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IBM-704 CODES FOR REACTIVITY STEP CALCULATIONS (RE-126 and RE-135)

by

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IBM-704 CODES FOR REACTIVITY STEP CALCULATIONS (RE-126 and RE-135)

I. Introduction

Two codes have been written for the IBM-704 computer to calculate the behavior of a reactor following a step change in reactivity, using one-group, space-independent, zero-power kinetic theory. The reactor is assumed to be running at constant level before the step is made, either at critical or subcritical conditions, with an external source.

One of the codes (RE-126) assumes all delayed-neutron precursors in equilibrium at the time of the step, while the other (RE-135) allows cases with nonequilibrium precursors to be handled. In addition, RE-126 can handle the case of zero final reactivity.

The codes have been applied to the calculation of the errors encountered in common types of reactivity measurements under various experimental conditions.[1,2]

II. Theory

The solution of the kinetic equations for the case of constant k_{eff} and without an extraneous source is readily available in the literature.

For the case with a constant source, the equations to be solved here are:

$$\frac{dn}{dt} = [k_{eff}(1 - \beta) - 1] \frac{n}{\ell^*} + \sum_{i=1}^{N} \lambda_i C_i + S_0 \tag{1a}$$

$$\frac{dC_i}{dt} = \frac{k_{eff}\beta_i n}{\ell^*} - \lambda_i C_i \tag{1b}$$

where

n = the total neutron concentration in neutrons/cm^3

t = the time

k_{eff} = the effective multiplication constant

$\beta = \sum_{i=1}^{N} \beta_i$ = the total fraction of neutrons which are delayed

N = the number of delayed neutron groups

β_i = the fraction of neutrons in the ith delayed group

λ_i = the decay constant of the precursor of the delayed neutrons in the ith group

C_i = the concentration of the precursors from which the ith group of delayed neutrons arise, in atomic nuclei/cm^3

S_0 = the number of neutrons/cm^3/sec due to the extraneous source

ℓ^* = the prompt neutron lifetime.

Consider first the steady-state solution of eq. (1). In that case

$$\frac{dC_i}{dt} = 0 = \frac{k_{eff}\beta_i n}{\ell^*} - \lambda_i C_i \quad .$$

Thus

$$C_i = \frac{k_{eff}\beta_i n}{\ell^* \lambda_i} \tag{2}$$

and

$$\frac{dn}{dt} = 0 = [k_{eff}(1 - \beta) - 1]\frac{n}{\ell^*} + \sum_i \frac{k_{eff}\beta_i n}{\ell^*} + S_0 \quad .$$

Accordingly

$$\frac{k_{eff} n}{\ell^*} - \frac{k_{eff}\beta n}{\ell^*} - \frac{n}{\ell^*} + \frac{k_{eff}\beta n}{\ell^*} + S_0 = 0$$

and

$$n = \frac{\ell^* S_0}{1 - k_{eff}} \quad . \tag{3}$$

The non-steady-state solutions are easily obtained if one takes the Laplace transforms of eq. (1). If s be the variable of the transformed functions, then

$$\left.\begin{aligned} L\{n(t)\} &= n(s) \\ L\{C_i(t)\} &= C_i(s) \end{aligned}\right\} \quad . \tag{4}$$

From eq. (1a) we obtain:

$$sn(s) - n_0 = \frac{k_{eff}(1-\beta) - 1}{\ell^*} n(s) + \sum_i \lambda_i C_i(s) + \frac{S_0}{s} \tag{5a}$$

and from eq. (1b)

$$sC_i(s) - C_{i0} = \frac{k_{eff}\beta_i}{\ell^*} n(s) - \lambda_i C_i(s) \quad , \tag{5b}$$

where n_0 and C_{i0} are, as usual, the initial values of n and C_i. Solving eq. (5b) for $C_i(s)$ and substituting in Eq.(5a) there is obtained

$$n(s)\left\{s - \frac{k_{eff}(1-\beta) - 1}{\ell^*} - \sum_i \frac{k_{eff}\lambda_i\beta_i}{\ell^*(s+\lambda_i)}\right\} = n_0 + \sum_i \frac{\lambda_i C_{i0}}{s+\lambda_i} + \frac{S_0}{s} \quad .$$

Thus

$$n(s) = \frac{n_0 + \sum_i \frac{\lambda_i C_{i0}}{s+\lambda_i}}{s - \frac{k_{eff}(1-\beta) - 1}{\ell^*} - \sum_i \frac{k_{eff}\lambda_i\beta_i}{\ell^*(s+\lambda_i)}} + \frac{S_0}{s\left[s - \frac{k_{eff}(1-\beta) - 1}{\ell^*} - \sum_i \frac{k_{eff}\lambda_i\beta_i}{\ell^*(s+\lambda_i)}\right]} = N_1(s) + N_2(s) \quad , \tag{6}$$

The quantity $N_1(s)$ is just the transformed function obtained for the case without an extraneous source, whereas $N_2(s)$ represents the source contribution.

Let s_j be the roots of the equation

$$s - \frac{k_{eff}(1-\beta) - 1}{\ell^*} - \sum_i \frac{k_{eff}\lambda_i\beta_i}{\ell^*(s+\lambda_i)} = 0 \quad , \tag{7}$$

which can be cast into the form

$$\rho = \frac{k_{eff} - 1}{k_{eff}} = \frac{\ell^* s + s\sum_{i=1}^{N} [\beta_i/(s+\lambda_i)]}{1 + \ell^* s} \quad , \tag{7a}$$

which is the inhour equation with ρ the final reactivity. This equation will have roots s_j, one more in number than the number of delayed-neutron groups. For positive ρ, one of the roots s_j is positive, the others being negative. For negative ρ, all of the s_j are negative. In either case, the N most negative s_j are associated with the transient terms of eq. (1). The reciprocal of the remaining s_j (algebraically the largest s_j) is known as the asymptotic period. We may write eq. (7) in rationalized form as

$$\prod_j (s - s_j) = 0 \quad . \tag{8}$$

In order to obtain the inverse transforms of $N_1(s)$ and $N_2(s)$ in eq. (6), use is made of two formulas from the theory of Laplace transforms. If f(s) is the ratio of polynomials p(s) and q(s), so that

$$f(s) = p(s)/q(s) \quad ,$$

where q(s) has only <u>simple</u> zeros which are denoted by s_j, then

$$f(t) = L^{-1}\{f(s)\} = \sum_j \frac{p(s_j)}{q'(s_j)} e^{s_j t} \quad . \tag{9}$$

Also, if

$$L^{-1}\{f(s)\} = F(t) \quad ,$$

then

$$L^{-1}\left\{\frac{1}{s} f(s)\right\} = \int_0^t F(\tau)\, d\tau \quad . \tag{10}$$

We may apply eq. (9) to $N_1(s)$ of eq. (6) to obtain

$$N_1(t) = \sum_j \frac{n_0 + \sum_i \frac{\lambda_i C_{i0}}{s_j + \lambda_i}}{1 + \sum_i \frac{k_{eff}\lambda_i \beta_i}{\ell^*(s_j + \lambda_i)^2}} e^{s_j t} \tag{11}$$

Assuming all delayed-neutron precursors in equilibrium, eq. (11) may be put in the form

$$\frac{n(t)}{n_0} = \sum_{j=1}^{N+1} A'_j \, e^{s_j t} \quad , \tag{12}$$

with

$$A'_j = (1 - \rho) \frac{\ell^* + \sum_i \frac{\beta_i}{s_j + \lambda_i}}{\ell^*(1 - \rho) + \sum_i \frac{\beta_i \lambda_i}{(s_j + \lambda_i)^2}} \tag{13}$$

where the C_{i0} have been obtained from eq. (2), assuming $k_{eff} = 1$ before the reactivity step. This, then, represents the behavior of the reactor, without an extraneous source, for reactivity steps starting from critical.

The inverse of $N_2(s)$ can be obtained with the aid of eq. (9) and eq. (10). We have

$$N_2(t) = \int_0^t \sum_j \left[\frac{S_0 \, e^{s_j \tau}}{1 + \sum_i \frac{k_{eff} \lambda_i \beta_i}{\ell^* (s_j + \lambda_i)^2}} \right] d\tau \quad . \tag{14}$$

Thus

$$N_2(t) = S_0 \sum_j \left\{ \frac{e^{s_j t} - 1}{s_j \left[1 + \sum_i \frac{k_{eff} \lambda_i \beta_i}{\ell^* (s_j + \lambda_i)^2} \right]} \right\} \quad .$$

The complete solution to the problem is therefore given by the sum of eq. (11) and eq. (14):

$$n(t) = \sum_{j=1}^{N+1} \frac{n_0 + \sum_i \frac{\lambda_i C_{i0}}{s_j + \lambda_i}}{1 + \sum_i \frac{k_{eff} \lambda_i \beta_i}{\ell^* (s_j + \lambda_i)^2}} e^{s_j t} + S_0 \sum_{j=1}^{N+1} \left\{ \frac{e^{s_j t} - 1}{s_j \left[1 + \sum_i \frac{k_{eff} \lambda_i \beta_i}{\ell^* (s_j + \lambda_i)^2} \right]} \right\} . \tag{15}$$

This can be put in the form:

$$\frac{n(t)}{n_0} = \sum_{j=1}^{N+1} (A_j + B_j)\, e^{s_j t} + C \quad . \tag{16}$$

Here

$$A_j = (1 - \rho)\, \frac{\ell^* + (k_{eff})_0 \sum_{i=1}^{N} \beta_i/(s_j + \lambda_i)}{\ell^*(1 - \rho) + \sum_{i=1}^{N} \beta_i \lambda_i/(s_j + \lambda_i)^2} \quad , \tag{17}$$

which is a generalization of eq. (13). Also,

$$B_j = (1 - \rho)\, \frac{1 - k_{eff_0}}{s_j \left[\ell^* (1 - \rho) + \sum_{i=1}^{N} \beta_i \lambda_i/(s_j + \lambda_i)^2 \right]} \tag{18}$$

and

$$C = [1 - (1/\rho)]\, [1 - k_{eff_0}] \quad . \tag{19}$$

Here k_{eff_0} is the value of k_{eff} before the reactivity step and is obtained from the equation

$$n_0 = \ell^* S_0/(1 - k_{eff_0}) \quad , \tag{20}$$

assuming the reactor to be at the steady power level n_0 before the step.

Equations (16)-(19) represent the general reactivity-step behavior for equilibrium precursors and nonzero final reactivity, and are the equations calculated in RE-126.

Now let us consider the case of zero final reactivity. Since then one of the s_j has a zero value, $N_2(t)$ will be given as

$$N_2(t)\Big|_{\rho=0} = \frac{S_0 t}{1 + \sum_i \frac{\beta_i}{\ell^* \lambda_i}} + S_0 \sum_{j,\, s_j \neq 0} \left\{ \frac{e^{s_j t} - 1}{s_j \left[1 + \sum_i \frac{\lambda_i \beta_i}{\ell^* (s_j + \lambda_i)^2} \right]} \right\} \quad , \tag{21}$$

where the first term is the $s_j = 0$ term of the sum and is obtained by expanding the exponential and taking the limit as $s_j \longrightarrow 0$. The second term is the sum over the remaining negative values of s_j. $N_1(t)$ has the value

$$N_1(t)\Big|_{\rho=0} = \frac{n_0 + \sum_i C_{i0}}{1 + \sum_i \frac{\beta_i}{\ell^* \lambda_i}} + \sum_{j, s_j \neq 0} \left[\frac{n_0 + \sum_i \frac{\lambda_i C_{i0}}{s_j + \lambda_i}}{1 + \sum_i \frac{\lambda_i \beta_i}{\ell^* (s_j + \lambda_i)^2}} e^{s_j t} \right] , \quad (22)$$

where the first term is simply the $s_j = 0$ term and the second term, as before, represents the sum over the remaining N negative values of s_j. The complete solution for $\rho=0$ is therefore the sum of eq. (21) and eq. (22), so that eq. (15) takes the form

$$N(t)\Big|_{\rho=0} = \frac{n_0 + \sum_i C_{i0}}{1 + \sum_i \frac{\beta_i}{\ell^* \lambda_i}} - \sum_{j, s_j \neq 0} \frac{S_0/s_j}{1 + \frac{\beta_i \lambda_i}{\ell^* (s_j + \lambda_i)^2}} + \frac{S_0 t}{1 + \sum_i \frac{\beta_i}{\ell^* \lambda_i}}$$

$$+ \sum_{j, s_j \neq 0} \frac{n_0 + \sum_i \frac{\lambda_i C_{i0}}{s_j + \lambda_i} + \frac{S_0}{s_j}}{1 + \sum_i \frac{\lambda_i \beta_i}{\ell^* (s_j + \lambda_i)^2}} e^{s_j t} , \quad (23)$$

where the constant term has been extracted from the sum in eq. (21). In eq. (23), it should be remembered that each sum over j involves only negative values of s_j, the zero-valued s_j term having already been dealt with. This has been indicated by writing the index of summation as $j, s_j \neq 0$. Since the exponential term in eq. (23) involves only negative values of s_j, it represents a transient term. It is seen therefore that if $\rho = 0$, then n(t) has the form of a constant plus a term which varies linearly with time after the exponential term has decayed away.

Equation (23) can be put in the form

$$\frac{n(t)}{n_0} = Ht + \sum_{j=1}^{N+1} A_j e^{s_j t} + \sum_{j=2}^{N+1} B_j (e^{s_j t} - 1) , \quad (24)$$

where

$$H = \frac{1 - k_{eff_0}}{\ell^* + \sum_{i=1}^{N} (\beta_i/\lambda_i)} \quad . \tag{25}$$

In this case B_1 is singular.

For the case of nonequilibrium delayed-neutron precursors, it is assumed that the reactor has been running at the steady power n_0 for a "buildup time" of T_B seconds. Then the precursor concentration for each delayed-neutron group will be given by:

$$C_{i0} = \frac{k_{eff_0} \beta_i n_0}{\ell^* \lambda_i} \left(1 - e^{-\lambda_i T_B}\right) \quad . \tag{26}$$

Substituting this in eq. (11), the coefficients A_j are found to be given by the equation

$$A_j = (1 - \rho) \frac{\ell^* + k_{eff_0} \sum_i \frac{\beta_i \left(1 - e^{-\lambda_i T_B}\right)}{s_j + \lambda_i}}{\ell^* (1 - \rho) + \sum_i \frac{\beta_i \lambda_i}{s_j + \lambda_i}} \quad . \tag{27}$$

This reduces to eq. (17) when the values of $\lambda_i T_B$ become large, i.e., for long buildup times. The remainder of the theory is unchanged. Code RE-135 does this calculation for the equilibrium case and for selected buildup times.

III. Method of Calculation

The codes are written in the Fortran language. Source program listings are given in Section VII. The major coding problem encountered was the determination of the roots of the inhour equation.

The behavior of the roots can be seen in Figure 10.25 of Glasstone and Edlund.[3] There it can be seen that one root lies to the right of $-\lambda_1$, while the others lie to the left, the second between $-\lambda_1$ and $-\lambda_2$, etc., and the last between $-\lambda_N$ and $-1/\ell^*$. To find the roots, an iterative procedure is used. A first guess is made placing the first root at zero and the other roots at the midpoints of their regions. For a given root, this first guess of s is substituted into eq. (7a) and the corresponding value of ρ is

calculated. If the absolute value of $(\rho - \rho_0)$, where ρ_0 is the specified final reactivity, satisfies a convergence criterion, s is taken as the root. If not, the derivative $d\rho/ds$ is calculated, where

$$\frac{d\rho}{ds} = \frac{1}{1 + \ell^* s} \left[\frac{\ell^* + \sum_{i=1}^{N} \frac{\beta_i}{s + \lambda_i}}{1 + \ell^* s} - s \sum_{i=1}^{N} \frac{\beta_i}{(s + \lambda_i)^2} \right] ,$$

and a correction Δs is found where

$$\Delta s = (\rho_0 - \rho) / (d\rho/ds) \quad .$$

This correction is added to s to produce an improved value for the next trial. In the process, a check is made to see that s has not been taken out of its proper region. If it has, Δs is reduced by a factor of 10 and again checked. This step is repeated as often as necessary to keep s inside its region. The process then repeats and continues until the convergence criterion is satisfied. The other roots are then calculated in the same manner.

The usual method of testing for convergence in such a process is to specify a convergence criterion ϵ, and to stop the iteration whenever $\rho - \rho_0$ becomes less than ϵ. This method was considered undesirable for the present application for two reasons. First of all, it is difficult to determine a proper criterion of convergence for the general case; too high a value would give poor accuracy and too low a value might prevent convergence. In addition, the size of an ϵ which could be used might be limited by only one of the roots, which means that the other roots would not be found with the maximum possible accuracy. Therefore, a way was sought in which the iteration could be automatically stopped at the right place. Examination of the Newton-Raphson method used for finding the roots showed that the process would always converge, that is, the magnitude of the deviation, $D = \rho - \rho_0$, will decrease with each iteration. This will go on indefinitely until D gets so small that round-off errors upset the calculation. When this happens, eventually the magnitude of a value of D will be equal to or greater than the previous value. This means that the iteration has come as close as possible and so is ended at this point. However, it is possible for the dependence of ρ upon s to be such that if D changes in sign during the process it might increase in magnitude. Therefore, if the present value of D is opposite in sign to the previous value, the above test is bypassed and the process is continued. It is also unconditionally continued after the first iteration, since then there is no previous value of D to use for comparison.

Cases in which the above conditions will not allow the iteration process to stop may occur. For example, D may eventually alternate its sign with each iteration. To take care of such cases, the process is terminated unconditionally after 100 iterations. (Even this may take only a second or so.) It is believed that these methods might have use in other iterative calculations, since the roots are obtained with about the maximum accuracy possible with ordinary single-precision floating-point arithmetic.

After the roots are available, the A_j, B_j, and C or H are calculated and the s_j, A_j and B_j are printed out. The number of iterations and the final value of $(\rho_0 - \rho)/(d\rho/ds)$ are also printed out for each root. Then for each value of time which has been read in, $\dot{n}(t)/n_0$ and $n(t)/n_0$ are calculated, as well as the instantaneous period $n(t)/\dot{n}(t)$ and the fractional deviation from the asymptotic period $1 - (s_1 n/\dot{n})$. These are also printed out. If $\rho_0 = 0$, the appropriate changes are made in the formulas, and B_1 is left out of consideration. Code RE-135 calculates the A_j, $n(t)/n_0$, $\dot{n}(t)/n_0$, etc., for all values of buildup time, T_B, which have been given, as well as for the equilibrium case. (Note that $\rho = 0$ is not admissible for RE-135.)

It can be shown that the quantities

$$1 - \sum_{j=1}^{N+1} A_j \text{ and } C + \sum_{j=1}^{N+1} B_j$$

should be equal to zero in an exact calculation. Therefore, these magnitudes provide a check on the accuracy of the roots. Hence, they are printed out as A CHECK and B CHECK, respectively (B CHECK does not apply when $\rho_0 = 0$). Values of the order of magnitude of 10^{-8} or less are obtained for these and indicate that the limiting factor for the accuracy of the calculation is the 8-significant-figure accuracy of the 704 floating-point arithmetic. When $\rho_0 \neq 0$, the quantities C and the asymptotic period $1/s_1$ are also printed out.

For RE-135 with finite buildup times the relation $\sum_j A_j = 1$ no longer holds. Therefore, the value of $\sum_j A_j$ is calculated for each case and printed out as "NORMALIZATION." Each A_j is divided by this quantity in order to normalize the flux to unity at t = 0.

IV. Input Specification

Input for both codes is on-line. The input deck for a given problem for RE-126 is made up as follows:

One card containing a problem designation number, ρ_0, $k_{ex_0} = (k_{eff_0} - 1) \leqslant 0$, ℓ^*, N, and M, according to format 1 (see Section VI). (Note that the subscript on ρ does not denote initial value. Although k_{ex_0} is the initial value of k_{ex}, the quantity ρ_0 is the final value of ρ.)

Cards containing λ_i, i = 1,. . ., N; N $\leqslant$ 30, 5 per card, according to format 2.

Cards containing β_i, i = 1, . . ., N; N $\leqslant$ 30, 5 per card, according to format 2.

Cards containing M values of t, M $\leqslant$ 500, 6 per card, according to format 3.

Here N is the number of delay groups and M is the number of times. The problem designation number must be an integer less than 32,768.

The λ_i must be in order of increasing absolute value, with λ_1 the smallest. The β_i must be ordered so that a given β_i is associated with the correct λ_i.

The cards for RE-135 are made up similarly to those for RE-126, with minor change. The T_B's are entered according to the same format as the t's, and are placed behind the t cards. The first card follows format 1A, and contains ρ_0, k_{ex_0}, ℓ^*, N, M, and L, the number of T_B's up to 500.

Within each floating-point field of the cards, data may be punched in any form allowed by the Fortran input routines.

V. Operating Details

The codes are run in the standard manner for Fortran object programs. Input is on-line; output is off-line, using logical tape 10. No sense switches are used. The standard Fortran error stops apply. After processing one set of data, the programs return to read more data. No end-of-files are written. Output tapes should be printed on Program Control.

A typical RE-126 problem with N = 15, M = 20 takes less than 3 seconds, while a typical RE-135 problem with N = 15, M = 20, L = 20 takes less than one minute.

Acknowledgements

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References

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2. C. E. Cohn, Errors in Reactivity Measurements due to Photoneutron Effects, Nuclear Science and Engineering 6, 284-287 (1959).

3. S. Glasstone and M. C. Edlund, The Elements of Nuclear Reactor Theory, D. Van Nostrand Co., Inc., New York, (1952), p. 299.

VI. INPUT CARD FORMATS

Cols. 1 6 7 18 19 33 34 42 43 45 46 49

1	3	0	0	0	1		+	1	.	0	0	0	0	E	-	0	3		+	0	.	0	0	0	0	0	0	0	E	+	0	0		4	.	0	0	E	-	0	5			6			1	2
Problem Identification							ρ_0												k_{ex_0}																ℓ^*								N					M			

FORMAT 1

Cols. 1 14 15 28 29 42 43 45 46 48 49 53

-	1	.	0	0	0	0	0	0	0	0	E	-	0	2		0	.	0	0	0	0	0	0	0	E	+	0	0		1	.	0	0	0	0	0	0	0	E	-	0	3		1	5			2	0			2	0
ρ_0																k_{ex_0}																ℓ^*														N				M				L		

FORMAT 1A

Cols. 1 14 15 28 29 42 43 56 57 70

	1	.	0	0	0	0	0	0	0	0	E	6	0	2		1	.	0	0	0	0	0	0	0	E	5	0	3		1	.	0	0	0	0	0	0	0	E	-	0	4		1	.	0	0	0	0	0	0	0	E	3	0	5		1	.	0	0	0	0	0	0	0	E	2	0	6
	λ_i β_i															λ_{i+1} β_{i+1}															λ_{i+2} β_{i+2}															λ_{i+3} β_{i+3}															λ_{i+4} β_{i+4}													

FORMAT 2

Cols. 1 11 12 22 23 33 34 44 45 55 56 66

	1	.	0	0	0	0	E	-	0	3		1	.	0	0	0	0	E	-	0	2		1	.	0	0	0	0	E	-	0	1		1	.	0	0	0	0	E		0	0		1	.	0	0	0	0	E	+	0	1		1	.	0	0	0	0	E	+	0	2
	t_K T_K											t_{K+1} T_{K+1}											t_{K+2} T_{K+2}											t_{K+3} T_{K+3}											t_{K+4} T_{K+4}											t_{K+5} T_{K+5}										

FORMAT 3

Floating Point Numbers:
e.g. 1.000E=02 1.000×10^{-2}

Cols. 72-80 Available for
Card Identification Symbols
on All Formats

VII. CODE LISTINGS

```
CODE FOR REACTIVITY STEP CALCULATIONS  RE-126
C
      DIMENSIONDC(30),BETA(30),T(500),S(31),A(31),B(31),BDD(30),
     1P(500),PDOT(500),PERIOD(500),ERROR(500),W(31),X(31),SD(30),BSD(30)
   47 READ1,NO,RHO,EXK,PNL,N,M,(DC(I),I=1,N)
    1 FORMAT(I6,1PE12.4,1PE15.7,1PE9.2,I3,I4/(1P5E14.7))
      READ3,(BETA(I),I=1,N)
    3 FORMAT(1P5E14.7)
      READ4,(T(K),K=1,M)
    4 FORMAT(1P6E11.4)
      NA=N+1
C
C ASSIGNMENT OF STARTING POINTS FOR ITERATIONS
C
      S(1)=0.0
    6 DO5 J=2,N
    5 S(J)=-(DC(J)+DC(J-1))/2.0
      S(N+1)=-(1.0/PNL+DC(N))/2.0
C
      WRITEOUTPUTTAPE10,44,NO,RHO,EXK,PNL,(I,BETA(I),DC(I),I=1,N)
   44 FORMAT(31H1REACTIVITY STEP PROBLEM NUMBERI6/17H0FINAL REACTIVITY1P
   441E12.4/17H0INITIAL EXCESS K1PE14.7/24H0PROMPT NEUTRON LIFETIME1PE9.
   4422/27H0DELAYED NEUTRON PARAMETERS/36H0I             BETA
   443LAMBDA/(I3,1PE21.6,1PE18.6))
      WRITEOUTPUTTAPE10,54
   54 FORMAT(25H0ROOTS OF INHOUR EQUATION/91H0J         S(J)
   541A(J)              B(J)            DEVIATION              ITERATIONS)
C
C OBTAINING ROOTS OF INHOUR EQUATION
C
  131 DO130J=1,NA
      IT=1
    7 RHOOFS=0.0
    8 DO9 I=1,N
      SD(I)=S(J)+DC(I)
      BSD(I)=BETA(I)/SD(I)
      BDD(I)=BSD(I)/SD(I)
    9 RHOOFS=RHOOFS+BSD(I)
      RHOOFS=(PNL*S(J)+S(J)*RHOOFS)/(1.0+PNL*S(J))
      DEV=RHOOFS-RHO
```

```
  137 IF(I-1)139,139,138
  138 IF(DEV*PREDEV)139,134,135
  135 IF(ABSF(DEV)-ABSF(PREDEV))139,134,134
  139 IF(IT-100)900,134,134
  900 PREDEV=DEV
      IT=IT+1
   13 U=0.0
      V=0.0
   14 DO901I=1,N
      U=U+BSD(I)
  901 V=V+BDD(I)
      RHODOT=((PNL+U)/(1.0+PNL*S(J))-S(J)*V)/(1.0+PNL*S(J))
      DELTA=-DEV/RHODOT
   16 IF(J-1)17,17,18
   18 IF(J-N-1)19,20,20
   17 IF(S(J)+DELTA+DC(1))21,21,250
   21 DELTA=DELTA/10.0
      GOTO17
   19 IF(S(J)+DELTA+DC(J))22,22,23
   22 DELTA=DELTA/10.0
      GOTO19
   23 IF(-DC(J-1)-S(J)-DELTA)24,24,250
   24 DELTA=DELTA/10.0
      GOTO23
   20 IF(S(J)+DELTA+1.0/PNL)25,25,26
   25 DELTA=DELTA/10.0
      GOTO20
   26 IF(-DC(N)-S(J)-DELTA)27,27,250
   27 DELTA=DELTA/10.0
   28 GOTO26
  250 S(J)=S(J)+DELTA
      GOTO7
C
CALCULATION OF A AND B COEFFICIENTS
C
  134 W(J)=0.0
      X(J)=0.0
   35 DO36 I=1,N
      W(J)=W(J)+BSD(I)
   36 X(J)=X(J)+DC(I)*BDD(I)
```

```
   37 A(J)=(1.0-RHO)*(PNL+(1.0+EXK)*W(J))/(PNL*(1.0-RHO)+X(J))
  102 IF(RHO)101,104,101
  104 IF(J-1)108,108,101
  101 B(J)=(RHO-1.0)*EXK/(S(J)*(PNL*(1.0-RHO)+X(J)))
      GOTO105
  108 L=1
      WRITEOUTPUTTAPE10,106,L,S(1),A(1),DELTA,IT
  106 FORMAT(1H I2,1P2E17.7,1PE34.7,I17)
      GOTO130
  105 WRITEOUTPUTTAPE10,38,J,S(J),A(J),B(J),DELTA,IT
   38 FORMAT(1H I2,1P4E17.7,I17)
  130 CONTINUE
      WRITEOUTPUTTAPE10,56
   56 FORMAT(12HOOUTPUT DATA/118HOTIME         NEUTRON DENSITY  TIME DERI
   561VATIVE OF DENSITY   REACTOR PERIOD  FRACTIONAL DEVIATION FROM ASYM
   562PTOTIC PERIOD)
  150 IF(RHO)151,152,151
C
CALCULATION OF TIME BEHAVIOR FOR ZERO FINAL REACTIVITY
C
  152 UA=0.0
  110 DO111 I=1,N
  111 UA=UA+BETA(I)/DC(I)
      H=-EXK/(PNL+UA)
  112 DO113 K=1,M
      WA=0.0
      XA=0.0
      YA=0.0
      ZA=0.0
  114 DO115 J=1,NA
      VA=EXPF(S(J)*T(K))
 1000 IFACCUMULATOROVERFLOW1001,1001
 1001 VB=A(J)*VA
 1002 IFACCUMULATOROVERFLOW1003,1004
 1004 WA=WA+VB
 1003 VC=(S(J)*VA)*A(J)
 1005 IFACCUMULATOROVERFLOW115,1006
 1006 XA=XA+VC
  115 CONTINUE
  116 DO117 J=2,NA
```

```
      VD=FXPF(S(J)*T(K))
 1007 IFACCUMULATOROVERFLOW1008,1008
 1008 VF=B(J)*VD
 1009 IFACCUMULATOROVERFLOW1010,1011
 1011 YA=YA+VE-B(J)
      GOTO1050
 1010 YA=YA-B(J)
 1050 VF=(S(J)*VD)*B(J)
 1012 IFACCUMULATOROVERFLOW117,1013
 1013 ZA=ZA+VF
  117 CONTINUE
      P(K)=H*T(K)+WA+YA
  113 PDOT(K)=H+XA+ZA
      GOTO107
C
CALCULATION OF TIME BEHAVIOR FOR NON-ZERO FINAL REACTIVITY
C
  151 C=(1.0-RHO)*FXK/RHO
   39 DO42 K=1,M
      P(K)=C
      PDOT(K)=0.0
   41 DO42 J=1,NA
      VG=FXPF(S(J)*T(K))
 1014 IFACCUMULATOROVERFLOW1015,1015
 1015 VH=(A(J)+B(J))*VG
 1016 IFACCUMULATOROVERFLOW1017,1018
 1018 P(K)=P(K)+VH
 1017 VI=(S(J)*VG)*(A(J)+B(J))
 1019 IFACCUMULATOROVERFLOW42,1020
 1020 PDOT(K)=PDOT(K)+VI
   42 CONTINUE
  107 DO40 K=1,M
      PERIOD(K)=P(K)/PDOT(K)
      ERROR(K)=1.0-S(1)*PERIOD(K)
   40 WRITEOUTPUTTAPE10,43,T(K),P(K),PDOT(K),PERIOD(K),ERROR(K)
   43 FORMAT(1H 1PE11.4,1PE16.7,1P2E23.7,1PE31.7)
      SUMA=0.0
      SUMB=0.0
   80 DO81 J=1,NA
   81 SUMA=SUMA+A(J)
```

```
      D=SUMA-1.0
  120 DO121 J=2,NA
  121 SUMB=SUMB+B(J)
  122 IF(RHO)123,124,123
  123 G=1.0/S(1)
      WRITEOUTPUTTAPE10,58,G,C
   58 FORMAT(18H0ASYMPTOTIC PERIOD1PE14.7/2H0C1PE14.7)
      F=SUMB+B(1)+C
      WRITEOUTPUTTAPE10,83,E
   83 FORMAT(9H0B CHECK 1PE14.7)
  124 WRITEOUTPUTTAPE10,82,D
   82 FORMAT(9H0A CHECK 1PE14.7)
      GOTO47
C
      FREQUENCY80(11),8(10),139(100,1,0),16(0,1,10),18(10,1,0),17(1,0,10
     1),19(1,0,10),23(1,0,10),20(1,0,10),26(1,0,10),137(0,1,10),35(10),
     239(15),41(11),80(11),102(1,0,1),110(10),112(15),114(11),116(10),
     3107(15),120(10),122(1,0,1),6(10),131(11),14(10),138(1,0,1),
     41000(0,1),1002(0,1),1005(0,1),1007(0,1),1009(0,1),1012(0,1),
     51014(0,1),1016(0,1),1019(0,1),135(10,0,1),104(0,1,6),150(1,0,1)
```

```
CODE FOR REACTIVITY STEPS WITH NONEQUILIBRIUM PRECURSORS  RE-135
C
      DIMENSIONDC(30),BETA(30),T(500),S(31),A(31),B(31),P(500),PDOT(500)
     1,PERIOD(500),ERROR(500),W(31),X(31),G(30),TB(500),SD(30),
     2BSD(30,31),BDD(30)
   47 READ1,RHO,EXK,PNL,N,M,LA,(DC(I),I=1,N)
    1 FORMAT(1P3E14.7,I3,2I4/(1P5E14.7))
      READ2,(BETA(I),I=1,N)
    2 FORMAT(1P5E14.7)
      READ3,(T(K),K=1,M)
    3 FORMAT(1P6E11.4)
      LB=LA+1
      READ3,(TB(L),L=2,LB)
      NA=N+1
C
C ASSIGNMENT OF STARTING POINTS FOR ITERATIONS
C
      S(1)=0.0
    6 DO5J=2,N
    5 S(J)=-(DC(J)+DC(J-1))/2.0
      S(N+1)=-(1.0/PNL+DC(N))/2.0
C
      WRITEOUTPUTTAPE10,45,RHO,EXK,PNL,(I,BETA(I),DC(I),I=1,N)
   45 FORMAT(17H1FINAL REACTIVITY1PE14.6/17H0INITIAL EXCESS K1PE14.6/24H
   4510PROMPT NEUTRON LIFETIME1PE14.6/27H0DELAYED NEUTRON PARAMETERS/36H
   4520I             BETA             LAMBDA/(I3,1PE21.6,1PE18.6))
      WRITEOUTPUTTAPE10,54
   54 FORMAT(25H0ROOTS OF INHOUR EQUATION/69H0J         S(J)
   541B(J)            DEVIATION         ITERATIONS)
      SUMB=0.0
C
C OBTAINING ROOTS OF INHOUR EQUATION
C
  131 DO130J=1,NA
      IT=1
    7 RHOOFS=0.0
    8 DO9I=1,N
      SD(I)=S(J)+DC(I)
      BSD(I,J)=BETA(I)/SD(I)
      BDD(I)=BSD(I,J)/SD(I)
```

```
    9 RHOOFS=RHOOFS+BSD(I,J)
      RHOOFS=(PNL*S(J)+S(J)*RHOOFS)/(1.0+PNL*S(J))
      DEV=RHOOFS-RHO
  137 IF(IT-1)139,139,138
  138 IF(DEV*PREDEV)139,134,135
  135 IF(ABSF(DEV)-ABSF(PREDEV))139,134,134
  139 IF(IT-100)10,134,134
   10 PREDEV=DEV
      IT=IT+1
   12 U=0.0
      V=0.0
   14 DO901I=1,N
      U=U+BSD(I,J)
  901 V=V+BDD(I)
      RHODOT=((PNL+U)/(1.0+PNL*S(J))-S(J)*V)/(1.0+PNL*S(J))
      DELTA=-DEV/RHODOT
   16 IF(J-1)17,17,18
   18 IF(J-N-1)19,20,20
   17 IF(S(J)+DELTA+DC(1))21,21,250
   21 DELTA=DELTA/10.0
      GOTO17
   19 IF(S(J)+DELTA+DC(J))22,22,23
   22 DELTA=DELTA/10.0
      GOTO19
   23 IF(-DC(J-1)-S(J)-DELTA)24,24,250
   24 DELTA=DELTA/10.0
      GOTO23
   20 IF(S(J)+DELTA+1.0/PNL)25,25,26
   25 DELTA=DELTA/10.0
      GOTO20
   26 IF(-DC(N)-S(J)-DELTA)27,27,250
   27 DELTA=DELTA/10.0
      GOTO26
  250 S(J)=S(J)+DELTA
      GOTO7
C
CALCULATION OF B COEFFICIENTS
C
  134 X(J)=0.0
  141 DO142I=1,N
```

```
  142 X(J)=X(J)+DC(I)*BDD(I)
      B(J)=(RHO-1.0)*EXK/(S(J)*(PNL*(1.0-RHO)+X(J)))
      SUMB=SUMB+B(J)
C
  130 WRITEOUTPUTTAPE10,38,J,S(J),B(J),DELTA,IT
   38 FORMAT(I3,1P3E17.7,I17)
      GA=1.0/S(1)
      C=(1.0-RHO)*EXK/RHO
      F=SUMB+C
      WRITEOUTPUTTAPE10,200,C,GA,F
  200 FORMAT(2H0C1PE14.7/18H0ASYMPTOTIC PERIOD1PE14.7/8H0B CHECK1PE14.7)
  600 DO601L=1,LB
  706 IF(L-1)701,701,700
  701 WRITEOUTPUTTAPE10,702
  702 FORMAT(17H1EQUILIBRIUM CASE)
  705 DO704I=1,N
  704 G(I)=1.0
      GOTO703
  700 WRITEOUTPUTTAPE10,602,TB(L)
  602 FORMAT(23H1PRECURSOR BUILDUP TIME1PE14.6/39H0I   FRACTION EQUILIBR
  6021IUM CONCENTRATION)
C
CALCULATION OF A COEFFICIENTS
C
  604 DO605I=1,N
      G(I)=1.0-EXPF(-DC(I)*TB(L))
  605 WRITEOUTPUTTAPE10,606,I,G(I)
  703 WRITEOUTPUTTAPE10,611
  606 FORMAT(I3,1PE27.7)
  611 FORMAT(13H0VALUES OF A  )
      SUMA=0.0
  607 DO608J=1,NA
      W(J)=0.0
  609 DO610I=1,N
  610 W(J)=W(J)+G(I)*BSD(I,J)
      A(J)=(1.0-RHO)*(PNL+(1.0+EXK)*W(J))/(PNL*(1.0-RHO)+X(J))
      SUMA=SUMA+A(J)
  608 WRITEOUTPUTTAPE10,612,J,A(J)
  612 FORMAT(1H I2,1PE17.7)
      WRITEOUTPUTTAPE10,330,SUMA
```

```
  710 IF(L-1)711,711,720
  711 ACHECK=SUMA-1.0
      WRITEOUTPUTTAPE10,712,ACHECK
  712 FORMAT(9H0A CHECK  1PE14.7)
  720 WRITEOUTPUTTAPE10,57
  300 DO301J=1,NA
      B(J)=B(J)/SUMA
  301 A(J)=A(J)/SUMA
      C=C/SUMA
C
CALCULATION OF TIME BEHAVIOR
C
  112 DO113K=1,M
      P(K)=C
      PDOT(K)=0.0
   41 DO42J=1,NA
      VG=EXPF(S(J)*T(K))
 1014 IFACCUMULATOROVERFLOW1015,1015
 1015 VH=(A(J)+B(J))*VG
 1016 IFACCUMULATOROVERFLOW1017,1018
 1018 P(K)=P(K)+VH
 1017 VI=(S(J)*VG)*(A(J)+B(J))
 1019 IFACCUMULATOROVERFLOW42,1020
 1020 PDOT(K)=PDOT(K)+VI
   42 CONTINUE
      PERIOD(K)=P(K)/PDOT(K)
      ERROR(K)=1.0-S(1)*PERIOD(K)
  113 WRITEOUTPUTTAPE10,43,T(K),P(K),PDOT(K),PERIOD(K),ERROR(K)
  601 CONTINUE
      GOTO47
C
   43 FORMAT(1H 1PE11.4,1PE16.7,1P2E23.7,1PE31.7)
   57 FORMAT(120HOTIME         NEUTRON DENSITY  TIME DERIVATIVE OF DENSIT
  571Y   REACTOR PERIOD   FRACTIONAL DEVIATION FROM ASYMPTOTIC PERIOD )
  330 FORMAT(16HONORMALIZATION   1PE14.7)
C
      FREQUENCY6(5),131(7),8(6),135(10,0,1),14(6),16(0,1,6),17(1,0,10),1
     19(1,0,10),23(1,0,10),20(1,0,10),26(1,0,10),141(6),18(6,1,0),600(30
     2),604(6),607(7),609(6),300(7),112(30),41(7),1014(0,1),1016(0,1),10
     319(0,1),137(0,1,9),138(1,0,4),139(100,1,0),706(0,1,29),710(0,1,29)
```

VIII. SAMPLE PROBLEMS

LISTING OF INPUT FOR SAMPLE RE-126 PROBLEM

```
 1001 -1.0000E-03 -1.0000000E-05 1.00E-04  6  18
1.2700000E-02 3.1700000E-02 1.1500000E-01 3.1100000E-01 1.4000000E 00
3.8700000E 00
2.4700000E-04 1.3850000E-03 1.2220000E-03 2.6460000E-03 8.3200000E-04
1.6900000E-04
0.0000E 00 1.0000E-01 2.0000E-01 5.0000E-01 1.0000E 00 2.0000E 00
5.0000E 00 1.0000E+01 2.0000E+01 5.0000E+01 1.0000E+02 2.0000E+02
5.0000E+02 1.0000E+03 2.0000E+03 5.0000E+03 1.0000E+04 2.0000E+04
```

SAMPLE RE-126 PROBLEM

REACTIVITY STEP PROBLEM NUMBER 1001

FINAL REACTIVITY-10.0000E-04

INITIAL EXCESS K-9.9999998E-06

PROMPT NEUTRON LIFETIME10.00E-05

DELAYED NEUTRON PARAMETERS

I	BETA	LAMBDA
1	2.470000E-04	1.270000E-02
2	1.385000E-03	3.170000E-02
3	1.222000E-03	1.150000E-01
4	2.646000E-03	3.110000E-01
5	8.320000E-04	1.400000E 00
6	1.690000E-04	3.870000E 00

ROOTS OF INHOUR EQUATION

J	S(J)	A(J)	B(J)	DEVIATION	ITERATIONS
1	-7.7651502E-03	5.6696573E-01	-5.6697183E-03	-6.4002525E-11	11
2	-1.6992855E-02	1.4796816E-01	-1.4796989E-03	-1.0965951E-10	6
3	-7.8748437E-02	8.8544829E-02	-8.8546396E-04	5.0683373E-10	5
4	-2.0914694E-01	4.9024398E-02	-4.9025899E-04	1.0434031E-09	5
5	-1.2571837E 00	1.3641038E-02	-1.3642865E-04	8.4764647E-09	15
6	-3.7871837E 00	2.7594904E-03	-2.7605486E-05	1.6711908E-08	15
7	-7.5318442E 01	1.3109635E-01	-1.3208252E-03	1.1482576E-06	7

OUTPUT DATA

TIME	NEUTRON DENSITY	TIME DERIVATIVE OF DENSITY	REACTOR PERIOD	FRACTIONAL DEVIATION FROM ASYMPTOTIC PERIOD
0.	9.9999998E-01	-9.8257155E 00	-1.0177376E-01	9.9920971E-01
10.0000E-02	8.6546080E-01	-5.0922915E-02	-1.6995508E 01	8.6802733E-01
2.0000E-01	8.6104505E-01	-4.1419780E-02	-2.0788257E 01	8.3857605E-01
5.0000E-01	8.4998388E-01	-3.3201629E-02	-2.5600668E 01	8.0120696E-01
1.0000E 00	8.3528361E-01	-2.6451342E-02	-3.1578118E 01	7.5479117E-01
2.0000E 00	8.1217320E-01	-2.0654555E-02	-3.9321748E 01	6.9466071E-01
5.0000E 00	7.6069750E-01	-1.4734292E-02	-5.1627693E 01	5.9910321E-01
1.0000E 01	6.9884400E-01	-1.0527689E-02	-6.6381519E 01	4.8453752E-01
2.0000E 01	6.1373485E-01	-7.0874897E-03	-8.6594108E 01	3.2758374E-01
5.0000E 01	4.5504643E-01	-4.1553471E-03	-1.0950864E 02	1.4964893E-01
1.0000E 02	2.9502320E-01	-2.4626553E-03	-1.1979882E 02	6.9744185E-02
2.0000E 02	1.3367931E-01	-1.0054885E-03	-1.3294960E 02	-3.2373652E-02
5.0000E 02	2.1601327E-02	-9.0284424E-05	-2.3925862E 02	-8.5787916E-01
1.0000E 03	1.0248144E-02	-1.8492869E-06	-5.5416736E 03	-4.2031928E 01
2.0000E 03	1.0010101E-02	-7.8454527E-10	-1.2759111E 07	-9.9075418E 04
5.0000E 03	1.0010000E-02	-5.9914546E-20	-1.6707128E 17	-1.2973335E 15
1.0000E 04	1.0010000E-02	-8.2361211E-37	-1.2153779E 34	-9.4375919E 31
2.0000E 04	1.0010000E-02	0.	0.0000000E-40	1.0000000E 00

ASYMPTOTIC PERIOD-1.2878051E 02

C 1.0010000E-02

B CHECK 2.3283064E-10

A CHECK -3.7252903E-08

LISTING OF INPUT FOR SAMPLE RE-135 PROBLEM

```
-1.0000000E-03-1.0000000E-05 1.0000000E-04  6  18   1
 1.2700000E-02 3.1700000E-02 1.1500000E-01 3.1100000E-01 1.4000000E 00
 3.8700000E 00
 2.4700000E-04 1.3850000E-03 1.2220000E-03 2.6460000E-03 8.3200000E-04
 1.6900000E-04
 0.0000E 00 1.0000E-01 2.0000E-01 5.0000E-01 1.0000E 00 2.0000E 00
 5.0000E 00 1.0000E+01 2.0000E+01 5.0000E+01 1.0000E+02 2.0000E+02
 5.0000E+02 1.0000E+03 2.0000E+03 5.0000E+03 1.0000E+04 2.0000E+04
 1.0000E+02
```

SAMPLE RE-135 PROBLEM

FINAL REACTIVITY-10.000000E-04

INITIAL EXCESS K-10.000000E-06

PROMPT NEUTRON LIFETIME 10.000000E-05

DELAYED NEUTRON PARAMETERS

I	BETA	LAMBDA
1	2.470000E-04	1.270000E-02
2	1.385000E-03	3.170000E-02
3	1.222000E-03	1.150000E-01
4	2.646000E-03	3.110000E-01
5	8.320000E-04	1.400000E 00
6	1.690000E-04	3.870000E 00

ROOTS OF INHOUR EQUATION

J	S(J)	B(J)	DEVIATION	ITERATIONS
1	-7.7651502E-03	-5.6697183E-03	-6.4002525E-11	11
2	-1.6992855E-02	-1.4796989E-03	-1.0965951E-10	6
3	-7.8748437E-02	-8.8546396E-04	5.0683373E-10	5
4	-2.0914694E-01	-4.9025899E-04	1.0434031E-09	5
5	-1.2571837E 00	-1.3642865E-04	8.4764647E-09	15
6	-3.7871837E 00	-2.7605486E-05	1.6711908E-08	15
7	-7.5318442E 01	-1.3208252E-03	1.1482576E-06	7

C 1.0010000E-02

ASYMPTOTIC PERIOD-1.2878051E 02

B CHECK 4.6566129E-10

EQUILIBRIUM CASE

VALUES OF A

1	5.6696573E-01
2	1.4796816E-01
3	8.8544829E-02
4	4.9024398E-02
5	1.3641038E-02
6	2.7594904E-03
7	1.3109635E-01

NORMALIZATION 9.9999995E-01

A CHECK -3.7252903E-08

TIME	NEUTRON DENSITY	TIME DERIVATIVE OF DENSITY	REACTOR PERIOD	FRACTIONAL DEVIATION FROM ASYMPTOTIC PERIOD
0.	1.0000000E 00	-9.8257158E 00	-1.0177376E-01	9.9920971E-01
10.0000E-02	8.6546081E-01	-5.0922916E-02	-1.6995508E 01	8.6802733E-01
2.0000E-01	8.6104507E-01	-4.1419781E-02	-2.0788257E 01	8.3857605E-01
5.0000E-01	8.4998391E-01	-3.3201629E-02	-2.5600668E 01	8.0120696E-01
1.0000E 00	8.3528364E-01	-2.6451343E-02	-3.1578118E 01	7.5479118E-01
2.0000E 00	8.1217322E-01	-2.0654555E-02	-3.9321748E 01	6.9466072E-01
5.0000E 00	7.6069752E-01	-1.4734292E-02	-5.1627693E 01	5.9910321E-01
1.0000E 01	6.9884403E-01	-1.0527689E-02	-6.6381519E 01	4.8453752E-01
2.0000E 01	6.1373487E-01	-7.0874899E-03	-8.6594107E 01	3.2758375E-01
5.0000E 01	4.5504645E-01	-4.1553472E-03	-1.0950865E 02	1.4964891E-01
1.0000E 02	2.9502321E-01	-2.4626554E-03	-1.1979882E 02	6.9744185E-02
2.0000E 02	1.3367931E-01	-1.0054886E-03	-1.3294960E 02	-3.2373652E-02
5.0000E 02	2.1601328E-02	-9.0284427E-05	-2.3925862E 02	-8.5787916E-01
1.0000E 03	1.0248145E-02	-1.8492869E-06	-5.5416737E 03	-4.2031929E 01
2.0000E 03	1.0010101E-02	-7.8454530E-10	-1.2759112E 07	-9.9075419E 04
5.0000E 03	1.0010000E-02	-5.9914548E-20	-1.6707128E 17	-1.2973336E 15
1.0000E 04	1.0010000E-02	-8.2361213E-37	-1.2153779E 34	-9.4375920E 31
2.0000E 04	1.0010000E-02	0.	0.	1.0000000E 00

PRECURSOR BUILDUP TIME 1.000000E 02

I	FRACTION EQUILIBRIUM CONCENTRATION
1	7.1916838E-01
2	9.5799640E-01
3	9.9998987F-01
4	1.0000000F 00
5	1.0000000E 00
6	1.0000000E 00

VALUES OF A

1	4.9438086E-01
2	1.7865057E-01
3	1.0448728E-01
4	5.6007870E-02
5	1.5411410E-02
6	3.1136034E-03
7	1.4794845E-01

NORMALIZATION 9.9999998E-01

TIME	NEUTRON DENSITY	TIME DERIVATIVE OF DENSITY	REACTOR PERIOD	FRACTIONAL DEVIATION FROM ASYMPTOTIC PERIOD
0.	1.0000000E 00	-1.1101230F 01	-9.0080103E-02	9.9930052E-01
10.0000F-02	8.4803162E-01	-5.7117202F-02	-1.4847219E 01	8.8470911E-01
2.0000E-01	8.4308465E-01	-4.6373220E-02	-1.8180420E 01	8.5882630E-01
5.0000F-01	8.3071760E-01	-3.7068588F-02	-2.2410284E 01	8.2598078E-01
1.0000F 00	8.1433791E-01	-2.9413450E-02	-2.7685903E 01	7.8501481E-01
2.0000E 00	7.8872307E-01	-2.2818141E-02	-3.4565614E 01	7.3159281E-01
5.0000E 00	7.3227112E-01	-1.6035303F-02	-4.5666185E 01	6.4539521E-01
1.0000E 01	6.6568585E-01	-1.1197677F-02	-5.9448566F 01	5.3837295E-01
2.0000F 01	5.7683970E-01	-7.2582629F-03	-7.9473518E 01	3.8287619E-01
5.0000F 01	4.1924650E-01	-4.0205176F-03	-1.0427675E 02	1.9027539E-01
1.0000E 02	2.6724894E-01	-2.2991741E-03	-1.1623693E 02	9.7402781E-02
2.0000E 02	1.1934537E-01	-9.0364596E-04	-1.3207093E 02	-2.5550649E-02
5.0000E 02	2.0112511E-02	-7.8781350E-05	-2.5529533E 02	-9.8240658E-01
1.0000E 03	1.0217351E-02	-1.6101786E-06	-6.3454764E 03	-4.8273578E 01
2.0000E 03	1.0010088E-02	-6.8309059F-10	-1.4654115E 07	-1.1379040E 05
5.0000F 03	1.0010000E-02	-5.2166604F-20	-1.9188522E 17	-1.4900175E 15
1.0000E 04	1.0010000E-02	-7.1710544E-37	-1.3958896E 34	-1.0839292E 32
2.0000E 04	1.0010000E-02	0.	0.0000000E-40	1.0000000E 00