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**MUICYCL and MUIFAP:
Models Tracking Minor Uranium Isotopes
in the Nuclear Fuel Cycle**

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IN THE NUCLEAR FUEL CYCLE

S. R. Blum and R. A. McLaren
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S. R. Blum

ABSTRACT

Two computer programs have been written to provide information on the buildup of minor uranium isotopes in the nuclear fuel cycle. The Minor Uranium Isotope Cycle Program, MUICYCL, tracks fuel through a multiyear campaign cycle of enrichment, reactor burnup, reprocessing, enrichment, etc. MUICYCL facilities include preproduction stockpiles, U^{235} escalation, and calculation of losses. The Minor Uranium Isotope Flowsheet Analyzer Program, MUIFAP, analyzes one minor isotope in one year of an enrichment operation.

The formulation of the enrichment cascade, reactors, and reprocessing facility is presented. Input and output descriptions and sample cases are presented. The programs themselves are documented by short descriptions of each routine, flowcharts, definitions of common blocks and variables, and internal documentation. The programs are written in FORTRAN for use in batch mode.

I. INTRODUCTION

The computer program MUICYCL was written to study the buildup of minor uranium isotopes in the nuclear fuel cycle over a campaign of up to 40 years. From input cascade data on feeds, products, and capacities plus reactor and reprocessing data, MUICYCL will track material through several cycles of enrichment, reactor fuel, and reprocessing. The model produces output tables listing yearly values of flows, concentrations, and capacities. Up to three minor isotopes - U^{232} , U^{234} , and U^{236} - may be studied in a case. The enrichment process is modeled by a single

matched abundance ratio cascade [1]; optional separative capacities may be specified at the user's option. For each type of reactor fuel (e.g., BWR, PWR, initial core, reload core), burnup is simulated by a relationship giving minor isotope concentrations in spent fuel as a quadratic function of minor isotope concentrations of the fuel charged to the reactor. Stockpiles of spent fuel, segregated by fuel type, are impartially processed up to the rated capacity of the single reprocessing plant. Buildup of Pu^{236} in the reactor and decay of Pu^{236} to U^{232} in the reprocessing phase are also tracked.

Other features of this model include the ability to define external returns to the reprocessing plant, a recovery factor for material losses, and user-supplied coefficients to define the escalation in U^{235} assay of both loaded and spent reactor fuel necessary to offset the presence of U^{236} . Initial stockpiles of unprocessed spent fuel and preproduction inventory at the enrichment plant may be input.

The time step for both input and internal calculation is one year. Input each year are enrichment and reprocessing capacities, external returns for reprocessing, and "stream cards" specifying feeds to and products from the enrichment facility. The program feeds to the enrichment plant any recycled streams from earlier years, then calculates concentrations of all minor isotopes in the product streams. Optionally determined in this phase are escalated U^{235} concentrations of reactor bound streams plus preproduction stream rates which balance stated separative capacities. All enrichment output targeted for reactors is loaded and labeled by year. Next, any reactor fuel completing the burn period in the current year is calculated and sent to reprocessing. Fuel is then

reprocessed to be fed to the enrichment plant along with the following year's input streams as the cycle is repeated.

The Minor Uranium Isotope Flowsheet Analyzer Program (MUIFAP) performs the same enrichment process for one year and one minor isotope per case. U^{235} concentrations are not escalated and preproduction is not adjusted for separative capacity.

The programs execute independently in batch mode. MUICYCL produces tabular data organized by isotope and stream type. Both programs were written in FORTRAN IV for the IBM/360-370 series of computers.

II. MATCHED ABUNDANCE RATIO CASCADE

The matched abundance ratio cascade formulated in [1] and used in both computer models is the multicomponent analogue of the (binary) ideal cascade. Multicomponent formulations of "value function" and "separative work" are derived.

In the binary ideal cascade no separative work is lost: all streams which are mixed have identical concentrations. A consequence of this is that the binary ideal cascade minimizes total flow and total separative work. While mixed streams in the matched abundance ratio cascade cannot have identical concentrations they are made to have identical values of the abundance ratio R . In a three-component cascade,

$$R = \frac{x}{1 - x - y} , \quad (2-1)$$

where x and y are the concentrations of U^{235} and the "minor isotope," respectively. No separative work will be lost in this type of cascade but this cascade does not minimize total flow. The authors of [1] did show that "for uranium isotope separation the total flow in the

matched U^{235}/U^{238} abundance ratio cascade exceeds the minimum by an insignificant fraction for a wide range of U^{236} concentrations" [1,p.188].

Let

$$H(x,y) = yR^{-(2k-1)} , \quad (2-2)$$

where

$$k = \frac{\psi_2}{\psi_1} .$$

ψ_1 is the stage separation factor for the two-component system of U^{235} and U^{238} ,

ψ_2 is the corresponding factor for separation of the minor isotope and U^{236} .

H is called the "homogeneous function." It can be shown [1] from separative work considerations that, in the matched abundance ratio cascade, an "H balance" applied over the whole cascade and over any portion of the cascade. For the cascade of Figure 1,

$$P \cdot H(x_p, y_p) + Q \cdot H(x_Q, y_Q) + S \cdot H(x_S, y_S) + W \cdot H(x_W, y_W) \quad (2-3)$$

$$- E \cdot H(x_E, y_E) - F \cdot H(x_F, y_F) = 0 .$$

An H balance applied over portions of the cascade produces an equation for each side withdrawal stream. For the Q stream

$$P \cdot H(x_p, y_p; x_Q, y_Q) = 0 , \quad (2-4)$$

and for the S stream

$$P \cdot H(x_p, y_p; x_S, y_S) + Q \cdot H(x_Q, y_Q; x_S, y_S) - E \cdot H(x_E, y_E; x_S, y_S) = 0 , \quad (2-5)$$

where

$$H(x,y;\alpha,\beta) = H(x,y) - H(\alpha,\beta) - (x-\alpha) \left. \frac{\partial H}{\partial x} \right|_{\alpha,\beta} - (y-\beta) \left. \frac{\partial H}{\partial y} \right|_{\alpha,\beta} .$$

For a cascade with M withdrawal streams, there are $M-2$ of these side-stream H balance equations, one cascade H balance equation, and material balance equations for U^{235} , the minor isotope, and total material. A separative work equation, defined in the next section, completes the formulation of the matched abundance ratio (or "matched R") cascade.

Fig. 1. Sample Enrichment Cascade.

III. MINOR URANIUM ISOTOPE MODELS

MUICYCL, the Minor Uranium Isotope Cycle Program, may be analyzed in its three phases - reactor operation, reprocessing, and enrichment. Each phase is executed once each year in the given order. MUIFAP involves enrichment only and is discussed in that section.

A. Reactor Operation

This phase calculates concentrations of minor uranium isotopes (MUI), Pu^{236} , and U^{235} in spent reactor fuel as functions of MUI concentrations of loaded fuel. All such functions are quadratic, or a sum of two quadratics of the form

$$y = A + Bx + Cx^2, \quad (3-1)$$

where $C=0$ is acceptable. Recently used function coefficients were generated by least squares correlations [2]. For U^{236} , the discharge concentration y is a function of the initial concentration x , and similarly for U^{234} . For U^{232}

$$y = A_1 + B_1x_1 + C_1x_1^2 + A_2 + B_2x_2 + C_2x_2^2 \quad (3-2)$$

where the discharge U^{232} concentration is a function both of the initial U^{232} concentration, x_1 , and the initial U^{236} concentration, x_2 . Generally $A_1 = C_1 = 0$. The discharge Pu^{236} concentration is a single quadratic function of the initial U^{236} concentration.

Finally, initial U^{235} reactor concentrations were escalated above target values (in the enrichment phase) to compensate for the presence

of U^{236} . A quadratic equation then defines the discharge U^{235} concentration, y , as a function of the escalation, x , in initial U^{235} concentration. The year in which reactor fuel is discharged is determined by the cycle time, an input parameter for each type of fuel.

B. Reprocessing

The reprocessing facility is modeled as a single plant whose capacity is input for each year. Stockpiles of spent fuel, segregated by fuel type, are accumulated and processed up to the rated capacity. If the total stockpile exceeds capacity, the same fraction of each stockpile is reprocessed, with one exception: when the stockpile of one fuel type is less than 2% of capacity, all of this stockpile is reprocessed.

Since PU^{236} decays to U^{232} with a half-life of 2.95 years, concentrations of U^{232} in reactor discharge awaiting reprocessing may change significantly. A time-dependent PU^{236} - U^{232} relationship developed in [2] is used in a modified form (Appendix A) which allows yearly additions to each stockpile.

As noted earlier, an input "recovery factor" defines material losses; specifically, the reduction in weight from the time material leaves the enrichment facility to the same time one cycle later. The recovery factor is applied each year to material when it is unloaded from the reactor.

The user may add external returns to the reprocessing queue in any year. The recovery factor is applied to these returns when they are added to the requested stockpile.

C. Enrichment

The enrichment phase is by far the most complex and time-consuming of the three phases in MUICYCL. A single matched abundance ratio cascade [1] is modeled. Additional complexity is provided by the use of preproduction streams to match a rated separative work value, and escalation of specified U^{235} values due to U^{236} .

This requires up to three levels of calculations:

- 1) Adjusting preproduction stream rates to attain the rated separative work value.
- 2) Iteration on U^{235} concentrations of reactor bound products.
- 3) Determination of minor isotope concentrations in cascade product streams which will satisfy material balances and matched abundance ratio equations.

While the first two levels are optional, the third level is always executed each year. In MUIFAP, only the third level is available. Each level is now discussed in more detail, and in reverse order.

Determination of Minor Isotope Concentrations

The formulation of the matched abundance ratio cascade is implemented in this level. The model calculates concentration values of all minor isotopes in each withdrawal stream. Other than the flow rates of any two streams, all other rate and concentration data are given. The three-component formulation of the matched R cascade is used, and each of the up to three minor isotopes is solved for the whole campaign independently of the other minor isotopes.

Each cascade with M withdrawal streams, and thus M unknown concentrations, satisfies $M-2$ sidestream H balance equations of the form of Equations (2-4) or (2-5), one cascade H balance (Equation (2-3)) and a minor isotope material balance equation. This system of equations is solved by a standard numerical technique, the Newton formulation of the Secant method [3]. The other two material balance equations, U^{235} and total material, are satisfied by adjusting two stream rates selected by the user.

Adjusting U^{235} Concentrations of Reactor Bound Material

Since the presence of U^{236} in reactor fuel reduces the fuel reactivity, the initial U^{235} assay of the fuel may be escalated in the enrichment phase to compensate for this. A quadratic equation of the forms of Equation (3-1) is again applied. However, the returned value y is defined as the increment in the initial U^{235} assay over the rated value. The independent variable x is the U^{236} assay of the stream as withdrawn from the cascade. Equation coefficients may be input for each type of fuel.

Adjusting Preproduction to Match Rates Separative Capacity

The separative capacity of the cascade may be forced to equal a specified value by feeding from, or adding product to, preproduction stockpiles. There are two preproduction stockpiles, each with a specified U^{235} assay -- the initial inventory and the inventory of new preproduction. When inventory is being fed to the cascade the initial inventory is exhausted first.

The three component "elementary value function" is

$$V(x,y) = \left(2x + \frac{2x}{2k-1} y - 1\right) \ln R. \quad (3-3)$$

The three component separative work equation for Figure 1 is

$$SW = P \cdot V(x_p, y_p) + Q \cdot V(x_Q, y_Q) + S \cdot V(x_S, y_S) - E \cdot V(x_E, y_E) - F \cdot V(x_F, y_F). \quad (3-4)$$

This is easily generalized to an M stream cascade.

IV. INPUT DESCRIPTION

A. MUICYCL

Introduction

The input is set up so that any number of independent cases may be run in one job. Each case is an analysis of one to three minor isotopes in the nuclear fuel cycle for a campaign of several years.

Data for each case are entered as follows:

Case Card

Preproduction Inventory Card

Reactor Fuel Cards for first minor isotope

U^{235}/U^{236} Cards (required only when first minor isotope is U^{236})

Yearly data for first year

Yearly data for second year

.

.

.

Yearly data for last year

End-of-Yearly-Data Card

Reactor Fuel Cards for second isotope if present

Reactor Fuel Cards for third isotope if present

Yearly data consist of the following cards, in order:

Year and Capacity Card
Returns Cards (Optional)
Stream Cards

The last data card of the job is the End-of-Job Card. A detailed description of the input data is provided in the next section.

Detailed Description

1. Case Card - First card of each case

<u>Column</u>	<u>Format</u>	<u>Description</u>
1-35	A35	Name of case (optional).
36-39, 40-43, 44-47	314	Molecular weight of the minor isotope(s) in the same order in which minor isotope data will be entered on succeeding cards. If there is more than one minor isotope in this case, the first entry must be "236".
48-50	A3	PPM flag - if the minor isotope weight fraction of U^{232} in all later input for this case is to be entered as parts per million of U^{235} , punch any character(s) here.
51-56	A6	Classification flag - leave blank if unclassified; punch "SECRET" if secret output; punch any other characters if confidential.
59-60	I2	Flag, KASEPR, to generate debugging output for all years in the case. KASEPR=1: limited output KASEPR=2: full output
63-66	A4	Yearly output suppression. Enter any characters to suppress printing of all yearly output.
67-70	A4	Enter any characters to suppress U^{235} escalation due to U^{236} , regardless of values on U^{235}/U^{236} card. Note, however, that an entry must be made in columns 51-60 of the U^{235}/U^{236} card.

1. Case Card (Cont'd)

<u>Column</u>	<u>Format</u>	<u>Description</u>
80	A1	Enter any character if an "Iteration Parameter Data Set" is to be included with each isotope definition. See Special MUICYCL Input.

2. Preproduction Inventory Card - Second card of each case.

<u>Column</u>	<u>Format</u>	<u>Description</u>
1-10	D10.2	Inventory of preproduction (by weight) at beginning of case.
11-20	D10.2	U ²³⁵ fraction in inventory.
21-30, 31-40, 41-50	3D10.2	Minor isotope weight fraction(s) in inventory, in the order as specified on the case card.
51-60	D10.2	U ²³⁵ fraction in all new preproduction.

3. Reactor Fuel Cards - Two cards for each type of reactor fuel when minor isotope is U²³⁵; otherwise one card. See note 3 in the next section.A. First Card - Required

<u>Column</u>	<u>Format</u>	<u>Description</u>
1	A1	Enter an asterisk (*) if this is the last type of reactor fuel defined.
2	I1	Fuel code number, KTYP. $1 \leq \text{KTYP} \leq$ number of fuel types input. No more than six fuel types may be defined.
3-8	A6	Fuel name (optional).
9-10	I2	Cycle time in years. See note 5.
11-20	E10.0	Weight of initial stockpile of this fuel type awaiting reprocessing at beginning of first year.
21-30	E10.0	Weight fraction of U ²³⁵ in initial stockpile.
31-40	E10.0	Weight fraction of minor isotope in initial stockpile.

A. First Card (Cont'd)

<u>Column</u>	<u>Format</u>	<u>Description</u>
41-50, 51-60, 61-70,	3E10.0	Coefficients A, B, and C, respectively, in the equation defining the concentration of the minor isotope when the fuel is removed from the reactor as a function of the minor isotope concentration when the core is loaded. The equation is the standard quadratic equation,

$$y = A + Bx + Cx^2 ,$$

where y and x are final and initial weight fractions, respectively.

71-78	F8.0	The recovery factor (≤ 1 .) applied to the weight of the fuel loaded in a reactor to derive the weight of the fuel after it is unloaded and reprocessed. The factor is applied to reactor fuel when it is unloaded from the reactor. The factor is also applied to returns (Returns Card) prior to reprocessing.
-------	------	--

B. Second Card - The second card is present only when the minor isotope is U^{232} .

<u>Column</u>	<u>Format</u>	<u>Description</u>
11-20, 21-30, 31-40	3E10.0	Coefficients A, B, and C, in the quadratic equation (see above), to generate final U^{232} concentration in the reactor as a function of initial U^{236} concentration in the reactor.
41-50, 51-60, 61-70	3E10.0	Coefficients A, B, C, respectively, in the quadratic equation (see above) to calculate final PU^{236} concentration as a function of initial U^{236} concentration in the reactor.
71-80	E10.0	Weight fraction of PU^{236} in initial stockpile.

4. U^{235}/U^{238} Card - Required only when minor isotope is U^{235} .

Column	Format	Description
1	A1	An asterisk (*) if this is the last data card of this type; blank otherwise.
2-3, 4-5, 6-7, 8-9, 10-11, 12-13	6I2	Enter the fuel code numbers of all fuel types to which the coefficients on the card apply.
21-30, 31-40, 41-50	3F10.5	Coefficients A, B, and C in the quadratic equation (see above) to generate the change in U^{235} assay of reactor requirements as a function of U^{235} assay.
51-60, 61-70, 71-80	3F10.5	Coefficients A, B, and C in the quadratic equation (see above) to calculate the U^{235} assay of spent reactor fuel due to the increment in U^{235} assay of loaded cores.

5. Year and Capacity Card - First card of data for each year in the case.

Column	Format	Description
2-5	I4	Current year.
6-15	F10.2	Capacity of reprocessing plant (in weight units for the year) after the recovery factor has been applied.
16-25	F10.2	Capacity of enrichment complex (in separative work units for the year). If blank, inventories will not be fed or produced.
30	A1	A non-blank character is entered if any Returns Cards are to follow.
31-35	I5	Flag, IYRPR, to affect printing of debug output for this year. The value of IYRPR may override (for this year only) the value of KASEPR on the case card. IYRPR<0: Suppress debug output IYRPR=0: Default to value of KASEPR IYRPR=1: Print limited debugging output IYRPR=2: Print full debugging output.

6. Returns Card - One card for each return to the reprocessing plant in a year. The card(s) immediately follow the Year and Capacity Card. Each such return has an associated "fuel code number", i.e., a Reactor Fuel Card must have been input for each type of return.

<u>Column</u>	<u>Format</u>	<u>Description</u>
1	A1	If this is the last Returns Card for this year, enter an asterisk (*) here.
2	I1	Fuel code number.
11-20	E10.0	Stream rate.
21-30	E10.0	Weight fraction of U^{235} . Default is "base value" on Reactor Fuel Card, Cols. 21-30.
31-40, 41-50, 51-60	3E10.0	Minor isotope weight fraction(s), in the order as specified on the Case Card.
61-70	E10.0	If U^{232} is one of the minor isotopes in this case, enter here the weight fraction of Pu^{236} .

7. Stream Cards - One card for each stream, in any order. See note 2.

<u>Column</u>	<u>Format</u>	<u>Description</u>
1	A1	If this is the last stream card for this year, enter an asterisk (*) here.
2	A1	"1" if stream is a feed ("Input" to cascade). "0" if stream is a withdrawal ("Output" from cascade).
3-9	A7	Stream name (optional).
10	I1	If this is a product stream to be used as reactor fuel or, if this is a feed stream which represents a reactor return, enter the "fuel code number" here (see Reactor Fuel Cards).
11-20	E10.0	Stream flow rate. Leave this field blank for one feed stream and one withdrawal stream. The values will be determined by material balance equations.

7. Stream Cards (Cont'd)

<u>Column</u>	<u>Format</u>	<u>Description</u>
21-30	E10.0	Weight fraction of U^{235} .
31-40, 41-50, 51-60	3E10.0	Weight fraction(s) of minor isotope(s). If this is a withdrawal stream, these fields are not processed.

8. End-of-Yearly-Data Card - Follows the last stream card of the last year in a case.

<u>Column</u>	<u>Format</u>	<u>Description</u>
1	A1	"**"

9. End-of-Job Card - This is the last data card in the job.

<u>Column</u>	<u>Format</u>	<u>Description</u>
1-3	A3	"END"

Notes on MUICYCL Input.

1. Any number of cases may be run in one job. The duration of each case plus the longest cycle time may not exceed 40 years.
2. A maximum of 20 feed streams and 19 product streams may be defined in each year, including recycle streams. No more than six types of reactor fuel streams may be defined.
3. The program expects at least one Reactor Fuel Card. When running a case which doesn't contain any recycle, enter a "dummy" reactor card with "*" in column 1, "1" in column 2. If this is a U^{232} case, follow this card with a blank card.
4. The PPM (part per million) flag defines the mode of entry of the U^{232} weight fraction on Preproduction Inventory Cards, Reactor Fuel Cards, Return Cards, and Stream Cards.
5. The definition of cycle time is as follows: If a fuel type has a cycle time of K years and leaves the enrichment facility in 1975, it will become available to be reprocessed and fed to the cascade in year $1975 + K$.
6. Reprocessing and enrichment both occur in the same year.

7. The recovery factor entered on the Reactor Fuel Card defines the weight reduction from the time material leaves the enrichment facility to the time it is re-fed to the reactor after completing a cycle. It is applied immediately prior to the reprocessing step, both to "cycling material" and to "Returns Card Material."
8. No assumptions are made on the units of material flow although some output is labeled "MTU's".
9. Do not input any stream flows with magnitude less than 0.01. Loss of accuracy will result. Increasing all stream rates by a constant factor will solve this problem.

Special MUICYCL Input

Occasionally a run will fail because an iteration procedure could not converge. The user can get more information on the cause of failure by setting the flags KASEPR on the Case Card and IYPRP on the Year and Capacity Card. See "Debugging Output".

If "trouble shooting" has established that some parameter(s) in an iteration phase requires adjustment, the "Iteration Parameter Data Set" will perform this function during execution. The data set is entered once for each minor isotope and its use is signaled by the flag in column 80 of the Case Card. This data set immediately precedes the yearly data for the first year. For the second and third minor isotopes the data set follows the pertinent Reactor Fuel Cards. Data are read by the "Namelist" format; thus the data set will look like

```
&PARMS a1 a2 ... an &END
```

where data may be entered from column 2 to column 80. At least one space must be left prior to a_1 and following a_n . Spacing between each a_i is optional. Each a_i takes the form

```
"Name = Value," ;
```

"Name" is one of the variable names following, and

"Value" is the value assigned to the variable.

Spaces are permitted adjacent to the "=" sign, but not elsewhere in a_i .

To continue onto another card, break after an a_i . There may be from zero to seven a_i entries. Each variable which is not entered takes its default value.

Variable Name

Description

EXP

EXP is used in generating the initial estimate of minor isotope concentration (Method B) and in "unmerging" merged streams. The ratio of minor isotope concentrations in adjacent streams is estimated as the ratio of the corresponding U^{235} concentrations raised to the EXP power. Default values are EXP=1.6 for U^{232} , EXP=1.3 for U^{234} , and EXP=.7 for U^{236} .

TOL235

In the enrichment phase, the U^{235} concentration of reactor bound product streams is escalated due to the presence of U^{236} . When the largest calculated increment in the U^{235} weight fraction does not exceed TOL235, this iteration phase is considered complete. Tested in S236. Default value is 5D-8.

<u>Variable Name</u>	<u>Description</u>
TOLSW	In the enrichment phase, stream rates may be recalculated to attain the rated separative capacity. When the difference between calculated and capacity values divided by the capacity is less than TOLSW, this iteration process is completed. Tested in DELTA. Default = 10^{-4} .
TOLGEN	The relative difference between the calculated SW value and the target value is compared with TOLGEN at the start of the lowest level of iterations (level 3) in the enrichment phase. If it exceeds TOLGEN, a new initial estimate is more likely to be generated rather than using the previous final estimate, which may be inadequate. Tested in DOYEAR. Default is TOLGEN = .300
TOLMRG	In the enrichment phase calculation of product stream minor isotopes, streams whose U^{235} weight fractions differ (in absolute value) by less than TOLMRG are temporarily merged into one stream. Larger TOLMRG values decrease the likelihood of non-convergence but increase the number of iteration steps. Executed in Subroutine MERGE. Default is TOLMRG = 50^{-4} .

<u>Variable Name</u>	<u>Description</u>
CR1	Convergence criterion of iterations to determine minor isotope concentrations. For a cascade with M withdrawal streams, there are M simultaneous equations to be solved. Convergence is achieved when the sum of squares of the M residuals is less than $M \cdot CR1$. Default is $CR1 = 2.5D-17$.
CR2	Iteration stall criterion, tested in the same stage as CR1 above. The program exits due to stall when the square of the distance between the previous and present estimate vectors is less than $M \cdot CR2$. Since each estimate component was initially scaled to 1, this is a relative change criterion. Default is $CR2 = 1D-16$.

The default values and changed values of these parameters are listed at the bottom of the Isotope Data Page of each minor isotope for which the data set has been entered.

B. MUIFAP

Any number of independent cases may be loaded in a run. Each case, the analysis of one minor uranium isotope for one cascade time period, consists of a Case Card, Stream Cards, and a Final Card.

1. Header Card - First input card in a run

<u>Column</u>	<u>Format</u>	<u>Description</u>
1-6	A6	Classification flag - leave blank if unclassified; punch "SECRET" if secret output; punch any other characters if confidential.
7-12	A6	Debug flag - punch any characters to generate iteration data.

2. Case Card - First card of each case

<u>Column</u>	<u>Format</u>	<u>Description</u>
1-35	A35	Name of case (optional).
37-39	I3	Molecular weight of the minor isotope; e.g., "232". Any uranium isotope other than U^{235} and U^{238} is acceptable.
40-41	A2	PPM flag - if the "weight fraction of minor isotope" is to be input as parts per million of U^{235} , punch any character here.

3. Stream Card - One card for each stream, in any order. A maximum of 20 feed streams and 20 withdrawal streams may be defined per case.

<u>Column</u>	<u>Format</u>	<u>Description</u>
1	A1	"1" if stream is feed (input to cascade); "0" if stream is withdrawal (output from cascade).
3-10	A8	Stream name (optional).
11-20	E10.0*	Stream flow rate. Leave this field blank for one feed stream and one withdrawal stream; these rates are calculated internally to satisfy material balance equations.

<u>Column</u>	<u>Format</u>	<u>Description</u>
21-30	E10.0*	Weight fraction of U^{235} .
31-40	E10.0*	Weight fraction of minor isotope. If PPM flag is on, parts per million of U^{235} . This field is not processed if the stream is a withdrawal.

4. Final Card - Last card of each case.

<u>Column</u>	<u>Format</u>	<u>Description</u>
1	A1	"*"

V. OUTPUT DESCRIPTION

A. Standard Output

Standard MUICYCL output from a case consists of a title page, case data page, isotope data pages, a set of summary reports and, optionally, an annual report for each year and each minor isotope. Each summary report presents a tabulation of assays, material flows, and capacities, listed year-by-year. Figure 2 portrays a sample summary report. The set of summary reports consists of the following:

Material Flows and U^{235} Concentrations - Feed Streams

Material Flows - Other Feed Streams

Material Flows and U^{235} Concentrations - Product Streams

Material Flows - Other Product Streams

Minor Isotope Concentrations in Products

Minor Isotope Concentrations in Feeds

*If the data are entered in exponential form, it must be right adjusted. If exponential form is not used, the data may be located anywhere in the field with a decimal point, or right adjusted without a decimal point.

YEAR	CORE TYPE:		MATERIAL FLOWS AND U-235 CONCENTRATIONS(X) - FEED STREAMS							
	ASSAY:		PWR IC		PWR RL		BWR IC		BWR RL	
1974	4.000E 00	0.740	1.900E 01	0.900	0.0	0.860	1.900E 01	0.840		
1975	0.0	0.0	1.900E 01	0.900	0.0	0.860	2.300E 01	0.840		
1976	2.580E 02	0.740	3.700E 01	0.900	0.0	0.860	5.700E 01	0.840		
1977	6.580E 02	0.740	6.100E 01	0.900	0.0	0.860	4.200E 01	0.840		
1978	8.490E 02	0.740	1.800E 02	0.900	0.0	0.860	6.700E 01	0.840		
1979	2.199E 02	0.743	1.391E 02	0.904	0.0	0.862	4.050E 02	0.840		
1980	4.399E 02	0.744	2.369E 02	0.906	0.0	0.863	1.207E 02	0.843		
1981	7.196E 02	0.745	6.041E 02	0.906	0.0	0.864	2.715E 02	0.844		
1982	5.702E 02	0.748	6.968E 02	0.912	0.0	0.867	3.361E 02	0.845		
1983	7.394E 02	0.751	1.067E 03	0.915	0.0	0.870	5.878E 02	0.849		
1984	1.193E 03	0.748	1.166E 03	0.912	0.0	0.867	5.922E 02	0.851		
1985	1.407E 03	0.748	1.246E 03	0.911	0.0	0.869	7.363E 02	0.849		
1986	1.367E 03	0.750	1.421E 03	0.914	0.0	0.870	8.317E 02	0.851		
1987	1.569E 03	0.752	1.537E 03	0.914	0.0	0.871	1.204E 03	0.852		
1988	1.499E 03	0.753	2.163E 03	0.920	0.0	0.871	1.655E 03	0.857		
1989	1.102E 03	0.753	2.709E 03	0.927	0.0	0.871	1.999E 03	0.862		
1990	7.781E 02	0.753	3.234E 03	0.930	0.0	0.871	1.999E 03	0.862		

Fig. 2. Sample Summary Report.

Preproduction Inventories and Summary

Unprocessed Returns Inventory (by core type)

Miscellaneous Annual Data

More detailed MUICYCL information and standard MUIFAP output are provided by annual reports for each isotope, as displayed in Fig. 3. The data INPUT-H and OUTPUT-H are the unsigned contributions of feed streams and product streams respectively to the H balance equation (2-3) of the cascade. The three component separative work values are calculated by Equation (3-4) while the two component SW value uses $V(x,0)$ in the same equation. Annual MUICYCL output may be suppressed by a flag on the Case Card and is always printed if a serious error occurs.

B. Debugging Output

Debugging output in MUICYCL is generated by setting to a positive value one of the input flags KASEPR or IYRPR.

To utilize this output, the enrichment iteration procedure must be understood (see Chapter VIII, Section C). One "cascade solution" step consists of solving a cascade with M withdrawal streams for the M minor isotope concentrations. Pairs of adjacent withdrawal streams with nearly identical concentrations may have been merged ($IMERGE > 0$) prior to this step as an aid to convergence. They will be "unmerged" for a later cascade solution step ($IMERGE = -1$). One level higher than the cascade solution, an iteration procedure to adjust U^{235} concentrations due to the presence of U^{236} is performed ($U236ITERS = \dots$). At the highest level, preproduction stream rates are adjusted to attain the

URANIUM FLOWSHEET ANALYZER
1985

CASE: GRAND TEST - 232+236+27A
DATE: 01-03-79

INPUT STREAMS	FLOW NAME	CODE	URANIUM WEIGHT	5-PERCENT	4-PERCENT	9-CONTENT	4-CONTENT
	2		4.80162D 02	3.2000000	0.003274854614	1.86532D 01	1.80194D-02
	2		2.70905D 03	0.9267151	0.00164937372	2.31082D 01	4.46831D-02
	4		8.33572D 02	0.8707115	0.00325443153	7.24180D 00	2.71114D-03
	1		1.65513D 03	0.8566779	0.000988446537	1.21773D 01	1.84181D-03
	1		1.10224D 03	0.7336319	0.00051015566	2.74992D 02	1.84237D-03
	0		3.44957D 04	3.7110000	0.0	0.0	0.0
	TOTAL		4.12485D 04			3.15492D 02	9.54634D-02
							1.83714D 02
OUTPUT STREAMS							
	2		8.10000D 00	95.0000000	0.057017233590	7.69500D 00	4.61840D-03
	2		3.06100D 00	95.1500000	0.050365556331	2.88172D 00	1.54180D-03
	4		3.89800D 03	3.2817851	0.00115251274	1.27922D 02	4.49187D-02
	4		3.29400D 03	2.7903139	0.000815880628	9.19129D 01	2.64781D-02
	0		3.40433D 04	0.2500000	0.000021822596	8.51084D 01	7.44957D-03
	TOTAL		4.12485D 04			3.15492D 02	8.54034D-02
							1.83714D 02
DEPLETED INVENTORIES (YR END):							
	NEW PREPROD		4.36350D 03	3.2000000	0.003274854614		
UNRECEIVED RETURNS (THIS YR):							
	2		2.25432D 03	0.7334039	0.000510155665		
	2		5.54058D 03	0.9267151	0.00164937372		
	3		1.70483D 03	0.8707115	0.00325443153		
	4		3.38500D 03	0.8566779	0.000988446537		
5.4.8 SEPARATIVE WORK			2.76018D 04			SW. DIFFERENCE/TOT:	3.29918D 00
5.8 SEPARATIVE WORK			2.61762D-01			TAILS 4-CENTENT/TOT:	8.73280D-02
DIFFERENCE							
URANIUM WEIGHTS DETERMINED BY BALANCE							

Fig. 3. Sample Annual Report.

rated separative work values (SWITERS = ...). These two upper level iterations are performed only when the minor isotope is U^{236} and their execution is not suppressed by input flag.

IPR is the internal print flag set each year to the value of KASEPR or IYRPR. When IPR = 1 initial and final data for each cascade solution step are printed. This includes values of iteration counters at the start of the solution step, a measure of convergence of the SW iteration phase (see the definition of TOLSW in the Iteration Parameter Data Set), a list of the initial and final minor concentration estimates, and the maximum possible minor isotope values (YPMAX) when used in the initial estimates. No extra reactor or reprocessing output is printed. The annual report comprises the final IPR = 1 output.

When IPR = 2, the IPR = 1 output is printed. Additionally, data for each iteration within a cascade solution step is printed - the scaled and unscaled concentration vector (X), the calculated function vector (G and F), and the estimate to be dropped from the basis. The estimate vector has been scaled so that each component of the initial estimate is 1. At the beginning of each cascade solution step a stream table is printed, the rates of the feed and product stream calculated to close the total material balance and U^{235} balance are displayed, and the estimates and function vectors entering the basis are evaluated and listed. At the end of the cascade solution step the mode of termination is explained. The operation of the iteration routine used, SECANT, is detailed in [4].

A running account of reactor and reprocessing operations is printed when IPR=2. Future reactor output, U^{235} fraction in reprocessing pots,

direct returns to reprocessing plants, present reactor output to reprocessing, and quantity reprocessed and remaining in each pot are all enumerated. Use of care in the request for IPR=2 output is advised. The user may expect up to 15 pages of debug output per year for U^{236} with no iterations suppressed, and less than 5 pages per year for U^{232} or U^{234} . IPR = 1 generates less than a page per year per minor isotope.

Debugging output from MUIFAP, set by the debug flag, is virtually identical to the extra MUICYCL output generated when IPR=2, as defined previously.

C. Error Messages

Warning messages and terminating messages are listed below in alphabetical order, followed by a short explanation where necessary. The subroutine from which the message was printed is displayed in parentheses. The messages refer to the MUICYCL program only unless otherwise noted.

BLEW IN YEAR *iiii* AFTER COMPLETING *jj* *kk* U^{236} LOOPS AND
SW LOOPS RESPECTIVELY. (DOYEAR)

This is a warning message only (IER=-2). It indicates some convergence difficulties. If the problem is not resolved by the end of the year, however, it results in the message "SERIOUS ERROR (IER=1)..." and termination of the case.

COLUMN 2 OF STREAM CARD FOR STREAM "*iiiiii*" IS
INCORRECT: "*k*" (SETUP)

The value of "*k*" must be either "I" or "O".

ERROR: ONE OF THE FOLLOWING MINOR ISOTOPE VALUES IS
INVALID. EXIT. *iii* *jjj* *kkk*. (NEWCAS)

On the Case Card, at least one nonzero minor isotope value, *m*, was outside the range $230 \leq m \leq 240$.

??FEED STREAM TYPE i, TO REPROCESSING?? NOT DEFINED. EXIT (REPROC)
A Returns Card has an undefined fuel code number.

ITERATION IS STALLED. RETURN BEST ESTIMATE. EXIT. (SECANT)
Before iterations had converged, the relative change in the estimate vector fell below a "trigger value". This is not usually of concern. Check final function values. This has the same implication in MUIFAP. In both programs this message is printed only when the full debug flag is on.

SERIOUS ERROR (IER=i) IN YEAR jjjj PREVENTED CONTINUATION OF CASE. PRINT REPORT AND EXIT FROM CASE. (MAIN)
The case is terminated with this year. Check input data for this year and previous years. Generate debug output for this year (IYRPR=2) and consult with programmer contact.

STOP: MAXIMUM ITES. RETURN BEST ESTIMATE (SECANT)
The SECANT routine couldn't converge in the maximum number of iterations, presently 30. This is a warning message only. With MUIFAP this is a serious error often implying an input data error.

***TERMINATING ERROR: FIRST COMPONENT LISTED ON CASE CARD (NEWCAS)
MUST BE 236.

TOO MANY COEFFICIENTS (ISOPAG)
More U^{235}/U^{236} cards were present than the maximum allowable number of core types (MAXKOR=6).

***WARNING: EXCEEDED MAXIMUM NUMBER OF ITERATIONS FOR (MAIN)
ATTAINING SW CAPACITY, ii. EXIT FROM THIS LOOP.
"ii" iterations were not sufficient to converge on the input separative capacity value by changing preproduction rates. Check input data.

WARNING: IN jjjj WITH S# ITES, U236 ITES, IMERGE=ii jj k, (DOYEAR)
CONVERGED TO A NEGATIVE CONCENTRATION.
This warning message (IER=-1) indicates convergence difficulties. It may be ignored if no higher level error messages follow.

WARNING...LAST ITERATIONS, IN iiij DIDN'T COMPLETELY CONVERGE (MAIN)
DUE TO VECTOR STILL. FINAL RESIDUAL WAS x.xxD-xx; TARGET
WAS y.yyD-yy. CONTINUE EXECUTION

The "final residual", which is the sum of the squares of the M balance equation values, is greater than the "target" value for convergence. If the final value exceeds the target value by two orders of magnitude or more, the results are suspect. Consultation with the programmer contact is suggested.

WARNING: MAXIMUM NUMBER OF ITES ON U235 ESCALATION, ii. (MAIN)
EXIT FROM THIS LOOP.
Check input data.

*** WARNING THERE IS A DEFICIENCY OF xxxxx.xx SWU OF (DELTA)
SEPARATIVE WORK CAPACITY THIS YEAR. TERMINATE THIS
YEAR jjjj, BUT CONTINUE CASE.
In year "jjjj" the cascade could not produce the
required products from given feeds plus all available
stockpiled production except by using "xxxxx.xx" SWU's
above capacity.

WARNING...YOU HAVE DEFINED THE MAXIMUM NUMBER OF FUEL TYPES (ISOPAG)
ALLOWED AND YOUR LAST REACTOR FUEL CARD HAS NO "*" IN COLUMN
1. PROGRAM ASSUMES THIS WAS YOUR LAST SUCH CARD AND CONTINUES.

WHEN RECYCLE STREAMS ARE ADDED, THE NUMBER OF STREAMS (NEWFDS)
EXCEEDS THE MAXIMUM.
In the present year being executed, the total number
of streams exceeds the maximum of 40. Recall also that
there are always two, and sometimes three, preproduction
streams involved in a solution when iterating upon U²³⁵
and matching SW capacity.

VI. DEMONSTRATION OF PROBLEM SOLUTION

A. MUICYCL

Use of MUICYCL to solve a sample problem is demonstrated here. A list of the setup deck, consisting of Job Control Language (JCL) and input data, is displayed in Fig. 4. The full output of the case is presented in Fig. 5.

The program is set up to run on the IBM 360/70 class of machines and was written in IBM FORTRAN IV. The user executes an object module, which resides on a 1600 bpi tape. The resource requests of "CPU95" and

[illegible]

Fig. 4. Setup Deck for MUICYCL

[illegible]

Fig. 4. Setup Deck for MUICYCL (cont'd).

MUICYCL - A MINOR URANIUM ISOTOPE CYCLE PROGRAM

VERSION OF 10/12/78

MUICYCL WAS PROGRAMMED BY S.P. BLUM & R.A. MCCLAREN,
COMPUTER SCIENCES DIVISION, FULL DOCUMENTATION IS
PROVIDED IN ORNL/CSO-37, MUICYCL AND MUICAP: MODELS
TRACKING MINOR URANIUM ISOTOPES IN THE NUCLEAR FUEL
CYCLE."

31-33-76

CASE DATA PAGE

PAGE 2

CASE NAME: GRAND TEST - 232+238+234 NOVR
MINOR ISOTOPE MOLECULAR WEIGHTS: 238 232 234
OUTPUT: UNCLASSIFIED
YEARLY CASCADE OUTPUT - SUPPRESSED

GRAND TEST - 232+238+234 NOVR

ISOTOPE DATA PAGE - MINOR ISOTOPES U238

PAGE 3

REPRODUCTION INVENTORY DATA:
INITIAL INVENTORY:
SUBSEQUENT REPRODUCTION:

1700+000TU U235 FRACTION=0.03000 U238 FRACTION= 1.100000-04

ALL FOLLOWING QUADRATIC FIT EQUATIONS ARE OF THE FORM $Q = A + Bx + Cx^2$, Q=P(12)

WHERE Q AND 2 ARE ISOTOPE CONCENTRATIONS, IN WTGT FRACTIONS

CODE	NAME	CYCLE TIME	WAITING REPROCESSING	RECYCLE FACTOR	REACTOR CONCENTRATION COEFFICIENTS
1	PUR IC	1	0.74000-02 3.0	0.940	U238P(U238) 3.27000-03
2	PUR IC	2	0.74000-02 3.0	0.940	U238P(U238) 3.27000-03
3	PUR IC	3	0.74000-02 3.0	0.940	U238P(U238) 3.27000-03
4	PUR IC	4	0.74000-02 3.0	0.940	U238P(U238) 3.27000-03

CHANGE IN U235 CONCENTRATION LOADED = F(U238 CONCENTRATION LOADED)

CORE	CODE	A	B	C
TYPE C	1	0.0	0.382000 00	-0.230400 02
PUR IC	2	0.0	0.382000 00	-0.230400 02
PUR IC	3	0.0	0.382000 00	-0.230400 02
PUR IC	4	0.0	0.382000 00	-0.230400 02

FINAL U235 CONCENTRATION IN SPENT FUEL = INCREASE IN U235 LOADED DUE TO U238 PRESENCE

CORE	CODE	A	B	C
TYPE C	1	0.240000-02	0.740000 00	0.0
PUR IC	2	0.240000-02	0.740000 00	0.0
PUR IC	3	0.240000-02	0.740000 00	0.0
PUR IC	4	0.240000-02	0.740000 00	0.0

Fig. 5. Output From MUICYCL.

PREPRODUCTION INVENTORY DATA:

INITIAL INVENTORY:

3700.00MTU

U235 FRACTION=0.03000

U232 FRACTION= 9.970000-11

SUBSEQUENT PREPRODUCTION:

U235 FRACTION=0.03200

ALL FOLLOWING QUADRATIC FIT EQUATIONS ARE OF THE FORM $Q = A + BZ + C(Z^2) + QF(Z)$
 WHERE Q AND Z ARE ISOTOPE CONCENTRATIONS, IN WEIGHT FRACTIONS

CCRE	NAME	CYCLE TIME	MTU'S	AWAITING REPROCESSING	REC'Y FACTOR	REACTOR CONCENTRATION	COEFFICIENTS
				FR U-235		A	B
1	PWR IC	5	0.0	0.74000-02 0.0 FR PU236=0.100000-08	0.940	U232=F(U232) U232=F(U236) PU236=F(U236)	0.0 1.02700-10 9.38400-10 5.30000-01 4.89400-08 3.61400-07 0.0 -4.62700-09 3.41700-08
2	PWR RL	5	0.0	0.90000-02 0.0 FR PU236=0.330000-08	0.940	U232=F(U232) U232=F(U236) PU236=F(U236)	0.0 2.47400-10 1.74000-09 4.20000-01 9.82400-08 5.39100-07 0.0 1.36000-07 9.47800-07
3	BWR IC	5	0.0	0.86000-02 0.0 FR PU236=0.100000-08	0.940	U232=F(U232) U232=F(U236) PU236=F(U236)	0.0 6.51000-11 5.10000-10 5.60000-01 3.64200-08 2.30900-07 0.0 -4.31400-08 -2.78700-07
4	BWR RL	6	0.0	0.84000-02 0.0 FR PU236=0.200000-08	0.940	U232=F(U232) U232=F(U236) PU236=F(U236)	0.0 1.53300-10 6.34000-10 4.40000-01 6.97700-08 3.48200-07 0.0 7.25900-09 8.52400-08

33

PREPRODUCTION INVENTORY DATA:

INITIAL INVENTORY:

3700.00MTU

U235 FRACTION=0.03000

U234 FRACTION= 2.700000-04

SUBSEQUENT PREPRODUCTION:

U235 FRACTION=0.03200

ALL FOLLOWING QUADRATIC FIT EQUATIONS ARE OF THE FORM $Q = A + BZ + C(Z^2) + QF(Z)$
 WHERE Q AND Z ARE ISOTOPE CONCENTRATIONS, IN WEIGHT FRACTIONS

CCRE	NAME	CYCLE TIME	MTU'S	AWAITING REPROCESSING	REC'Y FACTOR	REACTOR CONCENTRATION	COEFFICIENTS
				FR U-235		A	B
1	PWR IC	5	0.0	0.74000-02 0.0	0.940	U234=F(U234)	0.0 6.00000-01 0.0
2	PWR RL	5	0.0	0.90000-02 0.0	0.940	U234=F(U234)	0.0 5.55000-01 0.0
3	BWR IC	5	0.0	0.86000-02 0.0	0.940	U234=F(U234)	0.0 5.38000-01 0.0
4	BWR RL	6	0.0	0.84000-02 0.0	0.940	U234=F(U234)	0.0 5.58000-01 0.0

Fig. 5. Output From MUICYCL (cont'd).

24.0 2

U S E M I T I C A N A G E N C I E S . A T T E N T I O N . P L E A S E R E A D .

001

2000

BY TELETYPE, ALL VIDEOS TO 5PM WED/ 10PM THUR

Page 12

• WEIGHTED AVERAGE, ALL YEARS. ** SEE BUREAU REPORT

Fig. 5. Output From MUICYCL (cont'd).

• RECLASSIFIED AUTOMATICALLY, ALL YEARS DO NOT DISK STORAGE

• INDICATED AVERAGE. ALL VALUES ON SEPARATE REPORT

* REFINISHED APPROX. ALL YEARS ON 2 ASSAYS.

* WEIGHTED AVERAGE, ALL YEARS - OF 2 ASSAYS

00120700 0470000, 0' 1 YEARS 00 2 ASSAYS

Fig. 5. Output From MUICYCL (cont'd).

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0047 20

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"IO" are sufficient for running several long cases in one job. A typical case requires less than 5 CPU seconds on the IBM 360/195.

The sample problem is an analysis of three minor uranium isotopes. U^{232} , U^{234} , U^{236} , in a campaign from 1974-1990. Printout of annual reports was suppressed. A sample annual report is displayed in Fig. 3 or in the output from MUIFAP, Fig. 7.

B. MUIFAP

JCL setup, input, and output for a sample case solved by MUIFAP are presented here. Figure 6 displays the setup deck consisting of the JCL and input data, and Fig. 7 lists the full output.

The program is set up to run on the IBM 360/370 class of machines. MUIFAP was written in IBM FORTRAN IV and is executed as an object module on a 1600 bpi tape. The resource requests of "CPU95=10S" and "IO=1.0" are sufficient for running many successive cases. The sample case is an analysis of U^{232} in a five-stream cascade.

```
//BLUFAP JOB (16780),'KCSO-BLUR-J247'
//*  PPATH.JCL -- RUN MUIFAP HEX FROM TAPE
//*CLASS CPU95=1H,IO=1.0,REGION=200,LINES=2
//LG EXEC FORTHLG,GOSIZE=80K
//LKED.SYSIN DD DSN=A.H.BLU08066.MUIFAP,UNIT=TAPE62,LABEL=(2,SL),
//          DISP=(OLD,KEEP),DCB=(RECFM=PB,LRECL=80,BLKSIZE=2000,DEN=3),
//          VOL=SER=028351
//GO. PT02P001 DD DCB=(RECFM=VBS,LRECL=80,BLKSIZE=1000),UNIT=SYSDA,
//          SPACE=(1000,(25,5),RLSE)
//GO. PT09P001 DD DUMMY
//GO. PT05P001 DD *
```

HE VALIDITY TEST		232
I RETURNS 3500.	.008	80D-11
I NORMAL	.00711	
C HE 10.	.90	
O RX 6670.65	.032	
O TLS	.003	
*		
/*		
//		

Fig. 6. Setup Deck for MUIFAP.

PAGE 1

URANIUM FLOWSHEET ANALYZER

CASE: ME VALIDITY TEST
DATE: 01-03-70

INPUT STREAMS	FLW NAME	URANIUM WEIGHT	5-PERCENT	2-PERCENT	5-CONTENT	2-CONTENT	
ACMAL	•	3.50000 03	0.800000	0.000000000000	2.80000 01	2.800000-04	
		4.499240 04	0.7110000	0.0	3.198960 02	0.0	INPUT-M
TOTAL		4.849240 04			3.478960 02	2.800000-06	5.338550 00
OUTPUT STREAMS	ME	1.000000 01	90.00000000	0.000002972919	9.000000 00	2.972920-07	
YLS	•	4.670650 03	3.2000000	0.00000003324	2.134610 02	2.386370-06	
		4.161180 04	0.3000000	0.000000000344	1.252340 02	1.436670-07	OUTPUT-M
TOTAL		4.849240 04			3.478960 02	2.800000-04	5.338550 00

5-2-S SEPARATIVE WORK
5-3-S SEPARATIVE WORK
DIFFERENCE

5-W DIFFERENCE/TC: 2-INPUT
TAILS 2-CONTENT/TOT: 2-INPUT

2.695000 04
2.695020 04
9.761740-06

• URANIUM WEIGHTS DETERMINED BY BALANCE

Fig. 7. Output From MUIFAP.

VII. INTERNAL PROGRAM ORGANIZATION

A. MUICYCL Program Structure

Referring to the program chart (Fig. 8), MUICYCL is organized into more than 20 routines most of which are called directly by MAIN. Communication of variables is accomplished largely by seven labeled common blocks containing over 100 variables.

As much as possible, each significant step in the model is partitioned into a separate subroutine or entry point. Routines may be classified by the primary operation they perform - reactor use, reprocessing, enrichment, and input-output.

Reactor - REACTR

Reprocessing - REPROC

Enrichment - DELTA, DOYEAR, EVAL, INVSTR, MERGE, NEWFDS, NEWSTR,
PREVAL, SECANT, SETUP, S236, UNMERGE

Input-Output - BGNRUN, IDAY, ISOPAG, NEWCAS, REPORT, SCRIBE, TUNING,
YRPAGE

The enrichment phase contains several iteration procedures, described in Section C following. The input-output stage is organized by the type of data to be input, output, or prepared for output.

The evolutionary development of the program has resulted in an unusual structure for execution of a multiyear campaign with several minor isotopes: the full campaign is calculated for one minor isotope, and data are saved; then the full campaign is calculated for the next minor isotope, and similarly for a third minor isotope if one is present. This results in some repetition of calculations. For example, several reprocessing calculations are redone for each minor isotope rather than

Fig. 8. MUICYCL Program Chart.

Routine B is called by Routine A if line segment(s) go down or across from Routine A to Routine B.

saving the data. The most time-consuming calculations, isotope iterations in the enrichment phase, are minor isotope specific and thus not redundant.

After each year is solved for the first minor isotope, all yearly data are written (by MAIN and YRPAGE) onto a temporary data set (FT02) to be reread later (by MAIN, SETUP, and INVSTR) for enrichment calculations with the second and third isotopes if present. A flowchart outlining program flow is provided in Fig. 9.

Documentation of individual routines follows. Documentation of variables is provided in a later section within this chapter. Note also that extensive internal documentation exists in the two major routines, MAIN and DOYEAR. See the program listing, Appendix C.

The 24 MUICYCL routines are documented here by a short description of their use:

<u>Name</u>	<u>Description</u>	<u>Called by</u>	<u>Calls</u>
BGNRUN	Prints the header page when executed at the beginning of the run.	MAIN	—
DELTA	This routine calculates the difference between target and indicated cascade SW production and develops preproduction stream rates for the next iteration. Delta is called by MAIN in each SW iteration.	MAIN	NEWSTR
DMATEQ	Solves a system of linear equations.	SECANT	—
DOYEAR	This routine generates minor isotope concentrations in cascade product streams for fixed SW, U^{235} product stream concentrations, and stream merging policy for a given year.	MAIN	PREVAL, SECANT, MERGE, UNMERG
EVAL	This routine calculates the balance equation values for given minor isotope concentration values in each cascade product stream.	PREVAL	—

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Fig. 9. MUICYCL Flowchart.

<u>Name</u>	<u>Description</u>	<u>Called by</u>	<u>Calls</u>
IDAY	IDAY, a system routine, supplies the present date for output.	BGNRUN	—
INVSTR	This routine adds the three preproduction SETUP streams to the cascade when called by SETUP for each year.		—
ISOPAG	ISOPAG generates the isotope data page preceding the yearly data for each minor isotope. ISOPAG reads (rereads) the Preproduction Inventory Card, reads the Reactor Fuel Card(s) and the U235/U236 Card.	MAIN	—
MAIN	Reads Year and Capacity Card, executes SW and U235/U236 loops, and supervises all other processing.	—	13 Routines See Fig. 8
MERGE	This routine combines into one stream, pairs of product streams having U235 concentrations within tolerance TOLMRG of each other. Merge is selectively executed by DOYEAR to aid in convergence.	DOYEAR	—
NEWCAS	This routine reads the Case Card and generates the title page.	MAIN	—
NEWFDS	This entry point adds to the cascade any recycled feed streams when called by SETUP for each year. Entry point in INVSTR.	SETUP	—
NEWSTR	Change the rate of a preproduction feed stream or preproduction product stream as part of the SW iteration procedure.	DELTA	—
PREVAL	This routine unscales the cascade estimate, calls EVAL, then rescales	DOYEAR, SECANT	EVAL
REACTR	REACTR calculates concentrations in future reactor output from last year's cascade output. Call by MAIN Section D at the start of each year.	MAIN	—
REPORT	REPORT generates summary reports for each case. Called by MAIN Section G.	MAIN	—

<u>Name</u>	<u>Description</u>	<u>Called by</u>	<u>Calls</u>
REPROC	REPROC reads any "Returns Cards", streams to feed directly to reprocessing this year. These are merged with reactor returns this year. Depending on capacity, a percentage of available material is reprocessed here (RETRN) to be fed to cascade this year.	MAIN	—
S236	S236 escalates U^{235} in cascade product to reactor due to the presence of U^{236} . It is called by MAIN in each U^{235}/U^{236} iteration.	MAIN	—
SCRIBE	This routine stores information for the summary pages. Scribe is called at the end of each year by MAIN, Section F.	MAIN	—
SECANT	The SECANT routine finds the zeros of N simultaneous equations in N unknowns using the Newton formulation of the Secant method. SECANT is called here by DOYEAR to solve the cascade balance equations for each year.	DOYEAR	PREVAL
SETUP	SETUP generates a cascade stream table each year preparatory to solving.	MAIN	NEWFDS, INVSTR
TUNING	With each new isotope in a case, MAIN calls TUNING to set the values of iteration parameters. These "parms" are set either by default or by input values and are always printed.	MAIN	—
UNMERG	This entry point in MERGE is always executed at the end of the iterations in DOYEAR if any streams were merged at the start of the iterations.	DOYEAR	—
YRPAGE	YRPAGE records yearly data for the next isotope and generates a yearly cascade flowsheet.	MAIN	—

B. MUIFAP Program Structure

Referring to the program chart (Fig. 8), MUIFAP is organized into a MAIN program and seven subroutines, most of which are called directly by MAIN. As in MUICYCL, communication of variables is accomplished mainly through the use of labeled common blocks (see Section D).

The routines are documented here by a short description of their use:

<u>Name</u>	<u>Description</u>	<u>Called by</u>	<u>Calls</u>
DMATEQ	DMATEQ solves a system of linear equations.	SECANT, START	—
EVAL	EVAL calculates the balance equation values given minor isotope concentration values for each cascade product stream.	PREVAL	—
IDAY	IDAY is a system routine which returns the present date as output.	MAIN	—
MAIN	MAIN reads the Header Card, calculates the balance streams, builds the initial estimate matrix to pass to SECANT, calculates final data for the output table and prints the table.	—	IDAY, SETUP, SECANT, PREVAL
PREVAL	PREVAL unscales the present estimate, calls EVAL, then rescales.	MAIN, SECANT	EVAL
SECANT	SECANT finds the zeros of N simultaneous equations in N unknowns using the Newton formulation of the Secant method.	MAIN	PREVAL, DMATEQ
SETUP	SETUP reads all case data cards and organizes the streams prior to solution, setting up a stream table.	MAIN	—
START	START generates the initial estimate using a linear approximation to the matched abundance ratio balance equations.	MAIN	DMATEQ

C. Enrichment Iteration Procedure

As we discussed in Section V.C, Enrichment, as many as three levels of iteration are performed in the enrichment phase:

- 1) Determination of minor isotope concentrations in cascade product streams which will satisfy material balances and matched abundance ratio equations.
- 2) Iteration on U^{235} concentrations of reactor bound products.
- 3) Adjusting preproduction stream rates to attain the rated separative capacity value.

MUIFAP executes the first level only. Each level is now discussed:

Determination of Minor Isotope Concentrations (level 1)

In MUICYCL this iteration phase is performed almost completely in subroutine DOYEAR, but partially in MAIN, which calls DOYEAR.

This calculation is done for each minor isotope for each year. Assume the cascade has M withdrawal streams and thus M unknown minor isotope concentrations. The pertinent equations to be solved are $M-2$ sidestream H balance equations of the form of (2-4) or (2-5), one cascade H balance equation (2-3), and a minor isotope material balance equation. The two other material balance equations, U^{235} and total uranium, are always satisfied at the beginning of this stage in DOYEAR by adjusting two "balance stream" rates selected by the user. Thus, the mathematical system consists of M nonlinear equations in M unknowns. The system is solved by applying the Newton formulation of the Secant method [3]. Subroutine SECANT solves this system. An operationally identical version of SECANT is fully documented in [4], pp. 113-18 and 120-21.

Among the arguments to SECANT are a matrix of $M+1$ initial estimates. This is built by M perturbations on one initial estimate. The I^{th} estimate is generated by shifting variable $X(I)$ no more than 75% in the direction of $X(I+1)$. $X(M)$ is shifted by a fixed percentage of itself. Estimate $(M+1)$ is the initial estimate. This is generated by any one of three ways.

Method A: If this is not prior to the first iteration in the separative work calculation ($\text{ITERS} > 0$), or if this is not prior to the first iteration adjusting U^{235} assay due to U^{236} presence ($\text{ITERS6} > 0$), scale all concentrations up or down from the last returned values to satisfy the U^{236} material balance equation.

Method B: However, even if $\text{ITERS} + \text{ITERS6} > 0$, but the previous solution appears very distant from the ultimate solution, or if $\text{ITERS} + \text{ITERS6} = 0$, a heuristic method is used. The concentration of the highest product stream is estimated as $(1/M)$ times its maximum by material balance considerations. All other successive concentrations are a factor times the estimated previous concentration:

$$Y_P(J) = Y_P(J-1) \left(\frac{X_P(J)}{X_P(J-1)} \right)^{\text{EXP}},$$

where

X_P is U^{235} concentration
 Y_P is minor isotope concentration
 EXP is a factor fixed for each minor isotope.

Method C: If $\text{ITERS} + \text{ITERS6} = 0$ and streams were merged the previous iteration ($\text{IMERGE} = -1$ explained below), the previous solution is used.

Merging of streams is a procedure used to prevent convergence difficulties. The ordering properties of the H balance equations results in nonlinearities when minor isotope concentrations do not maintain an ascending or descending relationship corresponding to their respective U^{235} weight fractions. This difficulty is circumvented by temporarily merging into one stream any two product streams whose U^{235} weight

fractions are within a tolerance TOLMRG (default=0.0005) of each other. After reaching a solution, the two streams are separated, and their minor concentrations are shifted proportionately to their U^{235} concentrations. During the merged period, IMERGE=1. For the iteration immediately following this, IMERGE=-1.

The MUIFAP level 1 procedure is considerably less complex. The initial estimate matrix is also built by perturbations on one initial estimate. However, the I^{th} estimate is generated by reducing $X(I)$ by 50%. The initial estimate is generated by solving a linear approximation to the balance equations (subroutine START).

In both MUICYCL and MUIFAP, all estimate vectors passed to the SECANT program are normalized: the I^{th} component is divided by the value of the I^{th} component in the initial estimate. Thus, the initial estimate is always scaled to a vector of 1's.

Iteration on U^{235} Concentrations of Reactor Bound Products (level 2)

The presence of U^{236} reduces the reactivity of U^{235} in reactors. To compensate, the U^{235} assay is escalated using a quadratic equation of the form of Equation (3-1). This is performed (in subroutine S236) when the minor isotope is U^{236} and the user has not suppressed this calculation. This follows the previous level of iterations and is considered completed when each new U^{235} concentration differs from the previous concentration by less than a tolerance of TOL235, whose default value is 5×10^{-8} . If not converged, or if streams must be remerged, the program performs iteration level 1 again. If converged, level 3, if applicable, is executed; otherwise, enrichment iterations for this year and isotope are complete.

Adjusting Preproduction Stream Rates to Attain SW Capacity (level 3)

This calculation is performed unless the user has not entered a positive value for SWUCAP, the yearly separative capacity. Calculations occur each year for which the minor isotope is U^{236} , and following the previous two iteration levels. Subroutine DELTA determines the quantity of preproduction which should be fed or produced in order to match the value of SWUCAP. The estimate is generated by a linear approximation to the rate of change in separative work for a change in preproduction. Appendix B derives the working equations.

If the relative difference between the calculated SW value and capacity is within tolerance TOLSW (default=1D-4), the preproduction calculation is bypassed, and enrichment calculations for this year and isotope are complete. Otherwise, once a new preproduction stream rate is generated, the previous two iteration levels are recalculated and this phase is again executed.

Error Conditions (MUICYCL)

Error conditions within the enrichment iteration procedure in MUICYCL are denoted by the nonzero value of flag IER. Error conditions observed during iteration level 1 (determination of minor isotope concentrations) result in negative values of IER, set in DOYEAR:

- IER=-1 Indicates the concentration vector was not being moved significantly ("stall") although convergence had not been attained.
- IER=-2 Indicates one of two conditions, both noted by a warning message:
 - a) Convergence was not achieved within the maximum number of iterations, ITERMX=30, or
 - b) the system converged to a negative concentration.

If another iteration level is to be executed next, IER is reset to zero in MAIN on the assumption that further iterations will resolve the difficulty. If iterations are completed, IER is set to its absolute value and more severe measures are taken, as explained below.

Two error conditions, involving iteration levels 2 and 3, are noted in MAIN:

- IER = 2 Indicates that the number of iterations in level 2 (U^{235} escalation) exceeded the limit of MXITR6=10. An input error is probably responsible for this infrequent error. The program will transfer to the end of the enrichment section.
- IER = 3 Indicates that the number of iterations in level 3 (preproduction calculations) exceeded the limit of MXITR=10. This error is also likely caused by incorrect input.

At the end of the enrichment section each year, a value of IER>1 results in termination of the run. Whenever IER>0 at this point, an error message is printed.

D. Common Blocks and Common Block Variables

Both MUICYCL and MUIFAP use labeled common blocks to communicate between routines. MUICYCL uses seven such blocks (EVALU, RECYCL, RECORD, CYCLE, SUMRY, COEFFS, and C0236) containing over 100 variables. Table 1 provides a cross listing of common blocks and the routines in which they are present. MUIFAP has two blocks, EVALU and RECORD, for 31 variables, nearly all of which are used similarly in MUICYCL.

Following is an alphabetized dictionary of all variables in MUICYCL common blocks. They are identified by common block name, dimension if appropriate, and type if different from the implicit specification. The implicit specification is that integer variables (first letter I-N) are typed INTEGER*4, and real variables (first letter A-H or O-Z) are typed REAL*8.

Table 1. A Cross Listing of Routines* and Common Blocks in MUICYCL

	EVALU	RECYCL	RECORD	CYCLE	SUMRY	COEFS	C0236
MAIN	✓	✓	✓	✓	✓		
DOYEAR	✓		✓				
EVAL	✓		✓				
INVSTR		✓		✓			
ISOPAG	✓	✓	✓	✓		✓	✓
MERGE	✓						
NEWCAS			✓				
PREVAL	✓						
REACTR	✓	✓				✓	✓
REPORT		✓	✓		✓		
REPROC	✓	✓		✓			
S236							✓
SCRIBE	✓	✓	✓		✓		
SETUP	✓	✓	✓	✓			
YRPAGE	✓	✓	✓	✓			

*Unlisted routines NEWFDS and UNMERG are entry points; IDAY is a system routine; BGNRUN, DELTA, DMATEQ, DOYEAR, NEWSTR, SECANT, and TUNING contain no common blocks.

- A5M SUMRY, (40), R*4. This is the average U^{235} concentration of all miscellaneous feed streams in a year, subscripted by year. Calculated in SCRIBE each year, it is then used in REPORT.
- AM SUMRY, (3), R*4. AM(M) is the concentration (weight fraction) of the M^{th} minor isotope in the stockpile of original preproduction. This is set in SCRIBE and used in REPORT.
- AMM SUMRY, (40,3), R*4. AMM(IYR,M) is the average weight fraction of the M^{th} minor isotope in QFM(IYR), the sum of all miscellaneous feed streams in year IYR. Calculated in SCRIBE, it is then printed by REPORT in the column, "OTHER".
- AT5 SUMRY, (40), R*4. This is the U^{235} concentration in the cascade tails stream each year, subscripted by year. It is loaded in SCRIBE each year and printed by REPORT.
- ATM SUMRY, (40,3), R*4. ATM(IYR,M) is the weight fraction of the M^{th} minor isotope in the cascade tails stream in year IYR. It is loaded in SCRIBE and printed by REPORT.
- C22 COEFS, (3,5). C22(K,I) is the K^{th} quadratic coefficient in the first half of the equation (see Equation 3-2) which calculates the concentration of U^{232} when fuel type I is discharged from a reactor. This half quantifies the effect of initial U^{232} concentration upon final concentration. It is input from the Reactor Fuel Card by subroutine ISOPAG and is used in REACTR.
- C26 RECYCLE, (3,6). C26(K,I) is the K^{th} quadratic coefficient in the second half of Equation 3-2 which calculates the weight fraction of U^{232} when fuel type I is discharged from a reactor. This half quantifies the effect of the initial U^{236} weight fraction upon the final U^{232} weight fraction. It is input from the second U^{232} Reactor Fuel Card for each fuel type by subroutine ISOPAG and is used in REACTR.
- C44,C66 COEFS, (3,6). C44(K,I) or C66(K,I) are the K^{th} quadratic coefficients in the equation (see Equation 3-1) calculating the discharge weight fraction of U^{234} or U^{236} as a function of the initial weight fraction of U^{234} or U^{236} in fuel type I loaded into a reactor. These are input from the Reactor Fuel Cards by subroutine ISOPAG and used in REACTR.
- C55 RECYCL, (3,6). C55(K,J) is the K^{th} coefficient in the quadratic equation (see Equation 3-1) to define the weight fraction of U^{235} in spent reactor fuel as a function of the U^{235} escalation in a fuel type identified by J loaded into a reactor. See definition of KNUM. It is input from the U^{235}/U^{236} Card by subroutine ISOPAG and used in REACTR.

CASE RECORD, (5). This is the case name, read from the Case Card by subroutine NEWCAS and printed by NEWCAS, ISOPAG, and YRPAGE.

COEF C0236, (3,6). COEF(K,J) is the Kth coefficient in the quadratic equation (see Equation 3-1) to define the change in U²³⁵ assay reactor requirements as a function of U²³⁶ assay in cascade product. J identifies the fuel type through use of KNUM(J). COEF is input from the U²³⁵/U²³⁶ card by ISOPAG and used in S236.

COEFF COEFFS, (3,6,3). COEFF(-,-,1), (-,-,2) and (-,-,3) are equivalent to C22(-,-), C44(-,-) and C66(-,-). This arrangement permits easier input of these data by subroutine ISOPAG.

CONFID RECORD, L*4. This variable takes a value of "true" if the user has requested output to be classified "CONFIDENTIAL" through use of an input field on the Case Card. CONFID is initialized in NEWCAS and also accessed in MAIN, DOYEAR, ISOPAG, REPORT, and YRPAGE.

CORNAM RECORD, (6). CORNAM(I) is the name assigned by the user to fuel type I. It is input by ISOPAG from the Reactor Fuel Cards for the first minor uranium isotope. Also used in MAIN, REPORT, SETUP, and YRPAGE.

CPU COEFFS, (3,6). CPU(K,I) is the Kth quadratic coefficient in the equation (see Equation 3-1) calculating the discharge weight fraction of PU²³⁶ as a quadratic function of the initial weight fraction of U²³⁶ in fuel type I loaded into a reactor. This is input from the second U²³² Reactor Fuel Card for each fuel type in subroutine ISOPAG and is used in REACTR.

CYC SUMRY,(40), R*4. CYC(IYR) is the input total reprocessing capacity for year IYR. This is loaded in SCRIBE and printed by REPORT.

CYCCAP RECYCL. This is the reprocessing capacity, input each year on the Year and Capacity Card in MAIN, and used in REPROC and SCRIBE.

DATE RECORD. This is the eight-character yearly date when the job is run. It is returned to subroutine BGNRUN by the system routine IDAY and is used in MAIN, NEWCAS, SETUP, and DOYEAR.

F EVALU, (20). F(I) is the weight of the Ith feed stream to the cascade in a year, ordered by U²³⁵ concentration. Its value is loaded in SETUP each year for each isotope. The balance stream weight, F(KF), is calculated in DOYEAR. At year-end, its value may be written onto temporary storage in YRPAGE for later use. Also used in MAIN, EVAL, DELTA, and SCRIBE.

- FEED5** SUMRY, (40,6), R*4. FEED5(IYR,IF) is the U^{235} concentration (weight fraction) of stream FEEDQ(IYR,IF). It is loaded in SCRIBE and printed in step REPORT.
- FEEDM** SUMRY, (40,6,3), R*4. FEEDM(IYR,IF,M) is the weight fraction of the M^{th} minor isotope in stream FEEDQ(IYR,IF). It is loaded in SCRIBE and printed in REPORT.
- FEEDQ** SUMRY, (40,6), R*4. FEEDQ(IYR,IF) is the weight of the feed stream to the cascade in year IYR, representing returns from the reactor of core type IF. It is loaded in SCRIBE and printed in REPORT.
- FNAM** RECORD, (20). FNAM(I) is the name associated with the I^{th} feed stream in a particular year, generated either from input on the Stream Card or the pertinent Reactor Fuel Card, or from the internal name assigned a "feed from preproduction" stream. FNAM is loaded in SETUP and used in DOYEAR and YRPAGE.
- FSIN** RECORD, (20). FSIN(I) contains a star, "*", if the rate of the I^{th} feed stream to the cascade is to be calculated by material balance equations. Otherwise, FSIN(I) contains blanks. FSIN(I) is loaded from input in each year by SETUP and used in DOYEAR and YRPAGE.
- FXF,FYF** EVALU, (20). FXF(I) and FYF(I) are the quantity of U^{235} and of the minor isotope, respectively, in the I^{th} feed stream to the cascade in a year. They are calculated in DOYEAR and used in the annual report (if not suppressed) by YRPAGE.
- ICYCL** RECYCL, (6). ICYCL(I) is the cycle time in years of fuel type I as input on the Reactor Fuel Cards. The ICYCL values input with the first minor isotope are used with later isotopes. These data are input in ISOPAG and used in REACTR.
- IFSTR** RECORD, (20). IFSTR(I) is non-zero if the I^{th} feed stream to the enrichment process represents a reactor return. If $IFSTR(I) > 100$, then $IFSTR(I) - 100$ is the fuel type, and this stream card was entered by the user. If $1 < IFSTR(I) < 100$, then IFSTR(I) is the fuel type, and this stream has been recycled by the program from the reprocessing plant. IFSTR is set in SETUP each year and is used in SCRIBE and YRPAGE.
- IN** EVALU. This is the total number of feed streams to the cascade in a year, calculated in SETUP for each year and each isotope. Also used in DOYEAR, EVAL, SCRIBE, YRPAGE.
- IPSTR** RECORD, (20). IPSTR(I)=K $\neq$ 0 if product stream I is to be used as fuel type K in reactors the following year. Note that IPSTR and IPTYP are "inverses". IPSTR is initialized in SETUP each year from input and used in SCRIBE and YRPAGE.

IPTYP RECYCL, (6). IPTYP(K) is the product stream number of a cascade product stream which will be loaded in core type K on reactors the following year. This is set in SETUP each year from input and used in MAIN, REACTR, and S236.

ISTRM EVALU, (20). When subroutine MERGE is used temporarily to combine two adjacent cascade product streams into one, ISTRM handles stream number bookkeeping. Use of MERGE may mean there are N-1 unknown concentrations rather than N, but there are still data for the N streams. ISTRM(I) is the product stream number associated with the solution YP(I). This is initialized to ISTRM(I)=I, possibly reset in MERGE, used in cascade calculations in DOYEAR and EVAL, and reinitialized in UNMERG.

IUNIT CYCLE. This is the logical number of the temporary data set onto which all yearly data are written while modeling the first minor uranium isotope (MKASE=1), and from which yearly data are read for the second or third minor isotopes. IUNIT=2 is set in MAIN, "endfiled" in MAIN, "rewound" in ISOPAG, and also used in INVSTR, ISOPAG, NEWCAS, REPROC, SETUP, and YRPAGE.

IYR EVALU. This variable tracks the elapsed years of the case up to and including the year being modeled. It is initialized and incremented in MAIN. Also used in REACTR, REPROC, and SCRIBE as a subscript for dimensioned data.

IYRMAX EVALU. This is the dimension on all yearly data arrays and, thus, the maximum number of years to be modeled. It is initialized in MAIN to 40 and used in initialization of dimensioned data in REACTR.

JYEAR SUMRY, (40). JYEAR(IYR) is the "calendar year" associated with the IYRth year in the run. It is loaded in SCRIBE each year and used in all the summary report pages by REPORT.

JYR EVALU. This is the actual calendar year, read from the Year and Capacity Card, presently being modeled. Input in MAIN, it is used for output operations in MAIN, DOYEAR, REACTR, SCRIBE, SETUP, and YRPAGE.

KF EVALU. KF is the subscript of the feed stream to the cascade whose weight, F(KF), is to be calculated by closing the total material balance and U²³⁵ balance equations. KF is identified from input in SETUP each year, and F(KF) is calculated in DOYEAR. Also used in YRPAGE.

KNUM C0236, (6). KNUM(I)=J means that C55(.,J) are the appropriate C55 coefficients for reactor fuel type I. See the definition of C55. KNUM is calculated in ISOPAG and used in REACTR and S236.

KORES RECYCLE. This is the total number of fuel types, set in ISOPAG to the number of Reactor Fuel Cards. Also used in MAIN, NEWFOS, REACTR, REPORT, REPROC, SCRIBE, and YRPAGE.

KP EVALU. KP is the subscript of the cascade product stream whose weight, $P(KP)$, is to be calculated by closing the total material balance and U^{235} balance equations. KP is identified from input in SETUP each year, and $P(KP)$ is calculated in DOYEAR. Also used in YRPAGE.

MAXKOR RECYCL. This is the maximum number of reactor fuel types permitted. It is set to 6 in MAIN and also used in ISOPAG and SETUP.

MKASE CYCLE. MKASE is the sequence number of the minor isotope presently being modeled. It is initialized in NEWCAS and updated in MAIN. Also used in INVSTR, ISOPAG, REPROC, SETUP, and YRPAGE.

M2 EVALU. M2 is the molecular weight of the minor uranium isotope being modeled. Its value is set in ISOPAG. Also used in MAIN, REACTR, REPROC, and SETUP.

N EVALU. This is the number of product streams from the cascade in a year, initialized in SETUP, and subject to change due to use of subroutine MERGE. It is equivalent to OUT. Also used in DOYEAR, EVAL, MERGE, PREVAL, SCRIBE, SECANT, SETUP, and YRPAGE.

NRYS SUMRY. The total number of years in the case. NRYS is loaded in SCRIBE and used in REPORT.

NUM EVALU, (20). For the I^{th} product stream from the cascade in a year, $NUM(I)$ is the number of feed streams entered into the cascade above stream I. This is used by EVAL in modeling the cascade.

P EVALU, (20). $P(I)$ is the weight of the I^{th} product stream in the cascade in a year, ordered by U^{235} concentration. Its initial value is loaded in SETUP (and DOYEAR for the balance stream) each year for each isotope. The preproduction product stream rate is recalculated in NEWSTR. At year end $P(I)$ may be saved in temporary storage by YRPAGE for later use. Also used in MAIN, DELTA, EVAL, MERGE, REACTR, and SCRIBE.

PA5M SUMRY, (40), $R*4$. $PA5M(IYR)$ is the averaged U^{235} weight fraction in $QPM(IYR)$, total miscellaneous cascade product flow in a year. It is calculated by SCRIBE and used in REPORT.

PAGE RECORD, $I*4$. This variable tracks the total number of pages being printed so that each page is numbered in compliance with security regulations. PAGE is initialized in BGNRUN, incremented and printed in MAIN, DOYEAR, ISOPAG, NEWCAS, and REPORT.

- PAMM** SUMRY, (40,3), R*4. PAMM(IYR,M) is the averaged weight fraction of the Mth minor isotope in QPM(IYR), total miscellaneous cascade product flow in a year. It is calculated by SCRIBE and printed by REPORT.
- PNAM** RECORD, (20). PNAM(I) is the name associated with the Ith product stream in a particular year, generated either from input on the Stream Card or from the internal name assigned a preproduction stream. PNAM is loaded in SETUP and used in DOYEAR, SCRIBE, and YRPAGE.
- POT** RECYCL, (6). POT(I) is the running value of the weight of fuel type I awaiting reprocessing. It is initialized and updated in REPROC and used in MAIN, SCRIBE, and YRPAGE.
- POTI** EVALU, (6). POTI(K) is the initial stockpile weight of fuel type K awaiting reprocessing. This is read from the Reactor Fuel cards for the first minor isotope in subroutine ISOPAG and is used in REPROC.
- POTPU1** EVALU, (6). POTPU1(K) is the weight fraction of PU^{236} in the initial stockpile of fuel type K awaiting reprocessing. It is input by subroutine ISOPAG from the second Reactor Fuel Card for U^{232} and is used by REPROC.
- POTXP** RECYCL, (6). POTXP(I) is the present U^{235} weight fraction in the stockpile of fuel type I awaiting reprocessing. This is variable over time because U^{235} entering the reactors has been escalated due to U^{236} . Initialized (to XPKORS) and updated in REPROC, it is also used in MAIN, NEWFDS, SCRIBE, and YRPAGE.
- POTYP** RECYCL, (6). POTYP(I) is the running value of the weight fraction of the minor isotope in fuel type I awaiting reprocessing. It is initialized and updated in REPROC, used in NEWFDS to set the minor fraction in reprocessed streams fed back to the cascade, and also used in MAIN, SCRIBE, and YRPAGE.
- POTYP1** EVALU, (6). POTYP1(K) is the minor uranium isotope weight fraction in the initial stockpile of fuel type K awaiting reprocessing. This is input by subroutine ISOPAG from the Reactor Fuel cards for each minor isotope and is used in REPROC.
- PREIL** SUMRY, (40), R*4. PREIL(IYR) is the weight of the original preproduction stockpile at the end of year IYR. It is loaded in SCRIBE and printed in REPORT.
- PRE2FM** SUMRY, (40,3), R*4. PRE2FM(IYR,M) is the weight fraction of the Mth minor isotope in stream PREIIF(IYR), the feed in year IYR from the "new" preproduction stockpile. This is set in SCRIBE and used in REPORT.

- PRE2L** SUMRY, (40), R*4. PRE2L(IYR) is the weight of the "new" preproduction stockpile at the end of year IYR. It is loaded in SCRIBE and printed in REPORT.
- PRE2M** SUMRY, (40,3), R*4. PRE2M(IYR,M) is the weight fraction of the Mth minor isotope in the "new" cascade preproduction stockpile at the end of year IYR. It is loaded in SCRIBE and printed in REPORT.
- PRE2P,
PRE2P5,
PRE2PM** SUMRY, [(40), (40), (40,3)], R*4. PRE2P(IYR), PRE2P5(IYR), and PRE2PM(IYR,M) are, respectively, the weight, U²³⁵ weight fraction, and weight fraction of Mth minor isotope in preproduction product from the enrichment cascade in year IYR. These data are loaded in SCRIBE each year and printed in the summary reports by REPORT.
- PREI** SUMRY, (40), R*4. PREI(IYR) is the weight of the cascade stream in year IYR consisting of feed from the original preproduction stockpile. This is set in SCRIBE and used in REPORT.
- PREIIF** SUMRY, (40), R*4. PREIIF(IYR) is the weight of the stream in the enrichment cascade in year IYR consisting of feed from the stockpile of "new" preproduction. This is set in SCRIBE and used in REPORT.
- PRODM** SUMRY, (40,6,3), R*4. PRODM(IYR,ITYP,M) is the concentration of the Mth minor isotope in cascade product stream PRODQ(IYR,ITYP), product to reactors. It is loaded in SCRIBE and printed by REPORT.
- PROD5** SUMRY, (40,6), R*4. PROD5(IYR,ITYP) is the U²³⁵ weight fraction in PRODQ(IYR,ITYP) the cascade product stream in year IYR to be used in reactor core type ITYP. It is loaded in SCRIBE and printed by REPORT.
- PRODQ** SUMRY, (40,6), R*4. PRODQ(IYR,ITYP) is the weight of the cascade product stream in year IYR to be loaded as fuel type ITYP in reactors. It is loaded in SCRIBE each year and printed in the summary reports by REPORT.
- PSIN** RECORD, (20). PSIN(I) contains a star, "*", if the rate of the Ith product stream from the enrichment process is to be calculated by material balance equations. Otherwise, PSIN(I) contains blanks. PSIN is loaded from input in each year by SETUP and is used in DOYEAR and YRPAGE.
- PXP** EVALU, (20). PXP(I) is the quantity of U²³⁵ in the Ith product stream from the cascade in a year. It is calculated in DOYEAR and used in MERGE and YRPAGE.

- QFM SUMRY, (40), R*4. This is the sum in a year of the weight of all miscellaneous streams fed to the cascade, i.e., streams other than normal feed, reactor returns, or feed from preproduction. Calculated in SCRIBE, it is then printed by REPORT.
- QNORM SUMRY, (40), R*4. This is the flow rate of the normal feed stream in a year, subscripted by year. This is set in SCRIBE and printed in REPORT.
- QPM SUMRY, (40), R*4. QPM(IYR) is the total weight in year IYR of all miscellaneous product streams from the enrichment process, i.e., all product streams except preproduction, product to reactors, or tails stream. It is loaded by SCRIBE each year and used in REPORT.
- QTAIL SUMRY, (40), R*4. QTAIL(IYR) is weight of the cascade tails stream in year IYR. It is loaded in SCRIBE each year and printed by REPORT.
- RETRN RECYCL, (6). RETRN(K) is the weight of fuel type K which is reprocessed and ready to be fed to the enrichment plant this year. It is calculated in REPROC and used in NEWFDS.
- RPUG RECYCL, (6,40). RPUG(I,IRYR) is the weight fraction of PU^{236} in fuel of core type I when unloaded from reactors and ready for reprocessing in future year IRYR.
- RR RECYCL, (6,40). RR(I,IRYR) is weight of material from core type I when it is unloaded from the reactor and ready for reprocessing in future year IRYR. It is calculated in REACTR and used in REPROC.
- RXP RECYCL, (6,40). RXP(I,IRYR) is the weight fraction of U^{235} in fuel from core type I when it is unloaded from the reactor and ready for reprocessing in future year IRYR. This calculation is performed in REACTR when the minor isotope is U^{236} . The data are used in REPROC.
- RYP RECYCL, (6,40). RYP(I,IRYR) is the weight fraction of the minor uranium isotope in fuel from core type I when it is unloaded from the reactor and ready for reprocessing in future year IRYR. It is calculated in REACTR and used in REPROC.
- SECRET RECORD, L*4. This variable takes a value of "true" if and only if the user has specified "SECRET" on the Case Card. The variable is set in NEWCAS and also used in MAIN, DOYEAR, ISOPAG, REPORT, and YRPAGE.
- SEP SUMRY, (40), R*4. SEP(IYR) is the input three component (U^{235} , U^{236} , U^{238}) separative capacity of the enrichment plant in year IYR. It is loaded in SCRIBE each year and printed by REPORT.

- SHRINK RECYCL, (6). SHRINK(I) is the recovery factor for reactor fuel type I, input from the Reactor Fuel Cards in ISOPAG. The factor is applied in REPORC each year to reactor output and to Returns Card output before adding to reprocessing pot.
- TOTF5 EVALU. This is the total weight of U^{235} in the feeds to the cascade in a year. It is calculated in DOYEAR and written in the annual report (if not suppressed) by YRPAGE.
- TOTF6 EVALU. This is the total weight of U^{236} in the feeds to the cascade in a year. It is calculated in DOYEAR and used in the annual report (if not suppressed) in YRPAGE.
- TWOK This variable, calculated in ISOPAG for each minor uranium isotope, is used in the calculation of the H-balance (see Equation 2-2) and separative work (see Equation 3-3). Referenced in DOYEAR, EVAL, and YRPAGE.
- UNQ,UN5, SUMRY, [(40,6), (40,6), (40,6,3)], R*4. UNQ(IYR,ITYP),
UNM UN5(IYR,ITYP), and UNM(IYR,ITYP,M) are, respectively, the weight, U^{235} weight fraction, and weight fraction of the Mth minor isotope, in accumulated returns from reactors of core type IYR awaiting reprocessing at the end of year IYR. These data are loaded each year by SCRIBE and printed in the summary reports by REPORT.
- WRT RECORD, L*4. WRT=.TRUE. if the highest level debugging output is requested for the year being solved. This variable is set in MAIN from the values on input variables KASEPR and IYRPR. WRT is used in MAIN, DOYEAR, EVAL, MERGE, REPROC, REACTR, and SETUP.
- XF EVALU, (20). XF(I) is the U^{235} weight fraction in the Ith feed stream to the cascade in a year. It is loaded in SETUP, used in DOYEAR, EVAL, and SCRIBE, and may be saved in YRPAGE for later use.
- XNORM5 SUMRY, (40), R*4. XNORM5 is the U^{235} weight fraction in normal feed, subscripted by year. It is calculated in SCRIBE and printed [only XNORM5(1)] in REPORT.
- XNORMM SUMRY, (40,3), R*4. XNORMM is the minor isotope concentration in the normal feed stream, subscripted by year and minor isotope sequence number. This is loaded in SCRIBE and printed into summary data by REPORT.
- XP EVALU, (20). XP(I) is the U^{235} weight fraction in the Ith product stream from the cascade in a year. It is loaded in SETUP, may be escalated in S236 if targeted for a reactor, and at year end may be saved in YRPAGE for later use. Also referenced in MAIN, DOYEAR, EVAL, MERGE, REACTR, and SCRIBE.

- XPORS RECYCL, (6). XPORS(I) is the weight fraction of U^{235} in the initial stockpile of fuel type I awaiting reprocessing. This is input from the Reactor Fuel Cards for the first minor isotope by subroutine ISOPAG. Also used in REPORT and REPROC.
- YF EVALU, (20). YF(I) is the minor isotope weight fraction in the Ith feed stream to the cascade in a year. It is loaded in SETUP each year for each minor isotope value. Also used in DOYEAR, EVAL, SCRIBE, and YRPAGE.
- YP EVALU, (20). YP(I) is the weight fraction of the minor isotope in the Ith product stream from the cascade in a year. It is initially estimated in DOYEAR, calculated as part of several iteration procedures in EVAL, adjusted in MERGE-UNMERG, and may be written onto temporary storage by YRPAGE for use with later minor isotopes. Also referenced in MAIN, REACTR, S236, SCRIBE, and SETUP.
- YP6 EVALU, (20). If the minor isotope being modeled is U^{232} , SETUP loads YP6(I) with the U^{236} concentration of the Ith product stream. Subroutine REACTR requires these data to calculate discharge U^{232} concentrations (see Equation 3-2).

VIII. LIMITATIONS OF THE MODELS

Use of a small set of mathematical equations to model a dynamic and complex enrichment process must inevitably limit the applicability of the model. A crucial assumption of the matched abundance ratio model, as implemented in both MUICYCL and MUIFAP, is that the minor uranium isotopes may be modeled independently of each other. While generally true, this assumption is invalid when analyzing cascade products highly enriched in U^{235} . Significant inaccuracies may begin to occur when the U^{235} enrichment increases beyond 90%, ultimately causing the sum of the top product concentrations to exceed 100%. All other model limitations are explicitly defined, e.g., single enrichment and reprocessing plants, MUICYCL restriction to a subset of three specific MUI's and fixed cycle times.

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1. A. de la Garza, G. A. Garret, and J. E. Murphy, "Multicomponent Isotope Separation In Cascades", *Chemical Engineering Science*, 15:188-209, September 1961.
2. J. M. Friend, *Functional Relationships for Minor Uranium Isotopes in PWR and BWR Spent Fuels*, Oak Ridge Gaseous Diffusion Plant, Union Carbide Corporation, Nuclear Division, Report K/OA-2762 Revised, November 1975.
3. J. M. Ortega, and W. C. Rheinboldt, *Iterative Solution of Non-linear Equations in Several Variables*, Academic Press, Inc., New York and London, pp. 194-97, 1970.
4. S. R. Blum, *NEWFIX - A Multicomponent Fixed Plant Productivity Code. Users Guide*, Union Carbide Corporation, Nuclear Division, K/OA-4158, July 1978.

APPENDIX A
FORMULATION OF $\text{Pu}^{236} \rightarrow \text{U}^{232}$ DECAY EQUATION

FORMULATION OF $\text{PU}^{236} \rightarrow \text{U}^{232}$ DECAY EQUATION

From [2], p. 7, the formula for U^{232} concentration, in the presence of PU^{236} , over time is

$$y_t = y(t, y_0, p) = y_0 c^t - kp(d^t - c^t) ,$$

where

t = time in years after discharge from reactor

y_t = U^{232} concentration at time t , wt. fr.

y_0 = U^{232} concentration at discharge, wt. fr.

p = PU^{236} concentration at discharge, wt. fr.

$$c = e^{-0.009627}$$

$$d = e^{-0.2432}$$

$$k = 1.02357$$

After slight rearrangement

$$y_t = (y_0 + kp)c^t - kpd^t = V_t - W_t .$$

V_t and W_t are identified in the computer as yearly values of $\text{POTV}(I)$ and $\text{POTW}(I)$, where I identifies the reactor fuel type. They are updated by

$$V_{t+\tau} = V_t c^\tau$$

$$W_{t+\tau} = W_t d^\tau .$$

It will be shown that, when two streams of the same fuel type are combined by merging their V_t values and W_t values, the resultant U^{232} concentration over time is identical to the weighted sum of the concentration of uncombined streams. Thus, all material of one fuel type awaiting reprocessing

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may be accounted for by updating one pair of values, POTV(I) and POTW(I) each year.

Let quantity Q_0 of material be discharged from the reactors at time $t_0 = 0$, and quantity Q_1 be discharged at time t_1 .

Then for time $t_j > 0$

$$y_{0,j} = V_{0,0} c^{t_j} - W_{0,0} d^{t_j},$$

and for $t_k > t_1$

$$y_{i,k} = V_{1,1} c^{t_k - t_1} - W_{1,1} d^{t_k - t_1},$$

where

$y_{i,j}$ = U^{232} concentration in Q_i at time t_j ,

$V_{i,j}$ = V_t value of material Q_i at time t_j ,

$W_{i,j}$ = W_t value of material Q_i at time t_j .

Combining these streams at time $t_\alpha \geq t_1$, the weighted U^{232} concentration is (subscript z indicates combination)

$$\begin{aligned} y_{z,\alpha} &= (Q_0 y_{0,\alpha} + Q_1 y_{1,\alpha}) / (Q_0 + Q_1) \\ &= (Q_0 V_{0,0} c^{t_\alpha} + Q_1 V_{1,1} c^{t_\alpha - t_1} - Q_0 W_{0,0} d^{t_\alpha} - Q_1 W_{1,1} d^{t_\alpha - t_1}) / (Q_0 + Q_1) \\ &= \frac{Q_0 V_{0,1} + Q_1 V_{1,1}}{Q_0 + Q_1} c^{t_\alpha - t_1} - \frac{Q_0 W_{0,1} + Q_1 W_{1,1}}{Q_0 + Q_1} d^{t_\alpha - t_1} \end{aligned}$$

Setting $t_\alpha = t_1$ we produce the formulae for updating V and W values by combination of material at time t_1 ,

$$V_{Z,1} = \frac{Q_0 V_{0,1} + Q_1 V_{1,1}}{Q_0 + Q_1}, \text{ and}$$

$$W_{Z,1} = \frac{Q_0 W_{0,1} + Q_1 W_{1,1}}{Q_0 + Q_1}.$$

This combined stream will have, at time $t_2 > t_1$,

$$y_{Z,2} = V_{Z,1} c^{t_2-t_1} - W_{Z,1} d^{t_2-t_1},$$

which is identical to the value of $y_{Z,\alpha}$ when the material is combined at

$$t_\alpha = t_2.$$

APPENDIX B
DERIVATION OF PREPRODUCTION ESTIMATE

DERIVATION OF PREPRODUCTION ESTIMATE

Objective: Given SW, the value of separative capacity within a year, determine the increment in preproduction feed or product to attain the rated capacity.

Let

P, F = unsigned rates of the product and feed balance streams

R = rate of preproduction feed or product stream (negative if feed)

x_P, x_F, x_R = corresponding U^{235} concentrations.

The following algorithm is used:

$$\Delta R = \Delta SW / \frac{dSW}{dR} ,$$

where

ΔSW = the required increment or decrement in SW to attain capacity

$$SW = Pv(x_P) - Fv(x_F) + Rv(x_R) + \text{constants}$$

$$\frac{dSW}{dR} = v(x_P) \frac{\delta P}{\delta R} - v(x_F) \frac{\delta F}{\delta R} + v(x_R) .$$

The balance streams are calculated by

$$P - F + R + K_1 = 0$$

$$Px_P - Fx_F + Rx_R + K_2 = 0$$

where K_1 and K_2 are terms involving other streams. Using substitution and implicit differentiation on the above,

$$\frac{\delta P}{\delta R} = \frac{\delta F}{\delta R} - 1$$

and

$$\frac{\delta F}{\delta R} = \frac{x_p - x_R}{x_p - x_F} \quad .$$

Therefore,

$$\frac{dSW}{dR} = \frac{[v(x_p) - v(x_F)](x_p - x_R)}{x_p - x_F} + v(x_R) - v(x_p) \quad .$$

APPENDIX C
MUICYCL PROGRAM LISTING

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... INITIALIZE ITERATION PARAMS -- OPTIONALLY READ IN VALUES IN
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190 CONTINUE
   IF (ITERGE.EQ.2) ITERGE=-1
   IF (ITERGE.EQ.-1) GO TO 160
   IF (ITERGE.EQ.1.AND.SWTCAP.GT.3) GO TO 200
   CALL DELTA(SWTCAP,SW,11,22,F,P,PBE1,PBE2,IND1,IND2,TOLSW,JYP,6200)
   IF (PBE1) WRITE(6,7700) SW, SWTCAP
   ITERGE=ITERGE+1
   IF (ITERGE.EQ.2) GO TO 160
   ITER = 1
   WRITE(6,7700) WRITE
200 CONTINUE
   SUBROUTINE 2.5 - ITERATIONS COMPLETED FOR THIS YEAR. TEST FOR
   ERRORS AND UPDATE PREPRODUCTION STOCKPILES.
   ... IF THIS IS 2ND OR 3RD MINOR ISOTOPE IN THE CASE,
   UPDATE PREPRODUCTION STOCKPILES
210 CONTINUE
   IF (ITER.LT.3) ITER=ITER
   IF (ITER.EQ.1) CR=CR+1
   IF (ITER.EQ.1) WRITE(6,7400) JYP, CRITSW, CR
   IF (ITER.GT.1) WRITE(6,7500) IER, JYP
   P3=P(IND3(3))
   IF (ITERGE.EQ.1) GO TO 220
   IF (P3.GT.1D-3) PBE2=PBE2+P3
   IF (P(IND3(2)).GT.1D-3) PBE2=PBE2-P(IND3(2))
   IF (P(IND3(1)).GT.1D-3) PBE1=PBE1-P(IND3(1))
   IF (PBE1.LT.1D-3) PBE1=0.
   IF (PBE2.LT.1D-3) PBE2=0.
220 CONTINUE
   ... UPDATE PREPRODUCTION MINOR ISOTOPE ASSAY
   IF (P3.LT.1D-3) GO TO 240
   T=PBE2-P3
   AP2=(T/PBE2)*AP2 + (P3/PBE2)*P(IND3(1))
230 CONTINUE
   SECTION F -- DATA STORAGE AND CASCADE OUTPUT FOR THE YEAR, BEFORE
   STARTING THE NEXT YEAR.
240 CONTINUE
   SUBROUTINE SCFIB WAS ADDED 1/76 TO RECORD IN CONDOE /SUMRY/ THE
   DATA NEEDED FOR THE SUMMARY REPORTS. THESE REPORTS ARE WRITTEN
   BY SUBROUTINE REPORT, CALLED BELOW.
   CALL SCFIB (NN,AM1,AP2,SWTCAP,PBE1,PBE2,ITERGE)
   ... RECORD YEARLY DATA FOR NEXT ISOTOPE AND GENERATE YEARLY
   CASCADE FLOWSHEET.
   IF (ITER.NE.0.OF.ITER.GT.3) L=6
   CALL YPASC(NN,L,IND3,BLANK,STAR,PBACF,PSTW,TOTPS,TOTPA,ZERO
   ,PSTW,PBE1,PBE2,AP2,AP2,SW,SWRI)
   L=LSAV
   IF (ITER.LE.1) GO TO 100
250 CONTINUE
   SECTION G -- COMPLETED LAST YEAR OF THE RUN FOR THIS COMPONENT.
   WRITE FINAL DATA, THEN GO NEXT COMPONENT OR NEXT CASE.
260 CONTINUE
   IF (ITERGE.EQ.0) GO TO 300
   ITER = ITER+1
   CALL SEPPOC(1,ITER,0,PPN)
   WRITE(L,7600)
   DO 280 I=1,KORPS
280 WRITE(L,7900) CORNAN(I), I, POT(I), POTIP(I), POTIP(I)
290 CONTINUE
   IF (ITERGE.EQ.1) END FILE INHIT
   IF (ITER.GT.1) KORPS=KORPS
   IF (ITERGE.EQ.1) KORPS=KORPS
   CALL REPORT (AP1,AP2,KORPS,ITERSCP,NINR,PPN1)
   IF (ITER.GT.1) STOP
   GO TO 20
300 KORPS=KORPS+1
   GO TO 80
7000 FORMAT (A1,I4,2F10.2,4X,A1,I5)
7100 FORMAT (I5,' CAPACITIES: REPROCESSING (NTU)'=,IPD10.1,
   ' ENRICHMENT(SW)'=,IPD10.3)
7200 FORMAT ('WARNING: MAX NO OF ITER ON 0235 ESCALATION',I3,
   ' EXIT FROM THIS LOOP.')
7300 FORMAT ('*** WARNING: EXCEEDED MAXIMUM NO. OF ITERATIONS FOR',
   ' ATTAINING SW CAPACITY',I3,' EXIT FROM THIS LOOP.')
7400 FORMAT ('WARNING: LAST ITERATIONS, IN',I5,' DIDNT',
   ' COMPLETELY CONVERGE DUE TO VECTOR STALL',
   ' FINAL RESIDUAL WAS',IPF9.2,' TARGET WAS',E9.2,
   ' CONTINUE EXECUTION.')
7500 FORMAT ('SERIOUS ERROR (IER=',I1,') IN YEAR',I5,' PREVENTED'
   ' CONTINUATION OF CASE. PRINT REPORT AND EXIT FROM CASE.')
7600 FORMAT ('OPPORTUNITY AVAILABLE TO BE REPROCESSED NEXT YEAR:')
7700 FORMAT ('OPPORTUNITY LAST ITERATION',F10.2,5X,'CAPACITY',F10.2)
7800 FORMAT ('I')
7900 FORMAT (' ',('18,AR,A1,4X,IPD12.5,2PF16.7,
   ' F10.12,4X,IPD12.5,5X,IPD12.5))
8000 FORMAT ('T56,1---CONFIDENTIAL---')
8100 FORMAT ('T50,1---SECRET---',/,/,/,T61,'SECRET')
8200 FORMAT (I15,'PAGE',I3)
290

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SUBROUTINE PRINTN(DATE,IPAGE)                                BSNP 10
  IMPLICIT REAL*8(A-H,O-Z)                                  BSNP 20
  CALL ERSET(26,10,0,-1)                                    BSNP 30
  CALL ICAT(DATE)                                             BSNP 40
  IDATE=1                                                     BSNP 50
  WRITE(6,7000) IPAGE                                         BSNP 60
  WRITE(6,7100)                                                BSNP 70
  RETURN                                                       BSNP 80
7000 WRITE(6,7110,'PAGE',1)                                    BSNP 90
7100 FORMAT('A',10,'*****CYCL - A MINOR TRANSITION ISOTOPE CYCLE PROGRAM'// BSNP 100
  '*****CYCL VERSION OF 10/12/78'//                          BSNP 110
  '*****CYCL WAS PROGRAMMED BY S.P. BLIN & E.A. NCLAUSEN'//   BSNP 120
  '*****CYCL COMPUTER SCIENCES DIVISION. FULL DOCUMENTATION IS'// BSNP 130
  '*****CYCL PROVIDED IN ORNL/CSD-37, "CYCL AND RTIPAP: MODPLS"// BSNP 140
  '*****CYCL PROVIDING MINOR TRANSITION ISOTOPES IN THE RTIPAP FILE'// BSNP 150
  '*****CYCL'//                                              BSNP 160
  END                                                            BSNP 170

  STRUCTURE DOYEAR(54,54,SWCAP,ITER,ITER56,ITERGE,CRT,CPT2    DOYE 10
  ,EXP,TOLFE,TOLPE,IND,PSIN,PSIN,TOTPS,TOTPS                    DOYE 20
  ,IP,IS,CRTN)                                                  DOYE 30
  IMPLICIT REAL*8(A-H,O-Z)                                       DOYE 40
  LOGICAL WPT,SECRET, BADLIN, CONFID, YETNDA, METHDB          DOYE 50
  INTEGER OUT, PAGE                                              DOYE 60
  COMMON /DATA/ P(20),P(20),XP(20),XP(20),YF(20),YP(20),TOTP5,TOTP6 DOYE 70
  ,STN(20),FIF(20),PIF(20),PUP(20),IS,IS,XP,P               DOYE 80
  ,TOW, POT(6), POTPI(6), ITP, S2, IP6(20)                   DOYE 90
  ,POTPI(6), JTP, ITRNAX, ISTRN(20)                          DOYE 100
  COMMON/RECORD/ CASE(5),DATE,PHAN(20),PSIN(20),PHAN(20),PSIN(20) DOYE 110
  ,WPT, SECRET, PAGE, CONFID                                   DOYE 120
  ,COPNAR(6), IPSTR(20), IPSTR(20)                             DOYE 130
  DIMENSION IND(3), FEND(2), IPHAX(20)                         DOYE 140
  ,X Y(20,21), PHAY(20,21), CCRT(5), ANS(20), ISTRAS(20)     DOYE 150
  ,HSEC(20,1), WORE(20,20), CRIT(20,2)                       DOYE 160
  EXTERNAL PPEVAL                                              DOYE 170
  EQUIVALENCE (S,OUT)                                          DOYE 180
  V(X,1,2) = (200*X+Z*Y/(Z-1)-100)*DLOG(X/(100-X-Y))        DOYE 190
  DOYE 200
  DOYE 210
  THIS ROUTINE GENERATES MINOR ISOTOPE CONCENTRATIONS IN CASCADE DOYE 220
  PRODUCT STREAMS FOR FIRED GW, 7235 PRODUCT COMES, AND MERGING POLICY DOYE 230
  CALLED BY MAIN, SUBSECTION P.2.                               DOYE 240
  DOYE 250
  DOYE 260
  DOYE 270
  DOYE 280
  DOYE 290
  DOYE 300
  DOYE 310
  DOYE 320
  DOYE 330
  DOYE 340
  DOYE 350
  DOYE 360
  DOYE 370
  DOYE 380
  DOYE 390
  DOYE 400
  DOYE 410
  DOYE 420
  DOYE 430
  DOYE 440
  DOYE 450
  DOYE 460
  DOYE 470
  DOYE 480
  DOYE 490
  DOYE 500
  DOYE 510
  DOYE 520
  DOYE 530
  DOYE 540
  DOYE 550
  DOYE 560
  DOYE 570
  DOYE 580
  DOYE 590
  DOYE 600
  DOYE 610
  DOYE 620
  DOYE 630
  DOYE 640
  DOYE 650
  DOYE 660
  DOYE 670
  DOYE 680
  DOYE 690
  DOYE 700
  DOYE 710
  DOYE 720

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DOYE1630
DOYE1650
DOYE1700
DOYE1710
DOYE1720
DOYE174
DOYE1740
DOYE1750
DOYE1760
DOYE1770
DOYE1780
DOYE1790
DOYE1800
DOYE1810
DOYE1820
DOYE1830
DOYE184
DOYE185
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DOYE2160
DOYE2170
DOYE2180
DOYE2190
DOYE2200
DOYE2210
DOYE2220
DOYE2230
DOYE2240
DOYE2250
DOYE2260
DOYE2270
DOYE2280
DOYE2290
DOYE2300
DOYE2310
DOYE2320
DOYE2330
DOYE2340

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SUBROUTINE DELTA(SWCAP,SW,Z1,Z2,F,P,PREF,PREF2,IND1,IND2,TOLSW)
      JTP=0
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION P(20), P(20), IND(3)

```

THIS ROUTINE CALCULATES THE DIFFERENCE BETWEEN TARGET AND INDICATED CASCADE SW PRODUCTION AND DEVELOPS THE PARAMETERS FOR THE NEXT ITERATION. DELTA IS CALLED BY MAIN IN EACH SW ITERATION.

```

      DELT = SWCAP-SW
      ADEL2 = DABS(DELT)
      IF (ADELT/SWCAP.LE.TOLSW) IND1=5
      GO TO (20,100,160,180,200), IND1
      NO PREVIOUS ITERATION
20  IF (ADELT.LT.0.) GO TO 40
      PREPRODUCE
      ANT=ADELT/Z2
      CALL SUBSTR(ANT,F,P,IND3,3)
      PREF2=PREF2-ANT
      IND1=0
      RETURN
      IF (PREF.LE.0.) GO TO 80

```

```

      ACT=DELTA/21
      IF (ACT.GT.PRE1) GO TO 50
      CALL SUBSTR (ACT,P,1953,1)
      PRE1=PRE1+ACT
      IF1=1
      RETURN
50 CALL SUBSTR (PRE1,P,P,1953,1)
   ACT=ACT*(ACT-PRE1)
   PRE1=0
80 IF1=DELTA/22
   IF (PRE1.LT.ANT) GO TO 100
   CALL SUBSTR (ACT,P,P,1953,2)
   PRE2=PRE2+ACT
   IF2=1
   RETURN
100 IF (PRE1.LT.2.) GO TO 120
   CALL SUBSTR (PRE2,P,P,1953,2)
120 DEFIC=(ACT-PRE2)*K7
   WRITE(6,1000) DEFIC, JYF
   PRE2=0
   IF2=0
   GO TO 200
C PREVIOUS ITERATION FOR PRE1
140 IF (DELTA.LT.0) GO TO 80
   ACT=DELTA/21
   PRE1=PRE1+ACT
   CALL SUBSTR (ACT,P,P,1953,1)
   RETURN
C PREVIOUS ITERATION FOR PRE2; ASSUME ANY POT BACK IS TO PRE2 ONLY.
160 IF (DELTA.LT.2.) GO TO 80
   ACT=DELTA/22
   PRE2=PRE2+ACT
   CALL SUBSTR (ACT,P,P,1953,2)
   RETURN
C PREVIOUS ITERATION HAD PREPRODUCTION
180 ACT= DELTA/22
   PRE2=PRE2+ACT
   CALL SUBSTR (ACT,P,P,1953,3)
   RETURN
200 RETURN
/1000 FORMAT ('*** WARNING: THERE IS A DEFICIENCY OF P, P10.2, SUM OF SDELTA
' DEPLETIVE WORK CAPACITY THIS YEAR.*/' TERMINATE THIS YEAR,*,IS,
' * BY CONTINUE CASE.')
```

DELT 260
 DELT 270
 DELT 280
 DELT 290
 DELT 300
 DELT 310
 DELT 320
 DELT 330
 DELT 340
 DELT 350
 DELT 360
 DELT 370
 DELT 380
 DELT 390
 DELT 400
 DELT 410
 DELT 420
 DELT 430
 DELT 440
 DELT 450
 DELT 460
 DELT 470
 DELT 480
 DELT 490
 DELT 500
 DELT 510
 DELT 520
 DELT 530
 DELT 540
 DELT 550
 DELT 560
 DELT 570
 DELT 580
 DELT 590
 DELT 600
 DELT 610
 DELT 620
 DELT 630
 DELT 640
 DELT 650
 DELT 660
 DELT 670
 DELT 680
 DELT 690

```

SUBROUTINE EVAL(X,5)
  IMPLICIT REAL*8(A-H,O-Z)
  LOGICAL WPT,SECRET,BADLIN,CONFID
  INTEGER OUT,OTTP1,OTTP2,TOTRAS,PAGE
  COMMON/RECORD/ CASE(5),DATF,PHAN(20),PSIN(20),PYAN(20),PSIN(20)
  WPT, SECRET, PAGE, CONFID
  COMMON(6), IPSTR(20), IPSTR(20)
  DIMENSION X(20),G(20),HI(20),RO(20)
  COMMON /EVAL/ F(20),P(20),XP(20),IP(20),YP(20),YP(20),TOTF5,TOTF6
  ,YH(20),YF(20),YF(20),YF(20),IN,H,KF,KP
  ,TWOK, POT1(6), POTPY(6), IYF, H2, YP6(20)
  ,POTPT1(6), JYF, IYHAX, ISTRN(20)
  EQUIVALENCE (Y,OUT)
  DHOX(X,Y,2) = Y*(100-Z)*X**(-Z)*(100-X-Y)**(Z-200)*(100-Y)
  DHOY(X,Y,2) = Y*(100-Z)/(100-X-Y)*100*(X/(100-X-Y))**(100-Z)
C THIS ROUTINE CALCULATES THE BALANCE EQUATION VALUES FOR GIVEN HINOP
C ISOTOPE CONCENTRATION VALUES IN EACH CASCADE PRODUCT STREAM.
C
C
  ONE=1.00
  WRITE(6,1000) (X(I),I=1,N)
  IF (WPT) WRITE(6,1000) (X(I),I=1,N)
  YF = TWOF-ONE
  DO 20 J=1,IN
    HI(I)=YF(J)*((ONE-XP(J)-YF(J))/XP(J))*EIP
    DO 40 IP=1,OUT
      I = ISTRN(IP)
      H(IP) = X(IP)*((ONE-XP(I)-X(IP))/XP(I))*EIP
      YF2=Y-2
      IF (H2.LT.1) GO TO 160
      DO 100 IP=1,H2
        IY = ISTRN(IP+1)
        OHX = DHOX(XP(IY),X(IP+1),TWOK)
        OHY = DHOY(XP(IY),X(IP+1),TWOK)
        G(IP) = 0
        DO 40 PK = 1,IP
          K = ISTRN(KY)
          G(IP) = G(IP) + P(K)*(H(KK)-H(IP+1)-OHX*(XP(K)-XP(IY))
            -OHY*(X(KK)-X(IP+1)))
      40 CONTINUE
      HX = HON(IY)
      IF (H2.EQ.0) GO TO 120
      DO 100 J=1,H2
        100 G(IP) = G(IP) - P(J)*(HI(J)-H(IP+1)-OHX*(XP(J)-XP(IY))-OHY*(YF(J)
          -X(IP+1)))
      120 CONTINUE
```

EVAL 10
 EVAL 20
 EVAL 30
 EVAL 40
 EVAL 50
 EVAL 60
 EVAL 70
 EVAL 80
 EVAL 90
 EVAL 100
 EVAL 110
 EVAL 120
 EVAL 130
 EVAL 140
 EVAL 150
 EVAL 160
 EVAL 170
 EVAL 180
 EVAL 190
 EVAL 200
 EVAL 210
 EVAL 220
 EVAL 230
 EVAL 240
 EVAL 250
 EVAL 260
 EVAL 270
 EVAL 280
 EVAL 290
 EVAL 300
 EVAL 310
 EVAL 320
 EVAL 330
 EVAL 340
 EVAL 350
 EVAL 360
 EVAL 370
 EVAL 380
 EVAL 390
 EVAL 400
 EVAL 410
 EVAL 420
 EVAL 430
 EVAL 440
 EVAL 450
 EVAL 460
 EVAL 470
 EVAL 480

```

140 CONTINUE
150 G(9-1)=0
DO 190 I=1,2
160 G(9-I) = G(9-I)-P(I)*R(I)
G(9)=TOTP
DO 290 J=1,5
J = ISTRN(J)
G(9-I) = G(9-I)+P(J)*R(J)
290 G(9) = G(9) + X(J)*P(J)
IF (9-I) WRITE(6,7795) (G(I),I=1,9)
8795
7790 FORMAT(2X,50Z6.14)
7795 FORMAT('  G',1P50Z6.14)
END

SUBROUTINE INVTSTRN(SHAR,QUANT,R,FRCH,API,A91,AP2,AP3,
1 1902,I,ISTYP)
IMPLICIT REAL*8(A-H,O-Z)
COMMON /RECYCL/ IN(6,70), REPR(6,60), RODE(6,60), POTPH(6),
1 1903, POTPH(6), CYCLES, SHARK(6), RETRN(6),
1 1904, IPTR(6), CYCL(6), XPRGS(6), KOBES, SAKKOS,
1 1905, POTPH(6), IIP(6,60)
COMMON /CYCLE/ KBASE, ID(6)
DIMENSION STRN(6,5), SHAR(6), QUANT(6), R(6), FRCH(6), I902(6)
1 1906, ISTRN(6), O(6), CORNAM(6)
DATA IIP(1,1)/, PREPOT/FRCH 1//, PRETUP/FRCH 2//, PRETVP/FRCH 3//,
1 1907, 0//0//
C
C THIS ROUTINE ADDS THE 3 PREPRODUCTION STREAMS TO THE CASCADE WHEN
C CALLED BY SETUP FOR EACH YEAR.
C
C
C IF (KBASE.GT.1) READ(I902) (O(I),I=1,3)
C FEED FROM PRE1
J=J+1
STRN(J)=KIN
SPAT(J)=PRDQVE
QUANT(J)=1.0-6
IF (KBASE.GT.1) QUANT(J)=O(1)
S(J)=API
POTPH(J)=API
I902(J)=1
ISTYP(J)=0
C FEED FROM PRE2
J=J+1
STRN(J)=KIN
SHAR(J)=PRETUP
QUANT(J)=1.0-6
IF (KBASE.GT.1) QUANT(J)=O(2)
L(J)=AP2
POTPH(J)=API
I902(J)=2
ISTYP(J)=0
C PREPRODUCTION
J=J+1
STRN(J)=G
SHAR(J)=PRETUP
QUANT(J)=1.0-6
IF (KBASE.GT.1) QUANT(J)=O(3)
S(J)=AP2
POTPH(J)=G
I902(J)=3
ISTYP(J)=0
RETURN
C
C ENTRY NEWFDS(STRN,SHAR,QUANT,R,FRCH,J,ISTYP,CORNAM)
C
C THIS ENTRY POINT ADDS TO THE CASCADE ANY RECYCLED FEED STREAMS,
C WHEN CALLED BY SETUP FOR EACH YEAR.
C
C
C CALCULATE NEW FEED STREAMS TO CASCADE COMING FROM RECYCLE
DO 80 I=1,KOBES
IF (RETRN(I).EQ.0.) GO TO 40
J = J+1
IF (J.LE.60) GO TO 20
WRITE(6,7000)
CALL EXIT
20 CONTINUE
STRN(J) = KIN
SHAR(J) = CORNAM(I)
QUANT(J) = RETRN(I)
R(J) = POTPH(I)
FRCH(J) = POTPH(I)
ISTYP(J) = -1
40 CONTINUE
RETURN
7000 FORMAT('WHEN RECYCLE STREAMS ARE ADDED, THE NUMBER OF STREAMS',
1 8000, ' EXCEEDS THE MAXIMUM.')
END

```

```

EVAL 475
EVAL 507
EVAL 513
EVAL 520
EVAL 535
EVAL 540
EVAL 550
EVAL 560
EVAL 570
EVAL 580
EVAL 590
EVAL 600
EVAL 610
EVAL 620

INVS 10
INVS 20
INVS 30
INVS 40
INVS 50
INVS 60
INVS 70
INVS 80
INVS 90
INVS 100
INVS 110
INVS 120
INVS 130
INVS 140
INVS 150
INVS 160
INVS 170
INVS 180
INVS 190
INVS 200
INVS 210
INVS 220
INVS 230
INVS 240
INVS 250
INVS 260
INVS 270
INVS 280
INVS 290
INVS 300
INVS 310
INVS 320
INVS 330
INVS 340
INVS 350
INVS 360
INVS 370
INVS 380
INVS 390
INVS 400
INVS 410
INVS 420
INVS 430
INVS 440
INVS 450
INVS 460
INVS 470
INVS 480
INVS 490
INVS 500
INVS 510
INVS 520
INVS 530
INVS 540
INVS 550
INVS 560
INVS 570
INVS 580
INVS 590
INVS 600
INVS 610
INVS 620
INVS 630
INVS 640
INVS 650
INVS 660
INVS 670
INVS 680
INVS 690
INVS 700
INVS 710
INVS 720
INVS 730
INVS 740
INVS 750
INVS 760
INVS 770

```

THIS NOTICE GENERATES THE ISOTOPE DATA PAGE PRECEDING THE YEARLY DATA FOR EACH 4,000 ISOTOPE. ISOPAC BEADS (PREBADS) THE INSPECTION INVENTORY CARD, READS THE REACTOR FUEL CAP(S) AND THE 4235/4236 CARDS. IT IS CALLED BY NAME EACH TIME A NEW ISOTOPE IS TO BE PROCESSED.

```
WRITE(6,890)
IF (.NOT.PAGE) WRITE(6,910)
IF (.NOT.PAGE) WRITE(6,900)
PAGE=PAGE+1
WRITE(6,770) CASE, PAGE
N2 = TIME(CASE)
WRITE(6,710) N2
ENDDO INRT
N2 = N2-237
T2 = (T2-237)/2
TIME = 200*(23700-N2)/100
PPH = ELAPF
IF (PPH-237) PPH=PPH
```

(F) READ AND WRITE THE PRODUCTION INVENTORY CARD.

```

IF (WFASE-G2-1) READ(5,7200) PR1,AP1,PB1,AP2
IF (WFASE-G2-1) READ(17411) PR1,AP1,PB1,AP2
IF (WFASE-G2-1) WRITE(IUNIT) PR1,AP1,PB1,AP2
AP1 = PB1(WFASE)
IF (PB1-SE-BLANK) AP1=AT10AP10D-6
WRITE(6,7301) PR1, AP1, T2, AT1, AP2

```

READ AND WRITE PRACTICE CARD DATA

WRITE(6,7400)	1504	560
WRITE(6,7400) T3	1504	560
DO 40 I=1,NKTOP	1504	580
IF (N*PASE-ET-1) READ(5,7500) YIKY, KTTY, CORBAN(KTTY), ICTCL(KTTY)	1504	590
1, POTPI(KTTY)	1504	600
1, KPEKOS(KTTY), POTPI(KTTY), (CORFF(J,KTTY,NI), J=1,3)	1504	610
1, KTTY, NI, J=1,3)	1504	630
IF (N*PASE-ET-1) READ(5,7500) YIKY, KTTY, DUN, IDUN, DTY, DUN	1504	620
1, POTPI(KTTY), (CORFF(J,KTTY,NI), J=1,3), DUN	1504	630
1, (DUN-EE-BIANE) POTPI(KTTY) = POTPI(KTTY)+KPEKOS(KTTY)*ID-6	1504	640
WRITE(6,7400) KTTY, CORBAN(KTTY), ICTCL(KTTY), POT(KTTY)	1504	650
1, KPEKOS(KTTY), POTPI(KTTY), SHINK(KTTY), K2, K2	1504	660
1, (CORFF(J,KTTY,NI), J=1,3)	1504	670
IF (N2-SE-232) GO TO 20	1504	680
READ(5,7400) (C26(J,KTTY), J=1,3), (CPB(J,KTTY), J=1,3), POTPI(KTTY)	1504	690
WRITE(6,8000) POTPI(KTTY)	1504	700
1, (C26(J,KTTY), J=1,3), (CPB(J,KTTY), J=1,3)	1504	710
20 IF (NIFT-EC-STAR) GO TO 60	1504	720
40 CONTINUE	1504	730
WRITE(6,7700) NKTOP	1504	740
60 FOREC = I	1504	750

HEAD AND PRINT COEFFICIENTS FOR 236 EFFECT ON 235, 235 ON 236

```

IF (N2.NE.236) GO TO 280
I1=0
87 I1=I1+1
READ(6,4100) Y1F1,(PTER(I),I=1,6), (COEF(I,J),J=1,3)
I
I55(I,I)=I1,I1
DO 100 I=1,NOPER
IF (PTER(I).EQ.9) GO TO 110
KRUN(PTER(I)) = I1
100 CONTINUE
IF (Y1F1.EQ.STAR) GO TO 120
IF (I1.LE.NRANKC) GO TO 80
WRITE(6,8200)
CALL FVIT
120 CONTINUE
WRITE(6,4100)

```

```

WRITE(6,8433)
DO 100 I=1,NPAGES
  WRITE(6,8434) CORRUPT(I), I, (CORRUPTS(I),J),J=1,3
  WRITE(6,8435)
  SUM1 = 0.
  SUM2 = 0.
  WRITE(6,8436)
  DO 100 I=1,NPAGES
    IF (J.GT.1) SUM1 = SUM1 + C55(I,KWTS(I))*2
    SUM2 = SUM2 + C55(I,KWTS(I))*2
    WRITE(6,8436) CORRUPT(I), I, (C55(I,KWTS(I)),J=1,3)
  CONTINUE
  IF (EXESC.EQ.BLANK) GO TO 240
  DO 220 I=1,NPAGES
    DO 220 J=1,3
      220 CORRUPTS(I,J) = 0.
    DO 220 J=2,3
      220 C55(I,KWTS(I)) = 0.
    WRITE(6,8436)
  CONTINUE
  WRITE(6,8437)
  EXESC = SUM1*SUM2*DO.O. OR. EXESC.EQ.BLANK
  RETURN
7000 FORMAT(' ',518,T115,'PAGE',I3)
7000 FORMAT(' ',518,T115,'PAGE - 81999 ISOTOPE= 0',I3)
7200 "DATA" (6010.2)
7300 "DATA" (720,"PREPRODUCTION INVENTORY DATA:")
      7300 "INITIAL INVENTORY:" F17.2,"H2U" 0235 FRACTION="
      7300 "F7.5," 0",I3," FRACTION=" F12.5/
      7300 "T26,"SUBSEQUENT PREPRODUCTION:" F7.2,"0235 FRACTION=" F17.5)
7400 "DATA" (719,"ALL FOLLOWING QUADRATIC FIT EQUATIONS ARE OF THE")
      7400 "FORM Q = A + B*F + C*F**2, Q=F(I)/T27,"EXERCISE 2 AGE")
      7400 "ISOTOPE CONCENTRATIONS, IN WEIGHT FRACTIONS")
7500 FORMAT(A1,I',A6,I2,6D10.0,F10.0)
7600 FORMAT(10F,7D10.0)
7700 "DATA" (719,"WARNING.....")
      7700 "WARNING..... YOU HAVE DEFINED THE "
      7700 "EAKININ SYSTEM OF FUEL TYPES ALLOWED AND YOUR LAST "
      7700 "REACTOR FUEL CARD HAD 50"/" "" IN COL. 1. PROGRAM "
      7700 "ASSUMES THIS WAS YOUR LAST FUEL CARD AND CONTINUES.")
7800 FORMAT('CORE NAME CYCLE TIME ARBITRARY REPROCESSING')
      7800 "REACTOR FACTOR",I1X,"REACTOR CONCENTRATION ",
      7800 "COEFFICIENTS"/
      7800 "T11,"T12,"T13,"T14,"T15" PR 0-235 PR 0-235,II,T99,"A",T112,"B"
      7800 "T125,"C")
7900 FORMAT(I4,A1,A6,I8,I2,I7.3,0F2E12.0,F10.3)
      7900 "T23,"T24,"I1,"F(I,I),I",I2E11.4)
8000 FORMAT(100,"PR 0236=" F11.5
      8000 "T40,"0232-F(0236)*.I2E11.4/T27,"0236-F(0236)*.I2E11.4/)
8100 FORMAT(A1,6I2,7X,6F10.5)
8200 FORMAT('TOO MANY COEFFICIENTS')
8300 FORMAT('T22,"CHANGE IN 0235 CONCENTRATION LOADED = F(0236'
      8300 "CONCENTRATION LOADED)")
8400 FORMAT('0',T28,"CORE CODE",10X,"A",15X,"B",15X,"C"/T24,"TYPE")
8500 FORMAT(22X,A6,5X,I2,2X,4(4X,D12.5))
8600 FORMAT('F10,"FINAL 0235 CONCENTRATION IN SPENT FUEL = "
      8600 "F(0236) LOADED DUE TO 0236 PRESENCE")
8700 FORMAT('0235 ESCALATION DUE TO 0-235 DESPITE'
      8700 "NON-ZERO DELTA COEFFICIENTS"/)
8800 FORMAT('0')
8900 FORMAT('0')
9000 FORMAT('T56,"---CONFIDENTIAL---")
9100 FORMAT('T59,"---SECRET---"/,"T61,"SECRET')
9200 FORMAT(115X,"PAGE",I3)
END

SUBROUTINE WEDGE (INVERG,NP1,TOLNRC,NRT)
  IMPLICIT REAL*8 (A-H,O-Z)
  LOGICAL INT
  COMMON /EVALN/ P(20),P(20),XP(20),XP(20),YF(20),YP(20),TOTP5,TOTP6
  1 ,NUN(20),PEP(20),PYF(20),PEP(20),IN,N,KP,KP
  1 ,THOK, POT(6), POTY(6), ITR, N2, IP6(20)
  1 ,POTPH(6), JTR, ITHAX, ISTRN(23)
  DIMENSION INVERG(20), PSAY(20), XPSAY(20), YPSAY(20)
  C
  C
  C THIS ROUTINE COMBINES INTO ONE STREAM, PAIRS OF PRODUCT STREAMS
  C STREAMS HAVING 0235 CONCENTRATIONS WITHIN TOLERANCE TOLNRC OF EACH
  C OTHER. WEDGE IS SELECTIVELY EXECUTED BY DOWRUP TO AID IN
  C CONVERGENCE.
  C
  C
  DO 20 I=1,N
    INVERG(I) = 0
    PSAY(I) = P(I)
    XPSAY(I) = XP(I)
  20 CONTINUE
  NRT = N-1
  IDIPP = 0
  J = 0
  C
  C ... FOR SAKE OF COMPARISON IN DO-LOOP BELOW:
  C
  DO 20 I=1,N

```


SPRINTTIME REPORT (API,AP2,KCHPS,INRSCP,NIH,PST)	REPO	10
LOGICAL REALOR(A-H,0-7)	REPC	20
LOGICAL WRT,SECRET, BADLEN, CONFID, GENLIS	REPO	30
INTERP OUT, PAGE	REPO	40
COMMON /RECTOL/ RB(6,43), RYP(6,43), RPH6(6,80), POTPH(6)	REPO	50
1 POT(6), POTPH(6), CYCCAF, INRINK(6), RETURN(6)	REPC	60
1 RPT(6), ICTCL(6), KPHOS(6), KCBES, MARKOR	REPO	70
1 POTPH(6), RXP(6,80)	REPO	80
COMMON/RECORD/ CASE(6),DATE,PHAN(20),PSIN(20),PHAN(20),PSIN(20)	REPO	90
1 WRT, SECRET, PAGE, CONFID	REPO	100
1 CORNAN(6), IPSTR(20), IPSTR(20)	REPO	110
COMMON /SHUTY/ ASH(20), AH(3), AH(80,1), A5(80)	REPO	120


```

IF (CONFID) WRITE(6,8300)
IF (SECRET) WRITE(6,8100)
WRITE(6,8800)
WRITE(6,8900)
WRITE(6,8400)
TOT1=0.
TOT2=0.
DO 140 I=1,NPFR
TOT1=TOT1+PASE(I)*QPR(I)
140 TOT2=TOT2+QPR(I)
AST=0.
IF (TOT2.EQ.0.) GO TO 160
AST=TOT1/TOT2
160 WRITE(6,9000) PREZPS(I), AST
WRITE(6,8600)
DO 180 I=1,NPFR
WRITE(6,9100) JYEAR(I), PREZP(I), QTAIL(I), C2(I)
180 CONTINUE
WRITE(6,9200)
WRITE(6,9300)
IF (CONFID) WRITE(6,8000)
IF (SECRET) WRITE(6,8100)
C
C RING ISOTOPE CONCENTRATIONS IN PRODUCTS
C
DO 200 NINDX=1,NORPS
N2=NINDX(NINDX)
PAGE=PAGE+1
WRITE(6,7900) PAGE
IF (CONFID) WRITE(6,8000)
IF (SECRET) WRITE(6,8100)
WRITE(6,9400) N2
WRITE(6,11800) (CORBAN(I),I=1,KORPS)
WRITE(6,11900)
WRITE(6,8400) (THESCP(I),I=1,KGPES)
WRITE(6,12000) PREZPS(I), AST
WRITE(6,8600)
DO 200 I=1,NPFR
WRITE(6,9500) JYEAR(I), (PHODR(I,J,NINDX),J=1,KORPS)
WRITE(6,9600) PREZPH(I,NINDX), ATP(I,NINDX), PATR(I,NINDX)
200 CONTINUE
WRITE(6,9200)
WRITE(6,9300)
IF (CONFID) WRITE(6,8000)
IF (SECRET) WRITE(6,8100)
220 CONTINUE
C
C END OF RING ISOTOPE IN PRODUCTS
C
C
C RING ISOTOPE CONCENTRATIONS IN FEEDS
C
DO 240 NINDX=1,NORPS
N2=NINDX(NINDX)
PAGE=PAGE+1
WRITE(6,7900) PAGE
IF (CONFID) WRITE(6,8000)
IF (SECRET) WRITE(6,8100)
WRITE(6,9700) N2
WRITE(6,11800) (CORBAN(I),I=1,KORPS)
WRITE(6,11900)
WRITE(6,11500) AP1
WRITE(6,11600) (IPKORS(I),I=1,KORPS)
WRITE(6,11700) AP2,THORNS(I),AST
WRITE(6,8600)
DO 240 I=1,NPFR
WRITE(6,9500) JYEAR(I), (PREDR(I,J,NINDX),J=1,KORPS)
AVGINS=0.
PREX=PREI(I)*PREIIP(I)
IF (PREX.EQ.0.) GO TO 240
AVGINS=(PREI(I)*AR(NINDX)*PREIIP(I)*PREZPH(I,NINDX))/PREI
240 WRITE(6,9600) AVGINS,THORNS(I,NINDX),ARR(I,NINDX)
260 CONTINUE
WRITE(6,9200)
WRITE(6,9700)
IF (CONFID) WRITE(6,8000)
IF (SECRET) WRITE(6,8100)
280 CONTINUE
C
C END OF RING ISOTOPES IN FEEDS
C
C
C PREPRODUCTION INVENTORIES SUMMARY
C
PAGE=PAGE+1
WRITE(6,7900) PAGE
IF (CONFID) WRITE(6,8000)
IF (SECRET) WRITE(6,8100)
WRITE(6,9800)
WRITE(6,9900)
WRITE(6,10000) AP1, NINDX(I), PRR1(I), AP2
WRITE(6,8600)
IF (PCHPS.LT.2) GO TO 300
WRITE(6,10100) (NINDX(I), PRR1(I),I=2,KORPS)

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REPC1080
REPC1090
REPC1100
REPC1110
REPC1120
REPC1130
REPC1140
REPC1150
REPC1160
REPC1170
REPC1180
REPC1190
REPC1200
REPC1210
REPC1220
REPC1230
REPC1240
REPC1250
REPC1260
REPC1270
REPC1280
REPC1290
REPC1300
REPC1310
REPC1320
REPC1330
REPC1340
REPC1350
REPC1360
REPC1370
REPC1380
REPC1390
REPC1400
REPC1410
REPC1420
REPC1430
REPC1440
REPC1450
REPC1460
REPC1470
REPC1480
REPC1490
REPC1500
REPC1510
REPC1520
REPC1530
REPC1540
REPC1550
REPC1560
REPC1570
REPC1580
REPC1590
REPC1600
REPC1610
REPC1620
REPC1630
REPC1640
REPC1650
REPC1660
REPC1670
REPC1680
REPC1690
REPC1700
REPC1710
REPC1720
REPC1730
REPC1740
REPC1750
REPC1760
REPC1770
REPC1780
REPC1790
REPC1800
REPC1810
REPC1820
REPC1830
REPC1840
REPC1850
REPC1860
REPC1870
REPC1880
REPC1890
REPC1900
REPC1910
REPC1920
REPC1930
REPC1940
REPC1950
REPC1960
REPC1970
REPC1980
REPC1990
REPC2000
REPC2010
REPC2020

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350 WRITE(6,13200) (VIND(I),I=1,KCPS)
WRITE(6,13300)
DO 340 J=1,NPTS
DO 320 K=1,KCPS
320 PRE2E(J,K)=100.*PRE2E(J,K)
330 WRITE(6,10300) JYEAR(J), PRE1E(J), PRE2E(J), (PRE2E(J,K),K=1,KCPS)
WRITE(6,13400)
WRITE(6,11000)
IF (CONFID) WRITE(6,8000)
IF (SECRET) WRITE(6,8100)
C END PREPRODUCTION INVENTORIES SUMMARY
C
C UNPROCESSED RETURNS INVENTORY
C
DO 380 I=1,KOREZ
PAGE=PAGE+1
WRITE(6,7000) PAGE
IF (CONFID) WRITE(6,8000)
IF (SECRET) WRITE(6,8100)
WRITE(6,10400)
WRITE(6,10500) CORNAR(I)
WRITE(6,10600) (RIIR(I),II=1,KORP)
WRITE(6,10700) (BLANK,II=1,KORP)
WRITE(6,10800)
DO 360 J=1,NPTS
WRITE(6,10900) JYEAR(J), UNR(J,I)
IF (UNR(J,I).EQ.0.) GO TO 360
WRITE(6,10900) UNR(J,I), (UNR(J,I,II),II=1,KORP)
360 CONTINUE
WRITE(6,11000)
IF (CONFID) WRITE(6,8000)
IF (SECRET) WRITE(6,8100)
360 CONTINUE
C END OF UNPROCESSED RETURNS
C
C MISCELLANEOUS ANNUAL DATA
C
PAGE=PAGE+1
WRITE(6,7000) PAGE
IF (CONFID) WRITE(6,8000)
IF (SECRET) WRITE(6,8100)
WRITE(6,11100)
WRITE(6,11200)
DO 400 J=1,NPTS
400 WRITE(6,11300) JYEAR(J), REP(J), CYC(J), AT(J)
WRITE(6,11000)
IF (CONFID) WRITE(6,8000)
IF (SECRET) WRITE(6,8100)
C
C END OF MISC DATA
C
RETNB
7000 FORMAT('0',26X,'MATERIAL FLOWS AND U-235 CONCENTRATIONS (S) --
' FEED STREAMS')
7100 FORMAT('0',YEAR,6X,'ASSAY:',2P6F19.3)
7200 FORMAT('0',19X,'MATERIAL FLOWS - OTHER FEED STREAMS')
7300 FORMAT('0',T24,'PRE-PROD',5X,'NORMAL',1X,'OTHER')
7400 FORMAT(T24,2P6F.1,'')
7500 FORMAT('0',YEAR,ASSAY:',2P10.3,2P12.3,'')
7600 FORMAT(17,T21,1P12.4,A1,1P11.4,1P12.4)
7700 FORMAT('0',T34,'2 ASSAYS')
7800 FORMAT('0',T84,'1ST YR TO FEED NEW PRE-PROD')
7900 FORMAT('1',116X,'PAGE',17)
8000 FORMAT('0',T56,'---CONFIDENTIAL---')
8100 FORMAT('0',T59,'---SECRET---')
8200 FORMAT('0',26X,'MATERIAL FLOWS AND U-235 CONCENTRATIONS (S) --
' PRODUCT STREAMS')
8300 FORMAT('0',8X,'CORE TYPE:',8X,A6,5(1X,A6))
8400 FORMAT('0',YEAR,6X,'ASSAY:',6(2X,2P6F.3,8X))
8500 FORMAT('0',YEAR,6X,'ASSAY:',2P6F19.3)
8600 FORMAT('0')
8700 FORMAT(3X,14,12X,6(1P12.3,2P7.3))
8800 FORMAT('0',19X,'MATERIAL FLOWS - OTHER PRODUCT STREAMS')
8900 FORMAT('0',T24,'PRE-PROD',6X,'TAILS',6X,'OTHER')
9000 FORMAT('0',YEAR,ASSAY:',2P10.3,5X,'',5X,2P12.3,'')
9100 FORMAT(17,T21,1P12.4)
9200 FORMAT('0',WEIGHTED AVERAGE, ALL YEARS')
9300 FORMAT('0',T34,'SEE MISC REPORT')
9400 FORMAT('0',29X,'0-',13,' CONCENTRATION IN PRODUCTS (WEIGHT FRACTION)')
9500 FORMAT(3X,14,11X,1P12.5)
9600 FORMAT('0',T92,1P3E12.5)
9700 FORMAT('0',29X,'0-',13,' CONCENTRATION IN FEEDS (WEIGHT FRACTION)')
9800 FORMAT('0',29X,'PREPRODUCTION INVENTORIES - SUMMARY')
9900 FORMAT('0',14X,'INITIAL INVENTORY',29X,'SUBSEQUENT PREPRODUCTION
INVENTORIES')
10000 FORMAT(6X,235: ',2P10.7,1X,2X,13: ',2P9.7,1X,29X,
' U-235 ASSAY:',2P6F.3,'')
10100 FORMAT('0',5X,13: ',2P10.7,1X,2X,13: ',2P9.7,1X)
10200 FORMAT(1X,'YEAR',13X,'QUANTITY',25X,'QUANTITY',9X,3(1X,1X))
10300 FORMAT(3X,14,11X,1P10.3,23X,10.3,3(5X,1P10.3))
10400 FORMAT('0',29X,'UNPROCESSED RETURNS INVENTORY')
10500 FORMAT('0',29X,'CORE TYPE:',8X,12X,'ASSAYS IN WEIGHT PERCENT')
10600 FORMAT('0',5X,'YEAR',6X,'QUANTITY OF',8X,'U-235',3(10X,'0-',13))
10700 FORMAT(10X,'TRANSUR',9X,'ASSAY',1(6X,A8,'ASSAY'))

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11800 FORMAT (6X, I4, 7X, IPE12.5)
11801 FORMAT ('...', 10X, 2PF11.7, 3(4X, 2PF11.7))
11802 FORMAT ('...')
11803 FORMAT ('0', 29X, 'MISCELLANEOUS ANNUAL DATA')
11804 FORMAT ('0', 5X, 'YEAR', 10X, 'SEPARATIVE', 10X, 'REPROCESSING',
1 8X, 'TAILS 0235')
1 23X, 'MOB', 15X, 'CAPACITY', 13X, 'ASSAY'//
1 21X, 'CAPACITY', 32X, '(WT FRAC)'//
11805 FORMAT (6X, I4, 3(10X, IPE10.3))
11806 FORMAT ('...', 19X, 'PRE-PROD', 5X, 'NORMAL', 6X, 'OTHER')
11807 FORMAT ('...', 18X, 2PF12.3, '...')
11808 FORMAT ('...', 18X, 2PF12.3, '...')
11809 FORMAT ('...', 18X, 2PF12.3, '...')
11810 FORMAT ('0', 8X, 'CORE TYPE', 6(4X, I8))
11811 FORMAT ('...', 19X, 'PRE-PROD', 6X, 'TAILS', 7X, 'OTHER')
11812 FORMAT ('...', 18X, 2PF12.3, 5X, '...', 5X, 2PF12.3, '...')
END

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REPO2980
REPO2990
REPO3000
REPO3010
REPO3020
REPO3030
REPO3040
REPO3050
REPO3060
REPO3070
REPO3080
REPO3090
REPO3100
REPO3110
REPO3120
REPO3130
REPO3140

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SUBROUTINE REPROC(IEWD, WRT, SEUSE, PPR)
IMPLICIT REAL*8(A-H, O-Z)
REAL*8 SCAR, '...', BLANK, ' '
COMMON /EVAL/ P(20), P(20), KP(20), KP(20), YP(20), YP(20), TOTF5, TOTF6
1 8X, 20X, P(20), KP(20), KP(20), KP(20), IE, X, KP, KP
1 10X, POT(6), POT(6), POT(6), IE, X2, YP(20)
1 10X, POT(6), IE, X2, YP(6)
COMMON /RECYCL/ RY(6, 40), RY(6, 40), RY(6, 40), POT(6)
1 10X, POT(6), POT(6), CYCCAP, SEUSE(6), SEUSE(6)
1 10X, POT(6), IE, X2, YP(6), XPROS(6), ROES, RAYOR
1 10X, POT(6), IE, X2, YP(6, 40)
COMMON /CYCLE/ REUSE, IUNIT
DIMENSION POT(6), POT(6), FRAC(3), FRAC(6), REPSAV(6)
LOGICAL WLPOT
LOGICAL WRT

```

REPROC READS ANY "POTURNS CA-05", STREAMS TO FEED DIRECTLY TO
REPROCESSING THIS YEAR. THESE ARE MERGED WITH REACTOR RETURNS
THIS YEAR. DEPENDING ON CAPACITY, A PERCENTAGE OF AVAILABLE
MATERIAL IS REPROCESSED HERE(RETRE), TO BE FED TO CASCADE THIS YEAR.

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IF (IYP.GT.1) GO TO 80
YMAP ONE INITIALIZATION
EXP1 = DECP(-0.00962700)
EXP2 = DECP(-0.243200)
RE = 1.0235750
WLPOT=.TRUE.
DO 20 I=1, ROES
POT(I) = 0.
POT(I) = 0.
POT(I) = POT(I)
POT(I) = XPROS(I)
POT(I) = POT(I)
POT(I) = POT(I)
IF (POT(I).EQ.0) GO TO 20
WLPOT = .FALSE.
IF (W2.WE.232) GO TO 20
POT(I) = RE*POT(I)
POT(I) = POT(I) + POT(I)
20 CONTINUE
GO TO 80
40 CONTINUE
IF 7-232 CASE AND SOME UNPROCESSED POTS REMAIN FROM LAST YEAR,
CALC NEW 7-232 CONC DUE TO DECAY
IF (W2.WE.232.CB.WLPOT) GO TO 80
DO 60 I=1, ROES
IF (POT(I).EQ.0) GO TO 60
POT(I) = POT(I)*EXP1
POT(I) = POT(I)*EXP2
POT(I) = POT(I) - POT(I)
IF (POT(I).EQ.0) WRITE(6, 7000) I, POT(I)
60 CONTINUE
READ ANY STREAMS TO BE FED DIRECTLY TO REPROCESSING PLANT THIS
YEAR, AND MERGE THESE WITH REACTOR OUTPUT STREAMS FOR THIS YEAR.
NOTE THAT REACTOR OUTPUT VARIES BY YEAR DUE TO PRESENCE OF 0236
AND THEREFORE IS SAVED IN REP(CORETYP, YR). FOR EASE IN BLENDING
CALCULATIONS ONLY REP IS TEMPORARILY INCREMENTED, THEN RESTORED
TO ITS ORIGINAL VALUE THRU USE OF REPSAV.
40 CONTINUE
IF (SEUSE.EQ.0) GO TO 160
DO 100 I=1, ROES
100 REPSAV(I) = REP(I, YYP)
IF (WRT) WRITE(6, 7100)
DO 100 I=1, 20
IF (W2.WE.232) READ(5, 7200) YIY, KTY, WT, PPS, FRAC, FRAC
IF (W2.WE.232) WRITE(IUNIT) YIY, KTY, WT, PPS, FRAC, FRAC
IF (W2.WE.232) READ(IUNIT) YIY, KTY, WT, PPS, FRAC, FRAC

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11 (POT.EQ.0) PR=PPR*(POT)
PPR=PPR+PPR*(POT)
IF (POT.EQ.0) PPR=PPR*(POT)
IF (POT) WRITE(6,7500) PPR, WT, PPR*WT, PPR*WT, PPR
IF (POT.EQ.0) GO TO 120
WRITE(6,7400) PPR
CALL EXIT
120 CONTINUE
... PRESERVE STREAM WEIGHT NOW: IT WILL BE SHOWN NEXT SECTION:
WT = PR*(POT, IYR)
WT*(POT, IYR) = (WT*(POT, IYR)+WT*(POT, IYR))/(WT*(POT, IYR)+WT*(POT, IYR))
WT*(POT, IYR) = (WT*(POT, IYR)+WT*(POT, IYR))/(WT*(POT, IYR)+WT*(POT, IYR))
WT*(POT, IYR) = (WT*(POT, IYR)+WT*(POT, IYR))/(WT*(POT, IYR)+WT*(POT, IYR))
WT*(POT, IYR) = (WT*(POT, IYR)+WT*(POT, IYR))/(WT*(POT, IYR)+WT*(POT, IYR))
IF (WT.EQ.0) GO TO 140
140 CONTINUE
140 CONTINUE
ADD REACTOR OUTPUT OF THIS YEAR (AFTER LOSSES) TO POTS
150 CONTINUE
DO 160 I=1, NPTS
PR(I, IYR) = PR(I, IYR)+CHURN(I)
CHURN(I) = POT(I) + PR(I, IYR)
IF (CHURN(I).EQ.0) GO TO 200
POT(I) = (POT(I)+POT(I)+PR(I, IYR)+PR(I, IYR))/CHURN(I)
POT(I) = (POT(I)+POT(I)+PR(I, IYR)+PR(I, IYR))/CHURN(I)
POT(I) = CHURN(I)
IF (POT) WRITE(6,7500) I, PR(I, IYR), WT(I, IYR), POT(I), POT(I)
IF (POT.EQ.0) PR(I, IYR) = PR(I, IYR)
200 CONTINUE
IF (POT.EQ.0) RETURN
REPROCESSING STEP
CALC FRACTION FR OF TOTAL POT WHICH WILL BE RETURNED TO REPROCESSING PLANTS THIS YEAR
POTOT = 0
DO 220 I=1, NPTS
FRAC(I) = 0
220 POTOT = POTOT + POT(I)
WUPOT = POTOT*LE.CYCCAP
IF (POTOT.EQ.0) FR = WUPOT/(CYCCAP/POTOT, 100)
CALC POTS RETURNED FROM EACH POT THIS YR, AND DEplete POTS.
IF ANY POT HAS A SMALL PERCENTAGE OF RECYCLE CAPACITY, ALWAYS
RECYCLE IT COMPLETELY.
IF (WUPOT) GO TO 280
PREPR = 1.000
PREPR = .0200
FIRST = 0
DO 240 I=1, NPTS
IF (POT(I).EQ.0) PR=POT(I)...I.PREPR*(CYCCAP-FIRST) GO TO 240
FRAC(I) = 100
FIRST = FIRST + POT(I)
240 CONTINUE
IF (FIRST.EQ.0) GO TO 280
PRCLPT = (CYCCAP-FIRST)/(POTOT-FIRST)
DO 260 I=1, NPTS
260 IF (FRAC(I).EQ.0) FRAC(I)=PRCLPT
280 CONTINUE
DO 300 I=1, NPTS
IF (FRAC(I).EQ.0) FR=FRAC(I)
REPR(I) = PR*(POT(I))
IF (POT(I).EQ.0) GO TO 300
POT(I) = (100-FR)*POT(I)
IF (POT) WRITE(6,7600) REPR(I), I, POT(I)
300 CONTINUE
IF POTS NONZERO AND U-232 CASE, CALC NEW CORPPS FOR U-232 DECAY.
IF (P2.EQ.232) GO TO 360
DO 380 I=1, NPTS
IF (POT(I).EQ.0) GO TO 320
IF (FRAC(I).EQ.0) FR=FRAC(I)
ALPHA = PR(I, IYR)*(100-FR)/POT(I)
BZ = PR(I, IYR)*BZ
POT(I) = (100-ALPHA)*POT(I) + ALPHA*(PR(I, IYR)*BZ)
POT(I) = (100-ALPHA)*POT(I) + ALPHA*BZ
GO TO 380
320 CONTINUE
POT(I)=0
POT(I)=0
340 CONTINUE
360 CONTINUE
RETURN
7000 FORMAT(' NEW U232 FR IN REPROC POT', I2, E13.5)
7100 FORMAT(' FEED DIRECTLY TO REPROCESSING PLANTS:')
7200 FORMAT(A1, I1, E13.5)

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7500 IFPOT(51,"POT",12," WT",VPI2.5," WITH H-400 FRACTIONS",2252.5)P2P1713
      AND P2236",212.5," P2255",212.5) P2P1720
7430 P2POT(??? "POT STREAM TYPE",12," TO BEPROCESSING?? NOT DEFINED" P2P1722
      "???" P2P1740
7500 P2POT(51,"POT",12," WT",VPI2.5," MINOR",213.5," YIELDING",213.5," P2P1750
      " MINOR",213.5," ADDED 2235 ASSAY",212.5," P2P1760
7430 P2POT(51,"POT",12," WT",VPI2.5," LEAVING",213.5) P2P1770
      P2P1790

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SUBROUTINE S236(XP,XPOT,YP,YPOT,2235,DIP235,*) S236 10
      IMPLICIT REAL*8 (A-H,O-Z) S236 20
      COMMON/CO236/ XNEW(6), COEF(6,3) S236 30
      DIMENSION XPOT(20), YP(20), YPOT(6), XNEW(20) S236 40
      S236 50
      S236 60
      S236 70
      S236 80
      S236 90
      DIP235 = 0 S236 100
      DO 20 I=1,6 S236 110
      II=YPOT(I) S236 120
      IF (II.GT.0) GO TO 20 S236 130
      J=II S236 140
      DIP235=COEF(J,3) * COEF(J,2)*XPOT(J) * COEF(J,3) * TWO**J**0.5 S236 150
      XNEW(II) = YPOT(II) * DIP235 S236 160
      DIP235 = MAX(DIP235,DABS(XNEW(II)-YP(II))) S236 170
      S236 180
      S236 190
      S236 200
      ... NONSTANDARD RETURN (WITHOUT THIS XP ESCALATION) WHEN CONVERG: S236 210
      IF (DIP235.LT.TOL235) RETURN 1 S236 220
      DO 40 I=1,6 S236 230
      II=YPOT(I) S236 240
      IF (II.GT.0) GO TO 40 S236 250
      YP(II)=XNEW(II) S236 260
      S236 270
      S236 280
      S236 290
      S236 300

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SUBROUTINE Scribe (N1,N2,N3,SHCAP,PRE1,PRE2,NIND1) Scribe 10
      IMPLICIT REAL*8 (A-H,O-Z) Scribe 20
      LOGICAL SP,SECRET, BADLIN, CONFID, CPVLIN Scribe 30
      INTEGER OUT, PAGE Scribe 40
      COMMON /EVALU/ F(20),P(20),XP(20),YP(20),YPOT(6),TOTF5,TOTF6 Scribe 50
      F(20),XP(20),YP(20),PIP(20),FV,Y,XP,YP Scribe 60
      TWOK, POT(6), POTYP(6), YV, N2, YP6(20) Scribe 70
      POTPM(6), YV, IYRMAX Scribe 80
      COMMON /BCYCL/ RR(6,40), STP(6,40), SPN6(6,40), POTPM(6) Scribe 90
      POT(6), POTYP(6), CYCAR, SHLINK(6), RETSN(6) Scribe 100
      IPTYP(6), ICYCL(6), XPHOS(6), KOPES, HATHCP Scribe 110
      POTIP(6), STP(6,40) Scribe 120
      COMMON/RECORD/ CASE(5),DATE,PHASE(20),PSIN(20),PSAN(20),PSIN(20) Scribe 130
      SP, SECRET, PAGE, CONFID Scribe 140
      CORVAR(6), IPST(20), IPSTR(20) Scribe 150
      COMMON /SINH/ ASH(40), A(40), ANH(40,3), A75(40) Scribe 160
      ATN(40,3), CYC(40), FEED5(40,6), FEEDN(40,6,3) Scribe 170
      FEEDJ(40,6), FASH(40), PATH(40,3), PREVL(40) Scribe 180
      PRE2PH(40,3), PRE2L(40), PRE2N(40,3), PRE2P(40) Scribe 190
      PRE2P5(40), PRE2PH(40,3), PREI(40), PREIF(40) Scribe 200
      PRODN(40,6,3), PRODS(40,6), PRODQ(40,6), QPH(40) Scribe 210
      QPHN(40), QPH(40), QTAIL(40), SEP(40) Scribe 220
      INO(40,6), UN5(40,6), UNH(40,6,3), XCHMS(40) Scribe 230
      INORNT(40,3), JYR(40), NRTS Scribe 240
      REAL*8 ASH, AT, ANH, A75, ATN, CYC, FEED5, FEEDN, FEEDQ, FASH, JAHNSC Scribe 250
      PRE1L, PRE2PH, PRE2L, PRE2N, PRE2P, PRE2P5, PRE2PH, PREI Scribe 260
      PREIF, PRODN, PRODS, PRODQ, QPH, QPHN, QPH, QTAIL, SEP Scribe 270
      UNO, UN5, UNH, INORNT, INORNT Scribe 280
      DATA PREZNT/'PRE 1'/,PRETHO/'PRE 2'/,PRETHP/'PRE 2P'/ Scribe 290
      Scribe 300
      Scribe 310
      THIS ROUTINE STORES DATA FOR THE SUMMARY PAGES. Scribe IS CALLED AT Scribe 320
      THE END OF EACH YEAR BY MAIN, SECTION F. Scribe 330
      Scribe 340
      Scribe 350
      Scribe 360
      Scribe 370
      Scribe 380
      Scribe 390
      Scribe 400
      Scribe 410
      Scribe 420
      Scribe 430
      Scribe 440
      Scribe 450
      Scribe 460
      Scribe 470
      Scribe 480
      Scribe 490
      Scribe 500
      Scribe 510

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      VPDE(IYR, IYF, HINDX) = VP(I)
      GO TO 100
C  REPRODUCTION FRED
C  80 IF (PRAN(I) - SE.PRSONE) GO TO 63
      IF (P(I) - LT. 10-3) GO TO 100
      PREZ(IYR) = P(I)
      GO TO 100
C  60 IF (PRAN(I) - SE.PRETV) GO TO 83
      IF (P(I) - LT. 10-3) GO TO 100
      PREZP(IYR) = P(I)
      PREZPH(IYR, HINDX) = VP(I)
      GO TO 100
C  MISC FRED STREAMS
C  90 IF (F(I) - EQ. 0.) GO TO 100
      GOLD = OPH(IYR)
      OPH(IYR) = OPH(IYR) * P(I)
      ASH(IYR) = (ASH(IYR) * GOLD + IF(I) * P(I)) / OPH(IYR)
      LSH(IYR, HINDX) = (ASH(IYR, HINDX) * GOLD + VP(I) * P(I)) / OPH(IYR)
      100 CONTINUE
C  PRODUCED STREAMS
C  110 IF (L-1)
      OPH(IYR) = 0.
      DO 160 I=1, NMI
C  REACTOR PRODUCTS
      IF (IPSTR(I) - EQ. 0) GO TO 120
      IPR = IPSTR(I)
      PRODO(IYR, IPR) = P(I)
      PRODP(IYR, IPR) = XP(I)
      PRODR(IYR, IPR, HINDX) = VP(I)
      GO TO 160
C  PREPRODUCTION (NEW)
C  120 IF (PRAN(I) - SE.PRETV) GO TO 140
      IF (P(I) - LT. 1.0-3) GO TO 160
      PREZP(IYR) = P(I)
      PREZPH(IYR) = XP(I)
      PREZPN(IYR, HINDX) = VP(I)
      GO TO 160
C  MISC PRODUCT STREAMS
C  140 IF (P(I) - EQ. 0.) GO TO 160
      GOLD = OPH(IYR)
      OPH(IYR) = OPH(IYR) * P(I)
      PASH(IYR) = (PASH(IYR) * GOLD + XP(I) * P(I)) / OPH(IYR)
      PASH(IYR, HINDX) = (PASH(IYR, HINDX) * GOLD + VP(I) * P(I)) / OPH(IYR)
      160 CONTINUE
C  TAILS
      Q*AIL(IYR) = P(N)
      AT5(IYR) = XP(N)
      ATN(IYR, HINDX) = VP(N)
C  INDEX LIMITS AND MISC INFO.
C  170 IF (IYR - IYR)
      JYR = IYR
      JYR = IYR
C  INITIAL PREPRODUCTION
      AN(HINDX) = AN1
C  SEPARATIVE WORK AND UNPROCESSED RETURNS
      SEP(IYR) = SWWCRP
      DO 180 K=1, KOREZ
      HQ(IYR, K) = POT(K)
      HNS(IYR, K) = POT2P(K)
      180 HNR(IYR, K, HINDX) = COTTP(K)
C  INVENTORY LEVELS
      PREIL(IYR) = PRE1
      PREZL(IYR) = PRE2
      PREZPH(IYR, HINDX) = AN2
C  REPROCESSING CAPACITY
      CYC(IYR) = CYCCAP
      RETURN
      END
      SUBROUTINE SECANT(XRAY, PRAY, N, IS, ITERNX, CCRT, IYR, ISUBS,
      1 XNEW, PNEW, CRITNW, NSEC, WORK, CRIT, IDROP,
      1 EVAL, IURT, FLAG)
      IMPLICIT REAL*8(A-N, O-Z)
      DIMENSION XRAY(15, IS), YRAY(15, IS), CCRT(5), ISUBS(15), XNEW(15),
      1 PNEW(15), NSEC(15, 15), WORK(15, 15),
      1 CRIT(15, 2), CRITT(20), RMS(20), DEL(20)
      THE SECANT ROUTINE FINDS THE ZERGES OF N SIMULTANEOUS EQUATIONS
      IN N VARIABLES USING THE NEWTON FORMULATION OF THE SECANT METHOD.
      SECANT IS CALLED HERE BY DOYEAR TO SOLVE THE CASCADE BALANCE
      EQUATIONS FOR EACH YEAR.
      IFLAG = 0
      NPI = N+1
      DO 20 I=1, N
      SECA 10
      SECA 30
      SECA 30
      SECA 40
      SECA 50
      SECA 60
      SECA 70
      SECA 80
      SECA 90
      SECA 100
      SECA 110
      SECA 120
      SECA 130
      SECA 140
      SECA 150
      SECA 160
      SECA 170
      SECA 180

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      XNEW(I) = XRAY(I,NPI)
21  XNEW(2) = XRAY(2,NPI)
      .... GENERATE CONVERGENCE INDICATORS OF NPI INITIAL ESTIMATES
      DO 67 I=1,NPI
        CRIT(I)=0.
        DO 68 J=1,N
          CRIT(I) = CRIT(I) + XRAY(J,I)**2
        CONTINUE
      CONTINUE
      .... CALCULATE HATFEL TO GENERATE NEW ESTIMATE. CALL DHAATEQ
      WITH 'RHS' = RHS OF SATUR EQUATION; ON RETURN 'RHS' HAS = NEW
      DISPLACEMENT VECTOR
      DO 100 I=1,N
        FHS(I)=FNEW(I)
      DO 100 J=1,N
120  FHS(I,J) = XRAY(I,J) - FHS(I)
      CALL DHAATEQ('RHS',FHS,N,-1,IS)
      ITER=ITER+1
      DO 100 I=1,N
        DEL(I) = 0.
      DO 120 J=1,N
120  DEL(I) = DEL(I) - (XRAY(I,J)-XRAY(I,NPI))*RHS(J)
140  FNEW(I) = XNEW(I) + DEL(I)
      IF (ITER.GE.2) WRITE(6,7000) ITER, (XNEW(I),I=1,N)
      .... EVALUATE NEW ESTIMATE:
      CALL EVAL(FNEW,FNEW,ITER)
      .... CALCULATE CONVERGENCE INDICATORS OF NEW POINT
      SUN = 0.
      CRITNW=0.
      DO 160 I=1,N
        SUN = SUN + DEL(I)**2
160  CRITNW = CRITNW + FNEW(I)**2
      IF (ITER.GE.2) WRITE(6,7100) (FNEW(I),I=1,N),CRITNW,SUN
      .... TEST WHETHER TO RETURN NOW EITHER NORMAL OR ABNORMAL.
      IF (CRITNW.LE.CRIT(1)) GO TO 180
      .... TEST FOR STALLED ITERATION
      IF (SUN.GT.CRIT(2)) GO TO 200
      IF (ITER.GE.1) WRITE(6,7200)
      IFLAG = 1
      GO TO 220
      .... EXIT ON CONVERGED P'S
180  IFLAG=1
      IF (ITER.GE.1) WRITE(6,7300)
      RETURN
220  CONTINUE
      IF (ITER.LT.ITERNT) GO TO 300
      .... EXIT ON MAXIMUM STEPS
      IFLAG=2
      WRITE(6,7400)
220  CONTINUE
      .... SELECT BEST ESTIMATE
      J=0
      BEST = CRITNW
      DO 240 I=1,NPI
        IF (CRIT(I).GT.BEST) GO TO 240
        BEST = CRIT(I)
      CONTINUE
240  CONTINUE
      IF (J.EQ.0) GO TO 280
      DO 260 I=1,N
        XNEW(I) = XRAY(I,J)
260  FNEW(I) = XRAY(I,J)
      CRITNW = CRIT(J)
280  CONTINUE
      RETURN
300  CONTINUE
      ... DETERMINE WHICH OF THE NPI OLD POINTS TO DROP
      IDROP=1
      WORST=CRIT(1)
      DO 320 I=2,NPI
        IF (CRIT(I).LT.WORST) GO TO 320
        IDROP=I
        WORST=CRIT(I)
320  CONTINUE
      ... DROP 'IDROP', REORDER ARRAYS AND INCLUDE LATEST ESTIMATE.
      IF (ITER.GE.2) WRITE(6,7500) ISUBS(IDROP)
      IF (IDROP.EQ.NPI) GO TO 140

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SET2	720

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      I=I+1
      DO 160 I=1, ISTEP
        P(I-I+1)=P(I-I)
160    I(I-I+1)=I(I-I)
        P(J)=I*F
        I(J)=ISTEP
180    CONTINUE
      IF (.NOT. SET) GO TO 220
      DO 200 I=1, I
        I=I(I)
200    WRITE(6,7300) STRN(I), SHAN(I), ISTEP(I), QUANT(I), P(I),
      (CHIMP(I), J=1, 3)
220    CONTINUE

      SEPARATE TABLE INTO FEED AND PRODUCT STREAMS. SET OTHER DATA.

      IN=0
      OUT=0
      DO 350 I=1, IT
        II=I(I)
        IF (STRN(II).NE.IV) GO TO 280

        ...FEED STREAM:
        IS=IS+1
        IF (IS.LE.20) GO TO 243
        WRITE(6,7500)
        WRITE(6,7800)
        CALL EXIT
240    CONTINUE
        PHAN(I)=SHAN(II)
        P(I)=QUANT(II)
        IF (I) = UNIMP(II, NHASE)
          DO 260 J=1, 3
260    FRAC(I, J) = UNIMP(II, J)
        IF (I) = P(I)
        PSIN(I)=BLANK
        ISTEP(I) = 0
        IF (ISTYP(II).LT.0) IFSTR(I)=ISTYP(II)
        IF (ISTYP(II).GT.0) IFSTR(I)=ISTYP(II)+100
        IF (IND2(II).NE.0) IND3(IND2(II))=I+1
        IF (P(I).GT.0) GO TO 340
        PSIN(I)=STAR
        IP=I
        GO TO 340

        ...PRODUCT STREAM:
280    CONTINUE
        OUT=OUT+1
        IF (STRN(II).EQ.0) GO TO 300
        WRITE(6,7000) SHAN(II), STRN(II)
        WRITE(6,7800)
        CALL EXIT
300    CONTINUE
        IF (OUT.LE.20) GO TO 320
        WRITE(6,7700)
        WRITE(6,7800)
        CALL EXIT
320    CONTINUE
        ISTEP(OUT) = OUT
        PHAN(OUT)=SHAN(II)
        P(OUT)=QUANT(II)
        IF (OUT) = P(II)
        IF (OUT) = UNIMP(II, NHASE)
        IF (H2.EQ.232) IF6(OUT)=UNIMP(II, 1)
        IFSTR(OUT) = 0
        IF (ISTYP(II).GT.0) IFSTR(OUT)=ISTYP(II)
        IF (ISTYP(II).GT.0) IFSTR(OUT)=ISTYP(II)+OUT
        IF (IND2(II).NE.0) IND3(IND2(II))=OUT
        OUT(OUT)=I
        PSIN(OUT)=BLANK
        IF (P(OUT).GT.0) GO TO 340
        PSIN(OUT)=STAR
        IP=OUT
340    CONTINUE
        IF (SET) WRITE(6,7600) IS, OUT, PHAN(IP), PHAN(IP)
        RETURN
360    CONTINUE
        GO TO 80

7000  FORMAT('0000 COLUMN 2 OF STREAM CARD FOR STREAM "",A6," IS ',
      1 'INCORRECT: "",A1,"')
7100  FORMAT('12X,"CORE TYPE "QUANTITY",X,"5-FRACTIONS",10X
      1 ',"NIMON ISOTOPE FRACTIONS",120,15X,A8)
7200  FORMAT('A1,A1,A7,I1,SE10.0)
7300  FORMAT('1X,A1,1X,A8,16,1P16.0,OFF12.6,3D16.5)
7400  FORMAT('0000 NUMBER OF STREAMS EXCEEDS SIZE OF PROGRAM ***')
7500  FORMAT('0000 NUMBER OF INPUT STREAMS EXCEEDS MAXIMUM OF 20')
7600  FORMAT('01X=","12," OUT=","12," CALCULATED FEED=","A8," "CALCULATED "
      1 "PRODUCT=","A8)
7700  FORMAT('0000 NUMBER OF OUTPUT STREAMS EXCEEDS MAXIMUM OF 20')
7800  FORMAT('0,"T50,"TERMINATE EXECUTION"/,"T50,"TERMINATE EXECUTIONS
      1")
      END

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DOUBLE PRECISION FUNCTION DNATEC(A,B,III,JJJ,JD)

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APPENDIX D
MUIFAP PROGRAM LISTING

A TRICEX GRANITIC ISOTOPE PLOTSHEET ANALYZER PROGRAM. THIS IS A MODEL OF THE TRITIUM ENRICHMENT PROCESS FOR ONE YEAR AND ONE TRICEX ISOTOPE PER CASE. THE ENRICHMENT PROCESS IS MODELED BY A SIMPLE MATCHED REBOUNDANCE PATIC CASCADE. PERFORMED BY S.E. BLUM, COMPUTER SCIENCES DIVISION, TRICEX CASERIE CORPORATION, NUCLEAR DIVISION, OAK RIDGE, TN. ORIGINALLY FORMULATED BY A.D.E. LA GARZA, OAK RIDGE GASEOUS DIFFUSION PLANT, OAK RIDGE, TN. FILE DOCUMENTATION IS PROVIDED IN GDS/CSD-37. 12/78

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140 XRAY(I,I)=.5
150 IF (SECRET) WRITE(6,7700) (J,YPRAX(J),J=1,OUT)
160 IF (.NOT.(WPT.LND.(SECRET.OR.CONFID))) GO TO 163
170 IF (CONFID) WRITE(6,9500)
180 IF (SECRET) WRITE(6,9400)
190 WRITE(6,7200)
200 CONTINUE
210 DO 180 I=1,NP1
220 CALL PREVAL (XRAY(I,I),YPRAX(I,I),J)
230 ISTER(I)= -1
240 ISTER(NP1)=0
250 ISTER=0
260 ISTER=30
270 ISTER=0
280 IF (WPT) ISTER=2
290 CCRIT(1)=4*1.D-18
300 CCRIT(2)=4*1.D-16
310 CALL SECRET (YPRAX,YPRAY,N,20,ITERX,CCRIT,ITER,ISUBS,ASS,FEED,
320 CBITW,HSEC,WOPF,CBIT,EDOP,PREVAL,IMBY,IPLAG)
330
340 C SECTION D -- CALCULATE AND PRINT RESULTS OF CASE; RETURN TO SECH B.
350
360 IF (.NOT.WPT) GO TO 200
370 WRITE(6,7600) (K,ANS(K),K=1,OUT)
380 WRITE(6,7900) (I,FEED(I),I=1,N)
390 WRITE(6,7800)
400 WRITE(6,8000) ITER, CCRIT(1), CBITW
410 WRITE(6,7200)
420 IF (CONFID) WRITE(6,9100)
430 IF (SECRET) WRITE(6,9200)
440 PAGE=PAGE+1
450 WRITE(6,9300) PAGE
210 CONTINUE
220 SW=0.
230 SW=0.
240 HIN=0.
250 DO 220 I=1,IN
260 HIT=HIN+P(I)*H(XP(I),YP(I),TWOX)
270 SWH=SWH+P(I)*Y(XP(I),0.,TWOX)
280 SW=SW+P(I)*Y(XP(I),YP(I),TWOX)
290 TOTPE=0
300 HOUT=0.
310 DO 240 K=1,OUT
320 YP(K) = ANS(K)*YP(K)
330 HOUT=HOUT+P(K)*H(XP(K),YP(K),TWOX)
340 PYP(K) = P(K)*YP(K)
350 TOTPE=TOTPE+PYP(K)
360 SWH=SWH+P(K)*Y(XP(K),0.,TWOX)
370 SW=SW+P(K)*Y(XP(K),YP(K),TWOX)
380 DIP=SW-SWH
390 DIPPE=DIP/TOTPE
400 *L6OP6=PYP(OUT)/TOTPE
260 CONTINUE
410 WRITE(6,8100) CASE,DATZ
420 * = *2-230
430 WRITE(6,8200) NN,NN
440 WRITE(6,8300) (PHAN(I), PSIN(I), P(I), XP(I), YP(I), PXP(I), PYP(I),
450 I=1,IN)
460 WRITE(6,8400)
470 WRITE(6,8500) PSIN,TOTPE,TOTPE,HIN
480 WRITE(6,8700) (PHAN(I),PSIN(I),P(I),XP(I),YP(I),PXP(I),PYP(I),
490 I=1,N)
500 WRITE(6,8900) PSIN,TOTPE,TOTPE,HOUT
510 WRITE(6,8900) NN, SW, NN, DIPPE, SWH, NN, NN, *L6OP6, DIP
520 WRITE(6,9000)
530 IF (IPLAG.EQ.2) WRITE(6,8400)
540 IF (IPLAG.EQ.3) WRITE(6,7030)
550 IF (SECRET) WRITE(6,9000)
560 IF (CONFID) WRITE(6,9500)
570 GO TO 40
580
590 C7800 FORMAT('A',T59,'--SECRET--',/,',',T61,'SECRET')
600 FORMAT('WARNING--WARNING.... ITERATIONS QUIT DUE TO VECTOR',
610 ' STALL.')
620
630 FORMAT(2A6)
640 FORMAT('I')
650 FORMAT('P('',AA,')=',IPD10.3,' P('',A6,')=',D10.3,' TOTAL 5 IN'
660 ' ',FEED=',D10.3,' TOTAL 6 IN FEED=',D10.3,' TOTAL FEED=',D10.
670 ' 3)')
680 FORMAT(' WTH=',20I5)
690 FORMAT('OLIMPAR APPROX:', 6(I8,'-',1PG11.3)/(15X,6(I8,'-',1PG11.3
700 '))')
710 FORMAT('OPTIMAL X VECTOR',6(I8,'-',1PG11.3)/(15X,6(I8,'-',1PG11.3
720 '))')
730 FORMAT('OPTIMAL Y VECTOR',6(I8,'-',1PG11.3)/(15X,6(I8,'-',1PG11.3
740 '))')
750 FORMAT(' WHERE EQUATIONS 1 TO N-2 ARE SIDE STREAM WITHDRAWAL BA'
760 ' LANCES, EQUATION N-1 IS TOTAL R-BALANCE, AND NTH EQUATION IS '
770 ' N-236 BALANCE')
780 FORMAT('OPTIMAL P VALUES',4(I8,'-',1PG11.3)/(15X,6(I8,'-',1PG11.3
790 '))')
800 FORMAT(' ',I8,' ITERATIONS TO CONVERGENCE, TARGET SUM OF SQUARES'
810 ' ',I8,' OF Y ACTIONS WAS',IPD10.3,' ACTUAL WAS',IPD10.3)
820 FORMAT(T52,'ORANITH FLOW SHEET ANALYZER',/O',T99,'CASE: ',A8,A3
830 /T90,'DATE: ',A8)
840 FORMAT('O',T10,'FLOW BASE ORANITH WEIGHT 5-PERCENT',A2,

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      11, '-PERCENT', 8X, '-CONTENT', I10, '-CONTENT')
8500 FORMAT(' ', T12, 'INPUT STREAMS ', (T10, A8, A1, 5X, IPD12.5, 2PF16.7,
1 19-12, 6X, IPD12.5, 6X, IPD12.5))
8600 FORMAT(' ', T121, 'INPUT-H')
8700 FORMAT(' ', T20, 'TOTAL', T32, IPD12.5, T83, IPD12.5, 2(6X, IPD12.5))
8800 FORMAT('0', T10, 'NO CONVERGENCE TO SOLUTION. //')
1 110, 'TO CONVERGENCE TO SOLUTION. EXCEEDED MAX ITERATIONS.')
8900 FORMAT(' ', T12, 'OUTPUT STREAMS ', (T10, A8, A1, 5X, IPD12.5, 2PF16.7,
1 19-12, 6X, IPD12.5, 6X, IPD12.5))
8910 FORMAT(' ', T121, 'OUTPUT-H')
8920 FORMAT(' ', T25, '1, 11, 8 SEPARATIVE WORK', T48, IPD12.5, T70,
1 'S. B. DIFFERENCE/TOT.', T12, '-INPUT', T100, IPD12.5/
1 ' ', T25, '1, 8 SEPARATIVE WORK', T48, IPD12.5, T70, 'TAILS',
1 12, '-CONTENT/TOT.', T12, '-INPUT', T100, IPD12.5/
1 T25, 'DIFFERENCE', T48, IPD12.5)
9000 FORMAT('00' GRAMM WEIGHTS DETERMINED BY BALANCE')
9100 FORMAT(' ', T56, '---CONFIDENTIAL---')
9200 FORMAT(' ', T59, '---SECRET---', //, ' ', T61, 'SECRET')
9300 FORMAT(115X, 'PAGE', I3)
9400 FORMAT(' ', T59, '---SECRET---', //, ' ', T61, 'SECRET')
9500 FORMAT(' ', T56, '---CONFIDENTIAL---')
END

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SUBROUTINE SETUP
THIS ROUTINE READS ALL CASE DATA CARDS AND ORGANIZES THE STREAMS
FOR SOLUTIONS.
IMPLICIT REAL*8(A-H,O-T)
LOGICAL WRT, SECRET, BADID, CONFID
INTEGER CJT, TOTPAGE, PAGE
REAL*8 O/0//, STAP//, BLANK//
DIMENSION STPH(81), SWAN(81), QUANT(81), R(81), PER6(81), ID(80)
COMMON /EVALU/ F(20), P(20), IF(20), XP(20), YP(20), TOTF5, TOTF6
1 1, WTH(20), PTP(20), PTP(20), PTP(20), IN, N, KP, KP
1 1, TWOK, M2
COMMON/RECORD/ CASE(5), DATE, PHAN(20), PSIN(20), PHAN(20), PSIN(20)
1 1, VSPRD, WRT, SECRET, PAGE, TOTPAGE, BADID, CONFID
1 1, EQUIVALENCE (N, OUT)
READ(5, 7000, END=280) CASE, M2, PPH
TPOV = 200*(23800-M2)/300
IF (SECRET) WRITE(6, 7900)
IF (CONFID) WRITE(6, 7800)
PAGE=PAGE+1
WRITE(6, 8000) PAGE
IF (WRT) WRITE(6, 7100) CASE, DATE
DO 20 J=1, 31
READ(5, 7200, END=300) STPH(J), SWAN(J), QUANT(J), R(J), PER6(J)
IF (STPH(J).EQ.STAP) GO TO 40
20 CONTINUE
WRITE(6, 7400)
WRITE(6, 8100)
CALL EXIT
40 CONTINUE
IT=J-1
IF (PPH.EQ.BLANK) GO TO 80
.... CONVERT FROM PARTS PER MILLION N-235 INPUT OF MINOR ISOTOPE
TO STANDARD WEIGHT FRACTION.
DO 60 I=1, IT
60 PER6(I) = PER6(I)*10-6*R(I)
80 DO 100 I=1, IT
100 ID(I) = I
DO 140 I=2, IT
140 I=I-1
DO 180 J=1, IN
IF (R(J).GT.P(I)) GO TO 180
THP=P(I)
IDTHP=ID(I)
IJUMP=I-J
DO 120 K=1, IJUMP
R(I-K+1)=R(I-K)
120 ID(I-K+1)=ID(I-K)
R(J)=THP
ID(J)=IDTHP
130 CONTINUE
IF (.NOT.WRT) GO TO 180
DO 160 I=1, IT
160 WRITE(6, 7100) STPH(I), SWAN(I), QUANT(I), R(I), PER6(I)
180 CONTINUE
IN=0
OUT=0
DO 260 I=1, IT
260 ID(I)
IF (STPH(I).EQ.0) GO TO 220
IN=IN+1
IF (IN.LE.20) GO TO 210
WRITE(6, 7500)
WRITE(6, 8100)
CALL EXIT
200 CONTINUE
PHAN(IN)=SWAN(I)
F(IN)=QUANT(I)

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33

SUBROUTINE START	STAR 1
THIS ROUTINE GENERATES THE INITIAL ESTIMATE.	STAR 20
IMPLICIT REAL*8(A-H,O-Z)	STAR 30
INTEGER OUT	STAR 40
COMMON /VALUES/ P(20),XP(20),YP(20),ZP(20),TOTF5,TOTF6	STAR 50
1, NTH(20),FVF(20),FVP(20),PKP(20),IS,N,KF,KP	STAR 60
1, T00F, N2	STAR 70
EQUIVALENCE (C,OUT)	STAR 80
DIMENSION A(20,20),B(20),C(20,1)	STAR 100
EQUIVALENCE (B(1),C(1,1),YP(1))	STAR 110
G(I) = (1./I-1)**((1./3.))	STAR 120
DO 20 I=1,N	STAR 130
B(I)=0	STAR 140
DO 20 J=1,N	STAR 150
20 A(I,J)=0	STAR 160
IF (N-12-2) GO TO 120	STAR 170
NH1=N-1	STAR 180
DO 100 K=2,NH1	STAR 190
P1=0	STAR 200
PSUM=0	STAR 210
P1=0	STAR 220
PSUM=0	STAR 230
IF (NHN(N)-PG,0) GO TO 60	STAR 240
NK=NHN(K)	STAR 250
DO 40 I=1,NK	STAR 260
P1= P1+XP(I)	STAR 270
PSUM=PSUM+P(I)	STAR 280
40 B(K-1) = P(K-1) + P(I)*YP(I)*(XP(I)/(1-XP(I)-I))**(-1./3.)	STAR 290
60 CONTINUE	STAR 300
NH1=N-1	STAR 310
DO 40 J=1,NH1	STAR 320
P1= P1+XP(J)	STAR 330
PSUM=PSUM+P(J)	STAR 340
40 A(F-1,J)=G(XP(J))*P(J)	STAR 350
PSUM=PSUM-PSUM	STAR 360
A(K-1,K) = (P1-P1+XP(K)*PSUM)/(3*(1-XP(K))** (2./3.)*XP(K) *(0./3.))	STAR 370
1 G(XP(K)) =DSUM	STAR 380
100 CONTINUE	STAR 390
120 CONTINUE	STAR 400
DO 140 I=1,N	STAR 410
A(N-1,I)=P(I)*G(XP(I))	STAR 420
140 A(N,I)=P(I)	STAR 430
DO 160 I=1,N	STAR 440
160 B(N-1) = B(N-1)+P(I)*YP(I)*(XP(I)/(1-XP(I)-YP(I))**(-1./3.))	STAR 450
B(N)=TOTF6	STAR 460
	STAR 470


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      PRN(17), HSEC(15,15), NGR(15,15),
      CRIT(17,2), CRIT(20), PRN(20), DEL(20)
      IFLAG=0
      NPT = 0
      DO 20 I=1,N
      IPRN(I) = IPRN(I,NPT)
20 PRN(I) = IPRN(I,NPT)
      .... GENERATE CONVERGENCE INDICATORS OF NEW POINT ESTIMATES
      DO 40 I=1,NPT
      CRIT(I)=0
      DO 40 J=1,N
      CRIT(I) = CRIT(I) + PRN(J,I)**2
40 CONTINUE
      .... CALCULATE VALUES TO GENERATE NEW ESTIMATE. CALL DRATED
      WITH 'RES' = SQR OF MATRIX EQUATION: ON RETURN 'RES' HAS = NEW
      DISPLACEMENT VECTOR
      DO 50 I=1,N
      IPRN(I)=IPRN(I)
      DO 50 J=1,N
      PRN(I,J) = PRN(I,J) - PRN(I)
      CALL DRATED(RES,RES,N,1,15)
      IPRN(I)=IPRN(I)
      DO 50 J=1,N
      CRIT(I) = 0
      DO 50 J=1,N
      CRIT(I) = CRIT(I) + DEL(I) - (IPRN(I) - IPRN(I,NPT)) * PRN(J,I)
120 IPRN(I) = IPRN(I) + DEL(I)
      IF (IUPD.GE.2) WRITE(6,7000) ITER, (NPT(I),I=1,N)
      .... EVALUATE NEW ESTIMATE
      CALL EVAL(IPRN,PRN,ITER)
      .... CALCULATE CONVERGENCE INDICATORS OF NEW POINT
      SNR = 0
      CRITN=0
      DO 140 I=1,N
      SNR = SNR + DEL(I)**2
140 CRITN = CRITN + PRN(I)**2
      IF (IUPD.GE.2) WRITE(6,7100) (PRN(I),I=1,N), CRITN,SNR
      .... TEST WHETHER TO RETURN NOW EITHER NORMAL OR ABNORMAL.
      IF (CRITN.LE.CRIT(1)) GO TO 160
      .... TEST FOR STALLED ITERATION
      IF (SNR.GT.CRIT(2)) GO TO 180
      IF (IUPD.GE.3) WRITE(6,7200)
      IFLAG = 3
      GO TO 200
      .... EXIT ON CONVERGED P'S
160 IFLAG=1
      IF (IUPD.GE.3) WRITE(6,7300)
      RETURN
180 CONTINUE
      IF (IUPD.LT.ITER) GO TO 280
      .... EXIT ON MAXIMUM ITER
      IFLAG=2
      WRITE(6,7400)
200 CONTINUE
      .... SELECT BEST ESTIMATE
      J=0
      BEST = CRITN
      DO 220 I=1,NPT
      IF (CRIT(I).GT.BEST) GO TO 220
      BEST = CRIT(I)
      J=I
220 CONTINUE
      IF (J.EQ.0) GO TO 240
      DO 240 I=1,N
      IPRN(I) = IPRN(I,J)
240 PRN(I) = PRN(I,J)
      CRITN = CRIT(J)
260 CONTINUE
      RETURN
280 CONTINUE
      .... DETERMINE WHICH OF THE NEW OLD POINTS TO DROP
      IDROP=1
      WORST=CRIT(1)
      DO 300 I=2,NPT
      IF (CRIT(I).LT.WORST) GO TO 300
      IDROP=I
      WORST=CRIT(I)
300 CONTINUE
      ... DROP 'IDROP', REORDER ARRAYS AND INCLUDE LATEST ESTIMATE.

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SPCAY270

MOORE PRECISION PISTON '72 (A, B, C, D)
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DIMENSION A(10,1),B(10,1)
DOUBLE PRECISION A,B,E,C,D
KK=111
SV=IABS(JJJ)
D=1.
IP (JJJ.LT.0) D=0.
KK=KK-1
DO 180I=1,KK
  S=C,D
  DO 220J=1,KK
    W=IABS(L(J,I))
    IF (B(LT,7)) GO TO 23
    S=E
    I=J
20  CONTINUE
    IF (L.EQ.1) GO TO 100
    DO 40 J=1,FK
      C=A(I,J)
      A(I,J)=A(L,J)
30  A(L,J)=S
      IF (NV.LE.0) GO TO 80
      DO 60 J=1,NV
        S=B(I,J)
        B(I,J)=B(L,J)
        B(L,J)=S
60  B(L,J)=S
80  D=D
100 IF (A(I,1).EQ.0.) GO TO 180
    IPO=I-1
    DO 160J=IPO,FK
      IF (A(J,1).EQ.0.) GO TO 160
      S=A(J,1)/A(I,1)
      A(J,1)=0.,D
      DO 120 K=IPO,FK
        A(J,K)=A(J,K)-A(I,K)*S
120 IF (NV.LE.0) GO TO 160
        DO 140 K=1,NV
          B(J,K)=B(J,K)-B(I,K)*S
140 B(J,K)=B(J,K)-B(I,K)*S
160 CONTINUE
180 CONTINUE
    DO 200I=1,KK
      D=0*A(I,1)
200 IF (NV.LE.0) GO TO 260
      KKO = KK-1
      DO 240K=1,NV
        B(KK,K)=B(KK,K)/A(KK,KK)
240 DO 240I=1,KKO
          B=KK-I
          DO 220J=1,KKO
            B(B,K)=B(B,K)-A(B,J+1)*B(J+1,K)
220 B(B,K)=B(B,K)/A(B,B)
260 D=IATD=D
      D=1/D
      END

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