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KINETICS I

A NEUTRON KINETICS CODE IN FORTRAN IV

July 1965

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K I N E T I C S I

A NEUTRON KINETICS CODE IN FORTRAN IV

by

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July 1965

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

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SUMMARY

This paper describes a numerical solution to the lumped parameter kinetics equation. The method presented is particularly well-suited for the analysis of prompt critical excursions. In order to make the code useful for practical problems, a simple heat transfer model is attached to the kinetics equations.

A FORTRAN IV source deck listing, input information, and a sample problem are given in the appendices.

I. INTRODUCTION

In most numerical march-out procedures, the increment in the independent variable must be chosen so that the fractional change in the function is small for each step. Therefore, if the function changes many orders of magnitude in the region of interest, many steps are required.

It is well known that large positive reactivities cause the neutron density in a reactor to increase rapidly. More specifically, the neutron density profile is usually exponential in character during large excursions, and may traverse several orders of magnitude in a fraction of a second.

The approach presented in this paper rapidly solves kinetic problems involving large reactivities. It offers no advantage over present methods for small reactivities.

Although the basic kinetics algorithm has been discussed in the literature,^(1,2) this is the first detailed presentation of the computer code.

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- (1) Little, W. W., Hansen, K.F., Mason, E.A., Koen, B. V., "A Stable Numerical Solution of the Reactor Kinetics Equations," Trans. Am. Nucl. Soc., 7, 3(1964).
 - (2) Hansen, K.F., Koen, B.V., Little, W.W., "Stable Numerical Solutions of the Reactor Kinetics Equations," Nucl. Sci. and Eng., 22, 51-59 (May 1965).

II. MATHEMATICAL MODEL

Consider the lumped parameter kinetics equations

$$\frac{dn}{dt} = \frac{\rho - \beta}{\Lambda} n + \sum_{i=1}^G \lambda^i C^i \quad (2.1)$$

$$\frac{dC^i}{dt} = \frac{\beta^i n}{\Lambda} - \lambda^i C^i \quad (2.2)$$

where: n = Neutron or power density,

C^i = Precursor density for group i (cm^{-3}),

λ^i = Decay constant for group i (sec^{-1}),

β^i = Total delayed neutron fraction,

Λ = Neutron generation time (sec),

G = Number of precursor groups.

$-\omega_j n(t)$ is now added to both sides of Eq. (2.1) and then integrated.

Hence,

$$n_{j+1} = e^{\omega_j h} \left[n_j + \int_0^h d\xi \left\{ \frac{\rho(\xi) - \rho_j}{\Lambda} n(\xi) e^{-\omega_j \xi} + \sum_{i=1}^G \lambda_j^i \left(C^i(\xi) - C_j^i \frac{n(\xi)}{n_j} \right) e^{-\omega_j \xi} \right\} \right] \quad (2.3)$$

with: h = mesh spacing,

j = time index,

$$\omega_j = \frac{\rho_j - \beta}{\Lambda} - \frac{1}{n_j} \sum_{i=1}^G \lambda^i C_j^i .$$

In a similar manner, $-\gamma_j^i C_j^i(t)$ is added to both sides of Eq. (2.2) and then integrated. Therefore,

$$C_{j+1}^i = e^{\gamma_j^i h} \left[C_j^i + \int_0^h d\xi e^{-\gamma_j^i \xi} \left\{ \frac{\beta_j^i}{\Lambda} \left(n(\xi) - \frac{n_j}{C_j^i} C_j^i(\xi) \right) \right\} \right] \quad (2.4)$$

where $\gamma_j^i = \frac{\beta_j^i n_j}{\Lambda C_j^i}$.

Clearly, ω_j and γ_j^i 's are merely approximations to the instantaneous period at time mesh j for the neutron density and precursor densities, respectively.

To evaluate the integrals in Eqs. (2.3) and (2.4), the first approximations

$$n(\xi) = e^{\omega_j \xi} n_j \quad (2.5)$$

$$C^i(\xi) = e^{\gamma_j^i \xi} C_j^i \quad (2.6)$$

are placed in the integrals, and the integration is performed using the trapezoidal rule. This leads to the final march-out algorithm

$$n_{j+1} = e^{\omega_j h} \left\{ n_j \left(1 + \frac{h}{2\Lambda} \left\{ \rho_{j+1} - \rho_j \right\} \right) + \sum_1^G \lambda_j^i C_j^i \left[\frac{e^{h(\gamma_j^i - \omega_j)} - 1}{\gamma_j^i - \omega_j} - h \right] \right\} \quad (2.7)$$

$$C_{j+1}^i = e^{\gamma_j^i h} \left[C_j^i + \frac{n_j \beta_j^i}{\Lambda} \left\{ \frac{e^{h(\omega_j - \gamma_j^i)} - 1}{\omega_j - \gamma_j^i} - h \right\} \right] \quad (2.8)$$

The variable time step, h , is determined by the requirement that the first approximation for n_{j+1} , Eq. (2.5), agree with the second approximation, Eq. (2.7), within a prescribed tolerance. That is,

$$\left[\frac{n_{j+1}^{(2)} - n_{j+1}^{(1)}}{n_{j+1}^{(1)}} \right] \leq \epsilon \quad (2.9)$$

where epsilon is an input parameter.

III. REACTIVITY EQUATION

In each reactivity zone, the temperature and reactivity are computed using the differential and difference equations

$$\frac{dT(t)}{dt} = \frac{n(t)}{C_p} + kT(t) \quad (3.1)$$

$$\rho_{j+1} = \rho_j + \frac{\beta}{100} \left\{ b(t_{j+1} - t_j) + c(t_{j+1}^2 - t_j^2) + d \left(T(t_{j+1}) - T(t_j) \right) \right\} \quad 3.2)$$

where:

$T(t)$ = Temperature ($^{\circ}\text{K}$),

$n(t)$ = Neutron density or power (watts/cc),

C_p = Heat capacity (joules/cc- $^{\circ}\text{K}$),

k = Heat transfer coefficient (sec^{-1}),

b = Linear reactivity insertion rate (cents/sec),

c = Quadratic reactivity insertion rate (cents/ sec^2),

d = Temperature coefficient (cents/ $^{\circ}\text{K}$).

Two clarifications should be made at this point. First, observe that the constants k and d are usually negative in sign. Second, the loose term "temperature", as defined by Eq. (3.1), is usually interpreted as the difference between the fuel temperature and the coolant temperature.

IV. REMARKS ON CODE OPERATION

A typical kinetics calculation with six precursor groups requires approximately 10 seconds of IBM-7090 time. The computation time is roughly proportional to the reciprocal of the prompt neutron generation time.

For reasonable accuracy, the error criterion should be less than .01. The computation time, however, is rather insensitive to this value.

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APPENDIX A

FORTRAN IV SOURCE DECK LISTING

```
$IBFTC MAIN    LIST
  DIMENSION B(6),AL(6),GAM(6),ALPH(6),T(2),  AN(2),  RH(2),
1 C(6,2), HOL(12), TE(2), EN(2)
  COMMON B,AL,GAM,ALPH,T,AN,RH,C,HOL, TE, EN
  COMMON M,NSTART,NMAX,NPRT,NCYC,J, NIT, NOT
  COMMON ERROR,BB,STEPM,TMAX,HMAX,ALIFE,WZ,ANZ,H,W,R1,R2,R3,R4
  COMMON HTC1, HTC2
  NIT = 2
  NOT = 3
  STEPM = 1.5
1  CONTINUE
  CALL INPUT
  DO 4 IJK = 1, NCYC
  CALL CONST
  CALL CALC
  IF (NMAX) 2,2,4
2  KK = IJK + 1
  DO 3 K = KK,NCYC
3  CALL CONST
  GO TO 1
4  CONTINUE
  GO TO 1
  END
```

```

$IBFTC INPUT LIST
SUBROUTINE INPUT
DIMENSION B(6),AL(6),GAM(6),ALPH(6),T(2), AN(2), RH(2),
1 C(6,2), HOL(12), TE(2), EN(2)
COMMON B,AL,GAM,ALPH,T,AN,RH,C,HOL, TE, EN
COMMON M,NSTART,NMAX,NPRT,NCYC,J, NIT, NOT
COMMON ERROR,BB,STEPM,TMAX,HMAX,ALIFE,WZ,ANZ,H,W,R1,R2,R3,R4
COMMON HTC1, HTC2
READ (NIT,2)(HOL(I),I=1,12)
2 FORMAT (12A6)
WRITE (NOT,1)
1 FORMAT (1H1,20X,42H * * * * * K I N E T I C S 1 2 * * * * *)
WRITE (NOT,4)(HOL(I),I=1,12)
4 FORMAT (1H0//12A6//)
READ (NIT,6)M,NMAX,NPRT,NSTART,NCYC
6 FORMAT (5I6)
WRITE (NOT,8)M,NMAX,NPRT,NCYC
8 FORMAT (29HNUMBER OF PRECURSOR GROUPS = 12//
131H MAXIMUM NUMBER OF TIME STEPS = 15//
2 40H NUMBER OF INTERVALS BETWEEN PRINT OUT =13//
336H THE NUMBER OF REACTIVITY ZONES = 13//)
10 FORMAT (6E12.4)
READ (NIT,10)(B(I),I=1,M)
READ (NIT,10)(AL(I),I=1,M)
READ (NIT,10) AN(1), R1, WZ, ALIFE, HMAX, ERROR
BB = .0
DO 11 I = 1, M
11 BB = BB + B(I)
TE(1) = WZ
IF(NSTART -1) 14,14,12
12 READ (NIT,10)(C(I,1),I=1,M)
GO TO 20
14 DO 15 I=1,M
15 C(I,1) = AN(1)*B(I)/(ALIFE* AL(I))
20 CONTINUE
WRITE (NOT,22) AN(1), R1, WZ, ALIFE, HMAX, ERROR ,BB
22 FORMAT (34H INITIAL NEUTRON DENSITY(PER CC) = 1PE16.4//
130H INITIAL REACTIVITY (CENTS) = 1PE16.4//
1 31H INITIAL TEMPERATURE (DEG K) = 1PE16.4//
3 23H GENERATION TIME(SEC) = 1PE16.4//
2 25H MAXIMUM TIME STEP(SEC) = 1PE16.4//
125H CONVERGENCE CRITERION = 1PE16.4//
5 27H TOTAL PRECURSOR FRACTION = 1PE16.4///
6 48H GROUP B(I) LAMBDA(I) C(I)///)
DO 24 I=1,M
WRITE (NOT,26)I,B(I),AL(I),C(I,1)
24 WRITE (NOT,25)
25 FORMAT (1H0)
26 FORMAT (I3,1P3E16.4)
H = 100.* ALIFE
RH(1) = .01*BB*R1
T(1) = .0
EN(1) = .0
RETURN
END

```

```

$IBFTC CONST LIST
SUBROUTINE CONST
  DIMENSION B(6),AL(6),GAM(6),ALPH(6),T(2), AN(2), RH(2),
1 C(6,2), HOL(12), TE(2), EN(2)
  COMMON B,AL,GAM,ALPH,T,AN,RH,C,HOL, TE, EN
  COMMON M,NSTART,NMAX,NPRT,NCYC,J, NIT, NOT
  COMMON ERROR,BB,STEPM,TMAX,HMAX,ALIFE,WZ,ANZ,H,W,R1,R2,R3,R4
  COMMON HTC1, HTC2
  WRITE (NOT,1) (HOL(I), I=1,12)
1  FORMAT (1H1//12A6/////)
  READ (NIT,10) TMAX, R2, R3, R4, HTC1, HTC2
10  FORMAT (6E12.4)
  RH(1) = 100.*RH(1)/BB
  WRITE (NOT,12)T(1),RH(1),R2,R3, R4, HTC1, HTC2
12  FORMAT (41HOREACTIVITY INPUT DATA LISTED BELOW . . .////
126H THE CURRENT TIME (SEC) = 1PE16.4//
134H THE CURRENT REACTIVITY (CENTS) = 1PE16.4//
234H LINEAR COEFFICIENT (CENTS/SEC) = 1PE16.4//
338H QUADRATIC COEFFICIENT (CENTS/SEC2) = 1PE16.4//
449H TEMPERATURE COEFFICIENT (CENTS/DEGREE KELVIN) = 1PE16.4//
538H HEAT CAPACITY (JOULES/CC-DEGREE K) = 1PE16.4//
629H HEAT TRANSFER COEFFICIENT = 1PE16.4/////
  WRITE (NOT,2) (HOL(I),I=1,12)
2  FORMAT (1H1//12A6///37H SOLUTION OF KINETICS EQUATIONS BELOW////
1114H I TIME(SEC) POWER(WATTS/CC) RHO(CENTS) TEMP(DEG-K)
2ENERGY(JOULES/CC) C1/C4 C2/C5 C3/C6////)
  I = 1
  WRITE (NOT,6) I, T(I), AN(I), RH(I), TE(I), EN(I), (C(J,I),J=1,M)
6  FORMAT (I6, 1P8E14.3/76X,1P3E14.3)
  RH(1) = .01*BB*RH(1)
  R2 = .01*BB*R2
  R3 = .01*BB*R3
  R4 = .01*BB*R4
  HTC1 = 1./HTC1
  RETURN
END

```

```

$IBFTC CALC LIST
SUBROUTINE CALC
  DIMENSION B(6),AL(6),GAM(6),ALPH(6),T(2), AN(2), RH(2),
1 C(6,2), HOL(12), TE(2), EN(2)
  COMMON B,AL,GAM,ALPH,T,AN,RH,C,HOL, TE, EN
  COMMON M,NSTART,NMAX,NPRT,NCYC,J, NIT, NOT
  COMMON ERROR,BB,STEPM,TMAX,HMAX,ALIFE,WZ,ANZ,H,W,R1,R2,R3,R4
  COMMON HTC1, HTC2
  IEND = 0
  JKL = 1
  JIG = 0
  NWWL = 1
  DO 500 J =2,NMAX
  GC = .0
  DO 3 I=1,M
3 GC = GC + AL(I)*C(I,1)
  W = (RH(1) - BB)/ALIFE + GC/AN(1)
  DO 4 I=1,M
  GAM(I) = B(I)*AN(1 )/(ALIFE*C(I,1 ) - AL(I))
4 ALPH(I) = W - GAM(I)
5 G = W*H
8 ANZ = AN(1)*EXP(G)
9 T(2) = T(1) + H
  CALL SUBRHO
  CALL SUBNEU
  JIG = JIG + 1
  IF (JIG -150) 6,999,999
6 IF (ABS (ANZ - AN(2))/ANZ - ERROR) 12,12,17
12 IF (H - HMAX) 666, 22,22
666 IF (JIG -1) 13,13,14
13 NNS = 1
  HSTO = H
  ANSTO = AN(2)
  RHSTO = RH(2)
  H = H*STEPM
  GO TO 5
14 IF(NNS) 20,20,13
17 IF(JIG - 1) 18,18,19
18 NNS = 0
  H = H/STEPM
  GO TO 5
19 IF(NNS) 18,18,301
999 WRITE (NOT,1112)H
1112 FORMAT (23HONO CONVERGENCE H = 1PE16.4)
  GO TO 501
22 H = HMAX
  CALL SUBRHO
  CALL SUBNEU
  GO TO 20
301 H = HSTO
  AN(2) = ANSTO
  ANZ = AN(2)
  T(2) = T(1) + H
  CALL SUBRHO
20 JIG =0
  IF (AN(2) - 10.**22 ) 23,23,21
21 IEND = 1
23 T(2) = T(1) + H
  IF( T(2) - TMAX) 25,25,24

```

```
24  T(2) = TMAX
    IEND = 1
    H = TMAX - T(1)
    CALL SUBRHO
    CALL SUBNEU
25  CONTINUE
    CALL PRECUR
    J = J
35  IF(IEND) 501,40,501
40  JKL = JKL + 1
43  IF(JKL - NPRT) 500,45 ,45
45  JKL = 0
    RH(1) = 100.*RH(1)/BB
    WRITE (NOT,510)J,T(1), AN(1), RH(1), TE(1), EN(1), (C(K,1),K=1,M)
    RH(1) = .01*RH(1)*BB
    NWWL = NWWL + 1
    IF (NWWL - 17) 500,500,46
46  NWWL = 0
    WRITE (NOT,47) (HOL(I), I= 1,12)
47  FORMAT (1H1/12A6///
1114H  I      TIME(SEC)  POWER(WATTS/CC)  RHO(CENTS)  TEMP(DEG-K)
2ENERGY(JOULES/CC)  C1/C4      C2/C5      C3/C6///)
500  CONTINUE
    NMAX = 0
501  CONTINUE
    RH(1) = 100.*RH(1)/BB
    WRITE (NOT,510)J,T(1), AN(1), RH(1), TE(1), EN(1), (C(K,1),K=1,M)
    RH(1) = .01*RH(1)*BB
510  FORMAT (I6, 1P8E14.3/76X,1P3E14.3)
    RETURN
    END
```


\$IBFTC PRECUR LIST

```

SUBROUTINE PRECUR
  DIMENSION B(6),AL(6),GAM(6),ALPH(6),T(2),  AN(2),  RH(2),
1 C(6,2), HOL(12), TE(2), EN(2)
  COMMON B,AL,GAM,ALPH,T,AN,RH,C,HOL, TE, EN
  COMMON M,NSTART,NMAX,NPRT,NCYC,J, NIT, NOT
  COMMON ERROR,BB,STEPM,TMAX,HMAX,ALIFE,WZ,ANZ,H,W,R1,R2,R3,R4
  COMMON HTC1, HTC2
  DO 15 I=1,M
    IF(ABS (ALPH(I)*H) - .4) 7,5,5
5  C(I,2) = EXP (GAM(I)*H)*(C(I,1  ) + AN(1  )*B(I)*((EXP (H*ALPH(I))
1 - 1.)/ALPH(I) - H)/ALIFE)
    GO TO 15
7  C(I,2) = EXP (H*GAM(I))*(C(I,1  ) + AN(1  )*B(I)*H*H*ALPH(I)*
1 (1. + ALPH(I)*H/3. + (ALPH(I)*H)**2/12. + (ALPH(I)*H)**3/60.)
2 /(2.*ALIFE))
15 CONTINUE
    RH(1) = RH(2)
    AN(1) = AN(2)
    EN(1) = EN(2)
    TE(1) = TE(2)
    T(1) = T(2)
    DO 25 K = 1,M
25  C(K,1) = C(K,2)
    RETURN
  END

```

\$IBFTC SUBRHO LIST

```
SUBROUTINE SUBRHO
  DIMENSION B(6),AL(6),GAM(6),ALPH(6),T(2), AN(2), RH(2),
1 C(6,2), HOL(12), TE(2), EN(2)
  COMMON B,AL,GAM,ALPH,T,AN,RH,C,HOL, TE, EN
  COMMON M,NSTART,NMAX,NPRT,NCYC,J, NIT, NOT
  COMMON ERROR,BB,STEPM,TMAX,HMAX,ALIFE,WZ,ANZ,H,W,R1,R2,R3,R4
  COMMON HT,1, HTC2
  G = W*H
  IF (ABS(G) - .2) 3,2,2
2 G = EXP (G) - 1.
  GO TO 5
3 G = G + .5*G*G + G*G*G/6.
5 CONTINUE
  EN(2) = EN(1) + AN(1)*G/W
  TE(2) = TE(1) + HTC1*(EN(2) - EN(1)) + HTC2*H*TE(1)
  DO 12 K = 1,5
12 TE(2) = TE(1) + HTC1*(EN(2) - EN(1)) + .5*H*HTC2*(TE(1) + TE(2))
  RH(2) = RH(1) + R2*H + R3*( 2.*T(1)*H + H*H) + R4*(TE(2) - TE(1))
  RETURN
END
```

\$IBFTC SUBNEU LIST

```

SUBROUTINE SUBNEU
  DIMENSION B(6),AL(6),GAM(6),ALPH(6),T(2), AN(2), RH(2),
1 C(6,2), HOL(12), TE(2), EN(2)
  COMMON B,AL,GAM,ALPH,T,AN,RH,C,HOL, TE, EN
  COMMON M,NSTART,NMAX,NPRT,NCYC,J, NIT, NOT
  COMMON ERROR,BB,STEPM,TMAX,HMAX,ALIFE,WZ,ANZ,H,W,R1,R2,R3,R4
  COMMON HTC1, HTC2
  G = .0
  DO 6 I=1,M
    IF(ABS (ALPH(I)*H) - .01) 1,2,2
1 G = G + AL(I)*C(I,1 )*.5*H*H*(-ALPH(I) + H*ALPH(I)**2/3. -
  H*H*ALPH(I)**3/12.)
  GO TO 6
2 G = G + AL(I)*C(I,1 )*((1.-EXP (-H*ALPH(I)))/ALPH(I) - H)
6 CONTINUE
  AN(2) = EXP (W*H)*(AN(1 )*(1.+5*H*(RH(2)-RH(1 ))/ALIFE) + G )
  RETURN
  END

```

APPENDIX B

INPUT INFORMATION

<u>Card</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
* 1	2-72	Hollerith	Identification card.
2	1-6	Fixed	Number of precursor groups ($1 \leq N \leq 6$).
2	7-12	Fixed	Maximum number of time steps per reactivity zone.
2	13-18	Fixed	Intervals between prints (e.g.: $N = 1$, print every time step; $N = 2$, print every other time step).
2	19-24	Fixed	Initial conditions option: $N = 0$, code computes initial precursor densities; $N = 1$, initial precursor densities read into code (see card 6).
2	25-30	Fixed	Number of reactivity zones ($N \geq 1$).
3	1-12	Floating	Precursor yield for group 1.
3	13-24	Floating	Precursor yield for group 2.
...			
4	1-12	Floating	Precursor decay constant for group 1 (sec^{-1}).
4	13-24	Floating	Precursor decay constant for group 2 (sec^{-1}).
...			
5	1-12	Floating	Initial power or neutron density (watts/cc).
5	13-24	Floating	Initial reactivity (cents).
5	25-36	Floating	Initial temperature ($^{\circ}\text{K}$).
5	37-48	Floating	Neutron generation time (sec).
5	49-60	Floating	Maximum time step per iteration (sec).
5	61-72	Floating	Error criterion on march-out algorithm.

* To run a series of cases, repeat from Card 1 (ID card).

<u>Card</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
6 (Optional)	1-12	Floating	Initial precursor density card. See fourth word on second card. Density of first precursor group (cm^{-3}).
6 ...	13-24	Floating	Density of second precursor group (cm^{-3}).
7	1-12	Floating	End point of first time zone (sec).
7	13-24	Floating	Ramp reactivity insertion rate in first time zone (cents/sec).
7	25-36	Floating	Quadratic reactivity insertion rate ($\text{cents}/\text{sec}^2$).
7	37-48	Floating	Temperature coefficient (cents/ $^{\circ}\text{K}$).
7	49-60	Floating	Heat capacity (joules/cc- $^{\circ}\text{K}$).
7	61-72	Floating	Heat transfer coefficient (sec^{-1}).
8 (Optional)	Same as card seven for second time zone.		
...			

APPENDIX C

SAMPLE CASE

The following pages show the input data and computer output for a sample kinetics calculation employing six groups of delayed neutrons. The sample case has a 50¢ reactivity step with no shutdown coefficient.

INPUT DATA

SAMPLE CASE		FIFTY CENT STEP		TWO CYCLES		
6	2000	2	0	2		
.000008	.000588	.000454	.00069	.000214	.000074	49
.0129	.0311	.134	.331	1.26	3.21	49
1.0	50.	.0	.0001	.1	.005	
.50	.0	.0	.0	400.	.0	
1.0	.0	.0	.0	400.	.0	

S A M P L E C A S E

FIFTY CENT STEP

TWO CYCLES

NUMBER OF PRECURSOR GROUPS = 6

MAXIMUM NUMBER OF TIME STEPS = 2000

NUMBER OF INTERVALS BETWEEN PRINT OUT = 2

THE NUMBER OF REACTIVITY ZONES = 2

INITIAL NEUTRON DENSITY (PER CC) = 1.0000E+00

INITIAL REACTIVITY (CENTS) = 5.0000E+01

INITIAL TEMPERATURE (DEG K) = -0.

GENERATION TIME (SEC) = 1.0000E-04

MAXIMUM TIME STEP (SEC) = 1.0000E-01

CONVERGENCE CRITERION = 5.0000E-03

TOTAL PRECURSOR FRACTION = 2.1000E-03

GROUP	β_i	λ_i	C_i
1	8.0000E-05	1.2900E-02	6.2016E+01
2	5.8800E-04	3.1100E-02	1.8907E+02
3	4.5400E-04	1.3400E-01	3.3881E+01
4	6.9000E-04	3.3100E-01	2.0846E+01
5	2.1400E-04	1.2600E+00	1.6984E+00
6	7.4000E-05	3.2100E+00	2.3053E+01

S A M P L E C A S E

FIFTY CENT STEP

TWO CYCLES

REACTIVITY INPUT DATA LISTED BELOW

THE CURRENT TIME (SEC) = 0.

THE CURRENT REACTIVITY (CENTS) = 5.0000E 01

LINEAR COEFFICIENT (CENTS/SEC) = -0.

QUADRATIC COEFFICIENT (CENTS/SEC²) = -0.

TEMPERATURE COEFFICIENT (CENTS/DEGREE KELVIN) = -0.

HEAT CAPACITY (JOULES/CC-DEGREE K) = 4.0000E 02

HEAT TRANSFER COEFFICIENT = -0.

S A M P L E C A S E

FIFTY CENT STEP

TWO CYCLES

SOLUTION OF KINETICS EQUATIONS BELOW

I	TIME(SEC)	POWER(WATTS/CC)	RHO(CENTS)	TEMP(DEG-K)	ENERGY(JOULES/CC)	C1/C4	C2/C5	C3/C6
1	0,	1.000E-00	5.000E 01	-0,	0,	6,202E 01	1,891E 02	3,388E 01
2	6.667E-03	1.067E 00	5.000E 01	1.726E-05	6.905E-03	2,085E 01	1,698E 00	2,305E-01
4	2.000E-02	1.189E 00	5.000E 01	5.496E-05	2.199E-02	6,202E 01	1,891E 02	3,388E 01
6	3.333E-02	1.295E 00	5.000E 01	9.644E-05	3.858E-02	2,085E 01	1,699E 00	2,307E-01
8	5.333E-02	1.429E 00	5.000E 01	1.648E-04	6.590E-02	6,202E 01	1,891E 02	3,389E 01
10	7.333E-02	1.539E 00	5.000E 01	2.391E-04	9.565E-02	2,086E 01	1,703E 00	2,320E-01
12	1.033E-01	1.669E 00	5.000E 01	3.599E-04	1.440E-01	6,202E 01	1,891E 02	3,390E 01
14	1.333E-01	1.768E 00	5.000E 01	4.891E-04	1.956E-01	2,088E 01	1,709E 00	2,343E-01
16	1.783E-01	1.877E 00	5.000E 01	6.947E-04	2.779E-01	6,203E 01	1,891E 02	3,394E 01
18	2.346E-01	1.970E 00	5.000E 01	9.660E-04	3.864E-01	2,093E 01	1,725E 00	2,393E-01
20	3.190E-01	2.065E 00	5.000E 01	1.393E-03	5.571E-01	6,203E 01	1,892E 02	3,398E 01
22	4.455E-01	2.166E 00	5.000E 01	2.064E-03	8.255E-01	2,100E 01	1,745E 00	2,458E-01
23	5.000E-01	2.204E 00	5.000E 01	2.362E-03	9.446E-01	6,205E 01	1,893E 02	3,406E 01
						2,112E 01	1,781E 00	2,573E-01
						6,207E 01	1,894E 02	3,416E 01
						2,127E 01	1,824E 00	2,702E-01
						6,210E 01	1,897E 02	3,433E 01
						2,152E 01	1,895E 00	2,906E-01
						6,214E 01	1,900E 02	3,456E 01
						2,186E 01	1,989E 00	3,160E-01
						6,221E 01	1,905E 02	3,494E 01
						2,242E 01	2,135E 00	3,517E-01
						6,232E 01	1,913E 02	3,556E 01
						2,332E 01	2,351E 00	3,974E-01
						6,237E 01	1,917E 02	3,584E 01
						2,371E 01	2,442E 00	4,145E-01

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SAMPLE CASE

FIFTY CENT STEP

TWO CYCLES

REACTIVITY INPUT DATA LISTED BELOW

THE CURRENT TIME (SEC) = 5.0000E+01

THE CURRENT REACTIVITY (CENTS) = 5.0000E 01

LINEAR COEFFICIENT (CENTS/SEC) = -0.

QUADRATIC COEFFICIENT (CENTS/SEC²) = -0.

TEMPERATURE COEFFICIENT (CENTS/DEGREE KELVIN) = -0.

HEAT CAPACITY (JOULES/CC-DEGREE K) = 4.0000E 02

HEAT TRANSFER COEFFICIENT = -0.

SAMPLE CASE FIFTY CENT STEP TWO CYCLES

SOLUTION OF KINETICS EQUATIONS BELOW

I	TIME(SEC)	POWER(WATTS/CC)	RHO(CENTS)	TEMP(DEG-K)	ENERGY(JOULES/CC)	C1/C4	C2/C5	C3/C6
1	5.000E-01	2.204E 00	5.000E 01	2.362E-03	9.446E-01	6.237E 01 2.371E 01	1.917E 02 2.442E 00	3.584E 01 4.145E-01
2	6.000E-01	2.269E 00	5.000E 01	2.921E-03	1.169E 00	6.247E 01 2.446E 01	1.924E 02 2.602E 00	3.638E 01 4.421E-01
4	8.000E-01	2.391E 00	5.000E 01	4.087E-03	1.635E 00	6.268E 01 2.601E 01	1.939E 02 2.905E 00	3.750E 01 4.875E-01
6	1.000E-00	2.508E 00	5.000E 01	5.312E-03	2.125E 00	6.291E 01 2.761E 01	1.956E 02 3.185E 00	3.871E 01 5.245E-01
7	1.000E-00	2.508E 00	5.000E 01	5.312E-03	2.125E 00	6.291E 01 2.761E 01	1.956E 02 3.185E 00	3.871E 01 5.245E-01

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