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A COMPARISON BETWEEN THE
SIMPLE and ENERGY CODE MIXING MODELS

by: Kevin J. Burns
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DOE/ET/37240-78TR

July 1980

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NOMENCLATURE FOR SIMPLE

A	subchannel area for coolant flow
a	fluid interface area per unit length between adjacent subchannels
b, c	constants defined in Section 2.1
C_p	heat capacity of coolant
D	rod diameter
D_e	equivalent hydraulic diameter
D_w	wire diameter
f	friction factor
g_c	gravitational constant
$\bar{H}$	subchannel coolant enthalpy averaged over Δz
K	thermal conductivity of coolant
L_w	wire wrap lead length
m	subchannel coolant mass flow rate
P	rod pitch
P_w	subchannel wetted perimeter
Q''	heat flux
Re	Reynolds number
S	subchannel heated surface area per unit axial length
T	subchannel coolant temperature
$\bar{T}$	subchannel coolant temperature averaged over Δz
T°	subchannel inlet coolant temperature

U subchannel coolant velocity
 $\bar{U}$ subchannel average coolant velocity
 $W_{i \rightarrow j}$ coolant mass cross flow rate per unit axial length
 W' quantity defined by Eq. (2-5)
 z axial length

Greek

α thermal diffusivity of coolant
 β wire wrap interchange coefficient
 ΔP subchannel pressure drop
 δ centroid to centroid distance between adjacent subchannels
 ν kinematic viscosity of coolant
 ρ mass density of coolant

Subscripts

c denotes quantity evaluated at minimum subchannel area
 i, j subchannel identification number
 i denotes interior region subchannel
 e denotes edge region subchannel
 o denotes quantity evaluated at maximum subchannel area

1.0 Introduction

The computer code SIMPLE [1] utilizes a forced diversion mixing model for calculating the thermal-hydraulic conditions of the coolant in a wire wrapped rod bundle. The model is based on the assumption that the dominant energy transport mechanism is forced diversion, a result of changes in subchannel flow area and hydraulic diameter as the wire wrap enters and leaves a subchannel. The additional assumptions of uniform radial pressure gradient and equal flow diversion to all adjacent subchannels lead to an analytical expression for a crossflow mixing parameter, β . This mixing parameter is required as input to the SIMPLE code, which ultimately solves for the coolant temperature distribution in a lumped parameter fashion.

SIMPLE solves both a momentum equation and an energy equation. It is recommended [1], however, that the energy and momentum equations be decoupled for cases in which the physical properties ρ , C_p and γ are relatively constant. Thus, the momentum equation is solved independently of the energy equation, and the resulting velocity distribution is used as input to the energy equation. A similar scheme is used in the ENERGY code developed at M.I.T. [2]. ENERGY is also a lumped parameter code, which calculates the steady

state temperature distribution in wire wrapped rod bundles by solving the energy equation. A velocity distribution in the form of flow splits is required as input. Values of the sweeping flow mixing parameters ϵ_{1L}^* and C_{1L} are also required as input, and are currently evaluated according to the latest M.I.T. models reported in [3]. The predominant mixing mechanisms are modeled as an effective enhanced eddy diffusivity (ϵ_{1L}^*) in the interior region of the bundle, and a swirl velocity ratio (C_{1L}) in the edge region.

The ENERGY input parameters are calibrated by experimental mixing test data according to a phenomenological model [4]. The SIMPLE parameter β , on the other hand, is presented as an analytical expression. Furthermore, the ENERGY parameters are formulated as functions of P/D and H/D , whereas the SIMPLE parameter β is a function of P/D only. However, SIMPLE has been reported [5] to yield temperature predictions which are in close agreement with experimental fuel bundle data. These observations raise the question as to whether the additional effort required to evaluate the ENERGY code parameters is justified. The similarities between the SIMPLE and ENERGY codes suggest that this question can be resolved by a direct comparison of the mixing parameters evaluated by their respective mixing

models. The purpose of this study is to perform this comparison by reducing the mixing parameters for typical LMFBR subassembly geometries evaluated by the SIMPLE model, to the equivalent ENERGY mixing parameters. These parameters will then be compared to the ENERGY parameters evaluated according to the latest ENERGY model [3]. Any discrepancies between the mixing parameters evaluated by the two models will be quantified in terms of the temperature distributions calculated by ENERGY with the appropriate input mixing parameters.

As noted earlier, the ENERGY mixing model is calibrated according to experimental data over a wide range of geometries, whereas published results for temperature distributions calculated by SIMPLE are only for the case of a typical fuel bundle geometry. These temperature distributions are in reasonably good agreement with both experimental results [5], and results obtained from more sophisticated computer codes [1].

Hence, for a typical fuel bundle geometry, the numerical values of the appropriate mixing parameters and the resulting temperature distributions are expected to be approximately

the same for both the SIMPLE and ENERGY models. The results of extending the SIMPLE mixing model to other geometries, however, needs to be investigated.

The underlying assumption throughout this study is that the mixing parameters given by the ENERGY model represent the true values, and that the temperature distributions calculated by the ENERGY code utilizing these parameters are correct. This assumption is expected to be valid, based on the large data base used in the calibration of the ENERGY mixing parameters.

2.0 The SIMPLE Mixing Model

This section summarizes the mixing model [1] used to evaluate the parameter, β , required as input to the SIMPLE code.

The SIMPLE energy equation can be written as follows:

$$\rho C_p A_i U_i (T_i - T_i^\circ) = Q'' S_i \Delta z - \frac{K a}{\delta} \sum_j (\bar{T}_i - \bar{T}_j) \Delta z \quad (2-1)$$

$$+ W_{j \rightarrow i} \bar{H}_j \Delta z - W_{i \rightarrow j} \bar{H}_i \Delta z$$

$W_{j \rightarrow i}$, a positive quantity, represents the coolant mass crossflow rate per unit axial length from subchannel j to subchannel i . Similarly, $W_{i \rightarrow j}$ is a positive quantity which represents the crossflow rate per unit length from subchannel i to subchannel j . If it is assumed that, averaged over a wire wrap lead length, there is no net transverse mass exchange between subchannels i and j , then:

$$W_{j \rightarrow i} = W_{i \rightarrow j} \quad (2-2)$$

Using the symbol $\bar{W}$, defined as follows:

$$\bar{W} = W_{i \rightarrow j} = W_{j \rightarrow i} \quad (2-3)$$

the SIMPLE energy equation becomes:

$$\rho C_p A_i U_i (T_i - T_i^\circ) = Q'' S_i \Delta z - \frac{K a}{\delta} \int_j (\bar{T}_i - \bar{T}_j) \Delta z + \bar{W} (\bar{H}_j - \bar{H}_i) \Delta z \quad (2-4)$$

Defining W' as the coolant mass crossflow rate per unit length through the gap (a) between adjacent subchannels, the following relation follows from continuity:

$$\bar{W} D_w = W' a \quad (2-5)$$

Thus, assuming for simplicity that $a = D_w$ (where $a \equiv P - D$), it follows that:

$$\bar{W} = W' \quad (2-6)$$

The computer code COBRA [6] defines a parameter β as follows:

$$\beta = \frac{W' / D_w}{\rho \bar{U}} \quad (2-7)$$

Physically, β represents the fraction of the axial flow per unit area which is diverted in the transverse direction. The SIMPLE model utilizes Eq. (2-7) along with certain assumptions regarding W' to determine the mixing parameter β .

2.1 Interior Subchannels

Fig. 1 shows that, for the case of an interior subchannel, the wire wrap alternately occupies and vacates a given subchannel over intervals of $1/6$ of the wire wrap lead length. The subchannel area is a maximum (A_{O1}) over the $1/6$ lead length intervals when the wire is absent, and is a minimum (A_{C1}) over the $1/6$ lead length intervals when the wire is present. The SIMPLE mixing model assumes that the fluid displaced as a wire enters a subchannel is distributed equally to all adjacent subchannels. Thus, for interior subchannels, the crossflow per unit length which is diverted to an adjacent subchannel is:

$$W'_{11} = \frac{\frac{1}{3}\rho(A_{O1}U_{O1} - A_{C1}U_{C1})}{\frac{1}{6}L_W} \quad (2-8)$$

where W'_{11} denotes crossflow from an interior subchannel to an adjacent interior subchannel. If $\bar{U}_1$ is defined as $\frac{U_{O1} + U_{C1}}{2}$, then Eqs. (2-7) and (2-8) yield:

$$\beta_1 = \frac{4A_{O1}[1 - (A_{C1}U_{C1}/A_{O1}U_{O1})]}{L_W D_W [1 + (U_{C1}/U_{O1})]} \quad (2-9)$$

In order to evaluate the quantity (U_{C1}/U_{O1}) in Eq. (2-9), a uniform pressure gradient is assumed. That is, assuming a

friction factor of the form $f = cRe^b$ (where c and b are constants depending on the flow regime) and equal pressure drops for all subchannels:

$$\left(\frac{\Delta P}{z}\right)_{o1} = \left(\frac{\Delta P}{z}\right)_{c1} \quad (2-10)$$

and

$$c \left(\frac{\rho U_{o1} De_{o1}}{\mu} \right)^b \frac{1}{De_{o1}} \frac{\rho U_{o1}^2}{2g_c} = c \left(\frac{\rho U_{c1} De_{c1}}{\mu} \right)^b \frac{1}{De_{c1}} \frac{\rho U_{c1}^2}{2g_c} \quad (2-11)$$

Solving for (U_{c1}/U_{o1}) ,

$$\frac{U_{c1}}{U_{o1}} = \left(\frac{De_{c1}}{De_{o1}} \right)^{\frac{1-b}{2+b}} \quad (2-12)$$

Finally,

$$\beta_1 = \frac{\left\{ \frac{4A_{o1}}{L_W D_W} \left[1 - \left(\frac{A_{c1}}{A_{o1}} \right) \left(\frac{De_{c1}}{De_{o1}} \right)^{\frac{1-b}{2+b}} \right] \right\}}{\left[1 + \left(\frac{De_{c1}}{De_{o1}} \right)^{\frac{1-b}{2+b}} \right]} \quad (2-13)$$

where:

$$A_{o1} = \frac{\sqrt{3}}{4} P^2 - \frac{\pi D^2}{8} \quad (2-14a)$$

$$A_{C1} = \frac{\sqrt{3}}{4} P^2 - \frac{\pi D^2}{8} - \frac{\pi D_W^2}{4} \quad (2-14b)$$

$$\frac{De_{C1}}{De_{O1}} = \frac{A_{C1}}{A_{O1}} \frac{w_{O1}^P}{w_{C1}^P} \quad (2-14c)$$

$$w_{O1}^P = \frac{\pi D}{2} \quad (2-14d)$$

$$w_{C1}^P = \frac{\pi D}{2} + \pi D_W \quad (2-14e)$$

It should be noted that Eqs. (2-13), (2-14b) and (2-14e) appear incorrectly in Ref[1]. The above equations are the correct formulations, consistent with the SIMPLE model [7].

2.2 Edge Subchannels

As shown in Fig. 1 , the wire wrap appearance frequency in the edge region of the bundle is $2/3$ of that in the interior region for edge subchannels which have a single interior neighbor, and $1/3$ for edge subchannels which have no immediate interior neighbor. For large (217 pin) bundles, the developers of the SIMPLE model recommend [1] a value for β in the edge region which is $2/3$ of the β value calculated for the interior region.

Fig. 2 illustrates the subchannel divisions used in the ENERGY code. It is clear that the difference in edge subchannel geometry between SIMPLE and ENERGY will complicate the determination of input mixing parameters for ENERGY based on the SIMPLE mixing model. In order to accomplish this task, the same basic assumptions used to evaluate β for interior to interior subchannel crossflow will be extended to the edge region of a bundle with subchannel divisions corresponding to those of the ENERGY code. In other words, the SIMPLE mixing model will be applied towards the evaluation of an edge to edge subchannel mixing parameter for rectangular edge subchannel geometry. Since the SIMPLE and ENERGY code edge subchannel geometries are so

different, the validity of this procedure and its utility for model comparison is questionable. However, since the SIMPLE model is based on physical phenomena, an extension of the physical assumptions to different geometries seems reasonable.

For the rectangular edge subchannels shown in Fig. 2 , Eq.(2-8) can be reformulated to take into account the fact that the wire is present in an edge subchannel for $\frac{1}{4}$ of a lead length. Thus,

$$W'_{22} = \frac{\frac{1}{3}\rho (A_{O_2} U_{O_2} - A_{C_2} U_{C_2})}{\frac{1}{4}L_W} \quad (2-15)$$

where W'_{22} denotes crossflow from an edge subchannel to an adjacent edge subchannel. Eq.(2-15) is based on the assumption that the displaced fluid as a wire enters an edge subchannel is distributed equally to all three adjacent subchannels. Proceeding in a manner similar to that of Section 2.1 , the expression for the wire wrap interchange coefficient (β) is found to be:

$$\beta_2 = \frac{\left\{ \frac{8 A_{O_2}}{3L_W D_W} \left[1 - \left(\frac{A_{C_2}}{A_{O_2}} \right) \left(\frac{De_{C_2}}{De_{O_2}} \right)^{\frac{1-b}{2+b}} \right] \right\}}{\left[1 + \left(\frac{De_{C_2}}{De_{O_2}} \right)^{\frac{1-b}{2+b}} \right]} \quad (2-16)$$

where:

$$A_{O_2} = P (D/2 + D_w) - \pi D^2/8 \quad (2-17a)$$

$$A_{C_2} = P (D/2 + D_w) - \pi D^2/8 - \pi D_w^2/4 \quad (2-17b)$$

$$\frac{De_{C_2}}{De_{O_2}} = \frac{A_{C_2} w_{O_2}^P}{A_{O_2} w_{C_2}^P} \quad (2-17c)$$

$$w_{O_2}^P = P + \pi D/2 \quad (2-17d)$$

$$w_{C_2}^P = P + \pi D/2 + \pi D_w \quad (2-17e)$$

3.0 Comparison of SIMPLE and ENERGY Mixing Parameters

3.1 Interior to Interior Subchannel Sweeping Flow

The mixing parameters employed by the SIMPLE and ENERGY codes for interior subchannels will be compared in two ways. First, the energy equations will be reduced to a common form, and the equivalent forms of the mixing parameters will be identified. Secondly, both the SIMPLE and ENERGY mixing parameters will be reduced to a common form based on their definitions with respect to coolant mass crossflow. Although these two approaches are performed independently of each other, the same expressions relating the SIMPLE and ENERGY parameters should be obtained. The second approach is presented because of its simplicity. The first approach, however, is more fundamental and is presented for completeness.

3.1.1 Comparison of SIMPLE and ENERGY Energy Equations

The SIMPLE energy equation is given by Eq. (2-4).
If the following definitions are made:

$$\bar{T}_i \equiv \frac{1}{2} (T_i + T_i^0) \quad (3-1)$$

$$\bar{H}_i \equiv \frac{1}{2} C_p (T_i + T_i^o) \quad (3-2)$$

$$Q'' \Delta z \equiv \int_0^Z Q'' dz \quad (3-3)$$

$$\alpha \equiv \frac{K}{\rho C_p} \quad (3-4)$$

$$\bar{W}_{i1} = W'_{i1} \equiv \rho \beta_1 \bar{U}_1 D_w \equiv \rho \beta_1 \bar{U}_{i1} a \quad (3-5)$$

where the subscript 1 refers to interior region subchannels, then the energy equation which results is:

$$T_i - T_i^o = \frac{S_{i1} \int_0^Z Q'' dz}{\rho C_{p i1} U_{i1}} - \sum_j \frac{(T_i - T_j)}{\delta A_{i1} U_{i1}} \frac{1}{2} (\alpha + \beta_1 U_{i1} \delta_1) (a_{i1} \Delta z) \quad (3-6)$$

where i and j represent two adjacent subchannels. Hence,

$$T_i - T_i^o = \frac{S_{i1} \int_0^Z Q'' dz}{\rho C_{p i1} U_{i1}} - \sum_j \frac{(T_i - T_j)}{2 \delta_1} \left[\frac{a_{i1} \Delta z}{A_{i1} U_{i1}} \right] (\alpha + \beta_1 U_{i1} \delta_1) \quad (3-7)$$

represents the SIMPLE energy equation.

The ENERGY code energy equation is given in terms of a porous body formulation [3] as:

$$\rho^A_I \rho^C_p U_{AI} (T_{out} - T_{in}) = -(\rho^C_p \epsilon_{HNI} + \rho^K_{NI} K) \rho^P_I \Delta z V T + \rho^Q_I \Delta z \rho^A_I \quad (3-8)$$

The corresponding subchannel representation is obtained by introducing the appropriate porosity factors. Hence,

$$\left(\frac{S_I^A}{\lambda_{AI}} \right) \rho C_p (\lambda_{AI} V_{AI}) (T_{out} - T_{in}) = - \left(\frac{\rho C_p \epsilon_H}{\lambda_{LI}} + S_{NI}^K \right) (S_I^P) \Delta z VT + (\lambda_{AI} S_I^Q) \Delta z \left(\frac{S_I^A}{\lambda_{AI}} \right) \quad (3-9)$$

Thus,

$$(T_{out} - T_{in}) = \frac{S_I^Q \Delta z}{\rho C_p V_{AI}} - \frac{S_I^P \Delta z VT}{S_I^A V_{AI}} \left(\frac{\epsilon_H}{\lambda_{LI}} + S_{NI}^K \alpha \right) \quad (3-10)$$

is the subchannel formulation of the ENERGY code energy equation.

Comparing the two energy equations, Eq. (3-7) and Eq. (3-10), and making the following identifications between equivalent parameters,

$$S_I^P = a_{11} \quad (3-11a)$$

$$S_I^A = A_{i1} \quad (3-11b)$$

$$V_{AI} = U_{i1} \quad (3-11c)$$

$$S_{Q_I} \Delta z = S_{i_1} \int_0^z Q'' dz / A_{i_1} \quad (3-11d)$$

$$S_{K_{NI}} \alpha = \alpha \quad (3-11e)$$

$$\nabla T = (\bar{T}_i - \bar{T}_j) / \delta_1 = 1/2 (T_i - T_j) / \delta_1 \quad (3-11f)$$

results in the following expression relating the SIMPLE and ENERGY mixing parameters for interior to interior sweeping flow:

$$\frac{\epsilon_H}{\lambda_{LI}} = \beta_1 U_{i_1} \delta_1 \quad (3-12)$$

The ENERGY code parameter ϵ^* is defined as $\frac{\epsilon_H}{\lambda_A V_A De_1}$. Thus, with $U_{i_1} = V_{AI}$,

$$\beta_1 = \frac{\epsilon_H}{V_{AI} \delta_1 \lambda_{LI}} = \frac{\epsilon^* \lambda_A V_A De_1}{V_{AI} \delta_1 \lambda_{LI}} = \frac{\epsilon^*}{S_{X_1}} \left(\frac{De_1}{\delta_1} \right) \left(\frac{\lambda_A}{\lambda_{LI}} \right) \quad (3-13)$$

Finally, in terms of the parameter $\epsilon_{1L}^* \equiv \left[\frac{\epsilon^*}{S_{X_1}} \quad \frac{\lambda_A}{\lambda_{LI}} \right]$,

$$\beta_1 = \epsilon_{1L}^* \left[\frac{De_1}{\delta_1} \right] \quad (3-14)$$

Eq. (3-14) relates SIMPLE's mixing parameter β to ENERGY's mixing parameter ϵ_{1L}^* , for interior to interior subchannel flow.

3.1.2 Comparison of $\frac{\bar{W}_{ij}H}{m_i}$ Values Evaluated by the SIMPLE and ENERGY Models

For the ENERGY code, the energy equation employing the parameter $\bar{W}_{ij}$ for interior subchannels is as follows [4]:

$$m_i \frac{\partial h_i}{\partial x} = q'_i + \sum_j \bar{W}_{ij} (h_j - h_i) \quad (3-15)$$

where

$$\bar{W}_{ij} = \frac{\int_0^H |W_{ij}| dx}{2 H} \quad (3-16)$$

Eq. (3-16) follows from the definitions of W_{ij} and $\bar{W}_{ij}$.

Specifically, W_{ij} is the mass crossflow rate per unit axial length from subchannel i to subchannel j. W_{ij} is positive for flow from i to j, and negative for flow from j to i.

$\bar{W}_{ij}$, however, represents an equivalent turbulent interchange, W'_{ij} [8]. That is, assuming that W_{ij} is positive over one

half of the wire wrap lead length and negative over the

other half, it follows that there is no net crossflow when averaged over a lead length. For this reason, the energy

transport is modeled as an equivalent turbulent interchange,

W'_{ij} . Utilizing the turbulent interchange concept, the

energy transport due to crossflow averaged over a lead

length is [8]:

$$q'_{ji} = w'_{ji} (h_j - h_i) \equiv \bar{w}_{ji} (h_j - h_i) \quad (3-17)$$

where $\bar{w}_{ji}$ represents the equivalent net mass transfer rate per unit axial length from subchannel j to subchannel i which produces the same energy exchange as turbulence. However, since there is no net mass transfer when averaged over a lead length, it follows that $\bar{w}_{ij} = \bar{w}_{ji}$. Furthermore, by definition:

$$\bar{w}_{ij} + \bar{w}_{ji} = 2 \bar{w}_{ij} = \frac{\int_0^H |w_{ij}| dx}{H} \quad (3-18)$$

from which Eq. (3-16) follows directly. Eq. (3-15) is written without the conduction term for simplicity. Similarly, Eq. (3-10) can be written without the conduction term as:

$$\frac{\partial T_i}{\partial x} = \frac{S_{QI}}{\rho C_p V_{AI}} - \frac{(P-D) \epsilon_H}{\frac{(P-D)}{P} S_{AI} V_{AI} \eta_1} (T_i - T_j) \quad (3-19)$$

Thus,

$$m_i C_p \frac{\partial T_i}{\partial x} = \frac{\{\rho V_{AI} S_{AI}\} S_{QI}}{\rho V_{AI}} + \frac{P \epsilon_H \{\rho V_{AI} S_{AI}\} C_p}{S_{AI} V_{AI} \eta_1} (T_j - T_i) \quad (3-20)$$

and

$$m_i \frac{\partial h_i}{\partial x} = S_{AI}^A S_{AI}^Q + \frac{P \epsilon_H \rho}{\eta_1} (h_j - h_i) \quad (3-21)$$

Comparing the convective terms of Eq. (3-15) and Eq. (3-21),

$$\bar{W}_{ij} = \frac{P \epsilon_H \rho}{\eta_1} \quad (3-22)$$

However, by definition,

$$\epsilon_{1L}^* = \frac{\epsilon_1^*}{S_{AI}^X} = \frac{\epsilon_H}{De_1 \lambda_{LI} V_{AI}} \quad (3-23)$$

Thus,

$$\bar{W}_{ij} = \frac{P (\epsilon_{1L}^* De_1 \lambda_{LI} V_{AI}) \rho}{\eta_1} \quad (3-24)$$

With $\lambda_{LI} = \left(\frac{P-D}{P} \right)$,

$$\bar{W}_{ij} = \frac{(P-D) \rho \epsilon_{1L}^* De_1 V_{AI}}{\eta_1} \quad (3-25)$$

Finally, with $m_i = \rho V_{AI} S_{AI}^A$,

$$\frac{\bar{w}_{ij}^H}{m_i} = \frac{(P-D) H De_1}{\eta_1 S_I^A} \epsilon_{1L}^* \quad (3-26)$$

for interior to interior subchannel sweeping flow.

According to the SIMPLE mixing model,

$$\beta = \frac{w'/D_w}{\rho \bar{U}_i} \quad (2-7)$$

where, as noted earlier, $w' = \bar{w}$.

Comparison of Eqs. (2-4) and (3-15) shows that the parameters $\bar{w}$ and $\bar{w}_{ij}$ are analagous. Thus, by assuming that the following identifications can be made between the nomenclature for SIMPLE and ENERGY:

$$\bar{w}' = \bar{w} = \bar{w}_{ij} \quad (3-27a)$$

$$\bar{U}_i = V_{AI} \quad (3-27b)$$

$$D_w = P - D \quad (3-27c)$$

$$\delta_1 = \eta_1 \quad (3-27d)$$

the parameter $\frac{\bar{w}_{ij}^H}{m_i}$ evaluated according to the SIMPLE model is:

$$\frac{\bar{w}_{ij}^H}{m_i} = \frac{\beta_1 (P-D) H}{S_I^A} \quad (3-28)$$

for interior to interior subchannel sweeping flow. If the expressions for $\frac{\bar{W}_{ij} H}{m_i}$ for the SIMPLE and ENERGY models are set equal, the relationship between ϵ_{1L}^* and β_1 which results is identical to that of Section 3.1 (Eq. 3-14). That is, equating Eq. (3-26) and Eq. (3-28) yields:

$$\frac{(P-D) H De_1}{\eta_1 S_I^A} \epsilon_{1L}^* = \frac{\beta_1 (P-D) H}{S_I^A} \quad (3-29)$$

Hence,

$$\beta_1 = \epsilon_{1L}^* \left[\frac{De_1}{\eta_1} \right] = \epsilon_{1L}^* \left[\frac{De_1}{\delta_1} \right] \quad (3-30)$$

3.2 Edge to Edge Subchannel Sweeping Flow

The similarity between the mixing parameters employed by the SIMPLE and ENERGY models for interior subchannels facilitated the rather straightforward comparison presented in Section 3.1 . However, in contrast to ENERGY, SIMPLE fails to take explicit account of the swirl velocity effect in the edge region, except for the case of corner subchannels. The SIMPLE model assumes that all but corner subchannels divert the coolant displaced by the wire wrap equally to the three adjacent subchannels [9] . The

corner subchannels are assumed to divert all the displaced coolant forward to the adjacent corner subchannel, in the direction of the wire wrap rotation. This fundamental difference between the mixing mechanisms employed by ENERGY and SIMPLE in the edge region, precludes a direct comparison between the SIMPLE and ENERGY mixing parameters. In order to utilize the ENERGY code for the prediction of temperature distributions according to the SIMPLE model, the swirl flow velocity ratio (C_{1L}) required as input to ENERGY will be set equal to zero. The enhanced eddy diffusivities in the edge region (ϵ_{2L}^* and ϵ_{3L}^*) will be calculated in Section 4, on the basis of the analysis presented in Section 2.

4.0 Calculation of Appropriate ENERGY Code Parameters for Typical Geometries

The ENERGY code mixing parameters are calculated using both the SIMPLE and ENERGY models for the geometries given in Table 1. This section presents the results obtained for interior to interior, interior to edge and edge to edge subchannel sweeping flow.

4.1 Interior to Interior Sweeping Flow

4.1.1 ENERGY Model

The effective eddy diffusivities utilized in the ENERGY code are defined as follows [3]:

$$\epsilon_{1L}^* = \left(\frac{\lambda_A}{\lambda_{LI}} \right) \left(\frac{\epsilon_{H1}}{De_1 U_A} \right) \frac{1}{S^{X_1}} \quad (4-1a)$$

$$\epsilon_{2L}^* = \left(\frac{\lambda_A}{\lambda_{LI}} \right) \left(\frac{\epsilon_{H2}}{De_1 U_A} \right) \frac{1}{S^{X_2}} \quad (4-1b)$$

$$\epsilon_{3L}^* = \left(\frac{\lambda_A}{\lambda_{L2}} \right) \left(\frac{\epsilon_{H3}}{De_1 U_A} \right) \frac{1}{S^{X_2}} \quad (4-1c)$$

where ϵ_{1L}^* represents interior to interior subchannel sweeping flow, ϵ_{2L}^* represents edge to interior sweeping flow and ϵ_{3L}^* represents edge to edge sweeping flow. Comparison of the subchannel formulation of the ENERGY equations [10] to Eq. (3-15) yields the following expressions for the parameter $\frac{\bar{W}_{ij}^H}{m_i}$:

$$\frac{\bar{W}_{11}^H}{m_1} = \frac{(P - D) De_1 H}{S^{A_1} n_1} \epsilon_{1L}^* \quad (4-2a)$$

$$\frac{\bar{W}_{12} H}{m_1} = \frac{(P - D) D e_1 H}{S A_1 \eta_2} \left(\frac{S X_2}{S X_1} \right) \epsilon_{2L}^* \quad (4-2b)$$

$$\frac{\bar{W}_{21} H}{m_2} = \frac{(P - D) D e_1 H}{S A_2 \eta_2} \epsilon_{2L}^* \quad (4-2c)$$

$$\frac{\bar{W}_{22} H}{m_2} = \frac{(\text{gap}) D e_1 H}{S A_2 \eta_3} \epsilon_{3L}^* \quad (4-2d)$$

As shown by Eqs. (4-2b) and (4-2c), the same parameter ϵ_{2L}^* is used for interior to edge (i.e., $\frac{\bar{W}_{12} H}{m_1}$) and edge to interior (i.e., $\frac{\bar{W}_{21} H}{m_2}$) sweeping flow. The equations compensate for this by a factor of the ratio of flow splits, such that the condition of continuity ($\bar{W}_{12} = W_{21}$) is satisfied.

The values of ϵ_{iL}^* for the geometries listed in Table 1 are calculated directly from Chiu's model [4] (the latest correlation of the ENERGY mixing parameters) and appear in Table 2 . The corresponding values of $\left(\frac{\bar{W}_{11} H}{m_1} \right)$ shown in this table are calculated according to Eq. (4-2a) utilizing the following definitions:

$$S A_1 = \frac{\sqrt{3}}{4} P^2 - \frac{\pi D^2}{8} - \frac{\pi D_w^2}{8} \quad (4-3a)$$

$$w P_1 = (D + D_w) \frac{\pi}{2} \quad (4-3b)$$

$$De_1 = \frac{4 S A_1}{w P_1} \quad (4-3c)$$

$$n_1 = \frac{P}{\sqrt{3}} \quad (4-3d)$$

4.1.2 SIMPLE Model

The values of β_1 for the geometries given in Table 1 are calculated according to Eq. (2-13). Eq. (3-28) then yields the appropriate value of $\frac{\bar{W}_{11} H}{m_1}$. The results of these calculations for $b = -0.2$ (turbulent flow) and $b = -1.0$ (laminar flow) are shown in Table 2 . The corresponding ENERGY code parameters (ϵ_{1L}^*) shown in the table are computed either from Eq. (3-14) or Eq. (4-2a).

4.2 Edge to Edge Sweeping Flow

4.2.1 ENERGY Model

The parameter ϵ_{3L}^* is related to ϵ_{1L}^* through Eqs. (4-1), under the assumption that $\epsilon_{H1} = \epsilon_{H2} = \epsilon_{H3}$. Thus,

$$\epsilon_{3L}^* = \epsilon_{1L}^* \frac{SX_1}{SX_2} \quad (4-4)$$

where $\lambda_{L1} = \lambda_{L2} = (P - D)$. The flow split correlation contained in Ref. [1] was used to calculate a representative value of $\frac{SX_1}{SX_2}$ for turbulent flow. The resulting ϵ_{3L}^* values, as well as the $\frac{\bar{W}_{22} H}{m_2}$ values computed from Eq. (4-2d) appear in Table 3 . The appropriate geometrical factors in the edge region are:

$$SA_2 = P \left(\frac{D}{2} + D_w \right) - \frac{\pi D^2}{8} - \frac{\pi D_w^2}{8} \quad (4-5a)$$

$$\eta_3 = P \quad (4-5b)$$

In addition, values of the swirl flow parameter (C_{1L}), utilized in the ENERGY code, are calculated from Chiu's correlation [4] and presented in Table 4 .

4.2.2 SIMPLE Model

Eq. (2-16) is used to calculate β in the edge region. The parameter $\frac{\bar{W}_{22} H}{m_2}$ is computed from the following formula (similar to Eq. (3-28)), which is a result of the definition of β given by Eq. (2-7):

$$\frac{\bar{W}_{22} H}{m_2} = \frac{\beta_2 (P - D) H}{S A_2} \quad (4-6)$$

Comparing this equation to Eq. (4-2d) yields:

$$\epsilon_{3L}^* = \frac{\eta_3}{De_1} \beta_2 \quad (4-7)$$

The values of $\frac{\bar{W}_{22} H}{m_2}$ and ϵ_{3L}^* evaluated according to the SIMPLE model via Eqs. (4-6) and (4-7) appear in Table 3 .

As dicussed earlier, SIMPLE has no parameter analogous to C_{1L} , hence the value of C_{1L} used in calculations associated with the SIMPLE model is zero (see Table 4).

4.3 Edge to Interior Sweeping Flow

4.3.1 ENERGY Model

As shown by Eq. (4-1),

$$\epsilon_{2L}^* = \epsilon_{3L}^* = \epsilon_{1L}^* \frac{SX_1}{SX_2} \quad (4-8)$$

where $\epsilon_{H1} = \epsilon_{H2} = \epsilon_{H3}$ and $\lambda_{L1} = \lambda_{L2}$. Thus, values for ϵ_{2L}^* follow directly from the calculations performed in Section 4.2.1 to determine ϵ_{3L}^* . As discussed earlier, ENERGY uses the same parameter ϵ_{2L}^* to characterize both interior to edge and edge to interior sweeping flow. The continuity condition ($\bar{W}_{12} = \bar{W}_{21}$) is satisfied by appropriately formulating Eqs. (4-2b) and (4-2c) with a factor of the flow split ratio. Table 5 gives the values of ϵ_{2L}^* , $\frac{W_{21}H}{m_2}$ and $\frac{W_{12}H}{m_1}$ calculated from Eqs. (4-8), (4-2c) and (4-2b), respectively, with:

$$n_2 = \left[\left(\frac{D}{2} + D_w \right) + \frac{P}{\sqrt{3}} \right] \cdot \frac{1}{2} \quad (4-9)$$

4.3.2 SIMPLE Model

The choice of a single parameter to characterize both interior to edge and edge to interior sweeping flow consistent with the SIMPLE model, is complicated by the assumptions used in development of the model itself. As stated in Section 2 , it is assumed that one-third of the total flow displaced from a particular subchannel is diverted equally to each adjacent subchannel. As a result, the parameters $\bar{W}_{12}$ and $\bar{W}_{21}$ are not necessarily equal, due to the difference in subchannel area and wire wrap appearance frequency between interior and edge subchannels. This situation is resolved here through the use of a single, "average β ," which represents both interior to edge sweeping flow and edge to interior sweeping flow, thereby satisfying continuity. A representative average β ($\bar{\beta}$) can be estimated simply by the following equation:

$$\bar{\beta} = \frac{\beta_1 + \beta_2}{2} \quad (4-10)$$

The values of β_1 and β_2 are calculated according to Eq. (3-28) and Eq. (4-6) as:

$$\frac{\bar{W}_{12} H}{m_1} = \frac{\bar{W}_{11} H}{m_1} = \frac{\beta_1 (P - D) H}{S A_1} \quad (4-11a)$$

$$\frac{\bar{W}_{21} H}{m_2} = \frac{\bar{W}_{22} H}{m_2} = \frac{\beta_2 (P - D) H}{S A_2} \quad (4-11b)$$

where $\bar{W}_{12} = \bar{W}_{11}$ and $\bar{W}_{21} = \bar{W}_{22}$. These equalities follow from the assumption made in Section 2, that the mass crossflow rate out of a particular subchannel and into an adjacent subchannel is independent of the type (i.e., interior or edge) of the subchannel receiving the flow. However, if $\bar{W}_{12} = \bar{W}_{21}$ (as required by continuity), then it follows that:

$$\frac{\beta_1}{\beta_2} = \frac{S X_2}{S X_1} \quad (4-12)$$

Since there is no reason to believe that Eq. (4-12) is true in general, the need for a single, representative β value (i.e., $\bar{\beta}$) for both interior to edge and edge to interior crossflow is established. Table 6 shows the values of β_1 , β_2 , and $\bar{\beta}$ computed in the aforementioned manner. $\frac{\bar{W}_{21} H}{m_2}$ is then calculated according to the following formula (analogous to Eq. (4-2c) and Eq. (4-11b)):

$$\frac{\bar{W}_{21} H}{m_2} = \frac{(P - D) H}{S A_2} \bar{\beta} \quad (4-13)$$

while $\frac{\bar{W}_{12}H}{m_1}$ is calculated according to the following formula (analogous to Eq. (4-2b) and Eq. (4-11a)):

$$\frac{\bar{W}_{12}H}{m_1} = \frac{(P - D)H}{SA_1} \bar{\beta} \left(\frac{SX_2}{SX_1} \right) \quad (4-14)$$

These formulations are consistent with the continuity criterion, i.e., $\bar{W}_{12} = \bar{W}_{21}$. Comparing Eqs. (4-13) and (4-2c) yields:

$$\bar{\beta} = \frac{De_1}{\eta_2} \epsilon_{2L}^* \quad (4-15)$$

Thus, using the $\bar{\beta}$ values of Table 6 , values of $\frac{\bar{W}_{21}H}{m_2}$, $\frac{\bar{W}_{12}H}{m_1}$ and ϵ_{2L}^* are calculated according to Eqs. (4-13), (4-14) and (4-15). The results of these calculations appear in Table 7 .

4.4 Summary

At this point, a summary of the equations derived in the previous sections which directly relate the SIMPLE and ENERGY parameters may be useful. Thus,

$$\epsilon_{1L}^* = \beta_1 \left(\frac{\eta_1}{De_1} \right) \quad (4-16)$$

$$\epsilon_{3L}^* = \beta_2 \left(\frac{\eta_3}{De_1} \right) \quad (4-17)$$

$$\epsilon_{2L}^* = \bar{\beta} \left(\frac{\eta_2}{De_1} \right) \quad (4-18)$$

Eq. (4-16) is a rigorous expression relating the SIMPLE and ENERGY mixing parameters, based on the identification of analogous variables in each code's energy equation. Eqs. (4-17) and (4-18) in turn, are somewhat artificial due to the difference in edge subchannel geometries between the codes. Finally, the swirl flow parameter (C_{1L}) utilized by ENERGY, the dominant energy exchange mechanism in the edge region, is non-existent in the SIMPLE mixing model.

4.5 Discussion

The preceding sections produced detailed expressions and numerical values for the mixing parameters employed by the SIMPLE and ENERGY models. In order to gain a qualitative feel for the discrepancies between the two models, the parameters which represent the physical mass crossflow rates (i.e., $\frac{\bar{W}_{11} H}{m_1}$, $\frac{\bar{W}_{22} H}{m_2}$ and $\frac{\bar{W}_{21} H}{m_2}$) are plotted in Figs. 3, 4 and 5. Several observations can be made in regard to these figures. First, although the SIMPLE model is not explicitly claimed [1],[5],[9] to extend to the laminar flow regime, the effect of using a typical laminar friction factor [11] Reynolds number dependence (i.e., $f \sim Re^{-1.0}$) was calculated. Figs. 3 through 5 show that the resulting mixing parameters are larger than those calculated by assuming a typical turbulent friction fraction ($f \sim Re^{-0.2}$). This behavior is in opposition to the experimentally observed trend of numerically decreasing mixing parameters with decreasing Reynolds number [8]. Hence, the extension of the SIMPLE model to laminar flow conditions yields results which, on a physical basis, discredit the assumptions made in the development of the model.

Assuming that the SIMPLE model is valid in turbulent flow, regardless of its ability to be generalized to other flow regimes, another interesting observation can be made in regard to Figs. 3 through 5. That is, the SIMPLE and ENERGY values of $\frac{\bar{W}_{ij}H}{m_i}$ are closest for the fuel geometry, which is precisely the geometry for which test cases of the code's performance have been reported [1],[5]. In fact, for interior to interior sweeping flow, the values of $\frac{\bar{W}_{11}H}{m_1}$ evaluated according to the ENERGY and SIMPLE models vary by only 1% for the typical fuel geometry. For blanket bundle geometries, however, the values of $\frac{\bar{W}_{11}H}{m_1}$ evaluated according to the two models vary by about 70%. Similar behavior is observed for the parameters $\frac{\bar{W}_{22}H}{m_2}$ and $\frac{\bar{W}_{21}H}{m_2}$. Thus, it is expected that for fuel geometry, the SIMPLE model will generate temperature distributions which closely approximate those of the ENERGY model except for the edge region, where the SIMPLE model fails to account for a swirl effect. For the blanket geometry, however, the large discrepancies between the SIMPLE and ENERGY values of $\frac{\bar{W}_{ij}H}{m_i}$ suggest that there may be substantial differences in the calculated temperature distributions.

5.0 Comparison of SIMPLE and ENERGY Model Temperature Distributions

The purpose of this section is to analyze the temperature fields generated by the ENERGY code utilizing both the SIMPLE and ENERGY mixing models. In order to accomplish this objective, test cases of the ENERGY code were run for typical LMFBR fuel and blanket assembly geometries and operating conditions. The required input mixing parameters evaluated by both the SIMPLE and ENERGY models appear in Section 4.

5.1 Fuel Assembly Temperature Distributions

Table 8 specifies the geometry and operating conditions of the fuel bundle to be analyzed here. The prototypical (217 pin) fuel bundle is reduced to 61 pins for simplicity. That is, the radial power profile of the innermost 61 pins is renormalized to obtain a representative case utilizing only 61 pins. All other geometric characteristics of the prototypical fuel bundle appearing in Table 1 are used.

Fig. 6 shows the subchannel numbering scheme employed by the ENERGY code. The resulting temperatures of repre-

sentative interior and edge subchannels at various axial locations are shown by Figs. 7 and 8, respectively. Fig. 7 shows that the SIMPLE and ENERGY models yield almost identical axial temperature profiles for an interior subchannel, a result which was expected due to the very close agreement between the values of ϵ_{1L}^* calculated by both models. Fig. 8 shows that the SIMPLE and ENERGY models also yield almost identical temperature profiles for an edge subchannel. This result was not expected due to the absence of an edge subchannel swirl velocity in the SIMPLE model. However, the close agreement between the ENERGY and SIMPLE model temperature profiles in the edge region is attributed to the relatively small radial power skew used in this example (i.e., max./min. = 1.07).

5.2 Blanket Assembly Temperature Distributions

Figs. 9 and 10 show interior and edge subchannel axial temperature profiles for a prototypical 61 pin blanket assembly. The geometry and operating conditions germane to this example case appear in Table 9. Fig. 9 shows that the interior subchannel temperatures corresponding to the SIMPLE model deviate significantly from those corresponding to the ENERGY model. This was expected due to the rather large differences in

the blanket assembly values of ϵ_{1L}^* (and $\frac{\bar{W}_{11} H}{m_1}$) calculated according to each model in Section 4.

Examination of Fig. 10 shows that the edge subchannel temperatures of the SIMPLE model also deviate significantly from those of the ENERGY model. Furthermore, these deviations are even larger than for the case of interior subchannels, due to the SIMPLE model's neglect of an edge region swirl effect. That is, since the radial power skew for the blanket assembly (i.e., max. / min. = 1.86) is much larger than that of the fuel assembly (max./min. = 1.07), energy transport due to peripheral sweeping flow is a larger effect in the case of the blanket assembly.

6.0 Conclusion

The SIMPLE and ENERGY mixing models were compared in order to investigate the limitations of SIMPLE's analytically formulated mixing parameter, relative to the experimentally calibrated ENERGY mixing parameters. For interior subchannels, it was shown that when the SIMPLE and ENERGY parameters are reduced to a common form, there is good agreement between the two models for a typical fuel geometry. However, large discrepancies exist for typical blanket (lower P/D) geometries. Furthermore, the discrep-

ancies between the mixing parameters result in significant differences in terms of the temperature profiles generated by the ENERGY code utilizing these mixing parameters as input.

For edge subchannels, the assumptions made in the development of the SIMPLE model were extended to the rectangular edge subchannel geometry used in ENERGY. The resulting effective eddy diffusivities (used by the ENERGY code) associated with the SIMPLE model are again closest to those of the ENERGY model for the fuel assembly geometry. Finally, the SIMPLE model's neglect of a net swirl effect in the edge region is most limiting for assemblies exhibiting relatively large radial power skews.

TABLE 1

Geometric Characteristics of Typical LMFBR Subassemblies

<u>Type of Subassembly</u>	<u>Number of Pins</u>	<u>Rod Diameter, D (in.)</u>	<u>Wire Diameter, D_w (in.)</u>	<u>Rod Pitch, P (in.)</u>	<u>Wire Wrap Lead Length H (in.)</u>	<u>P/D</u>	<u>H/D</u>
Fuel	217	0.230	0.056	0.288	11.9	1.25	51.7
Blanket	61	0.506	0.033	0.542	4.00	1.07	7.91
Intermediate	37	0.501	0.075	0.578	10.5	1.15	21.0

TABLE 2

Interior to Interior Subchannel Mixing Parameter Values

	$\left(\frac{\bar{W}_{11}H}{m_1} \right)$			ϵ_{1L}^*		
	ENERGY Eq. (4-2a)	SIMPLE Eq. (3-28)		ENERGY Correlation [4]	SIMPLE Eq. (3-14) or Eq. (4-2a)	
		turb. $b = -0.2$	lam. $b = -1.0$		turb. $b = -0.2$	lam. $b = -1.0$
Fuel	1.06	1.07	2.31	0.0288	0.0289	0.0625
Blanket	0.974	0.301	0.745	0.448	0.138	0.343
Intermediate	1.07	0.674	1.56	0.100	0.0629	0.146

TABLE 3

Edge to Edge Subchannel Mixing Parameter Values

	$\left(\frac{\bar{W}_{22}H}{m_2} \right)$			ϵ_{3L}^*		
	ENERGY Eq. (4-2d) [†]	SIMPLE Eq. (4-6)		ENERGY Correlations [4], [11] [†]	SIMPLE Eq. (4-7)	
		turb. b = -0.2	lam. b = -1.0		turb. b = -0.2	lam. b = -1.0
Fuel	0.293	0.395	0.929	0.0269	0.0363	0.0852
Blanket	0.208	0.101	0.260	0.341	0.166	0.427
Intermediate	0.289	0.136	0.365	0.0930	0.0439	0.118

$$\epsilon_{3L}^* = \frac{S_1^X}{S_2^X} \epsilon_{1L}^*, \text{ where the following values were used for } \frac{S_1^X}{S_2^X} :$$

fuel : 0.934
 blanket : 0.762
 intermediate: 0.930

calculated according to [11] for Re = 16,000

TABLE 4

Swirl Velocity Ratios (C_{1L}) in the Edge Region

	C_{1L}	
	<u>ENERGY correlation [4]</u>	<u>SIMPLE</u>
Fuel	0.0967	0.0
Blanket	0.255	0.0
Intermediate	0.165	0.0

TABLE 5

Edge to Interior and Interior to Edge Mixing Parameters
from ENERGY Model

	Eq. (4-8) ϵ_{2L}^*	Eq. (4-2c) $\frac{\bar{W}_{21}H}{m_2}$	Eq. (4-2b) $\frac{\bar{W}_{12}H}{m_1}$
Fuel	0.0269	0.501	1.05
Blanket	0.341	0.376	1.02
Intermediate	0.0930	0.507	1.08

TABLE 6

Values of the SIMPLE Model's Wire Wrap
Interchange Coefficient, β

	$b = -0.2$ (turbulent)			$b = -1.0$ (laminar)		
	β_1 Eq. (2-13)	β_2 Eq. (2-16)	$\bar{\beta}$ Eq. (4-10)	β_1 Eq. (2-13)	β_2 Eq. (2-16)	$\bar{\beta}$ Eq. (4-10)
Fuel	0.0216	0.0156	0.0186	0.0466	0.0367	0.0417
Blanket	0.0548	0.0379	0.0464	0.136	0.0976	0.117
Intermediate	0.0366	0.0147	0.0257	0.0847	0.0394	0.0621

TABLE 7

Edge to Interior and Interior to Edge Mixing Parameters from SIMPLE Model

	Eq.(4-15)		Eq.(4-13)		Eq.(4-14)	
	ϵ_{2L}^*		$\frac{W_{21}H}{m_2}$		$\frac{W_{12}H}{m_1}$	
	$b = -0.2$ turb.	$b = -1.0$ lam.	$b = -0.2$ turb.	$b = -1.0$ lam.	$b = -0.2$ turb.	$b = -1.0$ lam.
Fuel	0.0253	0.0567	0.471	1.06	0.988	2.22
Blanket	0.112	0.283	0.124	0.312	0.335	0.844
Intermediate	0.0437	0.106	0.238	0.575	0.509	1.23

TABLE 8

Fuel Bundle Geometry and Operating ConditionsGEOMETRY

number of pins	61
number of subchannels	126
D	0.2300
D _w	0.0560
P/D	1.252
H/D	51.70

OPERATING CONDITIONS

radial power skew (max./min.)	1.86
bundle mass flowrate	175,790 lb _m /hr
average heat flux at pin outer surface	740,928 Btu/hr/ft ²
inlet pressure	10 psia
inlet temperature	750°F

TABLE 9

Blanket Bundle Geometry and Operating ConditionsGEOMETRY

number of pins	61
number of subchannels	126
D	0.5060
D _w	0.0330
P/D	1.072
H/D	7.91

OPERATING CONDITIONS

radial power skew (max./min.)	1.07
bundle mass flowrate	60,000 lb _m /hr
average heat flux at pin outer surface	15,581 Btu/hr/ft ²
inlet pressure	10 psia
inlet temperature	750°F

FIGURE 1 Wire Wrap Motion in Interior Subchannels
(from Ref. [1])

FIGURE 2 Edge Subchannel Wire Wrap Configuration

FIGURE 3 Interior to Interior Crossflow as a Function of Geometry for SIMPLE and ENERGY Models

FIGURE 4 Edge to Edge Crossflow as a Function of Geometry for SIMPLE and ENERGY Models

FIGURE 5 Edge to Interior Crossflow as a Function of Geometry for SIMPLE and ENERGY Models

FIGURE 6 61 Pin Bundle Subchannel Numbering Scheme
Utilized in the ENERGY code

FIGURE 7 Axial Temperature Profile for Fuel Bundle, Subchannel 1

FIGURE 8 Axial Temperature Profile for Fuel Bundle, Subchannel 102

FIGURE 9 Axial Temperature Profile for Blanket Bundle, Subchannel 1

FIGURE 10 Axial Temperature Profile for Blanket Bundle, Subchannel 102

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