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A Computer Program for Three-Dimensional Nuclear and Thermal-Hydraulic Analysis of BWR Core: STEADY-ACE

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A FORTRAN computer program named as STEADY-ACE has been developed to predict the three-dimensional distributions of neutron flux, power and void fraction in a BWR core. The program consists of two subprograms, i.e., the few-group three-dimensional diffusion subprogram DIFFUSION-ACE and the thermal-hydraulic subprogram HYDRO-ACE. The two subprograms are combined in an iterative way so that the interdependency of the power distribution and the void fraction distribution can be treated consistently.

The program STEADY-ACE provides a prediction of BWR core performance in a good accuracy in a reasonably short computation time. The computation time of the example case of JPDR quarter core (72/4 assemblies) is 7 CPU minutes on the machine FACOM 230-75.

Keywords : Computer Program, STEADY-ACE, Core Performance, BWR, JPDR, DIFFUSION-ACE, Three Dimension, Power Distribution, Neutron Diffusion, HYDRO-ACE, Multi-Channel, Thermal-Hydraulics, Void Fraction Distribution, Two Phase Flow, Leakage Iterative Method.

* General Electric Technical Services Co. Inc.

BWR 炉心3次元核熱水力計算プログラム：STEADY-ACE

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1979年6月14日　受理

計算機用プログラム STEADY-ACE は，BWR 炉心内の3次元中性子束，出力および減速材ボイド体積割合の空間分布を計算により求めるために開発された．このプログラムは2つのサブプログラムからなっている．即ち，少数群3次元拡散方程式を解くプログラム DIFFUSION-ACE と熱水力計算プログラム HYDRO-ACE の2つである．この2つのサブプログラムは，出力分布とボイド分布の相関性が矛盾なく取り扱えるように，繰り返し計算の形で結合されている．

プログラム STEADY-ACE は，実用的な範囲の少ない計算機時間で BWR の炉心特性を精度良く計算する．例を挙げるならば，72 燃料集合体よりなる JPDR の 1/4 炉心の場合の計算時間は，計算機 FACOM-230-75 で CPU 時間で7分間である．

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Contents

目　　次

1 Introduction

One of the objectives in the BWR core design is to verify that the power peaking factor does not exceed the limiting value. It is therefore very important to calculate the power peaking factor accurately.

The difficulties in the calculation of the power peaking factor are: (1) the power distribution is skewed both horizontally and vertically due to the insertion of the control rods and (2) the void fraction distribution and the power distribution are so strongly dependent on each other that they cannot be calculated separately. Three-dimensional calculation is required to overcome the first difficulty. The second difficulty can be solved by performing the iterative calculation between the thermal-hydraulic calculation to get the void fraction distribution and the neutron diffusion calculation to obtain the power distribution.

A number of computer programs have been developed to solve these difficulties. The commonly used program is FLARE[1], which has an advantage of short computation time, but also a disadvantage of low accuracy. One of the causes for its low accuracy is that the power distribution calculation is based on the pseudo-diffusion equation using the neutron transport kernel. Another cause is that the flow rate distribution in the flow channels is given apriori by the separate thermal-hydraulic calculations, such as by JP-HYDRO[2] or HYDRO-ACE[3]. The interdependency of the void fraction and power distributions cannot be treated by FLARE in a satisfactory manner. A computer program named as STEADY-ACE satisfying these requirements has been developed to overcome the disadvantages of FLARE.

The program STEADY-ACE combines the two computer programs; the thermal-hydraulic program HYDRO-ACE and the three-dimensional neutron diffusion program DIFFUSION-ACE[4], to treat the interdependency of the void fraction and the power distributions more accurately. HYDRO-ACE calculates the flow rates and the void distributions in the flow channels in the core shroud. DIFFUSION-ACE adopts a new method called "Leakage Iterative Method"[5] to solve the three-dimensional diffusion equation of two or three energy groups to obtain the power distribution. The new method is one of the synthesis methods which combine the z-directional one-dimension calculation with the x-y directional two-dimensional calculation. The computation time can be reduced significantly by the "Leakage Iterative Method" without sacrificing the accuracy. The advantage of short computation time in DIFFUSION-ACE allows the practical use of the void-power iteration in STEADY-ACE.

2 Geometry

STEADY-ACE simulates a BWR core performance. The calculational model in STEADY-ACE is explained here using an example of the JPDR-II core. JPDR is a small BWR located in Tokai Research Establishment of Japan Atomic Energy Research Institute. The reactor has been modified since 1964 to double the power capacity. The modified reactor is called as JPDR-II. The major core parameters of JPDR-II are given in TABLE 2.1. The x-y cross section of the JPDR-II core is illustrated in **Fig. 2.1**.

The calculational model of a BWR core for the thermal-hydraulic calculation HYDRO-ACE is discussed first. A BWR core, such as JPDR-II core, consists of parallel channels. As each fuel assembly is enclosed by a channel box, each flow path in a channel box can be treated separately to predict its thermal-hydraulic behaviors. The flow paths outside the channel boxes are treated collectively as one flow path named as "leakage flow channel". The leakage flow channel includes the flow paths between the channel boxes in the dummy fuel assemblies and near the surrounding core shroud. **Figure 2.2** shows the horizontal view of the JPDR-II core model for the thermal-hydraulic calculation. The flow paths are numbered, taking the symmetry into consideration. The example of JPDR-II core in **Fig. 2.2** is based on its 90 degree mirror symmetry. This numbering sequence is arbitrary except the leakage flow channel should have the last number.

The vertical model of each flow channel is given in **Fig. 2.3**. The flow channel is divided into a number of sections based on the flow area and thermal characteristics. The heated zone is treated separately from the unheated zone. In the example of **Fig. 2.3**, the flow channel is divided into 6 sections, i.e., lower supporter, nose piece, lower unheated zone, heated zone, upper unheated zone and upper supporter. The heated zone is divided equally further into "block".

TABLE 2.1 JPDR-II core data

(1) Fuel rod	
Pellet diameter	10.66 mm
Clad thickness	0.70 mm
Clad outer diameter	12.23 mm
Fuel effective length	1,467 mm
Gass plenum volume	13 cc
Fuel material	UO_2
Clad material	Zr-4
Fuel density	10.41 g/cc
(2) Fuel assembly	
Number of fuel assembly	72
Fuel rod array	7×7
Number of fuel rods per assembly	49
Fuel rod pitch	16.6 mm
UO_2 weight per assembly	1370×49 kg
Fuel assembly weight	about 100 kg
(3) Channel box	
Thickness	1.5 mm
Material	Zr-4
(4) Control rod	
Number	16
Type	cross-shaped section
Pitch (square array)	273.2 mm
Stroke	about 150 cm
Width	225.4 mm
Effective length	1,460 mm
Poison	B_4C powder
Clad & sheath material	S. S.
Width of follower	114.3 mm
Thickness of follower	6.35 mm
Effective length of Follower	1,283 mm
Follower material	Zr-4
B_4C density	70%
(5) Poison curtain	
Number	24
Type	flat board
Width	2.48 mm
Thickness	3.2 mm
Length	1,667 mm
Poison	Boron in SS
Boron concentration	1,030 ppm

The blocks are numbered sequentially from the bottom to the top. The elevation of the blocks should be equal for all of the flow channels.

Next, the calculational model of a BWR core for the nuclear calculation DIFFUSION-ACE is discussed. A BWR core is divided into square lattice cells of fuel bundles as shown in **Fig. 2.4**. The nuclear cross sections associated with the lattice cells are defined to be the homogenized nuclear cross sections for the fuel, cladding, channel box, interior water, exterior water, (if applicable) control rods and poison curtains. The fuel bundle cells are designated by the same number as the thermal-hydraulic model described earlier in this section. The regions outside the fuel bundles are called collectively as "side reflector". The number assigned to the side reflector is 0, as shown in **Fig. 2.4**. The cross sections associated with the side reflector are often assumed to be the cross sections of water without steam voids.

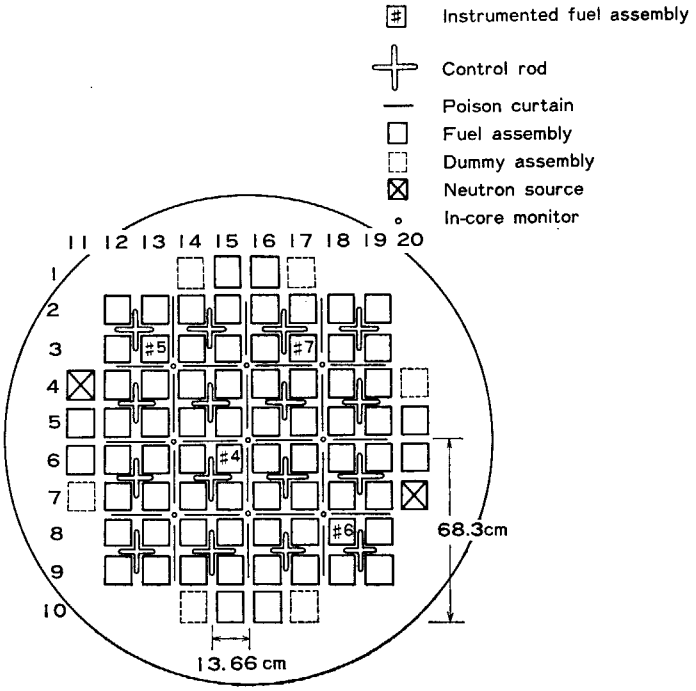


Fig. 2.1 X-Y cross section of JPDR-II core

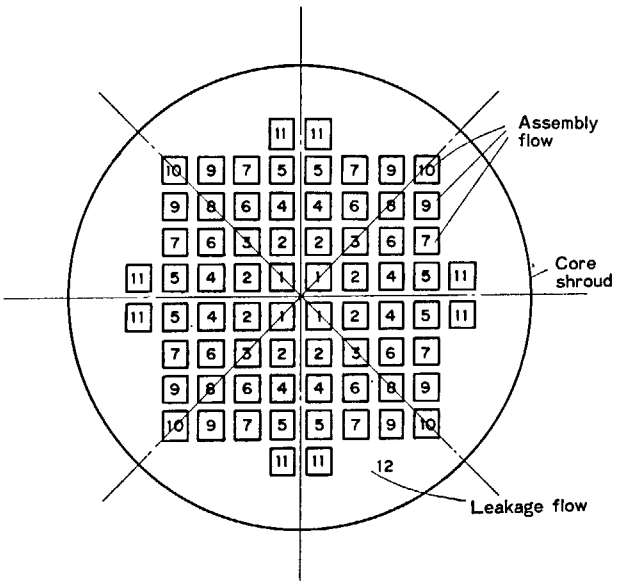


Fig. 2.2 Horizontal geometry for HYDRO-ACE

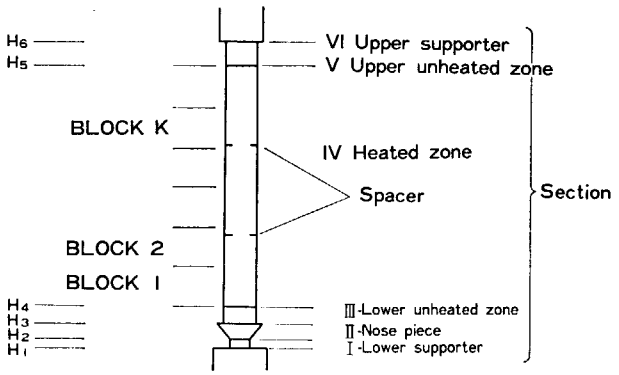


Fig. 2.3 Vertical geometry for HYDRO-ACE

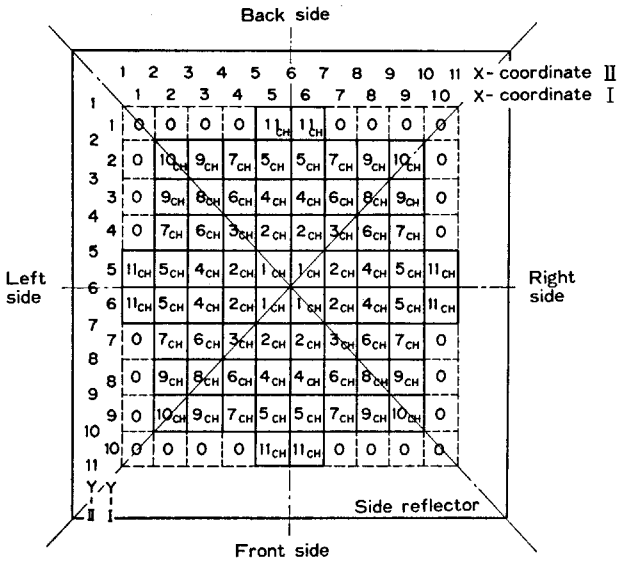


Fig. 2.4 Horizontal geometry for DIFFUSION-ACE

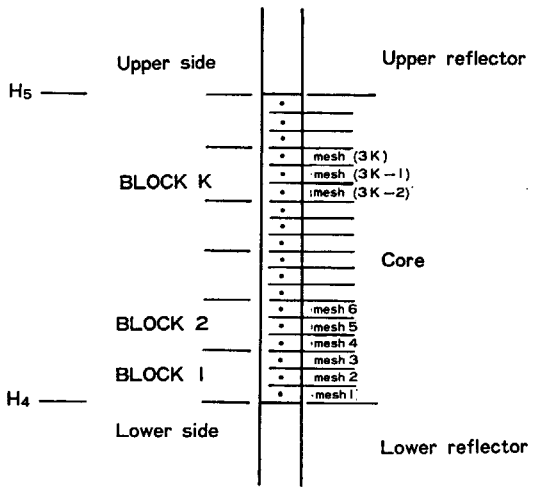


Fig. 2.5 Vertical geometry for DIFFUSION-ACE

The fuel bundle cells are also called as channels in this report. But there is a minor difference between the channels in the thermal-hydraulic model and the channels in the nuclear model. The channels in the nuclear model include the water between the channel boxes, control rods and poison curtains, but the channels in the thermal-hydraulic model do not. The water between the channel boxes is included in the leakage flow path in the thermal-hydraulic model.

The vertical geometry for nuclear calculation is shown in **Fig. 2.5**. The channel is divided into 3 regions. The region corresponding to the heated zone in the thermal-hydraulic model is now called as "core" in the nuclear model. The lower regions including lower unheated zones, nose piece and lower supporter in **Fig. 2.3** are called collectively as "lower reflector" in **Fig. 2.5** and assumed to be homogeneous in the nuclear properties. In other words, uniform cross sections are assigned to the lower reflector region. Similarly, the upper regions including the upper unheated zone and upper supporter in **Fig. 2.3** are called collectively as "upper reflector" in **Fig. 2.5** and assumed to be homogeneous in the nuclear properties.

The "core" region is further divided into blocks in the same way as discussed in the thermal-hydraulic model. The size, elevation and identification number of the blocks in the nuclear model should be identical to those in the thermal-hydraulic model. As the blocks of the same identification number are at the same elevation, they form a layer between the two horizontal parallel planes. In other words, a block is a parallel-piped defined by a channel and a layer.

The program DIFFUSION-ACE solves the three-dimensional diffusion equation by solving alternatively one-dimensional equation for each of the channels and two-dimensional equation for each of the layers. In order to improve the accuracy of calculations, blocks are further subdivided into meshes. For example, in the one-dimensional calculation for each of the channels, blocks are subdivided into meshes, as shown by the example in **Fig. 2.5**. The objective of the subdivision into meshes is to make the mesh size length comparable to the diffusion length of thermal neutrons. Similarly, a block is subdivided into a few meshes in the x and y directions in the two-dimensional diffusion calculation for each of the layers.

Finally, the coordinates in the x-y horizontal cross section are discussed. Two coordinate systems are used as shown in **Fig. 2.4**. X-coordinate I (or Y-coordinate I) is used to designate the channel location and x-coordinate II (or Y-coordinate II) is used to designate the locations of the control rods and the in-core monitors.

3 Basic Equations

STEADY-ACE is composed of the thermal-hydraulic subprogram HYDRO-ACE and the three-dimensional neutron diffusion subprogram DIFFUSION-ACE. The basic equations of the two subprograms and their interface are explained in this chapter.

3.1 Basic Equations in HYDRO-ACE

HYDRO-ACE calculates the flow rates and the void distributions in the flow channels in the core shroud. The power distributions in the channels are supplied from DIFFUSION-ACE.

The flow rates in the flow channels are determined so that the pressure differentials between the inlets and outlets are equal for all of the flow channels. The pressure differentials consist of head loss, friction loss, expansion/contraction loss, spacer loss and acceleration loss.

The head loss is expressed by the following equation.

$$\begin{aligned}\Delta P_{\mathrm{H}} &= \int_{Z_{\mathrm{in}}}^{Z_{\mathrm{out}}} \rho(z)dz \\ &= \int_{Z_{\mathrm{in}}}^{Z_L} \rho(z)dz + \int_{Z_L}^{Z_{\mathrm{u}}} \rho(z)dz + \int_{Z_{\mathrm{u}}}^{Z_{\mathrm{out}}} \rho(z)dz \\ &= \rho_{\mathrm{in}} \cdot (Z_L - Z_{\mathrm{in}}) + \sum_{k=1}^{K} \rho_k \Delta Z + \rho_{k+1} \cdot (Z_{\mathrm{out}} - Z_{\mathrm{u}}),\end{aligned} \tag{3.1}$$

where

ΔP_{H} : head loss [kg/m^2]
Z_{in} : height of the inlets of the flow channels [m]
Z_{out} : height of the outlets of the flow channels [m]
Z_L : height of the lower end of the heated zone [m]
Z_{u} : height of the upper end of the heated zone [m]
ρ_k : fluid density at the k-th block [kg/m^3]
ρ_{k+1} : fluid density at the upper end of the heated zone [kg/m^3]
ρ_{in} : fluid density at the inlet
ΔZ : length of one block
K : number of the blocks.

The friction loss depends on the flow characteristic, i.e. single phase flow or two phase flow. The friction loss for single phase flow is expressed by

$$\begin{aligned}\Delta P_{\mathrm{FR}} &= f \cdot \frac{\rho}{2g} V^2 \frac{dz}{De} \\ &= f \cdot \frac{W^2}{2g \cdot \rho \cdot A^2} \cdot \frac{dz}{De},\end{aligned} \tag{3.2}$$

where

ΔP_{FR} : single phase friction loss [kg/m^2]
f : friction factor
ρ : density [kg/m^3]
g : gravitational acceleration [9.8 m/sec^2]
V : velocity [m/sec]

De: equivalent hydraulic diameter [m]
dz: length [m]
W: mass flow rate [kg/sec]
A: flow area [m^2].

The friction factor f is non-dimensional and expressed as f function of the Reynolds number Re:
For $Re<2000$ (laminar flow)

$$f=\frac{64}{Re}, \tag{3.3}$$

For $2000<Re<10^4$ (Blasius' equation)

$$f=0.3164\,Re^{-0.25}, \tag{3.4}$$

For $10^4<Re<1.9\times10^6$ (Hermann's equation)

$$f=0.00540+0.397\cdot Re^{-0.3}, \tag{3.5}$$

Re is defined as

$$Re=\frac{De\cdot W}{\rho\cdot A\cdot\nu}, \tag{3.6}$$

where ν: viscosity [m^2/sec].

The friction loss for two phase flow has been studied by a number of researchers. HYDRO-ACE allows the user to select an equation from the following four correlations.

Martinelli-Nelson correlation

$$\Delta P_{TPF}=\phi_{ltt}\cdot\Delta P_l, \tag{3.7}$$

where

ΔP_{TPF}: two phase friction loss
ϕ_{ltt}: two phase friction multiplier

$$\Delta P_l=f\cdot\frac{W_l^2}{2g\cdot\rho_l\cdot A^2}\cdot\frac{dz}{De},$$

ρ_l: density of liquid
W_l: flow rate of liquid phase

$$W_l=W_o\cdot(1-x) \tag{3.8}$$

W_o: total flow rate
x: quality

The local two phase friction multiplier ϕ_{tt} is expressed as a function of the quality and the absolute pressure, as shown in **Fig. 3.1**.

Sher's correction

Sher proposed a correction of Martinelli-Nelson correlation. **Figure 3.2** gives the two phase friction multiplier as a function of the mass flow rate and quality based on Westinghouse data. **Figure 3.3** shows the relative value of the two phase friction multiplier to the value at $G=10^6$ ($lb/hr\cdot ft^2$).

Armand's correlation

Armand's correlation is based on the total flow rate rather than the liquid phase rate.

$$\Delta P_{TPF}=R_o\cdot\Delta P_o, \tag{3.9}$$

where

ΔP_{TPF}: two phase friction loss
R_o: two phase friction multiplier

$$\Delta P_o=f\cdot\frac{W_o^2}{2g\cdot\rho_l\cdot A^2}\cdot\frac{dz}{De}.$$

The two phase friction multiplier is expressed as

$$R_o=\begin{cases}(1-\alpha)^{-1.42} & \text{for } 0\leq\alpha\leq 0.65\\ 0.478(1-\alpha)^{-2.2} & \text{for } 0.65<\alpha\leq 0.9\\ 1.73(1-\alpha)^{-1.64} & \text{for } 0.9<\alpha\leq 0.999\end{cases} \tag{3.10}$$

where α is a void fraction.

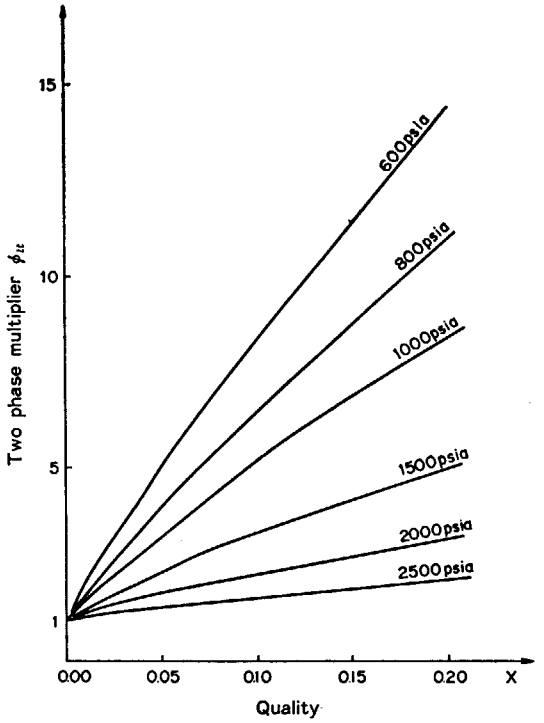


Fig. 3.1 Two phase flow friction loss multiplier by Martinelli-Nelson.

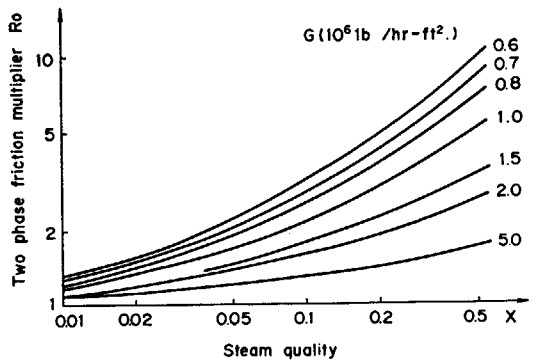


Fig. 3.2 Westinghouse two phase friction multiplier by Sher.

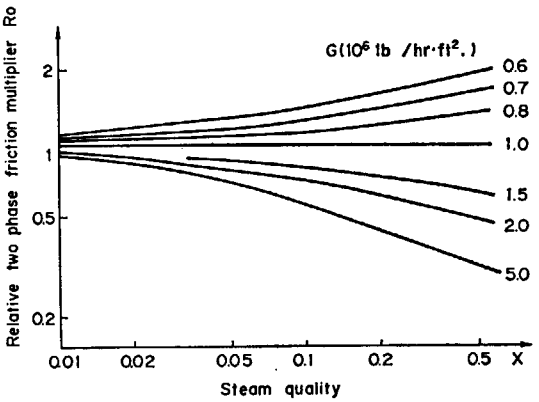


Fig. 3.3 Two phase friction loss multiplier normalized to that of 10^6 lb/hr-ft^2 (Sher's method).

Lottes-Finn's correlation

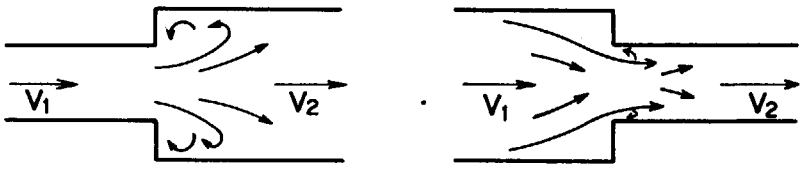
Lottes-Finn's correlation is similar to Armand's correlation. The difference lies in the expression of the two phase friction multiplier. It is expressed as

$$R_o=\left(\frac{1-x}{1-\alpha}\right)^2. \tag{3.11}$$

The pressure loss due to the change of the flow area is called E/C pressure loss in this document (see **Fig. 3.4**). For expansion flow, the pressure loss is expressed as

$$\Delta P_{E/C}=K_{E/C}\cdot\frac{\rho}{2g}V_1^2 \tag{3.12}$$

For contraction flow, it is expressed as



a) Expansion loss b) Contraction loss

Fig. 3.4 Model for calculating expansion contraction loss.

TABLE 3.1 Relation of contraction rate A_2/A_1 and loss coefficient $K_{E/C}$.

A_2/A_1	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
$K_{E/C}$	0.48	0.45	0.41	0.36	0.29	0.21	0.13	0.07	0.01

$$\Delta P_{E/C}=K_{E/C}\cdot\frac{\rho}{2g}V_1^2, \tag{3.13}$$

where

$\Delta P_{E/C}$: E/C pressure loss

$K_{E/C}$: E/C loss coefficient

ρ: average density at the location of flow area change [kg/m^3]

g: gravitational acceleration [9.8 m/sec^2]

V_1: velocity before flow area change [m/sec]

V_2: velocity after flow area change [m/sec].

The E/C loss coefficient $K_{E/C}$ is determined by the Weisbach's method. For expansion flow,

$$K_{E/C}=\left(1-\frac{A1}{A2}\right)^2, \tag{3.14}$$

$A1$: flow area before change [m^2]

$A2$: flow area after change [m^2].

For contraction flow the coefficient is derived by the interpolation between the values in TABLE 3.1.

The spacer pressure loss is estimated by

$$\Delta P_{sp}=K_{sp}\cdot\frac{\rho}{2g}V^2, \tag{3.15}$$

ΔP_{sp}: pressure loss due to spacer [kg/m^2]

K_{sp}: spacer pressure loss coefficient

ρ: average density at spacer location [kg/m^3]

g: gravitational acceleration (=9.8 m/sec^2)

V: average velocity of the two phase flow [m/s].

Finally, the acceleration loss is estimated by

$$\Delta P_{acc}=\frac{W}{g}(V_{out}-V_{in}), \tag{3.16}$$

ΔP_{acc}: acceleration loss [kg/m^2]

W: mass flow rate [kg/sec]

g: gravitational acceleration (=9.8 m/sec^2)

V_{in}: inlet flow velocity [m/s]

V_{out}: outlet flow velocity [m/s]

In the pressure loss calculations described above, the important variables are enthalpy, steam quality and void fraction. The estimation of these variables is discussed below.

The enthalpy is calculated as

$$H(z)=H_{in}+\frac{q(z)}{W}, \tag{3.17}$$

$H(z)$: enthalpy at a given position z [kcal/kg]
H_{in} : inlet enthalpy [kcal/kg]
$q(z)$: heat generated in the fuel bundle from inlet up to the position z [kcal/sec]
W : mass flow rate in the bundle [kg/sec].

The quality is calculated as

$$x(z)=\frac{H(z)-H_f}{H_g-H_f}, \tag{3.18}$$

$x(z)$: quality at the position z
$H(z)$: enthalpy at the position z [kcal/kg]
H_f : enthalpy of saturated water [kcal/kg]
H_g : enthalpy of saturated steam [kcal/kg].

The void fraction is estimated by the Maurer's method[6] for three different regions.

Region 1 : Subcooled region

Region 2 : Transition region from Region 1 to Region 3

Region 3 : Bulk boiling region

The boundary of the above three regions are :

Boundary between Region 1 and Region 2 : The average thickness of the steam film on the heated surface is 0.004 inch.

Boundary between Region 2 and Region 3 : The void fraction is 40%.

The void fraction correlation for the above three regions is as follows :

Region 1

The heat transfer coefficient at the heated surface is estimated by

$$h=0.030\frac{K}{De}(Re)^{0.8}(Pr)^{0.4}, \tag{3.19}$$

h : heat transfer coefficient [Btu/hr·ft²·°F]
k : thermal conductivity of water [Btu/hr·ft·°F]
De : hydraulic diameter [ft]
Re : Reynolds number
Pr : Prandtl number.

The wall temperature of the heated surface T_w is estimated by

$$T_w=T_{sat}+60\cdot\left(\frac{q}{10^6}\right)^{0.25}\cdot\exp\left[-\left(\frac{P}{90}\right)\right], \tag{3.20}$$

where T_w : wall temperature [°F]
T_{sat} : saturation temperature of water [°F]
q : heat flux [Btu/hr·ft²]
P : system pressure [psia].

The thickness of the steam film, a [ft] is calculated from the heat transfer coefficient h and the wall temperature as

$$a=\frac{[q-h(T_w-T_B)]\cdot Pr\cdot K}{1.07\cdot h^2\cdot(T_{sat}-T_B)}, \tag{3.21}$$

where a : thickness of the steam film [ft]
T_B : temperature corresponding to the bulk enthalpy at the given position [°F].

The thickness a is described by the MKS unit system as

$$a'=0.3048\cdot a, \tag{3.22}$$

a' : thickness of the steam film [m].

Then the void fraction is calculated as

$$\alpha=a'\cdot l_H/A, \tag{3.23}$$

α: void fraction
l_H: heated circumferential [m]
A: flow area [m^2].
The Eq. (3.23) is applicable for $a \leq 0.004/12\,\text{ft}$ ($a' \leq$ about 0.1 mm).

Region 2

The void fraction in Region 2 is calculated by the interpolation of the enthalpy.

$$\alpha=\alpha_1+(\alpha_3-\alpha_1)\frac{H-H_1}{H_3-H_1}, \tag{3.24}$$

α: void fraction for a given enthalpy H
H_1: enthalpy at the end point of Region 1, i.e. $a=0.004/12\,\text{ft}$
α_1: void fraction at the end point of Region 1
α_3: 0.40 (starting point of Region 3)
H_3: enthalpy at the starting point of Region 3, i.e. $\alpha_3=0.40$.

Region 3

The void fraction is calculated by the Bankoff's equation.

$$\alpha=\frac{0.71+10^{-4}\cdot P}{1+\frac{\rho_g}{\rho_f}\cdot\frac{1-x}{x}}, \tag{3.25}$$

α: void fraction
P: system pressure
ρ_g: density of saturated steam [kg/m^3]
ρ_f: density of saturated water [kg/m^3]
x: quality.

3.2 Basic Equations in DIFFUSION-ACE

DIFFUSION-ACE solves a three-dimensional diffusion equation by combining the z-directional one-dimension and the x-y-directional two dimension calculations. A new method called "Leakage Iterative Method" has been developed to perform the alternating one-dimensional and two-dimensional calculations effectively.

A general diffusion equation is

$$\nabla D\nabla\phi-\Sigma_T\phi+S=0, \tag{3.26}$$

where D: diffusion coefficient
ϕ: neutron flux
$\Sigma_T=\Sigma_a+\Sigma_r$
Σ_a: absorption cross section
Σ_r: slowing down cross section
S: source.

Integrating Eq. (3.26) over a block which is assumed to be homogeneous in its nuclear characteristics, we get

$$D\int_{\Delta x}\int_{\Delta y}\int_{\Delta z}dxdydz\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial x^2}\right)+D\int_{\Delta x}\int_{\Delta y}\int_{\Delta z}dxdydz\left(\frac{\partial^2\phi}{\partial z^2}\right)$$
$$-\Sigma_T\int_{\Delta x}\int_{\Delta y}\int_{\Delta z}\phi dxdydz+\int_{\Delta x}\int_{\Delta y}\int_{\Delta z}Sdxdydz=0, \tag{3.27}$$

where Δx, Δy and Δz give the dimensions of the block.

The leakage terms L_{xy} and L_z are defined as

$$-L_{xy}=\frac{D\int_{\Delta x}\int_{\Delta y}\int_{\Delta z}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}\right)dxdydz}{\int_{\Delta x}\int_{\Delta y}\int_{\Delta z}\phi dxdydz} \tag{3.28}$$

$$-L_z=\frac{D\int_{\Delta x}\int_{\Delta y}\int_{\Delta z}\left(\frac{\partial^2\phi}{\partial z^2}\right)dxdydz}{\int_{\Delta x}\int_{\Delta y}\int_{\Delta z}\phi dxdydz}. \tag{3.29}$$

The flux and source terms integrated over a block are given as

$$\phi_b=\int_{\Delta x}\int_{\Delta y}\int_{\Delta z}\phi dxdydz, \tag{3.30}$$

$$\theta_b=\int_{\Delta x}\int_{\Delta y}\int_{\Delta z}Sdxdydz. \tag{3.31}$$

Inserting Eqs. (3.28), (3.29), (3.30) and (3.31) into Eq. (3.27), it gives

$$-(L_{xy}+L_z+\Sigma_T)\phi_b+\theta_b=0. \tag{3.32}$$

Given θ_b, L_{xy}, L_z and Σ_T, the integrated flux ϕ_b can be easily derived from Eq. (3.32). But the leakage terms L_{xy} and L_z are not given apriori. The leakage terms L_{xy} and L_z must be derived from the two-dimensional calculations and the one-dimensional calculations, respectively.

Let ϕ_z and θ_z be defined as

$$\phi_z=\int_{\Delta x}\int_{\Delta y}\phi dxdy, \tag{3.33}$$

$$\theta_z=\int_{\Delta x}\int_{\Delta y}Sdxdy. \tag{3.34}$$

Rearranging Eq. (3.27) as follows:

$$D\int_{\Delta z}dz\int_{\Delta x}\int_{\Delta y}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}\right)dxdy+D\int_{\Delta z}dz\frac{\partial^2}{\partial z^2}\int_{\Delta x}\int_{\Delta y}\phi dxdy$$
$$-\Sigma_T\int_{\Delta z}dz\int_{\Delta x}\int_{\Delta y}\phi dxdy+\int_{\Delta z}dz\int_{\Delta x}\int_{\Delta y}Sdxdy=0, \tag{3.35}$$

and rewriting Eq. (3.35) by the use of the definitions given by Eqs. (3.33) and (3.34), i.e.,

$$-L_{xy}\int_{\Delta z}\phi_z dz+D\int_{\Delta z}\frac{\partial^2\phi_z}{\partial z^2}dz-\Sigma_T\int_{\Delta z}\phi_z dz+\int_{\Delta z}\theta_z dz=0, \tag{3.36}$$

we get finally,

$$D\frac{\partial^2\phi_z}{\partial z^2}-(L_{xy}+\Sigma_T)\phi_z+\theta_z=0. \tag{3.37}$$

Given L_{xy} for each block, ϕ_z can be derived by solving the one-dimensional equation (3.37). The leakage term L_z is then derived from ϕ_z. From the difinition of L_z, Eq. (3.29) is rewritten as

$$D\int_{\Delta z}\frac{\partial^2\phi_z}{\partial z^2}dz=-L_z\int_{\Delta z}\phi_z dz. \tag{3.38}$$

Inserting Eq. (3.38) into Eq. (3.36),

$$-L_z\int_{\Delta z}\phi_z dz-L_{xy}\int_{\Delta z}\phi_z dz-\Sigma_T\int_{\Delta z}\phi_z dz+\int_{\Delta z}\theta_z dz=0. \tag{3.39}$$

Then L_z is given as

$$L_z=\frac{\int_{\Delta z}\theta_z dz}{\int_{\Delta z}\phi_z dz}-(\Sigma_T+L_{xy}). \tag{3.40}$$

Given L_z, the x-y directional leakage term L_{xy} is then similarly calculated from two-dimensional calculation.

Next we derive the x-y dimensional diffusion equation. Let ϕ_{xy}, θ_{xy} be defined as

$$\phi_{xy} \equiv \int_{\Delta z} \phi dz, \tag{3.41}$$

$$\theta_{xy} \equiv \int_{\Delta z} S dz. \tag{3.42}$$

Reformulating Eq. (3.27) in the same way as performed in deriving Eq. (3.37), i.e.,

$$\begin{aligned} &D\int_{\Delta x}\int_{\Delta y} dxdy\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)\cdot\left(\int_{\Delta z}\phi dz\right) \\ &+D\int_{\Delta x}\int_{\Delta y} dxdy\int_{\Delta z}\left(\frac{\partial^2\phi}{\partial z^2}\right)dz \\ &-\Sigma_T\int_{\Delta x}\int_{\Delta y} dxdy\int_{\Delta z}\phi dz+\int_{\Delta x}\int_{\Delta y} dxdy\int_{\Delta z} S dz=0, \end{aligned} \tag{3.43}$$

$$\begin{aligned} &D\int_{\Delta x}\int_{\Delta y} dxdy\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)\phi_{xy}-L_z\int_{\Delta x}\int_{\Delta y}\phi_{xy}dxdy \\ &-\Sigma_T\int_{\Delta x}\int_{\Delta y}\phi_{xy}dxdy+\int_{\Delta x}\int_{\Delta y}\theta_{xy}dxdy=0, \end{aligned} \tag{3.44}$$

we have

$$D\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)\phi_{xy}-(L_z+\Sigma_T)\phi_{xy}+\theta_{xy}=0. \tag{3.45}$$

Given L_z for each block, ϕ_{xy} is calculated by solving the two-dimensional equation (3.45). L_{xy} is then to be derived from ϕ_{xy}. From the definition of L_{xy} in Eq. (3.28), the following relation is derived,

$$D\int_{\Delta x}\int_{\Delta y}\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)\phi_{xy}dxdy=-L_{xy}\int_{\Delta x}\int_{\Delta y}\phi_{xy}dxdy. \tag{3.46}$$

Inserting Eq. (3.46) into Eq. (3.44), we get

$$\begin{aligned} &-L_{xy}\int_{\Delta x}\int_{\Delta y}\phi_{xy}dxdy-L_z\int_{\Delta x}\int_{\Delta y}\phi_{xy}dxdy \\ &-\Sigma_T\int_{\Delta x}\int_{\Delta y}\phi_{xy}dxdy+\int_{\Delta x}\int_{\Delta y}\theta_{xy}dxdy=0. \end{aligned} \tag{3.47}$$

L_{xy} is then given as

$$L_{xy}=\frac{\int_{\Delta x}\int_{\Delta y}\theta_{xy}dxdy}{\int_{\Delta x}\int_{\Delta y}\phi_{xy}dxdy}-(L_z+\Sigma_T). \tag{3.48}$$

The leakage terms L_{xy} and L_z are derived from Eqs. (3.48) and (3.40) respectively, but L_{xy} (and L_z) should be given to get L_z (L_{xy}, vice versa). Then an iterative calculation is necessary to get L_{xy} and L_z.

The iterative calculations are performed as described in the following. Given initial guess of L_{xy} for each block, the one-dimensional calculation solving Eq. (3.37) is performed for each of the channel. The blockwise z-directional leakage term L_z is then calculated by Eq. (3.40). Given the value of L_z for each block, the two-dimensional calculation solving Eq. (3.45) is performed for each of the horizontal layer. The blockwise x-y directional leakage L_{xy} is then calculated by Eq. (3.48). The iterative calculations are performed until the consistency is achieved between L_{xy} and L_z. The convergence of the iteration is determined by comparing the following two quantities with each other.

$$(\phi_b)_z=\int_{\Delta x}\int_{\Delta y}\phi_z dxdy, \tag{3.49}$$

$$(\phi_b)_{xy}=\int_{\Delta z}\phi_{xy}dz. \tag{3.50}$$

If L_{xy} and L_z have consistency, the following relation should be satisfied;

$$\phi_b=(\phi_b)_z=(\phi_b)_{xy}. \tag{3.51}$$

The neutron balance is obtained by the iteration discussed above, which corresponds to the inner iteration in the finite difference calculation.

The advantage of the Leakage Iterative Method is to allow subdivisions of the blocks in the one-dimensional and/or two-dimensional calculations. The coarse mesh, such as 1 mesh point in an assembly (1/2 foot width), makes the finite difference method less accurate than desired, because the diffusion length of thermal neutrons in light water is less than the mesh width. As one-dimensional calculations and two-dimensional calculations are performed separately, the subdivisions of the blocks provide a desired accuracy in solving the diffusion equation without increasing the computation time significantly.

Another remarkable feature of DIFFUSION-ACE is the treatment of the reflector regions. In general, a large number of mesh points is assigned to the reflector regions because the thermal neutron flux have a peak in the reflector region, which increases the computation time and capacity requirement dramatically. In order to avoid assigning mesh points to the reflector regions, a new boundary condition has been developed by us. In the core region, the flux is determined by the finite difference method but in the reflector region, the flux is derived analytically. At the boundary between the core region and the reflector region, the continuities of the neutron current and the neutron flux are assumed. This approach is called here as "analytical boundary condition."

The approach is explained here by the example of one-dimensional geometry illustrated in **Fig. 3.5.**

In the reflector regions the one-dimensional diffusion equation is expressed as

$$\frac{d^2}{dr^2}\phi-k^2\phi=0, \tag{3.52}$$

where
$$k^2=(\Sigma_{TR}+D_RB^2)/D_R, \tag{3.53}$$

D_R : diffusion coefficient in the reflector region

Σ_{TR} : total cross section in the reflector region

B^2 : buckling of neutron flux

The differential equation (3.52) is solved on the conditions:

$$\phi_R=\phi_{B1} \qquad \text{at } r=0,$$
$$\phi_R=0 \qquad \text{at } r=+\infty,$$

where B1 refers to the boundary shown in **Fig. 3.5.** The solution of Eq. (3.52) is given by

$$\phi(r)=\phi_{B1}\cdot e^{-kr} \tag{3.54}$$

The continuity of the neutron current at the boundary is expressed as

$$-\left(-D_R\left(\frac{d\phi}{dr}\right)_{r=0}\right)=-D_1\cdot\frac{\phi_1-\phi_{B1}}{\left(\frac{\Delta z_1}{2}\right)}, \tag{3.55}$$

where the subscript 1 refers to the first mesh point in the core region. The left hand side of Eq. (3.55) is calculated from Eq. (3.54) as

$$D_R\left(\frac{d\phi}{dr}\right)_{r=0}=-D_Rk\phi_{B1}. \tag{3.56}$$

From Eqs. (3.55) and (3.56), we get

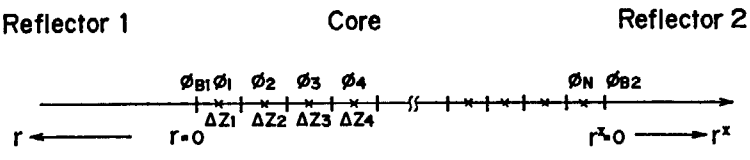


Fig. 3.5 Mesh distribution to calculate one-dimensional diffusion equation.

$$\phi_{B1}=A\cdot\phi_1, \tag{3.57}$$

where
$$A=\frac{2D_1}{D_R k\Delta z_1+2D_1}, \tag{3.58}$$

The one-dimensional diffusion equation is expressed by the following difference equation for the first mesh point in the core region;

$$D_1\frac{\phi_1-\phi_{B1}}{(\Delta z_1/2)}-D_1'(\phi_2-\phi_1)+D_1B^2\phi_1 z_1+\Sigma_{T1}\phi_1\Delta z_1=S_1\Delta z_1, \tag{3.59}$$

where
$$D_1'=\frac{2}{\frac{\Delta z_1}{D_1}+\frac{\Delta z_2}{D_2}}. \tag{3.60}$$

and the subscripts 1 and 2 refer to the first and second mesh points in the core region, respectively. Combining Eq. (3.57) with Eq. (3.59), we get

$$D_1\frac{\phi_1-A\phi_1}{(\Delta z_1/2)}-D_1'(\phi_2-\phi_1)+D_1'B^2\phi_1\Delta z_1+\Sigma_{T1}\phi_1\Delta z_1=S_1\Delta z_1. \tag{3.61}$$

As A is a constant, Eq. (3.61) does not include any neutron flux terms of the reflector region, which allows us to solve the finite difference equations only in the core region.

The approach explained above is for the first energy group in the one-dimensional calculation, but the same approach is applicable to any other energy groups and also to the two-dimensional calculation.

3.3 Interfaces Between HYDRO-ACE and DIFUSION-ACE

As mentioned before, STEADY-ACE consists of the thermal-hydraulic part HYDRO-ACE and the three-dimensional neutron diffusion part DIFFUSION-ACE. The interfaces between these two parts are explained here.

The interface from the thermal-hydraulic part into the nuclear part is descrived first. The output of the thermal-hydraulic calculation is the block-wise void fraction within the channel box, while the input of the nuclear calculation is the block-wise neutron cross sections. SUBROUTINE CROSS serves as an interface by calculating the block-wise neutron cross sections from the block-wise void volume fraction within the channel box.

The neutron macroscopic cross sections are prepared as quadratic functions of the void fraction within the channel box.

$$\Sigma_x=(\Sigma_x^0)+(\Sigma_x^1)\cdot\alpha+(\Sigma_x^2)\cdot\alpha^2, \tag{3.62}$$

where Σ_x refers to the neutron cross sections, such as absorption cross section, slowing down cross section, diffusion coefficient and emission cross section (product of neutrons per fission and fission cross section). α is a void fraction within the channel box. Σ_x^0, Σ_x^1 and Σ_x^2 are fitting constants.

The fitting constants are prepared by the multi-group calculations for the lattice cells parametrically as a function of void fraction within the channel box. These parametric calculations produce two or three group cross sections homogenized over the lattice cells. It is assumed usually that the void fraction outside the channel box is zero. A quadratic fitting program processes these data into tables of the fitting constants. The tables of the fitting constants are prepared by the user and input into the program STEADY-ACE. Then, given the block-wise void fraction within the channel box from the thermal-hydraulic part HYDRO-ACE, the block-wise cross sections are calculated by Eq. (3.62).

The cross sections of the upper reflector region are also dependent on the void fraction. The table of the fitting constants for the upper reflector is also prepared by the user in the same manuer as the table for the blocks. The void fractions at the outlet of the channels are used to determine the neutron cross sections for the upper reflector region.

As the void fractions in the lower reflector and side reflector regions are zero or close to zero, the void dependency of the neutron cross sections is not considered for these regions.

The interface from the nuclear part into the thermal-hydraulic part is described next. The output from the nuclear calculation is the normalized block-wise power distribution, where as the input to the thermal-hydraulic calculation is the block-wise thermal power distribution. Most of the heat generated in a block is transferred to the coolant within the channel box of the block, but some fraction of the heat is transferred to the coolant in the leakage flow by gamma-heating and heat transport through the channel boxes.

The heat transferred to the coolant within the channel box is obtained from the normalized power distribution:

$$q_{n,k}=Q\cdot(1-\eta)\cdot\frac{P_{n,k}}{\sum_{n'}\sum_{k'}P_{n',k'}}, \tag{3.63}$$

where n: channel identification number

k: axial position of the block

$q_{n,k}$: heat transferred to the coolant within the channel box in the block (n, k) [kcal/sec]

Q: reactor thermal power [kcal/sec]

η: heat fraction transferred to the coolant in the leakage flow path of the total heat generation

$P_{n,k}$: normalized power of the block (n, k).

The heat transferred to the coolant in the leakage flow path by gamma heating and heat transport through the channel boxes is calculated by

$$q_{L,k}=Q\cdot\eta\cdot\frac{\sum_{n'}P_{n',k'}}{\sum_{n'}\sum_{k'}P_{n',k'}}, \tag{3.64}$$

where L refers to the leakage flow path. The thermal power calculation by Eqs. (3.63) and (3.64) is performed in HYDRO-ACE.

The calculation starts from the initial power distribution guess specified by the user. From the power distribution the thermal-hydraulic subprogram HYDRO-ACE calculates the void fraction distribution. From the void fraction distribution, the subroutine CROSS calculates the neutron cross sections for the core and upper reflector regions. Given the cross sections, the nuclear subprogram DIFFUSION-ACE calculates the power distribution. The iterative calculations are performed until the consistency is obtained between the power and void fraction distributions. The convergence of the iteration is decided by comparing the power residuals with the convergence criterion specified by the user, where the power residual is defined as

$$(R_p)^n=\underset{l,k}{\mathrm{Max}}\left|\frac{P^n-P^{n-1}}{P^n}\right|_{l,k}, \tag{3.65}$$

n: number of iterations

l: channel identification number

k: axial block number

P: normalized power of the block (l, k).

The flow chart of the calculation is illustrated in **Fig. 3.6.**

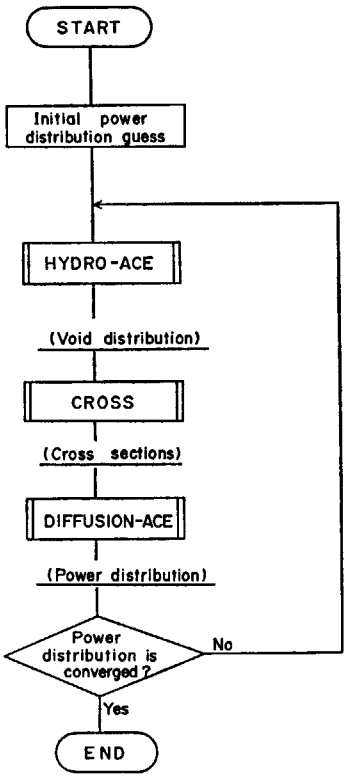


Fig. 3.6 General flow chart of STEADY-ACE.

4 Input Description

The input of STEADY-ACE consists of 70 classes of cards. Some classes of cards are not necessary, depending on the type of problems the user would like to solve. In general, (I3) formats are used for integer-type variables and (E10.0) or (F10.0) formats are used for real-type variables.

Class 1 (18A4) : Title card

col. 1～72 ITITLE : Problem name; the user can write any words for his own use.

Class 2 (I3, 7X, 2E10.0) : Convergence parameters for void-power iteration

col. 1～3 MAXCUP : Maximum number of void-power iterations.

col. 3～10 (blank)

col. 11～20 EPSCUP : Convergence criterion on power residual for void-power iteration, where power residual is defined by Eq. (3.65).

col. 21～30 WCUP : Relaxation factor for void-power iteration, where the new guess of power distribution for thermal-hydraulic calculation at the n-th iteration is calculated as $(P_{\text{guess}})_l^n = P_l^{n-1} \cdot \text{WCUP} + (1-\text{WCUP}) \cdot P_l^{n-2}$.

Class 3 (7 I3) : Options for thermal-hydraulic calculation

col. 1～3 KW1 : (not used)

col. 4～6 KW2 : (not used)

col. 7～9 KW3 : (not used)

col. 10～12 KWDPFR : Option for two-phase friction loss multiplier

=0 Martinelli-Nelson correlation

=1 Sher's correction with Martinelli-Nelson correlation

=2 Armand's correlation

=3 Lottes-Finn's correlation

=4 The multiplier is specified by the user. $\phi_{l\text{tt}}$ in Eq. (3.7) is to be input.

=5 The multiplier is specified by the user. R_0 in Eq. (3.9) is to be input.

col. 13～15 KWBALA : Option for calculation of core inlet enthalpy and feed-water enthalpy

=0 Feed-water enthalpy and core inlet enthalpy are calculated in the program by the heat balance equation. This option is available only for JPDR-II core calculation.

=1 Feed-water enthalpy is input. Core inlet enthalpy is calculated by the heat balance equation.

=2 Both feed-water enthalpy and core inlet enthalpy are input.

col. 16～18 KW6 : (not used)

col. 19～21 KW7 : (not used)

Class 4 (7 I3) : Option for pressure and heat balance calculations

col. 1～3 LPHYDR : Maximum number of iterations for pressure balance calculation to obtain the channel flow distribution.

col. 4～6 LP2 : (not used)

col. 7～9 LPHIN : Maximum number of iterations for the heat balance calculation to obtain the core inlet enthalpy.

col. 10～12 LP4 : (not used)

col. 13～15 LP5 : (not used)

col. 16～18 LP6 : (not used)

col. 19～21 LP7 : (not used)

Class 5 (7 E10.0) : Convergence criteria for pressure and heat balance calculations

col. 1～10 EPSHYD : Convergence criterion of pressure residual for the pressure balance calculation, where the residual is defined as

$$R_{\Delta P}=\underset{l}{\mathrm{Max}}\left\{\frac{(\Delta P)_l-(\Delta P)_{\mathrm{ave.}}}{(\Delta P)_{\mathrm{ave.}}}\right\},$$

l : channel number

$(\Delta P)_l$: pressure drop for channel l

$(\Delta P)_{\mathrm{ave.}}$: pressure drop averaged over all channels

col. 11～20 EPS2 : (not used)

col. 21～30 EPSHIN : Convergence criterion for the heat balance calculation to determine the core inlet enthalpy.

col. 31～40 EPS4 : (not used)

col. 41～50 EPS5 : (not used)

col. 51～60 EPS6 : (not used)

col. 61～70 EPS7 : (not used)

Class 6 (4 E10.0) : Elevation of channels (see **Fig. 2.3**)

col. 1～10 ZZIN : Elevation of the multi-channel zone inlet; H_1 in **Fig. 2.3** [m].

col. 11～20 ZIN : Elevation of the bottom of the heated zone; H_4 [m]

col. 21～30 ZOUT : Elevation of the top of the heated zone; H_5 [m]

col. 31～40 ZZOUT : Elevation of the multi-channel zone exit; H_6 [m]

(Note) The vertical length of a block is calculated by

$$(\mathrm{DZ})=\frac{(\mathrm{ZOUT})-(\mathrm{ZIN})}{(\mathrm{KMAX})},$$

where (KMAX) is input in Class 7.

Class 7 (A4, 2X, 4I3) : Core size (see **Fig. 2.4**)

col. 1～4 IZONE : Option for the calculation geometry

=(blank) Full core

=HALE 1/2 core

=QUAT 1/4 core.

col. 5～6 (blank)

col. 7～9 IMAX : Number of channels in the x-direction

col. 10～12 JMAX : Number of channels in the y-direction

col. 13～15 KMAX : Number of blocks in the z-direction

col. 16～18 NMAX : Number of channels in the core

Class 8 (24 I3) : Core geometry for the nuclear calculation (see **Fig. 2.4**)

col. 1～ (NC(I, J), I=1, IMAX) : Channel type array for the nuclear calculation. The channel numbers are specified according to the X-coordinate I and Y-coordinate I in **Fig. 2.4**. The reflector zones of no channels are designated by 0.

(Note) (JMAX) cards of Class 8 are necessary.

Class 9 (24 I3) : Core geometry for the thermal-hydraulic calculation (see **Fig. 2.2**)

col. 1～ (MG(N), N=1, NMAX+1) : Types of the thermal-hydraulic properties of channels. The last channel (NMAX+1) refers to the leakage flow channel. The thermal-hydraulic properties are in Classes 12, 13 and 14.

Class 10 (3 E10.0) : Thermal-hydraulic constants

col. 1～10 PRESS : System absolute pressure [kg/cm²a].

col. 11～20 PHITT1 : Two phase multiplier correction factor.

col. 21～30 PHITT2 : Two phase multiplier correction factor.

(Note) PHITT1 and PHITT2 should be input only when KWDPFR in Class 3 is 4 or 5. The correction factors R_1 in Eq. (3.7) and R_0 in Eq. (3.9) are expressed by a quadratic equation of the steam quality x as

$$R_1 \text{ (or } R_0) = 1 + (\text{PHITT1}) \cdot x + (\text{PHITT2}) \cdot x^2.$$

Class 11 (2 I3) : Channel types of the different thermal-hydraulic properties

col. 1～3 MGREAD : Number of channel types of the different thermal-hydraulic properties, corresponding to the maximum number in MG array in Class 9.

col. 4～6 KECCAL : Option for calculation of the expansion-contraction pressure loss factor (E/C factor).

=0 E/C factor is input.

=1 If the input specified E/C factors are positive, use the input value. If not, TABLE 3.1 is used to estimate the E/C factors.

=2 TABLE 3.1 is used to estimate the E/C factors.

Class 12 (3 I3, 1X, A10, E10.0) : Thermal-hydraulic properties of channels (see **Fig. 2.4**)

col. 1～3 M : Channel type number.

col. 4～6 LMAX(M) : Number of sections in the channel type (M).

col. 7～9 NPSMAX : Number of spacers in the channel type (M).

col. 10 (blank)

col. 11～20 NAMEC(M) : Name referring to the channel type (M).

col. 21～30 HPERIM(M) : Heated peripheral area per unit length of the channel type (M) [m²/m]

Class 13 (A4, 6X, 3 E10.0) : Thermal-hydraulic properties of the vertical sections in the channel type (M) (see **Fig. 2.3**)

col. 1～4 NAME(M, L) : Name referring to the section (L) in the channel type (M)

col. 5～10 (blank)

col. 11～20 ZZ(M, L) : Elevation of the inlet of the section (L) [m].

col. 21～30 A(M, L) : Flow area of the section (L) [m²].

col. 31～40 EC(M, L) : Expansion-contraction pressure loss factor at the inlet of the section (L).

(Note) (LMAX(M)+1) cards of Class 13 are necessary for each channel type.

Class 14 (7 F 10.0) : Thermal-hydraulic properties of spacers in the channel type (M)

col. 1～ (ZSP(M, NSP), ECSP(M, NSP), NSP=1, NSPMAX)

ZSP : Elevation of spacers

ECSP : Spacer pressure loss coefficient.

(Note 1) Class 14 is input only when NSPMAX is positive. When NSPMAX≥4, the input will continue to the subsequent cards.

(Note 2) (MGREAD) sets of Classes 12, 13 and 14 are necessary.

Class 15 (A4) : Option for the initial power distribution for the thermal-hydraulic calculation

col. 1～4 METHOD : Option for the initial power distribution for the thermal-hydraulic calculation in the first power-void loop

=ALL : Initial power guess is input for all of the blocks.

=EACH : Channel power and axial power shape are specified by input in Classes 17 and 18 for each channel.

Class 16 (7 E10.0) : Initial power distribution when METHOD=ALL

col. 1～ (S(N, K), K=1, KMAX) : Initial power guess of the block.

(Note) (NMAX) sets of Class 16 cards are necessary.

Class 17 (3(A4, 6X, F10.0)) : Initial channel power and axial power shape when METHOD=EACH
col. 1～4 NTYPE(N) : Option for axial power shape of the N-th channel
=CARD : Axial power distribution is specified by card input
=FLAT : Uniform distribution
=SINE : Sinusoidal distribution
=COMP : Bottom peaked distribution
=SAME : Power distribution calculated in the preceding case is used. This option cannot be used for the first case.
col. 5～10 (blank)
col. 11～20 SS(N) : Channel power of the N-th channel.
(Note) Each card includes input for 3 channels.
(NMAX/3+1) cards are necessary.

Class 18 (7 F10.0) : Axial power distribution when METHOD=EACH and NTYPE(N)=CARD
col. 1～ (S(N, k), K=1, KMAX) : Axial power distribution.
(Note) Class 18 is repeated by the number of channels with NTYPE(N)=CARD.

Class 19 (7 E10.0) : Core thermal parameters
col. 1～10 QTMW : Reactor thermal power [MW_{th}].
col. 11～20 WTTPH : Core inlet flow rate [ton/hr].
col. 21～30 WCLTPH : Flow rate of the clean-up line [ton/hr].
col. 31～40 ETA : Leakage flow fraction.
col. 41～50 XDC1 : Carry-under steam quality to down commer.
col. 51～60 BETA : Heat fraction transferred to the coolant in the leakage flow path of the total generated heat.
col. 61～70 NPCRL : Pump pressure [kg/m^2].

Class 20 (2 E10.0) : Inlet enthalpy when KWBALA≥1
col. 1～10 HFEED : Feed-water enthalpy [kcal/kg]
col. 11～20 HIN : Core inlet enthalpy [kcal/kg]

Class 21 (3 I3) : Option for neutron cross section input
col. 1～3 KKK : Option for input of the table of the fitting constants
=1 Fitting constants are the same for all the blocks
=2 Fitting constants are input for each block
=3 The blocks are categorized into the fuel types which have the same fitting constants.
col. 4～6 NGMAX : Number of energy groups. (NGMAX) should be either 2 or 3.
col. 7～9 NTMAX : Number of fuel types which have the same fitting constants. (NTMAX) should be specified when KKK=3.
(Note) When KKK=1 or 2, the fitting constants are input by Classes 22～28. When KKK=1, one set of Classes 22～28 is input. When KKK=2, (NMAX)*(KMAX) sets of Classes 22～28 are input in sequence such as block 1 in channel 1, block 2 in channel 1, block 3 in channel 1, ..., block 1 in channel 2, ..., block (KMAX) in channel (NMAX). When KKK=3, the fitting constants are input by Classes 29～36.

Class 22 (3 E10.0) : Fitting constants of diffusion coefficients of the fuel region when KKK=1 or 2
col. 1～10 D0 (N, K, NG) Fitting constants of the diffusion coefficient of the energy group
col. 11～20 D1 (N, K, NG) (NG) defined as
col. 21～30 D2 (N, K, NG) $D^g=(D0)^g+(D1)^g\cdot\alpha+(D2)^g\cdot\alpha^2$,
where α is the void fraction and g is the energy group.

(Note) (NGMAX) cards of Class 22 are necessary.

Class 23 (3 E10.0) : Fitting constants of absorption cross sections of the fuel region when KKK=1 or 2

col. 1～10 SVU0 (N, K, NG) Fitting constants of the emission cross section of the energy group
col. 11～20 SVU1 (N, K, NG) (NG) defined as
col. 21～30 SVU2 (N, K, NG) $(\nu\Sigma_f)^g=(\mathrm{SVU0})^g+(\mathrm{SVU1})^g\cdot\alpha+(\mathrm{SVU2})^g\cdot\alpha^2$.
The emission cross section is defined as the product of the number of neutrons per fission and the fission cross section.

(Note) (NGMAX) cards of Class 24 are necessary.

Class 25 (3 E10.0) : Fitting constants of slowing-down cross sections of the fuel region when KKK=1 or 2

col. 1～10 STR0 (N, K, NG) Fitting constants of the slowing-down cross section of the energy
col. 11～20 STR1 (N, K, NG) group (NG) defined as
col. 21～30 STR2 (N, K, NG) $(\Sigma_r)^g=(\mathrm{STR0})^g+(\mathrm{STR1})^g\cdot\alpha+(\mathrm{STR2})^g\cdot\alpha^2$.

(Note) (NGMAX) cards of Class 25 are necessary.

Class 26 (3 E10.0) : Energy per fission when KKK=1 or 2

col. 1～ (AKSF (N, K, NG), NG=1, NGMAX) : Released energy per fission for the energy group (NG).

Class 27 (3 E10.0) : Number of neutrons per fission when KKK=1 or 2

col. 1～ (ANU (N, K, NG), NG=1, NGMAX) : Emitted neutrons per fission for the energy group (NG).

Class 28 (3 E10.0) : Initial leakage guess L_{xy} when KKK=1 or 2

col. 1～ (ALXY (N, K, NG), NG=1, NGMAX) : Initial guess of the x-y direction leakage L_{xy} for the energy group (NG).

Class 29 (24 I3) : Fuel type when KKK=3

col. 1～ (NTYPE (N, K), K=1, KMAX) : Fuel type number of the block (n, k). A fuel group has the same fitting constants.

(Note) (NMAX) cards of Class 29 are necessary.

Class 30 (3 E10.0) : Fitting constants of diffusion coefficients of the fuel region when KKK=3

col. 1～10 DTP0 (NT, NG) Fitting constants of the diffusion coefficient of the energy group
col. 11～20 DTP1 (NT, NG) (NG) for the fuel type (NT).
col. 21～30 DTP2 (NT, NG)

(Note) (NGMAX) cards of Class 30 are necessary.

Class 31 (3 E10.0) : Fitting constants of absorption cross sections of the fuel region when KKK=3

col. 1～10 SSATP0 (NT, NG) Fitting constants of the absorption cross section of the energy
col. 11～20 SSATP1 (NT, NG) group (NG) for the fuel type (NT).
col. 21～30 SSATP2 (NT, NG)

(Note) (NGMAX) cards of Class 31 are necessary.

Class 32 (3 E10.0) : Fitting constants of the emission cross sections of the fuel region when KKK=3

col. 1～10 SVUTP0 (NT, NG) Fitting constants of the emission cross sections of the energy
col. 11～20 SVUTP1 (NT, NG) group (NG) for the fuel type (NT).
col. 21～30 SVUTP2 (NT, NG)

(Note) (NGMAX) cards of Class 32 are necessary.

Class 33 (3 E10.0) : Fitting constants of the slowing-down cross sections of the fuel region when KKK=3

col. 1～10 STRTP0 (NT, NG) Fitting constants of the slowing-down cross sections of the energy
col. 11～20 STRTP1 (NT, NG) group (NG) for the fuel type (NT).

col. 21～30 STRTP2 (NT, NG)

(Note) (NGMAX) cards of Class 33 are necessary.

Class 34 (3 E10.0) : Energy per fission when KKK=3

col. 1～ (AKSFTP (NT, NG), NG=1, NGMAX) : Released energy per fission for the energy group (NG)

Class 35 (3 E10.0) : Number of neutrons per fission when KKK=3

col. 1～ (ANUTR (NT, NG), NG=1, NGMAX) : Emitted neutrons per fission for the energy group (NG)

Class 36 (3 E10.0) : Initial leakage guess L_{xy} when KKK=3

col. 1～ (ALXYTP (NT, NG), NG=1, NGMAX) : Initial guess of the x-y direction leakage L_{xy} for the energy group (NG).

Class 37 (3 E10.0) : Diffusion coefficients of the upper reflector region

col. 1～10 SSAT0 (NG) Fitting constants of the absorption cross section of the energy group
col. 11～20 SSAT1 (NG) (NG) for the upper reflector region.
col. 21～30 SSAT2 (NG)

(Note) (NGMAX) cards of Class 38 are necessary.

Class 39 (3 E10.0) : Slowing-down cross sections of the upper reflector region.

col. 1～10 STRT0 (NG) Fitting constants of the slowing-down cross section of the energy group
col. 11～20 STRT1 (NG) (NG) for the upper reflector region.
col. 21～30 STRT2 (NG)

(Note) (NGMAX) cards of Class 39 are necessary.

Class 40 (3 E10.0) : Buckling of the upper reflector region

col. 1～10 BUKT0 (NG) Fitting constants of the buckling B^2 of the energy group (NG) for
col. 11～20 BUKT1 (NG) the upper reflector region.
col. 21～30 BUKT2 (NG)

(Note) (NGMAX) cards of Class 40 are necessary.

Class 41 (4 E10.0) : Cross sections of the lower reflector region

col. 1～10 DB (NG) : Diffusion coefficient of the energy group (NG) for the lower reflector region.
col. 11～20 SSAB (NG) : Absorption cross section of the energy group (NG) for the lower reflector region.
col. 21～30 STRB (NG) : Slowing-down cross section of the energy group (NG) for the lower reflector region.
col. 31～40 BUKB (NG) : Buckling of the energy group (NG) for the lower reflector region.

(Note) (NGMAX) cards of Class 41 are necessary.

Class 42 (4 E10.0) : Cross sections of the side reflector region

col. 1～10 DR (NG) : Diffusion coefficient of the energy group (NG) for the side reflector region.
col. 11～20 SSAR (NG) : Absorption cross section of the energy group (NG) for the side reflector region.
col. 21～30 STRR (NG) : Slowing down cross section of the energy group (NG) for the side reflector region.
col. 31～40 BUKR (NG) : Buckling of the energy group (NG) for the side reflector region.

(Note) (NGMAX) cards of Class 42 are necessary.

Class 43 (5 I3) : Subdivision for diffusion equation calculation

col. 1～3 ISECT : Number of subdivisions in a block in the x-direction.
col. 4～6 JSECT : Number of subdivisions in a block in the y-direction.
col. 7～9 KSECT : Number of subdivisions in a block in the z-direction.
col. 10～12 NRMIV : Number of mesh points in the side reflector region in the x or y direction.

col. 13~15 NZR : Number of mesh points in the upper or lower reflector region in the z direction

Class 44 (6 I3) : Options for diffusion equation calculation

col. 1~3 NCROD : Number of control rods ($\leq$16).

col. 4~6 INMAX : Number of in-core-monitors ($\leq$30).

col. 7~9 NSKO : Number of the subdivisions for smaller mesh width. In the z-directional one-dimension diffusion calculation, some of the subdivisions are further divided into 3 equal meshes in order to calculate the local effect of the control rods on the power distribution (see Class 48).

col. 10~12 MNZ : In the case of analytical boundary condition, the neutron fluxes in the lower and upper reflector regions are edited at (MNZ) points ($\leq$30) (see Class 49).

col. 13~15 IGS : Option for initial guess of the neutron source distribution

=0 Initial guess of the horizontal leakage L_{xy} is input. The source distribution is calculated from L_{xy}.

=1 Initial guess of the neutron source distribution is input (see Classes 66, 67 and 68).

col. 16~18 IPUNCH : Option for punch output

=0 No punch output

=1 The source distribution is punched so that it can be used as an initial guess for the next case (see Classes 66, 67 and 68).

Class 45 (5 E10.0) : Geometry for the diffusion equation calculation

col. 1~10 DX : Block width in the x-direction [cm].

col. 11~20 DY : Block width in the y-direction [cm].

col. 21~30 RFWID : Width of the side reflector region in the two-dimensional calculation [cm].

col. 31~40 CRWID : Width of the control rod [cm].

col. 41~50 REFZ : Length of the upper and lower reflector regions in the one-dimensional calculation [cm].

Class 46 (8 I3, 6X, E10.0) : Control rod position. This class 46 is necessary only when NCROD>0

col. 1~3 L : Control rod identification number.

col. 4~6 ICR (L) : Position of the control rod (L) in the x-direction. Use X-cooridinate II in **Fig. 2.4.**

col. 7~9 JCR (L) : Position of the control rod (L) in the y-direction. Use Y-coordinate II in **Fig. 2.4.**

col. 10~12 (NEIBCR (N, L), M=1, 4) : Identification numbers of the fuel assemblies neighbouring
col. 13~15 the control rod (L). The sequence of the four assemblies
col. 16~18 can be selected arbitrarily.
col. 19~21

col. 22~24 KCR (L) : Block number of the tip position of the control rod (L).

col. 25~30 (blank)

col. 31~40 ZCR (L) : Elevation of the tip of the control rod (L) from the bottom of the core [cm].

(Note) (NCROD) cards of Class 46 are necessary.

Class 47 (3 I3) : Position of the in-core-monitors. Class 47 is necessary only when (INMMAX>0 (see Class 44).

col. 1~3 K : Identification number of the in-core-monitor.

col. 4~6 IIN (K) : Position of the in-core-monitor (K) in the x-direction. Use X-coordinate II in **Fig. 2.4.**

col. 7~9 JIN (K) : Position of the in-core-monitor (K) in the y-direction. Use Y-coordinate II in **Fig. 2.4.**

(Note) (INMMAX) cards of Class 47 are necessary.

Class 48 (24 I3) : Position of fine divisions. Class 48 is necessary only when NSKO>0 (see Class 44).

col. 1～ (NSPNO (I), I=1, NSKO) : Identification number of z-directional mesh to be further divided (see **Fig. 2.5** for the mesh identification number).

Class 49 (E10.0) : Neutron flux edit for the upper and lower reflector regions. Class 49 is necessary only when (MNZ)>0

col. 1～10 DLZ : Interval of the points in the upper and lower reflector regions at which the neution fluxes are calculated and edited [cm].

Class 50 (6 I3) : Boundary conditions (see **Figs. 2.4** and **2.5**)

col. 1～3 KLB : Option for the bottom boundary condition (z-direction).

col. 4～6 KRT : Option for the top boundary condition (z-direction).

col. 7～9 KL : Option for the left boundary condition (x-direction).

col. 10～12 KR : Option for the right boundary condition (x-direction).

col. 13～15 KB : Option for the back-side boundary condition (y-direction).

col. 16～18 KT : Option for the front-side boundary condition (y-direction).

4 Options can be selected for each of the boundary conditions.

=0 Zero flux : $\phi=0$

=1 Zero derivative :

$$\left(\frac{d\phi}{dr}\right)=0$$

=2 Logarithmic derivative :

$$\left(\frac{d\phi}{dr}\right)=-\frac{\phi}{\gamma},$$

Where the derivative γ is specified by the user in classes 51～56.

=3 Neutron flux distribution outside the boundary is calculated analytically.

Class 51 (3 E10.0) : Class 51 is necessary only when KLB=2

col. 1～ (C1 (NG), NG=1, NGMAX) : Logarithmic derivative at the bottom boundary for the energy group (NG).

Class 52 (3 E10.0) : Class 52 is necessary only when KRT=2

col. 1～ (C2 (NG), NG=1, NGMAX) : Logarithmic derivative at the top boundary for the energy group (NG).

Class 53 (3 E10.0) : Class 53 is necessary only when KL=2

col. 1～ (C3 (NG), NG=1, NGMAX) : Logarithmic derivative at the left boundary for the energy group (NG).

Class 54 (3 E10.0) : Class 54 is necessary only when KR=2

col. 1～ (C4 (NG), NG=1, NGMAX) : Logarithmic derivative at the right boundary for the energy group (NG).

Class 55 (3 E10.0) : Class 55 is necessary only when KB=2

col. 1～ (C5 (NG), NG=1, NGMAX) : Logarithmic derivative at the back-side boundary for the energy group (NG).

Class 56 (3 E10.0) : Class 56 is necessary only when KT=2

col. 1～ (C6 (NG), NG=1, NGMAX) : Logarithmic derivative at the front-side boundary for the energy group (NG).

Class 57 (3 E10.0) : Fission spectrum

col. 1～ (YK (NG), NG=1, NGMAX) : Energy spectrum of fission neutrons.

Class 58 (3 I3) : Convergence parameters of the diffusion calculation to derive the initial value of

the 3-D source distribution.

col. 1～3 ITIN1 : Maximum number of the inner iterations of the 2-D diffusion calculation.

col. 4～6 IPMAX1 : Maximum number of the source iterations of the 2-D diffusion calculation

=0 SLOR (Successive Line Over Relaxation) method is applied both to the x- and y-directions

=1 SLOR method is applied to the x-direction.

Class 59 (4 E10.0) : Convergence parameters of the diffusion calculation to obtain the initial value of the 3-D source distribution

col. 1～10 EPSI (1) : Convergence criterion on the eigenvalue of the 1-D calculation.

col. 11～20 EPSI (2) : Convergence criterion on the source distribution of the 1-D calculation.

col. 21～30 EPS2 : Convergence criterion in the inner iteration of the 2-D calculation.

col. 31～40 EPS1 : Convergence criterion in the source iteration of the 2-D calculation.

Class 60 (2 E10.0) : Acceleration parameters in the diffusion calculation to obtain the initial value of the 3-D source distribution

col. 1～10 THETA : Acceleration factor of the source iteration of the 1-D calculation.

col. 11～20 W : Acceleration factor of the source iteration of the 2-D calculation.

Class 61 (4 I3) : Convergence parameters of the 3-D diffusion equation calculation

col. 1～3 IP3MAX : Maximum number of the outer iterations of the 3-D calculation.

col. 4～6 ITMAX : Maximum number of the inner iterations of the 3-D calculation.

col. 7～9 ITR1 : Number of the outer iteration cycles to determine the convergence criteria for

col. 10～12 ITR2 the inner iterations of the 3-D calculation.

Class 62 (3 E10.0) : Convergence parameters of the 3-D diffusion calculation

col. 1～10 EPI (1) : Temporary convergence criterion in the inner iteration of the 3-D calculation. This criterion is applied to the outer iteration cycles of less than (ITR1) in the first void-power iteration cycle.

col. 11～20 EPI (2) : Temporary convergence criterion in the inner iteration of the 3-D calculation. This criterion is applied to the outer iteration cycles of greater than (ITR1+1) and less than (ITR2) in the first void-power iteration cycle.

col. 21～30 EPI (3) : Final convergence criterion of the inner iteration of the 3-D calculation.

Class 63 (2 I3) : Convergence parameters of the 3-D diffusion calculation

col. 1～3 IDF1 : Number of the power-void iteration cycles to determine the convergence criteria

col. 4～6 IDF2 : for the outer iterations of the 3-D calculation.

Class 64 (3 E10.0) : Convergence parameters of the 3-D diffusion calculation

col. 1～10 CRT31 : Temporary convergence criterion in the outer iteration of the 3-D calculation. This criterion is applied to the power-void iteration cycles of less than (IDF1).

col. 11～20 CRT32 : Temporary convergence criterion in the outer iteration of the 3-D calculation. This criterion is applied to the power-void iteration cycles of greater than (IDF1+1) and less than (IDF2).

col. 21～30 CRT33 : Final convergence criterion in the outer iteration of the 3-D calculation.

Class 65 (3 E10.0) : Acceleration parameters in the 3-D calculation

col. 1～10 WXY : Acceleration factor of L_{xy} in the 3-D inner iterations.

col. 11～20 WZS : Acceleration factor of L_z in the 3-D inner iterations.

col. 21～30 WS : Acceleration factor of the 3-D outer iterations.

Class 66 (3 I3) : Number of the mesh points when IGS=0

col. 1～3 NAMAX : Number of the mesh points in the z-direction.

col. 4～6 IIMAX : Number of the mesh points in the x-direction.

col. 7～9 JJMAX : Number of the mesh points in the y-direction.

(Note) Class 66 is necessary only when IGS≠0. Classes 66 through 68 uses punched cards from the previous calculation.

Class 67 (7 E10.0) : Initial guess of the source distribution when IGS≠0

col. 1～ (A (N), N=1, NAMAX) : Initial guess of the source distribution in the 1-D calculation.

(Note) Class 67 is required only when IGS≠0. (NMAX) sets of Class 67 are necessary.

Class 68 (7 E10.0) : Initial guess of the source distribution when IGS≠0

col. 1～ (A (N), N=1, KKKMAX) : Initial guess of the source distribution in the 2-D calculation (KKKMAX=IIMAX*JJMAX).

(Note) Class 68 is required only when IGS=0. (KMAX) sets of Class 68 are necessary.

Class 69 (7 E10.0) : Nuclear cross sections of the control rod when NCROD≠0

col. 1～10 GBASE (NG) : Logarithmic derivative of the energy group (NG) for the control rod.

col. 11～20 GDD (NG) : Diffusion coefficient of the energy group (NG) for the control rod.

col. 21～30 GSR (NG) : Slowing-down cross section of the energy group (NG) for the control rod.

col. 31～40 GSA (NG) : Absorption cross section of the energy group (NG) for the control rod.

col. 41～50 GCR (NG) : Initial guess of the neutron leakage of the energy group (NG) into the control rod.

(Note) Classes 69 and 70 are required only when NCROD≠0. (NGMAX) sets of Class 69 are necessary.

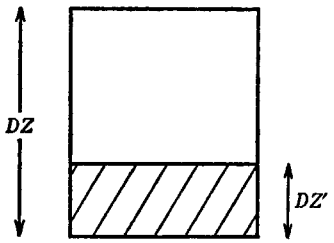
Class 70 (E10.0) : Correction parameter of the control rod nuclear constants when NCROD≠0

col. 1～10 WHT : Correction factor of the logarithmic derivative for the tip of the control rod :

$$\frac{\partial \phi}{\partial r} = -\frac{\phi}{\gamma}.$$

GBASE (NG) in Class 69 is the logarithmic derivative ($-\gamma$) in the above equation. When the tip of the control rod is in the middle of a block, the logarithmic derivative for the block is given by

$$-\gamma' = \text{GBASE (NG)} * \frac{DZ}{DZ'} * \text{WHT}$$



5 Major Output

STEADY-ACE gives print-out output and punched card output.

5.1 Print-out

STEADY-ACE gives the following output in addition to the print-out of the input data.

(1) Eigenvalue.
(2) Block-wise power distribution.
(3) Block-wise group-wise neutron flux distribution.
(4) Block-wise group-wise leakage distribution.
(5) Assembly power.
(6) Assembly flow.
(7) Pressure drop and its components.
(8) Core average void fraction.
(9) Block-wise distribution of heat flux, void fraction, quality, moderator density and CHFR (critical heat flux ratio).
(11) Gross peaking and MCHFR (minimum critical heat flux ratio).
(12) Neutron flux distribution in the reflector region.
(13) Thermal neutron flux at the in-core-monitor.

5.2 Punched Cards

STEADY-ACE has an option to give punched card output. Punched cards can be utilized as input cards in the subsequent calculations. Use of the punched cards reduces the computation time in the subsequent calculations significantly.

(1) Mesh-wise source distribution: The output cards will be the input data of Classes 66, 67 and 68 in the subsequent calculations as an initial guess of the source distribution.

(2) Block-wise horizontal leakage distribution L_{xy}: The output cards will be the input data of Class 28 in the subsequent calculations as an initial guess of the horizontal leakage distribution.

6 Numerical Examples

6.1 Sample Input and Output of STEADY-ACE

The JPDR-II core was analyzed to demonstrate the applicability of STEADY-ACE. A quarter symmetry was assumed to simplify the calculation. The JPDR-II core parameters and the geometry were described already in **Chapter 2.** The nuclear cross sections of the JPDR-II fuel assemblies were derived from the JPDR-II core design report[7]. The input data listings and output results for the example case are attached in the Appendices **A** and **B**, respectively. The computation time for the example case was 7 minutes for CPU time or 28 minutes for CORE time on the machine FACOM-230-75. The convergence history of power-void iteration is shown in TABLE 6.1 from which it is seen that the iterative scheme is converged smoothly.

TABLE 6.1 Convergence history of power-void iteration

No. of power-void iteration	No. of outer iteration	Eigenvalue	Relative error of power-void iteration
1	1	1.00323	—
1	2	1.00550	—
1	3	1.00409	—
1	4	1.00364	—
1	5	1.00328	—
1	6	1.00303	—
1	7	1.00326	—
1	8	1.00317	—
2	2	1.00780	—
2	3	1.00844	—
2	4	1.00844	—
2	5	1.00842	—
3	2	1.00868	0.020602
4	2	1.00883	—
4	3	1.00894	0.022520
5	2	1.00900	0.006153
6	2	1.00899	0.002230
7	2	1.00899	0.000811

6.2 Power Distribution in JPDR-II Core

The power distribution in JPDR-II core was estimated by measuring decay γ-rays of Ti-Cu wires in in-core monitors. A comparison of the power distribution obtained by measurement with the calculated result by STEADY-ACE is shown in **Figs. 6.1** and **6.2**. **Figuer 6.1** shows the axial power distributions in channels located at (16, 5), (17, 5) and (18, 5) in **Fig. 2.1**. The channels (16, 5) and (17, 5) are close to a control rod which is inserted into NO. 8 block from bottom. This figure shows the calculated power distributions near the control rod are flatter than measured ones. This is caused by an over-estimation of the neutron leakage to the control channel from neighbouring channels. **Figuer 6.2** shows the heat production rate in JPDR-II core. The heat rate in channels near the reflector is over estimated. The large errors, appear in channels near reflector or control rods, but the value is less than 10% at the region of the maximum power peaking.

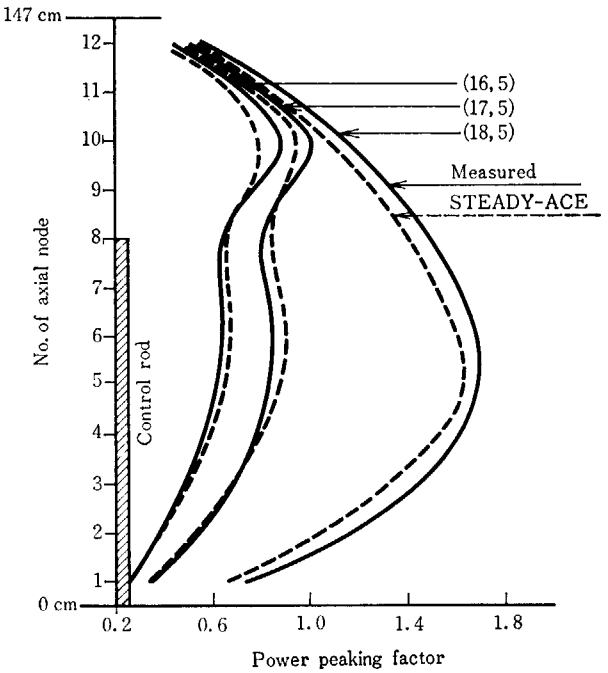


Fig. 6.1 Axial power distribution normalized to core average of unity

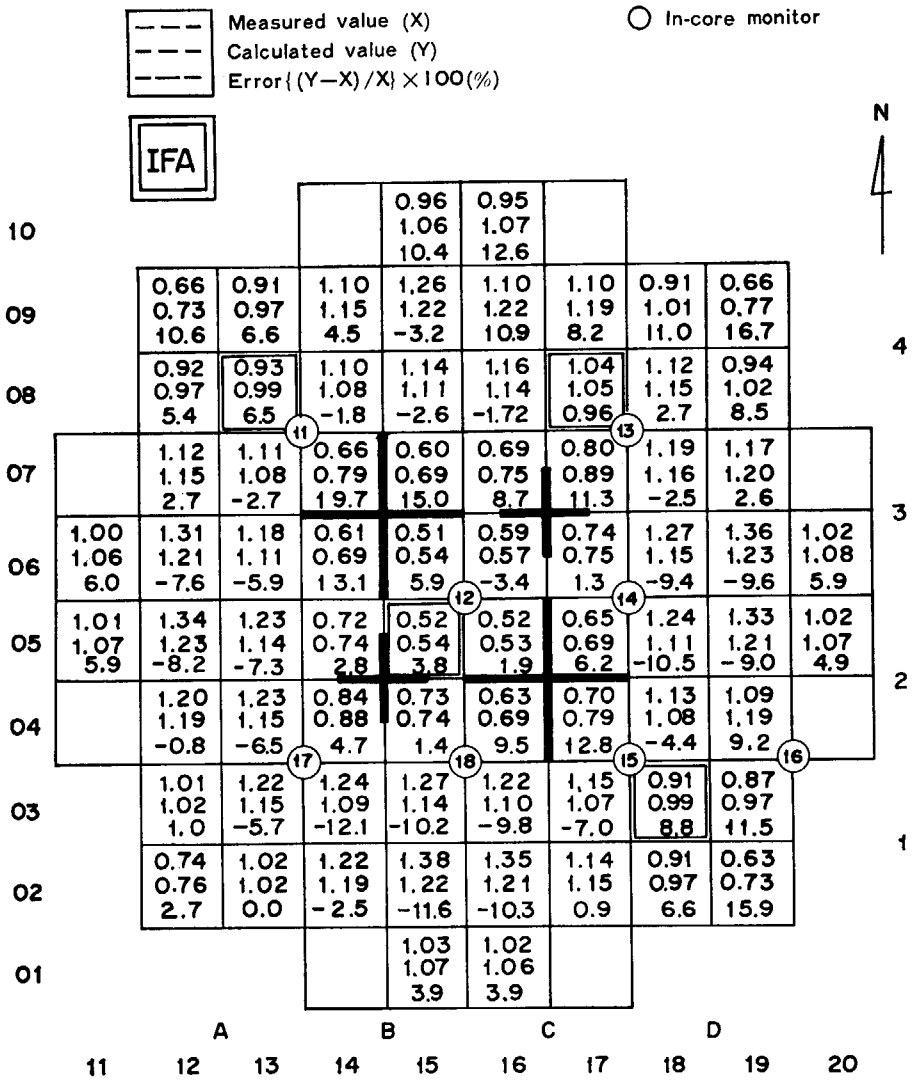


Fig. 6.2 Heat production rate in JPDR-II core

6.3 Coolant Flow Distribution in JPDR-II Core

Four instrumented fuel assemblies (IFA) were loaded in JPDR-II core and the coolant flow rate through IFA's were measured by a turbine flow meter attached to the inlet and the outlet of IFA's as shown in **Fig. 6.3**. Calculated coolant flow rates through IFA's were compared with the measured data and the results are given in **TABLES 6.2** and **6.3**. **TABLE 6.2** shows that the calculated results are in agreement with measured ones within a few percent error. In **TABLE 6.3** are shown relations between the nomalized heat production rate and the coolant flow rate. The more heat is produced in a channel, the less coolant flows through the channel near the rated flow rate (100% flow) but the more coolant flows at less than 80% flow rate. The

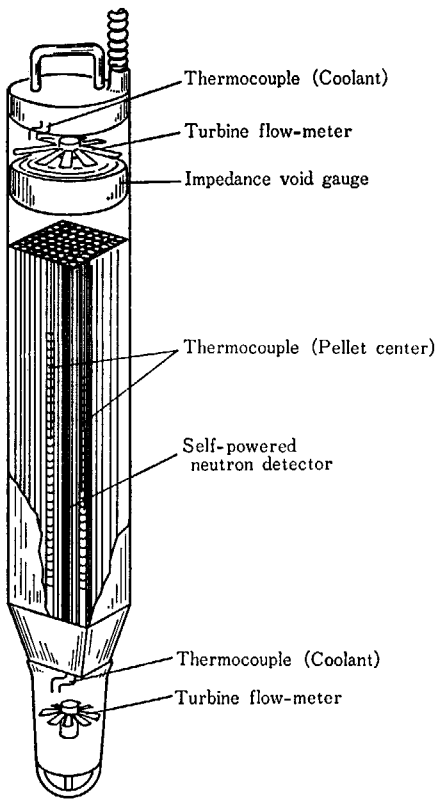


Fig. 6.3 JPDR-II instrumented fuel assembly

TABLE 6.2 Comparison of flow rate in IFA channels between calculation and measurement

Nominal flow rate		%	100	80	60	40
IFA	#4	kg/sec	6.50	5.10	4.04	2.80
HYDRO-ACE	(15, 6)	kg/sec	6.28	4.97	3.72	2.72
Error		%	−3.38	−2.55	−7.92	−2.86
IFA	#5	kg/sec	6.39	5.29	4.31	3.44
HYDRO-ACE	(13, 3)	kg/sec	6.51	5.34	4.26	3.40
Error		%	+1.88	+0.95	−1.16	−1.16
IFA	#6	kg/sec	6.65	5.56	4.27	3.59
HYDRO-ACE	(18, 8)	kg/sec	6.52	5.35	4.27	3.42
Error		%	−1.95	−3.78	−0.0	−4.74
IFA	#7	kg/sec	6.50	5.56	4.50	3.78
HYDRO-ACE	(17, 3)	kg/sec	6.55	5.41	4.35	3.53
Error		%	+0.77	−2.70	−3.33	−6.61

TABLE 6.3 Dependency of coolant flow rate on heat production

	Location of assembly	Normalized heat production rate in assembly	Coolant flow rate (kg/sec)			
			Nominal value (%)			
			100	80	60	40
Calculated by STEADY-ACE	(12, 6)	1.349	10.90	8.79	6.83	5.32
	(11, 5)	1.003	11.09	8.78	6.61	4.92
	(15, 5)	0.508	11.22	8.42	5.84	3.73
Measured	IFA #4	0.557	6.50	5.10	4.04	2.80
	IFA #5	0.912	6.39	5.29	4.31	3.44

above coolant flow characteristis in JPDR-II core are obtained both by measurement and by calculation. This shows again that STEADY-ACE is applicable to analyse efficiently the core performance of a BWR.

7 Conclusion

STEADY-ACE provides a very useful tool to make an accurate prediction of the BWR core performance in a reasonably short computation time. The applicability of the program are very wide. For example, it is useful for the detailed analysis of the start-up tests and the calibration of the simplified program such as FLARE[1].

The limitations of the computer program are as follows:

1. The program is applicable only to BWR core analyses, as the cross flow through the channel boxes are not included in the thermal-hydraulic subprogram HYDRO-ACE.
2. The exposure dependency of the unclear cross sections is not included in the program. Further efforts are required to make the program applicable to the control rod search for the exposed core and other core management analyses.

Acknowledgment

DIFFUSION-ACE, which is a major component of STEADY-ACE, was programmed with the assistance of Mr. Kazuo Shibuya (Fujitsu Co. Inc.). The authors express their appreciation for his great efforts. Thanks also due to S. Matsuura of JAERI for his valuable discussion and his critical reading of this manuscript.

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Appendix A : STEADY-ACE Sample Input

```
          JPDR      A QUARTER CORE
 25         0.01       1.5

 10 10 10 10 10 10 1
   0.01       0.01       0.01       0.01       0.01       0.01
 2.078      2.323      3.790      3.9415
QUAT     -  5  8 11
           0 11
   9 10  9  7  5
   0  9  8  6  4
   0  7  6  3  2
  11  5  4  2  1
   1  1  1  1  1  1  1  1  1  1  1  2
   62.5
   2  0
   1  5  2  JP-2 7*7    1.883
SUPP          2.078     0.005027   0.08       0.4038
EXPA          2.128   000.006362   0.09       0.
TIE           2.211     0.008339   0.0142     0.75
FUEL          2.236     0.008339   0.0142     0.
TIE           3.894     0.008339   0.0142     0.28
DUMY          3.9415                          0.1064
   2.768      0.526      3.308      0.526
   2  3  0   LEAKAGE     0.
SUP1          2.078     0.0896     0.038      0.6742
SUP2          2.109     0.04864    0.028      0.2569
FUEL          2.128     0.2485     0.0148     0.6468
DUMY          3.9415                          0.4913
EACH
SINE          1.        SINE       1.         SINE       1.
SINE          1.        SINE       1.         SINE       1.
SINE          1.        SINE       1.         SINE       1.
SINE          1.        SINE       1.         SINE       1.
   90.        3260.       3.4      0.1        0.002      0.018      0.
   3  3  1
   1  1  1  1  1  1  1  1  1  1  1  1
   1  1  1  1  1  1  1  1  1  1  1  1
   1  1  1  1  1  1  1  1  1  1  1  1
   1  1  1  1  1  1  1  1  1  1  1  1
   1  1  1  1  1  1  1  1  1  1  1  1
   1  1  1  1  1  1  1  1  1  1  1  1
   1  1  1  1  1  1  1  1  1  1  1  1
   1  1  1  1  1  1  1  1  1  1  1  1
   1  1  1  1  1  1  1  1  1  1  1  1
   1  1  1  1  1  1  1  1  1  1  1  1
  1.6903     0.43880    0.31036
  0.80625    0.30666    0.27090
  0.41354    0.16192    0.34548
  .0028169 -.27275E-3-.31258E-4
  .016610    .63046E-3 .75624E-2
  062154    -.78250E-2-.77068E-2
  .33217E-2-.28149E-3-.21250E-3
  .94623E-2 .46148E-3 .30625E-2
  .87355E-1-.75121E-2-.13957E-1
  .39588E-1-.23115E-1-.77498E-3
  .63019E-1-.45938E-1-.29378E-2
  0.
  3.111E-11 3.111E-11 3.111E-11
  2.645      2.43       2.442
  3.619E-03 1.726E-03 8.840E-04
  2.66193    1.33137    0.992551
  1.04664    0.588856   0.542857


  0.390606 0.238981    0.266002
  .30503E-3-.24231E-3 .42850E-5
  .79612E-3-.31560E-3 .25986E-8
  .13988E-1-.48697E-2-.48570E-3
  .35692E-1-.24104E-1-.99951E-4
  .70755E-1-.50182E-1-.14303E-4

  .1020 E-2
  .1020 E-2
  .1020 E-2
  2.66193    0.0003050 0.0356918 .10200E-2
  1.04664    0.0027657 0.0707551 .10200E-2
  0.390606   0.0391508           .10200E-2
  2.2459     0.000565  0.054836  .38210E-3
  0.7790     0.000719  0.114673  .38210E-3
  0.2501     0.010986            .38210E-3
   2  2  3  1  0

   13.66     13.66     0.1       0.        0.
   3  3  3  1  3  1
   1.
  50 50  1
   0.01       0.01       0.01       0.01
   0.8        1.4
 30100  3  5
   0.005      0.003      0.001
   3  5
   0.005      0.003      0.001
   0.0        0.0        1.5
```

Appendix B : STEADY-ACE Sample Output

```
        *** VERTICAL PLANE FIGURE ***

MULTI-CHANNEL ZONE
OUTLET HEIGHT                = 3.9415   ----------

     HEATED ZONE
     OUTLET HEIGHT  = ZN( 9) = 3.7900   ----------   Z( 9) = 3.7900
                      ZN( 8) = 3.6066   ------       Z( 8) = 3.6983
                      ZN( 7) = 3.4233   ------       Z( 7) = 3.5149
                      ZN( 6) = 3.2399   ------       Z( 6) = 3.3316
                      ZN( 5) = 3.0565   ------       Z( 5) = 3.1482
                      ZN( 4) = 2.8731   ------       Z( 4) = 2.9648
                      ZN( 3) = 2.6898   ------       Z( 3) = 2.7814
                      ZN( 2) = 2.5064   ------       Z( 2) = 2.5981
     HEATED ZONE      ZN( 1) = 2.3230   ----------   Z( 1) = 2.4147
     INLET HEIGHT

MULTI-CHANNEL ZONE           = 2.0780   ----------
INLET HEIGHT

                    ZN(KK) = NODE POINT HEIGHT        Z(K) = BLOCK MIDDLE POINT HEIGHT

                     KMAX1 =  9                       KMAX =  8

LENGTH OF A REGION (DZ) =  0.1834
```

*** ARRANGEMENT OF ASSEMBLIES ***
@UAT REGION OF THE CORE

	1	2	3	4	5
1					11 1 8
2		10 1 4	9 1 8	7 1 8	5 1 8
3		9 1 8	8 1 4	6 1 8	4 1 8
4		7 1 8	6 1 8	3 1 4	2 1 8
5	11 1 8	5 1 8	4 1 8	2 1 8	1 1 4

LEAKAGE
12
2
1

NOTE	
N	CONDITIONED NUMBER
MG	GEOMETRICAL TYPE NUMBER
NO	OCCUPIED NUMBER

$$* NCHANL = \sum_{N=1}^{11} NO(N) = 72 \qquad * NCHAN1 = \sum_{N=1}^{12} NO(N) = 73 \qquad * NBLOCK = KMAX*NCHANL = 576$$

```
        *** PROPERTIES OF WATER AND STEAM ***

    ABSOLUTE PRESSURE ..................... 62.5 KG/CM**2
                                            ( 889.0 PSIA )
    ENTHALPY OF SATURATED WATER ........... 291.6 KCAL/KG
    ENTHALPY OF SATURATED STEAM ........... 664.9 KCAL/KG
    SATURATION TEMPERATURE ................ 276.9 DEG-C
    DENSITY OF SATURATED WATER ............ 755.9 KG/M**3
    DENSITY OF SATURATED STEAM ............  31.6 KG/M**3
    DYNAMIC VISCOSITY OF SATURATED WATER ..... 0.98962E-05 KG.SEC/M**2
    KINEMATIC VISCOSITY OF SATURATED WATER .... 0.12839E-06 M**2/SEC
    DYNAMIC VISCOSITY OF SATURATED STEAM ..... 0.18972E-05 KG.SEC/M**2
    KINEMATIC VISCOSITY OF SATURATED STEAM .... 0.58970E-06 M**2/SEC
    THERMAL CONDUCTIVITY OF SATURATED WATER ... 0.13833E-03 KCAL/M.SEC.DEG-C
    THERMAL CONDUCTIVITY OF SATURATED STEAM ... 0.14222E-04 KCAL/M.SEC.DEG-C
    ISOBARIC SPECIFIC HEAT CAPASITY OF WATER .. 0.12473E 01 KCAL/KG.DEG-C
    PRANDTL NUMBER OF SATURATED WATER ......... 0.87512E 00
    TEMPERATURE OF SUBCOOLED WATER AS A FUNCTION OF ENTHALPY
       T = 276.9 - 0.8017 * ( 291.6 - H ) - 0.000995 * ( 291.6 - H )**2
    DENSITY OF SUBCOOLED WATER AS A FUNCTION OF ENTHALPY
       ROH= 755.9 + 1.5046 * ( 291.6 - H ) - 0.002675 * ( 291.6 - H )**2

         ** CONSTANTS AT THE CRITICAL POINT **

    CRITICAL PRESSURE ..................... 225.6 KG/CM**2
                                            (3208.2 PSIA )
    CRITICAL TEMPERATURE .................. 374.2 DEG-C

    GRAVITATIONAL CONSTANT ................ 9.807 M/SEC**2

         *** INNER CHANNEL GEOMETRY ***

GEOMETRICAL TYPE NUMBER .... 1      INDCTC=FULL
                  ( JP-2 7*7  )

 NO. NAME  HEIGHT(M)  LENGTH(M)  AREA(M2)  EQ.DIA(M)  E/C COEFT.  H.PERIM(M)
                2.0780                                    0.4038
  1  SUPP                0.0500   0.005027   0.0800
                2.1280                                    0.0
  2  EXPA                0.0830   0.006362   0.0900
                2.2110                                    0.7500
  3  TIE                 0.0250   0.008339   0.0142
                2.2360                                    0.0
  4  FUEL                1.6580   0.008339   0.0142                1.8830 .... HEATED DUCT
                3.8940                                    0.2800
  5  TIE                 0.0475   0.008339   0.0142
                3.9415                                    0.1064

     SPACER DESIGN
       NO.    HEIGHT   E/C COEFT.  DUCT  REGION
        1     2.7680     0.5260      4      3
        2     3.3080     0.5260      4      6

GEOMETRICAL TYPE NUMBER .... 2      INDCTC=FULL
                  ( LEAKAGE   )

 NO. NAME  HEIGHT(M)  LENGTH(M)  AREA(M2)  EQ.DIA(M)  E/C COEFT.  H.PERIM(M)
                2.0780                                    0.6742
  1  SUP1                0.0310   0.089600   0.0380
                2.1090                                    0.2569
  2  SUP2                0.0190   0.048640   0.0280
                2.1280                                    0.6468
  3  FUEL                1.8135   0.248500   0.0148                0.0    .... HEATED DUCT
                3.9415                                    0.4913

     NO DATUM ABOUT SPACER

  * AASSY(ASSEMBLY PART AREA)      = 0.6004 M**2
  * ALEAK(LEAKAGE PART AREA)       = 0.2485 M**2
  * ACORE(HEATED ZONE TOTAL AREA)  = 0.8489 M**2
```

*** NORMALIZED HEAT DISTRIBUTION ***
(INPUT MODE .... EACH)

	N= 1	N= 2	N= 3	N= 4	N= 5	N= 6	N= 7	N= 8	N= 9	N=10	N=11
SS(N)	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
S(N. 8)	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045
S(N. 7)	0.8671	0.8671	0.8671	0.8671	0.8671	0.8671	0.8671	0.8671	0.8671	0.8671	0.8671
S(N. 6)	1.2977	1.2977	1.2977	1.2977	1.2977	1.2977	1.2977	1.2977	1.2977	1.2977	1.2977
S(N. 5)	1.5307	1.5307	1.5307	1.5307	1.5307	1.5307	1.5307	1.5307	1.5307	1.5307	1.5307
S(N. 4)	1.5307	1.5307	1.5307	1.5307	1.5307	1.5307	1.5307	1.5307	1.5307	1.5307	1.5307
S(N. 3)	1.2977	1.2977	1.2977	1.2977	1.2977	1.2977	1.2977	1.2977	1.2977	1.2977	1.2977
S(N. 2)	0.8671	0.8671	0.8671	0.8671	0.8671	0.8671	0.8671	0.8671	0.8671	0.8671	0.8671
S(N. 1)	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045

*** HEAT BALANCE CALCULATION RESULTS ***

90.0MW. 905.6KG/SEC

BWR FLOW AND ENTHALPY TABLE

(1) INLET
FLOW 905.56 KG/SEC
ENTHALPY 284.20 KCAL/KG
DENSITY 766.92 KG/M**3

(2) OUTLET
FLOW 905.56 KG/SEC
(WATER) 865.92
(STEAM) 39.64
ENTHALPY 307.95 KCAL/KG
QUALITY 0.0438
VOID FR. 0.4179
DENSITY 453.23 KG/M**3

(3) STEAM PIPE
FLOW 37.90 KG/SEC
ENTHALPY 664.87 KCAL/KG

(5) FEED WATER
FLOW 38.84 KG/SEC
ENTHALPY 102.12 KCAL/KG

(6) DOWN COMMER 1
FLOW 867.66 KG/SEC
(WATER) 865.92
(STEAM) 1.74
ENTHALPY 292.35 KCAL/KG
QUALITY 0.0020
VOID FR. 0.0366
DENSITY 729.41 KG/M**3

(7) DOWN COMMER 2
FLOW 906.50 KG/SEC
ENTHALPY 284.20 KCAL/KG
DENSITY 766.92 KG/M**3

(8) CLEAN UP FLOW
FLOW 0.94 KG/SEC
ENTHALPY 284.20 KCAL/KG
DENSITY 766.92 KG/M**3

IEND 0

IEND 0

**** CALCULATION SYSTEM ****

NO. OF CHANNELS IN X-DIRECTION	5	NO. OF DIVISIONS IN ONE CHANNEL (X) ..	2
NO. OF CHANNELS IN Y-DIRECTION	5	NO. OF DIVISIONS IN ONE CHANNEL (Y) ..	2
NO. OF BLOCKS IN Z-DIRECTION	8	NO. OF DIVISIONS IN ONE BLOCK (Z)	3
NO. OF CHANNELS IN X-Y PLANE	11		
NO. OF DIVISIONS IN THE REFLECTOR (X-Y)	1		
NO. OF DIVISIONS IN THE REFLECTOR (Z)	0		
NO. OF CONTROL RODS	0		
NO. OF IN-CORE MONITORS	0		
NO. OF SPECIAL BLOCKS DIVIDED THINNER	0		

**** GEOMETRY ****

WIDTH OF ONE CHANNEL IN X-DIRECTION	13.6600	CM
WIDTH OF ONE CHANNEL IN Y-DIRECTION	13.6600	CM
LENGTH OF ONE BLOCK IN Z-DIRECTION	18.3375	CM
WIDTH OF THE REFLECTOR (X-Y)	0.1000	CM
THICKNESS OF THE CONTROL RODS	0.0	CM
LENGTH OF THE REFLECTOR (Z)	0.0	CM

CHANNELS POSITION IN X-Y PLANE

```
          BACK
      ********************************
LEFT  *                              *  RIGHT
      *   0  0  0  0 11              *
      *   0 10  9  7  5              *
      *   0  9  8  6  4              *
      *   0  7  6  3  2              *
      *  11  5  4  2  1              *
      ********************************
          FORE
```

**** BOUNDARY CONDITIONS ****

LOWER SIDE	ANALYTICAL
UPPER SIDE	ANALYTICAL
LEFT SIDE	ANALYTICAL
RIGHT SIDE	ZERO DERIVATIVE
BACK SIDE	ANALYTICAL
FORE SIDE	ZERO DERIVATIVE

**** FISSION SPECTRUM ****

NO. OF ENERGY GROUPS	3		
FISSION SPECTRUM	0.10000E 01	0.0	0.0

```
**** CONVERGENCE CRITERIA AND RELAXATION FACTORS ****
     CONVERGENCE CRITERIA WHEN CALCULATING  SOURCE GUESS

          CRITERIA ON EIGENVALUE IN 1-DIM. OUTER IT.                0.010000
          CRITERIA ON SOURCE DISTR. IN 1-DIM. OUTER IT.             0.010000
          CRITERIA IN 2 - DIMENSIONAL INNER IT.                     0.010000
          CRITERIA IN 2 - DIMENSIONAL OUTER IT.                     0.010000
          MAX. ITERATION TIMES IN 2-DIM. INNER IT.          50
          MAX. ITERATION TIMES IN 2-DIM. OUTER IT.          50
          OVER RELAXATION FACTOR OF 1-DIM. OUTER IT.                0.800000
          OVER RELAXATION FACTOR OF 2-DIM. INNER IT.                1.400000
          SLOR METHOD IN 2-DIM. INNER IT. IS APPLIED  TO ONLY X - AXIS
     CONVERGENCE CRITERIA WHEN CALCULATING  3-DIMENSIONAL SYNTHESIS

          TEMPORARY CRITERIA OF 3-DIM. INNER IT. WHEN   OUTER IT. TIMES ARE LESS THAN  3
                                                AND  LINK IT. TIMES ARE LESS THAN     2 .....   0.005000
          TEMPORARY CRITERIA OF 3-DIM  INNER IT. WHEN   OUTER IT. TIMES ARE LESS THAN  5
                                                AND  LINK IT. TIMES ARE LESS THAN     2 .....   0.003000
          FINAL CRITERIA OF 3-DIM INNER IT.                                           .....   0.001000
          MAX. ITERATION TIMES IN 3-DIM. INNER IT.      100
          MAX. ITERATION TIMES IN 3-DIM. OUTER IT.       30
          TEMPORARY CRITERIA OF 3-DIM OUTER IT. WHEN LINK IT. TIMES   ARE LESS THAN     3 .....   0.005000
          TEMPORARY CRITERIA OF 3- DIM OUTER IT. WHEN LINK IT. TIMES  ARE LESS THAN     5 .....   0.003000
          FINAL CONVERGENCE CRITERIA OF 3-DIM  OUTER ITERATION                        .....   0.001000
          RELAXATION FACTOR OF L-XY IN INNER IT.            0.0
          RELAXATION FACTOR OF L-Z IN INNER IT.             0.0
          RELAXATION FACTOR IN 3-DIM. OUTER IT.             1.500000


               *** YOUR CALCULATIONAL SYSTEM IS PROPER ***
                    NO. OF (A)  IS UNDER THE LIMIT BY  16826 WORDS


               *** YOUR CALCULATIONAL SYSTEM IS PROPER ***
                    NO. OF (NA) IS UNDER THE LIMIT BY   4852 WORDS


          MATERIAL MAP --- BLOCK NO.      0---

   X 0  1  2  3  4  5  6  7  8  9 10 11
 Y
 0  ***********************************
    *12 12 12 12 12 12 12 12 12 12 12*
 1  *                                 *
    *12 12 12 12 12 12 12 12 12*11 11*
 2  *                           *     *
    *12 12 12 12 12 12 12 12 12*11 11*
 3  *        ************************
    *12 12 12*10 10* 9  9* 7  7* 5  5*
 4  *     *     *     *     *     *
    *12 12 12*10 10* 9  9* 7  7* 5  5*
 5  *        ************************
    *12 12 12* 9  9* 8  8* 6  6* 4  4*
 6  *        *     *     *     *     *
    *12 12 12* 9  9* 8  8* 6  6* 4  4*
 7  *        ************************
    *12 12 12* 7  7* 6  6* 3  3* 2  2*
 8  *     *     *     *     *     *
    *12 12 12* 7  7* 6  6* 3  3* 2  2*
 9  *  ***********************************
    *12*11 11* 5  5* 4  4* 2  2* 1  1*
10  *  *     *     *     *     *     *
    *12*11 11* 5  5* 4  4* 2  2* 1  1*
11  ***********************************

SOURCE IT. OF 2-DIM. FOR SOURCE GUESS

          SOURCE IT.    MAX LAMBDA        LAMBDA          MIN LAMBDA        ACC. PARAMETER USED
     1    0.12969215E 01   0.10757099E 01   0.75232726E 00   0.0
     2    0.11748936E 01   0.10733767E 01   0.90317586E 00   0.0
          THETA VALUE 0.38668E-01 0.14196E-57 0.13242E-17 0.15449E-11 0.38427E-05
     3    0.11644045E 01   0.10821640E 01   0.95152529E 00   0.38667962E-01
          THETA VALUE 0.34857E 01 0.12649E 01 0.33216E 00 0.31721E-01 0.38427E-05
     4    0.12663551E 01   0.11055897E 01   0.10712258E 01   0.34857262E 01
     5    0.11307456E 01   0.11076283E 01   0.10750822E 01   0.12648881E 01
     6    0.11097576E 01   0.11066328E 01   0.10963507E 01   0.33215947E 00
```

FLUX AND SOURCE DISTRIBUTION

EIGEN VALUE 1.0816055

CHANNEL NO. 1

BLOCK NO.	SOURCE	FLUX-1G	FLUX-2G	FLUX-3G
1	0.14897E 01	0.32549E 02	0.19844E 02	0.15570E 02
2	0.23626E 01	0.57353E 02	0.27749E 02	0.24901E 02
3	0.23645E 01	0.67961E 02	0.30254E 02	0.24600E 02
4	0.18962E 01	0.55708E 02	0.26555E 02	0.19687E 02
5	0.14090E 01	0.43762E 02	0.20739E 02	0.14589E 02
6	0.97802E 00	0.31382E 02	0.14824E 02	0.10104E 02
7	0.61354E 00	0.20063E 02	0.94964E 01	0.63296E 01
8	0.32140E 00	0.99122E 01	0.46692E 01	0.33853E 01

CHANNEL NO. 2

BLOCK NO.	SOURCE	FLUX-1G	FLUX-2G	FLUX-3G
1	0.13771E 01	0.29938E 02	0.14572E 02	0.14395E 02
2	0.22404E 01	0.53090E 02	0.25706E 02	0.23522E 02
3	0.22460E 01	0.58664E 02	0.28236E 02	0.23373E 02
4	0.18179E 01	0.52142E 02	0.24890E 02	0.18845E 02
5	0.13472E 01	0.41026E 02	0.19449E 02	0.13966E 02
6	0.93408E 00	0.29420E 02	0.13925E 02	0.96646E 01
7	0.58487E 00	0.18794E 02	0.88769E 01	0.60423E 01
8	0.30484E 00	0.92621E 01	0.43705E 01	0.32119E 01

CHANNEL NO. 3

BLOCK NO.	SOURCE	FLUX-1G	FLUX-2G	FLUX-3G
1	0.12638E 01	0.27359E 02	0.13318E 02	0.13214E 02
2	0.20767E 01	0.48768E 02	0.23623E 02	0.21644E 02
3	0.21168E 01	0.54283E 02	0.26159E 02	0.22034E 02
4	0.17262E 01	0.48487E 02	0.23194E 02	0.17938E 02
5	0.12827E 01	0.38239E 02	0.18209E 02	0.13316E 02
6	0.88874E 00	0.27432E 02	0.13012E 02	0.92095E 01
7	0.55594E 00	0.17511E 02	0.82883E 01	0.57501E 01
8	0.28827E 00	0.86097E 01	0.40711E 01	0.30390E 01

CHANNEL NO. 4

BLOCK NO.	SOURCE	FLUX-1G	FLUX-2G	FLUX-3G
1	0.11423E 01	0.24820E 02	0.11984E 02	0.11941E 02
2	0.19045E 01	0.44135E 02	0.21381E 02	0.19823E 02
3	0.19679E 01	0.49462E 02	0.23856E 02	0.20477E 02
4	0.16283E 01	0.44483E 02	0.21330E 02	0.16936E 02
5	0.12076E 01	0.35130E 02	0.16753E 02	0.12548E 02
6	0.83599E 00	0.25207E 02	0.11980E 02	0.86725E 01
7	0.52228E 00	0.16086E 02	0.76270E 01	0.54118E 01
8	0.26970E 00	0.78902E 01	0.37412E 01	0.28436E 01

CHANNEL NO. 5

BLOCK NO.	SOURCE	FLUX-1G	FLUX-2G	FLUX-3G
1	0.81707E 00	0.17027E 02	0.82750E 01	0.85824E 01
2	0.14043E 01	0.30970E 02	0.14987E 02	0.14705E 02
3	0.15164E 01	0.35349E 02	0.17038E 02	0.15875E 02
4	0.13982E 01	0.32309E 02	0.15533E 02	0.13699E 02
5	0.99371E 00	0.25779E 02	0.12349E 02	0.10408E 02
6	0.69032E 00	0.18563E 02	0.88636E 01	0.72341E 01
7	0.42988E 00	0.11842E 02	0.56421E 01	0.45066E 01
8	0.21809E 00	0.57698E 01	0.27459E 01	0.23164E 01

CHANNEL NO. 6

BLOCK NO.	SOURCE	FLUX-1G	FLUX-2G	FLUX-3G
1	0.10345E 01	0.22210E 02	0.10808E 02	0.10814E 02
2	0.17397E 01	0.40003E 02	0.19378E 02	0.18112E 02
3	0.18243E 01	0.45115E 02	0.21770E 02	0.18982E 02
4	0.15297E 01	0.40788E 02	0.19589E 02	0.15908E 02
5	0.11386E 01	0.32306E 02	0.15431E 02	0.11838E 02
6	0.78225E 00	0.23202E 02	0.11045E 02	0.81854E 01
7	0.49190E 00	0.14803E 02	0.70290E 01	0.51026E 01
8	0.25261E 00	0.72418E 01	0.34392E 01	0.26631E 01

CHANNEL NO. 7

BLOCK NO.	SOURCE	FLUX-1G	FLUX-2G	FLUX-3G
1	0.78691E 00	0.14332E 02	0.69644E 01	0.84545E 01
2	0.13698E 01	0.26155E 02	0.12658E 02	0.14712E 02
3	0.15022E 01	0.29993E 02	0.14479E 02	0.16183E 02
4	0.13169E 01	0.27535E 02	0.13250E 02	0.14247E 02
5	0.10122E 01	0.22043E 02	0.10568E 02	0.10995E 02
6	0.70862E 00	0.15902E 02	0.76037E 01	0.77248E 01
7	0.44926E 00	0.10151E 02	0.48443E 01	0.48448E 01
8	0.22382E 00	0.49478E 01	0.23586E 01	0.24715E 01

CHANNEL NO. 8

BLOCK NO.	SOURCE	FLUX-1G	FLUX-2G	FLUX-3G
1	0.82195E 00	0.17541E 02	0.85329E 01	0.85952E 01
2	0.14093E 01	0.31891E 02	0.15447E 02	0.14680E 02
3	0.15146E 01	0.36423E 02	0.17597E 02	0.15817E 02
4	0.13078E 01	0.33278E 02	0.16017E 02	0.13602E 02
5	0.99079E 00	0.26553E 02	0.12728E 02	0.10297E 02
6	0.68757E 00	0.19122E 02	0.91577E 01	0.71448E 01
7	0.42789E 00	0.12195E 02	0.58140E 01	0.44465E 01
8	0.21715E 00	0.59344E 01	0.28295E 01	0.22877E 01

CHANNEL NO. 9

BLOCK NO.	SOURCE	FLUX-1G	FLUX-2G	FLUX-3G
1	0.80767E 00	0.10713E 02	0.51997E 01	0.65559E 01
2	0.14078E 01	0.19706E 02	0.95290E 01	0.11620E 02
3	0.12069E 01	0.22817E 02	0.11013E 02	0.13038E 02
4	0.10800E 01	0.21141E 02	0.10180E 02	0.11703E 02
5	0.84380E 00	0.17029E 02	0.81934E 01	0.91717E 01
6	0.59673E 00	0.12340E 02	0.59139E 01	0.65030E 01
7	0.37521E 00	0.78865E 01	0.37737E 01	0.40967E 01
8	0.18769E 00	0.38255E 01	0.18289E 01	0.20667E 01

CHANNEL NO. 10

BLOCK NO.	SOURCE	FLUX-1G	FLUX-2G	FLUX-3G
1	0.41911E 00	0.62894E 01	0.30485E 01	0.46201E 01
2	0.76251E 00	0.11670E 02	0.56384E 01	0.83959E 01
3	0.87753E 00	0.13670E 02	0.65979E 01	0.96770E 01
4	0.80521E 00	0.12802E 02	0.61703E 01	0.89052E 01
5	0.64274E 00	0.10410E 02	0.50089E 01	0.71290E 01
6	0.46147E 00	0.75823E 01	0.36435E 01	0.51311E 01
7	0.29267E 00	0.48572E 01	0.23318E 01	0.32601E 01
8	0.14498E 00	0.23477E 01	0.11260E 01	0.16235E 01

CHANNEL NO. 11

BLOCK NO.	SOURCE	FLUX-1G	FLUX-2G	FLUX-3G
1	0.53704E 00	0.84362E 01	0.40850E 01	0.58870E 01
2	0.96452E 00	0.15562E 02	0.75107E 01	0.10565E 02
3	0.10904E 01	0.18077E 02	0.87106E 01	0.11978E 02
4	0.98568E 00	0.16809E 02	0.80831E 01	0.10868E 02
5	0.77685E 00	0.13584E 02	0.65118E 01	0.85971E 01
6	0.55271E 00	0.98343E 01	0.47201E 01	0.61360E 01
7	0.34876E 00	0.63032E 01	0.30151E 01	0.38806E 01
8	0.17386E 00	0.30591E 01	0.14628E 01	0.19473E 01

LEAKAGE DISTRIBUTION

CHANNEL NO. 1

BLOCK NO.	LZ-1G	LZ-2G	LZ-3G	LXY-1G	LXY-2G	LXY-3G	POWER
1	0.30735E-02	0.85987E-03	-0.38026E-03	0.15511E-02	0.72141E-03	0.27355E-03	0.14901E 01
2	0.17776E-02	0.89658E-03	0.63030E-03	0.15472E-02	0.69409E-03	0.17644E-03	0.23924E 01
3	0.11509E-02	0.58263E-03	0.26464E-03	0.13326E-02	0.64587E-03	-0.21990E-05	0.23632E 01
4	0.49215E-03	0.22465E-03	-0.98653E-04	0.15031E-02	0.61357E-03	0.31968E-04	0.18944E 01
5	0.74055E-04	0.93300E-05	-0.12581E-03	0.14715E-02	0.65310E-03	0.18045E-04	0.14072E 01
6	-0.18992E-03	-0.11356E-03	-0.15901E-03	0.14793E-02	0.64732E-03	0.52516E-04	0.97661E 00
7	-0.36215E-03	-0.19771E-03	-0.19469E-03	0.15076E-02	0.66904E-03	0.67397E-04	0.61260E 00
8	0.16717E-02	-0.29912E-03	-0.50359E-02	0.15533E-02	0.69849E-03	0.15433E-03	0.32103E 00

CHANNEL NO. 2

BLOCK NO.	LZ-1G	LZ-2G	LZ-3G	LXY-1G	LXY-2G	LXY-3G	POWER
1	0.30076E-02	0.82519E-03	-0.40894E-03	0.16408E-02	0.76390E-03	0.31709E-03	0.13775E 01
2	0.17525E-02	0.87935E-03	0.61193E-03	0.16764E-02	0.72872E-03	0.19473E-03	0.22403E 01
3	0.11509E-02	0.58869E-03	0.28405E-03	0.16841E-02	0.69316E-03	0.27022E-04	0.22449E 01
4	0.51264E-03	0.22687E-03	-0.71997E-04	0.16923E-02	0.71010E-03	-0.10748E-03	0.18113E 01
5	0.84673E-04	0.24590E-04	-0.12692E-03	0.16509E-02	0.67159E-03	-0.27299E-04	0.13656E 01
6	-0.18564E-03	-0.11600E-03	-0.15656E-03	0.16489E-02	0.70513E-03	-0.11468E-04	0.93284E 00
7	-0.35736E-03	-0.19143E-03	-0.19499E-03	0.16525E-02	0.71056E-03	0.52428E-04	0.58402E 00
8	0.16478E-02	-0.30117E-03	-0.49263E-02	0.16846E-02	0.77076E-03	0.15940E-03	0.30451E 00

CHANNEL NO. 3

BLOCK NO.	LZ-1G	LZ-2G	LZ-3G	LXY-1G	LXY-2G	LXY-3G	POWER
1	0.29620E-02	0.80303E-03	-0.43092E-03	0.16880E-02	0.80184E-03	0.36199E-03	0.12645E 01
2	0.17144E-02	0.85500E-03	0.58634E-03	0.17518E-02	0.78729E-03	0.27426E-03	0.20791E 01
3	0.11577E-02	0.58962E-03	0.29609E-03	0.17764E-02	0.76209E-03	0.10977E-03	0.21164E 01
4	0.52445E-03	0.23993E-03	-0.33566E-04	0.18475E-02	0.78487E-03	-0.87535E-04	0.17252E 01
5	0.10304E-03	0.35836E-04	-0.12757E-03	0.18141E-02	0.73132E-03	-0.66954E-04	0.12815E 01
6	-0.17823E-03	-0.11198E-03	-0.15480E-03	0.18114E-02	0.76758E-03	-0.50143E-04	0.88777E 00
7	-0.35361E-03	-0.18909E-03	-0.19300E-03	0.18093E-02	0.77271E-03	0.20423E-04	0.55501E 00
8	0.16291E-02	-0.29263E-03	-0.47979E-02	0.18533E-02	0.82852E-03	0.13816E-03	0.28802E 00

CHANNEL NO. 4

BLOCK NO.	LZ-1G	LZ-2G	LZ-3G	LXY-1G	LXY-2G	LXY-3G	POWER
1	0.29095E-02	0.78031E-03	-0.46434E-03	0.17744E-02	0.85111E-03	0.41548E-03	0.11426E 01
2	0.16901E-02	0.83743E-03	0.57123E-03	0.17904E-02	0.83503E-03	0.44495E-03	0.19046E 01
3	0.11360E-02	0.56990E-03	0.29018E-03	0.18770E-02	0.90365E-03	0.31107E-03	0.19675E 01
4	0.56531E-03	0.27714E-03	0.21336E-04	0.19417E-02	0.86279E-03	0.13369E-03	0.16273E 01
5	0.10408E-03	0.29262E-04	-0.13388E-03	0.20082E-02	0.86790E-03	-0.52667E-04	0.12065E 01
6	-0.16997E-03	-0.10263E-03	-0.15331E-03	0.19836E-02	0.87069E-03	-0.31626E-04	0.83510E 00
7	-0.34428E-03	-0.19185E-03	-0.18745E-03	0.19785E-02	0.90019E-03	0.46143E-05	0.52167E 00
8	0.16120E-02	-0.26404E-03	-0.46455E-02	0.20095E-02	0.86247E-03	0.16482E-03	0.26947E 00

CHANNEL NO. 5

BLOCK NO.	LZ-1G	LZ-2G	LZ-3G	LXY-1G	LXY-2G	LXY-3G	POWER
1	0.27626E-02	0.70911E-03	-0.48656E-03	0.31283E-02	0.10906E-02	-0.13871E-02	0.81742E 00
2	0.16207E-02	0.79091E-03	0.50267E-03	0.32585E-02	0.11409E-02	-0.16222E-02	0.14045E 01
3	0.11254E-02	0.55508E-03	0.28751E-03	0.33401E-02	0.12357E-02	-0.16140E-02	0.15163E 01
4	0.58362E-03	0.28855E-03	0.86658E-04	0.34481E-02	0.13273E-02	-0.16453E-02	0.13080E 01
5	0.15355E-03	0.64415E-04	-0.34398E-04	0.35163E-02	0.13999E-02	-0.17759E-02	0.99337E 00
6	-0.13707E-03	-0.78511E-04	-0.12330E-03	0.36021E-02	0.13634E-02	-0.20222E-02	0.68998E 00
7	-0.30774E-03	-0.16534E-03	-0.16305E-03	0.36498E-02	0.13592E-02	-0.22443E-02	0.42962E 00
8	0.15906E-02	-0.22251E-03	-0.39684E-02	0.35863E-02	0.13661E-02	-0.19991E-02	0.21801E 00

CHANNEL NO. 6

BLOCK NO.	LZ-1G	LZ-2G	LZ-3G	LXY-1G	LXY-2G	LXY-3G	POWER
1	0.28625E-02	0.75850E-03	-0.48160E-03	0.18619E-02	0.90609E-03	0.41366E-03	0.10346E 01
2	0.16634E-02	0.81988E-03	0.54576E-03	0.19145E-02	0.89028E-03	0.39312E-03	0.17396E 01
3	0.11339E-02	0.56517E-03	0.29127E-03	0.19920E-02	0.99650E-03	0.34927E-03	0.18238E 01
4	0.57503E-03	0.28586E-03	0.53152E-04	0.20510E-02	0.10013E-02	0.29004E-03	0.15287E 01
5	0.12059E-03	0.39999E-04	-0.11943E-03	0.21691E-02	0.99475E-03	-0.12173E-04	0.11376E 01
6	-0.15980E-03	-0.96239E-04	-0.14873E-03	0.21571E-02	0.10011E-02	-0.27796E-04	0.78744E 00
7	-0.33618E-03	-0.18741E-03	-0.18282E-03	0.21437E-02	0.10321E-02	0.11289E-04	0.49134E 00
8	0.15953E-02	-0.25108E-03	-0.44983E-02	0.21500E-02	0.98317E-03	0.20698E-03	0.25240E 00

CHANNEL NO. 7

BLOCK NO.	LZ-1G	LZ-2G	LZ-3G	LXY-1G	LXY-2G	LXY-3G	POWER
1	0.27270E-02	0.68974E-03	-0.26745E-03	0.10068E-01	0.11208E-02	-0.10340E-01	0.78786E 00
2	0.16035E-02	0.78086E-03	0.47170E-03	0.10238E-01	0.11501E-02	-0.10908E-01	0.13712E 01
3	0.11231E-02	0.55305E-03	0.28305E-03	0.10423E-01	0.12267E-02	-0.11398E-01	0.15034E 01
4	0.59744E-03	0.29606E-03	0.11506E-03	0.10633E-01	0.12889E-02	-0.11982E-01	0.13178E 01
5	0.16651E-03	0.73810E-04	-0.20780E-04	0.10783E-01	0.13552E-02	-0.12505E-01	0.10127E 01
6	-0.12831E-03	-0.72734E-04	-0.94408E-04	0.10904E-01	0.13045E-02	-0.12998E-01	0.70889E 00
7	-0.27820E-03	-0.15354E-03	-0.11792E-03	0.10949E-01	0.12576E-02	-0.13389E-01	0.44340E 00
8	0.16105E-02	-0.22028E-03	-0.31214E-02	0.10998E-01	0.12711E-02	-0.12891E-01	0.22392E 00

CHANNEL NO. 8

BLOCK NO.	LZ-1G	LZ-2G	LZ-3G	LXY-1G	LXY-2G	LXY-3G	POWER
1	0.27718E-02	0.71551E-03	-0.52832E-03	0.19827E-02	0.10099E-02	0.42681E-03	0.82218E 00
2	0.16097E-02	0.78573E-03	0.50358E-03	0.21106E-02	0.10755E-02	0.31295E-03	0.14092E 01
3	0.11339E-02	0.55833E-03	0.29138E-03	0.21751E-02	0.11654E-02	0.42716E-03	0.15195E 01
4	0.58041E-03	0.28861E-03	0.83565E-04	0.22696E-02	0.12499E-02	0.35473E-03	0.13074E 01
5	0.15300E-03	0.63800E-04	-0.66044E-04	0.22990E-02	0.13319E-02	0.60180E-03	0.99029E 00
6	-0.13338E-03	-0.77037E-04	-0.12878E-03	0.23803E-02	0.13244E-02	0.40969E-03	0.68715E 00
7	-0.31114E-03	-0.17234E-03	-0.17111E-03	0.24484E-02	0.13167E-02	0.19593E-03	0.42759E 00
8	0.15654E-02	-0.21431E-03	-0.41542E-02	0.24079E-02	0.12389E-02	0.41229E-03	0.21705E 00

CHANNEL NO. 9

BLOCK NO.	LZ-1G	LZ-2G	LZ-3G	LXY-1G	LXY-2G	LXY-3G	POWER
1	0.26576E-02	0.65575E-03	-0.26782E-03	0.11785E-01	0.12687E-02	-0.12049E-01	0.60836E 00
2	0.15683E-02	0.75907E-03	0.45200E-03	0.11898E-01	0.13418E-02	-0.12395E-01	0.10791E 01
3	0.11071E-02	0.53980E-03	0.27809E-03	0.12109E-01	0.14670E-02	-0.12731E-01	0.12080E 01
4	0.60338E-03	0.29691E-03	0.12620E-03	0.12369E-01	0.15887E-02	-0.13153E-01	0.10808E 01
5	0.18498E-03	0.84540E-04	0.21174E-05	0.12530E-01	0.16981E-02	-0.13517E-01	0.84438E 00
6	-0.11011E-03	-0.60844E-04	-0.74782E-04	0.12634E-01	0.17404E-02	-0.13829E-01	0.59709E 00
7	-0.25933E-03	-0.14001E-03	-0.98541E-04	0.12656E-01	0.17454E-02	-0.14083E-01	0.37541E 00
8	0.16109E-02	-0.19256E-03	-0.27018E-02	0.12648E-01	0.17057E-02	-0.13709E-01	0.18782E 00

CHANNEL NO. 10

BLOCK NO.	LZ-1G	LZ-2G	LZ-3G	LXY-1G	LXY-2G	LXY-3G	POWER
1	0.25903E-02	0.62045E-03	-0.89469E-04	0.21641E-01	0.14249E-02	-0.20486E-01	0.41985E 00
2	0.15210E-02	0.73245E-03	0.41435E-03	0.21690E-01	0.15397E-02	-0.20528E-01	0.76376E 00
3	0.10914E-02	0.52651E-03	0.27393E-03	0.21892E-01	0.17180E-02	-0.20655E-01	0.87890E 00
4	0.60693E-03	0.29470E-03	0.13755E-03	0.22294E-01	0.18813E-02	-0.21003E-01	0.80642E 00
5	0.20813E-03	0.97126E-04	0.29415E-04	0.22503E-01	0.20249E-02	-0.21308E-01	0.64366E 00
6	-0.84457E-04	-0.44588E-04	-0.44799E-04	0.22676E-01	0.21153E-02	-0.21552E-01	0.46213E 00
7	-0.23072E-03	-0.12342E-03	-0.67619E-04	0.22733E-01	0.21514E-02	-0.21747E-01	0.29308E 00
8	0.16417E-02	-0.69544E-04	-0.18773E-02	0.22661E-01	0.20617E-02	-0.21359E-01	0.14520E 00

CHANNEL NO. 11

BLOCK NO.	LZ-1G	LZ-2G	LZ-3G	LXY-1G	LXY-2G	LXY-3G	POWER
1	0.26390E-02	0.64098E-03	-0.11819E-03	0.18657E-01	0.14781E-02	-0.18367E-01	0.53785E 00
2	0.15578E-02	0.75346E-03	0.43875E-03	0.18711E-01	0.15622E-02	-0.18536E-01	0.96592E 00
3	0.10915E-02	0.53065E-03	0.27302E-03	0.18963E-01	0.17033E-02	-0.18883E-01	0.10919E 01
4	0.61115E-03	0.29656E-03	0.13260E-03	0.19199E-01	0.18360E-02	-0.19299E-01	0.98697E 00
5	0.19033E-03	0.89859E-04	0.16462E-04	0.19391E-01	0.19379E-02	-0.19662E-01	0.77782E 00
6	-0.10254E-03	-0.56212E-04	-0.59256E-04	0.19497E-01	0.19984E-02	-0.19962E-01	0.55338E 00
7	-0.25032E-03	-0.13748E-03	-0.82557E-04	0.19504E-01	0.20126E-02	-0.20189E-01	0.34917E 00
8	0.16605E-02	-0.10537E-03	-0.21683E-02	0.19458E-01	0.19069E-02	-0.19739E-01	0.17409E 00

IEND 0

POWER-VOID IT. TIMES 16 ERROR 0.91360351E-02

POWER VOID ITERATION CONVERGED

*** HEAT DISTRIBUTION (KCAL/SEC) ***

TOTAL POWER = 90.0 MW = 21500.2 KCAL/SEC
LEAK HEAT RATE = 0.0188

	N= 1	N= 2	N= 3	N= 4	N= 5	N= 6	N= 7	N= 8	N= 9	N=10	N=11	N=12
@CHANL	419.63	397.05	373.48	347.01	270.19	322.13	269.90	270.31	219.06	161.63	199.14	404.20
@(N, 8)	11.76	11.15	10.55	9.87	7.98	9.24	8.20	7.95	6.88	5.32	6.38	11.88
@(N, 7)	22.44	21.39	20.33	19.11	15.73	18.00	16.24	15.66	13.75	10.73	12.79	23.23
@(N, 6)	35.77	34.17	32.51	30.59	25.27	28.84	25.96	25.17	21.87	16.93	20.27	37.12
@(N, 5)	51.54	49.28	46.93	44.19	36.38	41.66	37.09	36.27	30.93	23.57	28.49	53.22
@(N, 4)	69.38	66.34	63.19	59.60	47.91	55.99	48.26	47.88	39.59	29.54	36.15	70.33
@(N, 3)	86.55	82.22	77.51	72.06	55.54	66.80	55.06	55.65	44.24	32.19	39.99	83.06
@(N, 2)	87.62	82.05	76.15	69.75	51.44	63.71	50.22	51.61	39.52	27.97	35.38	78.75
@(N, 1)	54.57	50.45	46.31	41.85	29.94	37.89	28.86	30.11	22.28	15.38	19.70	46.62

*** FLOW AND PRESSURE DROP ***

	N= 1	N= 2	N= 3	N= 4	N= 5	N= 6	N= 7	N= 8	N= 9	N=10	N=11	N=12
W(N)	10.529	10.636	10.757	10.894	11.414	11.044	11.421	11.413	11.874	12.402	12.041	90.556
DP(N)	2273.1	2272.3	2271.0	2270.1	2266.3	2268.9	2266.3	2266.3	2264.4	2264.0	2264.3	1705.7
DPH(N)	941.0	960.9	983.3	1011.2	1099.7	1037.1	1102.6	1099.2	1179.0	1272.4	1213.3	1422.3
DPL(N)	1332.1	1311.4	1287.7	1258.9	1166.6	1231.8	1163.7	1167.1	1085.4	991.7	1051.1	283.4
DPFR(N)	596.8	584.8	570.0	552.5	488.1	534.4	485.6	488.6	430.9	359.9	407.6	25.0
DPEC(N)	278.8	283.7	289.4	295.8	321.3	303.0	321.6	321.2	344.7	372.9	353.3	258.4
DPSP(N)	195.1	192.8	190.5	187.7	182.2	185.9	181.6	182.3	179.1	176.6	177.3	0.0
DPAC(N)	261.4	250.1	237.8	223.0	175.0	208.5	174.8	175.1	130.7	82.2	112.9	0.0

$$DPAVE = \sum_{N=1}^{12} DP(N)*W(N)*NO(N) \Big/ \sum_{N=1}^{12} W(N)*NO(N) = 2267.6$$

*** CORE AVERAGE VOID FRACTION ***

$$ALPHA1 = \frac{\sum_{N=1}^{11}\sum_{K=1}^{8} ALPHA(N,K)*A(N)*NO(N)}{KMAX * \sum_{N=1}^{11} A(N)*NO(N)} = 0.2666$$

$$ALPHA2 = \frac{\sum_{N=1}^{12}\sum_{K=1}^{8} ALPHA(N,K)*A(N)*NO(N)}{KMAX * \sum_{N=1}^{12} A(N)*NO(N)} = 0.1886$$

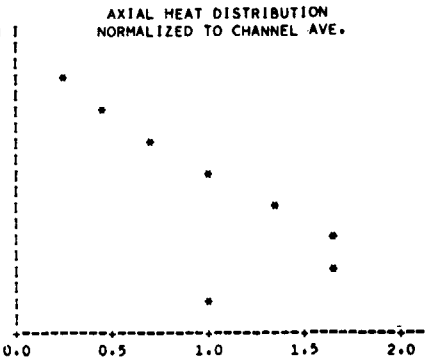
$$ALPHA3 = \frac{\sum_{N=1}^{11}\sum_{K=1}^{8} ALPHA(N,K)*@(N,K)*A(N)*NO(N)}{\sum_{N=1}^{11} @CHANL(N)*A(N)*NO(N)} = 0.2408$$

$$ALPHA4 = \frac{\sum_{N=1}^{12}\sum_{K=1}^{8} ALPHA(N,K)*@(N,K)*A(N)*NO(N)}{\sum_{N=1}^{12} @CHANL(N)*A(N)*NO(N)} = 0.1533$$

*** DETAILS OF THE 1-ST ASSEMBLY *** NO.1

* CHANNEL HEAT PRODUCT 431.65 KCAL/SEC
* RATE TO CORE AVE. 1.4732

REGION	HEIGHT (M)	HEAT (KC/S)	NORM.TO CHAN.AVE.	NORM.TO CORE AVE.	HEAT FLUX (KC/S.M2)	HEAT INTG. (KC/S)
	3.7900					431.65
K= 8		12.16	0.2254	0.3320	35.22	
	3.6066					419.49
K= 7		23.32	0.4322	0.6368	67.54	
	3.4233					396.17
K= 6		37.24	0.6901	1.0167	107.84	
	3.2399					358.93
K= 5		53.71	0.9954	1.4664	155.54	
	3.0565					305.22
K= 4		72.28	1.3397	1.9736	209.34	
	2.8731					232.94
K= 3		89.52	1.6591	2.4442	259.26	
	2.6898					143.42
K= 2		88.91	1.6479	2.4277	257.50	
	2.5064					54.50
K= 1		54.50	1.0102	1.4882	157.85	
	2.3230					0.0



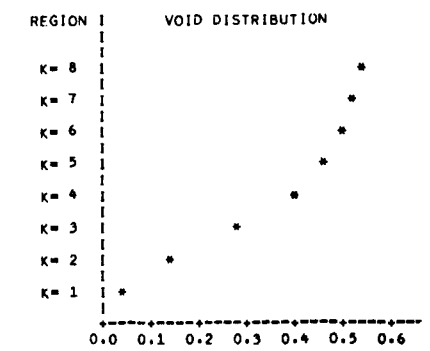
*** DETAILS OF THE 1-ST ASSEMBLY *** NO.2

* COOLANT FLOW 11.760 KG/SEC

* VARIATION FROM INLET TO EXIT

	VELOCITY (M/S)	ENTHALPY (KC/KG)	QUALITY	VOID FR.	DENSITY (KG/M3)
OUTLET	3.8371	320.91	0.0785	0.5362	367.53
INLET	1.8388	284.20	0.0	0.0	766.92

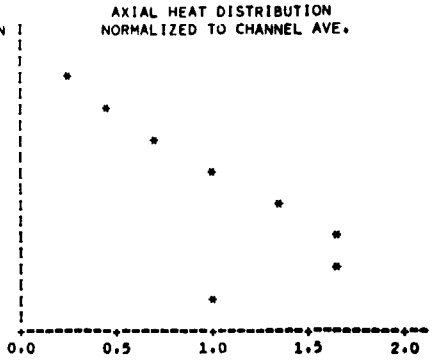
REGION	HEIGHT (M)	ENTHALPY (KC/KG)	QUALITY	VOID FR.	DENSITY (KG/M3)	CHFR (JANCEN)	CHFR (HENTI)
K= 9			0.07850	0.5362	367.53		
	3.7900	320.91					
K= 8			0.07732	0.5333	369.62	21.4025	20.9515
	3.6066	319.87					
K= 7			0.07334	0.5230	377.05	11.1592	11.0758
	3.4233	317.89					
K= 6			0.06649	0.5037	391.05	6.9892	7.1002
	3.2399	314.72					
K= 5			0.05617	0.4696	415.79	4.8457	5.0061
	3.0565	310.16					
K= 4			0.04179	0.4082	460.22	3.6004	3.7196
	2.8731	304.01					
K= 3			0.02302	0.2868	548.18	2.9072	3.0034
	2.6898	296.40					
K= 2			0.00205	0.1484	647.43	2.9270	3.0240
	2.5064	288.84					
K= 1			0.0	0.0406	734.13	4.7749	4.9330
	2.3230	284.20					



*** DETAILS OF THE 2-ND ASSEMBLY *** NO.1

* CHANNEL HEAT PRODUCT 405.48 KCAL/SEC
* RATE TO CORE AVE. 1.3839

REGION	HEIGHT (M)	HEAT (KC/S)	NORM.TO CHAN.AVE.	NORM.TO CORE AVE.	HEAT FLUX (KC/S.M2)	HEAT INTG. (KC/S)
	3.7900					405.48
K= 8		11.46	0.2260	0.3128	33.18	
	3.6066					394.02
K= 7		22.07	0.4354	0.6026	63.92	
	3.4233					371.95
K= 6		35.30	0.6964	0.9637	102.22	
	3.2399					336.65
K= 5		50.96	1.0054	1.3913	147.58	
	3.0565					285.70
K= 4		68.65	1.3544	1.8743	198.81	
	2.8731					217.05
K= 3		84.23	1.6618	2.2997	243.92	
	2.6898					132.82
K= 2		82.66	1.6309	2.2570	239.40	
	2.5064					50.16
K= 1		50.16	0.9896	1.3695	145.27	
	2.3230					0.0



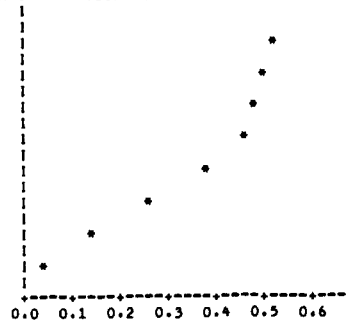
*** DETAILS OF THE 2-ND ASSEMBLY *** NO.2

* COOLANT FLOW 11.680 KG/SEC

* VARIATION FROM INLET TO EXIT

	VELOCITY (M/S)	ENTHALPY (KC/KG)	QUALITY	VOID FR.	DENSITY (KG/M3)
OUTLET	3.7116	318.92	0.0732	0.5226	377.37
INLET	1.8263	284.20	0.0	0.0	766.92

REGION	HEIGHT (M)	ENTHALPY (KC/KG)	QUALITY	VOID FR.	DENSITY (KG/M3)	CHFR (JANCEN)	CHFR (HENTI)
K= 9			0.07317	0.5226	377.37		
K= 8	3.7900	318.92	0.07206	0.5196	379.53	22.6774	22.6475
K= 7	3.6066	317.94	0.06826	0.5089	387.25	11.7725	11.9095
K= 6	3.4233	316.05	0.06173	0.4888	401.85	7.3611	7.6111
K= 5	3.2399	313.03	0.05188	0.4532	427.65	5.0987	5.2764
K= 4	3.0565	308.66	0.03812	0.3864	476.06	3.7848	3.9167
K= 3	2.8731	302.79	0.02026	0.2677	562.02	3.0848	3.1922
K= 2	2.6898	295.58	0.00053	0.1366	656.74	3.1431	3.2526
K= 1	2.5064	288.50	0.0	0.0354	738.20	5.1798	5.3603
	2.3230	284.20					



*** CORE MAP OF SOME CHARACTERISTIC VALUES ***

N	CHANNEL NUMBER
W	CHANNEL FLOW (KG/SEC)
SS	CHANNEL HEAT RATE TO CORE AVERAGE
SPEAK(K)	AXIAL PEAKING AND ITS OCCURED REGION
MCHFR(K)	MCHFR CALCULATED BY JANCEN-LEVY AND ITS REGION
XCOUT	CHANNEL EXIT QUALITY

	1	2	3	4	5
1					11 10.983 0.664 1.605(3) 6.562(3) 0.02761
2		10 10.793 0.537 1.591(3) 8.148(3) 0.01921	9 11.076 0.731 1.614(3) 5.931(3) 0.03200	7 11.244 0.909 1.630(3) 4.743(3) 0.04364	5 11.260 0.912 1.642(3) 4.696(3) 0.04372
3		9 11.076 0.731 1.614(3) 5.931(3) 0.03200	8 11.263 0.912 1.645(3) 4.686(3) 0.04374	6 11.425 1.100 1.657(3) 3.872(3) 0.05570	4 11.504 1.192 1.661(3) 3.570(3) 0.06150
4		7 11.244 0.909 1.630(3) 4.743(3) 0.04364	6 11.425 1.100 1.657(3) 3.872(3) 0.05570	3 11.591 1.294 1.663(3) 3.289(3) 0.06782	2 11.680 1.384 1.662(3) 3.085(3) 0.07317
5	11 10.983 0.664 1.605(3) 6.562(3) 0.02761	5 11.260 0.912 1.642(3) 4.696(3) 0.04372	4 11.504 1.192 1.661(3) 3.570(3) 0.06150	2 11.680 1.384 1.662(3) 3.085(3) 0.07317	1 11.760 1.473 1.659(3) 2.907(3) 0.07850

GROSS PEAKING 2.444 (1-ST ASSEMBLY, 3-RD REGION)

MCHFR 2.907 (1-ST ASSEMBLY, 3-RD REGION)

Z- DIRECTIONAL FLUX DISTRIBUTION **** CHANNEL NO. 1 ****

	POSITION	SOURCE	1G-FLUX	2G-FLUX	3G-FLUX
1	3.056250	0.1012370E 01	0.2077612E 02	0.1020599E 02	0.1069331E 02
2	9.168750	0.1502148E 01	0.3316830E 02	0.1610036E 02	0.1567268E 02
3	15.281250	0.1954607E 01	0.4368958E 02	0.2121302E 02	0.2034392E 02
4	21.393750	0.2192270E 01	0.5212941E 02	0.2521374E 02	0.2285663E 02
5	27.506250	0.2427218E 01	0.5810173E 02	0.2811167E 02	0.2526895E 02
6	33.618751	0.2558350E 01	0.6182822E 02	0.2992285E 02	0.2657853E 02
7	39.731251	0.2414591E 01	0.6363971E 02	0.3037949E 02	0.2518360E 02
8	45.843751	0.2381997E 01	0.6344449E 02	0.3049089E 02	0.2477955E 02
9	51.956251	0.2296935E 01	0.6179807E 02	0.2969689E 02	0.2383581E 02
10	58.068751	0.2035030E 01	0.5925794E 02	0.2825370E 02	0.2117990E 02
11	64.181252	0.1898301E 01	0.5586347E 02	0.2663022E 02	0.1969945E 02
12	70.293751	0.1755350E 01	0.5200191E 02	0.2478254E 02	0.1818271E 02
13	76.406250	0.1552687E 01	0.4797459E 02	0.2274290E 02	0.1610011E 02
14	82.518749	0.1407872E 01	0.4377242E 02	0.2074292E 02	0.1457207E 02
15	88.631248	0.1266530E 01	0.3953759E 02	0.1873236E 02	0.1309350E 02
16	94.743748	0.1106475E 01	0.3539535E 02	0.1672236E 02	0.1144166E 02
17	100.856247	0.9760290E 00	0.3134052E 02	0.1480402E 02	0.1008107E 02
18	106.968746	0.8515428E 00	0.2740955E 02	0.1294521E 02	0.8788810E 01
19	113.081245	0.7240791E 00	0.2363845E 02	0.1114373E 02	0.7473796E 01
20	119.193745	0.6117442E 00	0.2001639E 02	0.9434296E 01	0.6309933E 01
21	125.306244	0.5047861E 00	0.1653494E 02	0.7791066E 01	0.5205153E 01
22	131.418743	0.4005117E 00	0.1318614E 02	0.6202209E 01	0.4134018E 01
23	137.531242	0.3093728E 00	0.9935680E 01	0.4664056E 01	0.3220263E 01
24	143.643742	0.2543072E 00	0.6614776E 01	0.3142280E 01	0.2801509E 01

Z- DIRECTIONAL FLUX DISTRIBUTION **** CHANNEL NO. 2 ****

	POSITION	SOURCE	1G-FLUX	2G-FLUX	3G-FLUX
1	3.056250	0.9329858E 00	0.1906940E 02	0.9367611E 01	0.9853870E 01
2	9.168750	0.1387789E 01	0.3049684E 02	0.1480473E 02	0.1448108E 02
3	15.281250	0.1810526E 01	0.4024820E 02	0.1954343E 02	0.1884907E 02
4	21.393750	0.2045750E 01	0.4812522E 02	0.2329339E 02	0.2132984E 02
5	27.506250	0.2272278E 01	0.5377589E 02	0.2603764E 02	0.2366050E 02
6	33.618751	0.2403036E 01	0.5736911E 02	0.2778645E 02	0.2497474E 02
7	39.731251	0.2287208E 01	0.5917444E 02	0.2847868E 02	0.2385580E 02
8	45.843751	0.2263265E 01	0.5912179E 02	0.2845943E 02	0.2355152E 02
9	51.956251	0.2187450E 01	0.5769674E 02	0.2776926E 02	0.2271036E 02
10	58.068751	0.1943237E 01	0.5541068E 02	0.2645448E 02	0.2024619E 02
11	64.181252	0.1815377E 01	0.5229714E 02	0.2496284E 02	0.1886246E 02
12	70.293751	0.1680033E 01	0.4871941E 02	0.2325278E 02	0.1742496E 02
13	76.406250	0.1484310E 01	0.4496737E 02	0.2136521E 02	0.1541122E 02
14	82.518749	0.1346155E 01	0.4103848E 02	0.1949556E 02	0.1395147E 02
15	88.631248	0.1211025E 01	0.3707087E 02	0.1760711E 02	0.1253624E 02
16	94.743748	0.1057037E 01	0.3318748E 02	0.1571160E 02	0.1094698E 02
17	100.856247	0.9321789E 00	0.2938159E 02	0.1390637E 02	0.9642793E 01
18	106.968746	0.8130344E 00	0.2569076E 02	0.1215789E 02	0.8403980E 01
19	113.081245	0.6905889E 00	0.2215181E 02	0.1046480E 02	0.7138349E 01
20	119.193745	0.5831592E 00	0.1875015E 02	0.8856458E 01	0.6023530E 01
21	125.306244	0.4808521E 00	0.1547959E 02	0.7309304E 01	0.4965161E 01
22	131.418743	0.3809013E 00	0.1233434E 02	0.5812151E 01	0.3936567E 01
23	137.531242	0.2935634E 00	0.9282722E 01	0.4365158E 01	0.3057992E 01
24	143.643742	0.2400443E 00	0.6169131E 01	0.2934265E 01	0.2641145E 01