, 0.0, 0.0, 33660.00,
BAL2= 32235.00, 711.0, 0.0, 0.0, 0.0, 0.0, 32235.00,
      31243.00, 214.0, 244.0, 176.0, 0.0, 0.0, 31487.00,
BAL3= 32962.00, 925.0, 0.0, 0.0, 0.0, 0.0, 32962.00,
      31657.00, 244.0, 289.0, 206.0, 0.0, 0.0, 31946.00,
BAL4= 34119.00, 1071.0, 0.0, 0.0, 0.0, 0.0, 34119.00,
      32708.00, 304.0, 311.0, 227.0, 0.0, 0.0, 33019.00,
BAL5= 34545.00, 1028.0, 0.0, 0.0, 0.0, 0.0, 34545.00,
      33101.00, 271.0, 317.0, 228.0, 0.0, 0.0, 33418.00,
BAL6= 34119.00, 984.0, 0.0, 0.0, 0.0, 0.0, 34119.00,
      32728.00, 261.0, 309.0, 223.0, 0.0, 0.0, 33037.00,
BAL7= 34119.00, 1058.0, 0.0, 0.0, 0.0, 0.0, 34119.00,
      32703.00, 295.0, 311.0, 226.0, 0.0, 0.0, 33014.00,
BAL8= 34545.00, 1026.0, 0.0, 0.0, 0.0, 0.0, 34545.00,
      33115.00, 274.0, 315.0, 228.0, 0.0, 0.0, 33430.00,
BAL9= 34119.00, 1028.0, 0.0, 0.0, 0.0, 0.0, 34119.00,
      32704.00, 278.0, 311.0, 225.0, 0.0, 0.0, 33015.00,
BAL10= 34119.00, 1028.0, 0.0, 0.0, 0.0, 0.0, 34119.00,
      32704.00, 278.0, 311.0, 225.0, 0.0, 0.0, 33015.00,
BAL11= 34545.00, 1041.0, 0.0, 0.0, 0.0, 0.0, 34545.00,
      33112.00, 282.0, 315.0, 228.0, 0.0, 0.0, 33427.00,
BAL12= 34119.00, 1028.0, 0.0, 0.0, 0.0, 0.0, 34119.00,
      32704.00, 278.0, 311.0, 225.0, 0.0, 0.0, 33015.00,
BAL13= 34119.00, 1028.0, 0.0, 0.0, 0.0, 0.0, 34119.00,
      33250.70, 429.0, 249.6, 190.2, 0.0, 0.0, 33509.20,
BAL14= 34545.00, 1041.0, 0.0, 0.0, 0.0, 0.0, 34545.00,
      33650.70, 660.5, 161.1, 135.7, 0.0, 0.0, 33815.30,
&END

```

The printout of the case is the same as that in the first case except that IEDIT = 1 in Fig. 6.1, and the file edit is the same as that in Appendix C.

6.4 REFCO Printout

There are 20 tables or types of printout that may be requested for a case by REFCO input. This section gives the "request option" requirement of all printout and identifies the 14 figures shown as examples of output. While the printout is usually self descriptive, brief comments sometimes have been included. The output is printed in the order presented below:

1. Input card image edit and reference file contents. The input edit is printed if INEDIT = 1. This is shown in Fig. 6.1. The next 8 types of output are produced when IPRINT = 1.
2. Input edit of reactor design data and option signals. All options that control the methods used in the cost analysis are given. This is shown in Fig. 6.2.
3. Input edit of case constants and lead/lag times. All remaining case constants and lead or lag times are printed. This is shown in Figure 6.3.
4. Batch charge data (not shown). Fuel component and total heavy metal charges are given. Also, cycle numbers are printed indicating the times at the start of cycles when each batch is charged and discharged.
5. Batch discharge data (not shown). Fuel components and total heavy metal equivalent discharged are given.
6. Price edit from processed input data. Unit prices of all fuel cycle components are given, either directly as input or from calculating the escalated prices for all years after the last year in which data is input. This is shown in Fig. 6.4.
7. Operating period and delivered energy per batch (not shown). The cycle period numbers, corresponding charge and discharge dates, and tails assays of each batch are given.
8. Cycle time edit from input data. The reference file and input data used in computing the cycle time boundaries are given. This is shown in Fig. 6.5.
9. Edit of energy delivered per batch by cycles. This is shown in Fig. 6.6.

The next 9 tables are requested by various print levels specified by OUTOPT, as indicated:

10. Detailed accounting of component cost per batch. Fuel cycle component data, such as time, quantity, price, and cost, are given. Also, the present worth and cumulative costs are listed. A sample of this printout for batches 1 and 2 is shown in Fig. 6.7. (OUTOPT = 1).

11. Summary of levelized cost calculation. The main input constants and computed factors used in the cost analysis and the current and constant dollar computation of levelized fuel cycle costs are given. This is shown in Fig. 6.8. (OUTOPT \geq -2).
12. Electrical energy produced, tax deductions, and present worth factors by cycle (not shown). (OUTOPT \geq -1).
13. Levelized energy cost for each batch. The data listed for each batch include energy delivered and the present worth of the energy, both in 10^9 kWh, in addition to the levelized cost per batch and the cumulative levelized cost (not shown). (OUTOPT \geq -1).
14. Levelized energy cost for each cycle. The information listed for each cycle includes the energy delivered in 10^9 kWh, the present worth of the required revenue in millions of dollars, the levelized cost per cycle, and the cumulative levelized cost. This is shown in Fig. 6.9. (OUTOPT \geq 0).
15. Component cost breakdown by batch. The direct charges of the cost per batch for each component are listed. Also, the carrying charges, including cost of money, insurance, and taxes, and the total levelized cost per batch are printed. This shown in Fig. 6.10. (OUTOPT \geq 0).
16. Levelized component cost breakdown by batch (not shown). The levelized cost per batch for each component, including the sum of direct charges and corresponding carrying charges, plus the levelized cost per batch are given. (OUTOPT \geq 0).
17. Cumulative batchwise levelized cost with component breakdown. The cumulative batchwise totals of the levelized costs in the preceding table are printed. This is shown in Fig. 6.11. (OUTOPT \geq 0).
18. Component levelized cost over reactor lifetime. The total lifetime levelized costs by component are given in terms of constant TREF dollars and current dollars. This is shown in Fig. 6.12. (OUTOPT \geq -1).
19. Edit of constants in the Fuel Cycle Models of the Reference Parameters File. All scalar parameters of models are listed under the model name. This is shown in Fig. C.1, Appendix C. The edit requires IEDIT = 1.
20. Edit of array data 'n Reference Parameters File. Array data of the specific model are printed in a format similar to NAMELIST output. An example is shown in Fig. C.2, Appendix C. The edit requires IEDIT = 1.

6.5 Sample Job Control Language

Assume that a REFCO object deck (hex deck) is named REFCOHEX and a REFCO Reference Parameters File is named REPPARMF. Also, let these data sets reside, or be made, on a 3330-1 type unit named XXXXXX. The data set REPPARMF should be made, case 3, with a record length LRECL of 132. Then, the IBM 360 system JCL for the cases in Sects. 6.1 and 6.2

is:

```
//UID1 JOB (CH-NO,I01),'REFCO USER, ADDR.',TIME=(0,10)
//* ... SAMPLE CASES IN SECTIONS 6.1 & 6.2, REFCOC GUIDE ...
// EXEC FORTHLG,GOSIZE=270K
//LKED.SYSIN DD DSN=REFCOHEX,DISP=SHR
//GO.FT10F001 DD DSN=&&IN10,UNIT=SYSDA,DISP=(NEW,DELETE),
// SPACE=(TRK,(2,2),RLSE),DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//GO.FT20F001 DD DSN=REFPARMF,DISP=SHR
//JO.FT05F001 DD *
```

The JCL for the case in Sect. 6.3 is:

```
//UID3 JOB (CH-NO,I01),'REFCO USER, ADDR.'TIME=(0,10)
//* ... LAST SAMPLE CASE, SECTION 6.3, REFCOC GUIDE ...
// EXEC FORTHLG,GOSIZE=270K
//LKED.SYSIN DD DSN=REFCOHEX,DISP=SHR
//GO.FT10F001 DD DSN=&&IN10,UNIT=SYSDA,DISP=(NEW,DELETE),
// SPACE=(TRK,(2,2),RLSE),DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//GO.FT20F001 DD DSN=REFPARMF,DISP=(,CATLG),
// UNIT=3330-1,VOL=SER=XXXXXX,
// SPACE=(TRK,(10,5),RLSE),DCB=(RECFM=FB,LRECL=132,BLKSIZE=6600)
//GO.FT05F001 DD *
```

Appendix A.

DERIVATION OF LEVELIZED FUEL COST EQUATIONS

The objective of the analysis in this appendix is to show the logical formulation of the levelized fuel cycle cost equation using discounted cash flow (DCF) techniques. The approach used here follows that reported in various sources.⁶⁻¹² Terms are defined in Table A.1.

With the DCF methodology, as it is used here, an equivalent constant unit cost (levelized cost) is obtained such that the income received from the sale of power throughout the reactor life will pay all expenses, taxes, and return on outstanding investment and will return the investment by the end of life. If the cash payments are those associated with the nuclear fuel cycle, the resultant levelized cost is the levelized fuel cost.

Although the DCF method enters cash receipts and expenditures at the actual time they occur, it is simpler to develop the basic theory if discrete time periods are used. Adjustments will then be made to account for cash payments at other than discrete interval boundaries and for the continuous generation of power and thus revenues from the sale of this power.

Assume equal time periods (years, quarters, etc.). Capitalized investments are made at the beginning of the time periods, and revenues and operating costs are transacted at the end of the time periods.

The project is to be financed by both debt and equity capital (preferred included with equity). Both the rates of return and the capitalization fractions are to remain constant during the project life.

Capital outstanding at the start of the first time period is equal to the initial investment

$$V_1 = I_0 .$$

Income taxes paid at the end of the first period are equal to the tax rate times the revenue less the tax deductible costs.

$$T_1 = r(R_1 - O_1 - D_1^T - I_0 Bb) \quad (A.1)$$

where the operating cost, O_1 , is equal to the sum of all operating costs during period 1. The effective tax rate, r , used in REFCO is a combination of a gross revenues tax rate, g , a state income tax rate, s , and a federal income tax rate, f , as follows

$$r = g + (1 - g)s + f [1 - g - (1 - g)s] .$$

The gross revenues tax is assumed to be deductible for both state and federal income tax purposes and the state income tax is assumed to be deductible for federal income tax purposes.

Table A.1. Nomenclature and definition of terms

B	fraction of capitalization from debt
$\sum_{B \in j}$	indicates that summation is over all batches B contained in cycle j
BOT	Denominator of levelized cost equation
b	interest rate on debt
C_n	Funds available to recover outstanding capital at the end of period n
D^T	tax deductible depreciation
E	fraction of capital from equity (including preferred stock)
e	rate of return on equity investment, or base for the natural system of logarithms, 2.71828
e_w	escalation rate for waste disposal price
f	federal income tax rate
g	gross revenues tax rate
I	capitalized investment
I_0	total capitalized investment at start of operation
i	general inflation rate (measured by GNP implicit price deflator)
L	period between reference cost year and year of commercial operation
N	life of project, years
O	operating costs, or other expensed items which may include O&M costs, fuel, interim replacement, property taxes, waste disposal fee, and decommissioning fund
P_n	price in year n after startup
\bar{P}	current dollar levelized cost
\bar{P}_0	constant dollar levelized cost
\bar{P}_B	levelized power cost for a fuel batch B
$\bar{P}_{k,B}$	levelized cost of cost component k in batch B
P_w	reference price for nuclear waste disposal
PWRR	present worth of revenue requirements
R_n	revenue or revenue requirements in year n
r	effective tax rate

Table A.1 (continued)

S_B	total energy produced by a fuel batch
S_n	number of units (kWh) sold in year n
$S_{B,j}$	energy produced by a fuel batch in cycle j
S_j	energy produced in cycle j
S_t	electric power produced at time t
SLG	lag time for revenues received relative to power production
s	state income tax rate
T	income taxes paid
TOP	numerator in levelized cost equation
t	time relative to reactor startup
t_i	time fuel is placed in reactor
t_o	time fuel is removed from reactor
V_n	capital investment outstanding at beginning of period n
X	effective (tax adjusted) cost of money
X'	exponential discount rate
X'_A	exponential discount rate reduced by rate of inflation
X'_W	exponential discount rate adjusted for waste disposal cost escalation rate

Subscripts

B	refers to a fuel batch
cj	cycle j
j	index, signifying reactor cycle
k	fuel cycle subcost component
n	index, year relative to year of commercial operation
o	refers to initial or reference year or designates constant dollar levelization
T	total, or tax
t	time

The funds available to pay back (recover) the outstanding capital at the end of the first period are

$$C_1 = R_1 - O_1 - I_0(Bb + eE) - T_1 . \quad (A.2)$$

Substitute T_1 from Eq. (A.1) into Eq. (A.2) and rearrange,

$$C_1 = (1 - r)(R_1 - O_1) - I_0[eE + (i - r)Bb] + rD_1^T . \quad (A.3)$$

Capital outstanding at the start of the second period is

$$V_2 = (I_0 - C_1) + I_1 . \quad (A.4)$$

Substituting C_1 from Eq. (A.3) into Eq. (A.4),

$$V_2 = I_0 + I_1 - (1 - r)(R_1 - O_1) + I_0 [eE + (1 - r)Bb] - rD_1^T .$$

Rearrange,

$$V_2 = I_0[1 + eE + (1 - r)Bb] + I_1 + (1 - r)O_1 - rD_1^T - (1 - r)R_1 .$$

Define the tax adjusted discount rate or cost of money, X , as

$$X = eE + (1 - r)Bb . \quad (A.5)$$

Then

$$V_2 = (1 + X)I_0 + I_1 + (1 - r)O_1 - rD_1^T - (1 - r)R_1 .$$

The discount rate, X , is the effective cost of money to the project. As demonstrated in this derivation it is the mathematically rigorous discount rate to use when applying the recommended cash flow equations to obtain levelized product price. Income taxes paid for the second period of operation are

$$T_2 = r(R_2 - O_2 - V_2Bb - D_2^T)$$

and the funds available to recover outstanding capital at the end of the second period are

$$C_2 = R_2 - O_2 - V_2(Bb + Ee) - r(R_2 - O_2 - V_2Bb - D_2^T) .$$

Capital outstanding at the beginning of the third period is

$$V_3 = (1 + X)V_2 + I_2 + (1 - r)O_2 - rD_2^T - (1 - r)R_2 .$$

Substitute for V_2 and rearrange,

$$V_3 = I_0(1 + X)^2 + I_1(1 + X) + I_2 + (1 - r)[(1 + X)O_1 + O_2]$$

$$- r [(1 + X) D_1^T + D_2^T] - (1 - r)[(1 + X)R_1 + R_2] .$$

Continue this procedure through N-1 periods,

$$V_N = \sum_{n=0}^{N-1} I_n (1+X)^{N-n-1} + (1-r) \sum_{n+1}^{N-1} O_n (1+X)^{N-n-1} \\ - r \sum_{n=1}^{N-1} D_n^T (1+X)^{N-n-1} - (1-r) \sum_{n=1}^{N-1} R_n (1+X)^{N-n-1} .$$

At the end of the Nth period the project is over so that the outstanding capital must be zero, or $V_{N+1} = 0$. So

$$\sum_{n=0}^N I_n (1+X)^{N-n} + (1+r) \sum_{n=1}^N O_n (1+X)^{N-n} \\ - r \sum_{n=1}^N D_n^T (1+X)^{N-n} - (1-r) \sum_{n=1}^N R_n (1+X)^{N-n} = 0 .$$

Divide by $(1-r)(1+X)^n$ and rearrange. The present worth of the revenue requirements for the nuclear fuel is

$$PWRR = \sum_{n=1}^N \frac{R_n}{(1+X)^n} = \frac{1}{1-r} \sum_{n=0}^N \frac{I_n}{(1+X)^n} \\ + \sum_{n=1}^N \frac{O_n}{(1+X)^n} - \frac{r}{1-r} \sum_{n=1}^N \frac{D_n^T}{(1+X)^n} . \quad (A.6)$$

This equation relates the revenues (from the sale of electricity) with the cash flow expenses. In the REFCO code this PWRR is calculated for each batch separately.

The investments, I_n , are the actual cash payments for materials and services and do not contain any allowance for interest, therefore, the total tax depreciation equals the total capitalized investment,

$$\sum_{n=1}^N I_n = \sum_{n=1}^N D_n^T .$$

The revenues produced by a fuel batch in a period, R_n , are equal to the unit cost times the quantity of energy produced,

$$R_n = P_n S_n .$$

A levelized price, \bar{P} , is defined such that

$$\sum_{n=1}^N \frac{\bar{P} S_n}{(1+X)^n} = \sum_{n=1}^N \frac{P_n S_n}{(1+X)^n} = \sum_{n=1}^N \frac{R_n}{(1+X)^n} \quad (\text{A.7})$$

\bar{P} is a constant, so substituting in equation A.6 and rearranging,

$$\bar{P} = \frac{\frac{1}{1-r} \sum_{n=0}^N \frac{I_n}{(1+X)^n} - \frac{r}{1-r} \sum_{n=1}^N \frac{D_n^T}{(1+X)^n} + \sum_{n=1}^N \frac{O_n}{(1+X)^n}}{\sum_{n=1}^N \frac{S_n}{(1+X)^n}} \quad (\text{A.8})$$

It also should be noted that some investments will occur before start up and some after the end of reactor life. The revenues and depreciation, however, only occur during the operating life.

Equation (A.8) is the fuel cycle cost equation if payments and receipts are made at the boundary of equal time intervals. A more general relationship, in which cash transactions can be made at any time t relative to reactor startup, is

$$\bar{P} = \frac{\frac{1}{1-r} \sum_{\text{time}} \frac{I_t}{(1+X)^t} - \frac{r}{1-r} \sum_{\text{time}} \frac{D_t^T}{(1+X)^t} + \sum_{\text{time}} \frac{O_t}{(1+X)^t}}{\sum_{\text{time}} \frac{S_t}{(1+X)^t}} \quad (\text{A.9})$$

Although the purchases of the fuel cycle materials and services occur at discrete times, the sale of power occurs more or less continuously. Because of this continuous nature it is easier to represent the fuel cycle cost equation in its exponential form,

$$\bar{P} = \frac{\frac{1}{1-r} \int I_t e^{-X't} dt - \frac{r}{1-r} \int D_t^T e^{-X't} dt + \int O_t e^{-X't} dt}{\int S_t e^{-X't} dt} \quad (\text{A.10})$$

The discount factor is replaced by an exponent and the integration is

over the range of time in which cash transactions are made. Thus,

$$\frac{1}{(1 + X)^t} = e^{-X't}$$

or $X' = \ln(1 + X)$. Note that e is the base for the natural system of logarithms, 2.71828 ..., and not the return on equity. Except for continuous feed and discharge fuel cycles, cash payments for most cost items are made at discrete times corresponding to the refueling period plus or minus lead or lag time. Thus, the numerator for the most part is a series of delta functions having values only at discrete times. Energy, however, is produced on a continuous basis. The revenues from the energy produced will usually lag production. In the sample case a 0.5 year lag time is assumed. In addition to the power production, the taxes and the waste fund payment are also treated as continuous functions since they are related to revenues received and the power production.

Appendix B. NAMELIST INPUT INSTRUCTIONS

The following NAMELIST input instructions are a direct quotation, taken from an IBM Fortran Manual.¹³

'Input data must be in a special form in order to be read using a NAMELIST list. The first character in each record to be read must be blank. The second character in the first record of a group of data records must be an &, immediately followed by the NAMELIST name. The NAMELIST name must be followed by a blank and must not contain any embedded blanks. This name is followed by data items separated by commas. (A comma after the last item is optional.) The end of a data group is signaled by &END.

The form of the data items in an input record is:

- symbolic name = constant
The symbolic name may be an array element name or a variable name. Subscripts must be integer constants. The constant may be integer, real, literal, complex, or logical. (If the constants are logical, they may be in the form T or .TRUE. and F or .FALSE.)
- array name = set of constants (separated by commas)
The set of constants consists of constants of the type integer, real, literal, complex, or logical. The number of constants must be less than or equal to the number of elements in the array. Successive occurrences of the same constant can be represented in the form k*constant, where k is a nonzero integer constant specifying the number of times the constant is to occur.

The variable names and array names specified in the input data set must appear in the NAMELIST list, but the order is not significant. A name that has been made equivalent to a name in the input data cannot be substituted for that name in the NAMELIST list. The list can contain names of items in COMMON but must not contain dummy argument names.

Each data record must begin with a blank followed by a complete variable or array name or constant. Embedded blanks are not permitted in names or constants. Trailing blanks after integers and exponents are treated as zeros.'

Appendix C. REFERENCE PWR ONCE-THROUGH MODEL

The REFCO edit of the PWR Once-Through Fuel Cycle Model, contained in the REFCO Reference Parameters File, is shown in Figures C.1 and C.2. When the first seven characters of LIBNAM (see Sect. 5.2) are PWR-OT1, the data of this model are accessed by REFCO from the ORNL Reference Parameters File, produced in September 1983. (Note that the "O" in PWR-OT1 is the letter "O".)

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EDIT OF THE REFERENCE FUEL-CYCLE PARAMETERS FILE

PARAMETER	REACTOR-CYCLE MODELS
NAME	PWR-OT1
MILKWH	0
PRCOPT	0
ESCOPT	1
CREDOP	1
TOTLHM	1
TIMPTS	1
ENGYOP	1
ENCALC	1
ENDIST	1
OUTOPT	1
NPMAX	26
NBMAX	28
NYCOST	1982
NPRICE	1
NYMAX	2
PTR	0.0
FCORTX	0.0
PIR	0.0
DNB	0.5100
RRB	0.1000
RRE	0.1380
TXR	0.4600
RATINF	0.0600
ESCU33	0.0600
ESCUR	0.0918
ESCCV	0.0600
ESCSWU	0.0600
ESCFB1	0.0600
ESCBE1	0.0600
ESCPU	0.0600
ESCTLS	0.0600
ESCFB2	0.0600
ESCBE2	0.0600
ESCTH	0.0600
STX	0.0400
SGR	0.0
FABLTH	1.0000
FABLPV	1.0000
FABLU3	1.0000
CVLOSS	0.5000
FABLOS	1.0000
REPLU3	1.0000
REPLTH	1.0000
REPLVU	1.0000
REPLU5	1.0000
THEFF	0.3190
POWMWE	1210.0000
RLIFE	30.0000
UASSAY	0.0071
ALAG	0.5000
YRSTRT	1995.0000
TREF	1982.0000
STAY	3.0000
CYCKW	7.9600
TAILS	0.0020

Fig. C.1. Constants in Fuel Cycle Model PWR-OT1.

EDIT OF THE REFERENCE FUEL-CYCLE PARAMETERS FILE

ARRAY DATA FOR MODEL: PWR-OTI

INC=

1, 1, 1, 1, 1, 1, 1, 0, -1, 0, 0, 0, 0, 0, C,
 TLEAD= 0.0 * 0.0 * 0.0 * 1.75000, 1.42000, 1.25000, 0.50000, -5.00000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 PRICE= 0.0 * 0.0 * 0.0 * 1.00000, 0.67000, 0.50000, 0.25000, -5.00000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 RCYCL= 0.0 * 0.0 * 0.0 * 32.200, 8.000, 130.000, 180.000, 0.0 * 0.0 * 0.0 * 1.000, 0.0 * 0.0 * 0.0 * 0.0 *
 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000,
 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000, 1.000000,
 CFR= 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000,
 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000,
 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000, 0.750000,
 CF= 0.650000, 0.650000, 0.650000, 0.650000, 0.650000, 0.650000, 0.650000, 0.650000, 0.650000, 0.650000, 0.650000,
 0.650000, 0.650000, 0.650000, 0.650000, 0.650000, 0.650000, 0.650000, 0.650000, 0.650000, 0.650000, 0.650000,
 BAL1= 34119.0000, 565.0000, 203.0000, 157.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 33457.0000, 243.0000, 711.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 32235.0000, 214.0000, 248.0000, 176.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL2= 31243.0000, 925.0000, 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 *
 32962.0000, 244.0000, 289.0000, 206.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL3= 31657.0000, 1071.0000, 311.0000, 227.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 34119.0000, 304.0000, 317.0000, 228.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL4= 32708.0000, 1028.0000, 317.0000, 228.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 34545.0000, 271.0000, 984.0000, 223.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL5= 33101.0000, 1058.0000, 309.0000, 223.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 34119.0000, 261.0000, 311.0000, 226.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL6= 32728.0000, 295.0000, 311.0000, 226.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 34119.0000, 1026.0000, 315.0000, 228.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL7= 32703.0000, 274.0000, 311.0000, 225.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 34545.0000, 1028.0000, 311.0000, 225.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL8= 33115.0000, 1028.0000, 311.0000, 225.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 34119.0000, 1028.0000, 311.0000, 225.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL9= 32704.0000, 1028.0000, 311.0000, 225.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 34119.0000, 1041.0000, 315.0000, 228.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL10= 32704.0000, 282.0000, 315.0000, 228.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 34545.0000, 1028.0000, 311.0000, 225.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL11= 33112.0000, 278.0000, 311.0000, 225.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 34119.0000, 1028.0000, 311.0000, 225.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL12= 32704.0000, 1028.0000, 311.0000, 225.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 34119.0000, 1028.0000, 311.0000, 225.0000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL13= 33250.6953, 429.0000, 249.6000, 190.2000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 34545.0000, 1041.0000, 660.5000, 161.1000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *
 BAL14= 33650.6953, 660.5000, 161.1000, 135.7000, 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 * 0.0 *

Fig. C.2. Edit of PWR-OTI array data in the Reference Parameters File.

Appendix D. UPDATING REFERENCE PARAMETERS FILE

When a new Fuel Cycle Model is added to the Reference Parameters File, normally all models previously made are kept on the file (see Sect. 5.2). However the user may want to delete obsolete model data or replace a model with an updated model having the same name. This is done by writing another Reference Parameters File on a new data set, or tape, as part of a job containing multiple cases.

A set of two cases is required for copying or updating each Fuel Cycle Model that is kept. The two cases should have the following functions:

- (1) The first case should access the old model (LIBNAM) on the unit number LIBNUM. Any required modifications may then be added. Such modifications include reducing printout by setting IPRINT = 0 and OUTOPT = -2. OUTOPT may then be reset to the desired level of print in the second case and become part of the new model data. Always use NEWLIB = 0, the default, in this first case.
- (2) The second case requires a different unit number LIBNUM and either LSTART = 9999, when making the first model of the new file, or LSTART = 0, thereafter. The model name input for LIBNAM may be the same as that used in the first case, if desired. Modifications to the data may be added in the NAMELIST. However, to save the required model data, it makes no difference which case contains the altered data. The only modification that is always required for making a new model is NEWLIB = 1. While NEWLIB, IPRINT, and IEDIT are the only NAMELIST parameters not saved as part of the model data, OUTOPT is saved and may need to be reset.

As an example, suppose the old Reference Parameters File contains models named MODEL1, MODEL2, MODEL3, and MODEL4. Also, assume: (1) the first two models are to be deleted, (2) MODEL3 is to be kept and renamed MODEL1, and (3) MODEL4 is to be updated with operating capacity factors of 75% and not renamed. The user input could be as follows:

```

1
MODEL3
OLD MODEL3 CASE
  &IN IPRINT=0,OUTOPT=-2&END
MODEL1 219999
NEW MODEL1 ON UNIT 21
  &IN NEWLIB=1,OUTOPT=1&END
MODEL4
OLD MODEL4
  &IN &END
MODEL4 21
NEW MODEL 4 ON UNIT 21
  &IN NEWLIB=1, CF(1)=30*0.75, IEDIT=1, &END

```

The print was suppressed in the first case, since there were no changes in data. The print was not suppressed in the third and fourth

cases to observe the differences due to updating. Also, the new file was edited in the last case. The job control language requires the old file on unit number 20 and the new file on unit number 21.

Appendix E. BRIEF DESCRIPTION OF REFCO SUBPROGRAMS

There are 18 subprograms in the REFCO code. This appendix presents the general flow of the code in addition to a brief description of the subroutine functions. The chief control routines are MAIN and subroutine INPUT.

MAIN calls six subprograms in the following order: subroutines ZERO, INPUT, COSTS, and SALES, function CDOLLR, and subroutine OUT2. All except two of the other subroutines are called by INPUT in the following order for each case: LEADLG, PRICES, CAPFAC, MSBAL, LIBMAK, ENERGY, PAGEPR, and OUTIN. Also LIBMAK, again, and LIBED are called for a Reference Parameters File edit.

MAIN

The major functions of MAIN are: (1) to control the main flow of the code; to initialize defaults and other constants, (2) to compute the leveled fuel cycle costs using the direct charges or sales for the batch as calculated by COSTS and SALES and the economic, tax, and energy data input, and (3) to print all results except for the detailed batch accounting and fuel cycle component batchwise cost breakdowns. Multiple passes are made through a large part of MAIN as LCA ranges from 0 to 15. When LCA = 0, the summary costs and data are computed. COSTS and SALES are called for each batch, indexed by NB. When LCA > 0, computed costs and associated data apply to the fuel cycle component corresponding to the index LCA.

ZERO

All major common data are initialized to zero, by ZERO only, at the start of the first case in each job. In subsequent cases, the data are retained for possible modification.

INPUT

The main function of INPUT is to read input data and control the calls to data preprocessing routines. Fuel Cycle Model data are read first, when requested, and NAMELIST data are read last. It is called once at the beginning of each case and a second time when an edit of the reference file is requested. The next eight subroutines are called by INPUT.

LEADLG

LEADLG copies the lead or lag times for the last cycle input to array locations for the remaining cycles.

PRICES

PRICES computes unit prices for years or batches not input, using the last set input and the escalation factors.

CAPFAC

CAPFAC is called only if TIMPTS = 1, the signal indicating that cycle time points are computed instead of being input. It uses the case input capacity factors, reference capacity factors, and reference cycle lengths to compute the case operating cycle times. NBMAX, the total number of batches, and NPMAX, the total number of cycles, are computed in this process.

MSBAL

The mass balance data are processed from reduced input, as needed, in the method described in Sect. 5.5.2.

LIBMAK

The main function of LIBMAK is to add a new Fuel Cycle Model to the Reference Parameters File, if requested. The table of contents of the file is printed, which simply is a list of all of its model names.

ENERGY

The energy per batch and energy per cycle for each batch are computed in ENERGY, when not directly input. The models or options described in Sects. 4.9.1, 4.9.2, and 4.9.3 are performed, as specified by the option signals.

PAGEPR

PAGEPR prints the input option signals and all other input constants on the two problem definition pages, if IPRINT = 1.

OUTIN

All input data, other than that listed by PAGEPR, are printed by OUTIN. The input sometimes has been preprocessed by one of the above routines to the complete form used in the cost analysis.

COSTS

This and the next three subroutines are called by MAIN. COSTS computes the direct charges or costs of each fuel cycle component except for the subdivided back end components which are calculated in COSTSX.

A different batch, indexed by NB, is treated each time it is called. When $LCA > 0$ and $OUTOPT = 1$, it computes times, quantities, prices, direct costs, and present worth costs for component LCA and prints the corresponding line in the detailed batch accounting table, described in item 10 of Sect. 6.4.

SALES

SALES computes the direct costs and credits allowed for the appropriate fuel cycle back end components. Similar to COSTS, it prints a line in the detailed batch accounting table.

CDOLLR

The function CDOLLR computes the factor for converting the current dollar cost to constant dollar cost.

OUT2

The main function of OUT2 is to print, by batch, the levelized component cost breakdown for direct costs and carrying charges, total of direct costs and carrying charges, and cumulative levelized total costs. See item 15, 16, and 17 in Sect. 6.4.

COSTSX

The function of COSTSX is similar to that of COSTS, but applies only to the subdivided back end components. It is called from COSTS, if the special back end feature is requested by $MCOMP > 0$. During the first pass, COSTX reads NAMELIST/COMP/.

OUT2X

When $MCOST > 0$, OUT2X computes and prints the direct charge and levelized costs for each subdivided back end component. It is called from OUT2 after the standard component cost breakdowns are printed. The subdivided back end costs are shown only as a sum in the standard component cost breakdown.

LIBED

The function of LIBED is to edit in detail all Fuel Cycle Models in the Reference Parameters File.

Appendix F. SUBDIVIDING THE BACK END COST COMPONENTS

The 15 different types of cost components listed in Sect. 4.6 include the waste disposal fee and an additional back end processing cost. A more complete treatment of the back end cost should include several components, e.g., reprocessing for recovery of plutonium and uranium, waste treatment of fission products, storage and shipping of spent fuel assemblies, and storage of component materials after separation. Each of these back end components may require different masses, unit prices, and lag times. The standard model used by REFCO has been supplemented with a feature for subdividing the single back end processing component into several (≤ 6) cost components. The input requirements for using this feature and the additional printout are described here. (Since data used in this feature are not stored in the Reference Parameters File and the data are not saved for subsequent cases, the input is always required for each case.)

F.1 Back End Option Signal in NAMELIST/IN/

MCOMP - integer ≤ 6 , number of back end cost components replacing single component No. 8 of list in Sect. 4.6. (0)

F.2 Back End Component Data in NAMELIST/COMP/

This namelist is required only if MCOMP > 0 . Indices M range from M = 1 to M = MCOMP.

BENAME(M) - component names of 8 characters, or less, for identification of the type of back end costs in printout. Enter each name and positional blanks between apostrophes and follow immediately with a comma. The defaults for BENAME(M) are the single letters A through F.

ESCX(M) - Price escalation factors for components with corresponding indices in BENAME.

INCX(M) - type of tax treatment of cost for the corresponding back end component (0):
 = 0, cost is expensed;
 = 1, cost is capitalized.

The letter x in the following array names should be replaced with an A, B, C, D, E, or F. These letters, A through F, signify components corresponding to M = 1 through M = 6, respectively. As an example, if MCOMP = 3, PRICE_x is input as PRICE_A = (data list according to NAMELIST rules), followed by similar input for PRICE_B and PRICE_C.

PRICE_x(N) - unit price of back end cost component x, in \$/unit mass (for masses in units used in BAL_x). Values for each N

may pertain to either years ($PRCOPT < 2$) starting in year $NYCOST$ (see Sect. 5.4.6) or batches ($PRCOPT = 2$). While the code must use prices for all batches extending through the component processing time of all batches, the input may terminate at any $N \geq 1$. Then, for each increment in N , the price is increased by the escalation factor $ESCX(M)$.

$TLEADx(NY)$ - years of lag time, equal to the period of time between the time the fuel is discharged from the reactor until payment for the processing occurs. This is similar to $TLEAD$ described in Sect. 5.5.1.

$BALx(I)$ - mass, usually in kg, for batch I applied to component x . Indices I range from $I = 1$ to $I = NBMAX$. While the units of mass are allowed to be arbitrary, they should correspond to units used in $PRICEx(N)$. Note that there is no code computation of $BALx(I)$ for batch data omitted in the input, as provided for the $BALi$ arrays (see Sect. 5.5.2).

F.3 Printout of Subdivided Back End Components

The printout from subdividing the back end into several components differs from that of other components in some of the tables. These printout differences in the type of tables described in Sect. 6.4 are explained in the following:

1. There is no edit of the input data for this feature in the standard printout of input tables. The edit of the input data cards, however, may be requested with $INEDIT = 1$ (see Sect. 5.1).
2. The detailed batch accounting table shown in Fig. 6.7 includes each back end component in place of "BACK END 1."
3. The direct charges and levelized costs of all back end components are summed and printed as a total under "BACK END" in the component cost breakdown tables shown in Figs. 6.10 and 6.11. Following these tables, additional tables are printed for each back end component giving the direct charges, levelized cost and cumulative levelized costs by batch.
4. The levelized cost by component over the reactor lifetime for each back end component is printed in the summary table shown in Fig. 6.12.

REFERENCES

1. Royes Salmon, *Two Computer Codes (REFCO and POW 76) for Calculating the Fuel Cycle Cost of a Nuclear Power Reactor*, ORNL-4695 (August 1971).
2. Royes Salmon, *User's Manual for REFCO, A Discounted Cash Flow Code for Calculating Nuclear Fuel Cycle Costs*, ORNL/TM-3709 (April 1972).
3. B. E. Prince, J. P. Peerenboom, and J. G. Delene, *A Survey of Nuclear Fuel Cycle Economics: 1970-1985*, ORNL/TM-5703 (March 1977).
4. U.S. Department of Energy, *Report of the Nonproliferation Alternative Systems Assessment Program (NASAP)*, DOE/NE-0001 (June 1980).
5. U.S. Department of Energy, *Nuclear Energy Cost Data Base: A Reference Data Base for Nuclear and Coal-Fired Power Plant Power Generation Cost Analysis*, DOE/NE-0044 (October 1982).
6. Constantine W. Bary and W. T. Brown, "Some New Mathematical Aspects of Fixed Charges," *Transactions of the American Institute of Electrical Engineers*, Vol. 76, p. 230, *Part III Power Apparatus and Systems*, 1957.
7. D. R. Vondy, *Basis and Certain Features of the Discount Technique*, in Appendix F in *A Comparative Evaluation of Advanced Converters*, M. W. Rosenthal et al., ORNL-3686 (January 1965).
8. *Guide for Economic Evaluation of Nuclear Reactor Plant Designs*, NUS-531 (January 1969).
9. R. Michael Harmett and Doan L. Phung, *Three Modes of Energy Cost Analysis - Then-Current Dollars, Base-Year Dollars, and Perpetual Constant Dollar*, ORAU/IEA-78-10(M) (June 1978).
10. Doan L. Phung, *The Discounted Cash Flow (DCF) and Revenue Requirement (RR) Methodologies in Energy Cost Analysis*, ORAU/IEA-8-18(R) (September 1978).
11. Doan L. Phung and Howard H. Rohm, "A Unified Methodology for Cost Analysis of Energy Production," *First Miami International Conference on Alternative Energy Sources*, January 1977, Miami Beach, Florida.
12. Doan L. Phung, "Cost Analysis Methodologies: A Unified View," *Cost Engineering*, pp. 139-45, May/June 1980.
13. "IBM System/360 and System/370 FORTRAN IV Language" (Eleventh Edition), International Business Machines Corp., GC28-6515-10 (May 1974).

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