PREDICTION OF COOLANT TEMPERATURE FIELD
IN A BREEDER REACTOR
INCLUDING INTERASSEMBLY HEAT TRANSFER

by

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ABSTRACT

A general procedure for investigating the effect of the interassembly heat transfer on the temperature field of a breeder reactor is provided. This procedure utilizes a simple multiassembly code, SUPERENERGY, and a set of normalized assembly maps derived from this code. We applied this procedure to the Clinch River Breeder Reactor to study the effect of including various concentric rings of coupled assemblies on the temperature prediction of the central assembly. We found insignificant perturbation from the inclusion of second ring assemblies and important perturbation from the inclusion of first ring assemblies.

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Chapter 1

1. Introduction

Considerable amount of effort has been devoted over the last decade to the development of subchannel codes for predicting the coolant temperatures of a reactor. A few of the well-known codes are COBRA [1], THI-3D[2], THINC [3], HAMBO [4]. They use sophisticated physical modeling processes to simulate the cross flows between the subchannels. They couple the momentum equations with energy equations by solving the velocity distributions from the momentum equations and then by using these velocities in the energy equations. They also use iterative procedures for the finite difference equations to obtain convergent solutions. Because of these characteristics, most of these codes require large storage and long running time so that they are most useful for analysis of a single assembly. Hence interassembly heat transfer effects have not been extensively investigated to date. These interassembly heat transfer effects are specially significant for the blanket region of a breeder reactor because of the severe radial heat flux gradients which consequently will cause severe temperature gradients in this blanket region. These temperature gradients enhanced by the irradiation swelling can cause significant bowing and deformation of the assembly. It is unrealistic to neglect interassembly heat transfer and thereby obtain

an over-conservative design of a breeder reactor. Therefore it is desirable to understand and to know quantitatively how the inclusion of the interassembly heat transfer affects the temperature distribution. In studying this question in breeder reactors with wire wrapped fuel assemblies we adopt the methodology of the ENERGY Code [5] to analyze the performance of each subassembly. The physical model of simulating the cross flow caused by the wire wrap of the fuel pin by an effective eddy diffusivity is employed. The velocities in the interior region and the wall region of an assembly are obtained from the uniform theoretical flow split velocities [5,6]. These approximations enable the momentum equations to be decoupled from the energy equations. We shall also use the marching scheme instead of an iterative procedure for the finite difference equations. These simplifications enable us to reduce greatly the storage space and the running time required for computation.

As we shall see in the following sections, heat penetration from the neighboring assemblies to a central assembly can be represented by two-dimensional maps which are independent of the heat generation in the central assembly itself. By utilizing these maps, an estimate of the temperature increase or decrease due to interassembly heat transfer can be obtained

without running a multiassembly code at all. Furthermore, a simple multiassembly code SUPERENERGY, is developed to accurately assess temperature fields for cases where interassembly heat transfer is significant or to simply and conveniently calculate the temperature field for many assemblies in one run. The results of this multiassembly code will be compared with the fields estimated from the utilization of two-dimensional maps.

In Chapter 2 a short description of the breeder reactor core and a brief introduction of the physical modeling process, developed on the code ENERGY and generalized on the code SUPERENERGY, will be presented. In Chapter 3, the computational method will be discussed. Chapter 4 presents the parametric study obtained by using this code and the physical basis for obtaining and interpreting those two-dimensional maps. Chapter 5 discusses various computational strategies for coupling the assemblies. Chapter 6 compares the prediction from the parametric study with the prediction from the SUPERENERGY code. Chapter 7 gives an example of heat penetration on a central assembly due to different levels of insulated boundary conditions. Chapter 8 summarizes the finding of this study.

Chapter 2

2. Physical Model

The hexagonal assembly of a breeder reactor consists of wire wrapped bundles of fuel pins inside a duct wall. There are gaps between the duct walls of different assemblies. For reasons of symmetry we divide the gaps in the middle, as shown by the dashed line in Figure 1, and call the pins, the duct, and the gap associated with the duct all together as an assembly. If the temperature gradient across the gap vanishes, we call the assembly as an isolated assembly and the boundary condition as an isolated assembly boundary condition. If the temperature gradient across the duct vanishes, we call the boundary condition as an isolated wall boundary condition. The subchannels are defined as the region bounded by the lines joining the centers of the pin rods. The assembly can be divided into four regions as shown in Figure 2. Region I is the interior region where the wire wrap mixing effect can be modeled by an effective eddy diffusivity, ϵ_H . Region II is composed of the edge subchannels which can be modeled by an average circumferential swirl flow, v_θ , due to the unidirectional wire wrap in the edge subchannels. Region III is the duct wall and region IV is the gap.

The governing differential equations for the various regions in steady state are next written.

For region I, the differential equation is

$$\rho C_p \vec{v}_1 \cdot \nabla T = (k + \rho C_p \epsilon_1) \nabla^2 T + Q \quad (1)$$

under the assumptions that the fluid is incompressible and viscous effects are negligible, where Q is the heat generation rate. The flow velocity for this region is along the core length direction. For region II, the differential equation is

$$\rho C_p (\vec{v}_\theta + \vec{v}_2) \cdot \nabla T = (k + \rho C_p \epsilon_2) \nabla^2 T + Q \quad (2)$$

where $\vec{v}_\theta$ is the circumferential velocity along the wall, $\vec{v}_2$ is the longitudinal velocity along the length of the core and ϵ_{H_2} is the effective eddy diffusivity for region II which is in general different from ϵ_{H_1} of region I. In region III, the differential equation can be written as

$$\nabla^2 T = 0, \quad (3)$$

where we have assumed negligible heat generation in the wall. In region IV, the differential equation is

$$\rho C_p \vec{v}_4 \cdot \nabla T = k \nabla^2 T \quad (4)$$

where we have assumed that this is a laminar flow region, the boundary conditions for joining various regions are

$$T_{\text{region I}} = T_{\text{region II}}$$

$$\nabla T \cdot \hat{n}_{\text{region I}} = \nabla T \cdot \hat{n}_{\text{region II}} \quad (5)$$

at the boundary between region I and II,

$$T_{\text{region II}} = T_{\text{region III}}$$

$$h \nabla T \cdot \hat{n}_{\text{region II}} = k' \nabla T \cdot \hat{n}_{\text{region III}} \quad (6)$$

at the boundary between region II and III,

$$T_{\text{region III}} = T_{\text{region IV}}$$

$$k \nabla T \cdot \hat{n}_{\text{region III}} = h' \nabla T \cdot \hat{n}_{\text{region IV}} \quad (7)$$

at the boundary between region III and IV, and

$$T_{\text{region IV}} = T_{\text{region IV}'}$$

$$k \nabla T \cdot \hat{n}_{\text{region IV}} = k \nabla T \cdot \hat{n}_{\text{region IV}'} \quad (8)$$

at the boundary between region IV's of neighboring assemblies. In order to find the heat transfer coefficients between regions II and III and regions III and IV, we

should use the correlation given by Lyon-Martinelli[7],

$$Nu = 7 + 0.025 Pe^{0.8} \quad (9)$$

where Pe is the Peclet number defined as

$$Pe \equiv RePr \equiv \frac{D_e v \rho C_p}{k} . \quad (10)$$

The hydraulic diameters and the velocities in the above equations are computed for the wall subchannels adjacent to the duct.

Chapter 3

3. Computational Method

With the above physical picture in mind, it is easy to write down the finite difference equations for these differential equations. An equivalent method for writing down the finite difference equations is to draw a control volume for each individual subchannel and to balance the energy within the control volume. The result of this energy balance for region I is

$$T_{(i,0)}^{j+1} = T_{(i,0)}^j + \frac{Q_1 \Delta z}{\rho C_p v_1} + \frac{(p - d) \Delta z}{A_1} \frac{(k + \rho C_p \epsilon_H)}{\rho C_p v_1} .$$

$$\left[\frac{T_{(i,1)}^j + T_{(i,2)}^j - 2T_{(i,0)}^j}{\eta_1} + \frac{T_{(i,3)}^j - T_{(i,0)}^j}{\eta_2} \right] \quad (11)$$

where the superscripts for T refer to the axial level, the first subscripts refer to the numbering of the subchannel, and the second subscripts refer to the neighbors. Zero for the second subscripts means the subchannel itself. We should refer to Figure 3 for the numbering of the neighbors. For those interior subchannels whose neighbors are all interior subchannels, η_2 in Eq.(11) should be replaced by η_1 .

For region II, the difference equation is

$$\begin{aligned}
T_{(i,0)}^{j+1} = & T_{(i,0)}^j + \frac{Q_1 \Delta z}{\rho C_p v_2} + \frac{b \Delta z}{2A_2} \cdot \frac{v_\theta}{v_2} \cdot \left[T_{(i,2)}^j - T_{(i,3)}^j \right] \\
& + \frac{(p-d) \Delta z}{A_2} \cdot \frac{(k + \rho C_p \epsilon_{H_2})}{\rho C_p v_2} \cdot \frac{[T_{(i,1)}^j - T_{(i,0)}^j]}{\eta_2} \\
& + \frac{g \Delta z}{A_2} \cdot \frac{(k + \rho C_p \epsilon_{H_2})}{\rho C_p v_2} \cdot \left[\frac{T_{(i,2)}^j - T_{(i,0)}^j}{\eta_A} \right. \\
& \left. + \frac{T_{(i,3)}^j - T_{(i,0)}^j}{\eta_B} \right] + \frac{p \Delta z}{A_2} \cdot \frac{1}{\rho C_p v_2} \\
& \cdot \left[\frac{T_{(i,4)}^j - T_{(i,0)}^j}{R_1} \right] \quad (12)
\end{aligned}$$

for the wall channel, where η_A or η_B equals to η_4 when the wall subchannel has a corner subchannel as a neighbor.

Otherwise they are equal to η_3 . We have similar expression for the corner subchannels in this region with A_2 replaced by A_3 .

For region III, the equation for the wall channel is

$$\begin{aligned}
T_{(i,0)}^{j+1} = & 2T_{(i,0)}^j - T_{(i,0)}^{j-1} - \frac{s_1(\Delta z)^2}{A_4} \cdot \left[\frac{T_{(i,2)}^j - T_{(i,0)}^j}{\eta_C} \right. \\
& + \frac{T_{(i,3)}^j - T_{(i,0)}^j}{\eta_D} \left. \right] + \frac{(\Delta z)^2}{k' s_1} \cdot \left[\frac{T_{(i,1)}^j - T_{(i,0)}^j}{R_1} \right. \\
& \left. + \frac{T_{(i,4)}^j - T_{(i,0)}^j}{R_2} \right] \quad (13)
\end{aligned}$$

where η_C or η_D takes on the value of η_5 when the neighboring subchannel is a corner subchannel. Otherwise they take the value of η_3 . We have similar expression for the corner channels.

For region IV, the difference equation for the wall channel is

$$\begin{aligned}
 T_{(1,0)}^{j+1} = & T_{(1,0)}^j + \frac{p\Delta z}{\rho C_p v_4 A_4} \cdot \left[\frac{T_{(1,1)}^j - T_{(1,0)}^j}{R_2} \right. \\
 & + 2k \cdot \frac{T_{(1,4)}^j - T_{(1,0)}^j}{s_2} \left. \right] + \frac{ks_2\Delta z}{2\rho C_p v_4 A_4} \\
 & \cdot \left[\frac{T_{(1,2)}^j - T_{(1,0)}^j}{\eta_E} + \frac{T_{(1,3)}^j - T_{(1,0)}^j}{\eta_F} \right], \quad (14)
 \end{aligned}$$

where η_E or η_F equals to η_6 when the wall channel has a corner channel as a neighbor. Otherwise, they are equal to η_3 . A similar expression can be obtained for the corner channels.

In the actual code calculation, we make the following simplifications:

1) The conduction heat transfer in the axial direction is neglected since it is negligible compared to the convective heat transfer by the axial flow in regions I, II, and IV.

2) The conduction heat transfer in the axial and the azimuthal directions are small when compared to the heat conduction in the radial direction for the duct region III. This is due to the facts that the wall is thin ($\sim .11$ " in thickness) and the conductivity of the wall is much lower than the conductivity of the liquid sodium. And hence most of heat redistribution in the azimuthal direction will go through the liquid sodium instead of the duct. We therefore approximate the temperature distributions in the axial and the azimuthal directions by linear functions in this region III.

These approximations enable use of a simple marching scheme for solving the finite difference equations. That is, once temperatures in a given level are known, the temperatures in the next level are calculable uniquely without any iteration.

Chapter 4

4. Normalized Assembly Studies

Before using the code to study the penetration of an imposed heat flux into an assembly, an invariance characteristic of this penetration will be demonstrated. Let us write down a general energy transport equation which is valid for all the regions as

$$\rho C_p \vec{v} \cdot \nabla T = (k + \rho C_p \epsilon_H) \nabla^2 T + Q \quad (15)$$

The boundary conditions are isolated assembly boundary conditions for all the faces except one face where we impose a heat flux entering the assembly through the gap. Mathematically, this boundary condition can be expressed as

$$\nabla T \cdot \hat{n}_i = \begin{cases} 0 & \text{for } i = 2, 3, 4, 5, 6 \\ F & \text{for } i = 1 \end{cases}, \quad (16)$$

where $\hat{n}_i$ is the unit vector normal to the i th face of the assembly. There are six faces for a hexagonal assembly labeled in counter clockwise sequence one through six starting with the northeast face. We can write T as a summation of functions T_1 and T_2 which satisfy the following equations,

$$\rho C_p \vec{v} \cdot \nabla T_1 = (k + \rho C_p \epsilon_H) \nabla^2 T_1 + Q \quad (17)$$

and

$$\rho C_p \vec{v} \cdot \nabla T_2 = (k + \rho C_p \epsilon_H) \nabla^2 T_2 \quad (18)$$

The boundary condition for T_1 is an isolated assembly boundary condition. The boundary condition for T_2 is the same as that for T . They are

$$\nabla T_1 \cdot \hat{n}_1 = 0 \quad \text{for } i = 1, 2, 3, 4, 5, 6 \quad (19)$$

and

$$\nabla T_2 \cdot \hat{n}_1 = \begin{cases} 0 & \text{for } i = 2, 3, 4, 5, 6 \\ F & \text{for } i = 1 \end{cases} \quad (20)$$

The value $T - T_1 = T_2$ is the increment of temperature due to the externally imposed heat flux. This increment is independent of the internal heat generation and depends only on the velocity, hence on the flow rate, and the geometry of the assembly as well as the physical properties of the coolant as seen easily from Eq. (18). The rotational invariance of the geometry implies rotational invariance of the maps for these temperature increments. The dependence on the flow rate implies that the same maps will result for the assemblies with the same flow rates. These characteristics enable us to investigate only a few of the typical assemblies in the reactor and from these results

to understand the heat penetration effect for all the assemblies in the reactor core. Although the above argument holds for a single assembly, the same proof will hold for multiassemblies as well. Therefore the temperature increment maps for multiassemblies have the same characteristics. However, we would have less rotational invariance because the surrounding assemblies may not have the same flow rates.

By using the difference equations (11)-(14) with zero heat generation, we can obtain a set of maps for temperature increments due to a given external heat flux. We present such results in the next two subsections.

4.1 Single Assembly Studies

We take the Clinch River Breeder Reactor as an example for our study. A sector of the core with the orificing scheme and the nominal flow rates at plant thermal and hydraulic design conditions is shown in Fig. 4. Geometric characteristics of the assemblies are given in Table 1. The numbering of the subchannels and their actual positions in the fuel and the blanket assemblies are shown in Figs. 5 and 6. The maps for the temperature increments are given in Figures 7 through 15. There are five different orificing zones for fuel assemblies and four different orificing zones for blanket assemblies.

We impose a heat flux on the north face of each of the various assemblies. The heat flux has a uniform profile in the azimuthal direction and a linear profile in the axial direction. In our example, we use 20°F temperature difference between adjacent gaps at the top of the assemblies and 0°F temperature difference at the inlet end of the assemblies. This is equivalent to a heat flux of $1.73 \times 10^5 \text{ BTU/hr-ft}^2$ at the top of the assembly and a heat flux of 0 BTU/hr-ft^2 at the bottom of the assembly. The total heat entering into the 64 inch long assembly is $0.86 \times 10^5 \text{ BTU/hr}$. The input mixing parameters are those recommended by Khan, Ref. [5], i.e. $\epsilon^* = 0.01$ and $C = .08$ for the fuel assemblies, and $\epsilon^* = .007$ and $C = .40$ for the blanket assemblies. The flow rate inside the gap associated with an assembly (i.e. within the dotted line in Fig. 1) is 600 lbm/hr in our example.

We clearly see from these figures, the higher the axial flow rate, the less the heat penetrates. The swirl flow inside the duct wall carries the heat flux in the swirl direction and therefore enhances the heat penetration in the swirl direction. This is especially clear for the blanket assemblies where the swirl flow is strong.

4.2 Multiassembly Studies

We shall define all the assemblies adjacent to

the central assembly as the first ring assemblies. All the assemblies adjacent to the first ring assemblies except the central assembly and the first ring assemblies themselves are called the second ring assemblies. From the previous single assembly study, it can be concluded that the effect of the heat penetration through the first ring assemblies on the central assembly is extremely small when the first ring assemblies are fuel assemblies. This is due to the facts that the axial flow rates of the fuel assemblies are very high and their swirl flow rates are low. Hence the only necessary multiassembly studies are for the blanket assemblies.

The case of interest is a limiting one in which a central assembly is surrounded by six other assemblies each with an externally imposed heat flux from its outer neighbors and each with the lowest possible flow rate. This situation can be designated the second ring heat penetration effect and it can be examined in a normalized fashion, because of superposition principles, by considering the effect of an externally imposed heat flux on only one face of a first ring assembly. In our example, the assemblies all will have the flow rates of the ninth orificing zone. We pick the seven assemblies as B_2 , A_3 , C_2 , C_1 , B_1 , A_2 , B_3 in Fig. 4 and let the external heat flux go through the fourth face of the assembly C_1 ,

then the temperature rise in assemblies A_2 , B_3 , A_3 are extremely small for an imposed heat flux of the same characteristics as in the single assembly studies having a linear axial profile and a maximum value of 1.73×10^5 BTU/hr ft². This fact simplified the code calculation by allowing reduction of the number of coupled assemblies from seven to four. The worst four coupled assemblies in our actual example are assemblies C_2 , B_2 , A_3 , B_3 because of their low flow rates. The worst heat penetration case is the case of an imposed heat flux on the fourth face of the assembly C_2 . Results are given in Fig. 16-19 for assemblies C_2 , B_2 , A_3 , and B_3 respectively, which show that this heat flux causes a maximum of only 12°F in one of the gap subchannels in assembly A_3 . This small amount of temperature rise penetrates only the peripheral channels of assembly A_3 .

Chapter 5

5. Prediction of Interassembly Heat Transfer Between Blanket Assemblies

Such predictions for multiassembly arrays are possible by two methods

- 1) Utilization of normalized assembly temperature maps together with calculations of the desired assembly treated as an isolated assembly.
- 2) Direct calculation of the coupled multiassembly array.

5.1 Prediction of Assembly Temperature Fields Considering the Six (First Ring) Surrounding Assemblies

To predict the temperature distributions by the first method, we can use SUPERENERGY for each assembly individually with isolated assembly boundary condition. Utilizing these temperature distributions and the results of the simple, normalized assembly maps discussed in Chapter 4, we can predict the temperature distributions for the assemblies in a coupled configuration by using the expressions derived in the following section.

We define the average gap temperatures at the bundle exit for assembly 1 and assembly 2 as T_1 and T_2 before the assemblies are coupled, and as T'_1 and T'_2 after the assemblies are coupled, as shown in Figs.20(a) and 20 (b) respectively. From the normalized assembly maps, we can

represent the average axial temperature changes for assembly 1 and assembly 2 as Δt_{A1} and Δt_{A2} for a given temperature gradient, Δt_R , across the gaps between assemblies 1 and 2, as shown in Fig. 20(c). From eqs. (18) and (20), we can see that a linear proportionality exists between the temperature gradient across the gap and the average axial temperature rise in the assembly since the gap temperature gradient is directly proportional to F . By using this linear proportionality, we can write down two expressions relating the temperatures before the assembly coupling (Figure 20a) to the temperatures after the assembly coupling (Figure 20b) as

$$\frac{T'_1 - T_1}{\Delta t_{A1}} = \frac{T'_1 - T'_2}{\Delta t_R} \quad (21)$$

and

$$\frac{T'_2 - T_2}{\Delta t_{A2}} = \frac{T'_1 - T'_2}{\Delta t_R} \quad (22)$$

We can solve these two algebraic equations for T'_1 and T'_2 as

$$T'_1 = \frac{T_1(\Delta t_R + \Delta t_{A2}) - T_2\Delta t_{A1}}{\Delta t_R + \Delta t_{A2} - \Delta t_{A1}} \quad (23)$$

$$T'_2 = \frac{T_1\Delta t_{A2} + T_2(\Delta t_R - \Delta t_{A1})}{\Delta t_R + \Delta t_{A2} - \Delta t_{A1}}, \quad (24)$$

and the difference as

$$T'_1 - T'_2 = \frac{(T_1 - T_2) \Delta t_R}{\Delta t_R + \Delta t_{A2} - \Delta t_{A1}} \quad (25)$$

We evaluate $T'_1 - T'_2$ in eq. (25) by utilizing the SUPERENERGY temperature predictions for assemblies 1 and 2 treated with isolated assembly boundary conditions (for T_1 and T_2), and normalized assembly maps for assemblies 1 and 2 (for Δt_R , Δt_{A1} , Δt_{A2}). We can predict the distribution of the temperature changes in assembly 1 due to this assembly coupling as

$$\Delta T_{1_1} = \frac{T'_1 - T'_2}{\Delta t_R} \Delta t_{A1_1} \quad (26)$$

where i refers to the various subchannels and t_{A1_1} is obtained for each channel from the normalized assembly maps. Combining Eq.(25) and Eq.(26) gives the final result,

$$\Delta T_{1_1} = \frac{T_1 - T_2}{\Delta t_R + \Delta t_{A2} - \Delta t_{A1}} \cdot t_{A1_1} \quad (27)$$

We apply this prediction procedure to assemblies A_2 and E_1 of Fig. 4. Temperature distribution for assemblies A_2 and E_1 by using isolated assembly boundary conditions are given in Figs. (21) and (22) respectively. Results using this prediction for the temperature changes in assembly E_1 are shown in Fig. (23). The coupled two assembly code prediction (method 2) for assembly E_1 coupled to assembly A_2 is shown in Fig. (24). The depth of penetration of interassembly effects is well

predicted. Within the region where subchannel temperatures are affected by interassembly heat transfer, differences of several degrees exist with the largest deviations occurring in the third face of assembly E_1 . These are due to the approximation of using an average constant heat flux for the whole face of the assembly and the deviation of axial profile of the heat flux addition from the assumed linear profile.

To consider the effect of each of the six surrounding assemblies on a central assembly, we can invoke the principle of superposition to add all the temperature rises together. However care must be taken in computing the average temperature gradients for various faces of the assembly. When computing the difference between the average temperatures of the adjacent faces of the central assembly and first ring assemblies, the perturbations on the central assembly face temperatures due to previous coupling steps should be considered. Physically, we can picture this procedure as the following. We first bring one assembly in contact with the central assembly, and then we bring the second assembly in contact with the previous two and so on until all of them are in contact with each other. The final steady state is the same as if we bring all of them in contact at the same time.

5.2 Prediction of Assembly Temperature Fields Considering the Nineteen (First and Second Ring) Surrounding Assemblies

As we have illustrated in the previous two-assembly example, the normalized maps are extremely simple and convenient tools for estimating the heat penetration without coupled assembly code predictions when the number of coupled assemblies are small. The maps are also useful tools to estimate the importance of the heat penetration from the second ring assemblies to the central assembly. In this estimation, we can use either the single assembly normalized maps successively or the multiassembly normalized map once. To illustrate this point, we shall use the assemblies C_2 , B_2 , A_3 , and B_3 in Figure 4 as our example. We want to see the importance of heat penetration from assembly C_1 to assembly A_3 . From single assembly runs, we compute the difference of the average gap temperatures between assembly C_1 and assembly C_2 , i.e. $T_1 - T_2$, Figure (22a). Let us suppose it is 100°F. By using this difference and the single assembly normalized maps corresponding to assemblies C_2 and C_1 , i.e. zone 8, Figure 14 and zone 7, Figure 13 respectively, we can proceed as described in Section 5.1 to predict the temperature changes in assembly C_2 . The average gap temperature rise in the sixth face of assembly C_2 due to 100°F difference between the faces of

assembly C_1 and C_2 is, per eq. (27), $\frac{100}{20+142+130} \times 23 = 7.9^\circ\text{F}$,

where we have used

$$\Delta t_{A2} \Big|_{\text{Bundle } C_2} = \sum_1 \Delta t_{A2_1} = \frac{152 + 150 + 140 + 125}{4} = 142 \quad (28a)$$

$$\Delta t_{A1} \Big|_{\text{Bundle } C_1} = \sum_1 \Delta t_{A1_1} = \frac{135 + 136 + 130 + 119}{4} = 130 \quad (28b)$$

$$\Delta t_{A1} \Big|_{\substack{\text{face 6} \\ \text{Bundle } C_2}} = \sum_1 \Delta t_{A1} \Big|_{\substack{\text{face 6} \\ \text{Bundle } C_2}} = \frac{27 + 24 + 22 + 20}{4} = 23 \quad (28c)$$

By using this average temperature rise and the single assembly mormalized map for zone 9, we can further predict the temperature rise in the assembly A_3 . For example, the fifth face of assembly A_3 will have an average temperature rise of $\frac{7.9}{20 + 165 + 142} \times 41.5 = 1^\circ\text{F}$ from Eq. (27), where

$$\Delta t_{A2} \Big|_{\text{Bundle } A_3} = \sum_1 \Delta t_{A2_1} = \frac{187 + 178 + 161 + 136}{4} = 165 \quad (29a)$$

$$\Delta t_{A1} \Big|_{\text{Bundle } C_2} = \sum_1 \Delta t_{A1_1} = \frac{152 + 150 + 140 + 125}{4} = 142 \quad (29b)$$

$$\Delta t_{A1} \Big|_{\substack{\text{face 5} \\ \text{Bundle } A_3}} = \sum_1 \Delta t_{A1} \Big|_{\substack{\text{face 5} \\ \text{Bundle } A_3}} = \frac{48 + 44 + 39 + 35}{4} = 41.5 \quad (29c)$$

We can also use the multiassembly normalized map, Figure (16)-(19), to predict the average temperature rise in the fifth face of assembly A_3 . The expression we should use to compute the subchannel temperature changes in Assembly A_3 is again Eq. (27) with Δt_{A1} taken as the i th subchannel axial temperature change in the normalized map for assembly A_3 (i.e. Fig. 18). The result of this calculation is $\frac{100}{20 + 142 + 130} \times 0 = 0^\circ\text{F}$, where Δt_A 's are given by Eq. (28). Both of these type 1 methods predict insignificant temperature changes in assembly A_3 as we expected. We have not applied method 2 to the calculation of these assemblies by using a hypothetical $T_1 - T_2 = 100^\circ\text{F}$. Rather method 2 has been applied as well as method 1 (using a multiassembly normalized map) to assemblies B_2 , A_2 and E_1 operating at the Clinch River Design conditions (Ref. [8]) as described below. Temperature distribution for assemblies B_2 using ^{the} isolated assembly boundary condition is shown in Fig. (25). Temperature distributions for assemblies A_2 and E_1 coupled to each other are shown in Figs. (26) and (27) respectively. Normalized assembly map for two coupled zone 8 assemblies is shown in Figs. (28) and (29). Results using this prediction for the temperature changes in assembly E_1 are shown in Fig. (30). The three-coupled assembly code prediction (method 2) for assembly E_1 is shown in Fig. (31). The second ring heat penetration effects on the central assembly is insignificant as can be seen from the comparison of these two figures.

Chapter 6

6. COMPUTATIONAL STRATEGIES FOR LMFBR CORES

6.1 Classification of combinations of assemblies with different flow rates.

As we have stated before, the external heat flux can hardly penetrate a fuel assembly due to the high flow rate in the fuel assembly. The fuel assembly also has low swirl flow. The small amount of heat penetrating into the assembly will not be carried around to the other faces of the assembly. Both of these characteristics do not exist for a blanket assembly. Hence the relative position of a face to the position of the face with heat addition or subtraction is very important for a blanket assembly. We shall restrict our classifications of these relative positions to the blanket assemblies only.

As we have pointed out earlier, the only assemblies which are important in a seven assembly study are those adjacent to the heat addition assembly. There are four of them. The heat penetration from different paths are shown in Fig.(25). They can be categorized into three classes. For a given constant heat flux into the assembly D, the effect of the heat penetration depends on the path length and the flow rates of the assemblies D, E and A. For given flow rates, the heat penetrates the most for

the shortest heat path which is path 3 in Fig. (25). For a given heat path, the heat penetrates the most for the combination of lowest flow rates. By using these criteria, it is easy to determine which is the most important heat penetration from the second ring assemblies once code calculations have been made for all the assemblies using the isolated assembly boundary conditions. If the most important heat penetration from the second ring assemblies will not affect the central assembly significantly, then we can neglect all the rest of the second ring effects. The same procedure applies for the whole reactor. In such circumstances it is necessary to couple only seven assemblies in predicting the temperature distribution for the central assembly.

6.2 Strategies in selecting the number of assemblies for coupling.

We listed in Table 2 the storage space and the computation time the code requires for various bundle sizes and various numbers of coupled assemblies.

It is clear that the analytically simplest way of predicting the temperatures is to run the code for as many assemblies coupled as the computer allows. At the other extreme, single assembly results for each assembly when used with normalized maps are sufficient to compute temperatures including interassembly heat transfer effects.

A compromise procedure for typical LMFBR's is to confirm that sufficiently accurate central assembly temperature predictions can be obtained considering only the first ring assemblies. This confirmation requires the use of normalized multiassembly maps. The whole reactor can then be analysed by a series of seven-coupled assembly calculations treating each assembly in the core in turn as a central assembly.

Chapter 7

EXAMPLE OF HEAT PENETRATION FROM DIFFERENT LEVELS OF INSULATED BOUNDARY CONDITIONS

To demonstrate the effect of interassembly heat transfer we have calculated temperatures of blanket assembly E_1 with the following successively accurate assumptions.

1. Isolated wall boundary condition (figure 26)
2. Isolated assembly boundary condition with 600 lb/hr gap flow (figure 27)
3. Including surrounding first ring assemblies (figure 28)
4. Including surrounding first and second ring assemblies (figure 29)

Appendix 3 lists the SUPERENERGY calculation of case 4. All operating conditions for cases 1, 2 and 3 are the same as those listed for case 4.

From these results, the following conclusions can be made. Serious error will result if one uses the isolated wall boundary conditions to predict the temperature distribution for all the assemblies in a reactor. The prediction from seven coupled assemblies calculation will give adequate accuracy in the temperature distribution for the central assembly.

Chapter 8

8. CONCLUSION AND DISCUSSION

We have developed a code SUPERENERGY to study the effects of the interassembly heat transfer on the temperature distribution in a breeder reactor. We classified the effects according to the rings of the assemblies surrounding the central assembly. In our example of the Clinch River Breeder Reactor, we found that the first ring effects are important and the second ring effects are negligible. Although we did the study using a gap flow rate of 600 lb/hr, we also studied changes in the normalized assembly maps due to different gap flow rates varying from 600 lb/hr to 5 lb/hr. We found the changes small and the above conclusions valid even for the small gap flow rate of 5 lb/hr. We also have presented general procedures for obtaining various ring effects for any breeder reactor with hexagonal assemblies.

In summary, we can see changes of temperature corresponding to different levels of heat insulation for the assembly. There is significant amount of changes in the coolant temperatures for the interior subchannels of blanket assemblies when we allow heat transfer through the duct into the gap coolant instead of insulating the wall. In terms of boundary conditions, this is equivalent to replacing the isolated wall boundary

condition by the isolated assembly boundary condition. In our example, of Chapter 7, this change can be 21°F . Furthermore, if we allow the heat to transfer between gaps of different assemblies, we can see another significant change in the coolant temperatures as well as the duct wall temperatures. In our example this change can be $\sim 70^{\circ}\text{F}$. When we increase the number of coupled rings about a central assembly from one to two the changes in temperatures become smaller very quickly. For reactors with extremely small flow rates both in the gaps and inside the assemblies, the number of rings we have to couple in order to get an accurate prediction might be large. In order to determine this number of rings, one should do the normalized maps study as described in Section 5. Once the necessary number of rings for coupling has been determined, the code SUPERENERGY can be run with this number of rings for each assembly. The whole reactor core can be covered by successive calculations.

Interassembly heat transfer plays an important role in the heat redistribution of a breeder reactor. The present code assumes average constant physical properties for the coolant throughout the core. Hence it does not take the buoyancy effects and the recirculation phenomena of the coolant into consideration. Because of the steady state assumption, the code can deal neither with transient states nor with accident conditions. Future development

in extending the capability of this code to cover both above cases will be imperative and beneficial. However, investigation has been made on the importance of buoyancy effects on the Clinch River Breeder Reactor. It is found that the buoyancy effect is negligible even in the blanket assemblies with the lowest flow rate of 15310 lb/hr. The Grashof number corresponding to this flow rate is $Gr^* = 0.00237$, which is well below the critical Grashof number, $Gr_C^* = 0.025$, where the buoyancy effects are becoming significant [5].

NOMENCLATURE

A_1	= flow area of the interior subchannel
A_2	= flow area of the wall subchannel
A_3	= flow area of the corner subchannel
A_4	= flow area of the gap wall subchannel
A_5	= flow area of the gap corner subchannel
C	= ratio of swirl velocity to average axial velocity for the porous body model
C_p	= constant pressure heat capacity
d	= rod diameter
g	= distance between the surface of the rod next to the wall and the surface of the wall
h	= heat transfer coefficient between the wall channels and the duct wall
h'	= heat transfer coefficient between the gap channels and the duct wall
k	= conductivity for the coolant
k'	= conductivity for the duct wall
l	= lead
p	= rod pitch
Q_1	= heat generation rate per unit volume for subchannel 1
R_1	= total resistance between the edge subchannel and the duct subchannel

R_2	= total resistance between the duct subchannel and the gap subchannel
s_1	= thickness of the duct wall
s_2	= gap between duct walls of neighboring assemblies
$T_{(1,k)}^j$	= temperature at the axial level j and the neighboring subchannel k of the subchannel 1
T_1	= average gap temperature at the exit for the fifth face of assembly 1 under the isolated assembly boundary condition
T_2	= average gap temperature at the exit for the second face of assembly 2 under the isolated assembly boundary condition
T_1'	= average gap temperature at the exit for the fifth face of assembly 1 when it is coupled to the second face of assembly 2
T_2'	= average gap temperature at the exit for the second face of assembly 2 when it is coupled to the fifth face of assembly 1
V_1	= actual axial velocity for interior subchannels
V_2	= actual axial velocity for edge subchannels
V_4	= actual axial velocity for the gap region
V_θ	= actual azimuthal velocity in region II
x_1	= length of the inner edge of the wall corner subchannel
x_2	= length of the outer edge of the wall corner subchannel

- Δt_{A1} = average axial temperature change for assembly 1 for a given temperature gradient Δt_R across the gap between assemblies 1 and 2
- Δt_{A1_1} = axial temperature change in subchannel 1 of assembly 1 from normalized assembly temperature map for assembly 1
- Δt_{A2} = average axial temperature change for assembly 2 for a given temperature gradient Δt_R across the gaps between assemblies 1 and 2
- Δt_R = radial temperature gradient across the gap between two adjacent assemblies
- ΔT_{1_1} = axial temperature change in subchannel 1 of assembly 1
- ϵ^* = effective eddy diffusivity for the porous body model
- ϵ_1 = effective eddy diffusivity for the interior subchannels
- ϵ_2 = effective eddy diffusivity for the wall subchannels
- η_1 = distance between the centers of the interior subchannels
- η_2 = distance between the center of the interior subchannel to the center of the neighboring wall subchannel
- η_3 = distance between centers of neighboring wall subchannels

- η_4 = distance between the center of wall subchannel
and the center of the neighboring corner
subchannel
- η_5 = distance between the center of duct wall
subchannel and the center of duct
corner subchannel
- η_6 = distance between the center of gap wall
subchannel and the center of gap corner
subchannel
- ρ = density of the coolant

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SUBCHANNELS IN AN ASSEMBLY

1. Interior Subchannel	5. Duct corner subchannel
2. Wall subchannel	6. Gap wall subchannel
3. Corner subchannel	7. Gap corner subchannel
4. Duct wall subchannel	

Figure 1

REGIONS OF ASSEMBLY WITH DIFFERENT FLOW RATES

Figure 2

NUMBERING SCHEME FOR THE NEIGHBORING SUBCHANNELS

Figure 3

FUEL AND BLANKET ASSEMBLIES ORIFICING SCHEME AND NOMINAL
FLOW RATES AT PLANT THERMAL AND HYDRAULIC DESIGN CONDITIONS

Figure 4

SUBCHANNEL NUMBERING SCHEME FOR FUEL ASSEMBLY

SUBCHANNEL NUMBERING SCHEME FOR BLANKET ASSEMBLY

Figure 6

TEMPERATURE PREDICTION FOR ZONE 1 ASSEMBLY

Geometry: Fuel (Table 1)

Heat Generated: 0 Kw

Bundle flow rate (lb/hr) 184240

Heat Entered: 25.3 Kw

Gap flow rate (lb/hr) 600

Input Parameters (Ref.[5]):

Bundle Reynolds No. 6.92×10^4 $\epsilon^* = 0.01$ Gap Reynolds No. 2.94×10^3 $C = 0.08$

Figure 7

TEMPERATURE PREDICTION FOR ZONE 2 ASSEMBLY

Geometry: Fuel (Table 1) Heat Generated: 0 Kw
 Bundle flow rate (lb/hr) 165355 Heat Entered: 25.3 Kw
 Gap flow rate (lb/hr) 600 Input Parameters (Ref.[5]):
 Bundle Reynolds No. 6.21×10^4 $\epsilon^* = 0.01$
 Gap Reynolds No. 2.94×10^3 $C^* = 0.08$

Figure 8

TEMPERATURE PREDICTION FOR ZONE 3 ASSEMBLY

Geometry: Fuel (Table 1) Heat Generated: 0 Kw
 Bundle flow rate (lb/hr) 155690 Heat Entered: 25.3 Kw
 Gap flow rate (lb/hr) 600 Input Parameters (Ref.[5]):
 Bundle Reynolds No. 5.85×10^4 $\epsilon^* = 0.01$
 Gap Reynolds No. 2.94×10^3 $C = 0.08$

Figure 9

TEMPERATURE PREDICTION FOR ZONE 5 ASSEMBLY

Geometry: Fuel (Table 1)

Heat Generated: 0 Kw

Bundle flow rate (lb/hr) 126130

Heat Entered: 25.3 Kw

Gap flow rate (lb/hr) 600

Input Parameters (Ref.[5]):

Bundle Reynolds No. 4.74×10^4 $\epsilon^* = 0.01$ Gap Reynolds No. 2.94×10^3 $C = 0.08$

Figure 11

TEMPERATURE PREDICTION FOR ZONE 6 ASSEMBLY

Geometry: Blanket (Table 1)

Heat Generated: 0 Kw

Bundle flow rate (lb/hr) 53590

Heat Entered: 25.3 Kw

Gap flow rate (lb/hr) 600

Input Parameters (Ref.[5]):

Bundle Reynolds No. 3.46×10^4 $\epsilon^* = 0.007$ Gap Reynolds No. 2.94×10^3 $C = 0.40$

Figure 12

TEMPERATURE PREDICTION FOR ZONE 7 ASSEMBLY

Geometry: Blanket (Table 1)

Heat Generated: 0 Kw

Bundle flow rate (lb/hr) 49530

Heat Entered: 25.3 Kw

Gap flow rate (lb/hr) 600

Input Parameters (Ref.[5]):

Bundle Reynolds NO. 3.20×10^4 $\epsilon^* = 0.007$ Gap Reynolds No. 2.94×10^3 $C = 0.40$

Figure 13

TEMPERATURE PREDICTION FOR ZONE 9 ASSEMBLY

Geometry: Blanket (Table 1)

Bundle flow rate (lb/hr) 15310

Gap flow rate (lb/hr) 600

Bundle Reynolds No. 9.88×10^3 Gap Reynolds No. 2.94×10^3

Heat Generated: 0 Kw

Heat Entered: 25.3 Kw

Input Parameters (Ref.[5]):

 $\epsilon^* = 0.007$ $C = 0.40$

Figure 15

TEMPERATURE PREDICTION FOR ASSEMBLY C₂

Geometry: Blanket (Table 1)

Heat Generated: 0 Kw

Bundle flow rate (lb/hr) 28860

Heat Entered: 22 Kw

Gap flow rate (lb/hr) 600

Input Parameters (Ref.[5]):

Bundle Reynolds No. 1.86×10^4 $\epsilon^* = 0.007$ Gap Reynolds No. 2.94×10^3 $C = 0.40$

Figure 16

TEMPERATURE PREDICTION FOR ASSEMBLY B₂

Geometry: Blanket (Table 1)

Bundle flow rate (lb/hr) 28860

Gap flow rate (lb/hr) 600

Bundle Reynolds No. 1.86×10^4 Gap Reynolds No. 2.94×10^3

Heat Generated: 0 Kw

Heat Entered 2 Kw

Input Parameters (Ref.[5]):

 $\epsilon^* = 0.007$ $C = 0.40$

Figure 17

TEMPERATURE PREDICTION FOR ASSEMBLY A₃

Geometry: Blanket (Table 1)

Bundle flow rate (lb/hr) 15310

Gap flow rate (lb/hr) 600

Bundle Reynolds No. 9.88×10^3

Gap Reynolds No. 2.94×10^3

Heat Generated: 0 Kw

Heat Entered: 1 Kw

Input Parameters (Ref.[5]):

$\epsilon^* = 0.007$

$C = 0.40$

Figure 18

TEMPERATURE PREDICTION FOR ASSEMBLY B₃

Geometry: Blanket (Table 1)

Heat Generated: 0 Kw

Bundle flow rate (lb/hr) 15310

Heat Entered: 0 Kw

Gap flow rate (lb/hr) 600

Input Parameters (Ref.[5]):

Bundle Reynolds No. 9.88×10^3

$\epsilon^* = 0.007$

Gap Reynolds No. 2.94×10^3

$C = 0.40$

Figure 19

AVERAGE GAP TEMPERATURES FOR ASSEMBLIES OF ZONE 1 AND ZONE 2

(a)

(b)

Figure 20

Heat Generated: 756.6

Heat Entered: 0

Input Parameters (Ref.[5]):

$$\epsilon^* = 0.007$$
$$C_1 = 0.40$$

TEMPERATURE PREDICTION FOR ASSEMBLY E₁
BY USING ISOLATED ASSEMBLY BOUNDARY CONDITION

Geometry: Blanket (Table 1)

Heat Generated: 554.1

Bundle flow rate (lb/hr) 28860

Heat Entered; 0

Gap flow rate (lb/hr) 600

Input Parameters (Ref. [5]):

Bundle Reynolds No. 1.86×10^4

$\epsilon^* = 0.007$

Gap Reynolds No. 2.94×10^3

$C = 0.40$

Figure 22

TEMPERATURE PREDICTION OF ASSEMBLY E₁ BY USING NORMALIZED MAPS

Geometry: Blanket (Table 1)
 Bundle flow rate (lb/hr) 28860
 Gap flow rate (lb/hr) 600
 Bundle Reynolds No. 1.86×10^4
 Gap Reynolds No. 2.94×10^3

Heat Generated 0 Kw
 Heat Entered: 1 Kw
 Input Parameters (Ref.[5]):
 $\epsilon^* = 0.007$
 $C = 0.40$

Figure 23

TEMPERATURE PREDICTION OF ASSEMBLY E₁
FROM SUPERENERGY FOR TWO COUPLED ASSEMBLIES

Geometry: Blanket (Table 1)	Heat Generated	0 Kw
Bundle flow rate (lb/hr) 28860	Heat Entered:	1 Kw
Gap flow rate (lb/hr) 600	Input Parameters (Ref.[5]):	
Bundle Reynolds No. 1.86×10^4	$\epsilon^* = 0.007$	
Gap Reynolds No. 2.94×10^3	$C = 0.40$

Figure 24

TEMPERATURE PREDICTION FOR ASSEMBLY B₂
BY USING ISOLATED ASSEMBLY BOUNDARY CONDITION

Geometry: Blanket (Table 1)
Bundle flow rate (lb/hr) 28860
Gap flow rate (lb/hr) 600
Bundle Reynolds No. 1.86×10^4
Gap Reynolds NO. 2.94×10^3

Heat Generated: 648.5
Heat Entered: 0
Input Parameters (Ref.[5]):
 $\epsilon^* = 0.007$
 $C = 0.40$

Figure 25

TEMPERATURE PREDICTION FOR ASSEMBLY E₁
COUPLED TO ASSEMBLY A₂

Geometry: Blanket (Table 1)
 Bundle flow rate (lb/hr) 28860
 Gap flow rate (lb/hr) 600
 Bundle Reynolds No. 1.86×10^4
 Gap Reynolds No. 2.94×10^3

Heat Generated: 554.1 Kw
 Heat Entered: 14.1 Kw
 Input Parameters (Ref.[5]):
 $\epsilon^* = 0.007$
 $C = 0.40$

Figure 27

TEMPERATURE PREDICTION FOR TWO COUPLED ZONE 8

Geometry Blanket (Table 1)

Heat Generated 0

Bundle flow rate (lb/hr) 28860

Heat Entered 24.3

Gap flow rate (lb/hr) 600

Input Parameters (Ref.[5]):

Bundle Reynolds No. 1.86×10^4

$\epsilon^* = 0.007$

Gap Reynolds No. 2.94×10^3

$C = 0.40$

Figure 28

TEMPERATURE PREDICTION FOR TWO COUPLED ZONE 8 ASSEMBLIES

Geometry: Blanket (Table 1)

Bundle flow rate (lb/hr) 28860

Gap flow rate (lb/hr) 600

Bundle Reynolds No. 1.86×10^4

Gap Reynolds NO. 2.94×10^4

Heat Generated: 0 Kw

Heat Entered 0.8 Kw

Input Parameters (Ref.[5]):

$\epsilon^* = 0.007$

$C = 0.40$

Figure 29

TEMPERATURE PREDICTION OF ASSEMBLY E₁ BY USING NORMALIZED MAPS

Geometry: Blanket (Table 1) Heat Generated: 0 Kw
 Bundle flow rate (lb/hr) 28860 Heat Entered: 14.7 Kw
 Gap flow rate (lb/hr) 600 Input Parameters (Ref.[5]):
 Bundle Reynolds No. 1.86×10^4 $\epsilon^* = 0.007$
 Gap Reynolds No. 2.94×10^3 $C = 0.40$

Figure 30

TEMPERATURE PREDICTION OF ASSEMBLY E₁ FROM SUPERENERGY.
FOR THREE COUPLED ASSEMBLIES

Geometry: Blanket (Table 1)

Heat Generated: 0 Kw

Bundle flow rate (lb/hr) 28860

Heat Entered: 14.7 Kw

Gap flow rate (lb/hr) 600

Input Parameters (Ref.[5]):

Bundle Reynolds No. 1.86×10^4

$\epsilon^* = 0.007$

Gap Reynolds No. 2.94×10^3

$C = 0.40$

Figure 31

CLASSIFICATION OF HEAT PENETRATION PATHS

Figure 32

TEMPERATURE PREDICTION FOR ASSEMBLY E₁ BY USING ISOLATED WALL BOUNDARY CONDITION

Geometry: Blanket (Table 1)

Bundle flow rate (lb/hr)	28860
Gap flow rate (lb/hr)	600
Bundle Reynolds No.	1.86×10^4
Gap Reynolds No.	2.94×10^3

```
Heat Generated 554.1 Kw
Heat Entered: 0 Kw
Input Parameters (Ref.[5]):
    ε* = 0.007
    C = 0.40
```

Figure 33

TEMPERATURE PREDICTION FOR ASSEMBLY E₁ BY USING
ISOLATED ASSEMBLY BOUNDARY CONDITION

Geometry: Blanket (Table 1)
Bundle flow rate (lb/hr) 28860
Gap flow rate (lb/hr) 600
Bundle Reynolds No. 1.86×10^4
Gap Reynolds No. 2.94×10^3

Heat Generated: 554.1 Kw
Heat Entered: 0 Kw
Input Parameters (Ref.[5]):
 $\epsilon^* = 0.007$
 $C = 0.40$

Figure 34

TEMPERATURE PREDICTION FOR ASSEMBLY E, BY COUPLING
SURROUNDING FIRST RING SIX ASSEMBLIES

Geometry: Blanket (Table 1) Heat Generated: 554.1 Kw
 Bundle flow rate (lb/hr) 28860 Heat Entered: 22.2 Kw
 Gap flow rate (lb/hr) 600 Input Parameters (Ref.[5]):
 Bundle Reynolds No. 1.86×10^4 $\epsilon^* = 0.007$
 Gap Reynolds No. 2.94×10^3 $C = 0.40$

Figure 35

TEMPERATURE PREDICTION FOR ASSEMBLY E, BY COUPLING SURROUNDING SIXTEEN FIRST AND SECOND RINGS ASSEMBLIES

Geometry: Blanket (Table 1)

Heat Generated: 554.1 Kw

Bundle flow rate (lb/hr) 28860

Heat Entered: 21.7 Kw

Gap flow rate (lb/hr) 600

Input Parameters (Ref.[5]):

Bundle Reynolds No. 1.86×10^4

$\epsilon^* = 0.007$

Gap Reynolds No. 2.94×10^3

$C = 0.40$

Figure 36

FUEL RODS NUMBERING SCHEME
FOR 19 PIN ASSEMBLY

Figure 37

NUMBERING OF ASSEMBLIES WITH THEIR DATA PACKS

1	1	1	1	1	1
---	---	---	---	---	---

1	1	1	1	2	3
3	1	2	2	2	4
3	3	1	2	4	3
4	3	2	4	4	4

2	3	4	5	6	7
2	2	3	1	7	2
3	3	3	4	1	2
3	4	4	4	5	1
1	4	5	5	5	6
7	1	5	6	6	6
7	2	1	6	7	7

Figure 38

TABLE 1
Geometric Characteristics
Of Demo Plant Assemblies

Parameter	Fuel	Radial Blanket
Number of Rods	217	61
Cladding OD (inches)	0.230	0.520
Cladding ID (inches)	0.200	0.490
Pellet OD (inches)	0.1935	0.4850
Pellet Theoretical Density (%)	90.4	95.6%
Wire Wrap OD (inches)	0.056	0.037*
Wire Wrap Pitch (inches)	11.9	4.0
Rod Pitch (inches)	.2879	0.5600
Across Hex Flats (inches)	4.335	4.450
Hex Corner Radius (inches)	.16	.16
Duct Thickness (inches)	.16	.10
Gap Thickness Between Assemblies (inches)	.11	.11

TABLE 2

Computer Space and Time*
Required for SUPERENERGY

No. of Assemblies		1	7	19
Storage Space	Blanket	146K	198K	354K
	Fuel	146K	198K	354K
Running Time	Blanket	~.25 min.	~0.9 min.	~2.2 min.
	Fuel	~.4 min.	~2 min.	~5.0 min.

* Data based on IBM 370/168

Appendix 1 SUPERENERGY Manual

1 Purpose and description of the code

The purpose of SUPERENERGY is to predict the temperature distributions in the hexagonal assemblies of breeder reactor. These predictions include the temperature distribution in the coolant as well as in the act. In this code, heat is allowed to leak out of the act wall and to be carried away by the coolant in the up. Heat is also allowed to be transferred between neighboring assemblies. These two features are the main differences between SUPERENERGY and ENERGY I.

The code can be run for as many assemblies as the computer storage allows. The code as listed in Appendix can be run for 19 fuel assemblies with 217 fuel pins in each assembly. This is equivalent to running two full rings of fuel assemblies coupled to each other. For computation of more than 19 assemblies, only the dimensionality in the DIMENSION statements of the code has to be altered. One doesn't have to change the COMMON statements. Since the 19 assemblies do not have to be in concentric rings, these dimensions are sufficient for most of the practical calculations. For the Clinch River Breeder Reactor, we can use the code for all the blanket assemblies in a sector of the core since there are only blanket assemblies in the sector as shown in Fig. 4.

The code can handle three types of assemblies, fuel assembly, blanket assembly, and any third type to be specified. It can be used for any geometrical combination of them provided a proper numbering scheme is utilized. For example, they can be combined in a straight line fashion or in a doughnut shape fashion. We shall discuss the numbering scheme in the input section. The code assumes liquid sodium as coolant and 304 stainless steel as the duct. If any other material is used, then the physical properties in the subroutine PROP should be changed.

The code is written in Fortran IV. It requires 354 K bits of memory and 5 minutes running time for a 19 fuel assembly calculation in a IBM 370/168 computer.

1.2 Input Data

Section I. Multiassembly data pack

Card 1: Column 1-10 reads in the inlet temperature of the assemblies. Column 11-20 reads in the average outlet temperature of the assemblies. The units are °F and the formats are F10.1.

Card 2: Column 1-5 reads in the number of assemblies to be computed. Column 6-10 reads in number of axial temperature distributions to be printed. Column 11-15 reads in the number of increments in axial steps between each axial temperature print outs. We recommend

a total of 500 axial steps for the whole assembly length. Column 16-20 reads in the boundary conditions to be used for the assemblies. Zero means all the assemblies are to be coupled. One means all the assemblies are to be computed by using isolated assembly boundary conditions. Two means all the assemblies are to be computed by using isolated wall boundary conditions. The format to be used for this card is I5.

Section II. Assembly data pack

Card 1: Column 1-5 reads in the type for the assembly. One stands for the fuel assembly. Two stands for the blanket assembly. Three stands for any other third type of assembly. The format for this card is I5.

Card 2: Column 1-10 reads in the diameter of the fuel rod. Column 11-20 reads in the diameter of the wire wrap. Column 21-30 reads in the lead of the wire wrap. Column 31-40 reads in the rod pitch. Column 41-50 reads in the distance between the flats of the assembly. Column 51-60 reads in the length of the assembly. Column 61-70 reads in the thickness of the duct wall. Column 71-80 reads in the thickness of the gap between the assemblies. The dimensions are all in inches. The format for this card is 8I10.5.

Card 3: Column 1-10 reads in the average heat flux of the assembly in the units of BTU/hr-ft^2 . Column 11-20 reads in the flow rate of the assembly in the units

of lbm/hr. Column 21-30 reads in the flow rate in gap associated with the assembly in the units of lbm/hr. The format for this card is 8F10.1.

Card 4: Column 1-40 reads in four effective eddy diffusivities for the assembly. We recommend using the same values for all four of them. Column 41-50 reads in the ratio of swirl flow velocity to the axial flow velocity. These values are to be taken from reference 5. The format for this card is 8F10.5.

Card 5: Column 1-5 reads in the number of points to specify the axial flux shape. Column 6-10 reads in the number of fuel rods in the assembly. The formats are I5.

Card 6 to x: Column 1-10 reads in the first axial distance to specify the flux shape. This axial distance is expressed in terms of the fraction of the total length of the assembly. This number is between 0 and 1. Column 1-20 reads in the axial flux normalized to one over the whole length of the assembly. Column 21-30 reads in the second axial distance in terms of the fraction of the total length. Column 31-40 reads in the normalized flux. This input procedure repeats until the flux shape for the whole length of the core is specified. When the number of flux points equal to 32, it takes 8 cards to specify the axial flux shape. The first axial point shall be 0.0 and the last axial point shall be 1.0. The formats

for these cards are 8F10.5.

Card x+1 to y: These cards read in radial power distributions for all the fuel rods. The numbering of rods starts at the center rod and then go counter-clockwise along the ring. The beginning point of the ring is at 3 o'clock position. An example of the numbering scheme for 19 pins is given in Fig. 37. The formats for these cards are 8F10.5. For an assembly of 61 pins, it takes 8 cards to read in the radial power distributions. For multiassembly calculations, we shall repeat the input of Section II for all the assemblies.

Section III. Assembly numbering data pack

Assemblies can be numbered consecutively in any way which is convenient. But this ordering should be the same as the ordering of the data pack for the assemblies in Section II. After the numbering scheme is fixed, we shall define the upper right face (north east) of an assembly as the first face and the subsequent faces as the second face, the third face, and so on counter-clockwise. For each assembly, the code will read in the numbers of the neighboring assemblies starting from the first face of the assembly. Hence each assembly will take one data card.

Card 1: Column 1-5 reads in the number for the neighboring assembly to the first face of the first assembly. Column 6-10 reads in the number for the neighboring assembly to the second face of the first assembly.

The same procedure holds for the rest of the faces of the first assembly until all six faces are exhausted. There are 30 columns for six faces of the first assembly. When the assembly does not have a neighbor next to its face, the number for the neighboring assemblies of this face is the same as the number for the assembly itself. The format for this card is 6I5.

Card 2 will be reading in the numbers for the neighboring assemblies to the second assembly. The same procedure holds for the next card until all the assemblies are exhausted. Examples of assembly numberings and their data pack for section III are given in Fig. 38.

1.3 Output

The code prints out all the input data as soon as the data are read in. Hence it will print out the inlet temperature and the outlet temperature, number of assemblies to be computed, number of axial print outs, number of axial increments, and the boundary condition to be used for all the assemblies. It will then print out all the data pack for the assemblies. After the assembly data pack, the assembly numbering scheme will be printed. The above print outs are the input data. The following print outs are the computed quantities.

On the next page, it will print out the average

temperature inside the duct, the total heat generation of the assembly, the enthalpy increase inside the duct, and the enthalpy increase in the gap of the assembly. It prints out the radial temperature distribution of the assembly. The information on this page is for the first assembly. On the next new page, it will print out the same information for the second assembly and so on for all the assemblies. If the above information is desired for more than one axial level, the above print outs will be repeated for different levels. In Appendix 3, we shall give a sample problem with its input and output.

APPENDIX 2

LISTING OF CODE SUPERENERGY

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COMMON/PROP1/RHO,CP,COND,CONDW,ALPHA
COMMON/GEO /DR(3),DW(3),LEAD(3),P(3),DFLAT(3),POD(3),GAP(3),A1(3),
1A2(3),A3(3),A4(3),A5(3),A6(3),A7(3),ATOTAL(3),ATOTLG(3),DE1(3),
2DE2(3),DE3(3),DE6(3),DE7(3),HP1(3),HP2(3),HP3(3),HPTOTL(3),
3ETA1(3),ETA2(3),ETA3(3),ETA4(3),ETA6(3),ETA8(3),X1(3),X2(3),X3(3),
4S1(3),S2(3),LENGTH(3),V1R(3),V2R(3),V3R(3),V6R(3),V7R(3)
COMMON/NUM /NROD(3),NRING(3),NCHANL(3),N1(3),N2(3),N3(3),N4(3),
1N5(3),N6(3),N7(3),N8(3),LC(3,550,4),NR0D(3,440,3)
COMMON/TEMP/T(550)
COMMON FACTOR(3,3)
DIMENSION FLOW(19),FLOWGP(19),G(19),GGAP(19),VAVG(19),VAVGG(19),
1V1(19),V2(19),V3(19),V6(19),V7(19),VSWIRL(19)
DIMENSION ITYPE(19),NOOFAX(19),AXIAL(50,19),FAX(50,19),NA(19,6)
DIMENSION EH1(19),EH2(19),EH3(19),EH4(19)
DIMENSION PE2(19),PE3(19),PE6(19),PE7(19),NU2(19),NU3(19),NU6(19),
1NU7(19),RES2(19),RES3(19),RES6(19),RES7(19)
DIMENSION QTOTAL(19),DIFFH(19),DIFFHG(19),QSA(19),QSB(19),QSC(19)
DIMENSION QTPRIM(550,19),QTP(550,19),SUMM(440,19),POWER(220)
DIMENSION T1(550,19),T2(550,19),T3(550,19),QAVG(19),TAVG(19)
C INPUT DIMENSIONS DR(IN),DW(IN),LEAD(IN),P(IN),DFLAT(IN),LENGTH(IN),S1(IN),
C S2(IN),TIN(F),QAVG(B.T.U./HR-FT2),FLOW(L3M/HR)
INTEGER T
REAL LEAD,LENGTH
C ITYPE=1 FOR FUEL ASSEMBLY, ITYPE=2 FOR BLANKET ASSEMBLY, ITYPE=3 FOR ABSENCY
C I IS FOR ASSEMBLY AND J FOR ADJACENT ASSEMBLY IN FACTOR(I,J)
FACTOR(1,1)=1.
FACTOR(1,2)=0.5
FACTOR(2,1)=2.
FACTOR(2,2)=1.
CONTINUE
READ(5,50) TIN,TOUT
WRITE(6,1) TIN,TOUT
1 FORMAT(1X,18HINLET TEMPERATURE=,F10.1,10X,24HAVG. OUTLET TEMPERATU
1RE=,F10.1/)
TT=0.5*(TIN+TOUT)
CALL PROP(TT)
READ(5,10) NOASSM,NOPRNT,NOINCR,ISOLAT
WRITE(6,11) NOASSM,NOPRNT,NOINCR,ISOLAT
10 FORMAT(6I5)
11 FORMAT(1X,18HNO. OF ASSEMBLIES=,I5,5X,14HNO. OF PRINTS=,I5/,32HNO.
10F INCREMENTS BETWEEN PRINTS=,I5,5X,28HTYPE OF BOUNDARY CONDITIONS
2=,I5)
DO 30 L=1,NOASSM
WRITE(6,19) L
19 FORMAT(1X,22HDATA PACK FOR ASSEMBLY,I5)
READ(5,10) ITYPE(L)
WRITE(6,12) ITYPE(L)
12 FORMAT(1X,17HTYPE OF ASSEMBLY=,I5)
K=ITYPE(L)
WRITE(6,16)
16 FORMAT(1X,80HROD DIA. WIRE DIA. LEAD PITCH FLATS LEN
1GTH DUCT TH. GAP TH. )
READ(5,40) DR(K),DW(K),LEAD(K),P(K),DFLAT(K),LENGTH(K),S1(K),S2(K)
WRITE(6,40)DR(K),DW(K),LEAD(K),P(K),DFLAT(K),LENGTH(K),S1(K),S2(K)
WRITE(6,17)
17 FORMAT(1X,52HAVG HEAT FLJX,FLOW RATES IN THE ASSEMBLY AND THE GAP)
READ(5,50) QAVG(L),FLOW(L),FLOWGP(L)

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      WRITE(6,50)          QAVG(L),FLOW(L),FLOWGP(L)
50  FORMAT(8F10.1)
      WRITE(6,18)
18  FORMAT(1X,60HFOUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCIT
      1Y RATIO)
      READ(5,40) EHSTA1,EHSTA2,EHSTA3,EHSTA4,C1
      WRITE(6,40) EHSTA1,EHSTA2,EHSTA3,EHSTA4,C1
      READ(5,10) NOOFAX(L),NR0D(K)
      WRITE(6,13) NOOFAX(L),NR0D(K)
13  FORMAT(1X,12HNO. OF FLUX=.15,5X,12HNO. OF RODS=.15)
      NOUFA=NOOFAX(L)
      WRITE(6,14)
14  FORMAT(1X,35HAXIAL DISTANCE VS FLUX DISTRIBUTION)
      READ(5,40) (AXIAL(I,L),FAX(I,L), I=1,NOUFA)
      WRITE(6,40) (AXIAL(I,L),FAX(I,L), I=1,NOUFA)
40  FORMAT(8F10.5)
      NR0=NR0D(K)
      WRITE(6,15)
15  FORMAT(1X,38HRADIAL POWER DISTRIBUTION OF FUEL RODS)
      CONTINUE
      READ(5,40) (POWER(I),I=1,NR0)
      WRITE(6,40) (POWER(I),I=1,NR0)
      CALL NUMB(K)
      CALL GEOM(K)
      M2=N2(K)
      M3=N3(K)
      M4=N4(K)
      M8=N8(K)
      MK2=M2+1
      MK3=M3+1
      IOVER=NR0D(K)+1
      POWER(IOVER)=0
      DO 60 I=1,M4
      PROD=0
      DO 70 J=1,3
      M=NR0D(K,I,J)
      PROD=PROD+POWER(M)
70  CONTINUE
      SUMM(I,L)=PROD
60  CONTINUE
      QTPAVG=(QAVG(L)*HPTOTL(K)/ATOTAL(K))*12
      DO 80 I=1,M2
      QTPRIM(I,L)=QTPAVG*(ATOTAL(K)/A1(K))*(HP1(K)/HPTOTL(K))*SUMM(I,L)
      1/3.0
80  CONTINUE
      DO 90 I=MK2,M3
      QTPRIM(I,L)=QTPAVG*(ATOTAL(K)/A2(K))*(HP2(K)/HPTOTL(K))*SUMM(I,L)
      1/2.0
90  CONTINUE
      DO 100 I=MK3,M4
      QTPRIM(I,L)=QTPAVG*(ATOTAL(K)/A3(K))*(HP3(K)/HPTOTL(K))*SUMM(I,L)
100 CONTINUE
      G(L)=(FLOW(L)/ATOTAL(K))*144.0
      GGAP(L)=(FLOWGP(L)/ATOTLG(K))*144.0
      VAVG(L)=G(L)/RHO
      VAVGG(L)=GGAP(L)/RHO
      V1(L)=VAVG(L)*V1R(K)
      V2(L)=VAVG(L)*V2R(K)
      V3(L)=VAVG(L)*V3R(K)

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V6(L)=VAVGG(L)*V6R(K)
V7(L)=VAVGG(L)*V7R(K)
CONVER=VAVG(L)*DR(K)/12.
EH1(L)=EHSTA1*CONVER
EH2(L)=EHSTA2*CONVER
EH3(L)=EHSTA3*CONVER
EH4(L)=EHSTA4*CONVER
VSWIRL(L)=C1*VAVG(L)
PE2(L)=DE2(K)*V2(L)/(ALP+A*12.)
PE3(L)=DE3(K)*V3(L)/(ALP+A*12.)
PE6(L)=DE6(K)*V6(L)/(ALP+A*12.)
PE7(L)=DE7(K)*V7(L)/(ALP+A*12.)
NU2(L)=7.0+0.025*PE2(L)**0.9
NU3(L)=7.0+0.025*PE3(L)**0.8
NU6(L)=7.0+0.025*PE6(L)**0.8
NU7(L)=7.0+0.025*PE7(L)**0.8
RES2(L)=(1/NU2(L)+(S1(K)/DE2(K))*COND/CONDW/2)*DE2(K)/COND/12
RES3(L)=(1/NU3(L)+(S1(K)/DE3(K))*COND/CONDW/1.732)*DE3(K)/COND/12
RES6(L)=(1/NU6(L)+(S1(K)/DE6(K))*COND/CONDW/2)*DE6(K)/COND/12
RES7(L)=(1/NU7(L)+(S1(K)/DE7(K))*COND/CONDW/1.732)*DE7(K)/COND/12
30 CONTINUE
WRITE(6,31)
31 FORMAT(1X,24HNEIGHBORS FOR ASSEMBLIES)
DO 32 L=1,NOASSM
HEAD(5,10) (NA(L,I),I=1,6)
WRITE(6,10) (NA(L,I),I=1,6)
32 CONTINUE
CONTINUE
II=ITYPE(1)
DPRINT=LENGTH(II)/NOPRNT
PRINT=DPRINT
DZ=DPRINT/NOINCR
Z=DZ/2.
DO 115 L=1,NOASSM
QSA(L)=0
QSB(L)=0
QSC(L)=0
K=ITYPE(L)
M8=NB(K)
DO 110 I=1,M8
T2(I,L)=TIN
110 CONTINUE
115 CONTINUE
1000 CONTINUE
ZOL=Z/LENGTH(II)
DO 120 L=1,NOASSM
CALL CURVE(FAXL,ZOL,FAX,AXIAL,NOOFAX,L)
K=ITYPE(L)
M4=N4(K)
DO 130 I=1,M4
QTP(I,L)=QTPRIM(I,L)*FAXL
130 CONTINUE
120 CONTINUE
DO 140 L=1,NOASSM
K=ITYPE(L)
M1=N1(K)
M2=N2(K)
M3=N3(K)
M4=N4(K)
M5=N5(K)

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M6=N6(K)
M7=N7(K)
M8=N8(K)
MK1=N1(K)+1
MK2=N2(K)+1
MK3=N3(K)+1
MK4=N4(K)+1
MK5=N5(K)+1
MK6=N6(K)+1
MK7=N7(K)+1
DO 150 I=1,M1
MM1=LC(K,I,1)
MM2=LC(K,I,2)
MM3=LC(K,I,3)
T3(I,L)=T2(I,L)+QTP(I,L)*DZ/12/(V1(L)*RHO*CP)+((P(K)-DR(K))*DZ/
1A1(K))*((ALPHA+EH1(L))/V1(L))*(T2(MM1,L)+T2(MM2,L)+T2(MM3,L)-
23*T2(I,L))/ETA1(K)*12
QSA(L)=QSA(L)+QTP(I,L)
150 CONTINUE
DO 160 I=MK1,M2
MM1=LC(K,I,1)
MM2=LC(K,I,2)
MM3=LC(K,I,3)
R=(I-1)/6.
N=SQRT(R)+1.0001
IQ=(1-6*(N-1)*(N-1)-1)/(2*N-1)+0.0001
IR=1-6*(N-1)*(N-1)-IQ*(2*N-1)+0.0001
J=IR/2
IF (IR.EQ.2*J) GO TO 1160
EHA=EH1(L)
EHB=EH2(L)
ETAA=ETA1(K)
ETAB=ETA2(K)
GO TO 2160
1160 CONTINUE
EHA=EH1(L)
EHB=EH1(L)
ETAA=ETA1(K)
ETAB=ETA1(K)
2160 CONTINUE
T3(I,L)=T2(I,L)+QTP(I,L)*DZ/12/(V1(L)*RHO*CP)+((P(K)-DR(K))*DZ)/
1(A1(K)*V1(L))*((ALPHA+EHA)*(T2(MM1,L)+T2(MM2,L)-2*T2(I,L))/ETAA+
2(ALPHA+EHB)*(T2(MM3,L)-T2(I,L))/ETAB)*12
QSA(L)=QSA(L)+QTP(I,L)
160 CONTINUE
DO 170 I=MK2,M3
MM1=LC(K,I,1)
MM2=LC(K,I,2)
MM3=LC(K,I,3)
MM4=LC(K,I,4)
IF (MM2.GT.M3) GO TO 1170
ETAA=ETA3(K)
EHA=EH3(L)
GO TO 2170
1170 CONTINUE
ETAA=ETA4(K)
EHA=EH4(L)
2170 CONTINUE
IF (MM3.GT.M3) GO TO 3170
ETAB=ETA3(K)

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      EMB=EH3(L)
      GO TO 4170
3170  CONTINUE
      ETAB=ETA4(K)
      EMB=EH4(L)
4170  CONTINUE
      T2(I,L)=T2(I,L)+QTP(I,L)*DZ/12/(V2(L)*RHO*CP)+(GAP(K)*DZ/A2(K))*
      1(VSWIRL(L)/V2(L))*(T2(MM2,L)-T2(I,L))+12*(P(K)-DR(K))*DZ/A2(K)*
      2((ALPHA*EH2(L))/V2(L))*(T2(MM1,L)-T2(I,L))/ETA2(K)+12*(GAP(K)*DZ/
      3(V2(L)*A2(K)))*((ALPHA*EH4(L))*(T2(MM2,L)-T2(I,L))/ETAA+(ALPHA*EMB)*
      4(T2(MM3,L)-T2(I,L))/ETAB)+(P(K)*DZ/A2(K))*(T2(MM4,L)-T2(I,L))/
      5(V2(L)*RHO*CP*RES2(L))
      QSB(L)=QSB(L)+QTP(I,L)
170  CONTINUE
      DO 180 I=MK3,M4
      MM1=LC(K,I,1)
      MM2=LC(K,I,2)
      MM3=LC(K,I,3)
      T3(I,L)=T2(I,L)+QTP(I,L)*DZ/12/(V3(L)*RHO*CP)+(GAP(K)*DZ/A3(K))*
      1(VSWIRL(L)/V3(L))*(T2(MM1,L)-T2(I,L))+12*(GAP(K)*DZ/A3(K))*12*
      2((ALPHA*EH4(L))/V3(L))*(T2(MM1,L)+T2(MM2,L)-2*T2(I,L))/ETA4(K)+
      3(X1(K)*DZ/A3(K))*(T2(MM3,L)-T2(I,L))/(V3(L)*RHO*CP*RES3(L))
      QSC(L)=QSC(L)+QTP(I,L)
180  CONTINUE
      DO 210 I=MK6,M8
      MM1=LC(K,I,1)
      MM2=LC(K,I,2)
      MM3=LC(K,I,3)
      IF(I.GT.M7) GO TO 7210
      A=A6(K)
      V=V6(L)
      RES=RES6(L)
      X=P(K)
      TTT=T2(I,L)
      IQ=(I-M6-1)/NRING(K)+1.0001
      IR=I-M6-(IQ-1)*NRING(K)+0.0001
      J=IR/2
      JJ=IR-2*J
      LP=NA(L,IQ)
      I1=ITYPE(L)
      I2=ITYPE(LP)
      FAC=FACTOR(I1,I2)
      IF(I1.EQ.1) GO TO 2217
      IF(LP.EQ.L) GO TO 1215
      IF(IQ.GT.3) GO TO 1210
      MM4=N6(I2)*(IQ+2)*NRING(I2)*(NRING(K)-IR)*FAC+1
      GO TO 2210
1210  CONTINUE
      MM4=N6(I2)*(IQ+4)*NRING(I2)*(NRING(K)-IR)*FAC+1
      GO TO 2210
1215  CONTINUE
      TTT=T2(I,L)
      GO TO 2217
2210  CONTINUE
      IF(FAC.EQ.1) GO TO 2215
      IF(FAC.GT.1) GO TO 2213
      IF(IR.GE.(NRING(K)-1)) GO TO 2211
      TTT=T2(MM4,LP)-(T2(MM4,LP)-T2(MM4-1,LP))/4.+JJ*(T2(MM4,LP)-
      1T2(MM4-1,LP))/2.0
      GO TO 2217

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2211 TTT=T2(MM4,LP)-(T2(MM4+1,LP)-T2(MM4,LP))/4.0+JJ*(T2(MM4+1,LP)-
      T2(MM4,LP))/2.0
      GO TO 2217
2213 TTI=(T2(MM4,LP)+T2(MM4+1,LP))/2.0
      GO TO 2217
2215 CONTINUE
      TTT=T2(MM4,LP)
2217 CONTINUE
      IF(MM2.GT.M7) GO TO 3210
      ETAA=ETA3(K)
      GO TO 4210
3210 CONTINUE
      ETAA=ETA8(K)
4210 CONTINUE
      IF(MM3.GT.M7) GO TO 5210
      ETAB=ETA3(K)
      GO TO 6210
5210 CONTINUE
      ETAB=ETA8(K)
6210 CONTINUE
      GO TO 7210
7210 CONTINUE
      TTT=T2(I,L)
      A=A7(K)
      V=V7(L)
      RES=RES7(L)
      X=X2(K)
      ETAA=ETA8(K)
      ETAB=ETA8(K)
220 CONTINUE
      CONTINUE
      T3(I,L)=T2(I,L)+X*DZ/(RHO*CP*V*A)*((T2(MM1,L)-T2(I,L))/RES+(TTT-
      T2(I,L))*CON0*24/S2(K))+CON0*DZ*S2(K)/(2*RHO*CP*V*A)*((T2(MM2,L)-
      2T2(I,L))/ETAA+(T2(MM3,L)-T2(I,L))/ETAB)*12
      IJ=I-12*(NRING(K)+1)
      IF(ISOLAT.EQ.2) T3(I,L)=T3(IJ,L)
210 CONTINUE
      DO 190 I=MK4,M6
      MM1=LC(K,I,1)
      MM4=LC(K,I,4)
      IF(I.GT.M5) GO TO 1190
      T3(I,L)=(RES6(L)*T3(MM1,L)+RES2(L)*T3(MM4,L))/(RES6(L)+RES2(L))
      GO TO 190
1190 CONTINUE
      T3(I,L)=(RES7(L)*X1(K)*T3(MM1,L)+RES3(L)*X2(K)*T3(MM4,L))/
      1(RES7(L)*X1(K)+RES3(L)*X2(K))
190 CONTINUE
140 CONTINUE
      DO 230 L=1,NOASSM
      K=ITYPE(L)
      M8=M8(K)
      DO 240 I=1,M8
      T2(I,L)=T3(I,L)
240 CONTINUE
230 CONTINUE
      Z=Z+DZ
      DIFF=PRINT-Z
      IF(DIFF.GT.DZ) GO TO 1000
      PRINT=PRINT+DPRINT

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DO 250 L=1,NOASSM
K=ITYPE(L)
M2=N2(K)
M3=N3(K)
M4=N4(K)
M5=N5(K)
M6=N6(K)
M7=N7(K)
M8=N8(K)
MK2=M2+1
MK3=M3+1
MK6=M6+1
MK7=M7+1
DO 260 I=1,M8
T(I)=T2(I,L)
CONTINUE
260 CONTINUE
T11=0
T22=0
T33=0
T66=0
T77=0
DO 500 J=1,M2
500 T11=T11+T2(J,L)
DO 501 J=MK2,M3
501 T22=T22+T2(J,L)
DO 502 J=MK3,M4
502 T33=T33+T2(J,L)
DO 504 J=MK6,M7
504 T66=T66+T2(J,L)
DO 505 J=MK7,M8
505 T77=T77+T2(J,L)
TAVG(L)=(T11*V1(L)*A1(K)+T22*V2(L)*A2(K)+T33*V3(L)*A3(K))/
1(M2*V1(L)*A1(K)+(M3-M2)*V2(L)*A2(K)+(M4-M3)*V3(L)*A3(K))
QTOTAL(L)=(QSA(L)*A1(K)+QSB(L)*A2(K)+QSC(L)*A3(K))*DZ/12**3/3412
HIN=RH0*CP*TIN*(M2*A1(K)*V1(L)+(M3-M2)*A2(K)*V2(L)+(M4-M3)*A3(K)*
1V3(L))/144/3412
HING=RH0*CP*TIN*((M7-M6)*A6(K)*V6(L)+(M8-M7)*A7(K)*V7(L))/144/3412
HTOTAL=RH0*CP*(T11*A1(K)*V1(L)+T22*A2(K)*V2(L)+T33*A3(K)*V3(L))/
1144/3412
HTOTLG=RH0*CP*(T66*A6(K)*V6(L)+T77*A7(K)*V7(L))/144/3412
DIFFH(L)=HTOTAL-HIN
DIFFHG(L)=HTOTLG-HING
WRITE(6,503) TAVG(L),QTOTAL(L),DIFFH(L),DIFFHG(L)
503 FORMAT(1H1,1X,5HTAVG=,1X,F7.1/,1X,11HQTOTAL(KW)=,1X,F7.1/,1X,10HDI
1FFH(KW)=,1X,F7.1/,1X,11HDIFFHG(KW)=,1X,F7.1/)
WRITE(6,506) L
506 FORMAT(1X,37HTEMPERATURE DISTRIBUTION FOR ASSEMBLY,15)
CALL PRIN(K)
250 CONTINUE

IF(PRINT.GT.LENGTH(II)) GO TO 2000
GO TO 1000
2000 CONTINUE
3000 CONTINUE
STOP
END
SUBROUTINE PROP(TT)
COMMON/PROP1/RH0,CP,COND,CONDW,ALPHA
RH0=59.566-(7.9504E-3)*TT-(0.2872E-6)*TT*TT+(0.06035E-9)*TT**3

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CP=0.344021-(7.03539E-5)*TT+(2.68131E-8)*TT*TT
COND=54.306-(1.878E-2)*TT+(2.0914E-6)*TT*TT
ALPHA=COND/(RHO*CP)
CONDW=12.1
RETURN
END
SUBROUTINE CURVE(FX,X,F,Y,N,J)
DIMENSION F(50,7),Y(50,7),N(7)
M=N(J)
10 DO 20 KK=1,M
  IF(X-Y(KK,J))30,15,20
15 IF(KK.EQ.M) GO TO 40
20 CONTINUE
  GO TO 60
30 IF(KK.EQ.1) GO TO 60
40 B=(X-Y(KK-1,J))/(Y(KK,J)-Y(KK-1,J))
50 FX=F(KK-1,J)+B*(F(KK,J)-F(KK-1,J))
  RETURN
60 PRINT 61
61 FORMAT(1X,'PROG.STOPPED.IN CURVE')
  RETURN
END
SUBROUTINE PRIN(K)
COMMON/TEMP/T(550)
COMMON/NUM /NR0D(3),NRING(3),NCHANL(3),N1(3),N2(3),N3(3),N4(3),
INS(3),N6(3),N7(3),N8(3),LC(3,550,4),MR0D(3,440,3)
IF(NRING(K).EQ.4) GO TO 600
IF(NRING(K).EQ.8) GO TO 700
GO TO 800
600 CONTINUE
  WRITE(6,614) T(183),T(164),T(163),T(162),T(161),T(182)
  WRITE(6,615) T(153),T(134),T(133),T(132),T(131),T(152)
  WRITE(6,613) T(123),T(104),T(103),T(102),T(101),T(122)
  WRITE(6,602) T(68),T(65),T(64),T(62)
  WRITE(6,603) T(165),T(135),T(105),T(69),T(67),T(65),T(63),T(61),
1T(100),T(130),T(160)
  WRITE(6,604) T(70),T(34),T(32),T(30),T(60)
  WRITE(6,605) T(166),T(136),T(106),T(71),T(35),T(33),T(31),T(29),
1T(59),T(99),T(129),T(159)
  WRITE(6,606) T(72),T(36),T(12),T(10),T(28),T(58)
  WRITE(6,607) T(167),T(137),T(107),T(73),T(37),T(13),T(11),T(9),
1T(27),T(57),T(98),T(128),T(158)
  WRITE(6,608) T(74),T(38),T(14),T(2),T(8),T(26),T(56)
  WRITE(6,609) T(168),T(138),T(108),T(75),T(39),T(15),T(3),T(1),
1T(7),T(25),T(55),T(97),T(127),T(157)
  WRITE(6,610) T(184),T(154),T(124),T(121),T(151),T(181)
  WRITE(6,611) T(169),T(139),T(109),T(76),T(40),T(16),T(4),T(6),
1T(24),T(54),T(96),T(120),T(150),T(180)
  WRITE(6,608) T(77),T(41),T(17),T(5),T(23),T(53),T(95)
  WRITE(6,607) T(170),T(140),T(110),T(78),T(42),T(18),T(20),T(22),
1T(52),T(94),T(119),T(149),T(179)
  WRITE(6,606) T(79),T(43),T(19),T(21),T(51),T(93)
  WRITE(6,605) T(171),T(141),T(111),T(80),T(44),T(46),T(48),T(50),
1T(92),T(118),T(148),T(178)
  WRITE(6,604) T(81),T(45),T(47),T(49),T(91)
  WRITE(6,603) T(172),T(142),T(112),T(82),T(84),T(86),T(88),T(90),
1T(117),T(147),T(177)
  WRITE(6,612) T(83),T(85),T(87),T(89)
  WRITE(6,601) T(125),T(113),T(114),T(115),T(116),T(126)
  WRITE(6,615) T(155),T(143),T(144),T(145),T(146),T(156)

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        WRITE(6,614) T(185),T(173),T(174),T(175),T(176),T(186)
601 FORMAT(27X,5I10,I5)
602 FORMAT(37X,4I10///)
603 FORMAT(17X,3I5,5I10,3I5///)
604 FORMAT(32X,5I10///)
605 FORMAT(12X,3I5,6I10,3I5///)
606 FORMAT(27X,6I10///)
607 FORMAT(7X,3I5,7I10,3I5///)
608 FORMAT(22X,7I10///)
609 FORMAT(2X,3I5,8I10,3I5/)
610 FORMAT(1X,3I5,82X,3I5/)
611 FORMAT(2X,3I5,8I10,3I5///)
612 FORMAT(37X,4I10///)
613 FORMAT(27X,5I10,I5//)
614 FORMAT(17X,I10,10X,4I10,5X,I10)
615 FORMAT(22X,I10,5X,4I10,I10)
        GO TO 249
700 CONTINUE
        WRITE(6,721) T(543),T(508),T(507),T(506),T(505),T(504),T(503),
1T(502),T(501),T(542)
        WRITE(6,722) T(489),T(454),T(453),T(452),T(451),T(450),T(449),
1T(448),T(447),T(488)
        WRITE(6,719) T(435),T(400),T(399),T(398),T(397),T(396),T(395),
1T(394),T(393),T(434)
        WRITE(6,702) T(324),T(322),T(320),T(318),T(316),T(314),T(312),
1T(310)
        WRITE(6,703) T(509),T(455),T(401),T(325),T(323),T(321),T(319),
1T(317),T(315),T(313),T(311),T(309),T(392),T(446),T(500)
        WRITE(6,704) T(326),T(242),T(240),T(238),T(236),T(234),T(232),
1T(230),T(308)
        WRITE(6,705) T(510),T(456),T(402),T(327),T(243),T(241),T(239),
1T(237),T(235),T(233),T(231),T(229),T(307),T(391),T(445),T(499)
        WRITE(6,706) T(328),T(244),T(172),T(170),T(168),T(166),T(164),
1T(162),T(228),T(306)
        WRITE(6,707) T(511),T(457),T(403),T(329),T(245),T(173),T(171),
1T(169),T(167),T(165),T(163),T(161),T(227),T(305),T(390),T(444),
1T(498)
        WRITE(6,708) T(330),T(246),T(174),T(114),T(112),T(110),T(108),
1T(106),T(160),T(226),T(304)
        WRITE(6,709) T(512),T(458),T(404),T(331),T(247),T(175),T(115),
1T(113),T(111),T(109),T(107),T(105),T(159),T(225),T(303),T(389),
2T(443),T(497)
        WRITE(6,710) T(332),T(248),T(176),T(116),T(68),T(66),T(64),T(62),
1T(104),T(158),T(224),T(302)
        WRITE(6,711) T(513),T(459),T(405),T(333),T(249),T(177),T(117),
1T(69),T(67),T(65),T(63),T(61),T(103),T(157),T(223),T(301),T(388),
2T(442),T(496)
        WRITE(6,712) T(334),T(250),T(178),T(118),T(70),T(34),T(32),T(30),
1T(60),T(102),T(156),T(222),T(300)
        WRITE(6,713) T(514),T(460),T(406),T(335),T(251),T(179),T(119),
1T(71),T(35),T(33),T(31),T(29),T(59),T(101),T(155),T(221),T(299),
2T(387),T(441),T(495)
        WRITE(6,714) T(336),T(252),T(180),T(120),T(72),T(36),T(12),T(10),
1T(28),T(58),T(100),T(154),T(220),T(298)
        WRITE(6,715) T(515),T(461),T(407),T(337),T(253),T(181),T(121),
1T(73),T(37),T(13),T(11),T(9),T(27),T(57),T(99),T(153),T(219),
2T(297),T(386),T(440),T(494)
        WRITE(6,716) T(338),T(254),T(182),T(122),T(74),T(38),T(14),T(2),
1T(8),T(26),T(56),T(98),T(152),T(218),T(296)
        WRITE(6,720) T(516),T(462),T(408),T(339),T(255),T(183),T(123),

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1T(75),T(39),T(15),T(3),T(1),T(7),T(25),T(55),T(97),T(151),T(217),
2T(295),T(385),T(439),T(493)
WRITE(6,718) T(544),T(490),T(436),T(433),T(487),T(541)
WRITE(6,717) T(517),T(463),T(409),T(340),T(256),T(184),T(124),
1T(76),T(40),T(16),T(4),T(6),T(24),T(54),T(96),T(150),T(216),
2T(294),T(384),T(432),T(486),T(540)
WRITE(6,716) T(341),T(257),T(185),T(125),T(77),T(41),T(17),T(5),
1T(23),T(53),T(95),T(149),T(215),T(293),T(383)
WRITE(6,715) T(518),T(464),T(410),T(342),T(258),T(186),T(126),
1T(78),T(42),T(18),T(20),T(22),T(52),T(94),T(148),T(214),T(292),
2T(382),T(431),T(485),T(539)
WRITE(6,714) T(343),T(259),T(187),T(127),T(79),T(43),T(19),T(21),
1T(51),T(93),T(147),T(213),T(291),T(381)
WRITE(6,713) T(519),T(465),T(411),T(344),T(260),T(188),T(128),
1T(80),T(44),T(46),T(48),T(50),T(92),T(146),T(212),T(290),T(380),
2T(430),T(484),T(538)
WRITE(6,712) T(345),T(261),T(189),T(129),T(81),T(45),T(47),T(49),
1T(91),T(145),T(211),T(289),T(379)
WRITE(6,711) T(520),T(466),T(412),T(346),T(262),T(190),T(130),
1T(82),T(84),T(86),T(88),T(90),T(144),T(210),T(288),T(378),T(429),
2T(483),T(537)
WRITE(6,710) T(347),T(263),T(191),T(131),T(83),T(85),T(87),T(89),
1T(143),T(209),T(287),T(377)
WRITE(6,709) T(521),T(467),T(413),T(348),T(264),T(192),T(132),
1T(134),T(136),T(138),T(140),T(142),T(208),T(286),T(376),T(428),
2T(482),T(536)
WRITE(6,708) T(349),T(265),T(193),T(133),T(135),T(137),T(139),
1T(141),T(207),T(285),T(375)
WRITE(6,707) T(522),T(468),T(414),T(350),T(266),T(194),T(196),
1T(198),T(200),T(202),T(204),T(206),T(284),T(374),T(427),T(481),
2T(535)
WRITE(6,706) T(351),T(267),T(195),T(197),T(199),T(201),T(203),
1T(205),T(283),T(373)
WRITE(6,705) T(523),T(469),T(415),T(352),T(268),T(270),T(272),
1T(274),T(276),T(278),T(280),T(282),T(372),T(426),T(480),T(534)
WRITE(6,704) T(353),T(269),T(271),T(273),T(275),T(277),T(279),
1T(281),T(371)
WRITE(6,703) T(524),T(470),T(416),T(354),T(356),T(358),T(360),
1T(362),T(364),T(366),T(370),T(425),T(479),T(533)
WRITE(6,702) T(355),T(357),T(359),T(361),T(363),T(365),T(367),
1T(369)
WRITE(6,701) T(437),T(417),T(418),T(419),T(420),T(421),T(422),
1T(423),T(424),T(438)
WRITE(6,722) T(491),T(471),T(472),T(473),T(474),T(475),T(476),
1T(477),T(478),T(492)
WRITE(6,721) T(545),T(525),T(526),T(527),T(528),T(529),T(530),
1T(531),T(532),T(546)
701 FORMAT(32X,10I5)
702 FORMAT(37X,8I5/)
703 FORMAT(19X,15I5/)
704 FORMAT(34X,9I5/)
705 FORMAT(17X,16I5/)
706 FORMAT(32X,10I5/)
707 FORMAT(14X,17I5/)
708 FORMAT(29X,11I5/)
709 FORMAT(12X,18I5/)
710 FORMAT(27X,12I5/)
711 FORMAT(9X,19I5/)
712 FORMAT(24X,13I5/)

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713 FORMAT(7X,20I5/)
714 FORMAT(22X,14I5/)
715 FORMAT(4X,21I5/)
716 FORMAT(14X,15I5/)
717 FORMAT(2X,22I5/)
718 FORMAT(1X,3I5,82X,3I5)
719 FORMAT(32X,10I5/)
720 FORMAT(2X,22I5)
721 FORMAT(22X,15,10X,8I5,10X,15)
722 FORMAT(27X,15,5X,8I5,5X,15)
GO TO 249
800 CONTINUE
NN=NB(K)
WRITE(6,801) (T(I),I=1,NN)
801 FORMAT(10I10/)
249 CONTINUE
RETURN
END
SUBROUTINE NUMB(L)
COMMON/NUM /NR0D(3),NRING(3),NCHANL(3),N1(3),N2(3),N3(3),N4(3),
1N5(3),N6(3),N7(3),N8(3),LC(3,550,4),NR0D(3,440,3)
NWALLS=2
NOR0D=NR0D(L)
XNORIN=(NOR0D-1)/3.
NRING(L)=SQRT(XNORIN)
NORING=NRING(L)
NOTRG=6*NORING*NORING
NOTRG1=NOTRG+1
NOTG1=6*(NORING-1)*(NORING-1)
NOG01=3*(NORING-1)*NORING
NOINCR=6*(NORING+1)
LSTCH=NOTRG+NOINCR
LSTCH1=LSTCH+1
LSTW=LSTCH-6
LSTCHG=LSTCH+NOINCR
LSTWG=LSTCHG-6
N1(L)=NOTG1
N2(L)=NOTRG
N3(L)=LSTW
N4(L)=LSTCH
N5(L)=LSTCH+6*NORING
N6(L)=N5(L)+6
N7(L)=N6(L)+6*NORING
N8(L)=N7(L)+6
NCHANL(L)=N4(L)
DO 7 I=1,NOTRG
Z=(I-1)/6.
N=SQRT(Z)+1.0001
NOTR0=6*N*N
NOTR1=6*(N-1)*(N-1)
NOTR2=6*(N-2)*(N-2)
NOT01=3*N*(N-1)
NOT12=3*(N-1)*(N-2)
IQ=(I-NOTR1-1)/(2*N-1)+0.0001
IR=I-NOTR1-IQ*(2*N-1)+0.0001
IY=1.6-1/N
LC(L,I,4)=I
IF(I-NOTR1-1)901,902,901
901 IF(I.EQ.NOTR0)GO TO 903
J=IR/2

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      IF (IR-J*2) 905,905,904
905  IZ=1.0001/(NOTR0-I)
      LC(L,I,1)=NOTR2+IQ*(2*N-3)+IR-1
      LC(L,I,2)=I-1
      LC(L,I,3)=I+1
      MROD(L,I,1)=1+NOT12+IQ*(N-1)+IR/2
      MROD(L,I,2)=MROD(L,I,1)+1-6*IZ*(N-1)
      MROD(L,I,3)=NOT01+IQ*N+IR/2+2
      GO TO 6
904  LC(L,I,1)=I-1
      LC(L,I,2)=I+1
      MROD(L,I,1)= NOT12+IQ*(N-1)+(IR+1)/2+IY
      MROD(L,I,2)=1+NOT01+IQ*N+(IR+1)/2
      MROD(L,I,3)=MROD(L,I,2)+1
908  IF (N.EQ.NORING) GO TO 906
      LC(L,I,3)=NOTR0+IQ*(2*N+1)+IR+1
      GO TO 6
906  LC(L,I,3)=NOTR0+IQ*N+(IR+1)/2
      GO TO 6
903  LC(L,I,1)=NOTR1+1
      LC(L,I,2)=NOTR0-1
      MROD(L,I,1)=1+IY+NOT12
      MROD(L,I,2)=2+NOT01
      MROD(L,I,3)=1+3*N*(N+1)
      GO TO 908
902  LC(L,I,1)=NOTR1+2
      LC(L,I,2)=NOTR0
      MROD(L,I,1)=1+IY+NOT12
      MROD(L,I,2)=2+NOT01
      MROD(L,I,3)=MROD(L,I,2)+1
      GO TO 908
6  CONTINUE
7  CONTINUE
      DO 9 I=NOTRG1,LSTCH
      MROD(L,I,3)=NOROD+1
      IF (I.LE.LSTW) GO TO 801
      IQ=I-LSTCH+5
      LC(L,I,2)=NOTRG+IQ*NORING+1
      LC(L,I,3)=LSTCHG-5+IQ
      LC(L,I,4)=I
      MROD(L,I,1)=2+NOG01+IQ*NORING
      MROD(L,I,2)=NOROD+1
      IF (IQ.EQ.0) GO TO 802
      LC(L,I,1)=NOTRG+IQ*NORING
      GO TO 8
802  LC(L,I,1)=I-1
      GO TO 8
801  IZ=1.0001/(LSTCH-5-I)
      IQ=(I-NOTRG-1)/NORING+0.0001
      IR=I-NOTRG-IQ*NORING+0.0001
      LC(L,I,1)=NOTG1+IQ*(2*NORING-1)+2*IR-1
      LC(L,I,4)=LSTCH+IQ*NORING+IR
      MROD(L,I,1)=1+NOG01+IQ*NORING+IR
      MROD(L,I,2)=MROD(L,I,1)+1-6*IZ*NORING
      IF (IR.EQ.1) GO TO 803
      IF (IR.EQ.NORING) GO TO 804
      LC(L,I,2)=I-1
      LC(L,I,3)=I+1
      GO TO 8
803  LC(L,I,2)=LSTW+IQ+1

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      LC(L,I,3)=I+1
      GO TO 8
804  LC(L,I,2)=I-1
      LC(L,I,3)=(1-IZ)*(LSTW+IQ+2)+IZ*(I+1)
      GO TO 8
      8 CONTINUE
      9 CONTINUE
      DO 13 J=1,NWALLS
      DO 11 I=LSTCH1,LSTCHG
      IF(I.LE.LSTWG) GO TO 701
      IQ=I-LSTWG-1
      LC(L,I,1)=LSTW+1+IQ
      LC(L,I,3)=LSTCH+IQ*NORING+1
      IF(J.EQ.NWALLS) GO TO 12
      LC(L,I,4)=LSTWG+NOINCR+IQ+1
      GO TO 14
12  CONTINUE
      LC(L,I,4)=I
14  CONTINUE
      IF(IQ.EQ.0) GO TO 702
      LC(L,I,2)=LSTCH+IQ*NORING
      GO TO 10
702  LC(L,I,2)=I-1
      GO TO 10
701  IX=1.0001/(LSTWG+1-I)
      IQ=(I-LSTCH-1)/NORING+0.0001
      IR=I-LSTCH-IQ*NORING+0.0001
      LC(L,I,1)=NOTRG+IQ*NORING+IR
      IF(J.EQ.NWALLS) GO TO 16
      LC(L,I,4)=LSTCHG+IQ*NORING+IR
      GO TO 18
16  CONTINUE
      LC(L,I,4)=I
18  CONTINUE
      IF(IR.EQ.1) GO TO 703
      IF(IR.EQ.NORING) GO TO 704
      LC(L,I,2)=I-1
      LC(L,I,3)=I+1
      GO TO 10
704  LC(L,I,2)=I-1
      LC(L,I,3)=(1-IX)*(LSTWG+IQ+2)+IX*(I+1)
      GO TO 10
703  LC(L,I,2)=LSTWG+IQ+1
      LC(L,I,3)=I+1
      GO TO 10
10  CONTINUE
11  CONTINUE
      NOTRG=NOTRG+NOINCR
      LSTCH=LSTCH+NOINCR
      LSTCH1=LSTCH1+NOINCR
      LSTW=LSTW+NOINCR
      LSTWG=LSTWG+NOINCR
      LSTCHG=LSTCHG+NOINCR
13  CONTINUE
      RETURN
      END
      SUBROUTINE GEOM(L)
      COMMON/GEOM /DR(3),DW(3),LEAD(3),P(3),DFLAT(3),POD(3),GAP(3),A1(3),
      1A2(3),A3(3),A4(3),A5(3),A6(3),A7(3),ATOTAL(3),ATOTLG(3),DE1(3),
      2DE2(3),DE3(3),DE6(3),DE7(3),HP1(3),HP2(3),HP3(3),HPTOTL(3),

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3ETA1(3),ETA2(3),ETA3(3),ETA4(3),ETA6(3),ETA8(3),X1(3),X2(3),X3(3),
4S1(3),S2(3),LENGTH(3),V1R(3),V2R(3),V3R(3),V6R(3),V7R(3)
COMMON/NUM /NR0D(3),NRING(3),NCHANL(3),N1(3),N2(3),N3(3),N4(3),
1N5(3),N6(3),N7(3),N8(3),LC(3,550,4),MR0D(3,440,3)
N11=N2(L)
N22=N3(L)-N2(L)
N33=N4(L)-N3(L)
GAP(L)=(DFLAT(L)-1.732*NRING(L)*P(L)-DR(L))/2
DFACE=DFLAT(L)/1.732
PI=3.141592
X1(L)=(DR(L)+2*GAP(L))/1.732
X2(L)=X1(L)+2*S1(L)/1.732
X3(L)=X2(L)+S2(L)/1.732
ETA1(L)=P(L)/1.732
ETA2(L)=(ETA1(L)+GAP(L)+DR(L)/2)/2.
ETA3(L)=P(L)
ETA4(L)=ETA3(L)/2.+(X1(L)/4.
ETA6(L)=ETA3(L)/2.+(X1(L)+X2(L))/4.
ETA8(L)=ETA3(L)/2.+(X2(L)+X3(L))/4.
A1(L)=1.732*P(L)**2/4.-(DR(L)**2+DW(L)**2)*PI/8.
A2(L)=P(L)*(DR(L)/2+GAP(L))-(DR(L)**2+DW(L)**2)*PI/8.
A3(L)=(DR(L)/4+GAP(L)/2)*(DFACE-P(L)*NRING(L))-(DR(L)**2+DW(L)**2
1)*PI/24.
A4(L)=ETA3(L)*S1(L)
A5(L)=(X1(L)+X2(L))*S1(L)/2.
A6(L)=ETA3(L)*S2(L)/2
A7(L)=(X2(L)+X3(L))*S2(L)/4
ATOTAL(L)=N11*A1(L)+N22*A2(L)+N33*A3(L)
ATOTLG(L)=(NRING(L)*A6(L)+A7(L))*6
WP1=(DR(L)+DW(L))*PI/2.
WP2=P(L)*WP1
WP3=(DR(L)+DW(L))*PI/6+DFACE-P(L)*NRING(L)
WP6=ETA3(L)
WP7=X2(L)
DE1(L)=4.0*A1(L)/WP1
DE2(L)=4.0*A2(L)/WP2
DE3(L)=4.0*A3(L)/WP3
DE6(L)=4.0*A6(L)/WP6
DE7(L)=4.0*A7(L)/WP7
HP1(L)=DR(L)*PI/2
HP2(L)=DR(L)*PI/2
HP3(L)=DR(L)*PI/6
HPTOTL(L)=N11*HP1(L)+N22*HP2(L)+N33*HP3(L)
V1R(L)=ATOTAL(L)/(N11*A1(L)+N22*A2(L)*((DE2(L)/DE1(L))*0.714)+
1N33*A3(L)*((DE3(L)/DE1(L))*0.714))
V2R(L)=ATOTAL(L)/(N11*A1(L)*((DE1(L)/DE2(L))*0.714)+N22*A2(L)+
1N33*A3(L)*((DE3(L)/DE2(L))*0.714))
V3R(L)=ATOTAL(L)/(N11*A1(L)*((DE1(L)/DE3(L))*0.714)+N22*A2(L)*
1((DE2(L)/DE3(L))*0.714)+N33*A3(L))
V6R(L)=ATOTLG(L)/(NRING(L)*A6(L)+A7(L)*((DE7(L)/DE6(L))*2))/6
V7R(L)=ATOTLG(L)/(NRING(L)*A6(L)*((DE6(L)/DE7(L))*2)+A7(L))/6
RETURN
END

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APPENDIX 3

A SAMPLE PROBLEM

The sample problem predicts the temperature distribution for the 16 coupled assemblies surrounding the assembly E_1 in Figure (4). All the data are taken from the Clinch River Breeder Reactor. The first 8 pages are the print outs of the input data. The next 16 pages are the temperature distributions for assemblies E_1 , C_3 , A_2 , A_1 , A_1 , A_2 , C_3 , B_3 , B_2 , B_1 , 32, 25, 32, B_1 , B_2 , and A_3 respectively. Because of the core symmetry, there are two sets of print outs for assemblies C_3 , A_2 , A_1 , B_3 , B_2 , B_1 , and 32. Although their heat generation is symmetric with respect to the line joining the core central assembly and assembly E_1 , the temperature distributions are not symmetrical due to the swirl flow inside the assemblies.

INLET TEMPERATURE=			730.0			AVG. OUTLET TEMPERATURE=			995.0							
NO. OF ASSEMBLIES=			16			NO. OF PRINTS=			1							
O.OF INCREMENTS BETWEEN PRINTS=			500			TYPE OF BOUNDARY CONDITIONS=			0							
DATA PACK FOR ASSEMBLY						1										
TYPE OF ASSEMBLY=						2										
ROD DIA.		WIRE DIA.		LEAD		PITCH		PLATS		LENGTH		DUCT TH.		GAP TH.		
0.52000		0.03700		4.00000		0.56000		4.45000		64.00000		0.10000		0.11000		
AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP																
41908.0		28860.0		600.0												
FOUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO																
0.02000		0.02000		0.02000		0.02000		1.00000								
NO. OF FLUX=						32		NO. OF RODS=							61	
AXIAL DISTANCE VS FLUX DISTRIBUTION																
0.0		0.15100		0.01900		0.16200		0.05600		0.17100		0.09200		0.20500		
0.12200		0.24000		0.15300		0.28600		0.18700		0.48800		0.22000		0.60900		
0.25500		0.93000		0.29000		1.28700		0.32600		1.51900		0.35900		1.65800		
0.38800		1.79900		0.41900		1.93700		0.45300		2.06200		0.48600		2.14600		
0.51300		2.18800		0.53500		2.19600		0.56800		2.16900		0.60200		2.09400		
0.63500		1.97200		0.66900		1.43200		0.70200		1.24100		0.73600		1.05100		
0.76900		0.86000		0.81400		0.37100		0.84100		0.26600		0.87700		0.19000		
0.91300		0.12700		0.94800		0.07900		0.98400		0.04100		1.00000		0.02100		
RADIAL POWER DISTRIBUTION OF FUEL RODS																
1.02800		0.84300		0.92300		1.11500		1.22700		1.11500		0.92300		0.67300		
0.74600		0.80400		0.98600		1.18200		1.32000		1.44000		1.32000		1.18200		
0.99600		0.80400		0.74600		0.51800		0.58500		0.63700		0.67300		0.84300		
1.02800		1.22800		1.39200		1.53900		1.66500		1.53900		1.39200		1.22800		
1.02800		0.84300		0.67300		0.63700		0.59500		0.38000		0.43900		0.48600		
0.51900		0.53500		0.69200		0.86400		1.05000		1.25100		1.44100		1.61500		
1.77000		1.90300		1.76900		1.61400		1.44000		1.25100		1.05000		0.86400		
0.69200		0.53500		0.51900		0.48600		0.43900								
DATA PACK FOR ASSEMBLY						2										
TYPE OF ASSEMBLY=						2										
ROD DIA.		WIRE DIA.		LEAD		PITCH		PLATS		LENGTH		DUCT TH.		GAP TH.		
0.52000		0.03700		4.00000		0.56000		4.45000		64.00000		0.10000		0.11000		
AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP																
33126.5		15310.0		600.0												
FOUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO																
0.02000		0.02000		0.02000		0.02000		1.00000								
NO. OF FLUX=						32		NO. OF RODS=							61	
AXIAL DISTANCE VS FLUX DISTRIBUTION																
0.0		0.17200		0.01900		0.17900		0.05600		0.19300		0.09200		0.23300		
0.12200		0.28200		0.15300		0.34100		0.18700		0.41800		0.22000		0.66800		
0.25500		0.97100		0.29000		1.36700		0.32600		1.67100		0.35900		1.73700		
0.38800		1.80300		0.41900		1.86900		0.45300		1.94500		0.48600		2.00200		
0.51300		2.02400		0.53500		2.02300		0.56800		1.98400		0.60200		1.90300		
0.63500		1.78900		0.66900		1.62500		0.70200		1.35200		0.73600		1.09900		
0.76900		0.53000		0.80400		0.37500		0.84100		0.28300		0.87700		0.21100		
0.91300		0.15300		0.94800		0.10700		0.98400		0.07600		1.00000		0.05900		
RADIAL POWER DISTRIBUTION OF FUEL RODS																
1.03700		0.87200		0.93600		1.10500		1.21300		1.11900		0.94800		0.71800		
0.77900		0.82000		0.99000		1.15100		1.28500		1.40000		1.30200		1.18200		
1.00600		0.84000		0.79800		0.57700		0.63300		0.67100		0.69000		0.84000		
1.00100		1.17300		1.33300		1.47500		1.59700		1.49400		1.36900		1.22300		
1.04400		0.87400		0.71700		0.68700		0.64000		0.45000		0.50100		0.53600		
0.55300		0.55300		0.68900		0.83900		1.00000		1.17200		1.35600		1.52500		
1.67400		1.80200		1.69600		1.56700		1.44400		1.24300		1.06000		0.88900		
0.72900		0.58200		0.57300		0.54700		0.50500								
DATA PACK FOR ASSEMBLY						3										
TYPE OF ASSEMBLY=						2										
ROD DIA.		WIRE DIA.		LEAD		PITCH		PLATS		LENGTH		DUCT TH.		GAP TH.		
0.52000		0.03700		4.00000		0.56000		4.45000		64.00000		0.10000		0.11000		

AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP							
57547.7	28860.0	600.0					
FOUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO							
0.02000	0.02000	0.02000	0.02000	1.00000			
NO. OF FLUX= 32 NO. OF RODS= 61							
AXIAL DISTANCE VS FLUX DISTRIBUTION							
0.0	0.15400	0.01900	0.15600	0.05600	0.18000	0.09200	0.22000
0.12200	0.26300	0.15300	0.32100	0.18700	0.50200	0.22000	0.66400
0.25500	0.99000	0.29000	1.39700	0.32600	1.52400	0.35900	1.66300
0.38800	1.80100	0.41900	1.94000	0.45300	2.04400	0.48600	2.10800
0.51300	2.13400	0.52500	2.13200	0.56800	2.09300	0.60200	2.00900
0.63500	1.89300	0.66900	1.42800	0.70200	1.22500	0.73600	1.02300
0.76900	0.82000	0.80400	0.37500	0.84100	0.27100	0.87700	0.19500
0.91300	0.13400	0.94800	0.08800	0.98400	0.05600	1.00000	0.03900
RADIAL POWER DISTRIBUTION OF FUEL RODS							
1.03400	0.83800	0.92100	1.12300	1.24300	1.12700	0.92500	0.65800
0.73400	0.79100	0.98300	1.19900	1.33800	1.46500	1.34200	1.19800
0.99200	0.79900	0.73700	0.49500	0.56300	0.61500	0.65000	0.82900
1.02400	1.23300	1.47800	1.56500	1.69800	1.57000	1.41800	1.24600
1.03600	0.84100	0.66000	0.62200	0.56600	0.35000	0.41000	0.45700
0.48700	0.50100	0.66400	0.84500	1.04200	1.25200	1.45400	1.63900
1.80200	1.94200	1.80800	1.64900	1.46800	1.27000	1.05800	0.96100
0.67900	0.51300	0.49600	0.46300	0.41300			
DATA PACK FOR ASSEMBLY 4							
TYPE OF ASSEMBLY= 2							
ROD DIA.	WIRE DIA.	LEAD	PITCH	PLATS	LENGTH	DUCT TH.	GAP TH.
0.52000	0.03700	4.00000	0.56000	4.45000	64.00000	0.10000	0.11000
AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP							
92600.0	53590.0	600.0					
FOUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO							
0.02000	0.02000	0.02000	0.02000	1.00000			
NO. OF FLUX= 32 NO. OF RODS= 61							
AXIAL DISTANCE VS FLUX DISTRIBUTION							
0.0	0.12800	0.01900	0.14500	0.05600	0.17600	0.09200	0.23300
0.12200	0.30300	0.15300	0.39700	0.18700	0.53800	0.22000	0.83700
0.25500	1.19200	0.29000	1.41300	0.32600	1.63500	0.35900	1.76600
0.38800	1.89700	0.41900	1.95000	0.45300	1.98600	0.48600	1.98500
0.51300	1.96100	0.53500	1.92600	0.56800	1.84800	0.60200	1.74300
0.63500	1.61000	0.66900	1.44900	0.70200	1.26300	0.73600	0.97900
0.76900	0.70300	0.80400	0.39300	0.84100	0.26600	0.87700	0.18000
0.91300	0.12500	0.94800	0.09900	0.98400	0.06800	1.00000	0.05800
RADIAL POWER DISTRIBUTION OF FUEL RODS							
1.04000	0.83800	0.92400	1.13400	1.25700	1.13300	0.92400	0.65200
0.73100	0.78900	0.98900	1.20200	1.35700	1.48800	1.35500	1.20000
0.98700	0.79000	0.73100	0.48300	0.55400	0.60700	0.64000	0.82500
1.02700	1.24400	1.43000	1.59400	1.73100	1.59100	1.42600	1.23900
1.02500	0.82500	0.64100	0.60800	0.55500	0.33300	0.39600	0.44300
0.47200	0.48200	0.65100	0.83800	1.04000	1.25800	1.47500	1.67100
1.84300	1.99600	1.83900	1.66500	1.45800	1.25100	1.03600	0.83600
0.65100	0.48400	0.47400	0.44500	0.39700			
DATA PACK FOR ASSEMBLY 5							
TYPE OF ASSEMBLY= 2							
ROD DIA.	WIRE DIA.	LEAD	PITCH	PLATS	LENGTH	DUCT TH.	GAP TH.
0.52000	0.03700	4.00000	0.56000	4.45000	64.00000	0.10000	0.11000
AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP							
92600.0	53590.0	600.0					
FOUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO							
0.02000	0.02000	0.02000	0.02000	1.00000			
NO. OF FLUX= 32 NO. OF RODS= 61							
AXIAL DISTANCE VS FLUX DISTRIBUTION							
0.0	0.12800	0.01900	0.14500	0.05600	0.17600	0.09200	0.23300
0.12200	0.30300	0.15300	0.39700	0.18700	0.53800	0.22000	0.83700
0.25500	1.19200	0.29000	1.41300	0.32600	1.63500	0.35900	1.76600
0.38800	1.89700	0.41900	1.95000	0.45300	1.98600	0.48600	1.98500
0.51300	1.96100	0.53500	1.92600	0.56800	1.84800	0.60200	1.74300
0.63500	1.61000	0.66900	1.44900	0.70200	1.26300	0.73600	0.97900

TYPE OF ASSEMBLY= 2							
ROD DIA.	WIRE DIA.	LEAD	PITCH	PLATS	LENGTH	DUCT TH.	GAP TH.
0.52000	0.03700	4.00000	0.56000	4.45000	64.00000	0.10000	0.11000
AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP							
31739.9	15310.0	600.0					
POUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO							
0.02000	0.02000	0.02000	0.02000	1.00000			
NO. OF FLUX= 32 NO. OF RODS= 61							
AXIAL DISTANCE VS FLUX DISTRIBUTION							
0.0	0.17400	0.01900	0.18300	0.05600	0.19800	0.09200	0.24200
0.12200	0.29500	0.15300	0.35900	0.18700	0.44300	0.22000	0.70800
0.25500	1.02900	0.29000	1.35200	0.32600	1.60600	0.35900	1.69200
0.38800	1.79700	0.41900	1.91000	0.45300	1.97600	0.48600	2.01700
0.51300	2.02500	0.53500	2.01200	0.56800	1.96000	0.60200	1.86900
0.63500	1.75000	0.66900	1.54900	0.70200	1.27800	0.73600	1.02300
0.76900	0.59700	0.80400	0.36100	0.84100	0.27500	0.87700	0.20600
0.91300	0.15200	0.94800	0.11200	0.98400	0.08900	1.00000	0.07600
RADIAL POWER DISTRIBUTION OF FUEL RODS							
1.04000	0.87000	0.93600	1.11100	1.22100	1.12400	0.94800	0.71100
0.77300	0.81600	0.98200	1.15800	1.29500	1.41200	1.31100	1.18800
1.00700	0.83800	0.78300	0.56400	0.62200	0.66200	0.68200	0.83800
1.00500	1.19200	1.24500	1.48900	1.61100	1.50600	1.37800	1.22800
1.04500	0.87200	0.71100	0.68000	0.63000	0.43100	0.48300	0.52000
0.53900	0.53900	0.68200	0.83800	1.00500	1.18200	1.37000	1.54700
1.69100	1.81900	1.71100	1.57700	1.42200	1.24600	1.06100	0.88600
0.72300	0.57300	0.56300	0.53500	0.49000			
DATA PACK FOR ASSEMBLY 9							
TYPE OF ASSEMBLY= 2							
ROD DIA.	WIRE DIA.	LEAD	PITCH	PLATS	LENGTH	DUCT TH.	GAP TH.
0.52000	0.03700	4.00000	0.56000	4.45000	64.00000	0.10000	0.11000
AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP							
49304.8	24860.0	600.0					
POUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO							
0.02000	0.02000	0.02000	0.02000	1.00000			
NO. OF FLUX= 32 NO. OF RODS= 61							
AXIAL DISTANCE VS FLUX DISTRIBUTION							
0.0	0.15800	0.01900	0.17100	0.05600	0.18900	0.09200	0.23500
0.12200	0.28700	0.15300	0.35500	0.18700	0.51700	0.22000	0.72000
0.25500	1.05100	0.29000	1.32700	0.32600	1.52900	0.35900	1.66700
0.38800	1.80500	0.41900	1.94300	0.45300	2.02600	0.48600	2.07100
0.51300	2.09100	0.53500	2.06800	0.56800	2.01600	0.60200	1.92300
0.63500	1.79300	0.66900	1.42500	0.70200	1.21000	0.73600	0.99500
0.76900	0.78000	0.80400	0.37900	0.84100	0.27600	0.87700	0.19900
0.91300	0.14000	0.94800	0.09800	0.98400	0.07000	1.00000	0.05500
RADIAL POWER DISTRIBUTION OF FUEL RODS							
1.02700	0.83000	0.90800	1.11100	1.24000	1.12800	0.92200	0.65100
0.72300	0.77600	0.96600	1.17300	1.33100	1.47000	1.35100	1.22900
0.99600	0.80000	0.73400	0.49100	0.55500	0.60300	0.63300	0.80800
1.00200	1.21100	1.39700	1.56600	1.71500	1.98900	1.43900	1.26900
1.05000	0.84800	0.66500	0.62200	0.56400	0.35100	0.40800	0.45000
0.47700	0.48600	0.64400	0.82000	1.01400	1.22500	1.43700	1.63600
1.81600	1.97500	1.84200	1.68500	1.50500	1.30600	1.08300	0.87700
0.68900	0.52100	0.50100	0.46400	0.41400			
DATA PACK FOR ASSEMBLY 10							
TYPE OF ASSEMBLY= 2							
ROD DIA.	WIRE DIA.	LEAD	PITCH	PLATS	LENGTH	DUCT TH.	GAP TH.
0.52000	0.03700	4.00000	0.56000	4.45000	64.00000	0.10000	0.11000
AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP							
68102.2	52590.0	600.0					
POUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO							
0.02000	0.02000	0.02000	0.02000	1.00000			
NO. OF FLUX= 32 NO. OF RODS= 61							
AXIAL DISTANCE VS FLUX DISTRIBUTION							
0.0	0.12400	0.01900	0.14200	0.05600	0.17700	0.09200	0.23900
0.12200	0.31800	0.15300	0.42500	0.18700	0.59200	0.22000	0.90800
0.25500	1.27900	0.29000	1.47600	0.32600	1.68800	0.35900	1.81900

0.38800	1.93900	0.41900	1.98200	0.45300	1.99200	0.48600	1.96600
0.51300	1.91200	0.53500	1.85100	0.56800	1.78100	0.60200	1.66300
0.63500	1.52400	0.66900	1.37900	0.70200	1.21000	0.73600	0.91000
0.76900	0.66900	0.80400	0.40900	0.84100	0.27400	0.87700	0.18500
0.91300	0.11100	0.94800	0.09600	0.98400	0.07800	1.00000	0.07000
RADIAL POWER DISTRIBUTION OF FUEL RODS							
1.03900	0.84800	0.92600	1.12300	1.24300	1.12900	0.93200	0.67100
0.74400	0.79600	0.98300	1.18300	1.33300	1.46200	1.38100	1.15700
0.99500	0.81700	0.74900	0.51000	0.57600	0.62400	0.65200	0.82700
1.01500	1.21800	1.39800	1.55700	1.69300	1.56500	1.41300	1.23000
1.03400	0.84300	0.66700	0.63400	0.58100	0.36400	0.42400	0.46700
0.49300	0.49200	0.65900	0.83400	1.02300	1.22600	1.43500	1.62500
1.79400	1.93800	1.87200	1.64200	1.45900	1.25600	1.04900	0.85700
0.67900	0.51600	0.50500	0.47500	0.42800			
DATA PACK FOR ASSEMBLY 11							
TYPE OF ASSEMBLY= 1							
ROD DIA.	WIRE DIA.	LEAD	PITCH	PLATS	LENGTH	DUCT TH.	GAP TH.
0.23000	0.05600	11.90000	0.28790	4.33500	64.35400	0.16000	0.11000
AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP							
199012.5	165355.0	600.0					
POUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO							
0.02000	0.02000	0.02000	0.02000	0.10000			
NO. OF PLUX= 36 NO. OF RODS= 217							
AXIAL DISTANCE VS FLUX DISTRIBUTION							
0.0	0.07227	0.00590	0.07372	0.03780	0.08165	0.07340	0.10147
0.10700	0.15068	0.13540	0.20781	0.16970	0.27089	0.20250	0.35290
0.21840	0.39273	0.21850	1.05222	0.23590	1.15812	0.27130	1.36654
0.30620	1.56152	0.34170	1.73465	0.37270	1.82374	0.40080	1.91283
0.43340	1.98678	0.46720	2.02881	0.49870	2.03721	0.51900	2.02544
0.54880	1.98510	0.58150	1.90778	0.61520	1.80021	0.64840	1.71785
0.68160	1.59682	0.71480	1.39708	0.74800	1.16484	0.78120	0.93792
0.78130	0.13199	0.79940	0.15566	0.83620	0.10252	0.87250	0.06817
0.90810	0.03562	0.96110	0.02379	0.97830	0.01604	1.00000	0.01130
RADIAL POWER DISTRIBUTION OF FUEL RODS							
1.02900	1.00600	1.01000	1.03300	1.05300	1.08600	1.02200	0.98200
0.98600	0.98700	1.01100	1.03400	1.05700	1.07700	1.07000	1.06000
1.03600	1.01200	0.99900	0.95900	0.96300	0.96400	0.96100	0.98500
1.00800	1.03200	1.05800	1.08100	1.10100	1.09400	1.08400	1.07100
1.04700	1.02300	0.99900	0.98900	0.97500	0.93500	0.93900	0.94000
0.93800	0.93300	0.95600	0.98000	1.00300	1.02700	1.05600	1.08200
1.10500	1.12500	1.11800	1.10800	1.09500	1.07900	1.05500	1.03100
1.00700	0.98300	0.97600	0.96500	0.95200	0.91200	0.91600	0.91700
0.91500	0.91000	0.90100	0.92500	0.94800	0.97200	0.99500	1.01800
1.05100	1.09000	1.10600	1.12900	1.14900	1.14200	1.13200	1.11900
1.10300	1.08400	1.06000	1.03600	1.01200	0.98800	0.96400	0.96000
0.95200	0.94200	0.92800	0.88900	0.89300	0.89400	0.89200	0.88700
0.87800	0.86700	0.89000	0.91300	0.93700	0.96000	0.98400	1.00700
1.04200	1.07400	1.10400	1.13000	1.15300	1.17300	1.16600	1.15600
1.14300	1.12700	1.10900	1.08600	1.06700	1.03800	1.01400	0.99000
0.96600	0.94200	0.94100	0.93600	0.92900	0.91900	0.90500	0.86600
0.87000	0.87100	0.86900	0.86300	0.85500	0.84400	0.83000	0.85300
0.87600	0.89900	0.92300	0.94600	0.97000	0.99300	1.03100	1.06600
1.09800	1.12800	1.15400	1.17700	1.19800	1.19100	1.18100	1.16800
1.15200	1.13200	1.11000	1.08500	1.06100	1.03700	1.01200	0.98800
0.96500	0.94100	0.91700	0.91900	0.91700	0.91300	0.90500	0.89500
0.88200	0.84300	0.84700	0.84800	0.84600	0.84100	0.83200	0.82100
0.80700	0.78900	0.81200	0.83500	0.85900	0.88200	0.90500	0.92900
0.95200	0.97600	1.01700	1.05500	1.09000	1.12200	1.15200	1.17800
1.20100	1.22200	1.21500	1.23500	1.19200	1.17600	1.15700	1.13500
1.11000	1.08100	1.05700	1.03300	1.00800	0.98400	0.96000	0.93600
0.91300	0.88900	0.89300	0.89500	0.89400	0.88900	0.88200	0.87200
0.85900							
DATA PACK FOR ASSEMBLY 12							
TYPE OF ASSEMBLY= 1							
ROD DIA.	WIRE DIA.	LEAD	PITCH	PLATS	LENGTH	DUCT TH.	GAP TH.
0.23000	0.05600	11.90000	0.28790	4.33500	64.35400	0.16000	0.11000

AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP							
222383.4	165355.0	600.0					
FOUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO							
0.02000	0.02000	0.02000	0.02000	0.02000	0.10000		
NO. OF PLUX= 36		NO. OF RODS= 217					
AXIAL DISTANCE VS FLUX DISTRIBUTION							
0.0	0.06551	0.00590	0.06831	0.03780	0.07732	0.07340	0.09877
0.10790	0.14509	0.13540	0.19970	0.16970	0.27215	0.20250	0.37471
0.21840	0.42445	0.21850	1.13122	0.23590	1.24216	0.27130	1.46403
0.30620	1.66742	0.34170	1.83046	0.37270	1.93132	0.40080	1.99855
0.43340	2.04225	0.46720	2.05234	0.49870	2.03217	0.51900	2.00527
0.54880	1.94476	0.58150	1.85063	0.61520	1.72961	0.64840	1.61195
0.68160	1.46908	0.71480	1.27745	0.74800	1.07407	0.78120	0.87069
0.78130	0.18012	0.79940	0.15292	0.83620	0.09771	0.87250	0.06476
0.90810	0.03876	0.96110	0.02727	0.97830	0.02025	1.00000	0.01597
RADIAL POWER DISTRIBUTION OF FUEL RODS							
0.99700	0.97400	0.98500	1.00900	1.02000	1.00900	0.98500	0.95000
0.96200	0.97400	0.99700	1.02100	1.03200	1.04300	1.03200	1.02100
0.99700	0.97400	0.96200	0.92700	0.93900	0.95100	0.96300	0.98700
1.01000	1.03300	1.04400	1.05500	1.06600	1.05500	1.04400	1.03300
1.01000	0.99700	0.96200	0.95100	0.93900	0.90400	0.81600	0.92800
0.94000	0.95300	0.97600	0.99900	1.02300	1.04600	1.05600	1.06700
1.07800	1.09000	1.07800	1.06700	1.05600	1.04600	1.02300	0.99900
0.97600	0.95300	0.94000	0.92800	0.91600	0.88100	0.89300	0.90500
0.91700	0.93000	0.94300	0.95600	0.98900	1.01200	1.03600	1.05900
1.06900	1.07900	1.09000	1.10100	1.11300	1.10100	1.09000	1.07900
1.06900	1.05900	1.03600	1.01200	0.98900	0.96600	0.94300	0.93000
0.91700	0.90500	0.89300	0.85800	0.86900	0.88100	0.89400	0.90700
0.92000	0.93300	0.95600	0.97900	1.00300	1.02600	1.04900	1.07200
1.08200	1.09200	1.10300	1.11300	1.12500	1.13600	1.12500	1.11300
1.10300	1.09200	1.08200	1.07200	1.04900	1.02600	1.00300	0.97900
0.95600	0.93300	0.92000	0.90700	0.89400	0.88100	0.86900	0.83400
0.84600	0.85800	0.87100	0.88300	0.89600	0.91000	0.92300	0.94700
0.97000	0.99300	1.01600	1.03900	1.06300	1.08600	1.09500	1.10500
1.11500	1.12600	1.13700	1.14800	1.15900	1.14800	1.13700	1.12600
1.11500	1.10500	1.09500	1.08600	1.06300	1.03900	1.01600	0.99300
0.97000	0.94700	0.92300	0.91000	0.89600	0.88300	0.87100	0.85800
0.84600	0.81100	0.82300	0.83500	0.84700	0.86000	0.87300	0.88700
0.90000	0.91400	0.93700	0.96100	0.98400	1.00700	1.03000	1.05300
1.07700	1.10000	1.10900	1.11900	1.12800	1.13900	1.14900	1.16000
1.17100	1.18200	1.17100	1.16000	1.14900	1.13900	1.12800	1.11900
1.10900	1.10000	1.07700	1.05300	1.03000	1.00700	0.98400	0.96100
0.93700	0.91400	0.90000	0.88700	0.87300	0.86000	0.84700	0.83500
0.82300							
DATA PACK FOR ASSEMBLY 13							
TYPE OF ASSEMBLY= 1							
ROD DIA.	WIRE DIA.	LEAD	PITCH	PLATS	LENGTH	DUCT TH.	GAP TH.
0.23000	0.05600	11.90000	0.28790	4.33500	64.35400	0.16000	0.11000
AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP							
199012.5	165355.0	600.0					
FOUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO							
0.02000	0.02000	0.02000	0.02000	0.02000	0.10000		
NO. OF PLUX= 36		NO. OF RODS= 217					
AXIAL DISTANCE VS FLUX DISTRIBUTION							
0.0	0.07227	0.00590	0.07372	0.03780	0.08165	0.07340	0.10187
0.10790	0.15068	0.13540	0.20781	0.16970	0.27089	0.20250	0.35290
0.21840	0.39273	0.21850	1.05222	0.23590	1.15812	0.27130	1.36654
0.30620	1.56152	0.34170	1.73465	0.37270	1.82374	0.40080	1.91283
0.43340	1.98678	0.46720	2.02881	0.49870	2.03721	0.51900	2.02544
0.54880	1.98513	0.58150	1.90778	0.61520	1.80021	0.64840	1.71785
0.68160	1.59682	0.71480	1.39008	0.74800	1.16484	0.78120	0.93792
0.78130	0.18199	0.79940	0.15566	0.83620	0.10252	0.87250	0.06817
0.90810	0.03562	0.96110	0.02379	0.97830	0.01604	1.00000	0.01130
RADIAL POWER DISTRIBUTION OF FUEL RODS							
1.02900	1.00600	1.01000	1.03300	1.05300	1.04600	1.02200	0.98200
0.98600	0.98700	1.01100	1.03400	1.05700	1.07700	1.07000	1.06000

1.07500	1.01200	0.99000	0.95000	0.96300	0.96400	0.96100	0.98500
1.00900	1.03200	1.05800	1.08100	1.10100	1.09400	1.09400	1.07100
1.04700	1.02300	0.99900	0.98900	0.97500	0.93500	0.93900	0.94000
0.93800	0.93300	0.95600	0.98000	1.00300	1.02700	1.05600	1.08200
1.10500	1.12500	1.11900	1.10900	1.09500	1.07900	1.05500	1.03100
1.00700	0.98300	0.97600	0.96500	0.95200	0.91200	0.91600	0.91700
0.91500	0.91000	0.90100	0.92500	0.94800	0.97200	0.99500	1.01900
1.05100	1.08000	1.10600	1.12900	1.14900	1.14200	1.13200	1.11600
1.10300	1.09400	1.06000	1.03600	1.01200	0.98800	0.96400	0.96000
0.95200	0.94200	0.92800	0.89900	0.89300	0.89400	0.89200	0.89700
0.87800	0.86700	0.89000	0.91300	0.93700	0.96000	0.98400	1.00700
1.04200	1.07400	1.10400	1.13000	1.15300	1.17300	1.16600	1.15600
1.14300	1.12700	1.10900	1.08600	1.06200	1.03800	1.01400	0.99000
0.96600	0.94200	0.94100	0.93600	0.92900	0.91900	0.90500	0.86600
0.87000	0.87100	0.86900	0.86300	0.85500	0.84400	0.83000	0.85300
0.87600	0.89900	0.92300	0.94600	0.97000	0.99300	1.03100	1.06600
1.09800	1.12800	1.15400	1.17700	1.19800	1.19100	1.18100	1.16900
1.15200	1.13200	1.11000	1.09500	1.06100	1.03700	1.01200	0.98900
0.96500	0.94100	0.91700	0.91900	0.91700	0.91300	0.90500	0.89500
0.88200	0.84300	0.84700	0.84800	0.84600	0.84100	0.83200	0.82100
0.80700	0.73900	0.81200	0.83500	0.85900	0.88200	0.90500	0.92900
0.95200	0.97600	1.01700	1.05500	1.09000	1.12200	1.15200	1.17800
1.20100	1.22200	1.21500	1.21500	1.19200	1.17600	1.15700	1.13500
1.11000	1.09100	1.05700	1.03300	1.00800	0.98400	0.96000	0.93600
0.91300	0.88900	0.89300	0.89500	0.89000	0.88900	0.88200	0.87200
0.85900							

DATA PACK FOR ASSEMBLY 14

TYPE OF ASSEMBLY= 2

ROD DIA.	WIRE DIA.	LEAD	PITCH	PLATS	LENGTH	DUCT TH.	GAP TH.
0.52000	0.03700	4.00000	0.56000	4.45000	64.00000	0.10000	0.11000

AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP

68102.2 53590.0 600.0

FOUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO

0.02000 0.02000 0.02000 0.02000 1.00000

NO. OF PLUX= 32 NO. OF PODS= 61

AXIAL DISTANCE VS FLUX DISTRIBUTION

0.0	0.12400	0.01900	0.14200	0.05600	0.17700	0.09200	0.23900
0.12200	0.31800	0.15300	0.42500	0.18700	0.59200	0.22000	0.90800
0.25500	1.27900	0.29000	1.47600	0.32600	1.68800	0.35900	1.81900
0.38800	1.93900	0.41900	1.98200	0.45300	1.99200	0.48600	1.96600
0.51300	1.91200	0.53500	1.85100	0.56800	1.78100	0.60200	1.66300
0.63500	1.52400	0.66900	1.37900	0.70200	1.21000	0.73600	0.91000
0.76900	0.66900	0.80400	0.83900	0.84100	0.27400	0.87700	0.18500
0.91300	0.13100	0.94800	0.09600	0.98400	0.07800	1.00000	0.07000

RADIAL POWER DISTRIBUTION OF FUEL PODS

1.03800	0.84800	0.92600	1.12300	1.24300	1.12900	0.93200	0.67100
0.74400	0.79600	0.98300	1.18300	1.33300	1.46200	1.34100	1.19700
0.99500	0.80700	0.74900	0.51000	0.57600	0.62400	0.65200	0.82700
1.01500	1.21800	1.39800	1.55700	1.69300	1.56500	1.41300	1.24000
1.03400	0.84300	0.66700	0.63400	0.58100	0.36400	0.42400	0.46700
0.49300	0.49900	0.65900	0.83400	1.02300	1.22600	1.43500	1.62500
1.79400	1.93800	1.80300	1.64200	1.45900	1.25600	1.04900	0.85700
0.67900	0.51600	0.50500	0.47500	0.42800			

DATA PACK FOR ASSEMBLY 15

TYPE OF ASSEMBLY= 2

ROD DIA.	WIRE DIA.	LEAD	PITCH	PLATS	LENGTH	DUCT TH.	GAP TH.
0.52000	0.03700	4.00000	0.56000	4.45000	64.00000	0.10000	0.11000

AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP

49304.8 28867.0 600.0

FOUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO

0.02000 0.02000 0.02000 0.02000 1.00000

NO. OF PLUX= 32 NO. OF PODS= 61

AXIAL DISTANCE VS FLUX DISTRIBUTION

0.0	0.15800	0.01900	0.17100	0.05600	0.18900	0.09200	0.23500
0.12200	0.29700	0.15300	0.35500	0.18700	0.51700	0.22000	0.72000
0.25500	1.05100	0.29000	1.32700	0.32600	1.52900	0.35900	1.66700

0.38800	1.80500	0.41900	1.94300	0.45300	2.02600	0.48600	2.07100
0.51300	2.09100	0.53500	2.06800	0.56800	2.01600	0.60200	1.92100
0.63500	1.79300	0.66900	1.42500	0.70200	1.21000	0.73600	0.49500
0.76900	0.79000	0.80400	0.37900	0.84100	0.27600	0.87700	0.19900
0.91300	0.14000	0.94800	0.09800	0.98400	0.07000	1.00000	0.05500
RADIAL POWER DISTRIBUTION OF FUEL PODS							
1.02700	0.93000	0.90300	1.11100	1.24000	1.12800	0.92200	0.65100
0.72300	0.77600	0.96600	1.17300	1.33100	1.47000	1.35100	1.20900
0.99600	0.80000	0.73400	0.49100	0.55500	0.60300	0.63300	0.80800
1.00200	1.21100	1.39700	1.56600	1.71500	1.98900	1.43900	1.26900
1.05000	0.84800	0.66500	0.62200	0.56400	0.35100	0.40800	0.45000
0.47700	0.48600	0.64400	0.82000	1.01400	1.22500	1.43700	1.63600
1.81600	1.97500	1.84200	1.68500	1.50500	1.30600	1.08300	0.87700
0.68900	0.52100	0.50100	0.46400	0.41400			
DATA PACK FOR ASSEMBLY 16							
TYPE OF ASSEMBLY= 2							
ROD DIA.	WIPE DIA.	LEAD	PITCH	PLATS	LENGTH	DUCT TH.	GAP TH.
0.52000	0.03700	4.00000	0.56000	4.45000	64.00000	0.10000	0.11000
AVG HEAT FLUX, FLOW RATES IN THE ASSEMBLY AND THE GAP							
31739.9	15310.0	600.0					
FOUR EFFECTIVE EDDY DIFFUSIVITIES AND SWIRL VELOCITY RATIO							
0.02000	0.02000	0.02000	0.02000	1.00000			
NO. OF PLUVE= 32 NO. OF RODS= 61							
AXIAL DISTANCE VS FLUX DISTRIBUTION							
0.0	0.17400	0.01900	0.14300	0.05600	0.19800	0.09200	0.24200
0.12200	0.29500	0.15300	0.35900	0.18700	0.44300	0.22000	0.70800
0.25500	1.02900	0.29000	1.35200	0.32600	1.60600	0.35900	1.69200
0.38800	1.79700	0.41900	1.91000	0.45300	1.97600	0.48600	2.01700
0.51300	2.02500	0.53500	2.01200	0.56800	1.96000	0.60200	1.86900
0.63500	1.75000	0.66900	1.54900	0.70200	1.27800	0.73600	1.02300
0.76900	0.59700	0.80400	0.36100	0.84100	0.27500	0.87700	0.20600
0.91300	0.15200	0.94800	0.11200	0.98400	0.08900	1.00000	0.07600
RADIAL POWER DISTRIBUTION OF FUEL PODS							
1.04000	0.87000	0.93600	1.11100	1.22100	1.12400	0.94800	0.71100
0.77300	0.81600	0.98200	1.15800	1.29500	1.41200	1.31100	1.18800
1.00700	0.83800	0.78300	0.56400	0.62200	0.66200	0.68200	0.83800
1.00500	1.18200	1.34500	1.48900	1.61100	1.50600	1.37800	1.22900
1.04500	0.87200	0.71100	0.68000	0.63000	0.43100	0.48300	0.52000
0.53900	0.53900	0.68200	0.83800	1.00500	1.18200	1.37000	1.54000
1.69100	1.81900	1.71100	1.57700	1.42200	1.24600	1.06100	0.88600
0.72300	0.57300	0.56300	0.53500	0.49000			
NEIGHBORS FOR ASSEMBLIES							
2	3	4	5	6	7		
2	8	3	1	7	2		
8	9	10	4	1	2		
3	10	11	12	5	1		
1	4	12	13	18	6		
7	1	5	14	15	16		
7	2	1	6	16	7		
8	8	9	3	2	8		
9	9	9	10	3	8		
9	10	10	11	4	3		
10	11	11	11	12	4		
4	11	12	12	13	5		
5	12	13	13	13	14		
6	5	13	14	14	15		
16	6	14	15	15	15		
16	7	6	15	16	16		

TAVG = 350.5
 OTOPAL (KW) = 550.1
 DIFPH (KW) = 565.7
 DIFPHG (KW) = 10.7

TEMPERATURE DISTRIBUTION FOR ASSEMBLY

907	906	905	904	903	902	901	900	899	898	897	896	895	894	893	892	891	890	889	888	887	886	885	884	883	882	881	880	879	878	877	876	875	874	873	872	871	870	869	868	867	866	865	864	863	862	861	860	859	858	857	856	855	854	853	852	851	850	849	848	847	846	845	844	843	842	841	840	839	838	837	836	835	834	833	832	831	830	829	828	827	826	825	824	823	822	821	820	819	818	817	816	815	814	813	812	811	810	809	808	807	806	805	804	803	802	801	800	799	798	797	796	795	794	793	792	791	790	789	788	787	786	785	784	783	782	781	780	779	778	777	776	775	774	773	772	771	770	769	768	767	766	765	764	763	762	761	760	759	758	757	756	755	754	753	752	751	750	749	748	747	746	745	744	743	742	741	740	739	738	737	736	735	734	733	732	731	730	729	728	727	726	725	724	723	722	721	720	719	718	717	716	715	714	713	712	711	710	709	708	707	706	705	704	703	702	701	700	699	698	697	696	695	694	693	692	691	690	689	688	687	686	685	684	683	682	681	680	679	678	677	676	675	674	673	672	671	670	669	668	667	666	665	664	663	662	661	660	659	658	657	656	655	654	653	652	651	650	649	648	647	646	645	644	643	642	641	640	639	638	637	636	635	634	633	632	631	630	629	628	627	626	625	624	623	622	621	620	619	618	617	616	615	614	613	612	611	610	609	608	607	606	605	604	603	602	601	600	599	598	597	596	595	594	593	592	591	590	589	588	587	586	585	584	583	582	581	580	579	578	577	576	575	574	573	572	571	570	569	568	567	566	565	564	563	562	561	560	559	558	557	556	555	554	553	552	551	550	549	548	547	546	545	544	543	542	541	540	539	538	537	536	535	534	533	532	531	530	529	528	527	526	525	524	523	522	521	520	519	518	517	516	515	514	513	512	511	510	509	508	507	506	505	504	503	502	501	500	499	498	497	496	495	494	493	492	491	490	489	488	487	486	485	484	483	482	481	480	479	478	477	476	475	474	473	472	471	470	469	468	467	466	465	464	463	462	461	460	459	458	457	456	455	454	453	452	451	450	449	448	447	446	445	444	443	442	441	440	439	438	437	436	435	434	433	432	431	430	429	428	427	426	425	424	423	422	421	420	419	418	417	416	415	414	413	412	411	410	409	408	407	406	405	404	403	402	401	400	399	398	397
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TAVG = 1027.7
 TOTAL (KW) = 421.2
 DIFFIN (KW) = 425.1
 DIFFHC (KW) = 11.8

TEMPERATURE DISTRIBUTION FOR ASSEMBLY 2

926	951	949	946	944	928
937	940	941	938	937	910
937	937	933	930	930	937
1006	999	970	940		
968	945	941	1119	1048	1013
			972	936	933
				932	910
1087	1101	1058	1005	953	
955	952	949	1067	1133	1100
			1086	990	942
				939	938
				936	
1133	1167	1124	1165	1006	952
963	960	957	1095	1182	1159
				1102	1042
				983	940
				945	944
				943	
1153	1209	1171	1111	1050	991
				943	
969	967	966	1088	1209	1200
				1145	1083
				1023	967
					937
					952
					951
					949
962	964	966			
					958
					955
					954
939	951	968	1091	1213	1203
				1147	1084
				1028	970
					941
					954
					958
					957
1162	1215	1176	1115	1053	995
					951
941	957	972	1112	1196	1168
				1110	1049
				992	955
				964	963
					962
1153	1181	1135	1075	1016	968
944	960	975	1095	1153	1118
				1062	1007
				967	967
				967	966
1118	1126	1080	1026	980	
947	961	975	1059	1081	1048
				1007	973
					969
					969
					968
1049	1040	1011	982		
975	977	978	975	971	971
973	968	967	965	961	969
971	958	957	954	951	968

TAVG = 1115.6
 TOTAL (KV) = 756.6
 DISCH (KV) = 717.7
 DISCHG (KV) = 11.0

TEMPERATURE DISTRIBUTION FOR ASSEMBLY

925	927	929	934	932	936	932	937	938	935	933
			930	929	929	929	932	937		
			1000		990		950		931	
913	921	920	1018	1037	1007		956	926	938	939
			1085	1092	1087		983	938		
916	925	933	1063	1124	1084	1023	964	927	943	945
			1132	1158	1115	1139	976	928		
921	930	939	1093	1179	1144	1078	1012	952	922	949
			1157	1204	1154	1085	1078	957	918	
925	935	945	1088	1217	1148	1122	1053	988	934	921
942	943	945								960
936	944	953	1093	1213	1189	1123	1054	989	936	924
										961
			1168	1208	1156	1087	1020	960	924	
940	953	961	1113	1184	1148	1081	1015	959	916	967
			1153	1167	1110	1144	982	982		
951	960	969	1095	1181	1096	1033	977	950	972	968
										964
			1116	1110	1056	999	957			
957	964	975	1060	1073	1033	989	963	975	972	970
			1089	1034	1001	972				
			975	978	980	979	976	976		
			967	961	962	961	959	978		
972			944	988	943	982			972	

TAVG - 270.2
 TOTAL (KW) = 1125.0
 DIFFH (KW) = 1100.2
 DIFFHG (KW) = 11.6

TEMPERATURE DISTRIBUTION FOR ASSEMBLY

4

899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296	1297	1298	1299	1300	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343	1344	1345	1346	1347	1348	1349	1350	1351	1352	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362	1363	1
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911 906 902 975 904 960 922 899 920 927 933

1038 1142 996 945 908

915 917 916 1020 1072 1035 980 929 900 926 933 941

1082	1102	1054	995	934	899
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920 916 912 1048 1121 1088 1029 971 918 897 932 940 948

1105 1143 1097 1035 976 922 890

~~-926 -922 -919 - 7046 7150 7127 7068 7007 989 902 897 937 945 953~~

920 919 918 922 941 939

915 911 926 1051 1153 1128 1068 1007 950 904 901 983 934 925

1115	1105	1097	1036	976	924	897
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947	938	935	1068	1129	1090	1030	972	924	911	989	939	929
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1101 1108 1056 997 948 912

944 944 944 " 1052 1086 1043 988 940 924 954 945 935

1068 1058 1009 959 926

947 949 950 " " 1123 " 1031 " " " 993 " " " 954 " " " 937 958 949 939

1013 998 969 946

	951	956	959	960	960	960
951	944	946	948	948	948	948
951	932	934	935	936	936	936

-AVG- 000.7
 TOTAL (KW) = 1195.0
 TTPPH (KW) = 1191.6
 TTPPHG (KW) = 10.7

TEMPERATURE DISTRIBUTION FOR ASSEMBLY

905	928	929	931	932	918
905	916	918	919	921	915
905	905	906	907	911	916
	963	953	926	901	
920	912	905	976	998	961
				922	897
					917
					918
					918
	1039	1042	996	948	903
928	917	909	1022	1072	1035
				980	928
					899
					924
					924
					928
	1083	1102	1058	995	939
					898
930	923	915	1050	1121	1088
				1029	970
					918
					897
					931
					930
					929
	1106	1183	1097	1035	976
					922
					890
937	939	929	1087	1053	1127
				1068	1007
					944
					902
					898
					937
					936
					938
923	923	922			
					983
					981
					939
928	928	929	1052	1153	1128
				1068	1007
					950
					904
					901
					948
					980
					935
	1115	1186	1097	1036	976
					924
					897
934	936	938	1069	1129	1098
				1030	972
					924
					911
					950
					946
					981
	1102	1108	1056	997	948
					913
939	942	945	1053	1085	1083
					988
					980
					924
					954
					951
					948
	1068	1058	1009	958	926
941	946	951	1023	1029	993
					954
					936
					957
					955
					953
	1013	998	969	945	
	952	956	958	959	958
	950	937	940	940	958
		919	921	921	922
949					956
					958

TAUC= 1015.7
 TOTAL (KW) = 756.6
 DIFFH (KW) = 732.9
 DIFFHG (KW) = 11.5

TEMPERATURE DISTRIBUTION FOR ASSEMBLY 6

925	930	930	930	931	938
926	929	929	929	931	936
927	928	928	929	932	938
948	988	958	931		
934	932	920	1013	1136	999
			1084	1091	1040
				983	935
940	937	935	1063	1124	1084
			1133	1154	1105
				1139	976
947	945	942	1094	1179	1144
				1078	1012
					952
			1157	1204	1154
				1085	1018
					957
953	951	950	1090	1215	1188
				1122	1053
947	949	950			988
					934
					921
					954
					959
					958
					956
923	910	956	1094	1213	1189
				1123	1054
					949
					936
					924
					960
					954
					949
			1167	1208	1156
				1087	1020
					960
					928
928	945	960	1113	1184	1144
				1081	1015
					959
					936
					966
					961
					955
			1153	1167	1110
				1044	982
					942
933	951	964	1095	1141	1095
				1033	977
					950
					971
					967
					962
			1115	1110	1056
				999	957
937	955	972	1059	1073	1033
				989	963
					975
					971
					968
			1044	1034	1001
					972
		972	976	979	979
			967	965	964
			949	950	950
964	970				951
					975
					973

1970-1971 (KSA)	431.0
1971-1972 (KSA)	434.0
1972-1973 (KSA)	434.0

TELETYPE UNIT - DISCONTINUED - NO. 1, 1950

074	055	053	052	087	070
037	047	044	041	039	037
028	030	035	031	029	032
	005	009	007	041	

979	977	976	975	974	973	972	971	970
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1096	1101	1059	1005	952
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073	078	087	1064	1137	1100	1046	990	942	939	938	936
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1130 1166 1124 1165 1176 952

030	047	049	1001	1102	1150	1102	1042	983	940	946	984	943
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1150 1178 1171 1111 1050 991 943

941	940	955	1102	1200	1200	1145	1083	1023	967	937	952	950	949
952	953	955									950	955	954
949	955	961	1097	1212	1203	1147	1094	1028	970	941	959	950	957

1160 1215 1176 1115 1053 905

~~956 962 969 1117 1196 1168 1117 1049 992 955 964 963 962~~

1152 1181 1135 1075 1016 968

962 968 975 1096 1153 1118 1162 1107 967 968 967 966

1117 1126 1090 1026 980

966 972 978 1061 1082 1088 1007 978 977 970 969

1051 1041 1012 982

	978	981	977	972	977
977	967	968	966	965	975
976	950	957	954	952	969

$$\begin{aligned} \text{SAYC} &= 1012.1 \\ \text{SAYC} \cdot \text{PI} (\text{PI}) &= 411.2 \\ \text{SAYC} \cdot \text{PI} (\text{PI}) &= 303.0 \\ \text{SAYC} \cdot \text{PI} (\text{PI}) &= 11.1 \end{aligned}$$

TEMPERATURE DISTRIBUTION FOR ASSEMBLY

908	909	910	911	912	913	914	915	916	917
909	910	911	912	913	914	915	916	917	918
910	911	912	913	914	915	916	917	918	919
911	912	913	914	915	916	917	918	919	920
912	913	914	915	916	917	918	919	920	921
913	914	915	916	917	918	919	920	921	922
914	915	916	917	918	919	920	921	922	923
915	916	917	918	919	920	921	922	923	924
916	917	918	919	920	921	922	923	924	925
917	918	919	920	921	922	923	924	925	926
918	919	920	921	922	923	924	925	926	927
919	920	921	922	923	924	925	926	927	928
920	921	922	923	924	925	926	927	928	929
921	922	923	924	925	926	927	928	929	930
922	923	924	925	926	927	928	929	930	931
923	924	925	926	927	928	929	930	931	932
924	925	926	927	928	929	930	931	932	933
925	926	927	928	929	930	931	932	933	934
926	927	928	929	930	931	932	933	934	935
927	928	929	930	931	932	933	934	935	936
928	929	930	931	932	933	934	935	936	937
929	930	931	932	933	934	935	936	937	938
930	931	932	933	934	935	936	937	938	939
931	932	933	934	935	936	937	938	939	940
932	933	934	935	936	937	938	939	940	941
933	934	935	936	937	938	939	940	941	942
934	935	936	937	938	939	940	941	942	943
935	936	937	938	939	940	941	942	943	944
936	937	938	939	940	941	942	943	944	945
937	938	939	940	941	942	943	944	945	946
938	939	940	941	942	943	944	945	946	947
939	940	941	942	943	944	945	946	947	948
940	941	942	943	944	945	946	947	948	949
941	942	943	944	945	946	947	948	949	950
942	943	944	945	946	947	948	949	950	951
943	944	945	946	947	948	949	950	951	952
944	945	946	947	948	949	950	951	952	953
945	946	947	948	949	950	951	952	953	954
946	947	948	949	950	951	952	953	954	955
947	948	949	950	951	952	953	954	955	956
948	949	950	951	952	953	954	955	956	957
949	950	951	952	953	954	955	956	957	958
950	95								

021	017	013	005	1001	005	057	074	024	923	991
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1965 1987 1991 997 999

922	925	921	1042	1112	1092	1020	075	930	931	929	928
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1111 1147 1106 1249 991 939

936	933	930	1072	1162	1141	1085	1026	969	929	937	936	934
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1131 1189 1193 1194 1034 977 931

942 941 939 " " 1165 " 1180 " " 1181 " " " 1127 " " " 1166 " " " 1007 " " " 951 " " " 926 " 904 " 942 " 941

950 ' 947 946

941	944	947	1070	1193	1184	1129	1068	1009	956	931	951	050	040
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1142 1105 1157 1098 1037 991 939

948 952 955 1003 1176 1150 1093 1033 978 940 956 955 958

1134 1162 1117 1059 1002 956

955	959	963	1079	1135	1101	1046	293	956	960	959	959
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1102 1109 1064 1012 968

960	964	967	1986	1967	1935	995	963	967	962	961
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1037 1028 1000 972

967	977	970	968	965	968
966	962	961	959	956	962
965	954	952	949	947	961

TAVG = 977.4
 TOTAL (KW) = 649.5
 DIFFH (KW) = 624.5
 DIFFHG (KW) = 2.0

TEMPERATURE DISTRIBUTION FOR ASSEMBLY

894	886	888	891	896	901
885	887	889	892	898	903
889	889	891	894	899	906
	948	941	916	994	
885	886	888	961	981	951
				915	891
					907
					906
					904
			1024	1031	987
				939	899
889	890	891	1006	1060	1026
				974	928
					895
					918
					913
					912
			1069	1092	1045
				989	936
					896
896	897	897	1036	1111	1080
					1023
					966
					916
					893
					921
					920
					919
			1096	1137	1091
					1030
					973
					921
					890
904	904	905	1036	1147	1121
					1063
					1003
					948
					902
					895
					927
					926
					935
904	904	905			
					933
					931
					929
897	904	912	1044	1158	1130
					1066
					1004
					949
					905
					899
					934
					929
					923
			1117	1150	1098
					1038
					975
					925
					897
894	912	921	1149	1139	1093
					1030
					973
					925
					910
					980
					935
					930
			1107	1114	1058
					998
					986
					913
910	919	920	1050	1089	1045
					990
					942
					923
					944
					941
					937
			1067	1060	1011
					961
					928
915	925	935	1016	1028	993
					955
					934
					947
					945
					941
			1006	994	966
					983
			935	941	946
					988
					988
			935	938	942
					943
					944
					987
935			935	937	938
					939
					987

TAVG = 1005.7
 ATOTAT (K) = 4042.9
 ATFSH (K) = 4152.2
 ATFSHC (K) = 11.3

TEMPERATURE DISTRIBUTION FOR ASSEMBLY

930	931	932	927	924	920	918	916	914	910
931	932	931	928	924	921	918	916	915	913
932	933	932	929	925	922	919	917	917	918
952	958	957	951	948	943	937	929		
934	934	934	954	970	972	969	964	958	952
943	931	920	907	894					
975	998	998	995	989	982	975	963	945	
939	939	940	969	998	1009	1008	1002	996	989
979	963	940	923	910	896				
990	1018	1027	1025	1019	1012	1004	994	978	953
945	946	946	980	1016	1032	1033	1028	1022	1014
1006	993	973	944	925	912	898			
1030	1032	1044	1043	1038	1031	1023	1015	1003	985
956									
952	953	954	989	1027	1046	1049	1045	1038	1031
1023	1013	1000	977	946	925	913	901		
1009	1002	1055	1056	1050	1044	1036	1028	1019	1007
987	957								
960	960	961	996	1036	1056	1060	1056	1049	1042
1035	1027	1017	1022	979	946	925	914	902	
1016	1050	1064	1065	1060	1053	1046	1038	1030	1021
1009	988	957							
966	967	968	1003	1043	1064	1068	1065	1059	1051
1044	1036	1028	1018	1003	972	946	925	914	904
1020	1056	1071	1073	1068	1061	1054	1046	1039	1031
1022	1009	987	956						
972	973	974	1005	1047	1070	1075	1072	1066	1059
1051	1044	1036	1028	1018	1002	977	943	924	915
905									
1017	1056	1075	1079	1075	1068	1061	1053	1046	1038
1030	1020	1016	983	950					
974	975	976	998	1042	1070	1080	1078	1073	1065
1058	1050	1043	1035	1027	1015	997	969	937	925
915	907								
974	975	976							
977	978	978	999	1043	1072	1081	1080	1074	1067
1059	1052	1044	1037	1028	1017	999	971	939	930
921	911								
1020	1059	1078	1082	1078	1071	1064	1056	1049	1041
1033	1023	1009	985	953					
981	982	983	1012	1053	1076	1081	1078	1072	1064
1057	1049	1042	1033	1023	1007	982	949	934	924
914									
1029	1068	1079	1080	1075	1068	1061	1053	1046	1038
1028	1015	993	962						
985	986	987	1016	1055	1074	1078	1075	1068	1061
1053	1045	1037	1027	1012	987	954	936	926	916
1031	1063	1076	1076	1071	1058	1057	1049	1041	1032
1019	998	966							
988	989	991	1018	1053	1070	1074	1070	1063	1056
1048	1040	1030	1014	990	957	938	928	918	
1030	1059	1071	1071	1065	1058	1051	1043	1034	1021
1000	969								
990	991	992	1017	1048	1064	1067	1062	1056	1048
1040	1030	1015	991	959	939	930	920		
1027	1053	1063	1062	1057	1050	1042	1033	1021	1001
970									
990	991	993	1014	1041	1054	1055	1050	1043	1036
1026	1013	991	959	940	931	923			
1021	1043	1050	1048	1042	1035	1027	1016	998	970
988	989	991	1007	1027	1035	1034	1028	1022	1014
1003	985	958	942	934	926				
1010	1024	1026	1022	1017	1010	1001	988	966	
984	985	986	995	1003	1005	1001	997	991	983
972	955	945	937	929					
991	994	993	989	984	978	970	958		
994	997	977	975	972	969	965	960	957	950
981	979	974	974	970	966	962	957	952	945
979	977	976	972	969	964	960	955	950	942

OTYAL (KW) = 4517.0
 OTFHH (KW) = 4523.0
 OTFHHG (KW) = 12.7

TEMPERATURE DISTRIBUTION FOR ASSEMBLY 12

977	978	976	972	969	964	961	955	950	945
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978	979	977	974	969	964	959	955	951	947
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987 981 977 975 970 964 959 955 951 951

1202 1203 1008 1002 996 990 981 969

981 982 992 1034 1021 1225 1221 1015 1068 1000 998 958 952 944 936

1026 1049 1152 1049 1042 1034 1025 1010 985

986 986 997 1019 1050 1063 1162 1056 1047 1040 1028 1008 976 952 945 938

1038 1069 1079 1079 1071 1064 1055 1043 1022 989

991 992 993 1026 1065 1093 1085 1090 1073 1060 1054 1039 1014 976 951 946 940

1045 1079 1002 1092 1086 1077 1070-1061 1047 1020 988

997 998 999 1032 1072 1092 1096 1092 1085 1076 1068 1057 1040 1013 974 949 945 942

1049 1084 1099 1099 1004 1086 1078 1070 1059 1045 1021 985

1002 1003 1004 1036 1076 1097 1102 1098 1091 1083 1075 1065 1054 1037 1009 971 946 945 944

1053 1088 1103 1104 1090 1091 1083 1075 1066 1056 1041 1017 982

1005 1007 1008 1039 1079 1101 1106 1102 1095 1087 1079 1071 1062 1050 1033 1005 967 944 945 945

1053 1090 1106 1108 1103 1096 1088 1079 1071 1062 1052 1037 1012 977

1009 1009 1011 1038 1079 1103 1109 1106 1099 1092 1083 1075 1067 1057 1046 1028 999 962 943 945 946

1047 1087 1127 1111 1107 1100 1092 1083 1075 1067 1058 1047 1031 1005 969

1008 1009 1010 1020 1031 1101 1111 1110 1101 1095 1087 1079 1071 1062 1053 1040 1020 989 955 943 945 947
1005 1017 1029 945 947 938

1007 1008 1009 1028 1071 1101 1111 1110 1103 1096 1087 1079 1071 1062 1053 1040 1020 990 957 947 934 921

1047 1087 1107 1111 1107 1109 1092 1083 1075 1067 1058 1047 1031 1005 971

1009 1010 1011 1038 1080 1103 1109 1106 1099 1092 1083 1075 1067 1057 1046 1028 1001 967 952 938 923

1055 1090 1106 1108 1103 1096 1088 1079 1071 1062 1052 1037 1014 981

1011 1012 1014 1012 1081 1101 1106 1102 1095 1088 1079 1071 1062 1050 1034 1007 974 956 941 926

1256 1089 1107 1104 1099 1091 1083 1075 1066 1056 1042 1019 986

1013 1014 1016 1042 1079 1098 1102 1098 1091 1083 1075 1066 1054 1038 1012 977 958 943 929

1055 1086 1199 1101 1094 1087 1078 1070 1060 1045 1023 990

1014 1015 1016 1041 1075 1093 1096 1092 1085 1077 1068 1057 1041 1015 980 961 946 932

1053 1092 1093 1093 1087 1079 1071 1061 1048 1025 993

1013 1015 1016 1039 1070 1095 1086 1081 1074 1065 1055 1041 1016 983 963 949 935

1048 1073 1081 1079 1073 1065 1056 1044 1025 994

1011 1013 1015 1033 1057 1066 1065 1060 1053 1044 1032 1012 983 965 952 938

1037 1053 1057 1053 1047 1040 1031 1016 992

1006 1008 1010 1021 1031 1034 1031 1026 1020 1012 999 980 969 955 941

1917 1021 1020 1017 1012 1006 997 984

1007 1003 1000 998 996 993 989 984 977 974

996	969	967	965	962	959	956	952	949	958
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TAVG = 1226.0
 OTORAI (W4) = 4047.8
 DIFSI (W2) = 4057.1
 DIFPHG (W2) = 11.7

TEMPERATURE DISTRIBUTION POP ASSEMBLY 13

[illegible]

TABLE 3-23
 TOTAL (KW) = 881.6
 DIPP (KW) = 206.0
 DIPP (KW) = 2.4

TEMPERATURE DISTRIBUTION FOR ASSEMBLY 14

879	878	877	913	914	915	916	888
			895	896	897	899	887
			878	878	879	882	885
			908	900	882	866	
894	885	877	917	926	903	977	854
			956	957	925	890	864
896	897	878	947	978	952	915	879
			987	999	965	925	887
							861
900	891	901	966	1013	989	949	908
							873
							862
							893
							910
							927
			1003	1028	996	954	912
							875
							856
904	895	885	964	1033	977	934	894
							862
							863
							897
							914
							931
895	885	885					
							900
							900
							901
888	888	888	968	1036	1018	977	934
							895
							864
							865
							900
							903
							906
			1010	1031	998	955	914
							877
							860
893	893	893	979	1020	993	952	911
							878
							872
							908
							907
							909
			1001	1006	970	929	891
							871
898	898	898	968	991	961	923	889
							881
							907
							910
							913
			979	972	938	903	882
901	901	901	948	953	928	901	891
							909
							913
							917
			942	932	912	897	
			921	905	908	909	909
			902	905	908	909	909
							910

TAVI = 000.0
 TOTAL (WU) = 649.6
 DIFF (WU) = 653.8
 DIFF (WU) = 11.6

TEMPERATURE DISTRIBUTION FOR ASSEMBLY 15

917			945	946	946	946	927		
	918		932	933	933	934	927		
		919	920	919	920	923	928		
			965	955	929	907			
908	913	917	977	991	959	923	904	929	937
			1032	1034	990	942	906		
911	915	919	1018	1063	1029	976	927	904	936
			1075	1093	1046	989	937	901	
914	919	923	1046	1113	1080	1023	967	919	902
			1101	1138	1091	1030	973	922	898
918	923	928	1045	1149	1124	1063	1073	948	904
926	927	928							956
934	934	935	1054	1160	1137	1066	1004	989	906
			1122	1155	1098	1034	976	926	901
944	944	944	1078	1140	1093	1031	973	927	918
			1113	1115	1058	998	946	919	
952	952	952	1060	1092	1047	992	945	932	969
			1074	1063	1014	964	934		
959	959	958	1029	1036	1000	963	947	972	972
			1020	1076	978	956			
	959		965	970	973	974	974		
	961	961	966	971	973	974	974	974	

TIME: 1000.5
 ALTITUDE (KM): 111.2
 DIRECTION (KM): 105.3
 DISTANCE (KM): 12.3

TEMPERATURE DISTRIBUTION FOR ASSEMBLY 16

			936	955	953	951	948		930	
		936		946	944	941	940		932	
		937		937	934	931	931	934		
				997	999	962	934			
	947	943	940	1012	1032	1001	962	929	936	934
				1074	1085	1043	992	943		
	954	950	946	1055	1114	1094	1031	976	935	944
				1118	1149	1107	1049	992	952	
	961	958	954	1083	1165	1141	1085	1026	970	938
				1138	1190	1153	1094	1034	977	935
	967	964	962	1076	1191	1181	1127	1066	1007	955
	960	960	962							967
										965
	947	956	965	1080	1194	1184	1129	1068	1009	958
				1146	1196	1157	1098	1037	982	943
	952	961	970	1099	1177	1150	1093	1031	980	953
				1137	1162	1117	1059	1003	961	
	958	966	974	1083	1135	1102	1048	996	966	980
				1104	1110	1066	1015	975		
	962	960	976	1050	1070	1040	1002	976	983	982
					1041	1035	1009	988		
				976	980	984	985	985	985	
				975	980	984	985	985	984	
	974				980	984	985	984		988