FIBWR: A Steady-State Core Flow Distribution Code for Boiling Water Reactors

Computer Code User's Manual

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...kee Atomic Electric Company
...mingham, Massachusetts

ELECTRIC POWER RESEARCH INSTITUTE

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Prepared by

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EPRI PERSPECTIVE

PROJECT DESCRIPTION

This computer code manual, together with the companion report, EPRI Final Report NP-1923, FIBWR: A Steady-State Core Flow Distribution Code for Boiling Water Reactors--Code Verification and Qualification Report, documents the FIBWR steady-state BWR hydraulic computer code. This code was developed to calculate the steady-state flow and pressure distributions in the BWR core by taking into account the detailed description of the complex BWR flow paths.

PROJECT OBJECTIVE

The objective of modeling the complicated flow paths in the BWR core and explicitly the leakage flow to the bypass is to accurately predict the flow and pressure distributions throughout the core. These distributions have a determining influence on the moderator density distribution in the core. The moderator density in turn has a strong effect on the power distribution and, hence, behavior of the core.

PROJECT RESULTS

The FIBWR code has been used successfully to predict data from the Frigg test loop and Vermont Yankee. This computer code will be useful to utility engineers for various BWR applications. Some of the potential steady-state applications are:

1. Determination of the moderator density distribution for nuclear simulator codes such as SIMULATE
2. Initialization of input parameters for transient codes such as RETRAN, VIPRE, and COBRA
3. Calculation of the power and corresponding flow of the limiting assembly hot channel when at thermal limits
4. Determination of pressure loadings on internal structures such as the support plate and fuel channel walls

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ABSTRACT

A user's manual for the steady-state core flow distribution code (FIBWR) is described. FIBWR is a computer code developed for the steady-state thermal-hydraulic analysis of BWRs. Several models for calculating various pressure drop components and void distributions are incorporated as user options. This report describes the theory, required input, and the code output and shows a sample problem run with FIBWR. The companion volume describes the verification and qualification performed with FIBWR.

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SUMMARY

This report describes the FIBWR computer code, which was developed to provide an accurate and convenient steady-state core hydraulic simulator for BWR core reload design and licensing calculations.

In a BWR, the power distribution is closely coupled to the coolant density. Because BWRs are undermoderated, the neutron flux and power are strongly influenced by local variations in the steam void distribution, which is a direct function of the power-flow distribution in the core region. Thus, a synergistic relationship between flow and power exists in a BWR core. FIBWR provides the capability to accurately predict the flow distribution for a given power distribution. The total flow entering the lower plenum splits into an active component and a bypass component. The active component (referred to as active flow) flows up through the fuel channel. The bypass component (referred to as leakage or bypass flow) flows through the interstitial regions that surround the fuel channel. The leakage rate to the bypass is dependent on the pressure drop across the core, which is in turn dependent on the active-bypass flow split. A BWR hydraulic simulator must accurately predict the pressure drop, flow, and void distributions over a large range of power-flow operating conditions.

The FIBWR code incorporates a detailed geometrical representation of the complex flow paths in a BWR code and explicitly models the leakage flow to the bypass. FIBWR includes a selection of widely used and recently developed models available at user option to calculate the following: (a) void fraction in both the subcooled and bulk boiling regions, (b) the location of the onset of subcooled boiling, (c) flow quality as a function of equilibrium quality, (d) single-phase friction factor, (e) two-phase friction multiplier, and (f) two-phase local loss multiplier. These models have been reviewed and qualified against the latest multirod pressure drop and void data. The FIBWR code has been verified by analytic studies and comparisons to other thermal-hydraulic codes. Benchmark

comparisons of FIBWR predictions with measured data for the Vermont Yankee reactor have shown excellent agreement.

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Section 1

INTRODUCTION

The FIBWR code evaluates the flow and void distribution within a boiling-water reactor (BWR) core by solving the steady-state one-dimensional equations of continuity, momentum, and energy. FIBWR computes the coolant mass flow rates in each channel and in the bypass region for either a given total core mass flow or specified total core pressure drop.

FIBWR has great flexibility to handle the varied geometrical configurations of currently operating BWRs. The FIBWR code models the core of a BWR as up to one hundred parallel flow channel types plus a bypass region. Each channel type has a user-specified geometry and power distribution. The detailed geometric modeling of each fuel assembly includes the effects of the inlet orifice, fuel support piece, lower tie plate, unheated fuel regions, grid spacers, water tubes, upper tie plate, and chimney. Three bypass flow paths located after the orifice but before the active fuel region and up to eight bypass flow paths dependent on the core support plate pressure differential are allowed. All bypass flows are lumped into a single flow region representing the average bypass; however, as a supplemental calculation, a hot bypass region may be calculated using user input power and flow penalty factors.

Since there are numerous models available in the literature that describes void and pressure loss relationships of two-phase flow, several options have been incorporated which, in the opinion of the authors, represent the best of the widely known models. The user may select among several models for each of the following: initiation of subcooled boiling, relation of flow quality to equilibrium quality, relationship of void fraction to flow quality, single-phase friction factor, two-phase multiplier for frictional losses, and the two-phase multiplier for local (form) losses. The FIBWR code computes the acceleration, frictional, local, and elevation pressure losses in each channel based upon the above models and sums them to arrive at the axial pressure distribution in the channel. The code defaults to the recommended models; however, the user has the option to specify different models.

The following assumptions are basic to the solution methodology:

1. Static pressure at the inlet and outlet plenums is uniform for all channels,
2. Subcooled or saturated inlet conditions,
3. One-dimensional upward vertical flow in each flow channel,
4. Constant, uniform pressure for the evaluation of water properties.

The assumptions simplify the numerics of the equations considerably. For steady-state conditions at high system pressures, the impact on calculational accuracy of these assumptions is slight. Although it is well known that one-dimensional equations cannot completely describe the complex patterns of two-phase flow, the effects of these patterns have been incorporated in the thermal-hydraulic models and input coefficients for predicting flow quality, void fraction, and pressure drop.

Section 2

CALCULATIONAL METHOD

The pressure drop and flow distribution is obtained by an inner/outer iteration technique. The methodology used is illustrated in Table 2-1. Typically, the code is required to determine the core pressure drop and flow distribution for a given core flow. An initial estimate of core pressure drop is input by the user or internally calculated. On the inner iterations, the flow in each channel type is adjusted until the desired pressure drop is reached. During this process, the variation in leakage flows to the bypass and the water tubes is calculated, and the total flow which passes through the orifice, lower and upper tie plates is obtained. When converged to the estimated pressure drop, the flows from each of the channels and the bypass regions are summed to obtain the total core flow, which is compared against the required core flow. The outer iterations adjust core pressure drop until convergence is obtained. Alternately, the user may require the code to determine the core flow for a given core pressure drop. Here the calculational scheme is identical, with the exception that only inner iterations need be performed.

Table 2-1

FIBWR EXECUTION METHODOLOGY DESCRIPTION
FLOW CONVERGENT CASE

Step

1. An estimate of the core pressure drop is user input or automatically computed using total core parameters such as the total mass flow rate and power level. The initial estimate of the channel flow splits is made on the basis of the inlet orifice coefficient for each channel. If the pressure drop guess is user input, the initial guess of channel mass flows will be equal in all channels. Saturated water density is assumed for the bypass.

2. For a given channel the energy equation is solved, by integration up the channel to yield the axial distribution of equilibrium quality.

3. The flow quality and void fraction distributions are calculated in the channel as a function of the previously computed equilibrium quality.

4. The heated region pressure drop is evaluated next by integration of the two-phase flow momentum equation up the channel.

5. The pressure differentials for the leakage paths are determined, and the water tube flows and bypass flows are evaluated. The pressure drops for the unheated regions are computed consistent with the total flow, which passes through the orifice, tie plates, and other unheated zones. The heated and unheated region pressure drops are now summed to obtain the channel pressure drop.

6. The channel pressure drop computed above is compared to the core pressure drop. If they are not equal to within a user-specified degree of accuracy, a new estimate of channel inlet velocity is made, and execution returns to step 2 above. If the pressure losses agree, execution again proceeds to step 2, but this time the hydraulic conditions in a new channel are calculated. When the conditions in all channels in the core have been calculated, the bypass elevation head is reevaluated, and execution proceeds to step 7 below.

7. Now that all channel mass flows are known, the total computed channel mass flow is compared to the required core mass flow (user input). If the values agree to within the required accuracy, execution proceeds to step 8, below. If not, a new core pressure drop is guessed, and execution once again returns to step 2, where the whole process starts once again.

8. Now that all core hydraulic conditions are known, the output summary and other parameters such as CPR are calculated and printed.

Section 3

FIBWR REPRESENTATION OF THE REACTOR CORE

The FIBWR code does not solve for each fuel assembly discretely; rather, up to one hundred characteristic channel types are used to represent the hydraulic and power distribution variations present in the core. The user must specify the geometry, power distribution, and number of channels present in the core of each characteristic channel type. If the user requires a detailed hydraulic solution for each assembly, a "characteristic channel analysis" may be performed to determine the core pressure drop, and subsequent pressure drop convergent cases may be run to analyze the individual channels. It is therefore essential to select characteristic channels that have the same geometry, leakage coefficients, hydraulic resistance coefficients, and representative axial and radial power distributions of the channels they typify.

The input defines the characteristic channels in detail. Hydraulic descriptions of the orifice, lower tie plate, grid spacers, upper tie plates, and, where applicable, water tube inlet and outlet holes are represented as being separate and distinct local losses. Bypass leakage coefficients describe the fuel support-lower tie plate flow path, channel-lower tie plate flow path, and lower tie plate holes for each channel type. Additionally, the user may input bypass leakage coefficients for up to eight "common" bypass leakage paths (i.e., leakage paths whose flow is solely dependent on the core support plate pressure drop). For each channel, the active flow area and water tube areas, and the axial elevations of the local restrictions (e.g., tie plates, grid spacers) are input. The axial elevation data describes five axial zones for each channel: the height from the core support plate to the bottom of the rodded section, the lower unheated rodded section, the active fuel section, the upper unheated rodded section, and the upper unheated unrodded section (chimney). The grid spacer elevations are input as a fraction of the active fuel length. The elevation of the orifice below the core support plate is an additional input which is common for the core.

The power distribution data are presumed known and are supplied as input to the FIBWR code. The input is supplied as radial peaking factors and axial peaking factors (normalized power distributions) for each channel type. The number of

axial nodes is an input; up to 25 axial nodes are allowed. The axial peaking factors input should be node-averaged values. The code searches for the highest and lowest active fuel elevations; the axial nodes uniformly span the distance in between. An option is available to adjust the input axial power factors to the reference active fuel length for cores with mixed length fuels. Both radial and axial powers factors must be normalized to unity. The code checks the normalization, and the case terminates if the normalization is in error by more than 0.05 percent. An option is available to proceed with the calculation regardless of input errors or power distribution misnormalization.

Section 4

DESCRIPTION OF FIBWR EQUATIONS AND MODELS

The total pressure drop for each channel is calculated as the sum of the individual pressure drop components: friction, local (form) loss, acceleration (momentum change), and elevation. Acceleration and elevation can be evaluated once the flow quality and void fraction have been determined. The friction and local loss terms require input coefficients and models to account for two-phase effects. The details of the models contained in the FIBWR code are discussed below.

4.1 QUALITY AND VOID FRACTION

FIBWR calculates both the thermodynamic equilibrium quality and the flow quality. Equilibrium quality, $\langle X_{eq} \rangle$, is determined from the following relationship:

$$\langle X_{eq} \rangle = (H_i - H_{sat})/H_{fg} \quad . \tag{4-1}$$

where H_i is the bulk enthalpy of the node of interest. $\langle X_{eq} \rangle$ can be positive or negative. This is the quality that would be obtained if the flowing mixture were removed adiabatically, thoroughly mixed, and allowed to reach thermodynamic equilibrium. The flow quality is the true fraction of vapor that exists in the flowing mixture, defined as the ratio of vapor mass flow to total mass flow. It is always positive and less than or equal to unity. Typically, flow and equilibrium qualities are nearly equal for the high void elevations of a BWR fuel channel; they differ in those regions where subcooled boiling conditions exist. FIBWR uses the EPRI (1) model to predict the point of bubble departure; the Saha-Zuber (2) and Levy (3) models are available as options.

The EPRI subcooled void formation model (1), developed by Lellouche and Zolotar, is based on a mechanistic model. FIBWR contains Zolotar's simplified version of this model, which has been shown to be in agreement with the mechanistic model for steady state conditions. According to the EPRI model, the temperature, $T_{departure}$, at which subcooled void formation begins, may be found by:

$$T_{SAT} - T_{departure} = \frac{B - \sqrt{B^2 - 4AC}}{2A} \tag{4-2}$$

where,

$$A = 4H_B \, (H_{DB} + H_{HN})^2$$

$$B = 2H_{DB}^2 \, (H_{HN} + H_{DB}/2) + 8 \, q'' \, H_B \, (H_{HN} + H_{DB})$$

$$C = q'' \, (4H_B \, q'' + H_{DB}^2)$$

given

T = temperature - ^oF

q'' = wall heat flux at point of departure - Btu/hr-ft^2

p = Pressure - psia

Re = single phase Reynold's number

D_h = hydraulic diameter - ft

Pr = Prandtl number

K = thermal conduct' 'ty - BTu/hr-ft-^oF

and.

$$H_{HN} = C_{HN} \, (Re)^{0.662} Pr \, K/D_h$$

$$H_{DB} = C_{DB} \, (Re)^{0.8} Pr^{0.4} \, K/D_h$$

$$H_B = \exp \left[P/630\right] / (0.072)^2$$

where,

$$C_{DB} = \begin{cases} 0.023 & \text{for channels and tubes} \\ 0.033\varepsilon + 0.013 & \text{for rod bundles and annuli} \end{cases}$$

$$C_{HN} = \begin{cases} 0.2 & \text{for channels and tubes} \\ 0.2 \, D_h/4 \, RODD & \text{for rod bundles and annuli} \end{cases}$$

ε = fraction of area available for flow

$= A_{flow} \Big/ \left[A_{flow} + A_{rod}\right]$

RODD = heated rod radius - ft

A_{flow} = flow area - ft^2

$A_{rod} = N_{rod} \pi\ RODD^2$ - ft^2

N_{rod} = number of heated rods

The following calculational procedure is used to determine the flow quality once the equilibrium quality distribution is known. For each node, starting at the channel inlet the calculational procedure is,

1. Evaluate $T_{departure}$ using Eq. 4-2, from which $h_{departure}$ and $\langle Xeq_{departure}\rangle$ may be calculated.

2. If the mixture enthalpy is less than $h_{departure}$, set $\langle X_{flow}\rangle$ to zero and proceed to the next node.

3. If $h_{departure}$ is less than h_{inlet} then set $\langle Xeq_{departure}\rangle$ equal to $\langle Xeq_{inlet}\rangle$.

4. Compute the flow quality using the hyperbolic tangent profile fit:

$$\langle X_{flow}\rangle = \frac{\langle Xeq\rangle - \langle Xeq_{dep}\rangle\left[1-\mathrm{Tanh}\left(1 - \frac{\langle Xeq\rangle}{\langle Xeq_{dep}\rangle}\right)\right]}{1- \langle Xeq_{dep}\rangle\left[1-\mathrm{Tanh}\left(1 - \frac{\langle Xeq\rangle}{\langle Xeq_{dep}\rangle}\right)\right]}$$

5. If the difference between the flow and equilibrium qualities is less than 0.001 then they are set equal to each other for all subsequent nodes.

6. Evaluate the next node by returning to Step 1.

The equations for the Saha-Zuber and Levy models can be found in their original references, or in Table 5-1 of Lahey and Moody (4). For these models, FIBWR uses an exponential profile fit of the form suggested by Levy (3) to calculate the flow quality:

$$\langle X_{flow}\rangle = \langle X_{eq}\rangle - \langle X_{eq}\rangle_{departure} \quad \exp\left(\frac{\langle X_{eq}\rangle}{\langle X_{eq}\rangle_{departure}} - 1\right) . \qquad (4\text{-}3)$$

Once the flow quality has been determined, a void-quality relationship is used to determine the void (vapor volume) fraction. The relationship between the void

fraction and quality in a flowing system is dependent upon the phasic densities and the relative velocities of the two phases. The fundamental void quality relation (exact) is:

$$\langle\alpha\rangle = \frac{\langle X\rangle}{\langle X\rangle + S\,\frac{\rho_g}{\rho_\ell}\,(1-\langle X\rangle)} \tag{4-4}$$

where

$\langle\alpha\rangle$ - void fraction

S - slip ratio $= \frac{\overline{V}_v}{\overline{V}_\ell} = \frac{\text{mass-averaged vapor velocity}}{\text{mass-averaged liquid velocity}}$

$\langle X\rangle$ - flow quality

ρ_g, ρ_ℓ - densities of vapor and liquid .

Hence, in order to relate void fraction to quality, one need only know the slip ratio, S. The homogeneous model assumes a constant slip ratio of 1.0. However, because S is difficult to define for a system in general, it has been customary to define two more basic parameters, C_o and V_{gj}.

C_o, the concentration parameter, quantifies the effect of the radial void fraction and velocity distributions, while V_{gj}, the drift velocity, is a measure of the local velocity differences between the phases. An alternate (exact) void quality relation was derived by Zuber and Findlay (5):

$$\langle\alpha\rangle = \frac{\langle X\rangle}{C_o\left[\langle X\rangle + \frac{\rho_g}{\rho_\ell}\,(1-\langle X\rangle)\right] + \frac{\rho_g V_{gj}}{G}} \;. \tag{4-5}$$

We are now left with the task of defining V_{gj} and C_o instead of S in order to relate void fraction to quality. Most experimenters have chosen to correlate C_o and V_{gj} instead of slip ratio.

C_o has a value of unity if the liquid and vapor phases are uniformly distributed. If the vapor is concentrated in the high velocity or central flow regions, the concentration parameter is greater than 1. It is less than 1 if the opposite is true.

Historically, a value of C_o = 1.13 has been found appropriate for fully developed annular flow. In fact, both the Zuber-Findlay (5) and Levy (6) void-quality models specify a constant C_o equal to 1.13. However, C_o must be a function of flow regime, and should tend towards one in single-phase vapor flow.

The drift velocity, V_{gj}, may be modeled by considering a bubble rising in a liquid. A balance of forces gives the terminal rise velocity as

$$U_t = K_3 \left[\frac{(\rho_\ell - \rho_g)\sigma g g_c}{\rho_\ell^2}\right]^{0.25} \sin\theta , \tag{4-6}$$

where

σ = surface tension, lb_f/ft

g = gravitational constant, 32.174 lb_m/sec^2

g_c = $32.174 \frac{lb_m\text{-}ft}{lb_f\text{-}sec^2}$

K_3 = experimental constant

θ = angle with the horizontal.

For vertical flow it is often assumed that the drift velocity is proportional to the terminal rise velocity.

Lellouche and Zolotar (1) recommend an iterative technique, referred to as the EPRI model, to determine C_o and V_{gj}. C_o, the concentration parameter, is determined as follows:

$$C_o = L_N/A \tag{4-7}$$

where

$$A = K_o + (1-K_o) \langle\alpha\rangle^r$$

$$r = \left(1 + 1.57\ {}^{\rho_g}\!/_{\rho_\ell}\right) / (1 - K_1)$$

$$K_o = K_1 + (1-K_1) \left({}^{\rho_g}\!/_{\rho_\ell}\right)^{1/4}$$

$$K_1 = \mathrm{MIN}\,(K_1^G\ ,\ K_1^F)$$

$$K_1^F = \frac{1}{1 + \exp\left[-\,Re/10^5\right]}$$

$$K_1^G = \begin{cases} 0.8 & \text{for cylinders, annuli and rod bundles} \\ 0.72 & \text{for channels} \end{cases}$$

$$L_N = \begin{cases} 1 & \langle\alpha\rangle = 0.0 \\ 1 - \exp\left[-\,C_1\ \langle\alpha\rangle\right] & \langle\alpha\rangle > 0.0 \end{cases}$$

$$C_1 = \frac{4\ P_c{}^2}{P\ (P_c - P)}$$

P_c = critical pressure, psi

P = pressure, psi

The drift velocity, V_{gj}, is given as:

$$V_{gj} = 1.41\ \left[\frac{(\rho_\ell - \rho_g)\ \sigma g g_c}{\rho_\ell^2}\right]^{1/4} \sin\theta\ (1 - \langle\alpha\rangle)^{3/2} \qquad (4\text{-}8)$$

This is equivalent to Eq. 4-6 for the bubble terminal rise velocity <u>if</u> K_3 is set equal to 1.41 $(1 - \langle\alpha\rangle)^{3/2}$.

In the above equations, C_o and V_{gj} are functions of the void fraction, $\langle\alpha\rangle$. To facilitate the iterative solution, these equations are rewritten as follows:

given

$$YF = (1 - \langle X\rangle)\ \frac{\rho_g}{\rho_\ell}\ \left[1 + \frac{\rho_\ell\ A\ V_{gj}}{G L_N (1 - \langle X\rangle)}\right] \qquad (4\text{-}9)$$

then

$$\langle\alpha\rangle = \begin{cases} \dfrac{A}{(1 + YF/\langle X\rangle) L_N} & L_N \geq 0.2 \\ \sqrt{\dfrac{A}{(1 + YF/\langle X\rangle) C_1}} & L_N < 0.2\ . \end{cases} \qquad (4\text{-}10)$$

The void fraction, $\langle\alpha\rangle$, is adjusted until the new value is within 0.001 of the previous value, or the maximum number of iterations (20) has been exceeded.

Dix (7) developed a model for C_o which goes to zero as flow quality goes to zero (as in subcooled boiling where the bubbles cling to the heating surface) and which also goes to 1 as quality goes to 1 (as in single-phase vapor flow), and is greater than 1 for annular flow. The Dix model is:

$$C_o = \beta\left(1 + \left(\frac{1}{\beta} - 1\right)^b\right) \tag{4-11}$$

where

$$b = (\rho_g/\rho_\ell)^{0.1}$$

$$\beta = \frac{\langle X\rangle}{\langle X\rangle + \frac{\rho_g}{\rho_\ell}\,(1-\langle X\rangle)} \cdot$$

For the drift velocity, Dix chose the value

$$V_{gj} = 2.9\left[\frac{(\rho_\ell-\rho_g)\,\sigma g g_c}{\rho_\ell^2}\right]^{\frac{1}{4}} \sin\theta \tag{4-12}$$

which is equivalent to Eq. 4-6 with $K_3 = 2.9$

The recommended model in FIBWR is the model proposed by EPRI. The homogeneous, Dix, Zuber-Findlay, and Levy models are available as a user option. The Zuber-Findlay and Levy models, define C_o and K_3 (Eq. 4-6) as empirical constants. The relationship between the models for the values of C_o and K_3 is shown in Table 4-1 below:

Table 4-1

VOID MODEL CONSTANTS

Model	Appropriate Choice of Parameters C_o	K_3
EPRI	variable	$1.41\,(1-\langle\alpha\rangle)^{3/2}$
Dix	variable	2.9
Homogeneous	1	0
Zuber-Findlay	1.13	1.41
Levy	1.13	1.18

A graphic comparison of the void quality as predicted by several of these models is presented in Figure 4-1.

4.2 FRICTION PRESSURE DROP

The frictional pressure losses are correlated in terms of the single-phase velocity head:

$$\Delta p_{fric} = f \frac{\Delta Z}{D_h} \frac{G^2}{2 g_c \rho_\ell} \phi^2_{2\text{-phase friction}} \qquad (4\text{-}13)$$

where

f = the single-phase Darcy-Weisbach friction factor,

$\frac{G^2}{2 g_c \rho_\ell}$ = the single-phase velocity head,

G = mass flux, $lb_m/sec\text{-}ft^2$,

ρ_ℓ = liquid density, lb_m/ft^3,

$g_c = 32.174 \frac{lb_m\text{-}ft}{lb_f\text{-}sec^2}$,

and ϕ^2 = the multiplier to account for two-phase effects.

Three models have been included in FIBWR to predict the friction factor f. The recommended model is the well-known Blausius (8) relationship:

$$f = A\ Re^B \qquad (4\text{-}14)$$

where

A and B = input coefficients,

Re = the single-phase Reynolds number .

The second model is a fit to the Moody curves (8):

$$f = 0.0055 \left[1.0 + (20000\varepsilon/D_h + 10^6/Re)^{1/3}\right] \qquad (4\text{-}15)$$

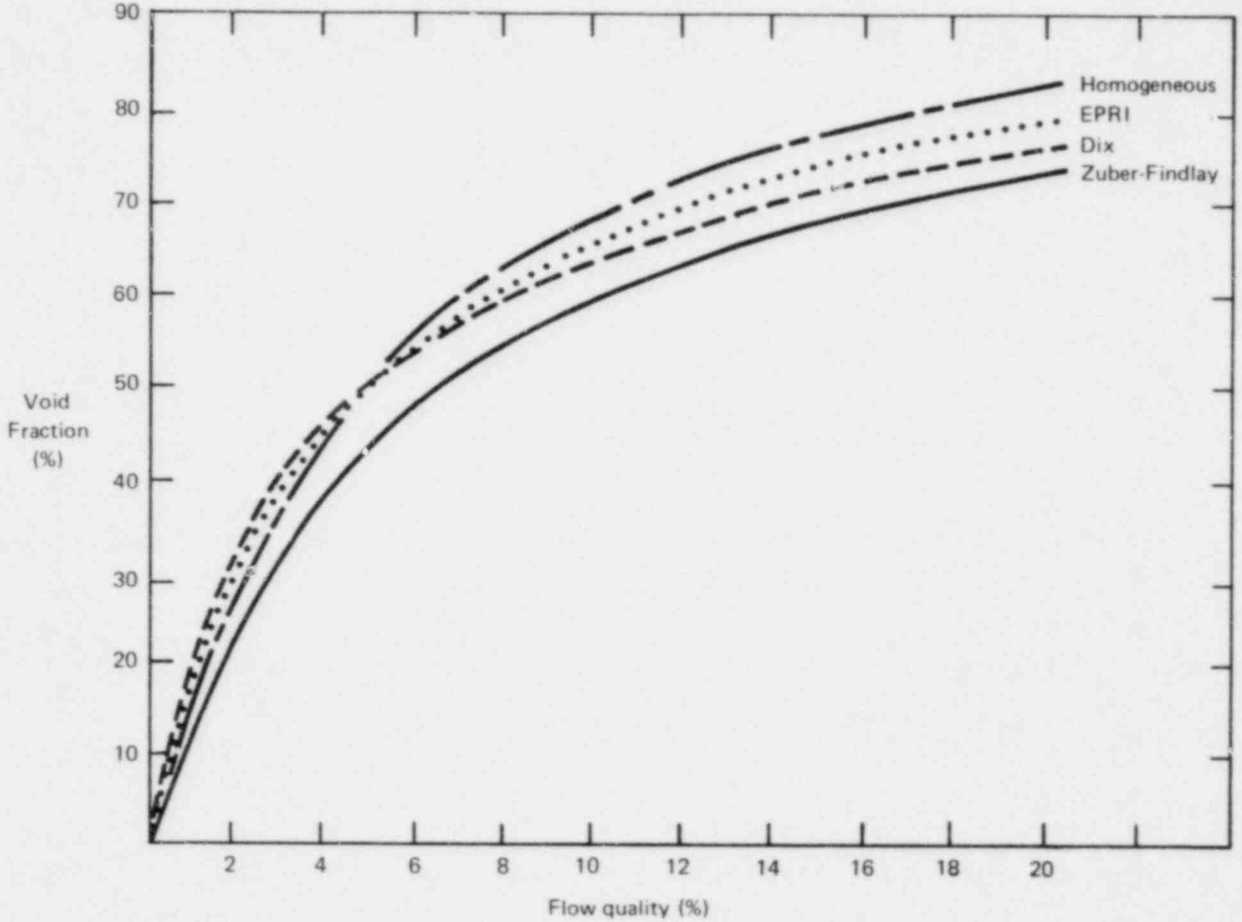


Figure 4-1. Void Fraction vs. Quality at 1000 psia, $G=1\times10^6$ lbm/hr ft^2

where

ε is the surface roughness, and

D_h is the hydraulic diameter.

The third model is the Colebrook equation (8):

$$\frac{1}{\sqrt{f}} = 1.74 - 2\ \mathrm{Log}_{10}\left[\frac{2\varepsilon}{D_h} + \frac{18.7}{\mathrm{Re}\sqrt{f}}\right] \tag{4-16}$$

This expression must be iteratively evaluated.

There are four two-phase friction multiplier ($\phi^2_{\text{2-phase friction}}$) models in FIBWR. The recommended model is the modified Baroczy (9, 10) which is graphically presented in Figures 5-16 and 5-17 of Lahey and Moody (4). The second model is the homogeneous flow relationship:

$$\phi^2_{\text{2-phase friction}} = 1 + \langle X \rangle \left(\frac{\rho_\ell}{\rho_g} - 1 \right) \tag{4-17}$$

The third model is the Jones-Dight (11) fit to the Martinelli-Nelson curves (12):

$$\phi^2_{\text{2-phase friction}} = \exp\left[\sum_{k=1}^{4} a_k\,(w)^k\right] \tag{4-18}$$

where

$$w = \ell n\left[100(\langle X \rangle + 0.01)\right]$$

$$a_k = \sum_{i=0}^{7} C_{ki}\,(P/1000)^i$$

The matrix of (untruncated) coefficients C_{ki} is as follows:

i	k = 1	k = 2	k = 3	k = 4
0	2.5448316	-0.51756752	0.10193956	-0.0080606798
1	-7.8896201	1.9550200	-0.37233785	0.026160876
2	15.575870	-0.96886164	-0.19025685	0.060288725
3	-17.340906	-4.6129079	2.2654839	-0.32426871
4	10.409842	8.4910340	-3.4925414	0.46553847
5	-3.2044877	-5.9583098	2.3299085	-0.30333482

6	0.42484805	1.8989183	-0.72534973	0.093379834
7	-0.010804871	-0.22867680	0.086169847	-0.011021915

The fourth model is the Martinelli-Nelson with a mass flux and pressure correction:

$$\phi^2_{\text{2-phase friction}} = \phi^2_{\substack{\text{Martinelli}\\\text{Nelson}}}\,\Omega \tag{4-19}$$

where

$$\Omega = \begin{cases} 1.36 + \dfrac{0.5P}{1000} + 0.1\left(\dfrac{G}{10^6}\right) - \dfrac{0.714P}{1000}\left(\dfrac{G}{10^6}\right), & \dfrac{G}{10^6} \leq 0.7 \\[2ex] 1.26 - \dfrac{0.4P}{1000} + 0.119\left(\dfrac{10^6}{G}\right) + \dfrac{0.28P}{1000}\left(\dfrac{10^6}{G}\right), & \dfrac{G}{10^6} > 0.7 \end{cases}$$

The fifth model is the Chisholm (13) relationship:

$$\phi^2_{\text{2-phase friction}} = 1 + (\Gamma^2 - 1)\left[EG^m\,(\langle X\rangle(1-\langle X\rangle))^{(2+B)/2} + \langle X\rangle^{(2+B)}\right] \tag{4-20}$$

where

B - constant as in Blausius relationship

e.g., $f = A(Re^B)$

$$\Gamma = \left(\frac{\rho_\ell}{\rho_g}\right)^{0.5}\left(\frac{\mu_g}{\mu_\ell}\right)^{-B/2}$$

ρ = liquid or vapor density, lb_m/ft^3 or Kg/m^3

μ = liquid or vapor viscosity, lb_m/ft-sec or Kg/m-sec

G = mass flux in Kg/sec-m^2

E, m are input constants. (see Reference (13) for typical values of E and m).

Figure 5-18 of Lahey and Moody (4) presents a graphic comparison of several of the two-phase friction multiplier models.

4.3 LOCAL LOSSES

The local pressure drop is defined as the irreversible pressure loss associated with an area change, such as an orifice, tie plate, or grid spacers. The general local pressure drop equation is similar to that for friction pressure drop:

$$\Delta p_{local} = K \frac{G^2}{2g_c\rho_\ell} \phi^2_{2\text{-phase local}} \tag{4-21}$$

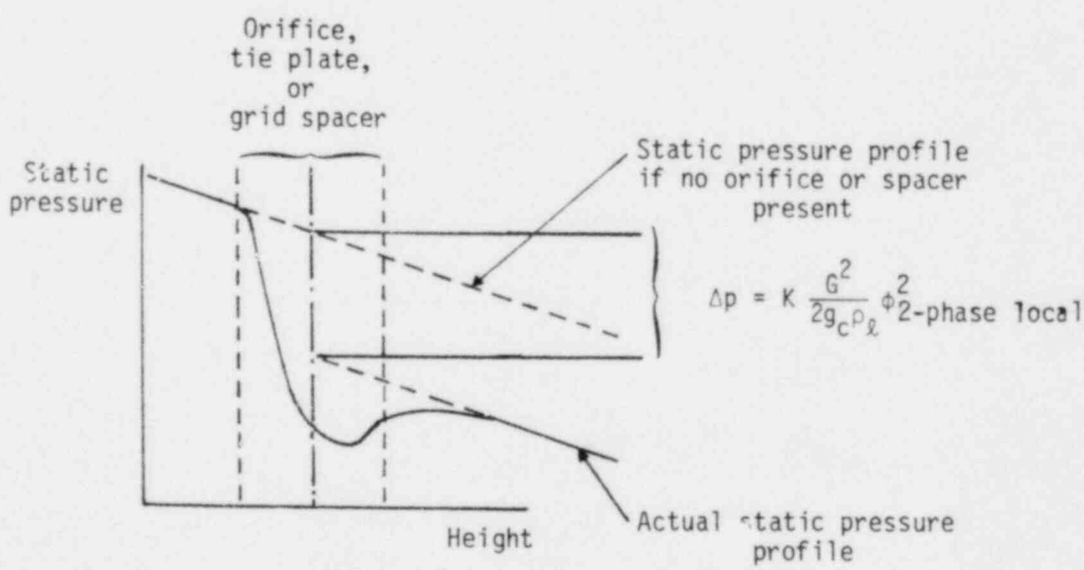
where

K = the single phase form loss coefficient

$\frac{G^2}{2g_c\rho_\ell}$ = the single-phase velocity head,

$\phi^2_{2\text{-phase local}}$ = the two-phase multiplier for local losses.

The loss coefficients are determined empirically or from handbooks of hydraulic resistances, such as Idel'chik (14), and are user input. The FIBWR model assumes that the local losses are zero thickness restrictions. This implies that the K should reflect the net static pressure loss superimposed on the fully developed pressure gradient:



It should also be noted that the G in the above expression is based on the channel flow area. Coefficient values for orifices, tie plates, and spacers which are based on the restriction flow area must therefore be corrected:

$$K^1 = K_{actual} \frac{A^2_{channel\ flow}}{A^2_{restriction}} \tag{4-22}$$

Similarly, the coefficients for inlet and outlet holes for the water tubes must be corrected:

$$K^1 = K_{actual} \frac{A^2_{water\ tube}}{A^2_{inlet\ or\ outlet\ water\ tube\ holes}} \tag{4-23}$$

The FIBWR code has three models for the two-phase local loss multiplier.

The default model is the modified homogeneous expression:

$$\phi^2_{2\text{-phase local}} = 1 + (E) \langle X \rangle \left(\frac{\rho_\ell}{\rho_g} - 1\right) \tag{4-24}$$

where

E = an empirical adjustment factor. A separate value of E may be input for spacer grids and the upper tie plate.

The homogeneous expression is obtained by setting E equal to 1.0.

The second model is a version of the Janssen (15) model modified by Weisman (16). Janssen's local loss multiplier for short restrictions is:

$$\phi^2_{2\text{-phase local}} = \left[\frac{\rho_\ell}{\rho_g} \langle X^2 \rangle \langle \alpha_3 \rangle \left(\frac{1}{\langle \alpha_3^2 \rangle} - \frac{\sigma^2 C^2}{\langle \alpha_5^2 \rangle}\right) + (1-\langle X \rangle)^2 (1-\langle \alpha_3 \rangle) \right. \tag{4-25}$$

$$\left(\frac{1}{(1-\langle \alpha_3 \rangle)^2} - \frac{\sigma^2 C^2}{(1-\langle \alpha_5 \rangle)^2}\right) - 2\sigma C \left(\frac{\rho_\ell \langle X \rangle^2}{\rho_g} \left(\frac{1}{\langle \alpha_3 \rangle} - \frac{\sigma C}{\langle \alpha_5 \rangle}\right)\right.$$

$$\left.\left. + (1-\langle X \rangle)^2 \left(\frac{1}{1-\langle \alpha_3 \rangle} - \frac{\sigma C}{(1-\langle \alpha_5 \rangle)}\right)\right)\right] \Big/ \left[\frac{(1-\sigma C)^2}{(\sigma C)^4}\right]$$

where

$<\alpha_3>$ - void fract at vena contracta

$<\alpha_5>$ - flow channel vo d fraction

$<X>$ - flow ity

σC - net reduction in flow area factor, i.e., vena contracta area/original flow area

$= 1/(1+\sqrt{K})$

Weisman has developed a correlation for obtaining $<\alpha_3>$. His correlation is

$$<\alpha_3>=<\alpha_{VC}> + A(<\alpha_{homo}>-<\alpha_{VC}>) \tag{4-26}$$

where

$<\alpha_{VC}>$ = flow channel void fraction evaluated at the vena contracta flow velocity

$A = K\left(\frac{L}{D}\right)^b$

with the restriction that $0 \leq A \leq 1$
and the constants (experimental):

$K = - 1.8<\alpha_5> + 1.05$

$b = 3.1\ (<\alpha_5> - .36)$

$\frac{L}{D}$ = empirical length to diameter ratio of restriction, which is input to the code.

It can be shown that Janssen's model reduces to the homogeneous model if both $<\alpha_3>$ and $<\alpha_5>$ are set equal to $<\alpha$homogeneous$>$, calculated by assuming slip equals one.

The third model is the Romie (19) or slip expression:

$$\phi^2_{2\text{-phase local}} = \frac{\rho_\ell <X>^2}{\rho_g <\alpha>} + \frac{(1-<X>)^2}{1-<\alpha>} \tag{4-27}$$

It also can be shown that Janssen's model reduces to the Romie (slip) model if $<\alpha_3>$ is set equal to $<\alpha_5>$.

Figure 4-2 presents a comparison of the three two-phase local loss multiplier models.

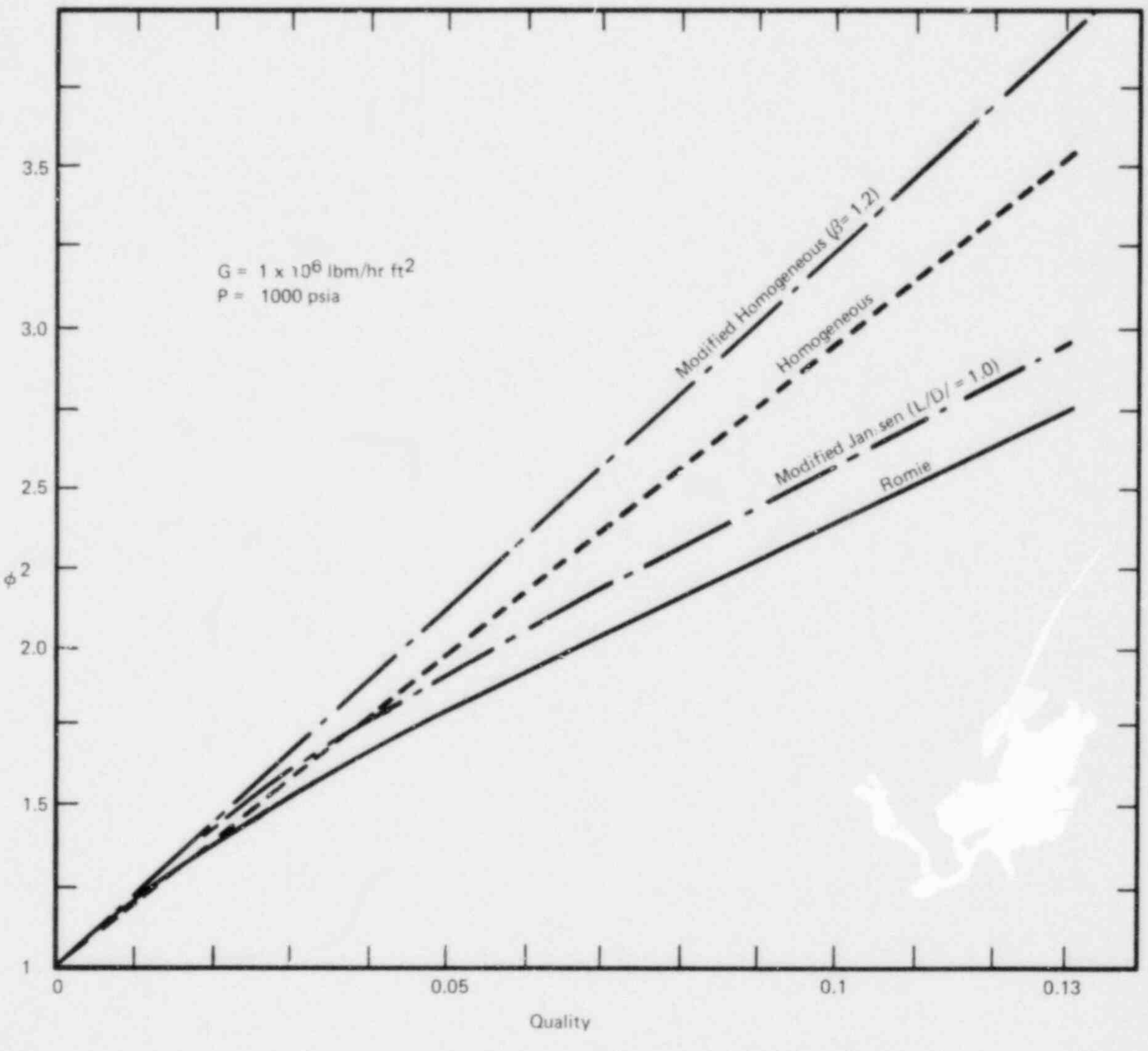


Figure 4-2. Form Loss Multiplier Comparison at BWR Conditions

4.4 ACCELERATION PRESSURE DROP

The acceleration pressure drop includes the reversible pressure change experienced at contractions and expansions, or resulting from the acceleration of the fluid during the boiling process (density change). The reversible pressure change from a flow area change when the fluid is in single phase is:

$$\Delta P_{ACC} = (1 - \sigma_A^2) \frac{G_2^2}{2 g_c \rho_\ell} \qquad (4\text{-}28)$$

where

$$\sigma_A = \frac{A_2}{A_1} = \frac{\text{final flow area}}{\text{initial flow area}}$$

$\frac{G_2^2}{2 g_c \rho_\ell}$ = the single-phase velocity head with respect to the final flow area.

When two phases are present:

$$\Delta P_{ACC} = \frac{2}{g_c (A_1 + A_2)} \left[\left(\frac{1}{\rho_{M_2}}\right) G_2^2 A_2 - \left(\frac{1}{\rho_{M_1}}\right) G_1^2 A_1 \right] \qquad (4\text{-}29)$$

where, ρ_M, the momentum density is defined by:

$$\frac{1}{\rho_M} = \frac{\langle X \rangle^2}{\rho_g \langle \alpha \rangle} + \frac{(1 - \langle X \rangle)^2}{\rho_\ell (1 - \langle \alpha \rangle)} \qquad (4\text{-}30)$$

$\langle \alpha \rangle$ = void fraction at A_2

$\langle X \rangle$ = flow quality at A_2

and other terms are as previously defined.

The basic formulation for the acceleration pressure change due to density change is

$$\Delta P_{ACC} = \frac{G^2}{g_c} \left[\frac{1}{\rho_{M_{OUT}}} - \frac{1}{\rho_{M_{IN}}} \right] \qquad (4\text{-}31)$$

where the momentum density, ρ_M, is evaluated at the inlet and outlet of each axial node. Other terms are as previously defined. The total acceleration pressure drop in boiling water reactors is on the order of a few percent of the total pressure drop.

4.5 ELEVATION PRESSURE DROP

The elevation (gravitational) pressure drop is evaluated as follows:

$$\Delta P_{elev} = \bar{\rho}\ \Delta Z \tag{4-32}$$

where

$$\bar{\rho} = \rho_\ell(1-\langle\alpha\rangle) + \rho_g\langle\alpha\rangle$$

4.6 BYPASS FLOW

Due to the low flow velocity, the pressure drop in the bypass region above the core support plate is essentially all elevation head. Thus, the sum of the core support plate differential pressure and the bypass region elevation head is equal to the core differential pressure.

The flow through the bypass flow paths is expressed by the form:

$$W = C_1\ \Delta P^{\frac{1}{2}} + C_2\ \Delta P^{C_4} + C_3\ \Delta P^2 \tag{4-33}$$

The leakage paths to the bypass for a typical BWR geometry are shown in Figure 4-3. The pressure drops used to evaluate the above expression are functions of channel pressure differential ($P_{active} - P_{bypass}$), and are evaluated at the lower tie plate-fuel support piece interface, the lower tie plate holes and the channel-lower tie plate interface (paths 6, 9, and 8 of Figure 4-3). The other paths (with the exception of the control rod coolant flow, which is input) are functions of the pressure differential across the core support plate. These paths are referred to as the "common paths." The quantity of paths number 1, 2, and 5 is equal to the number of control rods. The quantity of path number 10 is equal to the number of spring plugs. The quantity of path number 3 is equal to the number of instrument and source locations. There is one path number 4. In order to simplify the use of the code, the user may renumber these common paths and lump several of these paths together. The number of such paths and the coefficients C_1 through C_4 are user input.

The coefficients for these paths may be analytically or empirically determined, and should include the effects of long-term service. Long-term service may result in a net decrease or a net increase in total core leakage flow. Experience indicates that crud deposition to some extent should be expected in some of the leakage

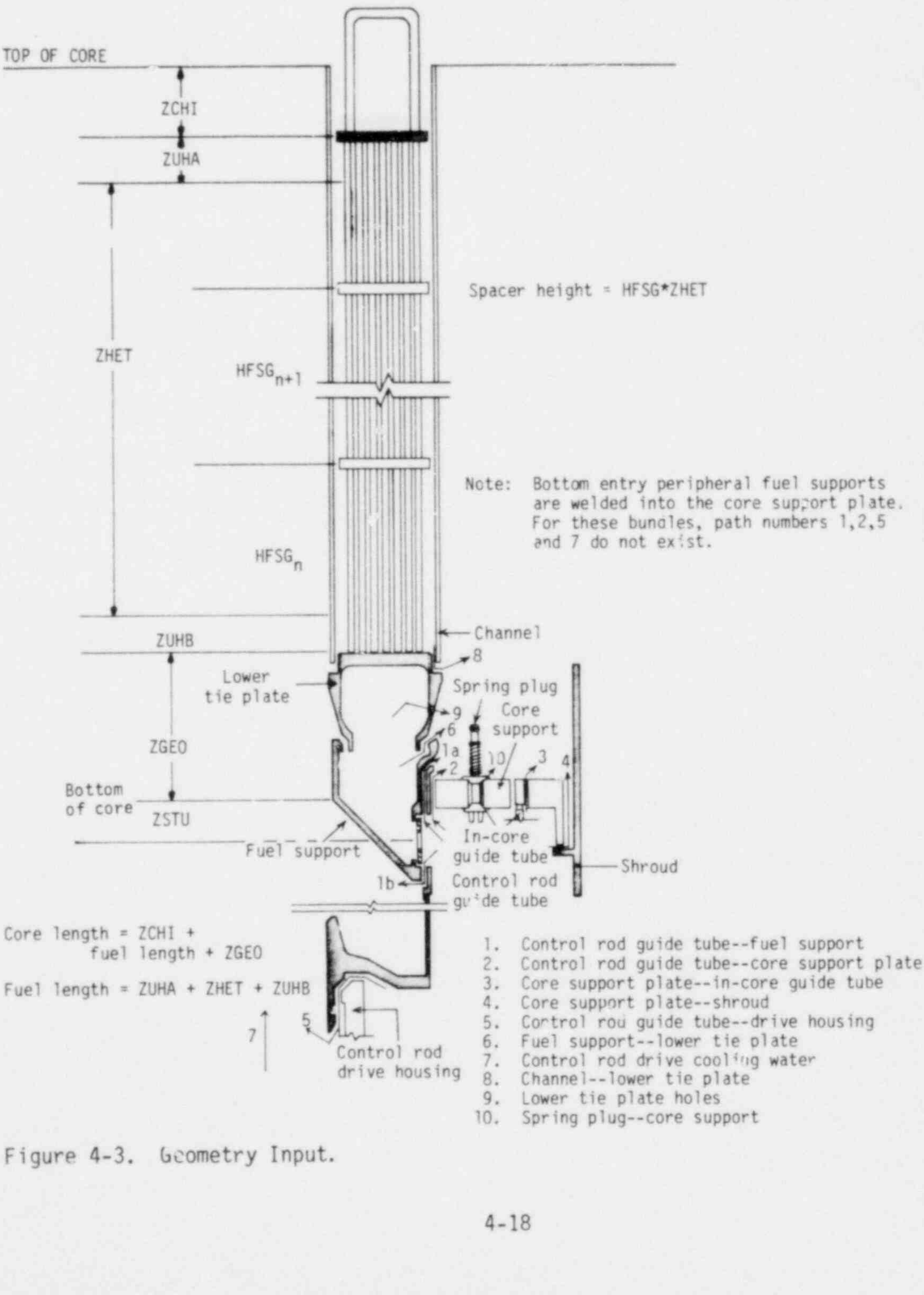


Figure 4-3. Geometry Input.

flow paths. The result will be a decrease in leakage flow where the deposition occurs. On the other hand, long-term channel pressure loading is expected to result in some amount of permanent channel deformation yielding an increase in leakage flow through path number 8. The bypass leakage coefficients, C_1 through C_4, for the Vermont Yankee BWR have been documented (18).

The total bypass flow is the sum of the flows through each of these paths. On each outer iteration, the bypass enthalpy and void distribution are recalculated, and the bypass elevation head is reevaluated. After FIBWR converges on the channel and bypass flow distribution, the enthalpy and void distribution of a user-defined hot bypass region is calculated. The results of the hot bypass region calculation appear in a supplementary edit. Typically, the hot bypass region calculation is used to determine the onset of boiling in a particular bypass subchannel. The mass flux used in the hot bypass region calculation is the total bypass mass flux times and input flow factor. The power deposition in the hot bypass is the average bypass power deposition per channel times an input factor. These factors may be bounding values or may be evaluated with a subchannel thermal hydraulics code. It should be noted that due to the lower density head, cross-flow redistribution will tend to quench a boiling subchannel. If significant boiling is experienced in the hot bypass region, a more detailed calculation should be used to determine the hot bypass void distribution profile.

The user may omit the bypass calculation and input the bypass flow. The code will then assume that all bypass flow passes through the common paths; for example, no leakage flow must pass through the fuel channel orifices. No bypass enthalpy rise calculations are performed if this option is selected.

4.7 WATER TUBES

FIBWR calculates the water tube flow consistent with the pressure drop of the active coolant parallel to the tube. The entrance and exit elevations are input with reference to the start of the heated region of each channel. The water tube is assumed to start at or above the bottom of the reference length, but may extend up into the upper unheated region. The FIBWR code models the water tube pressure drop in a similar manner to the active coolant, with the exception that the homogeneous void relationship and two-phase local loss multiplier models are used should the water tube experience bulk boiling. No friction loss multiplier or two-phase corrections to the acceleration pressure drop are included; if the flow rate is low enough to allow the water tube water to boil, these pressure loss components will not be significant.

Section 5

CALCULATIONAL DETAILS

5.1 WATER PROPERTIES

The water properties consistent with the 1967 ASME steam tables are evaluated using the STHLIB routines from RELAP4. The STHLIB routines require an external file of water properties; this file is expected to be supplied to FIBWR on TAPE15. A complete description of these routines is presented in Appendix D of Reference 17.

5.2 MINIMUM FLOW REQUIREMENTS

During the iteration process, the program continually checks to ensure that the flow does not fall below the minimum flow. This minimum flow is calculated to ensure that a very high (>.99) quality is not reached and the steam leaving the top of the channel does not become superheated. The minimum flow is:

$$W_{MIN} = Q_B \Big/ (h_f + .99h_{fg} - h_{IN}) \quad (5\text{-}1)$$

where

Q_B = the channel power deposited in the active flow, Btu/Sec

h_f = saturated liquid enthalpy, Btu/lb

h_{fg} = latent heat of vaporization, Btu/lb

h_{IN} = inlet enthalpy, Btu/lb

If, during iteration for a given required pressure drop, the program makes a flow guess less than the minimum flow given in the above equation, the program will first calculate the pressure drop for the minimum flow. If this pressure drop is less than the required pressure drop, the iteration for the flow continues. If the minimum flow pressure drop is greater than the required pressure drop, the required pressure drop is changed to this new value. In this way, the program will not allow convergence on a required core flow or pressure drop that will

result in one or more channels with exit enthalpies greater than that of saturated steam. If, on a flow-required run, the program finds it cannot converge on the flow without going below the minimum channel flow limit, it converges to the minimum possible total flow, with at least one or more channels operating at the channel minimum. The following warning is printed to the user: "WARNING - CHANNEL XXX NOT CONVERGED AS CORE PRESSURE DROP REQUIRES INLET VELOCITY BELOW MINIMUM."

Similar minimum flow requirements exist for the water tubes and the bypass region flows.

5.3 CONVERGENCE TECHNIQUES

The basic iteration problem is to force the channel types that the user specifies for the core to converge to a given pressure drop. If the user is making a required pressure drop run, each channel type will be forced to converge to the user-specified pressure drop, provided the minimum flow requirement is met. If the user is making a required total flow run, the first guess for pressure drop that the channel types are converged to is either input by the user, or the program makes the first guess. This pressure drop guess must then be corrected until the total flow requirement is met, but the lowest level iteration problem is to find the flow required to produce a given channel pressure drop. To start the iteration process, the code will guess an initial mass flow rate for each channel. If the first guess does not produce the required pressure drop, a second flow guess is generated from the following simple ratio:

$$G_2 = G_1 \left(\frac{\Delta p \text{ req'd}}{\Delta p_1} \right) . \tag{5-2}$$

where the subscripts indicate the iteration number.

For the second iteration, a simple linear interpolation method is used:

$$G_{n+1} = G_{n-1} - (G_{n-1} - G_n) \left(\frac{\Delta p_{n-1} - \Delta p_{req'd}}{\Delta p_{n-1} - \Delta p_n} \right) . \tag{5-3}$$

where, again, the subscripts indicate the iteration, the (n+1) being the next iteration.

On the third and subsequent iterations, the following polynomial extrapolation method is used:

$$G_n = A + B\Delta p_{req'd} + C\Delta p^2_{req'd} \tag{5-4}$$

where

$$C = \left[\frac{G_{n-2}-G_{n-1}}{\Delta p_{n-2}-\Delta p_{n-1}} - \frac{G_{n-2}-G_n}{\Delta p_{n-2}-\Delta p_n}\right] \Big/ (\Delta p_{n-2}-\Delta p_n)$$

$$B = \frac{G_{n-2}-G_{n-1}}{\Delta p_{n-2}-\Delta p_{n-1}} - C\left(\Delta p_{n-2} + \Delta p_{n-1}\right)$$

and

$$A = G_{n-2} - B\Delta p_{n-2} - C\left(\Delta p_{n-2}\right)^2$$

For the required flow case, the individual pressure drop converged channel flows are added up, the leakage flow fraction added on, and the total compared to the required total flow. If they are not within user-specified convergence limits, a new pressure drop guess is made and the channel types converged to this new guess. If the total flow fails to match the required total flow, an iterative procedure for core pressure drop similar to that for channel flow is used.

Under certain conditions, the pressure drop versus flow curve for the reactor channel may become very flat, or may not even be single-valued, with several possible channel flows giving the same pressure drop. This seems to be true particularly at low flow conditions. In a tightly orificed channel, typical of current designs, this is highly unlikely. However, the program may have difficulty converging swiftly in some situations. If the user input maximum number of iterations is exceeded, a warning message will be printed and the run terminated. The user may increase the maximum number of iterations permitted and force the program to converge. Alternately, the user can either relax the convergence criterion, or disable the bypass leakage calculation option. The program can then be rerun using the converged core pressure drop from the relaxed convergence or no bypass option case as the input guess.

5.4 SYSTEM ENERGY (HEAT) BALANCE

The FIBWR code has the option of computing the core inlet enthalpy by solving an energy balance on the system composed of the reactor vessel, recirculation loop piping, and cleanup demineralizer piping (shown in Figure 5-1). Flows entering this system are the reactor feedwater flow, W_{FW}, and the control rod drive system flow, W_{cr}. The only flow leaving the system is the primary steam flow, W_{STM}. Nonflow energy inputs to the system are the core thermal power (CTP) and recirculation pump power, Q_p; nonflow energy losses are the radiative power loss, Q_{RAD}, and the net cleanup demineralizer power loss, Q_{cu}. The energy balance can be expressed as follows:

$$CTP = Q_{flow} + Q_{cu} + Q_{RAD} - Q_P \quad (5\text{-}5)$$

where

$$CTP = C\ (W_{STM}\ H_{STM} + W_{DC}H_{DC} - H_{IN}W_{core}),$$

$$Q_{flow} = C\ (W_{STM}H_{STM} - W_{FW}H_{FW} - W_{cr}H_{cr}),$$

and

C is a conversion factor from Btu/sec to MW_t (0.001055), and the subscript DC refers to the flow at the entrance to the downcomer (i.e., the core exit flow that is continuously recirculated rather than discharged from the vessel as steam).

The system energy balance for inlet enthalpy is thus

$$H_{IN}\ W_{core} = W_{DC}H_{DC} + W_{FW}H_{FW} + W_{cr}H_{cr} + \frac{1}{C}(Q_P - Q_{cu} - Q_{RAD}) \quad . \quad (5\text{-}6)$$

For two recirculation loop reactors, Q_p can be expressed as:

$$Q_p = (PUP01 + PUP02)\ PUEF \quad (5\text{-}7)$$

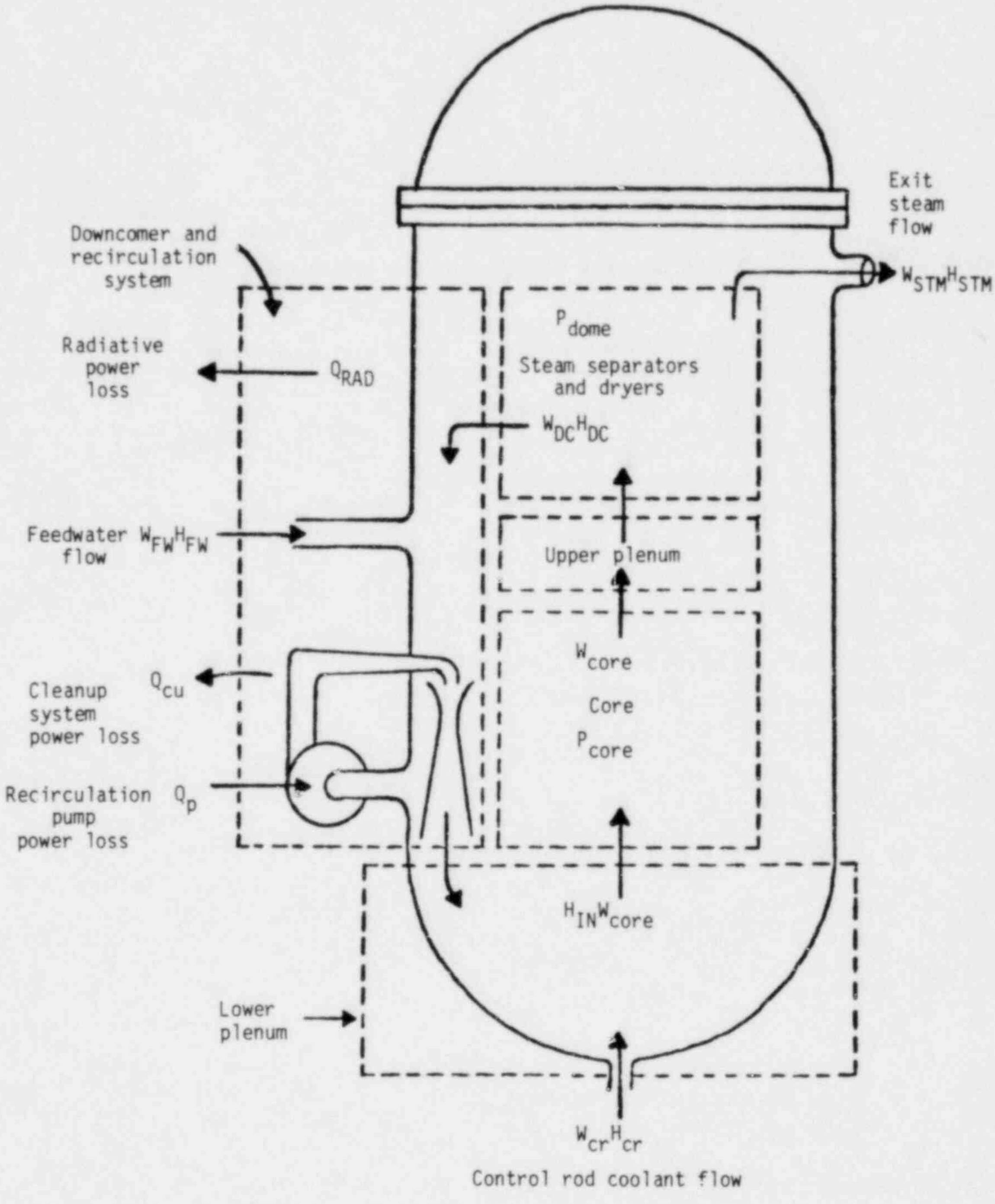


Figure 5-1. Control Volumes and Flows for the BWR Heat Balance

where

$\begin{bmatrix} PUPO1, \\ PUPO2 \end{bmatrix}$ = pump 1 and 2 motor powers, MW

PUEF = assumed efficiency of each pump

$Q_{CU} = C[W_{CU}(h_{CU\ IN} - h_{CU\ OUT})]$

The downcomer entrance flow is simply:

$$W_{DC} = W_{core} - W_{STM} = W_{core} - W_{FW} - W_{cr} \quad . \tag{5-8}$$

The downcomer enthalpy is:

$$H_{DC} = H_f^{dome} + CUC(H_{fg}^{dome}) \quad . \tag{5-9}$$

where CUC is the steam carry under fraction, and the superscript "dome" implies that the saturation enthalpies must be evaluated at the dome pressure:

$$P_{dome} = P_{core} - DPCD \quad . \tag{5-10}$$

where DPCD is the pressure differential between the core and the dome.

Note that the following variables are required to evaluate H_{IN} based on Eqs. 5-5 through 5-10.

Flows: W_{FW}, W_{cr}, W_{cu}

Temperatures: T_{FW}, T_{cr}, $T_{cu\ IN}$, $T_{cu\ OUT}$

Pressures: DPCD

Pump Parameters: PUPO1, PUPO2, PUEF

Carry Under Coefficient: CUC

Radiative Power Loss: Q_{RAD}

All of the above, with the exception of DPCD, PUEF, Q_{RAD}, and CUC are directly measured and edited by the NSSS process computer. PUEF, Q_{RAD}, and CUC are assumed to be constants, and can be obtained from the process computer data bank. The NSSS process computer measures P_{DOME}, from which DPCD may be evaluated if P_{core} is known. Typically, DPCD is 15 psi at full power, full-flow conditions. The variation of DPCD for part-load conditions may be evaluated with a code such as RETRAN (10).

5.5 HEATED CORE DIMENSIONS AND NODE HEIGHTS

When the fuel assemblies specified have varying active fuel lengths, FIBWR automatically selects a uniform reference heated core length for all channels. The reference core starts at the bottom of the active fuel zone of the lowest channel and extends to the top of the active fuel zone of the tallest channel. Nodes uniformly span the reference core. Input axial power distribution data should be midnode values for the reference heated core. This method is consistent for axial power data from 3-D simulator calculations or process computer edits. However, design or scoping axial power distributions are typically quoted with respect to each channel's heated length. For user convenience, the FIBWR code contains an option, IOP(5) = 1, whereby the input power distribution is interpreted as uniformly spanning the individual channel's heated length. If a particular channel's dimensions differ from the reference core dimensions, its input axial power data will be renormalized to preserve its power distribution for the revised node structure.

Section 6

INPUT DESCRIPTION

6.1 INPUT DECK FORMAT

A FIBWR problem consists of a title card, comment cards (optional), data cards, and a terminator card. A listing of the cards is printed at the beginning of each problem. The order of the title, data, and comment cards is unimportant except that the last title card or the last data card with a duplicate card number will be used.

When a card format error is detected, a line is printed that contains a dollar sign ($) located under the character causing the error and a comment giving the card column of the error. An error flag is set to terminate the run after processing the balance of the input data.

Title Card

A title card must be entered for each problem. A title card is identified by an equal sign (=) as the first nonblank character. The title (the remainder of the title card) is printed as the first line of every page. The title card is normally placed first in the problem.

Comment Cards

An asterisk (*) or a dollar sign ($) appearing as the first nonblank character identifies the card as a comment card. Any information may be entered on the remainder of the card. Blank cards are treated as comment cards. The only processing of comment cards is printing of contents. Comment cards may be placed anywhere in the input deck.

Data Cards

The data cards contain a varying number of fields which may be integer, floating point, or alphanumeric. Blanks preceding and following fields are ignored.

The first field on a data card is a card number which must be an unsigned integer and must agree with a card number present in the list of card types (pages 6-5 through 6-21). If the format of the card number or the data items on the remainder of the card do not agree with the required format, an error flag is set. Consequently, data on the card are not used, and the card will be identified by the card number in the list of unused data cards. Valid cards, describing additional geometries not required for the channel types of the case being executed, will also be included in the list of unused data cards. After each card number and the accompanying data are read, the card number is compared to previously entered card numbers. If a matching card number is found, the data entered on the previous card is replaced by the data on the current card. If the card being processed contains only a card number, the card number and the data on the previous card are deleted. If a card causes replacement or deletion of data, a statement is printed indicating that the card is a replacement card.

Comment information may follow the data fields on any data card by preceding the comment with an asterisk or dollar sign.

A number field is started by either a digit (0 through 9), a sign (+ or -), or a decimal point (.). A comma or a blank (with one exception subsequently noted) terminates the number field. The number field has a number part, and, optionally, an exponent part. A number field without a decimal point or an exponent, or both, is a floating-point field. A floating-point field without a decimal point is assumed to have a decimal point immediately in front of the first digit. The exponent denotes the power of ten to be applied to the number part of the field. The exponent part is a sign or an E or D, or an E or D and a sign followed by a number giving the power of ten. These rules for floating-point numbers are identical to those for entering data in FORTRAN E or F formatted fields except that no blanks (one exception) are allowed between characters.

Floating-point data punched by FORTRAN programs can be read. To permit reading of floating-point data, a blank following an E or D denoting an exponent is treated as a plus sign. Acceptable ways of entering floating-point numbers are illustrated by the following six fields, all containing the quantity 12.45.

12.45,+12.45 1245+2 1.245+1, 1.245E1 1.245E+1

A field starting with a letter is an alphanumeric field. The field is terminated by a comma, a blank, or the end of the card. All characters except commas and blanks are allowed.

Terminator Cards

The input data for FIBWR problems are separated by slash cards: the final problem is terminated by a period card instead of a slash card. The slash and period cards have a (/) and (.), respectively, as the first nonblank character. Comments may follow the slash and period on the slash and period cards.

When a slash card is used as a terminator, the list of card numbers and associated data used in a problem is passed to the next problem. Cards entered for the next problem are added to the passed list or act as replacement cards, depending on the card number. The resulting input is the same as if all previous slash cards were removed from the input to the problem set.

6.2 DETAILED DESCRIPTION OF FIBWR INPUT VARIABLES

In the following description of the data cards, the card number is given along with a descriptive title of the data contained in the card. Next, the order of the data (Word 1, 2, ...), the format (I, R, or A), the variable name, and the input data requirements are given where applicable. The format of the field, integer, real or floating, or alphanumeric is indicated by I, R, or A, respectively. Please note that for common bypass path cards, geometry set cards, and channel type data cards, the common path number, the geometry set number (referred to in this section as II), and channel type numbers (referred to as JJ) are included as part of their respective card numbers.

Card	Word	Format	Description	
100000			Problem Dimension	
	1	I	NCHAN (>0)	Total number of channels in core.
	2	I	NCT (>0, ≤100)	Number of characteristic channel types.
	3	I	NSTEP (>0, ≤25)	NSTEP is the number of axial nodes in the active core.
	4	I	NGSET (>0, ≤100)	Number of geometry sets.
200000 - 200002			Options	
200000	1	I	IOP(1)	MODCAL
	2	I	IOP(2)	IINLT
	3	I	IOP(3)	ICHEK
	4	I	IOP(4)	NALL
200001	1	I	IOP(5)	IFLUX
	2	I	IOP(6)	NFLOPO
	3	I	IOP(7)	NBYPC
	4	I	IOP(8)	NWATR
	5	I	IOP(9)	NCHF
200002	1	I	IOP(10)	NSCQ
	2	I	IOP(11)	IVOID
	3	I	IOP(12)	IFRIC
	4	I	IOP(13)	IPHSQ
	5	I	IOP(14)	NFORM
	6	I	IOP(15)	NKP

Table 6-1 presents definitions of the above variables.

Card	Word	Format	Description
200003	1	I	ITLIM
	2	R	FERR
	3	R	CALMD

ITLIM - Iteration limit

This limit defines the maximum number of inner and outer iterations. The inner loop calculates the channel inlet velocities for a given core pressure drop, while the outer loop adjusts the given core pressure drop in order to satisfy the given total core flow. The convergence criteria are given by FERR.

FERR - Fractional error

Convergence criteria on flow and pressure drop. It is specified in terms of a fraction of the total. For the outer iteration loop convergence is checked on $(W_T^I - W_T^{Req'd})/W_T^{Req'd} < FERR$ and for the inner iteration loop $(P_K^I - P_K^{Req'd})/P_K^{Req'd} < FERR$, where W_T is the total core flow, P_K is the channel K pressure drop and I is the iteration counter. For the water tube model, convergence is based on $(P_W^I - P_W^C)/P_W^C < FERR$ where P_W^I is the water tube pressure drop and P_W^C is the channel pressure drop parallel to the water tube.

CALMD - Core pressure drop

The definition of this variable varies; see IOP(1). The current version of FIBWR has two mode options. CALMD is only necessary when IOP(1) is 1. In this case it represents the given core pressure drop in psi and COFL represents an estimate of the core flow. When IOP(1) is 0 and CALMD is a number greater than zero, CALMD will be used as an initial estimate of the core pressure drop in psi, bypassing the internal estimating routine.

Card	Word	Format	Description
200004	1	R	FCHE
	2	R	FCHM

FCHE, FCHM - Coefficients for CHISHOLM Model

FCHE and FCHM are the E and M factors required for the CHISHOLM Two phase friction multiplier model (IOP (13) = 15). Typically, FCHE is set to 2400 and FCHM to -1.0 for BWR conditions.

Card	Word	Format	Description	
300000			System Parameters at Rated Conditions	
	1	R	CPOW	
	2	R	COFL	
	3	R	PS	(>14.0, ≤3200.)
	4	R	CIN	

CPOW - Core power (MWt, 10^6 Btu/hr, 10^6 Btu/hr-ft^2, W/cm^2)

This item specifies the rated core power. It is used in conjunction with PCTP to arrive at the proper power for the problem at hand. The units are specified by IOP(6).

COFL - Core flow (10^6 lbm/hr, 10^6 lbm/hr-ft^2, kg/m^2-sec)

This specifies the rated core flow and is used in conjunction with PCTF to arrive at the proper flow for the problem at hand. The units are specified by IOP(6).

PS - System pressure (psia)

The system pressure at which the core water properties are to be evaluated. Dome water properties are evaluated at PS-DPCD (See DPCD on card 300004).

CIN - Inlet condition (^{o}F, Btu/lbm, quality)

This item specifies the inlet temperature, enthalpy, or subcooling to the core, depending on the option specified in IOP(2). It is used to specify the inlet enthalpy. If IOP(2) is 1, 2, or 8 this variable is ignored.

Card	Word	Format	Description
300001			System Parameters at Current Conditions
	1	R	PCTP (>0.0)
	2	R	PCTF (>0.0)
	3	R	BPF
	4	R	CRFL

PCTP - Percent power

The value for CPOW is the nominal power value. It is adjusted by the percent power figure to obtain the actual power.

PCTF - Percent flow

The value of COFL is the nominal flow value. It is adjusted by the percent flow.

BPF - Bypass fraction

This is the fraction of the total recirculation flow that does not go through the heated region of the fuel assemblies. If IOP(7) is ≥1 this value is calculated internally and BPF is an initial guess.

CRFL - Control rod drive coolant flow

This is the amount of flow entering the core from the control rod drive housings (10^6 lb/hr).

Card	Word	Format	Description
300002	1	R	FPGR
	2	R	FPGC
	3	R	FPCB

FPGR - Fraction of power deposited in fuel rods

Fraction of power that is conducted through clad and deposited in active coolant. Used in calculating the appropriate heat flux for subcooled boiling and for the critical heat flux ratio, if requested.

FPGC - Fraction of power deposited in bypass region

Part of the power is generated in the water of the bypass flow, control rods, and channel walls, and eventually manifests itself in an enthalpy rise of the bypass flow. This fraction is specified by FPGC.

FPCB - Bypass conduction factor

Fraction of the power deposited in the bypass region (FPGC) which has been conducted through the channel walls. Channel wall heat conduction, therefore, equals FPCB* FPGC* CHANNEL POWER. Used to calculate the channel wall heat flux for subcooled boiling in the bypass region.

The following two cards provide information required to perform the system energy (heat) balance. The units of the feedwater, control rod and cleanup flows inputs are °F if IOP(2) = 1, and Btu/lb of IOP(2) = 2. For all other values of IOP(2), the data items on these card are ignored.

Card	Word	Format	Description	
300003 and 300004			Heat Balance Inputs	
300003	1	R	FWFL	Feedwater flow rate (10^6 lb/hr)
	2	R	TFWF	Temperature/enthalpy of feed water (°F, Btu/lbm)
	3	R	TCRF	Temperature/enthalpy of control rod drive flow (°F, Btu/lbm)
	4	R	CDFL	Cleanup and demineralizer (CD) flow (10^6, lb/hr)
	5	R	TCUIN	Input temperature/enthalpy to CD (°F, Btu/lbm)
	6	R	TCUOT	Exit temperature/enthalpy from CD (°F, Btu/lbm)
300004	1	R	CUC	Carry under fraction
	2	R	PUPO1	Recirculation pump 1 power (MW)
	3	R	PUPO2	Recirculation pump 2 power (MW)
	4	R	PUEF	Recirculation pump efficiency
	5	R	QRAD	System thermal losses (MW)
	6	R	DPCD	Core to dome pressure drop (psi)

Card	Word	Format	Description
400000			Common Geometry Input
	1	R	ALPLEN
	2	R	ZSTU
	3	R	AINLT
	4	R	ACHIM
	5	R	DECH
	6	R	APLEN
	7	R	BHDIAM
	8	R	BAREA

ALPLEN - Channel entrance flow are. (in^2)

Lower plenum flow area per channel. Used to account for acceleration losses from the lower plenum to support tube. If not defined or set to zero, ALPLEN is set equal to AINLT.

ZSTU - Support tube length (in)

See AINLT for further information.

AINLT - Fuel support piece flow area (in^2)

This variable can be used to account for acceleration, elevation, and friction losses in the fuel support piece. The flow for each fuel assembly enters from the inlet plenum into the support piece. AINLT is generally used in conjunction with ZSTU. When not defined or set to zero AINLT is set equal to AF(I). If ZSTU is zero then only an acceleration pressure drop will be calculated from AINLT to AF(I).

ACHIM - Chimney flow area (in^2)

The chimney is defined as the section of the fuel channel above the fuel bundle upper tie plate. For this section a friction and elevation pressure drop are calculated.

DECH - Chimney equivalent hydraulic diameter (in)

This variable is used to evaluate the friction loss in the chimney section. It is used in conjunction with ACHIM and ZCHI(I). If DECH is input as 0.0, then it defaults to DE(I).

APLEN - Channel exit flow area (in^2)

This is the upper plenum flow area per channel which is to be used in calculating the exit pressure change due to deceleration. When this variable is not specified or set to zero APLEN is set to AF(I).

BHDIAM - Bypass hydraulic diameter (in^2)

Defines the bypass flow hydraulic diameter. Used in the evaluation of total bypass region fluid properties.

BAREA - Bypass flow area (in^2)

Total of core bypass flow cross-sectional area.

Card	Word	Format	Description	
400001 - 40000NBYPC			Common Bypass Paths	
	1	I	NPATH	Number of paths of this type
	2 - 5	R	C1-C4	Coefficients for determination of path flow

Above information is repeated NBYPC (IOP(7)) times. The bypass flow is calculated by the following formula:

$$G_I = C_{1_I} \sqrt{dP_I}' + C_{2_I}\, dP_I^{\,C_{4_I}} + C_{3_I}\, dP_I^{\,2}$$

where: G_I is the bypass flow for path I in lb/hr and dP_I is the delta pressure for path I in psi. The core support plate pressure differential is used to evaluate the leakage flow for all common bypass paths.

Card	Word	Format	Description		
40II00			Geometry Data for Set II		
	1	A	IDGEOM		
	2	R	AF		
	3	R	DE		
	4	R	RODN	(>0.0)	Number of fuel rods
	5	R	RODD	(>0.0)	Fuel rod outer diameter
	6	R	TDE		

IDGEOM - Hollerith geometry set identifier

Geometry set input must be supplied for each unique hydraulic type (e.g., dimensions, leakage paths, orifice, and other loss coefficients). IDGEOM is an input 10-character hollerith identifier; the first character must be alphabetical, or be preceded by "10H."

AF(II) - Fuel assembly flow area (in^2)

This array defines the active flow area of the rodded section of the whole assembly. The inlet velocity calculated by the code corresponds to this flow area. If AF(II) is set to zero, all calculations for this channel type are omitted.

DE(II) - Fuel assembly equivalent hydraulic diameter (in)

This variable defines the hydraulic diameter of the bundle located in channel II. This equivalent diameter is based on the wetted perimeter and is used to evaluate friction losses, and in critical heat flux correlations.

$$DE = \frac{\text{4X cross-sectional flow area}}{\text{wetted perimeter}}$$

TDE(II) - Fuel assembly thermal diameter (in)

Thermal diameter:

$$TDE = \frac{\text{4X cross-sectional flow area}}{\text{heated perimeter}}$$

The input is required for critical power ratio (CPR) calculations.

Card	Word	Format	Description
40II01			Heights
	1	R	ZGEO
	2	R	ZHUB
	3	R	ZHET
	4	R	ZUHA
	5	R	ZCHI

ZGEO(II) - Reference length (in)

This is a reference length to account for different geometries that may exist in the same core (see Figure 4-3). This number is only used to calculate an additional elevation head.

ZUHB(II) - Unheated rodded length below active fuel (in)

See Figur -3 for explanation.

ZHET(II) - Active fuel rod length (in)

Heated length of the fuel rod. See Figure 4-3 for explanation.

ZUHA(II) - Unheated rodded length above active fuel (in)

See Figure 4-3 for explanation.

ZCHI(II) - Chimney height (in)

See Figure 4-3 for explanation.

Card	Word	Format	Description
40II02	1 - NGRD	R	HFSG(II,J)

HFSG(II,J) - Spacer grid location

II = channel number; J = relative spacer grid location within II. The spacer grid midpoint location is specified in terms of a fractional length of the active length (heated) of channel (II) with reference to bottom of the active length.

Card	Word	Format	Description	
40II03			Local Loss Coefficients (single phase)	
	1	R	ORCO	ORIFICE
	2	R	TICO	LTP
	3	R	GRCO	GRIDS
	4	R	EXCO	UTP

ORCO(II) - Single-phase orifice coefficient

The orifice pressure loss coefficient includes the losses due to the flow direction changes before and after the orifice and is based on the rodded flow area, AF(II).

TICO(II) - Lower tie plate loss coefficient

TICO is based on the rodded flow area, AF(II).

GRCO(II) - Single-phase spacer grid loss coefficient

Within a given assembly, it is assumed that each spacer grid has the same single-phase loss coefficient, based on the rodded flow area, AF(II). The pressure losses occurring under two-phase conditions are accounted for by a two-phase multiplier.

EXCO(II) - Exit loss coefficient

This coefficient takes into account the single-phase irreversible pressure losses of the upper tie plate and any obstructions beyond the upper unheated section of the fuel rod. The loss coefficient is based on the fuel assembly flow area, AF(II). The pressure losses occurring under two-phase conditions are accounted for by a two-phase multiplier.

Card	Word	Format	Description
40II04			Friction and Form Multiplier Data
	1	R	AA
	2	R	BB
	3	R	ELDG
	4	R	ELDE

AA(II) - Coefficient

Used in conjunction with BB if BLAUSIUS friction factor equation is used (see BB) or interpreted as the roughness (micro inch) if the Moody curve approximation or the COLEBROOK model is used (IOP(12) = 2 or 3).

BB(II) - Second coefficient for the BLAUSIUS relation

If the BLAUSIUS relation is chosen (IOP(12) = 1) the friction factor equation, $f = AA\ Re^{BB}$, is used.

ELDE(II), ELDG(II) - Form model coefficients

Coefficients for the upper tie plate (ELDE) and grid spacers (ELDG) for when the modified homogeneous (IOP(14) = 1) and Janssen (IOP(14) = 2) two-phase form multiplier model is used.

Card	Word	Format	Description	
40II05			Water Tube Data	
	1	R	NWTB	
	2	R	ZWHIN	
	3	R	ZWHOT	
	4	R	WTUID	Inner diameter of water tube (in)
	5	R	WTUOD	Outer diameter of water tube (in)
	6	R	PCIWT	
	7	R	PCEWT	
	8	R	FPGW	

NWTB(II) - Number of water tubes

The number of water tubes in an assembly of geometry type II.

ZWHIN(II) - Height of entrance to water tube (in)

Defines the elevation of the entrance to the water tube with reference to the bottom of the heated length for geometry type II. Assumes a single entrance.

ZWHOT(II) - Height of exit from water tube (in)

Defines the elevation of the exit from the water tube with reference to the bottom of the heated length for geometry type II. Assumes a single exit.

PCIWT(II), PCEWT(II) - Coefficients for entrance and exit effects

Coefficients used to evaluate the losses for entrance to (PCIWT) and exit from (PCEWT) the water tube. The water tube flow area is the reference area for these loss coefficients.

FPGW(II) - Fraction of power deposited in water tube

Fraction of channel power deposited per water tube. Used to calculate enthalpy rise in water tube.

Card	Word	Format	Description		
40II06	1-4	R	C1-C4	Bypass path 6	See card 400001 for usage of C-coefficients.
40II08	1-4	R	C1-C4	Bypass path 8	
40II09	1-4	R	C1-C4	Bypass path 9	See Figure 4-3 for path definition.

Card	Word	Format	Description
500000			Hot Bypass Region Definition
	1	R	HBAREA
	2	R	HBFFAC
	3	R	HRADP
	4	R	HDIAMB

HBAREA - Hot bypass flow area (in^2)

Cross-sectional area for bypass flow in the hot bypass region. Used in calculation of hot bypass region fluid properties. If HBAREA is not defined or set to zero, the hot bypass region calculation is omitted.

HBFFAC - Hot bypass flow factor

Ratio of hot bypass mass flux to average bypass mass flux ($lb/hr\text{-}ft^2$). Used in calculation of hot bypass region fluid properties.

HRADP - Hot bypass radial power factor

Ratio of power deposited in the hot bypass region to the power deposited in the bypass region per channel.

HDIAMB - Hot bypass region hydraulic diameter (in^2)

Defines the hydraulic diameter which will be used in the evaluation of the hot bypass region fluid properties.

Card	Word	Format	Description
50JJ00			Power and Channel Type Data for CT JJ
	1	R	NCHN
	2	R	RADP
	3	A	IDCHAN

NCHN(JJ) - Channels per channel type

This is an array of channels present for channel type JJ. The sum of NCHN(JJ),JJ = 1, NCT must equal NCHAN.

RADP(JJ) - Radial power distribution

This is the axially integrated relative channel power (including bypass and water tube power depositions). This value goes with AXP(K) to generate a three-dimensional power distribution. The values should be normalized over the whole core to an average of 1 (1.0 ± 0.0005 is allowed as input when ICHEK, IOP(3), is equal to zero).

IDCHAN(JJ) - Hollerith descriptor for each channel type

Channel types are distinguished by power peaking or R-factor differences. IDCHAN is a 10-character alphanumeric descriptor; it must begin with an alphabetic character, or be preceded by "10H."

Card	Word	Format	Description
50JJ01	1	I	NORF
	2	R	PEKL
	3	R	RFAC
	4	R	HINN

NORF(JJ) - Geometry set designator array

NORF defines the geometry set to be used in conjunction with channel type JJ.

PEKL(JJ) - Local peaking factor

Maximum power of a fuel rod in the given assembly relative to all other rods at the peak axial power node. Used only to evaluate the Critical Heat Flux Ratio.

RFAC(JJ) - R-factors

R-factors of the given assembly to be used in conjunction with the Critical Power Ratio correlation.

HINN(JJ) - Inlet enthalpy of channel JJ

HINN(JJ) need only be input for each channel if IOP(2) = 8 (IINLT = 8). The lowest inlet enthalpy specified for all channels is used as the inlet enthalpy of the bypass region.

Card	Word	Format	Description	
50JJ02	1-25	R	AXP(K,JJ)	Axial shape

AXP(K,JJ) - Axial power distribution

The relative axial power distribution can be used for design or exploratory calculations. This variable works in conjunction with RADP(JJ) to specify the local relative power. Input of AXP may take two forms (see IOP(5)), with reference to the channel (JJ) heated length or with reference to the internally calculated reference heated length. Values should be normalized over the core to a value of 1 (1.0 $\pm$ 0.0005 is allowed as input when ICHEK, IOP(3), is equal to zero).

As a user convenience, the AXP array need only be specified for the first channel type. If omitted, the AXP values of the last channel type for which the AXP array was specified will be used. If the 3-D power distribution is to be read in (e.g., IOP(5) = 2), the AXP values will be replaced by values read from the external file.

Table 6-1

AVAILABLE OPTIONS IN FIBWR

IOP(1) (MODCAL) — Calculational Modes

- *0 - The core pressure drop is calculated for a given core flow. CALMD is not necessary.
- 1 - The core flow is calculated for a given core pressure drop. CALMD (in psi) is required.

IOP(2) (IINLT) — Inlet Conditions

- *0 - CIN is inlet enthalpy (HIN) in Btu/lbm.
- 1 - Inlet enthalpy (HIN) is calculated from given flows and temperatures.
- 2 - Inlet enthalpy (HIN) is calculated from given flows and enthalpies.
- 3 - CIN is inlet temperature, °F.
- 4 - CIN is inlet subcooling in Btu/lbm.
- 5 - CIN is inlet subcooling in °F.
- 6 - CIN is inlet subcooling in °C.
- 7 - CIN is inlet quality.
- 8 - Inlet enthalpy is input for each channel in Btu/lbm.

IOP(3) (ICHEK) — Input Checking

- *0 - Exit on unacceptable input value.
- 1 - Bypass checking of input and execute.
- 2 - Check input deck; do not execute.

IOP(4) (NALL) — Printout

- 1 - Summary of results only
- *0 - Results (channel edits + summary) only
- 1 - Results + input echo
- 2 - Results + input echo + steam tables
- 3 - Results + input echo + nodal pressure drop components
- 4 - Results + input echo + nodal pressure drop components + steam tables
- 5-7 - All of above + increasing amounts of intermediate calculation results (warning: these options may generate a voluminous output).

IOP(5) (IFLUX) — Power Distribution

- *0 - Power distribution calculated from input AXP and RADP arrays.
- 1 - Correct AXP array based on the channel length and position relative to the lowest and tallest channel geometries in the core.
- 2 - Three dimensional distribution input (not operational at this time).

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*Default values are indicated by an asterisk.

Table 6-1 (continued)

IOP(6) Power and Flow Input Units (CPOW and COFL)

(NFLOPO) *0,1 - Power in MWT and flow in 10^6 lbm/hr
2 - Power in 10^6 Btu/hr-ft^2 and flow in 10^6 lbm/hr-ft^2
3 - Power in MWt and flow in 106 lbm/hr-ft^2
4 - Power in 10^6 Btu/hr-ft^2 and flow in 10^6 lbm/hr
5 - Power in w/cm^2 and flow in kg/m^2-sec

IOP(7) Bypass Models

(NBYPC) *0 - No bypass calculation. The user input bypass fraction and core flow are used to determine the bypass flow.
>0 - Number of common bypass paths (must be ≤ 8)

IOP(8) Water Tube Calculation Indicator

(NWATR) *0 - No water tube flow calculation
1 - Water tube flow and enthalpy rise calculated

IOP(9) Critical Power/Heat Flux Correlations

(NCHF) *0 - No critical power calculations will be performed.
1 - Reserved
2 - Janssen-Levy
3 - W-3 with Tong's bulk boiling f factor
4 - W-3 with Tong's subcooled boiling f factor
5 - B&W2 with B&Ws' subcooled boiling f factor

IOP(10) Subcooled Boiling Model

(NSCQ) *0,1 - EPRI model
2 - Saha-Zuber model
3 - Levy's model
4 - Equilibrium model

IOP(11) Void Fraction Correlations

(IVOID) *0,1 - EPRI model
2 - Dix
3 - Levy void fraction
4 - Zuber-Findlay
5 - Homogeneous

IOP(12) Single-Phase Friction Factor Correlations

(IFRIC) *0,1 - Friction factor is calculated from f + AA*RE**BB where the coefficients AA and BB are read in (BLAUSIUS relationship).
2 - Uses built-in friction factor approximation of Moody diagram.
3 - Colebrook equation

Table 6-1 (continued)

IOP(13) Two-Phase Fricti ı Multiplier

(IPHSQ) *0,1 - Baroczy
2 - Homogeneous
3 - Martinelli-Nelson without mass flux correction
4 - Martinelli-Nelson with mass flux correction
5 - Chisholm model (note: card 200004 is required)

IOP(14) Two-Phase Form Losses

(NFORM) *0,1 - Modified homogeneous model
2 - Modified Janssen model
3 - Romie slip model

IOP(15) Kinetic and Potential Effects in Energy Equation

(NKP) *0,1 - Effects are ignored.
2 - Kinetic and potential energy effects are included in intermediate enthalpy calculations used for the subcooled boiling model.

6.23 SAMPLE INPUT

Section 7.1

LISTING OF INPUT DATA FOR CASE 1

```
*  FIBWR MODEL FOR VERMONT YANKEE      SAMPLE PROBLEM
*
*****  PROGRAM DIMENSIONS, OPTIONS, CONVERGENCE
*
100000     368      4      24      6
200000     0     4     0     4
200001     0     0     3     1      0
200002   0    0     0    0    0 0
200003  50     0.0001      0.0
*
*
******  RATED CONDITIONS  ***********
*
300000      1593.0     48.0    1035.0    20.0
300001      100.0     100.0   0.11      0.023
300002       0.98      0.02       0.00000
*
*
****  HEAT BALANCE DATA  *******************
300003  6.41  372.0   100.0  0.0641  534.0  430.0
300004    0.0020  2.8263  2.8263  0.93  0.6  15.0
*
*
400000  24.04   4.563   7.31    27.233   4.338   45.46   4.554   11283.2
*
*LEAKAGE COEFFICIENTS FOR CHANNEL INDEPENDANT LEAKAGE FLOW PATHS
400001  89     3774.0   0.0   0.0    0.0  * CONTROL ROD DEPENDANT PATHS
400002  30     114.0      0.0   0.0    0.0  * INSTRUMENT TUBE DEPNDNT PATHS
400003  1    26496.0  0.0    0.0    0.0  * SHROUD-PERIPHERAL PATH
*  GEOMETRY SET-1 FOR CENTRAL 7X7 FUEL
400100  CEN-7   15.535  0.5765  49.0  0.563   0.7170
400101  7.7  1.25  144.0  17.932  2.43
400102  0.132  0.271  0.411  0.551  0.690  0.830  0.970
400103  29.65  7.58   1.21  1.35  * ORIF+LTP+STACER+UPPR GRID LOSS COEFFS
400104  0.1892   -0.2041   1.0   1.0
400106  75.0   0.0   0.0   0.0  *  FUEL SUPPORT-LTP LEAKAGE COEFF
400108  0.0   702.0  0.0   0.7106 * FINGER SPRING LEAKAGE COEFF
400109   1783.0   0.0   0.0    0.0   *  LTP  HOLES
*  GEOMETRY SET-2 FOR PERIPHERAL 7X7 FUEL
400200  PER-7   15.535  0.5765  49.0  0.563  0.7170
400201  7.7  1.25   144.0   17.932   2.43
400202  0.132  0.271  0.411  0.551   0.690   0.830  0.970
400203  164.76  7.58   1.21   1.35  * ORIF+LTP+SPACER+UPPR GRID LOSS COEFFS
400204  0.1892  -0.2041   1.0  1.0
400206  75.0  0.0  0.0  0.0   *  FUEL SUPPORT-LTP LEAKAGE COEFF
400208  0.0   702.0   0.0   0.7106  * FINGER SPRING LEAKAGE COEFF
400209    1783.0   0.0   0.0   0.0  * LTP  HOLES
* GEOMETRY SET-3 FOR CENTRAL 8X8 FUEL
400300  CEN-8  15.516  0.5162  63.0  0.493  0.6261
400301  7.7  1.25  144.0  17.872  2.49
400302  0.131  .272  0.411  0.551  0.691  0.831  0.971
400303  29.58  7.56  1.38  1.     * ORIF+LTP+SPACER+UPPR GRID LOSS COEFFS
400304  0.1892  -0.2041   1.0     .0
400305  1  2.0  146.0  0.425  0.493  75.1  0.5  0.0003 * WATER TUBE INFO
400306  75.0  0.0  0.0  0.0  * FUEL SUPPORT-LTP LEAKAGE COEFF
400308  0.0   702.0 0.0  0.7106  * FINGER SPRING LEAKAGE COEFF
400309  1783.0  0.0  0.0  0.0  * LTP HOLES LEAKAGE COEFF
* GEOMETRY SET-4 FOR PERIPHERAL 8X8 FUEL
400400  PER-8  15.516  0.5162  63.0  0.493  0.6261
400401  7.7  1.25  144.0  17.872  2.49
400402  0.131  .272  0.411  0.551  0.691  0.831  0.971
400403  164.38  7.56  1.38  1.41 * ORIF+LTP+SPACER+UPPR GRID LOSS COEFFS
```

```
400404  0.1892  -0.2041  1.0  1.0
400405  1 2.0  146.0  .425  .493   75.1  0.5  0.0003  * WATER TUBE INFO
400406  75.0  0.0  0.0  0.0  * FUEL SUPPORT-LTP LEAKAGE COEFF
400408  0.0  702.0  0.0  0.7106  * FINGER SPRING LEAKAGE COEFF
400409  1783.0  0.0  0.0  0.0  * LTP HOLES LEAKAGE COEFF
 * GEOMETRY SET-5 FOR CENTRAL 8X8R FUEL
400500  CEN-8R  15.8248  0.5324  62.0  0.483  0.6728
400501  7.7  1.25  150.0  11.872  2.49
400501  7.7  1.25  144.0  17.872  2.49  * CHNG IN 8X8R GEOM DUE TO SIMULATE
CARD ABOVE IS REPLACEMENT CARD.
400502  0.126  0.261  0.395  0.529  0.664  0.798  0.932
400502  .131 .272 .411 .551 .692 .831 .971 * CHNG DUE TO SIMULATE
CARD ABOVE IS REPLACEMENT CARD.
400503  30.77  7.86  1.24  1.46  * ORIF+LTP+SPACER+UPPR GRID LOSS COEFFS
400504  0.1892  -.2041  1.0  1.0
400505  2  2.0  152.0  .531  0.591  63.4  1.3  0.0007 * WATER TUBE INFO
400505  2 2.0 146.0 0.531 0.591 63.4 1.3 0.0007 * CHNG DUE TO SIMULATE
CARD ABOVE IS REPLACEMENT CARD.
400506  75.0  0.0  0.0  0.0  * FUEL SUPPORT-LTP LEAKAGE COEFF
400508  0.0  702.0  0.0  0.7106  * FINGER SPRING LEAKAGE COEFF
400509  1783.0  0.0  0.0  0.0  * LTP HOLES LEAKAGE COEFF
 * GEOMETRY SET-6 FOR PERIPHERAL 8X8R FUEL
400600  PER-8R  15.8248  0.5324  62.0  0.483  0.6728
400601  7.7  1.25  150.0  11.872  2.49
400602  0.126  0.261  0.395  0.529  0.664  0.798  0.932
400603  170.99 7.86  1.24  1.46  * ORIF+LTP+SPACER+UPPR GRID LOSS COEFFS
400604  0.1892  -0.2041  1.0  1.0
400605  2  2.0  152.0  0.531  0.591  63.4  1.3  0.0007  * WATER TUBE INFO
400605  2  2.0  146.0  0.531  0.591  63.4 1.3 0.0007* CHNG DUE TO SIMULATE
CARD ABOVE IS REPLACEMENT CARD.
400606  75.0  0.0  0.0  0.0  *  FUEL SUPPORT-LTP LEAKAGE COEFF
400608  0.0  702.0  0.0  0.7106  * FINGER SPRING LEAKAGECOEFF
400609  1783.0  0.0  0.0 0.0  * LTP HOLES LEAKAGE COEFF
 * POWER DISTRIBUTION DATA
500100     68   0.90588      CEN-7X7
500101      1    1.14      1.050
500102    .5775  .5775  1.1  1.1  1.22 1.22  1.15  1.15
+          1.10  1.10  1.07  1.07  1.03  1.03  1.06  1.06
+          1.1  1.1  1.1  1.1  0.92  0.92  0.5775  0.5775
500200    80   1.1   CEN-8X8
500201   3   1.14   1.050
500300    60   0.6          PER-8X8
500301    4   1.140    1.050
500400    160   1.14  CEN-8X8R
500401    5   1.14   1.050
 *
```

Section 7

FIBWR OUTPUT DESCRIPTION

7.1 GENERAL FORMAT

FIBWR output optionally consists of three distinct sections, input and case initialization, intermediate and characteristic channel calculations, and a results summary. By manipulating user option IOP(4), NALL, various sections of output may be generated including extensive intermediate calculation edits. To facilitate the explanation and understanding of the FIBWR output format, a sample output (which corresponds to the sample input of Section 6.3) is given at the end of this chapter. Note that the print option IOP(4) is set equal to 4 for this case.

The first item in each FIBWR case output is a card image echo of the input deck as submitted. This is followed by monitor messages from the input processing routines, when necessary, to identify replacement (overlayed) cards and data cards not used for that particular case. Referring to the sample input of Section 6, if the user establishes a "base" input deck with data available for several cases (e.g., geometry sets) and executes a case which uses some, but not all the input data, the unused cards will be referenced. The user should review that section to verify that the unused cards in the case are actually unnecessary. The required amount of storage for input and a processing flag value are returned from the input processing routines and printed. FIBWR is currently dimensioned to allow 4000 words of storage for user input. A value other than zero for the returned processing flag indicates a fatal error in input processing. The description of the error can be found with the input monitor messages.

Page headings are given for the remaining output. The heading contains the case sequence number, case title (user input), run date, and page number. Throughout the formatted output, the internal variable name has been included in the data heading to aid the user.

The balance of output, in order of appearance, is described below. Optional sections of output, based on the calculational model chosen, are enclosed in

parentheses. Sections affected by the value of IOP(4) contain the value of NALL for which they appear.

7.2 INPUT AND CASE INITIALIZATION (NALL > 0)

1. Core wide and general case input values. Card series 100000 and 300000, card 400000.

2. User option (IOP) array. Card series 200000. Option values, as input or default, are identified. A text section follows which defines several optional input variables and indicates the models and correlations chosen.

(3.) Optional heat balance calculation data. Cards 300003 and 300004.

4. Characteristic channel data. Composite of channel-type data (50JJ00 series) and geometry-type data (40II00 series).

(5.) Common bypass path coefficients. Cards 400001-40000NBYPC.

(6.) Characteristic channel dependent bypass coefficients. Cards 40II06, 40II08, and 40II09.

7. Characteristic channel spacer grid location array. Card 40II02.

(8.) Axial power distribution arrays. Card 50JJ02.

9. Radial power distribution array.

10. Relative power distribution (S) array. Calculated from the radial and axial power distribution arrays and normalized to the reference channel heated length (see IOP(5)). As an option the S array may be input directly (see IOP(5)).

11. Average radial and axial distribution factors. Output as a check on user normalization of input power distribution arrays.

12. NALL = 2 or NALL > 3. Water properties for subcooled and saturated conditions. Summarizes the 25-point interpolation table used internally. Calculated for the temperature interval from core input temperature to saturation temperature at the given core pressure.

7.3 INTERMEDIATE CALCULATIONS

(13.) Heat balance calculation results. Values are given in internal units. Printed if NALL > 0, and IINLT = 1 or 2.

14. Initial guess on core pressure drop. Value input as variable CALMD or as calculated by subroutine GUESS.

(15.) Iteration monitor. IOP(1) = 0. Selected results of outer iteration calculations. Data given are (L to R) Outer Iteration Number,

Converged Core Pressure Drop for that iteration, Calculated Core Flow, Relative Convergence Value, Bypass Region and Water Tube Flow, and the Estimated Core Pressure Drop, used as the required core pressure drop for the next outer iteration.

The remaining intermediate results describe converged calculations for each characteristic channel.

16. NALL > 2. Nodal pressure drop components. Pressure drop components and two-phase multipliers are given for each axial node.

(17.) NALL > 2. Water hole calculations. Values calculated for water tube from inlet to exit (user input dimensions).

18. NALL > 2. Pressure drop components for unheated channel regions (refer to Figure 4-3). Values calculated for combinations of channel, water tube, and bypass mass flows, where appropriate. Friction factors and two-phase multipliers are also included.

19. Results for each characteristic channel. Nodal fluid properties and conditions are summarized. Power depositions, active and bypass flows and pressure drops are given (bypass flow includes an average amount of common bypass flow). Top of node values are given for fluid properties, quality and voids, and channel wall pressure drop differentials. The path 6-9 leakage flow rates are printed.

7.4 CASE SUMMARY

(20.) Bypass flow calculations. Common or core support plate path data are given first along with the core support plate pressure differential. This is followed by a nodal summary of data for the total bypass region (top of node values are printed).

(21.) Hot bypass region results. If user has input data necessary for hot bypass calculations (card 500000), input data are echoed along with nodal summary of hot bypass fluid properties.

22. Data summary. Several input data values of interest are repeated along with final flow and fluid property values.

23. Summary of characteristic channel calculations. Channel identification and brief description (input) are followed by calculated values of interest for each channel.

24. An end of case and end of job banner follow the summary output.

7.5 SAMPLE OUTPUT

An execution of the sample input of Section 6.3 is presented in the following section. Underlined headings on the right hand margin refer to the output description contained in Sections 7.1 through 7.4.

```
STORAGE WORDS REQUIRED FOR INPUT =       527    INP RETURN INDICATOR =   0

******** THE FOLLOWING CARDS WERE NOT USED

              400609
              400608
              400606
              400605
              400604
              400603
              400602
              400601
              400600
              400209
              400208
              400206
              400204
              400203
              400202
              400201
              400200
```

Section 7.2
Part 1, 2

```
                    -INPUT DATA-
                    ------------

NCHAN  - NUMBER OF CHANNELS IN CORE REGION      =       368
NCT    - NUMBER OF CHANNEL TYPES                =         4
NSTEP  - NUMBER OF AXIAL NODES                  =        24

CPOW   - RATED CORE POWER                       =   1593.0000    PCTP   - PERCENT RATED POWER                       =   100.0000
COFL   - RATED CORE FLOW                        =     48.0000    PCTF   - PERCENT RATED CORE FLOW                   =   100.0000
PS     - CORE PRESSURE (PSIA)                   =   1035.0000    FPGR   - FRACTION POWER GEN IN FUEL RODS           =      .9800
BPF    - BYPASS FLOW FRACTION                   =       .1100    FPGC   - FRACTION POWER DEP. IN BYPASS             =      .0200
BAREA  - CORE BYPASS FLOW AREA (SQ. IN.)        =  11283.2000    FPGW   - FRACTION POWER GEN. IN WATER RODS         =      .0007
CRFL   - CONTROL ROD FLOW (MLB/HR)              =       .0230    FPCB   - FRAC. BYPASS POWER DEP. BY CONDUCTION     =     0.0000
HBAREA - HOT BYPASS FLOW AREA (SQ. IN.)         =      0.0000    HBFFAC - HOT BYPASS PENALTY FACTOR                 =     0.0000
BHDIAM - BYPASS HYDRAULIC DIAMETER (IN.)        =      4.5540    HRADP  - HOT BYPASS PEAKING FACTOR                 =     0.0000
APLEN  - CHANNEL EXIT FLOW AREA (SQ.IN.)        =     45.4600    DECH   - CHIMNEY HYDRAULIC DIAMETER (IN.)          =     4.3380
ALPLEN - CHANNEL INLET FLOW AREA (SQ.IN.)       =     24.0400    ZSTU   - SUPPORT TUBE LENGTH (IN.)                 =     4.5630
ACHIM  - CHIMNEY FLOW AREA (SQ.IN.)             =     27.2330    DSTU   - SUPPORT TUBE DIAMETER (IN.)               =     3.0508
ITLIM  - ITERATION LIMIT                        =          50    CALMO  - CORE PRESSURE DROP GUESS (PSIA)           =     0.0000
FERR   - CONVERGENCE CRITERIA                   =       .0001    CIN    - SEE NOTE BELOW FOR -CIN- DEFINITION       =    20.0000

          OPTIONS ARRAY

01 JOCAL  - CALCULATIONAL MODE                   =  0    02 IINLT  - INLET UNITS AND HEAT BALANCE        =  4
03 ICHEK  - INTERNAL INPUT CHECKING              =  0    04 NALL   - PRINT OUT INDICATOR                 =  4
05 IFLUX  - POWER DISTRIBUTION                   =  0    06 NFLOPO - POWER AND FLOW UNITS                =  0
07 NBYPC  - COMMON BYPASS PATHS CALCULATED       =  3    08 NWATR  - WATER TUBE CALCULATION IND.         =  1
09 NCHF   - CPR/CHF CORRELATION USED             =  0    10 NSCQ   - SUBCOOLED QUALITY MODEL             =  1
11 IVOID  - VOID FRACTION CORRELATION            =  1    12 IFRIC  - SINGLE PHASE FRICTION CORREL.       =  1
13 IPHSG  - TWO PHASE FRICT. MULTI. MODEL        =  1    14 NFORM  - TWO PHASE FORM LOSSES               =  1
15 NKP    - KE AND PE EFFECTS IN ENERGY EQUATN   =  1    16           NOT USED AT PRESENT                =  0

          PLEASE NOTE
          -----------

INTERPRET -CIN- AS INLET SUBCOOLING IN BTU/LBM.

INTERPRET -COFL- AS MASS FLOW IN MILLIONS OF LBM/HR

INTERPRET -CPOW- AS TOTAL POWER IN MEGAWATTS THERMAL

VOID FRACTION CORRELATION:                        EPRI
INITIATION OF SUBCOOLED BOILING METHOD:           EPRI
SUBCOOLED QUALITY MODEL:                          HYPERBOLIC TANGENT PROFILE FIT
SINGLE PHASE FRICTION CORRELATION:                BLAUSIUS RELATION
TWO PHASE FRICTION FACTOR MULTIPLIER MODEL:       BAROCZY
TWO PHASE FORM MULTIPLIER MODEL:                  HOMOGENEOUS
```

INPUT DATA CONTINUED

CHAN TYPE	GEO TYPE	NUMBER OF CHANNELS	FLOW AREA (SQ.IN.)	HYDRAULIC DIAMETER (IN.)	ROD DIAMETER	NUMBER OF RODS	RADIAL POWER	LOCAL PEAKING FACTOR	R FACTOR	THERMAL DIAMETER
L	IDGEOM	NCHN	AF	DE	RODD	RODN	RADP	PEKL	RFAC	TDE
1	CEN=7	68	15.5350	.5765	.5630	49.	.9059	1.1400	1.0500	.7170
2	CEN=8	80	15.5160	.5162	.4930	63.	1.1000	1.1400	1.0500	.6261
3	PER=8	60	15.5160	.5162	.4930	63.	.6000	1.1400	1.0500	.6261
4	CEN=8R	160	15.8248	.5324	.4830	62.	1.1400	1.1400	1.0500	.6728

CHAN TYPE	REFERENCE LENGTH (IN.)	LOWER UNHEATED ROD LENGTH (IN.)	ACTIVE FUEL LENGTH (IN.)	UPPER UNHEATED ROD LENGTH (IN.)	CHIMNEY HEIGHT (IN.)	ORIFICE LOSS COEF	TIEPLATE LOSS COEF	GRID LOSS COEF	EXIT LOSS COEF	WATER TUBE POWER FRACTION
L	ZGEO	ZUHB	ZHET	ZUHA	ZCHI	ORCO	TICO	GRCO	EXCO	FPGW
1	7.7000	1.2500	144.0000	17.9320	2.4300	29.6500	7.5800	1.2100	1.3500	0.0000
2	7.7000	1.2500	144.0000	17.8720	2.4900	29.5800	7.5600	1.3800	1.4100	.0003
3	7.7000	1.2500	144.0000	17.8720	2.4900	164.3800	7.5600	1.3800	1.4100	.0003
4	7.7000	1.2500	144.0900	17.8720	2.4900	30.7700	7.8600	1.2400	1.4600	.0007

CHAN TYPE	FRICTION MODEL COEFFICIENTS		FORM MODEL COEFFICIENTS		NUMBER OF WATER TUBES	WATER TUBE DIAMETERS (IN.)		WATER TUBE ELEVATIONS (IN.)		WATER TUBE ORIFICE LOSS COEFFICIENTS	
						INNER	OUTER	ENTRANCE	EXIT	ENTRANCE	EXIT
L	AA	BB	ELOG	ELDE	NWTB	WTUID	WTUOD	ZWHIN	ZWHOT	PCIWT	PCEWT
1	.1892	-.2041	1.0000	1.0000	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	.1892	-.2041	1.0000	1.0000	1	.4250	.4930	2.0000	146.0000	75.1000	.5000
3	.1892	-.2041	1.0000	1.0000	1	.4250	.4930	2.0000	146.0000	75.1000	.5000
4	.1892	-.2041	1.0000	1.0000	2	.5310	.5910	2.0000	146.0000	63.4000	1.3000

INPUT DATA CONTINUED

Section 7.2
Part 5, 6

BYPASS PATH COEFFICIENTS

COMMON PATHS	PATH	NUMBER	C-1	C-2	C-3	C-4
	1	89	3774.000	0.000	0.000	0.000
	2	30	114.000	0.000	0.000	0.000
	3	1	26496.000	0.000	0.000	0.000

CHANNEL DEPENDENT PATHS

CHAN TYPE	PATH					
1	6	1	75.000	0.000	0.000	0.000
	8	1	0.000	702.000	0.000	.711
	9	1	1783.000	0.000	0.000	0.000
2	6	1	75.000	0.000	0.000	0.000
	8	1	0.000	702.000	0.000	.711
	9	1	1783.000	0.000	0.000	0.000
3	6	1	75.000	0.000	0.000	0.000
	8	1	0.000	702.000	0.000	.711
	9	1	1783.000	0.000	0.000	0.000
4	6	1	75.000	0.000	0.000	0.000
	8	1	0.000	702.000	0.000	.711
	9	1	1783.000	0.000	0.000	0.000

INPUT DATA CONTINUED

SPACER GRID LOCATION ARRAY = HFSG(I,J) = FRACTION OF HEATED LENGTH

GEOMETRY								
1 CEN=7	.1320	.2710	.4110	.5510	.6900	.8300	.9700	0.0000
2 CEN=8	.1310	.2720	.4110	.5510	.6910	.8310	.9710	0.0000
3 PER=8	.1310	.2720	.4110	.5510	.6910	.8310	.9710	0.0000
4 CEN=8R	.1310	.2720	.4110	.5510	.6920	.8310	.9710	0.0000

AXIAL POWER DISTRIBUTION ARRAYS = AXP(K,I) = BY CHANNEL TYPE

1 CEN=7X7	.578	.578	1.100	1.100	1.220	1.220	1.150	1.150	1.100	1.100	1.070	1.070	1.030
	1.030	1.060	1.060	1.100	1.100	1.100	1.100	.920	.920	.578	.578		
2 CEN=8X8	.578	.578	1.100	1.100	1.220	1.220	1.150	1.150	1.100	1.100	1.070	1.070	1.030
	1.030	1.060	1.060	1.100	1.100	1.100	1.100	.920	.920	.578	.578		
3 PER=8X8	.578	.578	1.100	1.100	1.220	1.220	1.150	1.150	1.100	1.100	1.070	1.070	1.030
	1.030	1.060	1.060	1.100	1.100	1.100	1.100	.920	.920	.578	.578		
4 CEN=8X8R	.578	.578	1.100	1.100	1.220	1.220	1.150	1.150	1.100	1.100	1.070	1.070	1.030
	1.030	1.060	1.060	1.100	1.100	1.100	1.100	.920	.920	.578	.578		

Section 7.2
Part 9, 10, 11

INPUT RADIAL POWER DISTRIBUTION

CHANNEL				
1=10	.9059	1.1000	.6000	1.1400

RELATIVE POWER - S ARRAY - CALCULATED FROM AXP AND RADP DISTRIBUTIONS

CHANNEL													
1 CEN=7X7	.523	.523	.996	.996	1.105	1.105	1.042	1.042	.996	.996	.969	.969	.933
	.933	.960	.960	.996	.996	.996	.996	.833	.833	.523	.523		
2 CEN=8X8	.635	.635	1.210	1.210	1.342	1.342	1.265	1.265	1.210	1.210	1.177	1.177	1.133
	1.133	1.166	1.166	1.210	1.210	1.210	1.210	1.012	1.012	.635	.635		
3 PER=8X8	.347	.347	.660	.660	.732	.732	.690	.690	.660	.660	.642	.642	.618
	.618	.636	.636	.660	.660	.660	.660	.552	.552	.347	.347		
4 CEN=8X8R	.658	.658	1.254	1.254	1.391	1.391	1.311	1.311	1.254	1.254	1.220	1.220	1.174
	1.174	1.208	1.208	1.254	1.254	1.254	1.254	1.049	1.049	.658	.658		

AVERAGE RADIAL FACTOR = 1.00000

A CHECK ON USER NORMALIZATION (UNITY) OF INPUT POWER DISTRIBUTION ARRAYS

AVERAGE AXIAL FACTOR = 1.00042

Section 7.2
Part 12

WATER PROPERTIES FOR 1035,00000 PSIA

PROPERTY TABLES FOR SUBCOOLED LIQUID

TEMPERATURE (DEG-F)	DENSITY (LBM/CU.FT.)	ENTHALPY (BTU/LBM)	PRANDTL NUMBER	SPECIFIC HEAT (BTU/LBM)	VISCOSITY (LBM/FT. SEC.)	KINEMATIC VISCOSITY (SQ.FT./SEC.)	CONDUCTIVITY (BTU/SEC. FT. DEG-F)	DELTA ENTHALPY/ DELTA VOLUME
TEM	RHO	ENT	PRA	CP	EMU	ENU	CONC	DH/DV
533,0321	47,1375	527,9024	,8850	1,2569	,6504E-04	,1380E-05	,9238E-04	,4511E+05
533,6883	47,0963	528,7246	,8859	1,2586	,6496E-04	,1379E-05	,9228E-04	,4458E+05
534,3445	47,0548	529,5555	,8868	1,2603	,6487E-04	,1379E-05	,9219E-04	,4407E+05
535,0007	47,0128	530,3865	,8878	1,2620	,6479E-04	,1378E-05	,9210E-04	,4357E+05
535,6569	46,9704	531,2177	,8887	1,2637	,6471E-04	,1378E-05	,9201E-04	,4308E+05
536,3132	46,9277	532,0489	,8897	1,2654	,6462E-04	,1377E-05	,9192E-04	,4260E+05
536,9694	46,8845	532,8803	,8906	1,2671	,6454E-04	,1377E-05	,9182E-04	,4214E+05
537,6256	46,8409	533,7118	,8916	1,2688	,6446E-04	,1376E-05	,9173E-04	,4168E+05
538,2818	46,7970	534,5434	,8925	1,2705	,6438E-04	,1376E-05	,9164E-04	,4124E+05
538,9380	46,7526	535,3752	,8934	1,2722	,6429E-04	,1375E-05	,9155E-04	,4081E+05
539,5942	46,7078	536,2071	,8944	1,2739	,6421E-04	,1375E-05	,9146E-04	,4039E+05
540,2504	46,6627	537,0392	,8953	1,2756	,6413E-04	,1374E-05	,9136E-04	,3998E+05
540,9066	46,6172	537,8715	,8962	1,2773	,6405E-04	,1374E-05	,9127E-04	,3958E+05
541,5628	46,5713	538,7040	,8972	1,2789	,6396E-04	,1373E-05	,9118E-04	,3919E+05
542,2190	46,5250	539,5368	,8981	1,2806	,6388E-04	,1373E-05	,9109E-04	,3881E+05
542,8752	46,4784	540,3699	,8990	1,2823	,6380E-04	,1373E-05	,9100E-04	,3845E+05
543,5314	46,4314	541,2032	,9000	1,2840	,6372E-04	,1372E-05	,9091E-04	,3809E+05
544,1876	46,3840	542,0370	,9009	1,2857	,6363E-04	,1372E-05	,9081E-04	,3775E+05
544,8438	46,3363	542,8712	,9018	1,2874	,6355E-04	,1371E-05	,9072E-04	,3743E+05
545,5000	46,2883	543,7059	,9027	1,2891	,6347E-04	,1371E-05	,9063E-04	,3712E+05
546,1562	46,2399	544,5412	,9037	1,2908	,6338E-04	,1371E-05	,9054E-04	,3682E+05
546,8124	46,1912	545,3773	,9046	1,2925	,6330E-04	,1370E-05	,9045E-04	,3655E+05
547,4686	46,1423	546,2143	,9055	1,2942	,6322E-04	,1370E-05	,9035E-04	,3631E+05
548,1248	46,0930	547,0526	,9064	1,2959	,6314E-04	,1370E-05	,9026E-04	,3610E+05
548,7810	46,0460	547,9027	,9075	1,2978	,6305E-04	,1369E-05	,9017E-04	,3930E+05

PROPERTY TABLE FOR SATURATED CONDITIONS

TSAT	- SATURATED TEMPERATURE (DEG-F)	548,7810	HF	- FLUID ENTHALPY (BTU/LBM)	=	547,9027
RHOF	- FLUID DENSITY (LBM/CU.FT.)	46,0460	HFG	- EVAPORATION ENTHALPY (BTU/LBM)	=	643,7135
RHOG	- STEAM DENSITY (LBM/CU.FT.)	2,3304	HG	- STEAM ENTHALPY (BTU/LBM)	=	1191,6159
EMUS	- SATURATION VISCOSITY (LBM/FT.SEC)	,6305E-04	RFDRG	- RHOF / RHOG	=	19,7590
PRSAT	- PRANDTL NUMBER	,9075	EMUVL	- VISC. STEAM / VISC. WATER	=	,2037E+00
CONSAT	- CONDUCTIVITY (BTU/SEC FT. DEG-F)	,9017E-04	SIG	- SURFACE TENSION (LBS/FT.)	=	,1192E-02
CPSAT	- SPECIFIC HEAT (BTU/LBM DEG-F)	1,2978				

Section 7.3
Part 14, 15

INITIAL GUESS ON CORE PRESSURE DROP = 19.4015 PSIA

********** ITERATION MONITOR **********

OUTER ITERATION NUMBER	CALCULATED CORE PRESSURE DROP (PSI)	CALCULATED CORE FLOW (MLB/HR)	RELATIVE CONVERGENCE RATIO	BYPASS+WT FLOW (MLB/HR)	ESTIMATED CORE PRESSURE DROP (PSI)
ITROT	CODP	QFW	EPS	BPFW	
1	19.4015	41.3863	.1378E+00	4.5178	22.5019
2	22.5019	46.2169	.3715E-01	4.9748	23.6463
3	23.6463	47.8609	.2897E-02	5.1195	23.7452
4	23.7452	47.9977	.4780E-04	5.1308	23.7452

Section 7.3
Part 16, 17, 18

CHANNEL 1 INLET VELOCITY = 7.2320 FT/SEC

NODAL PRESSURE DROP COMPONENTS (PSI) — 2-PHASE MULTIPLIERS

NODE K	ACCELERATION DPAC1	ELEVATION DPEL1	FRICTION DPFR1	LOCAL DPFO1	FRICTION FI8Q	LOCAL FRM1
1	.0014	.1635	.0414	0.0000	1.0000	0.0000
2	.0014	[illegible]	.0415	0.0000	1.0000	0.0000
3	.0192	.1606	.0431	0.0000	1.0375	0.0000
4	.0199	.1545	.0460	.3334	1.1051	1.0237
5	.0299	.1480	.0495	0.0000	1.1849	0.0000
6	.0396	.1398	.0547	0.0000	1.3073	0.0000
7	.0443	.1310	.0617	.4148	[illegible]	[illegible]
8	.0505	.1224	.0695	0.0000	1.6548	0.0000
9	.0516	.1152	.0769	0.0000	1.8289	0.0000
10	.0521	.1070	.0844	.5848	2.0069	1.6544
11	.0478	.1008	.0918	0.0000	2.1799	0.0000
12	.0532	.0953	.0992	0.0000	2.3556	0.0000
13	.0507	.0903	.1063	0.0000	2.5247	0.0000
14	.0500	.0859	.1119	.6803	2.6575	2.0643
15	.0508	.0819	.1176	0.0000	2.7923	0.0000
16	.0503	.0782	.1233	0.0000	2.9290	0.0000
17	.0516	.0749	.1292	.8205	3.0683	2.4895
18	.0512	.0718	.1352	0.0000	3.2101	0.0000
19	.0509	.0690	.1411	0.0000	3.3520	0.0000
20	.0505	.0664	.1471	.9669	3.4963	2.9340
21	.0425	.0642	.1533	0.0000	3.6418	0.0000
22	.0419	.0628	.1590	0.0000	3.7760	0.0000
23	.0273	.0609	.1636	0.0000	3.8850	0.0000
24	.0265	.0598	.1671	1.0727	3.9691	[illegible]

PRESSURE DROP COMPONENTS (PSI) - UNHEATED REGIONS

	ACCELERATION	ELEVATION		FRICTION		LOCAL
LOW PLEN-SUP	1.2356	.1245	SUPPORT TUBE	.0183	ORIFICE	8.9376
SUP TUBE-CHAN	-1.0600	.2100	LOWER UNHEATED	.0086	LOWER TIEPLATE	2.1095
LOWER UNHEATED	---	.0341	UPPER UNHEATED	.5047	UPPER TIEPLATE	1.2152
UPPER UNHEATED	---	.1773	CHIMNEY	.0026		
CHIMNEY	-.4061	.0240				

TWO PHASE MULTIPLIERS

UPPER UNHEATED 4.0111 CHIMNEY 4.6663 UPPER TIEPLATE 3.3048

FRICTION FACTOR - F

SUPPORT TUBE .0090 L-UNHEATED .0149 RODDED .0149 U-UNHEATED .0149 CHIMNEY .0110

CHANNEL 1 TYPE: CEN-7X7 GEOMETRY: CEN-7 NUMBER: 68

INLET VELOCITY	7,23201 FT./SEC.	FLOW AREA	.1098 SQ.FT.
MASS FLUX	1,2272 MLB/HR,SQ.FT.	HYDRAULIC DIAMETER	.0480 FT.
ACTIVE FLOW	.1324 MLB/HR	BYPASS+WT FLOW (X1,0E4)	1,2936 LB/HR
ACTIVE POWER	3,8429 MWT	BYPASS+WT POWER	.0784 MWT
AVERAGE DENSITY	29,5814 LBM/CU.FT.	ACTIVE EXIT FLOW QUALITY	.1229
AVERAGE VOID FRACTION	.3805	ACTIVE EXIT VOID FRACTION	.6625
BOILING HEIGHT	5,7000 IN.	CHIMNEY FLOW QUALITY	.1229
DELTA ENTHALPY	99,6307 BTU/LBM	CHIMNEY VOID FRACTION	.6610

PRESSURE DROP COMPONENTS

FRICTION	2,9486 PSI	LOCAL	17,0956 PSI
ELEVATION	3,0350 PSI	ACCELERATION	.6644 PSI

NODE K	EQUIL. QUAL.	FLOW QUAL.	TOTAL ENTHAL. (BTU/LB)	VOID FRACT.	FLOW DENSITY (LB/CU.FT)	WATER TUBE DENSITY (LB/CU.FT)	WATER TUBE ENTHALPY (BTU/LB)	CHAN. WALL DELTA P (PSI)	RELATIVE POWER	PEAK HEAT FLUX (MBTU/HR,SQ.FT)	TOP OF NODE ELEVATION (IN.)
INL	-.0311	0,0000	527.9024	0,0000	47,1375	47,0837	528,9766	7,7497	---	---	0.00
1	-.0274	0,0000	530,2857	0,0000	47,0179	47,0720	529,2118	7,7070	.5231	.0996	6,00
2	-.0237	0,0000	532,6690	0,0000	46,8955	47,0602	529,4470	7,6645	.5[illegible]	.0996	12,00
3	-.0166	.0009	537,2086	.0316	45,2838	47,0375	529,8950	7,6055	.9965	.1897	18,00
4	-.0096	.0028	541,7482	.0634	43,7053	47,0150	530,3430	7,2149	.9965	.1897	24,00
5	-.0017	.0064	546,7831	.1094	41,5348	46,9897	530,8398	7,1503	1,1052	.2104	30,00
6	.0061	.0112	551,8179	.1652	38,9836	46,9643	531.3367	7,0788	1,1052	.2104	36,00
7	.0135	.0167	556,5639	.2210	36,4818	46,9402	531,8051	6,5895	1,0418	.1984	42,00
8	.0208	.0229	561,3099	.2769	33,9967	46,9160	532,2734	6,5094	1,0418	.1984	48,00
9	.0279	.0292	565,8495	.3269	31,7889	46,8927	532,7214	6,4288	.9965	.1897	54,00
10	.0349	.0358	570,3891	.3712	29,8374	46,8693	533,1694	5,8024	.9965	.1897	60,00
11	.0418	.0418	575,3481	.4072	28,2470	46,8465	533,6052	5,7237	.9693	.1846	66,00
12	.0487	.0487	579,7639	.4432	26,6697	46,8235	534,0410	5,6375	.9693	.1846	72,00
13	.0553	.0553	584,0146	.4740	25,3247	46,8013	534,4664	5,5515	.9331	.1777	78,00
14	.0619	.0619	588,2654	.5014	24,1270	46,7790	534,8799	4,7844	.9331	.1777	84,00
15	.0687	.0687	592,6399	.5266	23,0239	46,7560	535,3116	4,6950	.9602	.1828	90,00
16	.0755	.0755	597,0144	.5494	22,0299	46,7328	535,7433	4,6038	.9602	.1828	96,00
17	.0825	.0825	601,5541	.5707	21,0988	46,7087	536,1913	3,6881	.9965	.1897	102,00
18	.0896	.0896	606,0937	.5900	20,2522	46,6844	536,6393	3,5902	.9965	.1897	108,00
19	.0966	.0966	610,6333	.6077	19,4796	46,6601	537,0873	3,4892	.9965	.1897	114,00
20	.1037	.1037	615,1729	.6239	18,7709	46,6356	537,5353	2,4168	.9965	.1897	120,00
21	.1096	.1096	618,9697	.6367	18,2142	46,6151	537,9100	2,3134	.8334	.1587	126,00
22	.1155	.1155	622,7665	.6484	17,6994	46,5944	538,2847	2,2050	.8334	.1587	132,00
23	.1192	.1192	625,1498	.6558	17,3789	46,5814	538,5199	2,1070	.5231	.0996	138,00
24	.1229	.1229	627,5331	.6625	17,0835	46,5684	538,7551	.9338	.5231	.0996	144,00

	PATH 6 LTP-FUEL SUPPORT	PATH 9 LTP HOLES	PATH 8 CHANNEL-LTP	WATER TUBE
PRESSURE DROP (PSI)	8,81	8,81	7.76	0.00
LEAKAGE FLOW (LB/HR)	222.59	5291,60	3010.27	0.00

CHANNEL 2 INLET VELOCITY = 6.6131 FT/SEC

NODAL PRESSURE DROP COMPONENTS (PSI) 2-PHASE MULTIPLIERS

NODE K	ACCELERATION DPAC1	ELEVATION DPEL1	FRICTION DPFR1	LOCAL DPFO1	FRICTION FISQ	LOCAL FRM1
1	.0015	.1634	.0403	0.0100	1.0000	0.0000
2	.0030	.1626	.0404	0.0000	1.0014	0.0000
3	.0243	.1579	.0437	0.0000	1.0814	0.0000
4	.0282	.1494	.0475	.3270	1.1699	1.0498
5	.0446	.1392	.0540	0.0000	1.3244	0.0000
6	.0556	.1272	.0638	0.0000	1.5616	0.0000
7	.0596	.1156	.0742	.4629	1.8151	1.4750
8	.0602	.1056	.0846	0.0000	2.0684	0.0000
9	.0568	.0974	.0950	0.0000	2.3206	0.0000
10	.0614	.0904	.1048	.6408	2.5594	2.0389
11	.0576	.0842	.1126	0.0000	2.7496	0.0000
12	.0568	.0791	.1203	0.0000	2.9371	0.0000
13	.0540	.0747	.1278	0.0000	3.1212	0.0000
14	.0534	.0709	.1352	.8192	3.3017	2.6064
15	.0545	.0675	.1427	0.0000	3.4849	0.0000
16	.0541	.0644	.1510	0.0000	3.6878	0.0000
17	.0558	.0615	.1599	.9981	3.9033	3.1758
18	.0556	.0589	.1688	0.0000	4.1225	0.0000
19	.0555	.0565	.1778	0.0000	4.3415	0.0000
20	.0554	.0543	.1868	1.1838	4.5603	3.7666
21	.0464	.0524	.1947	0.0000	4.7533	0.0000
22	.0464	.0508	.2009	0.0000	4.9050	0.0000
23	.0269	.0497	.2059	0.0000	5.0283	0.0000
24	.0291	.0488	.2098	1.3172	5.1234	4.1910

SUMMARY OF WATER HOLE CALCULATION

TOTAL FLOW FOR ONE WATER TUBE	= 740.1047 LBM/HR	WATER TUBE POWER	=	1.4291 KW
TOTAL ACCELERATION PRESS DROP	= .0007 PSI	TOTAL ELEVATION PRESSURE DROP	=	3.6549 PSI
TOTAL FORM PRESSURE DROP	= 7.5463 PSI	TOTAL FRICTION PRESSURE DROP	=	.5877 PSI

PRESSURE DROP COMPONENTS (PSI) - UNHEATED REGIONS

	ACCELERATION	ELEVATION		FRICTION		LOCAL
LOW PLEN-SUP	1.0679	.1245	SUPPORT TUBE	.0161	ORIFICE	7.7258
SUP TUBE-CHAN	-.9155	.2100	LOWER UNHEATED	.0084	LOWER TIEPLATE	1.7998
LOWER UNHEATED	---	.0341	UPPER UNHEATED	.0344	UPPER TIEPLATE	1.3768
UPPER UNHEATED	---	.1449	CHIMNEY	.0030		
CHIMNEY	-.4773	.0202				

TWO PHASE MULTIPLIERS

UPPER UNHEATED 5.1435 CHIMNEY 6.1475 UPPER TIEPLATE 4.2354

FRICTION FACTOR - F

SUPPORT TUBE .0091 L-UNHEATED .0156 RODDED .0155 U-UNHEATED .0155 CHIMNEY .0112

CHANNEL 2 TYPE: CEN-8X8 GEOMETRY: CEN-8 NUMBER: 80

INLET VELOCITY	6,61311 FT./SEC.	FLOW AREA	,1076 SQ.FT.
MASS FLUX	1,1222 MLB/HR,SQ.FT.	HYDRAULIC DIAMETER	,0430 FT.
ACTIVE FLOW	,1209 MLB/HR	BYPASS+WT FLOW (X1,0E4)	1,4508 LB/HR
ACTIVE POWER	4,6650 MWT	BYPASS+WT POWER	,0967 MWT
AVERAGE DENSITY	26,1870 LBM/CU,FT.	ACTIVE EXIT FLOW QUALITY	,1735
AVERAGE VOID FRACTION	,4574	ACTIVE EXIT VOID FRACTION	,7347
BOILING HEIGHT	7,0521 IN.	CHIMNEY FLOW QUALITY	,1725
DELTA ENTHALPY	132,1504 BTU/LBM	CHIMNEY VOID FRACTION	,7328

PRESSURE DROP COMPONENTS

FRICTION	3,6045 PSI	LOCAL	16,6515 PSI
ELEVATION	2,7159 PSI	ACCELERATION	,7716 PSI

NODE K	EQUIL. QUAL.	FLOW QUAL.	TOTAL ENTHAL. (BTU/LB)	VOID FRACT.	FLOW DENSITY (LB/CU,FT)	WATER TUBE DENSITY (LB/CU,FT)	WATER TUBE ENTHALPY (BTU/LB)	CHAN. WALL DELTA P (PSI)	RELATIVE POWER	PEAK HEAT FLUX (MBTU/HR,SQ,FT)	TOP OF NODE ELEVATION (IN.)
INL	-,0311	0,0000	527,9024	0,0000	47,1375	47,0846	528,9583	9,2967	---	---	0,00
1	-,0261	0,0000	531,0701	0,0000	46,9780	47,0767	529,1168	9,2550	,0353	,1074	6,00
2	-,0212	,0000	534,2379	,0033	46,6680	47,0688	529,2753	9,2126	,0353	,1074	12,00
3	-,0119	,0021	540,2717	,0516	44,2760	47,0537	529,5771	9,1506	1,2100	,2046	18,00
4	-,0025	,0060	546,3056	,1039	41,7868	47,0384	529,8790	8,7610	1,2100	,2046	24,00
5	,0079	,0125	552,9977	,1784	38,3895	47,0215	530,2138	8,6862	1,3420	,2270	30,00
6	,0183	,0207	559,6897	,2574	34,8610	47,0046	530,5486	8,6024	1,3420	,2270	36,00
7	,0281	,0294	565,9978	,3281	31,7360	46,9885	530,8642	8,0525	1,2650	,2139	42,00
8	,0379	,0386	572,3059	,3877	29,1113	46,9724	531,1798	7,9643	1,2650	,2139	48,00
9	,0473	,0473	578,7880	,4355	27,0076	46,9569	531,4817	7,8772	1,2100	,2046	54,00
10	,0567	,0567	584,8218	,4803	25,0513	46,9413	531,7835	7,1416	1,2100	,2046	60,00
11	,0658	,0658	590,6911	,5165	23,4649	46,9262	532,0772	7,0487	1,1770	,1991	66,00
12	,0749	,0749	596,5604	,5479	22,0923	46,9110	532,3708	6,9540	1,1770	,1991	72,00
13	,0837	,0837	602,2102	,5745	20,9334	46,8963	532,6535	6,8588	1,1330	,1916	78,00
14	,0924	,0924	607,8601	,5980	19,9050	46,8816	532,9361	5,9411	1,1330	,1916	84,00
15	,1015	,1015	613,6745	,6196	18,9595	46,8663	533,2270	5,8373	1,1660	,1972	90,00
16	,1105	,1105	619,4890	,6390	18,1099	46,8511	533,5179	5,7285	1,1660	,1972	96,00
17	,1199	,1199	625,5228	,6573	17,3137	46,8352	533,8196	4,6136	1,2100	,2046	102,00
18	,1293	,1293	631,5566	,6738	16,5913	46,8192	534,1216	4,4905	1,2100	,2046	108,00
19	,1386	,1386	637,5905	,6889	15,9322	46,8033	534,4235	4,3608	1,2100	,2046	114,00
20	,1480	,1480	643,6243	,7027	15,3277	46,7872	534,7254	3,0392	1,[illegible]100	,2046	120,00
21	,1558	,1558	648,6708	,7134	14,8577	46,7738	534,9779	2,9023	1,[illegible]120	,1712	126,00
22	,1637	,1637	653,7173	,7235	14,4184	46,7603	535,2303	2,7591	1,0120	,1712	132,00
23	,1686	,1686	656,8850	,7289	14,1821	46,7519	535,5888	2,6304	,0353	,1074	138,00
24	,1735	,1735	660,0528	,7347	13,9301	46,7433	535,5473	1,1782	,0353	,1074	144,00

	PATH 6 LTP-FUEL SUPPORT	PATH 9 LTP HOLES	PATH 8 CHANNEL-LTP	WATER TUBE
PRESSURE DROP (PSI)	10,19	10,19	9,31	11,99
LEAKAGE FLOW (LB/HR)	239,41	5691,47	3425,39	740,10

CHANNEL 3 INLET VELOCITY = 4.1051 FT/SEC

NODAL PRESSURE DROP COMPONENTS (PSI) 2-PHASE MULTIPLIERS

NODE K	ACCELERATION DPAC1	ELEVATION DPEL1	FRICTION DPFR1	LOCAL DPFU1	FRICTION FISQ	LOCAL FHM1
1	.0005	.1634	.0171	0.0000	1.0000	0.0000
2	.0005	.1629	.0172	0.0000	1.0000	0.0000
3	.0077	.1592	.0182	0.0000	1.0612	0.0000
4	.0085	.1523	.0197	.1241	1.1455	1.0351
5	.0128	.1440	.0220	0.0000	1.2742	0.0000
6	.0164	.1341	.0256	0.0000	1.4756	0.0000
7	.0185	.1238	.0300	.1653	1.7283	1.3681
8	.0198	.1143	.0344	0.0000	1.9782	0.0000
9	.0199	.1058	.0389	0.0000	2.2402	0.0000
10	.0191	.0986	.0435	.2233	2.5033	1.8440
11	.0199	.0923	.0483	0.0000	2.7754	0.0000
12	.0196	.0868	.0517	0.0000	2.9719	0.0000
13	.0186	.0820	.0551	0.0000	3.1655	0.0000
14	.0184	.0779	.0584	.2835	3.3562	2.3409
15	.0188	.0742	.0618	0.0000	3.5504	0.0000
16	.0186	.0708	.0652	0.0000	3.7481	0.0000
17	.0191	.0677	.0687	.3441	3.9503	2.8811
18	.0190	.0648	.0727	0.0000	4.1773	0.0000
19	.0189	.0622	.0768	0.0000	4.4142	0.0000
20	.0189	.0598	.0809	.4070	4.6520	3.3603
21	.0146	.0579	.0847	0.0000	4.8711	0.0000
22	.0157	.0562	.0882	0.0000	5.0714	0.0000
23	.0103	.0549	.0911	0.0000	5.2349	0.0000
24	.0099	.0539	.0933	.4521	5.3612	3.7[illegible]32

SUMMARY OF WATER HOLE CALCULATION

TOTAL FLOW FOR ONE WATER TUBE = 372.3552 LBM/HR WATER TUBE POWER = .7795 KW
TOTAL ACCELERATION PRESS DROP = .0002 PSI TOTAL ELEVATION PRESSURE DROP = 3.8542 PSI
TOTAL FORM PRESSURE DROP = 1.9099 PSI TOTAL FRICTION PRESSURE DROP = .1712 PSI

PRESSURE DROP COMPONENTS (PSI) - UNHEATED REGIONS

	ACCELERATION	ELEVATION		FRICTION		LOCAL
LOW PLEN-SUP	.3958	.1245	SUPPORT TUBE	.0066	ORIFICE	15.9131
SUP TUBE-CHAN	-.3393	.2100	LOWER UNHEATED	.0036	LOWER TIEPLATE	.6771
LOWER UNHEATED	---	.0341	UPPER UNHEATED	.2821	UPPER TIEPLATE	.4719
UPPER UNHEATED	---	.1605	CHIMNEY	.0013		
CHIMNEY	-.1670	.0224				

TWO PHASE MULTIPLIERS

UPPER UNHEATED 5.3959 CHIMNEY 6.1222 UPPER TIEPLATE 3.7759

FRICTION FACTOR - F

SUPPORT TUBE .0101 L-UNHEATED .0172 RODDED .0171 U-UNHEATED .0170 CHIMNEY .0124

CHANNEL 3 TYPE: PER-8X8 GEOMETRY: PER-8 NUMBER: 60

INLET VELOCITY	4,10513 FT./SEC.	FLOW AREA	,1078 SQ.FT.
MASS FLUX	,6966 MLB/HR,SQ.FT.	HYDRAULIC DIAMETER	,0430 FT.
ACTIVE FLOW	,0751 MLB/HR	BYPASS+WT FLOW (X1,0E4)	,9112 LB/HR
ACTIVE POWER	2,5446 MWT	BYPASS+WT POWER	,0527 MWT
AVERAGE DENSITY	27,8374 LBM/CU.FT.	ACTIVE EXIT FLOW QUALITY	,1487
AVERAGE VOID FRACTION	,4200	ACTIVE EXIT VOID FRACTION	,7016
BOILING HEIGHT	5,7000 IN.	CHIMNEY FLOW QUALITY	,1480
DELTA ENTHALPY	116,1778 BTU/LBM	CHIMNEY VOID FRACTION	,6982

PRESSURE DROP COMPONENTS

FRICTION	1,5569 PSI	LOCAL	19,0613 PSI
ELEVATION	2,8713 PSI	ACCELERATION	,2536 PSI

NODE K	EQUIL. QUAL.	FLOW QUAL.	TOTAL ENTHAL. (BTU/LB)	VOID FRACT.	FLOW DENSITY (LB/CU.FT)	WATER TUBE DENSITY (LB/CU.FT)	WATER TUBE ENTHALPY (BTU/LB)	CHAN. WALL DELTA P (PSI)	RELATIVE POWER	PEAK HEAT FLUX (MBTU/HR,SQ.FT)	TOP OF NODE ELEVATION (IN.)
INL	-,0311	0,0000	527,9024	0,0000	47,1375	47,0910	528,8302	2,3420	---	---	0,00
1	-,0267	0,0000	530,6859	0,0000	46,9976	47,0825	529,0020	2,3245	,3465	,0586	6,00
2	-,0224	0,0000	533,4694	0,0000	46,8536	47,0739	529,1738	2,3074	,3465	,0586	12,00
3	-,0142	,0015	538,7713	,0395	44,8699	47,0575	529,5011	2,2855	,6600	,1116	18,00
4	-,0059	,0043	544,0731	,0813	42,8432	47,0410	529,8284	2,1441	,6600	,1116	24,00
5	,0032	,0093	549,9534	,1401	40,1198	47,0227	530,1914	2,1281	,7320	,1238	30,00
6	,0123	,0158	555,8337	,2067	37,1161	47,0043	530,5544	2,1147	,7320	,1238	36,00
7	,0209	,0230	561,3766	,2718	34,2203	46,9868	530,8965	1,9395	,6900	,1167	42,00
8	,0295	,0307	566,9195	,3314	31,5896	46,9694	531,2387	1,9333	,6900	,1167	48,00
9	,0378	,0385	572,2214	,3828	29,3281	46,9525	531,5659	1,9307	,6600	,1116	54,00
10	,0460	,0460	577,9753	,4254	27,4503	46,9357	531,8932	1,7082	,6600	,1116	60,00
11	,0540	,0540	583,1326	,4645	25,7398	46,9192	532,2116	1,7093	,6420	,1086	66,00
12	,0620	,0620	588,2899	,4985	24,2537	46,9027	532,5299	1,7127	,6420	,1086	72,00
13	,0698	,0698	593,2544	,5273	22,9958	46,8868	532,[illegible]	1,7183	,6180	,1045	78,00
14	,0775	,0775	598,2189	,5529	21,8778	46,8707	533,1428	1,4411	,6180	,1045	84,00
15	,0854	,0854	603,3280	,5764	20,8492	46,8542	533,4582	1,4473	,6360	,1076	90,00
16	,0933	,0933	608,4371	,5975	19,9243	46,8377	533,7736	1,4534	,6360	,1076	96,00
17	,1016	,1016	613,7389	,6174	19,0576	46,8203	534,1008	1,1142	,6600	,1116	102,00
18	,1098	,1098	619,0408	,6353	18,2714	46,8030	534,4281	1,1179	,6600	,1116	108,00
19	,1180	,1180	624,3427	,6518	17,5543	46,7856	534,7554	1,1200	,6600	,1116	114,00
20	,1263	,1263	629,6446	,6668	16,8969	46,7682	535,0827	,7120	,6600	,1116	120,00
21	,1332	,1332	634,0789	,6775	16,4296	46,7536	535,3564	,7114	,5520	,0934	126,00
22	,1401	,1401	638,5132	,6884	15,9524	46,7389	535,6301	,7062	,5520	,0934	132,00
23	,1444	,1444	641,2967	,6953	15,6500	46,72[illegible]	535,8019	,7037	,3465	,0586	138,00
24	,1487	,1487	644,0802	,7016	15,3759	46,7204	535,9738	,2473	,3465	,0586	144,00

	PATH 6 LTP-FUEL SUPPORT	PATH 9 LTP HOLES	PATH 8 CHANNEL-LTP	WATER TUBE
PRESSURE DROP (PSI)	2,68	2,68	2,35	5,94
LEAKAGE FLOW (LB/HR)	122,86	2920,69	1286,57	372,36

CHANNEL 4 INLET VELOCITY = 6.5980 FT/SEC

NODAL PRESSURE DROP COMPONENTS (PSI) 2-PHASE MULTIPLIERS

NODE K	ACCELERATION DPAC1	ELEVATION DPEL1	FRICTION DPFR1	LOCAL DPFO1	FRICTION FISQ	LOCAL FRM1
1	.0015	.1634	.0286	0.0000	1.0000	0.0000
2	.0044	.1623	.0387	0.0000	1.0031	0.0000
3	.0237	.1575	.0420	0.0000	1.0836	0.0000
4	.0289	.1490	.0458	.2932	1.1753	1.0522
5	.0458	.1385	.0522	0.0000	1.3357	0.0000
6	.0570	.1263	.0620	0.0000	1.5816	0.0000
7	.0605	.1146	.0722	.41[illegible]	1.8342	1.49[illegible]8
8	.0612	.1046	.0824	0.0000	2.0984	0.0000
9	.0590	.0963	.0926	0.0000	2.3565	0.0000
10	.0609	.0893	.1018	.5811	2.5899	2.0670
11	.0582	.0833	.1094	0.0000	2.7834	0.0000
12	.0573	.0782	.1169	0.0000	2.9743	0.0000
13	.0545	.0738	.1242	0.0000	3.1617	0.0000
14	.0540	.0701	.1315	.7434	3.3454	2.6444
15	.0551	.0667	.1388	0.0000	3.5319	0.0000
16	.0547	.0636	.1472	0.0000	3.7450	0.0000
17	.0564	.0608	.1558	.9074	3.9643	3.2279
18	.0563	.0582	.1646	0.0000	4.1874	0.0000
19	.0561	.0558	.1733	0.0000	4.4103	0.0000
20	.0561	.0536	.1821	1.0752	4.6329	3.8246
21	.0470	.0518	.1893	0.0000	4.8170	0.0000
22	.0470	.0502	.1954	0.0000	4.9713	0.0000
23	.0272	.0490	.2003	0.0000	5.0969	0.0000
24	.0295	.0482	.2041	1.196[illegible]	5.1936	4.2563

SUMMARY OF WATER HOLE CALCULATION

TOTAL FLOW FOR ONE WATER TUBE =	1205.9536 LBM/HR	WATER TUBE POWER =	3.4558 KW
TOTAL ACCELERATION PRESS DROP =	.0012 PSI	TOTAL ELEVATION PRESSURE DROP =	3.8476 PSI
TOTAL FORM PRESSURE DROP =	7.0381 PSI	TOTAL FRICTION PRESSURE DROP =	.4861 PSI

PRESSURE DROP COMPONENTS (PSI) - UNHEATED REGIONS

	ACCELERATION	ELEVATION		FRICTION		LOCAL
LOW PLEN-SUP	1.1260	.1245	SUPPORT TUBE	.0169	ORIFICE	8.1462
SUP TUBE-CHAN	-.9760	.2100	LOWER UNHEATED	.0080	LOWER TIEPLATE	1.9056
LOWER UNHEATED	---	.0341	UPPER UNHEATED	.0247	UPPER TIEPLATE	1.4651
UPPER UNHEATED	---	.1441	CHIMNEY	.0031		
CHIMNEY	-.4618	.0201				

TWO PHASE MULTIPLIERS

UPPER UNHEATED 5.1538 CHIMNEY 6.1287 UPPER TIEPLATE 4.2578

FRICTION FACTOR - F

SUPPORT TUBE .0091 L-UNHEATED .0155 RODDED .0154 U-UNHEATED .0153 CHIMNEY .0112

CHANNEL 4 TYPE: CEN-8X8R GEOMETRY: CEN-8R NUMBER: 160

INLET VELOCITY	6,59799 FT./SEC.	FLOW AREA	.1099 SQ.FT.
MASS FLUX	1,1196 MLB/HR.SQ.FT.	HYDRAULIC DIAMETER	.0444 FT.
ACTIVE FLOW	.1230 MLB/HR	BYPASS+WT FLOW (X1.0E4)	1,5899 LB/HR
ACTIVE POWER	4,8292 MWT	BYPASS+WT POWER	.1056 MWT
AVERAGE DENSITY	25,9803 LBM/CU.FT.	ACTIVE EXIT FLOW QUALITY	.1771
AVERAGE VOID FRACTION	.4621	ACTIVE EXIT VOID FRACTION	.7387
BOILING HEIGHT	5,3359 IN.	CHIMNEY FLOW QUALITY	.1737
DELTA ENTHALPY	134,3988 BTU/LBM	CHIMNEY VOID FRACTION	.7347

PRESSURE DROP COMPONENTS

FRICTION	3,5137 PSI	LOCAL	16,7322 PSI
ELEVATION	2,6978 PSI	ACCELERATION	.8006 PSI

NODE K	EQUIL. QUAL.	FLOW QUAL.	TOTAL ENTHAL. (BTU/LB)	VOID FRACT.	FLOW DENSITY (LB/CU.FT)	WATER TUBE DENSITY (LB/CU.FT)	WATER TUBE ENTHALPY (BTU/LB)	CHAN. WALL DELTA P (PSI)	RELATIVE POWER	PEAK HEAT FLUX (MBTU/HR.SQ.FT)	TOP OF NODE ELEVATION (IN.)
INL	-.0311	0,0000	527,9024	0,0000	47,1375	47,0837	528,9766	8,7732	---	---	0,00
1	-.0261	.0000	531,1250	.0000	46,9751	47,0720	529,2118	8,7332	.6584	.1155	6,00
2	-.0211	.0001	534,3477	.0064	46,5242	47,0602	529,4470	8,6913	.6584	.1155	12,00
3	-.0115	.0022	540,4860	.0534	44,1912	47,0376	529,8950	8,6314	1,2540	.2200	18,00
4	-.0020	.0062	546,6244	.1072	41,6361	47,0150	530,3430	8,2776	1,2540	.2200	24,00
5	.0086	.0130	553,4324	.1835	38,1611	46,9897	530,8398	8,2039	1,3908	.2440	30,00
6	.0192	.0215	560,2404	.2658	34,5769	46,9643	531,3367	8,1213	1,3908	.2440	36,00
7	.0291	.0304	566,6578	.3347	31,4453	46,9402	531,8051	7,6180	1,3110	.2300	42,00
8	.0391	.0397	573,0752	.3945	28,8168	46,9160	532,2734	7,5321	1,3110	.2300	48,00
9	.0486	.0486	579,6285	.4433	26,6679	46,8927	532,7214	7,4462	1,2540	.2200	54,00
10	.0582	.0582	585,7668	.4867	24,7705	46,8693	533,1694	6,7751	1,2540	.2200	60,00
11	.0675	.0675	591,7378	.5226	23,1983	46,8465	533,6052	6,6859	1,2198	.2140	66,00
12	.0767	.0767	597,7088	.5538	21,8384	46,8235	534,0410	6,5949	1,2198	.2140	72,00
13	.0857	.0857	603,4565	.5800	20,6904	46,8013	534,4604	6,5035	1,1742	.2060	78,00
14	.0946	.0946	609,2042	.6033	19,6719	46,7790	534,8799	5,6657	1,1742	.2060	84,00
15	.1038	.1038	615,1194	.6247	18,7355	46,7560	535,3116	5,5660	1,2084	.2120	90,00
16	.1130	.1130	621,0346	.6440	17,8941	46,7328	535,7433	5,4612	1,2084	.2120	96,00
17	.1228	.1225	627,1729	.6620	17,1057	46,7087	536,1913	4,4413	1,2540	.2200	102,08
18	.1320	.1320	633,3113	.6784	16,3903	46,6844	536,6393	4,3225	1,2540	.2200	108,00
19	.1416	.1416	639,4497	.6933	15,7375	46,6601	537,0873	4,1973	1,2540	.2200	114,00
20	.1511	.1511	645,5880	.7070	15,1387	46,6356	537,5353	2,9890	1,2540	.2200	120,00
21	.1591	.1591	650,7219	.7177	14,6732	46,6151	537,9100	2,8576	1,0488	.1840	126,00
22	.1671	.1671	655,8559	.7276	14,2380	46,5944	538,2847	2,7199	1,0488	.1840	132,00
23	.1721	.1721	659.[illegible]35	.7330	14,0045	46,5814	538,5199	2,5971	.6584	.1155	138,00
24	.1771	.1771	667,3011	.7387	13,7549	46,5684	538,7551	1,2715	.6584	.1155	144,00

	PATH LTP-FUEL SUPPORT	PATH 9 LTP HOLES	PATH 8 CHANNEL-LTP	WATER TUBE
PRESSURE DROP (PSI)	9,71	9,71	8,78	11,37
LEAKAGE FLOW (LB/HR)	233,72	5556,24	3287,20	2411,91

SUMMARY OF BYPASS FLOW CALCULATIONS

CORE SUPPORT PLATE PRESSURE DROP IS 19,1240 PSI

COMMON LEAKAGE PATHS

PATH	NUMBER OF PATHS	LEAKAGE FLOW (MLB/HR)
1	89	1,4689
2	30	,0150
3	1	,1159
		======
		1,5997

CRD COOLANT FLOW ,0230

CHANNEL DEP. FLOW 3,0403

[illegible]TAL BYPASS FLOW 4,6630 MLB/HR

BYPASS REGION RESULTS

NODE K	EQUIL. QUAL.	FL[illegible] QUAL.	TOTAL ENTHAL. (BTU/LB)	VOID FRACT.	TOTAL DENSITY (LB/CU.FT)	POWER DEPOSITION (BTU/LB)	TOP OF NODE ELEVATION (IN.)
INL	-,0311	0,0000	527,9024	0,0000	47,1375	---	0,00
1	-,0302	0,0000	528,4638	0,0000	47,1094	,5614	6,00
2	-,0293	0,0000	529,0252	0,0000	47,0813	,5614	12,00
3	-,0277	0,0000	530,0946	0,0000	47,0276	1,0694	18,00
4	-,0260	0,0000	531,1640	0,0000	46,9732	1,0694	24,00
5	-,0242	0,0000	532,3500	0,0000	46,9120	1,1860	30,00
6	-,0223	0,0000	533,5361	0,0000	46,8501	1,1860	36,00
7	-,0206	0,0000	534,6540	0,0000	46,7910	1,1180	42,00
8	-,0188	0,0000	535,[illegible]720	0,0000	46,7312	1,1180	48,00
9	-,0172	0,0000	536,8414	0,0000	46,6734	1,0694	54,00
10	-,0155	0,0000	537,9108	0,0000	46,6150	1,0694	60,00
11	-,0139	0,0000	538,9510	0,0000	46,5576	1,0402	66,00
12	-,0123	0,0000	539,9912	0,0000	46,4996	1,0402	72,00
13	-,0107	0,0000	540,9925	0,0000	46,4433	1,0013	78,00
14	-,0092	0,0000	541,9939	0,0000	46,3865	1,0013	84,00
15	-,0076	0,0000	543,0244	0,0000	46,3275	1,0305	90,00
16	-,0060	0,0000	544,0549	0,0000	46,2681	1,0305	96,00
17	-,0043	0,0000	545,1242	0,0000	46,2060	1,0694	102,00
18	-,0027	0,0000	546,1936	0,0000	46,1435	1,0694	108,00
19	-,0010	0,0000	547,2630	0,0000	46,0814	1,0694	114,00
20	,0007	,0007	548,9721	,0083	45,6820	1,0694	120,00
21	,0021	,0021	549,8665	,0213	45,1164	,8944	126,00
22	,0034	,0034	550,7608	,0331	44,5988	,8944	132,00
23	,0043	,0043	551,3223	,0403	44,2841	,5614	138,00
24	,0052	,0052	551,8837	,0471	43,9870	,5614	144,[illegible]

SUMMARY OF CALCULATIONS

TOTAL CORE POWER (MWT)	1593,0000
REQUIRED MASS FLOW (MLB/HR)	48,0000
SYSTEM PRESSURE (PSIA)	1035,0000
INLET ENTHALPY (BTU/LBM)	527,9024
FRACTION OF POWER COND. THROUGH CLAD	,9800
FRACTION OF POWER DEPOSITED IN BYPASS	,0200
FRACTION OF POWER DEP. IN WATER TUBES	,0007
TOTAL ACTIVE FLOW AREA (SQ. FT.)	40,0041
TOTAL HEAT TRANSFER AREA (1000 SQ. FT.)	34,6063
ACTIVE COOLANT DENSITY (LBM/CU,FT)	26,9934
AVERAGE ACTIVE COOLANT VOID FRACTION	,4393
AVERAGE EXIT VOID FRACTION	,7178
PLENUM TO PLENUM PRESSURE DROP (PSI)	23,7452
STEAM FLOW RATE (MLB/HR)	6,9646
NUMBER OF CHANNELS	368
CALCULATED MASS FLOW (MLB/HR)	47,9974
CALCULATED MASS FLUX (MLB/HR/SQ,FT)	1,0716
INLET SUBCOOLING (BTU/LBM)	20,0003
ACTIVE COOLANT FLOW (MLB/HR)	42,8669
BYPASS COOLANT FLOW (MLB/HR)	4,6630
WATER TUBE COOLANT FLOW (MLB/HR)	,4675
MAXIMUM HEAT FLUX (MBTU/HR/SQ,FT)	,2440
AVERAGE HEAT FLUX (MBTU/HR/SQ,FT)	,1539
AVERAGE MODERATOR DENSITY (LBM/CU,FT)	29,0254
AVERAGE UPPER PLENUM QUALITY	,1451
CHANNEL EXIT QUALITY	,1602
CORE SUPPORT PLATE PRESSURE DROP (PSI)	19,1240
BYPASS AND WATER TUBE FLOW FRACTION	,1069

MAXIMUM HEAT FLUX OCCURS IN CHANNEL 4 AT STEP 5

CHANNEL SUMMARY

CHANNEL NUMBER	1	2	3	4
CHANNEL TYPE	CEN-7X7	CEN-8X8	PER-8X8	CEN-8X8R
CHANNEL GEOMETRY	CEN-7	CEN-8	PER-8	CEN-8R
NUMBER PER TYPE	68	80	60	160
NUMBER OF FUEL RODS	49,0000	63,0000	63,0000	62,0000
ACTIVE FUEL LENGTH (IN)	144,0000	144,0000	144,0000	144,0000
REL ASSEMBLY POWER FRACTION	,9059	1,1000	,6000	1,1400
ASSEM HEAT TRANS AREA (SQ,FT)	86,6671	97,5747	97,5747	94,0781
ASSM HEAT TRAN (MBTU/HR/SQFT)	,1513	,1632	,0890	,1754
ASSEMBLY FLOW AREA (SQ,IN)	15,5350	15,5160	15,5160	15,8248
ASSEM HYDRAULIC DIAM (IN)	,5765	,5162	,5162	,5324
MASS FLUX (MLB/HR,SQ,FT)	1,2272	1,1222	,6966	1,1196
INLET FLOW VELOCITY (FT/SEC)	7,2320	6,6131	4,1051	6,5980
ACTIVE FLOW RATE (1000 LB/HR)	132,3965	120,9181	75,0607	123,0428
LEAKAGE FLOWS (1000 LB/HR):				
LTP-FUEL SUPPORT	,2226	,2394	,1229	,2337
LTP HOLES	5,2916	5,6915	2,9207	5,5562
CHANNEL-LTP	3,0103	3,4254	1,2866	3,2872
WATER TUBE	0,0000	,7401	,3724	2,4119
NON BOILING LENGTH (IN)	5,7000	7,0521	5,7000	5,3350
ACTIVE EXIT QUALITY	,1229	,1735	,1487	,1771
VOID FRACT AT TOP OF ACTIVE	,6625	,7347	,7016	,7387
AVERAGE VOID FRACTION	,3805	,4574	,4200	,4621

END OF CASE: FIBWR MODEL FOR VERMONT YANKEE SAMPLE PROBLEM 81/01/26

END OF JOB

Section 8

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1. EPRI NP-1924-CCM 2. RP1754-1 3. Code Development and Validation Program
4. Core Flow Distribution

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CODE DEVELOPMENT AND VALIDATION PROGRAM

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Computer Code Manual
July 1981

FIBWR: A Steady-State Core Flow Distribution Code for Boiling Water Reactors

Computer Code User's Manual

Contractor: Yankee Atomic Electric Company

This computer code manual describes the FIBWR steady-state BWR hydraulic computer code including the theory, required input, code output, and an FIBWR sample problem run. Several models for calculating various pressure drop components and void distributions are incorporated as user options. 98 pp.

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