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EXCURS - A COMPUTING PROGRAMME FOR  
ANALYSIS OF CORE TRANSIENT BEHAVIOUR  
IN A SODIUM COOLED FAST REACTOR

September, 1977

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EXCURS—A Computing Programme for Analysis of Core Transient Behaviour  
in a Sodium Cooled Fast Reactor

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(Received August 24, 1977)

In the code EXCURS developed for core transient behaviour calculation of a sodium-cooled fast reactor, a one-channel model is used to represent thermal behaviour of the reactor core. Calculations are made for three different channels; i.e. average, hot and hottest. In the average channel the power density and coolant velocity are equal to the mean values of the whole core. In the hot channel, a maximum power density of the core and a specific coolant velocity are introduced. In the hottest channel, engineering hot channel factors are considered to the hot channel.

A one-point neutron kinetics equation with six delayed neutron groups is used to calculate the time-dependent power behaviour. Externally introduced reactivity effect and control rod movement in the case of a scram are taken into account. In the feedback effects evaluated on the basis of the average channel temperatures are considered Doppler effect, fuel axial expansion, cladding expansion, coolant expansion and structure expansion. The decay heat after reactor scram is also considered.

Heat balance is taken in each cross section, neglecting the axial heat transfer except for the coolant region. Temperature dependence of the physical properties of materials is considered by second-order polynomials approximation, and also the fuel melting process. Each channel can be divided into a maximum of 20 regions in both radially and axially.

The reactor core transient behaviour due to reactivity insertion or loss-of-coolant flow can be studied by EXCURS. The calculated results are plotted optionally by connected code EXPLOT.

Keywords : Sodium Cooled FBR, EXCURS code, Accident Analysis, Reactor Kinetics, Transient Behaviour, Fuel Melting, Heat Balance, Channel Model, Reactivity Insertion, Loss of Flow, Decay Heat.

EXCURS—ナトリウム冷却高速炉用炉心過渡挙動解析コード

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(1977年8月24日受理)

ナトリウム冷却高速炉用の炉心過渡挙動解析コード EXCURS を開発した。本コードでは炉心をチャンネルで代表しその過渡挙動を解析する。チャンネルは平均チャンネル、ホットチャンネルおよびホットテストチャンネルから成る。平均チャンネルでは出力密度、冷却材流速とも全炉心の平均値を用い、ホットチャンネルでは炉心の最高出力密度および任意の流速を、ホットテストチャンネルではホットチャンネルに更に工学的ホットチャンネル係数を考慮に入れて計算する。

炉心の出力挙動については 6 群の遅発中性子を考慮に入れた 1 点近似の中性子動特性方程式により求める。反応度の外乱およびスクラムによる制御棒効果が採り入れられ、又、フィードバック効果としては平均チャンネルの温度に基いて計算し、ドップラー効果、燃料軸方向膨張、被覆材膨張、冷却材密度変化、構造材膨張等による効果を考慮する。原子炉停止後の出力については崩壊熱の式により計算する。

熱計算については軸方向の各断面で冷却材領域以外では軸方向の熱伝達を無視して熱平衡式を導き計算する。物性値の温度依存については、温度に関する二次式で近似し、又、燃料の溶融過程についても考慮している。各チャンネルは半径方向および軸方向についてそれぞれ最大 20 点までとれる。

本コードにより、反応度挿入および冷却材流量低下による炉心の過渡挙動が解析出来、結合コード EXPLOR によって、結果の図式化も可能である。

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1. INTRODUCTION

The EXCURS code calculates the core behaviour of a sodium cooled fast reactor under transient conditions in case of a reactivity insertion or loss-of-coolant flow accident. The calculations are restricted to an equivalent unit cell (channel) consisted of fuel, cladding, coolant and equivalent structure. They, however, can be performed for three different types of channel, defined as "average", "hot" and "hottest" channel.

- In the "average" channel the power density and coolant velocity are equal to the mean values of the whole core.
- In the "hot" channel the power density is equal to the maximum power density in the core, while the coolant velocity might differ from the mean value.
- In the "hottest" channel the engineering hot channel factors are introduced, i.e., uncertainties in,
  - o thermal conductivity of fuel
  - o density of fuel
  - o heat transfer coefficient across the gap between fuel and cladding
  - o coolant velocity
  - o tolerance in dimensions, etc.

Based upon the power distribution in the fuel pin during the stationary condition and neutron kinetics equations, the time dependent power behaviour of the core can be calculated. At the same time the temperatures of the fuel, cladding, coolant, etc. are calculated as a function of time. The reactivity feedback introduced by the expansions of the fuel, cladding, etc. and the Doppler effect can be taken into account. The same applies for reactivity effects caused by external sources (step and/or ramp functions).

In the thermal transient calculation the reactor core is represented by one channel as shown in Figure 1. The channel can be divided into 20 radial and 20 axial zones as maximum. Figure 2 illustrates mesh layout for the radial and axial rows. For each cross section a heat balance is made, neglecting the axial heat transfer except for the coolant region. In the time dependent equations the fuel melting process can be handled, however sodium boiling is excluded. The equations are solved by the Runge-Kutta-Gill method.

The calculation results can be plotted optionally by the connected code, EXPLOT.

## 2. BASIC EQUATIONS

### 2.1 Neutron Kinetics Equation

One point neutron kinetics equation is used to calculate the time dependent power behaviour. In general, one point neutron kinetics equation can be written as follows:

$$\frac{d n(t)}{dt} = \frac{(1 + \delta k(t))(1 - \beta) - 1}{\lambda} n(t) + \sum_i \lambda_i c_i(t) + s_0 \quad (1)$$

$$\frac{d c_i(t)}{dt} = \frac{(1 + \delta k(t))\beta_i}{\lambda} n(t) - \lambda_i c_i(t) \quad (2)$$

where,

$n(t)$  : neutron density

$c_i(t)$ : concentration of i-th group delayed neutron precursor

$\beta$  : delayed neutron fraction

$\beta_i$  : i-th group delayed neutron fraction

$\lambda_i$  : decay constant of i-th group delayed neutron precursor

$\delta k(t)$ : reactivity

$\lambda$  : prompt neutron life time

$s_0$  : neutron source

Maximum number of delayed neutron groups is set to be 6. Equations (1) and (2) can be rewritten if the second order term  $\beta \delta k$  is neglected and are replaced as follows, introducing the relative values in respect of the initial values.

$$\frac{d n(t)}{dt} = \frac{\beta}{\lambda} ((r(t) - 1) n(t) + \sum_i f_i w_i(t) + s) \quad (3)$$

$$\frac{d w_i(t)}{dt} = - \lambda_i (w_i(t) - n(t)) \quad (4)$$

where,

$$r(t) = \delta k(t)/\beta$$

$$f_i = \beta_i/\beta$$

$$w_i(t) = \lambda_i c_i(t)/\beta f_i$$

$$s = \lambda s_0/\beta$$

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$$\frac{d w_i(t)}{dt} = - \lambda_i (w_i(t) - n(t)) \quad (4)$$

where,

$$r(t) = \delta k(t)/\beta$$

$$f_i = \beta_i/\beta$$

$$w_i(t) = \lambda_i c_i(t)/\beta f_i$$

$$s = \lambda s_0/\beta$$

The reactivity term,  $\delta k(t)$ , can be written as

$$\delta k(t) = \delta k_{ex}(t) + \sum_i \alpha_i (T_i - T_{i,o}) + \alpha_d \ln\left(\frac{T_f}{T_{f,o}}\right) - \delta k_{rod}(t) \quad (5)$$

in which:

$\delta k_{ex}(t)$  : externally inserted reactivity ( $= \delta k_{step} + \delta k_{ramp}$ )

$\alpha_i$  : reactivity coefficient, except Doppler effect

$\alpha_d$  : Doppler effect

$\delta k_{rod}(t)$ : control rod reactivity by scram

$T_i$  : Temperatures of fuel, cladding, coolant, structure corresponding to  $\alpha_i$

$T_{i,o}$  : Initial temperatures of above materials

$T_f$  : Fuel temperature

$T_{f,o}$  : Initial fuel temperature.

Doppler feedback is introduced by assuming that the Doppler effect is constant, i.e. the product of Doppler temperature coefficient and temperature is constant.

$$\delta k_{dop}(t) = \int_{T_o}^{T(t)} \frac{\alpha_d}{T(t)} dT = \alpha_d \ln\left(\frac{T(t)}{T_o}\right) \quad (6)$$

The control rod reactivity  $k_{rod}$ , is obtained from the perturbation theory by the following equation:

$$\delta k_{rod}(t) = \alpha_{rod} \left\{ \frac{\alpha(t - t_{rod})^2}{2H} - \frac{1}{2\pi} \left( \sin \frac{\pi(2z_o + \alpha(t - t_{rod})^2)}{H} - \sin \frac{2\pi z_o}{H} \right) \right\}$$

in which:

$\alpha_{rod}$  : Total control rod reactivity

$\alpha$  : Acceleration

$H$  : Control rod length

$z_o$  : Pre-inserted control rod length

As the decay heat generated after a reactor shut-down, influences to a great extend the coolant temperature increase, in the case of loss-of-coolant flow accident, the decay heat is taken into account. It has been introduced as follows:

$$\frac{P_f(t)}{P_0} = \begin{cases} 0.065 & (0 \leq t \leq 10 \text{ sec}) \\ 0.13 t^{-0.2} & (10 \leq t \leq 3600 \text{ sec}) \\ 0.3 t^{-0.33} & (t \geq 3600 \text{ sec}) \end{cases} \quad (8)$$

in which:

$P_f(t)$  : Decay heat power at  $t$  sec after shut-down  
 $P_0$  : Initial power

## 2.2 Heat Balance Equations

A heat balance is made at each node as shown in Fig. 2, and is here introduced. For each cell in the fuel element zone mesh, we have a heat balance expression,

$$\text{Rate of change of heat content} = (\text{Heat flowing in} - \text{Heat flowing out} + \text{Heat generation}) \text{ per unit time.} \quad (9)$$

Referring to Fig. 2, and neglecting axial heat transfer except in the coolant region, the above heat balance equations can be written, for solid regions:

$$(V \rho C_p)_I \frac{dT_I}{dt} = \left(\frac{k A}{d}\right)_{I-1,I} (T_{I-1} - T_I) - \left(\frac{k A}{d}\right)_{I,I+1} (T_I - T_{I+1}) + q_1(I, J, t) \quad (10)$$

and for coolant region,

$$(V \rho C_p) \frac{dT}{dt} = -v (V \rho C_p) \frac{dT}{dz} + q_2(v, z, t) \quad (11)$$

in which:

- $k$  : Thermal conductivity
- $\rho$  : Density
- $C_p$  : Specific heat
- $V$  : Volume
- $A$  : Heat transfer area
- $d$  : Distance between successive two nodes.
- $T$  : Temperature

$v$  : Coolant velocity

$q_1(I, J, t)$  : Power generation rate of fuel at node point  $(I, J)$

$q_2(v, z, t)$  : Heat flux from cladding surface to coolant.

In the input description the fuel region can be optionally divided into a number of radial zones. The other regions, however, are defined as shown in Fig. 2. If the maximum number of mesh points in the fuel region is equal to  $N$ , then the heat balance equation at each mesh point is as follows:

$$I = 1$$

$$(V \rho C_p)_1 \frac{dT_1}{dt} = - \left( \frac{k A}{d} \right)_{1,2} (T_1 - T_2) + q_1(1, J, t) \quad (12)$$

$$I = 2$$

$$(V \rho C_p)_2 \frac{dT_2}{dt} = \left( \frac{k A}{d} \right)_{1,2} (T_1 - T_2) - \left( \frac{k A}{d} \right)_{2,3} (T_2 - T_3) + q_1(2, J, t) \quad (13)$$

$$I = I$$

$$(V \rho C_p)_I \frac{dT_I}{dt} = \left( \frac{k A}{d} \right)_{I-1,I} (T_{I-1} - T_I) - \left( \frac{k A}{d} \right)_{I,I+1} (T_I - T_{I+1}) + q_1(I, J, t) \quad (14)$$

$$I = N$$

$$(V \rho C_p)_N \frac{dT_N}{dt} = \left( \frac{k A}{d} \right)_{N-1,N} (T_{N-1} - T_N) - h_1 A_{N,N+1} (T_N - T_{N+1}) + q_1(N, J, t) \quad (15)$$

$$I = N + 1$$

$$(V \rho C_p)_{N+1} \frac{dT_{N+1}}{dt} = h_1 A_{N,N+1} (T_N - T_{N+1}) - \left( \frac{k A}{d} \right)_{N+1,N+2} (T_{N+1} - T_{N+2}) \quad (16)$$

$$I = N + 2$$

$$(V \rho C_p)_{N+2} \frac{dT_{N+2}}{dt} = \left( \frac{k A}{d} \right)_{N+1,N+2} (T_{N+1} - T_{N+2}) - h_2 A_{N+2,N+3} (T_{N+2} - T_{N+3}) \quad (17)$$

$$I = N + 3$$

$$(V \rho C_p)_{N+3} \frac{dT_{N+3}}{dt} = h_2 A_{N+2,N+3} (T_{N+2} - T_{N+3}) - (V \rho C_p)_{N+3} \frac{dT_{N+3}}{dz} - h_2 A_{N+3,N+4} (T_{N+3} - T_{N+4}) \quad (18)$$

$$I = N + 4$$

$$(V \rho C_p)_{N+4} \frac{d T_{N+4}}{dt} = h_2 A_{N+3, N+4} (T_{N+3} - T_{N+4}) \quad (19)$$

in which:

$h_1$  : Gap conductance

$h_2$  : Heat transfer coefficient between cladding and coolant.

In the cladding, the power generation by  $\gamma$ -heating is not taken into account.

#### Power generation

The power generation  $q_1(I, J, t)$  is considered to be a function of time, and to have distributions in the radial direction as well as in the axial. If these variables can be separated from each other,  $q_1(I, J, t)$  can be written as follows:

$$q_1(I, J, t) = Q(K) \cdot \mu(I) \cdot \delta(J) \cdot n(t) \quad (20)$$

in which:

$Q(K)$  :  $K=1$  Initial power generation rate at the average channel

$K=2$  Initial power generation rate at the hot channel

$\mu(I)$  : Power distribution in the radial direction

$\delta(J)$  : Power distribution in the axial direction

The values of  $\mu(I)$  and  $\delta(J)$  are given as relative values by input, and these values are normalized in the code by the following equation:

$$PF(I, J) = \frac{\mu(I) \cdot \delta(J)}{PF_{av}} \quad (21)$$

in which:

$$PF_{av} = \frac{\sum_{I, J} \pi \Delta r_I (r_I + r_{I+1}) \Delta z_J \mu(I) \delta(J)}{\pi L r_f^2}$$

$r_f$  : Fuel radius

$L$  : Core axial length

If the axial power distribution is assumed to be cosine, it can be written as:

$$\begin{aligned}\delta(J) &= \frac{1}{2\Delta z} \int_{(J-1)\Delta z}^{(J+1)\Delta z} \sin\left(\frac{z + \delta L}{L + 2\delta L} \pi\right) dz \\ &= \frac{L + 2\delta L}{\pi \Delta z} \sin\left(\frac{J\Delta z + \delta L}{L + 2\delta L} \pi\right) \sin\left(\frac{\Delta z}{L + 2\delta L} \pi\right)\end{aligned}\quad (22)$$

in which:

$\Delta z$  : Axial mesh size

$\delta L$  : Core extrapolation length

In this special case, it is not necessary to specify the axial power distribution for each mesh, but to input the core extrapolation length.

#### Heat transfer coefficient

The heat transfer coefficient between cladding surface and coolant is introduced by the following equation, which is convenient for parameter study.

$$Nu = a_1 + a_2 (Pe)^{a_3} \quad (23)$$

in which:

$Nu$  : Nusselt number

$Pe$  : Peclet number

$a_i$  : Constant, given by the input.

In case of the flow blockage in the channel, only heat conduction in the radial direction is assumed.

#### Fuel melting process

The fuel melting process is treated as follows: temperatures are first calculated neglecting any melting during the time increment, and an apparent temperature rise,  $(\Delta T_i)_{app}$ , above the melting temperature,  $T_{melt}$ , is obtained. The fraction of fuel melted is then given by:

$$x_i = C_p (\Delta T_i)_{app} / L_h \quad (24)$$

in which:

$x_i$  : Fraction of fuel melted

$L_h$  : Latent heat of fuel melting

During the transition from the solid to the liquid phase the temperature of the fuel will be constant and equal to  $T_{melt}$ . However, when  $C_p(T_i)_{app} > L_h$ , then,  $x_i = 1$  and the temperature of the liquid fuel is raised by  $(\Delta T_i)_1$  above the melting point. For the calculation of  $(\Delta T_i)_1$  the following equation is used:

$$(\Delta T_i)_1 = \frac{C_p(\Delta T_i)_{app} - L_h}{C_p} \quad (25)$$

The above sketched procedure is reversed during a cooling process.

#### Coolant velocity

Coolant velocity as a function of time is introduced by:

$$\frac{v(t)}{v_0} = a_1 + a_2 t + a_3 \exp(a_4 t) \quad (26)$$

in which:

$v(t)$  : Coolant velocity at time  $t$

$v_0$  : Initial coolant velocity

$a_i$  : Constant settled by input

Physical properties such as thermal conductivity, density, specific heat, gap heat transfer coefficient are considered to be constant or temperature dependent optionally.

#### 2.3 Calculation of Temperatures in the Hottest Channel

In the calculation of the temperatures in the hottest channel the engineering hot channel factors are taken into account. These factors are shown in Table 1, and are introduced to the calculation of the hottest channel in a statistical manner as follows:

##### 2.3.1 Coolant temperature

Let  $\Delta T_{co}(J)$  be the temperature difference between coolant temperature at the axial node  $J$  and inlet coolant temperature. The coolant temperature at the node  $J$  in the hottest channel is obtained from the temperature in the hot channel as follows:

$$T_{coolant}(J,3) = T_{coolant}(J,2) + \sqrt{\sum_{L=1}^{10} ((F(L,1) - 1)\Delta T_{co}(J))^2} \quad (27)$$

in which:

$T_{coolant}(J,3)$  : Coolant temperature at the node J in the hottest channel

$T_{coolant}(J,2)$  : Coolant temperature at the node J in the hot channel

$F(L,1)$  : Engineering hot channel factor as shown in Table 1

$\Delta T_{co}(J)$  : Temperature difference between coolant temperature at the axial node J in the hot channel and inlet coolant temperature.

### 2.3.2 Cladding outer surface temperature

The same method as mentioned above is introduced to calculate the cladding outer surface temperature in the hottest channel. Let  $\Delta T_{co,cl}(J)$  be the temperature difference between the coolant temperature and cladding outer surface temperature at the axial node J in the hot channel, the cladding outer surface temperature in the hottest channel is obtained as follows:

$$T_{cl,o}(J,3) = T_{cl,o}(J,2) + \sqrt{\sum_{L=1}^{10} \{(F(L,1)-1)\Delta T_{co}(J) + (F(L,2)-1)\Delta T_{co,cl}(J)\}^2} \quad (28)$$

in which:

$T_{cl,o}(J,3)$  : Cladding outer surface temperature at the node J in the hottest channel

$T_{cl,o}(J,2)$  : Cladding outer surface temperature at the node J in the hot channel

$\Delta T_{co,cl}(J)$  : Temperature difference between the coolant and cladding outer surface at the axial node J in the hot channel

### 2.3.3 Cladding inner surface temperature

The cladding inner surface temperature in the hottest channel is obtained as follows:

$$T_{cl,i}(J,3) = T_{cl,i}(J,2)$$

$$+ \sqrt{\sum_{L=1}^{10} \{(F(L,1)-1)\Delta T_{co}(J) + (F(L,2)-1)\Delta T_{co,cl}(J)\}}$$

$$+ (F(L,3)-1)\Delta T_{cl}(J)\}^2 \quad (29)$$

in which:

$T_{cl,i}(J,3)$  : Cladding inner surface temperature at the node J in the hottest channel

$T_{cl,i}(J,2)$  : Cladding inner surface temperature at the node J in the hot channel

$\Delta T_{cl}(J)$  : Temperature difference between cladding outer surface and cladding inner surface at the axial node J in the hot channel.

#### 2.3.4. Fuel surface temperature

The fuel surface temperature in the hottest channel is obtained considering the uncertainties of gap heat transfer coefficient, tolerance in the dimension of fuel pellet and so on.

$$T_{f,o}(J,3) = T_{f,o}(J,2) + \sqrt{\sum_{L=1}^{10} \{(F(L,1)-1)\Delta T_{co}(J) + (F(L,2)-1)\Delta T_{co,cl}(J) + (F(L,3)-1)\Delta T_{cl}(J) + (F(L,4)-1)\Delta T_{c,f}(J)\}^2} \quad (30)$$

in which:

$T_{f,o}(J,3)$  : Fuel surface temperature at the node J in the hottest channel

$T_{f,o}(J,2)$  : Fuel surface temperature at the node J in the hot channel

$\Delta T_{c,f}(J)$  : Temperature difference between cladding inner surface and fuel surface at the axial node J in the hot channel.

#### 2.3.5 Fuel temperature

Let  $\Delta T_f(J)$  be the temperature difference between fuel surface and fuel at the given radial node at the axial node J in the hot channel, the fuel temperature at the given radial node in the hottest channel is obtained as follows:

$$T_f(J,3) = T_f(J,2) + \sqrt{\sum_{L=1}^{10} \{(F(L,1)-1)\Delta T_{co}(J) + (F(L,2)-1)\Delta T_{co,cl}(J) + (F(L,3)-1)\Delta T_{cl}(J) + (F(L,4)-1)\Delta T_{c,f}(J) + (F(L,5)-1)\Delta T_f(J)\}^2} \quad (31)$$

in which:

$T_f(J,3)$  : Fuel temperature at the given radial node and axial node J in the hottest channel

$T_f(J,2)$  : Fuel temperature at the given radial node and axial node J in the hot channel

$\Delta T_f(J)$  : Temperature difference between fuel surface and fuel at the given radial node at axial node J in the hot channel.

#### 2.3.6 Structure temperature

The structure temperature in the hottest channel is obtained by the same method to get coolant temperature.

$$T_{st}(J,3) = T_{st}(J,2) + \sqrt{\sum_{L=1}^{10} \{(F(L,1)-1) T_{co}(J)\}^2} \quad (32)$$

in which:

$T_{st}(J,3)$  : Structure temperature at the axial node J in the hottest channel

$T_{st}(J,2)$  : Structure temperature at the axial node J in the hot channel.

Table 1 Engineering Hot Channel Factor

	Coolant	Cladding outer surface	Cladding inner Surface	Fuel outer Surface	Fuel
Tolerance in dimension	F (1,1)	F (1,2)	F (1,3)	F (1,4)	F (1,5)
Non-uniformity of fission distribution	F (2,1)	-	-	-	-
Uncertainty in coolant physical values ( $k, \rho, C_p$ )	F (3,1)	-	-	-	-
Uncertainty in cladding physical values ( $k, \rho, C_p$ )	F (4,1)	-	-	-	-
Uncertainty in gap conductance	F (5,1)	-	-	-	-
Uncertainty in fuel physical values ( $k, \rho, C_p$ )	F (6,1)	-	-	-	-
Uncertainty in power level	F (7,1)	-	-	-	-
Uncertainty in coolant velocity	F (8,1)	-	-	-	-
Uncertainty in film coefficient	F (9,1)	-	-	-	-
Other factors	F(10,1)	-	-	-	F(10,5)

3. NUMERICAL SOLUTION AND PROGRAMME COMPOSITION3.1 Numerical Solution

The numerical method to solve the differential equations mentioned in the foregoing chapter is based on Runge-Kutta method. The modified Runge-Kutta method derived by E. R. Cohen<sup>1)</sup> is introduced to solve the neutron kinetics equations. In this method the special constants are introduced empirically to revise the Runge-Kutta method. (Details are described in Ref. 1).

In the heat balance equations, the term of  $dT/dZ$  in Eq. (11) is rewritten in the differential form as follows:

$$\frac{dT}{dZ}(J) = \frac{T(J) - T(J-1)}{\Delta Z} \quad (33)$$

in which:

$\Delta Z$  : Axial mesh size

When J in the above equation is 1,  $T(J-1)$  represents inlet coolant temperature. So the heat balance equations (12) - (19) can be solved at each axial node, and the Runge-Kutta-Gill method is introduced to solve these simultaneous differential equations. When the temperature dependency of material physical properties is taken into account, the heat balance equations become non-linear. These non-linear equations in the computer can be solved by iteration method. However, this would take an extraordinary amount of computing time. A resonable approach has been to introduce the material physical constants calculated based on the temperatures from the foregoing time interval. In this code the iteration method is only used to calculate the initial values.

3.2 Method to set Time Interval

The time interval used in the calculation is kept constant or, if desired, self-adjusting. In the former case the time intervals have to be described in the input. The constant time interval can be changed to the other value at the pre-set time during the transient if necessary. However, the maximum time interval is limited for calculational instability reasons. It mainly depends on the term  $\Delta t/(\Delta r)^2$ , in which  $\Delta r$  is the radial mesh spacing in the fuel region. So, the smaller  $\Delta r$  is, the shorter the time

interval should be.

In the self-adjusting mode, Cohen's method which has already been used in the AIREK code<sup>2)</sup> is introduced. In this method the time interval can be changed to be double or half according to the special criteria as shown in Fig. 3. Where, Q value is calculated as follows:

$$Q = \frac{h c_2(\alpha_0 h')}{1 + c_1(\alpha_0 h')} (|\omega_0 - 2\bar{\omega} + \omega_1|) \quad (34)$$

in which:

$$\alpha_0 := \frac{\beta}{\ell} (r(t_0)-1)$$

$\omega_0$  : Instantaneous inverse period at time  $t_0$

$\omega_1$  : Instantaneous inverse period at time  $(t_0 + h)$

$\bar{\omega}$  : Average inverse period at time  $(t_0, t_0+h)$

$c_i(\alpha_0 h')$  is a special constant derived by E. R. Cohen. Accordance to reference 2), the calculational error in  $N(t)$  is presented as referred in Table 2.

Table 2. Calculational Error in Several Q Values

Max. Q	Min. Q	Error in $N(t)$
$10^{-3}$	$10^{-4}$	$2.5 \times 10^{-3}$
$10^{-4}$	$10^{-5}$	$0.9 \times 10^{-4}$
$10^{-5}$	$10^{-6}$	$0.6 \times 10^{-5}$
$10^{-6}$	$10^{-7}$	$4.0 \times 10^{-6}$

### 3.3 Programme Description

The EXCURS is composed of a main programme and 12 subroutines. The main programme and these subroutines are used as follows:

MAIN : reads input data, controls subroutines and writes calculational results

INTER : calculates transient neutron behaviour

RNFBT : supports INTER and calculates feedback term by delayed neutron precursors

CNFBT : supports INTER and calculates special constants

RANAL : calculates external and rod reactivities

DIREC : decides time interval  
DECAY : calculates decay heat after shut-down  
INIVA : calculates initial temperature  
TEMP : calculates transient temperature  
HOTSPPT: calculates transient temperature in the hottest channel  
OUTPUT: writes input data  
TEST : checks end of computation  
EXCPL : plots initial and final temperature distribution

The flow chart of the EXCURS is shown in Fig. 4.

### 3.4 Plotting Routine

The calculational results are optionally presented by the computer in a graphical way. The CDC 6600 has no enough core memory, so the plotting routine has to be separated from the EXCURS programme. The calculational results obtained by the EXCURS are stored on the magnetic tape, and the plotting of the calculational results is made by the separate programme, EXPLOT, using the data from the magnetic tape. The figures obtained by the programme are as follows:

- o Power, integral power, reactor period and total reactivity as a function of time,
- o Power, total reactivity, inserted reactivity, feedback reactivity and rod reactivity as a function of time,
- o Temperatures of maximum fuel, maximum cladding and outlet coolant, power, and coolant velocity as a function of time in each channel,
- o Axial temperature distribution in each channel at initial and final state,
- o Radial temperature distribution in each channel at initial and final state.

4. INPUT AND OUTPUT4.1 Input Data

For convenience all input data are numbered, making it easy to calculate several cases in one job. If this is done, it is necessary only to prepare the title card and the data which differ from the data in the preceding case. Input data and their format are as follows:

- #1 NCASE (I2) Number of cases in the job
  - #2 TITLE (8A10) Title card
  - #3 L1,L2,L3,L4(4I10)
    - L1: First datum number read in the series
    - L2: Last datum number read in the series
    - L3: +1;Data to be read in the case are continued
    - 1;Data to be read in the case are finished.
    - L4: 0;Data are read from the tape (this case is restarted one)
- All of the data are read from the tape.

The format of the following data is 5E14.7.

Data No.	Comment	Unit
1	Index of time interval setting 0.0 : self adjusting $T(>0)$ : change to the different time interval set at data (14) or self adjusting at time T sec. $-M(<0)$ : change to self adjusting after M points calculation	
2	Initial inverse period	$\text{sec}^{-1}$
3	Initial time interval	sec
4	Minimum time interval	sec
5	Maximum time interval	sec
6	Upper accuracy (Q value)	
7	Lower accuracy (Q value)	
8	Effective delayed neutron fraction	
9	Prompt neutron lifetime	sec

Data No.	Comment				Unit
10	Neutron source				
11	Average inverse period				sec <sup>-1</sup>
12	Reactivity				
13	Time of end of calculation				sec
14	Second time interval, if 0.0: self adjusting				sec
15	Initial power level				relative
16	Initial concentration of 1st group delayed neutron precursor				"
17	" 2nd	"	"		"
18	" 3rd	"	"		"
19	" 4th	"	"		"
20	" 5th	"	"		"
21	" 6th	"	"		"
22	Relative value of 1st group delayed neutron fraction				
23	" 2nd	"	"		
24	" 3rd	"	"		
25	" 4th	"	"		
26	" 5th	"	"		
27	" 6th	"	"		
28	Decay constant of 1st group delayed neutron precursor				sec <sup>-1</sup>
29	" 2nd	"	"		"
30	" 3rd	"	"		"
31	" 4th	"	"		"
32	" 5th	"	"		"
33	" 6th	"	"		"
34	1.0				
35	Step reactivity				Δk/k
36	Step reactivity continuation time				sec
37	Ramp reactivity				Δk/k/sec
38	Ramp reactivity continuation time				sec
39	Scram option + 1.0 : Yes				
	- 1.0 : No				
40	Control rod worth				Δk/k
41	Control rod stroke				cm
42	Pre-inserted control rod length				cm
43	Acceleration of control rod insertion				cm/sec <sup>2</sup>
44	Scram setting point by power				relative

Data No.	Comment	Unit
45	Scram setting point by period	sec
46	Scram delayed time	sec
47	Doppler coefficient	$\Delta k/k$
48	Reactivity coefficient by fuel axial expansion	$\Delta k/k/\text{ }^{\circ}\text{C}$
49	Reactivity coefficient by cladding expansion	"
50	Reactivity coefficient by coolant expansion	"
51	Reactivity coefficient by structure expansion	"
52	Coolant flow transient index $\geq$ blockage <no blockage	
53	Scram setting point by coolant flow	relative
54	Scram setting time by timer	sec
55	Fuel pellet radius	cm
56	Cladding inner radius	"
57	Cladding outer radius	"
58	Coolant equivalent radius	"
59	Structure equivalent radius	"
60	Equivalent diameter	"
61	Heat conductivity of fuel	cal/cm $\text{ }^{\circ}\text{C}$ sec
62	Density of fuel	g/cm $^3$
63	Specific heat of fuel	cal/g $\text{ }^{\circ}\text{C}$
64	Heat conductivity of cladding	cal/cm $\text{ }^{\circ}\text{C}$ sec
65	Density of cladding	g/cm $^3$
66	Specific heat of cladding	cal/g $\text{ }^{\circ}\text{C}$
67	Heat conductivity of coolant	cal/cm $\text{ }^{\circ}\text{C}$ sec
68	Density of coolant	g/cm $^3$
69	Specific heat of coolant	cal/g $\text{ }^{\circ}\text{C}$
70	Heat conductivity of structure	cal/cm $\text{ }^{\circ}\text{C}$ sec
71	Density of structure	g/cm $^3$
72	Specific heat of structure	cal/g $\text{ }^{\circ}\text{C}$
73	Gap conductance	cal/cm $^2\text{ }^{\circ}\text{C}$ sec
74	Core height	cm
75	Reflector saving	cm
76	Constants in equation of coolant velocity as a function of time	
78	$\frac{v(t)}{v_0} = D(76) \exp(D(77) \times t) + D(78) \times t + D(79)$	
79		

Data No.	Comment	Unit
80	Initial coolant velocity in the average channel	cm/sec
81	Initial coolant velocity in the hot channel	"
82	Initial power density in the average channel	cal/cm <sup>3</sup> sec
83	Initial power density in the hot channel	"
84	Number of division in the axial length	≤ 20
85	Number of division in fuel radius	≤ 13
86	Inlet coolant temperature	°C
87	Fuel melting temperature	°C
88	Constants in heat transfer equation	
89	Nu = D(88) + D(89) × Pe <sup>D(90)</sup>	
90		
91	Print interval	
92	Convergence accuracy in iteration calculation	
93	Print interval in iteration calculation	
94	Index of temperature dependency of physical value 1: Yes 0: No	
95	Number of channels to be calculated (1 ~ 3)	sec
96	Time interval in calculation of decay heat	min
97	Time to write data to tape	
98	Index of power distribution 0.0: (axi) cosine (rad) flat 1.0: (axi) cosine (rad) input 2.0: (axi) input (rad) input (Input is made in data number 201-250)	
99	Specific heat of molten fuel	cal/g°C
100	Latent heat of fuel in process of melting	cal/g

Data numbered 101-150 are concerned with engineering hot channel factors. If datum 95 is not 3.0, these data are not necessary. These data correspond to the data in Table 1.

Data No.	Comment
101	Tolerance in dimension (in coolant region, cladding outer surface, cladding inner surface, fuel)
105	
106	Non-uniformity of fission distribution
110	

Data No.	Comment
111 115	Uncertainty in coolant physical values
116 120	Uncertainty in cladding physical values
121 125	Uncertainty in gap conductance
126 130	Uncertainty in fuel physical values
131 135	Uncertainty in power level
136 140	Uncertainty in coolant velocity
141 145	Uncertainty in film coefficient
146 150	Other factors

Data numbered 151 to 189 are reserved for the temperature dependent physical properties of each material. If datum 94 is 0.0, these data are not necessary. The temperature dependent physical values are represented by an second-order polynomials of temperature. The expression is as follows:

$$\left. \begin{array}{l} k(T) \\ \rho(T) \\ C_p(T) \\ h(T) \end{array} \right\} = D(I) + D(I+1) \times T + D(I+2) \times T^2$$

Data No.	Comment
151 153	Thermal conductivity of fuel $k(T) = D(151) + D(152) \times T + D(153) \times T^2$
154 156	Thermal conductivity of cladding
157 159	Thermal conductivity of coolant
160 162	Thermal conductivity of structure

Data No.	Comment
163 165	Density of fuel
166 168	Density of cladding
169 171	Density of coolant
172 174	Density of structure
175 177	Specific heat of fuel
178 180	Specific heat of cladding
181 183	Specific heat of coolant
184 186	Specific heat of structure
187 189	Gap conductance

Data numbered 201-250 are concerned with power distribution in the fuel pin. If datum 98 is 0.0, these data are not necessary, and if 1.0, only the data of radial power distribution is requested.

Data No.	Comment
201 225	Relative power in the radial node of fuel. (number of data is D(85)+1)
226 250	Relative power in the axial node of fuel (number of data is D(74))

Data numbered 251-280 are concerned with plotter routine. If plotting is not necessary, these data are not requested.

Data No.	Comment	Unit
251	Plotter option 1.0: Yes 0.0: No	
252	Length in time axis	cm

Data No.	Comment	Unit
253	Maximum time in axis if negative, scaling is made automatically	cm
254	Length in power axis	cm
255	Maximum power in axis if negative, scaling is made automatically	relative
256	Length in integral power axis	cm
257	Maximum integral power in axis if negative, scaling is made automatically	relative
258	Length in reactivity axis	cm
259	Minimum reactivity in axis	$\Delta k/k$
260	Maximum reactivity in axis if negative, scaling is made automatically	"
261	Length in period axis	cm
262	Minimum period in axis	sec
263	Maximum period in axis if negative, scaling is made automatically	sec
264	Length in fuel temperature axis	cm
265	Minimum fuel temperature in axis	$^{\circ}\text{C}$
266	Maximum fuel temperature in axis if negative, scaling is made automatically	"
267	Length in cladding and coolant temperature axis	cm
268	Minimum cladding and coolant temperature in axis	$^{\circ}\text{C}$
269	Maximum cladding and coolant temperature in axis if negative, scaling is made automatically	"
270	Length in coolant velocity axis	cm
271	Minimum coolant velocity in axis	cm/sec
272	Maximum coolant velocity in axis if negative, scaling is made automatically	"
273	Plotting option of temperature distribution 0.0 : No 1.0 : Axial distribution 2.0 : Radial distribution 3.0 : Axial and radial distributions	
274	Plotting option of state 1.0 : initial state 2.0 : final state 3.0 : initial and final states	

Data No.	Comment	Unit
275	Plotting option of channel 1.0 : channel 1 2.0 : channel 2 3.0 : channel 3 4.0 : channels 1 and 2 5.0 : channels 1, 2 and 3	
276	Length in channel axial direction axis	cm
277	Length in channel radial direction axis	"
278	Length in temperature axis	"
279	Minimum temperature in axis	°C
280	Maximum temperature in axis if negative, scaling is made automatically	°C

- \* Data 61-73 are used to calculate first initial temperature in the iteration procedure when datum 94 equals 1.0.
- \*\* All data are written here in CGS system, but also other system is possible as far as they are consistent.
- \*\*\* Input data for EXPLOR are prepared in EXCURS.

#### 4.2 Output Data

Title and all of the input data are printed out in the output list of EXCURS. The following values at each print interval set by input including initial state are printed.

(1) number of calculation steps	<u>unit</u>
(2) time	sec
(3) time interval	sec
(4) total reactivity	$\Delta k/k$
(5) instantaneous inverse period	$sec^{-1}$
(6) average inverse period	"
(7) power	relative
(8) integral power	relative power $\times$ sec
(9) concentration of delayed neutron precursors	relative
(10) feedback reactivity	$\Delta k/k$
(11) control rod reactivity	"
(12) coolant velocity in channel 1	cm/sec
(13) coolant velocity in channel 2	"

- (14) temperature in each radial and axial node in  
each channel °C
- (15) average temperatures of fuel, cladding, coolant  
and structure in channel 1 °C

In EXPLOT, title, input data which are necessary for plotting, and calculational values used for plotting as a function of time are printed.

## 5. SAMPLE CALCULATIONS

### 5.1 Reactivity Insertion Accident

A sample calculation is shown in which reactivity of 0.5 \$/sec. is inserted externally to the typical fast reactor core. The main calculational conditions are as follows:

o Reactivity insertion rate	0.00165 Δk/k/sec
o Fuel pellet diameter	5.5 mm
o Cladding outer diameter	6.3 mm
o Cladding thickness	0.35 mm
o Core height	60 cm
o Delayed neutron fraction	0.0033
o Prompt neutron lifetime	$1.0 \times 10^{-7}$ sec

### Reactivity temperature coefficient

o Doppler ( $T \frac{dk}{dt}$ )	$-5.0 \times 10^{-3} \Delta k/k$
o Fuel axial expansion	$-4.0 \times 10^{-6} \Delta k/k^\circ C$
o Cladding expansion	$-5.0 \times 10^{-7}$ "
o Coolant expansion	$-5.0 \times 10^{-6}$ "
o Structure expansion	$-2.0 \times 10^{-6}$ "

### Power density (initial)

o Average channel	300 cal/cm <sup>3</sup> sec.
o Hot channel	450 "

- (14) temperature in each radial and axial node in  
each channel °C
- (15) average temperatures of fuel, cladding, coolant  
and structure in channel 1 °C

In EXPLOT, title, input data which are necessary for plotting, and calculational values used for plotting as a function of time are printed.

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o Coolant expansion	$-5.0 \times 10^{-6}$ "
o Structure expansion	$-2.0 \times 10^{-6}$ "

### Power density (initial)

o Average channel	300 cal/cm <sup>3</sup> sec.
o Hot channel	450 "

Coolant velocity

o Average channel	5 m/sec
o Hot channel	5.5 "
Inlet coolant temperature	370 °C

Heat transfer equation between cladding and coolant

$$Nu = 0.625 Pe^{0.4}$$

Power distribution

o axial	chopped cosine
o radial	flat

Scram condition

o Power setting	120 %
o Scram delay time	200 msec
o Acceleration rate	9.8 m/sec <sup>2</sup>
o Rod worth	0.033 Δk/k

The physical constant is assumed to be temperature independent in the case. The output is shown in Figures 5~16, and also input and a part of output lists are added in the appendix. Power reaches 120% level of the initial at 0.37 seconds, and control rod insertion by scram starts at 0.57 seconds. The computing time by CDC - 6600 took about 35 seconds in this case (2 channels, 12 axial meshes, 14 radial meshes, physical values not temperature dependent, 500 time steps), except plotting time.

5.2 Loss of Coolant Flow Accident

A sample calculation for a loss-of-coolant flow accident is presented. Most of the input data in the case are the same as those in the former case. The input data concerned with coolant flow and scram condition are as follows:

Coolant flow

$$\frac{v(t)}{v_0} = 0.8 e^{-1.0t} + 0.2 \quad (35)$$

Scram condition

o Coolant flow setting	80 %
o Scram delay time	500 msec
o Acceleration rate	9.8 m/sec <sup>2</sup>
o Rod worth	0.033 Δk/k

In the case the material physical properties are assumed to be temperature dependent.

The output is shown in Figures 17~24. The coolant velocity goes down to 80% at 0.29 seconds and the control rod starts to drop at 0.79 seconds. A part of the output list is presented in the Appendix.

5.3 Hottest Channel Calculation

A sample calculation for the hottest channel is made at the initial value. The following engineering hot channel factors are assumed in the calculation.

o Tolerance in dimension	3 %
o Uncertainty in gap conductance	10 %
o Uncertainty in power level	10 %
o Uncertainty in coolant velocity	5 %
o Uncertainty in film coefficient	5 %

Other calculational conditions are the same as those in the former case. The output is shown in Figures 25~26.

6. REMARKS

The EXCURS programme was developed about 11 years ago<sup>3)</sup> and has been used for the safety analysis of fast reactors as well as kinetics analysis, although it does not contain sodium boiling calculation. The report is published by many requests because the original one was classified report. As the code uses only a small amount of computing time, it is quite convenient to make survey calculations in the design state of fast reactors. The EXCURS is easily extended to a multi-channel model and it is also possible to change the code for core transient behaviour calculation for

Scram condition

o Coolant flow setting	80 %
o Scram delay time	500 msec
o Acceleration rate	9.8 m/sec <sup>2</sup>
o Rod worth	0.033 Δk/k

In the case the material physical properties are assumed to be temperature dependent.

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other types of reactors in changing the coolant heat transfer characteristics. In fact, for instance, the calculational code for the TRIGA-type reactor based on the EXCURS, EXCURS-NSRR<sup>4)</sup>, has been developed.

ACKNOWLEDGMENT

The original EXCURS code was developed more than 10 years ago when the author was involved in the design work of the experimental fast reactor. The author is indebted to Dr. M. Nozawa who was the chief of the fast breeder reactor design laboratory for his encouragement and helpful advice in performing this work.

REFERENCES

- 1) E. R. Cohen, Some Topics in Reactor Kinetics, Proceedings of the Second International Conference on Peaceful Uses of Atomic Energy, Vol.11, 1958.
- 2) L. R. Blue, AIREK-II, NAA-SR-4980.
- 3) S. Saito, et al., Dynamic Analysis of Large Fast Reactor, J. of Nucl. Sci. and Tech., Vol.4, 11, 1957.
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- 3) S. Saito, et al., Dynamic Analysis of Large Fast Reactor, J. of Nucl. Sci. and Tech., Vol.4, 11, 1957.
- 4) S. Saito, Internal Report, 1971.

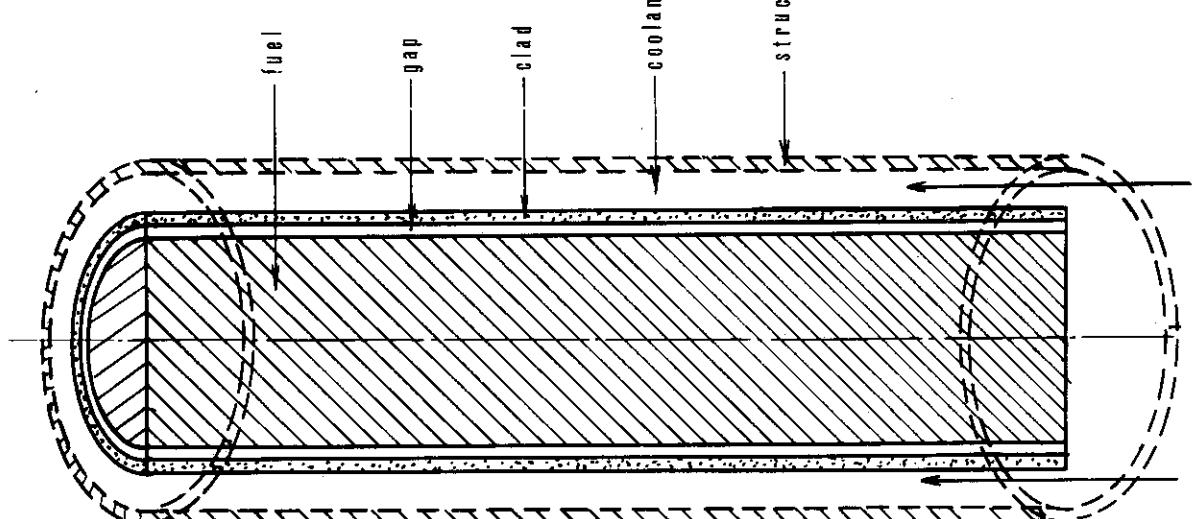


Fig. 1 Layout of equivalent unit cell (no scale)

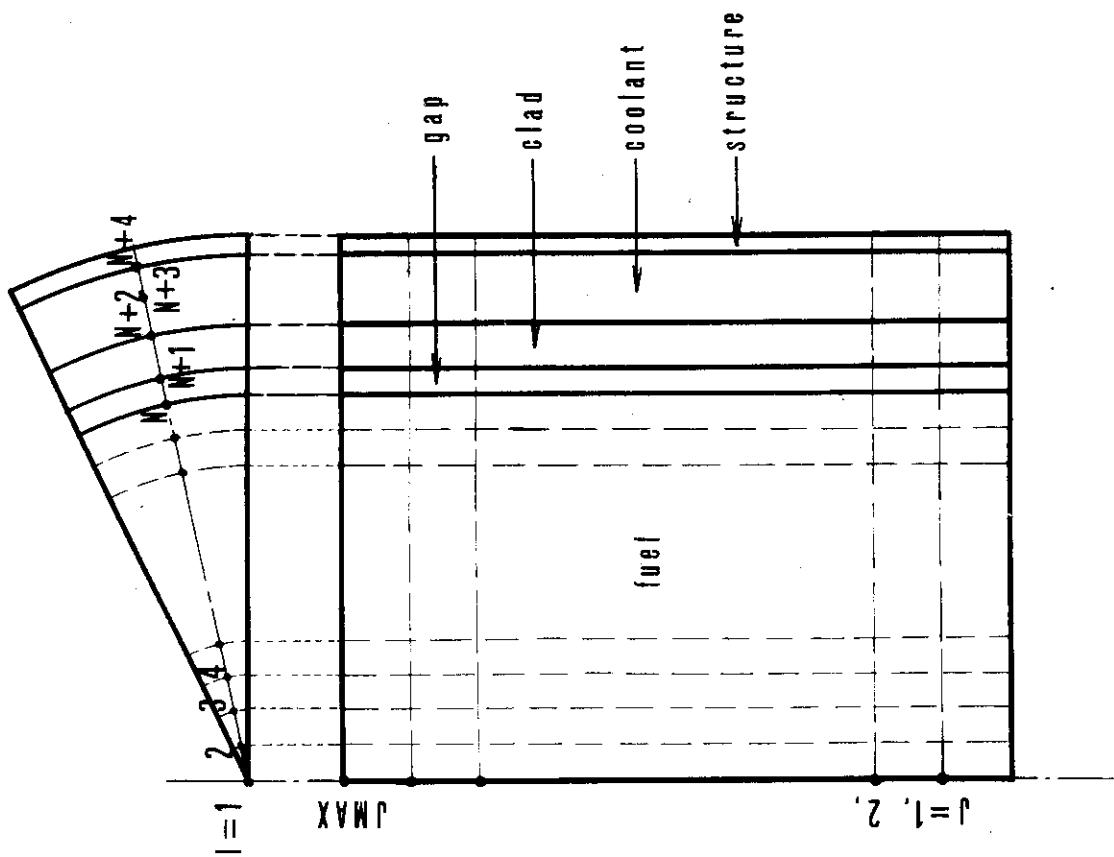


Fig. 2 Radial and axial division in each region

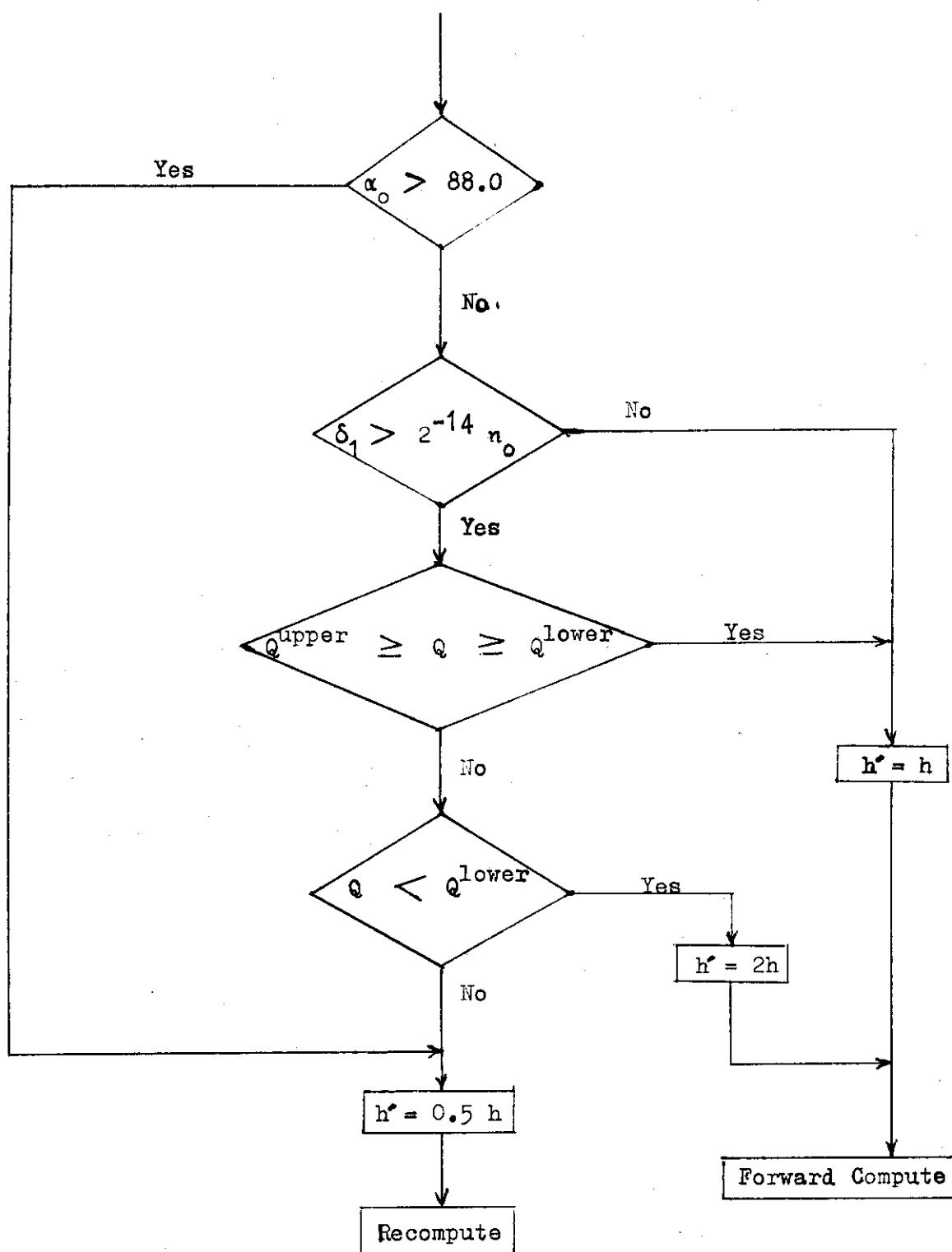


Fig. 3 Method of self-adjusting time interval

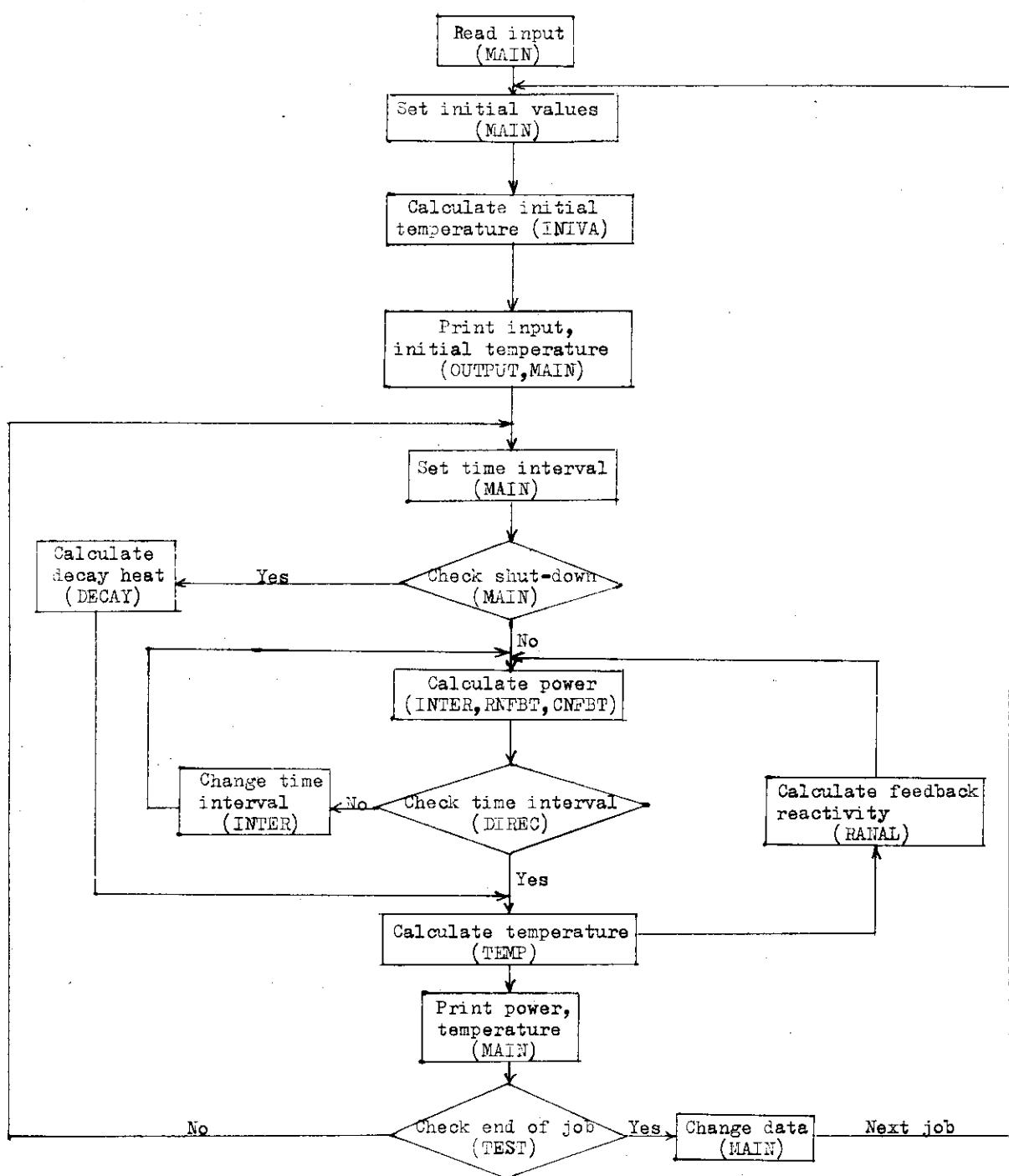


Fig. 4 "EXCURS" flow chart

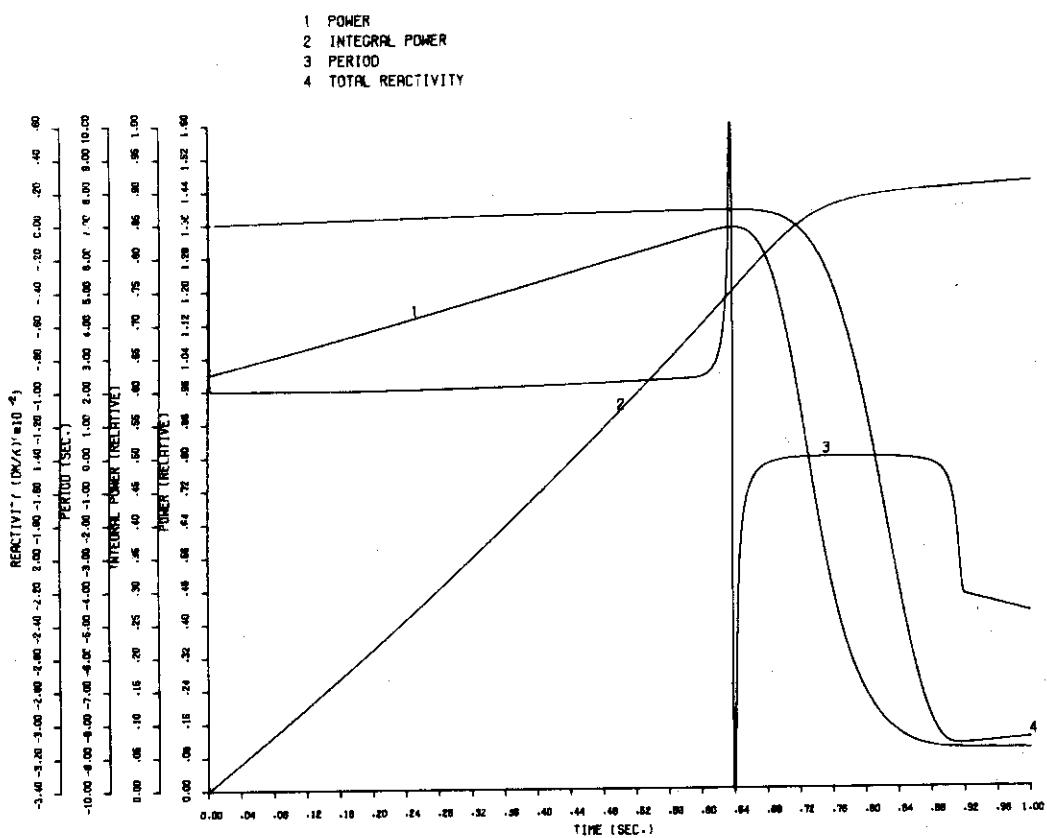


Fig. 5 Reactivity insertion accident (0.5 dollars/sec.)

- 1 POWER  
2 TOTAL REACTIVITY  
3 FEEDBACK REACTIVITY  
4 CONTROL ROD REACTIVITY  
5 INSERTED REACTIVITY

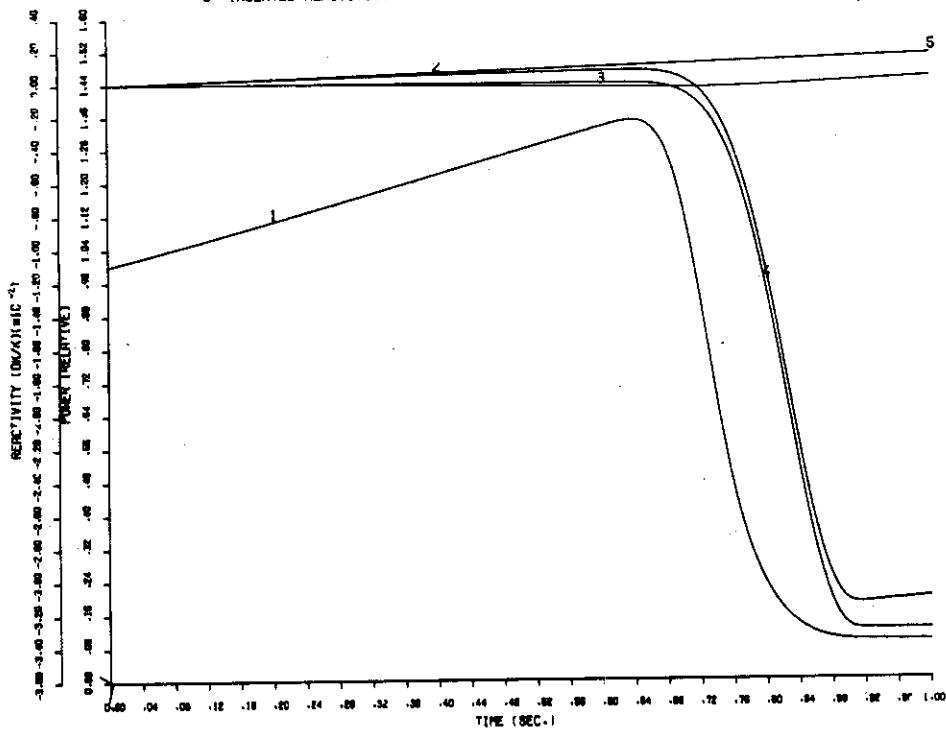


Fig. 6 Reactivity insertion accident (0.5 dollars/sec.)

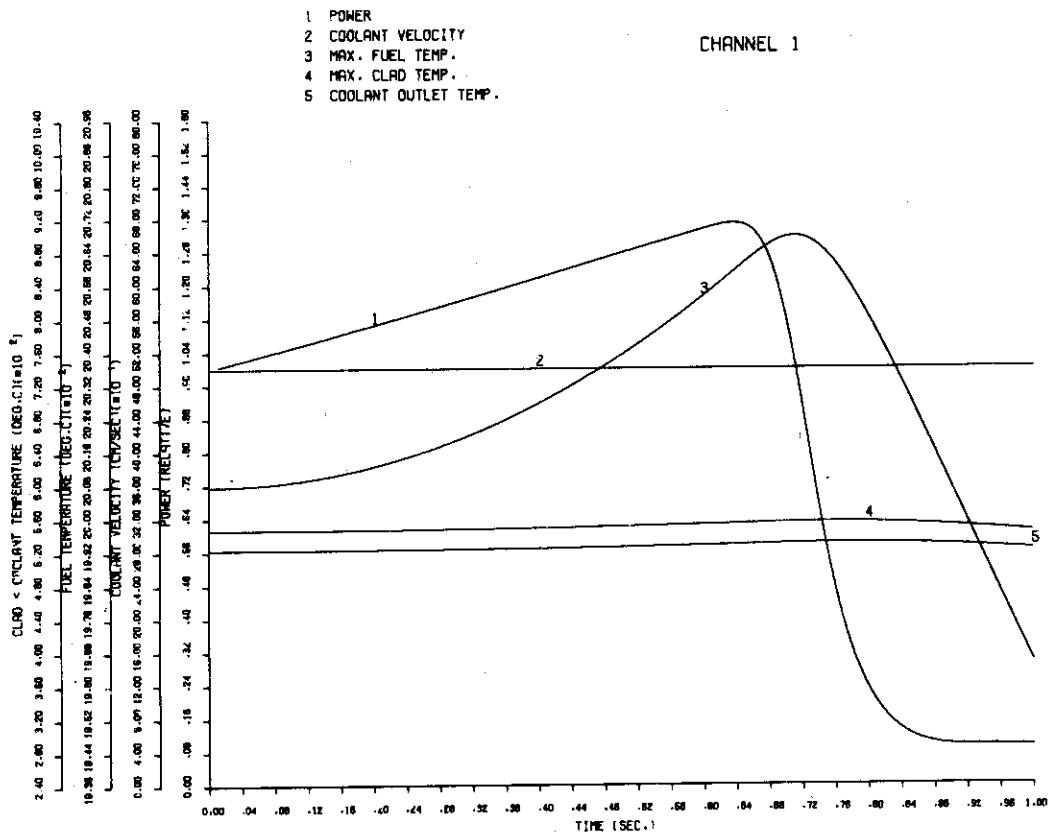


Fig. 7 Reactivity insertion accident (0.5 dollars/sec.)

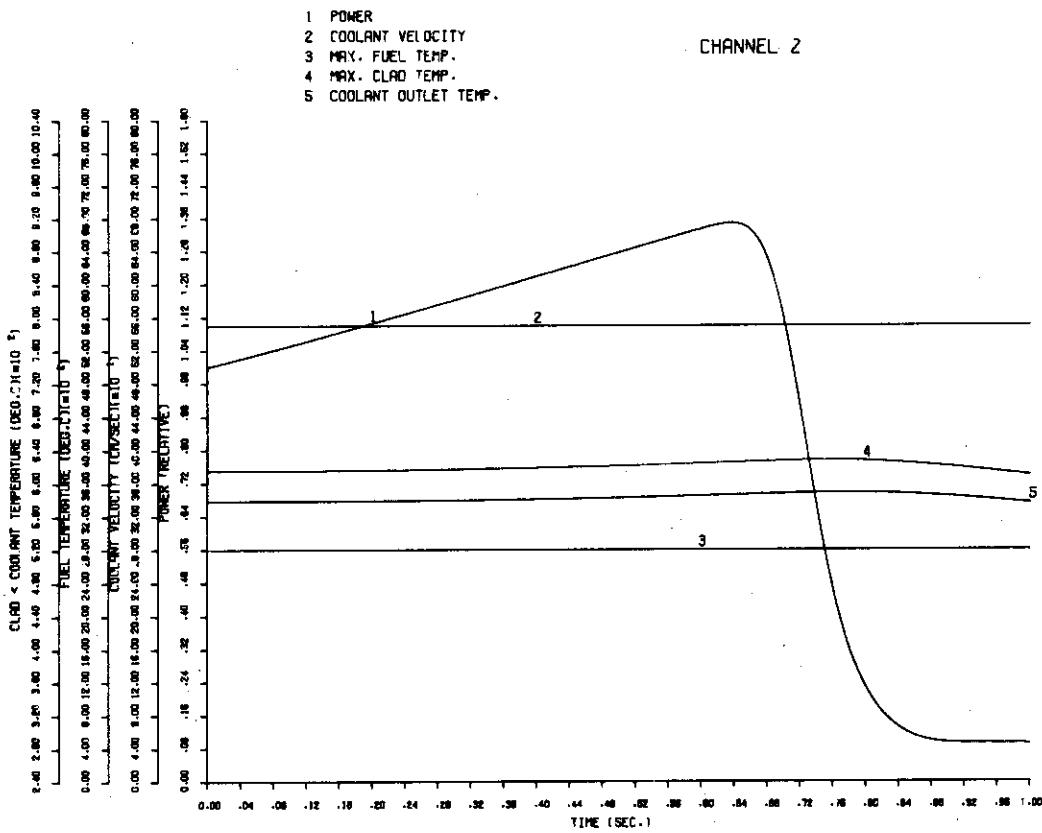


Fig. 8 Reactivity insertion accident (0.5 dollars/sec.)

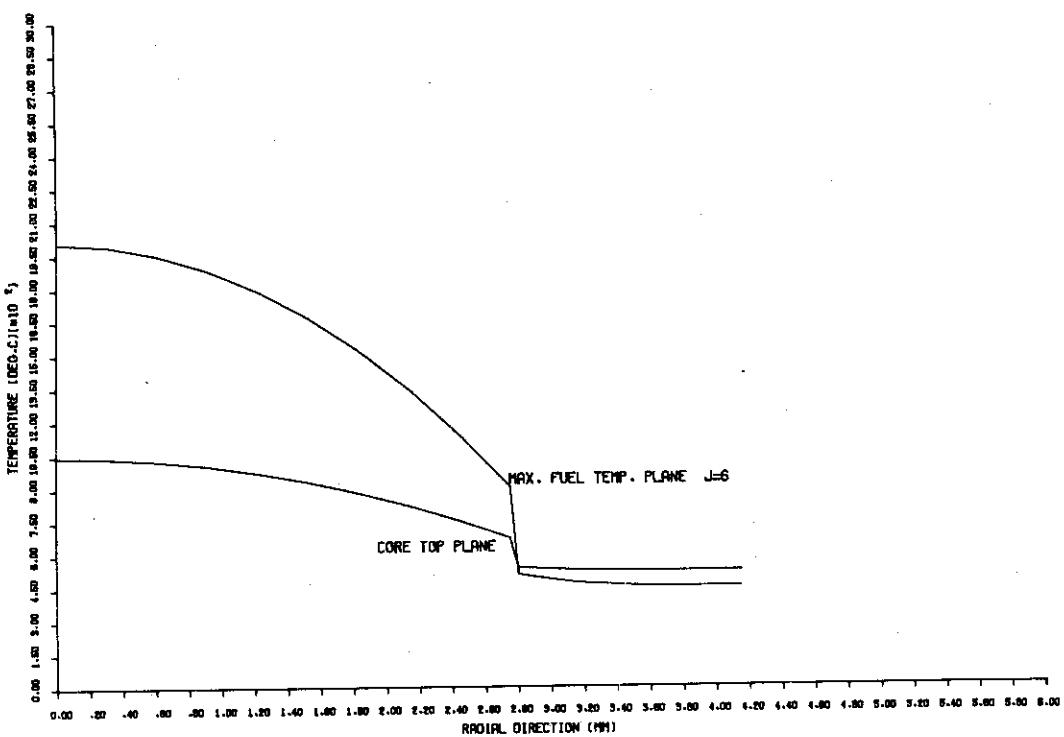


Fig. 9 Reactivity insertion accident (0.5 dollars/sec.)  
Initial temperature distribution of channel 1 (radial)

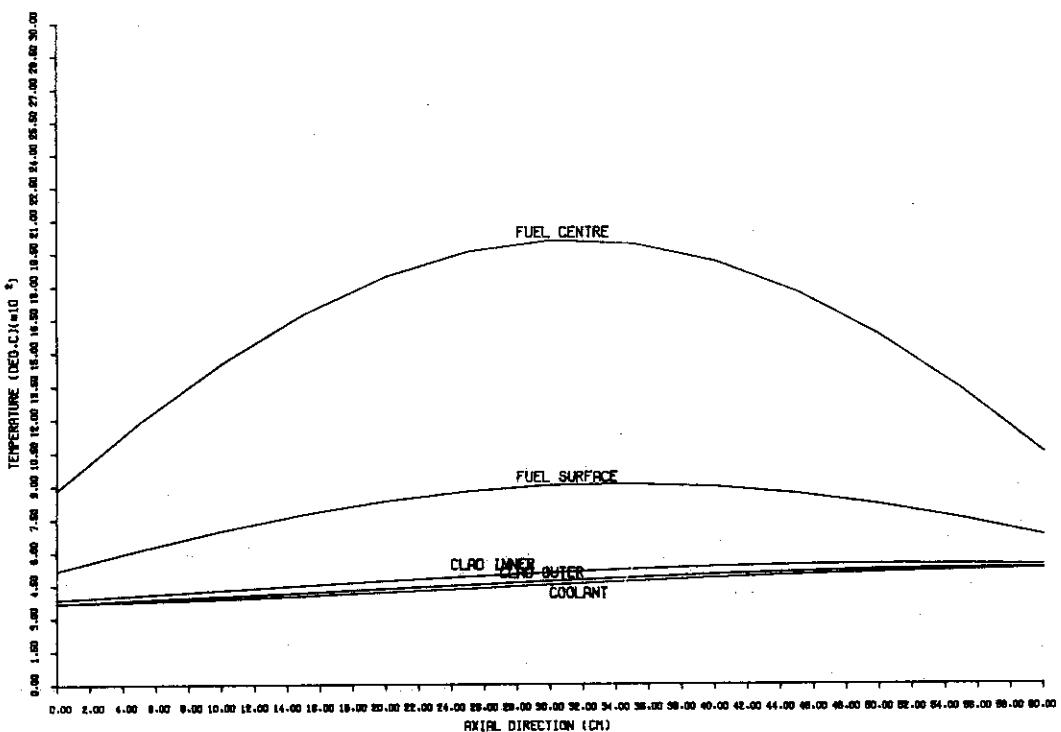


Fig. 10 Reactivity insertion accident (0.5 dollars/sec.)  
Initial temperature distribution of channel 1 (axial)

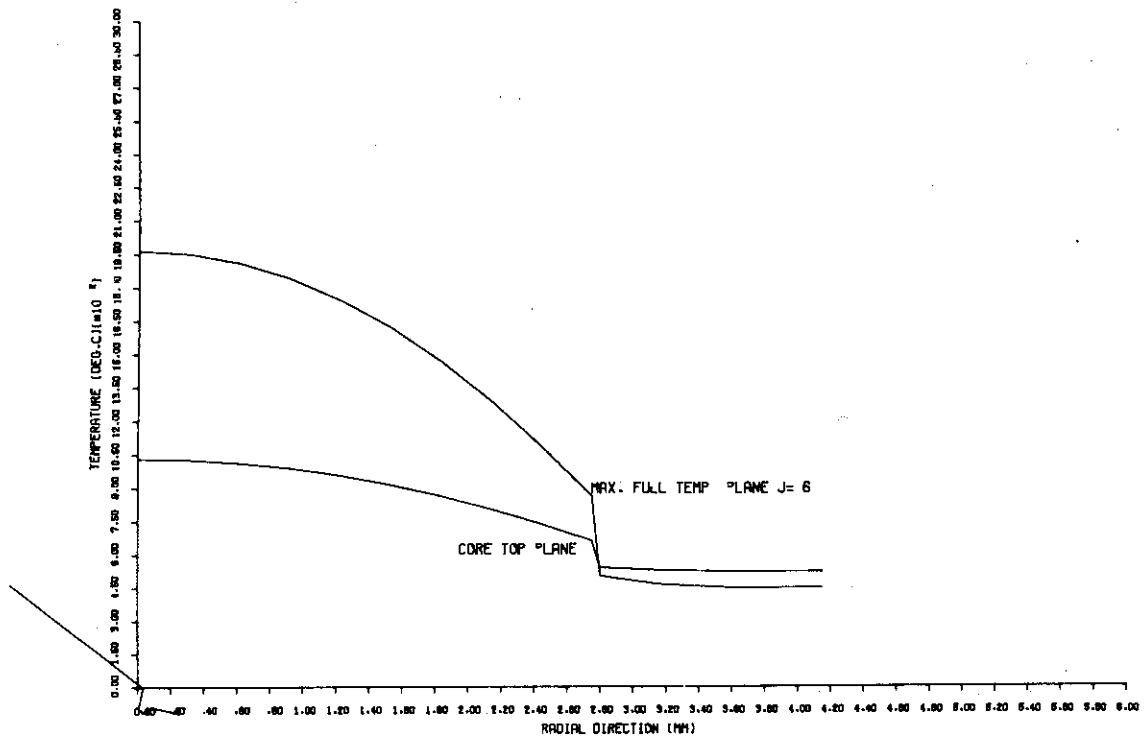


Fig. 11 Reactivity insertion accident (0.5 dollars/sec.)  
Initial temperature distribution of channel 1 (radial)

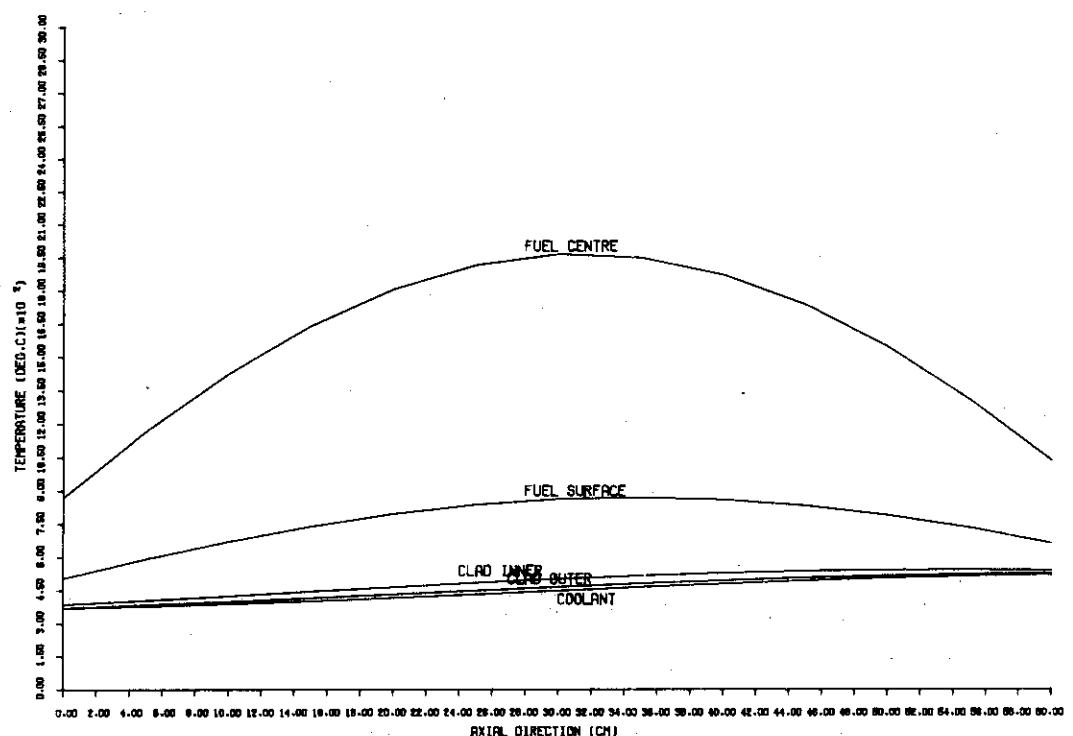


Fig. 12 Reactivity insertion accident (0.5 dollars/sec.)  
Initial temperature distribution of channel 1 (axial)

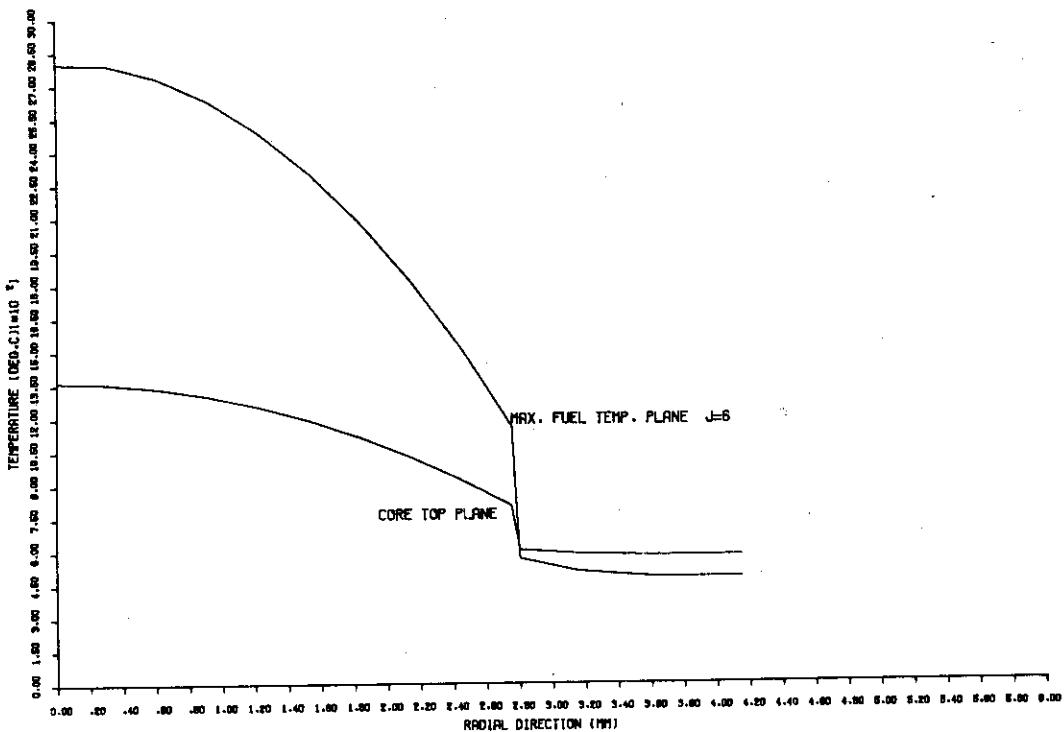


Fig. 13 Reactivity insertion accident (0.5 dollars/sec.)  
Initial temperature distribution of channel 2 (radial)

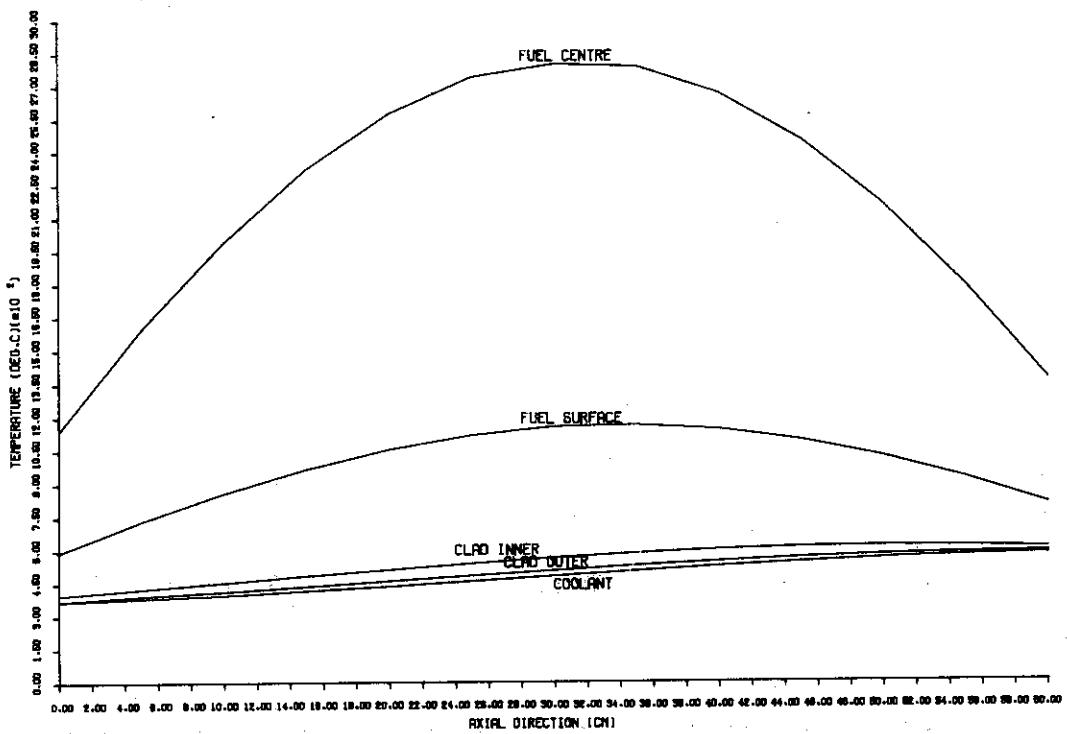


Fig. 14 Reactivity insertion accident (0.5 dollars/sec.)  
Initial temperature distribution of channel 2 (axial)

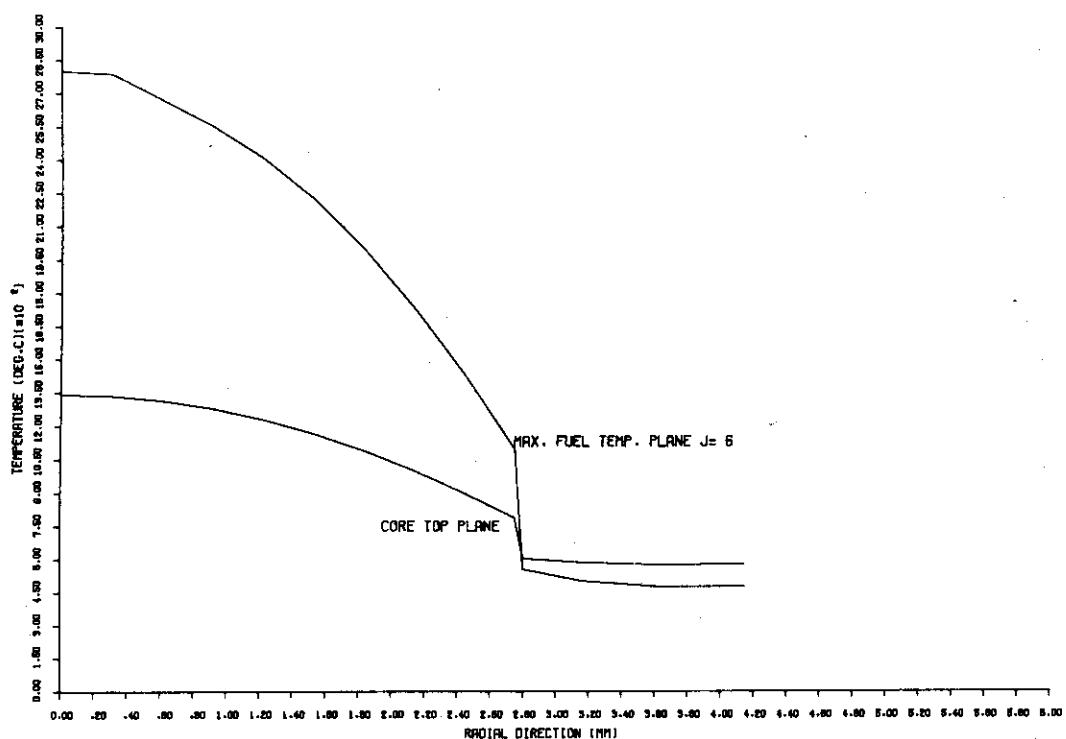


Fig. 15 Reactivity insertion accident (0.5 dollars/sec.)  
Final temperature distribution of channel 2 (radial)

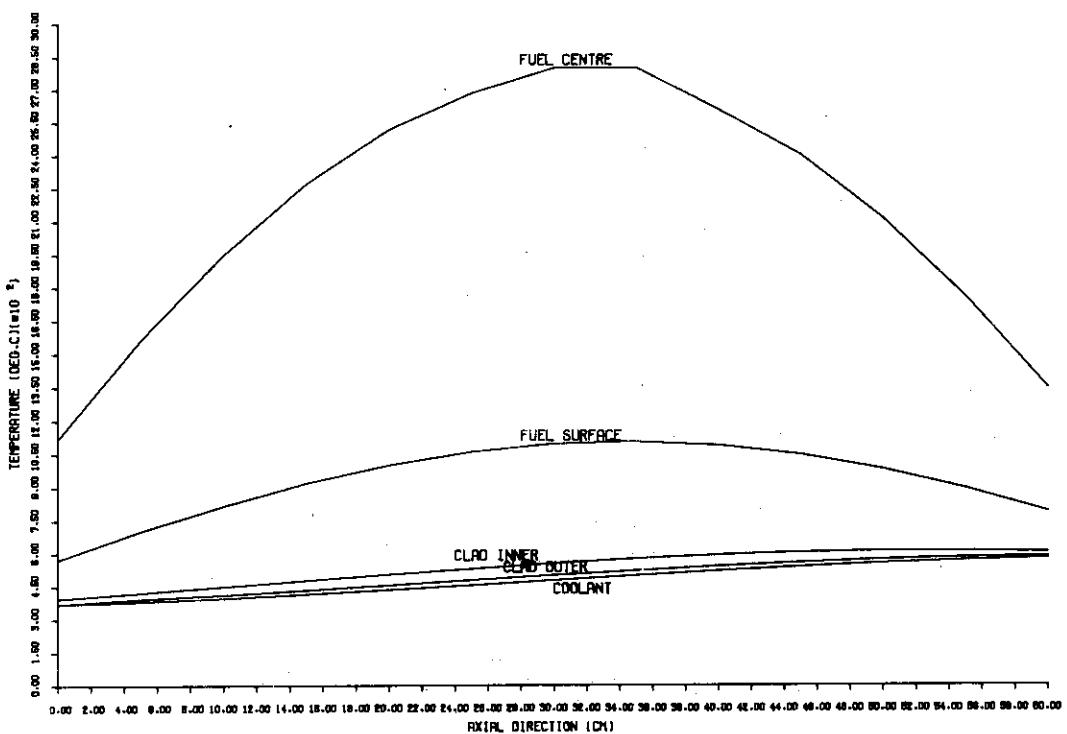


Fig. 16 Reactivity insertion accident (0.5 dollars/sec.)  
Final temperature distribution of channel 2 (axial)

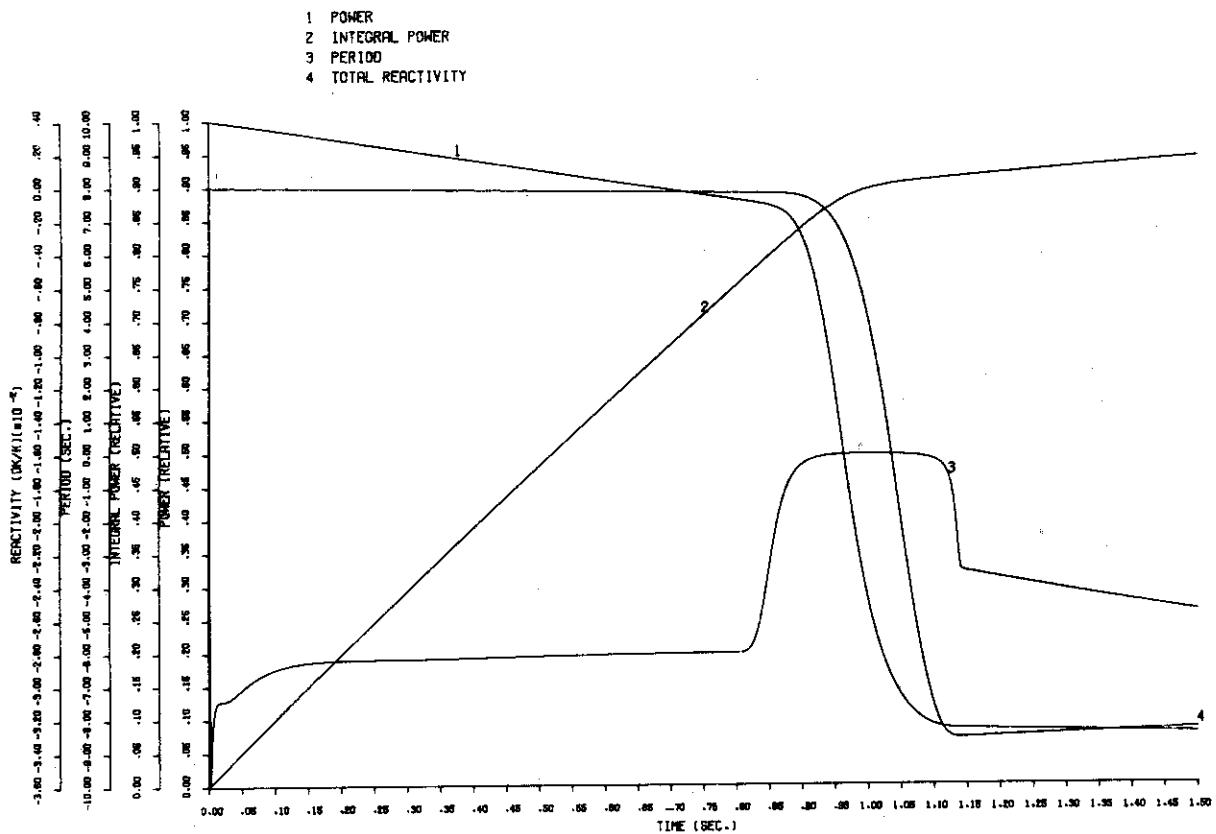


Fig. 17 Loss of cooling flow accident (temp. dependent)

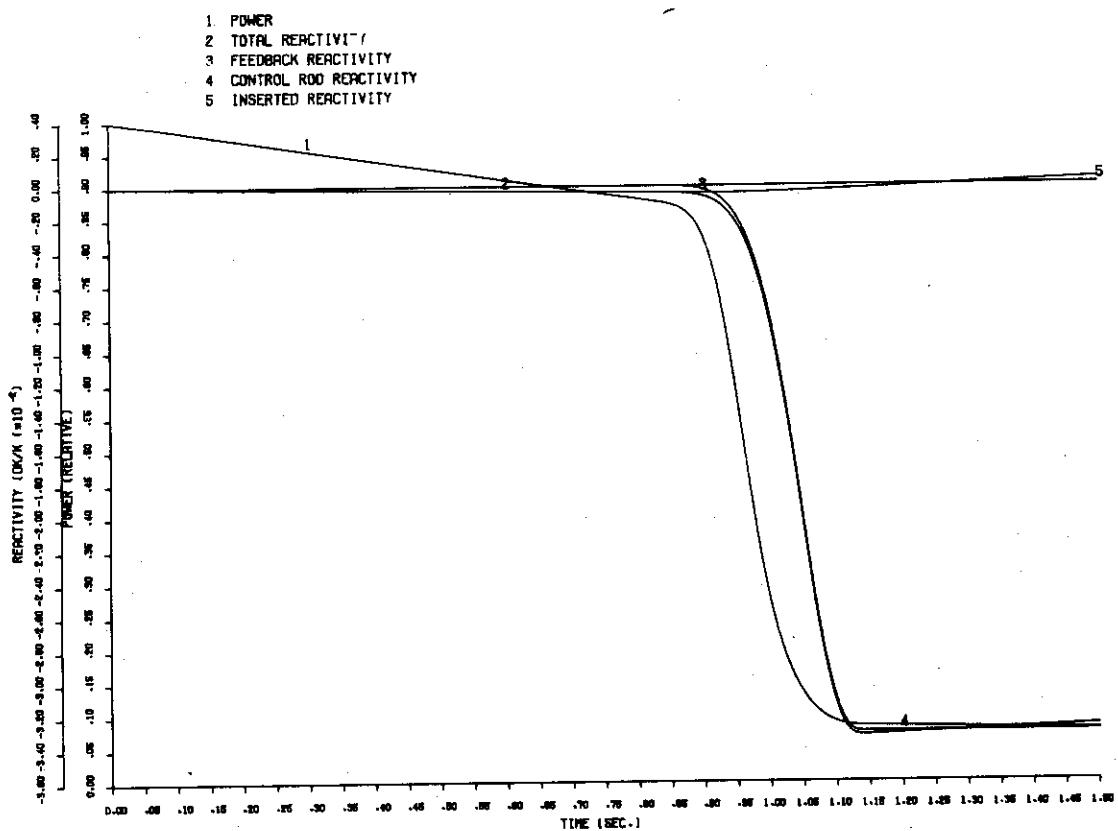


Fig. 18 Loss of coolant flow accident (temp. dependent)

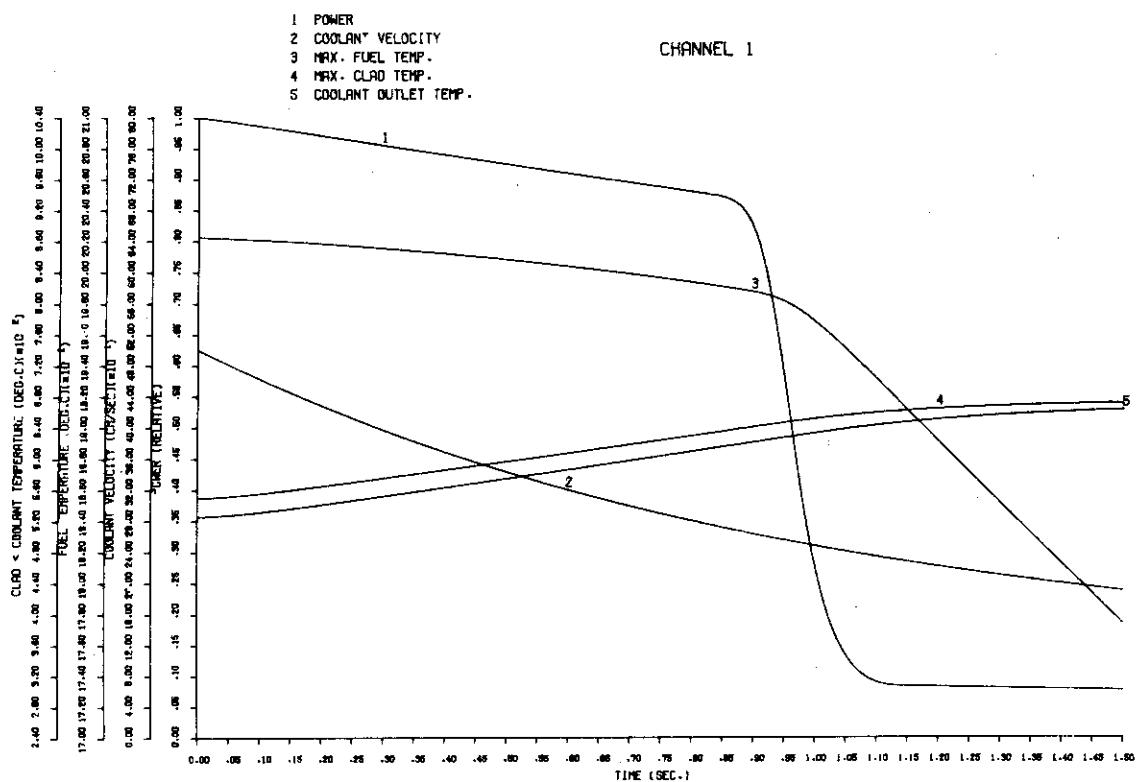


Fig. 19 Loss of coolant flow accident (temp. dependent)

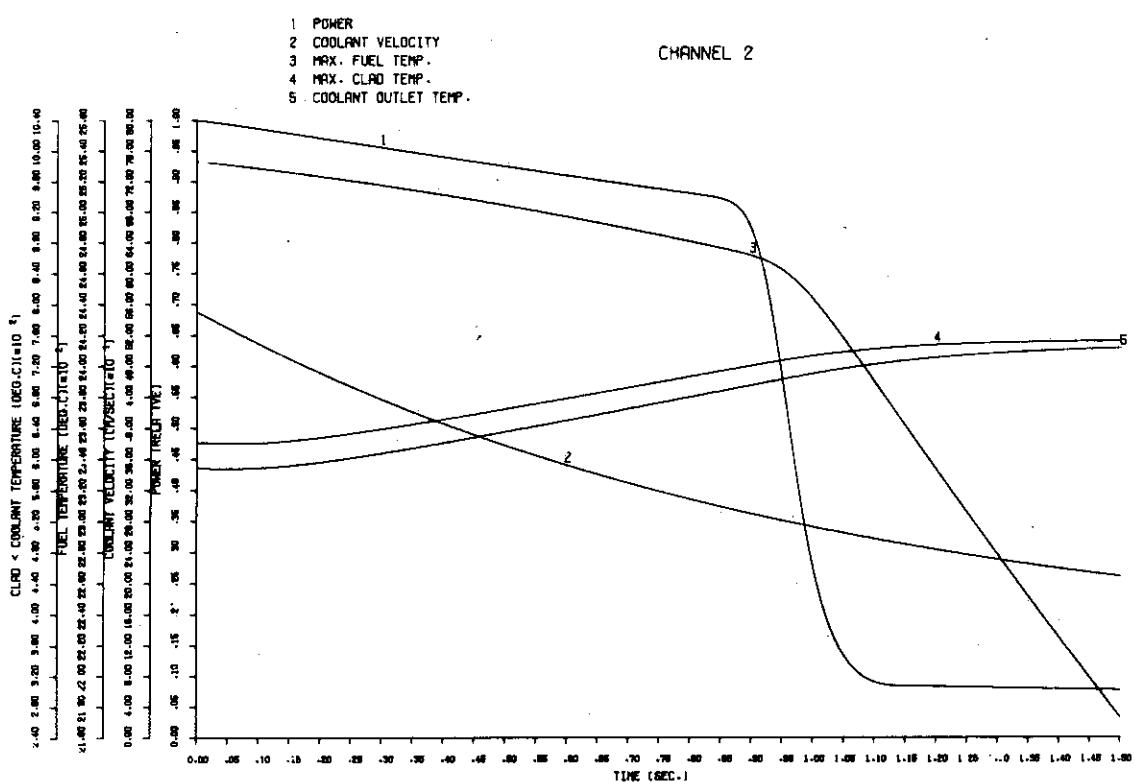


Fig. 20 Loss of coolant flow accident (temp. dependent)

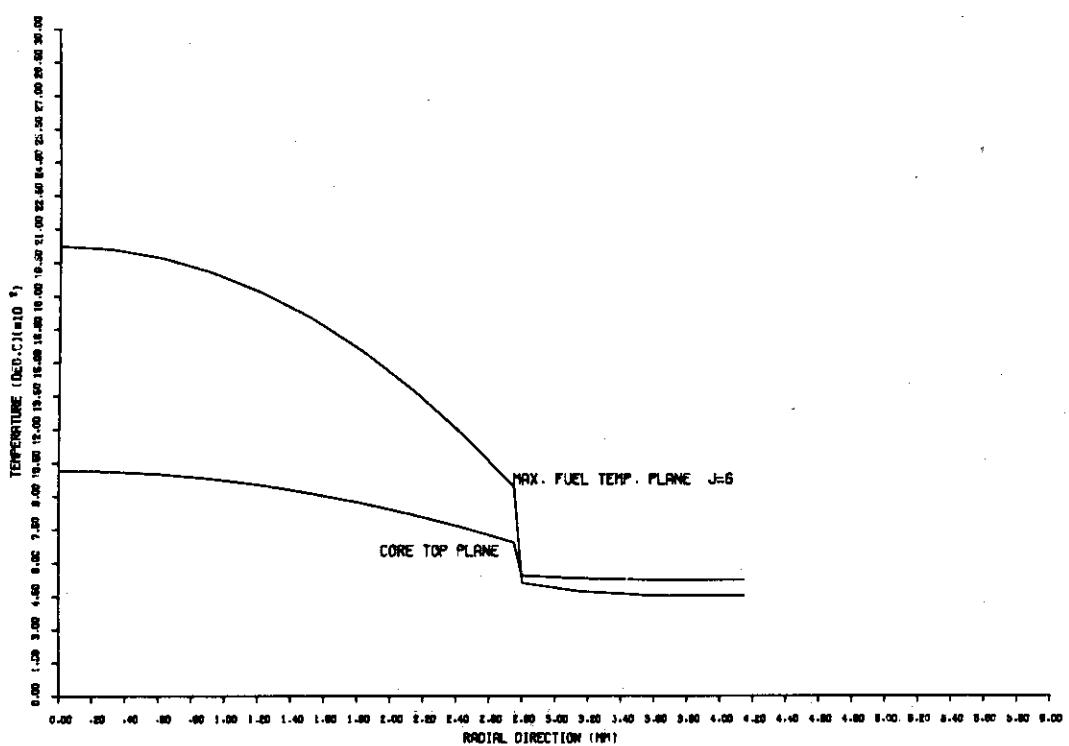


Fig. 21 Loss of coolant flow accident (temp. dependent)  
Initial temperature distribution of channel 1 (radial)

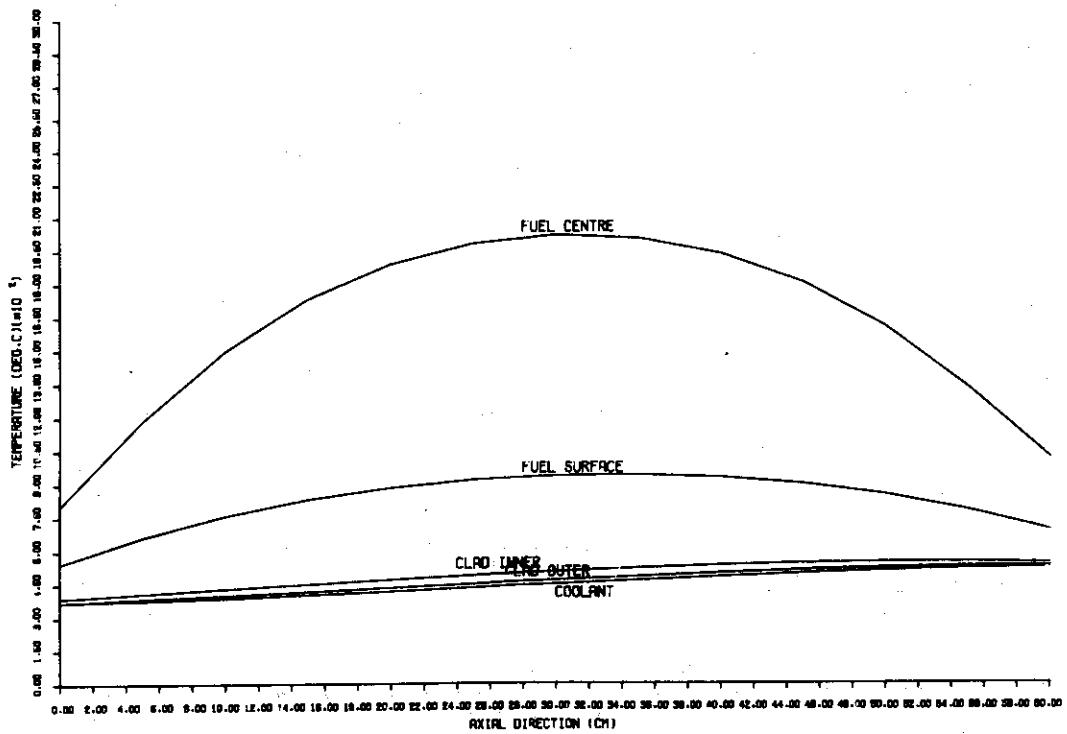


Fig. 22 Loss of coolant flow accident (temp. dependent)  
Initial temperature distribution of channel 1 (axial)

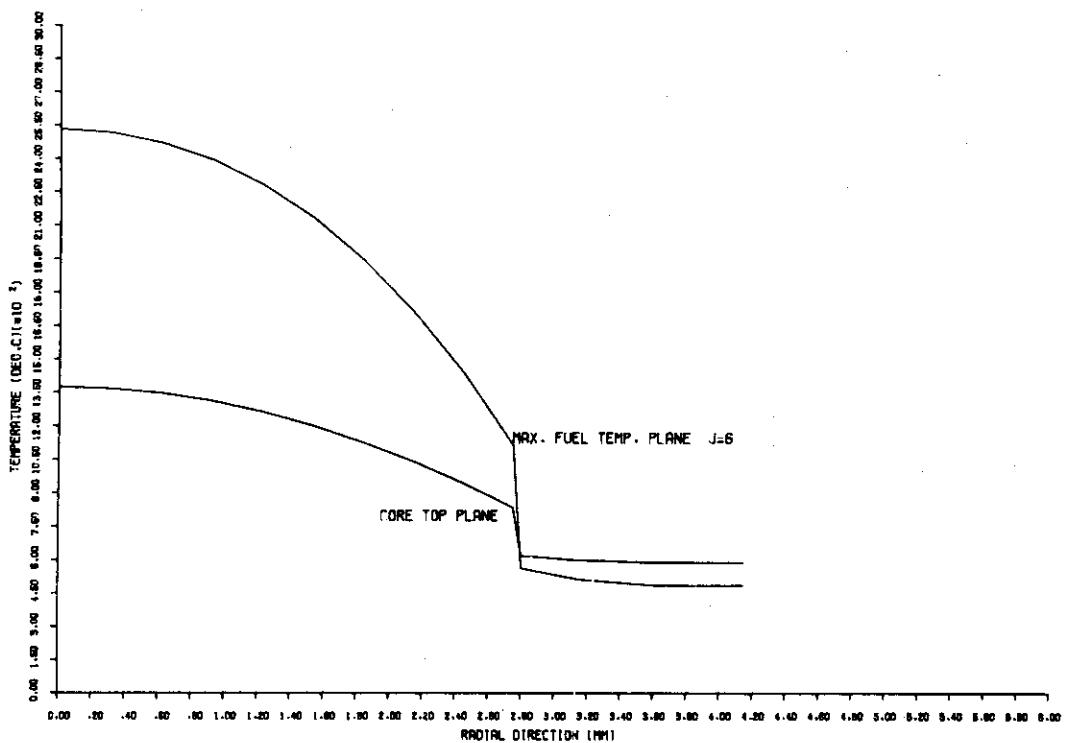


Fig. 23 Loss of coolant flow accident (temp. dependent)  
Initial temperature distribution of channel 2 (radial)

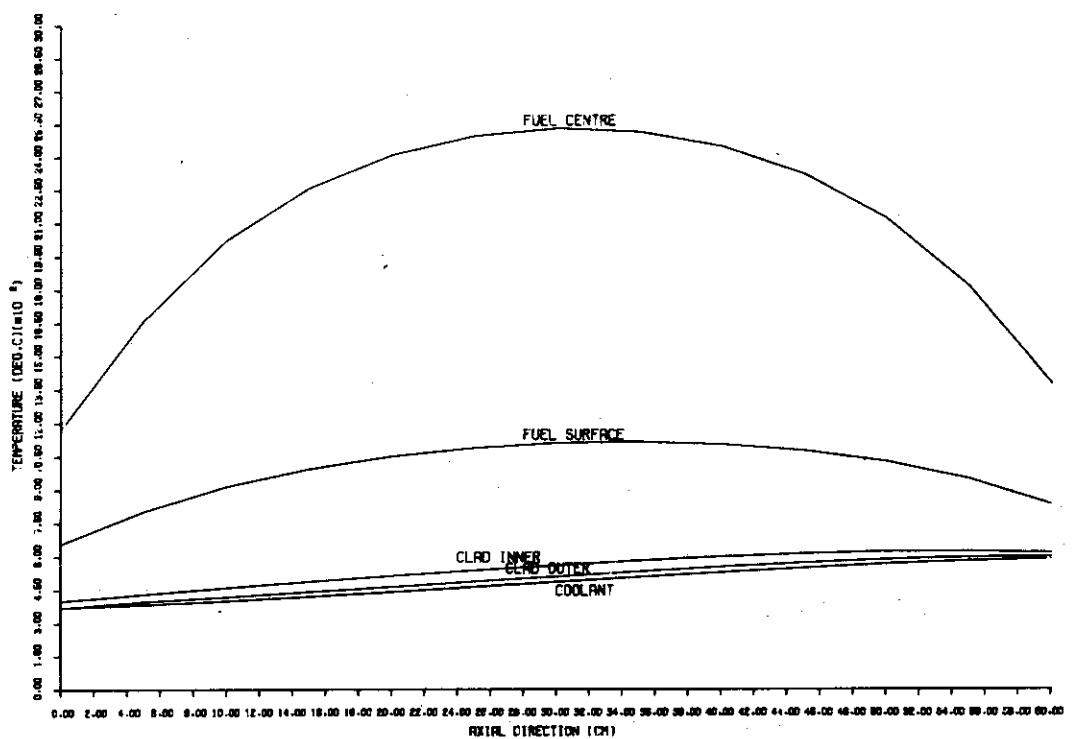


Fig. 24 Loss of coolant flow accident (temp. dependent)  
Initial temperature distribution of channel 2 (axial)

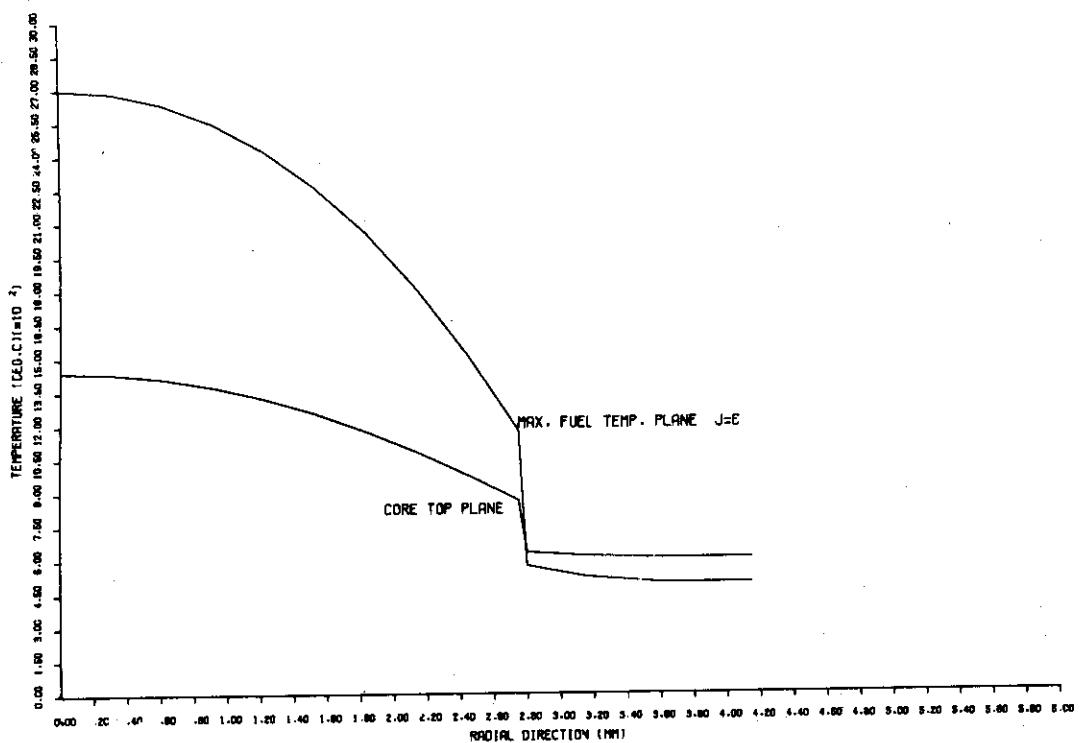


Fig. 25 Hottest channel calculation  
Initial temperature distribution of channel 3 (radial)

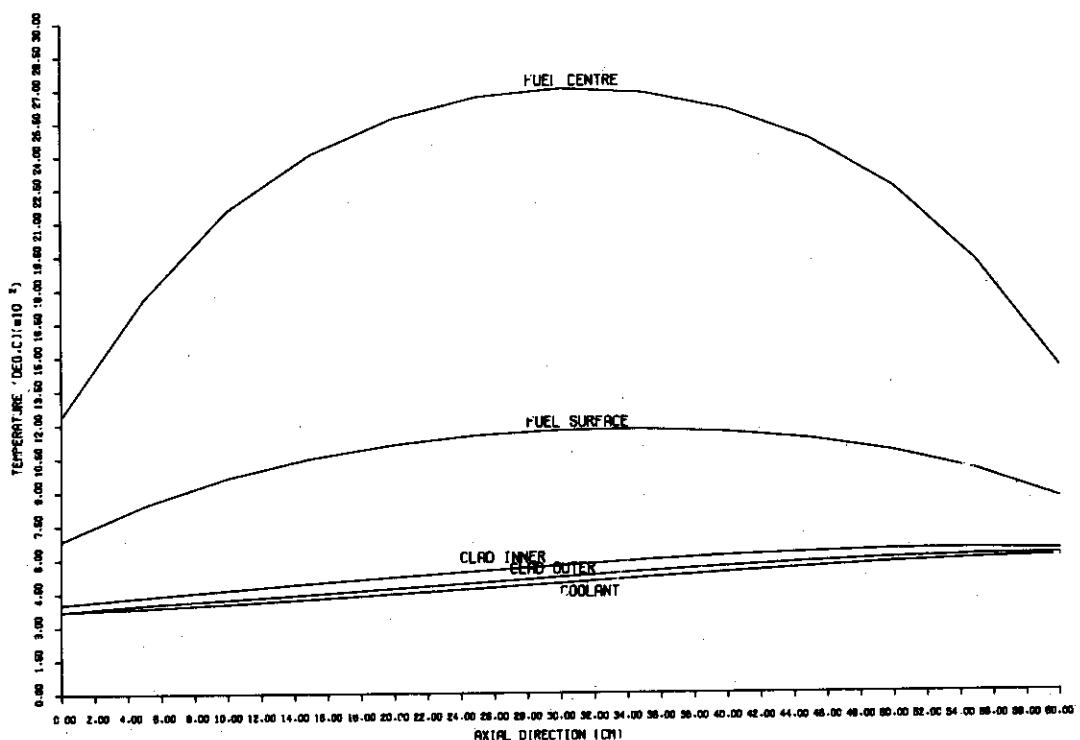


Fig. 26 Hottest channel calculation  
Initial temperature distribution of channel 3 (axial)

Appendix 1

## Input Data Sheet of Sample Calculation on Reactivity Insertion Accident

REACTIVITY INSERTION ACCIDENT ( 0.5 DOLLARS / SEC. )		1973-07-05		
1	1.00	1	1	
0.0	E+00 0.0	E+00 0.2	E-02 0.1	E-02 0.3
0.5	E-01 0.5	E-02 0.33	E-02 0.1	E-06 0.0
0.0	E+00 0.0	E+00 0.1	E+01 0.2	E-02 0.1
0.1	E+01 0.1	E+01 0.1	E+01 0.1	E+01 0.1
0.1	E+01 0.381	E-01 0.2125	E+00 0.1877	E+00 0.4073
0.1 278	E+00 0.261	E-01 0.127	E-01 0.317	E-01 0.1167
0.3 142	E+00 0.14007	E+01 0.38803	E+01 0.01	E+01 0.0
0.0	E+00 0.165	E-02 0.1	E+01 0.1	E+01 0.33
0.6	E+02 0.0	E+00 0.98	E+03 0.12	E+01 0.15
0.2	E+00 -0.5	E-02 -0.4	E-05 -0.5	E-06 -0.5
-0.2	E-05 -0.1	E+01 0.8	E+00 0.5	E+02 0.275
0.2 8	E+00 0.315	E+00 0.498	E+00 0.421	E+00 0.4147
0.6 71	E-02 0.103	E+02 0.82	E-01 0.465	E-01 0.782
0.1 38	E+00 0.165	E+00 0.864	E+00 0.307	E+00 0.465
0.7 82	E+01 0.0138	E+00 0.1356	E+00 0.6	E+02 0.84
0.0	E+00 0.0	E+00 0.0	E+00 0.1	E+01 0.5
0.55	E+03 0.3	E+03 0.45	E+03 0.12	E+02 0.9
0.37	E+03 0.28	E+04 0.0	E+00 0.625	E+00 0.4
0.1	E+02 0.1	E-03 0.2	E+01 0.0	E+00 0.2
0.2 25	E-02 0.5	E+02 0.0	E+00 0.6992	E-01 0.696
2 51	2.80	-1	1	
0.1	E+01 0.25	E+02 -0.1	E+01 0.2	E+02 -0.1
0.2	E+02 -0.1	E+01 0.2	E+02 0.0	E+00 -0.1
0.2	E+02 -0.1	E+02 0.1	E+02 0.2	E+02 0.0
-0.1	E+01 0.2	E+02 0.0	E+00 -0.1	E+01 0.2
0.0	E+00 -0.1	E+01 0.3	E+01 0.3	E+01 0.4
0.3	E+02 0.3	E+02 0.2	E+02 0.0	E+00 0.3

## Appendix 2 Output List of Sample Calculation on Reactivity Insertion Accident

\*\*\*\*\*  
FAST BREEDER REACTOR CORE TRANSIENT CALCULATION CODE  
\*\*\*\*\*

FUEL VELVETING PROCESS CONSIDERED  
\*\*\*\*\*

FOCUS OUTPUT LIST  
\*\*\*\*\*

REACTIVITY INSERTION ACCIDENT ( 3.5 DOLLARS/SEC. ) 1973-07-05  
\*\*\*\*\*

CASE NO. 1 THIS OUTPUT IS AT TIME WRITTEN OUTPUT TO TAPE # 500 MIN.

\*\*\*\*\* EXECUTIVE INPUT \*\*\*\*\*

#### CALCULATIONAL OPTION

NUMBER OF CHANNEL = 2  
TEMP. DEPENDENCE OF PHYSICAL VALUE = NO  
SCRA1 = YES  
CONSTANT VELOCITY CONDITION = -1.03  
CALCULATION TIME IN CODE = 1.000 SEC.

INIT. OMEGA INIT. INTERVAL MIN. INTERVAL MAX. INTERVAL LOWER ACCURACY UPPER ACCURACY  
0. 2.00000E-03 1.00000E-10 3.000000E-03 5.000000E-02 5.000000E-03

INITIAL VALUES OF NEUTRON AND DELAYED NEUTRON PRECURSORS  
1.000000E+01 1.142000E+00 1.00000000E+00

DELAYED NEUTRON FRACTION GROUP-WISE RELATIVE VALUE  
3.91250105E-02 2.125001E-01 1.8770009E-01 4.0740009E-01 1.2780000E-01 2.0100000E-02

DECAY CONSTANTS OF DELAYED NEUTRON PRECURSORS  
1.273036E-02 3.175000E-02 1.167000E-01 3.142000E-01 1.407000E+00 3.0803000E+00

FEEDBACK REACTIVITY COEFFICIENTS  
-5.0000000E-03 4.0000000E-06 -5.0000000E-07 -5.0000000E-06

NO. OF AXIAL, NO. OF FUEL, RADIAL POWER DENSITY1 POWER DENSITY2 COOLANT VEL.1 COOLANT VEL.2 INLET TEMP.  
12 9 3.000000E+02 4.500000E+02 5.000000E+02 5.500000E+02 3.7300000E+32

FUEL PARTUS CLAD INNER RAD. CLAD OUTER RAD. COOLANT PWD. STRUCTURE RAD. EQUIV. RAD. CORE HEIGHT  
2.750000E-01 2.900000E-03 3.1500000E-01 4.0000000E-01 4.2100000E-01 4.1170000E-01 6.0000000E+00

#### MATERIAL PHYSICAL VALUES

	DENSITY	SPECIFIC HEAT
FUEL	6.71600E-03	1.03000E+01
CLAD	4.65000E-02	7.02000E-02
STRUCTURE	1.65000E-01	9.64000E-01
GAP CONDUCTANCE	4.65000E-02	7.02000E+00
FUEL MELTING TEMP.	1.35600E-01	1.35600E-01
SPEC. HEAT OF MOLTEN FUEL	2.40000E+03	1.99000E-02
LATENT HEAT OF FUEL	6.96100E-01	6.96100E-01

HFM TRANSFER COEFFICIENT BETWEEN CLAD AND COOLANT  
HFM = 0. + 6.250E-01 \* (P1) \* 4.0000E-01

EXTERNAL REACTIVITY INSERTION CONDITION  
STEP DFAC. 2A/P DFAC.  
0. 0. 1.650000E-03 1.0300000E+03

COOLANT VELOCITY CHANGE  
VVEL= 0. + EXP(-J. \* T) + G. \* T + 1.0300E+03





4	1774	47729	1555	46595	512	4214	461	16394	436	6940
5	1963	5654	1115	2572	549	1531	485	5497	458	9132
6	1556	5162	1156	5126	565	5065	529	5356	481	6013
7	1375	9695	1166	177	565	9231	503	8166	503	8166
8	1462	7344	1143	4415	666	5667	549	9353	524	6328
9	1378	1343	1396	5769	511	0157	566	9959	563	1823
10	1259	4612	1219	7143	613	4059	576	4178	558	5917
11	1277	3263	421	4554	613	7651	586	4638	570	5146
12	4122	6164	455	3617	656	1206	587	1402	578	1540

PERCENT TRANSMISSION OF CHANNEL 1			
FUEL	CLAD	ECOLAN	STRUCTURE
220.52%	684.24%	456.24%	456.24%

	T( 1,J,1)	T( 2,J,1)	T( 3,J,1)	T( 4,J,1)	T( 5,J,1)	T( 6,J,1)	T( 7,J,1)	T( 8,J,1)	T( 9,J,1)
1	11.64, 4.77	11.32, 7.575	11.64, 5.147	11.25, 4.566	11.75, 6.693	10.11, 6.548	9.33, 4.160	9.40, 4.920	9.96, 4.738
2	14.57, 6.612	14.64, 7.549	13.61, 6.932	13.64, 3.790	12.20, 4.018	11.17, 7.58	11.28, 9.445	12.76, 6.160	12.32, 86.19
3	17.75, 6.725	16.84, 5.671	15.25, 5.187	15.25, 2.029	13.96, 7.686	12.76, 6.160	12.32, 86.19	13.95, 6.413	13.03, 83.88
4	23.42, 6.714	23.33, 6.737	17.88, 3.792	17.83, 7.631	16.46, 1.619	15.33, 3.946	14.77, 5.754	14.77, 5.867	14.77, 5.867
5	1.64, 3.734	1.64, 3.734	1.42, 4.246	1.43, 4.213	1.74, 4.887	1.62, 4.887	1.51, 4.027	1.33, 6.760	1.33, 6.760
6	2.62, 7.735	1.64, 3.734	1.35, 1.759	1.88, 3.314	1.79, 3.860	1.66, 5.435	1.51, 5.017	1.33, 6.760	1.29, 32.771
7	4.64, 6.724	4.77, 6.747	4.97, 1.740	4.31, 3.516	4.77, 7.986	4.65, 5.845	4.65, 1.271	4.65, 1.271	4.65, 1.271
8	4.54, 6.735	4.92, 6.735	4.65, 9.642	4.74, 2.455	4.71, 5.378	4.59, 1.230	4.36, 3.701	4.22, 22.96	4.14, 39.645
9	4.74, 6.735	4.75, 6.747	4.75, 6.747	4.63, 6.726	4.56, 5.571	4.56, 1.230	4.36, 3.701	4.22, 22.96	4.14, 39.645
0	4.57, 6.727	4.57, 6.727	4.56, 6.755	4.68, 6.231	4.62, 7.327	4.38, 7.327	4.23, 6.105	4.14, 39.645	4.06, 7.327
1	4.79, 6.749	4.32, 7.323	4.29, 4.795	4.26, 3.743	4.24, 6.430	4.15, 6.294	4.07, 7.936	4.07, 7.936	4.07, 7.936
2	4.34, 6.2263	4.74, 2.2263	4.02, 4.345	4.05, 4.432	4.73, 2.553	4.91, 8.788	4.81, 2.898	4.21, 51.23	4.21, 51.23

T( 1,J,2)	T( 2,J,2)	T( 3,J,2)	T( 4,J,2)	T( 5,J,2)	T( 6,J,2)	T( 7,J,2)	T( 8,J,2)
1597.4477	1546.1144	1554.4973	1501.4627	1422.7423	1350.7600	1213.4018	1074.7028
1922.3592	1973.1623	1935.3752	1865.0968	1768.1269	1642.1657	1498.2131	1306.2691
2392.7674	2356.1544	2354.8551	2301.9469	2155.6422	2276.5324	1904.7179	1720.5937
2742.7491	2723.0561	2652.9511	2562.7251	2422.3972	2211.9742	1760.8463	1656.6415
3142.7495	2732.9779	2732.5568	2636.1961	2483.8826	2312.6190	2077.4678	1811.2493
3542.7497	2754.4565	2752.9548	2631.7524	2467.3904	2216.7773	2066.3668	1795.7498
3942.7495	2764.3565	2759.8924	2495.9596	2365.4078	2195.4068	1989.7768	1744.5777

9	245.4698	2397.5347	7292.9435	2442.6704	2032.0192	1947.8899
10	2157.4187	2139.6229	2097.4358	2077.4573	1929.4697	1669.5733
11	1784.3185	1775.5271	1743.5003	1690.1556	1615.4731	1514.4527
12	1364.3765	1357.1702	1336.4963	1301.9999	1253.7180	1115.7598
J	T(1,J,2)	T(1,J,2)	T(1,J,2)	T(1,J,2)	T(1,J,2)	T(1,J,2)
1	314.6716	733.5078	425.5597	306.7160	781.9229	781.9229
2	1296.3215	954.6135	454.5512	415.5587	391.3324	391.3323
3	1361.6916	357.7298	693.7143	477.6928	415.8919	415.8918
4	1374.8711	1155.4524	512.3252	461.1639	436.5991	436.5991
5	1452.1612	1149.3316	540.4955	524.2642	481.9134	458.9133
6	1456.4624	1150.3706	568.5732	508.2641	481.9015	431.6314
7	1553.4547	1154.4740	594.5640	539.9236	507.8168	507.8167
8	1462.4621	1149.3674	520.5530	509.6358	524.6330	524.6329
9	1373.1040	1196.4206	511.2189	564.9814	543.1824	543.1824
10	1367.4635	1319.7544	615.2107	575.4182	558.6919	558.6919
11	1153.7542	921.0849	613.7515	534.4096	570.5147	570.5146
12	122.8614	495.2469	606.4184	587.1404	578.1581	578.1580

AUGMENTED TRANSPORTATION OF CHANNEL 1

CONSTANT STRUCTURE

CONSTANT

STRUCTURE

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NU TIME IN SEC. TIME INTERVAL REACTIVITY PRT-INVERSE PER. NEUTRON FLUX - DELTA FL. INTEG.  
 20 4.001E+01 0.001E+02 2.1000E+02 6.5005406E+05 5.189049520E+01 5.12270764E+01 1.02025426E+00 4.044239826E+02

CONCENTRATION OF EACH ROWS OF RELATED ELEMENT PRECIPITATES

1.02025426E+01 4.044239826E+02 1.02025426E+03 1.02025426E+04 1.02025426E+05 1.02025426E+06 1.02025426E+07 1.02025426E+08

FREQ BACK REAC. RND REAC. CONSTANT VEL.(1) CONSTANT VFL.(2)  
 -9.04530101E+07 2.04530101E+07 5.030059303E+02 5.030059303E+02

K=1

1	T(1,J,1)	T(2,J,1)	T(3,J,1)	T(4,J,1)	T(5,J,1)	T(6,J,1)	T(7,J,1)	T(8,J,1)
2	1163.4659	1482.4633	1616.4639	1535.5381	1075.7441	1611.7356	935.4918	946.5918
3	1467.4654	1464.4352	1531.3236	1363.3746	1304.4784	1220.0343	1117.8592	996.5731
4	1673.9716	1554.7126	1631.2316	1575.4373	1497.3218	1395.8977	1274.4349	1120.5635
5	1465.4639	1464.5164	1505.5164	1733.2345	1646.2353	1533.2331	1395.7477	1232.7752
6	1375.9457	1195.4910	1135.3871	1938.5631	1745.8111	1624.4291	1477.7178	1363.3771
7	2.077.6120	1324.4658	1352.3214	1995.6795	1789.5314	1666.6890	1516.5482	1339.4039
8	1.961.7755	1973.4156	1838.3164	1777.4631	1777.4934	1657.6584	1510.4671	1336.9363
9	1.214.5434	1.474.5667	1962.9975	1793.3325	1710.7212	1593.0159	1363.2605	1297.6510
10	1.758.7757	1.754.6563	1724.5943	1554.7815	1540.5781	1490.2019	1267.8840	1222.4174
11	1.137.4564	1.166.7753	1534.7753	1428.8125	1422.8033	1338.8151	1236.2500	1114.9238
12	1.177.4564	1.162.4725	1260.4725	1263.9371	1214.4152	1151.4152	1071.3653	979.4622
13	1.163.4576	1.142.6783	1224.6485	1165.6922	973.5303	931.3138	921.3748	921.3513

k=2

REACTIVITY INSERTION ACCIDENT (0.5 DOLLARS/SEC.) 1973-07-05

NUMBER OF CHANNEL = 2  
 NUMBER OF AXIAL POINT = 12  
 NUMBER OF FUEL POINT = 12  
 NUMBER OF CLAD POINT = 12  
 MAX. FUEL TEMP. POINT (J) = 6  
 MAX. CLAD TEMP. POINT (J) = 10  
 MAX. PLATE TEMP. POINT (J) = 10

CHANNEL DIRECTION (C4)  
 FUEL PT# 960. CLAD INNER RAD. .4150  
 .2750 CLAD OUTER RAD. .4060  
 .2916 COOLANT RAD. .4210  
 .3150 STRUCTURE RAD. .60.00030

## PLOTTED PARAMETERS

PLOTTING OPTION	LENGTH IN TIME AXIS	MAXIMUM TIME	LENGTH IN POWER AXIS	MAXIMUM POWER
1.0	25.0	-1.0	20.0	-1.0
LENGTH IN TIME, POWER, INTG. POWER	20.0	0.0	MIN. REACTIVITY	MAX. REACTIVITY
20.0	-1.0	20.0	0.0	-1.0
LENGTH IN POSITION AXIS	MIN. PERIOD	MAX. PERIOD	LENGTH IN FUEL TEMP. AXIS	MIN. FUEL TEMP.
20.0	-10.0	10.0	20.0	0.0
MAX. FUEL TEMP.	LENGTH IN COOLANT TEMP.	MAX. COOLANT TEMP.	LENGTH IN VELOCITY AXIS	
-1.0	20.0	0.0	-1.0	
MIN. VELOCITY	MAX. VELOCITY	TEMP. DIST. OPTION	PLOTTED STATE	PLOTTED CHANNEL
0.0	-1.0	3.0	3.0	4.0
LENGTH IN AXIAL AXIS	LENGTH IN PANTAL AXIS	LENGTH IN TEMP. AXIS	MIN. TEMPERATURE	MAX. TEMPERATURE
30.0	30.0	20.0	0.0	3000.0

TIME IN SEC.	POWER (W.E.)	INTEN.	PWR	PERIOD IN SEC.	TOTAL REAC.	FEED BACK REAC.	RDD REAC.	INSERTED REAC.
1.00000E+00	2.029497E-03	5.30000E-06	-0.0	1.00000E+30	3.30000E-06	-0.0	-0.0	3.30000E-06
1.00000E+00	4.3395E-03	6.59494E-06	-0.0	1.00000E+30	6.59494E-06	-0.0	-0.0	6.59494E-06
1.00000E+00	1.002490E-02	9.99449E-06	-0.0	1.00000E+30	9.99449E-06	-0.0	-0.0	9.99449E-06
1.00000E+00	9.0591E-03	1.31639E-05	-0.0	1.00000E+30	1.31639E-05	-0.0	-0.0	1.31639E-05
1.00000E+00	1.09593E-02	1.64481E-05	-0.0	1.00000E+30	1.64481E-05	-0.0	-0.0	1.64481E-05
1.00000E+00	1.26154E-02	2.12912E-05	-0.0	1.00000E+30	2.12912E-05	-0.0	-0.0	2.12912E-05
1.00000E+00	1.46673E-02	2.79932E-05	-0.0	1.00000E+30	2.79932E-05	-0.0	-0.0	2.79932E-05
1.00000E+00	1.60661E-02	3.57252E-05	-0.0	1.00000E+30	3.57252E-05	-0.0	-0.0	3.57252E-05
1.00000E+00	1.80151E-02	4.48151E-05	-0.0	1.00000E+30	4.48151E-05	-0.0	-0.0	4.48151E-05
1.00000E+00	2.02151E-02	5.52753E-05	-0.0	1.00000E+30	5.52753E-05	-0.0	-0.0	5.52753E-05
1.00000E+00	2.24217E-02	6.65013E-05	-0.0	1.00000E+30	6.65013E-05	-0.0	-0.0	6.65013E-05
1.00000E+00	2.41644E-02	7.9239E-05	-0.0	1.00000E+30	7.9239E-05	-0.0	-0.0	7.9239E-05
1.00000E+00	2.61866E-02	9.29194E-05	-0.0	1.00000E+30	9.29194E-05	-0.0	-0.0	9.29194E-05
1.00000E+00	2.84131E-02	1.06151E-02	-0.0	1.00000E+30	1.06151E-02	-0.0	-0.0	1.06151E-02
1.00000E+00	3.10141E-02	1.20933E-02	-0.0	1.00000E+30	1.20933E-02	-0.0	-0.0	1.20933E-02
1.00000E+00	3.40151E-02	1.36479E-02	-0.0	1.00000E+30	1.36479E-02	-0.0	-0.0	1.36479E-02
1.00000E+00	3.72122E-02	1.52173E-02	-0.0	1.00000E+30	1.52173E-02	-0.0	-0.0	1.52173E-02
1.00000E+00	4.10178E-02	1.68959E-02	-0.0	1.00000E+30	1.68959E-02	-0.0	-0.0	1.68959E-02
1.00000E+00	4.52095E-02	1.85830E-02	-0.0	1.00000E+30	1.85830E-02	-0.0	-0.0	1.85830E-02
1.00000E+00	5.00178E-02	2.03620E-02	-0.0	1.00000E+30	2.03620E-02	-0.0	-0.0	2.03620E-02
1.00000E+00	5.52131E-02	2.21411E-02	-0.0	1.00000E+30	2.21411E-02	-0.0	-0.0	2.21411E-02
1.00000E+00	6.10192E-02	2.40022E-02	-0.0	1.00000E+30	2.40022E-02	-0.0	-0.0	2.40022E-02
1.00000E+00	6.72254E-02	2.59424E-02	-0.0	1.00000E+30	2.59424E-02	-0.0	-0.0	2.59424E-02
1.00000E+00	7.40315E-02	2.79736E-02	-0.0	1.00000E+30	2.79736E-02	-0.0	-0.0	2.79736E-02
1.00000E+00	8.10402E-02	3.00227E-02	-0.0	1.00000E+30	3.00227E-02	-0.0	-0.0	3.00227E-02
1.00000E+00	8.82495E-02	3.21223E-02	-0.0	1.00000E+30	3.21223E-02	-0.0	-0.0	3.21223E-02
1.00000E+00	9.56602E-02	3.43234E-02	-0.0	1.00000E+30	3.43234E-02	-0.0	-0.0	3.43234E-02
1.00000E+00	1.03270E-02	3.66337E-02	-0.0	1.00000E+30	3.66337E-02	-0.0	-0.0	3.66337E-02
1.00000E+00	1.11233E-02	3.90451E-02	-0.0	1.00000E+30	3.90451E-02	-0.0	-0.0	3.90451E-02
1.00000E+00	1.20477E-02	4.15574E-02	-0.0	1.00000E+30	4.15574E-02	-0.0	-0.0	4.15574E-02
1.00000E+00	1.30923E-02	4.42075E-02	-0.0	1.00000E+30	4.42075E-02	-0.0	-0.0	4.42075E-02
1.00000E+00	1.42572E-02	4.70286E-02	-0.0	1.00000E+30	4.70286E-02	-0.0	-0.0	4.70286E-02
1.00000E+00	1.55477E-02	5.00000E-02	-0.0	1.00000E+30	5.00000E-02	-0.0	-0.0	5.00000E-02
1.00000E+00	1.70577E-02	5.30423E-02	-0.0	1.00000E+30	5.30423E-02	-0.0	-0.0	5.30423E-02
1.00000E+00	1.87777E-02	5.62424E-02	-0.0	1.00000E+30	5.62424E-02	-0.0	-0.0	5.62424E-02
1.00000E+00	2.06179E-02	6.00323E-02	-0.0	1.00000E+30	6.00323E-02	-0.0	-0.0	6.00323E-02
1.00000E+00	2.25777E-02	6.40497E-02	-0.0	1.00000E+30	6.40497E-02	-0.0	-0.0	6.40497E-02
1.00000E+00	2.46577E-02	6.82667E-02	-0.0	1.00000E+30	6.82667E-02	-0.0	-0.0	6.82667E-02
1.00000E+00	2.68607E-02	7.26032E-02	-0.0	1.00000E+30	7.26032E-02	-0.0	-0.0	7.26032E-02
1.00000E+00	3.91927E-02	7.71497E-02	-0.0	1.00000E+30	7.71497E-02	-0.0	-0.0	7.71497E-02
1.00000E+00	4.26477E-02	8.20000E-02	-0.0	1.00000E+30	8.20000E-02	-0.0	-0.0	8.20000E-02
1.00000E+00	4.63115E-02	8.71752E-02	-0.0	1.00000E+30	8.71752E-02	-0.0	-0.0	8.71752E-02
1.00000E+00	5.02579E-02	9.26497E-02	-0.0	1.00000E+30	9.26497E-02	-0.0	-0.0	9.26497E-02
1.00000E+00	5.44137E-02	9.83227E-02	-0.0	1.00000E+30	9.83227E-02	-0.0	-0.0	9.83227E-02
1.00000E+00	5.87707E-02	1.04334E-01	-0.0	1.00000E+30	1.04334E-01	-0.0	-0.0	1.04334E-01
1.00000E+00	6.33370E-02	1.10612E-01	-0.0	1.00000E+30	1.10612E-01	-0.0	-0.0	1.10612E-01
1.00000E+00	6.80932E-02	1.17080E-01	-0.0	1.00000E+30	1.17080E-01	-0.0	-0.0	1.17080E-01
1.00000E+00	7.30487E-02	1.23730E-01	-0.0	1.00000E+30	1.23730E-01	-0.0	-0.0	1.23730E-01
1.00000E+00	7.82042E-02	1.30567E-01	-0.0	1.00000E+30	1.30567E-01	-0.0	-0.0	1.30567E-01
1.00000E+00	8.35607E-02	1.37594E-01	-0.0	1.00000E+30	1.37594E-01	-0.0	-0.0	1.37594E-01
1.00000E+00	8.89993E-02	1.44815E-01	-0.0	1.00000E+30	1.44815E-01	-0.0	-0.0	1.44815E-01
1.00000E+00	9.45495E-02	1.52230E-01	-0.0	1.00000E+30	1.52230E-01	-0.0	-0.0	1.52230E-01
1.00000E+00	1.00960E-01	1.60000E-01	-0.0	1.00000E+30	1.60000E-01	-0.0	-0.0	1.60000E-01
1.00000E+00	1.07558E-01	1.68250E-01	-0.0	1.00000E+30	1.68250E-01	-0.0	-0.0	1.68250E-01
1.00000E+00	1.14294E-01	1.76700E-01	-0.0	1.00000E+30	1.76700E-01	-0.0	-0.0	1.76700E-01
1.00000E+00	1.21098E-01	1.85400E-01	-0.0	1.00000E+30	1.85400E-01	-0.0	-0.0	1.85400E-01
1.00000E+00	1.28030E-01	1.94300E-01	-0.0	1.00000E+30	1.94300E-01	-0.0	-0.0	1.94300E-01
1.00000E+00	1.35070E-01	2.03400E-01	-0.0	1.00000E+30	2.03400E-01	-0.0	-0.0	2.03400E-01
1.00000E+00	1.42200E-01	2.12600E-01	-0.0	1.00000E+30	2.12600E-01	-0.0	-0.0	2.12600E-01
1.00000E+00	1.59430E-01	2.21900E-01	-0.0	1.00000E+30	2.21900E-01	-0.0	-0.0	2.21900E-01
1.00000E+00	1.76860E-01	2.31300E-01	-0.0	1.00000E+30	2.31300E-01	-0.0	-0.0	2.31300E-01
1.00000E+00	1.94490E-01	2.40900E-01	-0.0	1.00000E+30	2.40900E-01	-0.0	-0.0	2.40900E-01
1.00000E+00	2.12300E-01	2.50700E-01	-0.0	1.00000E+30	2.50700E-01	-0.0	-0.0	2.50700E-01
1.00000E+00	2.30200E-01	2.60600E-01	-0.0	1.00000E+30	2.60600E-01	-0.0	-0.0	2.60600E-01
1.00000E+00	2.48100E-01	2.70600E-01	-0.0	1.00000E+30	2.70600E-01	-0.0	-0.0	2.70600E-01
1.00000E+00	2.66000E-01	2.80600E-01	-0.0	1.00000E+30	2.80600E-01	-0.0	-0.0	2.80600E-01
1.00000E+00	2.83900E-01	2.90600E-01	-0.0	1.00000E+30	2.90600E-01	-0.0	-0.0	2.90600E-01
1.00000E+00	3.01700E-01	3.00600E-01	-0.0	1.00000E+30	3.00600E-01	-0.0	-0.0	3.00600E-01
1.00000E+00	3.20000E-01	3.10600E-01	-0.0	1.00000E+30	3.10600E-01	-0.0	-0.0	3.10600E-01
1.00000E+00	3.39300E-01	3.20600E-01	-0.0	1.00000E+30	3.20600E-01	-0.0	-0.0	3.20600E-01

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Appendix 3

Output List of Sample Calculation on  
Loss of Coolant Flow Accident

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* LOSS OF COOLANT FLOW ACCIDENT ( TSPD, DEPENDENT ) : 1973-07-05
* FAST PREDETER REACTOR CORE TRANSIENT CALCULATION CODE
* FUEL MELTING PROCESS CONSIDERED
* EXCUSES OUTPUT LIST
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## INITIAL TEMPERATURE OF ITERATION CALCULATION

K=1

J	TG(1,J,1)	TG(2,J,1)	TG(3,J,1)	TG(4,J,1)	TG(5,J,1)	TG(6,J,1)	TG(7,J,1)
1	1139.832	1192.876	1161.3497	1125.7857	1075.9944	1011.9848	933.7451
2	1456.3476	1676.6166	1622.2056	1576.4089	1305.8797	1221.0855	861.2221
3	1846.9473	1933.4998	1797.9257	1735.3055	1698.2974	1534.9311	997.1545
4	1845.6128	1967.3557	1917.2623	1840.4392	1765.8367	1625.5144	1130.0355
5	2011.2588	1995.6197	1942.2265	1864.2601	1791.5423	1569.4394	1305.0524
6	1932.5911	1941.8182	1864.2601	1836.4261	1780.7555	1660.4745	1341.4599
7	1916.3412	1772.4271	1721.7052	1694.4204	1713.9727	1601.2854	1339.7225
8	1772.4645	1566.7794	1538.7370	1492.5867	1426.7716	1342.7972	1226.0533
9	1577.5599	1732.1285	1731.6781	1658.1149	1214.3266	1154.3130	1118.9560
10	1372.1285	1466.6466	1672.8492	1079.8578	977.6699	936.2855	943.6101
11	1051.2422						825.9239
12							

J	TG(8,J,1)	TG(9,J,1)	TG(10,J,1)	TG(11,J,1)	TG(12,J,1)	TG(13,J,1)	TG(14,J,1)
1	774.5979	613.6784	608.2155	598.6493	578.9178	578.9178	578.9178
2	952.1975	604.5797	421.0430	433.3923	390.6163	390.6163	390.6163
3	952.5449	772.9350	450.5667	419.9762	404.6079	404.6079	404.6079
4	1045.5299	832.5674	471.9843	437.4474	420.3093	420.3093	420.3093
5	1115.5425	874.9332	491.1071	437.3660	424.1660	424.1660	424.1660
6	1135.7225	946.6868	510.3921	472.8544	454.1793	454.1793	454.1793
7	1139.5275	912.4532	525.9771	449.2215	472.9359	472.9359	472.9359
8	1112.3671	890.9755	538.2123	503.7713	486.6373	486.6373	486.6373
9	1059.5561	868.5971	546.5475	515.5972	500.5289	500.5289	500.5289
10	978.9603	822.2911	550.7542	525.0934	512.3275	512.3275	512.3275
11	976.0277	756.3257	555.5383	530.9768	521.2453	521.2453	521.2453
12	756.5529	679.7822	545.9482	531.3020	527.0106	527.0106	527.0106

K=2

J	TG(1,J,2)	TG(2,J,2)	TG(3,J,2)	TG(4,J,2)	TG(5,J,2)	TG(6,J,2)	TG(7,J,2)
1	1597.9392	1597.9392	1555.2625	1501.9179	1427.2355	1331.2152	1075.1610
2	1992.3923	1979.9972	1937.6162	1867.0317	1769.0619	1643.1007	1307.2041
3	2374.6416	2357.7346	2357.7346	2175.0371	2175.0371	2122.0813	1504.4765
4	2579.4975	2560.1129	2560.1129	2416.1366	2278.6468	2109.5879	1558.7548
5	2745.9211	2725.9671	2725.9671	2556.5722	2425.1581	2244.7352	2024.2182
6	2797.9175	2735.1815	2735.1815	2556.4971	2425.1581	2244.7352	1763.5073
7	2777.1957	2711.9087	2711.9087	2613.6128	2491.2956	2080.8217	1614.6631
8	2659.6453	2656.8658	2594.5671	2505.5844	2369.5925	2200.0316	1991.4015
9	2455.6512	2438.5101	2394.5101	2304.9758	2181.9027	1831.0221	1635.4148
10	2158.9639	2144.5691	2102.9810	2037.0025	1935.0726	1809.0713	1473.1744
11	1792.1214	1791.2175	1760.4467	1696.9020	1622.3105	1521.2991	1269.2467
12	1376.0409	1362.2024	1362.5102	1300.0232	1250.7413	1197.6646	1032.1269

K=2

J	TG(11,J,2)	TG(12,J,2)	TG(13,J,2)	TG(14,J,2)	TG(15,J,2)	TG(16,J,2)	TG(17,J,2)
1	616.1272	733.7556	625.5536	796.2118	782.1506	782.1506	782.1506
2	1297.2647	459.3428	455.3169	416.5458	399.1132	399.1132	399.1132
3	1253.7013	96.9.4980	485.2741	439.2383	417.1927	417.1927	417.1927
4	1376.0466	1657.6494	515.0347	463.3.7433	438.6036	438.6036	438.6036
5	1462.9074	1112.1034	542.9893	511.7563	484.7699	461.4576	461.4576
6	1517.5569	1150.5033	568.6514	534.3422	507.5399	529.0509	529.0509
7	1510.6584	1158.2498	589.1757	553.5250	529.0509	548.1303	548.1303
8	1467.4361	1148.6968	610.2119	570.1760	549.1303	564.3829	564.3829
9	1396.7204	1599.7659	614.2119	582.1516	556.0429	576.2436	576.2436
10	1252.2389	1625.3120	621.0367	592.1516	564.3829	584.1054	584.1054
11	1139.2117	927.8739	619.6766	590.2963	564.3829	584.1054	584.1054
12	924.6657	811.4794	612.1587	585.9239	556.0429	576.2436	576.2436

ITERATION CAL.

2

K=1

J	T0(1,J,1)	T0(2,J,1)	T0(3,J,1)	T0(4,J,1)	T0(5,J,1)	T0(6,J,1)	T0(7,J,1)	T0(8,J,1)
1	1191.5381	1184.7186	1156.2975	1118.4659	1042.2738	1266.4043	950.9003	466.5670
2	1505.7531	1493.3228	1466.0491	1416.2041	1300.3504	1156.7120	1046.1294	1046.1294
3	1739.5531	1728.2964	1698.5089	1639.3361	1559.3898	1457.7878	1333.8119	1188.2441
4	1899.2495	1887.0316	1855.2821	1815.2636	1765.7057	1701.8911	1593.4667	1451.3144
5	1941.1237	1971.4418	1941.2636	1925.9661	1876.1598	1785.5040	1667.6225	1522.1577
6	2026.2448	2113.4619	1971.9661	1910.2789	1818.6879	1698.3945	1551.7777	1375.7946
7	2132.5445	1935.2593	1895.4222	1855.5679	1764.4360	1632.9092	1495.5955	1332.7893
8	1939.5147	1927.4555	1893.1756	1850.3312	1764.4360	1529.2447	1405.4286	1259.4063
9	1939.7542	1797.6717	1766.3670	1708.6647	1636.3429	1522.9245	1371.6378	1267.7732
10	1503.2105	1597.7545	1562.3923	1522.9161	1455.9245	1271.5057	1160.7049	1146.7332
11	1334.9339	1327.8758	1306.7316	1271.5057	1222.5684	1084.1564	996.0113	980.2558
12	1025.5748	1816.4603	1902.9436	983.8958	954.1564	917.2096	872.4882	820.2558
J	T0(9,J,1)	T0(13,J,1)	T0(14,J,1)	T0(15,J,1)	T0(16,J,1)	T0(17,J,1)	T0(18,J,1)	T0(19,J,1)
1	771.2233	666.0222	410.0954	389.4939	379.6580	378.6590	378.6590	378.6590
2	911.9759	763.5445	431.9594	403.4555	390.2560	390.2560	390.2560	390.2560
3	1822.5653	834.7274	451.5145	420.0020	404.1716	404.1716	404.1716	404.1716
4	1154.5662	891.7512	477.9338	437.3317	419.6610	419.6610	419.6610	419.6610
5	1140.4103	926.0395	492.9878	454.8574	436.0792	436.0792	436.0792	436.0792
6	1172.0743	944.3176	510.1107	472.0502	452.8379	452.8379	452.8379	452.8379
7	1171.2771	946.6615	525.1984	498.3544	469.3550	469.3550	469.3550	469.3550
8	1145.7373	935.5942	531.5761	503.1457	485.0447	485.0447	485.0447	485.0447
9	1392.5264	906.1283	546.4495	515.7027	499.2655	499.2655	499.2655	499.2655
10	1600.1551	855.2145	550.9311	511.2867	511.2867	511.2867	511.2867	511.2867
11	895.7782	784.5598	550.3441	510.9943	520.4035	520.4035	520.4035	520.4035
12	765.9387	694.6199	544.8916	532.7739	526.1279	526.1279	526.1279	526.1279
K=2								
J	T0(1,J,2)	T0(2,J,2)	T0(3,J,2)	T0(4,J,2)	T0(5,J,2)	T0(6,J,2)	T0(7,J,2)	T0(8,J,2)
1	1565.6293	1654.2879	1622.8330	1567.7915	1462.1192	1394.9713	1138.4277	1138.4277
2	2335.6978	2617.1748	1977.6642	1911.2344	1917.1740	1694.6560	1543.0566	1362.4520
3	2255.6335	2261.2194	2198.7150	2126.7621	2122.9958	1688.6364	1718.7735	1512.9860
4	2394.1663	2373.5817	2373.5235	2261.8873	2153.8598	2011.9662	1932.3176	1612.2319
5	2473.7570	2458.9754	2416.2592	2378.6192	2229.4299	2084.4748	1900.1093	1672.8440
6	2564.1712	2489.7692	2441.6645	2360.6456	2259.4252	2144.0027	1924.7841	1699.9561
7	2494.4117	2473.7579	2410.8826	2367.7474	2295.5887	2103.1056	1920.5486	1695.3220
8	2425.1559	2375.2376	2255.5047	2204.6722	2180.8643	1874.8491	1654.3403	1654.3403
9	2372.4799	2291.2376	2104.5319	2162.9131	2041.3473	1951.9956	1793.2703	1595.6013
10	2107.3125	2066.5319	1905.2626	1772.4553	1911.9075	1645.6928	1565.5713	1565.5713
11	1816.9263	1764.2957	1628.9562	1575.5621	1645.5294	1546.9948	1291.0110	1130.1423
12	1375.1643	1264.7791	1244.5398	1313.1227	1261.4648	1204.2911	1130.1423	1043.5937
K=2								
J	T0(9,J,2)	T0(14,J,2)	T0(15,J,2)	T0(16,J,2)	T0(17,J,2)	T0(18,J,2)	T0(19,J,2)	T0(20,J,2)
1	941.3261	807.5232	433.3385	398.2650	383.2382	383.2382	383.2382	383.2382
2	1154.0225	920.5511	460.2947	419.3700	400.1454	400.1454	400.1454	400.1454
3	1271.7693	905.5495	491.5667	441.5415	419.5417	419.5417	419.5417	419.5417
4	1352.6030	1049.1295	513.1131	464.6860	443.5951	443.5951	443.5951	443.5951
5	1456.5057	1084.4177	517.3944	487.9512	462.6434	462.6434	462.6434	462.6434
6	1424.4543	1104.6442	555.9840	510.9281	485.6716	485.6716	485.6716	485.6716
7	1424.9965	1110.4139	589.3980	532.9659	507.2752	507.2752	507.2752	507.2752
8	1451.1515	1121.2946	590.3120	567.3956	528.6093	528.6093	528.6093	528.6093
9	1367.9874	1075.5621	611.9799	571.4233	549.3732	549.3732	549.3732	549.3732
10	1262.7511	1028.9562	620.1175	596.0260	565.7226	565.7226	565.7226	565.7226
11	1172.8475	953.9943	621.4153	595.7559	579.5379	579.5379	579.5379	579.5379
12	945.0297	835.5567	616.9662	599.3755	588.5177	588.5177	588.5177	588.5177

ITERATION CAL.

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J	T0(1,J,1)	T0(2,J,1)	T0(3,J,1)	T0(4,J,1)	T0(5,J,1)	T0(6,J,1)	T0(7,J,1)	T0(8,J,1)
1	1192.3295	1156.6213	1127.7229	1080.6238	1020.5934	948.1248	863.8344	764.4434
2	1493.1987	1464.3543	1446.2471	1364.4845	1264.3632	1162.4063	1043.5177	911.7203

CASE NO. 1 TIME WRITTEN OUTPUT TO TAPE = 50.0 MIN.

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SIXCURS INPUT LIST  
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CALCULATIONAL OPTION  
NUMBER OF CHANNEL = 2  
TEMP. DIFFERENCE OF PHYSICAL VALUE = YES  
SCRAM = YES  
COOLANT VELOCITY CONDITION = -1.00  
CALCULATION TIME IN CODE = 1.499 SEC.

INIT. OMEGA	INIT. INTERVAL	MIN. INTERVAL	MAX. INTERVAL	LOWER ACCURACY	UPPER ACCURACY
1.	2.50000E-02	1.000000E-10	3.000000E-02	5.000000E-03	
DEL. NEUT. FRAC.	NEUTRON LIFETIME SOURCE TERM	SUM F1*WT			
2.70000E-03	1.500000E-07	1.400000E+00			
INITIAL VALUES OF NEUTRON AND DELAYED NEUTRON PRECursors				1.000000E+00	1.000000E+00
1.000000E+00	1.000000E+00	1.000000E+00			
DELAYED NEUTRON FRACTION (GROUP-WISE RELATIVE VALUE)					
3.11000E-02	2.12500E-01	1.497000E-01	6.075000E-01	1.278000E-01	2.610000E-02
DECAY CONSTANTS OF DELAYED NEUTRON PRECursors					
1.27E03E-02	3.17E02E-02	1.467000E-01	3.142000E-01	1.406700E+00	3.8A03000E+00
FEEDBACK REACTIVITY COEFFICIENTS					
FUEL	FUEL EXPANSION COOL. EXPANSION	STRUCT. EXPANSION			
-5.00000E-03	-0.100000E-06	-5.00000E-06	-2.000000E-06		
NO. OF AXIAL	NO. OF FUEL RADIAL	POWER DENSITY	COOLANT VEL.1	COOLANT VEL.2	INLET TEMP.
12	9	4.500000E+02	5.000000E+02	5.500000E+02	3.700000E+02
FUEL RADIUS	CLAD INNER RAD.	COOLANT RAD.	STRUCTURE RAD.	STRUCTURE RAD.	COOLING SAVING
2.50000E-01	2.401000E-01	4.045000E-01	4.045000E-01	4.117000E-01	8.400000E+00
MATERIAL PHYSICAL VALUES					
HEAT CONDUCT.	DENSITY	SPECIFIC HEAT			
FUEL	6.71061E-03	1.03000E+02	8.20000E+02		
CLAD	4.4E010E-02	7.87000E+00	1.38000E-01		
COOLANT	1.65000E-01	8.40000E-01	3.07000E-01		
STRUCTURE	4.65000E-02	7.40000E+00	1.78000E-01		
RAD CONDUCTANCE					
FUEL HEATING TEMP.	1.35600E-01	2.80000E+03			
STRUCT. HEAT OF MOLTEN FUEL	8.99230E-02				
LATENT HEAT OF FUEL	8.05000E+01				
HEAT TRANSFER COEFFICIENT BETWEEN CLAD AND COOLANT					
$\mu_f = 0.$	+ 6.250E-01 * TPE1**	4.000E-01			
EXTERNAL REACTIVITY INSERTRION CONDITION					
STEP REAC.	STEP TIME	RAMP TIME			
0.	0.	0.			
COOLANT VELOCITY CHANGE					
V/V = 8.000E-01 * TPE1** + (-1.000E+00 * T) + 2.			*T + 2.000E-01		

SCALED CONDITIONS  
 ACCELERATION POWER SETTING DEFON SETTING VELOCITY SETTING TIMER SETTING SCRAM DELAY ROD WORTH  
 $9.81 \times 10^{-5}$  1.200100E+0 1.500000E-31 8.000000E-01 5.000000E+01 5.000000E-01 3.300000E-02  
 ROD LENGTH PRE-INSERTED LENGTH  
 $6.000000E+01$

CALCULATION CONDITION  
 DELAY INTERVAL: 0.000000E+00  
 1.000000E+01 1.000000E+01 1.000000E+01 1.000000E+01 1.000000E+01  
 POINT INT. (INIT.) 1.000000E+00 2.000000E+00 2.500000E+00 3.000000E+00 3.500000E+00

NORMALISED PEEPING FACTOR (RADIAL)		1	2	3	4	5	6	7	8	9	10
1	-6.816	-6.816	-6.816	-6.816	-6.816	-6.816	-6.816	-6.816	-6.816	-6.816	
2	-8.941	-8.941	-8.941	-8.941	-8.941	-8.941	-8.941	-8.941	-8.941	-8.941	
3	1.8693	1.0693	1.0693	1.0693	1.0693	1.0693	1.0693	1.0693	1.0693	1.0693	
4	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	
5	1.2967	1.2937	1.2937	1.2937	1.2937	1.2937	1.2937	1.2937	1.2937	1.2937	
6	1.3779	1.3779	1.3779	1.3779	1.3779	1.3779	1.3779	1.3779	1.3779	1.3779	
7	1.2357	1.2867	1.2867	1.2867	1.2867	1.2867	1.2867	1.2867	1.2867	1.2867	
8	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	
9	1.6693	1.6693	1.6693	1.6693	1.6693	1.6693	1.6693	1.6693	1.6693	1.6693	
10	-8.941	-8.941	-8.941	-8.941	-8.941	-8.941	-8.941	-8.941	-8.941	-8.941	
11	-6.816	-6.816	-6.816	-6.816	-6.816	-6.816	-6.816	-6.816	-6.816	-6.816	
12	-4.406	-4.406	-4.406	-4.406	-4.406	-4.406	-4.406	-4.406	-4.406	-4.406	

## MATERIAL PHYSICAL VALUES DEPENDENT ON TEMPERATURE

CONDUCTIVITY		FUEL	CLAD	COOLANT	STRUCTURE	FUEL	CLAD	COOLANT	STRUCTURE	FUEL	CLAD	COOLANT	STRUCTURE
		1.280000E+02	-8.220000E-05	2.750000E-09									
		3.220000E+02	3.420000E-05	0.4									
		2.220000E+01	-1.390000E-04	2.410000E-08									
		3.220000E+02	3.420000E-05	0.									
DENSITY		1.030000E+01	-2.520000E-04	-5.685000E-08									
		7.900000E+01	-4.310000E-04	0.									
		9.510000E+01	-2.450000E-04	0.									
		7.900000E+01	-4.330000E-04	0.									
SPECIFIC HEAT		7.666000E+02	3.423000E-05	1.740000E-09									
		1.155000E+01	4.476000E-05	0.									
		3.412000E+01	-1.295000E-04	1.105000E-07									
		1.157000E+01	4.478000E-05	0.									
GAS CONDUCTANCE		8.263000E+02	7.180000E-05	0.									

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NUM TIME IN SEC. TIME INTERVAL ACTIVITY PRY-INVERSE PER-AVG- INVERSE PER. NEUTRON FLUX DELTA FL. INTEG.  
0. 0. 0.

CONCENTRATION OF EACH GROUP OF DELAYED NEUTRON PRECURSORS  
1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00

FEED BACK REAC. ROD READ. COOLANT VEL.(1) COOLANT VEL.(2)  
0. 0. 0.001000E+32 5.500000E+02

X=1

J	T( 1,J,1)	T( 2,J,1)	T( 3,J,1)	T( 4,J,1)	T( 5,J,1)	T( 6,J,1)	T( 7,J,1)	T( 8,J,1)
1	1157.7177	1182.5137	1182.5137	1182.5137	1182.5137	1182.5137	1182.5137	1182.5137
2	1435.9156	1453.4587	1453.4587	1453.4587	1453.4587	1453.4587	1453.4587	1453.4587
3	1736.0631	1723.7798	1723.7798	1723.7798	1723.7798	1723.7798	1723.7798	1723.7798
4	1803.2665	1881.6696	1881.6696	1881.6696	1881.6696	1881.6696	1881.6696	1881.6696
5	1945.1624	1917.2746	1917.2746	1917.2746	1917.2746	1917.2746	1917.2746	1917.2746
6	2022.4775	2129.6926	2129.6926	2129.6926	2129.6926	2129.6926	2129.6926	2129.6926
7	2306.1492	1993.5663	1993.5663	1993.5663	1993.5663	1993.5663	1993.5663	1993.5663
8	1935.8259	1923.7731	1923.7731	1923.7731	1923.7731	1923.7731	1923.7731	1923.7731
9	1905.5613	1736.3929	1736.3929	1736.3929	1736.3929	1736.3929	1736.3929	1736.3929
10	1675.1674	1595.9116	1595.9116	1595.9116	1595.9116	1595.9116	1595.9116	1595.9116
11	1372.4973	1325.4634	1325.4634	1325.4634	1325.4634	1325.4634	1325.4634	1325.4634
12	1016.2170	1112.2747	1112.2747	1112.2747	1112.2747	1112.2747	1112.2747	1112.2747

T(13,J,1) T(14,J,1) T(15,J,1) T(16,J,1) T(17,J,1) T(18,J,1)

J	T(13,J,1)	T(14,J,1)	T(15,J,1)	T(16,J,1)	T(17,J,1)	T(18,J,1)
1	757.9453	662.1865	439.7547	348.5247	278.5850	178.5850
2	908.1524	754.2194	431.5455	401.2174	390.1150	390.1150
3	1017.4539	835.3156	452.9411	419.6392	403.9227	403.9227
4	1307.5793	986.3057	473.2516	461.4565	419.3055	419.3055
5	1145.2621	921.6213	492.1779	456.3044	435.6334	435.6334
6	1159.1599	946.5488	510.5702	471.4376	452.7123	452.7123
7	1169.1492	944.4496	526.4457	487.6422	468.7666	468.7666
8	1412.4284	932.7724	526.7558	492.4095	486.7494	486.7494
9	1089.4889	902.9194	545.8856	514.3112	493.5512	493.5512
10	1006.7442	853.8649	556.2589	524.3768	510.5268	510.5268
11	897.4652	767.2105	549.4795	510.1324	519.6228	519.6228
12	758.4603	692.5538	563.9146	531.8461	525.2857	525.2857

K=2

J	T( 1,J,2)	T( 2,J,2)	T( 3,J,2)	T( 4,J,2)	T( 5,J,2)	T( 6,J,2)	T( 7,J,2)	T( 8,J,2)
1	1561.2669	1618.0192	1618.0192	1618.0192	1618.0192	1618.0192	1618.0192	1618.0192
2	2023.6117	2011.5156	1971.5113	1924.4851	1810.8727	1688.5843	1537.2482	1376.8238
3	2259.4934	2245.6903	2202.4864	2129.7197	2026.0125	1889.6657	1716.8229	1512.2847
4	2411.3451	2396.4137	2351.3261	2276.5555	2165.9557	2021.7668	1839.7960	1647.5437
5	2498.2557	2484.9168	2437.3981	2360.6487	2248.3550	2100.3042	1912.7286	1642.3914
6	2572.7479	2518.0585	2471.4227	2397.6541	2281.9447	2132.7019	1943.7265	1711.6669
7	2516.9859	2501.7989	2456.1493	2378.0567	2268.2982	2121.5868	1935.6203	1707.1039
8	2464.4547	2432.7437	2393.4997	2314.6337	2267.5257	2065.8876	1886.9119	1667.9895
9	2324.9887	2307.0916	2265.1112	2194.7667	2093.7761	1960.4613	1792.5579	1590.9666
10	2119.2893	2105.6209	2068.4578	2004.2669	1913.1918	1794.2195	1645.7398	1468.9605
11	1813.9241	1803.3721	1771.6471	1718.5817	1563.9180	1547.5214	1429.3101	1289.6493
12	1374.8094	1367.9592	1347.3079	1312.9993	1255.0792	1203.5562	1129.6393	1042.9001

J	T( 1,J,2)	T( 2,J,2)	T( 3,J,2)	T( 4,J,2)	T( 5,J,2)	T( 6,J,2)	T( 7,J,2)	T( 8,J,2)
1	276.4676	301.5681	433.5791	708.6229	1712.4221	383.1432	383.1432	383.1432
2	1149.4123	916.6467	459.6416	419.6625	419.3457	399.9650	399.9650	399.9650
3	1253.9617	936.4736	497.1697	461.4736	419.3748	419.3748	419.3748	419.3748

	4	5	6	7	8	9	10	11	12
AVG FUEL TEMPERATURE OF CHANNEL 1	1753.9583	1553.8455	517.3184	454.7038	440.4915	440.4915	440.4915	440.4915	440.4915
FUEL CLAD COOLANT STRUCTURE	14.7.3075	10.83.8497	6.3.340	4.83.2557	4.62.7229	4.62.7229	4.62.7229	4.62.7229	4.62.7229
14.7.566	11.1.5555	5.11.5555	5.11.5064	4.95.3413	4.95.3413	4.95.3413	4.95.3413	4.95.3413	4.95.3413
14.7.6397	11.16.6397	5.11.6198	5.11.7974	5.07.8193	5.07.8193	5.07.8193	5.07.8193	5.07.8193	5.07.8193
14.7.7405	11.06.5657	5.99.3550	5.94.3981	5.92.6577	5.92.6577	5.92.6577	5.92.6577	5.92.6577	5.92.6577
14.7.4354	12.2.4599	6.12.5272	5.72.5474	5.69.2516	5.69.2516	5.69.2516	5.69.2516	5.69.2516	5.69.2516
12.2.5615	12.9.7829	6.22.6035	5.96.9966	5.65.6156	5.65.6156	5.65.6156	5.65.6156	5.65.6156	5.65.6156
12.2.4517	12.9.7829	6.22.6035	5.95.6554	5.82.4399	5.82.4399	5.82.4399	5.82.4399	5.82.4399	5.82.4399
12.0.4528	9.0.3514	6.2.1490	5.99.9673	5.89.4096	5.89.4096	5.89.4096	5.89.4096	5.89.4096	5.89.4096
9.0.2707	8.1.9454	6.17.7400	5.99.9673	5.89.4096	5.89.4096	5.89.4096	5.89.4096	5.89.4096	5.89.4096

NUW TIME IN SEC. TIME INTERVAL RECITIVITY PRT INVERSE PFR.AVG. INVERSE PER. NEUTRON FLUX DELTA FL. INTEG.  
 1C 2.500000E-02 2.500000E-03 -9.65625467F-05 5.60992657F-04 -1.34372406F-01 9.37067333E-01 2.4965213E-02  
 CONCENTRATION OF EACH GROUP OF DELAYED NEUTRON PRECURSORS  
 9.000000E-01 9.000000E-01 9.000000E-01 9.000000E-01 9.000000E-01 9.000000E-01 9.000000E-01

FROM BACK REAC. 200 SEC. COOLANT VEL.(1) COOLANT VEL.(12)  
 -9.05629457E-06 0. 5.39573451E+02

k=1

J	T(1,J,1)	T(2,J,1)	T(3,J,1)	T(4,J,1)	T(5,J,1)	T(6,J,1)	T(7,J,1)	T(8,J,1)
1	1187.7962	1180.9784	1161.5019	1126.7558	1119.6950	1019.7559	947.7714	863.1729
2	1438.8592	1483.4216	1461.1225	1414.0215	1264.2619	1264.1744	1152.1551	1043.1956
3	1730.7824	1723.6554	1631.6280	1632.0245	1585.1679	1453.6942	1329.7692	1184.3972
4	1492.6443	1683.7757	1814.1735	1782.8222	1626.3239	1584.2357	1465.7975	1283.6335
5	1945.5771	1971.0213	1933.4241	1870.5205	1745.9084	1652.9084	1517.6336	1344.7769
6	2222.5546	2609.2420	1976.8129	1905.1817	1914.6992	1695.5712	1546.1506	1372.3736
7	2517.7552	1897.1735	1955.7105	1871.7265	1611.7729	1644.7159	1539.9915	1367.5774
8	1935.4918	1847.5267	1762.5223	1760.8146	1627.2320	1629.5033	1492.5134	1329.7836
9	1935.2225	1781.1697	1765.9526	1725.3855	1627.2320	1526.3056	1402.6343	1256.6128
10	1660.4732	1591.8244	1561.4726	1529.2667	1454.0563	1269.1574	1265.8469	1146.7053
11	1372.5222	1325.4707	1306.3414	1269.2252	1220.2477	1157.7944	1082.1748	993.4008
12	1016.2985	1012.1571	999.7513	949.1457	956.4497	913.8144	869.4498	817.5035

k=2

J	T(1,J,1)	T(2,J,1)	T(3,J,1)	T(4,J,1)	T(5,J,1)	T(6,J,1)	T(7,J,1)	T(8,J,1)
1	747.4934	411.4128	349.2096	349.2014	349.2014	349.2014	349.2014	349.2014
2	974.8146	432.2578	454.6616	391.2766	391.2766	391.2766	391.2766	391.2766
3	1018.6524	827.6128	452.9191	621.2076	425.5037	405.2211	405.2211	405.2211
4	1095.6591	885.2201	470.2201	438.6152	421.1632	420.8079	420.8079	420.8079
5	1145.6591	921.0256	493.1792	456.1378	477.5337	437.2306	437.2306	437.2306
6	1180.1765	943.9956	516.3767	477.2521	454.3452	452.9144	452.9144	452.9144
7	1194.7289	525.3740	516.4772	480.4225	470.7387	470.3095	470.3095	470.3095
8	1162.6322	932.6466	537.5295	507.9797	496.7337	485.8202	485.8202	485.8202
9	1249.7541	937.2162	540.3262	516.2855	510.1988	499.8167	499.8167	499.8167
10	1300.6740	785.7092	556.6651	525.5297	511.9352	511.5981	511.5981	511.5981
11	889.4434	782.6051	549.9312	521.6147	508.7372	520.4525	520.4525	520.4525
12	754.55613	692.7065	544.2456	532.4934	525.9974	525.9974	525.9974	525.9974

k=3

J	T(1,J,2)	T(2,J,2)	T(3,J,2)	T(4,J,2)	T(5,J,2)	T(6,J,2)	T(7,J,2)	T(8,J,2)
1	1661.7234	1617.9596	1564.4157	1688.4139	1391.2678	1272.9545	1134.2007	1007.2007
2	2023.2114	2013.1161	1956.4151	1910.5945	1688.3923	1537.1609	1356.8577	1209.8577
3	2259.1765	2044.9958	2210.4128	2045.4970	1869.2669	1718.5165	1512.2009	1312.2009
4	2415.3949	2395.4776	2276.2471	2165.2630	2021.2033	1879.3961	1617.3532	1417.3532
5	2694.1521	2482.8768	2350.9894	2247.5100	2090.6159	1812.2269	1682.1743	1482.1743
6	2522.4813	2516.1129	2470.7746	2322.6382	2395.5970	2131.9610	1943.3837	1711.3837
7	2515.7741	2503.6926	2377.9899	2257.4226	2120.4727	1935.1072	1706.6117	1486.4977
8	2447.4183	2432.7769	2349.5516	2313.7771	2065.2645	1667.7119	1486.4977	1209.4977

5	2172.9.62	2158.2276	2114.6794	2039.6919	1934.6790	1798.4908	1632.3589	1439.7632
7	2163.9.914	2163.5498	2135.9376	2083.1903	1930.9236	1796.7207	1634.3386	1446.4656
9	2116.1.56	2102.1573	2080.1772	1989.7750	1902.2813	1810.4909	1762.8654	1600.9405
9	2032.20.56	2033.0368	1959.4518	1819.1579	1759.7259	1677.6129	1691.6854	1548.7122
15	1956.7.61	1856.4759	1810.8529	1581.7111	1533.5773	1467.3589	1572.4306	1447.4013
12	1626.5.672	1610.8529	1581.7111	1533.5773	1467.3589	1384.6313	1287.8284	1146.5494
12	1253.9.923	1247.9441	1229.9555	1201.5626	1160.7152	1111.8247	1055.7939	994.9371
J	T(1,J,2)	T(10,J,2)	T(11,J,2)	T(12,J,2)	T(13,J,2)	T(14,J,2)	T(15,J,2)	T(16,J,2)
1	949.7492	719.8776	436.9803	412.6475	395.0449	396.0240	428.4140	428.4140
2	997.5872	816.3152	478.6162	449.4411	428.4140	428.4140	464.6706	464.6706
3	1083.7019	886.2952	520.2357	488.4882	464.7273	464.7273	503.8119	503.8119
4	1151.7755	934.6124	561.3356	529.6482	503.1449	503.1449	542.4372	542.4372
5	1198.6943	978.6939	601.3019	568.9224	542.4372	542.4372	581.3390	581.3390
F	1227.7944	1239.4761	539.4921	505.1654	581.4359	581.4359	619.1059	619.1059
7	1246.6451	1252.6395	574.9643	545.3756	619.1059	619.1059	654.2999	654.2999
8	1254.6114	1232.6552	736.5417	679.4756	654.4287	654.4287	686.1574	686.1574
9	1249.4154	1225.6759	737.1554	710.6162	672.8188	712.8188	712.8188	712.8188
10	1185.6600	1201.6606	752.6504	732.6444	732.6444	732.6444	732.6444	732.6444
11	1057.2445	992.3449	762.5124	747.4137	732.6444	732.6444	732.4751	732.4751
12	931.8254	863.9574	759.5964	751.2367	742.1827	742.1827	742.9016	742.9016

AVERAGE TEMPERATURE OF CHANNEL 1  
FUEL CLAD COOLANT STRUCTURE  
1110.4510 567.9437 543.2113 547.6818

TIME OVER AT NUM= 690

NUM TIME IN SEC. TIME INTERVAL REACTIVITY PRT INVERSE PFR. AVG. INVERSE PFR. NUTRON FLUX DELTA FL. INTEG.  
690 1.600000E+30 2.500000E-03 -3.26664075E-02 -2.50423099E-01 -2.59264040E-01 7.64527835E-02 9.42361296E-01  
CONCENTRATION OF EACH GROUP OF DELAYED NEUTRON PRECURSORS  
3.32145E-01 9.8251204E-01 9.374995E-01 8.2172750E-01 4.97551091E-01 1.85250120E-01  
SECOND BACK REAC. END REAC. COOLANT VFL.(1) COOLANT VEL.(2)  
3.3292477E-06 3.3000000E-02 1.99363769E+02 2.043603146E+02

V=1	T(1,J,1)	T(2,J,1)	T(3,J,1)	T(4,J,1)	T(5,J,1)	T(6,J,1)	T(7,J,1)	T(8,J,1)
J	1256.2679	1243.6264	1231.5237	1228.6120	1215.5157	1197.5170	1180.5190	1162.5115
1	1325.5397	1315.3157	1304.6055	1284.6262	1264.6323	1241.5163	1218.5163	1193.5115
2	1527.6492	1632.6099	1650.5262	1615.3238	1566.5846	1475.9252	1422.7728	1452.7790
3	1632.6492	1741.3655	1727.3564	1692.4578	1671.5367	1566.6374	1432.0059	1249.7357
4	1741.3655	1733.5574	1724.6169	1676.7195	1646.7810	1572.6154	1310.9572	1166.4472
5	1733.5574	1757.1213	1751.1244	1715.1473	1655.3028	1572.7328	1460.7425	1195.1465
6	1757.1213	1759.1255	1662.7377	1606.1476	1527.5659	1428.3610	1341.3292	1199.6426
7	1759.1255	1632.7924	1592.7456	1561.7955	1510.6004	1471.9458	1310.9742	1179.2433
8	1632.7924	1437.6969	1429.5159	1433.1624	1360.4460	1301.7706	1229.2480	1131.1245
9	1437.6969	1242.5159	1232.6647	1187.6641	1153.3029	1111.8729	1051.9218	1050.9984
10	1242.5159	932.5598	928.5789	912.3404	991.4560	894.7997	834.6983	937.4953
11	932.5598	T(1,J,1)	T(2,J,1)	T(3,J,1)	T(4,J,1)	T(5,J,1)	T(6,J,1)	T(7,J,1)
J	594.2783	605.4236	615.7618	615.9579	389.5394	389.6295	413.3372	413.3372
1	823.2652	692.3615	448.4682	448.4682	460.1291	462.3225	442.2764	442.2764
2	895.7052	761.6598	487.7452	487.7452	473.8758	473.8758	473.8680	473.8680
3	964.8450	813.5659	518.5644	492.4944	527.1052	506.5326	538.9166	538.9166
4	1011.2111	451.9511	552.4122	552.4122	559.7942	536.9120	570.9197	570.9197
5	1073.6619	973.1263	613.1064	507.7777	598.4946	598.4946	622.7161	622.7161
6	1164.8754	932.6655	579.7575	579.7575	640.7095	643.4131	643.4131	643.4131
7	1173.8754	994.2273	642.2539	642.2539	643.4131	643.4131	643.4131	643.4131
8	1177.8111	852.3946	659.5372	659.5372	655.7679	655.7679	655.7679	655.7679

		T(1,J,2)		T(2,J,2)		T(3,J,2)		T(4,J,2)		T(5,J,2)		T(6,J,2)		T(7,J,2)		T(8,J,2)	
		J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J
11	970.1012	902.3572	675.6600	665.5908	656.5111	656.2690	656.2139	656.2139	656.2139	656.2139	656.2139	656.2139	656.2139	656.2139	656.2139	656.2139	656.2139
12	768.3201	735.4142	571.3488	565.3178	565.3178	565.3178	565.3178	565.3178	565.3178	565.3178	565.3178	565.3178	565.3178	565.3178	565.3178	565.3178	565.3178
K=2																	
J	T(1,J,2)	T(2,J,2)	T(3,J,2)	T(4,J,2)	T(5,J,2)	T(6,J,2)	T(7,J,2)	T(8,J,2)									
1	1651.1674	1656.5677	1619.9763	1366.5661	1294.5661	1233.9829	1097.9905	977.5268									
2	1745.5153	1759.5153	1713.5153	1649.4852	1559.5153	1450.3954	1255.1900	1127.8503									
3	1356.1574	1392.1595	1403.1495	1829.3059	1721.0477	1503.9916	1450.5481	1276.8503									
4	2275.5077	2661.4964	2617.2614	1944.2762	1946.5268	1756.0711	1544.4845	1357.3273									
5	2144.5173	2129.7365	2055.4901	2011.2389	1905.7456	1752.3981	1603.0834	1440.4497									
6	2172.0162	2158.2276	2114.5164	2073.6919	1934.5095	1798.4908	1632.3579	1430.7632									
7	2153.9114	2149.5190	2106.3816	2072.1903	1930.2316	1795.1227	1634.3386	1446.4656									
8	2116.1065	2102.1578	2060.1672	1989.7750	1895.6246	1752.8654	1607.9405	1420.5902									
9	2522.2055	2579.0148	1959.4518	1932.2113	1910.9190	1691.0854	1544.7122	1385.5033									
10	1946.7861	1894.8758	1819.5179	1759.2664	1677.0129	1572.1306	1447.4013	1306.7887									
11	1621.6177	1615.8529	1581.7311	1533.5673	1467.7589	1384.6113	1287.6244	1188.5404									
12	1273.9929	1247.9441	1229.9555	1209.5826	1160.7152	1111.8124	1055.7909	996.9371									
J	T(9,J,2)	T(11,J,2)	T(13,J,2)	T(15,J,2)	T(17,J,2)	T(19,J,2)	T(21,J,2)	T(23,J,2)									
1	943.7392	913.8776	876.9303	476.5452	412.975	396.0280	396.0280	396.0280									
2	987.5872	916.3152	478.5452	460.4514	428.4514	428.4514	428.4514	428.4514									
3	1243.7713	895.2952	526.2337	498.4882	466.273	466.273	466.273	466.273									
4	1151.7756	939.6124	561.3066	528.6876	593.1569	507.0809	507.0809	507.0809									
5	1103.4443	978.0419	601.3709	558.3914	542.4212	542.4212	542.4212	542.4212									
6	1227.7064	1605.7621	539.4930	508.4654	581.4309	581.4309	581.4309	581.4309									
7	1241.6464	1125.5365	674.3647	545.3795	619.4214	619.4214	619.4214	619.4214									
8	1234.5444	1632.6552	738.6467	579.4256	654.2989	654.2989	654.2989	654.2989									
9	1214.4444	1625.6769	737.1584	709.0167	686.1674	586.5157	586.5157	586.5157									
10	1155.9616	1501.5616	752.6534	732.4414	712.8118	712.8118	712.8118	712.8118									
11	1257.1745	952.3449	762.5274	747.4197	732.4751	732.4751	732.4751	732.4751									
12	931.9354	949.9574	759.5964	751.2357	743.1427	742.9406	742.9406	742.9406									

AVERAGE TEMPERATURE OF CHANNEL 1  
SUSPENDED COOLANT STRUCTURE  
1119.4516 557.9337 543.2119

**Appendix 4**  
**Output List of Sample Calculation on**  
**Hottest Channel Calculation**

```
*****
*          J A E R I - M 7 2 8 0          *
*          H O T T E S T C H A N N E L   *
*          C A L C U L A T I O N   *
*          C A L C U L A T I O N   *
*****
```

<b>FAST BREEDER REACTOR CORE TRANSIENT CALCULATION CODE</b>
FUEL MELTING PROCESS CONSIDERED

```
*****
*          E X C U R S   O U T P U T   L I S T          *
*          H O T T E S T C H A N N E L   C A L C U L A T I O N   *
*          C A L C U L A T I O N   *
*****
```

<b>HOTTEST CHANNEL CALCULATION</b>
1973-07-05

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*****
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CASE NO. 1  
THIS OUTPUT IS FIRST TIME WRITTEN OUTPUT TO TAPE = 50.0 MIN.

	*****	*****	*****	*****	*****
	EXCURS	INPUT	LIST	LIST	LIST
INIT. OMEGA	INIT. INTERVAL	MIN. INTERVAL	MAX. INTERVAL	LOWER ACCURACY	UPPER ACCURACY
0.	2.51000E-03	1.00000E-10	3.00000E-03	5.00000E-02	5.00000E-03

CALCULATIONAL OPTION = 3  
NUMBER OF CHANNEL = 3  
TEMP. DEPENDENCE OF PHYSICAL VALUE = YES  
SCRAW = YES  
COOLANT VELOCITY CONDITION = -1.00  
CALCULATION TIME IN CODE = .002 SEC.

INIT. OMEGA	INIT. INTERVAL	MIN. INTERVAL	MAX. INTERVAL	LOWER ACCURACY	UPPER ACCURACY
0.	2.51000E-03	1.00000E-10	3.00000E-03	5.00000E-02	5.00000E-03
DEL. NEUT. FRAC.	NEUTRON LIFETIME SOURCE TERM	SUM FI*WI			
3.3C000E-03	1.00000E-07	1.00000E+00			
INITIAL VALUES OF NEUTRON AND DELAYED NEUTRON PRECURSORS					
1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00
DELAYED NEUTRON FRACTION (GROUP-WISE,RELATIVE VALUE)					
3.61100E-02	2.12500E-01	1.87700E-01	4.77800E-01	1.27800E-01	2.61000E-02
DECAY CONSTANTS OF DELAYED NEUTRON PRECURSORS					
1.27500E-02	3.17000E-02	1.16700E-01	3.14200E-01	1.401700E+00	3.880300E+00
FEEDBACK REACTIVITY COEFFICIENTS					
DOPPLER	FUEL EXPANSION	COOL. EXPANSION	STRUCT. EXPANSION		
-5.00000E-03	-4.00000E-06	-5.00000E-07	-2.00000E-06		
NO. OF AXIAL	NO. OF FUEL RADIAL	POWER DENSITY <sub>1</sub>	POWER DENSITY <sub>2</sub>	COOLANT VEL. <sub>1</sub>	INLET TEMP.
12	9	3.03000E+02	4.50000E+02	5.00000E+02	5.50000E+02
FUEL RADIUS	CLAD INNER RAD.	COOLANT RAD.	STRUCTURE RAD.	EQUIV. RAD.	CORE HEIGHT
2.75000E-01	2.80000E-01	3.15000E-01	4.080300E-01	4.21000E-01	6.00000E+01
MATERIAL PHYSICAL VALUES					
FUEL	HEAT CONDUCT.	DENSITY	SPECIFIC HEAT		
	6.71000E-03	1.03000E+01	3.20000E-02		
CLAD		7.82000E+00	1.38300E-01		
COOLANT		6.40000E-01	3.07000E-01		
STRUCTURE	4.65000E-02	7.32000E+00			
GAP CONDUCTANCE		1.35600E-11			
FUEL MELTING TEMP.		2.80000E+03			
SPEC. HEAT OF MOLTEN FUEL		8.99200E-02			
LATENT HEAT OF FUEL		6.96000E+01			
HEAT TRANSFER COEFFICIENT BETWEEN CLAD AND COOLANT					
NU = 0.	+ 6.250E-01 * (PE)**	4.300E-01			
EXTERNAL REACTIVITY INSERTION CONDITION					
STEP REAC.	STEP TIME	RAMP REAC.	RAMP TIME		
0.	0.	0.	0.		
COOLANT VELOCITY CHANGE					
V/V = 3.00E-01 * EXP(-1.05E+00*T) + 5.			*T + 2.000E-01		

SCRAM CONDITIONS POWER SETTING PERIOD SETTING VELOCITY SETTING TIMER SETTING SCRAM DELAY ROB MORTH  
 ACCELERATION 9.81G COGE+C2 1.230000E+00 1.500000E-31 8.000000E-01 5.000000E+01 3.300000E-02  
 ROB LENGTH 1.0.00000E+11 1.030000E-05 2.000000E+00 2.500000E-03 2.500000E-03 0.0  
 PRE-INSERTED LENGTH 6.000000E+01 0.

CALCULATION CONDITION PRINT INT. 1ST TIME INT. 2ND TIME INT. 3RD TIME INT. POWER DISTR. PLOT OPTION  
 PRINT INTERVAL CONVERG. CRIT. 1.0.00000E+11 1.030000E-05 2.000000E+00 2.500000E-03 2.500000E-03 0.0  
 10.0

NORMALISED PEAKING FACTOR (RADIAL)	TIME (S)									
	1	2	3	4	5	6	7	8	9	10
(AXIAL)	.6816	.6816	.6816	.6816	.6816	.6816	.6816	.6816	.6816	.6816
1	*.8941	*.8941	*.8941	*.8941	*.8941	*.8941	*.8941	*.8941	*.8941	*.8941
2	1.0693	1.0693	1.0693	1.0693	1.0693	1.0693	1.0693	1.0693	1.0693	1.0693
3	1.2006	1.2006	1.2006	1.2006	1.2006	1.2006	1.2006	1.2006	1.2006	1.2006
4	1.2807	1.2807	1.2807	1.2807	1.2807	1.2807	1.2807	1.2807	1.2807	1.2807
5	1.3079	1.3319	1.3079	1.3379	1.3079	1.3079	1.3079	1.3079	1.3079	1.3079
6	1.3679	1.2867	1.2310	1.2867	1.2310	1.2867	1.2310	1.2867	1.2867	1.2867
7	1.2807	1.2310	1.2006	1.2310	1.2006	1.2006	1.2006	1.2006	1.2006	1.2006
8	1.2006	1.2006	1.0693	1.2006	1.0693	1.0693	1.0693	1.0693	1.0693	1.0693
9	1.0693	1.0693	.8941	1.0693	.8941	.8941	.8941	.8941	.8941	.8941
10	.8941	.8941	.6816	.8941	.6816	.6816	.6816	.6816	.6816	.6816
11	.6816	.6816	.6816	.6816	.6816	.6816	.6816	.6816	.6816	.6816
12	.4406	.4406	.4406	.4406	.4406	.4406	.4406	.4406	.4406	.4406

MATERIAL PHYSICAL VALUES DEPENDENT ON TEMPERATURE ( $F(T) = A + B * T + C * T^2$ )

CONDUCTIVITY	A		
	B	C	
FUEL	-9.220000E-02	-9.220000E-02	2.750000E-09
CLAD	3.250000E-02	3.429000E-05	0.
COOLANT	2.220000E-01	-1.336000E-04	2.810000E-08
STRUCTURE	3.250000E-02	3.429000E-05	0.
DENSITY			
FUEL	1.03700000E+01	-2.62600000E-04	-6.68500000E-06
CLAD	7.93920000E+00	-4.33000000E-04	0.
COOLANT	9.51000000E-01	-2.46000000E-04	0.
STRUCTURE	7.93920000E+00	-4.33000000E-04	0.
SPECIFIC HEAT			
FUEL	7.66600000E-02	3.82300000E-06	1.74000000E-09
CLAD	1.15700000E-01	4.47000000E-05	0.
COOLANT	3.43220000E-01	-1.38690000E-04	1.10540000E-07
STRUCTURE	1.15700000E-01	4.47000000E-05	0.
GAP CONDUCTANCE			
	6.26300000E-02	7.18000000E-05	0.

## ENGINEERING HOT CHANNEL FACTOR

	COOLANT	CLAD INNER	CLAD OUTER	FUEL
UNCERTAINTY IN DIMENSION	1.0307	1.0307	1.0307	1.0307
UNCERTAINTY IN FISSION DISTR.	1.0003	1.0003	1.0003	1.0003
UNCERTAINTY IN COOL.PHYS.VAL.	1.0300	1.0300	1.0300	1.0300
UNCERTAINTY IN CLAD PHYS.VAL.	1.0002	1.0002	1.0002	1.0002
UNCERTAINTY IN GAP CONDUCTANCE	1.0003	1.0003	1.0003	1.0003
UNCERTAINTY IN FUEL PHYS.VAL.	1.0300	1.0300	1.0300	1.0300
UNCERTAINTY IN POWER LEVEL	1.0000	1.0000	1.0000	1.0000
UNCERTAINTY IN COOLANT VEL.	1.0500	1.0500	1.0500	1.0500
UNCERTAINTY IN FILM COEFF.	1.0007	1.0506	1.0309	1.0000
OTHER FACTORS	1.0003	1.0003	1.0003	1.0000

\*\*\*\*\* EXCURS OUTPUT LIST \*\*\*\*\*

NUM TIME IN SEC. TIME INTERVAL REACTIVITY PRI. INVERSE PER.AVG. INVERSE PER. NEUTRON FLUX DELTA FL. INTEG.

J. J. 0. 0. 0. 1. 1.0000000E+00 1.0000000E+00 1.0000000E+00 1.0000000E+00 1.0000000E+00

CONCENTRATION OF EACH GROUP OF DELAYED NEUTRON PRECURSORS

1.0000000E+00 1.0000000E+00 1.0000000E+00 1.0000000E+00 1.0000000E+00 1.0000000E+00

FEED BACK REAC. ROD REAC. COOLANT VEL.(1) COOLANT VEL.(12)

J. J. 0. 0. 5. 5.0000000E+02 5.5000000E+02

K=1

J T( 1,J,1) T( 2,J,1) T( 3,J,1) T( 4,J,1) T( 5,J,1) T( 6,J,1) T( 7,J,1) T( 8,J,1)

1 1160.5106 1160.5106 1160.5106 1160.5106 1160.5106 1160.5106 1160.5106 1160.5106

2 1489.4587 1489.4587 1489.4587 1489.4587 1489.4587 1489.4587 1489.4587 1489.4587

3 1731.9631 1731.9631 1731.9631 1731.9631 1731.9631 1731.9631 1731.9631 1731.9631

4 1903.2651 1903.2651 1903.2651 1903.2651 1903.2651 1903.2651 1903.2651 1903.2651

5 1986.0524 1986.0524 1986.0524 1986.0524 1986.0524 1986.0524 1986.0524 1986.0524

6 2122.4775 2122.4775 2122.4775 2122.4775 2122.4775 2122.4775 2122.4775 2122.4775

7 2005.1493 2005.1493 2005.1493 2005.1493 2005.1493 2005.1493 2005.1493 2005.1493

8 1955.8208 1955.8208 1955.8208 1955.8208 1955.8208 1955.8208 1955.8208 1955.8208

9 1805.4419 1805.4419 1805.4419 1805.4419 1805.4419 1805.4419 1805.4419 1805.4419

10 1602.3614 1602.3614 1602.3614 1602.3614 1602.3614 1602.3614 1602.3614 1602.3614

11 1322.4973 1322.4973 1322.4973 1322.4973 1322.4973 1322.4973 1322.4973 1322.4973

12 1116.2170 1116.2170 1116.2170 1116.2170 1116.2170 1116.2170 1116.2170 1116.2170

J T( 9,J,1) T(10,J,1) T(11,J,1) T(12,J,1) T(13,J,1) T(14,J,1) T(15,J,1) T(16,J,1)

1 767.6940 666.1805 409.7647 388.3247 378.5850 378.5850 378.5850 378.5850

2 909.1024 758.9084 431.5455 403.2174 390.1160 390.1160 390.1160 390.1160

3 1017.8038 833.3156 452.9411 419.6392 403.9227 403.9227 403.9227 403.9227

4 1091.6798 983.5057 473.2056 436.8566 419.3056 419.3056 419.3056 419.3056

5 1145.2021 921.6213 492.1779 454.3044 435.6334 435.6334 435.6334 435.6334

6 1165.0189 904.6938 509.3922 471.4376 452.3133 452.3133 452.3133 452.3133

7 1163.1892 904.4196 524.4457 487.6582 468.7695 468.7695 468.7695 468.7695

8 1144.2734 935.3714 536.7556 502.4095 484.3946 484.3946 484.3946 484.3946

9 1049.4169 902.9584 545.5856 514.9112 498.5512 498.5512 498.5512 498.5512

10 1106.7542 953.5648 550.0588 524.3968 510.5268 510.5268 510.5268 510.5268

11 894.4812 782.0205 549.4385 530.1324 519.6028 519.6028 519.6028 519.6028

12 759.4360 692.5538 543.9346 531.8861 525.2857 525.2857 525.2857 525.2857

K=2

J T( 1,J,2) T( 2,J,2) T( 3,J,2) T( 4,J,2) T( 5,J,2) T( 6,J,2) T( 7,J,2) T( 8,J,2)

1 1661.2559 1650.4298 1518.0792 1564.0968 1489.4554 1391.2596 1272.8568 1134.1458

2 2223.6407 2010.5356 1911.0713 1914.7602 1610.8427 1688.5343 1537.2462 1356.8238

3 2251.8931 2251.6023 2222.4804 2129.7197 2026.0125 1889.6957 1718.6729 1512.2447

4 2411.3451 2396.4133 2151.3226 2157.0465 2165.9757 2165.9757 1839.1960 1617.5337

5 2490.2557 2494.0158 2437.9551 2360.0487 2248.3550 2100.3082 1912.2866 1692.3914

6 2531.3438 2518.0585 2471.8727 2393.6541 2281.4967 2132.7019 1943.9655 1711.6669

7 2516.8958 2514.7988 2456.1883 2378.9687 2268.2982 2121.5868 1935.5303 1707.1039

8 2446.4407 2433.7487 2389.4897 2314.6337 2207.5267 2065.8836 1886.9619 1667.9935

9 2322.9837 2337.0810 2265.1412 2194.3467 2193.3761 1960.4413 1793.5519 1590.9666

10 2110.2960 2116.6209 2168.4578 2004.2568 1913.1988 1794.2156 1646.3398 1468.9605

11 1813.9231 1813.3721 1771.6478 1718.5867 1563.9380 1567.5214 1429.3121 1289.5693

12 1376.8494 1367.9583 1347.3079 1312.9693 1265.0792 1203.8562 1129.5383 1042.8001

J T( 9,J,2) T(10,J,2) T(11,J,2) T(12,J,2) T(13,J,2) T(14,J,2) T(15,J,2)

1 976.4076 911.6481 430.5799 398.0629 383.1432 383.1432 399.9460 399.9460

2 1144.4123 914.6847 459.6810 419.1626 441.4536 441.4536 419.3368 419.3368

3 1269.9617 994.4736 487.1697

4	1353.9083	1350.8455	513.3154	464.7038	460.4915	440.4915
5	1457.3676	1450.8493	538.2557	462.7229	462.7229	462.7229
6	1453.5466	1450.9726	511.5049	485.3813	485.3813	485.3813
7	1433.7856	1436.6397	533.7934	507.8193	507.8193	507.8193
8	1457.4355	1466.5657	599.3050	529.3577	529.3577	529.3577
9	1352.0515	1278.5272	613.1599	572.4574	549.2516	549.2516
10	1262.4617	1229.7829	622.0235	585.6356	566.6356	566.6356
11	1220.4528	950.3514	624.1490	595.6559	586.4399	586.4399
12	944.2797	834.5854	617.7430	599.9673	589.4096	589.4096
K=3			T( 1,J,3)	T( 3,J,3)	T( 5,J,3)	T( 7,J,3)
J	1762.5387	1756.7258	1715.2747	1656.1620	1573.4397	1467.384
1	2153.3948	2139.0204	2095.7461	2023.6802	1320.3133	1786.7231
2	2401.5927	139.9116	2304.6161	2264.8579	2151.2979	2016.2642
3	257.637	2557.6197	2504.1562	2420.5515	2301.0716	2143.4135
4	256.7445	2546.9841	2596.4816	2511.3266	2389.6779	2226.7820
5	2690.2579	2612.4834	2631.8135	2496.0392	2623.1690	2264.5916
6	2680.2563	2663.6876	2613.6434	2528.9631	2607.7170	2247.2517
7	260.0931	258.1130	2540.4534	2458.3566	2341.6171	2186.6927
8	2466.3495	2451.0949	2401.9784	2327.4461	2216.8269	1991.9639
9	2247.4265	2233.5267	2191.6638	2121.2768	2021.5363	1889.5061
10	191.5306	1900.1953	1870.1693	1812.3245	1730.3348	1691.4716
11	1441.4649	1433.8666	1411.2731	1373.7276	1321.4331	1254.7689
12			T(10,J,3)	T(11,J,3)	T(12,J,3)	T(13,J,3)
J	1521.3553	840.9816	472.9941	399.3613	383.9096	283.9096
1	1204.7647	963.1020	463.4653	422.0788	401.6922	601.6922
2	1333.8039	154.6818	492.3022	445.7643	422.2114	422.2114
3	1422.4879	1103.5996	519.8279	470.3571	444.6018	444.6018
4	1478.3935	1148.3105	545.9082	495.2683	468.1296	468.1296
5	1505.1939	1170.2706	570.1698	519.9587	492.1092	492.1092
6	1504.41757	1175.2310	592.0631	541.4320	515.8554	515.8554
7	1474.7672	1162.6726	610.9752	565.2176	538.6498	538.6498
8	1414.4854	1130.6933	625.5915	581.3361	559.7036	559.7036
9	1317.5647	1175.3022	635.2666	590.5905	578.1015	578.1015
10	1174.5420	989.4334	637.8319	603.8969	592.7106	592.7106
11	976.2149	962.8160	631.4144	613.3870	602.2033	602.2033
K=1			AVERAGE TEMPERATURE OF CHANNEL 1 FUEL CLAD COOLANT STRUCTURE			
J	1252.3917	485.4193	457.2504	457.2504		
1	2.500000E+03	2.500000E+03	0			
CONCENTRATION OF EACH GROUP OF DELAYED NEUTRON PRECURSORS	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00	1.000000E+00
FED BACK REAC.	ROD REAC.	3.	COOLANT VEL.(1) COOLANT VEL.(2)	4.99503624E+02	5.499506687E+02	
K=1			T( 1,J,1)	T( 2,J,1)	T( 3,J,1)	T( 4,J,1)
J	1187.7217	1183.9119	1166.5195	1126.6736	1079.5995	1019.6337
1	1498.8974	1489.4460	1461.453	1414.3253	1348.3394	947.3394
2	1734.9452	1723.7625	1693.1682	1634.0367	1555.2309	1166.0793
3	1893.2175	1881.6424	1844.4194	1783.0419	1453.7176	1329.7333
4	1985.0250	1973.3614	1935.2478	1871.2418	1596.846	1283.3445
5	2122.4367	2049.6522	1971.1567	1905.4570	1517.5975	1344.7221
6					1695.7457	1372.3540