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A SIMPLE LMFBR AXIAL-FLOW
FRICTION-FACTOR CORRELATION

by

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MIT COOLANT MIXING IN LMFBR ROD BUNDLES PROJECT

A. Quarterly Progress Reports (Available from:
National Technical Information Service
U. S. Department of Commerce
Springfield, Virginia 22151)

COO-2245-1	Period June 1, 1972 - November 30, 1972
COO-2245-2	Period December 1, 1972 - February 28, 1973
COO-2245-3	Period March 1, 1973 - May 31, 1973
COO-2245-6	Period June 1, 1973 - August 31, 1973
COO-2245-7	Period September 1, 1973 - November 30, 1973
COO-2245-8	Period December 1, 1973 - February 28, 1974
COO-2245-10	Period March 1, 1974 - May 31, 1974
COO-2245-13	Period June 1, 1974 - August 31, 1974
COO-2245-14	Period September 1, 1974 - November 30, 1974
COO-2245-15	Period December 1, 1974 - February 28, 1975
COO-2245-23	Period March 1, 1975 - May 31, 1975
COO-2245-25	Period June 1, 1975 - August 31, 1975
COO-2245-26	Period September 1, 1975 - November 30, 1975
COO-2245-28	Period December 1, 1975 - February 29, 1976
COO-2245-30	Period March 1, 1976 - May 31, 1976
COO-2245-31	Period June 1, 1976 - August 31, 1976
COO-2245-34	Period September 1, 1976 - November 30, 1976
COO-2245-38	Period December 1, 1976 - February 28, 1977
COO-2245-50	Period March 1, 1977 - May 31, 1977
COO-2245-53	Period June 1, 1977 - August 31, 1977
COO-2245-60	Period September 1, 1977 - November 30, 1977
COO-2245-63	Period December 1, 1977 - February 28, 1978
COO-2245-64	Period March 1, 1978 - May 31, 1978
COO-2245-65	Period June 1, 1978 - August 31, 1978
COO-2245-66	Period September 1, 1978 - November 30, 1978

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ABSTRACT

Complicated LMFBR axial lead-length averaged friction-factor correlations are reduced to an easy, ready-to-use function of bundle Reynolds number for wire-wrapped bundles. The function together with the power curves to calculate the associated constants are incorporated in a computer pre-processor, EZFRIC.

The constants required for the calculation of the sub-channels and bundle friction factors are derived and correlated into power curves of geometrical parameters. A computer program, FRIC, which can alternatively be used to accurately calculate these constants is also included. The accurate values of the constants and the corresponding values predicted by the power curves and percentage error of prediction are tabulated for a wide variety of geometries of interest.

PURPOSE OF REVISION

When this report was first issued, the correlations and tabulations for constant eighteen were valid for bundles with rod diameters greater than 0.35 inches only. Since then the corresponding results have been obtained for rod diameters ≤ 0.35 inches. The purpose of this revision is, therefore, to incorporate the modifications introduced by the additional results; the modifications are too extensive to be listed here. The pagination has also been changed.

The Hawley-Chan-Todreas (H-C-T) correlations (COO-2-79TR) were the starting point for this work which presents friction factor correlations in an algebraic simple format. The underlying physical assumptions of the H-C-T correlations are under review at MIT presently in an effort to consider the expanded world data base since Hawley's time and to make more consistent models for the laminar through turbulent flow regimes for friction, flow split and mixing parameters. Since this work will not be completed until late 1983, this present work was undertaken as an interim step.

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NOMENCLATURE

Ar_i	Projected area of wires in a subchannel, m^2 (ft^2)
As_i	Axial average subchannel area, m^2 (ft^2)
C_α	Constant introduced in Eqn. (2-9)
C_f	Constant defined in Eqns. (2-15)
C_{T1}	2200
C_{T2}	1.9
D	Rod diameter, m (ft)
D_e	Equivalent hydraulic diameter, m (ft)
D_g	Gap between the rods and duct wall, m (ft)
D_w	Wire diameter, m (ft)
f	Friction factor
F	Looseness factor
G	Ratio of edge to interior flowsplit parameters.
H	Wire lead length, m (ft)
l	Exponent used to obtain the transition friction factors by combining the corresponding laminar and turbulent friction factors.
n	Parameter defined in Reference [7] which relates the ratio of transverse to axial velocity in the gap between two edge subchannels to the average of that ratio within an edge subchannel.
N	Number of subchannels in the bundle
N_R	Number of rings of rods in the assembly
N_{ROD}	Number of rods in the assembly
P	Rod pitch, m (ft); P equals $D + D_w$ only when bundle tolerance, T_{ff} , equals zero.

Pw	Wetted perimeter, m(ft)
Re	Reynolds number = $\rho V D_e / \mu$
S	Parameter defined in Eqn (2-4)
T _{ff}	Bundle total tolerance, m (ft)
$\frac{V_T}{\bar{V}_A} \Big _{\text{gap}}$	Ratio of transverse velocity (V_T) to axial velocity which is correlated in Reference [7].
X	Flow split factor
ρ	Coolant density, kg/m ³ (lb/ft ³)
μ	Dynamic viscosity, kg/m.sec (lb/hr.ft)
θ	Angle which the wire makes with respect to vertical
p,q,r,s	constants and exponents in Eqn. (1-1)

Subscripts

i	1,2,3 or b which denote interior, edge, corner subchannel types, and the bundle, respectively.
L	Denotes laminar flow
TR	Denotes transition flow
T	Denotes turbulent flow

Superscripts

'	Denotes equivalent bare rod parameter
*	Denotes bare rod bundle quantity transformed for use in a wire-wrapped rod bundle.

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It is only personal weakness that makes us content with what others or we ourselves have found out in this hunt for knowledge. An abler man will not rest content with it. There is always room for a successor, yes, and for ourselves, and a road in another direction.

MONTAIGNE

A SIMPLE LMFBR AXIAL-FLOW
FRICTION-FACTOR CORRELATION

by

Y.-N. Chan
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1. SUMMARY

Subchannel friction factors are essential inputs to the widely-used subchannel codes, such as COBRA. Bundle friction factors are required for design analysis. However, current recommended correlations are complicated and require significant user effort and computer time.

In this report, the MIT friction factor correlation [1,2] is reduced to easy, ready-to-use functions of Reynolds number for wire-wrapped bundles of the form:

$$f = \frac{p}{Re_b} \left[1 + \frac{q}{Re_b^r} \right]^s \quad (1-1)$$

where p , q , r , and s are constants. The final form that Eq. (1-1) takes is

$$f_i = \frac{\textcircled{19}}{Re_b} \left[1 + \frac{\textcircled{18}}{Re_b^{\textcircled{9} \ell - \ell}} \right]^{1/\ell} \quad (1-2)$$

where $i = 1$ for interior subchannels,

$= 2$ for edge subchannels,

$= b$ for bundle

$$\textcircled{9} = 0.18$$

$$\ell = 1.49$$

Re_b = bundle Reynolds number

The laminar and turbulent friction factor correlations are easily expressible in the form of Eq. (1-2) which can be interpreted as a superposition of laminar and a turbulent

components. In the fully turbulent flow regime, Eq. (1-2) can be taken as the turbulent friction factor correlation because the laminar "component" becomes negligible. However, in the fully laminar flow regime, the turbulent "component" is not negligible and constant 18 is therefore set to zero. In the broad intermediate or transition region, Eq. (1-2) in its entirety is valid.

Constants 18 and 19 have been correlated as functions of the number of rods in the bundle (NROD), P/D , and H/D by the least square method. These functions have been arranged in a computer pre-processor, EZFRIC (see Appendix G). The determination of the flow regime and hence the above-mentioned requirement to save or delete constant 18 has been embodied in EZFRIC. Therefore, the user has only to run EZFRIC to obtain the subchannel and bundle friction factors for any bundle geometry and flow regime.

Alternatively, the user may find it more convenient to estimate constants 18 and 19 by interpolation from the appropriate tables in Appendix F and subsequently insert the corresponding constants in Eq. (1-2) for the desired friction factors. The bundle Reynolds number must always be used. The user is advised to study the Sample Problem in Section 3.5 first, irrespective of his choice of method.

A second program, FRIC, is presented in Appendix D. This program, like WIWRAP[3], calculates flow splits and friction factors from the complete governing MIT correlations. Addi-

tionally, however, it (1) calculates and prints constants 1 through 19 as defined in Section 2, (2) generates the tables of Appendix F, and (3) finds the exponents and constant for the polynomial fits of constants 18 and 19. It thus serves as the benchmark for comparison with the predictions of EZFRIC.

2. FRICTION FACTOR CORRELATIONS

This chapter summarizes the current LMFBR flow split and friction factor correlations for wire-wrapped bundles. Special attention was paid to maintaining the distinctions caused by the distribution of tolerance between the pitch, P , of the rod and the sum of the rod and wire diameters, $(D+D_w)$; and between the wire diameter, D_w , and the space between the rods and the duct wall, D_g . These variables were used interchangeably in our previous reports.

2.1 Flow Split Parameters

The laminar and turbulent flow split parameters were derived from phenomenological subchannel pressure drop models [4 and 5]. In transition flow, the flow split parameters were derived [7] from subchannel pressure drop expressions which utilize empirically determined expressions for the subchannel friction factors. All the above results were obtained by correlating experimental data for edge and interior subchannels. The corner subchannel flowsplit was taken equal to the edge flowsplit because no corner data was available; the resulting uncertainties in the interior and edge flowsplits was $\pm 1\%$ provided that

$$N_{\text{ROD}} > 37$$

$$0.6 < X_3 < 1.4$$

$$1.0 < P/D < 1.4 \quad (2-1)$$

The flow split parameters were simplified by Symolon [6] as

$$X_1 = \frac{1 + S}{1 + GS} \quad (2-2)$$

$$X_2 = \frac{1 + S}{\frac{1}{G} + S} \quad (2-3)$$

for either laminar or turbulent flow.

The size-dependent factor, S , was defined as

$$S = \left(\frac{As_2}{As_1}\right) \frac{1}{N_R} + \left(\frac{As_3}{As_1}\right) \frac{1}{N_R^2} \quad (2-4)$$

and the geometry-dependent factor, G , was defined as

$$G_T \equiv \frac{X_{2T}}{X_{2T}} = \left\{ \frac{1 + C_{T1} \left(\frac{De_1}{H}\right) \left(\frac{Ar_1}{As_1}\right) \left(\frac{D+D_w}{\sqrt{\pi^2 (D+D_w)^2 + H^2}}\right)^2}{1.2 \left\{ 1 + \left[C_{Tn} \frac{V_T}{V_A} \right]_{\text{gap}}^2 \right\}^{1.375}} \right\}^{0.571} \left(\frac{De_2}{De_1}\right)^{0.714} \quad (2-5)$$

for turbulent flow, and as

$$G_L \equiv \frac{X_{2L}}{X_{1L}} = \frac{C^*_{1L} + C_{\alpha 1} \left(\frac{Ar_1}{As_1}\right) \left(\frac{De_1}{H}\right) \left(1 - \frac{D_w}{2De_1}\right)}{C^*_{2L} + C_{\alpha 2} \left(\frac{Ar_2}{As_2}\right) \left(\frac{De_2}{H}\right) \left(1 - \frac{D_w}{2De_2}\right)} \left(\frac{De_2}{De_1}\right)^2 \quad (2-6)$$

for laminar flow.

These results were based on the previously assumed m value of 0.25 (the Reynolds number exponent obtained by averaging the exponents which characterized the turbulent flow data base; see Ref.7). Note that for our subsequent choice of $m=0.18$ (see page 16 of Ref. 2), the exponents 0.571 and 0.714 in Equation (2-5) should be 0.549 and 0.648, respectively. However, the changes in the predicted values of X_{1T} and X_{2T} were only about 1% and hence, no changes were made in Equation (2-5). The geometrical parameters appearing in Equations (2-4) to (2-6) are summarized in Appendix A.

The transition flow split parameters were obtained from the bundle and the subchannel friction factors

$$X_{1,TR} = \left(\frac{f_{b,TR}}{f_{1,TR}} \frac{De_1}{De_b} \right)^{.5} \quad (2-7)$$

$$X_{2,TR} = \left(\frac{f_{b,TR}}{f_{2,TR}} \frac{De_2}{De_b} \right)^{.5} \quad (2-8)$$

2.2 Laminar Subchannel and Bundle Friction Factors

The laminar flow subchannel friction factors were calibrated [2] as

$$f_{iL} = \frac{C^*_{\alpha i}}{Re_i} + \left(\frac{A_{ri}}{A'_{si}} \right) \left(\frac{De_i}{H} \right) \left(1 - \frac{D_w}{2De_i} \right) \frac{C_{\alpha i}}{Re_i} \quad (2-9)$$

$$\text{where } Re_i = Re_b X_{iL} \frac{De_i}{De_b} \quad (2-10)$$

The bundle friction factor for laminar flow was obtained [2], by the equal pressure drop assumption, as

$$f_{bL} = f_{2L} \left(\frac{De_b}{De_2} \right) X_{2L}^2 \quad (2-11)$$

2.3 Reduction of Laminar Friction Factors to Functions of Reynolds Number

Equation (2-9) can be reduced to the form of Eqn (1-1) as

$$\begin{aligned}
 f_{iL} &= \frac{(1)}{Re_{iL}} + \frac{(2)}{Re_{iL}} \\
 &= \frac{(1)}{Re_{iL}} [1 + (3)]
 \end{aligned}
 \tag{2-12}$$

where (C) denotes constant C

$$(3) = (2) / (1)$$

$$p = (1)$$

$$q = (3)$$

$$r = 0$$

$$s = 1$$

Similarly, equation (2-11) can be expressed as

$$\begin{aligned}
 f_{bL} &= (4) f_{2L} \\
 &= \frac{(5)}{Re_{iL}} [1 + (3)]
 \end{aligned}
 \tag{2-13}$$

$$\text{where } (5) = (4) \times (1)$$

2.4 Turbulent Subchannel and Bundle Friction Factors

The expression for the turbulent edge subchannel friction factor was [2]

$$f_{2T} = \left\{ 1 + \left[C_{T2} n \frac{V_T}{V_A} \right]_{\text{gap}}^2 \right\}^{1.375} \frac{C_{f2}}{Re_{2T}^{1.8}}
 \tag{2-14}$$

where C_{f2} was given empirically as

$$C_{f2} = .235(p/D)^{.685} / (H/D)^{.094}, \text{ all } N_{\text{ROD}}; .196 \text{ in.} < D < .250 \text{ in.}
 \tag{2-15a}$$

$$\begin{aligned}
 C_{f2} &= .477 (P/D)^{.656} / (H/D)^{.333}, N_{ROD} > 19 & (2-15b) \\
 & & \left. \begin{array}{l} \\ \\ \end{array} \right\} .472 \text{ in.} < D < .525 \text{ in.} \\
 C_{f2} &= .475 (P/D)^{.645} / (H/D)^{.356}, N_{ROD} = 19 & (2-15c)
 \end{aligned}$$

The above equations were generated from available data. If a conservative (maximum) bound on f_{2T} is desired, the user should compare predictions of equations (2-15a) and (2-15b) for his exact geometry. The character of these equations appears such that a maximum C_{f2} will results from Equation (2-15a) for $H \leq 6"$ and $D \leq 0.350"$ and Equation (2-15b) for other cases.

The turbulent interior subchannel friction factor was defined as

$$f_{1T} = f_{2T} \left(\frac{De_1}{De_2} \right) x_{2T}^2 / x_{1T}^2 \quad (2-16)$$

using the turbulent flow split parameters defined in Equations (2-2) and (2-3).

The bundle friction factor for turbulent flow was obtained, by the equal pressure drop assumption, as

$$f_{bT} = f_{2T} \left(\frac{De_b}{De_2} \right) x_{2T}^2 \quad (2-17)$$

2.5 Reduction of Turbulent Friction Factors to Functions of Reynolds Number

Equation (2-14) can be reduced to

$$f_{2T} = [1 + \textcircled{6}] \frac{\textcircled{7} \textcircled{8}}{Re_{2T} \textcircled{9}} \quad (2-18)$$

$$\begin{aligned}
 \text{where } \textcircled{7} &= 1.375 \\
 \textcircled{9} &= 0.18
 \end{aligned}$$

Similarly, Eqn. (2-16) can be expressed as

$$\begin{aligned}
 f_{1T} &= \textcircled{10} [f_{2T}] \\
 &= [1 + \textcircled{6}] \frac{\textcircled{7} \textcircled{11}}{Re_{2T} \textcircled{9}} \quad (2-19)
 \end{aligned}$$

where (11) = (8) x (10)

The bundle turbulent friction factor, Equation (2-17), can be rewritten as

$$\begin{aligned} f_{bT} &= (12) [f_{2T}] \\ &= [1 + (6)]^{(7)} \frac{(13)}{\text{Re}_{2T}^{(9)}} \end{aligned} \quad (2-20)$$

where (13) = (8) x (12)

2.6 Transition Subchannel and Bundle Friction Factors

The transition friction factor was obtained by Hawley et al [2] with the Churchill and Ozoë method as

$$f_{i,TR} = \{ (f_{iL})^\ell + (f_{iT})^\ell \}^{1/\ell} \quad (2-21)$$

where $\ell = 1.49$ was recommended.

Similarly, the bundle average friction factor for transition flow was given by

$$f_{b,TR} = \{ (f_{bL})^\ell + (f_{bT})^\ell \}^{1/\ell} \quad (2-22)$$

2.7 Reduction of Transition Friction Factors to Functions of Reynolds Number.

Substituting Equations (2-12) and (2-18) into Equations (2-21) and (2-22), the transition and the bundle average friction factors can both be rewritten as

$$f_{i,TR} = \left[\left\{ \frac{m}{\text{Re}_{iL}} [1 + (3)] \right\}^\ell + \left\{ [1 + (6)]^{(7)} \frac{n}{\text{Re}_{2T}^{(9)}} \right\}^\ell \right]^{1/\ell} \quad (2-23)$$

where $Re_{iL} = Re_{1L}$ for interior subchannel
 $= Re_{2L}$ for edge subchannel and bundle

$f_{i,TR} = f_{b,TR}$ for bundle

$m = (1)$ for $i = 1, 2$

$= (5)$ for b

$n = (8)$ for $i = 2$

$= (11)$ for $i = 1$

$= (13)$ for b

Equation (2-23) can be simplified as

$$f_{i,TR} = \left[\frac{(14)}{Re_{iL}^\ell} + \frac{(15)}{Re_{2T}^{(9)\ell}} \right]^{1/\ell} \quad (2-24)$$

where $(14) = \{m[1 + (3)]\}^\ell$

and $(15) = \{[1 + (6)]^{(7)}n\}^\ell$

Using the subchannel-bundle Reynolds number relation,
 Equation (2-10), Equation (2-24) can be expressed in terms of
 bundle Reynolds number as

$$f_{i,TR} = \left\{ \frac{(14)}{\left[Re_b \left(\frac{De_i}{De_b} \right) X_{iL} \right]^\ell} + \frac{(15)}{\left[Re_b \left(\frac{De_2}{De_b} \right) X_{2T} \right]^{(9)\ell}} \right\}^{1/\ell} \quad (2-25)$$

Equation (2-25) can be reduced to

$$f_{i,TR} = \left\{ \frac{(16)}{Re_b^\ell} + \frac{(17)}{Re_b^{(9)\ell}} \right\}^{1/\ell} \quad (2-26)$$

where $(16) = \frac{(14)}{[(De_i/De_b)X_{iL}]^\ell}$

$$(17) = \frac{(15)}{[(De_2/De_b) X_{2T}]^{(9)\ell}}$$

Factoring Equation (2-26), the transition friction factor is given by

$$f_{i,TR} = \left\{ \frac{(16)}{Re_b^\ell} \left[1 + \frac{(18)}{Re_b^{(9)\ell-\ell}} \right] \right\}^{1/\ell} \quad (2-27)$$

where $(18) = (17) / (16)$

Equation (2-27) can be further simplified as

$$f_{i,TR} = \frac{(19)}{Re_b} \left[1 + \frac{(18)}{Re_b^{(9)\ell-\ell}} \right]^{1/\ell} \quad (2-28)$$

where $(19) = (16)^{1/\ell}$

$$(9) = 0.18$$

$i = 1$ for interior subchannels,

$= 2$ for edge subchannels, and

$= b$ for bundle.

[Note: The subscript "TR" should be deleted for fully laminar or turbulent friction factors]

Comparing Equation (2-28) with Equation (1-1), the constants in the latter equation are

$$p = (19)$$

$$q = (18)$$

$$r = (9) \ell - \ell$$

$$s = 1/\ell$$

3. CALCULATIONS OF FRICTION FACTORS

In Section 2.7, the transition friction factors are reduced to the form of Eqn. (2-28). As explained in the Summary, this is the valid friction factor correlation over the entire Reynolds number range if the turbulent "component", constant 18, is disregarded for fully laminar flow.

Constants 18 and 19 were generated and tabulated in Appendix F by FRIC (the reader is referred to Appendix D for the computer program) for the following possible bundle geometries:

NROD = 19, 37, 61, 127 and 271

P/D = 1.067, 1.10, 1.15, 1.20, 1.25 and 1.343

H/D = 4, 8, 12, 16, 24, 48 and 96

As shown in Appendix B, there are no experimental friction factor data for 127- and 271-rod bundles. They were, however, included in the correlation of constants 18 and 19 because such geometrics are of interest to the industry.

3.1 Curve Options

Constants 18 and 19, as tabulated in Appendix F, may be fitted by a function of the type

$$y = aB^bC^c \quad (3-1)$$

for a fixed H/D (or P/D or NROD) by the least square method. Alternatively, a harmonic function of the form [8]

$$y = \frac{1}{2}a_0 = \sum_{n=1}^{\infty} (a_n \cos n\chi + b_n \sin n\chi) \quad (3-2)$$

may be used to fit the constants 18 and 19 for a fixed H/D (or P/D or NROD). As can be seen in Appendix F, constants 18 and 19 do not always follow the exponential or harmonic trend for a fixed H/D (or P/D or NROD). Besides, by fixing H/D (or P/D or NROD), a total of 252 (or 216 or 6, respectively) correlations will be required for a subchannel or bundle constant 18 or 19. The computation of all these functions is further complicated by some cases where a single trend is not followed for a fixed H/D (or P/D or NROD). Such a case is afforded by NROD = 19, P/D = 1.10 where there is a "plateau" from H/D = 8 to H/D = 24.

3.2 Power Curves of Constants 18 and 19

The purpose of this task is to reduce complicated LMFBR friction factor correlations into easy, ready-to-use functions of Reynolds number. As such, a pair of power curves of the form

$$\text{Constant 18} = A (\text{NROD})^B (\text{P/D})^C (\text{H/D})^E \quad (3-3)$$

$$\text{Constant 19} = F (\text{NROD})^G (\text{P/D})^J (\text{H/D})^K \quad (3-4)$$

were fitted for the interior and edge subchannels and for the bundle. In order to accommodate the gap between the two ranges of rod diameter, D , in Eqn. (2-15), the two ranges were extended by Wang [3] to meet at $D = 0.35$ ". Such a method was adopted in the computer program, FRIC. Consequently, the power curves for constant 18 are different for $D < 0.35$ " and $D > 0.35$ ". Constants 19 are independent of C_{f2} and are shown

in Tables 3-1 and 3-2 to be the same for all rod diameters.

The "three exponents and a constant" sets of Table 3-1 correspond to the exponents and constants of Eqns. (3-5) to (3-13). Similarly, Table 3-2 corresponds to Eqns. (3-5a) to (3-13a). The derivations of Tables 3-1 and 3-2 are elaborated in Section 4.2.

Hence, for the interior subchannels*

if $H/D \leq 4$ all NROD's and P/D's

or $H/D \leq 8$ all NROD's where $P/D \geq 1.20$,

or $H/D \leq 12$ all NROD's where $P/D \geq 1.343$,

and $D \leq 0.35$ inches,

$$\text{Constant 18} = 0.00118 (\text{NROD})^{0.083} (\text{P/D})^{8.698} (\text{H/D})^{-2.113} \quad (3-5)$$

and $D > 0.35$ inches,

$$\text{Constant 18} = 0.00313 (\text{NROD})^{0.101} (\text{P/D})^{8.648} (\text{H/D})^{-2.475} \quad (3-5a)$$

For the remaining cases not included above, with $D \leq 0.35$ inches,

$$\text{Constant 18} = 0.0000177 (\text{NROD})^{0.158} (\text{P/D})^{0.978} (\text{H/D})^{0.176} \quad (3-6)$$

with $D > 0.35$ inches,

$$\text{Constant 18} = 0.000125 (\text{NROD})^{0.011} (\text{P/D})^{1.092} (\text{H/D})^{-0.269} \quad (3-6a)$$

*If it is desired to match a particular bundle geometry with the appropriate equation(s) for either constants 18 or 19, it is most easily done by locating the geometry among the tables in Appendix F where the corresponding equation(s) of this section have been indicated. Notice, however, that there is a pair of constants 18 and 19 each for the interior and edge subchannels and the bundle.

TABLE 3-1
Table of Exponents and Constants for $D < 0.35$ " for Eqs. 3-5 to 3-13

$$\begin{aligned} \text{EXP. 3-5} &= \dots \\ \text{EXP. 3-6} &= \dots \\ \text{CONST.} &= \dots \end{aligned}$$

$$\begin{aligned} \text{EXP. 3-7} &= \dots \\ \text{EXP. 3-8} &= \dots \\ \text{CONST.} &= \dots \end{aligned}$$

$$\begin{aligned} \text{EXP. 3-9} &= \dots \\ \text{EXP. 3-10} &= \dots \\ \text{CONST.} &= \dots \end{aligned}$$

$$\begin{aligned} \text{EXP. 3-11} &= \dots \\ \text{EXP. 3-12} &= \dots \\ \text{CONST.} &= \dots \end{aligned}$$

$$\begin{aligned} \text{EXP. 3-13} &= \dots \\ \text{EXP. 3-14} &= \dots \\ \text{CONST.} &= \dots \end{aligned}$$

$$\begin{aligned} \text{EXP. 3-15} &= \dots \\ \text{EXP. 3-16} &= \dots \\ \text{CONST.} &= \dots \end{aligned}$$

$$\begin{aligned} \text{EXP. 3-17} &= \dots \\ \text{EXP. 3-18} &= \dots \\ \text{CONST.} &= \dots \end{aligned}$$

$$\begin{aligned} \text{EXP. 3-19} &= \dots \\ \text{EXP. 3-20} &= \dots \\ \text{CONST.} &= \dots \end{aligned}$$

$$\begin{aligned} \text{EXP. 3-21} &= \dots \\ \text{EXP. 3-22} &= \dots \\ \text{CONST.} &= \dots \end{aligned}$$

TABLE 3-2
Table of Exponents and Constants for $D > 0.35$ " for Eqs. 3-5a to 3-13a

$$\begin{aligned} \text{EXPONENT} &= 1.0 \\ \text{EXPONENT} &= 0.0 \\ \text{EXPONENT} &= 0.0 \\ \text{CONSTANT} &= 0.0 \end{aligned}$$

$$\begin{aligned} \text{EXPONENT} &= 1.0 \\ \text{EXPONENT} &= 0.0 \\ \text{EXPONENT} &= 0.0 \\ \text{CONSTANT} &= 0.0 \end{aligned}$$

$$\begin{aligned} \text{EXPONENT} &= 1.0 \\ \text{EXPONENT} &= 0.0 \\ \text{EXPONENT} &= 0.0 \\ \text{CONSTANT} &= 0.0 \end{aligned}$$

$$\begin{aligned} \text{EXPONENT} &= 1.0 \\ \text{EXPONENT} &= 0.0 \\ \text{EXPONENT} &= 0.0 \\ \text{CONSTANT} &= 0.0 \end{aligned}$$

$$\begin{aligned} \text{EXPONENT} &= 1.0 \\ \text{EXPONENT} &= 0.0 \\ \text{EXPONENT} &= 0.0 \\ \text{CONSTANT} &= 0.0 \end{aligned}$$

$$\begin{aligned} \text{EXPONENT} &= 1.0 \\ \text{EXPONENT} &= 0.0 \\ \text{EXPONENT} &= 0.0 \\ \text{CONSTANT} &= 0.0 \end{aligned}$$

$$\begin{aligned} \text{EXPONENT} &= 1.0 \\ \text{EXPONENT} &= 0.0 \\ \text{EXPONENT} &= 0.0 \\ \text{CONSTANT} &= 0.0 \end{aligned}$$

$$\begin{aligned} \text{EXPONENT} &= 1.0 \\ \text{EXPONENT} &= 0.0 \\ \text{EXPONENT} &= 0.0 \\ \text{CONSTANT} &= 0.0 \end{aligned}$$

$$\begin{aligned} \text{EXPONENT} &= 1.0 \\ \text{EXPONENT} &= 0.0 \\ \text{EXPONENT} &= 0.0 \\ \text{CONSTANT} &= 0.0 \end{aligned}$$

For all D's, NROD's, P/D's, and H/D's

$$\text{Constant 19} = 483(\text{NROD})^{-0.066}(\text{P/D})^{0.455}(\text{H/D})^{-0.372}$$

(3-7, 3-7a)

For the edge subchannels,

if $H/D \leq 4$ all NROD's where $P/D \geq 1.20$,
 or $H/D \leq 8$ all NROD's where $P/D \geq 1.25$,
 or $H/D \leq 12$ all NROD's where $P/D \geq 1.343$,
 or $H/D \leq 16$ all NROD's where $P/D \geq 1.343$,

and $D \leq 0.35$ inches,

$$\text{Constant 18} = 0.0000395(\text{NROD})^{0.084}(\text{P/D})^{10.005}(\text{H/D})^{-0.697}$$

(3-8)

and $D > 0.35$ inches,

$$\text{Constant 18} = 0.000103(\text{NROD})^{0.105}(\text{P/D})^{9.960}(\text{H/D})^{-1.059}$$

(3-8a)

For the remaining cases not included above, with $D \leq 0.35$ inches,

$$\text{Constant 18} = 0.0000499(\text{NROD})^{0.086}(\text{P/D})^{-1.272}(\text{H/D})^{0.270}$$

(3-9)

with $D > 0.35$ inches,

$$\text{Constant 18} = 0.000125(\text{NROD})^{0.117}(\text{P/D})^{-1.318}(\text{H/D})^{-0.092}$$

(3-9a)

For all D's, NROD's, P/D's, and H/D's,

$$\text{Constant 19} = 223(\text{NROD})^{-0.066}(\text{P/D})^{1.654}(\text{H/D})^{-0.330}$$

(3-10, 3-10a)

For the bundle,

if $H/D \leq 4$ all NROD's and P/D's
 or $H/D \leq 8$ all NROD's where $P/D \geq 1.20$,
 or $H/D \leq 12$ all NROD's where $P/D \geq 1.343$,

and $D \leq 0.35$ inches,

$$\text{Constant 18} = 0.000221 (\text{NROD})^{0.166} (\text{P/D})^{8.297} (\text{H/D})^{-1.457} \quad (3-11)$$

and $D > 0.35$ inches,

$$\text{Constant 18} = 0.000584 (\text{NROD})^{0.185} (\text{P/D})^{8.247} (\text{H/D})^{-1.818} \quad (3-11a)$$

For the remaining cases not included above, with $D \leq 0.35$ inches,

$$\text{Constant 18} = 0.0000395 (\text{NROD})^{0.063} (\text{P/D})^{0.174} (\text{H/D})^{0.178} \quad (3-12)$$

with $D > 0.35$ inches,

$$\text{Constant 18} = 0.000278 (\text{NROD})^{-0.084} (\text{P/D})^{0.289} (\text{H/D})^{-0.268} \quad (3-12a)$$

For all D's, NROD's, P/D's, and H/D's,

$$\text{Constant 19} = 251 (\text{NROD})^{0.007} (\text{P/D})^{0.997} (\text{H/D})^{-0.354} \quad (3-13, 3-13a)$$

3.3 Constants 18 and 19 by Interpolation

Instead of using the computer pre-processor, EZFRIC, the user may choose to estimate constants 18 and 19 by interpolation from the appropriate tables in Appendix F and subsequently insert the corresponding constants into Eqn. (1-2) for the desired friction factors. As explained in Appendix F, constants 18 are different for $D \leq 0.35$ " and $D > 0.35$ " whereas constants 19 are good for the entire range of rod diameters.

For the interior or edge subchannel friction factors, the "turbulent" component, constant 18, is set to zero if the corresponding subchannel Reynolds number is less than 400. For the bundle friction factor, however, constant 18 is set to

zero only if both the interior and edge subchannel Reynolds numbers are less than 400. Therefore, unless the subchannel Reynolds numbers are easily ascertained or it is clear that flow regime cannot possibly be laminar, it is recommended that EZFRIC be used.

3.4 Limitation on the Application of Constants 18 and 19

The user should note that only one lead length-averaged axial friction factor correlation was considered for this work. As such, the simplifications expounded in this report are not applicable to calculate the axial friction factors for fractions of a lead length or the transverse friction factors.

3.5 Sample Problem

Problem Statement

Calculate the friction factors for the interior, edge subchannels and the bundle for the following bundle geometries. Use bundle Reynolds numbers representative of the laminar, transition, and turbulent flow regimes.

	<u>Case 1</u>	<u>Case 2</u>	<u>Case 3</u>
Total number of rods	61	217	91
Rod diameter (inches)	0.5059	0.25	0.2559
P/D	1.085	1.24	1.211
H/D	7.78	52.00	47.23

SolutionMethod One

Run the computer pre-processor, EZFRIC, as shown in Appendix H. The results for the friction factors corresponding to the bundle Reynolds numbers representative of the laminar, transition, and turbulent flow regimes may be summarized from Appendix H as:

Case 1

<u>Bundle Re</u>	<u>Interior</u>	<u>Edge</u>	<u>Bundle</u>
200	0.890594	0.494138	0.677540
4000	0.094580	0.070664	0.084846
150000	0.037964	0.031512	0.036378

Case 2

<u>Bundle Re</u>	<u>Interior</u>	<u>Edge</u>	<u>Bundle</u>
200	0.429402	0.302905	0.398727
4000	0.050526	0.047033	0.049954
150000	0.021185	0.021395	0.021421

Case 3

<u>Bundle Re</u>	<u>Interior</u>	<u>Edge</u>	<u>Bundle</u>
200	0.466198	0.318256	0.400346
4000	0.050449	0.047566	0.048300
150000	0.020428	0.021447	0.020441

Method Two

Constants 18 and 19 are first interpolated linearly (see

the discussion on accuracy in Section 3.6) from the Tables of Appendix F. The desired friction factors are then obtained by inserting the appropriate constants and bundle Reynolds numbers into Eqn. (1-2). The user is advised to read the note on Reynolds number in Section 3.3.

The results of the interpolations are tabulated below. The tables from which the interpolations are done are also given (in parentheses). Notice that the total number of rods for Case 3 (91) is not tabulated and the validity of interpolating between two corresponding total numbers of rods has been assumed.

	<u>Case 1</u>	<u>Case 2</u>	<u>Case 3</u>
<u>Interior subchannel</u>			
Constant 18	0.000111 (F-39) *	0.000086 (F-5)	0.000077 (F-3 & F-4)
Constant 19	165.785406 (F-9)	86.767219 (F-11)	93.730448 (F-9 & F-10)
<u>Edge subchannel</u>			
Constant 18	0.000151 (F-45)	0.000158 (F-17)	0.000147 (F-15 & F-16)
Constant 19	95.199494 (F-21)	65.519651 (F-23)	68.563074 (F-21 & F-22)
<u>Bundle</u>			
Constant 18	0.000124 (F-51)	0.000099 (F-29)	0.000096 (F-27 & F-28)
Constant 19	128.078237 (F-33)	80.558677 (F-35)	82.871541 (F-33 & F-34)

*Numbers in parentheses refer to the tables in Appendix F.

The desired friction factors obtained from Eqn. (1-2) by inserting the above constants are:

Case 1

<u>Bundle Re</u>	<u>Interior</u>	<u>Edge</u>	<u>Bundle</u>
200	0.828927	0.475997	0.640391
4000	0.101435	0.068216	0.082838
150000	0.043147	0.030437	0.035894

Case 2

<u>Bundle Re</u>	<u>Interior</u>	<u>Edge</u>	<u>Bundle</u>
200	0.433836	0.327598	0.402793
4000	0.047004	0.048098	0.046620
150000	0.019043	0.021593	0.019423

Case 3

<u>Bundle Re</u>	<u>Interior</u>	<u>Edge</u>	<u>Bundle</u>
200	0.468652	0.342815	0.414358
4000	0.048307	0.048435	0.047260
150000	0.019109	0.021531	0.019574

3.6 Error Analysis

The selection of either method of Section 3.5 is dictated by convenience and accuracy. As for accuracy, the user should be aware of the nature of least square fits used in method one and the validity of the linear interpolation approach of method two. The user is referred to Reference [8] or other texts on numerical analysis for more accurate interpolation

procedures.

The accuracies of the friction factors obtained by either method can, however, only be evaluated by comparing with the corresponding friction factors calculated by running the computer program FRIC (see Appendices D and F). Such a run has been made for cases 1 and 2 of the sample problem of Section 3.5. The results may be summarized from Appendix F as

Case 1

<u>Bundle Re</u>	<u>Interior</u>	<u>Edge</u>	<u>Bundle</u>
200	0.824676	0.476256	0.639555
150000	0.039893	0.029773	0.034628

Case 2

<u>Bundle Re</u>	<u>Interior</u>	<u>Edge</u>	<u>Bundle</u>
200	0.430275	0.325976	0.399864
150000	0.018911	0.021517	0.019308

Using the above results as the absolute values to compare with the results tabulated in Section 3.5, it is clear that the friction factors obtained by linear interpolation are more precise than those resulting from EZFRIC. However, EZFRIC is more convenient to use and the determination of the subchannel Reynolds number from the bundle Reynolds number and geometry is also embodied in EZFRIC. The latter convenience is especially handy for $300 < Re_b < 500$.

4. CONCLUSIONS

Complicated friction factor correlations have been reduced to an easy, ready-to-use function of bundle Reynolds number for wire-wrapped bundles.

4.1 Recommendations for Design Use

In order to calculate the subchannel and bundle friction factors for the entire Reynolds number range and any bundle geometry, the user has only to run the computer pre-processor, EZFRIC. The user is advised to read Sections 3.5 and Appendices G and H prior to using EZFRIC.

Alternatively, the user may find it more convenient to estimate constants 18 and 19 by interpolation from the tables in Appendix F. These constants are subsequently inserted into Eqn. (1-2) to obtain the desired friction factors. The user is cautioned that in the fully laminar flow regime, constant 18 is set to zero. The determination of such a flow regime is elaborated in Section 3.3. It is recommended that Section 3.5 be read first.

4.2 Future Changes in the Friction Factors Recommended in

This Report

More refined modelling and experimental research is underway and should result in some modifications of the current formulae for friction factor correlations. The constants tabulated in Appendix F and the power curves will, as a result, be invalidated. Such a scenario has been envisaged and the com-

puter program FRIC has been deliberately designed to handle such possible changes and regenerate the tables in Appendix F and the power curves easily. The following steps are suggested:

1. Read the computer program, FRIC (see Appendix D).
2. Introduce the modifications to the MAIN and/or the relevant subroutines of FRIC (File name is GATSBY.FOR;7 on magnetic tape called NING). Care must be taken to ensure that no Fortran errors are introduced in the process.
3. To ascertain what has been affected, run FRIC for one of the tabulated geometries and a transition bundle Reynolds number of 7000. Use IMAT=0. It is possible that constants 18 and 19 may not be both affected.
4. If the above test (Step 3) confirms a need to replace the tabulated results, run FRIC first with file FRIEDA.DAT;5 (for rod diameter of 0.25", i.e., <0.35") as input data. Use the IMAT=1 option. Assign NZELDA.LIS;5 as the output file. Repeat with FRIEDA.DAT;6 as input data for rod diameter of 0.5" (i.e., >0.35"). For the second run, assign NZELDA.LIS;6 as the output file.
5. The new constants and exponents for Eqns. (3-5) to (3-13) are tabulated in NZELDA.LIS;5 in the same format as Table 3-1. NZELDA.LIS;6 has the corresponding new constants and exponents for Eqns. (3-5a) to (3-13a). The 36 tables

of NZELDA.LIS;5, although not labelled (because the convenience of the labelled tables is not commensurate with the complications introduced into FRIC by the excessively many variables in the title of the tables), are the corresponding new tables F-1 to F-36 in Appendix F. The order is exactly the same. The first six tables of NZELDA.LIS;6 are the new tables F-37 to F-42. The second six tables correspond exactly to the new F-7 to F-12 and are, therefore, redundant. This is because constant 19 is independent of rod diameter. Tables 13 to 18 of NZELDA.LIS;6 are the new tables F-43 to F-48 and similarly, tables 25 to 30 of NZELDA.LIS;6 are the new tables F-49 to F-54.

6. If the tabulation in Appendix F is to be extended or reduced:
 - (a) Change the do-loops and common blocks accordingly in the main to accommodate the extension or reduction.
 - (b) Repeat in subroutine ATRIX.
 - (c) Regenerate the data block of subroutine ATRIX. These are merely the left hand side of summations of Eqns. (C-5) to (C-8) of Appendix C arranged columnwise.
 - (d) Make other changes in statements 605 to 742 of FRIC to set up the new matrices.
 - (e) The method of solution as outlined in statements 743 to 814 of FRIC remains unchanged.
 - (f) Statements 815 to 892 of FRIC must be corrected ac-

cordingly too.

- (g) The changes to be made are too many to be listed down, but the logic is simple and clear-cut. Care must be taken to avoid Fortran errors.

REFERENCES

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- 2) J.T. HAWLEY, C.CHIU, W.M. ROHSENOW and N.E. TODREAS, "Correlations for Subchannel and Bundle Friction Factors and Flowsplit Parameters for Laminar, Transition, and Turbulent Longitudinal Flows in Wire Wrap Spaced Hexagonal Arrays," DOE/ET/37240/79TR, August, 1980.
- 3) S.F. WANG and N.E. TODREAS, "Computer Model for MIT Correlations for Friction Factors, Flow Splits, and Mixing Parameters in LMFBR Wire-wrapped Rod Assemblies," DOE/ET/37240/87TR, Feb. 1981.
- 4) Y.N. CHAN and N.E. TODREAS, "Turbulent Sweeping Flow Mixing Model for Wire-Wrapped LMFBR Assemblies," COO-2245-55TR, Revision 2, Dec. 1980.
- 5) K.J. BURNS, W.M. ROHSENOW and N.E. TODREAS, "Laminar/Transition Sweeping Flow Mixing Model for Wire-Wrapped LMFBR Assemblies," DOE/ET/37240/81TR, July 1980.
- 6) SYMOLON, P. Private Communication.
- 7) Y.N. CHAN and N.E. TODREAS, "Turbulent Flow Split Model and Supporting Experiments for Wire Wrapped Core Assemblies," COO-2245-56TR, (Rev.1), December 1980.
- 8) KAJ L. NIELSEN, "Methods in Numerical Analysis", Second Edition, Macmillan, 1964.

APPENDIX A. DEFINITIONS OF TERMS USED IN THE FLOW
SPLIT AND FRICTION FACTORS CORRELATIONS

$$C_1^* = (-336 (P/D-1)^2 + 340 (P/D-1) + 40) \left(\frac{A_{s1}}{A_{r1}} \right) \left(\frac{De_1}{De_{r1}} \right)^2 \quad (A-1)$$

$$C_2^* = (-318.2 (P/D-1)^2 + 290.9 (P/D-1) + 37.4) \left(\frac{A_{s2}}{A_{r2}} \right) \left(\frac{De_2}{De_{r2}} \right)^2 \quad (A-2)$$

$$P = D + D_w + \frac{F \cdot T_{ff}}{\sqrt{3} N_R} \quad (A-3)$$

$$Dg = \frac{1}{2} (1-F) \cdot T_{ff} + D_w \quad (A-4)$$

$$N_R = \frac{[3 + (12 N_{ROD} - 3)^{1/2}]}{6} - 1 \quad (A-5)$$

$$C_{T1} = 2200.0 \quad (A-6)$$

$$C_{T2} = 1.9 \quad (A-7)$$

$$C_{\alpha 1} = 5835 (H/D)^{.198} / (P/D)^{3.264} \quad (A-8)$$

$$C_{\alpha 2} = 6805 (H/D)^{.257} / (P/D)^{4.337} \quad (A-9)$$

$$\eta = \frac{\frac{P}{2} \cdot Dg}{\frac{P}{2} \left(\frac{D}{2} + Dg \right) - \frac{\pi}{16} D^2} \quad (\text{See Appendix A of Ref. 3}) \quad (A-10)$$

$$\left. \frac{V_T}{V_A} \right|_{\text{gap}} = \frac{10.5}{\pi} \left(\frac{Dg}{P} \right)^{.35} \left(\frac{A_r}{A_{s2}} \right)^{.5} \sin \theta \quad (A-11)$$

$$N_1 = 6 N_R^2 \quad (A-12)$$

$$N_2 = 6 N_R \quad (A-13)$$

$$N_3 = 6 \quad (A-14)$$

$$\cos\theta = \frac{H}{\sqrt{\pi^2 (D+D_w)^2 + H^2}} \quad (A-15)$$

$$\sin\theta = \frac{\pi (D+D_w)}{\sqrt{\pi^2 (D+D_w)^2 + H^2}} \quad (A-16)$$

Interior Subchannel

$$A'_{s1} = \sqrt{3}/4 P^2 - \pi/8 D^2 \quad (A-17)$$

$$A_{s1} = A'_{s1} - \frac{\pi}{8\cos\theta} D_w^2 \quad (A-18)$$

$$P'_{w1} = \pi/2 D \quad (A-19)$$

$$P_{w1} = P'_{w1} + \frac{\pi}{2\cos\theta} D_w \quad (A-20)$$

$$De'_1 = 4A'_{s1}/P'_{w1} \quad (A-21)$$

$$De_1 = 4A_{s1}/P_{w1} \quad (A-22)$$

$$\begin{aligned} A_{r1} &= 1/6 [\pi (D/2 + D_w) - \pi/4 D^2] \\ &= \pi/6 D_w (D+D_w) \end{aligned} \quad (A-23)$$

Edge Subchannel

$$A'_{s2} = P (D/2 + D_g) - \pi/8 D^2 \quad (A-24)$$

$$A_{s2} = A'_{s2} - \frac{\pi}{8\cos\theta} D_w^2 \quad (A-25)$$

$$P'_{w2} = P + \pi/2 D \quad (A-26)$$

$$P_{w2} = P'_{w2} + \frac{\pi}{2\cos\theta} D_w \quad (A-27)$$

$$De'_2 = 4A'_{s2}/P'_{w2} \quad (A-28)$$

$$De_2 = 4A_{s2}/P_{w2} \quad (A-29)$$

$$\begin{aligned}
A_{r2} &= 1/4 [\pi (D/2 + D_w)^2 - \pi/4 D^2] \\
&= \pi/4 D_w (D + D_w) \\
&= 1.5 A_{r1}
\end{aligned} \tag{A-30}$$

Corner Subchannel

$$A'_{s3} = 1/\sqrt{3} (D/2 + D_g)^2 - \pi/24 D^2 \tag{A-31}$$

$$A_{s3} = A'_{s3} - \frac{\pi}{24 \cos \theta} D_w^2 \tag{A-32}$$

$$P'_{w3} = \pi/6 D + 2/\sqrt{3} (D/2 + d_g) \tag{A-33}$$

$$P_{w3} = P'_{w3} + \frac{\pi}{6 \cos \theta} D_w \tag{A-34}$$

$$De'_3 = 4A'_{s3}/P'_{w3} \tag{A-35}$$

$$De_3 = 4A_{s3}/P_{w3} \tag{A-36}$$

Bundle Average

$$A'_b = N_1 A'_{s1} + N_2 A'_{s2} + N_3 A'_{s3} \tag{A-37}$$

$$A_b = N_1 A_{s1} + N_2 A_{s2} + N_3 A_{s3} \tag{A-38}$$

$$P'_{wb} = N_1 P'_{w1} + N_2 P'_{w2} + N_3 P'_{w3} \tag{A-39}$$

$$P_{wb} = N_1 P_{w1} + N_2 P_{w2} + N_3 P_{w3} \tag{A-40}$$

$$De'_b = 4A'_b/P'_{wb} \tag{A-41}$$

$$De_b = 4A_b/P_{wb} \tag{A-42}$$

APPENDIX B. EXPERIMENTAL FRICTION FACTOR DATA BASE

To date the following experimental friction factor data have been reported [2]:

21 cases for 19-pin bundles,
30 cases for 37-pin bundles,
9 cases for 61-pin bundles,
and 3 cases for 217-pin bundles.

All these cases were plotted in Figs B-1 to B-4.

Fig. B-1. Experimental Friction Factor Data Base. Number of Rods = 19

Fig B-2. Experimental Friction Factor Data Base, Number of Rods = 37.

Fig B-3. Experimental Friction Factor Data Base. Number of Rods = 61.

Fig. B-4. Experimental Friction Factor Data Base. Number of Rods = 217

APPENDIX C. LEAST SQUARE METHOD USED TO GENERATE
POWER CURVES OF CONSTANTS EIGHTEEN
AND NINETEEN

Consider the case of:

$$\text{Constant 18} = A (N_{\text{ROD}})^B (P/D)^C (H/D)^E \quad (\text{C-1})$$

Rewriting Eqn. (C-1) as

$$y = a N^b P^c H^e \quad (\text{C-2})$$

Taking the natural logarithms of both sides,

$$\ln y = \ln a + b \ln N + c \ln P + e \ln H \quad (\text{C-3})$$

Let subscript i denote the i -th data point and define

$$\begin{aligned} M &= \sum_i (\ln y_i - \ln y)^2 \quad (\text{C-4}) \\ &= \sum_i (\ln y_i - \ln a - b \ln N - c \ln P - e \ln H)^2 \end{aligned}$$

Minimizing M with respect to the constant " a " and exponents " b , c and e " yields four equations in these four unknowns.

Rearranging them gives:

$$[\sum (\ln N)^2]b + [\sum (\ln N \cdot \ln P)]c + [\sum (\ln N \cdot \ln H)]e + [\sum (\ln N)]a = [\sum (\ln N \cdot \ln y_i)] \quad (\text{C-5})$$

$$[\sum (\ln N \cdot \ln P)]b + [\sum (\ln P)^2]c + [\sum (\ln P \cdot \ln H)]e + [\sum (\ln P)]a = [\sum (\ln P \cdot \ln y_i)] \quad (\text{C-6})$$

$$[\sum (\ln N \cdot \ln H)]b + [\sum (\ln P \cdot \ln H)]c + [\sum (\ln H)^2]e + [\sum (\ln H)]a = [\sum (\ln H \cdot \ln y_i)] \quad (\text{C-7})$$

$$[\sum (\ln N)]b + [\sum (\ln P)]c + [\sum (\ln H)]e + [\sum (i)]a = [\sum (\ln y_i)] \quad (\text{C-8})$$

The four unknowns, a , b , c and e may be solved by Cramer's rule.

APPENDIX D. THE COMPUTER PROGRAM, FRIC

FRIC was written in Fortran IV. It is comprised of a main and six subroutines. The flow diagram is illustrated in Fig. D-1.

D.1 Flow Diagram

The subroutines GEOM and CORCON first calculate the geometrical parameters and the empirical constants, respectively, from the INPUT data and return their results to the MAIN. The subroutine FLOSPT next calculates the turbulent and laminar flow split parameters independently of the bundle Reynolds number. Back in the MAIN, the pseudo-turbulent and laminar subchannel Reynolds numbers are then obtained from the corresponding turbulent and laminar flow split parameters, as

$$Re_i^T = Re_b^{X_{iT}} \left(\frac{De_i}{De_b} \right) \quad (D-1)$$

$$\text{and} \quad Re_i^L = Re_b^{X_{iL}} \left(\frac{De_i}{De_b} \right) \quad (D-2)$$

Figure D-1 Flow Diagram of FRIC

The critical subchannel Reynolds numbers for the transitions from laminar to transition and from transition to turbulent flow regimes were recommended [2] as 400 and 100,000, respectively. The pseudo-Reynolds numbers are used in the MAIN to determine the subchannel and the bundle flow conditions based on the recommended critical subchannel Reynolds numbers.

The subchannel and bundle friction factors are then calculated and printed in subroutine FRIFAC in accordance with the flow conditions. In the transition flow regime, the transitional subchannel and bundle friction factors are returned to the MAIN to determine the transition flow splits.

By now many of the constants outlined in Section 2 have been extracted. The remaining constants are subsequently calculated in subroutine CONST, culminating with the calculation of constants 18 and 19 for the interior and edge subchannels and the bundle respectively.

At this point, IMAT, the correlation of constants 18 and 19 option is tested. If IMAT=0, command is terminated unless there are more data sets. If, however, IMAT=1, the calculated constants 18 and 19 are assigned to their respective matrices. The process is repeated 252 times. Subroutine ATRIX is then called to generate the constants and exponents for EZFRIC and Tables for Appendix F.

D.2 Listing of FRIC

Listed below are the MAIN of FRIC and the following sub-routines:

GEOM

CORCON

FLOSPT

FRIFAC

CONST

ATRIX

```

1      *****
2      *                                     *
3      *                                     *
4      *      FRIC
5      *      THIS PROGRAM CALCULATES THE FLOW-SPLITS, FRICTION FACTORS AND
6      *      ALL THE CONSTANTS DERIVED IN SECTION 2 FOR WIRE-WRAPPED BUNDLES.
7      *      IT CAN ALSO BE USED TO CORRELATE CONSTANTS 18 AND 19 BY THE
8      *      LEAST SQUARE METHOD. THE CORRELATED VALUES ARE TABULATED AND
9      *      ALSO COMPARED WITH THEIR CORRESPONDING CALCULATED VALUES.
10     *      YTC-NING CHAN
11     *      MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1982
12     *****
13
14     NSET      NUMBER OF INPUT DATA SETS
15     NRWD      NUMBER OF RODS
16     ISPLIT    --NO FLOW SPLIT CALCULATIONS
17              1--FLOW SPLIT CALCULATIONS
18     IFRIC     --NO FRICTION FACTOR CALCULATIONS
19              1--FRICTION FACTOR CALCULATIONS
20     ICONS     --WRITE CONSTANTS EIGHTEEN AND NINETEEN ONLY
21              1--WRITE ALL CONSTANTS
22     IMAT      --CORRELATION OF CONSTANTS 18 AND 19 NOT DONE
23              1--CORRELATION OF CONSTANTS 18 AND 19 DONE
24
25     D         ROD DIAMETER (IN)
26     DW        WIRE DIAMETER (IN)
27     L         WIRE LEAD LENGTH (IN)
28     GAP       GAP BETWEEN RODS AND WALL (IN)
29     TOL J     BUNDLE TOTAL TOLERANCE (IN)
30     FAC       BUNDLE LOOSENESS FACTOR (DIMENSIONLESS)
31     REB       BUNDLE AVG. REYNOLDS NUMBER (FOR IMAT=1, REB=7000 IS ADEQUATE)
32     NR HB     NUMBER OF REYNOLDS NUMBER TO BE INPUT
33
34     IFLOW     FLOW CONDITIONS:
35              1--LAMINAR
36              2--TURBULENT
37              3--TRANSITION
38     FICL      SUBCHANN L FRICTION FACTOR IN LAMINAR FLOW
39     FITUT     SUBCHANN L FRICTION FACTOR IN TURBULENT FLOW

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38 C FRICR SUBCHANNEL FRICTION FACTOR IN TRANSITION FLOW
39 C XL FLOW SPLIT PARAMETER IN LAMINAR FLOW
40 C XTR FLOW SPLIT PARAMETER IN TRANSITION FLOW
41 C XT FLOW SPLIT PARAMETER IN TURBULENT FLOW
42 C
43 INT GER HFLOW
44 REAL CT1,CT2,XLV,KT2,MI
45 COMMON/362 GK/NROD,0,DW,H,TOLN,FAC,NRING,NCH(3),P,PDR,PDRM1,DPR,ON
46 1MOP,HDR,GAP,WIRLN,ULT4,SINH,COSTH,COSIN,AR(3),ASP(3),PWP(3),DEP(
47 3),AS(3),PM(3),DE(3),AT,PWT,DLB
48 COMMON/SCORCO/CT1,CT2,CALF(2),CP(2),CFTWO,XLV,XLVIN,KT2,MT,ICONS
49 COMMON/3FLASP/ANG,VTVA,EN,ENVTVA,CTF1,CON6,CON7,CON9,CTS2,GT,S,XT(
50 12),XTR0,CSIR(2),CLF(2),GL,XL(2),XLR
51 COMMON/3FRIFA/FRICL(2),CON4(2),FRIBL,CON10,FRICT(2),CON12,FRIBT,FR
52 ICTR(2),FRIBTR,IFLOW(3),IFRIC,ISPLT,HFLOW,RELAM(2),RETRN(2),RETRC
53 (2),IMAT
54 COMMON/3CONS/CON11,CON13,CON18,CON19,CON18,CON19,CONB18,CONB19
55 COMMON/3ATRI/ATI18(6,7,5),ATI19(6,7,6),ATE18(6,7,6),ATE19(6,7,6),A
56 TB18(6,7,6),ATE19(6,7,6)
57 DIMENSION RFB(10),F(3),XTR(3),X(3)
58 DIMENSION CON3(2),CON5(2)
59 DATA PI,SQRT3/3.1415926,1.7320508/
60 TWOPI = 2.*PI
61 READ(5,1000) NCHT,IMAT
62 C
63 C IF IMAT = 1, NCHT MUST BE 252 FOR SUBROUTINE ATRIX TO WORK.
64 C NOTE ALSO THAT THE DATA SETS ARE TO BE ARRANGED IN THIS ORDER
65 C OF INCREMENTS: P/D, H/D, NROD.
66 C
67 IF (IMAT.EQ.1) GO TO 19
68 DO 100 JK = 1,4
69 DO 100 JJ = 1,7
70 DO 100 II = 1,8
71 19 READ(5,1000) NROD,NRCH,ISPLT,IFRIC,ICONS
72 IF (IMAT.EQ.2.AND.NROD.EQ.0) STOP
73 WRITE(5,1000) NROD
74 READ(5,1000) DW,H,TOLN,FAC

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75      IF (IMAT.EQ.3.AND.D. Q.0.0) STOP
76      IF (IMAT.EQ.3)  XIT (5,1(10) D,BW,H
77      IF (IMAT.EQ.8) WRITE (6,2020) TOLIN,FAC
78      X AD(5,1010) (FIB(N),N-1,NR-B)
79      DO 3 I=1,3
80      C5I(I) = 0.0
81      C6I(I) = 0.0
82      CONI(I) = 1.0
83      CON4(I) = 0.0
84      5) CON (I) = 1.0
85      CON  = 0.0
86      CON7 = 0.0
87      CFIW0 = 0.
88      CON9 = 0.
89      CON10 = 0.
90      CALCULATION OF GEOMETRICAL PARAMETERS
91      CALL G7M
92      IF (IMAT.EQ.3) WRITE (6,2030) NRING,(NCH(1),I=1,3)
93      WRITE (6,2040) P,PDR,HDR,GAP
94      IF (IMAT.EQ.1) GO TO 70
95      WRITE (6,2050) AS(1),Dr (1),AS (2),Dr (2),AS (3),Dr (3)
96      WRITE (6,2060) AT,DUB
97      70 DO 20 J=1,NRUB
98      IF (IMAT.EQ.3) WRITE (6,5000) REB(J)
99      IF (J.GT.1) GO TO 10
100
101      CALCULATION OF EMPIRICAL CONSTANTS
102
103      CALL C0CON
104
105      CALCULATION OF FLOWSPLITS
106
107      CALL FL0MPI
108      IF (ISPLIT.EQ.0) GO TO 200
109      IF (IC0N .E. 0.1.AND.IMAT. 0.0) WRITE (6,5050) CON6,CON7,CON9
110      100 IF (IMAT.EQ.3) WRITE (5, 500) (XI(I),I=1,2)

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111         IF (IMAT.EQ.1) GO TO 200
112         WRITE(5,700) XT(I)
113         IF (ICONS.EQ.1) WRITE(6,5570) (CSTR(I),I=1,2),(CLF(I),I=1,2)
114         WRITE(5,6000) (XL(I),I=1,2)
115         WRITE(6,6000) XLR
116     200 BFLOW = 4
117         FRIBL = 2.
118         FRIPR = 0.5
119         FRIRTR = 0.5
120         DO 300 I=1,2
121             XC(I) = 0.7
122             FC(I) = 1.0
123             FRICL(I) = 0.0
124             FRICI(I) = 0.0
125             FRICR(I) = 0.
126             IFLOW(I) = 3
127             RFLAM(I) = REB(J)*OL(I)*XL(I)/DEB
128     300 RFTUR(I) = REB(J)*OT(I)*XT(I)/DEB
129         IF (IMAT.EQ.2) WRITE(6,5050) (RFLAM(I),I=1,2),(RFTUR(I),I=1,2)
130         IF (ISPLT.EQ.0.AND. (FRIC.EQ. ) GO TO 900
131     400
132     400 TERMINATE THE BUNDLE FLOW CONDITION
133
134         IF (ISPLT.EQ.1.0) GO TO 500
135         IF (RELAM(1).GT.400.) GO TO 400
136         IFLOW(1) = 1
137         XC(1) = XL(1)
138         IF (IMAT.EQ.0) WRITE(5,5050) X(1)
139     400 IF (RELAM(2).GT.400.) GO TO 400
140         IFLOW(2) = 1
141         XC(2) = XL(2)
142         IF (IMAT.EQ.2) WRITE(6,5050) X(2)
143         IF (IFLOW(1).EQ.1.AND. (IFLOW(2).EQ.1) BFLOW = 1
144     400 IF (RFTUR(1).LT.10000.) GO TO 500
145         IFLOW(1) = 2
146         XC(1) = XT(1)

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147      IF (IMAT.EQ.7) WRITE (6,5750) X(1)
148      IF (KTOP(2).LT.1000.0) GO TO 550
149      IFLOW(2) = 2
150      X(2) = X(1)
151      IF (IMAT.EQ.8) WRITE (6,5600) X(2)
152      540 IF (IFLOW(1).EQ.2.AND. IFLOW(2).EQ.2) BFLOW = 2
153      550 IF (IFLOW(1).EQ.3.AND. IFLOW(2).EQ.3) BFLOW = 3
154      IF (IFLOW(1).EQ.1.OR. IFLOW(2).EQ.3) GO TO 600
155
156      CALCULATION OF FRICTION FACTOR
157
158      IF (FRIC.LT.1) GO TO 570
159      560 CALL FRIFAC
160      IF (ISPLT.EQ.6) GO TO 870
161
162      CALCULATION OF FLOW SPLITS FOR TRANSITION FLOW
163
164      DO 65 I=1,2
165      IF (IFLOW(I).LT.3) GO TO 850
166      XTR(I) = SQRT((RIBI*Q(I)/(FRICTR(I)*D_B))
167      X(I) = XTR(I)
168      R_TRN(I) = R_B(J)*Q(I)*XTR(I)/D_B
169      IF (IMAT.EQ.7) WRITE (6,8700) I,XTR(I)
170      600 CONTINUE
171      XTR = X(1)/X(2)
172      IF (IMAT.EQ.8) WRITE (6,8730) XTR
173      R_TR1 = R_B(J)*Q(1)*X(1)/D_B
174      R_TR2 = R_B(J)*Q(2)*X(2)/D_B
175      IF (IMAT.EQ.7) WRITE (6,8750) R_TR1,R_TR2
176
177      DETERMINE THE MAIN AND SUBCHANNEL FRICTION FACTORS
178
179      570 IF (BFLOW.EQ.3) GO TO 870
180      DO 65 I=1,2
181      IF (IFLOW(I).LT.1) GO TO 880
182      F(I) = FRICL(I)

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183      GO TO 825
184      33) IF(IFLOW(I).GT.2) GO TO 823
185      F(I) = FRIC(I)
186      GO TO 825
187      34) F(I) = FRICR(I)
188      345 CONTINUE
189      IF(IMAT.EQ.0) WRITE(6,8700) (F(I),I=1,2)
190      IF(IMAT.EQ.0) WRITE(6,8750) FRIBTR
191
192      C CALCULATION OF REMAINING CONSTANTS IN FRICTION FACTOR CORRELATIONS
193
194      377 CALL CONST
195
196      C ASSIGNMENT OF CONSTANTS 18 AND 19 TO THEIR RESPECTIVE MATRICES.
197
198      ATR18(IJ,JK) = CON18
199      ATR19(IJ,JK) = CON19
200      ATR18(IJ,JK) = CON18
201      ATR19(IJ,JK) = CON19
202      ATR18(IJ,JK) = CON18
203      ATR19(IJ,JK) = CON19
204      380 CONTINUE
205      IF(IMAT.EQ.0) GO TO 10
206      IF(IMAT.EQ.1) CALL ATRIX
207      200) FORMAT(15)
208      201) FORMAT(8F10.0)
209      202) FORMAT(777) 21H TOTAL NO. OF RODS = ,I5)
210      203) FORMAT(20H DIA. OF FULL PIN = ,F10.5,4H IN ,/ 16H DIA. OF WIRE =
211      1,81.5,4H IN ,/ 20H WIRE LEAD LENGTH = ,F10.5,4H IN )
212      204) FORMAT(24H BUNDLE TOTAL TOLERANCE = ,F10.7,4H IN ,/ 12H BUNDLE F-
213      RFACTOR = ,F10. )
214      205) FORMAT(17H PINGS OF PIN = ,I5,/ 31H NO. OF INTERIOR SUBCHANNELS
215      1 = ,I5,/ 27H NO. OF CORNER SUBCHANNELS = ,I5,/ 29H NO. OF CORNER SUBC
216      HANNELS = ,I5)
217      206) FORMAT(15H ROD PITCH = ,F10.7,4H IN ,/ 32H PITCH-TO-DIAMETER RATIO
218      1), 27D ,F5.5/ 31H LEAD-TO-DIAMETER RATIO ,H/D = ,F8.2/ 29H GAP B

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210      ' TW IN BODS AND WALL = ,F10.7,4H IN )
220      135) FOR ATC 37H FLOW AREA FOR INTERIOR SUBCHANNEL = ,F12.9,7H IN**2 ,/
221      1 42H HYDRAULIC DIA. FOR INTERIOR SUBCHANNEL = ,F12.9,3H IN,/ 35H F
222      LOW AREA FOR EDGE SUBCHANNEL = F12.9,7H IN**2 ,/ 37H HYDRAULIC DIA
223      3.FOR EDGE SUBCHANNEL = ,F12.9,4H IN ,/35H FLOW AREA FOR CORNER SUB
224      CHANNEL = ,F12.9,7H IN**2 ,/40H HYDRAULIC DIA. FOR CORNER SUBCHANN
225      EL = ,F12.9,4H IN )
226      15) FORMAT( 20H BUNDLE FLOW AREA = ,F10.5,7H IN**2 ,/ 30H BUNDLE AVG.
227      2HYDRAULIC DIA. = ,F10.5,4H IN )
228      5000 FORMAT(///5X,12H *** BUNDLE REYNOLDS NUMBER = ,F10.1,5H *** /
229      1X,17H ***** //)
230      505) FORMAT(X,25H FLOW SPLIT PARAMETERS X1 = ,F7.5)
231      5350 FORMAT(X,15H FLOW SPLIT PARAMETERS X2 = ,F7.5//)
232      579) FORMAT(X,55H SUBCHANNEL REYNOLDS NUMBER ACCORDING TO XL_ RE(1) =
233      1 ,F10.1,4H RE(2) = ,F10.1/32X,24H ACCORDING TO XT_ RE(1) = ,F10.1
234      1,3H RE(2) = ,F10.1/5X,11H THEREFORE //)
235      500) FORMAT(4X,18H CONSTANT SIX = ,F9.6/40X,18H CONSTANT SEVEN = ,F5
236      1.3/40X,18H CONSTANT NINE = ,F4.2)
237      550) FORMAT( 5X,30H FLOW SPLIT PARAMETER XT(1) = ,F7.5 /5X,30H FLOW SP
238      LIT PARAMETER XT(2) = ,F7.5)
239      555) FORMAT(5X,27H RATIO OF XT(1) TO XT(2) = ,F5.3//)
240      577) FORMAT(60X,25H INTERIOR CONSTANT ONE = ,F9.6/40X,25H EDGE CONSTANT
241      1 ON = ,F9.6/40X,24H INTERIOR CONSTANT TWO = ,F9.6/40X,25H EDG
242      E CONSTANT TWO = ,F4.6)
243      500) FORMAT( 5X,30H FLOW SPLIT PARAMETER XL(1) = ,F7.5 /5X,30H FLOW SP
244      LIT PARAMETER XL(2) = ,F7.5)
245      555) FORMAT(5X,27H RATIO OF XL(1) TO XL(2) = ,F5.3//)
246      573) FORMAT(5X,24H FLOW SPLIT PARAMETERS X,11,3H = ,F7.5)
247      573) FORMAT( 5X,21H RATIO OF X1 TO X2 = ,F5.3//)
248      575) FORMAT(5X,18H RETR1 = ,F10.1,3X,18H RETR2 = ,F10.1//)
249      590) FORMAT( 5X,55H SUBCHANNEL FRICTION FACTOR F1 = ,F9.6/32X,6H F2 = ,
250      1 F4.6)
251      55) FORMAT( 5X,29H BUNDLE FRICTION FACTOR FB = ,F9.6//)
252      STOP

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253      END
254      SUBROUTINE GEOM
255      COMMON/GEOM/NROD,D,DW,H,TOLN,FAC,NRING,NCH(3),P,PDR,PDRM1,DPR,ON
256      1MDP,HDR,GAP,WIRLN,DELTA,SINIH,COSTH,COSIN,AR(3),ASP(3),PWP(3),DEP(
257      3),AS(3),PW(3),DEL(3),AT,PWT,DEB
258      DATA PI,SQRT(3)/3.1415926,1.7320568/
259
260      C CALCULATION OF NUMBER OF RINGS, NUMBER OF DIFFERENT SUBCHANNELS, ROD
261      C PITCH AND GAP WITH TOLERANCE INCLUDED (EQNS. A-5,A-12,A-13,A-14,A-3,A
262      C -4,A-15 AND A-15).
263
264      NRING = (3.+SQRT(12.*NROD-3.))/6.-1.
265      NCH(1) = 6*NRING**2
266      NCH(2) = 6*NRING
267      NCH(3) = 6
268      P = D+DW+FAC*TOLN/(SQRT(3)*NRING)
269      PDR = P/D
270      PDRM1 = PDR-1.
271      DPR = D/P
272      ONMDP = 1.-DPR
273      HDR = H/D
274      GAP = 1.5*(1.-FAC)*TOLN+DW
275      WIRLN = SQRT(H**2+(PI*(D+DW))**2)
276      DELTA = WIRLN/H
277      SINIH = PI*(D+DW)/WIRLN
278      COSTH = 1./DELTA
279      COSIN = DELTA
280
281      C WIRL PROJECTED AT A IN INTERIOR AND EDGE SUBCHANNELS (EQNS A-23 AND A
282      C -33).
283
284      AR(1) = PI*DW*(D+DW)/6.
285      AR(2) = 1.7*AR(1)
286
287      SUBCHANNEL FLOW AREA, WETTED PERIMETER, AND HYDRAULIC DIAMETER
288      C FOR BAR ROD BUNDLE (EQNS. A-17,A-24,A-31,A-19,A-26,A-33,A-21,A-28 AN

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289      U = A-31).
290
291      ASP(1) = SQRT3*P**2/4.-PI*D**2/8.
292      ASP(2) = P*(D/2.+GAP)-PI*D**2/8.
293      ASP(3) = (D/2.+GAP)**2/SQRT3-PI*D**2/24.
294      PWP(1) = PI*D/2.
295      PWP(2) = P*PI*D/2.
296      PWP(3) = PI*(D/2.+2.*(D/2.+GAP)/SQRT3
297      DP(1) = 4.*ASP(1)/PWP(1)
298      DP(2) = 4.*ASP(2)/PWP(2)
299      DP(3) = 4.*ASP(3)/PWP(3)
300
301      SUBCHANNEL FLOW AREA, WETTED PERIMETER, AND HYDRAULIC DIAMETER
302      FOR WIRE WRAPPED ROD BUNDLE (EQNS. A-18,A-25,A-32,A-29,A-27,A-34,A-22
303      ,A-29 AND A-31).
304
305      AS(1) = ASP(1)-COSIN*PI*DW**2/8.
306      AS(2) = ASP(2)-PI*COSIN*DW**2/8.
307      AS(3) = ASP(3)-PI*(LW**2*COSIN)/24.
308      PW(1) = PWP(1)+PI*DW*COSIN/2.
309      PW(2) = PWP(2)+PI*COSIN*DW/2.
310      PW(3) = PWP(3)+PI*DW*COSIN/2.
311      DL(1) = 4.*AS(1)/PW(1)
312      DL(2) = 4.*AS(2)/PW(2)
313      DL(3) = 4.*AS(3)/PW(3)
314
315      BUNDLE TOTAL FLOW AREA, TOTAL WETTED PERIMETER, AND AVERAGE
316      HYDRAULIC DIAMETER FOR WIRE WRAPPED ROD BUNDLE (EQNS. A-38,A-40 AND A
317      -41).
318
319      AT = NCH(1)*AS(1)+NCH(2)*AS(2)+NCH(3)*AS(3)
320      PWT = NCH(1)*PW(1)+NCH(2)*PW(2)+NCH(3)*PW(3)
321      DT = 4.*AT/PWT
322      RETURN
323

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320      SUBROUTINE CORCON
321      REAL CT1,CT2,XLV,KT2,MT
322      COMMON/SGEOM/NROD, J,DW,H,TOLEN,FAC,NRINC,NCH(3),P,PDR,PDRM1,DPR,ON
323      IMOP,HDP,GAP,WI(LEN,D,LTA,SINTH,COSTH,COSIN,AR(3),ASP(3),PWP(3),DEP(
324      23),AS(3),PW(3),D(3),AT,PWT,DEB
325      COMMON/SERIFA/FRICL(2),CON4(2),FRIBL,CON10,FRICT(2),CON12,FRIHT,FR
326      ICT(2),FRIBTR,IFLOW(3),IFRIC,ISPL1,BFLOW,RELAM(2),RETRN(2),RETUR(
327      22),IMAT
328      COMMON/SCORCO/CT1,CT2,CALF(2),CP(2),CFTWO,XLV,XLVIN,KT2,MT,ICONS
329      DATA PI,SQRT3/3.1415926,1.7320508/
330
331      C
332      CALCULATION OF EMPIRICAL CONSTANTS (EQNS. A-6,A-7,A-8,A-9,2-15A TO 2-
333      15C,1-2 AND A-11).
334      C
335      CT1 = 2700.
336      CT2 = 1.9
337
338      CALF(1) = 5835.*HUR**1.98/PDR**3.264
339      CALF(2) = 4205.*HUR**2.57/PJR**4.337
340      CP(1) = 40.*PDRM1*(340.-336.*PDRM1)
341      CP(2) = 37.4+PDRM1*(290.9-318.2*PDRM1)
342      IF(0.67.0.5) GO TO 15
343      CFTWO = .23*(PDR**685)/(HUR**894)
344      IF(0.17.0.09.0.67.0.25) WRITE(6,9960)
345      IF(ICON=.0.1.AND.IMAT=.0.0) WRITE(6,9975) CFTWO
346      GO TO 1
347
348      15 IF(AROD.67.19) GO TO 16
349      CFTWO = .47*(PDR**645)/(HUR**356)
350      IF(ICON = 1.1.AND.IMAT = 0.0) WRITE(6,9975) CFTWO
351      GO TO 17
352
353      16 CFTWO = .477*(PDR**65)/(HUR**333)
354      17 IF(0.17.0.472.0.0.67.0.25) WRITE(6,9970)
355      IF(ICON=.0.1.AND.IMAT=.0.0) WRITE(6,9975) CFTWO
356
357      18 XLV = 1.4
358      XLVIN = 1.7*XLV
359      KT2 = 10.5/PI
360      MT = .3

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359 3360 FORMAT(7X,66H ***** THE ROD DIAMETER IS OUT OF THE CALIBRATED R
361     RANGE OF CFTWO. /14X,57H THE CORRELATION FOR .136IN<D<.250IN HAS BE
362     BEEN USED ***** /)
363 3370 FORMAT(7X,66H ***** THE ROD DIAMETER IS OUT OF THE CALIBRATED R
364     RANGE OF CFTWO. /14X,57H THE CORRELATION FOR .472IN<D<.525IN HAS BE
365     BEEN USED ***** /)
366 3375 FORMAT(40X,18H CONSTANT FIGHT = ,F12.6)
367     RETURN
368     END
369     SUBROUTINE FLOSP1
370     REAL CT1,CT2,XLV,KT2,MT
371     COMMON/SGEOM/NROD,D,DW,H,TOLEN,FAC,NRING,NCH(3),P,PDR,PORM1,DPR,ON
372     LMDP,HDR,GAP,WIRLN,DELTA,SINTH,COSTH,COSIN,AR(3),ASP(3),PWP(3),DEP(
373     23),AS(3),PW(3),DE(3),AT,PWT,DEB
374     COMMON/SCORCO/CT1,CT2,CALF(2),CP(2),CFTWO,XLV,XLVIN,KT2,MT,ICONS
375     COMMON/SELOSP/ANG,VIVA,CN,ENVIVA,CTF1,CON6,CON7,CON9,CTS2,GT,S,XT(
376     12),XTRO,CSTR(2),CLF(2),GL,XL(2),XLR
377     DATA PI,SQRT377,1415926,1.7320508/
378
379 C   CALCULATION OF TERMS IN CHIU'S CORRELATION FOR (VTVA)GAP IN
380 C   TURBULENT FLOW.
381
382     ANG = (1+DW)/WIRLN
383     VTVA = KT2*(GAP/P)**MT*SINTH*SQRT(AR(2)/ASP(2))
384
385 C   CALCULATION OF TERMS IN CHIU'S CORRELATION FOR XT(1) AND XT(2) (EQNS
386 C   A-10,2-3 AND 2-4).
387
388     FN = .5*P*GAP/((.5+D+GAP)**.5*(P-PI*D)**2/16.)
389     ENVIVA = FN*VIVA
390     CTF1 = CT1*(AR(1)/ASP(1))*(DE(1)/H)*ANG**2
391     CON6 = (CT2*ENVIVA)**2
392     CON7 = 1.375
393     CON9 = .18
394     CTS2 = (1.+(CT1*ENVIVA)**2)**1.375
395     GT = ((1.+(CTF1)/(1.7*CTS2))**.571*(DE(2)/D(1))**.714

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346      S = (AS(2)/AS(1)+AS(3)/(AS(1)*NRING))/NRING
397      :
398      C  VALU'S FOR XT(1) AND XT(2) (EQNS. 2-2 AND 2-3).
399      :
400      XT(1) = (1.+S)/(1.+GT*3)
401      XT(2) = (1.+S)/(S+1./GT)
402      XTR0 = XT(1)/XT(2)
403      C
404      C  CALCULATION OF TERMS IN XL(1) AND XL(2) (EQNS. A-1,A-2 AND 2-5).
405      C
406      DO 10 I=1,2
407      CSTR(I) = CP(I)*(AS(I)/ASP(I))*(DE(I)/DLP(I))**2
408      20 CLF(I) = CALF(I)*(AR(I)/ASP(I))*(DE(I)/H)*(1.-DW/(2.*DE(I)))
409      GL = (CSTR(1)+CLF(1))/(CSTR(2)+CLF(2))*(DE(2)/DE(1))**2
410      C
411      C  VALU'S FOR XL(1) AND XL(2) (EQNS. 2-2 AND 2-5).
412      C
413      XL(1) = (1.+S)/(1.+S*GL)
414      XL(2) = (1.+S)/(S+1./GL)
415      XLR = XL(1)/XL(2)
416      RETURN
417      END
418      SUBROUTINE FRIFAC
419      INTEGER BFLOW
420      REAL CT1,CT2,XLV,KT1,MT
421      COMMON/SGEOM/NROD,D,DW,H,TOLN,FAC,NRING,NCH(3),P,PDR,PDRM1,DPR,ON
422      IMOP,HDR,GAP,WIRLN,9 LTA,SINTH,COSTH,COSIN,AR(3),ASP(3),PWP(3),DLP(
423      3),AS(3),Pw(3),DE(3),AT,PWT,DEB
424      COMMON/SCORCO/CT1,CT2,CALF(2),CP(2),CFTW0,XLV,XLVIN,KT2,MT,ICONS
425      COMMON/SELOSP/ANG,VIVA,FN,FNVTVA,CF1,CON5,CON7,CON9,CTS2,GT,S,XT(
426      1),XTR0,CSTR(2),CLF(2),GL,XL(2),XLR
427      COMMON/SEFRIFA/FRICL(2),CON4(2),FRIBL,CON10,FRICT(2),CON12,FRIBT,FR
428      ICT(2),FRIBTR,BFLOW(3),IFRIC,ISPLT,BFLOW,RELAM(2),RETRN(2),RETRN(
429      2),IMAT
430      C
431      C  CALCULATION OF SUBCHANNEL FRICTION FACTORS FOR LAMINAR FLOW (EQN.2-9)
432      C

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433     GO TO 800 IF (IFLOW.EQ.2) GO TO 800
434     DO 700 I=1,2
435     IF (IFLOW(I).EQ.2) GO TO 700
436     FRICL(I) = (CSTR(I)+CLF(I))/RELAM(I)
437     700 CONTINUE
438     IF (IFLOW.EQ.1.AND.IMAT.LQ.0) WRITE(6,7000) (FRICL(I),I=1,2)
439     7001 FORMAT(//5X,47H LAMINAR SUBCHANNEL FRICTION FACTOR FRICL(1) = ,F9.
440     15/4X,12H FRICL(2) = ,F9.6)
441
442 C   CALCULATION OF BUNDLE FRICTION FACTORS FOR LAMINAR FLOW. A DO-LOOP HAS
443 C   BEEN USED BECAUSE THE INTERIOR AND EDGE SUBCHANNELS CAN BE IN DIFFER-
444 C   ENT FLOW REGIMES FOR A GIVEN BUNDLE REYNOLDS NUMBER. (EQNS. 2-11 AND 2-
445 C   13).
446
447     DO 750 I = 1,2
448     IF (IFLOW(I).EQ.2) GO TO 750
449     CON4(I) = (DEB/D (I))*AL(1)**2
450     FRIBL = FRICL(I)*CON4(I)
451     750 CONTINUE
452     IF (CON4.LQ.1.AND.IMAT.LQ.0) WRITE(6,7500) (CON4(I),I=1,2)
453     IF (IFLOW.EQ.1.AND.IMAT.LQ.0) WRITE(6,7500) FRIBL
454     7501 FORMAT(40X,24H INTERIOR CONSTANT FOUR = ,F9.6/40X,22H EDGE CONSTAN
455     1T FOUR = ,F9.6)
456     7502 FORMAT(13X,34H BUNDLE AVERAGE FRICTION FACTOR = ,F9.6/)
457     IF (IFLOW.EQ.1) GO TO 900
458
459 C   CALCULATION OF SUBCHANNEL FRICTION FACTORS FOR TURBULENT FLOW (EQNS.
460 C   2-14 AND 2-19).
461
462     CON10 = (DE(1)/DE(2))*(XT(2)/XT(1))**2
463     IF (CON10.LQ.1.AND.IMAT.LQ.0) WRITE(6,7700) CON10
464     FRIC(2) = CFT20*CL52/(TUR(2)**.18)
465     IF (IFLOW(1).EQ.1) GO TO 800
466     FRIC(1) = FRIC(2)*CON10
467     IF (IFLOW.EQ.2.AND.IMAT.LQ.0) WRITE(6,7700) (FRIC(I),I=1,2)
468     7701 FORMAT(10X,12H CONSTANT TEN = ,F9.6)

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467      175) FORMAT(//5X,40H TURBULENT SUBCHANNEL FRICTION FACTOR FRICT(1) = ,
470      1F9.6//4X,12H FRICT(2) = ,F9.6)
471      C
472      C CALCULATION OF BUNDLE FRICTION FACTORS FOR TURBULENT FLOW (EQNS. 2-16
473      C AND 2-20).
474      C
475      85) CON12 = (D B/D (2))*X1(2)**4
476      IF(ICONS.EQ.1.AND.IMAT.EQ.0) WRITE(5,8050) CON12
477      FRIBT = FRICT(2)*CON12
478      IF(BFLOW.EQ.2.AND.IMAT.EQ.0) WRITE(6,8000) FRIBT
479      8000 FORMAT(15X,34H BUNDLE AVERAGE FRICTION FACTOR = ,F9.6)
480      8050 FORMAT(40X,19H CONSTANT TWELVE = ,F9.6)
481      IF(BFLOW.EQ.2) GO TO 919
482      C
483      C CALCULATION OF SUBCHANNEL FRICTION FACTORS FOR TRANSITION FLOW (EQN.
484      C 2-21).
485      C
486      85) DO 860 I=1,2
487      IF(IFLOW(I).LT.3) GO TO 860
488      FRICTR(I) = (FRIC(1)**XLV+FRICT(I)**XLV)**XLVIN
489      85) CONTINUE
490      IF(BFLOW.EQ.3.AND.IMAT.EQ.0) WRITE(6,8300) (FRICTR(I),I=1,2)
491      8300 FORMAT(//5X,51H TRANSITION SUBCHANNEL FRICTION FACTOR FRICTR(1) =
492      1,F9.6//4X,13H FRICTR(2) = ,F9.6)
493      C
494      C CALCULATION OF BUNDLE FRICTION FACTOR, IN TRANSITION FLOW (EQN. 2-22).
495      C
496      FRIBTR = (FRIBL**XLV+FRIBT**XLV)**XLVIN
497      IF(BFLOW.EQ.3.AND.IMAT.EQ.0) WRITE(6,8500) FRIBTR
498      8500 FORMAT(15X,34H BUNDLE AVERAGE FRICTION FACTOR = ,F9.6//)
499      90) RETURN
500      END
501      SUBROUTINE CONST
502      REAL CT1,CT2,XLV,K1,MT
503      COMMON/15-16/NUOD,DDW,H,TDLEN,FAC,NRING,NCH(3),P,PDR,PDRM1,DPP,ON
504      LMP,HDR,GAP,WIRLN,D,LT4,SINTH,COSTH,COSIN,AP(3),ASP(3),PWP(3),DEP(

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505      25),AS(3),PW(3),DL(3),AT,PWT,DEB
506      COMMON/BCORCO/C11,C12,CALF(2),CP(2),CFTWO,XLV,XLVIN,KT2,MT,ICONS
507      COMMON/SFLOSP/ANG,VTV,EN,ENVTV,CTF1,CON6,CON7,CON9,CTS2,GT,S,XT(
508      12),XTRD,CSTR(2),CLF(2),GL,XL(2),XLR
509      COMMON/SFRIFA/FRICL(2),CON4(2),FRIBL,CON10,FRICT(2),CON12,FRIBT,FR
510      ICTR(2),FRIBTR,IFLOW(3),IFRIC,ISPLT,BFLOW,RELAM(2),RETRN(2),REIUR(
511      22),IMAT
512      COMMON/SCONC/CON11,CON13,CONI18,CONI19,CONE18,CONE19,CONB18,CONB19P1119
513      DIMENSION CON3(2),CON5(2)
514      C
515      C EQNS. 2-10,2-13,2-19 AND 2-20.
516      C
517      DO 220 I=1,2
518          CON3(I) = CLF(I)/CSTR(I)
519      220 CON4(I) = CON4(I)*CSTR(I)
520      CON11 = CFTWO*CON10
521      CON13 = CFIM0*CON12
522      IF(ICONS.EQ.1.AND.IMAT.EQ.0) WRITE(6,8965) (CON3(I),I=1,2),(CON5(I
523      1),I=1,2),CON11,CON13
524      C
525      C FOR INTERIOR SUBCHANNELS (EQNS. 2-24,2-26,2-27 AND 2-28).
526      C
527      CONI14 = ((1.+CON3(1))*CSTR(1))*1.49
528      CONI15 = (((1.+CON5)*CON7)*CON11)*1.49
529      CONI16 = CONI14/((DL(1)*XL(1)/DEB)*XLV)
530      CONI17 = CONI15/((DL(2)*XL(2)/DEB)*((CON9*XLV))
531      CONI18 = CONI17/CONI16
532      CONI19 = CONI17*((1./1.49)
533      IF(ICONS.EQ.1.AND.IMAT.EQ.0) WRITE(6,8970) CONI14,CONI15,CONI16,CO
534      NI17
535      IF(IFLOW(1).EQ.1) CONI18 = 1.0
536      WRITE(6,8971) CONI18,CONI19
537      C
538      C FOR CORE SUBCHANNELS (EQNS. 2-14,2-26,2-27 AND 2-28).
539      C
540      CON 14 = ((1.+CON3(2))*CSTR(2))*1.49

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541     CON 15 = (((1.+CON5)**(CON7)*CFTWO)**1.4)
542     CON 16 = CONE14/((DL(2)*XL(2)/DEB)**XLV)
543     CONE17 = CONE14/((DL(2)*XT(2)/DEB)**(CON9*XLV))
544     CON 18 = CONE17/CON 16
545     CONE19 = CONE18**(.1/1.49)
546     IF (ICONS.EQ.1.AND.IMAT.EQ.0) WRITE(6,8975) CONE14, CONE15, CONE16, CO
547     INE17
548     IF (IFLOW(2).EQ.1) CONE18 = 0.0
549     WRITE(6,8976) CONE18, CONE19
550
551 C   FOR BUNDLE (BUNDL = 2-24, 2-25, 2-27 AND 2-28).
552 C
553     CONB14 = ((1.+CON3(2))*CON5(2))**1.49
554     CONB15 = (((1.+CON5)**CON7)*CON13)**1.49
555     CONB16 = CONB14/((DL(2)*XL(2)/DEB)**XLV)
556     CONB17 = CONB14/((DL(2)*XT(2)/DEB)**(CON9*XLV))
557     CONB18 = CONB17/CONB16
558     CONB19 = CONB18**(.1/1.49)
559     IF (ICONS.EQ.1.AND.IMAT.EQ.0) WRITE(6,8980) CONB14, CONB15, CONB16, CO
560     INB17
561     IF (IFLOW.EQ.1) CONB18 = 0.0
562     WRITE(6,8981) CONB18, CONB19
563
564 896) FORMAT(40X, 27H INTERIOR CONSTANT THREE = ,F9.6/40X, 27H EDGE CONSTA
565     INT THR = ,F9.6/40X, 27H INTERIOR CONSTANT FIVE = ,F9.6/40X, 2
566     27H DGE CONSTANT FIVE = ,F9.6/40X, 22H CONSTANT ELEVEN = ,F
567     31.6/40X, 22H CONSTANT THIRTEEN = ,F9.6)
568 897) FORMAT(31X, 31H INTERIOR CONSTANT FOURTEEN = ,F12.6/31X, 31H INTERI
569     10R CONSTANT FIFTEEN = ,F9.6/31X, 31H INTERIOR CONSTANT SIXTEEN
570     = ,F12.6/31X, 31H INTERIOR CONSTANT SEVENTEEN = ,F12.6)
571 8971) FORMAT(31X, 31H INTERIOR CONSTANT EIGHTEEN = ,F12.6/31X, 31H INTERI
572     10R CONSTANT NINETEEN = ,F12.6)
573 8972) FORMAT(35X, 27H DGE CONSTANT FOURTEEN = ,F12.6/35X, 27H EDGE CONST
574     ANT FIFTEEN = ,F9.6/35X, 27H EDGE CONSTANT SIXTEEN = ,F12.6/35X
575     27H DGE CONSTANT SEVENTEEN = ,F12.6)
576 8973) FORMAT(35X, 27H DGE CONSTANT EIGHTEEN = ,F12.6/35X, 27H EDGE CONST
577     ANT NINETEEN = ,F12.6)

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577      333 FORMAT(3X,29H BUNDLE CONSTANT FOURTEEN = ,F12.6/33X,29H BUNDLE C
578      16X,CONSTANT FIFTEEN = ,F9.6/33X,29H BUNDLE CONSTANT SIXTEEN = ,F12
579      2.6/33X,29H BUNDLE CONSTANT SEVENTEEN = ,F12.6)
580      334 FORMAT(3X,29H BUNDLE CONSTANT EIGHTEEN = ,F12.6/33X,29H BUNDLE C
581      16X,CONSTANT NINETEEN = ,F12.6)
582      RETURN
583      END
584      SUBROUTINE ATRIX
585      COMMON/5ATRI/A1118(6,7,6),A1119(6,7,6),ATE18(6,7,6),ATE19(6,7,6),A
586      11B18(6,7,6),ATE15(6,7,6)
587      REAL A41(16),A42(16),A43(16),A44(16),A252(16),TEMP(6,3),NR0D(6)
588      DIMENSION PD(6),HQ(7),A(16),H(4),BI18(4),BI118(4),BI19(4),HB18(4)
589      DIMENSION HFE18(4),H19(4),HB18(4),HB19(4)
590      DATA A41/8.8,33.5,47.904476,35.9,41721,185.447038,47.904476,2.88
591      14.31,21.5,31.43,10.84334,35.9,641721,21.591843,169.553598,81.451569
592      2.18,447038,10.84334,2.88,1.4,1569,42.000000/
593      DATA A42/124.09123,52.867535,451.457500,264.924340,52.867535,2.7
594      137772,21.4,3378,11.373426,41.457500,21.455378,184.067169,102.2459
595      235,264.924340,11.373426,102.245985,0.000000/
596      DATA A43/5915.829175,132.634047,2711.258951,847.757889,132.634047
597      1,5.7,10003,100.601516,5.038927,2711.208982,100.601516,2192.919073,
598      2323.381159,847.757889,50.038927,629.880050,192.000000/
599      DATA A44/84.931953,137.597106,2372.941725,927.235191,137.597106
600      1,5.7,34404,100.465052,31.162959,2872.991725,100.465052,2207.332668,
601      2,56.7,1000,27.235191,31.162959,650.674400,210.000000/
602      DATA A252/140.538319,185.5,1582,3232.633446,1112.682229,185.50158
603      12,5.7,14725,122.056835,42.011353,3232.633446,122.056835,2370.986266
604      1,73.1,2,35,1112.682229,42.12353,732.12503,252.000000/
605
606      SUMMIN UP THE RIGHT-HAND SIDE TERMS.
607
608      S1118 = 0.
609      S1118 = 0.
610      S1113 = 0.0
611      S1113 = 0.
612      S1118 = 0.0

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613      SEI18 = 0.0
614      SEH18 = 0.0
615      SEIY18 = 0.0
616      SEBH18 = 0.0
617      SEBP18 = 0.0
618      SEBH018 = 0.0
619      SEHY18 = 0.0
620      DO I=0,NING = 1,4
621      BI18(NING) = 0.0
622      BF18(NING) = 0.0
623      BB18(NING) = 0.0
624      PD(1) = 1.067
625      PD(2) = 1.10
626      PD(3) = 1.15
627      PD(4) = 1.20
628      PD(5) = 1.25
629      PD(6) = 1.343
630      HD(1) = 4.
631      HD(2) = 8.
632      HD(3) = 12.
633      HD(4) = 16.
634      HD(5) = 24.
635      HD(6) = 48.
636      HD(7) = 96.
637      NR00(1) = 13.
638      NR00(2) = 57.
639      NR00(3) = 61.
640      NR00(4) = 127.
641      NR00(5) = 217.
642      NR00(6) = 271.
643      DO 100 KK = 1,7
644      DO 100 JJ = 1,7
645      DO 100 II = 1,7
646      SEIN18 = SEIN18+ALOG(ATI18(II,JJ,KK))*ALOG(NR00(KK))
647      SEIP18 = SEIP18+ALOG(ATI18(II,JJ,KK))*ALOG(PD(II))
648      SEIH18 = SEIH18+ALOG(ATI18(II,JJ,KK))*ALOG(HD(JJ))
649      SEIY18 = SEIY18+ALOG(ATI18(II,JJ,KK))

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650      SEEN18 = SEEN18+ALOG(AFE18(II,JJ,KK))*ALOG(NROD(KK))
651      SEEP18 = SEEP18+ALOG(AFE18(II,JJ,KK))*ALOG(PD(II))
652      SEEH18 = SEEH18+ALOG(AFE18(II,JJ,KK))*ALOG(HD(JJ))
653      SEFY18 = SEFY18+ALOG(AFE18(II,JJ,KK))
654      SBHN18 = SBHN18+ALOG(ATB18(II,JJ,KK))*ALOG(NROD(KK))
655      SEBP18 = SEBP18+ALOG(ATB18(II,JJ,KK))*ALOG(PD(II))
656      SBH18 = SBH18+ALOG(ATB18(II,JJ,KK))*ALOG(HD(JJ))
657      SEBY18 = SEBY18+ALOG(ATB18(II,JJ,KK))
658      BI19(1) = BI19(1)+ALOG(ATI19(II,JJ,KK))*ALOG(NROD(KK))
659      BI19(2) = BI19(2)+ALOG(ATI19(II,JJ,KK))*ALOG(PD(II))
660      BI19(3) = BI19(3)+ALOG(ATI19(II,JJ,KK))*ALOG(HD(JJ))
661      BI19(4) = BI19(4)+ALOG(ATI19(II,JJ,KK))
662      B119(1) = B119(1)+ALOG(ATE19(II,JJ,KK))*ALOG(NROD(KK))
663      B119(2) = B119(2)+ALOG(ATE19(II,JJ,KK))*ALOG(PD(II))
664      B119(3) = B119(3)+ALOG(ATE19(II,JJ,KK))*ALOG(HD(JJ))
665      B119(4) = B119(4)+ALOG(ATE19(II,JJ,KK))
666      BB19(1) = BB19(1)+ALOG(ATB19(II,JJ,KK))*ALOG(NROD(KK))
667      BB19(2) = BB19(2)+ALOG(ATB19(II,JJ,KK))*ALOG(PD(II))
668      BB19(3) = BB19(3)+ALOG(ATB19(II,JJ,KK))*ALOG(HD(JJ))
669      100 BB19(4) = BB19(4)+ALOG(ATB19(II,JJ,KK))
670
671      C  ADJUSTMENTS FOR RIGHT HAND SIDE MATRICES OF CONSTANT 18.
672      C
673      DO 170 NN=1,4
674      BI19(NN) = 0.0
675      170 BB19(NN) = 0.0
676      DO 200 KK = 1,4
677      DO 250 JJ = 1,5
678      N = 5
679      IF(JJ.EQ.1) M = 1
680      IF(JJ.EQ.2) M = 4
681      IF(JJ.EQ.3) M = 6
682      DO 300 II = M,N
683      BI19(1) = BI18(1)+ALOG(ATI18(II,JJ,KK))*ALOG(NROD(KK))
684      BI19(2) = BI18(2)+ALOG(ATI18(II,JJ,KK))*ALOG(PD(II))
685      BI19(3) = BI18(3)+ALOG(ATI18(II,JJ,KK))*ALOG(HD(JJ))

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685      BI18(4) = BI18(4)+ALOG(ABI18(II,JJ,KK))
687      BB18(1) = BB18(1)+ALOG(AB18(II,JJ,KK))*ALOG(NROD(KK))
688      BB18(2) = BB18(2)+ALOG(AB18(II,JJ,KK))*ALOG(PD(II))
689      BB18(3) = BB18(3)+ALOG(AB18(II,JJ,KK))*ALOG(HD(JJ))
690      200 BB18(4) = BB18(4)+ALOG(AB18(II,JJ,KK))
691      C
692      DO 250 M=1,4
693      250 BL18(M) = 0.0
694      DO 300 KK = 1,6
695      DO 300 JJ = 1,4
696      NN = 6
697      IF(JJ.EQ.1) M = 4
698      IF(JJ.EQ.2) M = 5
699      IF(JJ.EQ.3.OR.JJ.EQ.4) M = 6
700      DO 300 II = M,NN
701      BE18(1) = BE18(1)+ALOG(ABE18(II,JJ,KK))*ALOG(NROD(KK))
702      BE18(2) = BE18(2)+ALOG(ABE18(II,JJ,KK))*ALOG(PD(II))
703      BE18(3) = BE18(3)+ALOG(ABE18(II,JJ,KK))*ALOG(HD(JJ))
704      300 BF18(4) = BF18(4)+ALOG(ABE18(II,JJ,KK))
705      C
706      BII18(1) = SEIN18-BI18(1)
707      BII18(2) = SEIP18-BI18(2)
708      BII18(3) = SEIH18-BI18(3)
709      BII18(4) = SEIY18-BI18(4)
710      BEL18(1) = SEEN18-BL18(1)
711      BEL18(2) = SEEP18-BL18(2)
712      BEL18(3) = SEEH18-BL18(3)
713      BEL18(4) = SEIY18-BL18(4)
714      BB18(1) = SEBN18-BB18(1)
715      BB18(2) = SEBP18-BB18(2)
716      BB18(3) = SEBH18-BB18(3)
717      BB18(4) = SEBY18-BB18(4)
718      C
719      C REASSIGNMENT OF A AND B MATRICES. NOTICE THAT MATRICES A AND
720      B ARE STORED COLUMNWISE.
721      C

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722      DO 100 I=MARI = 1, 1
723      DO 400 KMARI = 1, 1
724      IF (JMARI.EQ.1) A(KMARI) = A10(KMARI)
725      IF (JMARI.EQ.2) A(KMARI) = A192(KMARI)
726      IF (JMARI.EQ.3) A(KMARI) = A252(KMARI)
727      IF (JMARI.EQ.4) A(KMARI) = A12(KMARI)
728      IF (JMARI.EQ.5) A(KMARI) = A210(KMARI)
729      IF (JMARI.EQ.6) A(KMARI) = A252(KMARI)
730      IF (JMARI.EQ.7) A(KMARI) = A50(KMARI)
731      IF (JMARI.EQ.8) A(KMARI) = A192(KMARI)
732      400 IF (JMARI.EQ.9) A(KMARI) = A252(KMARI)
733      DO 400 IMARI = 1, 4
734      IF (JMARI.EQ.1) B(LMARI) = B118(LMARI)
735      IF (JMARI.EQ.2) B(LMARI) = B118(LMARI)
736      IF (JMARI.EQ.3) B(LMARI) = B119(LMARI)
737      IF (JMARI.EQ.4) B(LMARI) = B118(LMARI)
738      IF (JMARI.EQ.5) B(LMARI) = B118(LMARI)
739      IF (JMARI.EQ.6) B(LMARI) = B119(LMARI)
740      IF (JMARI.EQ.7) B(LMARI) = B118(LMARI)
741      IF (JMARI.EQ.8) B(LMARI) = B118(LMARI)
742      400 IF (JMARI.EQ.9) B(LMARI) = B119(LMARI)
743
744      C METHOD OF SOLUTION IS BY ELIMINATION USING LARGEST PIVOTAL
745      C DIVISOR. EACH STAGE OF ELIMINATION CONSISTS OF INTERCHANGING
746      C ROWS WHEN NECESSARY TO AVOID DIVISION BY ZERO OR SMALL
747      C ELEMENTS. THE FORWARD SOLUTION TO OBTAIN VARIABLE N IS DONE
748      C IN N STAGES. THE BACK SOLUTION FOR THE OTHER VARIABLES IS
749      C CALCULATED BY SUCCESSIVE SUBSTITUTIONS. FINAL SOLUTION
750      C VALUES ARE DEVELOPED IN VECTOR B.
751      C FORWARD SOLUTION.
752
753      TOL = 1.E-5
754      N = 4
755      J1 = -N
756      DO 765 J = 1, N

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757      JY = J+1
758      JJ = JJ+N+1
759      BIGA = 1
760      IT = JJ-J
761      DO 760 I = J,N
762  C
763      SEARCH FOR MAXIMUM COEFFICIENT IN COLUMN.
764  C
765      IJ = IT+1
766      IF (ABS(BIGA)-ABS(A(IJ))) 720,730,730
767 720 BIGA = A(IJ)
768      IMAX = I
769 730 CONTINUE
770  C
771  C INTERCHANGE ROWS IF NECESSARY.
772  C
773      I1 = J+1*(J-2)
774      IT = IMAX-J
775      DO 780 K = J,N
776      I1 = I1+N
777      I2 = I1+IT
778      SAV = A(I1)
779      A(I1) = A(I2)
780      A(I2) = SAV
781  C
782  C DIVIDE EQUATION BY LEADING COEFFICIENT
783  C
784      I5 A(I1) = A(I1)/BIGA
785      SAV = A(IMAX)
786      B(IMAX) = B(J)
787      B(J) = SAV /BIGA
788  C
789  C ELIMINATE NEXT VARIABLE
790  C
791      IF(J=N) 75,77,77
792      I5 I5 = N*(J-1)

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793      DO 755 IX = JY,N
794      IXJ = IOS+IX
795      II = J-IX
796      DO 750 JX = JY,N
797      IXJX = N*(JX-1)+IX
798      JXJ = IXJX+II
799      760 A(IXJX) = A(IXJX)-(A(IXJ)*A(JXJ))
800      760 B(IX) = B(IX)-(B(J)*A(IXJ))
801      C
802      C BACK SOLUTION
803      C
804      770 NY = N-1
805      IF = N*N
806      DO 780 J=1, NY
807      IA = II-J
808      IB = N-J
809      IC = N
810      DO 780 K=1,J
811      B(IB)=B(IB)-A(IA)*B(IC)
812      IA = IA-N
813      780 IC = IC-1
814      B(J) = EXP(B(J))
815
816      C RETURNING THE CALCULATED VALUES BACK TO THE RESPECTIVE B MATRICES
817
818      DO 800 IMAXI = 1,4
819      IF(IMAXI.EQ.1) B1B(IMARI) = B(IMARI)
820      IF(IMAXI.EQ.2) B11B(IMARI) = B(IMARI)
821      IF(IMAXI.EQ.3) B12B(IMARI) = B(IMARI)
822      IF(IMAXI.EQ.4) B13B(IMARI) = B(IMARI)
823      IF(IMAXI.EQ.5) B14B(IMARI) = B(IMARI)
824      IF(IMAXI.EQ.6) B15B(IMARI) = B(IMARI)
825      IF(IMAXI.EQ.7) B16B(IMARI) = B(IMARI)
826      IF(IMAXI.EQ.8) B17B(IMARI) = B(IMARI)
827      800 IF(IMAXI.EQ.9) B18B(IMARI) = B(IMARI)
828      WRITE(6,950) (B(J),J=1,9)

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829      13) FORMAT(73X,'EXPONENT FOR NR/D = ',F15.1/3X,'EXPONENT FOR P/D = ',
830      1F15.10/3X,'EXPONENT FOR H/D = ',F15.10/3X,'CONSTANT = ',F15.10/)
831      100) CONTINUE
832
833      C TABULATION OF CONSTANTS 18 AND 19, THEIR CORRESPONDING
834      C CORRELATED VALUES, AND THE PREDICTION ERRORS.
835
836      DO 2000 NA = 1,6
837      DO 2000 KK = 1,6
838      WRITE(6,1010)
839      1010) FORMAT('1',1X,'H/D',4X,'P/D')
840      WRITE(6,1020)
841      1020) FORMAT(9X,'1.007',5X,'1.10',7X,'1.15',7X,'1.20',7X,'1.25',7X,'1.34
842      13'//)
843      DO 2000 JJ = 1,7
844      DO 1300 II = 1,6
845
846      C SELECTION OF THE RESPECTIVE CORRELATIONS
847
848      DO 1130 JUNE = 1,4
849      IF(NA.NE.1) GO TO 1110
850      B(JUNE) = B115(JUN )
851      IF(JJ.EQ.1) B(JUNE) = B118(JUNE)
852      IF(JJ.LE.2.AND.II.EQ.1) B(JUNE) = B118(JUNE)
853      IF(JJ.EQ.2.AND.II.EQ.5) B(JUNE) = B118(JUNE)
854      IF(JJ.EQ.2.AND.II.EQ.6) B(JUNE) = B118(JUNE)
855      IF(JJ.EQ.3.AND.II.EQ.6) B(JUNE) = B118(JUNE)
856      1110) IF(NA.EQ.2) B(JUNE) = B119(JUNE)
857      IF(NA.NE.3) GO TO 1120
858      B(JUNE) = B118(JUN )
859      IF(JJ.EQ.1.AND.II.EQ.4) B(JUNE) = B118(JUNE)
860      IF(JJ.EQ.1.AND.II.EQ.7) B(JUNE) = B118(JUNE)
861      IF(JJ.EQ.1.AND.II.EQ.8) B(JUNE) = B118(JUNE)
862      IF(JJ.EQ.2.AND.II.EQ.5) B(JUNE) = B118(JUNE)
863      IF(JJ.EQ.2.AND.II.EQ.6) B(JUNE) = B118(JUNE)
864      IF(JJ.EQ.3.AND.II.EQ.8) B(JUNE) = B118(JUNE)

```

```

865      IF (JJ.EQ.4.AND.II.EQ.6) B(JUNE) = B18(JUNE)
866      112) IF (NA.EQ.4) B(JUNE) = B19(JUNE)
867      IF (NA.EQ.5) GO TO 113.
868      B(JUNE) = BB18(JUNE)
869      IF (JJ.EQ.1) B(JUNE) = BB18(JUNE)
870      IF (JJ.EQ.2.AND.II.EQ.4) B(JUNE) = BB18(JUNE)
871      IF (JJ.EQ.2.AND.II.EQ.5) B(JUNE) = BB18(JUNE)
872      IF (JJ.EQ.2.AND.II.EQ.6) B(JUNE) = BB18(JUNE)
873      IF (JJ.EQ.3.AND.II.EQ.6) B(JUNE) = BB18(JUNE)
874      113) IF (NA.EQ.5) B(JUNE) = BB19(JUNE)
875
876      C SELECTION OF THE ORIGINAL MATRIX FOR CONSTANTS 18 OR 19.
877      C
878      IF (NA.EQ.1) TEMP(II,1) = AT18(II,JJ,KK)
879      IF (NA.EQ.2) TEMP(II,1) = AT19(II,JJ,KK)
880      IF (NA.EQ.3) TEMP(II,1) = AT18(II,JJ,KK)
881      IF (NA.EQ.4) TEMP(II,1) = AT19(II,JJ,KK)
882      IF (NA.EQ.5) TEMP(II,1) = AT18(II,JJ,KK)
883      IF (NA.EQ.6) TEMP(II,1) = AT19(II,JJ,KK)
884      TEMP(II,2) = B(4)*VPOD(KK)**B(1)*PD(II)**B(2)*HD(JJ)**B(3)
885      1900 TEMP(II,3) = (TEMP(II,2)-TEMP(II,1))/TEMP(II,1)*100.
886      WRITE (5,1910) HD(JJ), (TEMP(II,1), II = 1,6)
887      1910 FORMAT(72X,F3.0,2X,F10.5,5F11.6)
888      WRITE (5,1920) (TEMP(II,2), II = 1,6)
889      1920 FORMAT(6X,6F11.6)
890      WRITE (5,1930) (TEMP(II,3), II = 1,6)
891      1930 FORMAT(7X,F3.2,'%',5(4X,F6.2,'%'))
892      2000 CONTINUE
893      RETURN
894      END

```

D.3 User's Note

Since the program has been deliberately designed with the option to generate the constants and exponents for the computer pre-processor, EZFRIC (see Appendix G) and the tables for Appendix F, it is imperative that IMAT be decided and input prior to typing in any data set. If IMAT=1, note that NSET must be 252 (unless the tabulation in Appendix F is either extended or reduced; see step 6 of Section 4.2) for subroutine ATRIX to work. The data sets are also to be arranged in the order of increments of P/D, H/D, NROD; this point is illustrated in either file FREIDA.DAT;5 or FREIDA.DAT;6 of the magnetic tape called NING.

The user has merely to read in NROD, the number of rods (or pins); NREB, the number of Reynolds numbers (up to thirty; if only constants 18 and 19 are desired, use $Re_p = 7000$ alone) at which the flow splits and friction factors are to be calculated; ISPLT and IFRIC, the flow split and friction factor calculation or no-calculation options; and ICONS, the option of printing only constants 18 and 19 or all the constants.

The user is advised to note that some constants are solely laminar or turbulent entities and in order to obtain a printout of all the constants, a transition bundle Reynolds number, say $Re_p = 7000$, must be input. A fully laminar and a fully turbulent Reynolds number will together produce a printout of all the constants too. If only constants 18 and 19 are desired, an input of a fully laminar Reynolds number alone

will produce zeroes for the interior and bundle constants 18 because constants 11 (Eqn. (2-19)) and 13 (Eqn. (2-20)) are not calculated for laminar flow; a fully turbulent or even a transition Reynolds number will not encounter such problems. See Appendix E.

The diameter of the rod, D , must also be read in inches and so must D_w , the diameter of the wire in inches; H , the wire lead length in inches; TOL , the bundle total tolerance in inches; and FAC , the dimensionless bundle looseness factor (a measure of the packing distribution; see Reference [1]).

The Reynolds numbers are then read in. If $IMAT=1$, $Re_b = 7000$ alone is suggested.

APPENDIX E. SAMPLE RUN OF FRIC

Figure E-1 is the input of an IMAT=0 sample run of FRIC. Notice that the two bundle geometries correspond exactly to cases 1 and 2, respectively, of the sample problem in Section 3.5.

The relevant geometrical parameters were printed as the "header" block. The bundle Reynolds number was first written, followed by the fully turbulent and laminar flow splits. The pseudo-laminar and turbulent subchannel Reynolds numbers were next written. At this stage the flow regime was determined and the subchannel and bundle friction factors were calculated accordingly. The correct subchannel Reynolds numbers were printed as RETR1 and RETR2. Since the ICONS=1 calculational option was selected, all the constants were written out.

100	2					
200	51	5	1	1	1	
300		.0000	.0429	5.937	0.0	0.0
400		200.	7000.	1.0000.		
500	217	3	1	1	1	
600		.25	.00	15.	0.0	0.0
700		200.	7000.	1.0000.		

Figure E-1 Input of Sample Run

TOTAL NO. OF RODS = 81
 DIA. OF FULL PIN = 0.40591 IN
 DIA. OF WIRE = 0.4250 IN
 WIRE LEAD LENGTH = 3.73700 IN
 BUNDLE TOTAL TOLERANCE = 0.000000 IN
 BUNDLE F-FACTOR = 0.000000
 RINGS OF PINS = 4
 NO. OF INTERIOR SUBCHANNELS = 76
 NO. OF EDGE SUBCHANNELS = 24
 NO. OF CORNER SUBCHANNELS = 4
 ROD PITCH = 0.548001 IN
 PITCH-TO-DIAMETER RATIO, P/D = 1.385
 LEAD-TO-DIAMETER RATIO, H/D = 7.78
 GAP BTW N RODS AND WALL = 0.0429000 IN
 FLOW AREA FOR INTERIOR SUBCHANNEL = 0.023121052 IN**2
 HYDRAULIC DIA. FOR INTERIOR SUBCHANNEL = 0.134162620 IN
 FLOW AREA FOR EDGE SUBCHANNEL = 0.061068144 IN**2
 HYDRAULIC DIA. FOR EDGE SUBCHANNEL = 0.172383308 IN
 FLOW AREA FOR CORNER SUBCHANNEL = 0.016769087 IN**2
 HYDRAULIC DIA. FOR CORNER SUBCHANNEL = 0.106296822 IN
 BUNDLE FLOW AREA = 4.3717 IN**2
 BUNDLE AVG. HYDRAULIC DIA. = 0.14402 IN

*** BUNDLE REYNOLDS NUMBER = 200.0 ***

CONSTANT EIGHT = 1.254080
 CONSTANT SIX = 0.047190
 CONSTANT SEVEN = 1.375
 CONSTANT NINE = 0.18

FLOW SPLIT PARAMETER XT(1) = 0.89925
 FLOW SPLIT PARAMETER XT(2) = 1.17787
 RATIO OF XT(1) TO XT(2) = 0.762

INTERIOR CONSTANT ONE = 51.349770
 EDGE CONSTANT ONE = 51.704094
 INTERIOR CONSTANT TWO = 79.242531
 EDGE CONSTANT TWO = 92.837128

FLOW SPLIT PARAMETER XL(1) = 0.84996
 FLOW SPLIT PARAMETER XL(2) = 1.26781
 RATIO OF XL(1) TO XL(2) = 0.670

SUBCHANNEL REYNOLDS NUMBER ACCORDING TO XL_ RE(1) = 158.4 RE(2) = 303.5
 ACCORDING TO XT_ RE(1) = 167.5 RE(2) = 282.4
 THEREFORE_

FLOW SPLIT PARAMETERS X1 = 0.84996
 FLOW SPLIT PARAMETERS X2 = 1.26781

LAMINAR SUBCHANNEL FRICTION FACTOR FRICL(1) = 0.924676

FRICL(2) = 0.475256
 INTERIOR CONSTANT FOUR = 9.775522
 EDGE CONSTANT FOUR = 1.342879

BUNDLE AVERAGE FRICTION FACTOR = 0.639595

RATIO OF X1 TO X2 = 0.670

RETR1 = 158.4 RETR2 = 303.5

	INTERIOR CONSTANT THREE	=	1.545192
	EDGE CONSTANT THREE	=	1.795547
	INTERIOR CONSTANT FIVE	=	39.822872
	EDGE CONSTANT FIVE	=	69.432320
	CONSTANT ELEVEN	=	0.000000
	CONSTANT THIRTEEN	=	0.000000
INTERIOR	CONSTANT FOURTEEN	=	1421.405320
INTERIOR	CONSTANT FIFTEEN	=	0.000000
INTERIOR	CONSTANT SIXTEEN	=	2012.784302
INTERIOR	CONSTANT SEVENTEEN	=	0.000000
INTERIOR	CONSTANT EIGHTEEN	=	0.000000
INTERIOR	CONSTANT NINETEEN	=	164.935196
EDGE	CONSTANT FOURTEEN	=	1653.435523
EDGE	CONSTANT FIFTEEN	=	0.142703
EDGE	CONSTANT SIXTEEN	=	888.213318
EDGE	CONSTANT SEVENTEEN	=	0.130086
EDGE	CONSTANT EIGHTEEN	=	0.000000
EDGE	CONSTANT NINETEEN	=	95.251198
BUNDLE	CONSTANT FOURTEEN	=	2565.442871
BUNDLE	CONSTANT FIFTEEN	=	0.000000
BUNDLE	CONSTANT SIXTEEN	=	1378.136108
BUNDLE	CONSTANT SEVENTEEN	=	0.000000
BUNDLE	CONSTANT EIGHTEEN	=	0.000000
BUNDLE	CONSTANT NINETEEN	=	127.910797

*** BUNDLE REYNOLDS NUMBER = 7000.0 ***

FLOW SPLIT PARAMETER XT(1) = 0.80423
 FLOW SPLIT PARAMETER XT(2) = 1.17987
 RATIO OF XT(1) TO XT(2) = 0.762

INTERIOR CONSTANT ONE = 51.349770
EDGE CONSTANT ONE = 51.704094
INTERIOR CONSTANT TWO = 79.242531
EDGE CONSTANT TWO = 92.837128

FLOW SPLIT PARAMETER XL(1) = 0.84096
FLOW SPLIT PARAMETER XL(2) = 1.26781
RATIO OF XL(1) TO XL(2) = 0.670

SUBCHANNEL REYNOLDS NUMBER ACCORDING TO XL_ RE(1) = 5542.5 RE(2) = 10622.3
ACCORDING TO XT_ RE(1) = 5863.7 RE(2) = 9885.6
THEREFORE_

INTERIOR CONSTANT FOUR = 0.775522

EDGE CONSTANT FOUR = 1.342879
CONSTANT TEN = 1.339890
CONSTANT TWELVE = 1.163060

TRANSITION SUBCHANNEL FRICTION FACTOR FRICTR(1) = 0.078299
FRICTR(2) = 0.056338
BUNDLE AVERAGE FRICTION FACTOR = 0.066755

FLOW SPLIT PARAMETERS X1 = 0.89137
FLOW SPLIT PARAMETERS X2 = 1.19115
RATIO OF X1 TO X2 = .748

REF(1) = 5813.4 REF(2) = 998.1

INTERIOR CONSTANT THREE = 1.543192
 EDGE CONSTANT THREE = 1.795547
 INTERIOR CONSTANT FIVE = 39.822872
 EDGE CONSTANT FIVE = 69.432320
 CONSTANT ELEVEN = 0.340440
 CONSTANT THIRTEEN = 0.295511
 INTERIOR CONSTANT FOURTEEN = 1421.403320
 INTERIOR CONSTANT FIFTEEN = 0.220682
 INTERIOR CONSTANT SIXTEEN = 2012.784302
 INTERIOR CONSTANT SEVENTEEN = 0.201170
 INTERIOR CONSTANT EIGHTEEN = 0.000100
 INTERIOR CONSTANT NINETEEN = 164.935196
 EDGE CONSTANT FOURTEEN = 1653.436523
 EDGE CONSTANT FIFTEEN = 0.142703
 EDGE CONSTANT SIXTEEN = 838.213318
 EDGE CONSTANT SEVENTEEN = 0.133086
 EDGE CONSTANT EIGHTEEN = 0.000146
 EDGE CONSTANT NINETEEN = 95.251198
 BUNDLE CONSTANT FOURTEEN = 2565.442871
 BUNDLE CONSTANT FIFTEEN = 0.178723
 BUNDLE CONSTANT SIXTEEN = 1378.136108
 BUNDLE CONSTANT SEVENTEEN = 0.162921
 BUNDLE CONSTANT EIGHTEEN = 0.000118
 BUNDLE CONSTANT NINETEEN = 127.917797

*** BUNDLE REYNOLDS NUMBER = 15000.0 ***

FLOW SPLIT PARAMETER XT(1) = 0.87923
 FLOW SPLIT PARAMETER XT(2) = 1.17087
 RATIO OF XT(1) TO XT(2) = 0.762

INTERIOR CONSTANT ONE = 51.349770
 EDGE CONSTANT ONE = 51.704094
 INTERIOR CONSTANT TWO = 79.242531
 EDGE CONSTANT TWO = 92.837128
 FLOW SPLIT PARAMETER XL(1) = 0.84396
 FLOW SPLIT PARAMETER XL(2) = 1.26781
 RATIO OF XL(1) TO XL(2) = 0.670

SUBCHANNEL REYNOLDS NUMBER ACCORDING TO XL_ RE(1) = 118765.9 RE(2) = 227621.0
 ACCORDING TO XT_ RE(1) = 125650.7 RE(2) = 211833.6
 THEREFORE_

FLOW SPLIT PARAMETERS X1 = 0.89923
 FLOW SPLIT PARAMETERS X2 = 1.17987

CONSTANT TEN = 1.339890

TURBULENT SUBCHANNEL FRICTION FACTOR FRIC(1) = 0.039893
 FRIC(2) = 0.029773
 CONSTANT TWELVE = 1.163060
 RUNCL AVERAGE FRICTION FACTOR = 0.039628
 RATIO OF X1 TO X2 = 0.762

RETR1 = 125650.7 RETR2 = 211833.6

INTERIOR CONSTANT THREE	=	1.543192
EDGE CONSTANT THREE	=	1.795547
INTERIOR CONSTANT FIVE	=	39.822872
EDGE CONSTANT FIVE	=	69.432320
CONSTANT ELEVEN	=	0.340440
CONSTANT THIRTEEN	=	0.295511
INTERIOR CONSTANT FOURTEEN	=	1421.403320
INTERIOR CONSTANT FIFTEEN	=	0.220682
INTERIOR CONSTANT SIXTEEN	=	2012.784302
INTERIOR CONSTANT SEVENTEEN	=	0.201170
INTERIOR CONSTANT EIGHTEEN	=	0.000100
INTERIOR CONSTANT NINETEEN	=	154.935196
EDGE CONSTANT FOURTEEN	=	1653.436523
EDGE CONSTANT FIFTEEN	=	0.142703
EDGE CONSTANT SIXTEEN	=	888.213318
EDGE CONSTANT SEVENTEEN	=	0.130086
EDGE CONSTANT EIGHTEEN	=	0.000146
EDGE CONSTANT NINETEEN	=	25.251198
BUNDLE CONSTANT FOURTEEN	=	2565.442871
BUNDLE CONSTANT FIFTEEN	=	0.178723
BUNDLE CONSTANT SIXTEEN	=	1376.136108
BUNDLE CONSTANT SEVENTEEN	=	0.162921
BUNDLE CONSTANT EIGHTEEN	=	0.000118
BUNDLE CONSTANT NINETEEN	=	127.910797

TOTAL NO. OF RODS = 217
 DIA. OF FUEL PIN = 0.2500 IN
 DIA. OF WIRE = 0.003 IN
 WIRE LEAD LENGTH = 13.0000 IN
 BUNDLE TOTAL FUEL LANC = 0.66300 IN
 BUNDLE F-FACTOR = 1.0000
 RINGS OF PIN =
 NO. OF INTERIOR SUBCHANNELS = 384
 NO. OF EDGE SUBCHANNELS = 43

NO. OF CORNER SUBCHANNEL = 3
 ROD PITCH = 1.316000 IN
 PITCH-TO-DIAMETER RATIO, P/D = 1.240
 LEAD-TO-DIAMETER RATIO, L/D = 52.5
 GAP BETWEEN RODS AND WALL = 0.050000 IN
 FLOW AREA FOR INTERIOR SUBCHANNEL = 0.015651152 IN**2
 HYDRAULIC DIA. FOR INTERIOR SUBCHANNEL = 0.128495902 IN
 FLOW AREA FOR EDGE SUBCHANNEL = 0.031388633 IN**2
 HYDRAULIC DIA. FOR EDGE SUBCHANNEL = 0.157492235 IN
 FLOW AREA FOR CORNER SUBCHANNEL = 0.01110625 IN**2
 HYDRAULIC DIA. FOR CORNER SUBCHANNEL = 0.118141904 IN
 BUNDLE FLOW AREA = 7.58333 IN**2
 BUNDLE AVG. HYDRAULIC DIA. = 0.15527 IN

*** BUNDLE REYNOLDS NUMBER = 209.9 ***

CONSTANT EIGHT = 0.187827
 CONSTANT SIX = 0.010205
 CONSTANT SEVEN = 1.375
 CONSTANT NINE = 0.18

FLOW SPLIT PARAMETER XT(1) = 0.97220
 FLOW SPLIT PARAMETER XT(2) = 1.00980
 RATIO OF XT(1) TO XT(2) = 0.963

INTERIOR CONSTANT ONE = 51.210781
 EDGE CONSTANT ONE = 60.489342
 INTERIOR CONSTANT TWO = 27.331516
 EDGE CONSTANT TWO = 32.274307

FLOW SPLIT PARAMETER XL(1) = 0.4660
 FLOW SPLIT PARAMETER XL(2) = 1.01401
 RATIO OF XL(1) TO XL(2) = 0.460

SUBCHANNEL REYNOLDS NUMBER ACCORDING TO XL_ RE(1) = 182.6 RE(2) = 284.6
 ACCORDING TO XT_ RE(1) = 191.3 RE(2) = 243.4
 THEREFORE_

FLOW SPLIT PARAMETERS X1 = 0.94660
 FLOW SPLIT PARAMETERS X2 = 1.20401

LAMINAR SUBCHANNEL FRICTION FACTOR FRICL(1) = 0.430275
 FRICL(2) = 0.325976
 INTERIOR CONSTANT FOUR = 0.929321
 EDGE CONSTANT FOUR = 1.226667
 BUNDLE AVERAGE FRICTION FACTOR = 0.399864

RATIO OF X1 TO X2 = 0.786

RETR1 = 182.6 RETR2 = 284.6

INTERIOR CONSTANT THREE = 0.533706
 EDGE CONSTANT THREE = 0.533554
 INTERIOR CONSTANT FIVE = 47.591236
 EDGE CONSTANT FIVE = 74.200272
 CONSTANT ELEVEN = 0.000000
 CONSTANT THIRTEEN = 0.218454

INTERIOR CONSTANT FOURTEEN = 666.353027
 INTERIOR CONSTANT FIFTEEN = 0.000000

INTERIOR CONSTANT SIXTEEN	=	753.513672
INTERIOR CONSTANT SEVENTEEN	=	0.000000
INTERIOR CONSTANT EIGHTEEN	=	0.000000
INTERIOR CONSTANT NINETEEN	=	86.055038
EDGE CONSTANT FOURTEEN	=	853.872681
EDGE CONSTANT FIFTEEN	=	0.084515
EDGE CONSTANT SIXTEEN	=	504.871521
EDGE CONSTANT SEVENTEEN	=	0.080179
EDGE CONSTANT EIGHTEEN	=	0.000000
EDGE CONSTANT NINETEEN	=	65.195168
BUNDLE CONSTANT FOURTEEN	=	1157.698975
BUNDLE CONSTANT FIFTEEN	=	0.105847
BUNDLE CONSTANT SIXTEEN	=	684.515686
BUNDLE CONSTANT SEVENTEEN	=	0.100417
BUNDLE CONSTANT EIGHTEEN	=	0.000147
BUNDLE CONSTANT NINETEEN	=	79.972733

*** BUNDLE REYNOLDS NUMBER = 7000.0 ***

FLOW SPLIT PARAMETER XT(1) = 0.97220
 FLOW SPLIT PARAMETER XT(2) = 1.32980
 RATIO OF XT(1) TO XT(2) = 0.733

INTERIOR CONSTANT ONE	=	51.210781
EDGE CONSTANT ONE	=	60.489342
INTERIOR CONSTANT TWO	=	27.331516
EDGE CONSTANT TWO	=	32.274307

FLOW SPLIT PARAMETER XL(1) = 0.74600
 FLOW SPLIT PARAMETER XL(2) = 1.25401
 RATIO OF XL(1) TO XL(2) = 0.595

SUBCHANNEL REYNOLDS NUMBER ACCORDING TO XL_ RE(1) = 6388.9 RE(2) = 9960.0
 ACCORDING TO XT_ RE(1) = 6696.7 RE(2) = 8518.9
 THEREFORE_

INTERIOR CONSTANT FOUR = 0.929321
 EDGE CONSTANT FOUR = 1.226667
 CONSTANT TEN = 0.878903
 CONSTANT TWELVE = 0.897377

TRANSITION SUBCHANNEL FRICTION FACTOR FRICTR(1) = 0.037754
 FRICTR(2) = 0.040458
 BUNDLE AVERAGE FRICTION FACTOR = 0.037909

FLOW SPLIT PARAMETERS X1 = 0.96395
 FLOW SPLIT PARAMETERS X2 = 1.05229
 RATIO OF X1 TO X2 = 0.930

RETR1 = 641.0 RETR2 = 8704.3

INTERIOR CONSTANT THREE = 0.533706
 EDGE CONSTANT THREE = 0.533554
 INTERIOR CONSTANT FIVE = 47.591236
 EDGE CONSTANT FIVE = 74.200272
 CONSTANT ELEVEN = 0.165081
 CONSTANT THIRTEEN = 0.168551
 INTERIOR CONSTANT FOURTEEN = 666.353027
 INTERIOR CONSTANT FIFTEEN = 0.069728
 INTERIOR CONSTANT SIXTEEN = 763.513672
 INTERIOR CONSTANT SEVENTEEN = 0.066150
 INTERIOR CONSTANT EIGHTEEN = 0.090087

INTERIOR CONSTANT NINETEEN	=	86.055038
EDGE CONSTANT FOURTEEN	=	853.872681
EDGE CONSTANT FIFTEEN	=	0.084515
EDGE CONSTANT SIXTEEN	=	504.871521
EDGE CONSTANT SEVENTEEN	=	0.080179
EDGE CONSTANT EIGHTEEN	=	0.000159
EDGE CONSTANT NINETEEN	=	65.195168
BUNDLE CONSTANT FOURTEEN	=	1157.698975
BUNDLE CONSTANT FIFTEEN	=	0.071923
BUNDLE CONSTANT SIXTEEN	=	684.515686
BUNDLE CONSTANT SEVENTEEN	=	0.068232
BUNDLE CONSTANT EIGHTEEN	=	0.000100
BUNDLE CONSTANT NINETEEN	=	79.972733

*** BUNDLE REYNOLDS NUMBER = 150000.0 ***

FLOW SPLIT PARAMETER XT(1) = 0.94220
 FLOW SPLIT PARAMETER XT(2) = 1.02980
 RATIO OF XT(1) TO XT(2) = 0.963

INTERIOR CONSTANT ONE	=	51.210781
EDGE CONSTANT ONE	=	60.489342
INTERIOR CONSTANT TWO	=	27.331516
EDGE CONSTANT TWO	=	32.274307

FLOW SPLIT PARAMETER XL(1) = 0.74660
 FLOW SPLIT PARAMETER XL(2) = 1.20401
 RATIO OF XL(1) TO XL(2) = 0.766

SUBCHANNEL REYNOLDS NUMBER ACCORDING TO XL	RE(1) =	136904.7	RE(2) =	213429.2
ACCORDING TO XT	RE(1) =	143500.3	RE(2) =	182548.4

THE FURF _

FLOW SPLIT PARAMETERS X1 = 0.99220
FLOW SPLIT PARAMETERS X2 = 1.02980

CONSTANT TEN = 0.878903

TURBULENT SURCHANNEL FRICTION FACTOR FRICT(1) = 0.018911

FRICT(2) = 0.021517

CONSTANT TWELVE = 0.897377

BUNDLE AVERAGE FRICTION FACTOR = 0.019308

RATIO OF X1 TO X2 = 0.964

REFR1 = 143500.3 REFR2 = 182546.4

INTERIOR CONSTANT THREE = 0.533706

EDGE CONSTANT THREE = 0.533554

INTERIOR CONSTANT FIVE = 47.591236

EDGE CONSTANT FIVE = 74.200272

CONSTANT ELEVEN = 0.165041

CONSTANT THIRTEEN = 0.168551

INTERIOR CONSTANT FOURTEEN = 606.353027

INTERIOR CONSTANT FIFTEEN = 0.369728

INTERIOR CONSTANT SIXTEEN = 753.513672

INTERIOR CONSTANT SEVENTEEN = 0.066150

INTERIOR CONSTANT EIGHTEEN = 0.000087

INTERIOR CONSTANT NINETEEN = 80.055038

EDGE CONSTANT FOURTEEN	=	853.872681
EDGE CONSTANT FIFTEEN	=	0.084515
EDGE CONSTANT SIXTEEN	=	504.871521
EDGE CONSTANT SEVENTEEN	=	0.080179
EDGE CONSTANT EIGHTEEN	=	0.000159
EDGE CONSTANT NINETEEN	=	65.195168
BUNDLE CONSTANT FOURTEEN	=	1157.698975
BUNDLE CONSTANT FIFTEEN	=	0.071923
BUNDLE CONSTANT SIXTEEN	=	684.515686
BUNDLE CONSTANT SEVENTEEN	=	0.068232
BUNDLE CONSTANT EIGHTEEN	=	0.000100
BUNDLE CONSTANT NINETEEN	=	79.972733

APPENDIX F. TABULATIONS OF CONSTANTS 18 and 19

Constants 18 and 19 were generated and tabulated in this Appendix by FRIC for the following possible bundle geometries:

NROD = 19, 37, 61, 127, 217, and 271

P/D = 1.067, 1.10, 1.15, 1.20, 1.25 and 1.343

H/D = 4, 8, 12, 16, 24, 48 and 96

In the computer program FRIC, a rod diameter of 0.35 inches was chosen as the demarcation point of the gap between the two ranges of rod diameters valid for Eqns. (2-15a, b, and c) so as to be consistent with Reference [3]. As such, two runs of FRIC were made with $D = 0.25$ " and $D = 0.5$ " to generate the tables of constants 18 and 19 in this Appendix. Constants 19 are, however, independent of Eqns. (2-15a, b, and c) and to avoid redundancy, the tabulations of constants 19 from $D = 0.5$ " have been duly omitted.

As shown in Appendix B, there are hitherto no experimental friction factor data for 127- and 271-rod bundles. They were, however, included in the correlation of constants 18 and 19 because such geometries are of interest to the industry.

The tables are arranged in ascending NROD order as follows:

Tables

F-1 to F-6 Interior Subchannel Constant 18 for $D \leq 0.35$ "

F-7 to F-12 Interior Subchannel Constant 19 for all Rod Diameters

F-13 to F-18 Edge Subchannel Constant 18 for $D \leq 0.35$ "

F-19 to F-24 Edge Subchannel Constant 19 for all Rod Diameters

F-25 to F-30 Bundle Constant 18 for $D \leq 0.35$ "

F-31 to F-36 Bundle Constant 19 for all Rod Diameters

F-37 to F-42 Interior Subchannel Constant 18 for $D > 0.35$ "

F-43 to F-48 Edge Subchannel Constant 18 for $D > 0.35$ "

F-49 to F-54 Bundle Constant 18 for $D > 0.35$ "

The tabulation format is illustrated in Figure F-1.

P/D	1.067
H/D	
4	0.000239
	0.000239
	0.00%

constant generated by FRIC

constant predicted by power curves

percentage error of prediction

Figure F-1 The Tabulation Format

The constants and the percentage error of prediction have been rounded to six and two decimal places, respectively. This has inevitably introduced some "rounding-off" errors.

TABLE F-1 Interior Subchannel Constant 18 for 19-Rod Bundle with $D \leq 0.35$ "

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000145	0.000143	0.000282	0.000397	0.000545	0.000740	
	0.000147	0.000145	0.000272	0.000394	0.000561	0.000748	
	-1.25%	-4.20%	-3.74%	-0.90%	3.03%	11.4%	
8.	0.000250	0.000255	0.000675	0.000100	0.000128	0.000210	
	0.000243	0.000245	0.000647	0.000091	0.000130	0.000242	
	-25.39%	-31.55%	-40.97%	-8.71%	1.00%	15.54%	
12.	0.000353	0.000352	0.000655	0.000662	0.000673	0.000105	
	0.000346	0.000348	0.000650	0.000652	0.000654	0.000105	
	-17.14%	-7.47%	-8.55%	-15.58%	-25.32%	-1.82%	
16.	0.000554	0.000551	0.000651	0.000655	0.000661	0.000631	
	0.000549	0.000650	0.000653	0.000653	0.000657	0.000661	
	-3.53%	-1.14%	2.77%	0.37%	-6.75%	-24.15%	
24.	0.000657	0.000654	0.000654	0.000655	0.000661	0.000675	
	0.000653	0.000654	0.000657	0.000657	0.000661	0.000666	
	-0.13%	-0.65%	5.11%	0.20%	1.26%	-12.00%	
48.	0.000653	0.000652	0.000653	0.000667	0.000673	0.000690	
	0.000659	0.000661	0.000664	0.000667	0.000669	0.000674	
	-0.56%	-2.13%	0.43%	-0.39%	-4.66%	-17.12%	
96.	0.000655	0.000657	0.000672	0.000675	0.000685	0.000688	
	0.000667	0.000669	0.000672	0.000675	0.000678	0.000684	
	1.42%	2.67%	2.41%	-1.42%	-7.66%	-22.47%	

Eqn. (3-5)

Eqn. (3-6)

TABLE F-2 Interior Subchannel Constant 18 for 37-Rod Bundle with $D \leq 0.35$ "

H/D	1.057	1.10	1.15	1.20	1.25	1.543
4.	0.000135 0.000130 -3.45%	0.000205 0.000195 -4.91%	0.000278 0.000287 -3.75%	0.000421 0.000415 -1.21%	0.000581 0.000593 2.10%	0.001019 0.001107 8.71%
8.	0.000135 0.000148 -21.53%	0.000270 0.000270 -29.01%	0.000384 0.000352 -38.22%	0.000105 0.000096 -9.06%	0.000137 0.000137 0.38%	0.000225 0.000256 13.51%
12.	0.000137 0.000132 -10.14%	0.000275 0.000253 -4.15%	0.000358 0.000356 -4.51%	0.000365 0.000352 -11.68%	0.000377 0.000360 -21.96%	0.000112 0.000109 -3.04%
16.	0.000358 0.000354 -1.58%	0.000375 0.000356 2.77%	0.000354 0.000356 7.25%	0.000353 0.000351 4.71%	0.000365 0.000363 -2.46%	0.000356 0.000368 -21.05%
4.	0.000362 0.000353 -2.58%	0.000359 0.000350 2.67%	0.000377 0.000353 5.71%	0.000359 0.000343 10.21%	0.000364 0.000358 0.15%	0.000379 0.000373 -8.01%
48.	0.000359 0.000355 -1.02%	0.000377 0.000358 5.44%	0.000357 0.000371 5.22%	0.000371 0.000374 4.55%	0.000377 0.000377 0.34%	0.000355 0.000363 -12.72%
64.	0.000372 0.000374 5.73%	0.000372 0.000377 5.35%	0.000375 0.000387 6.75%	0.000381 0.000384 5.13%	0.000389 0.000387 -2.60%	0.000114 0.000393 -17.90%

Eqn. (3-5)

Eqn. (3-6)

TABLE F-3 Interior Subchannel Constant 18 for 61-Rod Bundle with $D \leq 0.35"$

H/D	P/D	1.057	1.17	1.15	1.29	1.25	1.343
4.		0.000163	0.000214	0.000316	0.000439	0.000608	0.001077
		0.000156	0.000203	0.000299	0.000433	0.000614	0.001114
		-4.53%	-4.1%	-3.57%	-1.19%	1.70%	7.11%
8.		0.000169	0.000173	0.000087	0.000110	0.000143	0.000237
		0.000012	0.000054	0.000056	0.000100	0.000143	0.000267
		-21.06%	-26.38%	-35.98%	-9.14%	0.15%	12.71%
12.		0.000051	0.000058	0.000061	0.000068	0.000081	0.000117
		0.000056	0.000058	0.000060	0.000063	0.000065	0.000113
		-3.54%	-1.42%	-1.21%	-8.46%	-19.16%	-3.64%
16.		0.000062	0.000058	0.000057	0.000061	0.000068	0.000050
		0.000059	0.000061	0.000063	0.000065	0.000069	0.000074
		-1.12%	5.04%	10.94%	8.55%	1.11%	-18.42%
24.		0.000165	0.000062	0.000060	0.000062	0.000067	0.000063
		0.000163	0.000065	0.000068	0.000071	0.000074	0.000079
		-4.93%	5.34%	13.47%	14.35%	10.23%	-4.64%
48.		0.000074	0.000071	0.000071	0.000074	0.000080	0.000048
		0.000071	0.000073	0.000077	0.000080	0.000083	0.000049
		-3.76%	3.45%	2.82%	8.61%	4.45%	-9.05%
96.		0.000075	0.000077	0.000079	0.000084	0.000093	0.000118
		0.000081	0.000083	0.000087	0.000091	0.000094	0.000101
		3.71%	4.28%	10.32%	7.59%	1.56%	-14.14%

Egn. (3-5)

Egn. (3-6)

TABLE F-4 Interior Subchannel Constant 18 for 127-Rod Bundle with $D \leq 0.35"$

H/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000175 0.000166 -1.43%	0.000226 0.000216 -4.45%	0.000327 0.000318 -2.68%	0.000462 0.000461 -0.41%	0.000644 0.000657 1.98%	0.001157 0.001226 5.95%
8.	0.000175 0.000158 -22.27%	0.000176 0.000166 -23.11%	0.000093 0.000063 -52.10%	0.000115 0.000105 -8.63%	0.000151 0.000152 0.57%	0.000252 0.000213 12.38%
12.	0.000055 0.000063 -11.40%	0.000113 0.000105 3.22%	0.000065 0.000067 4.18%	0.000072 0.000070 -2.82%	0.000085 0.000073 -14.21%	0.000125 0.000120 -3.71%
16.	0.000067 0.000065 -1.99%	0.000062 0.000065 10.57%	0.000060 0.000071 17.50%	0.000064 0.000074 15.26%	0.000072 0.000077 7.39%	0.000016 0.000033 -13.66%
24.	0.000072 0.000071 -1.26%	0.000066 0.000073 11.22%	0.000065 0.000076 20.05%	0.000065 0.000077 21.54%	0.000071 0.000085 17.31%	0.000088 0.000089 1.31%
48.	0.000081 0.000089 -1.05%	0.000076 0.000082 8.9%	0.000075 0.000086 15.15%	0.000073 0.000091 15.64%	0.000084 0.000093 11.56%	0.000115 0.000111 -2.73%
72.	0.000085 0.000091 5.52%	0.000083 0.000093 12.48%	0.000083 0.000097 16.53%	0.000089 0.000101 14.61%	0.000097 0.000105 8.67%	0.000128 0.000115 -7.74%

Eqn. (3-5)

Eqn. (3-6)

TABLE F-5 Interior Subchannel Constant 18 for 217-Rod Bundle with $D \leq 0.35"$

H/D	P/D	1.05	1.10	1.15	1.20	1.25	1.343
4.	0.000185	0.000234	0.000337	0.000477	0.000667	0.001298	
	0.000173	0.000226	0.000332	0.000481	0.000686	0.001241	
	-5.41%	-3.54%	-1.41%	0.82%	2.93%	6.03%	
8.	0.000077	0.000062	0.000056	0.000120	0.000156	0.000262	
	0.000064	0.000065	0.000068	0.000111	0.000153	0.000246	
	-15.53%	-19.68%	-28.66%	-7.66%	1.56%	13.01%	
12.	0.000070	0.000065	0.000067	0.000075	0.000088	0.000130	
	0.000068	0.000070	0.000073	0.000077	0.000080	0.000126	
	-2.24%	7.71%	4.74%	2.17%	-9.81%	-3.04%	
16.	0.000071	0.000064	0.000063	0.000065	0.000074	0.000099	
	0.000072	0.000074	0.000077	0.000081	0.000084	0.000090	
	1.21%	14.75%	23.17%	21.20%	12.96%	-9.37%	
24.	0.000075	0.000069	0.000068	0.000068	0.000073	0.000091	
	0.000077	0.000079	0.000083	0.000087	0.000090	0.000097	
	1.13%	14.3%	26.0%	27.90%	23.56%	6.60%	
32.	0.000085	0.000080	0.000078	0.000081	0.000086	0.000106	
	0.000087	0.000090	0.000094	0.000098	0.000102	0.000109	
	1.83%	12.47%	23.81%	21.81%	17.74%	2.76%	
40.	0.000090	0.000086	0.000087	0.000091	0.000100	0.000126	
	0.000095	0.000101	0.000106	0.000110	0.000116	0.000123	
	5.45%	17.2%	22.2%	26.76%	14.84%	-2.25%	

Eqn. (3-5)

Eqn. (3-6)

TABLE F-6 Interior Subchannel Constant 18 for 271-Rod Bundle with $D \leq 0.35$ "

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000195 0.000175 -7.21%	0.000267 0.000230 -3.12%	0.000341 0.000338 -0.72%	0.000483 0.000490 1.50%	0.000675 0.000699 3.51%	0.001227 0.001305 6.32%	
8.	0.000333 0.000366 -15.19%	0.000423 0.000468 -18.75%	0.000547 0.000671 -27.95%	0.000822 0.000915 -7.11%	0.001158 0.001262 2.14%	0.002066 0.002302 13.48%	
12.	0.000571 0.000571 -7.67%	0.000665 0.000673 9.68%	0.000668 0.000675 12.15%	0.000675 0.000677 4.49%	0.000687 0.000683 -7.77%	0.000631 0.000628 -2.59%	
16.	0.000672 0.000674 .30%	0.000665 0.000677 16.7%	0.000664 0.000680 25.86%	0.000657 0.000685 23.96%	0.000675 0.000687 15.54%	0.000601 0.000643 -7.35%	
24.	0.000673 0.000640 4.65%	0.000676 0.000682 17.13%	0.000667 0.000685 28.75%	0.000668 0.000690 3.84%	0.000674 0.000693 26.45%	0.000632 0.000690 9.06%	
32.	0.000647 0.000646 .37%	0.000651 0.000643 14.56%	0.000674 0.000677 15.46%	0.000681 0.000691 24.65%	0.000687 0.000695 29.59%	0.000617 0.000613 5.29%	
40.	0.000632 0.000612 17.44%	0.000638 0.000615 19.41%	0.000638 0.000610 24.44%	0.000635 0.000614 25.50%	0.000610 0.000619 17.66%	0.000612 0.000628 0.25%	

Eqn. (3-5)

Eqn. (3-6)

TABLE F-7 Interior Subchannel Constant 19 for 19-Rod Bundle with Any Rod Diameter

H/D	P/D					
	1.057	1.10	1.15	1.20	1.25	1.343
4.	23.080612	268.315015	197.355438	310.544281	312.387268	296.142533
	244.125626	247.532379	252.589601	257.528473	262.356323	271.063873
	5.41%	-7.54%	-15.05%	-17.07%	-16.02%	-8.47%
8.	163.442596	187.180296	205.557245	215.004486	218.008774	212.396469
	183.535242	191.225662	195.132538	198.947922	202.677567	209.404388
	11.96%	2.16%	-5.58%	-7.47%	-7.03%	-1.41%
12.	142.737030	155.768936	160.536514	174.800653	176.317535	170.895172
	162.155011	164.425642	167.789053	171.069794	174.270825	180.061020
	15.61%	5.58%	-0.44%	-2.13%	-1.10%	5.36%
16.	123.373724	138.819443	148.534542	152.610107	153.016418	147.078476
	143.693385	147.727142	150.745318	153.692795	156.574051	161.770706
	17.96%	3.42%	1.93%	0.71%	2.33%	9.93%
24.	113.330720	120.725227	126.822581	129.604903	127.655006	120.832405
	123.278229	127.26482	129.521735	132.156187	134.633698	139.102158
	9.55%	5.22%	2.57%	2.76%	5.47%	15.12%
48.	92.438896	100.893127	102.654733	101.967457	99.367439	91.326241
	93.730922	98.131455	100.130391	102.094333	104.003278	107.460289
	-1.68%	-2.74%	-2.45%	0.12%	4.57%	17.67%
76.	83.617589	84.135477	83.157425	80.889587	83.306007	74.521035
	71.702233	75.999333	77.358147	78.870703	80.342289	83.016030
	-1.57%	-1.55%	-1.75%	-2.23%	-3.55%	11.40%

Eqn. (3-7 or 3-7a)

TABLE F-8 Interior Subchannel Constant 19 for 37-Rod Bundle with Any Rod Diameter

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.		221.826172	253.353745	281.563477	293.299774	293.674713	275.297719
		257.571171	36.531131	41.659769	246.395081	251.014221	259.345306
		5.23%	-6.52%	-14.17%	-15.99%	-14.53%	-5.79%
8.		156.581314	177.614570	195.865284	204.857422	207.255417	200.521683
		187.443113	182.5849	186.596625	193.347061	193.915482	200.351486
		15.73%	5.01%	-4.50%	-7.08%	-6.44%	-0.08%
12.		136.382294	147.314357	160.934877	167.045639	168.291580	162.285707
		157.155884	157.521050	160.555248	165.574164	166.742533	172.276688
		1.46%	6.56%	-0.25%	-2.00%	-0.92%	6.16%
16.		121.384077	131.542743	141.737359	146.061935	146.363539	140.135757
		137.395401	141.540537	144.228355	147.048401	149.605095	154.777344
		14.34%	7.22%	1.76%	3.66%	2.35%	10.45%
24.		107.559719	114.25417	121.070615	123.282318	122.404610	115.583408
		117.362444	121.734912	124.017960	126.442848	128.813263	133.088547
		11.45%	6.2%	2.43%	2.55%	5.24%	15.14%
32.		97.333551	105.482059	116.181407	117.884285	115.545563	107.813769
		97.555516	103.484099	105.837326	107.580618	109.511826	102.814518
		5.22%	-1.7%	-2.45%	-1.21%	4.15%	17.03%
40.		87.343489	100.33730	111.193654	113.439781	110.219955	101.908138
		71.535591	72.531537	74.613517	75.460991	76.875656	79.427132
		-14.78%	-14.70%	-13.13%	-1.56%	-4.17%	10.46%

Egn. (3-7 or 3-7a)

TABLE F-9 Interior Subchannel Constant 19 for 61-Rod Bundle with Any Rod Diameter

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	211.776047	243.115254	70.706356	281.617341	281.158325	261.610415	
	22.055732	229.108475	233.789357	238.366553	242.879071	250.888534	
	.70%	-5.76%	-13.64%	-15.36%	-13.63%	-4.10%	
8.	151.593350	170.875824	189.142517	197.872421	199.933273	192.570129	
	176.556747	176.192676	183.668765	184.146152	187.592224	193.818359	
	15.14%	3.78%	-4.61%	-6.94%	-6.17%	0.65%	
12.	124.464767	142.584523	155.568436	161.676437	162.788925	156.475479	
	153.395912	152.191161	155.300476	158.337021	161.305344	166.659927	
	15.84%	6.89%	-0.17%	-2.07%	-0.91%	6.51%	
16.	115.310977	126.423255	137.115452	141.514495	141.794403	135.428772	
	138.849945	136.731766	139.525255	142.253387	144.920212	149.730672	
	15.24%	7.73%	1.75%	5.52%	2.20%	10.56%	
24.	103.71725	110.529483	117.175781	119.571053	118.775085	112.004417	
	115.955735	117.271769	119.973945	120.319756	124.612877	128.748749	
	15.89%	6.56%	2.39%	2.30%	4.91%	14.95%	
48.	85.128732	92.112747	95.308286	95.031128	92.885282	85.398132	
	89.577434	90.827138	92.583212	94.459415	96.266914	99.461983	
	1.74%	-1.29%	-2.45%	-0.56%	3.64%	16.47%	
96.	74.949509	81.76507	82.315586	81.027621	78.368443	70.098763	
	83.231095	79.166724	71.630357	75.000336	74.368866	76.837151	
	-15.44%	-14.55%	-13.15%	-9.91%	-4.74%	9.61%	

Egn. (3-7 or 3-7a)

TABLE F-10 Interior Subchannel Constant 19 for 127-Rod Bundle with Any Rod Diameter

D/D	D/D					
	1.067	1.10	1.15	1.20	1.25	1.343
4.	145.024434	230.714422	257.146727	267.162415	265.798218	245.014318
	215.231351	18.734421	222.693110	227.047363	231.303802	238.980713
	5.14%	-5.70%	-13.45%	-17.02%	-17.98%	-2.46%
8.	145.720457	152.535541	180.652646	189.139725	190.841080	182.802078
	165.271851	168.592165	172.936671	175.400405	178.698629	184.619247
	15.50%	3.85%	-4.77%	-7.26%	-6.37%	0.99%
12.	125.937335	155.561053	148.352413	154.939774	155.925254	149.301351
	145.972549	144.967728	147.929520	150.821945	153.649599	158.748978
	15.22%	7.10%	-0.51%	-2.66%	-1.46%	6.33%
16.	105.175343	120.673080	131.276033	135.798523	136.075378	129.599762
	125.445531	130.42126	132.713076	135.501694	138.041731	142.623535
	17.65%	7.3%	1.24%	-5.22%	1.45%	10.05%
24.	95.559157	104.773138	112.249878	114.897285	114.225540	107.556282
	115.450274	111.91668	114.279676	116.514162	118.698441	122.638074
	15.55%	6.75%	1.51%	1.41%	3.92%	14.07%
48.	85.714722	87.561752	81.019677	91.431752	89.548813	82.380188
	85.325912	86.516532	88.254253	90.010427	91.697445	94.741272
	3.15%	-0.77%	-3.51%	-1.55%	2.40%	15.60%
72.	75.337227	77.427048	78.574027	77.985170	75.357841	67.828751
	65.916741	66.35752	67.12322	67.535561	70.339134	73.190259
	-17.93%	-13.8%	-13.7%	-17.83%	-5.00%	7.90%

Egn. (3-7 or 3-7a)

TABLE F-11 Interior Subchannel Constant 19 for 217-Rod Bundle with Any Rod Diameter

P/D	P/D					
	1.067	1.10	1.15	1.20	1.25	1.343
4.	191.405715 207.713442 -8.52%	112.11197 110.18175 -1.85%	244.121216 214.721275 -12.71%	256.663300 217.123581 -15.79%	256.827282 223.231476 -13.08%	235.409236 230.640457 -2.03%
8.	137.399017 162.462786 17.53%	157.228943 162.728420 3.49%	175.599060 166.932684 -5.45%	183.967102 169.273068 -7.98%	185.481155 172.452530 -7.02%	177.087906 178.176178 0.61%
12.	111.425575 137.782725 19.52%	131.158254 139.103463 6.07%	144.815979 142.766907 -1.41%	150.939423 145.558369 -3.57%	151.868362 148.287155 -2.36%	145.089142 153.208755 5.60%
16.	105.379528 123.256835 17.97%	116.134044 115.696777 -0.37%	127.771245 128.254862 0.37%	132.399913 130.772797 -1.23%	132.687927 133.224380 0.40%	126.170189 137.646042 9.19%
24.	92.315635 105.599553 14.72%	101.607556 108.685183 6.97%	109.308723 110.291412 0.90%	111.114861 112.447406 1.20%	111.525933 114.555962 2.72%	104.932554 118.358032 12.79%
48.	71.473747 81.348106 12.52%	64.380368 83.497549 -1.23%	84.637317 85.253178 -0.73%	89.283377 86.869133 -2.71%	87.562263 83.497665 1.07%	80.593628 91.434858 13.45%
60.	71.532519 68.615127 -4.47%	74.587576 64.705760 -13.67%	76.878022 69.821325 -14.53%	76.168007 67.108818 -11.99%	73.745851 68.356905 -7.29%	66.481155 70.635979 6.25%

Eqn. (3-7 or 3-7a)

TABLE F-12 Interior Subchannel Constant 19 for 271-Rod Bundle with Any Rod Diameter

H/D	P/D	1.067	1.10	1.15	1.20	1.25	1.343
4.	181.647751 201.681107 -2.50%	191.735718 207.137415 -5.65%	146.233887 111.777577 -13.95%	255.614304 215.918396 -15.53%	253.607803 219.966187 -13.27%	231.984604 227.266810 -2.03%	
8.	151.473862 151.121857 11.72%	155.183545 167.328436 3.18%	175.776276 163.604050 -5.85%	182.105469 166.802977 -6.40%	183.556152 169.930008 -7.42%	175.042633 175.569931 0.30%	
12.	111.793129 131.064600 18.44%	127.638147 137.661769 6.34%	143.566114 143.678585 -1.47%	149.498169 143.425247 -4.06%	150.408905 146.118103 -2.85%	143.579025 150.967712 5.15%	
16.	101.597613 121.153534 17.51%	115.582245 123.558170 7.16%	126.533012 126.548680 -0.11%	131.174774 128.859940 -1.76%	131.468842 131.275650 -0.15%	124.939529 135.632645 8.55%	
24.	91.584509 101.335445 11.53%	100.427109 106.562770 5.75%	103.246452 108.578151 9.45%	111.111275 115.803093 -3.28%	110.553459 112.880302 2.10%	103.990051 116.626762 12.15%	
48.	71.301365 81.143170 11.65%	83.575156 82.175725 -1.55%	87.777512 85.556872 -4.35%	87.512123 87.5596473 -3.25%	86.846054 87.203171 0.41%	79.950844 80.017470 12.69%	
60.	71.769343 61.689553 -11.43%	73.106119 63.266466 -14.77%	72.651147 64.339924 -14.75%	75.512841 66.127197 -12.43%	73.161674 67.365875 -7.32%	65.995725 69.602760 5.47%	

Egn. (3-7 or 3-7a)

TABLE F-13 Edge Subchannel Constant 18 for 19-Rod Bundle with $D \leq 0.35$ "

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000078 0.000086 10.45%	0.000070 0.000083 18.87%	0.000083 0.000076 -9.71%	0.000111 0.000119 2.62%	0.000174 0.000180 3.32%	0.000314 0.000308 -4.25%	
8.	0.000109 0.000104 -4.91%	0.000038 0.000100 13.63%	0.000085 0.000074 11.53%	0.000097 0.000089 -7.47%	0.000121 0.000111 -8.16%	0.000205 0.000227 10.64%	
12.	0.000131 0.000115 -11.53%	0.000103 0.000112 7.74%	0.000092 0.000105 13.92%	0.000097 0.000100 3.51%	0.000110 0.000095 -13.95%	0.000160 0.000171 7.04%	
16.	0.000147 0.000126 -14.83%	0.000116 0.000121 4.26%	0.000100 0.000114 13.39%	0.000101 0.000108 7.00%	0.000110 0.000102 -6.77%	0.000146 0.000140 -4.14%	
24.	0.000169 0.000140 -17.48%	0.000133 0.000134 0.74%	0.000114 0.000127 11.72%	0.000110 0.000120 8.96%	0.000116 0.000114 -1.18%	0.000142 0.000104 -26.29%	
48.	0.000202 0.000169 -17.62%	0.000142 0.000142 0.00%	0.000137 0.000143 11.69%	0.000130 0.000145 11.31%	0.000132 0.000138 4.11%	0.000151 0.000136 -16.82%	
96.	0.000226 0.000203 -10.98%	0.000183 0.000186 7.17%	0.000152 0.000185 16.79%	0.000147 0.000175 16.09%	0.000148 0.000166 12.06%	0.000144 0.000172 -7.50%	

Eqn. (3-8)

Eqn. (3-9)

TABLE F-14 Edge Subchannel Constant 18 for 37-Rod Bundle with $D \leq 0.35"$

H/D	W/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000084	0.000074	0.000088	0.000123	0.000185	0.000417	
	0.000091	0.000088	0.000083	0.000126	0.000190	0.000389	
	0.03%	17.66%	-5.49%	2.39%	2.43%	-6.60%	
8.	0.000118	0.000095	0.000090	0.000105	0.000128	0.000220	
	0.000110	0.000106	0.000100	0.000099	0.000117	0.000240	
	-5.98%	11.94%	11.06%	-7.59%	-8.65%	9.08%	
12.	0.000142	0.000111	0.000098	0.000103	0.000117	0.000171	
	0.000123	0.000118	0.000112	0.000106	0.000100	0.000161	
	-15.75%	6.38%	15.41%	5.04%	-14.27%	5.80%	
16.	0.000169	0.000124	0.000107	0.000107	0.000117	0.000156	
	0.000133	0.000128	0.000121	0.000114	0.000108	0.000148	
	-17.07%	2.83%	12.83%	6.75%	-7.03%	-5.92%	
24.	0.000185	0.000143	0.000121	0.000117	0.000123	0.000150	
	0.000148	0.000142	0.000135	0.000127	0.000121	0.000110	
	-15.75%	-0.74%	11.17%	8.83%	-1.23%	-26.54%	
40.	0.000221	0.000175	0.000146	0.000135	0.000140	0.000130	
	0.000175	0.000172	0.000162	0.000154	0.000146	0.000135	
	-15.20%	-1.56%	11.55%	11.56%	4.46%	-16.47%	
60.	0.000245	0.000177	0.000166	0.000155	0.000155	0.000172	
	0.000165	0.000177	0.000158	0.000185	0.000176	0.000161	
	-15.05%	5.12%	17.55%	19.24%	13.30%	-6.62%	

Eqn. (3-8)

Eqn. (3-9)

TABLE F-15 Edge Subchannel Constant 18 for 61-Rod Bundle with $D \leq 0.35$ "

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000188	0.000078	0.000051	0.000128	0.000194	0.000441	
	0.000195	0.000072	0.000067	0.000132	0.000198	0.000405	
	3.01%	17.81%	-5.15%	2.48%	2.09%	-7.90%	
8.	0.000125	0.000099	0.000054	0.000107	0.000134	0.000231	
	0.000115	0.000110	0.000104	0.000099	0.000122	0.000210	
	-4.46%	11.23%	11.05%	-7.51%	-8.79%	8.23%	
12.	0.000151	0.000117	0.000103	0.000107	0.000122	0.000179	
	0.000128	0.000123	0.000117	0.000110	0.000105	0.000189	
	-10.23%	5.50%	13.21%	3.04%	-14.31%	5.21%	
16.	0.000179	0.000131	0.000112	0.000112	0.000122	0.000163	
	0.000159	0.000133	0.000126	0.000110	0.000113	0.000155	
	-15.64%	1.71%	12.69%	8.77%	-7.01%	-5.40%	
24.	0.000197	0.000131	0.000127	0.000122	0.000128	0.000157	
	0.000155	0.000147	0.000141	0.000133	0.000126	0.000115	
	-21.41%	-1.71%	10.95%	8.95%	-1.05%	-26.53%	
48.	0.000235	0.000184	0.000155	0.000140	0.000145	0.000165	
	0.000195	0.000170	0.000165	0.000161	0.000152	0.000150	
	-21.01%	-2.08%	15.81%	10.64%	4.93%	-16.03%	
6.	0.000252	0.000228	0.000174	0.000162	0.000161	0.000178	
	0.000225	0.000215	0.000204	0.000194	0.000184	0.000168	
	-10.21%	3.76%	17.80%	17.56%	13.98%	-5.77%	

Eqn. (3-8)

Eqn. (3-9)

TABLE F-16 Edge Subchannel Constant 18 for 127-Rod Bundle with $D \leq 0.35"$

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000295 0.000101 7.27%	0.000582 0.000098 18.53%	0.000046 0.000072 -4.91%	0.000135 0.000140 3.39%	0.000205 0.000211 2.48%	0.000473 0.000432 -8.81%	
8.	0.000135 0.000122 -9.91%	0.000105 0.000118 10.48%	0.000103 0.000111 11.78%	0.000113 0.000105 -6.74%	0.000142 0.000130 -8.31%	0.000245 0.000266 8.08%	
12.	0.000134 0.000137 -1.35%	0.000125 0.000131 5.90%	0.000130 0.000134 13.71%	0.000113 0.000118 3.79%	0.000129 0.000112 -13.73%	0.000191 0.000201 5.25%	
16.	0.000135 0.000148 -24.25%	0.000140 0.000142 1.42%	0.000119 0.000134 13.15%	0.000113 0.000127 12.57%	0.000129 0.000121 -6.29%	0.000173 0.000164 -5.15%	
24.	0.000214 0.000155 -27.10%	0.000182 0.000118 -2.55%	0.000134 0.000130 11.41%	0.000129 0.000142 9.88%	0.000135 0.000135 -0.08%	0.000166 0.000123 -25.94%	
48.	0.000258 0.000199 -22.93%	0.000138 0.000111 -3.24%	0.000162 0.000131 11.24%	0.000152 0.000171 12.79%	0.000153 0.000162 6.33%	0.000174 0.000148 -14.75%	
60.	0.000287 0.000113 -15.55%	0.000124 0.000110 2.34%	0.000134 0.000218 13.11%	0.000171 0.000205 20.05%	0.000189 0.000195 15.73%	0.000136 0.000177 -3.95%	

Eqn. (3-8)

Eqn. (3-9)

TABLE F-17 Edge Subchannel Constant 18 for 217-Rod Bundle with $D \leq 0.35$ "

H/D	P/D	1.10	1.15	1.20	1.25	1.343
4.	0.000033 0.000100 7.01%	0.000080 0.000102 19.82%	0.000094 0.000097 -2.56%	0.000140 0.000146 4.74%	0.000213 0.000220 3.51%	0.000474 0.000412 -8.66%
8.	0.000143 0.000126 -10.24%	0.000110 0.000123 11.53%	0.000103 0.000116 13.01%	0.000117 0.000119 -5.57%	0.000147 0.000136 -7.35%	0.000236 0.000279 8.76%
12.	0.000175 0.000143 -17.51%	0.000130 0.000138 7.40%	0.000113 0.000139 14.84%	0.000117 0.000123 5.02%	0.000134 0.000117 -12.71%	0.000198 0.000210 6.05%
16.	0.000143 0.000133 -20.75%	0.000146 0.000146 1.5%	0.000173 0.000146 14.15%	0.000129 0.000133 3.86%	0.000133 0.000126 -5.14%	0.000140 0.000172 -4.51%
24.	0.000126 0.000172 -20.55%	0.000149 0.000166 -2.11%	0.000139 0.000157 12.55%	0.000134 0.000148 11.28%	0.000139 0.000141 1.23%	0.000172 0.000179 -25.00%
48.	0.000172 0.000203 -20.65%	0.000177 0.000200 -3.58%	0.000168 0.000169 12.32%	0.000157 0.000179 14.54%	0.000157 0.000170 8.00%	0.000179 0.000155 -13.55%
96.	0.000304 0.000331 -17.43%	0.000273 0.000241 2.3%	0.000191 0.000228 19.05%	0.000175 0.000211 22.54%	0.000174 0.000205 17.69%	0.000191 0.000157 -2.01%

Eqn. (3-8)

Eqn. (3-9)

TABLE F-18 Edge Subchannel Constant 18 for 271-Rod Bundle with $D \leq 0.35$ "

H/D	270	1.067	1.10	1.15	1.20	1.25	1.343
4.	0.000100 0.000108 7.82%	0.000106 0.000104 20.36%	0.000100 0.000098 -1.31%	0.000141 0.000143 5.48%	0.000215 0.000224 4.13%	0.000502 0.000403 -8.40%	
8.	0.000145 0.000151 -10.18%	0.000112 0.000100 12.4%	0.000104 0.000117 13.71%	0.000113 0.000112 -4.73%	0.000148 0.000138 -6.79%	0.000250 0.000284 9.25%	
12.	0.000170 0.000145 -14.31%	0.000153 0.000140 5.77%	0.000115 0.000152 15.51%	0.000119 0.000127 5.70%	0.000135 0.000119 -12.14%	0.000201 0.000214 6.58%	
16.	0.000190 0.000175 -20.78%	0.000149 0.000152 1.8%	0.000125 0.000143 14.81%	0.000124 0.000155 7.58%	0.000135 0.000129 -4.50%	0.000142 0.000175 -3.78%	
24.	0.000250 0.000175 -29.71%	0.000172 0.000179 -1.50%	0.000131 0.000190 15.1%	0.000137 0.000151 12.04%	0.000141 0.000144 2.02%	0.000174 0.000151 -24.4%	
32.	0.000273 0.000112 -25.74%	0.00010 0.000204 -3.12%	0.000171 0.000195 12.77%	0.000153 0.000185 15.16%	0.000159 0.000173 5.87%	0.000171 0.000154 -12.53%	
40.	0.000313 0.000205 -17.55%	0.000209 0.000246 7.34%	0.000194 0.000252 15.74%	0.000173 0.000220 23.45%	0.000170 0.000209 18.64%	0.000193 0.000191 -1.11%	

Eqn. (3-8)

Eqn. (3-9)

TABLE F-19 Edge Subchannel Constant 19 for 19-Rod Bundle with Any Rod Diameter

W/D	P/D					
	1.067	1.10	1.15	1.20	1.25	1.343
4.	120.721734	106.358170	181.557776	189.418884	186.371094	166.218658
	120.336441	135.620157	146.399002	157.077362	168.050858	189.232635
	2.83%	-13.51%	-19.41%	-17.07%	-9.83%	13.85%
8.	90.832138	112.658051	132.485123	140.904312	141.837741	132.640488
	100.897487	108.215459	116.472673	124.968215	133.698547	150.550430
	13.28%	-3.74%	-12.09%	-11.31%	-5.77%	13.50%
12.	70.595306	74.551031	110.952333	118.558029	120.180301	113.964073
	90.014365	74.665031	101.885404	109.321228	116.958458	131.700333
	17.52%	0.53%	-8.17%	-7.79%	-2.68%	15.50%
16.	63.648552	54.051910	98.579619	105.637428	107.427376	102.601616
	81.863363	56.694437	92.663765	90.422670	106.368385	119.775444
	17.25%	2.43%	-6.10%	-5.88%	-0.99%	16.74%
24.	59.860718	72.008333	84.944482	91.065153	92.922646	89.449417
	71.513758	75.514758	81.051554	86.974177	93.050247	104.778643
	15.63%	3.73%	-4.57%	-4.49%	0.14%	17.14%
36.	40.550731	59.260220	66.818031	73.846535	75.674103	73.615616
	50.974915	59.513201	54.421277	69.195259	74.029274	83.360199
	16.74%	1.11%	-6.29%	-6.30%	-2.17%	13.24%
46.	40.431758	51.150730	58.968956	63.282467	65.050461	63.808273
	40.529529	47.70746	51.308271	55.050629	58.836488	66.320023
	9.25%	-6.20%	-12.44%	-13.01%	-9.46%	3.94%

Egn. (3-10 or 3-10a)

TABLE F-20 Edge Subchannel Constant 19 for 37-Rod Bundle with Any Rod Diameter

H/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	115.125723 125.746400 9.71%	147.205123 150.141327 -11.55%	172.310391 140.071594 -18.57%	178.909375 150.288437 -15.99%	175.207138 160.787659 -8.23%	154.518921 181.053925 17.17%
3.	85.514473 95.472735 15.13%	106.607618 103.558338 -3.14%	126.245232 111.438598 -11.75%	134.254379 119.567055 -10.94%	134.889084 127.920067 -5.17%	125.224747 144.043579 15.03%
12.	75.111945 85.123924 13.43%	89.597420 90.574339 1.09%	105.528169 97.485718 -7.97%	115.298264 104.596344 -7.68%	114.710289 111.903488 -2.45%	108.222710 126.008217 16.43%
15.	65.608303 75.325775 21.23%	79.827590 82.373413 3.19%	94.290825 88.558813 -5.97%	101.104744 95.125603 -5.91%	102.760689 101.771118 -0.96%	97.758392 114.598724 17.23%
4.	55.299994 65.518791 21.72%	68.594114 72.053431 4.98%	81.219994 77.558022 -4.51%	87.292871 85.215149 -2.39%	89.100777 89.024595 -0.08%	85.563789 100.250912 17.15%
43.	45.507525 55.512444 15.55%	56.159440 57.529475 2.31%	65.802871 61.79375 -6.39%	75.889084 66.204625 -12.61%	72.763519 70.829712 -2.66%	70.784279 79.757347 12.68%
16.	45.728114 43.559117 4.93%	48.425522 45.19451 -5.82%	56.537259 49.07645 -12.83%	60.767739 52.67132 -13.33%	62.640682 55.550971 -10.04%	61.571997 63.45351 3.05%

Egn. (3-10 or 3-10a)

TABLE F-21 Edge Subchannel Constant 19 for 61-Rod Bundle with Any Rod Diameter

H/D	P/D	1.00	1.10	1.20	1.25	1.343
4.	112.777595	141.531563	165.377649	171.774734	167.739822	146.836578
	112.712387	125.838750	135.505295	145.387084	155.546021	175.151111
	1.15%	-11.23%	-18.95%	-15.36%	-7.27%	19.28%
8.	81.744474	102.641732	121.899673	129.676666	130.123566	120.259033
	91.241241	100.163610	107.805817	111.669197	123.749901	139.347714
	11.50%	-2.70%	-11.55%	-10.80%	-4.90%	15.87%
12.	68.735531	86.244415	102.415059	109.656563	110.957534	104.348013
	81.315307	87.21834	94.507791	101.186531	108.255463	121.900375
	2.35%	1.00%	-7.92%	-7.72%	-2.44%	16.82%
16.	61.743535	78.647221	91.216393	97.956985	99.548843	94.474800
	71.772377	79.588557	85.768555	92.024529	98.453407	110.862531
	2.71%	3.70%	-5.97%	-6.06%	-1.10%	17.35%
24.	51.768295	66.355588	78.507162	84.665024	86.458817	82.914299
	61.285555	69.710719	75.129678	80.502357	85.125289	96.981956
	23.94%	5.75%	-4.55%	-4.92%	-0.38%	16.37%
48.	41.455318	54.744388	63.501998	68.822823	70.740616	68.837135
	51.735557	55.582548	59.512374	64.646371	69.525683	77.157272
	1.62%	2.62%	-5.73%	-6.74%	-3.14%	12.09%
100.	31.733291	46.516575	54.599888	59.013172	60.950617	60.021694
	41.555591	44.123516	47.490303	53.954254	54.513943	61.385073
	5.15%	-5.14%	-12.86%	-13.66%	-10.58%	2.27%

Egn. (3-10 or 3-10a)

TABLE F-22 Edge Subchannel Constant 19 for 127-Rod Bundle with Any Rod Diameter

D/P	P/D					
	1.067	1.10	1.15	1.20	1.25	1.343
4.	161.333703	154.293713	137.393933	162.957840	158.575943	137.524338
	111.032745	119.224836	129.075577	138.490372	148.165375	166.840083
	7.59%	-10.70%	-17.84%	-15.01%	-6.57%	21.32%
6.	71.361355	97.701336	116.418070	123.353703	124.206047	114.158943
	91.723046	15.110236	102.630437	110.180702	117.877968	132.735748
	17.83%	-2.34%	-11.60%	-11.11%	-5.09%	16.27%
12.	64.897408	81.293267	97.280570	105.087440	105.291876	99.563849
	77.362353	83.464160	85.352369	90.385231	103.118744	116.116211
	27.27%	1.80%	-3.32%	-6.28%	-2.98%	16.62%
16.	53.113833	73.364720	87.331411	94.000328	95.533069	90.408501
	71.170387	75.406462	81.638837	87.657967	93.781792	105.602334
	24.21%	3.89%	-6.45%	-6.75%	-1.83%	16.81%
4.	71.361355	63.17437	70.302628	81.355657	83.147064	79.621414
	63.133374	60.402748	71.409521	78.682520	82.039597	92.380173
	24.88%	5.48%	-5.97%	-7.74%	-1.33%	16.02%
48.	41.724313	51.312311	61.118112	60.216093	68.196617	66.404447
	51.335023	62.28003	65.339993	61.007377	65.264379	73.496170
	27.39%	2.45%	-7.41%	-7.87%	-4.23%	10.68%
6.	51.334134	44.352471	52.17317	58.790037	58.844044	58.078011
	57.754737	62.322006	45.236832	45.530473	51.927258	58.472357
	7.33%	-4.67%	-15.32%	-14.74%	-11.75%	0.68%

Egn. (3-10 or 3-10a)

TABLE F-23 Edge Subchannel Constant 19 for 217-Rod Bundle with Any Rod Diameter

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	101.528105	129.811785	152.111025	157.773743	153.213543	132.130510	
	11.053444	115.740569	124.072113	133.658432	142.975865	161.019572	
	1.97%	-10.74%	-18.1%	-15.28%	-6.67%	21.86%	
8.	74.031349	94.527864	113.171051	120.563805	129.717628	110.590469	
	87.555740	92.681406	99.167559	101.336487	113.765198	128.104554	
	13.17%	-2.69%	-12.43%	-11.80%	-5.76%	15.84%	
12.	64.476078	70.444572	75.336335	102.374268	103.515700	96.754921	
	71.533264	80.552101	85.558532	95.022339	99.520920	112.064953	
	21.50%	1.39%	-9.10%	-9.14%	-3.86%	15.82%	
16.	55.933473	70.920310	85.913176	91.647842	93.155510	88.016037	
	61.658714	73.728451	78.848358	84.595579	90.709743	101.917723	
	24.55%	3.47%	-7.25%	-7.65%	-2.84%	15.79%	
24.	43.557885	61.110416	73.329525	79.387535	81.181200	77.679176	
	61.935413	64.085545	58.975541	74.037065	79.177231	89.157021	
	21.29%	4.7%	-5.94%	-6.78%	-2.47%	14.78%	
48.	45.985927	49.878511	59.41557	64.662538	65.683739	64.964317	
	45.437412	50.85741	54.576144	58.878822	62.992123	70.931877	
	21.55%	2.3%	-7.15%	-6.94%	-5.54%	9.13%	
50.	54.355504	42.50105	50.541637	55.473643	57.583744	56.924137	
	51.772236	40.2347	43.658567	47.843037	51.115509	56.432257	
	11.55%	-4.7%	-14.55%	-15.56%	-12.97%	-0.86%	

Egn. (3-10 or 3-10a)

TABLE F-24 Edge Subchannel Constant 19 for 271-Rod Bundle with Any Rod Diameter

H/D	P/D	1.067	1.10	1.14	1.20	1.25	1.343
4.	10	105.451165	108.192522	110.427124	115.913834	121.303040	130.208099
	105.444392	114.48144	122.750455	131.703888	140.904785	158.664932	
	7.35%	-11.53%	-18.40%	-15.53%	-6.87%	21.85%	
8.	75.953343	75.517212	111.996292	119.343773	119.464706	109.313282	
	81.275357	80.734855	97.658272	104.781487	112.101563	126.231255	
	1.10%	-2.98%	-12.40%	-12.20%	-6.16%	15.48%	
12.	62.693379	78.524300	94.381938	101.396697	102.521164	95.747833	
	75.473900	79.574151	85.430716	91.662041	98.065990	110.426132	
	21.52%	1.28%	-7.48%	-5.60%	-4.35%	15.33%	
16.	55.141251	63.982338	84.176094	91.799744	92.299583	87.15746	
	67.640765	72.187150	77.55535	83.362442	89.136180	100.427528	
	24.43%	3.14%	-7.70%	-2.19%	-3.37%	15.23%	
24.	47.542551	60.45037	72.516436	78.674887	85.474121	76.981415	
	61.045311	63.148706	67.967255	72.924828	78.019386	87.853241	
	2.25%	4.55%	-1.40%	-7.31%	-3.05%	14.1%	
43.	35.438773	45.88710	58.344651	64.101845	65.158344	64.446140	
	47.771177	50.24178	54.173057	58.017815	62.070961	69.84415	
	2.34%	2.55%	-8.11%	-2.49%	-6.15%	8.45%	
6.	35.334263	42.12772	50.300425	54.996674	57.129112	56.50842	
	33.00519	39.7755	43.520134	45.158531	49.382052	55.607021	
	1.55%	-5.19%	-14.47%	-15.07%	-13.56%	-1.50%	

Eqn. (3-10 or 3-10a)

TABLE F-25 Bundle Constant 18 for 19-Rod Bundle with $D \leq 0.35$ "

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.0000195	0.000007	0.0000193	0.0000173	0.0000250	0.0000507	
	0.0000752	0.0000105	0.0000155	0.0000217	0.0000305	0.0000573	
	-17.85%	8.33%	23.54%	25.73%	21.86%	8.78%	
8.	0.0000368	0.0000079	0.0000093	0.0000098	0.0000124	0.0000217	
	0.000070	0.0000070	0.0000071	0.0000079	0.0000111	0.0000201	
	-20.70%	-11.20%	-14.55%	-19.14%	-19.15%	-2.76%	
12.	0.0000093	0.0000079	0.0000075	0.0000081	0.0000093	0.0000135	
	0.0000075	0.0000075	0.0000076	0.0000075	0.0000077	0.0000111	
	-10.26%	-4.58%	1.32%	-5.29%	-17.48%	-17.68%	
16.	0.0000103	0.0000083	0.0000076	0.0000078	0.0000086	0.0000115	
	0.0000079	0.0000079	0.0000080	0.0000080	0.0000081	0.0000082	
	-20.35%	-4.97%	4.82%	2.59%	-6.20%	-28.65%	
24.	0.0000111	0.0000073	0.0000083	0.0000083	0.0000088	0.0000109	
	0.0000085	0.0000085	0.0000086	0.0000085	0.0000087	0.0000088	
	-20.73%	-8.45%	2.56%	4.02%	-1.26%	-18.84%	
48.	0.0000124	0.0000110	0.0000099	0.0000093	0.0000103	0.0000121	
	0.0000096	0.0000096	0.0000097	0.0000098	0.0000098	0.0000100	
	-20.05%	-12.73%	-2.44%	-9.60%	-4.11%	-17.55%	
6.	0.0000140	0.0000122	0.0000112	0.0000111	0.0000117	0.0000137	
	0.0000108	0.0000108	0.0000110	0.0000111	0.0000111	0.0000113	
	-20.59%	-10.54%	-1.54%	-0.76%	-4.40%	-19.01%	

Eqn. (3-11)

Eqn. (3-12)

TABLE F-26 Bundle Constant 18 for 37-Rod Bundle with $D \leq 0.35$ "

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.		.000104	0.000115	0.000143	0.000233	0.000301	0.000354
		.0001042	0.000118	0.000170	0.000243	0.000340	0.000617
		-13.84%	2.4%	14.8%	16.40%	13.0%	2.20%
8.		.000139	0.000151	0.000174	0.000194	0.000132	0.000223
		.000173	0.000173	0.000174	0.000088	0.000124	0.000225
		-1.00%	-10.48%	-15.35%	-15.10%	-6.24%	1.05%
12.		.000051	0.000078	0.000075	0.000081	0.000095	0.000138
		.000078	0.000078	0.000077	0.000083	0.000080	0.000125
		-14.45%	0.7%	1.31%	-2.19%	-15.15%	-9.80%
16.		.000037	0.000042	0.000075	0.000073	0.000085	0.000115
		.000082	0.000033	0.000083	0.000084	0.000084	0.000085
		-13.42%	1.14%	10.7%	7.94%	-1.60%	-25.12%
24.		.000105	0.000090	0.000021	0.000082	0.000087	0.000107
		.000058	0.000054	0.000042	0.000033	0.000091	0.000042
		-13.13%	-1.5%	2.71%	10.45%	4.57%	-14.3%
40.		.000125	0.000107	0.000047	0.000075	0.000101	0.000121
		.000123	0.000110	0.000101	0.000102	0.000103	0.000104
		-13.05%	-6.1%	4.95%	5.62%	1.41%	-13.7%
60.		.000113	0.000118	0.000103	0.000117	0.000115	0.000138
		.000113	0.000114	0.000114	0.000117	0.000116	0.000118
		-1.07%	-3.3%	4.07%	3.6%	0.74%	-14.54%

Egn. (3-11)

Egn. (3-12)

TABLE F-27 Bundle Constant 18 for 61-Rod Bundle with $D \leq 0.35$ "

H/D	P/D	1.067	1.10	1.15	1.20	1.25	1.343
4.	0.000120	0.000130	0.000170	0.000239	0.000344	0.000645	
	0.000099	0.000128	0.000185	0.000264	0.000370	0.000671	
	-14.20%	-1.16%	9.14%	10.37%	7.47%	-2.07%	
8.	0.000090	0.000084	0.000090	0.000109	0.000139	0.000234	
	0.000075	0.000075	0.000076	0.000096	0.000135	0.000244	
	-17.14%	-9.99%	-15.91%	-11.75%	-2.92%	4.33%	
12.	0.000090	0.000078	0.000075	0.000082	0.000096	0.000140	
	0.000080	0.000081	0.000082	0.000082	0.000083	0.000135	
	-11.02%	3.73%	8.19%	0.07%	-13.44%	-3.38%	
16.	0.000096	0.000081	0.000075	0.000077	0.000086	0.000115	
	0.000085	0.000085	0.000086	0.000086	0.000087	0.000088	
	-11.42%	5.46%	15.01%	11.82%	1.76%	-23.03%	
24.	0.000106	0.000089	0.000080	0.000081	0.000086	0.000107	
	0.000091	0.000092	0.000092	0.000093	0.000094	0.000095	
	-13.83%	2.78%	14.59%	15.11%	8.82%	-11.04%	
48.	0.000122	0.000105	0.000096	0.000095	0.000100	0.000120	
	0.000103	0.000104	0.000104	0.000105	0.000106	0.000107	
	-15.51%	-1.33%	9.95%	10.12%	5.41%	-10.81%	
96.	0.000131	0.000116	0.000108	0.000104	0.000115	0.000138	
	0.000117	0.000117	0.000118	0.000119	0.000120	0.000121	
	-11.22%	1.27%	9.31%	9.79%	4.51%	-11.99%	

Eqn. (3-11)

Eqn. (3-12)

TABLE F-28 Bundle Constant 18 for 127-Rod Bundle with $D \leq 0.35"$

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000107	0.000103	0.000295	0.000287	0.000412	0.000810	
	0.000112	0.000145	0.000209	0.000298	0.000418	0.000758	
	-15.24%	-5.14%	2.43%	3.88%	1.51%	-6.39%	
8.	0.000752	0.000687	0.000675	0.000115	0.000148	0.000250	
	0.000773	0.000679	0.000672	0.000108	0.000152	0.000276	
	-15.83%	-8.17%	-10.15%	-5.92%	3.00%	10.37%	
12.	0.000610	0.000676	0.000676	0.000063	0.000097	0.000143	
	0.000634	0.000685	0.000685	0.000086	0.000087	0.000173	
	-7.01%	8.68%	12.49%	3.55%	-10.73%	7.14%	
16.	0.000754	0.000670	0.000674	0.000077	0.000085	0.000115	
	0.000689	0.000659	0.000699	0.000091	0.000091	0.000092	
	-10.51%	11.72%	21.22%	17.52%	6.73%	-19.44%	
24.	0.000103	0.000067	0.000072	0.000083	0.000085	0.000106	
	0.000095	0.000045	0.000097	0.000097	0.000098	0.000099	
	-7.71%	7.58%	21.53%	21.87%	15.00%	-6.14%	
40.	0.000114	0.000103	0.000064	0.000094	0.000100	0.000110	
	0.000108	0.000108	0.000134	0.000110	0.000111	0.000112	
	-5.37%	5.28%	15.71%	16.64%	11.25%	-6.41%	
64.	0.000127	0.000113	0.000106	0.000107	0.000114	0.000138	
	0.000122	0.000123	0.000124	0.000125	0.000125	0.000127	
	-4.14%	9.53%	16.12%	17.28%	10.02%	-2.20%	

Egn. (3-11)

Egn. (3-12)

TABLE F-29 Bundle Constant 18 for 217-Rod Bundle with $D \leq 0.35$ "

H/D	270	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000150 0.000123 -17.33%	0.000139 0.000138 -6.57%	0.000228 0.000227 0.37%	0.000322 0.000325 1.11%	0.000461 0.000457 -0.95%	0.000700 0.000829 -7.93%	
8.	0.000393 0.000381 -1.03%	0.000438 0.00042 -7.38%	0.000818 0.00082 -15.43%	0.000119 0.000119 -0.74%	0.000154 0.000166 8.35%	0.000260 0.000302 15.31%	
12.	0.000583 0.000587 -0.31%	0.00078 0.000588 12.55%	0.000976 0.000988 15.72%	0.00084 0.00089 6.29%	0.00098 0.00099 -8.53%	0.000144 0.000157 15.81%	
16.	0.000793 0.000792 -1.35%	0.00079 0.000792 16.31%	0.000974 0.000973 25.80%	0.000977 0.000994 21.75%	0.000985 0.000994 10.46%	0.000115 0.000095 -16.71%	
24.	0.000102 0.000099 -3.21%	0.000097 0.000097 14.52%	0.000079 0.00010 26.75%	0.000079 0.000101 25.82%	0.000085 0.000101 19.55%	0.000135 0.000133 -2.58%	
48.	0.000117 0.000112 -4.34%	0.000101 0.000112 10.59%	0.000093 0.000117 21.37%	0.000094 0.000114 21.39%	0.000095 0.000115 15.55%	0.000190 0.000116 -3.12%	
66.	0.000125 0.000125 1.01%	0.000111 0.000127 13.5%	0.000105 0.000128 22.36%	0.000107 0.000129 27.88%	0.000114 0.000130 14.09%	0.000139 0.000131 -5.31%	

Egn. (3-11)

Egn. (3-12)

TABLE F-30 Bundle Constant 18 for 271-Rod Bundle with $D \leq 0.35$ "

H/D	ρ/ρ_0	1.067	1.10	1.15	1.20	1.25	1.343
4.	0.000155	0.000176	0.000233	0.000336	0.000481	0.000936	
	0.000127	0.00014	0.000237	0.000338	0.000474	0.000800	
	-17.51%	-6.77%	-7.04%	0.46%	-1.50%	-8.16%	
6.	0.000034	0.00005	0.000094	0.000121	0.000156	0.000264	
	0.000082	0.000063	0.000085	0.000123	0.000173	0.000313	
	-17.73%	-7.63%	-15.73%	1.06%	10.87%	14.52%	
12.	0.000003	0.000007	0.0000076	0.0000044	0.0000098	0.0000145	
	0.000038	0.000034	0.000093	0.000093	0.000091	0.000173	
	-7.4%	13.07%	17.22%	7.49%	-7.56%	19.68%	
18.	0.000003	0.0000079	0.0000074	0.0000077	0.0000085	0.0000115	
	0.000033	0.000044	0.000064	0.000093	0.000096	0.000097	
	.42%	18.02%	27.73%	27.54%	12.04%	-15.56%	
24.	0.000011	0.000006	0.0000077	0.0000077	0.0000085	0.0000105	
	0.000099	0.000101	0.000101	0.000102	0.000103	0.000104	
	-1.35%	16.67%	28.59%	29.88%	21.45%	-1.07%	
48.	0.000011	0.000001	0.000003	0.0000094	0.0000097	0.000013	
	0.000113	0.000114	0.000115	0.000115	0.000116	0.000119	
	-1.43%	12.0%	23.15%	23.37%	17.33%	-1.74%	
76.	0.000124	0.000111	0.000117	0.000106	0.000114	0.000139	
	0.000128	0.000128	0.000130	0.000131	0.000132	0.000133	
	.14%	15.16%	24.2%	22.83%	15.80%	-4.03%	

Egn. (3-11)

Egn. (3-12)

TABLE F-31 Bundle Constant 19 for 19-Rod Bundle with Any Rod Diameter

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	151.677033 165.733351 7.98%	184.848524 171.727109 -6.97%	212.801889 174.720372 -15.55%	222.484115 187.512589 -15.72%	221.480270 195.304138 -11.42%	199.579880 209.794037 5.12%	
8.	107.243433 131.452667 1.42%	131.725773 134.476212 1.43%	172.555172 140.771838 -7.84%	161.735885 146.666763 -9.32%	163.421234 152.761002 -6.52%	154.790314 164.094574 6.01%	
12.	97.300463 117.733502 27.41%	110.770970 116.474426 5.43%	126.780022 121.754050 -3.96%	137.401001 127.033087 -5.48%	136.154109 132.311523 -2.81%	130.013596 142.127897 9.32%	
16.	87.356270 107.034143 27.99%	98.260551 105.183243 7.5%	112.325851 107.751067 -2.11%	118.840408 114.718330 -3.47%	120.342155 119.485062 -0.71%	115.131470 128.549858 11.48%	
24.	72.755967 87.375977 21.45%	95.107759 91.192783 7.5%	96.512661 95.752354 -1.7%	101.560247 97.361459 -2.17%	102.652069 103.490074 0.82%	98.133033 111.168152 13.28%	
48.	61.137532 67.125509 10.07%	70.76475 71.757571 1.77%	78.119742 74.987877 -4.05%	81.537503 77.717527 -4.80%	82.121535 80.946815 -1.43%	78.103180 86.952525 11.53%	
96.	57.242374 57.053130 -0.32%	61.151411 59.735748 -8.7%	67.269673 58.262137 -13.42%	67.804131 67.788315 -12.52%	67.838931 63.314167 -3.41%	66.067642 68.011536 2.94%	

Eqn. (3-13 or 3-13a)

TABLE F-32 Bundle Constant 19 for 37-Rod Bundle with Any Rod Diameter

H/D	1.00	1.10	1.15	1.20	1.25	1.345
4.	15.321391 167.512363 7.85%	186.501376 172.578999 -6.50%	215.572943 180.506241 -17.31%	224.672821 188.332657 -16.17%	221.949753 196.158157 -11.62%	199.700882 210.711426 5.51%
8.	111.963742 131.925117 17.02%	134.469406 135.364240 0.44%	154.706636 141.185533 -8.74%	163.534805 147.308121 -9.92%	164.864899 153.429001 -6.94%	155.624603 164.812119 5.90%
12.	94.659508 115.483589 15.83%	112.410782 116.983742 4.97%	126.535538 122.286464 -4.86%	135.791015 127.588585 -5.04%	137.192657 132.890091 -3.14%	130.546112 142.749405 9.35%
16.	8.131323 105.482545 2.33%	100.187485 105.643131 5.45%	113.847833 110.431875 -3.00%	119.982789 115.219978 -3.97%	121.144923 120.007545 -0.94%	115.411797 128.911067 11.70%
24.	77.749355 85.763443 1.75%	86.812125 91.501152 5.49%	97.573775 95.648796 -2.07%	102.437599 99.755437 -2.58%	103.165083 103.942612 0.75%	98.105492 111.654274 13.81%
48.	65.918594 65.424385 10.35%	71.573318 71.565443 -0.01%	75.171463 74.513696 -5.94%	82.253410 78.057381 -5.10%	82.345627 81.300781 -1.27%	77.73547 87.33203 12.35%
72.	65.934154 65.304352 -0.92%	62.582642 55.77415 -10.50%	68.248566 53.518949 -14.20%	70.312219 61.054131 -13.17%	69.985069 63.591022 -9.14%	65.537468 68.308937 4.25%

Egn. (3-13 or 3-13a)

TABLE F-33 Bundle Constant 19 for 61-Rod Bundle with Any Rod Diameter

P/D	P/D					
	1.057	1.10	1.15	1.20	1.25	1.343
4.	155.743343 165.061534 7.28%	159.720812 173.745056 -8.58%	161.755038 181.77838 -16.41%	227.420041 188.950089 -16.18%	222.391668 196.801270 -11.50%	199.536772 211.402237 5.95%
8.	115.183464 131.452582 15.14%	135.502670 135.507065 0.00%	155.407833 141.649429 -8.51%	164.132751 147.791677 -9.96%	165.302414 153.732022 -6.88%	155.813431 165.352433 6.12%
12.	95.720348 115.855644 1.35%	113.278576 117.567237 3.81%	123.147202 122.637401 -5.00%	135.197937 128.006882 -6.01%	137.433548 133.325775 -2.99%	130.550720 143.217437 9.70%
16.	85.114362 105.313320 17.53%	100.73267 105.282140 4.47%	114.362930 110.793222 -3.11%	120.276932 115.557725 -3.89%	121.258141 120.400993 -0.71%	115.271552 129.333725 12.20%
24.	75.552279 87.054111 17.73%	87.522354 91.801147 4.89%	98.196046 95.962377 -2.13%	102.616074 100.123123 -2.43%	103.145370 104.293394 1.10%	97.795830 112.020332 14.55%
48.	65.784471 69.655738 5.90%	72.128107 71.04102 -0.15%	75.521612 75.058854 -0.61%	82.334518 78.313285 -4.88%	82.194557 81.567329 -0.76%	77.250634 87.618927 13.42%
66.	55.793393 58.481597 -4.77%	63.231129 56.162408 -11.11%	68.567761 58.708871 -14.40%	75.558084 61.254299 -17.95%	69.791382 63.799511 -9.50%	64.979652 68.532810 5.47%

Egn. (3-13 or 3-13a)

TABLE F-34 Bundle Constant 19 for 127-Rod Bundle with Any Rod Diameter

H/D	2/0	1.057	1.10	1.1	1.20	1.25	1.343
4.	155.444335 165.871531 5.74%	150.832778 174.78781 -8.81%	17.541657 181.969559 -16.35%	225.920288 189.859391 -15.96%	222.617935 197.748352 -11.17%	199.303711 212.419586 6.58%	
8.	116.235237 132.085281 13.55%	136.527499 135.159180 -0.10%	156.518937 142.531155 -8.77%	164.458969 148.502304 -9.70%	155.493988 154.672791 -6.54%	155.833862 166.148153 6.52%	
12.	95.734334 116.405564 13.53%	113.527712 117.532008 3.48%	129.509262 123.277817 -4.31%	135.335815 128.622911 -5.06%	137.410477 133.967377 -2.51%	130.331772 143.906516 10.42%	
16.	87.597798 105.315135 15.63%	101.51592 106.492523 4.80%	114.645157 111.527103 -2.81%	120.309052 116.154031 -3.45%	121.102875 120.980408 -0.10%	114.881233 129.956115 13.1%	
20.	75.544352 87.433017 15.73%	88.10520 92.4228 4.70%	98.310519 96.424157 -1.92%	102.548691 101.604351 -1.00%	102.854912 104.735240 1.88%	97.214005 112.559418 15.71%	
24.	65.530614 69.39121 5.81%	72.799514 72.14943 -0.9%	79.735215 75.430097 -5.38%	82.197533 75.030163 -4.27%	81.742519 81.959854 0.20%	76.484755 88.040581 15.11%	
28.	55.537743 58.744723 5.77%	55.32629 55.43377 0.19%	58.735927 55.9-1527 -4.74%	61.255457 61.547073 0.47%	69.360774 64.106737 -7.53%	64.147622 68.862594 7.35%	

Eqn. (3-13 or 3-13a)

TABLE F-35 Bundle Constant 19 for 217-Rod Bundle with Any Rod Diameter

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	155.177765	151.375713	217.830673	226.083115	222.690379	199.221710	
	165.455623	174.690369	182.638871	195.526423	198.443100	213.165878	
	1.45%	-8.75%	-15.17%	-15.73%	-10.89%	7.00%	
8.	114.834551	136.660335	156.165675	164.508148	165.491226	155.790675	
	135.543532	136.737543	142.831146	149.024033	155.215217	166.731334	
	11.43%	-0.77%	-8.54%	-7.41%	-6.21%	7.02%	
12.	97.18135	114.24210	129.581711	136.286484	137.284744	130.131821	
	115.805196	118.346428	123.710350	125.074793	134.438049	144.412201	
	1.15%	3.55%	-4.53%	-5.25%	-2.07%	10.57%	
16.	87.503741	101.873317	114.733503	120.207773	120.905602	114.578323	
	105.575102	106.873772	111.718224	116.562111	121.405449	130.412689	
	13.43%	4.73%	-2.57%	-3.03%	3.41%	13.87%	
24.	75.791377	88.545640	98.325417	102.402193	102.588402	96.801113	
	89.777504	92.567551	96.702755	100.958403	105.153389	112.954865	
	15.03%	4.78%	-1.57%	-1.41%	2.50%	16.67%	
36.	65.117775	73.556847	79.722663	82.628854	81.475777	75.972748	
	75.237316	72.403122	75.665066	76.966621	82.247610	88.349812	
	7.55%	-0.64%	-0.65%	-3.73%	3.95%	16.27%	
48.	55.174753	64.12211	68.535337	70.078506	69.047630	63.604723	
	55.737126	55.3147	60.18532	61.765523	61.331764	69.104639	
	-1.07%	-11.07%	-14.00%	-11.86%	-6.83%	8.65%	

Egn. (3-13 or 3-13a)

TABLE F-36 Bundle Constant 19 for 271-Rod Bundle with Any Rod Diameter

H/D	P/D					
	1.057	1.10	1.15	1.20	1.25	1.343
4.	157.427460	171.556671	177.714307	226.129272	222.715195	199.210495
	167.719573	174.744792	182.874756	190.803835	198.732025	213.476257
	5.45%	-8.57%	-16.01%	-15.62%	-10.77%	7.16%
8.	115.015075	136.760986	156.197647	164.507377	165.476318	155.771240
	132.742340	136.836472	143.039108	144.241013	155.442200	166.974656
	15.41%	0.06%	-8.42%	-4.28%	-6.06%	7.19%
12.	97.349457	114.524537	129.588343	136.251265	137.224792	130.051987
	114.972664	118.13738	123.851052	127.262726	134.633789	144.622482
	17.10%	3.57%	-4.40%	-5.13%	-1.89%	11.90%
16.	87.665733	101.729250	114.650534	120.155063	120.820419	114.460312
	105.827557	107.723373	111.450890	116.731827	121.587214	130.602555
	18.44%	0.00%	-2.45%	-2.85%	0.63%	14.10%
24.	77.149233	88.419551	98.515665	102.334865	102.479469	96.643616
	87.923146	92.701782	96.503847	101.105400	105.306488	113.115351
	10.56%	4.74%	-1.44%	-1.20%	2.76%	17.05%
48.	67.274434	73.133604	77.716614	81.955975	81.350769	75.730373
	77.330088	72.708557	75.705265	77.081595	82.567561	88.478551
	14.75%	-2.66%	-4.49%	-3.51%	1.25%	16.76%
60.	55.345152	64.714215	68.594551	71.012238	68.923058	63.402559
	57.717117	56.715977	57.234777	61.855247	64.423430	69.205245
	-3.71%	-11.00%	-13.45%	-11.55%	-6.53%	9.15%

Eqn. (3-13 or 3-13a)

TABLE F-37 Interior Subchannel Constant 18 for 19-Rod Bundle with $D > 0.35$ "

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.		0.001239	0.00318	0.000465	0.000655	0.000893	0.001553
		0.000033	0.000311	0.000457	0.000660	0.000939	0.001747
	-0.33%	-2.75%	-1.82%	1.12%	5.22%	13.93%	
8.		0.000075	0.000082	0.000039	0.000125	0.000161	0.000261
		0.000079	0.000082	0.000086	0.000119	0.000169	0.000314
	5.38%	-0.41%	-13.66%	-4.96%	5.19%	20.21%	
12.		0.000057	0.000055	0.000059	0.000066	0.000078	0.000111
		0.000071	0.000073	0.000077	0.000080	0.000084	0.000115
	25.35%	31.52%	50.78%	21.63%	8.36%	3.53%	
16.		0.000052	0.000049	0.000049	0.000052	0.000058	0.000077
		0.000065	0.000068	0.000071	0.000074	0.000078	0.000084
	25.96%	38.09%	44.65%	41.91%	33.18%	9.67%	
24.		0.000047	0.000045	0.000044	0.000045	0.000049	0.000051
		0.000059	0.000061	0.000064	0.000067	0.000070	0.000075
	24.76%	55.71%	44.62%	45.88%	41.42%	24.45%	
48.		0.000040	0.000039	0.000040	0.000042	0.000045	0.000055
		0.000049	0.000050	0.000053	0.000055	0.000058	0.000063
	24.20%	28.71%	53.59%	52.95%	28.15%	12.71%	
96.		0.000032	0.000032	0.000034	0.000035	0.000040	0.000051
		0.000043	0.000042	0.000044	0.000046	0.000048	0.000052
	27.56%	32.17%	50.51%	26.64%	19.47%	1.55%	

Eqn. (3-5a)

Eqn. (3-6a)

TABLE F-38 Interior Subchannel Constant 18 for 37-Rod Bundle with $D > 0.35"$

H/D	P/D	1.047	1.10	1.15	1.20	1.25	1.343
4.		0.001271	0.000357	0.000520	0.000732	0.001008	0.001763
		0.000236	0.000333	0.000488	0.000705	0.001005	0.001869
		-1.73%	-6.84%	-6.34%	-5.58%	-9.38%	6.01%
8.		0.000043	0.000075	0.000114	0.000144	0.000185	0.000305
		0.000373	0.000082	0.000026	0.000127	0.000181	0.000336
		-11.98%	-13.67%	-24.35%	-11.57%	-2.42%	10.39%
12.		0.000058	0.000066	0.000069	0.000077	0.000091	0.000151
		0.000071	0.000074	0.000077	0.000081	0.000085	0.000123
		1.83%	12.39%	12.77%	5.90%	-6.63%	-5.93%
16.		0.000362	0.000058	0.000058	0.000062	0.000069	0.000091
		0.000066	0.000058	0.000072	0.000075	0.000078	0.000045
		5.15%	15.34%	23.45%	21.33%	13.74%	-6.91%
24.		0.000058	0.000054	0.000055	0.000055	0.000059	0.000073
		0.000059	0.000051	0.000064	0.000067	0.000070	0.000076
		2.70%	13.17%	21.77%	23.15%	19.39%	4.52%
48.		0.000053	0.000048	0.000048	0.000051	0.000055	0.000068
		0.000049	0.000051	0.000053	0.000055	0.000058	0.000053
		-2.07%	4.57%	9.77%	9.61%	6.06%	-6.6%
96.		0.000041	0.000041	0.000043	0.000043	0.000050	0.000053
		0.000041	0.000042	0.000044	0.000045	0.000048	0.000052
		-1.34%	3.07%	4.63%	1.20%	-3.23%	-17.51%

Eqn. (3-5a)

Eqn. (3-6a)

TABLE F-39 Interior Subchannel Constant 18 for 61-Rod Bundle with $D > 0.35$ "

H/D	P/D	1.05	1.10	1.15	1.20	1.25	1.343
4.	0.000281	0.000373	0.000541	0.000763	0.001055	0.001464	
	0.000289	0.000350	0.000514	0.000742	0.001057	0.001455	
	-5.89%	-6.19%	-5.01%	-2.67%	0.14%	5.42%	
8.	0.000095	0.000100	0.000119	0.000150	0.000193	0.000320	
	0.000040	0.000083	0.000087	0.000134	0.000190	0.000354	
	-15.72%	-17.37%	-27.15%	-19.83%	-1.74%	10.52%	
12.	0.000072	0.000069	0.000072	0.000081	0.000095	0.000137	
	0.000072	0.000074	0.000078	0.000081	0.000085	0.000130	
	-7.80%	7.45%	8.42%	1.14%	-10.11%	-5.71%	
15.	0.000055	0.000061	0.000061	0.000064	0.000072	0.000095	
	0.000055	0.000069	0.000072	0.000075	0.000079	0.000085	
	1.50%	11.57%	18.86%	16.88%	9.57%	-10.59%	
24.	0.000051	0.000057	0.000055	0.000057	0.000061	0.000076	
	0.000057	0.000061	0.000064	0.000063	0.000071	0.000076	
	-5.08%	7.24%	17.05%	18.74%	15.20%	0.78%	
48.	0.000053	0.000051	0.000051	0.000053	0.000057	0.000070	
	0.000043	0.000051	0.000053	0.000056	0.000059	0.000063	
	-7.73%	-0.41%	5.96%	5.01%	2.61%	-9.65%	
96.	0.000044	0.000043	0.000044	0.000047	0.000052	0.000066	
	0.000041	0.000042	0.000044	0.000045	0.000049	0.000053	
	-5.42%	-2.01%	0.55%	-1.30%	-6.23%	-19.83%	

Egn. (3-5a)

Egn. (3-6a)

TABLE F-40 Interior Subchannel Constant 18 for 127-Rod Bundle with $D > 0.35$ "

H/D	P/D	1.10	1.15	1.20	1.25	1.343
	1.067					
4.	1.000306	0.000345	0.000569	0.000864	0.001118	0.002002
	1.000287	0.000377	0.000553	0.000799	0.001138	0.002116
	-0.51%	-4.19%	-2.81%	-0.58%	1.78%	5.70%
8.	1.000103	0.000167	0.000126	0.000158	0.000205	0.000341
	0.000381	0.000683	0.000647	0.000144	0.000205	0.000381
	-21.53%	-21.77%	-30.61%	-7.11%	0.01%	11.70%
12.	1.000078	0.000074	0.000076	0.000065	0.000103	0.000146
	0.000072	0.000075	0.000078	0.000082	0.000086	0.000140
	-7.86%	1.12%	3.07%	-3.59%	-14.34%	-4.49%
16.	1.000072	0.000066	0.000064	0.000063	0.000076	0.000101
	1.000057	0.000089	0.000073	0.000076	0.000079	0.000086
	-6.96%	4.17%	12.76%	11.45%	4.51%	-15.03%
24.	1.000067	0.000061	0.000058	0.000060	0.000065	0.000069
	1.000060	0.000062	0.000065	0.000063	0.000071	0.000077
	-17.25%	1.48%	11.24%	13.34%	10.10%	-3.84%
36.	1.000053	0.000051	0.000054	0.000056	0.000060	0.000074
	1.000050	0.000051	0.000054	0.000057	0.000059	0.000064
	-14.35%	-6.50%	0.2%	1.36%	-1.50%	-13.24%
48.	1.000048	0.000046	0.000047	0.000050	0.000054	0.000059
	1.000041	0.000043	0.000045	0.000047	0.000049	0.000053
	-15.85%	-8.17%	-4.55%	-5.58%	-3.90%	-22.14%

Eqn. (3-5a)

Eqn. (3-6a)

TABLE F-41 Interior Subchannel Constant 18 for 217-Rod Bundle with $D > 0.35"$

H/D	P/D	1.067	1.10	1.15	1.20	1.25	1.343
4.		0.000320	0.00049	0.000587	0.000830	0.001157	0.002011
		0.000305	0.000328	0.000584	0.000844	0.001201	0.002234
		-4.55%	-2.79%	-0.57%	1.65%	3.75%	6.84%
8.		0.000103	0.000111	0.000130	0.000164	0.000212	0.000354
		0.000081	0.000084	0.000098	0.000152	0.000216	0.000402
		-24.37%	-24.64%	-32.60%	-7.24%	2.00%	13.44%
12.		0.000083	0.000077	0.000079	0.000088	0.000104	0.000132
		0.000073	0.000075	0.000079	0.000083	0.000086	0.000147
		-11.57%	-2.70%	-0.01%	-6.29%	-10.75%	-2.88%
16.		0.000076	0.000065	0.000067	0.000071	0.000079	0.000105
		0.000067	0.000069	0.000073	0.000075	0.000080	0.000086
		-11.13%	1.18%	9.57%	8.34%	1.62%	-17.54%
24.		0.000070	0.000064	0.000061	0.000062	0.000067	0.000083
		0.000063	0.000062	0.000065	0.000069	0.000072	0.000077
		-14.41%	-2.27%	7.70%	15.26%	7.20%	-6.46%
48.		0.000062	0.000067	0.000050	0.000053	0.000062	0.000076
		0.000059	0.000062	0.000064	0.000057	0.000059	0.000064
		-13.96%	-10.10%	-2.76%	-1.30%	-3.99%	-15.21%
96.		0.000051	0.000049	0.000047	0.000051	0.000055	0.000070
		0.000041	0.000043	0.000044	0.000047	0.000049	0.000053
		-18.15%	-11.59%	-7.47%	-6.03%	-11.98%	-24.23%

Eqn. (3-5a)

Eqn. (3-6a)

TABLE F-42 Interior Subchannel Constant 18 for 271-Rod Bundle with $D > 0.35"$

H/D	P/D	1.067	1.10	1.15	1.20	1.25	1.343
4.	0.000325	0.000414	0.000574	0.000840	0.001172	0.002124	
	0.000312	0.000497	0.000597	0.000865	0.001228	0.002284	
	-1.95%	-1.84%	0.54%	2.75%	4.77%	7.56%	
8.	0.000110	0.000113	0.000132	0.000166	0.000215	0.000359	
	0.000081	0.000084	0.000088	0.000155	0.000221	0.000411	
	-2.57%	-25.59%	-33.30%	-6.30%	3.00%	14.38%	
12.	0.000084	0.000078	0.000080	0.000089	0.000105	0.000154	
	0.000073	0.000075	0.000079	0.000085	0.000087	0.000151	
	-13.43%	-3.76%	-1.10%	-7.24%	-17.59%	-2.02%	
16.	0.000077	0.000070	0.000058	0.000071	0.000080	0.000106	
	0.000067	0.000070	0.000073	0.000077	0.000080	0.000097	
	-12.53%	-0.17%	5.16%	7.26%	3.62%	-16.42%	
24.	0.000072	0.000065	0.000061	0.000063	0.000068	0.000094	
	0.000059	0.000062	0.000066	0.000069	0.000072	0.000078	
	-17.58%	-3.15%	6.73%	9.18%	6.19%	-7.35%	
48.	0.000053	0.000058	0.000057	0.000058	0.000063	0.000077	
	0.000050	0.000062	0.000064	0.000057	0.000060	0.000064	
	-20.41%	-11.56%	-3.52%	-2.23%	-4.82%	-15.75%	
96.	0.000052	0.000050	0.000044	0.000050	0.000057	0.000071	
	0.000042	0.000043	0.000045	0.000047	0.000049	0.000053	
	-19.51%	-13.17%	-8.12%	-8.89%	-12.71%	-24.73%	

Egn. (3-5a)

Egn. (3-6a)

TABLE F-43 Edge Subchannel Constant 18 for 19-Rod Bundle with $D > 0.35$ "

H/D	0.70	1.10	1.15	1.20	1.25	1.343
4.	0.000123 0.000132 19.43%	0.000116 0.000137 18.10%	0.000117 0.000129 -5.63%	0.000191 0.000199 4.34%	0.000285 0.000299 5.11%	0.000627 0.000612 -2.50%
8.	0.000138 0.000134 -3.02%	0.000111 0.000128 15.81%	0.000107 0.000121 13.65%	0.000121 0.000115 -5.48%	0.000151 0.000144 -4.71%	0.000256 0.000234 14.92%
12.	0.000141 0.000129 -8.73%	0.000111 0.000124 11.81%	0.000099 0.000117 17.65%	0.000105 0.000119 6.75%	0.000118 0.000105 -11.03%	0.000170 0.000191 12.47%
16.	0.000142 0.000129 -11.41%	0.000111 0.000121 8.45%	0.000095 0.000114 18.67%	0.000095 0.000107 11.48%	0.000105 0.000102 -2.81%	0.000139 0.000141 1.56%
24.	0.000139 0.000121 -13.15%	0.000110 0.000116 6.58%	0.000095 0.000110 17.51%	0.000090 0.000104 14.85%	0.000094 0.000098 4.22%	0.000115 0.000089 -22.19%
48.	0.000127 0.000113 -11.51%	0.000101 0.000109 7.48%	0.000086 0.000103 19.91%	0.000081 0.000097 19.67%	0.000082 0.000092 12.00%	0.000094 0.000084 -10.43%
72.	0.000107 0.000107 -0.54%	0.000087 0.000102 17.51%	0.000074 0.000097 30.11%	0.000071 0.000091 30.60%	0.000070 0.000086 23.62%	0.000077 0.000079 1.54%

Eqn. (3-8a)

Eqn. (3-9a)

TABLE F-44 Edge Subchannel Constant 18 for 37-Rod Bundle with $D > 0.35"$

H/D	0.70 1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000143 0.000154 0.35%	0.000130 0.000148 13.88%	0.000155 0.000140 -8.39%	0.000214 0.000214 -0.26%	0.000322 0.000321 -0.24%	0.000721 0.000656 -9.04%
8.	0.000112 0.000145 -10.47%	0.000129 0.000133 7.73%	0.000125 0.000131 6.89%	0.000133 0.000124 -11.08%	0.000174 0.000154 -11.37%	0.000298 0.000315 5.81%
12.	0.000168 0.000133 -17.15%	0.000131 0.000134 2.15%	0.000118 0.000122 8.81%	0.000121 0.000119 -1.08%	0.000137 0.000113 -17.71%	0.000290 0.000235 -23.3%
16.	0.000171 0.000136 -20.49%	0.000132 0.000130 -1.42%	0.000114 0.000123 8.15%	0.000114 0.000116 2.31%	0.000124 0.000110 -10.91%	0.000165 0.000151 -8.24%
24.	0.000173 0.000151 -25.27%	0.000132 0.000126 -5.16%	0.000111 0.000118 6.32%	0.000103 0.000112 4.07%	0.000112 0.000106 -5.57%	0.000158 0.000137 -29.73%
48.	0.000179 0.000123 -21.02%	0.000126 0.000118 -6.24%	0.000115 0.000111 -4.77%	0.000099 0.000105 6.09%	0.000100 0.000100 0.0%	0.000114 0.000091 -20.47%
72.	0.000158 0.000115 -15.54%	0.000111 0.000111 0.0%	0.000095 0.000104 11.58%	0.000087 0.000094 7.47%	0.000087 0.000093 7.47%	0.000098 0.000085 -11.43%

Eqn. (3-8a)

Eqn. (3-9a)

TABLE F-45 Edge Subchannel Constant 18 for 61-Rod Bundle with $D > 0.35$ "

H/D	1.067	1.10	1.15	1.20	1.25	1.343
4.	0.000154 0.000163 5.31%	0.000135 0.000157 15.52%	0.000152 0.000145 -6.33%	0.000223 0.000223 0.87%	0.000337 0.000338 0.48%	0.000763 0.000671 -9.37%
8.	0.000171 0.000153 -10.51%	0.000135 0.000147 8.73%	0.000128 0.000131 8.54%	0.000145 0.000131 -9.61%	0.000182 0.000162 -10.59%	0.000313 0.000332 6.13%
12.	0.000179 0.000148 -17.37%	0.000138 0.000142 2.96%	0.000121 0.000134 10.40%	0.000126 0.000127 0.48%	0.000144 0.000120 -16.46%	0.000210 0.000216 2.88%
16.	0.000182 0.000144 -20.73%	0.000132 0.000138 -0.77%	0.000119 0.000130 5.62%	0.000113 0.000123 5.94%	0.000129 0.000117 -9.49%	0.000173 0.000159 -7.64%
24.	0.000182 0.000139 -23.64%	0.000132 0.000133 -4.51%	0.000117 0.000126 7.77%	0.000112 0.000113 5.31%	0.000117 0.000113 -3.91%	0.000144 0.000102 -28.66%
48.	0.000170 0.000139 -23.53%	0.000133 0.000125 -5.33%	0.000110 0.000111 7.20%	0.000103 0.000111 7.00%	0.000104 0.000106 1.50%	0.000116 0.000096 -18.79%
72.	0.000148 0.000122 -17.31%	0.000117 0.000117 0.1%	0.000098 0.000111 13.58%	0.000091 0.000103 12.21%	0.000093 0.000099 9.82%	0.000099 0.000090 -9.22%

Egn. (3-8a)

Egn. (3-9a)

TABLE F-46 Edge Subchannel Constant 18 for 127-Rod Bundle with $D > 0.35"$

H/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000165 0.000178 7.72%	0.000144 0.000171 19.1%	0.000167 0.000161 -3.65%	0.000235 0.000243 3.33%	0.000357 0.000365 2.42%	0.000819 0.000746 -8.89%
8.	0.000185 0.000167 -7.89%	0.000145 0.000161 11.00%	0.000135 0.000151 11.77%	0.000153 0.000143 -6.75%	0.000192 0.000175 -8.73%	0.000533 0.000558 7.57%
12.	0.000194 0.000161 -17.05%	0.000148 0.000155 4.77%	0.000129 0.000146 13.45%	0.000133 0.000139 3.54%	0.000152 0.000131 -13.94%	0.000223 0.000233 4.50%
16.	0.000177 0.000157 -20.56%	0.000144 0.000151 0.4%	0.000125 0.000142 12.52%	0.000125 0.000134 7.14%	0.000135 0.000127 -6.64%	0.000153 0.000172 -5.99%
24.	0.000178 0.000151 -23.56%	0.000150 0.000145 -2.6%	0.000124 0.000137 10.72%	0.000119 0.000125 4.19%	0.000124 0.000123 -0.72%	0.000152 0.000117 -26.45%
48.	0.000155 0.000142 -20.70%	0.000143 0.000136 -4.44%	0.000117 0.000128 10.12%	0.000107 0.000121 11.65%	0.000109 0.000115 5.23%	0.000124 0.000105 -15.58%
56.	0.000162 0.000133 -17.71%	0.000125 0.000126 1.0%	0.000104 0.000121 16.55%	0.000095 0.000114 19.14%	0.000095 0.000109 14.93%	0.000104 0.000098 -5.31%

Eqn. (3-8a)

Eqn. (3-9a)

TABLE F-47 Edge Subchannel Constant 18 for 217-Rod Bundle with $D > 0.35$ "

H/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000173 0.000190 -7.73%	0.000149 0.000182 22.83%	0.000173 0.000172 -0.53%	0.000243 0.000257 5.86%	0.000369 0.000386 4.61%	0.000895 0.000790 -7.71%
8.	0.000193 0.000173 -1.71%	0.000151 0.000171 13.48%	0.000149 0.000161 14.91%	0.000159 0.000152 -3.99%	0.000199 0.000185 -6.73%	0.000346 0.000379 9.46%
12.	0.000204 0.000171 -15.33%	0.000154 0.000155 6.94%	0.000133 0.000151 16.51%	0.000134 0.000147 8.53%	0.000157 0.000139 -11.47%	0.000232 0.000247 6.49%
16.	0.000208 0.000167 -19.72%	0.000156 0.000150 2.97%	0.000131 0.000151 15.62%	0.000130 0.000143 10.25%	0.000141 0.000136 -3.94%	0.000190 0.000132 -4.08%
24.	0.000209 0.000161 -22.83%	0.000158 0.000155 -1.96%	0.000125 0.000142 13.68%	0.000123 0.000134 12.44%	0.000128 0.000131 2.33%	0.000197 0.000119 -24.24%
48.	0.000193 0.000151 -26.12%	0.000149 0.000145 -2.75%	0.000121 0.000137 13.36%	0.000112 0.000129 15.07%	0.000113 0.000123 8.69%	0.000128 0.000119 -12.33%
76.	0.000171 0.000142 -17.25%	0.000132 0.00013 2.0%	0.000165 0.000178 19.33%	0.000099 0.000121 22.85%	0.000098 0.000115 17.97%	0.000107 0.000105 -1.82%

Eqn. (3-8a)

Eqn. (3-9a)

TABLE F-48 Edge Subchannel Constant 18 for 271-Rod Bundle with $D > 0.35$ "

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000176	0.000151	0.000175	0.000245	0.000374	0.000829	
	0.001195	0.000187	0.000175	0.000263	0.000395	0.000808	
	10.85%	23.74%	0.74%	7.10%	5.72%	-7.01%	
8.	0.000199	0.000153	0.000142	0.000161	0.000201	0.000351	
	0.000183	0.000175	0.000155	0.000156	0.000190	0.000388	
	-8.02%	14.73%	16.44%	-7.66%	-5.74%	10.46%	
12.	0.000208	0.000155	0.000155	0.000147	0.000159	0.000235	
	0.000175	0.000164	0.000159	0.000151	0.000143	0.000253	
	-15.51%	8.66%	18.00%	7.97%	-10.27%	7.52%	
16.	0.000212	0.000158	0.000155	0.000131	0.000143	0.000192	
	0.000171	0.000155	0.000155	0.000147	0.000139	0.000156	
	-17.12%	4.73%	17.11%	11.75%	-2.62%	-3.10%	
24.	0.000213	0.000159	0.000155	0.000124	0.000129	0.000159	
	0.000155	0.000159	0.000155	0.000141	0.000134	0.000122	
	-27.55%	-0.67%	17.13%	14.00%	3.73%	-23.14%	
40.	0.000221	0.000152	0.000125	0.000114	0.000114	0.000129	
	0.000155	0.00014	0.000145	0.000133	0.000125	0.000114	
	-27.62%	-1.7%	14.5%	19.71%	10.52%	-11.48%	
60.	0.000175	0.000155	0.00015	0.000108	0.000099	0.000108	
	0.000145	0.000145	0.000155	0.000125	0.000118	0.000107	
	-16.85%	3.25%	10.3%	24.61%	19.73%	-0.21%	

Eqn. (3-8a)

Eqn. (3-9a)

TABLE F-49 Bundle Constant 18 for 19-Rod Bundle with $D > 0.35"$

H/D	P/D	1.067	1.10	1.15	1.20	1.25	1.343
4.	0.000157	0.00011	0.000235	0.000284	0.000410	0.000828	
	0.000158	0.000178	0.000256	0.000364	0.000510	0.000921	
	-17.21%	10.44%	25.06%	28.29%	24.38%	11.51%	
8.	0.000111	0.000190	0.000134	0.000125	0.000154	0.000258	
	0.000127	0.000128	0.000130	0.000103	0.000145	0.000211	
	19.48%	28.57%	24.98%	-15.82%	-6.43%	1.54%	
12.	0.000100	0.000085	0.000080	0.000085	0.000099	0.000144	
	0.000114	0.000115	0.000111	0.000113	0.000119	0.000125	
	15.00%	35.70%	44.89%	36.45%	19.74%	-13.17%	
16.	0.000075	0.000050	0.000075	0.000075	0.000082	0.000109	
	0.000105	0.000106	0.000104	0.000107	0.000110	0.000115	
	3.82%	52.88%	47.54%	45.48%	53.96%	3.18%	
24.	0.000042	0.000070	0.000058	0.000063	0.000072	0.000088	
	0.000075	0.000095	0.000097	0.000098	0.000097	0.000101	
	5.28%	25.57%	41.72%	44.25%	37.90%	14.78%	
32.	0.000031	0.000047	0.000052	0.000061	0.000064	0.000075	
	0.000074	0.000079	0.000087	0.000081	0.000082	0.000084	
	-5.26%	14.74%	23.25%	32.67%	28.90%	11.81%	
40.	0.000037	0.000043	0.000053	0.000053	0.000055	0.000055	
	0.000055	0.000057	0.000057	0.000067	0.000068	0.000070	
	-5.59%	12.5%	23.31%	27.4%	23.60%	7.41%	

Eqn. (3-11a)

Eqn. (3-12a)

TABLE F-50 Bundle Constant 18 for 37-Rod Bundle with $D > 0.35"$

H/D	P/D	1.067	1.10	1.15	1.20	1.25	1.343
4.	0.000170	0.000200	0.000259	0.000362	0.000522	0.001045	
	0.000155	0.000201	0.000249	0.000412	0.000576	0.001042	
	-17.80%	0.24%	12.10%	13.60%	10.33%	-0.34%	
8.	0.000122	0.000111	0.000118	0.000141	0.000179	0.000391	
	0.000121	0.000121	0.000115	0.000117	0.000163	0.000235	
	-1.43%	8.85%	5.62%	-17.44%	-8.85%	-1.83%	
12.	0.000108	0.000092	0.000088	0.000096	0.000111	0.000162	
	0.000108	0.000099	0.000110	0.000111	0.000113	0.000141	
	-1.16%	17.69%	24.37%	16.28%	1.51%	-12.54%	
16.	0.000104	0.000097	0.000080	0.000082	0.000091	0.000111	
	0.000100	0.000100	0.000102	0.000103	0.000104	0.000106	
	-3.77%	15.61%	27.45%	25.07%	14.75%	-12.04%	
24.	0.000100	0.000095	0.000075	0.000075	0.000080	0.000098	
	0.000084	0.000090	0.000091	0.000092	0.000094	0.000096	
	-15.19%	8.10%	21.77%	23.42%	17.60%	-2.57%	
48.	0.000090	0.000077	0.000070	0.000069	0.000073	0.000090	
	0.000074	0.000075	0.000075	0.000077	0.000078	0.000077	
	-17.47%	-2.75%	8.74%	10.93%	7.19%	-7.43%	
72.	0.000075	0.000066	0.000061	0.000061	0.000065	0.000077	
	0.000062	0.000062	0.000063	0.000064	0.000065	0.000066	
	-13.67%	-6.75%	2.15%	1.01%	0.09%	-14.13%	

Egn. (3-11a)

Egn. (3-12a)

TABLE F-51 Bundle Constant 18 for 61-Rod Bundle with $D > 0.35$ "

H/D	1.067	1.10	1.15	1.20	1.25	1.343
4.	0.000110 0.000171 -15.37%	0.000228 0.000220 -2.28%	0.000296 0.000312 7.53%	0.000415 0.000452 8.71%	0.000597 0.000632 5.82%	0.001156 0.001173 -3.51%
8.	0.000123 0.000115 -5.81%	0.000114 0.000116 1.71%	0.000123 0.000117 -4.51%	0.000143 0.000128 -13.40%	0.000188 0.000179 -4.76%	0.000317 0.000324 2.51%
12.	0.000107 0.000103 -7.50%	0.000092 0.000104 13.04%	0.000089 0.000105 18.73%	0.000097 0.000107 10.57%	0.000112 0.000108 -3.75%	0.000154 0.000155 -5.45%
16.	0.000102 0.000095 -6.35%	0.000086 0.000096 12.51%	0.000079 0.000098 23.91%	0.000082 0.000099 20.41%	0.000091 0.000100 10.28%	0.000121 0.000102 -15.63%
24.	0.000136 0.000135 -17.21%	0.000132 0.000138 5.28%	0.000174 0.000138 19.21%	0.000174 0.000138 15.54%	0.000179 0.000139 13.73%	0.000137 0.000132 -5.96%
48.	0.000094 0.000071 -17.05%	0.000076 0.000072 -5.01%	0.000069 0.000073 5.73%	0.000069 0.000074 7.48%	0.000072 0.000075 3.55%	0.000086 0.000076 -11.33%
6.	0.000077 0.000075 -21.05%	0.000065 0.000070 -8.57%	0.000060 0.000070 0.00%	0.000061 0.000061 0.71%	0.000064 0.000062 -3.50%	0.000077 0.000073 -17.82%

Eqn. (3-11a)

Eqn. (3-12a)

TABLE F-52 Bundle Constant 18 for 127-Rod Bundle with $D > 0.35"$

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000240	0.000266	0.000354	0.000493	0.000715	0.001411	
	0.000196	0.000202	0.000364	0.000517	0.000724	0.001308	
	-14.30%	-5.24%	2.84%	3.71%	1.31%	-6.62%	
8.	0.000125	0.000118	0.000125	0.000157	0.000200	0.000338	
	0.000103	0.000109	0.000110	0.000147	0.000205	0.000371	
	-14.04%	-7.63%	-14.36%	-6.41%	2.43%	9.79%	
12.	0.000106	0.000092	0.000069	0.000098	0.000114	0.000167	
	0.000097	0.000098	0.000099	0.000100	0.000102	0.000177	
	-8.45%	6.56%	10.86%	2.74%	-10.85%	6.27%	
16.	0.000100	0.000085	0.000075	0.000082	0.000091	0.000171	
	0.000090	0.000091	0.000092	0.000093	0.000094	0.000096	
	-10.40%	6.76%	16.43%	13.64%	3.87%	-20.79%	
4.	0.000093	0.000081	0.000073	0.000073	0.000078	0.000097	
	0.000081	0.000081	0.000082	0.000083	0.000084	0.000096	
	-17.51%	0.20%	12.57%	13.65%	7.94%	-10.74%	
8.	0.000085	0.000074	0.000058	0.000063	0.000071	0.000086	
	0.000067	0.000068	0.000069	0.000069	0.000070	0.000072	
	-21.75%	-3.72%	1.03%	2.23%	-1.87%	-16.50%	
16.	0.000072	0.000064	0.000054	0.000060	0.000064	0.000077	
	0.000055	0.000055	0.000057	0.000058	0.000058	0.000060	
	-23.43%	-11.77%	-4.52%	-4.28%	-8.73%	-23.00%	

Egn. (3-11a)

Egn. (3-12a)

TABLE F-53 Bundle Constant 18 for 217-Rod Bundle with $D > 0.35$ "

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.	0.000252	0.000245	0.000397	0.00041	0.000801	0.001557	
	0.000217	0.000274	0.000402	0.000571	0.000799	0.00144	
	-17.25%	-5.74%	1.23%	1.95%	-0.16%	-7.24%	
8.	0.000127	0.000121	0.000153	0.000162	0.000208	0.000352	
	0.000103	0.000134	0.000136	0.000162	0.000227	0.000410	
	-13.80%	-13.8%	-10.58%	-0.29%	8.83%	16.35%	
12.	0.000103	0.000142	0.000090	0.000098	0.000115	0.000169	
	0.000193	0.000144	0.000095	0.000096	0.000097	0.000176	
	-12.03%	1.68%	5.47%	-2.51%	-15.57%	16.01%	
16.	0.000399	0.00034	0.000079	0.000082	0.000090	0.000121	
	0.000335	0.000187	0.000088	0.000087	0.000090	0.000092	
	-15.44%	2.55%	11.70%	8.83%	-0.62%	-24.22%	
24.	0.000394	0.000060	0.000075	0.000075	0.000076	0.000036	
	0.000377	0.000078	0.000075	0.000085	0.000081	0.000082	
	-13.07%	-2.2%	8.55%	5.32%	5.72%	-14.51%	
48.	0.000384	0.000073	0.000057	0.000067	0.000071	0.000086	
	0.000364	0.000055	0.000055	0.000055	0.000067	0.000068	
	-25.94%	-11.2%	-2.57%	-1.64%	-5.73%	-20.10%	
6.	0.000377	0.000053	0.000055	0.000060	0.000064	0.000077	
	0.000353	0.000054	0.000054	0.000055	0.000056	0.000057	
	-24.45%	-14.40%	-7.1%	-7.74%	-12.55%	-26.60%	

Egn. (3-11a)

Egn. (3-12a)

TABLE F-54 Bundle Constant 18 for 271-Rod Bundle with $D > 0.35"$

H/D	P/D	1.057	1.10	1.15	1.20	1.25	1.343
4.		0.000270	0.000307	0.000414	0.000585	0.000835	0.001620
		0.000225	0.000240	0.000415	0.000595	0.000833	0.001595
		-11.52%	-5.58%	1.33%	1.70%	-0.31%	-7.09%
8.		0.000123	0.000192	0.000155	0.000164	0.000211	0.000357
		0.000131	0.000112	0.000104	0.000169	0.000236	0.000427
		-20.55%	-15.35%	-22.52%	2.54%	11.80%	19.46%
12.		0.000105	0.000042	0.000090	0.000099	0.000115	0.000170
		0.000141	0.000042	0.000095	0.000094	0.000095	0.000204
		-15.43%	-0.03%	3.37%	-4.57%	-17.41%	20.38%
16.		0.000099	0.000014	0.000078	0.000082	0.000090	0.000191
		0.000084	0.000015	0.000088	0.000087	0.000088	0.000090
		-14.71%	0.05%	2.77%	5.83%	-2.44%	-25.53%
24.		0.000094	0.000030	0.000070	0.000073	0.000078	0.000096
		0.000075	0.000076	0.000077	0.000075	0.000079	0.000081
		-19.13%	-4.51%	1.43%	7.54%	1.99%	-15.37%
48.		0.000034	0.000073	0.000067	0.000067	0.000071	0.000096
		0.000053	0.000053	0.000064	0.000065	0.000066	0.000097
		-24.88%	-12.35%	-1.57%	-1.24%	-7.59%	-21.51%
50.		0.000070	0.000012	0.000055	0.000060	0.000064	0.000077
		0.000052	0.000013	0.000055	0.000054	0.000055	0.000055
		-25.35%	-15.44%	-1.05%	-1.46%	-14.03%	-28.03%

Eqn. (3-11a)

Eqn. (3-12a)

APPENDIX G. THE COMPUTER PRE-PROCESSOR, EZFRIC.

EZFRIC was also written in Fortran IV but unlike FRIC, EZFRIC has only a MAIN.

G.1 Flow Diagram (Fig. G-1).

The geometrical parameters of the bundle and the pseudo-laminar subchannel Reynolds number are calculated from the INPUT data. Constants eighteen and nineteen are then calculated for the interior and edge subchannels and the bundle. The interior and edge pseudo laminar subchannel Reynolds number is next individually compared with a Reynold number of 400 and the decision to keep or delete constant 18, the turbulent "component" in eqn (1-2), is made as a result. For the bundle, constant

18 is deleted only if both the interior and edge pseudo laminar subchannel Reynolds number are less than 400.

G.2 Listing of EZFRIC

Listed below is the EZFRIC computer pre-processor:

Fig. G-1. Flow Diagram of EZFRIC

```

1  *****
2  *                                     *
3  * THIS COMPUTER PRE-PROCESSOR CALCULATES CONSTANTS EIGHTEEN AND *
4  * NINETEEN AND THE FRICTION FACTORS FOR WIRE-WRAPPED BUNDLES. *
5  * (NOT APPLICABLE TO SHAVED WIRE BUNDLES) *
6  * YEE-NING CHAN *
7  * C MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1982 *
8  *****
9
10 C NRJD    NUMBER OF RODS
11 C D       ROD DIAMETER (IN)
12 C DW      WIRE DIAMETER (IN)
13 C H       WIRE LEAD LENGTH (IN)
14 C GAP     GAP BETWEEN RODS AND WALL (IN)
15 C TOLCN   BUNDLE TOTAL TOLERANCE (IN)
16 C FAC     BUNDLE LOOSENESS FACTOR (DIMENSIONLESS)
17 C ICONS   0--DO NOT WRITE CONSTANTS EIGHTEEN AND NINETEEN
18 C         1--WRITE CONSTANTS EIGHTEEN AND NINETEEN
19 C FRICI   INTERIOR SUBCHANNEL FRICTION FACTOR
20 C FRICE   EDGE SUBCHANNEL FRICTION FACTOR
21 C FRICB   BUNDLE AVERAGE FRICTION FACTOR
22 C FRICIL  LAMINAR INTERIOR SUBCHANNEL FRICTION FACTOR
23 C FRICEL  LAMINAR EDGE SUBCHANNEL FRICTION FACTOR
24 C FRICBL  LAMINAR BUNDLE AVERAGE FRICTION FACTOR
25 C NST     NUMBER OF SETS OF DATA TO BE READ IN
26 C REB     BUNDLE AVERAGE REYNOLDS NUMBER
27 C NRFB    NUMBER OF REYNOLDS NUMBER TO BE READ IN
28 C RESUB   SUBCHANNEL REYNOLDS NUMBER
29 C         (1)--INTERIOR
30 C         (2)--EDGE
31 C XL      FLOW SPLIT PARAMETER IN LAMINAR FLOW
32 C
33 C DIM NSI N AR(3),AS(3),PW(3),DE(3),ASP(3),PWP(3),DEP(3),NCH(3)
34 C DIM NSI N CLF(3),CLF(2),CP(3),CSTR(3),XL(3),RESUB(2)
35 C DIM NSI N FBC(3),CNIC(2),CONE(2),CONB(2)
36 C DATA PI,SQR(3/5),1415926,1.73205087
37 C RTA(5,1000) NSI

```

```

33      NM = 0
34      1 READ(5,100) NRJD,NREB,ICON
35      READ(5,150) D,DW,H,TOL,N,FAC
36      READ(5,150) (REB(N),N=1,NREB)
37      CON118 = 0.0
38      CON119 = 0.0
39      CON118 = 0.0
40      CON119 = 0.0
41      CON118 = 0.0
42      CON119 = 0.0
43      CON118 = 0.0
44      CON119 = 0.0
45      FRIC1 = 0.0
46      FRIC2 = 0.0
47      FRIC3 = 0.0
48      FRIC4 = 0.0
49      FRIC5 = 0.0
50      FRIC6 = 0.0
51      FRIC7 = 0.0
52      FRIC8 = 0.0
53      FRIC9 = 0.0
54      NRING = (3.+SQRT(12.*NRJD-3.))/6.-1
55      NCH(1) = 6*NRING**2
56      NCH(2) = 6*NRING
57      NCH(3) = 6
58
59      : CALCULATION OF ROT PITCH AND GAP (EQNS. A-3,A-4,A-15 AND A-16)
60
61      P = D+DW+FAC*TOLN/(SQRT(3)*NRING)
62      PDR = P/D
63      PDRM1 = PDR-1.
64      DRK = H/D
65      GAP = 0.5*(1.-FAC)*TOLN+DW
66      WIRLN = SQRT(H**2+(PI*(D+DW))**2)
67      DELTA = WIRLN/H
68      LINTH = PI*(D+DW)/WIRLN
69      COSH = 1./DELTA
70      COSIN = DELTA
71      WRITE(6,200) (RDE, ),PDR,H
72
73      : WIRE PROJECTED AREA IN INTERIOR AND EDGE SUBCHANNELS (EQNS. A-23 AND

```

```

74 C A-39).
75 C
76 AR(1) = PI*DW*(D+DW)/6.
77 AR(2) = 1.5*AR(1)
78 C
79 C SUBCHANNEL FLOW AREA, WETTED PERIMETER AND HYDRAULIC DIAMETER FOR BARE
80 C ROD BUNDLE (EQNS. A-17, A-24, A-31, A-19, A-26, A-33, A-21, A-28 AND A-35).
81 C
82 ASP(1) = SQRT3*P**2/4.-PI*D**2/8.
83 ASP(2) = P*(D/2.+GAP)-PI*D**2/8.
84 ASP(3) = (D/2.+GAP)**2/SQRT3-PI*D**2/24.
85 PWP(1) = PI*D/2.
86 PWP(2) = P+PI*D/2.
87 PWP(3) = PI*D/6.+2.*(D/2.+GAP)/SQRT3
88 D_P(1) = 4.*ASP(1)/PWP(1)
89 D_P(2) = 4.*ASP(2)/PWP(2)
90 D_P(3) = 4.*ASP(3)/PWP(3)
91 C
92 C SUBCHANNEL FLOW AREA, WETTED PERIMETER, AND HYDRAULIC DIAMETER FOR
93 C WIRE WRAPPED ROD BUNDLE (EQNS. A-18, A-25, A-32, A-20, A-27, A-34, A-22, A-29
94 C AND A-36).
95 C
96 AS(1) = ASP(1)-COSIN*PI*DW**2/8.
97 AS(2) = ASP(2)-PI*COSIN*DW**2/8.
98 AS(3) = ASP(3)-PI*(DW**2)*COSIN/24.
99 PW(1) = PWP(1)+PI*DW*COSIN/2.
100 PW(2) = PWP(2)+PI*COSIN*DW/2.
101 PW(3) = PWP(3)+PI*DW*COSIN/6.
102 D_L(1) = 4.*AS(1)/PW(1)
103 D_L(2) = 4.*AS(2)/PW(2)
104 D_L(3) = 4.*AS(3)/PW(3)
105 C
106 C BUNDLE TOTAL FLOW AREA, TOTAL WETTED PERIMETER AND AVERAGE HYDRAULIC
107 C DIAMETER FOR WIRE WRAPPED ROD BUNDLE (EQNS. A-38, A-40 AND A-42).
108 C
109 AT = NCH(1)*AS(1)+NCH(2)*AS(2)+NCH(3)*AS(3)

```

```

110      PWT = NCH(1)*PW(1)+NCH(2)*PW(2)+NCH(3)*PW(3)
111      UB = 4.*AT/PWT
112      DO 58 J=1,NREB
113      WRITE(5,3000) PWB(J)
114      IF(J.GT.1) ICONS = 1
115      IF(J.GT.1) GO TO 21
116
117      C  IF FOLLOWING ARE EMPIRICAL CONSTANTS (EQNS. A-8, A-9, A-1 AND A-2).
118
119      CALF(1) = 5835.*HDR**1.08/PDR**3.254
120      CALF(2) = 6805.*HDR**2.57/PDR**4.557
121      CP(1) = 40.*PDRM1*(340.-536.*PDRM1)
122      CP(2) = 37.4+PDRM1*(290.7-518.2*PDRM1)
123
124      C  CALCULATION OF TERMS IN XL(1) AND XL(2) (EQNS. 2-4 AND 2-6).
125
126      DO 10 I=1,2
127      CSTR(I) = CP(I)*(AS(I)/ASP(I))*(DE(I)/D*P(I))**2
128      CLF(I) = CALF(I)*(AR(I)/ASP(I))*(DL(I)/H)*(1.-OW/(2.*DE(I)))
129      GL = (CSTR(1)+CLF(1))/(CSTR(2)+CLF(2))*(DL(2)/DL(1))**2
130      S = (AS(2)/AS(1)+AS(3)/(AS(1)*NRING))/NRING
131
132      C  VALUES OF XL(1) AND XL(2).
133
134      XL(1) = (1.+S)/(1.+*GL)
135      XL(2) = (1.+S)/(S+1./GL)
136
137      DO 10 I=1,2
138      REB(J)*D*(1)*XL(I)/DEB
139
140      C  INTERIOR SUBCHANNEL FRICTION FACTOR (EQNS. 3-5, 3-6 AND 3-7).
141
142      IF(OR.L..3.) GO TO 730
143      IF(OR.L..4.) GO TO 730
144      IF(OR.L..5..AND..PDR.G..1.2) GO TO 730
145      IF(OR.L..12..AND..PDR.G..1.043) GO TO 730
146      CONT1 = .7701*(NROD**2.11)*(PLR**1.092)/(HDR**2.69)

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```

146      GO TO 742
147      730 CONI18 = .06315*(NR0D**101)*(PDR**3.648)/(HDR**2.475)
148      GO TO 745
149      750 IF(HDR.LE.4.) GO TO 740
150      IF(HDR.LE.8..AND.PDR.GE.1.2) GO TO 740
151      IF(HDR.LE.12..AND.PDR.GE.1.343) GO TO 740
152      CONI18 = .0000177*(NR0D**118)*(PDR**978)*(HDR**176)
153      GO TO 745
154      740 CONI18 = .00117*(NR0D**083)*(PDR**8.698)/(HDR**2.113)
155      740 CONI19 = 483.*(PDR**4.33)/((NR0D**066)*(HDR**372))
156      IF(RESUB(1).LT.400.) GO TO 750
157      FRIC1 = CONI19*((1.+CONI18/REH(J))**(.18*1.49-1.49))**((1./1.49))/RE
158      15(J)
159      GO TO 740
160      750 FRIC1L = CONI18/REH(J)
161      790 IF(ICON3.EQ.1) WRITE(6,7000) CONI18,CONI19
162      IF(RESUB(1).LT.400.) WRITE(6,7050) FRIC1L
163      IF(RESUB(1).LT.400.) GO TO 795
164      WRITE(6,7010) FRIC1
165
166      2000 SUBCHANNEL FRICTION FACTOR (EQNS. 3-8,3-9,AND 3-10).
167      730 IF(D.LE.5.) GO TO 830
168      IF(HDR.LE.4..AND.PDR.GE.1.2) GO TO 800
169      IF(HDR.LE.8..AND.PDR.GE.1.25) GO TO 800
170      IF(HDR.LE.12..AND.PDR.GE.1.343) GO TO 800
171      IF(HDR.LE.16..AND.PDR.GE.1.343) GO TO 800
172      CON 18 = .000125*(NR0D**117)/((PDR**1.313)*(HDR**092))
173      GO TO 845
174      800 CON 18 = .000113*(NR0D**101)*(PDR**9.950)/(HDR**1.059)
175      GO TO 845
176      830 IF(HDR.LE.4..AND.PDR.GE.1.2) GO TO 840
177      IF(HDR.LE.8..AND.PDR.GE.1.25) GO TO 840
178      IF(HDR.LE.12..AND.PDR.GE.1.343) GO TO 840
179      IF(HDR.LE.16..AND.PDR.GE.1.343) GO TO 840
180      CON 18 = .000497*(NR0D**075)/(PDR**1.972)*(HDR**27)
181      GO TO 845

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182      44) CON 18 = .0000575*(NR0D**-.054)*(PDR**10.005)/(HDR**-.697)
183      44) CON 19 = 225.*(PDR**1.654)/((NR0D**-.066)*(HDR**-.33))
184      IF(RSUB(2).LT.400.) GO TO 150
185      PRICE = CON 18*((1.+CON 18/REB(J))**(.18*1.49-1.49))**((1./1.49))/RE
186      18(J)
187      GO TO 150
188      45) FRICBL = CON 17/REB(J)
189      84) IF(ICON 1.EQ.1) WRITE(6,8000) CON 18,CON 19
190      IF(RSUB(2).LT.400.) WRITE(6,8050) FRICBL
191      IF(RSUB(2).LT.400.) GO TO 89)
192      WRITE(6,8050) FRICBL
193
194      BUNDLE AVERAGE FRICTION FACTOR (EQNS. 3-11,3-12 AND 3-13).
195
196      89) IF(D.LT..35) GO TO 930
197      IF(HDR.LE.4.) GO TO 900
198      IF(HDR.LE.3..AND.PDR.GT.1.2) GO TO 900
199      IF(HDR.LE.12..AND.PDR.GT.1.343) GO TO 900
200      CON 18 = .000278*(PDR**-.289)/((NR0D**-.054)*(HDR**-.268))
201      GO TO 945
202      90) CON 18 = .000584*(NR0D**-.187)*(PDR**8.247)/(HDR**1.818)
203      GO TO 945
204      930 IF(HDR.LE.4.) GO TO 940
205      IF(HDR.LE.8..AND.PDR.GT.1.2) GO TO 940
206      IF(HDR.LE.12..AND.PDR.GT.1.343) GO TO 940
207      CON 18 = .000557*(NR0D**-.053)*(PDR**-.178)*(HDR**-.178)
208      GO TO 945
209      94) CON 18 = .000271*(NR0D**-.162)*(PDR**8.247)/(HDR**1.457)
210      94) CON 19 = 251.*(NR0D**-.257)*(PDR**-.397)/(HDR**-.354)
211      IF(RSUB(1).LT.400..AND.RSUB(2).LT.400.) GO TO 950
212      FRICP = CON 19*((1.+CON 18/REB(J))**(.18*1.49-1.49))**((1./1.49))/RE
213      18(J)
214      GO TO 945
215      95) FRICBL = CON 17/REB(J)
216      99) IF(ICON 1.EQ.1) WRITE(6,9000) CON 18,CON 19
217      IF(RSUB(1).LT.400..AND.RSUB(2).LT.400.) WRITE(6,9050) FRICBL

```

```

218      IF (P SUB(1).LT.400..AND.RESUB(2).LT.400.) GO TO 998
219      WRIT (C,9050) FRICH
220      995 CONTINUE
221      999 NN = NN+1
222      IF (NSET.GT.NN) GO TO 1
223      GO TO 9999
224      1000 FORMAT(10I1)
225      1500 FORMAT(8F10.0)
226      2000 FORMAT(/// 21H TOTAL NO. OF RODS = ,I5/ 16H DIA. OF WIRE = ,F10.
227      15,4H IN ,/ 31H PITCH-TO-DIAMETER RATIO,P/D = ,F5.3/ 30H LEAD-TO-DI
228      2AMETER RATIO,H/D = ,F8.2)
229      3000 FORMAT(///5X,32H *** BUNDLE REYNOLDS NUMBER = ,F10.1,5H *** /
230      10X,38H ***** //)
231      4000 FORMAT(31X,30H INT RIOR CONSTANT EIGHTEEN = ,F12.6/31X,30H INTERIO
232      1R CONSTANT NINETEEN = ,F12.6)
233      4500 FORMAT(5X,39H INTERIOR SUBCHANNEL FRICTION FACTOR = ,F9.6)
234      5000 FORMAT(35X,26H EDGE CONSTANT EIGHTEEN = ,F12.6/35X,26H EDGE CONSTA
235      INT NINETEEN = ,F12.6)
236      5500 FORMAT(5X,39H EDGE SUBCHANNEL FRICTION FACTOR = ,F9.6)
237      6000 FORMAT(33X,28H BUNDLE CONSTANT EIGHTEEN = ,F12.6/33X,28H BUNDLE CO
238      INSTANT NINETEEN = ,F12.6)
239      6500 FORMAT(5X,34H BUNDLE AVERAGE FRICTION FACTOR = ,F9.6)
240      9999 STOP
241      END

```


G.3 User's Note

The inputs for the computer pre-processor, EZFRIC, are similar to those required for FRIC (see Appendix D.3) except that ISPLT and IFRIC are not required inputs for EZFRIC.

APPENDIX H. SAMPLE RUNS OF EZFRIC

Table H-1 is the input parameters for the sample runs of EZFRIC. Notice that these sample runs are for bundle geometries corresponding exactly to cases 1 through 3 of the Sample Problem of Section 3.5. The output is self-explanatory.

TABLE H-1 Input Parameters for Sample Runs of EZFRIC

100	3							
200	51	11	1					
300	.5055	.9429	3.937	0.0	0.0			
400	10.	50.	100.	200.	400.	1000.	4000.	10000.
500	40000.	100000.	100000.					
600	217	11	1					
700	.20	.06	15.	0.0	0.0			
800	10.	50.	100.	200.	400.	1000.	4000.	10000.
900	40000.	100000.	100000.					
1000	51	11	1					
1100	.205	.0539	12.007	0.0	0.0			
1200	10.	50.	100.	200.	400.	1000.	4000.	10000.
1300	40000.	100000.	100000.					

TOTAL NO. OF RODS = 61
 DIA. OF BERT = 0.559 IN
 PITCH-TO-DIAMETER RATIO, P/D = 1.35
 LEAD-TO-DIAMETER RATIO, H/D = 7.78

*** BUNDLE REYNOLDS NUMBER = 10.0 ***

INTERIOR CONSTANT EIGHTEEN = 0.000082
 INTERIOR CONSTANT NINETEEN = 179.118835
 INTERIOR SUBCHANNEL FRICTION FACTOR = 17.811884
 EDGE CONSTANT EIGHTEEN = 0.000150
 EDGE CONSTANT NINETEEN = 98.827515
 EDGE SUBCHANNEL FRICTION FACTOR = 9.882751
 BUNDLE CONSTANT EIGHTEEN = 0.000116
 BUNDLE CONSTANT NINETEEN = 139.507950
 BUNDLE AVERAGE FRICTION FACTOR = 13.550795

*** BUNDLE REYNOLDS NUMBER = 50.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 3.562377
 EDGE SUBCHANNEL FRICTION FACTOR = 1.976550
 BUNDLE AVERAGE FRICTION FACTOR = 2.710175

*** BUNDLE REYNOLDS NUMBER = 100.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 1.781188
EDGE SUBCHANNEL FRICTION FACTOR = 0.983275
BUNDLE AVERAGE FRICTION FACTOR = 1.355080

*** BUNDLE REYNOLDS NUMBER = 200.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.891594
EDGE SUBCHANNEL FRICTION FACTOR = 0.494138
BUNDLE AVERAGE FRICTION FACTOR = 0.677540

*** BUNDLE REYNOLDS NUMBER = 400.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.44297
EDGE SUBCHANNEL FRICTION FACTOR = 0.283461
BUNDLE AVERAGE FRICTION FACTOR = 0.377636

*** BUNDLE REYNOLDS NUMBER = 1000.0 ***

INT RIOR SUBCHANNEL FRICTION FACTOR = 0.221200
EDG SUBCHANNEL FRICTION FACTOR = 0.140883
BUNDLE AVERAGE FRICTION FACTOR = 0.180909

*** BUNDLE REYNOLDS NUMBER = 4000.0 ***

INT RIOR SUBCHANNEL FRICTION FACTOR = 0.094580
EDG SUBCHANNEL FRICTION FACTOR = 0.070664
BUNDLE AVERAGE FRICTION FACTOR = 0.084846

*** BUNDLE REYNOLDS NUMBER = 10000.0 ***

INT RIOR SUBCHANNEL FRICTION FACTOR = 0.067726
EDG SUBCHANNEL FRICTION FACTOR = 0.054120
BUNDLE AVERAGE FRICTION FACTOR = 0.063410

*** BUNDLE REYNOLDS NUMBER = 40000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.044704
EDGE SUBCHANNEL FRICTION FACTOR = 0.040315
BUNDLE AVERAGE FRICTION FACTOR = 0.46654

*** BUNDLE REYNOLDS NUMBER = 100000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.040939
EDGE SUBCHANNEL FRICTION FACTOR = 0.033944
BUNDLE AVERAGE FRICTION FACTOR = 0.139200

*** BUNDLE REYNOLDS NUMBER = 150000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.037064
EDGE SUBCHANNEL FRICTION FACTOR = 0.031512
BUNDLE AVERAGE FRICTION FACTOR = 0.136378

TOTAL NO. OF RODS = 217
DIA. OF WIRE = 0.2500 IN
PITCH-TO-DIAMETER RATIO, P/D = 1.240
LOAD-TO-DIAMETER RATIO, H/D = 52.00

*** BUNDLE REYNOLDS NUMBER = 10.0 ***

	INTERIOR CONSTANT EIGHTEEN =	0.000102
	INTERIOR CONSTANT NINETEEN =	85.880463
INTERIOR SUBCHANNEL FRICTION FACTOR =	8.588746	
	EDGE CONSTANT EIGHTEEN =	0.000175
	EDGE CONSTANT NINETEEN =	60.581055
EDGE SUBCHANNEL FRICTION FACTOR =	6.058105	
	BUNDLE CONSTANT EIGHTEEN =	0.000116
	BUNDLE CONSTANT NINETEEN =	79.745316
BUNDLE AVERAGE FRICTION FACTOR =	7.474532	

*** BUNDLE REYNOLDS NUMBER = 50.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR =	1.717604
EDGE SUBCHANNEL FRICTION FACTOR =	1.211621
BUNDLE AVERAGE FRICTION FACTOR =	1.594906

*** BUNDLE REYNOLDS NUMBER = 100.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.858805
EDG SUBCHANNEL FRICTION FACTOR = 0.605811
BUNDLE AVERAGE FRICTION FACTOR = 0.797453

*** BUNDLE REYNOLDS NUMBER = 200.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.423402
EDG SUBCHANNEL FRICTION FACTOR = 0.302905
BUNDLE AVERAGE FRICTION FACTOR = 0.398727

*** BUNDLE REYNOLDS NUMBER = 400.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.214701
EDG SUBCHANNEL FRICTION FACTOR = 0.177305
BUNDLE AVERAGE FRICTION FACTOR = 0.222256

*** BUNDLE REYNOLDS NUMBER = 1000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.111432
EDGE SUBCHANNEL FRICTION FACTOR = 0.090242
BUNDLE AVERAGE FRICTION FACTOR = 0.106486

*** BUNDLE REYNOLDS NUMBER = 4000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.050326
EDGE SUBCHANNEL FRICTION FACTOR = 0.047033
BUNDLE AVERAGE FRICTION FACTOR = 0.049954

*** BUNDLE REYNOLDS NUMBER = 10000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.037250
EDGE SUBCHANNEL FRICTION FACTOR = 0.036477
BUNDLE AVERAGE FRICTION FACTOR = 0.037337

*** BUNDLE REYNOLDS NUMBER = 40000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.027210
EDGE SUBCHANNEL FRICTION FACTOR = 0.02733
BUNDLE AVERAGE FRICTION FACTOR = 0.027472

*** BUNDLE REYNOLDS NUMBER = 100000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.022835
EDGE SUBCHANNEL FRICTION FACTOR = 0.023041
BUNDLE AVERAGE FRICTION FACTOR = 0.023083

*** BUNDLE REYNOLDS NUMBER = 150000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.021185
EDGE SUBCHANNEL FRICTION FACTOR = 0.021395
BUNDLE AVERAGE FRICTION FACTOR = 0.021421

TOTAL NO. OF RODS = 91
 DIA. OF WIRE = 0.0090 IN
 PITCH-TO-DIAMETER RATIO, P/D = 1.211
 LEAD-TO-DIAMETER RATIO, L/D = 47.25

*** BUNDLE REYNOLDS NUMBER = 10.0 ***

INTERIOR CONSTANT EIGHTEEN =	0.000086
INTERIOR CONSTANT NINETEEN =	93.239540
INTERIOR SUBCHANNEL FRICTION FACTOR =	9.323954
EDGE CONSTANT EIGHTEEN =	0.000163
EDGE CONSTANT NINETEEN =	63.651207
EDGE SUBCHANNEL FRICTION FACTOR =	6.365121
BUNDLE CONSTANT EIGHTEEN =	0.000108
BUNDLE CONSTANT NINETEEN =	80.069145
BUNDLE AVERAGE FRICTION FACTOR =	8.006914

*** BUNDLE REYNOLDS NUMBER = 50.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR =	1.864791
EDGE SUBCHANNEL FRICTION FACTOR =	1.273074
BUNDLE AVERAGE FRICTION FACTOR =	1.601383

*** BUNDLE REYNOLDS NUMBER = 100.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.932393
EDGE SUBCHANNEL FRICTION FACTOR = 0.636512
BUNDLE AVERAGE FRICTION FACTOR = 0.800691

*** BUNDLE REYNOLDS NUMBER = 200.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.466198
EDGE SUBCHANNEL FRICTION FACTOR = 0.318256
BUNDLE AVERAGE FRICTION FACTOR = 0.400346

*** BUNDLE REYNOLDS NUMBER = 400.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.233393
EDGE SUBCHANNEL FRICTION FACTOR = 0.184512
BUNDLE AVERAGE FRICTION FACTOR = 0.21514

*** BUNDLE REYNOLDS NUMBER = 1000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.116692
EDG SUBCHANNEL FRICTION FACTOR = 0.002874
BUNDLE AVERAGE FRICTION FACTOR = 0.105070

*** BUNDLE REYNOLDS NUMBER = 4000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.050449
EDG SUBCHANNEL FRICTION FACTOR = 0.047566
BUNDLE AVERAGE FRICTION FACTOR = 0.048300

*** BUNDLE REYNOLDS NUMBER = 10000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.036420
EDG SUBCHANNEL FRICTION FACTOR = 0.036685
BUNDLE AVERAGE FRICTION FACTOR = 0.035811

*** BUNDLE REYNOLDS NUMBER = 4010 .1 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.026298

EDGE SUBCHANNEL FRICTION FACTOR = 0.027426
BUNDLE AVERAGE FRICTION FACTOR = 0.026237

*** BUNDLE REYNOLDS NUMBER = 100000.6 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.022026
EDGE SUBCHANNEL FRICTION FACTOR = 0.023106
BUNDLE AVERAGE FRICTION FACTOR = 0.022030

*** BUNDLE REYNOLDS NUMBER = 150000.0 ***

INTERIOR SUBCHANNEL FRICTION FACTOR = 0.021428
EDGE SUBCHANNEL FRICTION FACTOR = 0.021447
BUNDLE AVERAGE FRICTION FACTOR = 0.020441